Searches for Quark Compositeness and Heavy Resonances in Hadronic Final States

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on behalf of the D0 Collaboration

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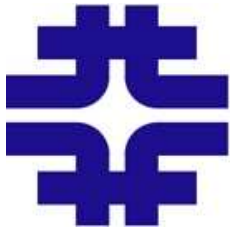
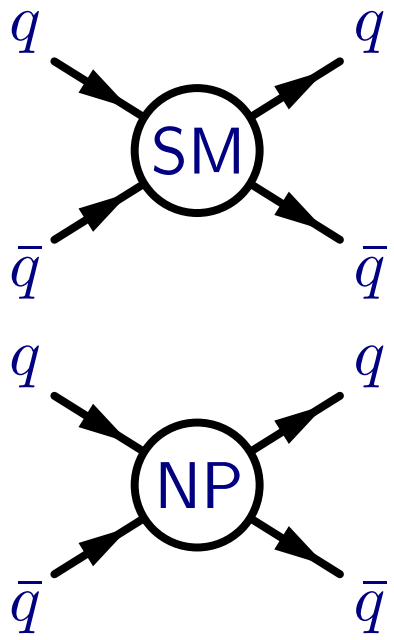


DPF Meeting, July 27–31, 2009

Searches Beyond the Standard Model

- The Standard Model is incomplete
- New models try to explain observed anomalies in astrophysics and direct dark matter searches, as well as predicting collider signatures
- In general, a model independent search assumes modification of the SM Lagrangian by a term representing new physics (NP):

$$\mathcal{L} = \mathcal{L}_{\mathrm{SM}} + \mathcal{L}_{\mathrm{NP}}$$

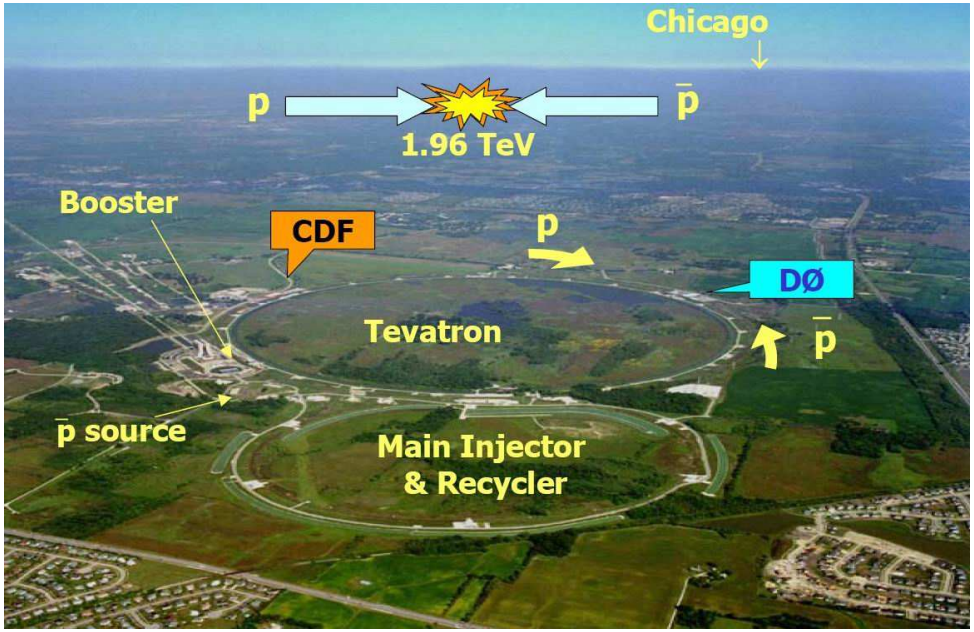


- The cross section for new physics models includes

$$d\sigma \propto |\mathcal{M}_{\mathrm{SM}} + \mathcal{M}_{\mathrm{NP}}|^2 d\Phi$$

- This approach allows physicists to study new interactions before a consistent theory is formulated

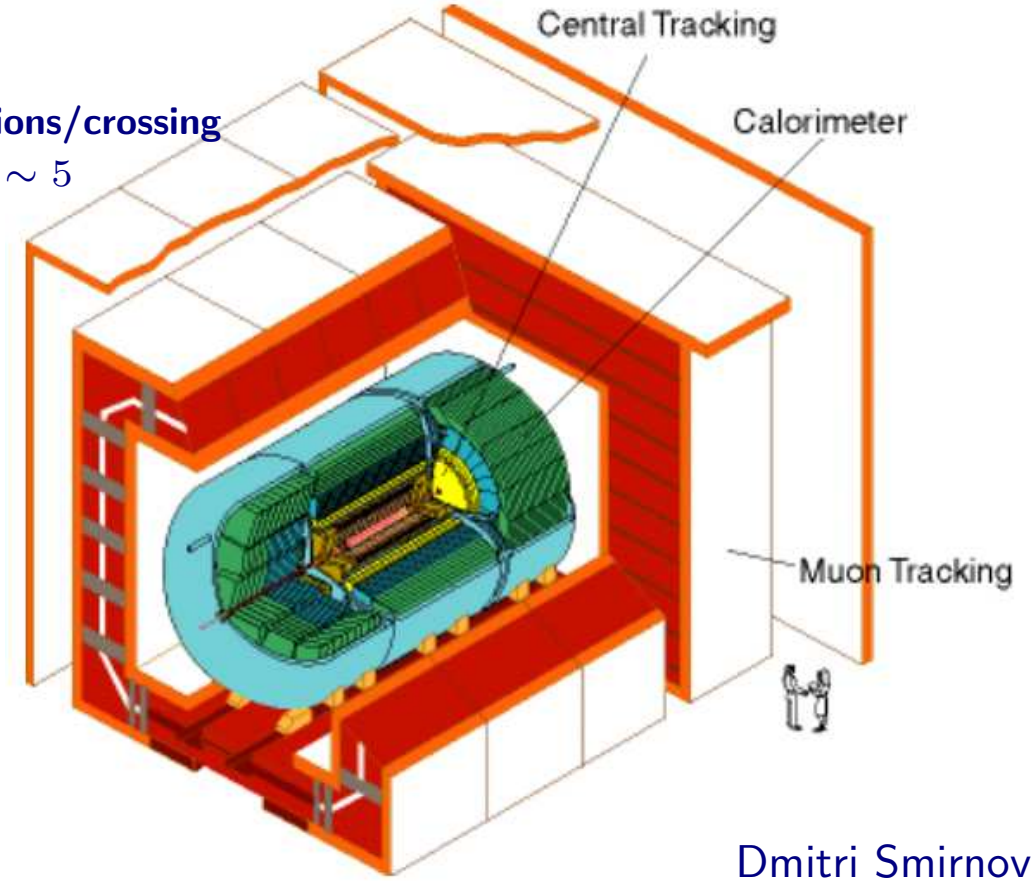
The Fermilab Tevatron Collider and D0 Detector



