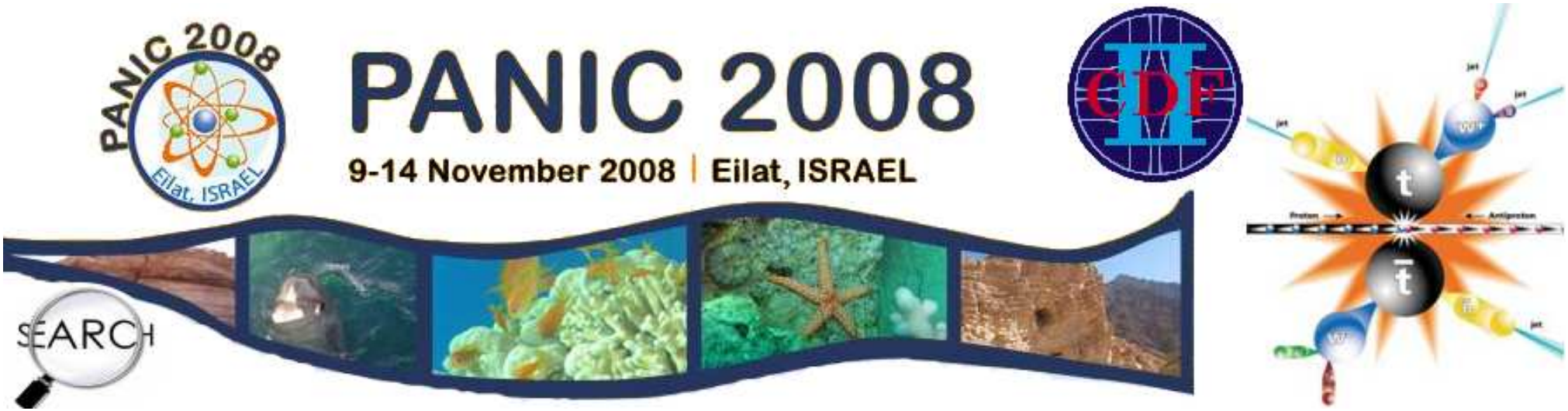
CDF Searches for New Physics Hidden in the Top Quark Sector

Andrey Loginov

Yale University

PANIC 2008, Eilat, Israel,

November 9 - 14, 2008



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- Why
- Where
- Techniques
- Physics
- Summary

Why

Top quark

- The newest and heaviest quark (so far)
  - Special role in EW symmetry breaking (large mass, Yukawa coupling$\sim$1)
  - Sensitive to New Physics (NP) (mass near the EW scale)
- The only quark without resonant $q\bar{q}$ states (yet): $\tau = 10^{-24}s$
- The last quark in the last generation?

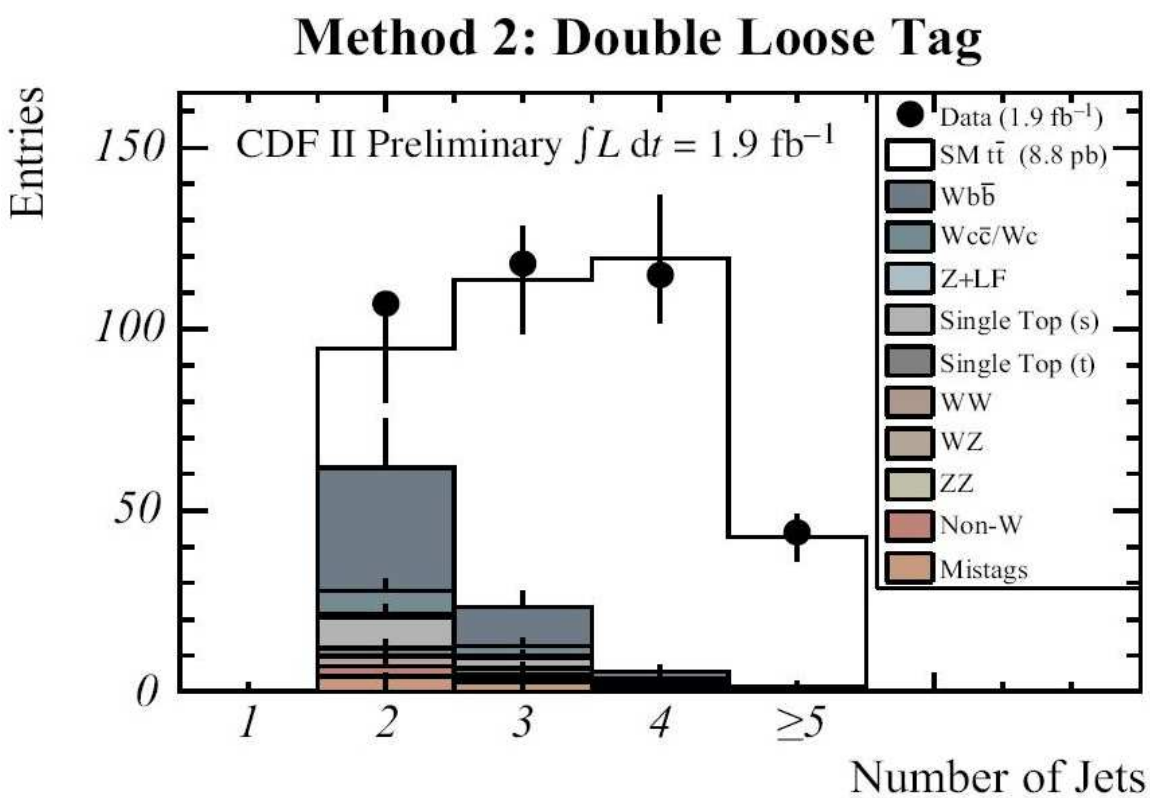
What do we find?

- Do we find top?
- Do we find the SM top?
- Do we find nothing but the SM top?

Why

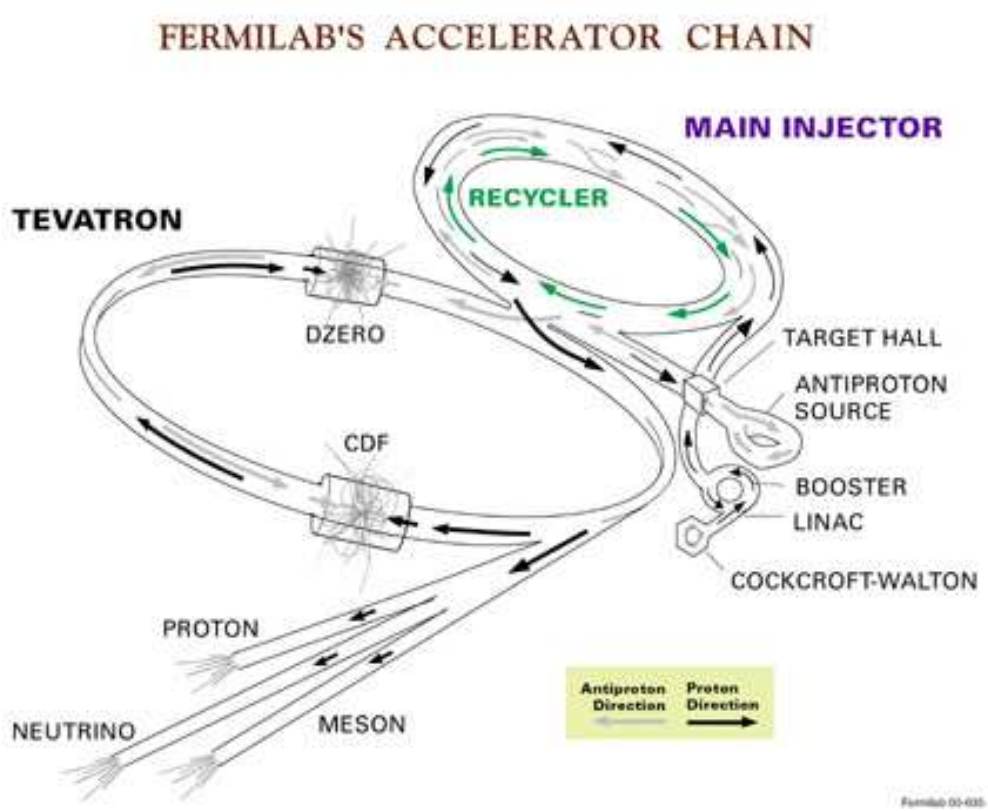
Top physics

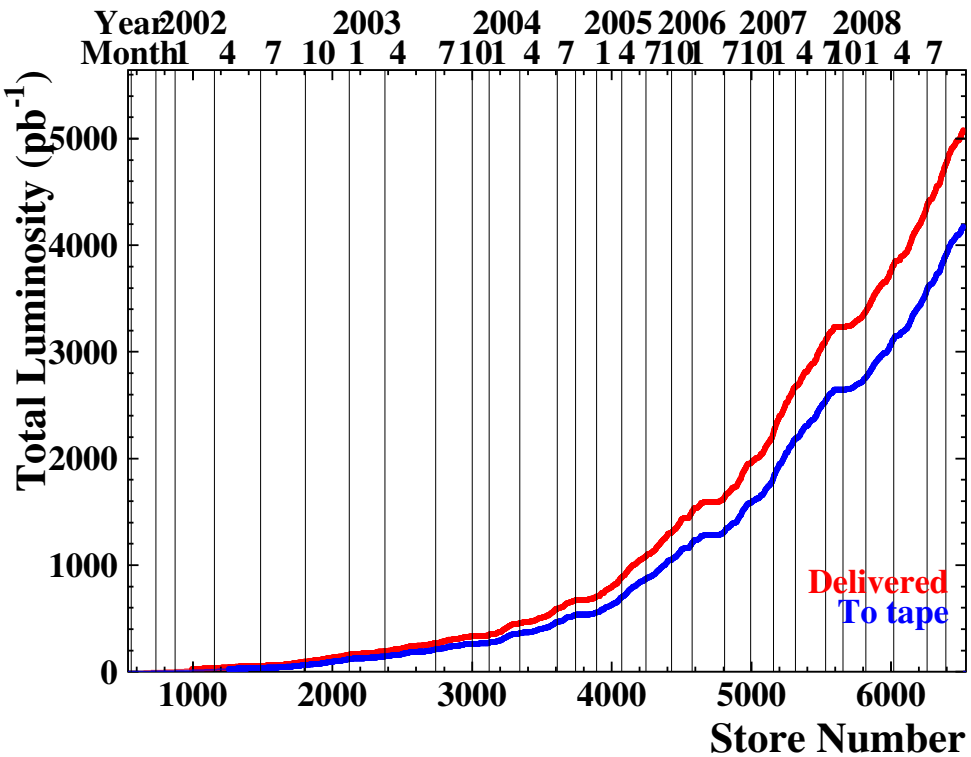
- Huge statistics (Run II = 30-50 × Run I)
- Can isolate pure top samples
- We understand the SM - crucial for searches for physics beyond the SM



