Measurement of the $t\bar{t}$ Production Cross Section in the Dimuon Final State with the DØ Detector

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DØ Collaboration

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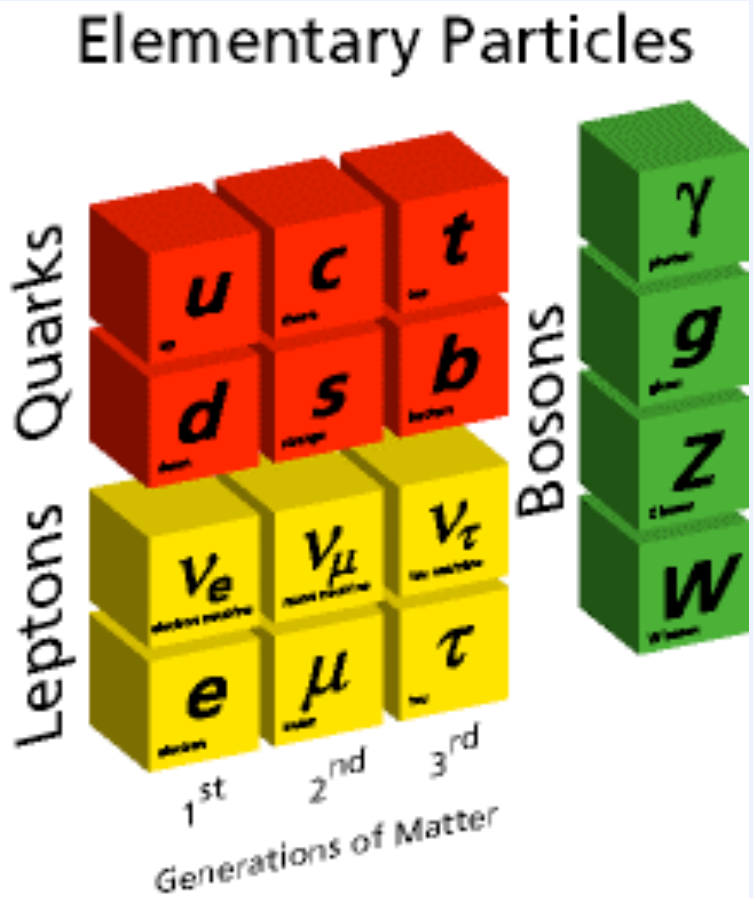
Standard Model

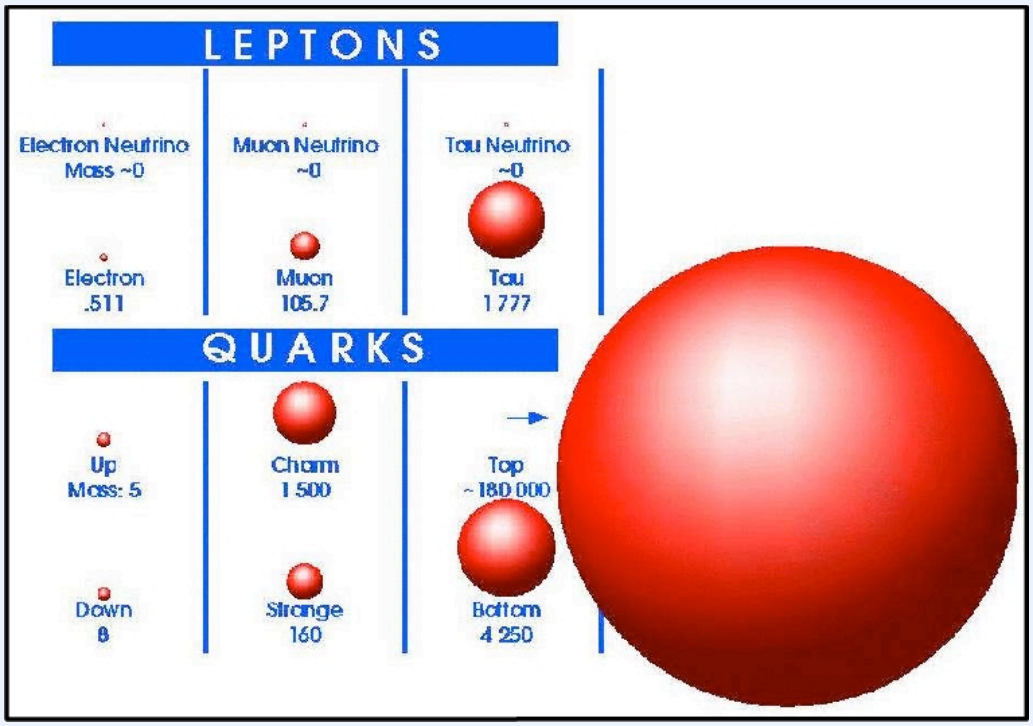


- Describes elementary particles and their interactions
  - Fermions: 6 quarks and 6 leptons
  - Gauge bosons mediate interactions
    - Strong
    - Weak
    - Electromagnetic
    - (Gravity not yet unified)
- Consists of QCD ($SU(3)_C$) and electroweak theory ($SU(2)_L \otimes U(1)_Y$)
  - Mass imputed via spontaneous symmetry breaking (Higgs Mechanism)

- All measurements have confirmed Standard Model predictions
- But multiple families, unpredicted parameters, no Higgs boson, … make completeness of the Standard Model suspect

Top Quark

- "New"
  - First observed in 1995
  - Bottom quark observed in 1977



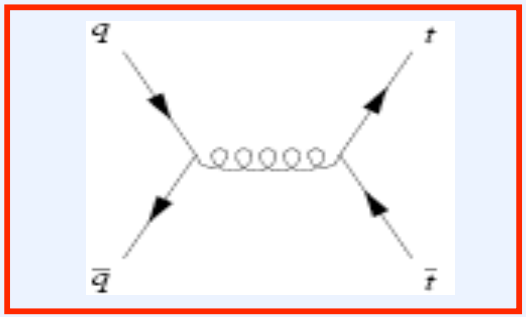
- Heavy!
  - >35× as heavy as the bottom
  - Heaviest elementary particle observed so far
  - Decay to exotic particles ?

- Short-lived
  - Lifetime is 4×10^{-25}s , which is less than the hadronization time
  - Study the top quark free of confinement

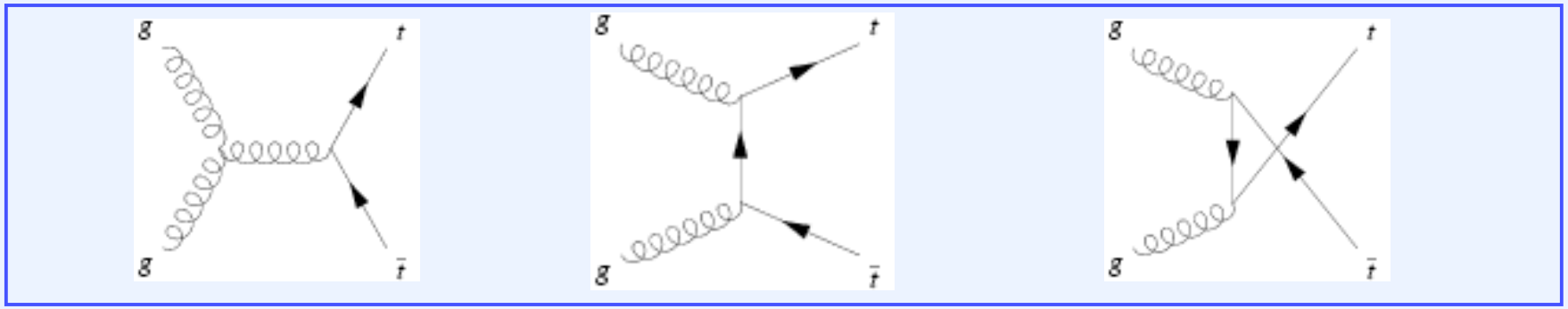
Top Quark Pair Production

- For $p\bar{p}$ collisions at Tevatron, $\sqrt{s} = 1.96$ TeV :

- Quark-antiquark annihilation 85%



- Gluon-gluon fusion 15%



Theoretical Cross Section Prediction

- Cross section σ : proportionality constant interpreted as the interaction probability

$$\sigma(s,m_t^2) = \sum_{i,j} \int dx_1 \int dx_2 f_i(x_i,\mu_f^2) f_j(x_j,\mu_f^2) \hat{\sigma}_{ij}(\hat{s},m_t,\alpha_s(\mu_r^2))$$

σ_{ij} = Partonic cross section for i+j→ $t\bar{t}$

$x_{i,j}$ = Fraction of proton momentum carried by parton i,j

f_i = Parton distribution functions (PDF's): probability that parton i has momentum fraction x

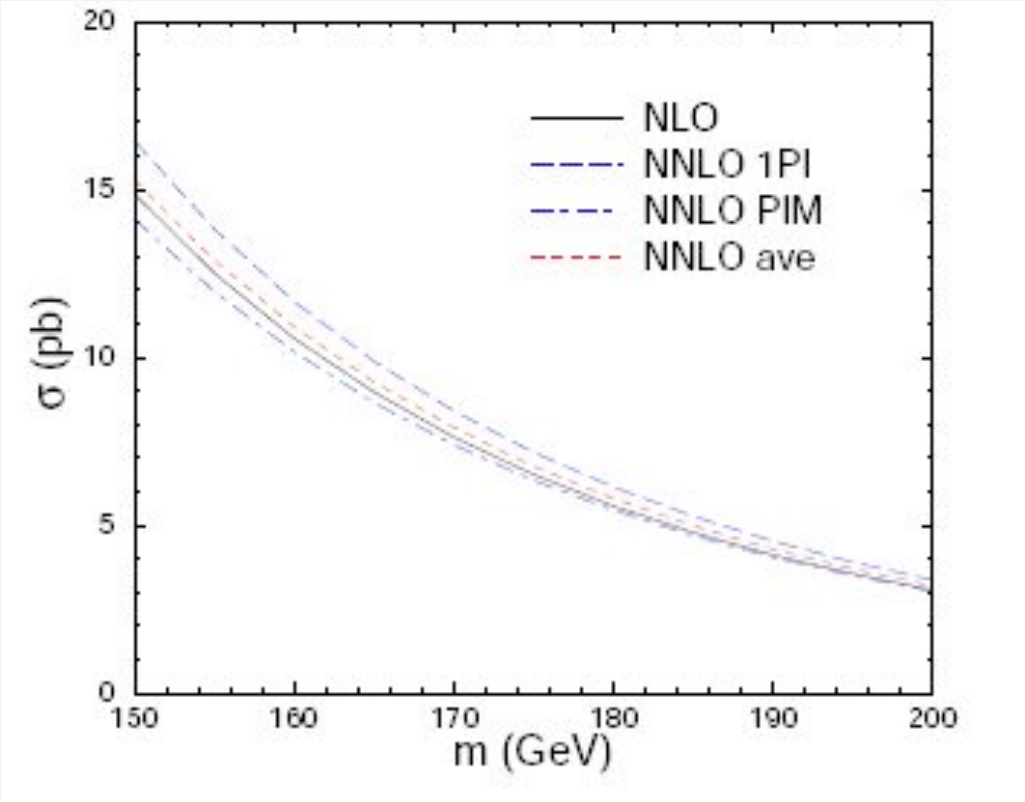
$\hat{s} = x_i x_j s$

m_{top} = mass of the top quark

$\mu_{f,r}$ = Factorization and renormalization scales ($\mu_f = \mu_r = \mu$)

- Partonic cross sections found via perturbative expansion in strong coupling constant
  - $\sigma_{ij} \sim C_0\alpha_s^2 + C_1\alpha_s^3 + C_2\alpha_s^4 + \ldots$
- PDF's determined from global QCD fits to data

Theoretical Cross Section Prediction



$$1PI : q(p_a) + \overline{q}(p_b) \rightarrow t(p_1) + X[\overline{t}](p_2)$$

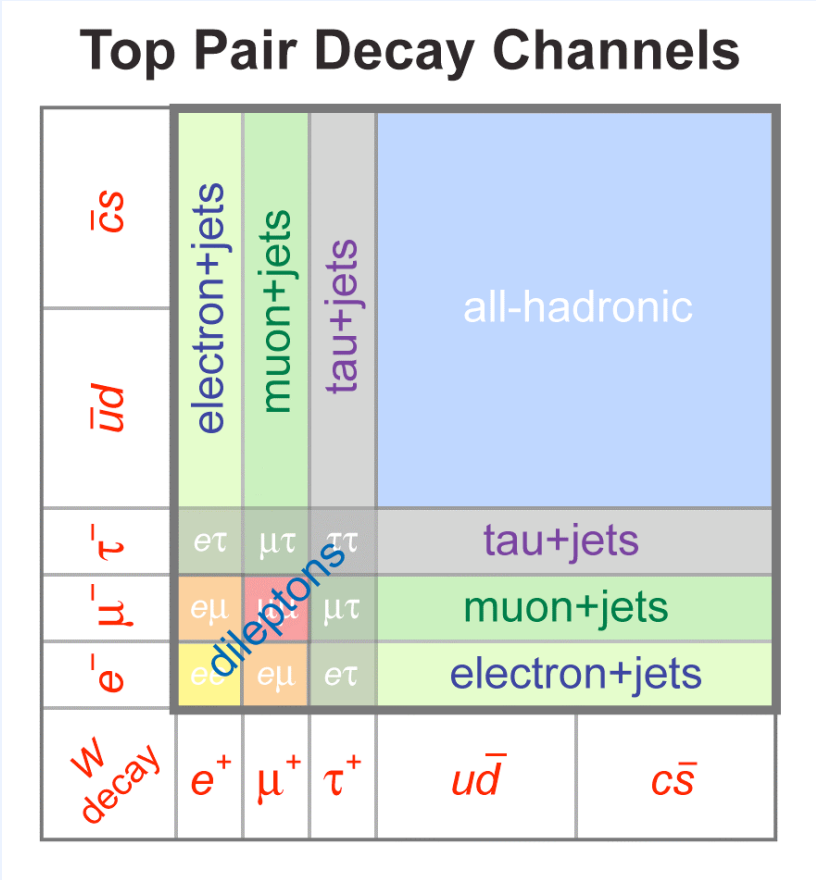
$$PIM : q(p_a) + \overline{q}(p_b) \rightarrow t\overline{t}(p) + X(k)$$

- Next-to-Leading Order (NLO) with Next-to-Leading Logarithm (NLL) corrections
  - 5.82 - 7.41 pb, $m_{top}/2 < \mu_{r,f} < 2\, m_{top}$
  - 6.7 ± 1 pb, $\mu = m_{top} = 175$ GeV
  - Logarithmic corrections due to soft gluon emissions
  - Cacciari et al. (2004)
- NNLO-NNNLL
  - 6.77 ± 0.42 pb, $\mu = m_{top} = 175$ GeV
  - Different kinematic schemes
  - Logarithmic corrections due to soft gluon emissions
  - Kidonakis & Vogt (2003)

Top Quark Decay

- Br(t → Wb) ~100% in Standard Model

- Final decay states determined by W decay mode:
  - · 2 b-quark jets
  - · Up to 2 leptons + neutrino pairs
  - · Up to 4 additional jets



- Branching ratios (%)
  - All hadronic ~ 44 %
  - Lepton + Jets ~ 46%
  - Dilepton ~ 10%

- Dimuon channel Br ~1/81
  - including μ's originating from τ's (W→ τν decay) BR = 0.01571

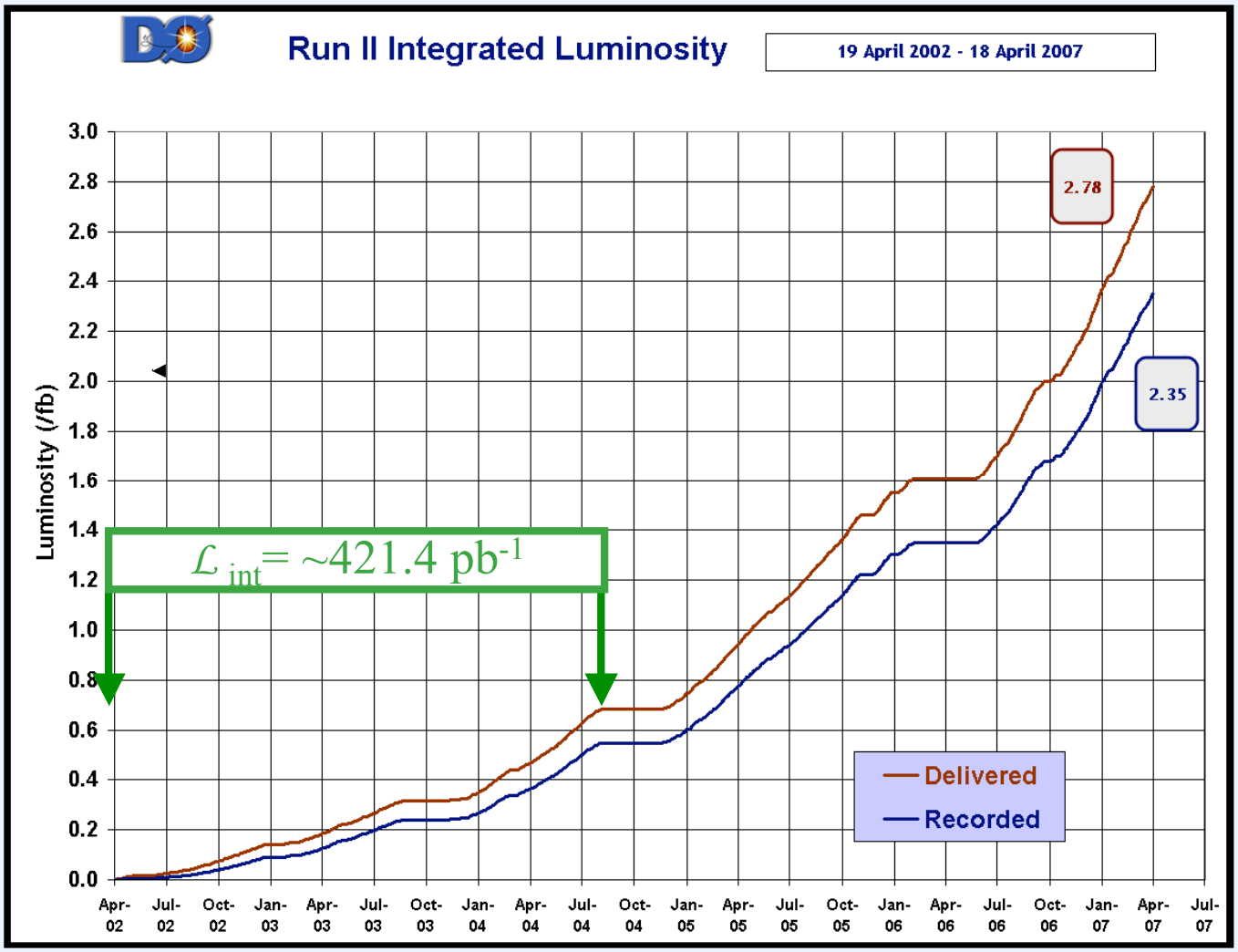
Why Measure the Cross Section?