- Tevatron is a superconducting synchrotron 2 km in diameter
- Physics at the Tevatron:
  - Precision measurements of W, Z bosons and top quark
  - B physics and QCD studies
  - Searches for Higgs boson
  - **Searches for new physics**

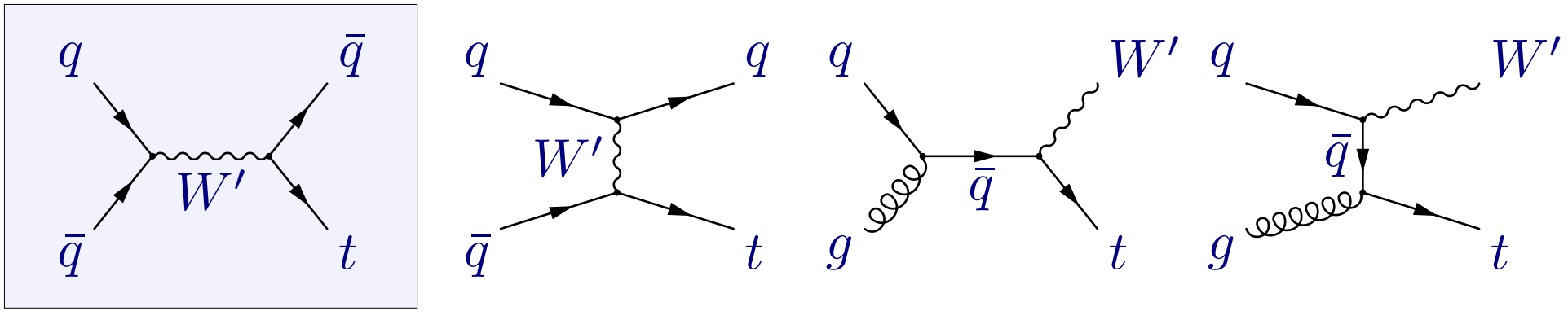
	$\sqrt{s}$	Inst. Luminosity	Interactions/crossing
Run II 2002–2009	1.96 TeV	$\lesssim 3 \times 10^{32}$ cm^{-2}s^{-1}	~ 5

- D0 is a general purpose hadron collider detector
- **The detector is very well understood!**
- **Collecting data with 90% efficiency**
- **5 fb^{-1} of data is ready to be analyzed**



W' Production

- Heavy gauge bosons W' and Z' are predicted by many extensions of the SM
  - Composite and Little Higgs models, GUTs, UED, Technicolor, . . .
- LO production channels
  - s-channel, t-channel, and associated production
  - The s-channel (resonance) is most interesting since W' contribution to the other channels is too small



- Effective Lagrangian $\mathcal{L} = \frac{V_{ij}}{2\sqrt{2}} g_W \bar{f}_i \gamma^\mu \left(\mathbf{a_{ij}^R}(1+\gamma^5) + \mathbf{a_{ij}^L}(1-\gamma^5) \right) W' f_j + h.c.$

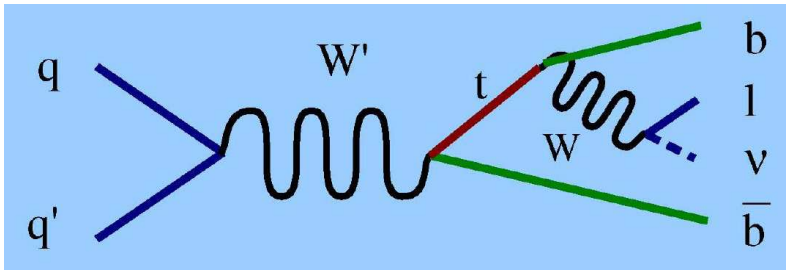
$\mathbf{a_{ij}^R}$ and $\mathbf{a_{ij}^L}$ are left and right couplings to quarks

W' Interference with the SM

- Only W'_{L} interferes with the SM W

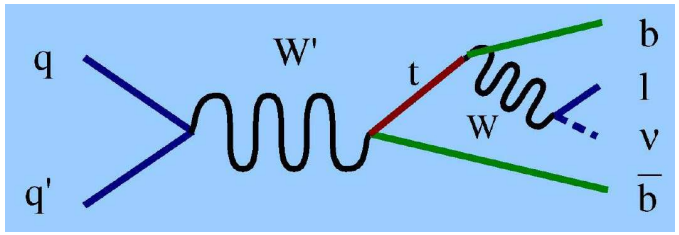
$$\sigma = \sigma_{\mathrm{SM}} + \mathbf{A^{L}} \cdot \sigma_{W/W'_{\mathrm{L}}} + \mathbf{A^{L,R}} \cdot \sigma_{W'}$$