Where: Tevatron

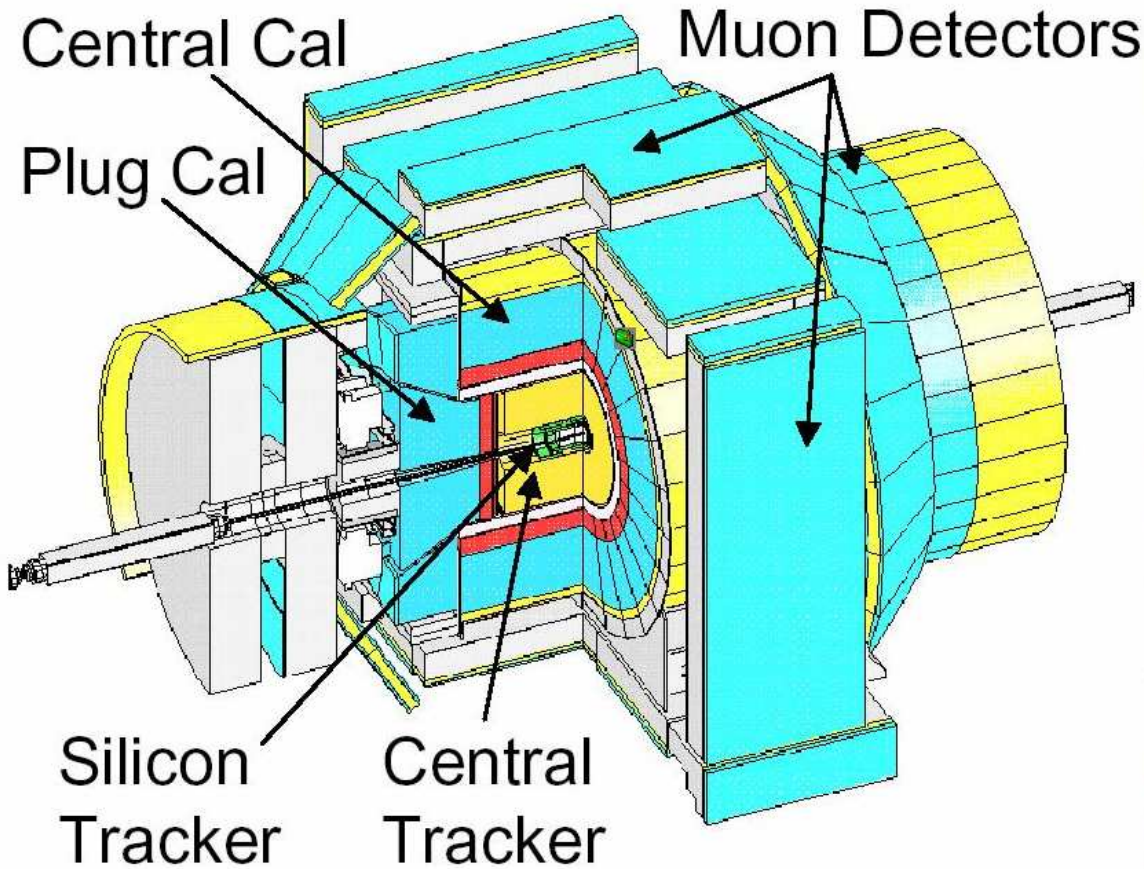
- $p\bar{p}$ **Collisions**
- $\sqrt{s}$=**1.96** TeV
- $\mathcal{L}_{peak}$ = **3.2**$\times 10^{32}$ **cm**$^{-2}$**s**$^{-1}$
  July, 2008

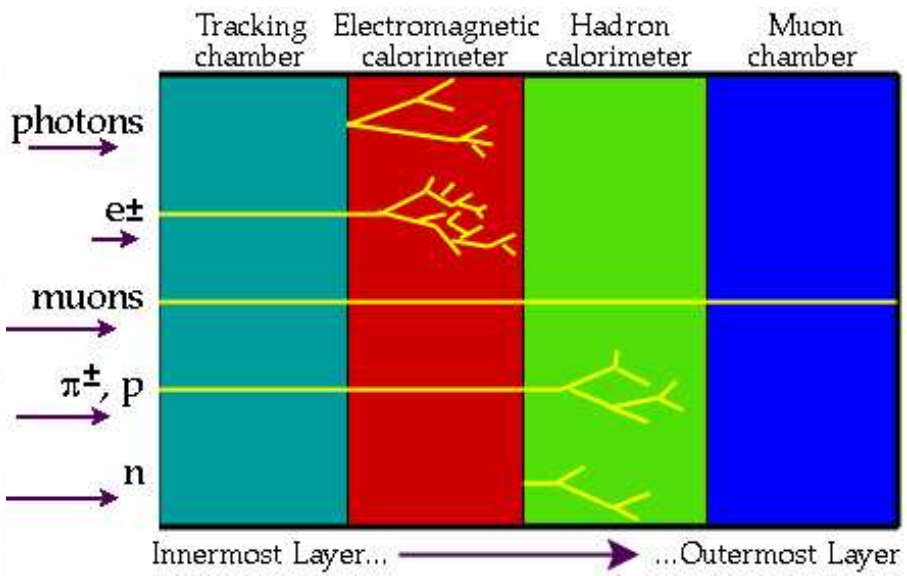




- 5 fb^{-1} delivered, 4 fb^{-1} on tape
- In this talk $\sim$ 2 - 3 fb^{-1} results

Where: CDF





Detectors and identified objects:

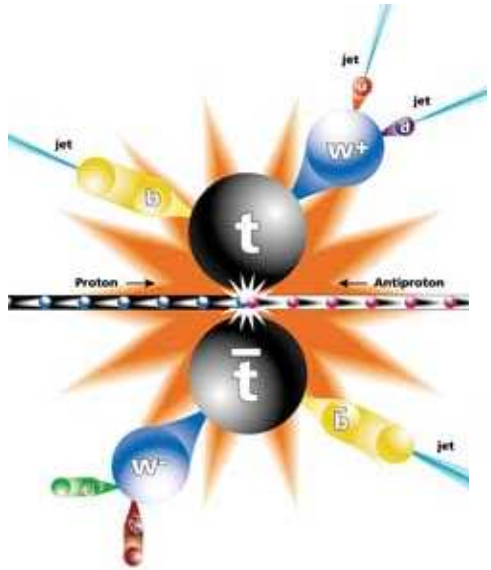
- Trackers: e, μ, $b-jets$, γ
- Calorimeters: e, μ, $jets$, $\not{E}_{\mathrm{T}}$, γ
- Muon Detectors: μ, $b-jets$ (soft $\mu's$)

