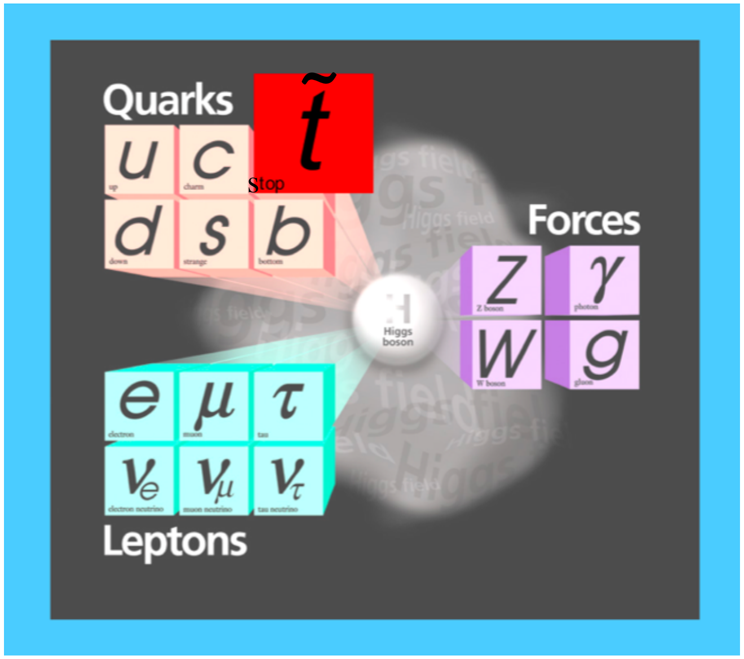
Searches for stop squarks at the Tevatron



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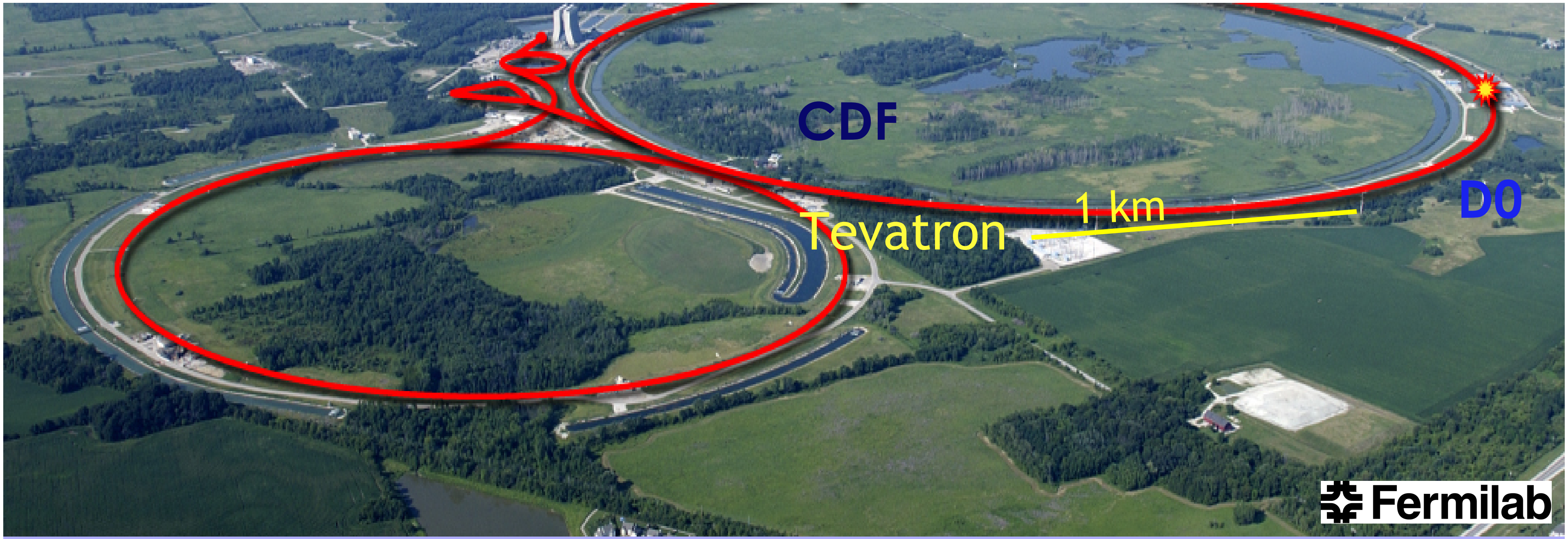
The Tevatron (RIP)

Fermilab's Tevatron Run II $p\bar{p}$ collider at 1.96 TeV.

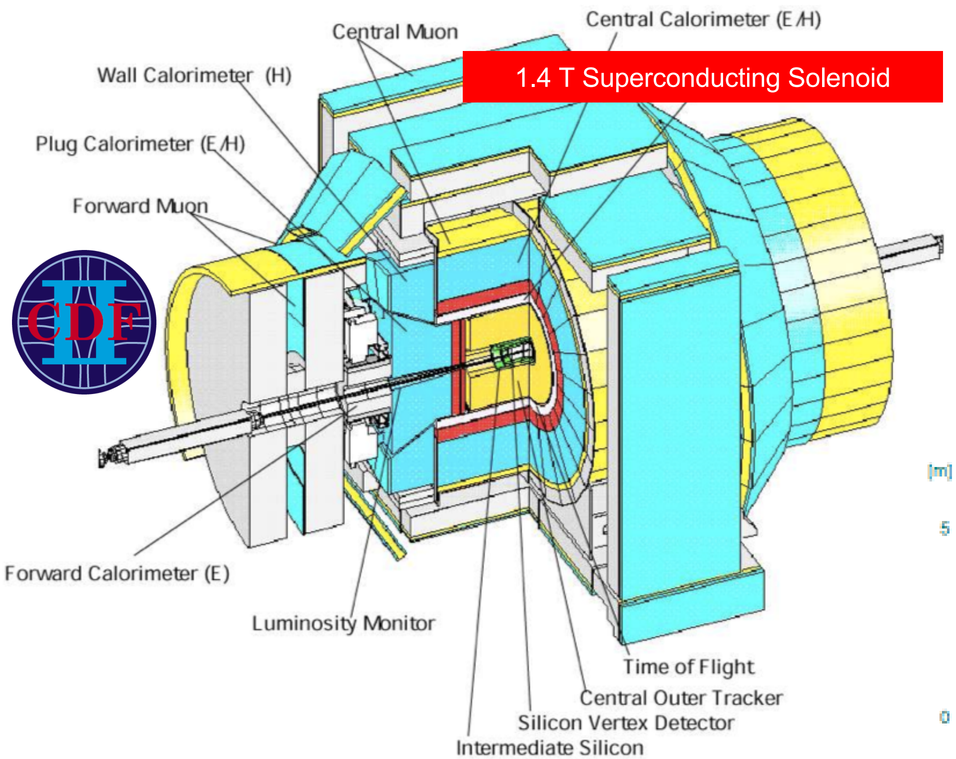
Almost three decades at the energy frontier

- Record instantaneous luminosity $4 \cdot 10^{32}$ cm^{-2} s^{-1}
- Record in delivered luminosity 2.5 fb^{-1} per year
- Two multi-purpose, well-understood detectors CDF and D0

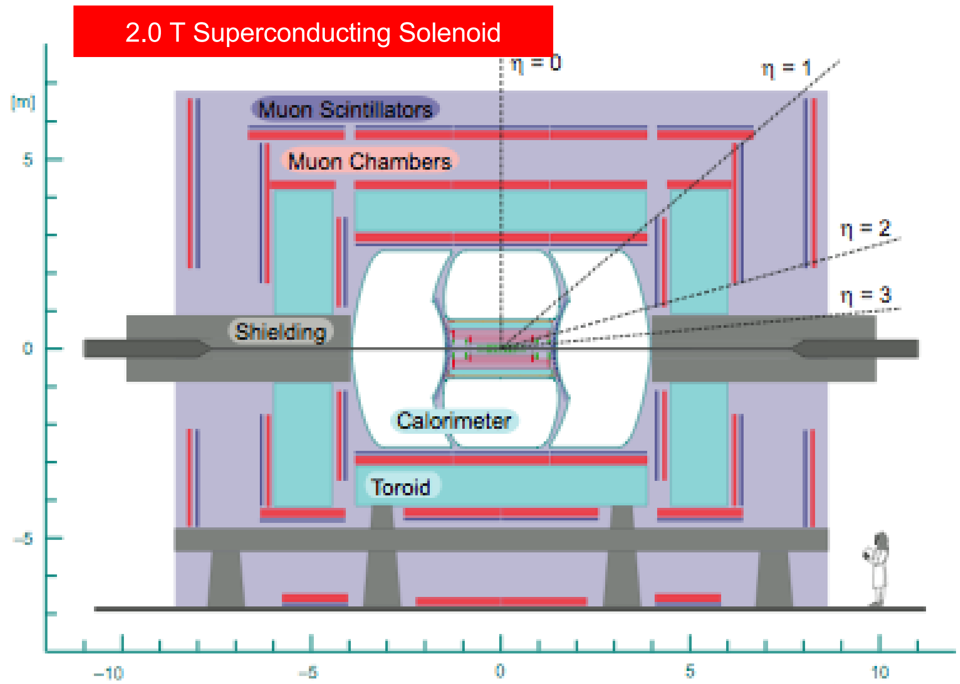
Stop created in 1 in O(10^{11}) or less collisions at the Tevatron



Its detectors



Calorimeter (EM+HAD)
Shower maximum detector in EM
Cal coverage: $|\eta|<3.6$ CDF
$|\eta|<4.2$ D0