- Compare to Standard Model predictions
  - Measurement ↓ : exotic top decays (supersymmetric particles)
  - Measurement ↑: new production mechanisms ($t\bar{t}$ resonances)
- Consistency check with other channels
  - New physics in unexpected places
- Contributes to top quark properties measurements
  - Event selection used for top mass or W helicity
- Value to future measurements
  - Develop analysis techniques
  - Understand systematic uncertainties for when they dominate statistical uncertainties

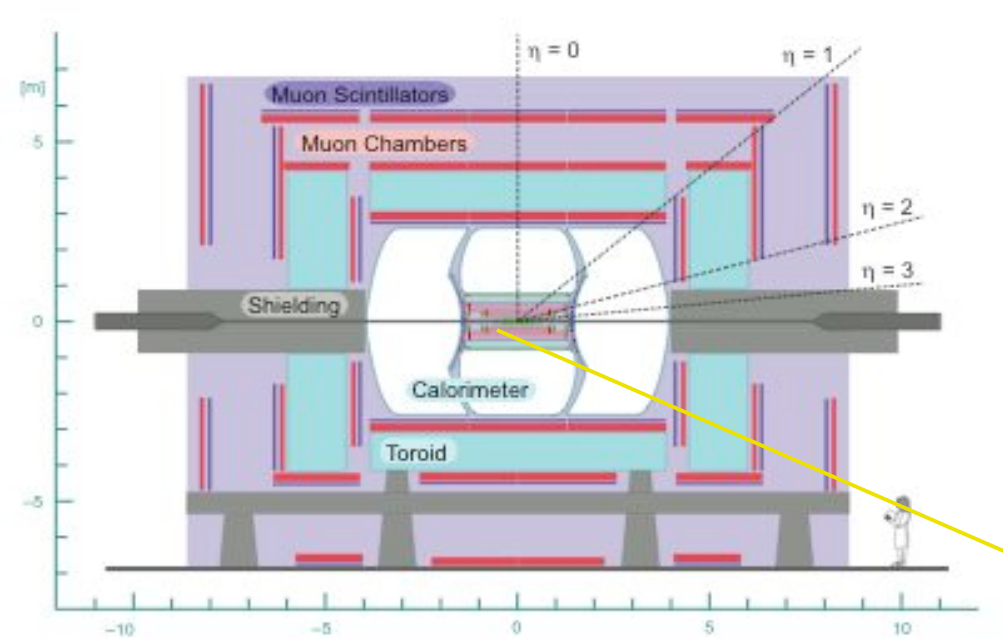
The Experiment

Fermilab Tevatron

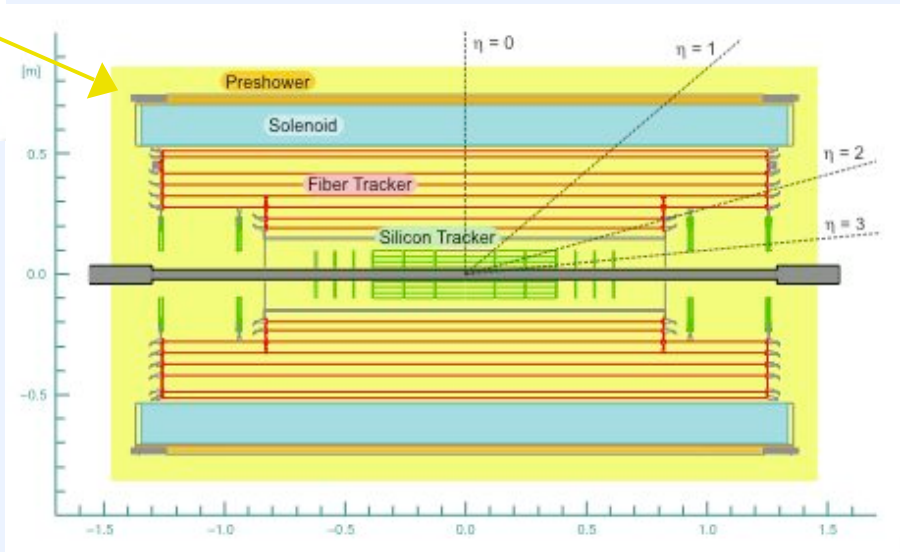
- $p\bar{p}$ Collider at $\sqrt{s} = 1.96$ TeV
- Data collected from April 2002-August 2004



DØ Detector

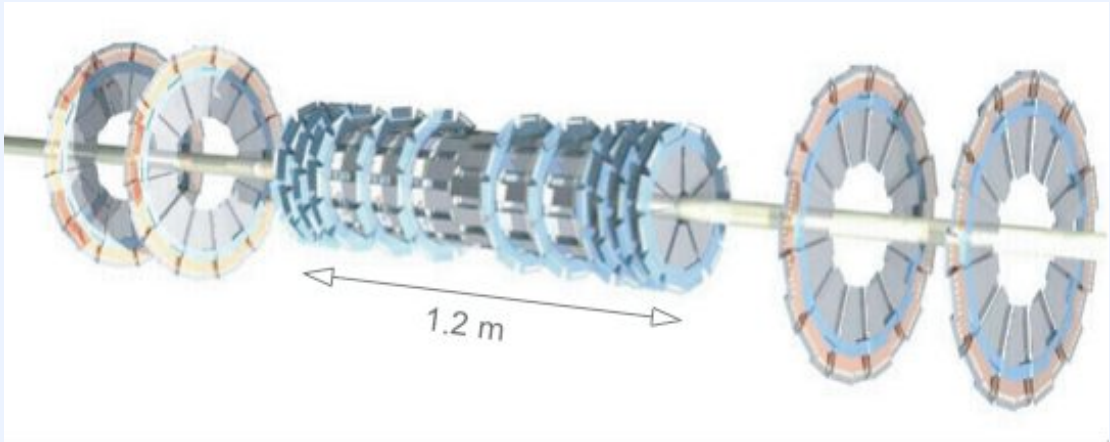


- Central Tracking Detectors
  - Silicon and Fiber tracker within 2T solenoid
  - Precision vertex and momenta measurements of charged particles



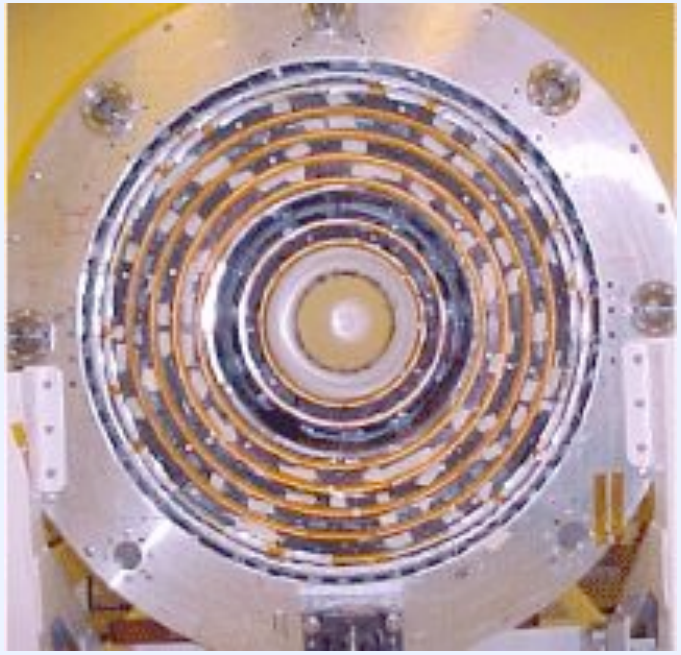
- Calorimeter
  - Measures energy of electrons, photon and jets
- Muon Spectrometer
  - Identify and measure muon momenta

Central Tracking Detectors

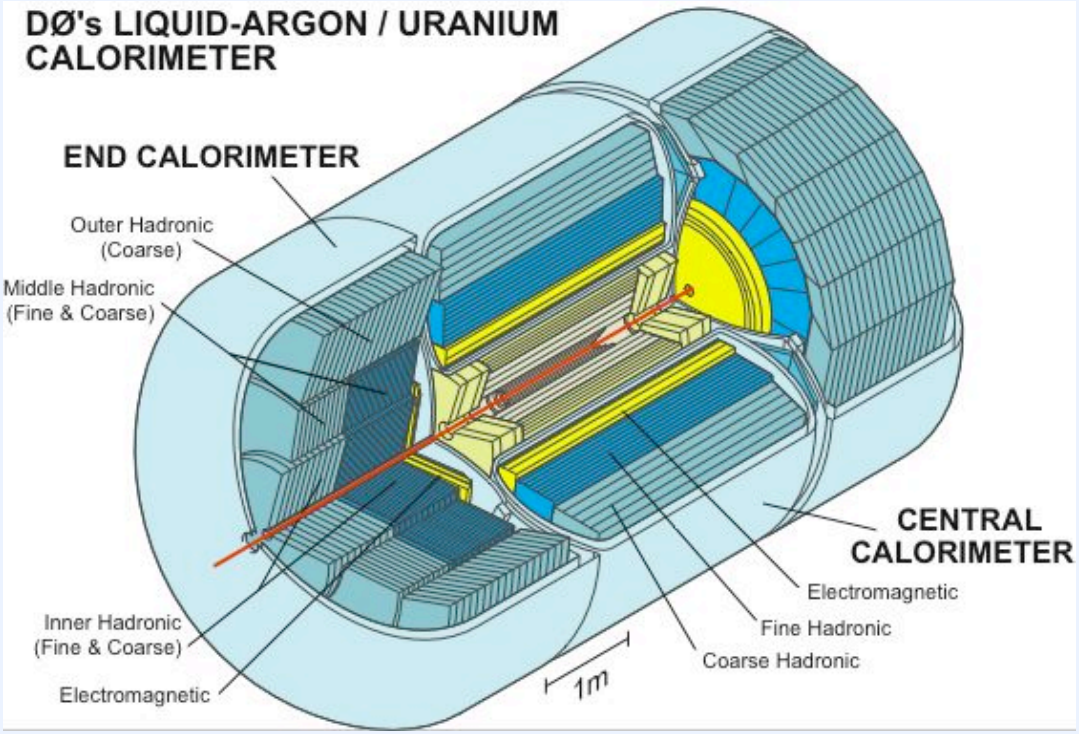


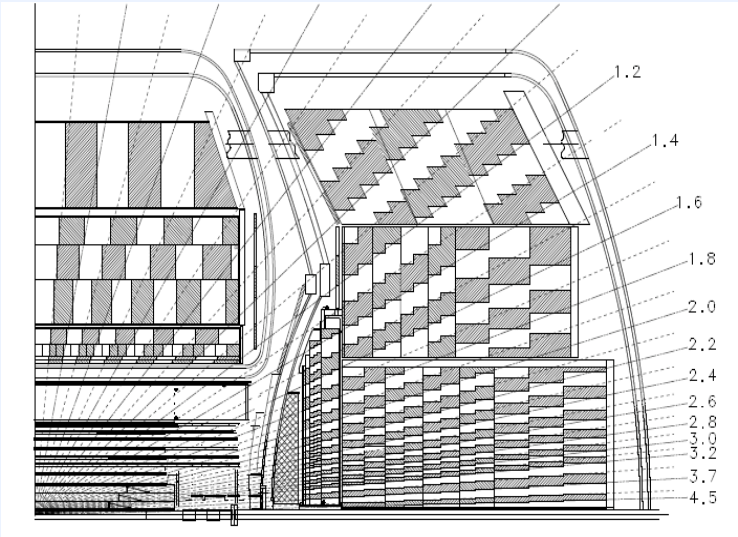
- Silicon Microstrip Tracker
  - 6 Barrels
  - 16 Disks
  - 800,000 channels
- Position resolution of 15 μm

- Central Fiber Tracker
  - Eight concentric cylinders of scintillating fibers
  - Two layers of fibers per cylinder
    - Axial
    - Stereo ± 3º
  - 80,000 channels
- Position resolution of 100 μm



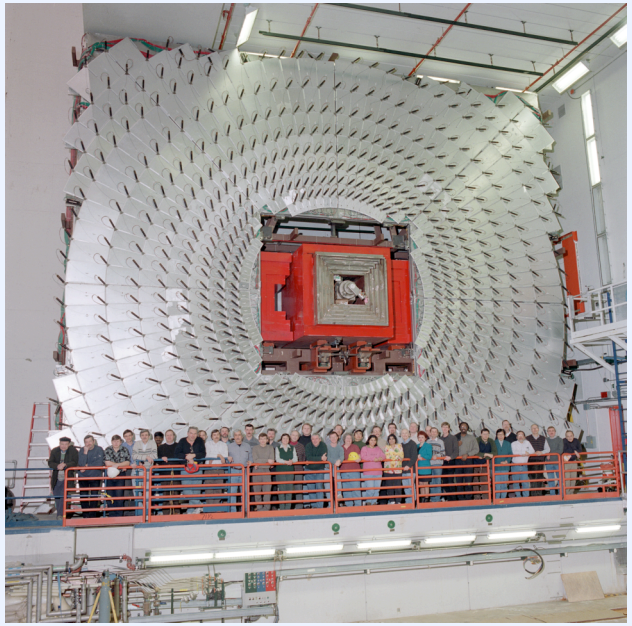
Calorimeter

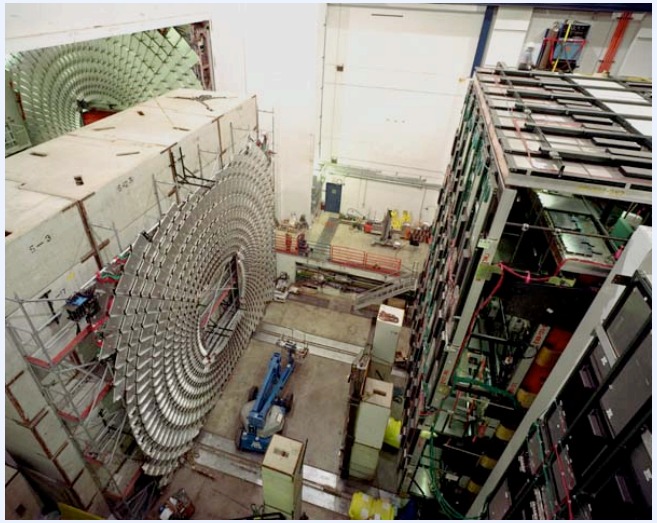




- Liquid Argon Calorimeter
  - Uranium/Copper/stainless steel absorber plates
- Energy resolutions
  - 5 -7% for 20 GeV electrons
  - 30% for 20 GeV jets

Muon Spectrometer





- Three layers of wire chambers
  - Position information
- Three layers of scintillation counters
  - Timing information
- Toroid magnet outside innermost layer with B = 1.8 T
- Position resolution: 0.7 to 1.0 mm
- Momentum resolution:
  ~20% for muons < 40 GeV (forward)

Trigger System

- $p\bar{p}$ collision rate ~ 2 MHz
- Don't have resources to record them all!
- Three-tiered triggering system selects interesting physics events
  - Level 1: Hardware-based triggers (with inputs from different detector subsystems)

~ 2 MHz → L1 Muon

↓

~ 2 kHz → L1 Calorimeter-Track

  - Level 2: DSP-based triggers

~ 2 kHz

↓

~ 1 kHz

  - Level 3: Online event reconstruction

~ 1 kHz

↓

50 Hz recorded for offline analysis

My analysis starts with 970, 000, 000 events!