Methods

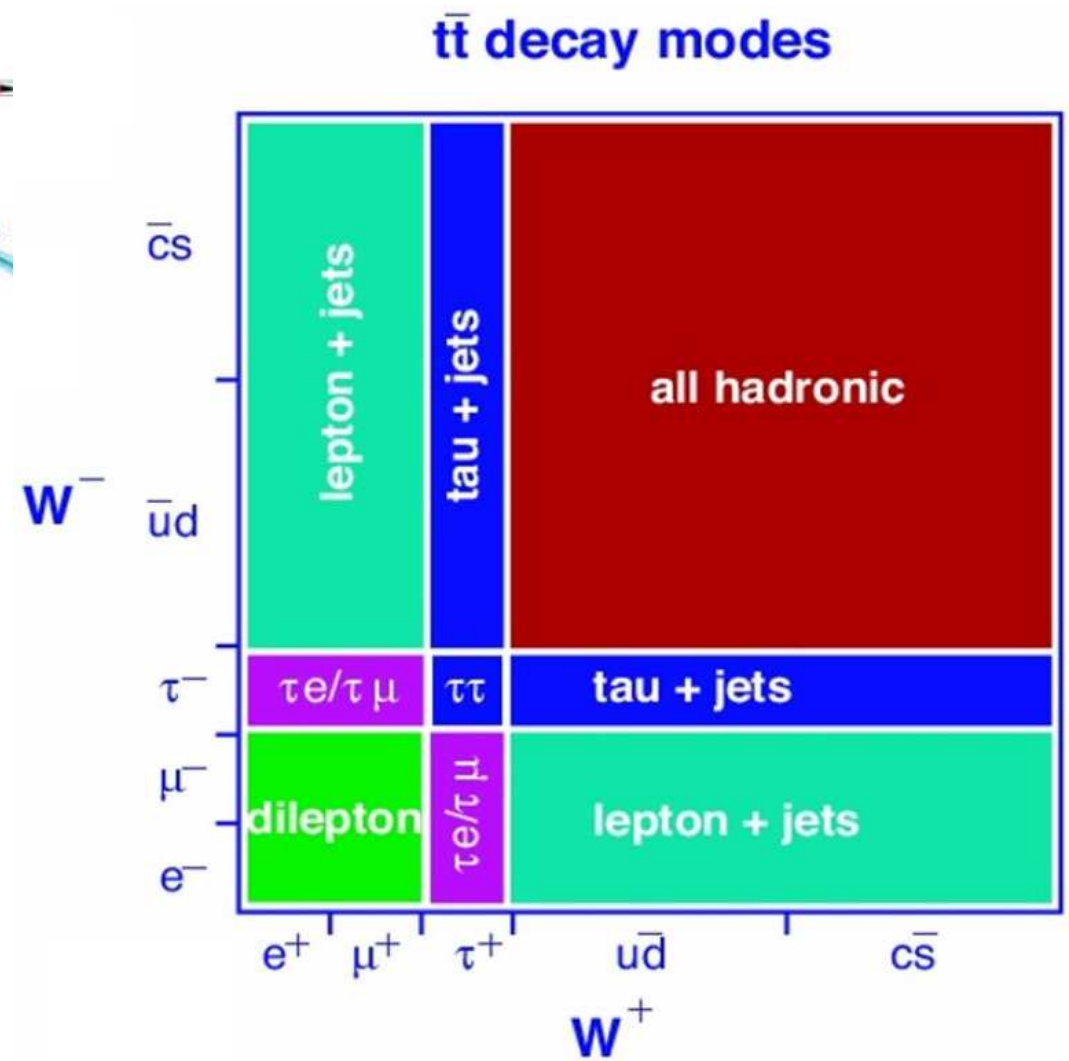
Background Estimates

- MC
  - WW, WZ, ZZ, Single Top, Z+Jets
- Data-Driven
  - QCD (Non-W)
    - Study $\not\!\!E_T$ in low-$\not\!\!E_T$ region (in jets or "antileptons" sample)
    - Calorimeter Isolation vs $\not\!\!E_T$
    - Track Isolation
  - W + Heavy Flavour
    - Simultaneous Fit of W+1 jet events, use secondary vertex mass, track parameters etc
  - MisTags
    - Mistag Matrix measured from inclusive jets sample
    - Detector resolution effects $\Rightarrow$ negative tags
    - HF $\Rightarrow$ positive tags

Physics



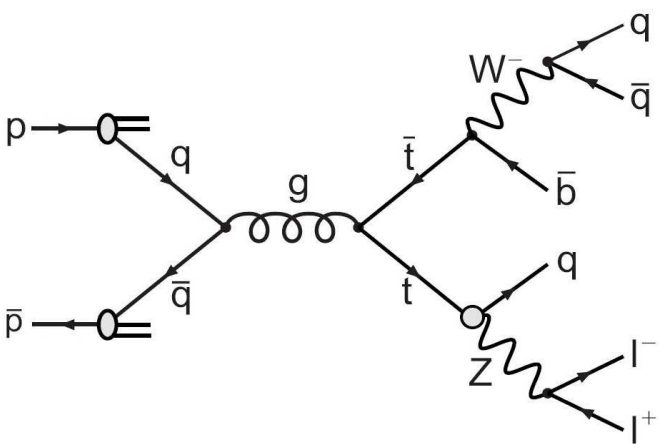
- Search for FCNC
  $\Rightarrow \ \ell\ell + \geq 4\ jets$
- Invisible Top Decays
  $\Rightarrow \ \ell \not{E}_T + \geq 2\ btags$
- Search for t'
  $\Rightarrow \ \ell \not{E}_T + \geq 4\ jets$
- $t\bar{t}$ Differential Cross-Section $d\sigma/dMt\bar{t}$
  $\Rightarrow \ \ell \not{E}_T + \geq 4\ jets$
- Charged Higgs
  $\Rightarrow \ \ell \not{E}_T + \geq 4\ jets$
- Search for Stop Quarks
  $\Rightarrow \ \ell\ell \not{E}_T + 2\ b - jets$
- $\ell\gamma \not{E}_T b$ Search and $t\bar{t}\gamma$
  $\Rightarrow \ \ell\gamma \not{E}_T b$ and $\ell\gamma \not{E}_T b + \geq 2\ jets$



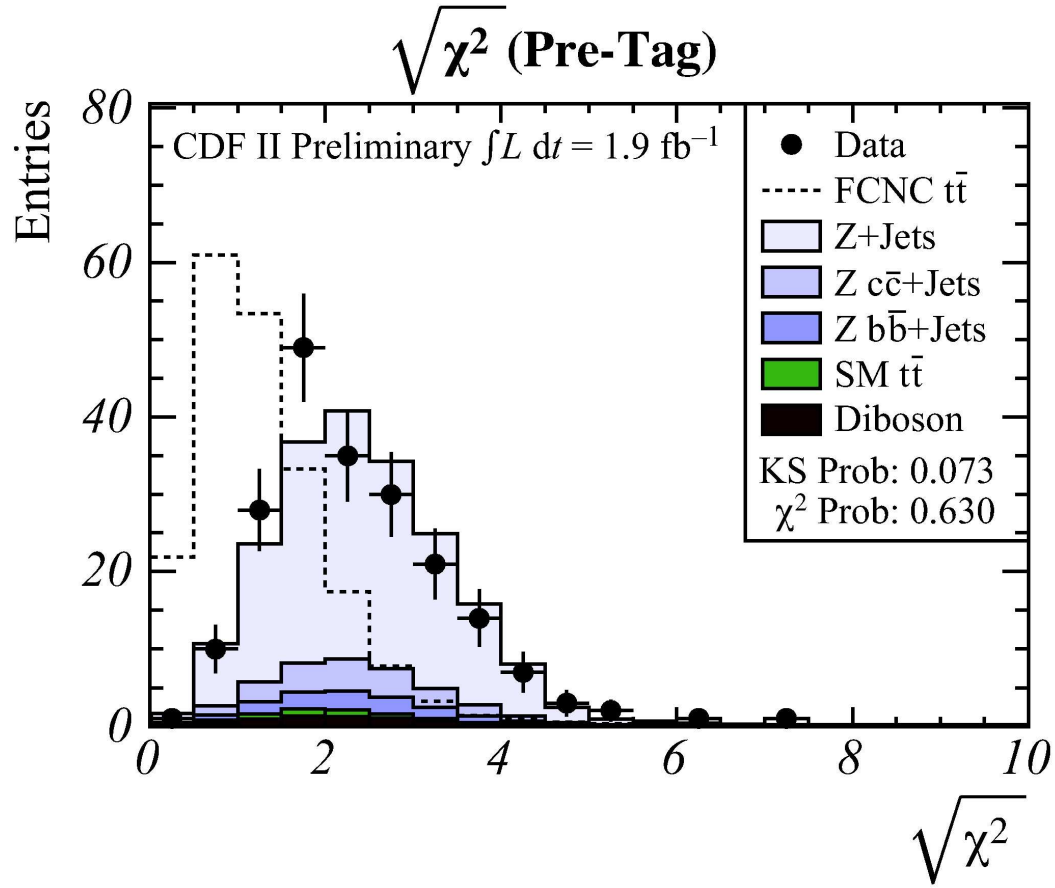
Physics

√ Search for the FCNC ($t \to Zq$)

- FCNC in the SM $O(10^{-14})$ (no tree level diagrams)
- FCNC in the NP $O(10^{-4})$ the search proposed by H.Fritzsch (1989)