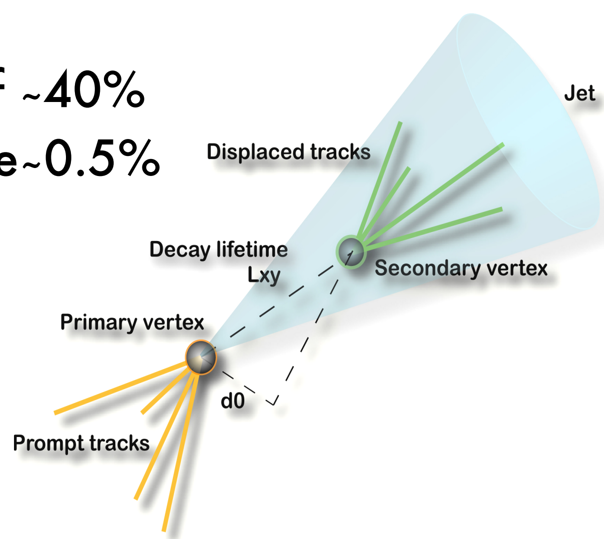


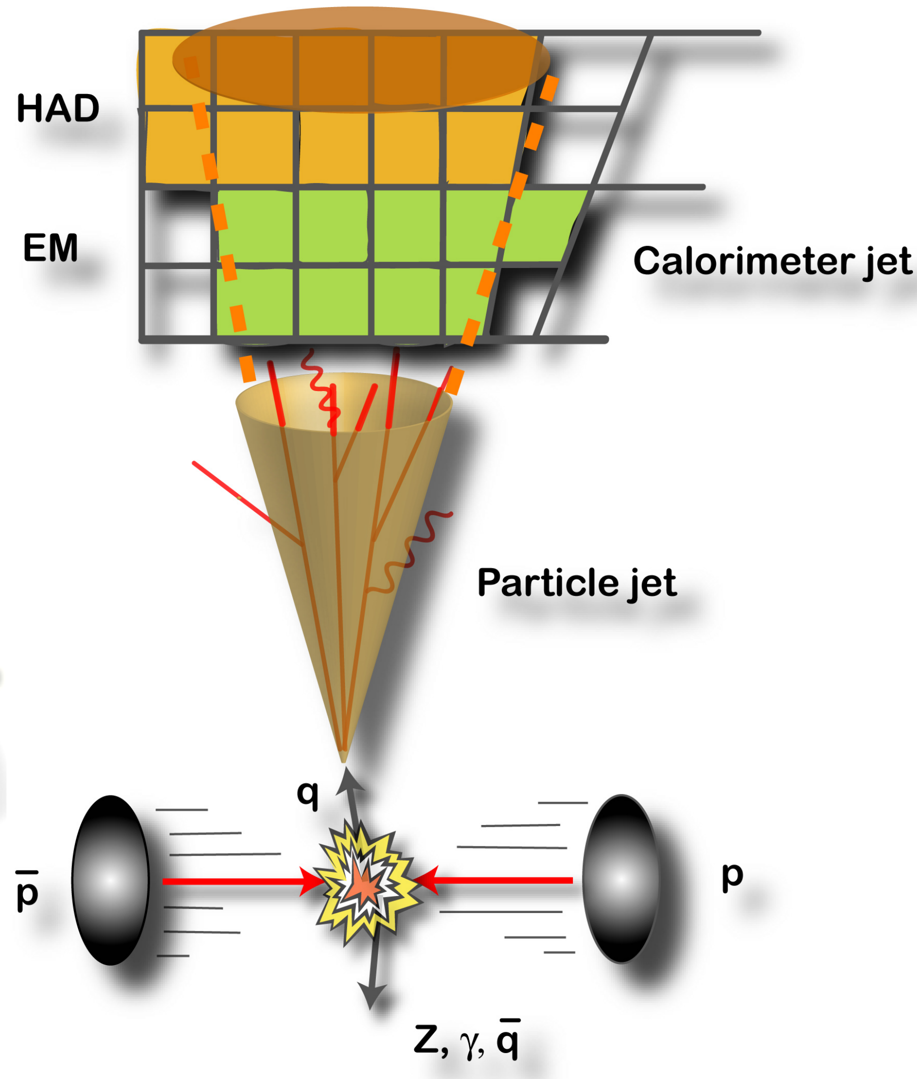
- ✓ Tracking: silicon tracker allows precision vertex detection $|\eta|<2$ (2.5) for CDF (D0) and spectrometer up to $|\eta|<1.5$ (3) for CDF (D0)
  - ✓ Muon chamber outside calorimeter coverage $|\eta|<1.5$ (2.0) for CDF (D0)

Jets at the Tevatron

- Use cone based jet reconstruction algorithm
  - energy resolution driven by HAD cal resolution $80\%/\sqrt{E_T}$
  - Non-instrumented regions in calorimetry+resolution effects lead to mismeasurement of jet $E_T \rightarrow$ source of apparent MET

- Typical b-tagging id numbers at CDF/D0:
  - b-tag eff ~40%
  - fake rate~0.5%





$\tilde{t} \to ?$

- $\sigma(\tilde{t}\tilde{t}) \sim 1/10\ \sigma(tt)$
- Too many final states
- D0/CDF investigated:

$\tilde{t} \to b\tilde{\chi}^{\pm} \to b\tilde{\nu}l$

$\tilde{t} \to c\tilde{\chi}$

$\tilde{t} \to b\tilde{\chi}^{\pm} \to b\tilde{\chi}^{0}l\nu$

- For stop heavier than top, the decay $\tilde{t} \to t\chi^0$ could be the favorite one
  - Main topic of this talk

$$\tilde{t} \to t\tilde{\chi}^{0}$$

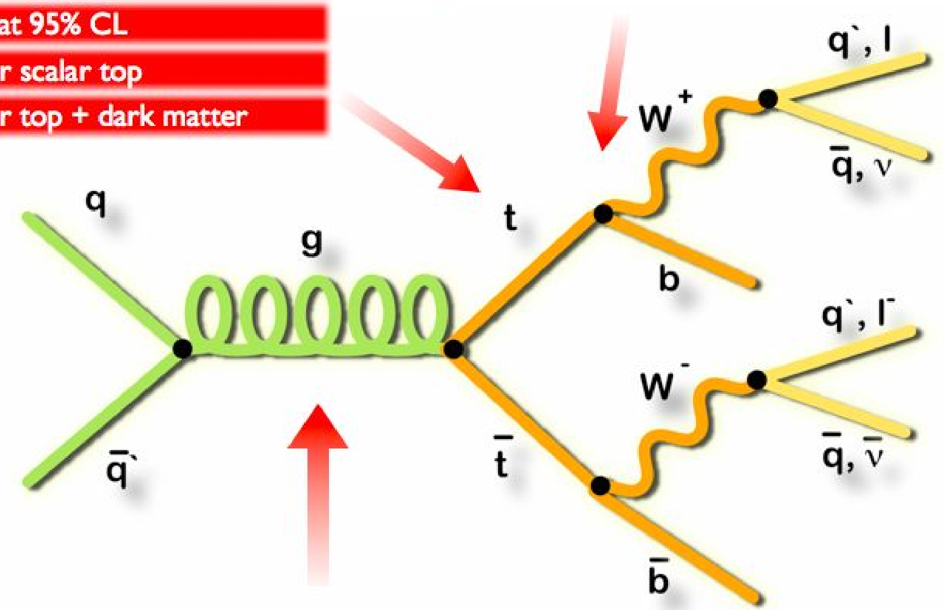
Is it really the SM top?

Intrinsic properties

- $M_t = 173.3 \pm 1.1$ GeV/c^2
- $M_t - M_{tbar} = -3.3 \pm 1.7$ GeV/c^2
- $\Gamma_t < 7.5$ GeV at 95% CL
- Exclude q = -4/3 at 95%CL
- $M_{t'} > 335$ GeV at 95% CL
- No evidence for scalar top
- No evidence for top + dark matter

Decay properties

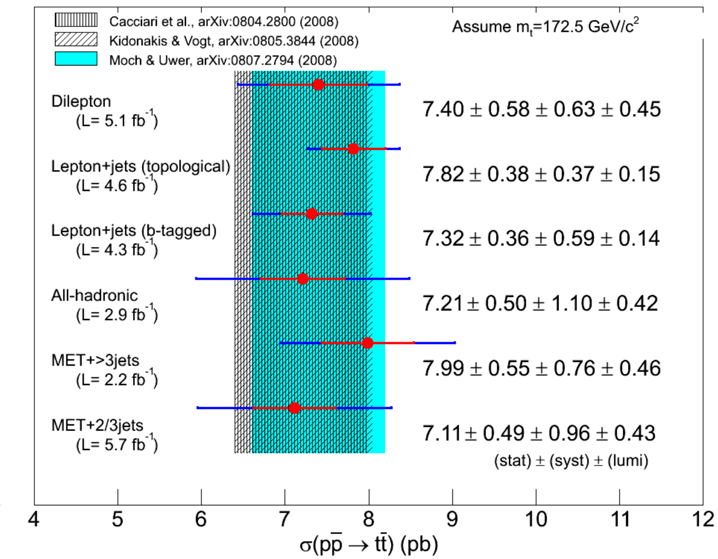
- Vtb = 0.91 ± 0.11 (exp) ± 0.07 (theory)
- No evidence for charged Higgs
- $F_0 = 0.67 \pm 0.10$ & $F_+ = 0.02 \pm 0.05$
- BR(t→Zq) < 3.3% at 95% CL
- BR(t→gu) < 0.2% at 95% CL

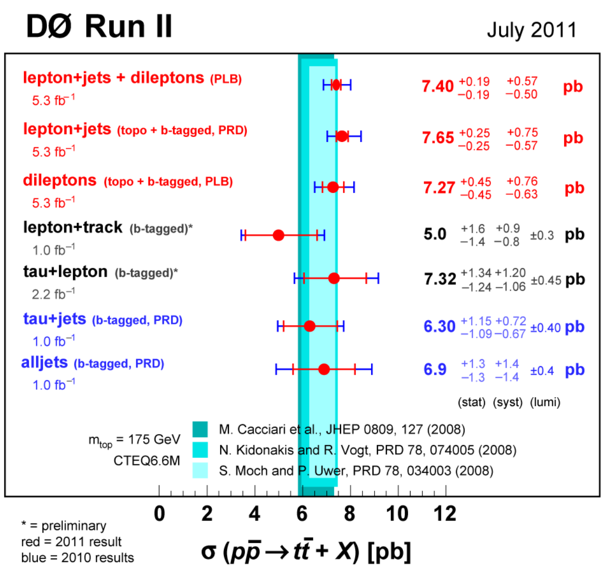


Production properties

- $M_{Z'} > 900$ GeV at 95% CL
- $M_{W'} > 800$ GeV at 95% CL
- $M_{b'} > 372$ GeV at 95% CL
- $F_{gg} = 0.07^{+0.15}_{-0.07}$ (stat+sys)
- A_{fb} = 15-40% (parton level)
- Spin Correlations $\kappa = 0.6 \pm 0.5_{stat} \pm 0.2_{sys}$

