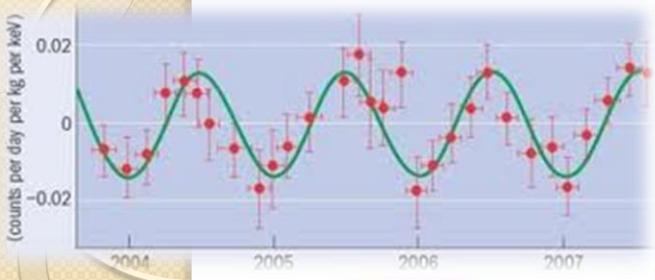
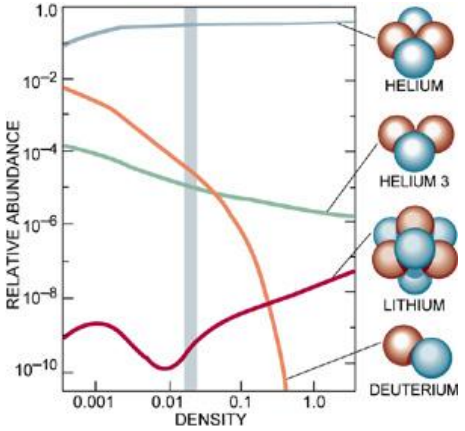
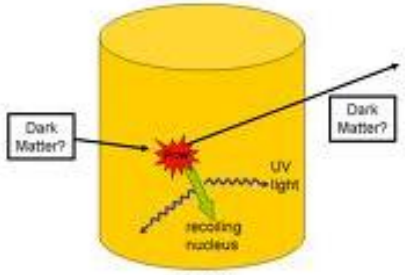
Search for dark matter and top pairs associated production at CDF II

Marco Bentivegna

University La Sapienza of Rome – Purdue University

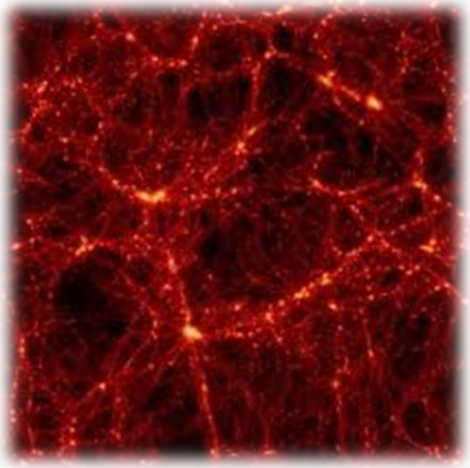


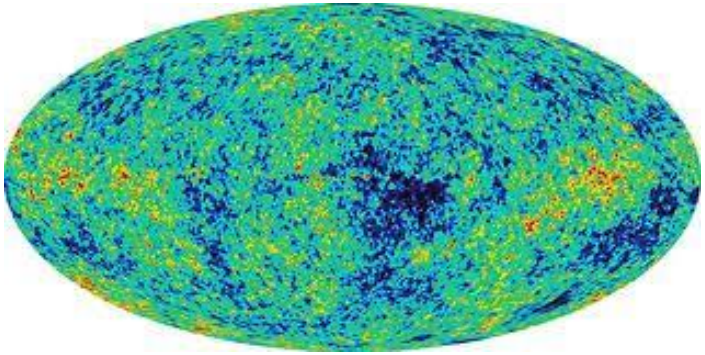


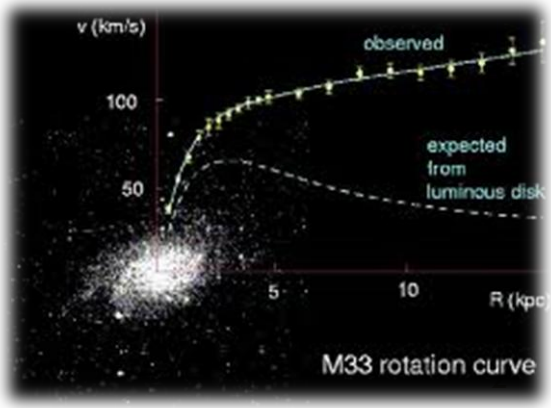


DARK MATTER

There is always more than what appears…







The need for Dark Matter

- From 1930 to now, evidences from many astronomical observations for the existence of long-lived, hardly detectable massive particles
- Also required in cosmology for Big Bang Nucleosynthesis and structure formation
- Recent DAMA and CoGeNT results seems to show DM interaction with SM are not only gravitational, so it could be produced at colliders
- For a large set of theoretical models, DM produced in association with top quark pairs

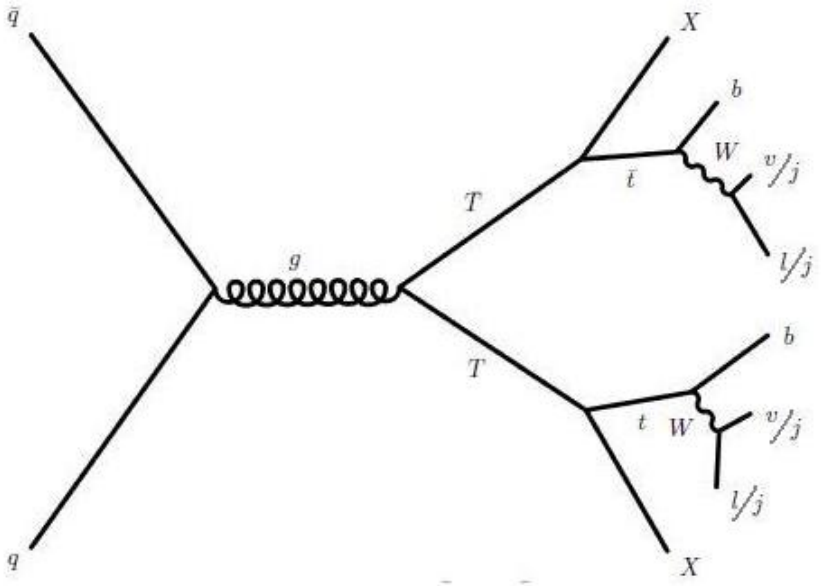
T' quarks as "connector particles"

- Long lifetime could be explained by charge under a new, unbroken symmetry
- Interaction with SM through "connector particles" carrying both SM and "dark" charges
- For example:
  - Supersymmetry (R-parity, squarks)
  - Extra dimensions (KK-parity, KK quarks)
- Our search is focused on a recent model in which the connector particles are exotic fourth generation T' quarks