- Signature: $Z^0 \to \ell^+\ell^-$ (ℓ+track) + 4 jets

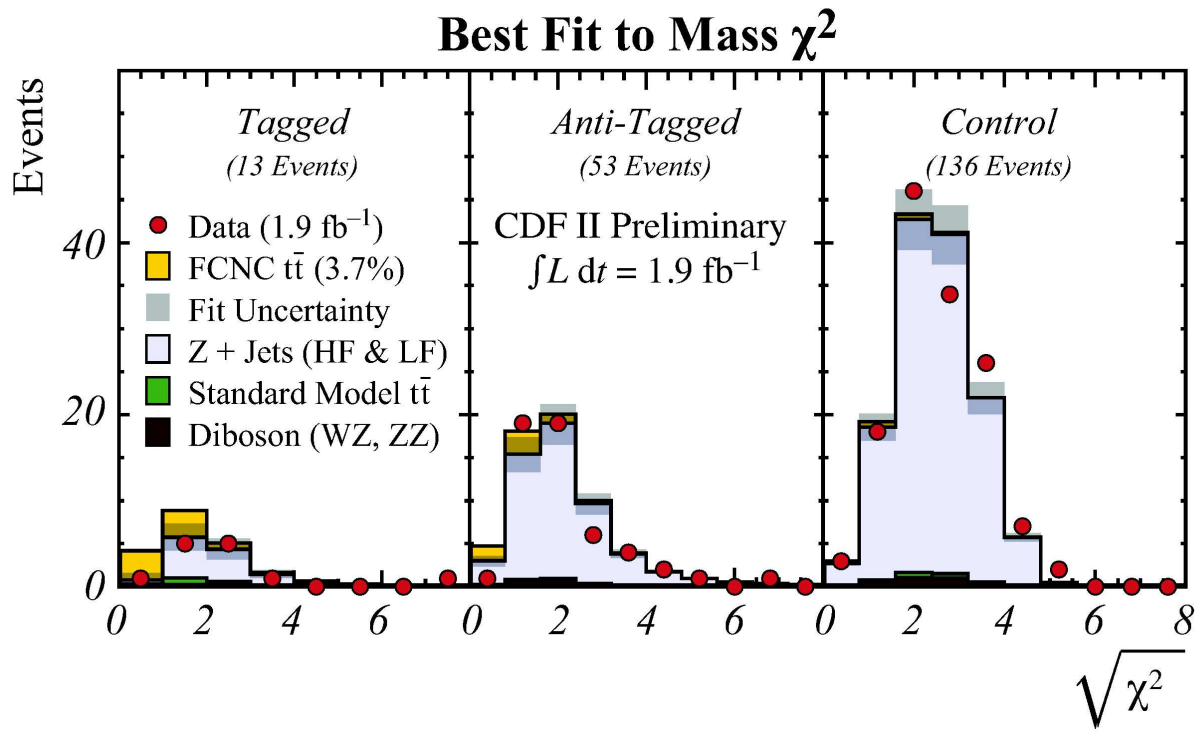


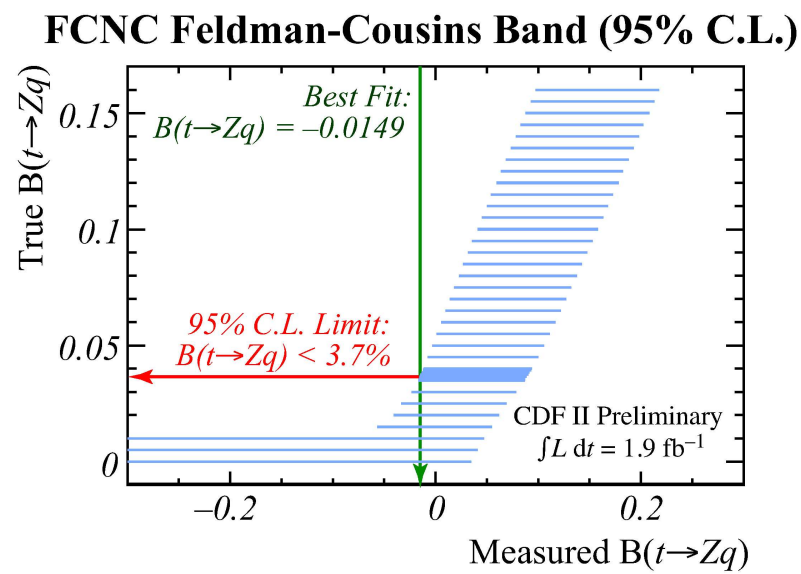
Mass χ^2

$$\chi^2 = \left(\frac{m_{W,rec} - m_{W,PDG}}{\sigma_{W,rec}}\right)^2 + \left(\frac{m_{t\to Wb,rec} - m_t}{\sigma_{t\to Wb}}\right)^2 + \left(\frac{m_{t\to Zq,rec} - m_t}{\sigma_{t\to Zq}}\right)^2$$

Physics

√ Search for the FCNC ($t \to Zq$)





- World's Best Limit

FCNC decays:

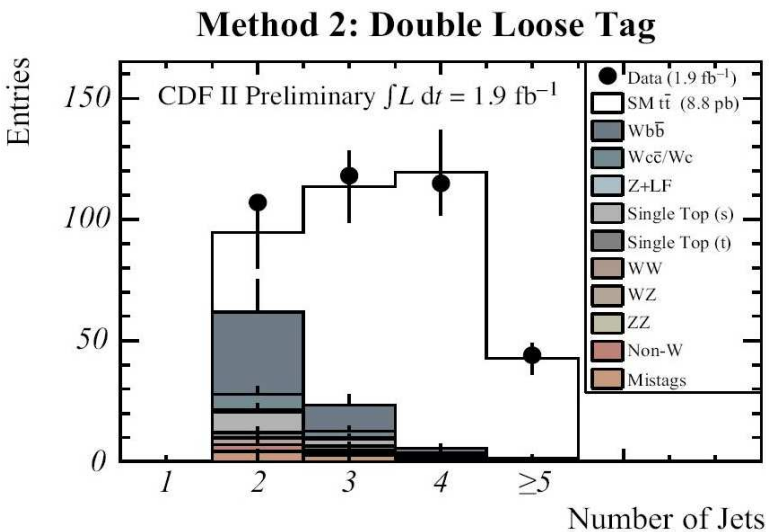
the observed 95% C.L. upper limit is

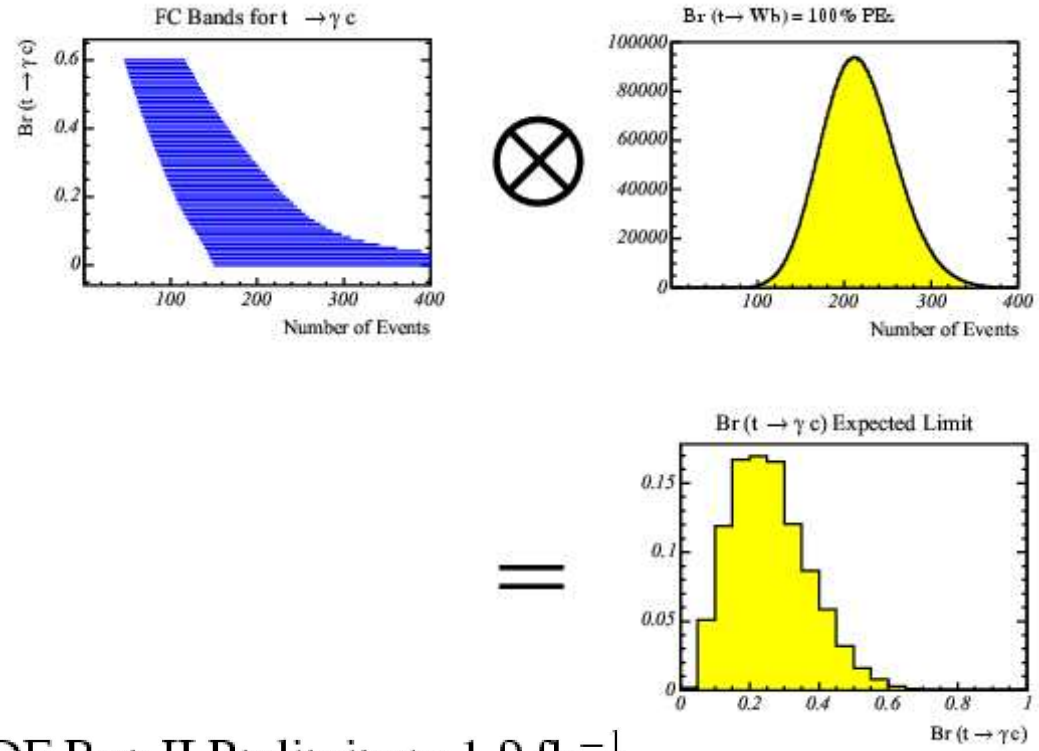
$\mathbf{Br(t \to Zq) = 3.7\%}$.

Physics

√ Invisible Top Decays

- Indirect search
- First Limit on B(t→invisible)
- $\ell + \not{E}_T + jets(2\ b - tags)$





CDF Run II Preliminary 1.9 fb^{-1}

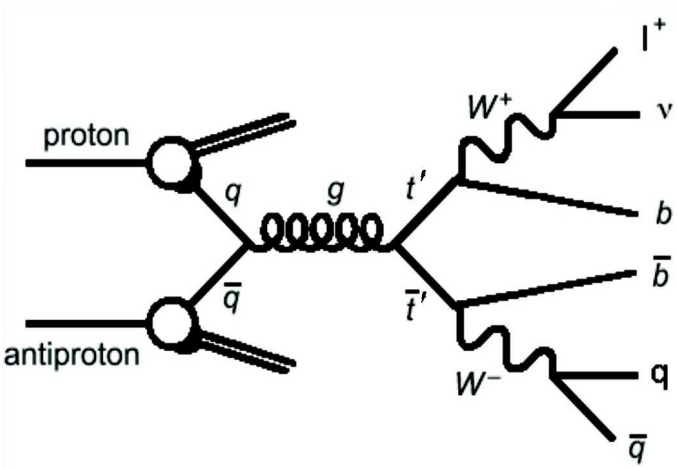
Decay	$\mathscr{R}_{wx/ww}$ (%)	Upper Limit (%) (175 GeV)
$\mathscr{B}(t \to Zc)$	32	13
$\mathscr{B}(t \to gc)$	27	12
$\mathscr{B}(t \to \gamma c)$	18	11
$\mathscr{B}(t \to \text{invisible})$	0	9

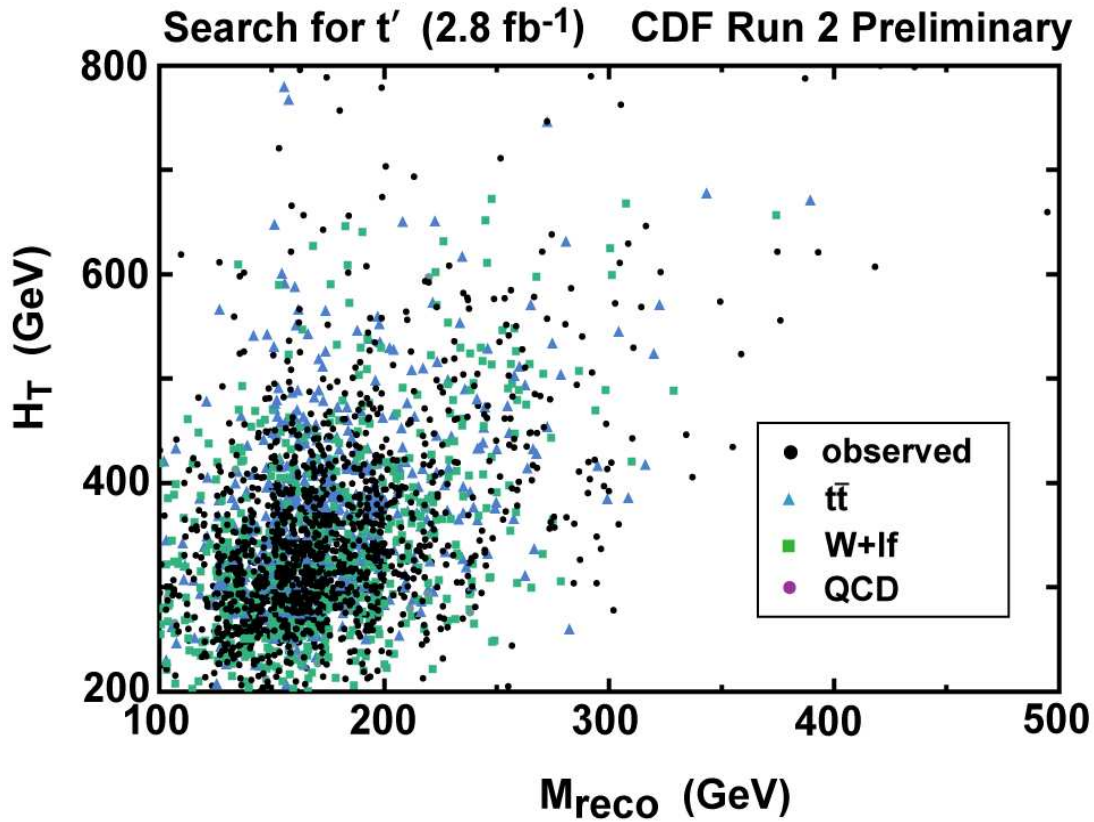
Physics

√ Search for t' Phys. Rev. Lett. 100, 161803 (2008)