Hints from σ(tt̄) measurements

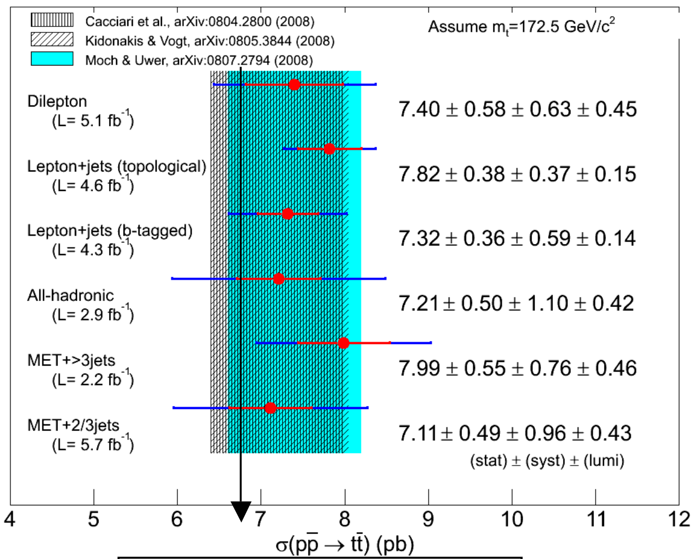




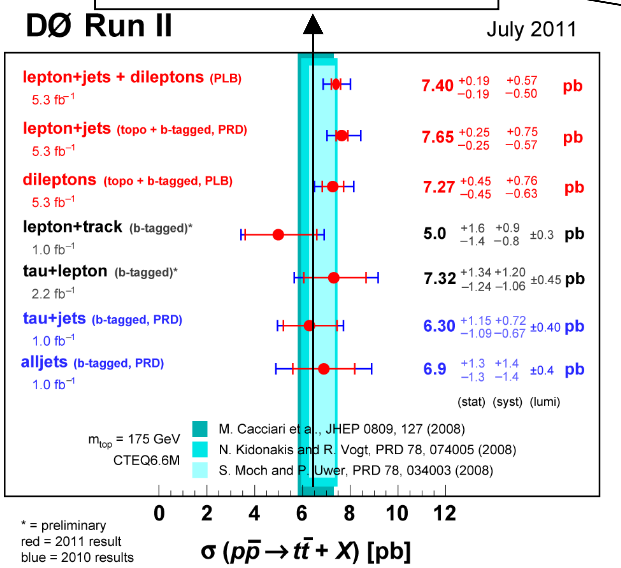
Measurements in good agreement with theory
CDF's world's most precise <7% uncertainty

Most precise determinations (in leptonic channels) > theory

Hints from σ(tt̄) measurements



Ahrens et al 1105.5824



Measurements in good agreement with theory
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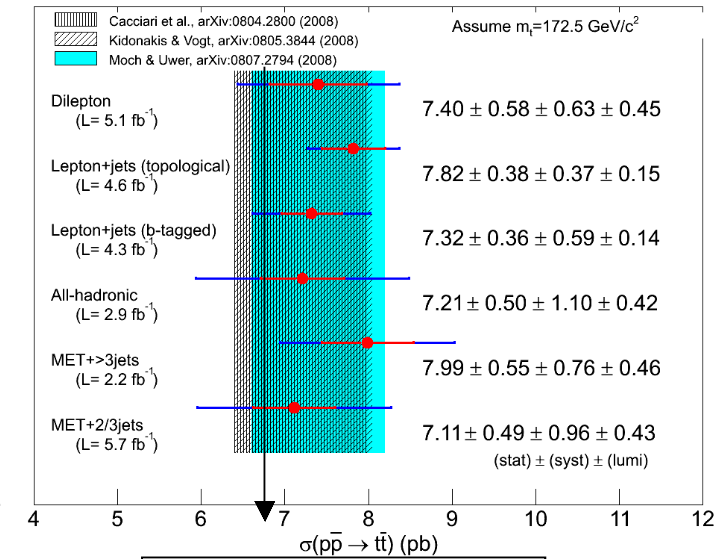
Most precise determinations (in leptonic channels) > theory

Interestingly, one theoretician group computes a quite lower value - room for new physics?

Isidori/Kamenik PLB 700 145-149
Suggest SUSY with flavor violationg could account for the anomalous top AFB

Hints from σ(tt̄) measurements



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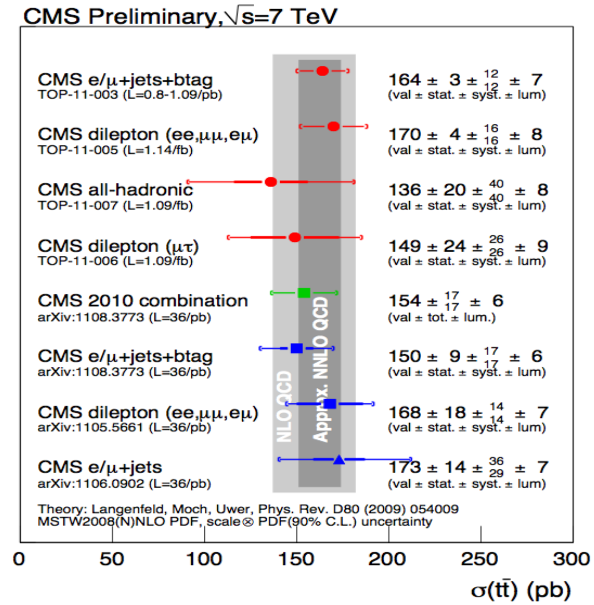
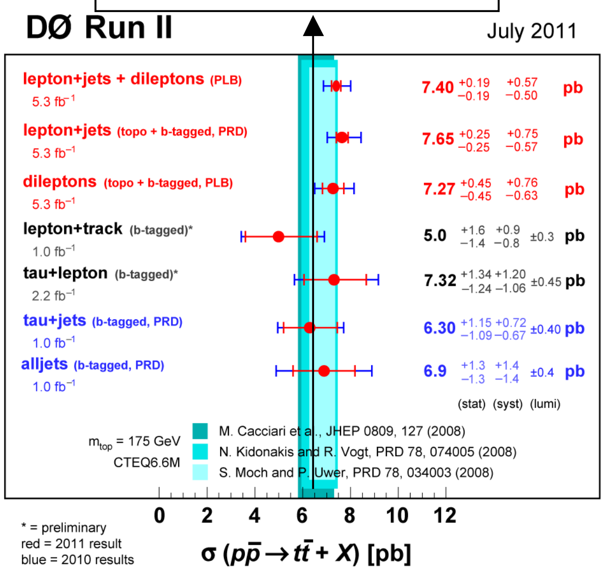
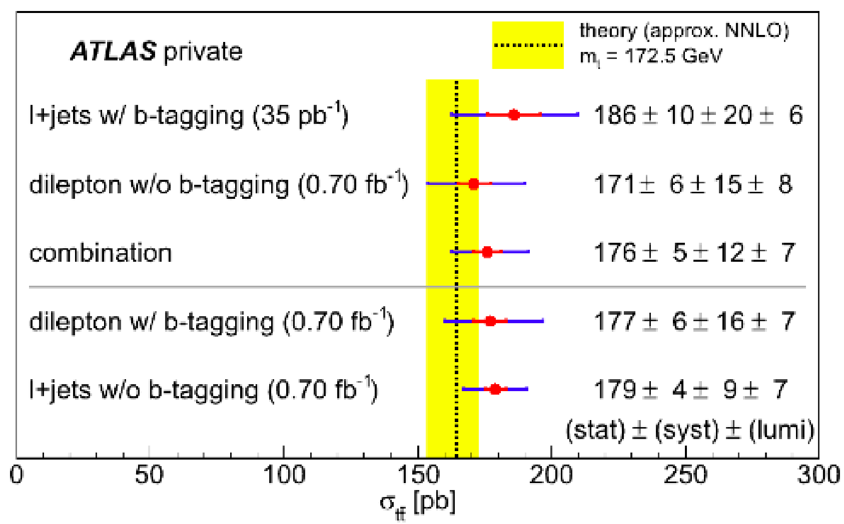
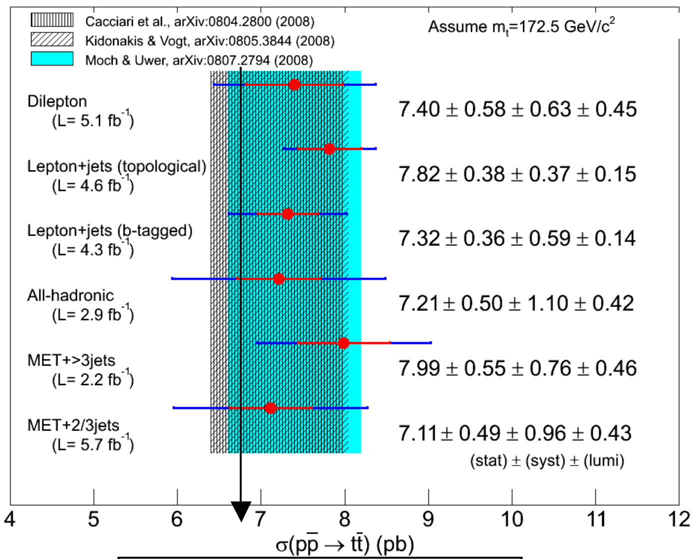
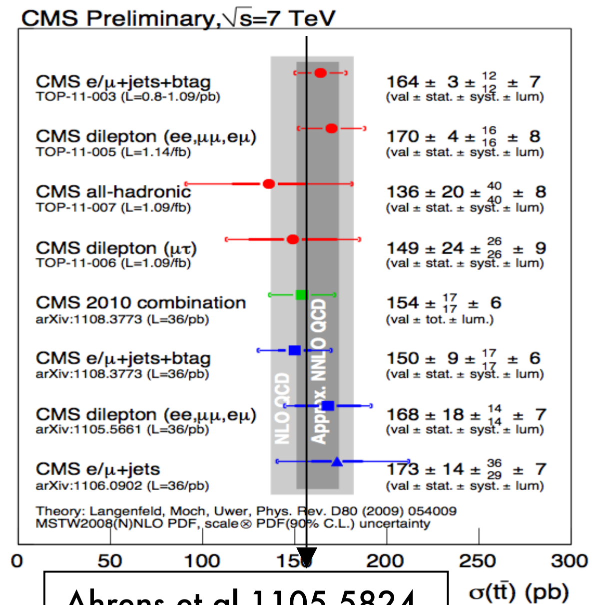