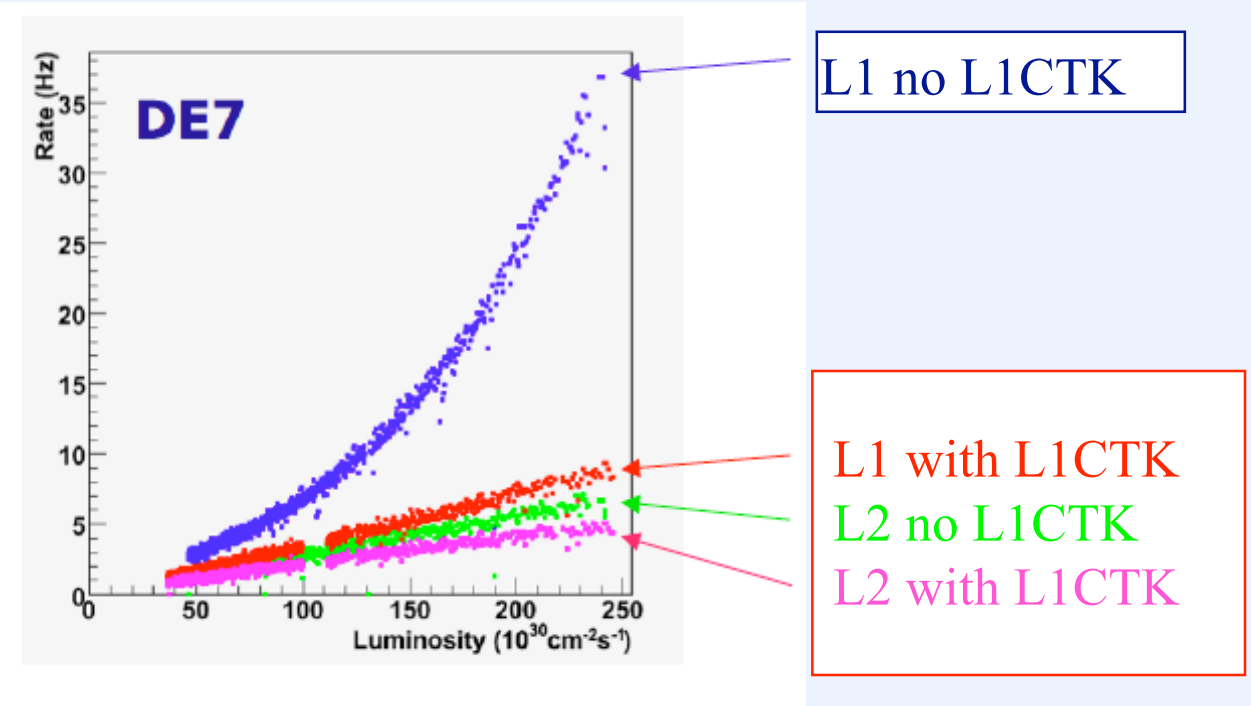
L1 Calorimeter-Track Trigger

- Level 1 Calorimeter-Track Trigger (L1CTK)
  - Matches tracks from central tracking detectors with EM and jet objects from calorimeter
    - Matching in ϕ
    - Matching in P_T & E_T
- Commissioned for DØ's Run IIb
  - Lower Level 1 trigger rate
  - Increase trigger capabilities for electrons and tau particles

L1 Calorimeter-Track Trigger

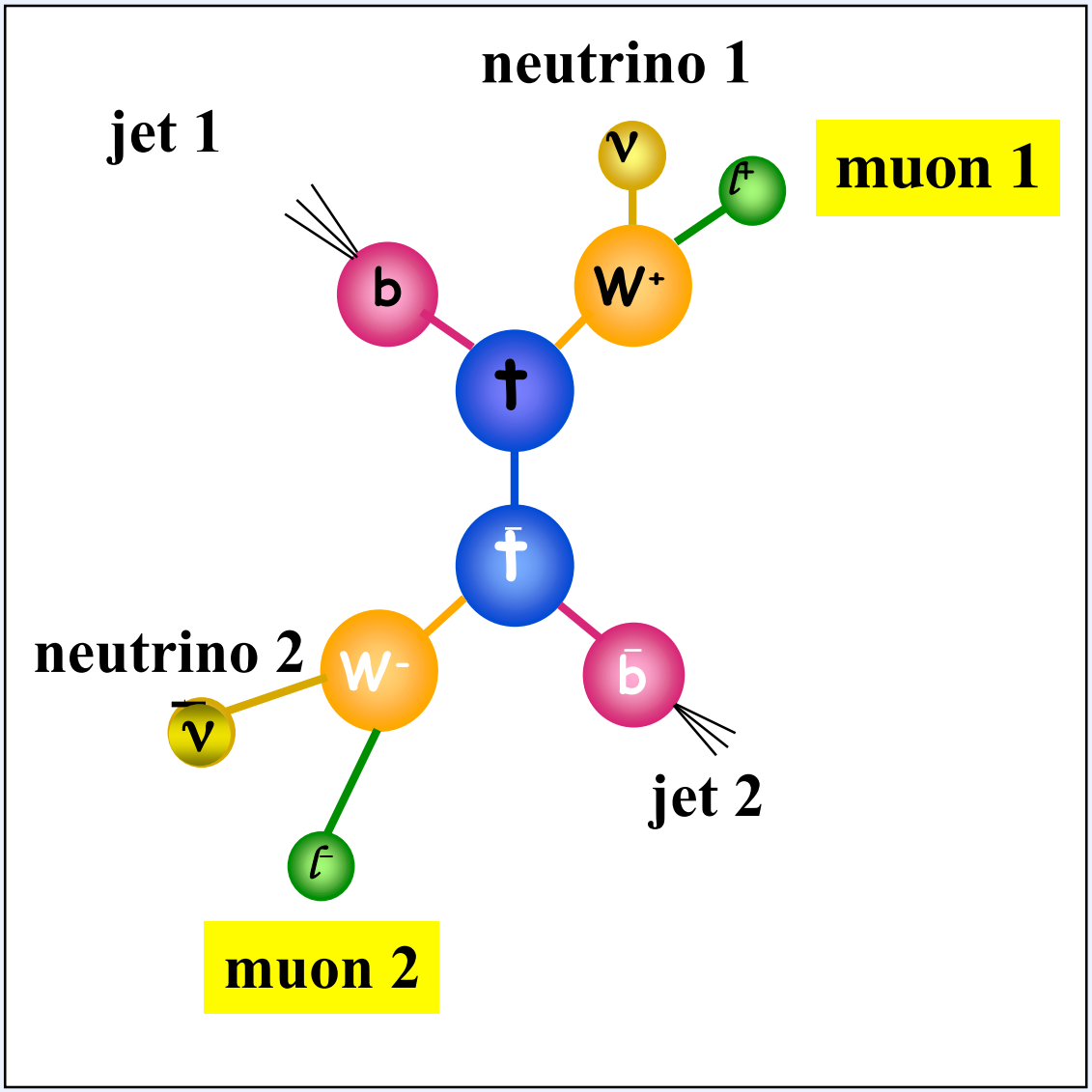
- Incorporated into DØ's global trigger list January 2007
- With L1CTK, we don't need to prescale physics triggers up to $\mathcal{L} = 260 \times 10^{30}\ cm^{-2}s^{-1}$(without L1CTK, 170-200 x $10^{30}\ cm^{-2}s^{-1}$)

- Dielectron Trigger



Analysis

$t\bar{t} \rightarrow \mu\mu$ Signature



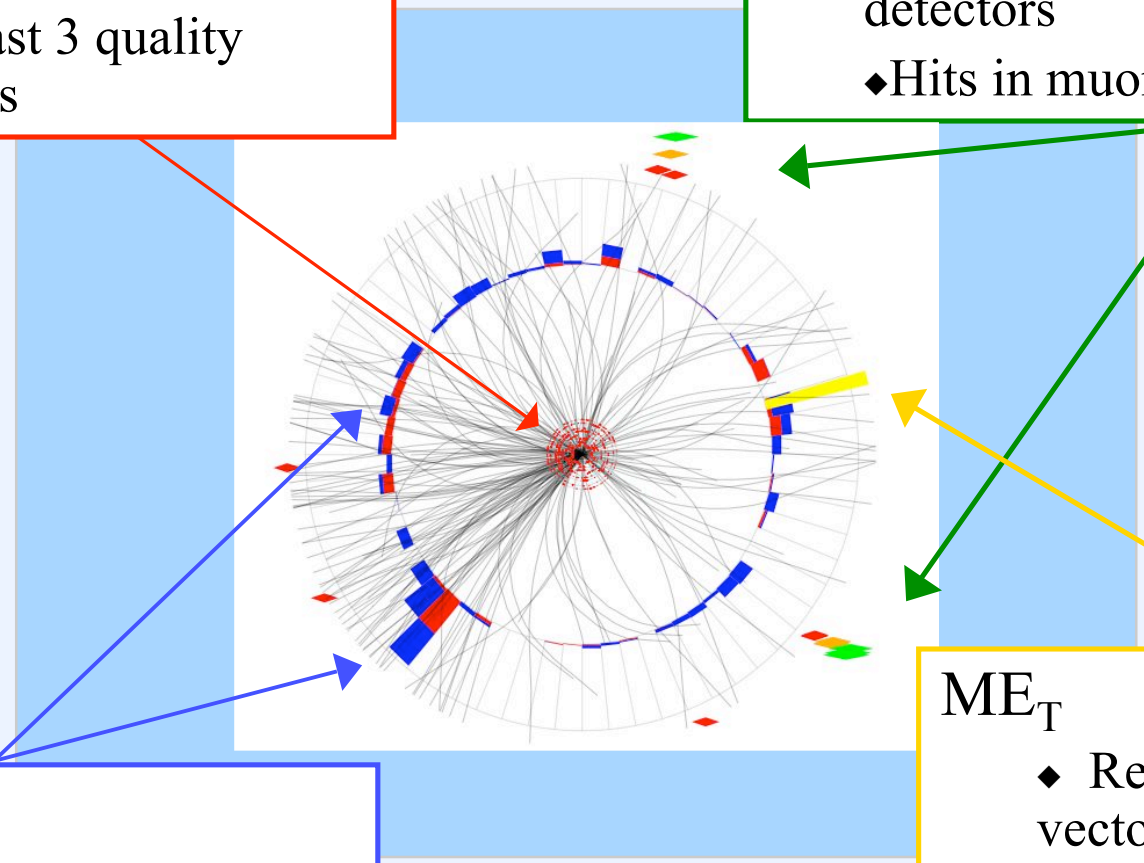
Object Identification

Primary Vertex

- Reconstructed from at least 3 quality tracks

Muons

- Tracks in central tracking detectors
- Hits in muon spectrometer



Jets

- Energy clusters in calorimeter

ME_T

- Reconstructed from vector addition of calorimeter E_T, corrected for muon P_T

How to Measure the Cross Section

- Develop event selection criteria to find $t\bar{t} \rightarrow \mu\mu$ events
- Measure signal efficiency (ε_{sig}) using Monte Carlo
- Estimate number of background events (N_{bkg})
- Count data events passing selection criteria (N_{obs})

$$\sigma_{t\bar{t}} = \frac{N_{obs} - N_{bkg}}{\varepsilon_{sig} \times Br(t\bar{t} \rightarrow \mu\mu) \times \mathcal{L}_{\text{int}}}$$

- where BR ($t\bar{t} \rightarrow \mu\mu$) is the branching ratio and $\mathcal{L}_{\text{int}}$ is the luminosity integrated over the time the data set was recorded

Event Selection: Preselection

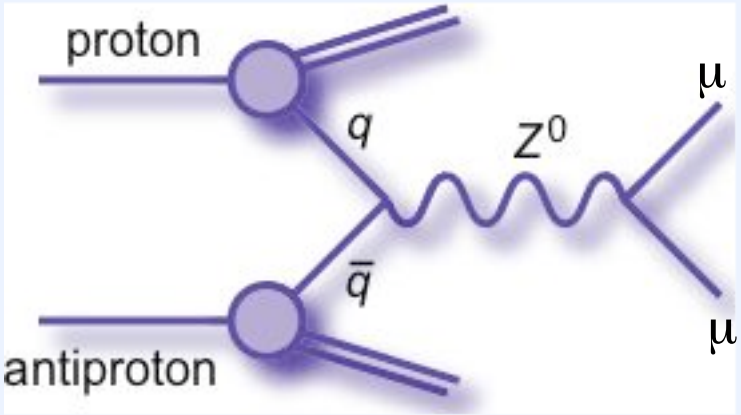
- 2 Muons, $P_T > 15$ GeV
  - "loose" muon quality
  - Opposite charge
  - With quality track match
  - Cuts against cosmics
  - Fiducial region
    - $|\eta_{det}| < 2.0$
    - not in bottom hole
- Muon Promptness
  - DCA significance < 3
  - $\Delta Z(\mu, \text{vertex}) < 1$ cm
- Muon Isolation
  - Tracking: $\varepsilon^{trk}_{halo} < 0.12$
  - Calorimeter: $\varepsilon^{cal}_{halo} < 0.12$
- Trigger Requirement
  - Single Muon or Dimuon Trigger
- Primary Vertex Cuts
  - Ntracks ≥ 3, $|z_V| < 60$ cm
  - Consistency between reconstruction algorithms
- 2 Jets, $P_T > 20$ GeV
  - Cuts against fake jets
  - Cuts against EM objects
- Channel Orthogonality
  - Electron Veto

Trigger Requirement

- Muon triggers have tighter muon quality cuts (hits in multiple layers of the muon spectrometer) than the muon identification requirement ⟶ could cost signal efficiency!

- Dimuon triggers
  - Pro: Unprescaled
  - Con: Requires two muons with tighter quality cuts
- Single muon triggers
  - Pro: Only requires one muon with tighter quality cuts
  - Con: Sometimes prescaled
- Compromise
  - Use single muon trigger if unprescaled (85%)
  - Otherwise require dimuon trigger (15%)

Type of Backgrounds

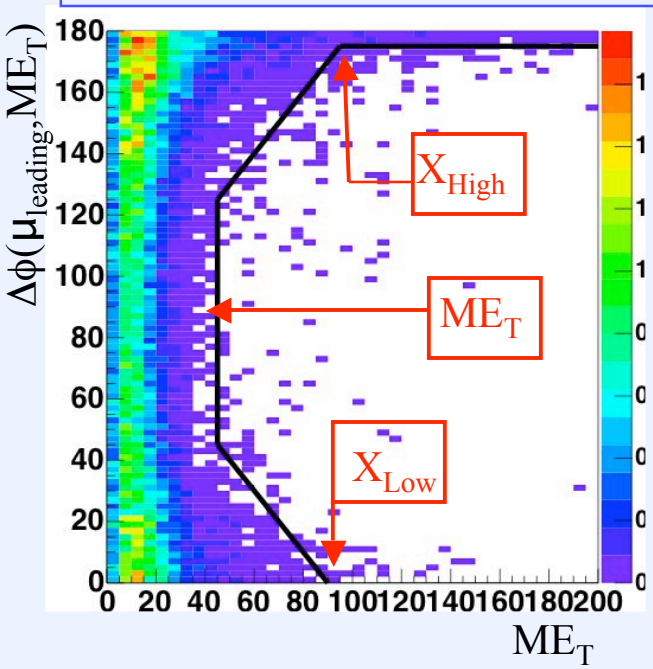


- Physics Backgrounds
  - With intrinsic ME_T
  - WW + jets → μμ + νν + jets
  - WZ + jets → μμ(μ) + ν + jets
  - Z/γ* + jets → ττ + jets→ μμ + νννν + jets
- Instrumental Backgrounds
  - No intrinsic ME_T or isolation
  - Z/γ* + jets → μμ + jets
    - fake ME_T due to event misreconstruction
  - Multijet and W + jets production
    - Muons from b/c decay fake isolation

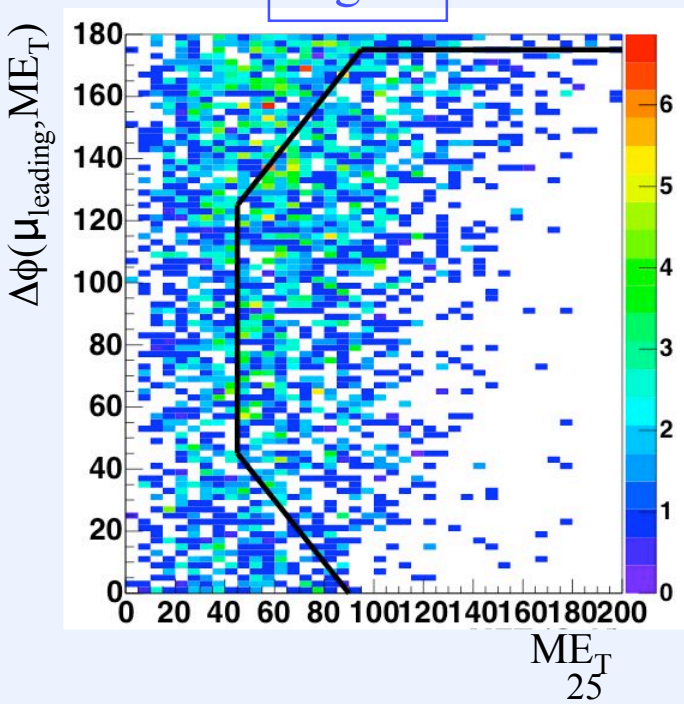
Background Rejection Cuts

- Contour cut in ME_T and $\Delta\phi(\mu_{leading}, ME_T)$ plane
  - ME_T : 45 GeV
  - X_{low} : 90 GeV
  - X_{high} : 95 GeV
  - All events > 175° are cut

WW and Z/γ* Background

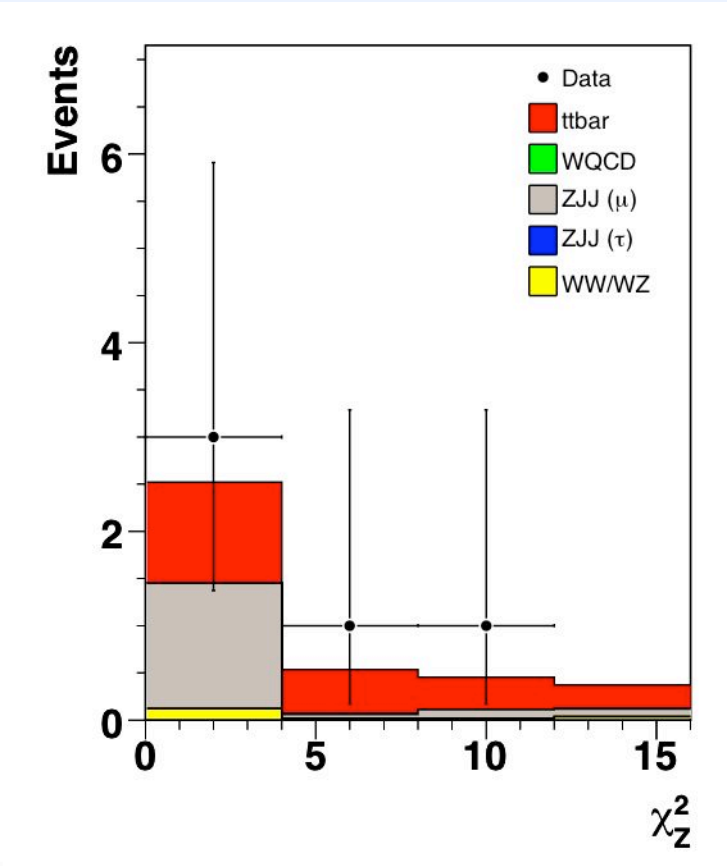


Signal



Background Rejection Cuts

- $\chi^2_Z > 4$
  - χ^2_Z is an event variable that measures the consistency of the dimuon system with the *Z* mass hypothesis



$$\chi^2_Z(\kappa_1,\kappa_2) = \sum_{i=1}^{2}\left(\frac{\kappa_i - \kappa_i^0}{\sigma_i(P_T^i,\eta_i)}\right)^2 + (M_{\mu\mu} - M_Z)$$