Models

- Little Higgs ⇒ heavy "top"
- New heavy quarks: $(q' \to Wb)$
- EWK precision data: $A^b_{FB} \sim 2.9\sigma$ away





The Search

- $t' \to Wb'$ suppressed ⇒ $t' \to Wq$
- $V_{t'q} \approx V_{t'b}$, $BR(t' \to Wb) \approx$ 100%
- $\ell + \not{E}_T + jets$

Physics

√ Search for t' Phys. Rev. Lett. 100, 161803 (2008)

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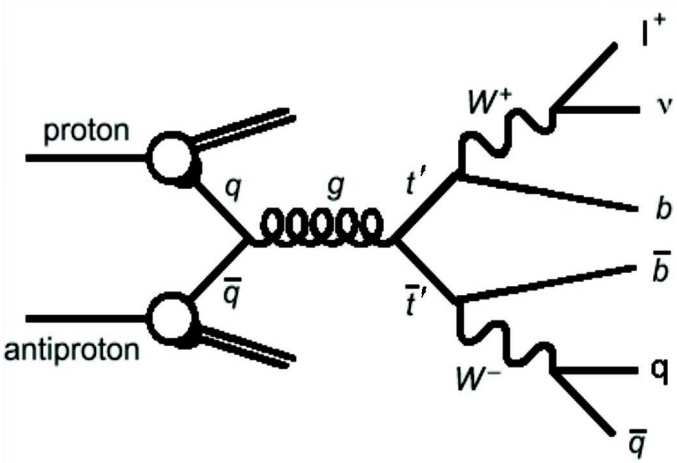

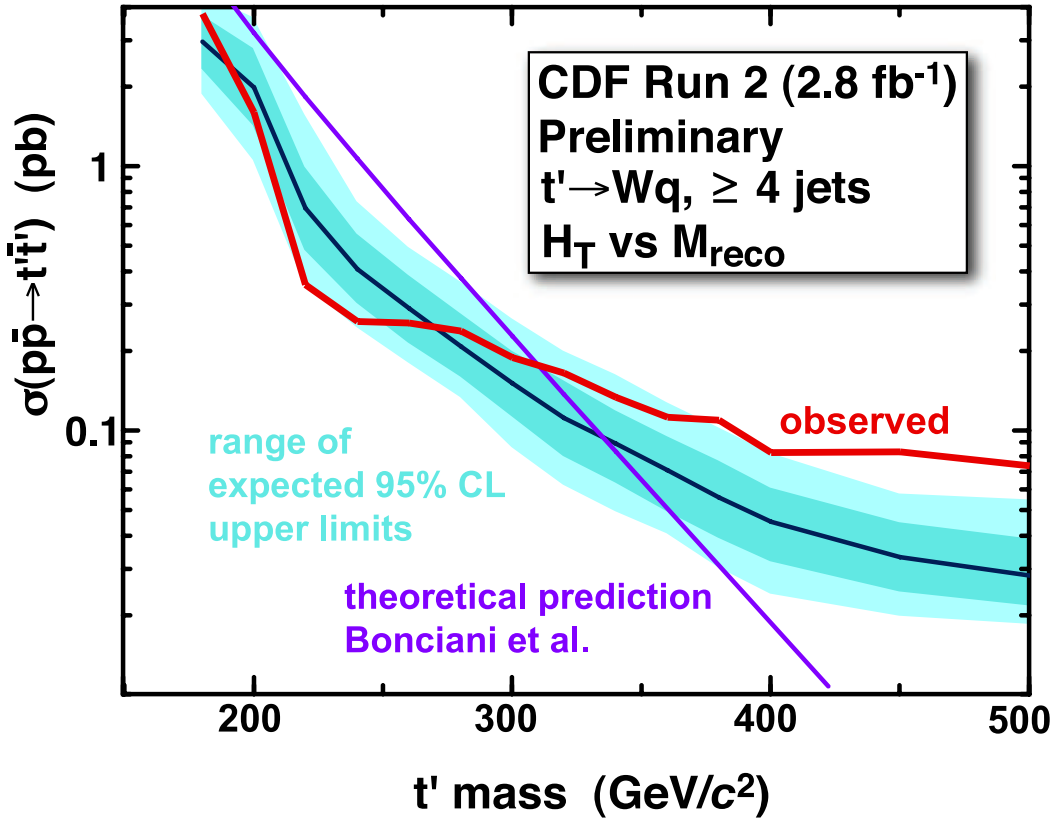

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- $V_{t'q} \approx V_{t'b}$, $BR(t' \to Wb) \approx$ 100%
- $\ell + \not{E}_T + jets$

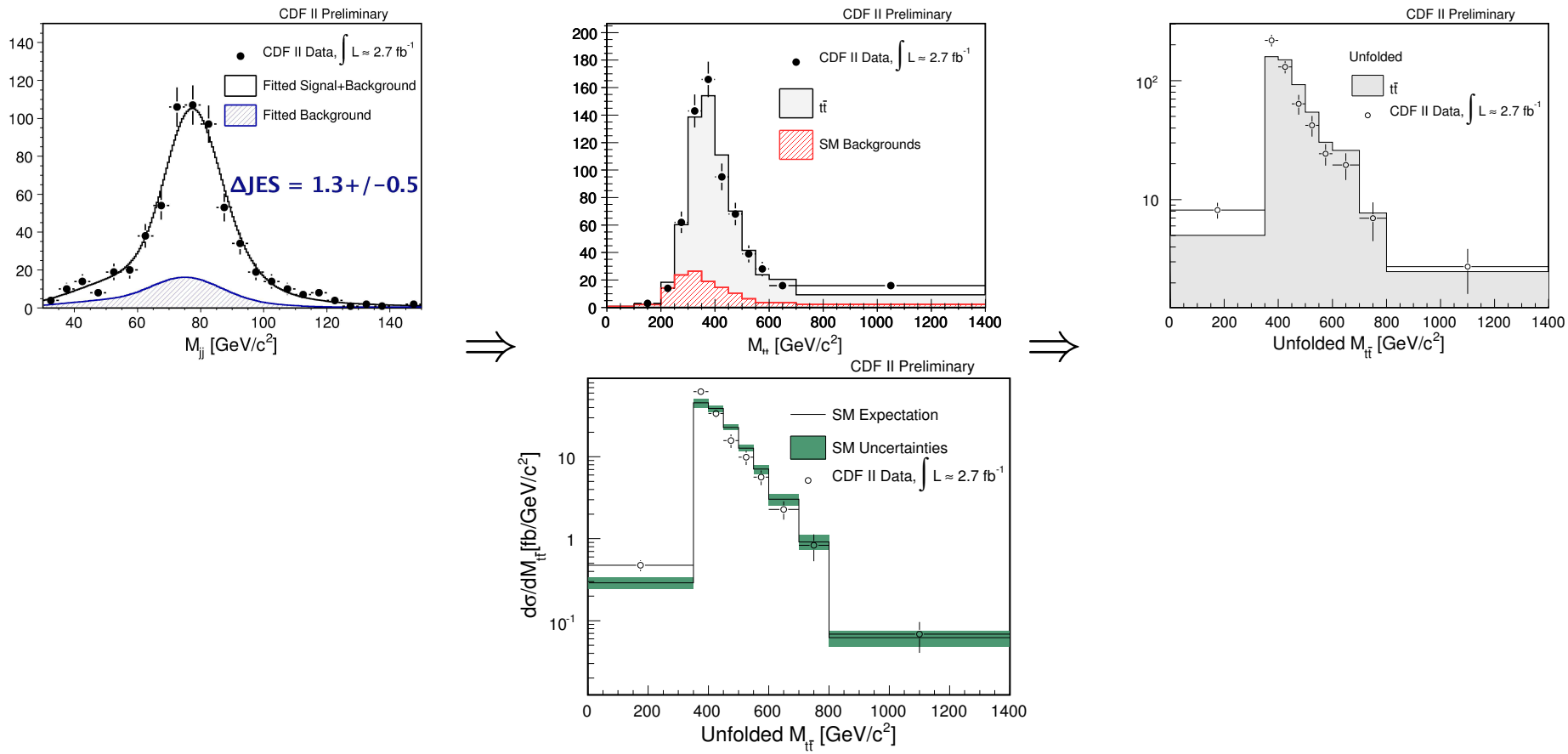
The purple curve is a theoretical $\sigma(p\bar{p} \to t't')$. The blue band represents $\pm 1\sigma$ expectation limit (light blue: $\pm 2\sigma$)

Physics

√ $t\bar{t}$ Differential Cross-Section $d\sigma/dMt\bar{t}$

- $\ell + \not{E}_T + 4\ jets$
- in-situ calibration of the jet energy scale (JES)
- unfolding technique