Hints from σ(tt̄) measurements





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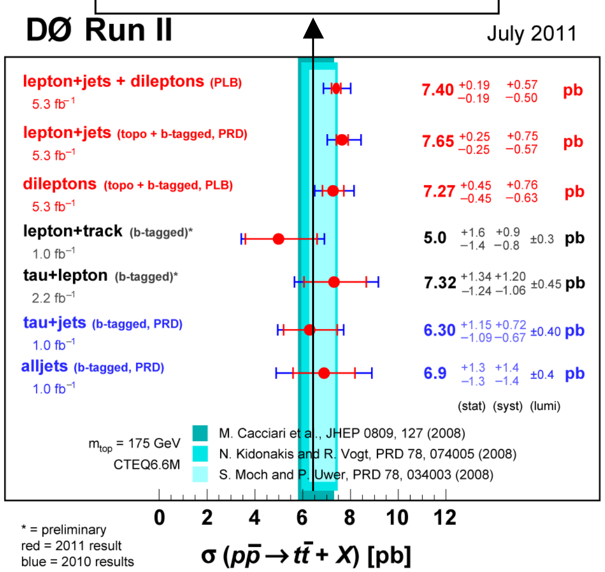

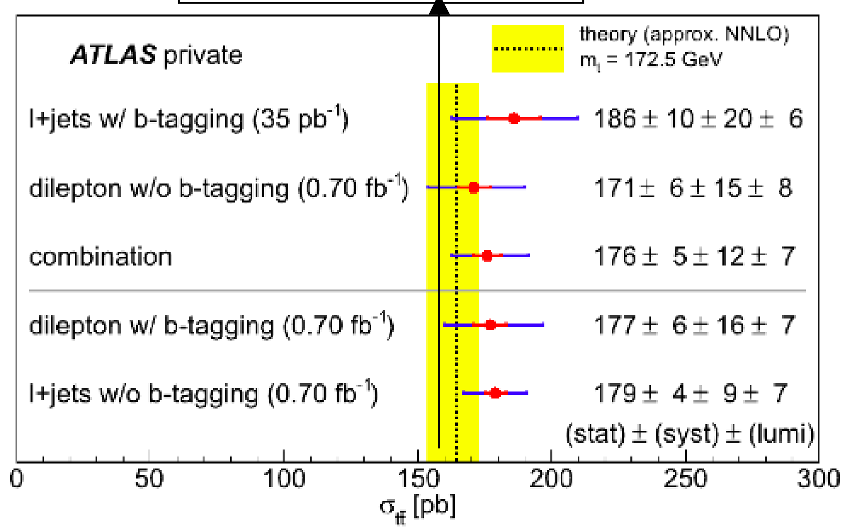

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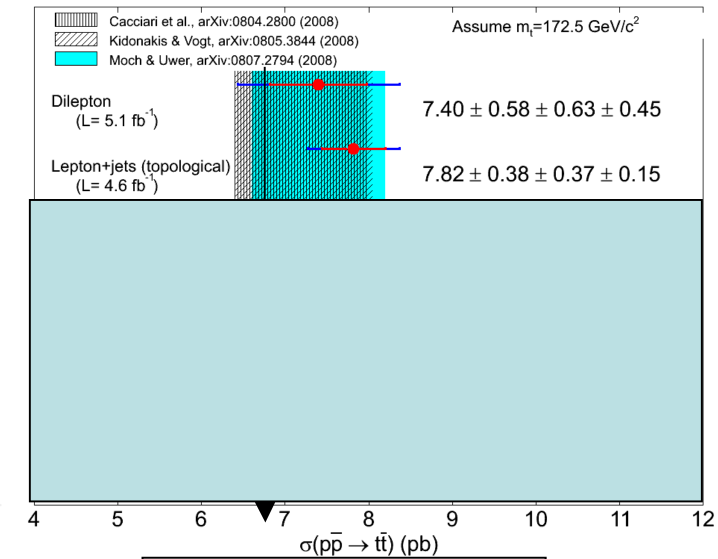

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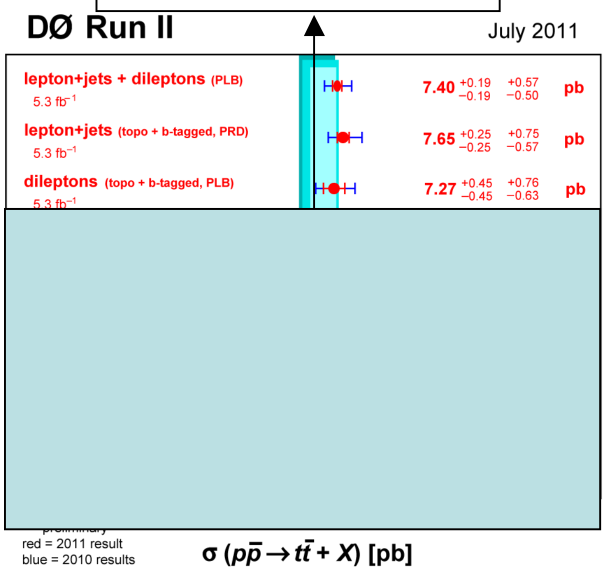

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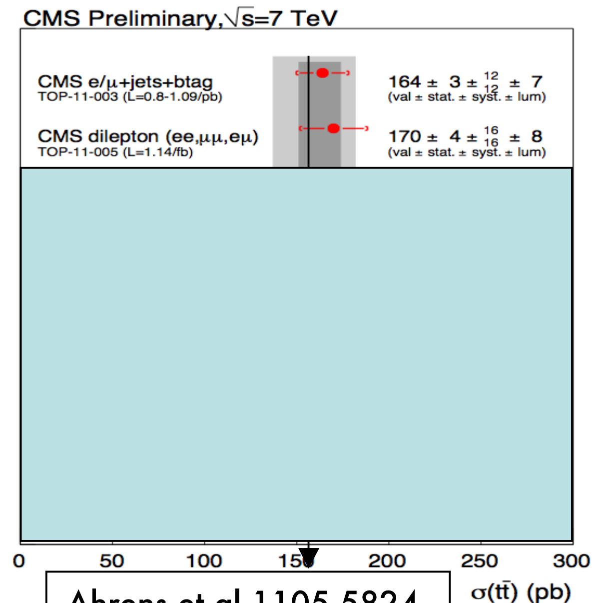

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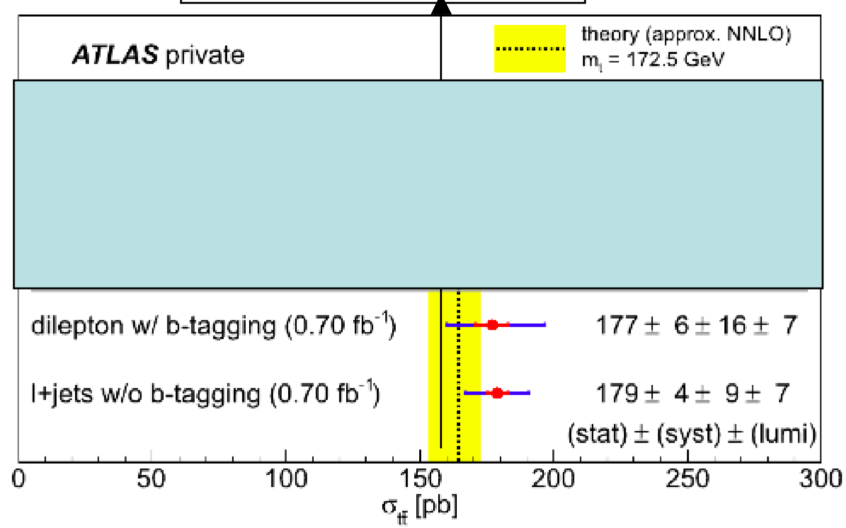
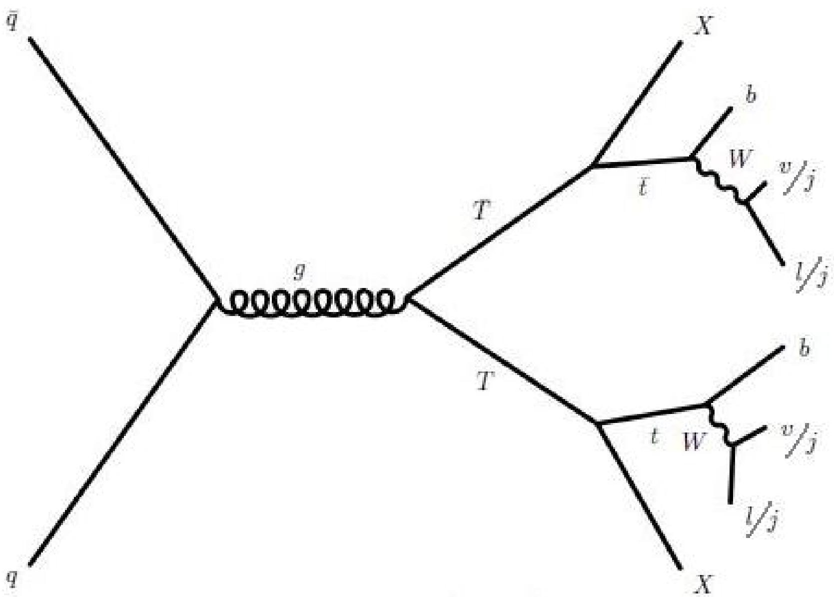
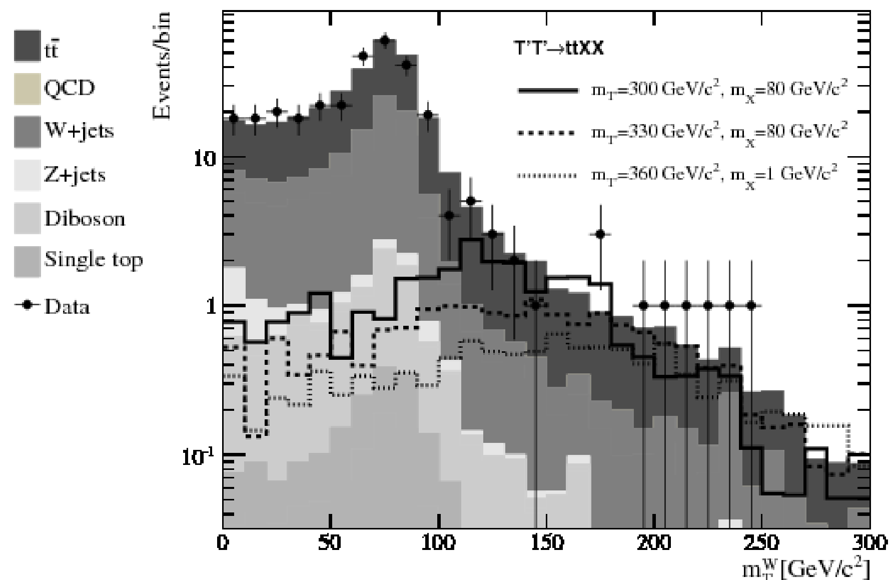