The T' → t + X hypothesis

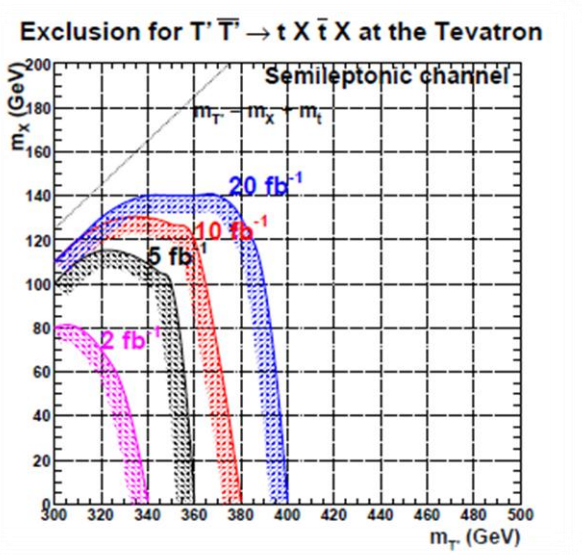
- From perturbativity, $m_{T'} < \approx 600$ GeV/c^2
- Carrying dark charge, our T' quarks cannot decay only in SM particles ("traditional" searches T' → Wq)
- In this model, the T' quark is expected to decay into a top quark and the lightest particle carrying dark charge (DM)

- Signal: top pair + large MET
- Final signature depending on W decay modes

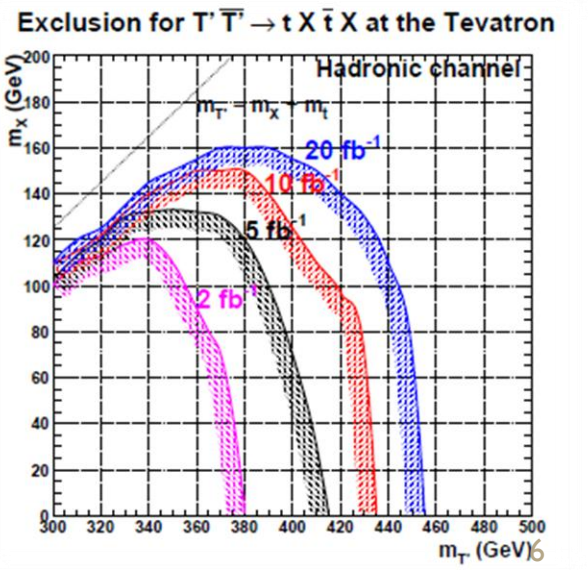


Expected results for T'T' → ttXX

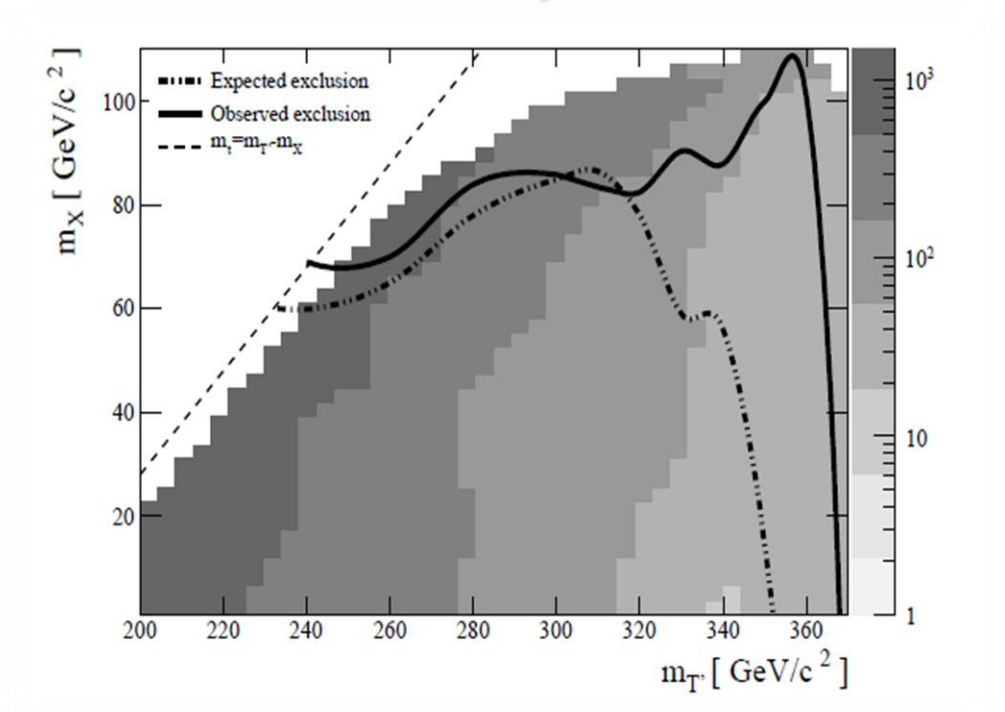
- Theoretical: *Alwall et al., hep-ph 1002-3366*