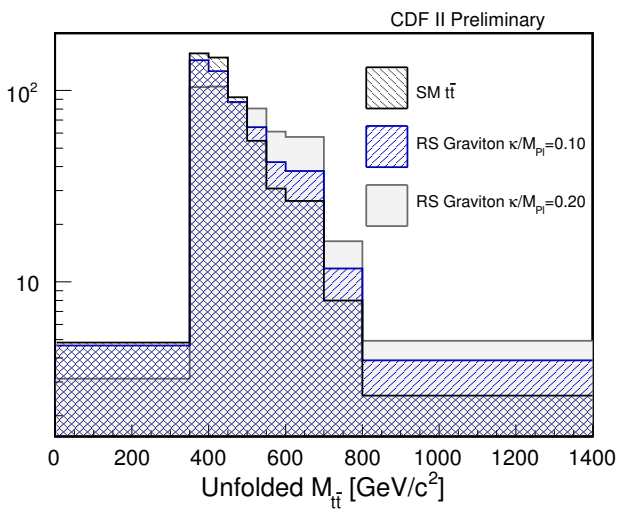
Hocker and Kartvelishvili, http://arxiv.org/abs/hep-ph/9509307



Physics

√ $t\bar{t}$ Differential Cross-Section $d\sigma/dMt\bar{t}$

- A limit on gravitons in the RS model
- Exclude $k/M_{Pl} > 0.16$ at the 95% CL



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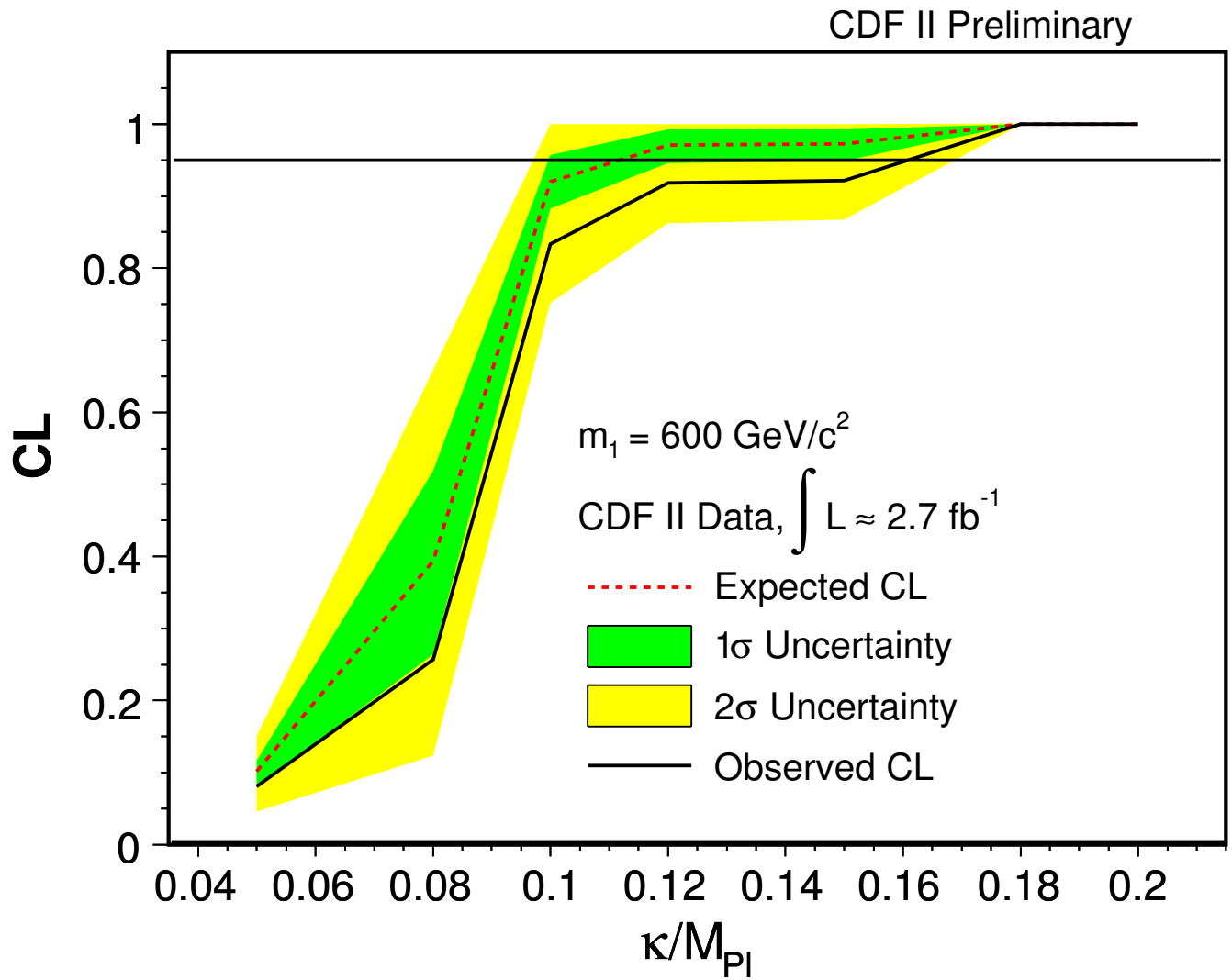
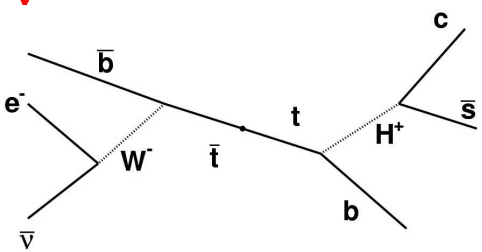
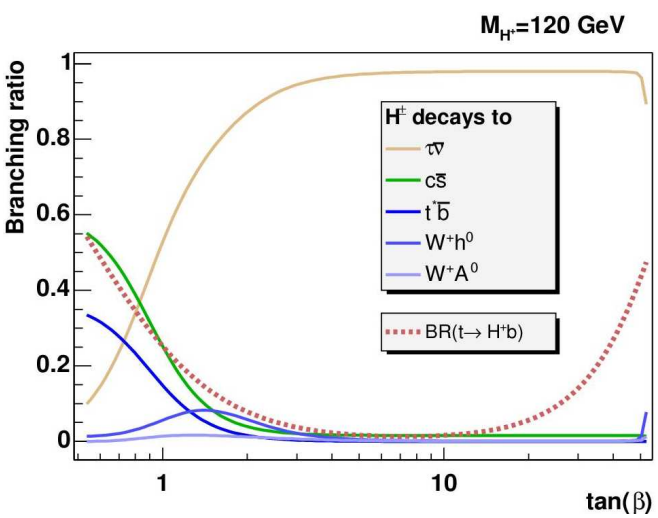


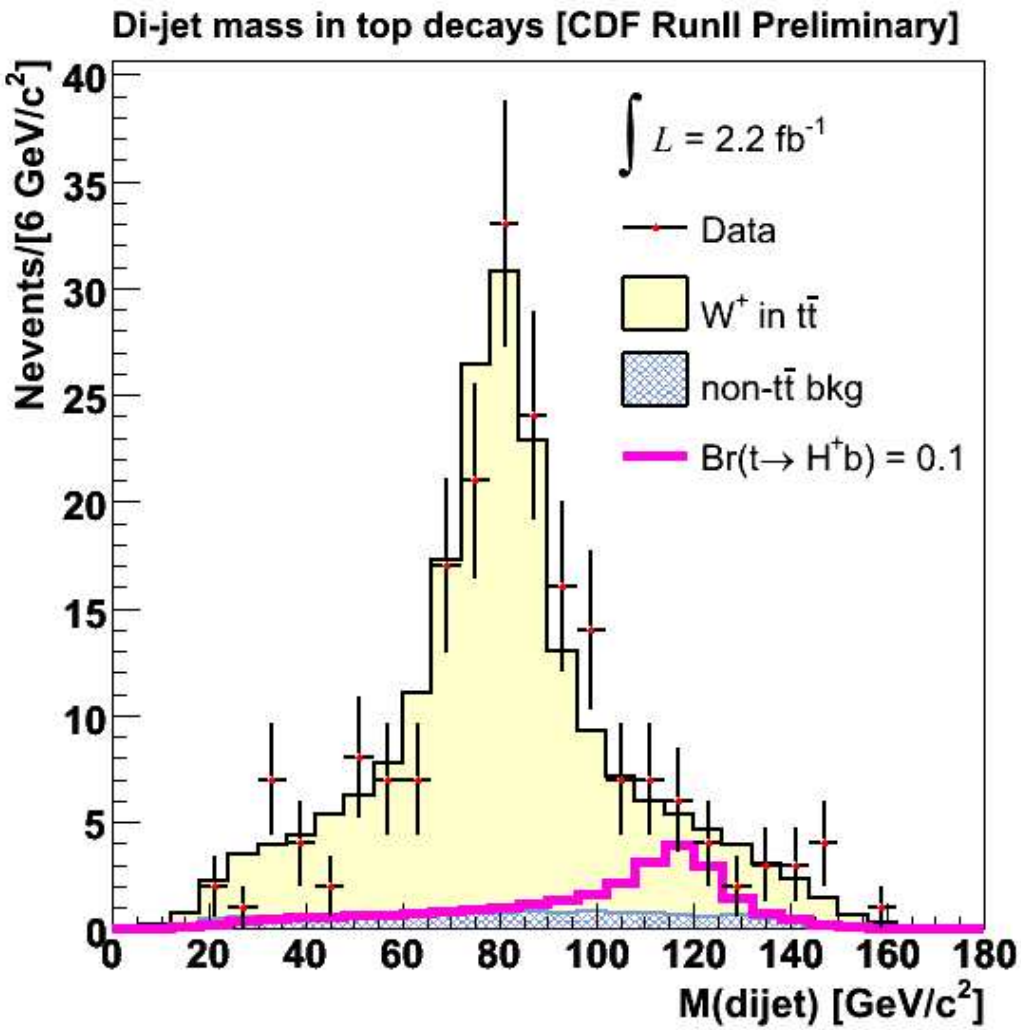
Physics

√ Search for Charged Higgs



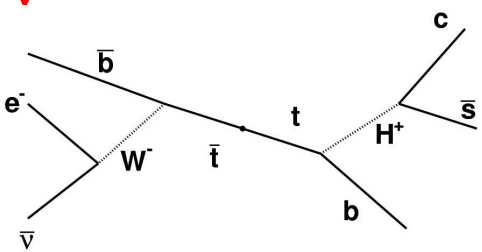
- MSSM Charged Higgs
- Assume: $B(H^+ \to c\bar{s}) = 1$, $B(t \to H^+ b) + B(t \to W^+ b) = 1$
- at low $\tan(\beta)$ $H+ \to c\bar{s}$ dominates
- $\ell + \not{E}_T + at\ least\ 4\ jets$