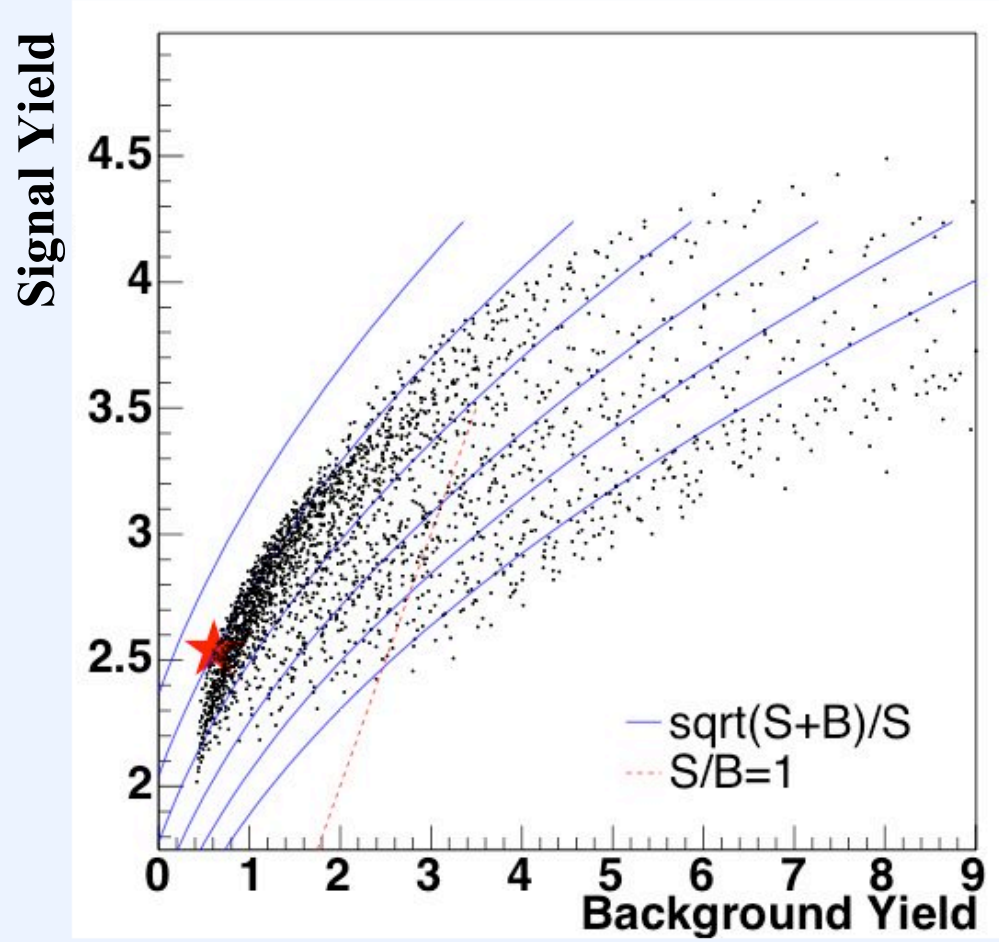
where $\kappa_i = \dfrac{1}{p_\mu^i}$

Cut Optimization

- Grid Search
  - χ^2_Z and Contour cut varied simultaneously
  - 2401 points considered
  - Monte Carlo samples
    - $t\bar{t}$ signal
    - Zjj and WWjj backgrounds
- Figure of Merit

$$\frac{\sqrt{(S+B)}}{S}$$

  - Modified to account for 25% uncertainty on Zjj background



- Before optimization: S/B = 1.62
  After optimization: S/B = 4.16

Signal Efficiency

- Calculated using $t\bar{t}$ Monte Carlo
  - $\varepsilon_{cut} = N_{cut} / N$
- 8 scale factors that make data-to-Monte Carlo corrections
- Errors are statistical
- Muon identification 69.5%, up from 51% in prior analysis!
- Final $\varepsilon_{sig} = 6.4 \pm 0.2$ %

Cut	Efficiency	Error
2 Muons	0.695	0.004
κ Muon ID	1.000	0.000
TrackMatch	0.996	0.001
κ track match	0.968	0.000
κ track $\chi 2$	0.970	0.000
Opposite Charge	0.868	0.003
Muon PT > 15 GeV/c	0.687	0.005
Electron veto	0.998	0.001
Trigger Requirement	0.911	0.004
2 jets	0.795	0.005
Jet PT > 20 GeV/c	0.940	0.003
Vertex Quality Cuts	0.986	0.002
κ vertex quality cuts	0.993	0.000
Dz(reco,d0root)	0.998	0.001
κ Δz reco	0.998	0.000
Dz(mu, vertex)	0.999	0.001
κ Δzmu	0.987	0.000
DCA	0.852	0.005
κ DCA	0.991	0.000
Isolation	0.757	0.007
κ Isolation	1.000	0.000
Z Fitter	0.722	0.008
Contour	0.546	0.011
Total Efficiency	0.064	0.002

Diboson Backgrounds

- Background Processes:
  - WW + jets → μμ + νν + jets
  - WZ + jets → μμ(μ) + ν + jets
- Estimated in Monte Carlo
  - Normalized to theoretical cross section
  - Scaled to integrated luminosity of data set

Cut	WW	WZ	Total
$N_{\mu}^{PT>15} \geq 2$	19.280 ±0.241	-	-
$+N_{jets}^{PT>20} \geq 1$	1.631±0.067	-	-
Preselection	0.784±0.060	1.753±0.046	2.537±0.076
$+\chi_Z^2$ Cut	0.561±0.049	0.119±0.012	0.680±0.051
+ Contour Cut	0.188±0.030	0	0.188±0.030

Only statistical errors are shown

Z/γ^* Background

- Background Processes:
  - Z/γ^* + jets $\rightarrow \tau\tau$ + jets$\rightarrow \mu\mu + \nu\nu\nu\nu$ + jets
  - Z/γ^* + jets $\rightarrow \mu\mu$ + jets
    - No intrinsic ME_T, fake ME_T due to muon misreconstruction, noise in calorimeter, other instrumental effects
- Estimated in Monte Carlo
  - Constrained to data
    - Ratio of data and Monte Carlo yields in preselected events in "Z mass window" of 70 to 110 GeV
  - Kinematic distributions tested against a control sample in data

$Z/\gamma^* \rightarrow \tau\tau = 0.158 \pm 0.33$

$Z/\gamma^* \rightarrow \mu\mu = 0.313 \pm 0.075$

Errors are statistical only

Multijet and W + jets Background

- At least one fake isolated muon
- Estimated with matrix method

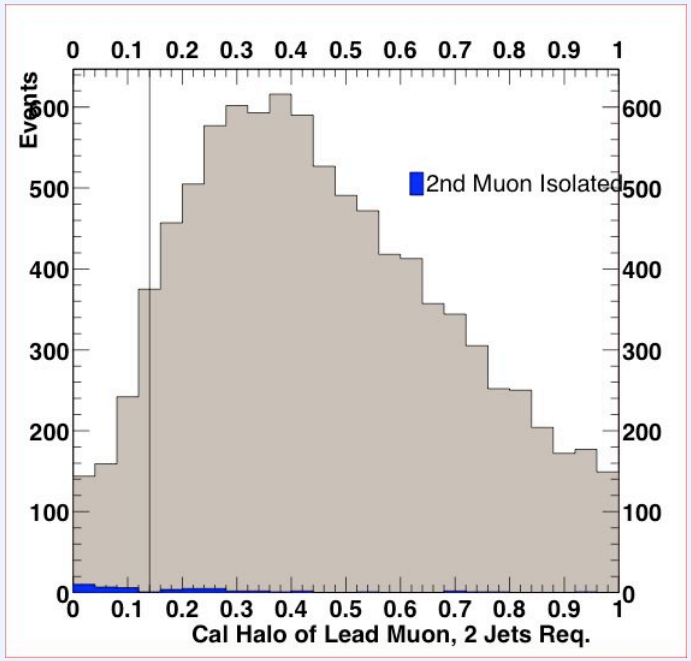
$$N_L = N^{Z+top} + N^{W+QCD}$$

$$N_T = \varepsilon_{iso} N^{Z+top} + f_\mu N^{W+QCD}$$

$$N^{W+QCD} = \frac{N_T - \varepsilon_{iso} N_L}{f_\mu - \varepsilon_{iso}}$$

Jet Multiplicity	$\epsilon_{iso}(\%)$	f_μ (%)
≥ 0	96.4 ± 0.1	0.56 ± 0.07
≥ 1	91.9 ± 0.3	0.34 ± 0.05
≥ 2	87.0 ± 0.4	0.18 ± 0.05

- ε_{iso} = efficiency for isolated muons to pass isolation criteria
- f_μ = rate for non-isolated muons to pass isolation criteria, "fake rate"



- Estimating the fake rate
  - Require lead muon to be non-isolated
  - Calculate isolation efficiency of second lead muon
  - $M_{\mu\mu} < 70$ GeV (to remove Z contamination)

Cut Flow Table

Data

Signal + Background

Dominant Background

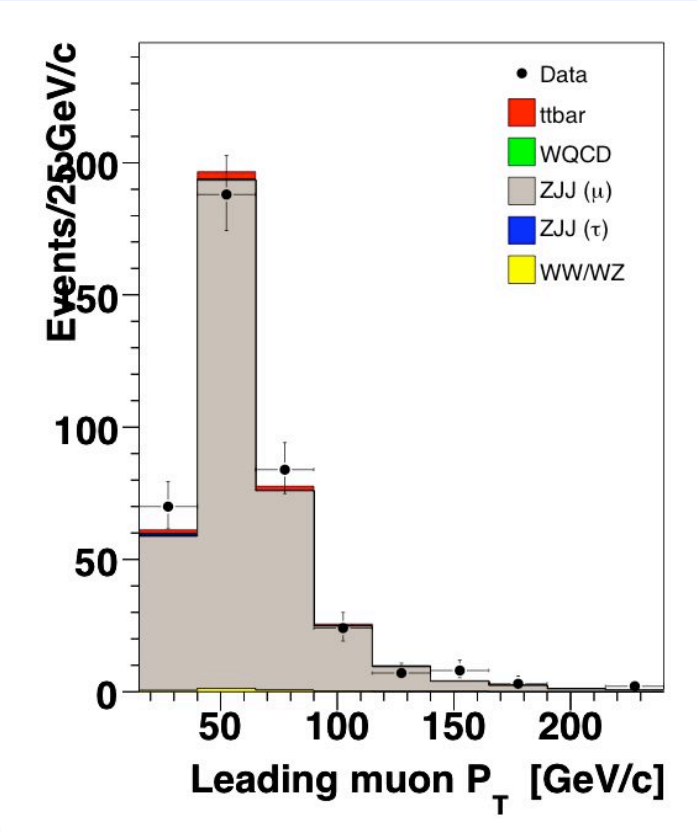
Other Background

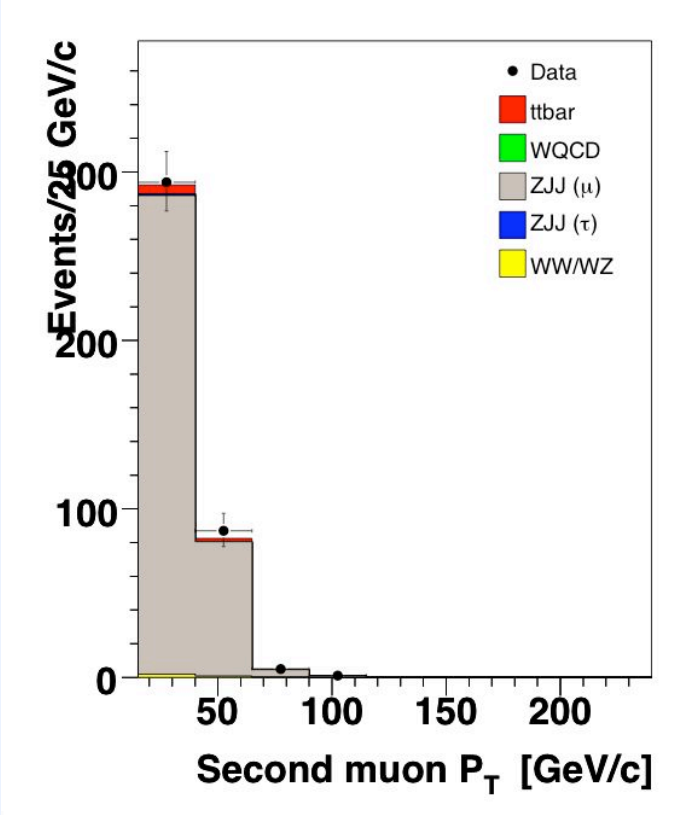
Signal

Cut	Data	All	Z/γ^* (μ or τ)	Fake Isolated Muon Bkg	WW/WZ	$t\bar{t}$
$N_\mu^{p_T>15} \geq 2$	21910	27383 $\pm$2922	27333$\pm$2919	20.22$\pm$2.56	19.28$\pm$6.06	10.29$\pm$0.91
$+N_{jets}^{p_T>20} \geq 1$	2938	2800$\pm$94.4	2782$\pm$94.1	6.47$\pm$0.96	1.63$\pm$0.58	10.19$\pm$0.90
Preselection	387	382.8$\pm$23.9	371.1$\pm$23.6	1.61$\pm$0.45	2.54 $\pm$0.84	7.56$\pm$0.69
$+\chi_Z^2$ cut	96	$74.8^{+7.48}_{-6.65}$	$67.13^{+7.14}_{-6.30}$	$1.54^{+0.43}_{-0.43}$	$0.68^{+0.24}_{-0.24}$	$5.45^{+0.48}_{-0.50}$
+ Contour Cut	2	$3.64^{+0.49}_{-0.51}$	$0.47^{+0.17}_{-0.18}$	$0.01^{+0.01}_{-0.01}$	$0.19^{+0.10}_{-0.07}$	$2.96^{+0.31}_{-0.35}$