- Hadronic channel is expected to give higher sensitivity

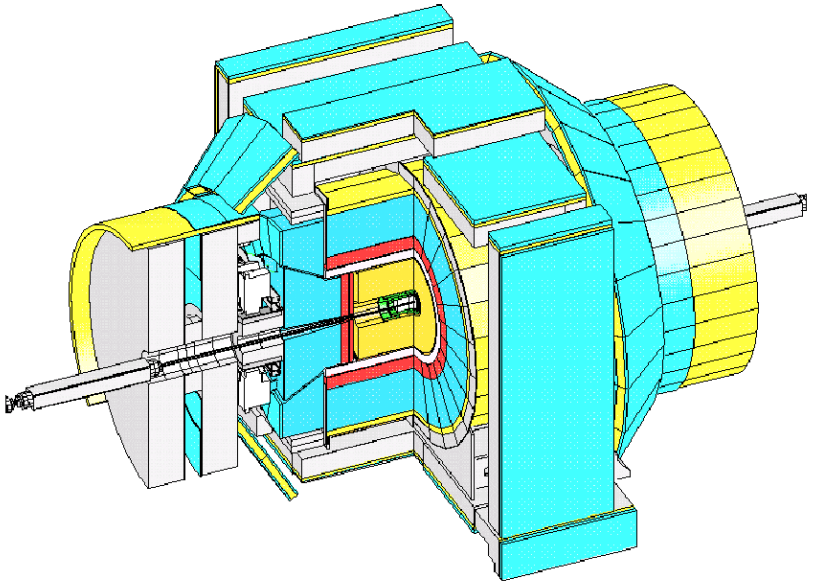


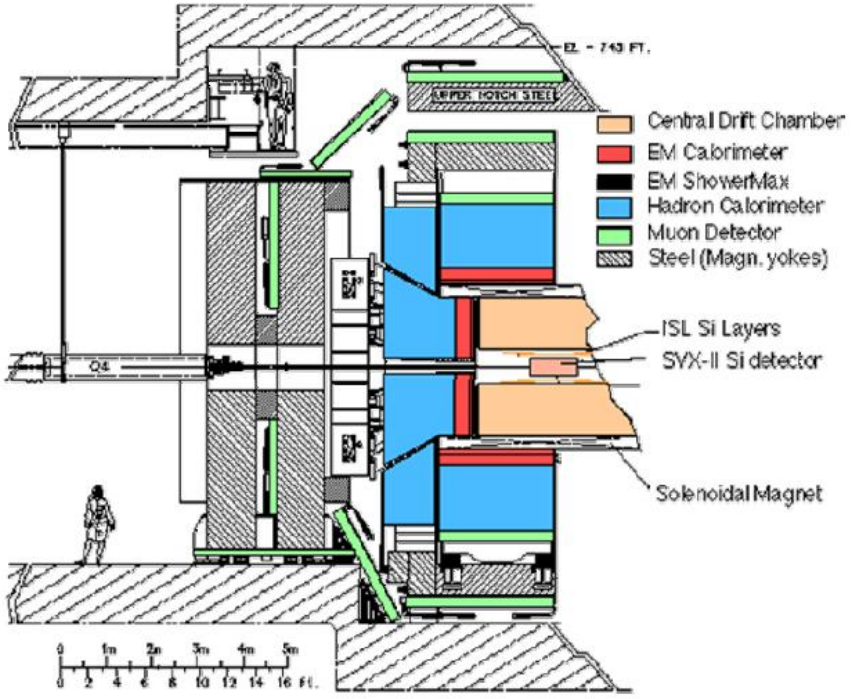
Recent exclusions (T'T' → ttXX) Semileptonic



- With 4.8 fb^{-1}, CDF set a 95% exclusion up to $m_{T'}$ = 360 GeV (*arxiv:1103.2482*)
- Hadronic channel was still unexplored…

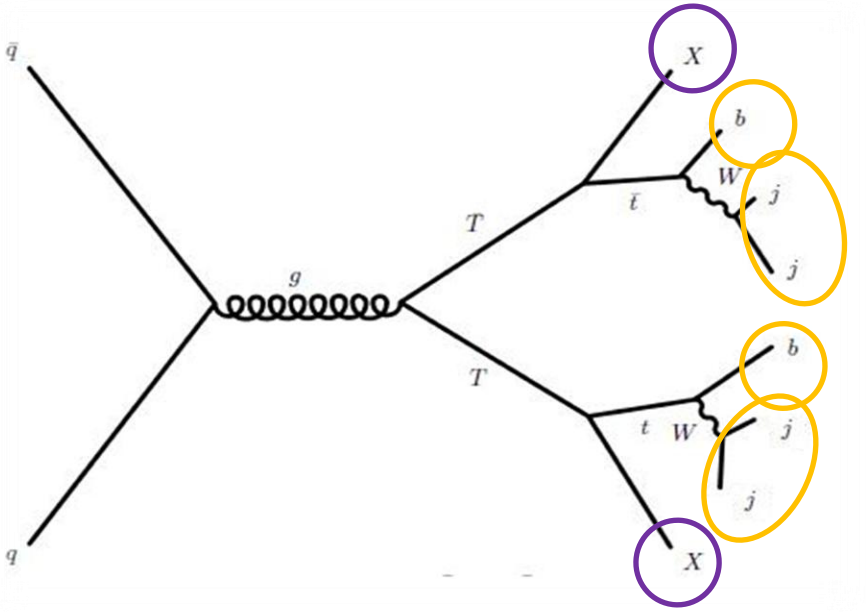
CDF II Detector





- MET resolution ≈ 80% / $\sqrt{\sum_{\text{towers}} E_T^i}$
- Tracking volume: η <≈ 1.2
- JES uncertainty ≈ 3%

Searching for T'T' → ttXX in the hadronic channel



6 jets + Missing Energy

Main expected backgrounds, and modeling:

- Top pair production (mainly semileptonic with unidentified lepton)
- EWK + jets

→ **Monte Carlo simulations**

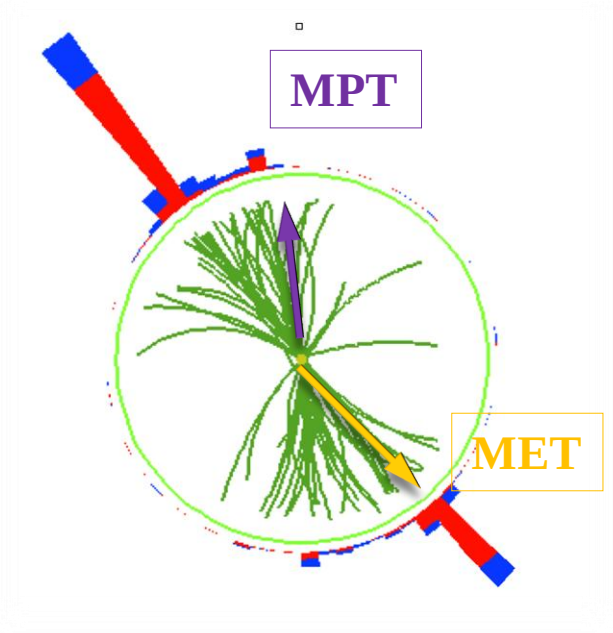
- QCD multijet with fake MET (large production rates, large systematic uncertainties in MC simulations…)

→ **???**

The MPT variable

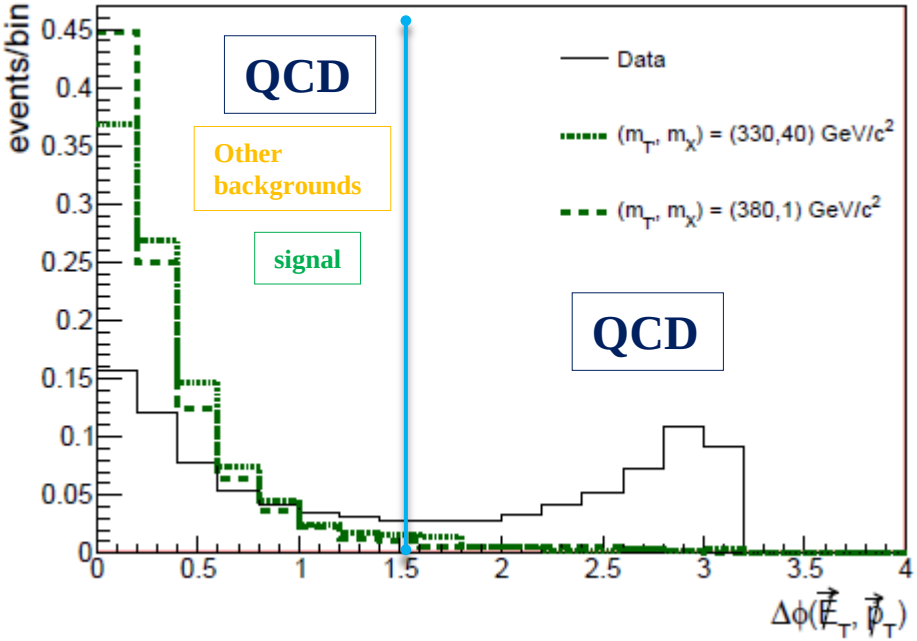
- While MET is measured with calorimeter info, MPT depends only on track info
- In true-MET events, they have almost the same directions