$\tilde{t}\rightarrow t\tilde{\chi}^0$, semileptonic tops

- CDF investigated the same signature in the context of a vector-like top partner, decaying to top plus dark matter candidate.
- Kinematics basically identical to SUSY $t\rightarrow t\chi^0$ scenario
- First signature studied: l+MET+jets+b-tag



Phys.Rev.Lett.106 191801



$$m_T^W \equiv m_T(p_T^\ell, \not{\phi}_T)$$

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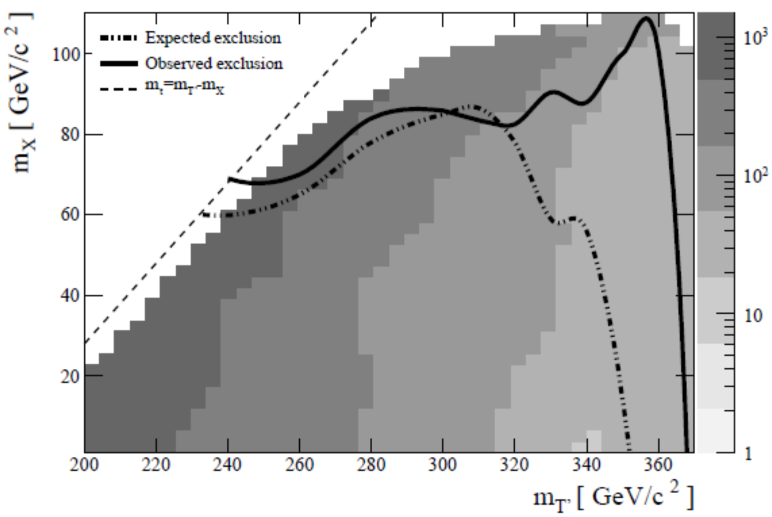
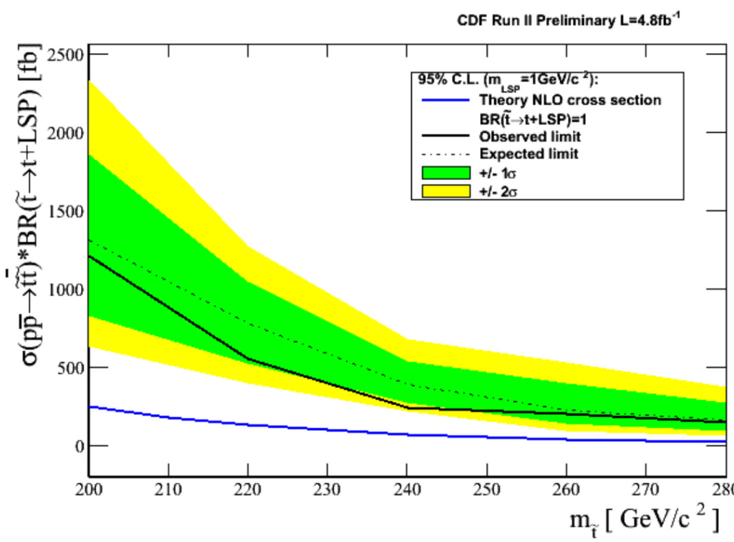


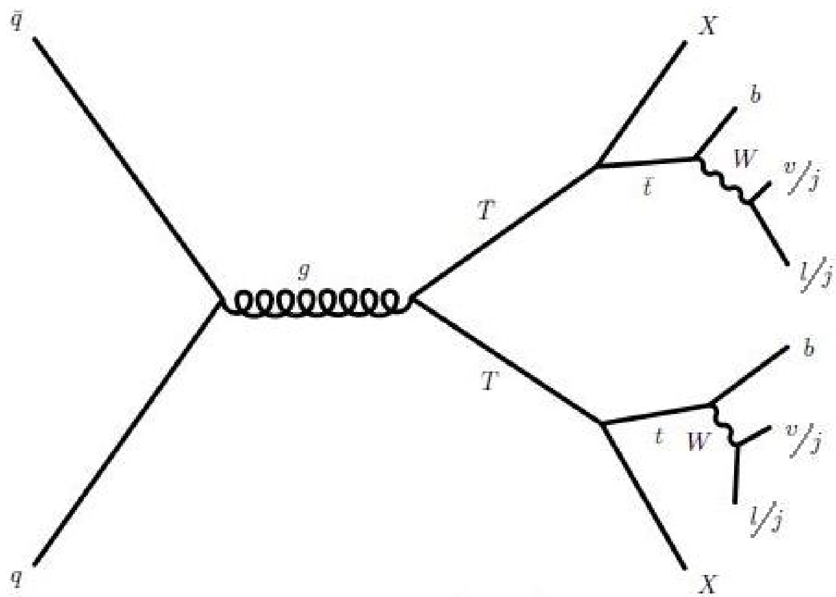


Phys.Rev.Lett.106 191801

Need 25Xmore data O(100fb) to exclude it

$\tilde{t} \to t\tilde{\chi}^0$, all-hadronic tops

- CDF investigated the same signature in the context of a vector-like top partner, decaying to top plus dark matter candidate.
- Kinematics basically identical to SUSY $t \to t\chi^0$ scenario
- Second signature studied: MET+many jets



Process	Events
$t\bar{t}$	1566 ± 210
$W+$ jets	$395,7 \pm 160.1$
$Z+$ jets	98.9 ± 40.0
$WW/WZ/ZZ$	80.0 ± 10.0
Single top	7.2 ± 1.0
Total MC	2148 ± 267
Observed	49979
$(m_{T'} = 330\,GeV/c^2, m_X = 40\,GeV/c^2)$	91.5 ± 12.3
$(m_{T'} = 380\,GeV/c^2, m_X = 1\,GeV/c^2)$	35.2 ± 4.7

- Yields after selection of $N_{jets} \geq 5$, MET>50
- QCD O(3) larger than signal
  - O(4) for SUSY signal

Missing E_T, and more

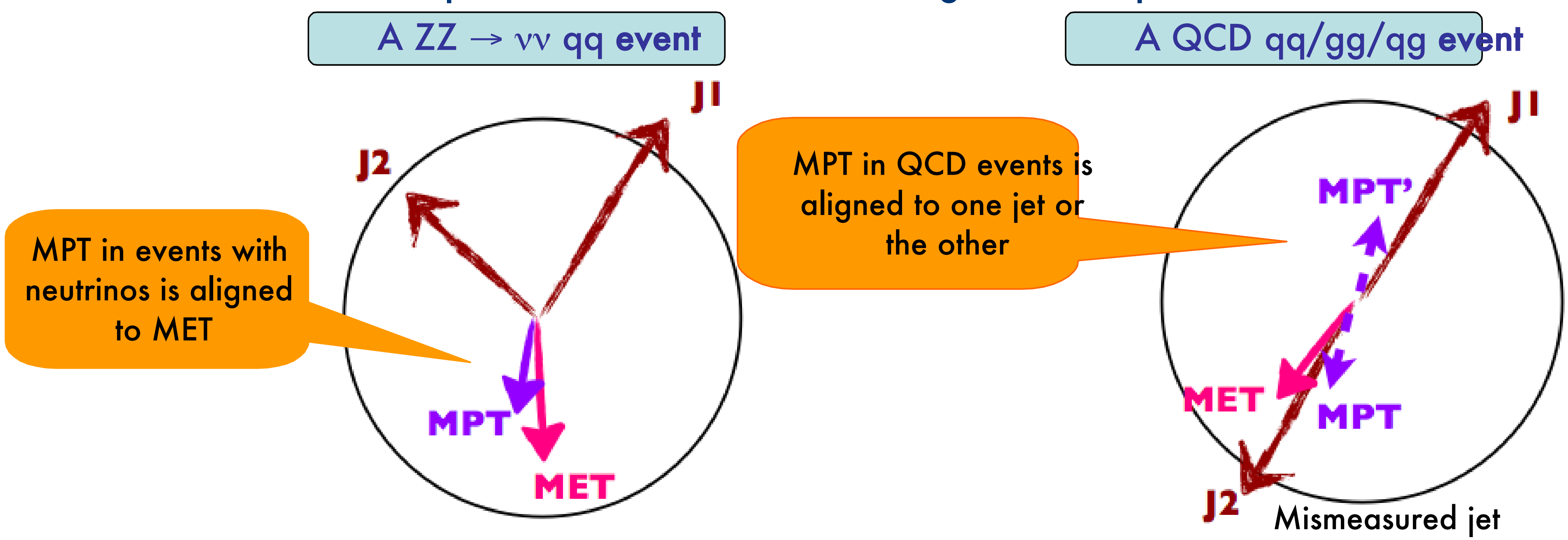
Neutrinos:

measured using the missing transverse energy (MET) from calorimeter.

Now using also the ***momentum flow imbalance in the transverse plane*** as measured from the *spectrometer*: the missing transverse momentum (MPT) *New!*

- MPT largely correlated to true neutr(al)ino momentum/direction
- For QCD events, MPT very different!

Example: events selected with large MET, 2 jets



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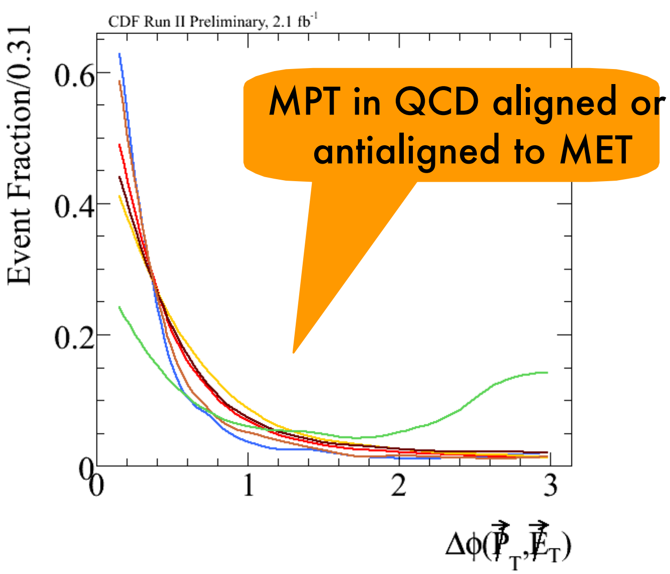
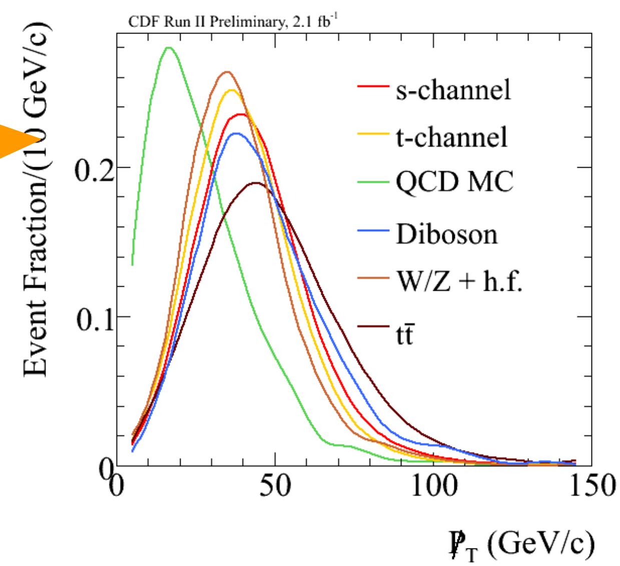