Physics

√ Search for Charged Higgs



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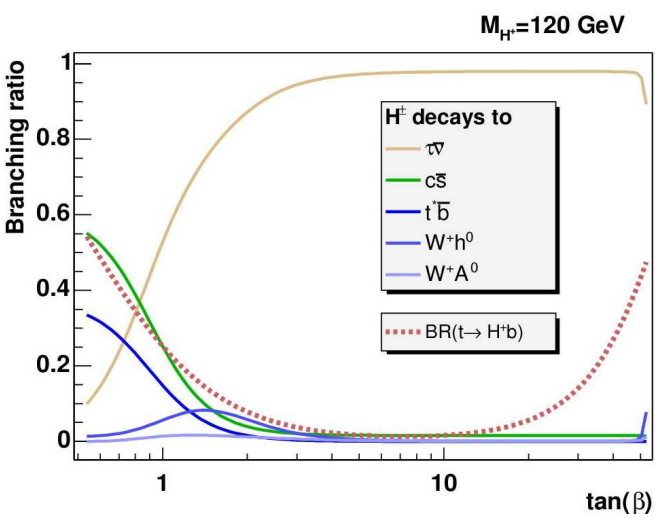
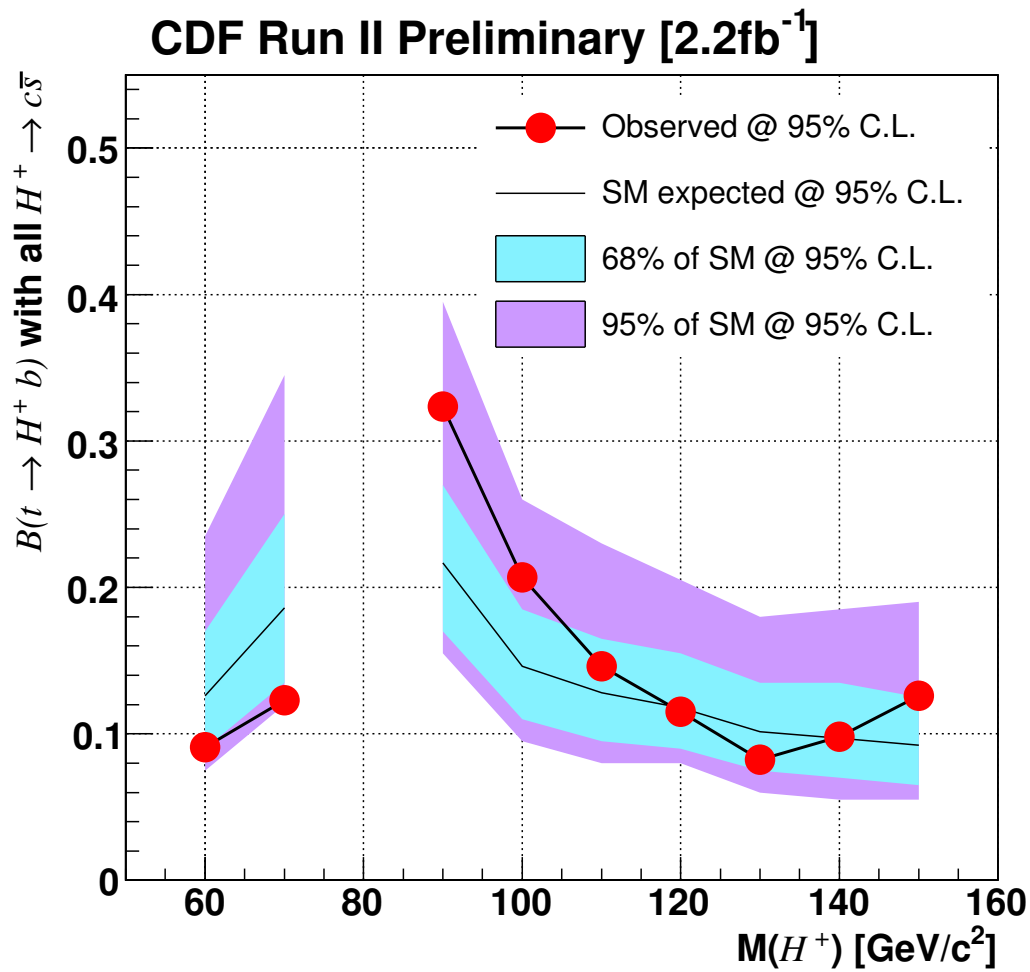
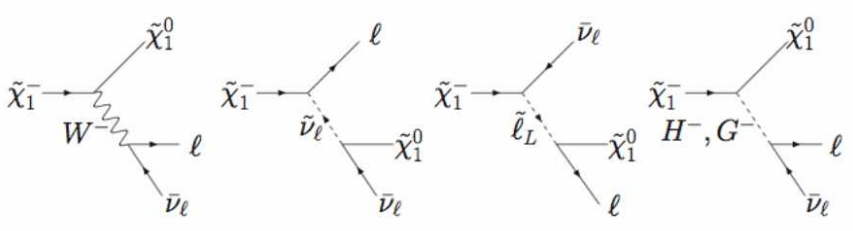


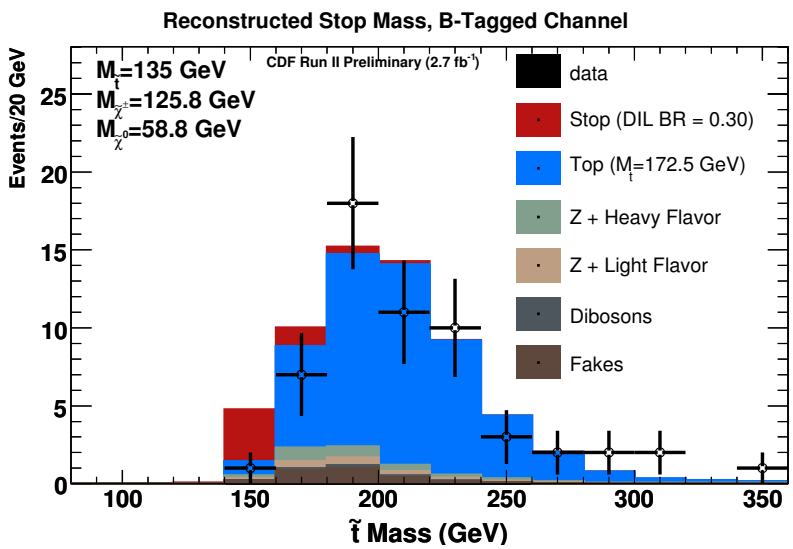


Physics

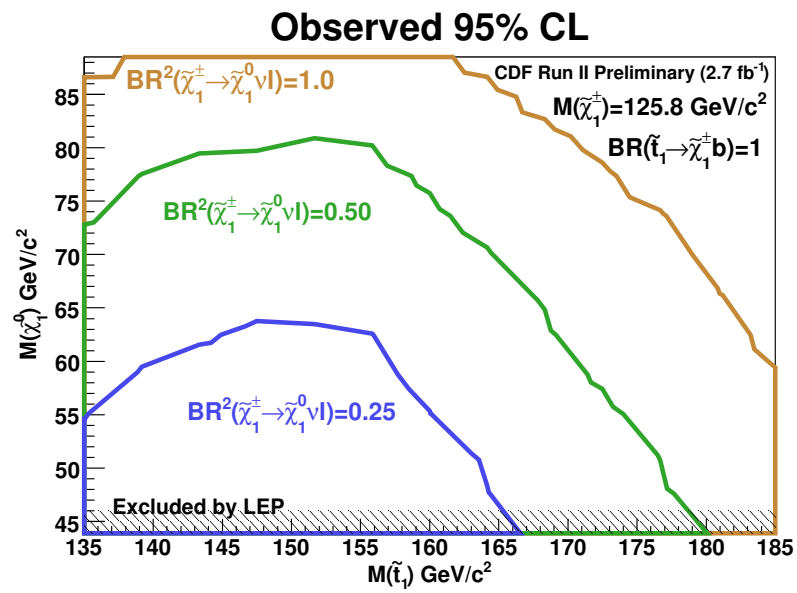
√ Search For Pair Production of Stop Quarks

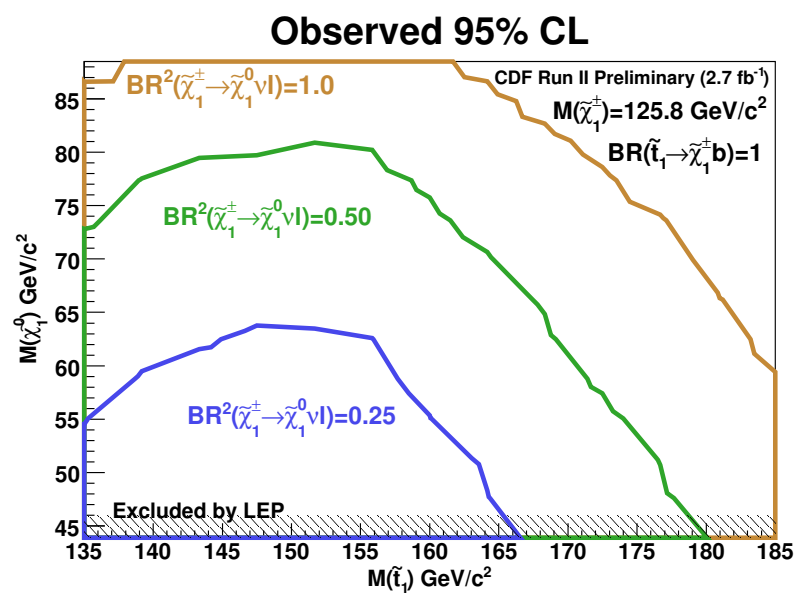
- $\tilde{t} \rightarrow b\tilde{\chi}_1^{\pm} \rightarrow b\tilde{\chi}_1^0 \ell\nu$
- $\ell\ell \not{E}_T + 2\ b - jets$