- Interference contributes as much as 16-33% of the total rate
  - W/W' interference is generated with the CompHEP MC generator
- W'_R can decay leptonically if $M_{\nu,R} < M_{W'_R}$
- Assume the coupling of the W' to quarks is identical to that of the SM W
- Single top production is the ideal channel to search for W' decaying hadronically



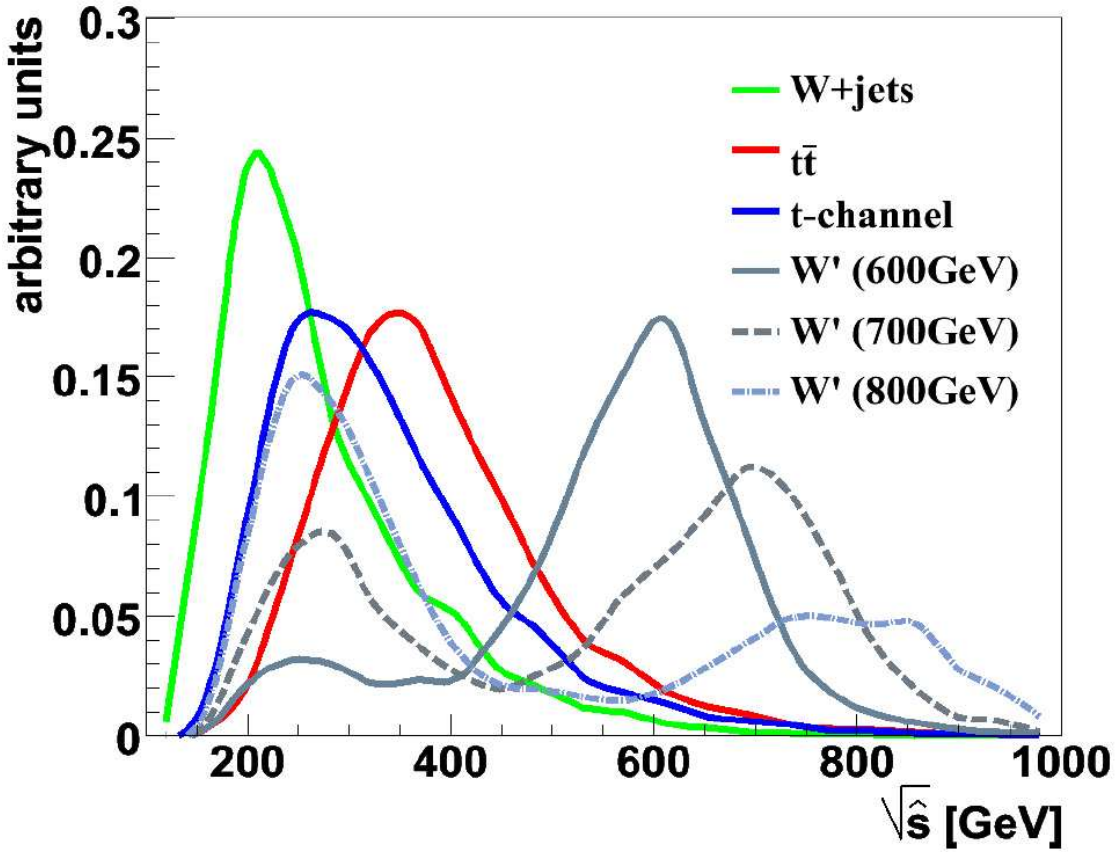
- Relatively small QCD background in comparison to light jet channels

