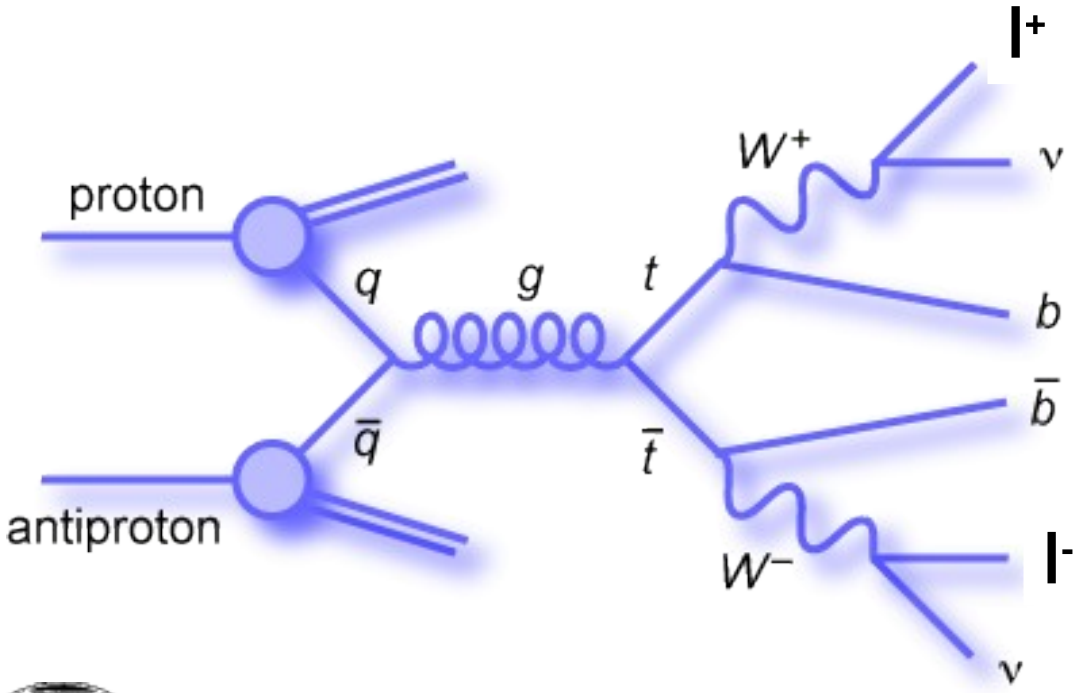
Measurement of the $t\bar{t}$ Production Cross Section and Spin Correlation in the Dileptonic Decay Channel

Jens Konrath for the DØ Collaboration



Outline

- Top production & decay
- Event selection
- Instrumental & SM Backgrounds
- Cross section measurements
- Kinematic reconstruction of dilepton events
- Spin correlation

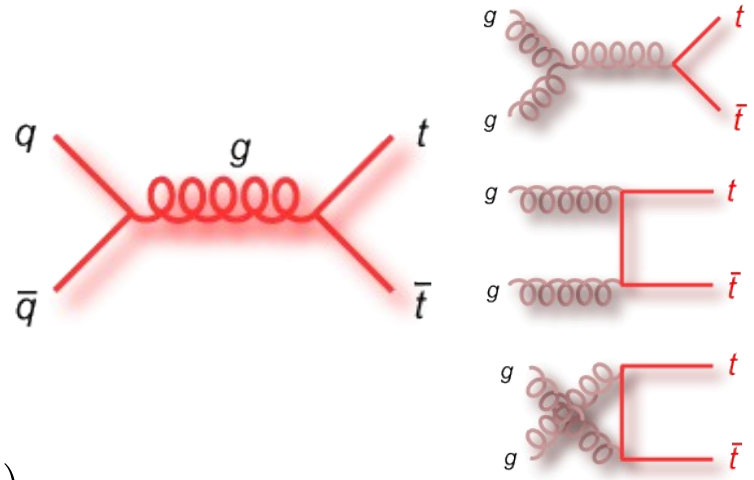
ALBERT-LUDWIGS-UNIVERSITÄT FREIBURG

Deutsche Forschungsgemeinschaft DFG

bmb+f - Förderschwerpunkt Elementarteilchenphysik Großgeräte der physikalischen Grundlagenforschung

Top Production, Decay & Branching Ratios

- At the Tevatron, top quarks are produced mainly in pairs via the strong interaction: 85% $q\bar{q}$,15% gg at LO and $\sqrt{s}$ = 1.96 TeV
- Decay channels defined by W decays
- Branching ratios (τ only included as τ->e,μ)
  - All-hadronic: 44%
  - Lepton+Jets: 34%
  - Dilepton: 1% ee and $\mu\mu$, 2% eμ
- Dilepton final state: 2 leptons, 2 jets and $\not\!\!E_T$
- Small BR, but small standard model backgrounds