- In fake-METdijet (but also dijet-like) events, MET depends on mesmeasurement in calorimeter, while MPT depends from fluctuations in the number of charged particles in jets
- So, they tend to be on the dijet axis, with roughly the same probability to be aligned or back-to-back



A QCD data-driven model

- Good to remove QCD multijet background
- **Very powerful instrument to obtain a higly-populated QCD sample**



- We assume the region $\Delta\phi$ (MET, MPT) > $\pi/2$ as pure QCD
- We take the events in this region to model QCD in the signal region (left)
- Since distribution is not exactly symmetric, we will need a scale factor to renormalize our QCD sample

Selection cuts

- No isolated electrons, muons with $p_T > 20$ GeV/c
- MET > 50 GeV
- MPT > 20 GeV
- METsignificance > 3 $\sqrt{\text{GeV}}$
- $\Delta\phi$ (MET, MPT) < 1,57 (π/2)
- $\Delta\phi$ (MET, p^j_T) > 0.4 for i = 1, 2, 3
- $\Delta\phi$ (MET, p^j_T) > 0.2 for i = 4, 5
- $5 \leq N_{jets} \leq 10$
- $H_T > 220$ GeV

Reject EWK and semileptonic ttbar

Reject QCD multijet

Reject QCD pile-up

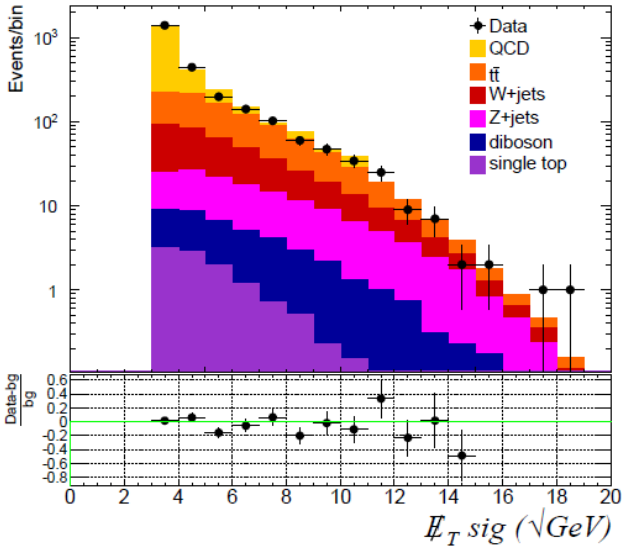
Reject most of the BGs

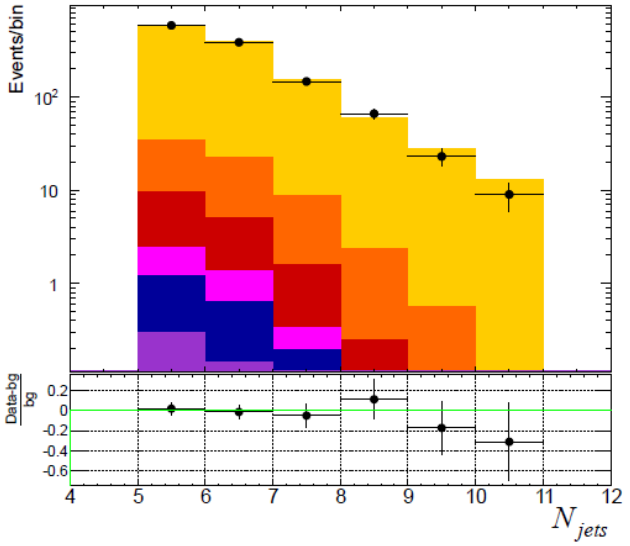
$$\text{METsignificance} \equiv \text{MET}/\sqrt{\sum_{towers} E^i_T}$$

$$H_T \equiv \sum_{jets} E^j_T$$

Control Regions

- Three signal-depleted regions to get QCD scale factor and check overall BG modeling:
  - MET significance < 3 $\sqrt{GeV}$
  - N_{jets} = 4
  - MPT < 20 GeV
- We calculate QCD scale factor in each region as the one to exactly match the number of observed events. The scale factor applied in the signal region will be an average of those obtained in control regions
- In first two regions, enough statistic to validate the distributions' shapes