MPT in QCD events is lower than the one coming from processes giving neutr(al)inos

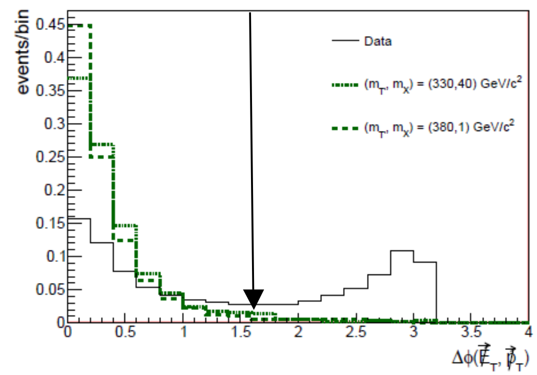
PRD 81 072003
PRL 104 141801



Controlling backgrounds

- No ele/mu — suppress ttbar semileptonic
- MET > 50 GeV
- MET/ $\sqrt{\sum Et}$ > 3 $\sqrt{GeV}$
- MET not aligned to any jet
- MPT>20 GeV
- $\Delta\varphi$(MET,MPT)<π/2

} suppress QCD, ttbar hadronic



- 5 ≤ N_{jets} ≤ 10 — suppress Pile-up
  - B-tag not found to improve sensitivity

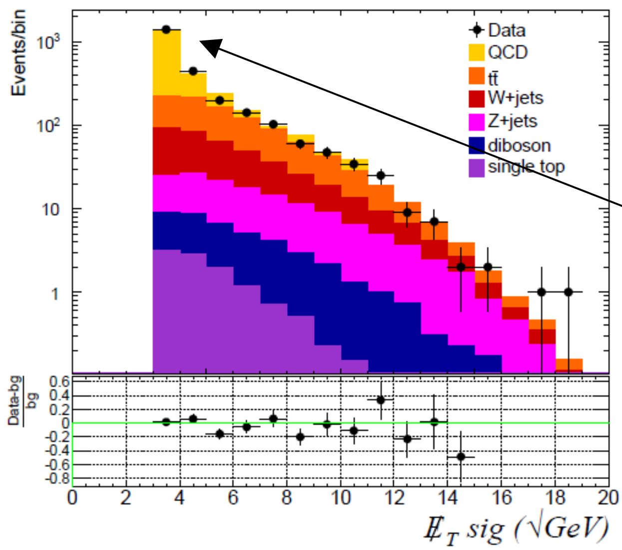
$T'T' \rightarrow ttXX$ [GeV/c^2]	Events
$m_{T'}, m_X$ = 260, 80	88.5 ± 11.9
$m_{T'}, m_X$ = 330, 100	66.4 ± 8.9
$m_{T'}, m_X$ = 360, 100	39.7 ± 5.3
$m_{T'}, m_X$ = 380, 1	27.3 ± 3.7
$m_{T'}, m_X$ = 400, 1	17.5 ± 2.3
QCD	745.4 ± 124.3
$t\bar{t}$	498.2 ± 66.8
W+jets	119.7 ± 48.4
Z+jets	39.4 ± 15.9
Diboson	17.9 ± 2.2
Single top	5.3 ± 0.8
Total Background	1423 ± 150
Data	1507

Eff 70-90%

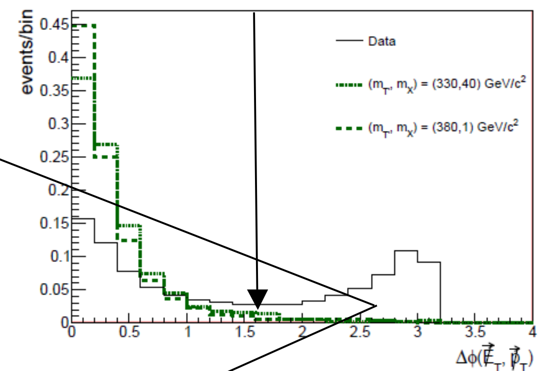
Reduced by 2 orders of magnitude

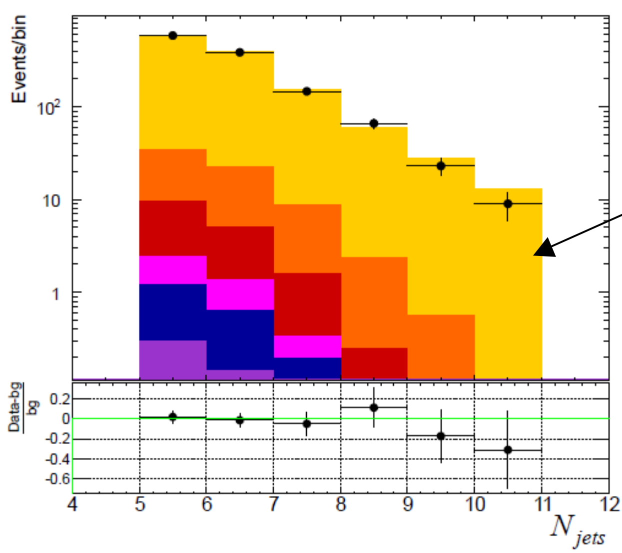
Reduced by a factor of 3

QCD modeling



The rejected events have kinematics very similar to the ones falling in the signal region



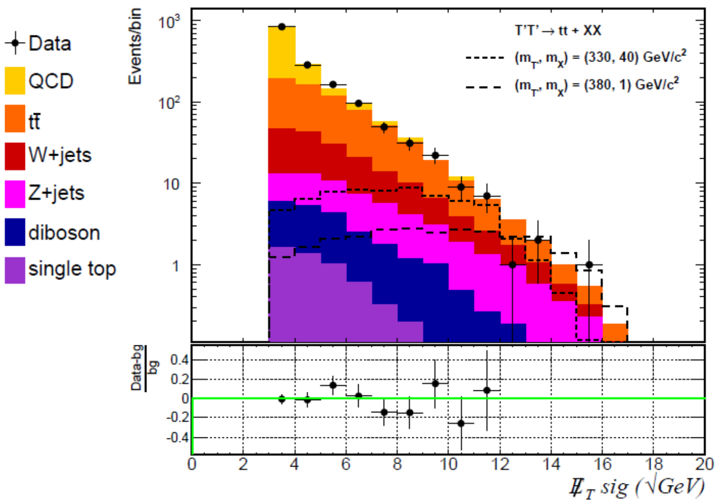


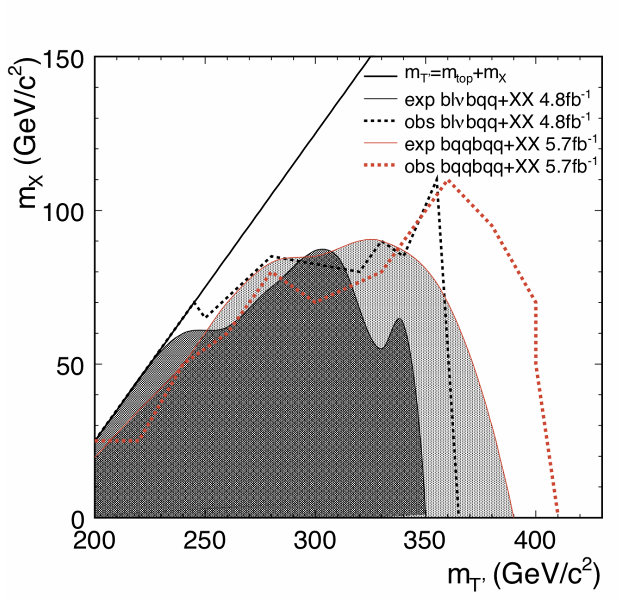
Model tested with data/MC comparison in 2/3 jet events, and in control regions:

- N_{jets}=4
- MET/√∑Et<3
- MPT<20

Results

- Main difference with backgrounds is large MET/$\sqrt{\sum}$Et for high M(T′) and low M(X)
- Do a likelihood fit of this distribution, in absence of a signal extract 95% CL upper limits
- Analysis extends sizeably the MT,MX exclusion range.
- ≈25% better sensitivity than semileptonic

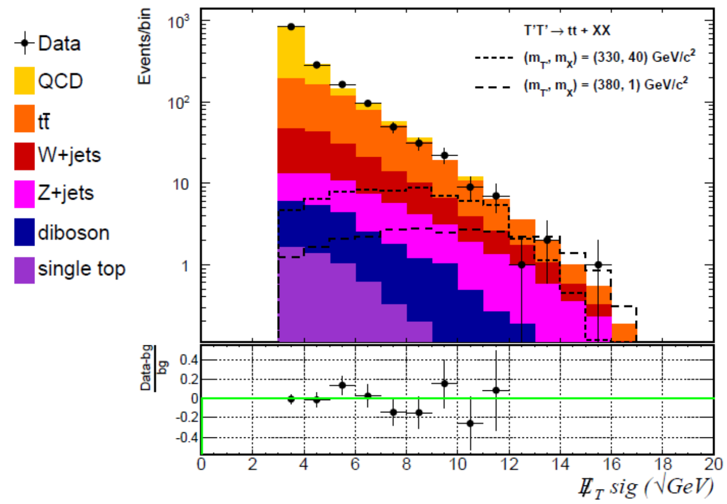


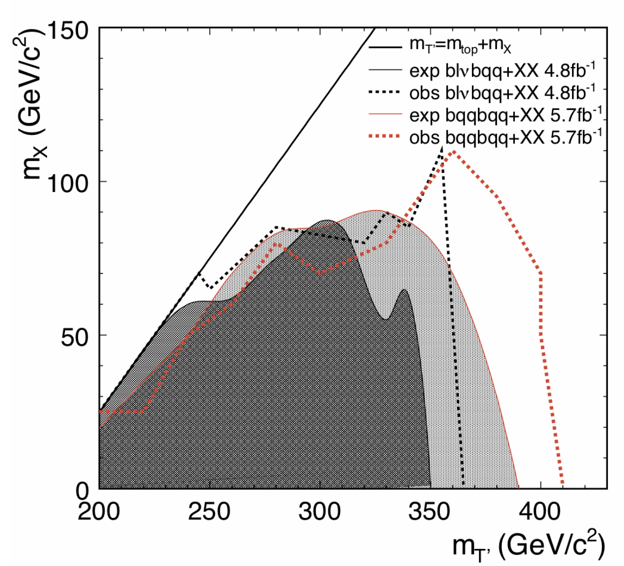


arXiv:1107.3574, accepted by PRL

Comments

- All-hadronic better than semileptonic should be even more true at the LHC
  - CMS/ATLAS better jet energy resolution, b-tagging, tau identification will allow better QCD, WZ+jets, ttbar rejection
- Contrarily to the semileptonic analysis, the all-hadronic one is not optimized for each point in the M(T) M(X) space
  - Room for improvement
- Lots of inspiration can come from the existing expertise on all-hadronic ttbar analysis
  - PRD 76 072009
  - PRD 81 052011
  - CDF Conf. Note 10433





