Search for top-antitop resonances using DØ Run I data at Tevatron

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Outline

- Motivation.
- Final states in $t\bar{t}$ decays.
- Event selection.
- Kinematic fit.
- $\mathrm{m}_{\mathrm{t\bar{t}}}$ distribution.
- Upper limits on $\sigma(p\bar{p} \to X)B(X \to t\bar{t})$.
- Systematic uncertainties.
- Results and Conclusions.

Motivation

- One of the major current questions in HEP is what breaks electroweak and flavor symmetries.

- The 'standard' solution uses one or more physical Higgs particles. This requires supersymmetry to avoid having to fine-tune Higgs parameters.

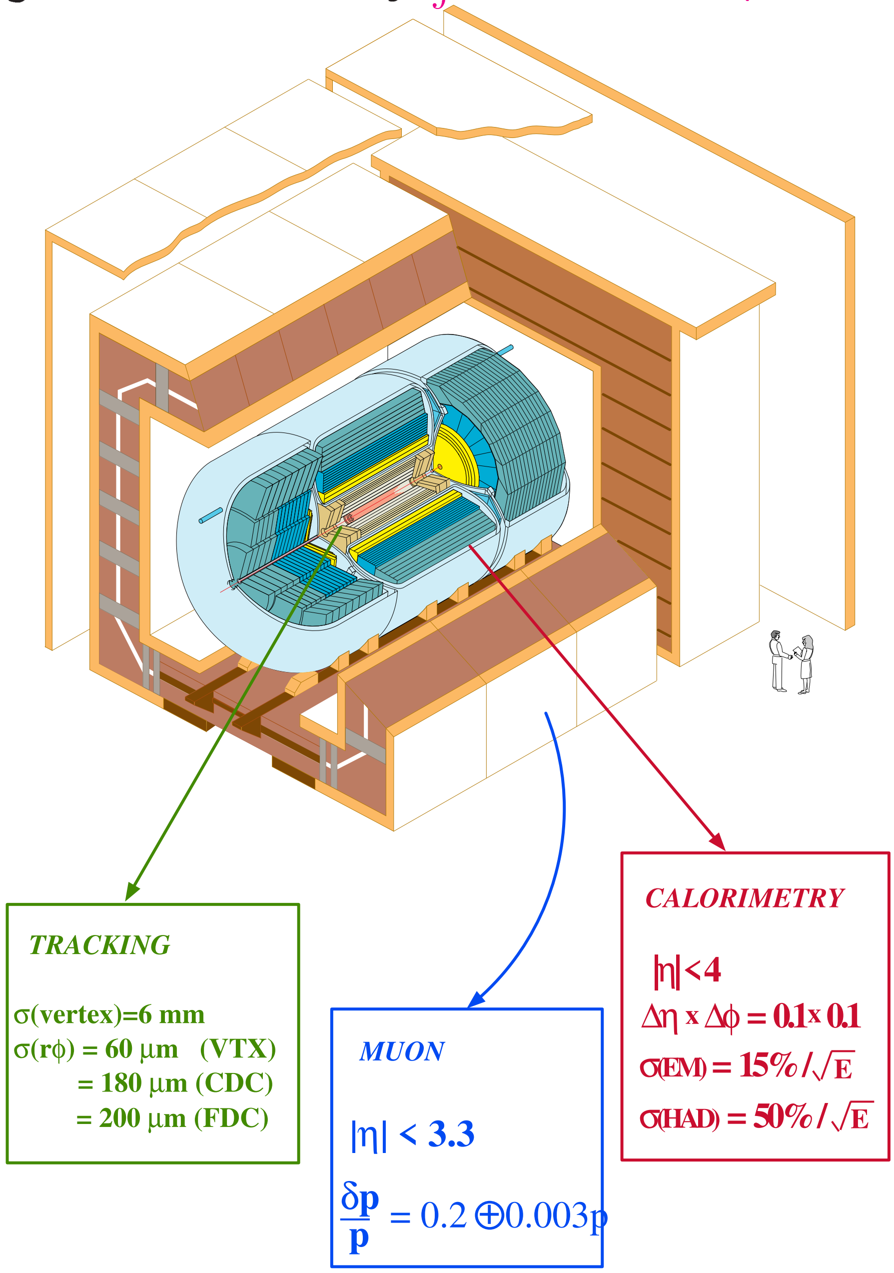
- But there are other possibilities.