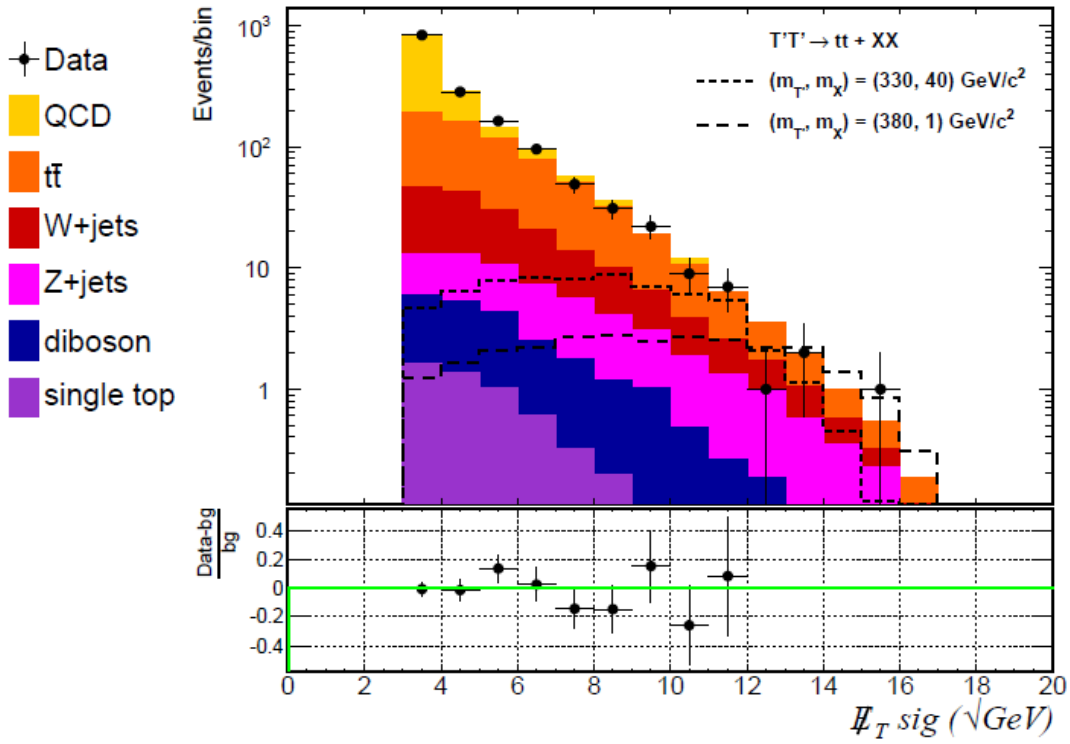




Signal Region

$T'T' \rightarrow ttXX$ [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

METsig distribution in signal region

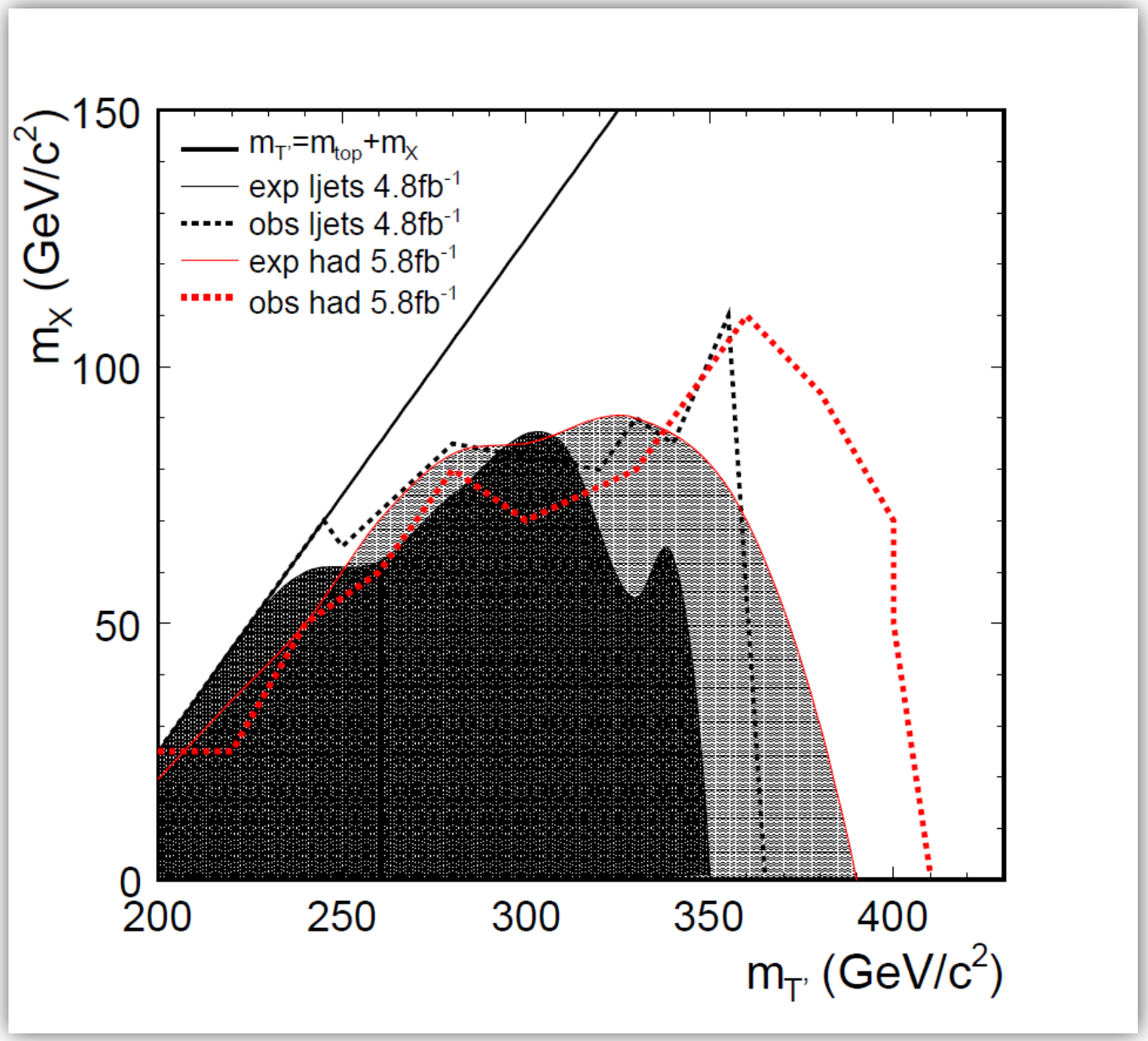


- Most powerful variable to discriminate signal from background
- Binned maximum-likelihood fit to investigate our signal hypothesis
- Bayesian likelihood method, using flat prior for signal cross section, integrating over gaussian priors for systematic uncertainties

Sistematic uncertainties

- Cross sections:
  - ttbar ±12%
  - W/Z + Jets ± 40%
  - Diboson ± 11%
  - Single top ± 13%
  - T' ± 12%
- For ttbar we also have:
  - Herwig-Pythia ± 9%
  - ISR/FSR ± 6%
  - Color reconnection ± 3%
  - JES ± 10%
- JES give also a ± 3% on signal, and is assigned as a shape sistematic for ttbar and signal
- For QCD we assign a ± 20% to the scale factor
- Finally, we have a ± 6% uncertainty on the luminosity

New exclusion limits



Conclusions

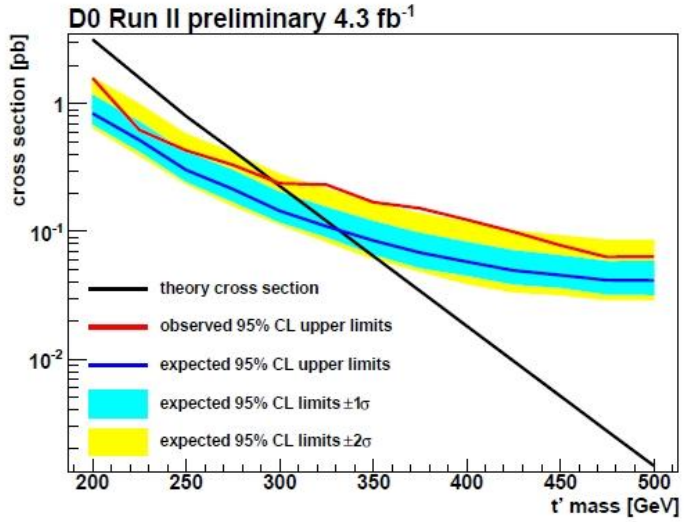
- Our results are consistent with SM expectations; we set 95% confidence exclusion limits on the production of T' up to mT' = 400 GeV/c^2 , for m_X < 70 GeV/c^2
- We also tested the behaviour of a QCD data-driven model based on the $\Delta\phi$ (MET, MPT) variable
- We showed that hadronic channel is the most sensitive for the generic production of top pairs plus dark matter candidates, and thus for search of scalar top decaying in top plus neutralino