arXiv:1107.3574, accepted by PRL

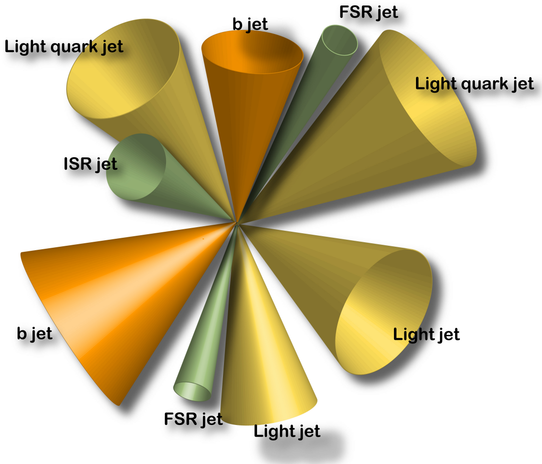
Summary

- We know very little about stops
- Stop lighter than top could still be possible
  - Complex problem, many final states
- Stop heavier than top is basically unprobed
  - It is a difficult search! Some pioneering work done at the Tevatron
- For $\tilde{t} \rightarrow t\tilde{\chi}^0$, all-hadronic final state is better than semileptonic
  - This statement will be stronger at LHC thanks to its state-of-the-art detectors

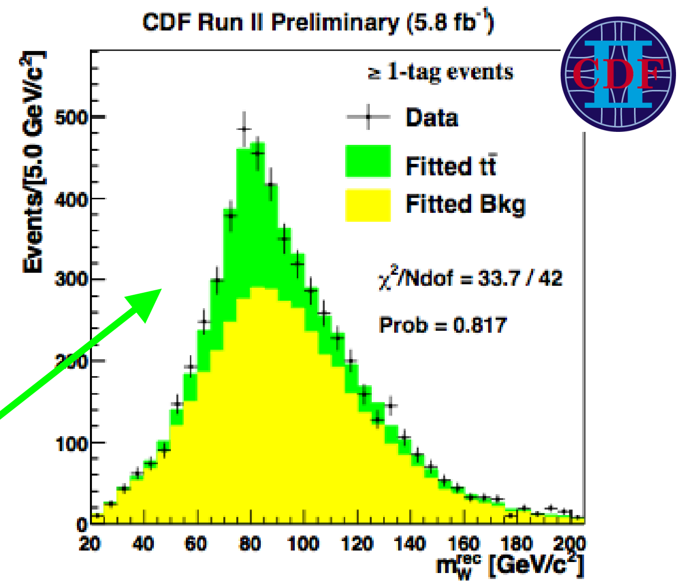
Thanks!

Back-up

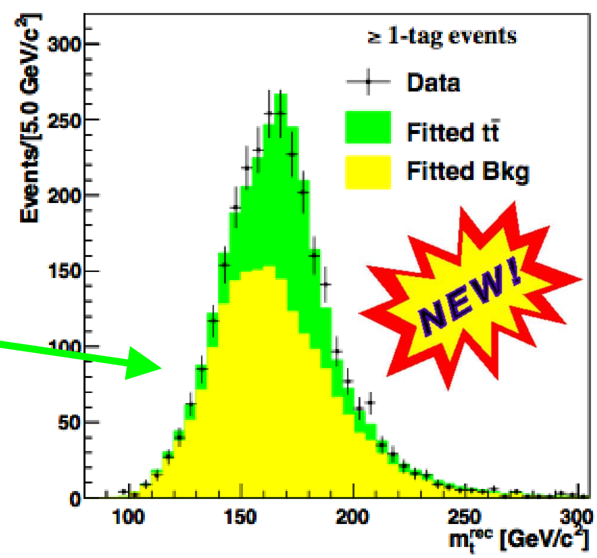
M_{top} measurement in tt→bbqqqq



Use b-tagging and multivariate techniques to isolate the signal from the overwhelming QCD background



- Jet energy scale is the largest syst uncertainty: use W→qq decays to constrain it in situ
- Fully reconstruct the kinematics so to reconstruct the top quark mass

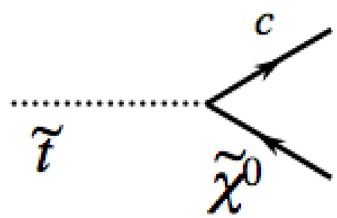


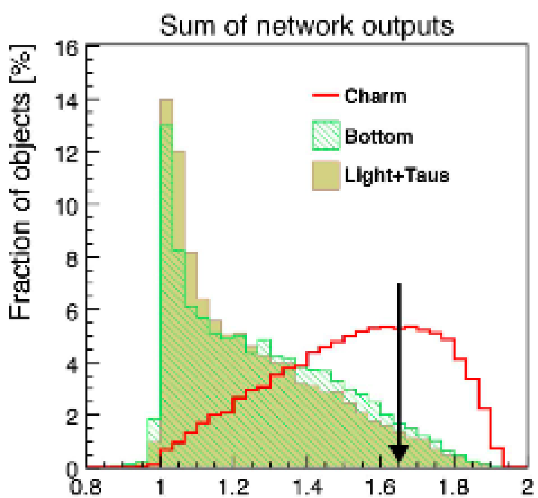
M_{top}= 172.5 +/- 1.7 (stat.+JES) +/- 1.2 (syst.) GeV/c^2

$\tilde{t} \rightarrow c\tilde{\chi}$

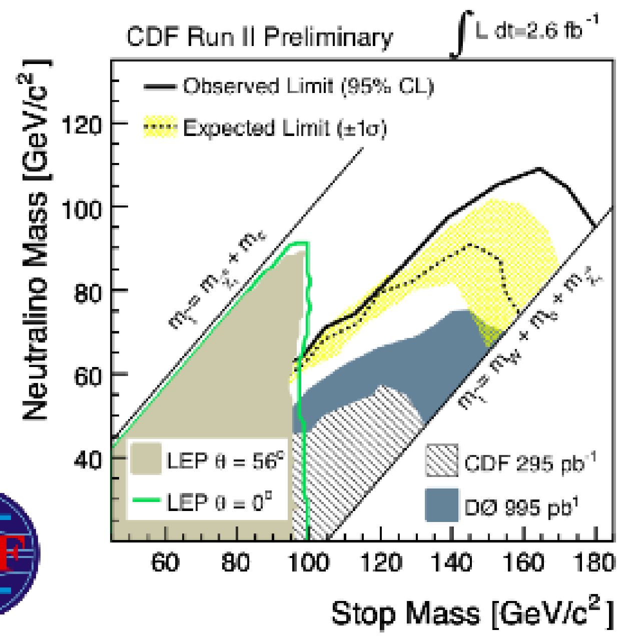
Charm is hard to find with just vertex detectors

Typically τ(*b* hadrons) > τ(*c* hadrons)
⇒ no high-purity selection





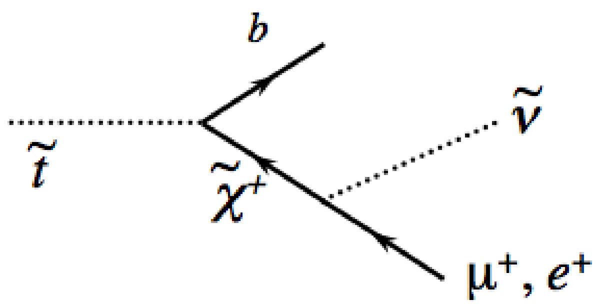
2 output, 22 input Neural Net



CDF CONF Note 9834

$\tilde{t} \rightarrow b\tilde{\chi}^{\pm} \rightarrow b\tilde{\nu}l$

$\tilde{t}$ pairs in $e\,\mu\,\not{E}_T$



Backgrounds are

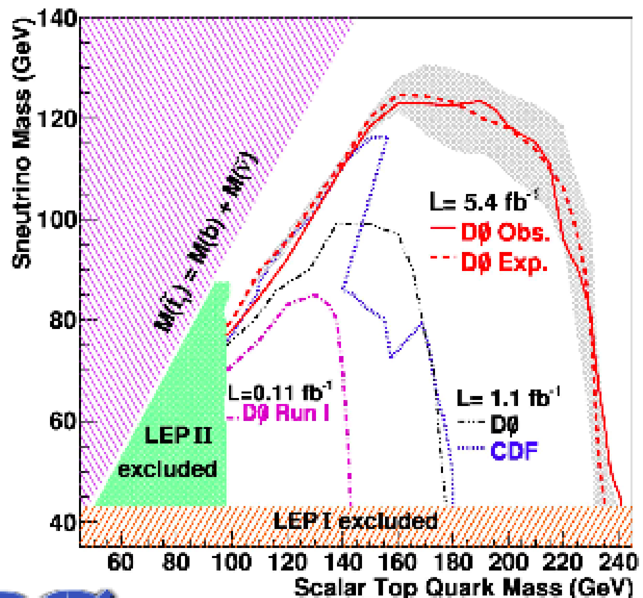
$p\bar{p} \rightarrow Z/\gamma^* \rightarrow \tau^+\tau^- \rightarrow e^+\mu^- 4\nu$
occurs at relatively low $\not{E}_T, p_T(\ell^{\pm})$
(< 20 GeV) and large opening angle
($\Delta\phi > 2.8$) in the transverse plane

$p\bar{p} \rightarrow t\bar{t}$ is basically the same thing
without the SUSY; it can be suppressed
with MVA methods