- EW symmetry and flavor symmetry could also be broken dynamically, with a new interaction on the TeV scale, such as the 'Topcolor-assisted Technicolor' models:
  - 'Technicolor' can generate masses of $W^{\pm}$, Z bosons and most fermions.
  - Large mass of top quark is explained by 'topcolor', which provides a heavy top quark condensate X that can decay into $t\bar{t}$.

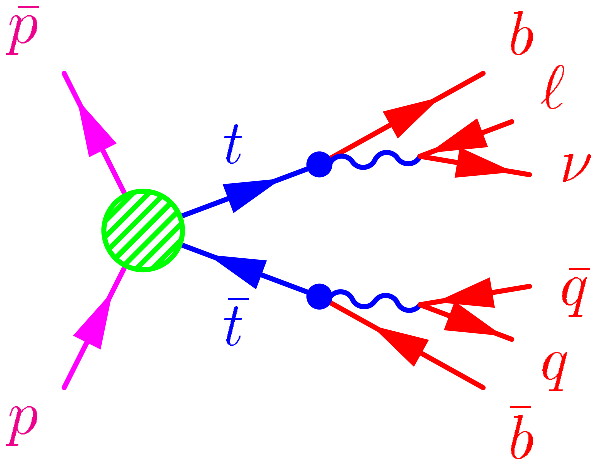
- We search for $X \to t\bar{t}$ assuming the resonance is narrow (compared to the detector resolution)
  - Not sensitive to the details of the model.

DØ detector at Tevatron

- Using $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV.
- Data recorded from 1992-1996 (Run I).
- Integrated Luminosity $\int \mathcal{L}dt \sim 130$ pb^{-1}.



Final states in $t\bar{t}$ Decays



- 'Lepton + jets' channels characterized by:
  - One high-p_T, isolated, lepton (e or μ).
  - Large $\not{E}_T$.
  - $\geq$ 4 jets (2 b-jets, 2 light-quark jets from W).
- Signal: $X \to t\bar{t} \to \ell +$ jets.
- Backgrounds:
  - Standard Model $t\bar{t} \to \ell +$ jets production.
  - W ($\to$ $\ell\nu$) + jets production.
  - Multijet events in which one jet is misidentified as a lepton, and instrumental effects mimic $\not{E}_T$.

Event Selection

- Two strategies used to reduce non–$t\bar{t}$ events:
  - Cut hard on event-shape variables in 'topological' channels: e+jets & μ+jets.
  - Use tagged b-jets (from $b \to \mu$ decay) in 'μ-tag' channels: e+jets/μ & μ+jets/μ.

- Selections common to all channels:
  - $p_T(\ell) > 20\,\mathrm{GeV}$, $|\eta(e)| < 2.0$, $|\eta(\mu)| < 1.7$.
  - $\not\!\!E_T > 20\,\mathrm{GeV}$; calorimeter-only $\not\!\!E_T^{\mathrm{cal}} > 25\,\mathrm{GeV}$.
  - Four jets with $E_T > 15\,\mathrm{GeV}$ and $|\eta| < 2$.

- If there is a μ-tag, use additional selections on $\not\!\!E_T$ and $\Delta\phi(\not\!\!E_T, \mu)$ to reduce multijet background.

- If no μ-tag, require:
  - $|p_T(\ell)| + |p_T(\nu)| > 60\,\mathrm{GeV}$.
  - $|\eta(W)| < 2$ (reconstruct W from $\ell\nu$).