arxiv:1107.3574

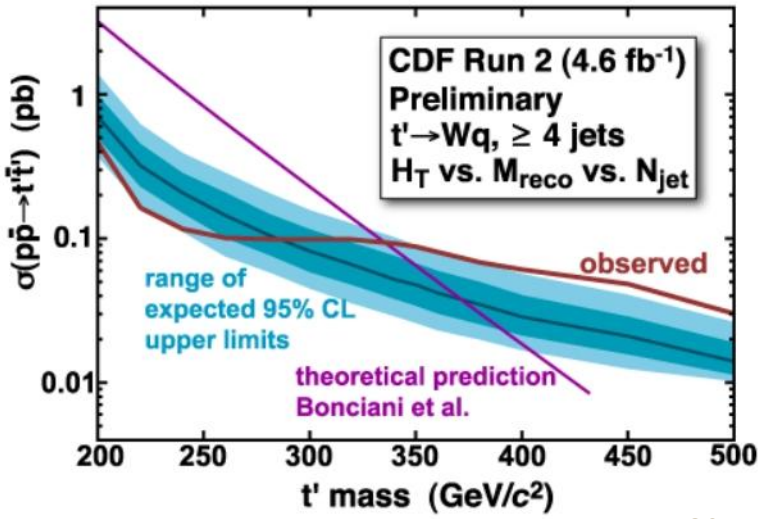
Backup

Recent exclusions (T'T' → WWqq) in semileptonic channel

- D0 excluded T' decaying into Wq for $m_{T'} \leq 296$ GeV/c^2



- CDF exclusion goes up to $m_{T'} \leq 335$ GeV/c^2



Data and MonteCarlo samples

- Starting data sample: 5.7 fb^{-1} (dijet+MET trigger)
- ttbar: Pythia (m_t = 172.5 GeV/c^2) normalized to NLO cross section
- W/Z+jets: Alpgen, interfaced with parton-shower model from Pythia
- Diboson: Pythia
- Single top: MadGraph
- T' signals: MadGraph (thanks to Daniel Whiteson) theoretical cross sections from *Bonciani et al., hep-ph 9801375*

Preselection

- No isolated electrons, muons with $p_T > 20$ GeV
- MET > 50 GeV
- At least 5 jets with $|\eta| < 2.4$, $p_T(J_i) > 30$ GeV for $(i = 1, 2)$, $p_T(J_i) > 20$ GeV for $(i = 3, 4, 5)$, others with $p_T > 15$ GeV

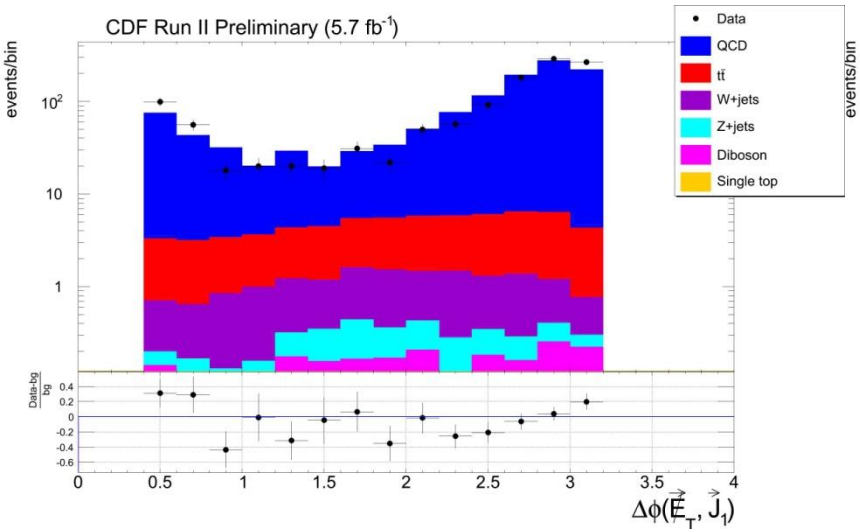
Preselection sample is > 95% QCD

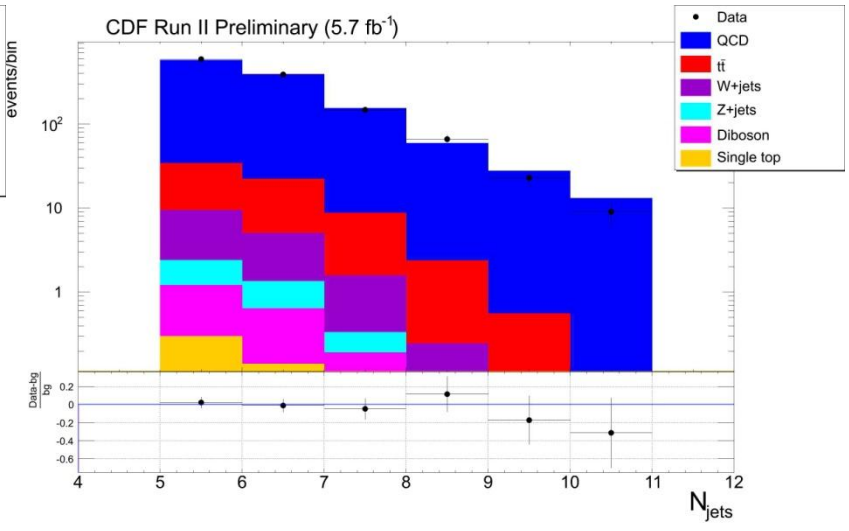
Selection cuts

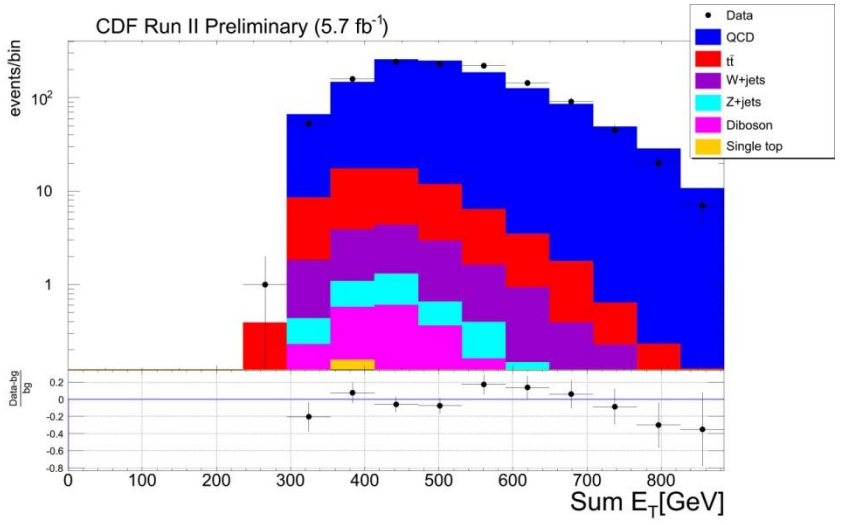
- $\Delta\phi$ (MET, p_T^j) > 0.4 for i = 1, 2, 3
- $\Delta\phi$ (MET, p_T^j) > 0.2 for i = 4, 5
- $\Delta\phi$ (MET, MPT) < 1,57 (π/2)
- METsignificance > 3 $\sqrt{}$GeV
- MPT > 20 GeV
- H_T > 220 GeV
- Njets ≤ 10