Event Selection and Backgrounds

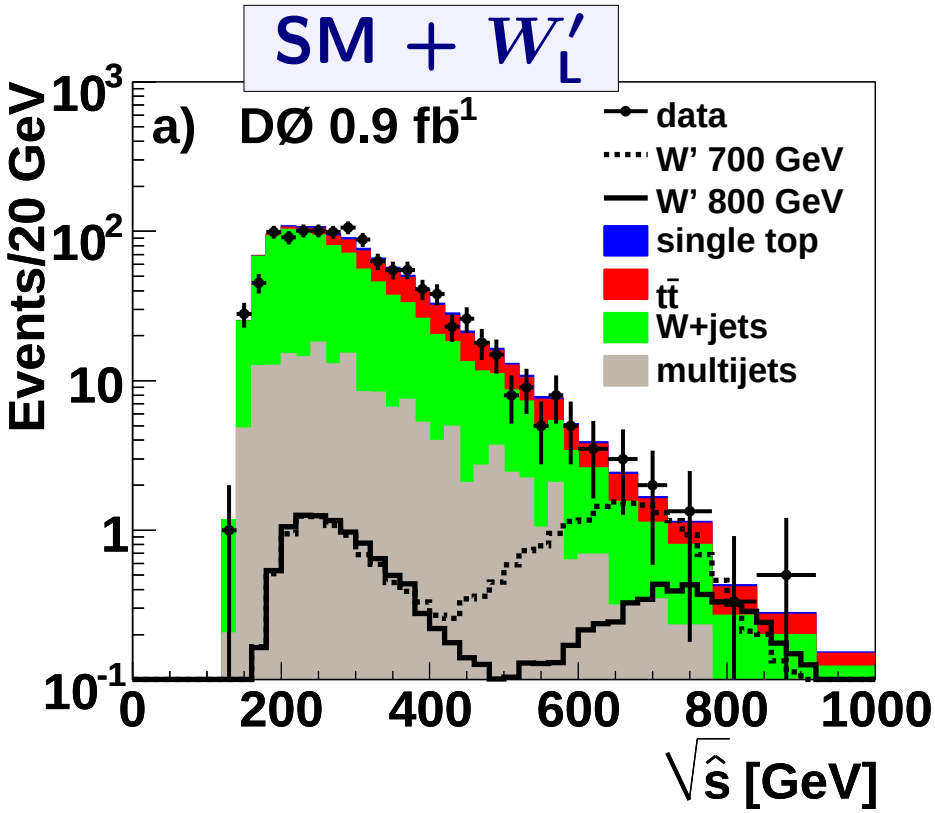


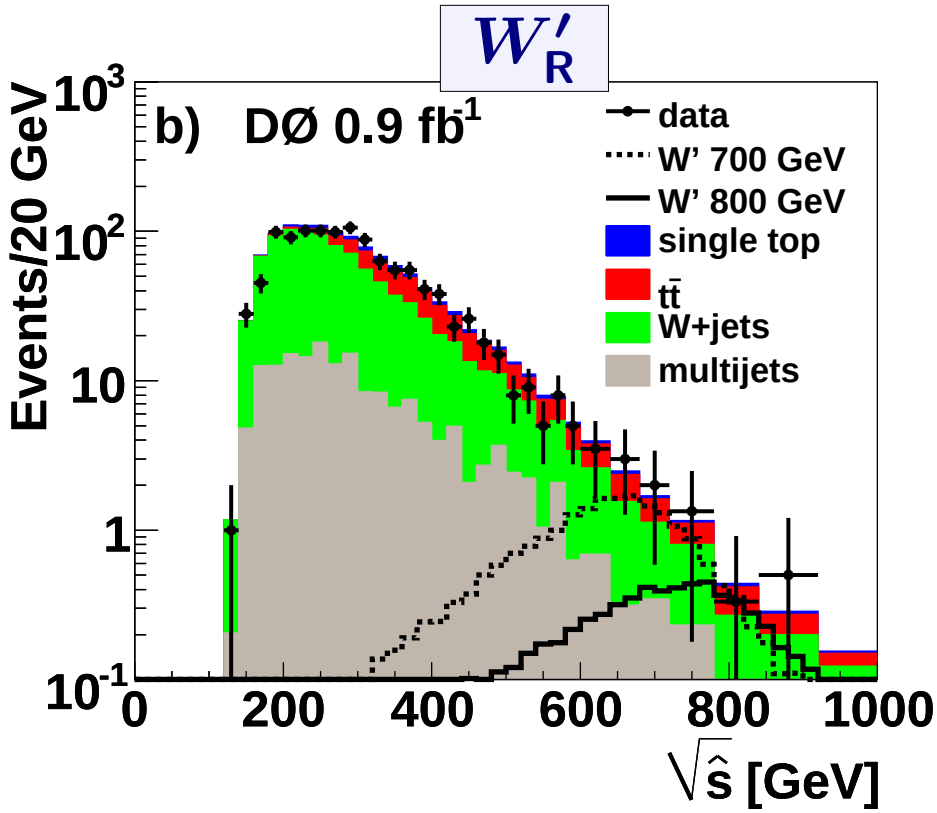
- Data sample used $\mathcal{L} = 0.9$ fb^{-1}
- Event topology similar to single top searches
- Largest backgrounds come from W+jets and $t\bar{t}$
  - Reduce $t\bar{t}$ background by restricting analysis to 2-3 jets

- High p_T electron or muon, large missing energy $\not\!\!E_T$ from neutrino, and up to two b-jets
  - Two or three jets with $p_T > 15$ GeV
  - $\not\!\!E > 15$ GeV
  - Leading jet $p_T > 25$ GeV and $|\eta| < 2.5$
  - Second leading jet $p_T > 20$ GeV
  - Lepton $p_T > 15$ GeV
  - At least one b-jet