- Select 90 events using $\sim 130\,\mathrm{pb}^{-1}$ of data.

$e+$jets	$\mu+$jets	$e+$jets/μ	$\mu+$jets/μ
42	41	4	3

Kinematic Fit

- Use four leading jets, corrected back to parton level.

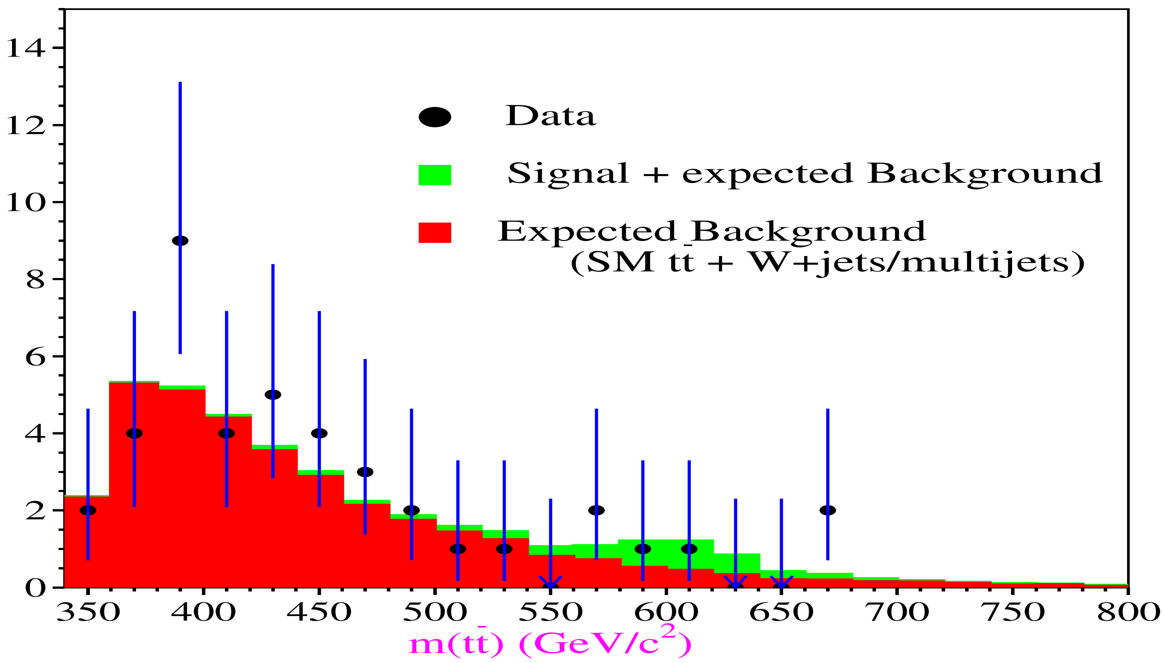
- Perform a 3C kinematic fit to $t\bar{t} \to (l\nu b)(q\bar{q}\bar{b})$.
  - One unknown: $p_z(\nu)$.
  - Four constraints:
    * $m(l\nu) = M_W$.
    * $m(jj) = M_W$.
    * $m(l\nu j) = m_t = 173.3\text{GeV/c}^2$.
    * $m(jjj) = m_t = 173.3\text{GeV/c}^2$.
  - 12 ways of assigning 4 jets to $b\bar{b}jj$ (6 if event is tagged). Try all possibilities.
  - 3C fit $\to m_{t\bar{t}}$, χ^2.
  - Pick $m_{t\bar{t}}$ corresponding to fit with smallest χ^2. (Require $\chi^2 < 10$.)

- Yields 41 events (with 4 b-tags).