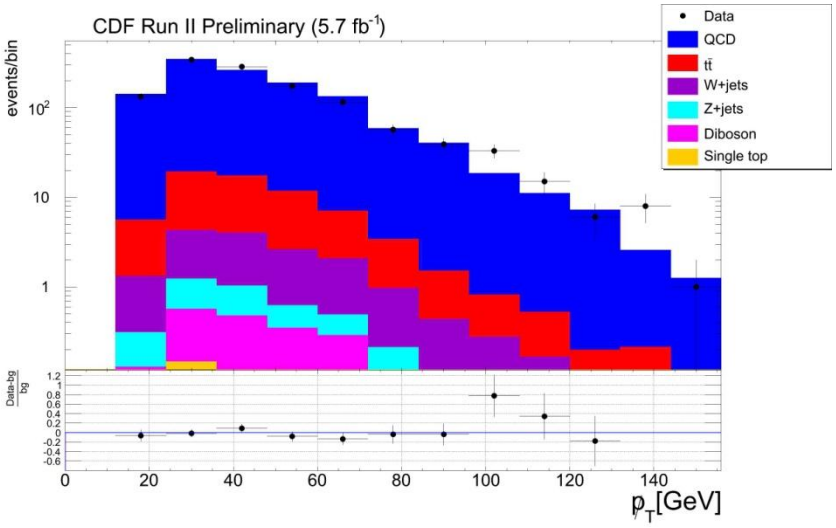
QCD is reduced to about 50% of the sample

MET significance < 3 √GeV Control Region

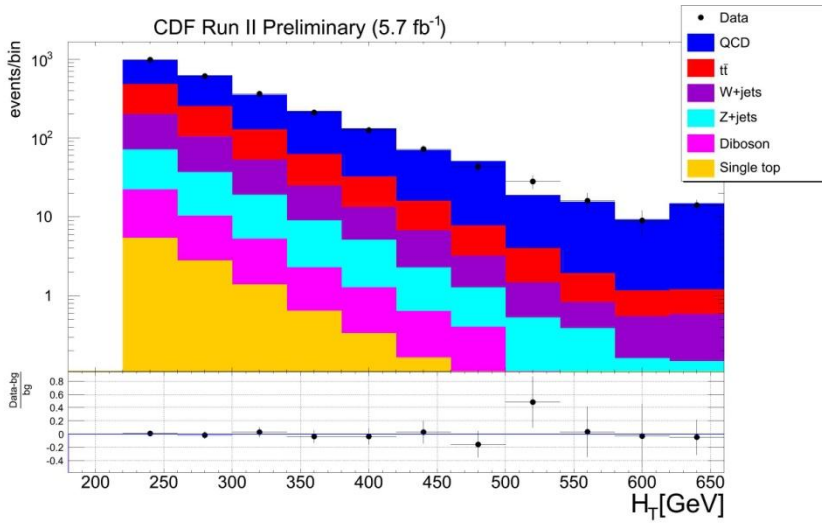


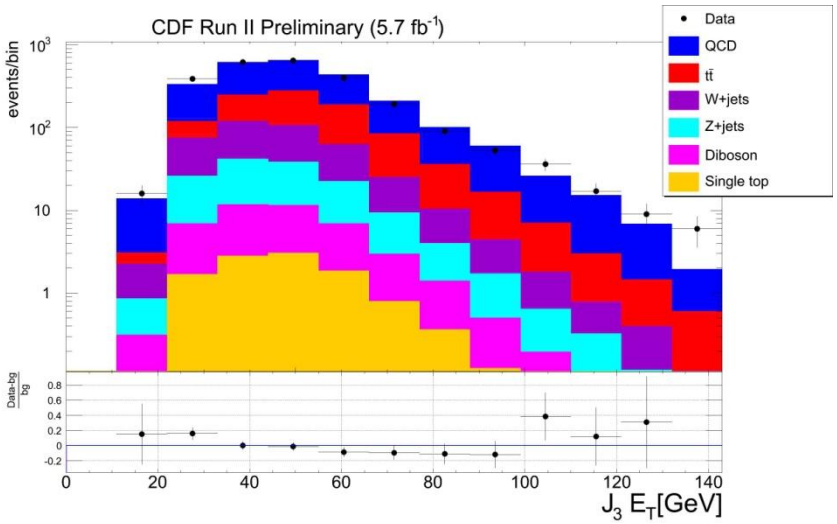


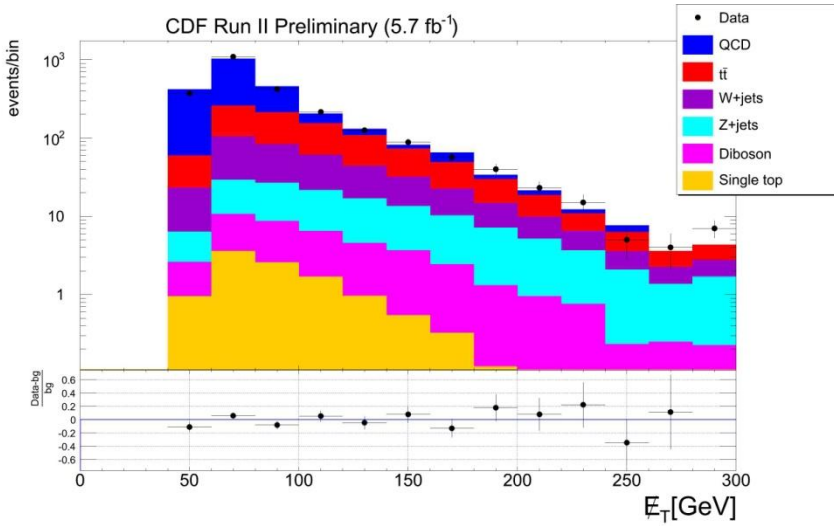


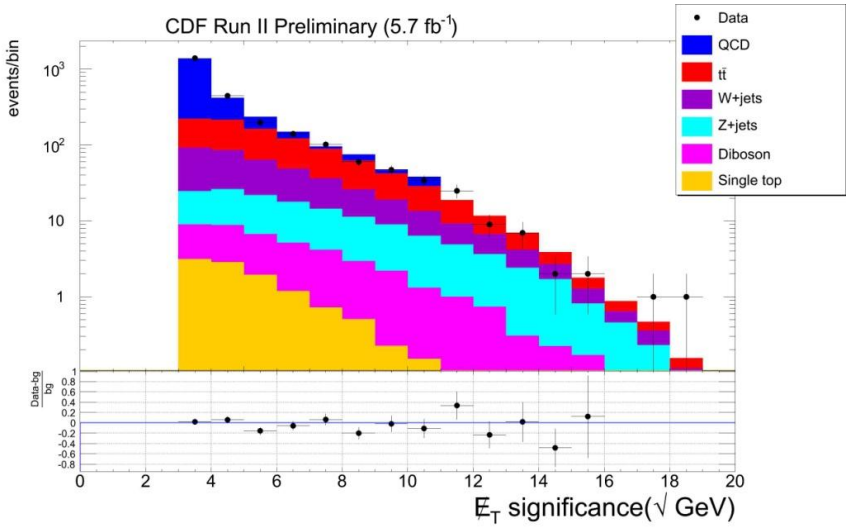


N_{jets} = 4 Control Region









Control Regions

MET sig < 3 $\sqrt{\text{GeV}}$ Njets = 4 MPT < 20 GeV

Process	Events
Observed	1219
QCD(scaled)	1151 ± 39
$t\bar{t}$	52.1 ± 7.0
$W+$ jets	12.2 ± 4.9
$Z+$ jets	2.1 ± 0.8
$WW/WZ/ZZ$	1.6 ± 0.2
Single top	0.30 ± 0.04
Observed Scale Factor	1.18 ± 0.04