Data and Background Comparison

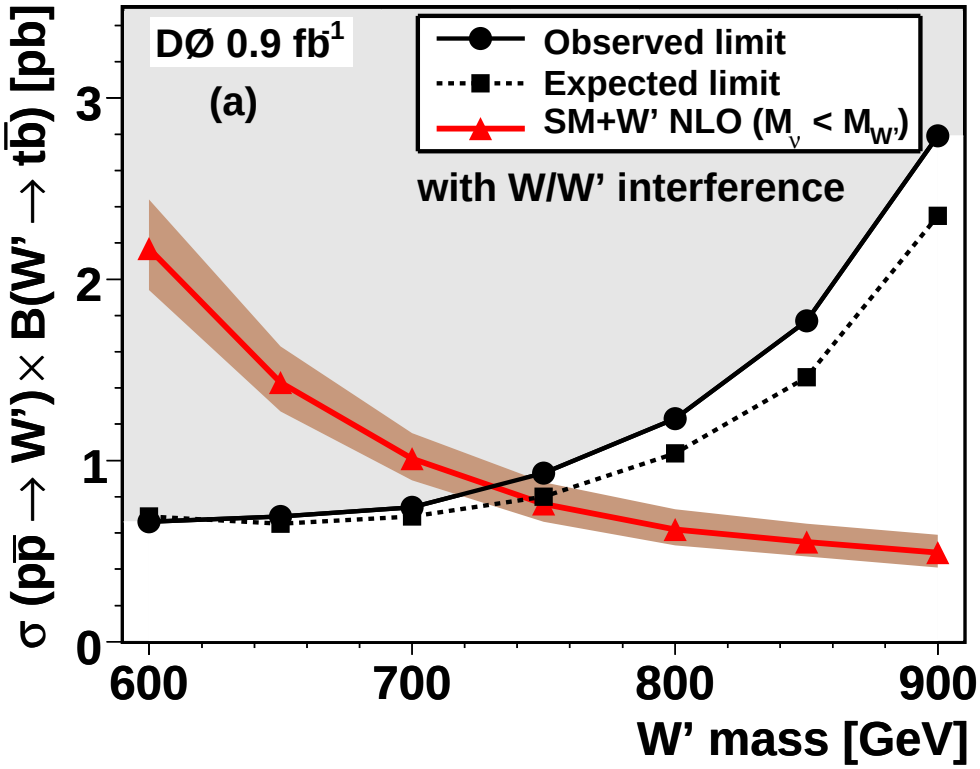


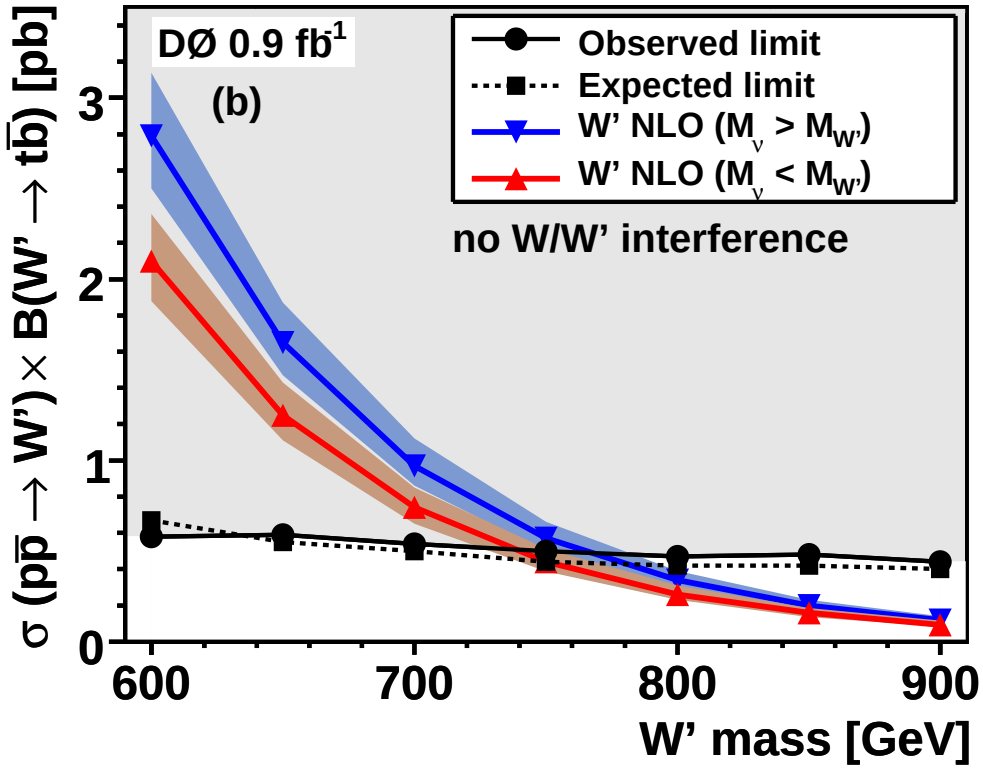


Process	Events	
	SM+W'_L search	W'_R search
Single top	6.4 ± 1.4	10.2 ± 2.2
$t\bar{t}$	59.1 ± 14.4	
W+jets	91.0 ± 18.8	
Multijets	29.7 ± 5.9	
Total background	186.1 ± 40.4	190.0 ± 41.2
Data	182	

- $\sqrt{\hat{s}}$ includes quark jets, lepton, and neutrino from the top quark and subsequent W boson decays
- **Observe no significant excess in the final state invariant mass distribution**