$e+$jets	$\mu+$jets	$e+$jets$/\mu$	$\mu+$jets$/\mu$
16	21	1	3

$m_{t\bar{t}}$ distribution

- For $M_X = 600\text{GeV/c}^2$ and $m_t = 175\text{GeV/c}^2$.
  - Data: 41 events.
  - $X \rightarrow t\bar{t}$: 4.2±3.2 events.
  - SM $t\bar{t}$: 23.7±11.6 events.
  - W+jets + Multijets: 15.4±10.6 events.



- No statistically significant excess is observed, so proceed to set a limit on $\sigma_X B(X \rightarrow t\bar{t})$.

Upper Limits on $\sigma_X B(X \to t\bar{t})$

- Define expected number of events in the data:
  - From $X \to t\bar{t}$: n_X.
  - From SM $t\bar{t}$: n_t.
  - From $W+$jets and Multijets: n_b.
- Using Bayesian statistics, fit data $m_{t\bar{t}}$ distribution to a weighted sum of the three sources.
- With $p(D|n_X, n_t, n_b, K)$ as the likelihood, write the posterior probability

$$p(n_X|D,K) = \int p(D|n_X, n_t, n_b, K) dn_t\, dn_b$$

(assuming flat priors).

- With

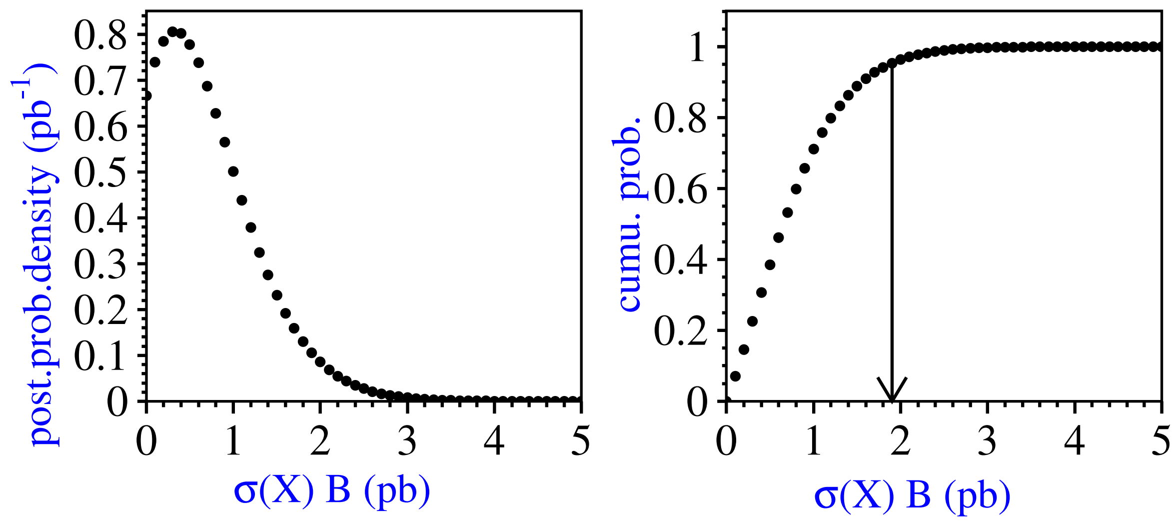
$$n_X = \sigma_{\scriptscriptstyle X} \times B(X \to t\bar{t}) \sum_i A_i \mathcal{L}_i,$$

where A_i is the acceptance for channel i and $\mathcal{L}_i$ is its integrated luminosity, write $p(\sigma_{\scriptscriptstyle X} B|D,K)$ in terms of $p(n_X|D,K)$.