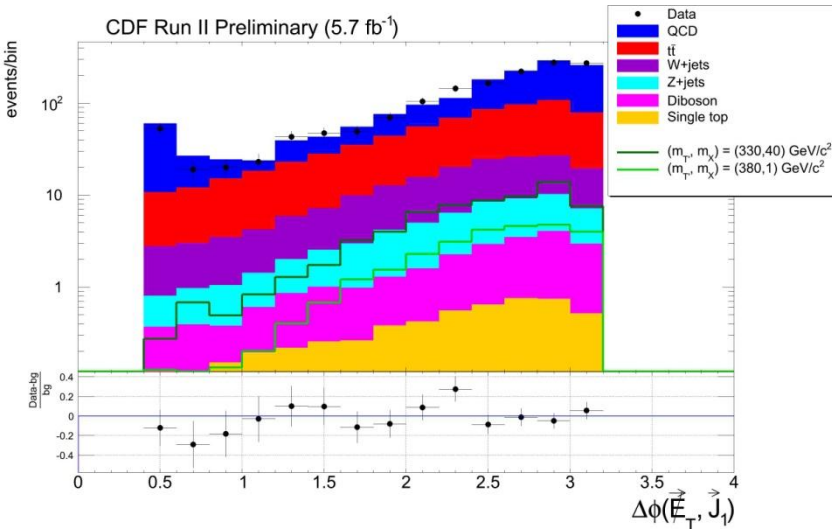
Process	Events
Observed	2467
QCD(scaled)	1482 ± 140
$t\bar{t}$	580.6 ± 77.9
$W+$ jets	263.5 ± 106.6
$Z+$ jets	103.1 ± 41.7
$WW/WZ/ZZ$	31.9 ± 4.0
Single top	10.8 ± 1.5
Observed Scale Factor	1.35 ± 0.12

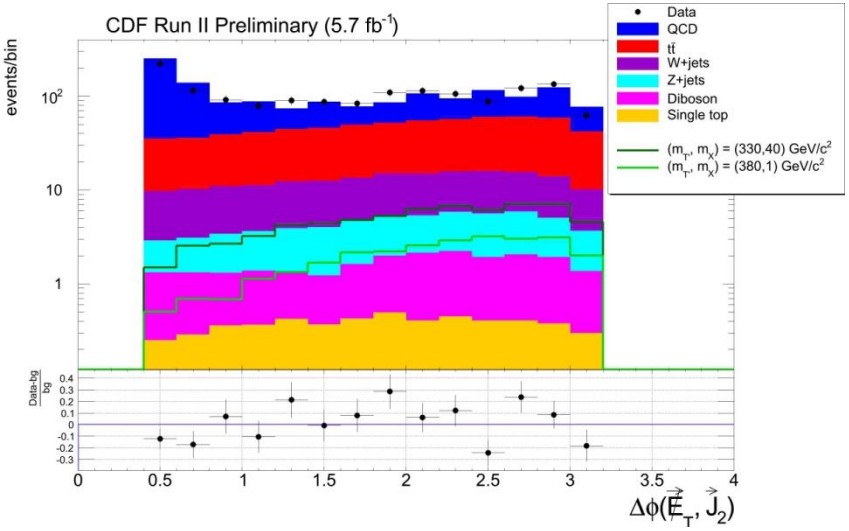
Process	Events
Observed	289
QCD(scaled)	222.4 ± 18.9
$t\bar{t}$	50.2 ± 6.7
$W+$ jets	12.0 ± 4.8
$Z+$ jets	2.4 ± 1.0
$WW/WZ/ZZ$	1.8 ± 0.2
Single top	0.30 ± 0.04
Observed Scale Factor	1.06 ± 0.09

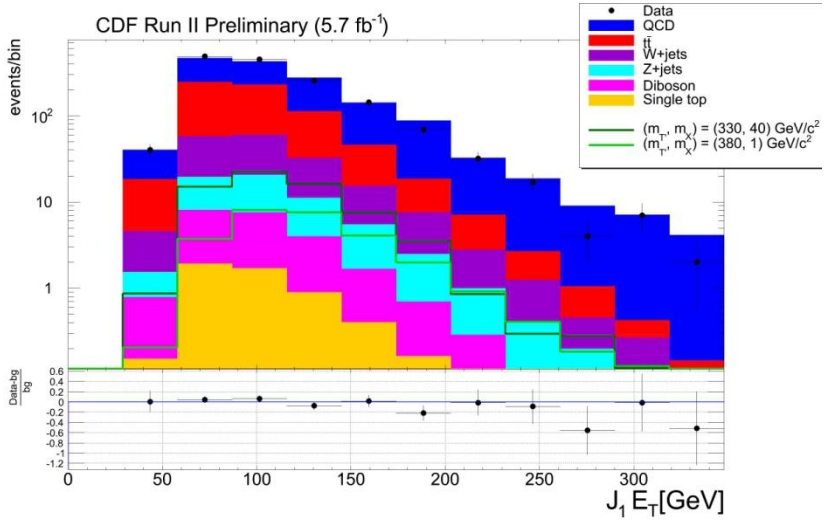
FINAL SCALE FACTOR

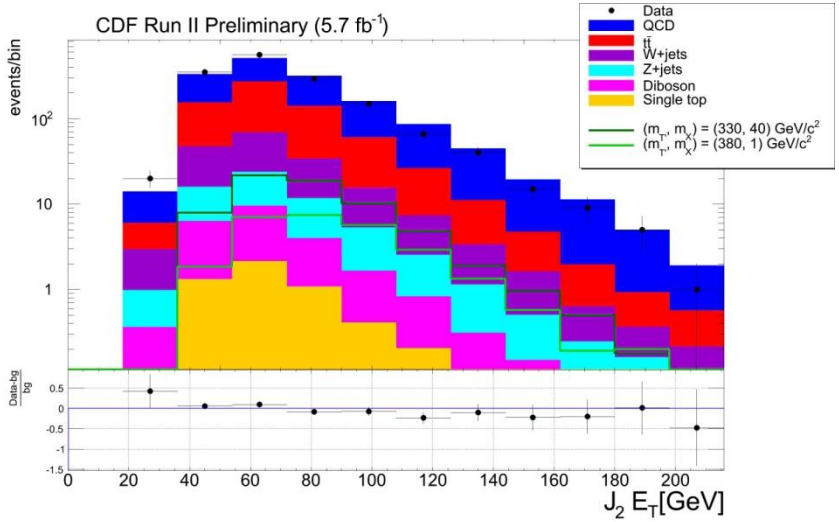
1.2 ± 0.2

Signal Region









Signal Region