Limits on W' Production Cross Section

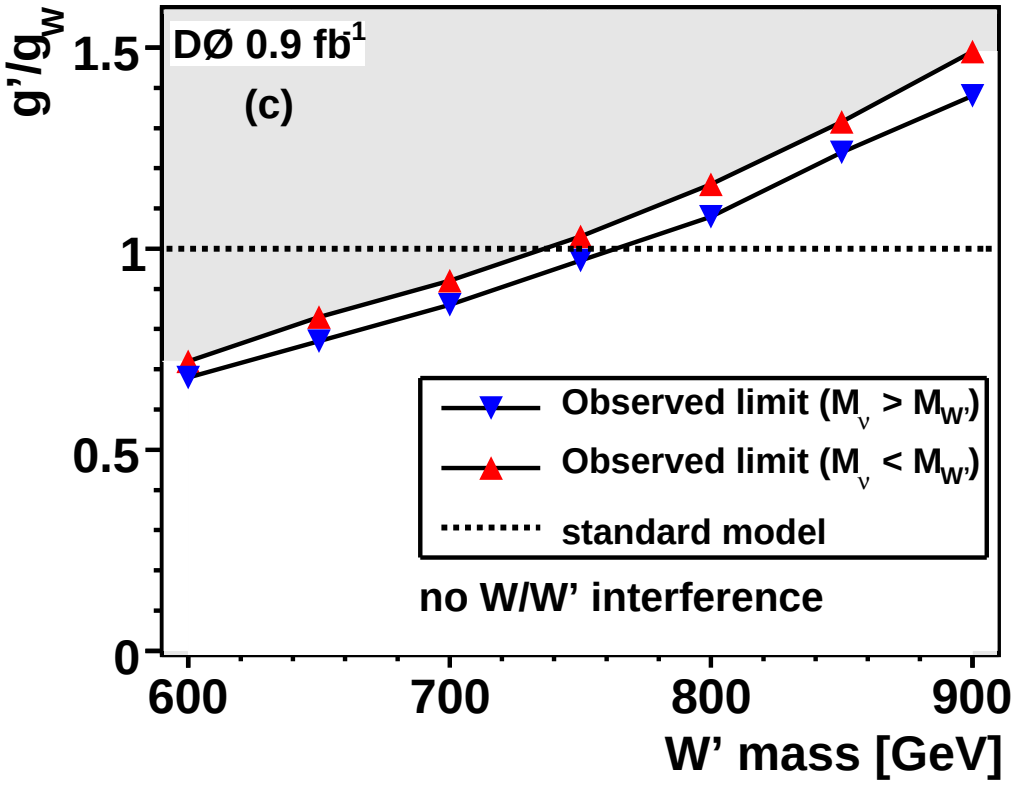




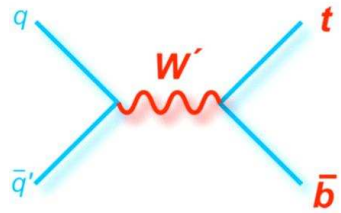
- Use $\sqrt{\hat{s}}$ distributions to set limits separately for models with left and right W'
  Phys. Rev. Lett. 100, 211803 (2008)
  - $M(W'_L) > 731$ GeV
  - $M(W'_R) > 768$ GeV if $M_\nu > M_{W'}$
  - $M(W'_R) > 739$ GeV if $M_\nu < M_{W'}$

- Previous D0 results (230 pb^{-1})
  Phys. Lett. B 641 (2006)
  - $M(W'_L) > 610$ GeV
  - $M(W'_R) > 670$ GeV if $M_\nu > M_{W'}$
  - $M(W'_R) > 630$ GeV if $M_\nu < M_{W'}$

W' Coupling Strength



- The observed limits can be converted into limits on the W' coupling strength
- The leading order s-channel production process has two $W'qq$ vertices. Therefore,



$$\sigma(p\bar{p} \to W') \times \mathrm{Br}(W' \to tb) \propto g'^4$$

- W' coupling strength limit is calculated from the fourth root of the ratio of the experimentally excluded W' cross section and the cross section with SM couplings
- For $M_{W'} = 600$ GeV we exclude gauge couplings at 95% C.L.
  - $\boldsymbol{g'/g_W > 0.68}$ if $M_\nu > M_{W'}$
  - $\boldsymbol{g'/g_W > 0.72}$ if $M_\nu < M_{W'}$

Search for Quark Compositeness and Extra Dimensions

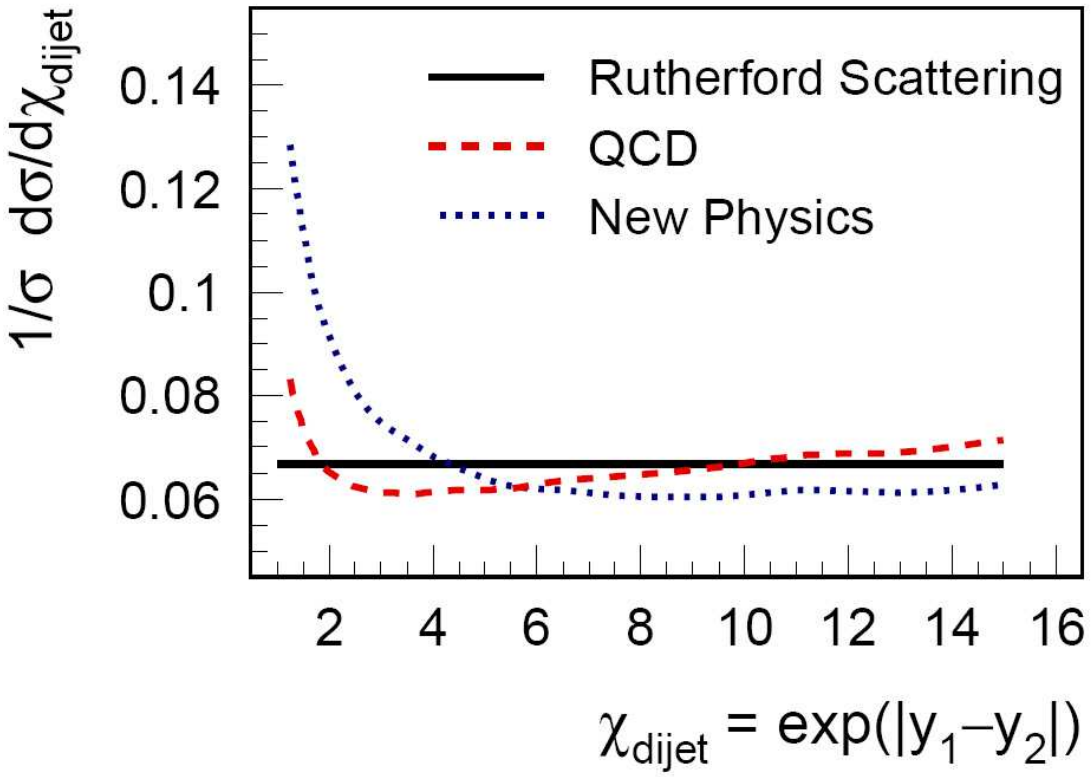
- Dijet variables used in this analysis are

$$\chi_{\text{dijet}} = e^{(|y_1 - y_2|)}$$

$y = \frac{1}{2} \ln \frac{1+\beta \cos\Theta}{1-\beta \cos\Theta}$ is the rapidity of the jet with $\beta = |\vec{p}|/E$