Errors shown are statistical and systematic added in quadrature

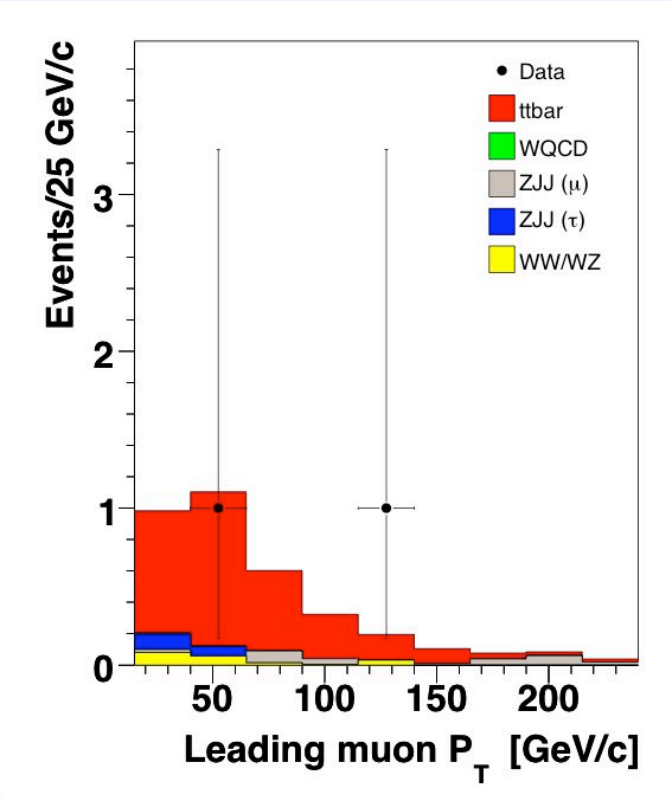
Cross-Check Plots

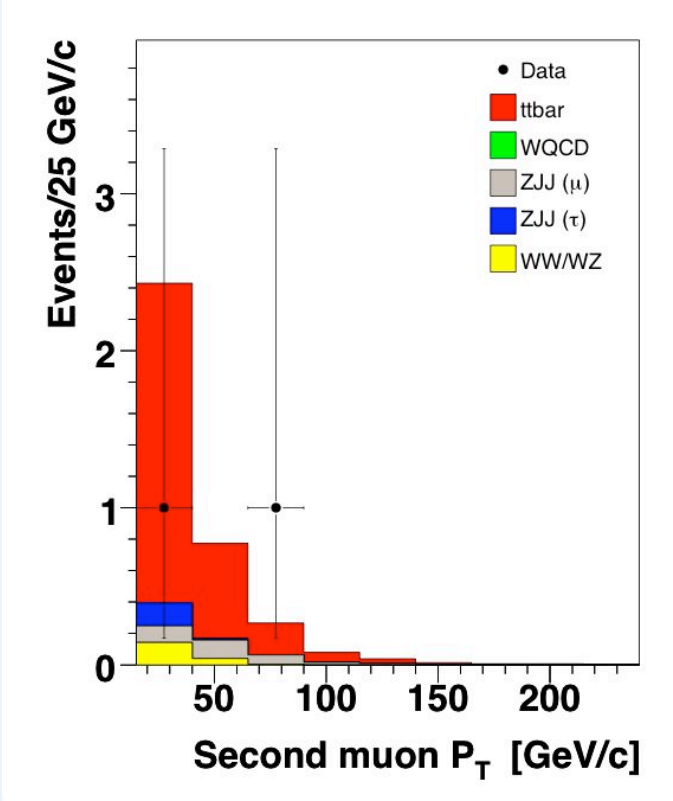




- After preselection cuts
  - Histograms: Monte Carlo
  - Points: data

Cross-Check Plots

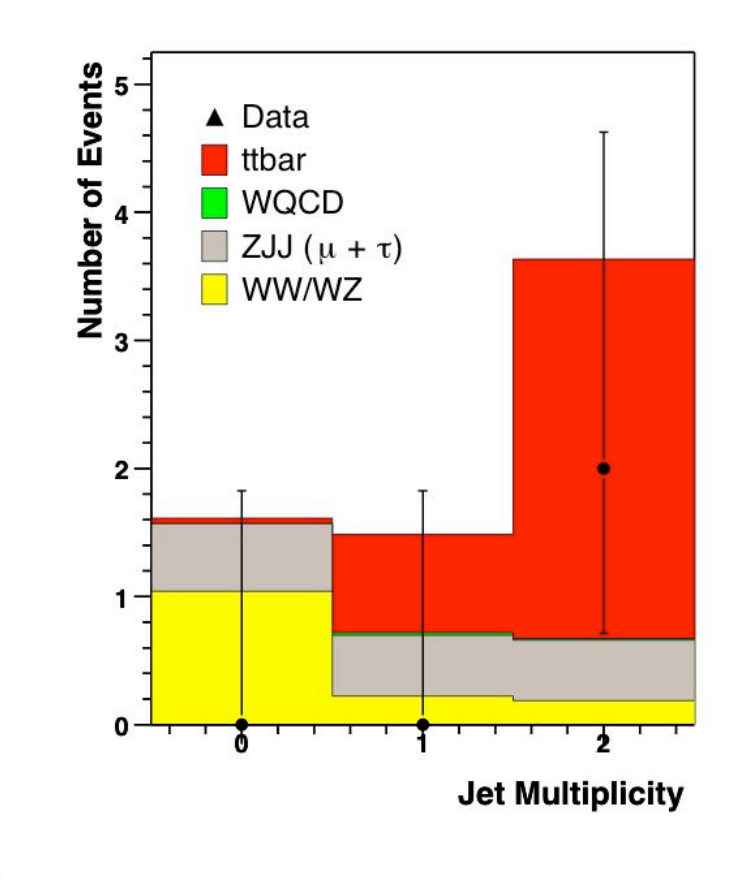




- After all selection cuts
  - Histograms: Monte Carlo
  - Points: data

Final Yields

- After all selection criteria have been applied



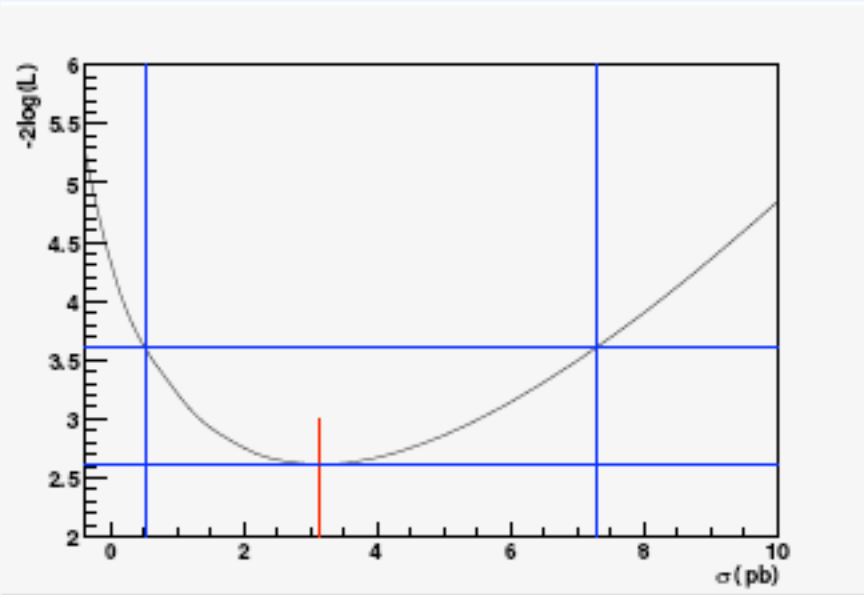
Category	Yield	Stat Err	Sys Err
WW/WZ	0.188	0.030	$^{+0.092}_{-0.062}$
Z/γ^* (μ or τ)	0.471	0.082	$^{+0.144}_{-0.155}$
WQCD (Isolation Fakes)	0.014	0.006	$^{+0.004}_{-0.004}$
Total Bkg	0.673	0.087	$^{+0.224}_{-0.206}$
Expected signal	2.962	0.079	$^{+0.297}_{-0.338}$
Selected Events	2	–	–

- Signal-to-background ratio: ≥ 4
- Expected signal + background yield = 3.6 events
- 2 events are observed

Cross Section Measurement

N_{obs}	N_{bkg}	ε_{sig}	$Br(t\bar{t} \to \mu\mu)$	$\mathcal{L}_{int}$ (pb^{-1})
2	$0.67^{+0.24}_{-0.22}$	0.064 ± 0.002	0.01571 ± 0.00031	421.4 ± 25.7

$$\sigma_{t\bar{t}} = \frac{N_{obs} - N_{bkg}}{\varepsilon_{sig} \times Br(t\bar{t} \to \mu\mu) \times \mathcal{L}_{int}}$$



- Extract cross section by minimizing a negative log-likelihood that assumes Poisson statistics
  - Statistical uncertainty: vary likelihood by half unit above minimum
  - Systematic uncertainty: vary N_{BKG} and ε_{sig} within $\pm$ 1 σ and repeat likelihood minimization

$$\sigma_{t\bar{t}} = 3.13^{+4.17}_{-2.60}(stat)^{+0.92}_{-0.86}(sys) \pm 0.19(lumi)\,pb$$

Systematic Uncertainties

Fractional uncertainties (%) on signal efficiency ε_{sig}

Source	$t\bar{t}$
μ ID	± 3.0
μ tracking	± 2.5
χ^2	± 0.2
μ isolation	± 0.8
μ σ_{dca}	± 0.6
Primary vertex	± 0.4
$\Delta z(D\emptyset reco, D\emptyset root)$	± 0.2
Lepton promptness	± 0.1
μ smearing	-0.2 +0.1
Level 1 trigger	+3.9 -4.8
Level 2 trigger	+0.2 -0.4
JES	+5.7 -7.4
Jet ID	+0.4 -4.9
Jet energy resolution	-2.5 -1.4
Uncorrelated	$\pm$ 3.1

Systematic uncertainties propagated into cross section uncertainty through likelihood fit

Systematic Uncertainties

Fractional uncertainties on background yield N_{BKG}

Source	WW	Z/γ^* (μ or τ)
μ ID	± 3.0	N/A
μ tracking	± 2.5	N/A
χ^2	± 0.2	N/A
μ isolation	± 0.8	N/A
μ σ_{dca}	± 0.6	N/A
Primary vertex	± 0.4	N/A
$\Delta z(D\emptyset reco, D\emptyset root)$	± 0.2	N/A
Lepton promptness	± 0.1	N/A
μ smearing	-3.9 0.0	+25.4 -20.9
Level 1 trigger	+4.9 -5.7	-1.3 +1.4
Level 2 trigger	+0.3 -0.5	-0.3 +0.3
JES	+37.3 -10.8	+15.9 -24.7
Jet ID	+57.8 +53	N/A
Jet energy resolution	+22.1 +21.1	+26.3 +13.2
Theoretical cross sections/ Normalization	± 35.0	± 5.8
Uncorrelated	± 13.0	

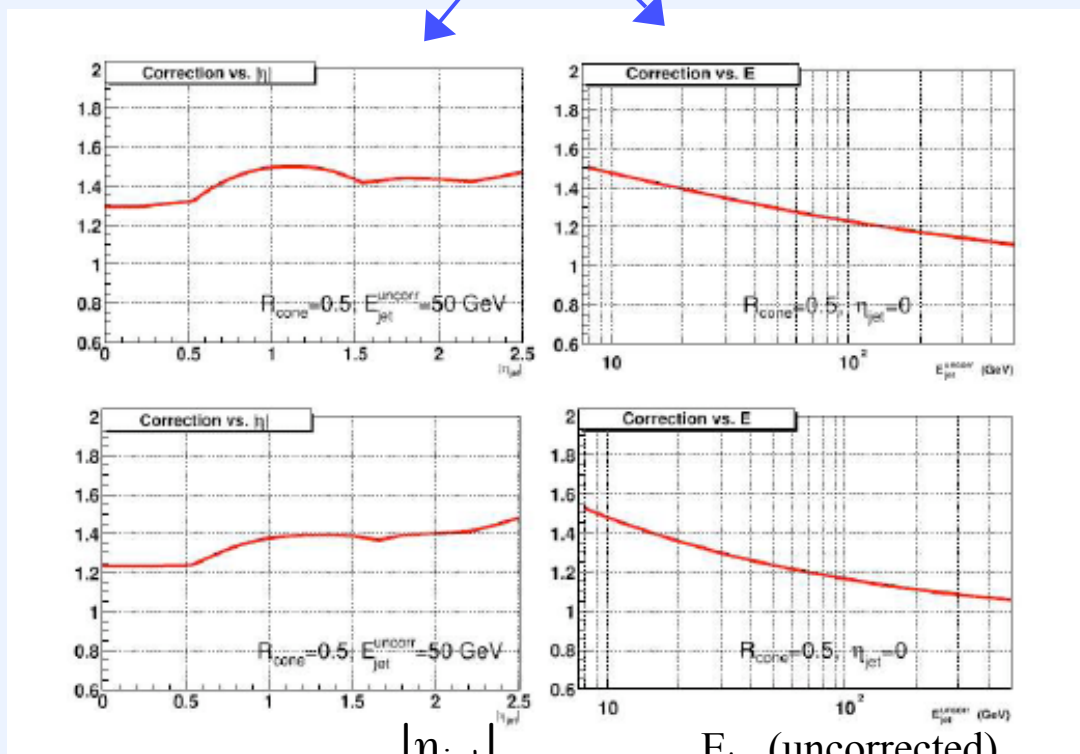
Systematic uncertainties propagated into cross section uncertainty through likelihood fit

Jet Energy Scale (JES) Corrections

$$E_{jet}^{particle} = \frac{E_{jet}^{meas} - O}{R \times S}$$

- O - offset energy from noise (electronic and radioactive) pileup, multiple interactions, etc
- R - calorimeter response for jets (< 1 from undetected particles in hadronic shower)
- S - showering of jet particles outside reconstruction cone and showering of non-jet particles inside jet reconstruction cone

Data



$|\eta_{jet}|$ E_{jet} (uncorrected)

Monte Carlo

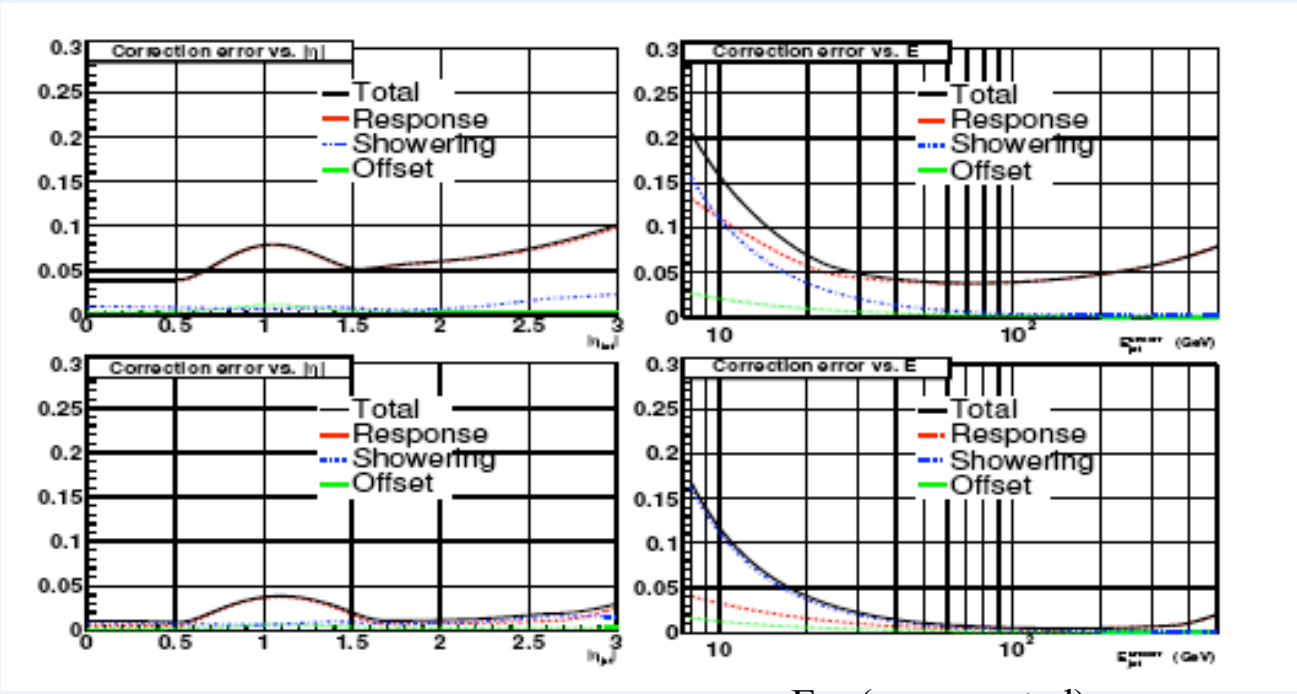
Jet Energy Scale Uncertainties

- We calculate uncertainty by varying JES corrections by ± σ

  where $\sigma = \sqrt{(\sigma^2_{data} + \sigma^2_{MC})}$

- σ_{data} and σ_{MC} include both statistical and systematic components

- Subcorrection contributions to jet energy scale systematic uncertainties



σ_{data}

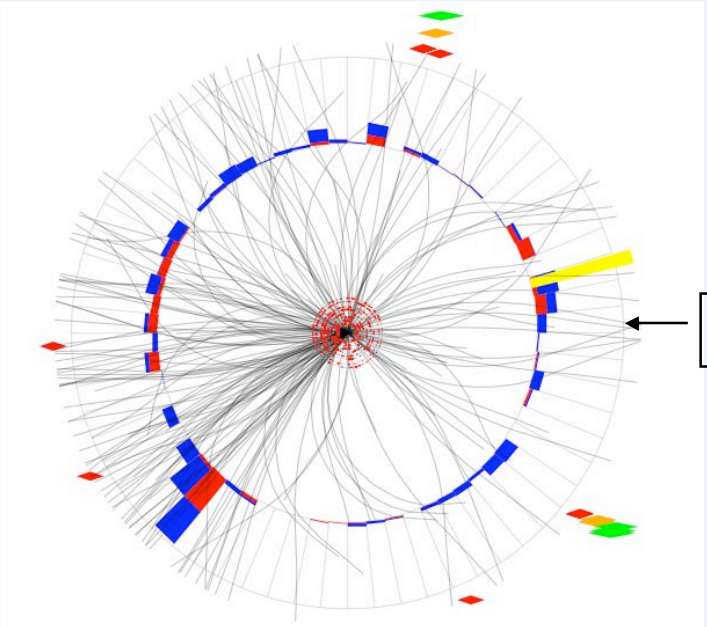
σ_{MC}

$|\eta_{jet}|$

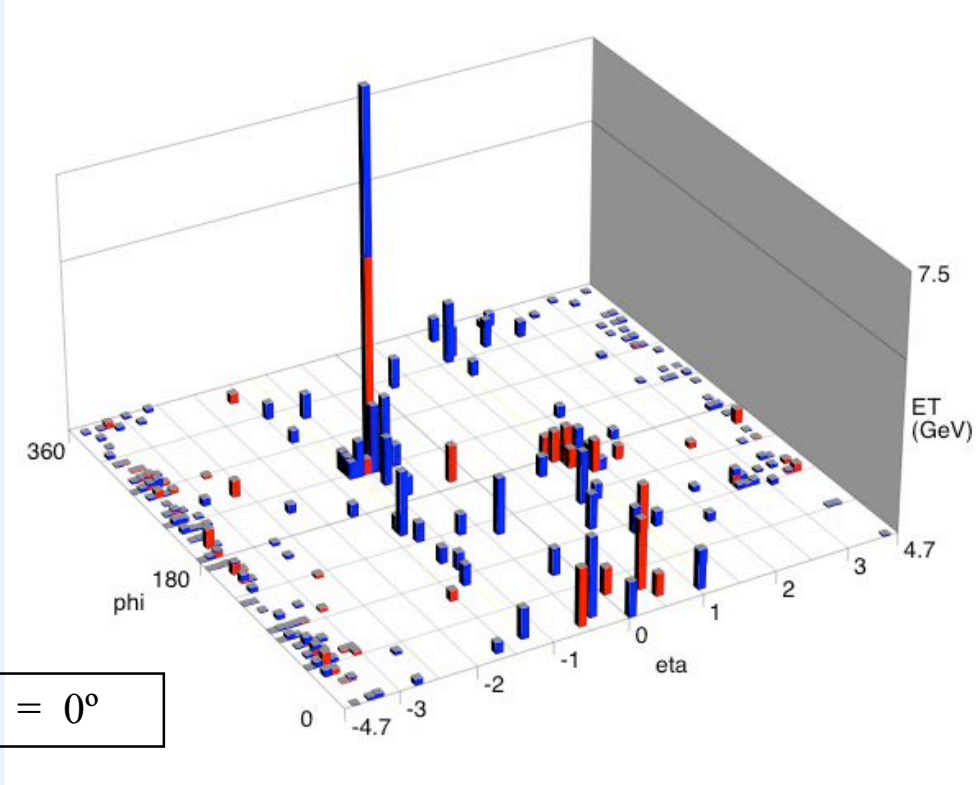
E_{jet} (uncorrected)

Candidate Events

	Candidate 1		
Object	p_T (GeV)	η	ϕ
μ_1	134.9	2.01	72°
μ_2	74.9	1.82	322°
jet_1	50.3	-0.87	225°
jet_2	20.7	1.26	173°
$\not{E}_T$	87.0		
$M_{\mu\mu}$	166.1		