- Solve

$$\int_0^{\sigma_{95}} p(\sigma_X B|D,K)\,d(\sigma_X B) = 0.95$$

to find the 95% confidence limit. Example:



Systematic Uncertainties

- Have uncertainties in A_i and $\mathcal{L}_i$: $\delta(\sum_i A_i \mathcal{L}_i)$.
- Consider $\sum_i A_i \mathcal{L}_i$ as another unknown in the probability. Integrate over it with a Gaussian prior:

$$p(\sigma_X B | D, K) = \int p(D | \sigma_X B \ a, n_t, n_b, K) g(a) da \, dn_t \, dn_b$$

where

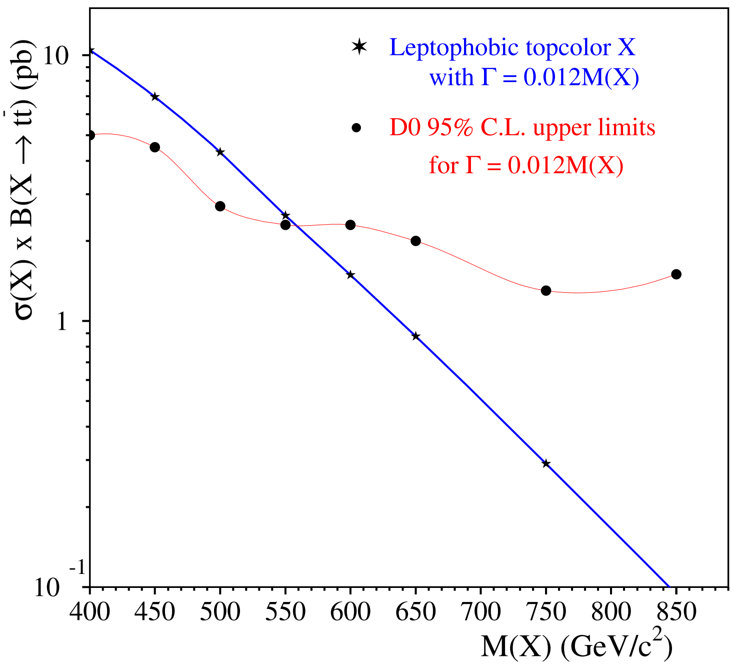
$$g(a) = \exp\left(-\frac{(a - \sum_i A_i \mathcal{L}_i)^2}{2 \left[\delta(\sum_i A_i \mathcal{L}_i)\right]^2} \right).$$

- Systematic uncertainties:
  - Jet energy scale:
    - Uncertainty of $\delta E_T = \pm(2.5\% + 0.5\,\text{GeV}) E_T$.
    - Scale the jets in MC up and down by this amount.
  - Initial/final state radiation (ISR/FSR):
    - Rerun Pythia with radiation switched off.
  - Parton distribution function (PDF):
    - MC was generated using CTEQ3M.
    - Generate an additional sample using GRV94L.

Results

- For $\Gamma_X = 0.012 M_X$, $m_t = 175\text{GeV}/c^2$, and flat priors:

M_X	95% upper limit on $\sigma_X B(X \to t\bar{t})$ (pb)
400	5.0
450	4.5
500	2.7
550	2.3
600	2.3
650	2.0
750	1.3
850	1.5
1000	2.0



- Exclude narrow, leptophobic X boson (C. T. Hill and S. Parke, hep-ph/9911288) with $M_X < 560\text{GeV}/c^2$.

Conclusions

- We have searched for a narrow resonance X decaying to $t\bar{t}$.

- No statistically significant excess has been seen.

- Assuming $\Gamma_X = 0.012 M_X$, $m_t = 175 \mathrm{GeV/c^2}$, and flat priors, we have set 95% confidence limits on $\sigma_{\scriptscriptstyle X} B(X \to t\bar{t})$.

- For a particular model of leptophobic topcolor, we have excluded, at 95% confidence,
  $M_X < 560 \mathrm{GeV/c^2}$.
  Corresponding limit from CDF is
  $M_X < 480 \mathrm{GeV/c^2}$.

- Before LHC turns on, we expect to improve limits using data from DØ Run II with $\sqrt{s} = 2.0$ TeV, and 15 fb^{-1} of integrated luminosity.