- In massless $2 \to 2$ scattering limit

$$\chi_{\text{dijet}} = \frac{1 + \cos\Theta^*}{1 - \cos\Theta^*}$$

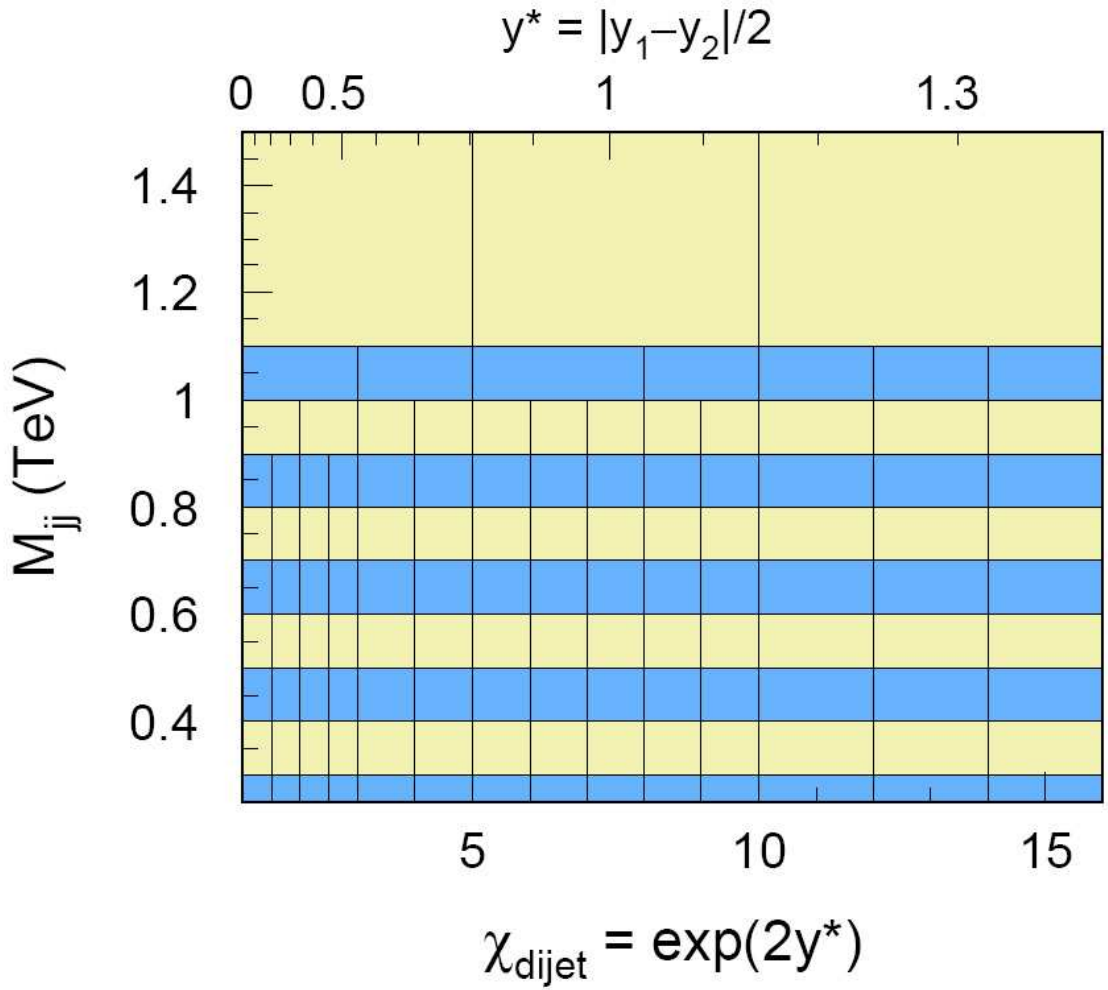


- The cross section for new physics can be expressed:

$$\sigma = \sigma_{\text{SM}} + \eta \cdot \sigma_{\text{int}} + \eta^2 \cdot \sigma_{\text{NP}},$$

  - $\eta = \lambda/\Lambda^2$ for compositeness, Λ is compositeness scale
  - $\eta = \mathcal{F}/M_S^4$ for ADD LED, M_S is the fundamental Planck scale
  - $\eta = 1/M_c^2$ for TeV^{-1} ED, M_c is the compactification scale

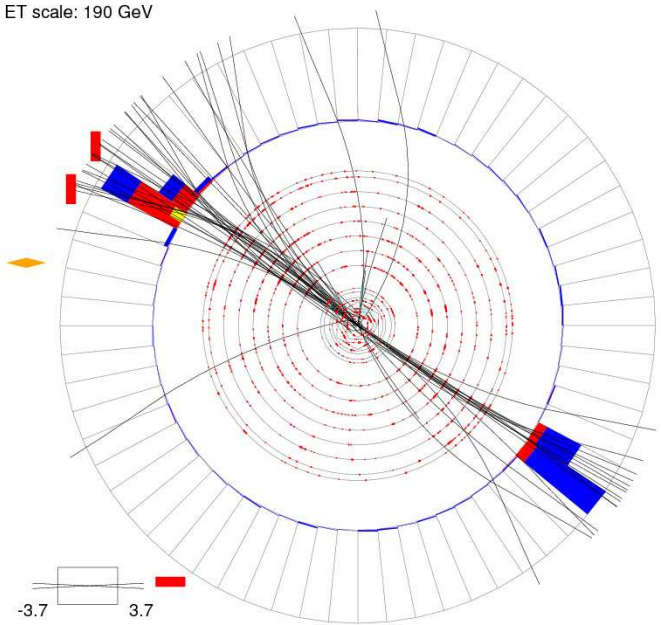
Analysis Bins

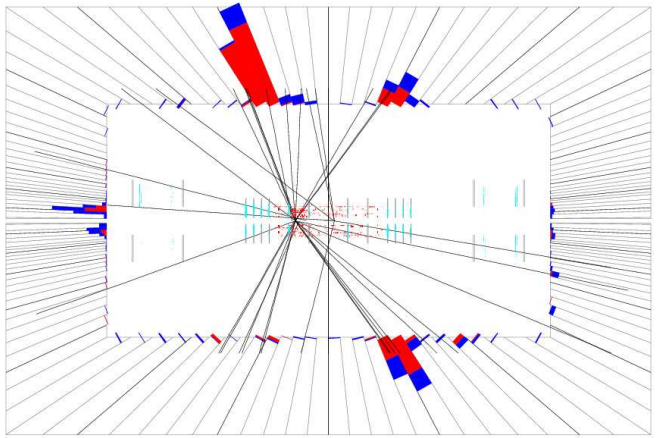


- Use 10 dijet mass bins in the range from 0.25 to $\sqrt{s}$
- Covering rapidity up to ~ 2.4