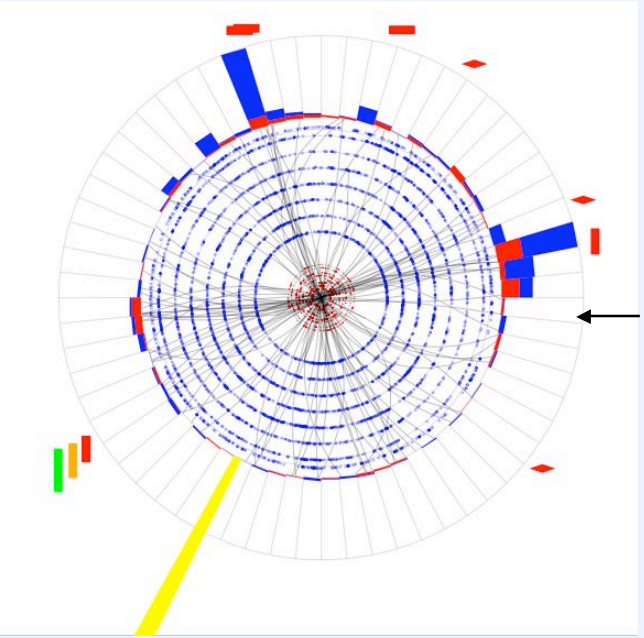


$\phi = 0^o$

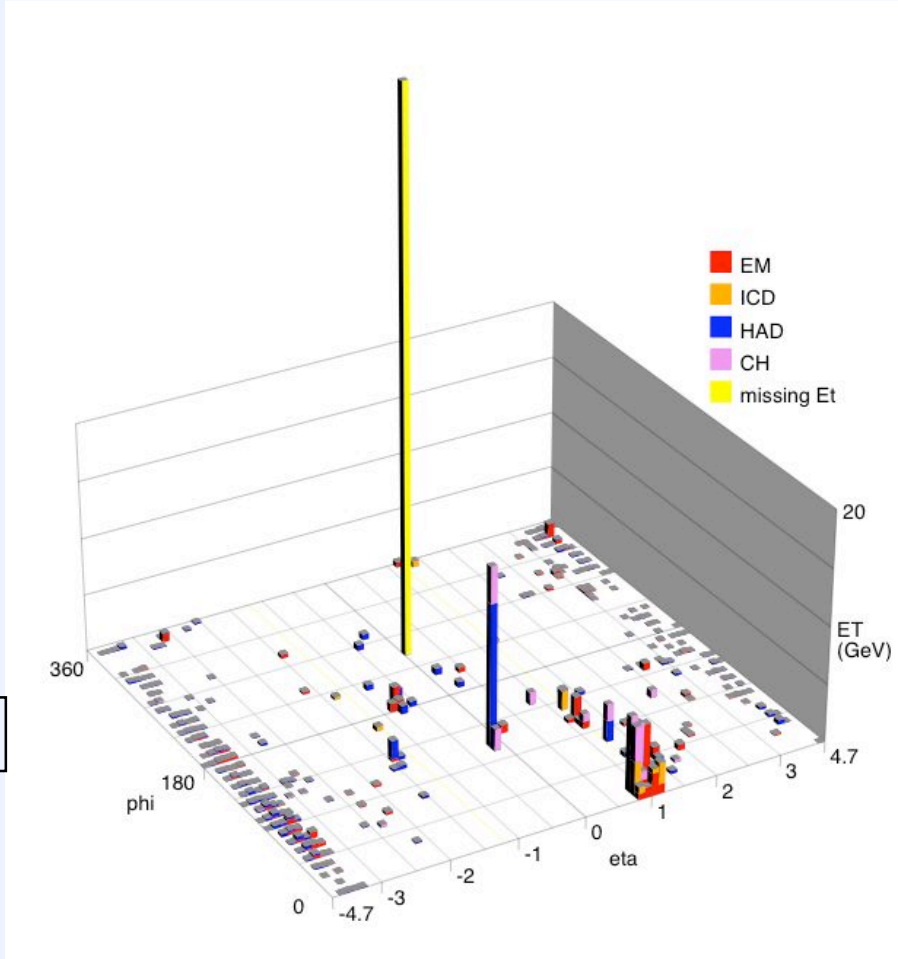


Candidate Events

	Candidate 2		
Object	p_T (GeV)	η	ϕ
μ_1	56.59	-0.00	213°
μ_2	28.76	-0.26	109°
jet_1	29.3	-0.25	111°
jet_2	23.9	1.08	103°
$\not{E}_T$	87.1		
$M_{\mu\mu}$	64.3		



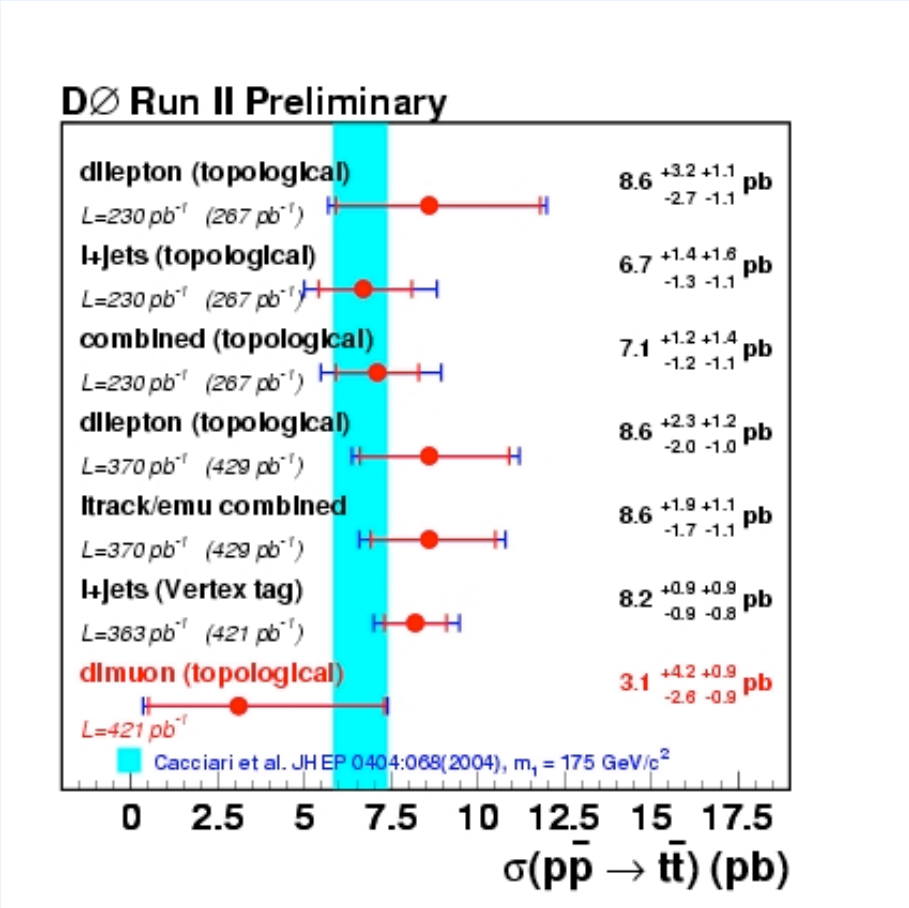
$\phi = 0^o$



Comparison

- We measure the top pair production cross section in the dimuon channel to be:

$$\sigma_{t\bar{t}} = 3.13^{+4.17}_{-2.60}(stat)^{+0.92}_{-0.86}(sys) \pm 0.19(lumi)\,pb$$



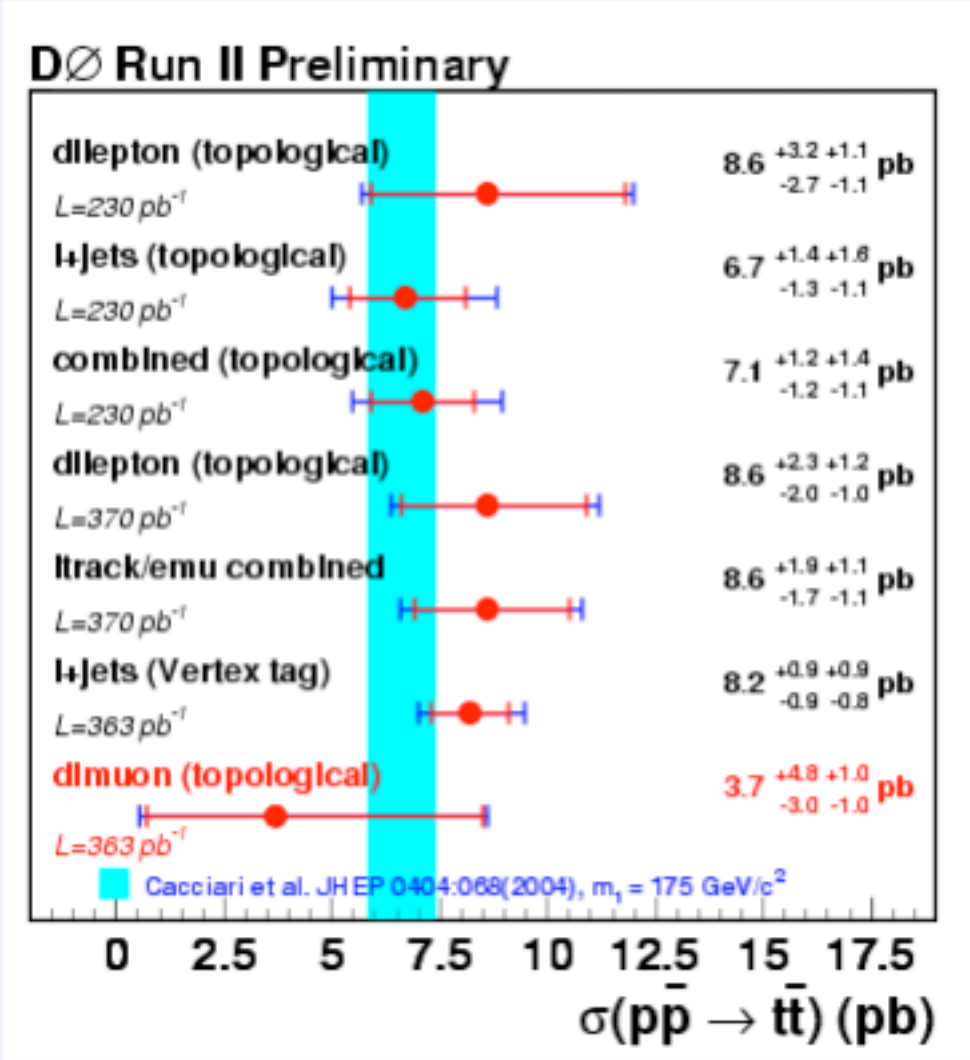
- NNLO-NNNLL 6.77 ± 0.42

- Our result is consistent with the Standard Model prediction!

  - Also consistent with other DØ measurements
  - Luminosity adjustment +16%

Comparison

- Same cross section measurement before 16% luminosity adjustment



Combined Dilepton Cross Section

- This result has been combined with four other dilepton channels:

  - Dielectron $t\bar{t} \rightarrow ee$
  - Electron Muon $t\bar{t} \rightarrow e\mu$
  - Muon + track $t\bar{t} \rightarrow \mu + track$
  - Electron + track $t\bar{t} \rightarrow e + track$

$$7.4 \pm 1.4(stat) \pm 0.9(syst) \pm 0.5(lumi)\,pb$$

- Combination method accounts for correlations between $t\bar{t} \rightarrow ee$ and $t\bar{t} \rightarrow e + track$ as well as between $t\bar{t} \rightarrow \mu\mu$ and $t\bar{t} \rightarrow \mu + track$

- To be submitted to PRD (currently under internal review)
- Results consistent with Standard Model but still statistically limited

Improvements

Signal Efficiency 6.4 % → we only find 6.4/100 signal events!

- Muon Identification (70%)
  - Already improved from 51%
  - Muon + track selection ?
- Muon Isolation (76%)
  - Consider loosening $\varepsilon^{trk}_{halo} < 0.12$ and $\varepsilon^{cal}_{halo} < 0.12$
  - Isolation-based likelihood instead of cut?
- Background rejection: χ^2_Z (72%) and contour cut (55%)
  - Expand χ^2_Z to include ME_T information (currently P_T -based)
  - Multivariate discriminants : likelihood, neural net
  - b-tag at least one jet
- Consider including one jet bin in measurement

Tevatron vs. Large Hadron Collider

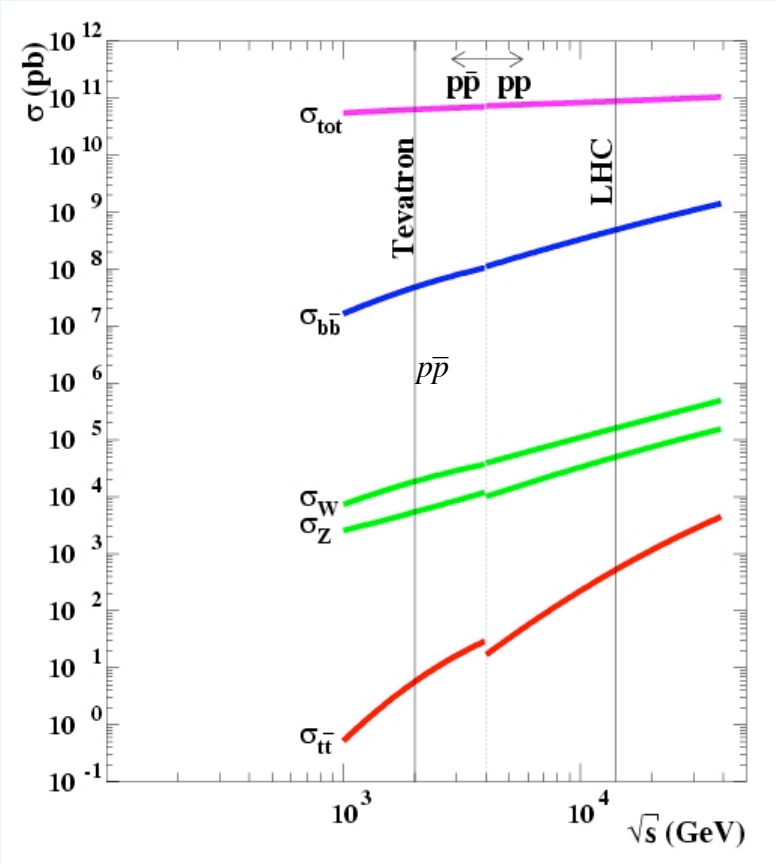
Tevatron

- $p\bar{p}$ collider

  $\sqrt{s} = 1.96$ TeV

- $\sigma_{p\bar{p}} = 80$ mb
- $\sigma_{t\bar{t}} = 7$ pb
  - Quark-antiquark (85%)
  - Gluon-gluon (15%)
- $\int \mathcal{L}\, dt = 0.5–2$ fb^{-1}/yr

- 3500 – 14000 top pairs per year
- Measurements statistics limited!



LHC (CERN)

- pp collider

  $\sqrt{s} = 14$ TeV

- $\sigma_{pp} = 125$ mb
- $\sigma_{t\bar{t}} = 830$ pb
  - Quark-antiquark (10%)
  - Gluon-gluon (90%)
- $\int \mathcal{L}\, dt = 10 – 100$ fb^{-1}/yr

- 8 million top pairs in first year!
- Measurements systematics limited!

Conclusions

- We have measured the top pair production cross section in the dimuon decay channel for proton-antiproton collisions at $\sqrt{s} = 1.96$ TeV

$$\sigma_{t\bar{t}} = 3.13^{+4.17}_{-2.60}(stat)^{+0.92}_{-0.86}(sys) \pm 0.19(lumi)\,pb$$

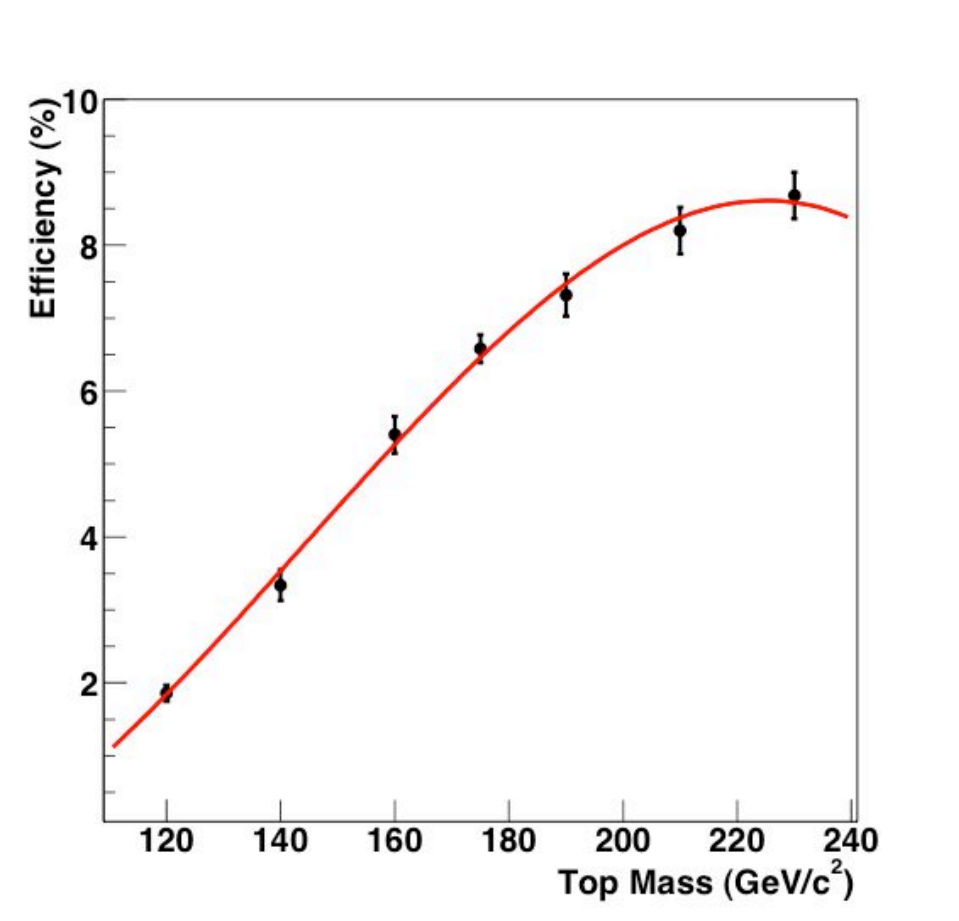
which is consistent with the theoretical prediction to NNLO.