WW likewise

Abazov et.al., Phys.Lett. B696,321(2011)

Aaltonen et al. Phys. Rev. D82, 092001 (2010)



Other stop searches:

- top-like $\ell\ell$
  Aaltonen etal, Phys.Rev.Lett. 104,251801(2010)
  Abazov etal, Phys.Lett. B675,289 (2009)
- top-like ℓ+*jet* Abazov Phys.Lett.B674,4(2009)

$\tilde{t} \to b\tilde{\chi}^{\pm} \to b\tilde{\chi}^{0} l\nu$

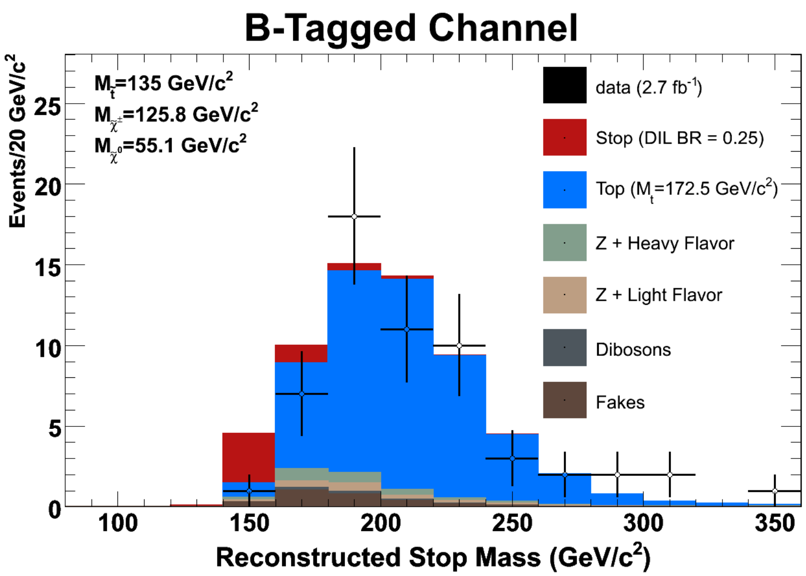
Event kinematics determined by stop, chargino, & neutralino masses

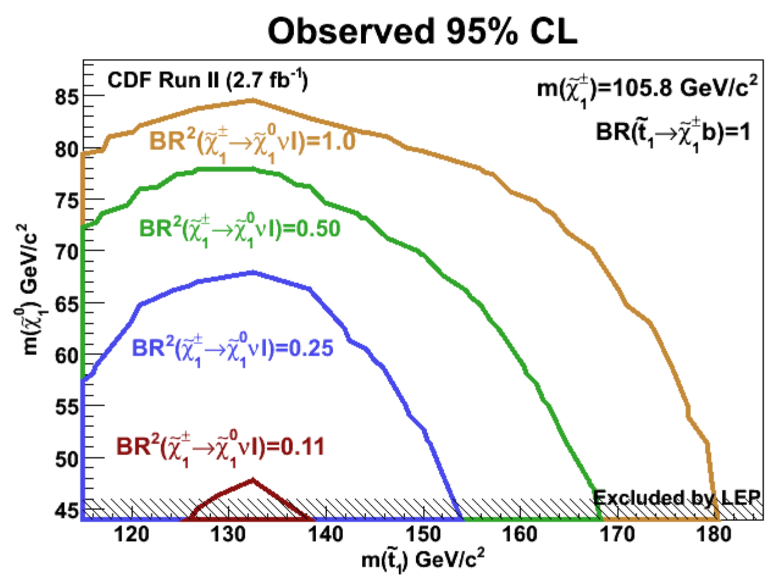
- Dilepton branching ratio determined by SUSY parameters
- Reconstruct event under stop hypothesis
- Use reconstructed stop mass to discriminate stop from SM

$\tilde{\chi}_1^0$ is the LSP, and $\tilde{q}, \tilde{\ell}, \tilde{\nu}$ are heavy

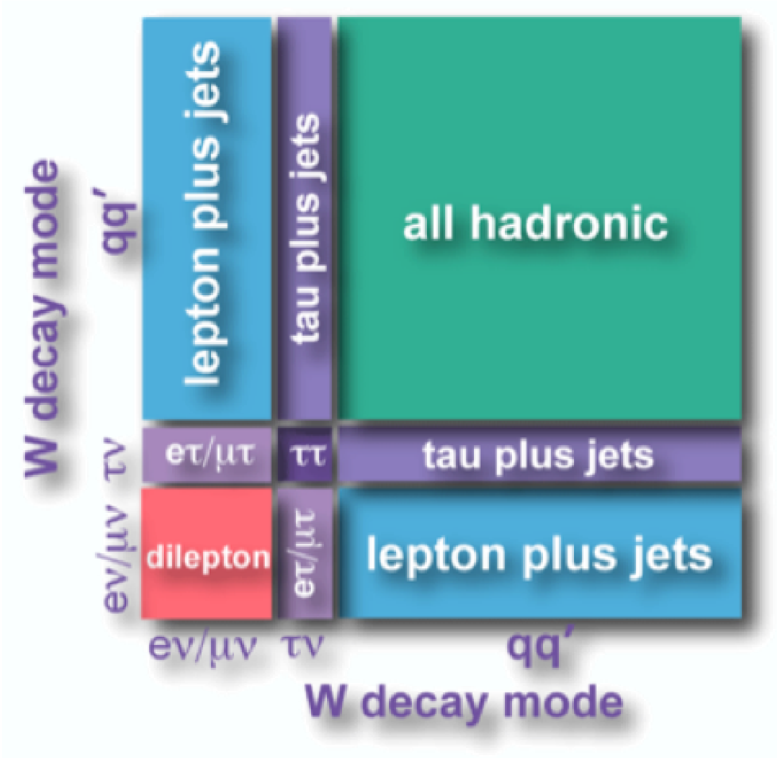
$m_{\tilde{t}_1} \lesssim m_t$

$m_{\tilde{\chi}_1^+} < m_{\tilde{t}_1} - m_b$

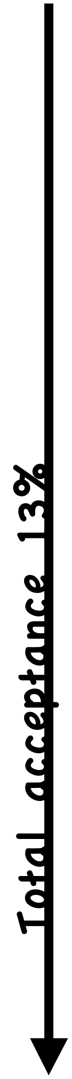




Pair production decay signatures



Potential to analyze more than 30 000 top quarks by end 2011



Lepton+Jets

- large BR(30%)
- good S/B ratio.

Dileptonic

- Highest S/B
- lowest BR(5%)

All hadronic

- highest BR(44%)
- Very large QCD background

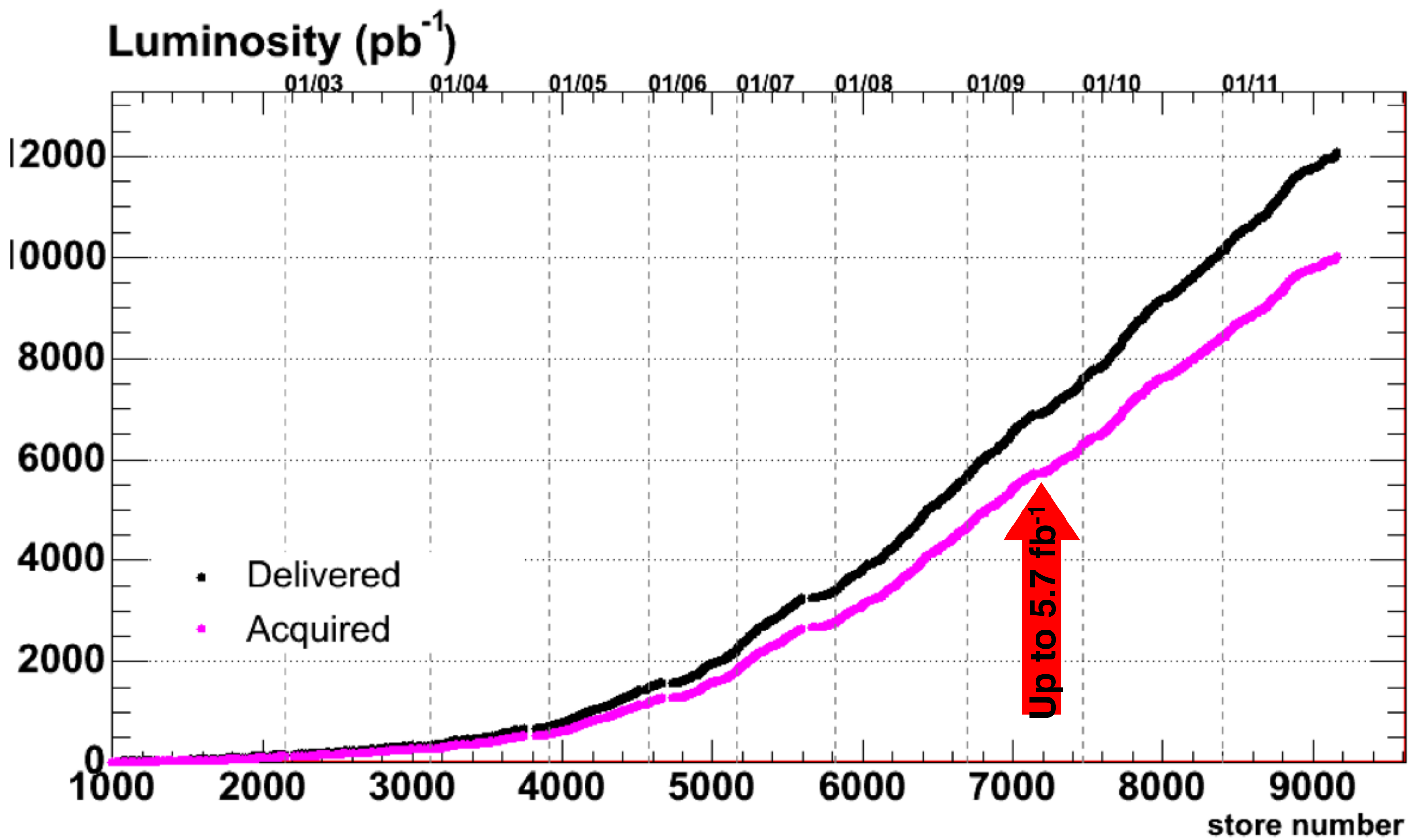
Tau modes (DØ)

- explicit tau identification

MET + jets (CDF)

- Lepton+jets and dileptonic decays where electron/muon is not id'ed. Large acceptance to taus

Its collisions



Delivered 12.0 fb^{-1}
Acquired 10 fb^{-1}
slightly less w/ silicon on