$\Rightarrow$



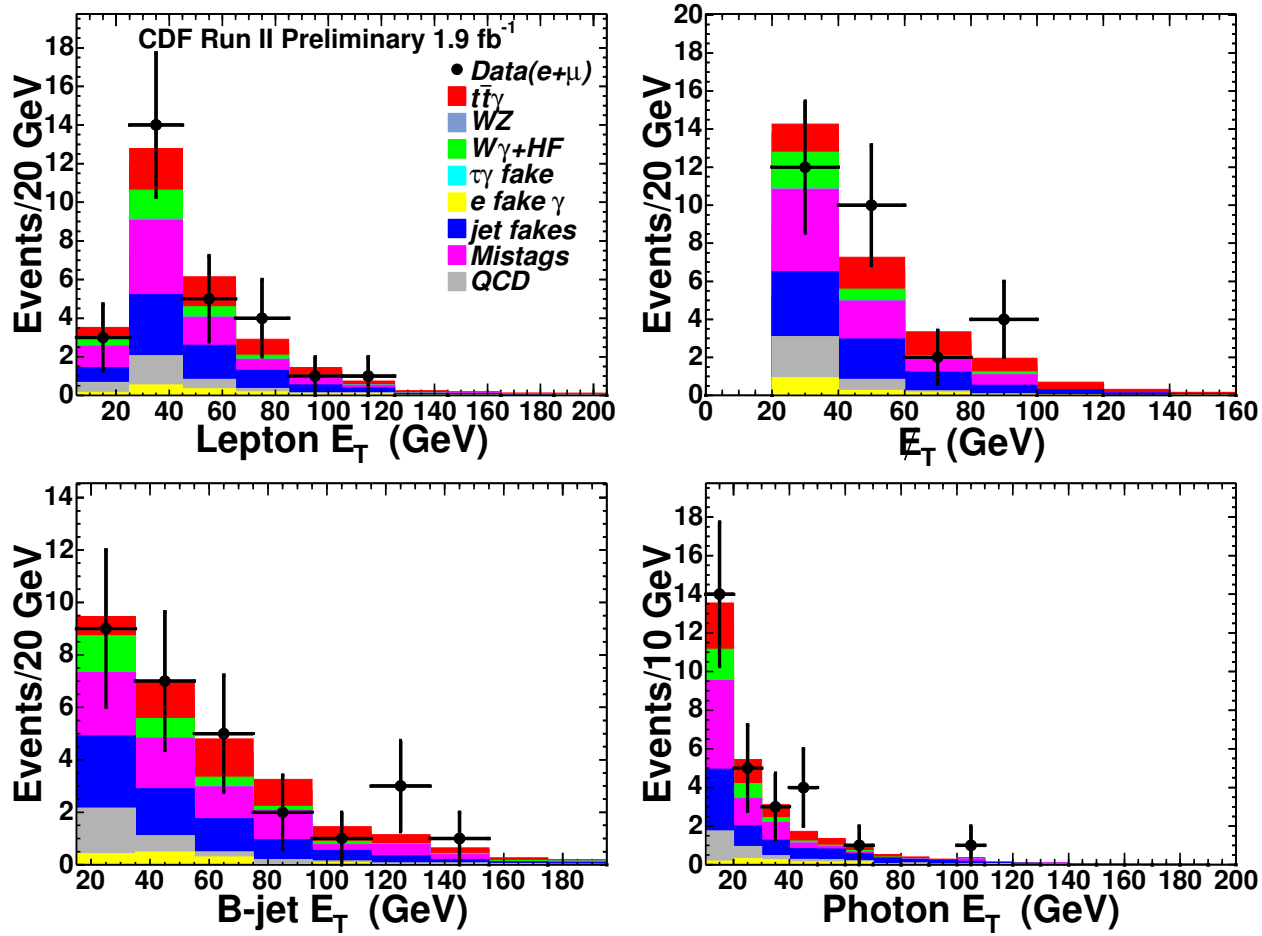


Physics

√ $\ell\gamma\not{E}_{\mathrm{T}}b$ Search and $\sigma_{t\bar{t}\gamma}$

Motivation

- Extension of $\ell\gamma\not{E}_{\mathrm{T}}$
- Signature with b and t, W and γ
- $t\bar{t}\gamma$: control sample for $t\bar{t}H$ (LHC), Q(top)



Results

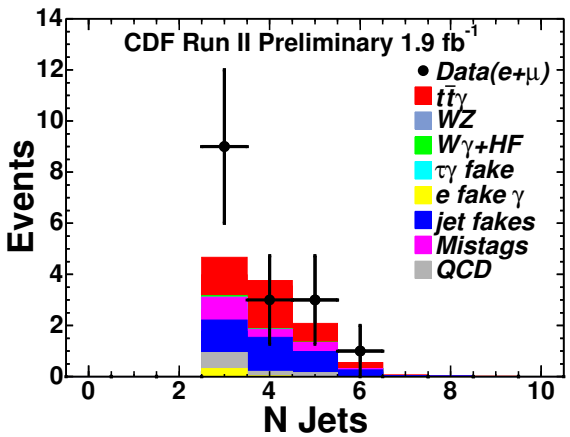
CDF Run II Preliminary, $1.9\mathrm{fb}^{-1}$			
$\ell\gamma\not{E}_{\mathrm{T}}b$	$e\gamma\not{E}_{\mathrm{T}}b$	$\mu\gamma\not{E}_{\mathrm{T}}b$	$(e+\mu)\gamma\not{E}_{\mathrm{T}}b$
Expected	16.8 ± 2.2	$11.1^{+1.7}_{-1.4}$	$27.9^{+3.6}_{-3.5}$
Observed	16	12	28

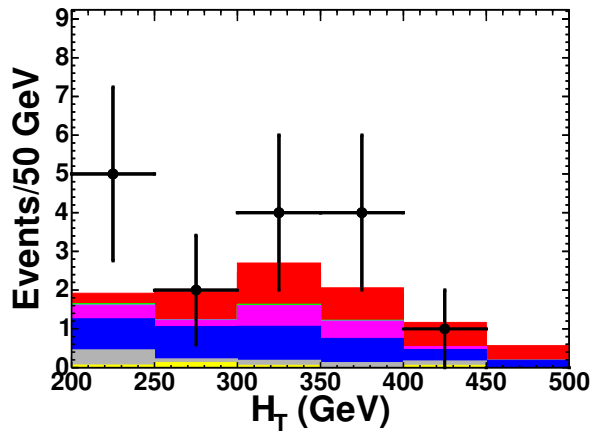
Physics

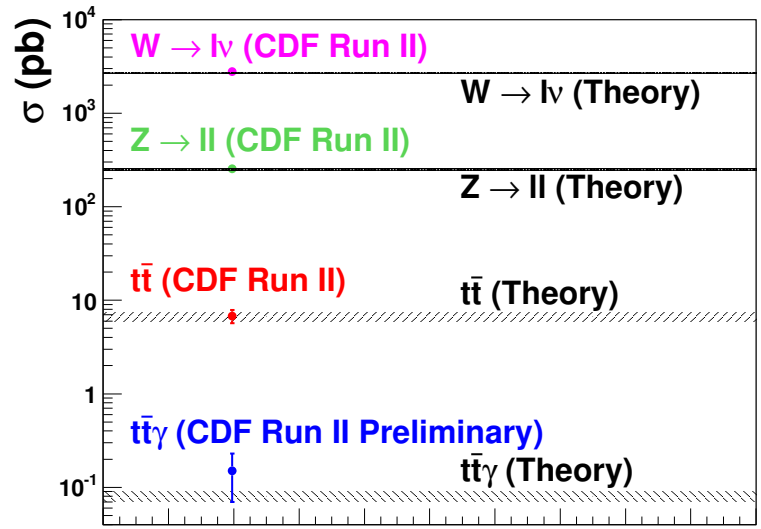
√ $\ell\gamma\not{E}_T b$ Search and $\sigma_{t\bar{t}\gamma}$

CDF Run II Preliminary, 1.9fb^{-1}

$t\bar{t}\gamma$	$t\bar{t}\gamma(e)$	$t\bar{t}\gamma(\mu)$	$t\bar{t}\gamma(e+\mu)$
Predicted	$6.7 \pm 1.4(tot)$	$4.4^{+1.3}_{-0.8}(tot)$	$11.1^{+2.3}_{-2.1}(tot)$
Observed	8	8	16







- No SM $t\bar{t}\gamma \Rightarrow$ 1% (2.3σ) to observe 16 events
- $\sigma_{\mathbf{t\bar{t}\gamma}} = \mathbf{0.15 \pm 0.08}$ pb.
- $\sigma^{\mathbf{SM}}_{\mathbf{t\bar{t}\gamma}} = \mathbf{0.080 \pm 0.011}$ **pb**.

- Signature: $\ell\gamma\not{E}_T$+**b jet**+H_T+$N_{jets} > 2$

Summary

- **Tevatron and CDF are running very well**
- **Top sample is getting bigger**
  - **Can look at the rarer signatures**
  - **Precision top physics**

- **Keep digging and pushing limits**
  - $Br(t \to Zq) < 3.7\%$ **@ 95% CL**
  - $Br(t \to \ invisible) < 9\%$ **@ 95% CL**
  - **Exploring fb cross-sections territory** ($t\bar{t}\gamma$)
- **Will have ~3 times more $\mathcal{L}$ than presented in the talk**
- **CDF Top Physics Results: http://www-cdf.fnal.gov/physics/new/top/top.html**