- This measurement has a ~30 % increase in muon identification efficiency and improved signal-to-background ratio with respect to prior measurement
- A combination with 4 other dilepton channels has been performed and result to be submitted to PRD (under internal review)
- Methods developed for this analysis are being used in the 1 fb^{-1} analysis

- Systematics limited measurements will soon be possible…

Backup Slides

Top Mass Dependence



Efficiency almost linear in m_t=160-190GeV

Shift top mass down by one GeV

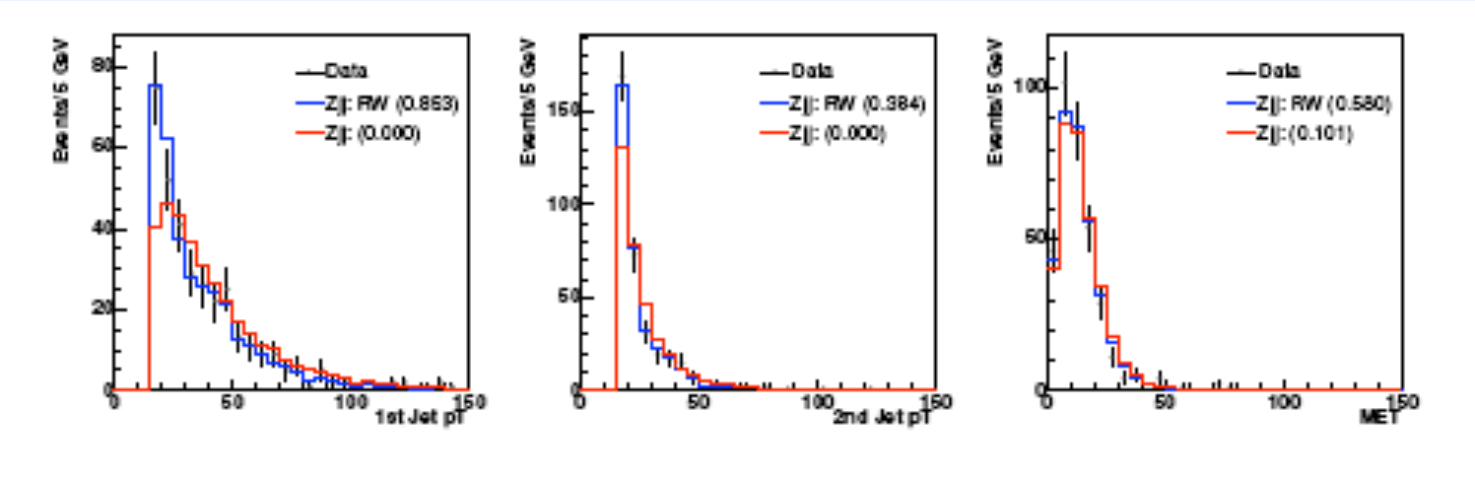
→ efficiency decreases by 0.08%

→ cross section increases by 0.05 pb

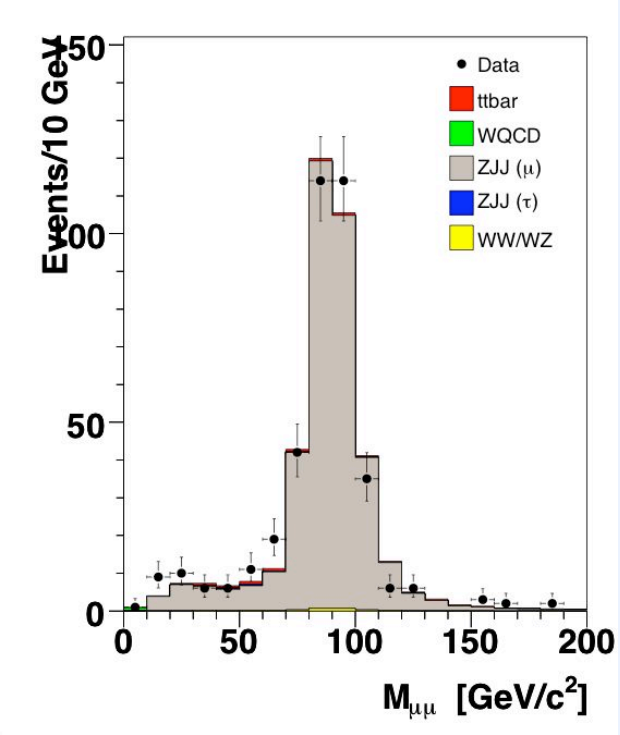
For top mass of 171 GeV, cross section increases by 0.17 pb

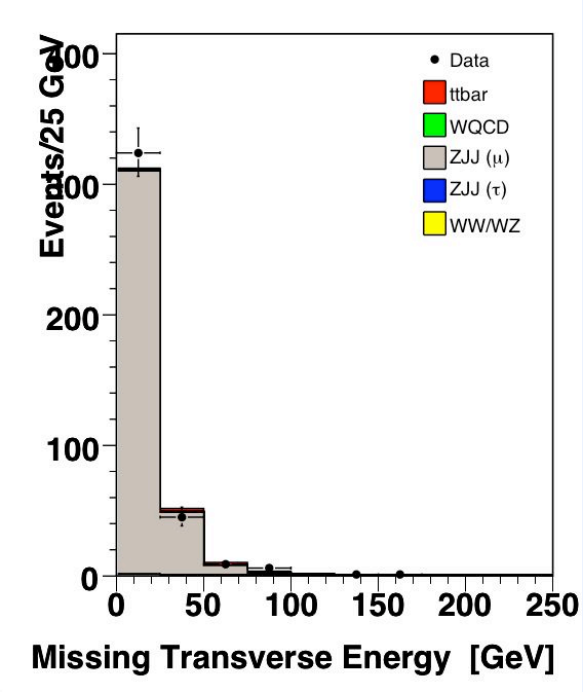
Z/γ*

Jet Multiplicity	Observed Yield	Expected Yield	K_Z
≥ 1	2349	2106.96	1.115 ± 0.026
≥ 2	305	342.18	0.891 ± 0.052



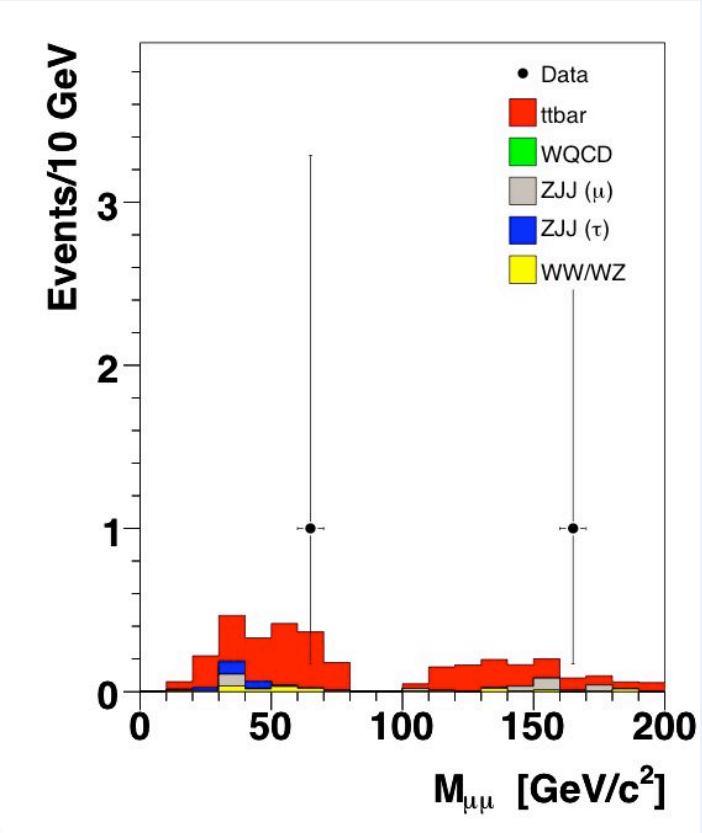
Cross-Check Plots

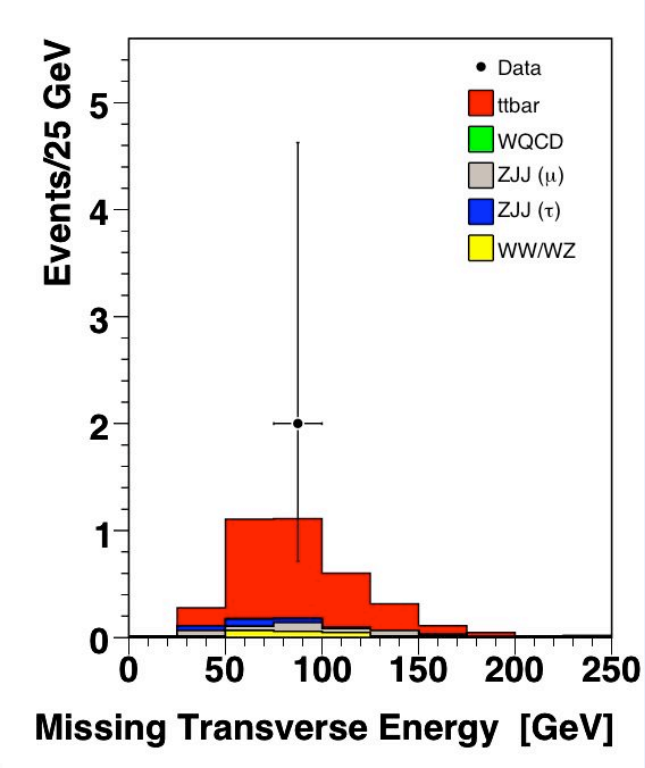




- After preselection cuts
- Histograms: Monte Carlo
- Points: data

Cross-Check Plots





- After preselection cuts
- Histograms: Monte Carlo
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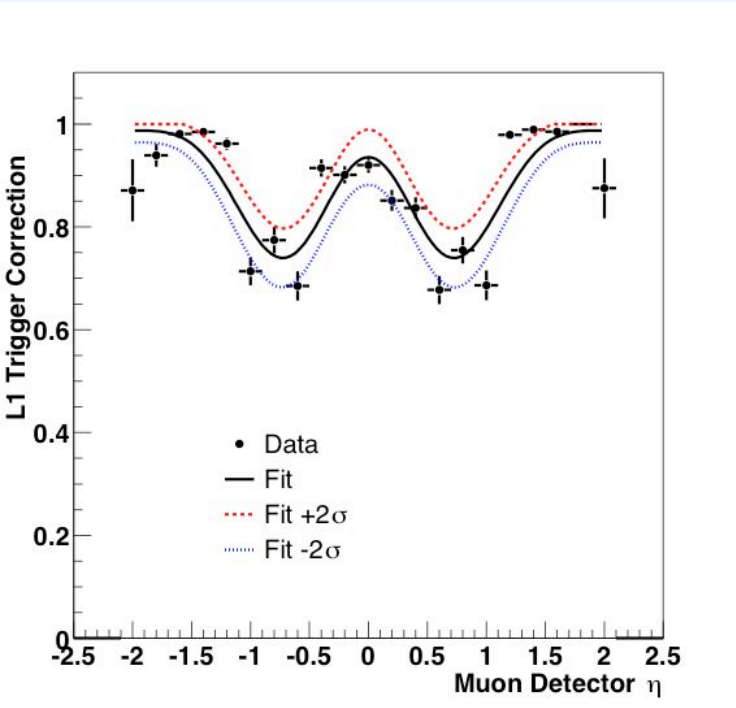
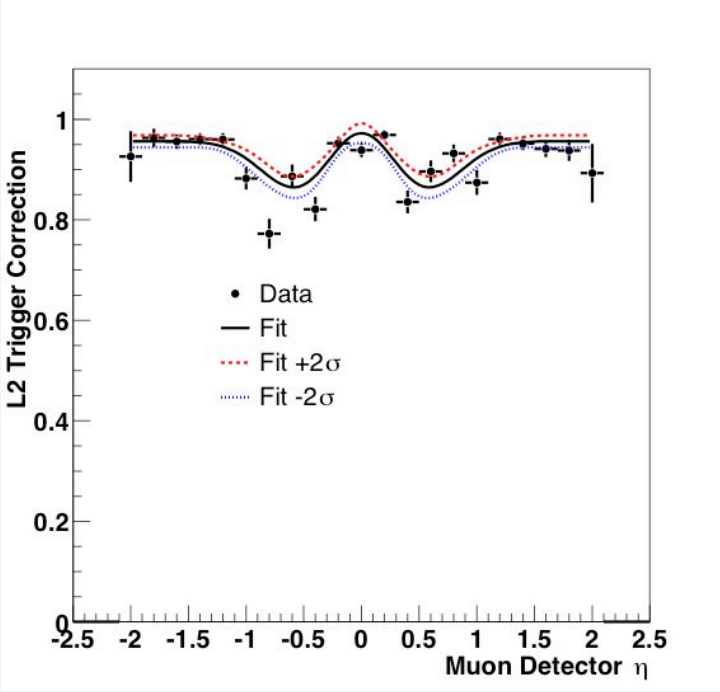
Trigger Efficiency

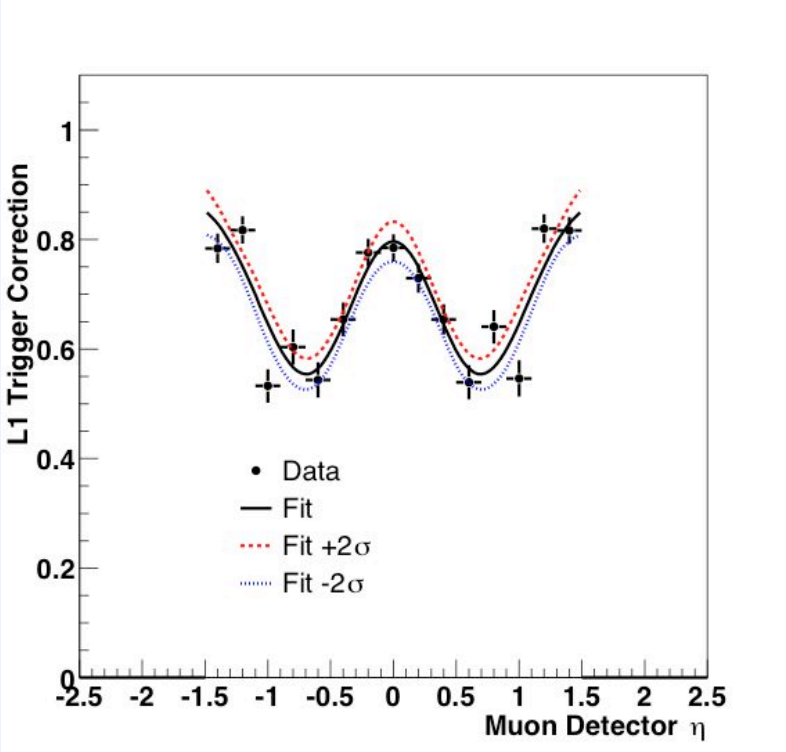
Dimuon Trigger mu1ptatxx, 1 medium muon

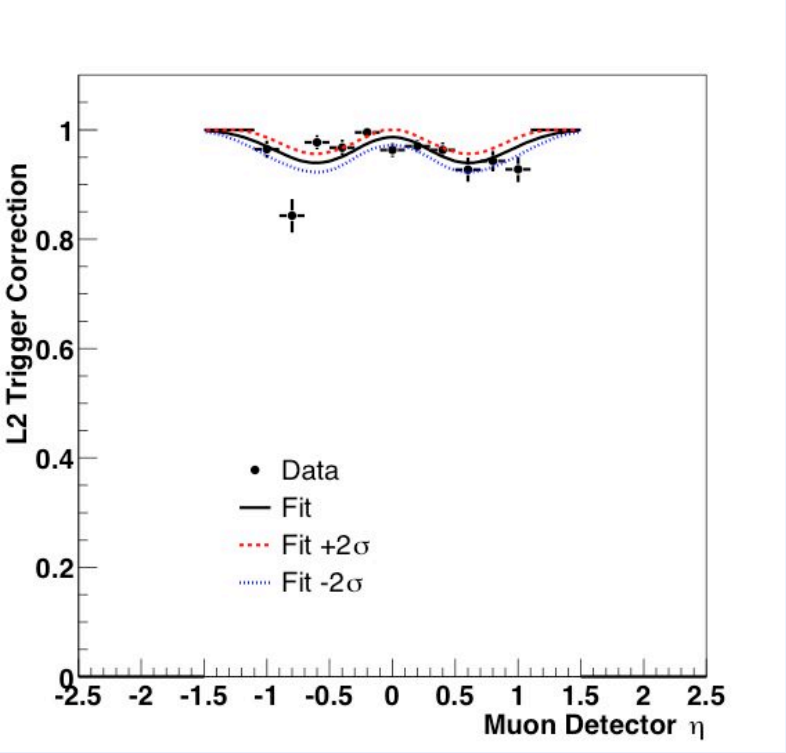




Trigger Efficieny

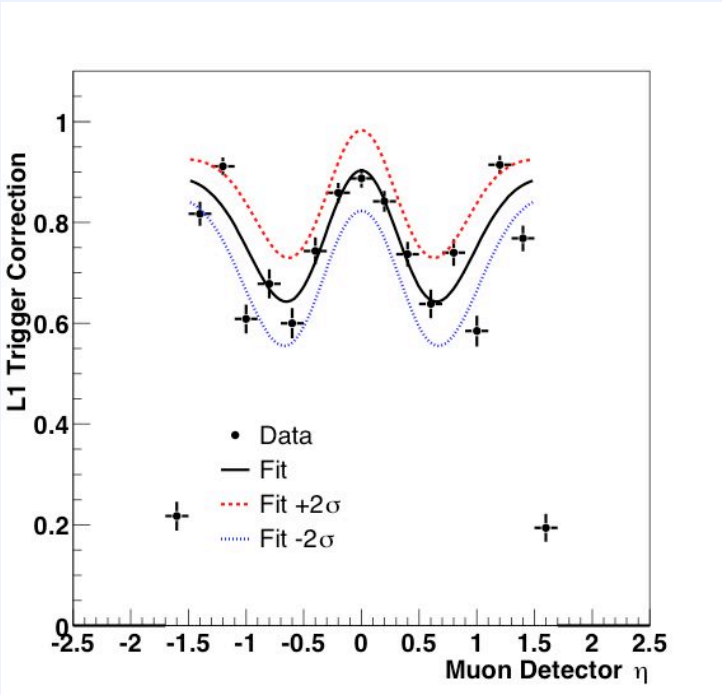
- Single muon mu1ptxatlx + 10 GeV track, 3 GeV medium