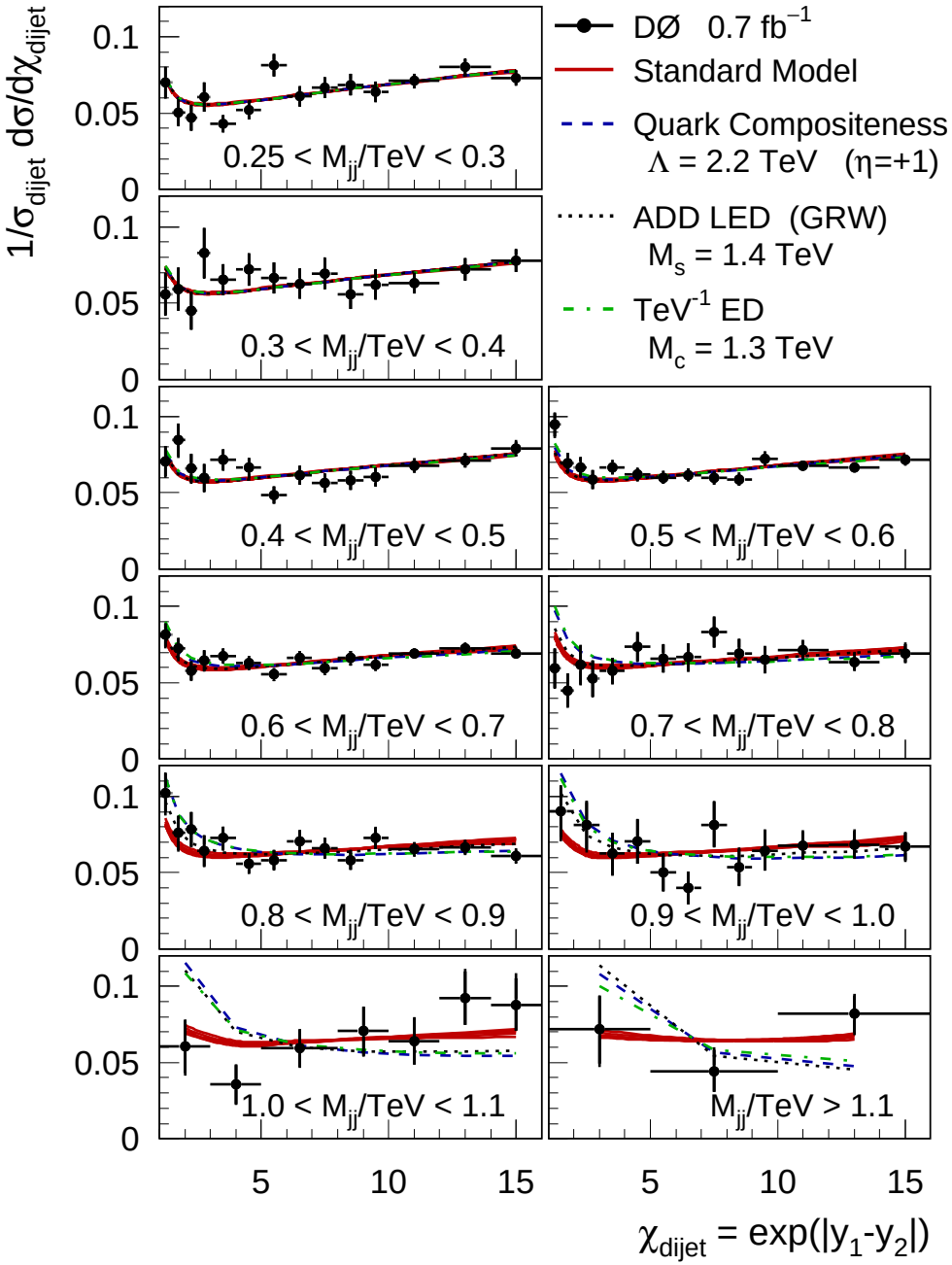
Event Selection and Backgrounds

- Data sample used $\mathcal{L} = 0.7$ fb^{-1}
- Jets are defined with a cone jet algorithm with $R = 0.7$
- The jets energy is corrected for showers and multiple $p\bar{p}$ interactions
- Difference in electron/photon and real jet showers is used to suppress the background
- Fraction of background events is below 0.1% in all mass bins





Dijet Angular Distributions and Limits



- Data are well described by the NLO pQCD
- New physics models change shape in χ_{dijet} at higher M_{dijet}
- Quark compositeness
  - $\boldsymbol{\Lambda > 2.2}$ GeV at 95% C.L.
- TeV^{-1} extra dimensions
  - $\boldsymbol{M_s > 1.4}$ GeV at 95% C.L.
- ADD large extra dimensions
  - $\boldsymbol{M_c > 1.3}$ GeV at 95% C.L.

Submitted to PRL arXiv.org:0906.4819

Conclusions

- D0 has performed a model independent search for compositeness, LED, and W' resonance in hadronic decay channel with 0.7 and 0.9 fb^{-1} of data respectivelly

  - More than 5 times of data available now
- Better analysis techniques and more statistics improved previously reported Tevatron results
  - Many data-driven methods to estimate background
  - Valuable experience for upcoming LHC data
- **No indication of new physics detected. . .**

. . . but the search continues with more data available!