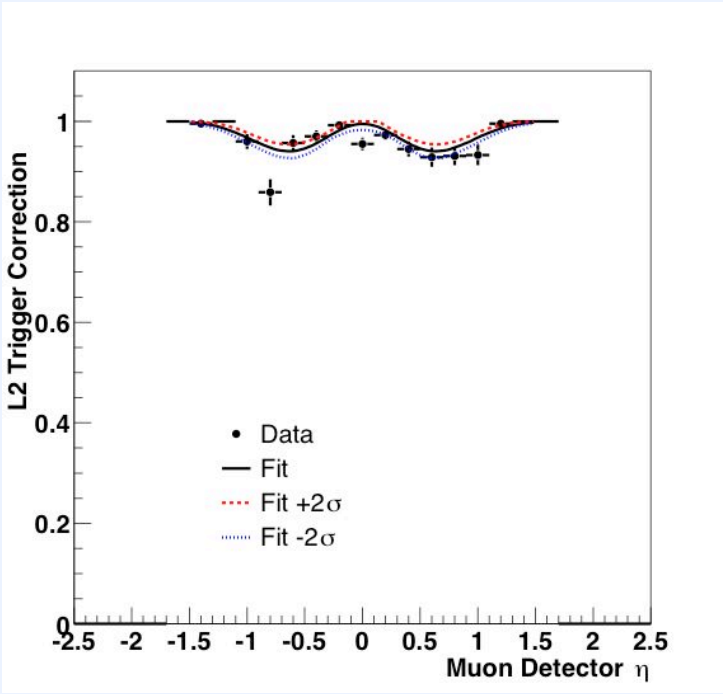




Trigger Efficiency

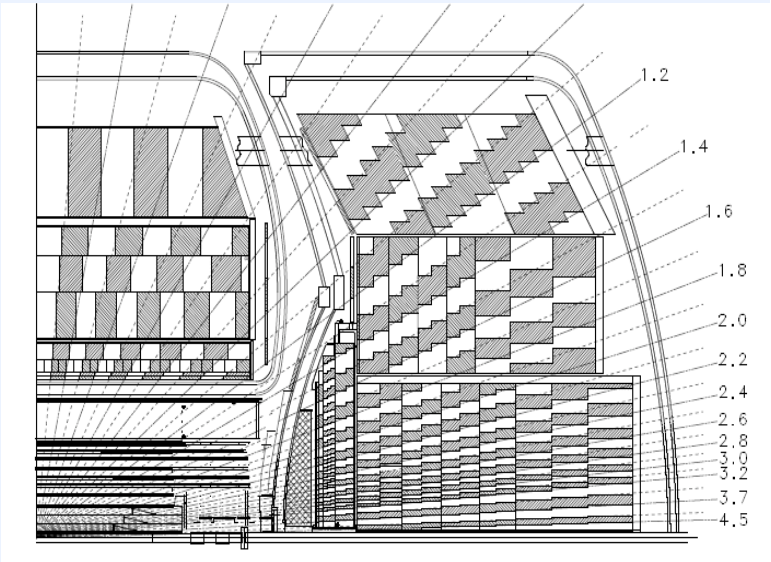
- Single muon mu1ptxwtlx, 3 GeV medium





Jet Reconstruction

- Reconstruction Procedure
  - Remove noisy cells from calorimeter towers
  - Cluster towers in a ‘cone’ above a certain energy threshold
  - Clusters are bases for proto-jets
  - Add proto-jets together based on separation & energy
    - Midpoint addition
    - Merging & splitting
  - List of jet candidates
- Apply cuts
  - Distinguish jets from noise/fakes
  - Distinguish from EM objects
- Apply Corrections
  - Jet identification (data-to-Monte Carlo scale factor)
  - Jet energy resolution corrections (resolution better in Monte Carlo than data → smear Monte Carlo)
  - Biggest correction: Jet Energy Scale…



Fermilab

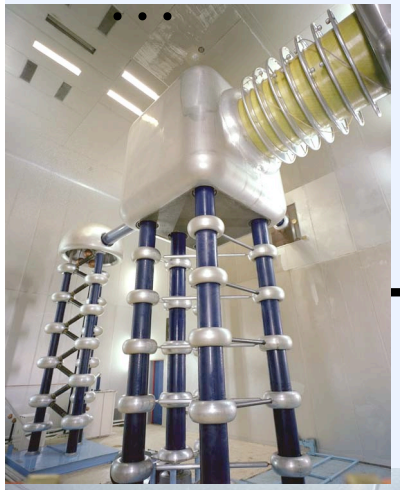
- Infrastructure
  - Original facility built in 1967 for $243M
  - Tevatron built in 1983 for $120M
  - Main Injector built in 1999 for $259M
- Highlights
  - Bottom quark discovered in 1977
  - Top quark discovered in 1995
  - B_s oscillation mixing in 2006
  - Evidence for single top quark in 2006

Protons and Antiprotons

- How do we obtain protons?
  - Hydrogen gas is ionized to create negative ions
  - Ions are accelerated and passed through carbon foil that removes electrons
  - Protons are sent to the Main Injector
    - Some sent to the Tevatron for collisions
    - Some sent to the antiproton source
- How do we obtain antiprotons?
  - Protons collide with a nickel target, producing a shower of particles including antiprotons
  - Antiprotons collected and stored in Recycler before being accelerated in Main Injector and sent to Tevatron for collisions

Fermilab's Accelerators

Cockroft-Walton



750 keV
0.04 c

Linear Accelerator

400 MeV
0.71 c

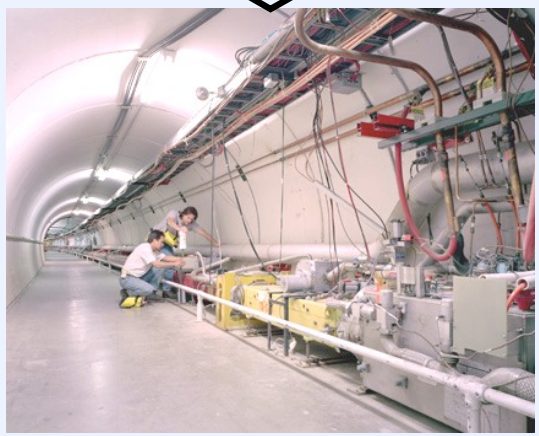
Booster

8 GeV
0.994 c

Main Injector
and Recycler

150 GeV
0.99998 c

Tevatron



980 GeV
0.9999995 c

Accumulator Ring

pbar 8 GeV

Z/γ* Background

- Background Processes:
  - Z/γ* + jets → ττ + jets→ μμ + νννν + jets
  - Z/γ* + jets → μμ + jets
    - No intrinsic ME_T, fake ME_T due to muon misreconstruction, noise in calorimeter, other instrumental effects
- Estimated in Monte Carlo
  - Constrained to data
    - Ratio of data and Monte Carlo yields in preselected events in "Z mass window" of 70 to 110 GeV
  - Kinematic distributions tested against a control sample in data

	$M_{\mu\mu}(GeV)$	$\sigma \times BR$ (pb)	Generated Events	Selected Events	Expected Yield
$Z/\gamma^* \to \tau\tau$	15-60	3.060	12033	0	0
	60-130	2.899	68127	9.3	0.149 ± 0.033
	>130	0.025	2042	2.1	0.010 ± 0.006
			Total $Z/\gamma^* \to \tau\tau$		0.158 ± 0.033

Z/ γ*→ττ =0.158 ± 0.33

Errors are statistical only

	$M_{\mu\mu}(GeV)$	$\sigma \times BR$ (pb)	Generated Events	Selected Events	Expected Yield
$Z/\gamma^* \to \mu\mu$	15-60	24.7	233500	1.8	0.071 ± 0.051
	60-130	23.4	269500	4.2	0.138 ± 0.054
	>130	0.2	66500	91.7	0.104 ± 0.010
			Total $Z\gamma^* \to \mu\mu$		0.313 ± 0.075

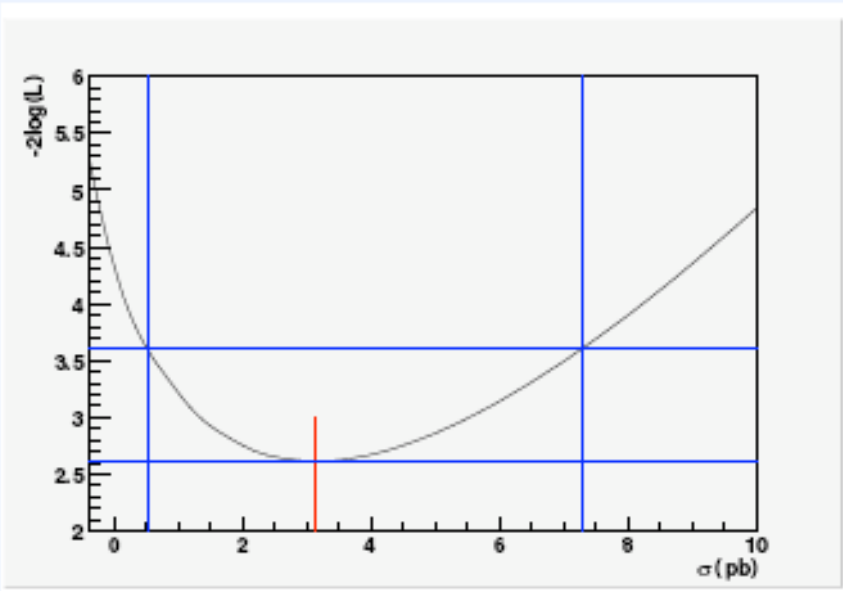
Z/ γ*→μμ =0.313 ± 0.075

Top Pair Production Cross Section

Define: $\mu = \sigma_{t\bar{t}}\, Br\, \mathcal{L}\, \varepsilon_{sig} + N^{bkg}$

Maximize: $L\left(\sigma, \left\{N^{obs}, N^{bkg}, Br, \mathcal{L}, \varepsilon_{sig}\right\}\right) = P\left(N^{obs}, \mu\right) = \frac{\mu^{N^{obs}}}{N^{obs}!} e^{-\mu}$

Or minimize: $-\log L\left(\sigma, \left\{N^{obs}, N^{bkg}, Br, \mathcal{L}, \varepsilon_{sig}\right\}\right) \approx -N^{obs} \log \mu + \mu$

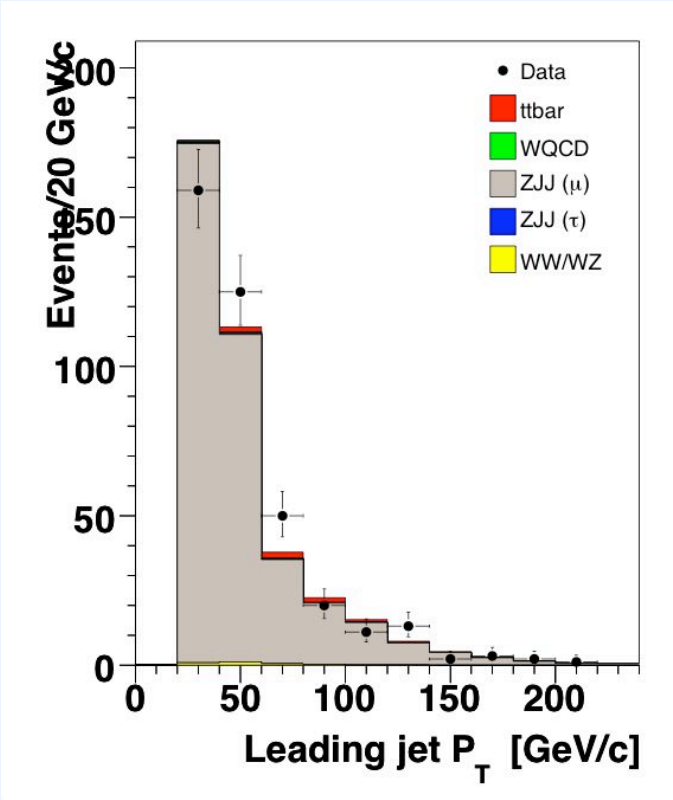


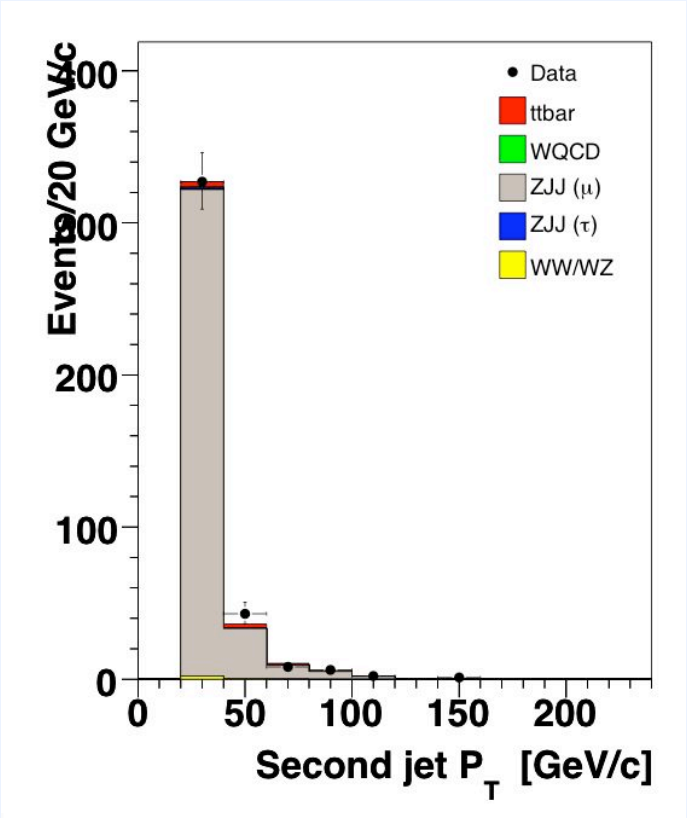
Statistical Uncertainty:
vary negative log-likelihood half a unit (full unit as pictured) above the minimum

Systematic Uncertainty:
vary N_{BKG} and ε_{sig} within $\pm$ 1 σ and repeat likelihood minimization

$$\sigma_{t\bar{t}} = 3.13^{+4.17}_{-2.60}(stat)^{+0.92}_{-0.86}(sys) \pm 0.19(lumi)\, pb$$

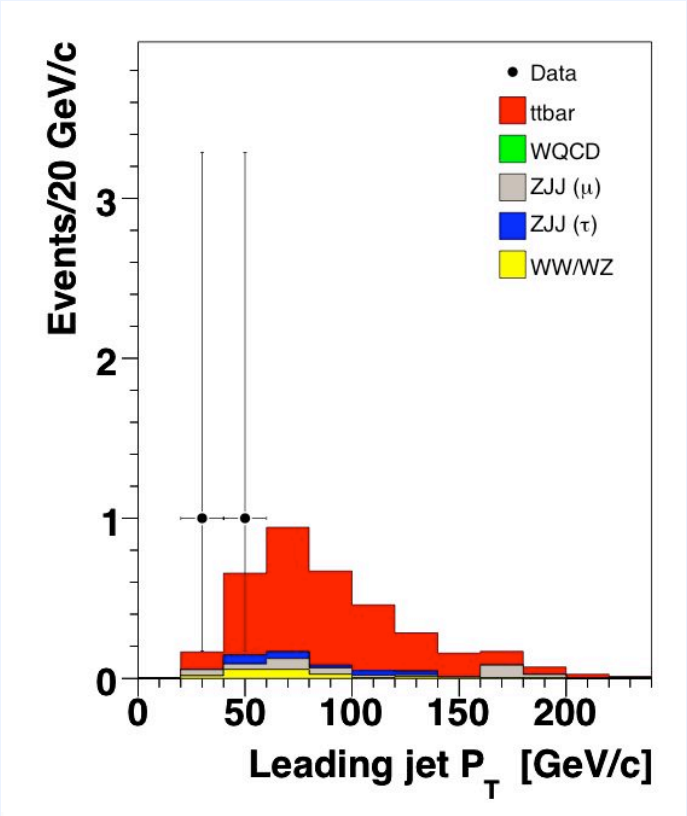
Cross-Check Plots

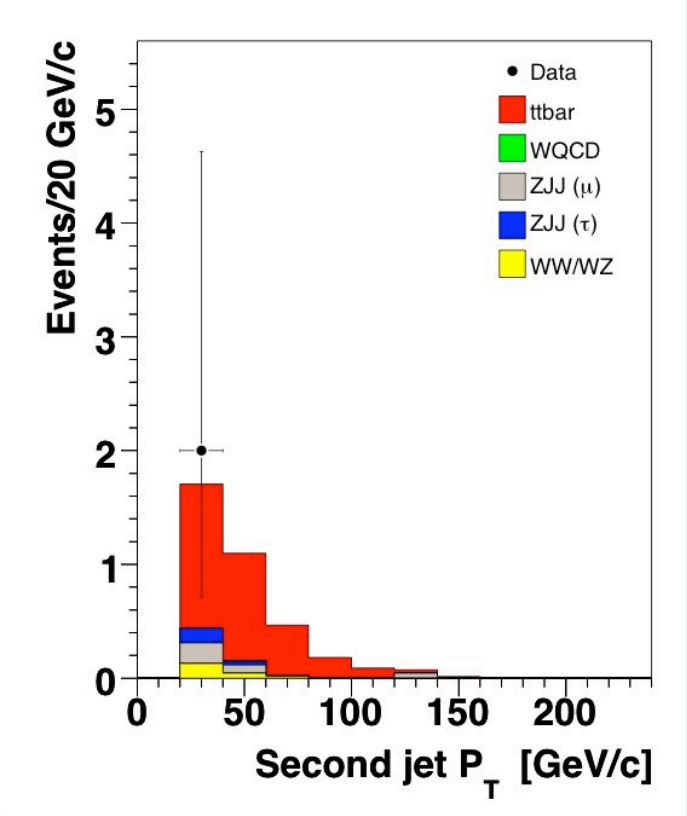




- After preselection cuts
  - Histograms: Monte Carlo
  - Points: data

Cross-Check Plots





- After all selection cuts
  - Histograms: Monte Carlo
  - Points: data