Top Pair Decay Channels

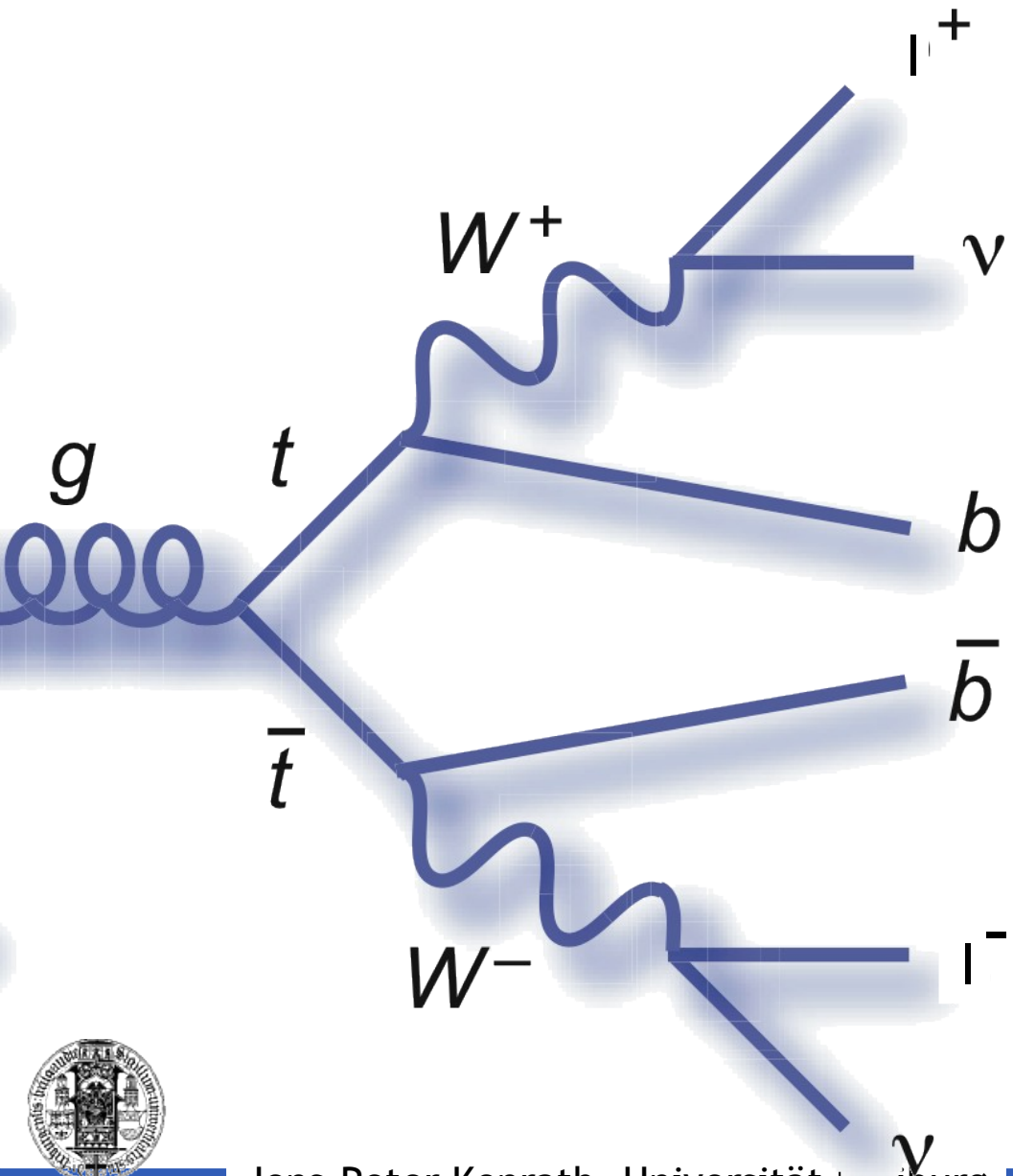
W decay	e^+	μ^+	τ^+	$u\bar{d}$	$c\bar{s}$
e^-	ee	eμ	eτ	electron+jets	
μ^-	eμ	μμ	μτ	muon+jets	
τ^-	eτ	μτ	ττ	tau+jets	
$\bar{u}d$	electron+jets	muon+jets	tau+jets	all-hadronic	
$\bar{c}s$					

dileptons

Top Production Cross-section

- Important test of QCD at high p_T
  - Test QCD NLO prediction
  - Higher x-section if resonant top production or non-SM production
- Measurements of different decay channels
  - Exotic top decays modify contributions to different channels
- Measurements with different methods
  - Kinematic analyses vs. B-tagging analyses show descrepancies if t->Wb is different from SM
- Sample verification for properties measurements

Event Selection



isolated lepton passing quality cuts, $p_T > 15$ GeV

$\not{E}_T > 35$ GeV

≥ 2 jets, $p_T > 20$ GeV

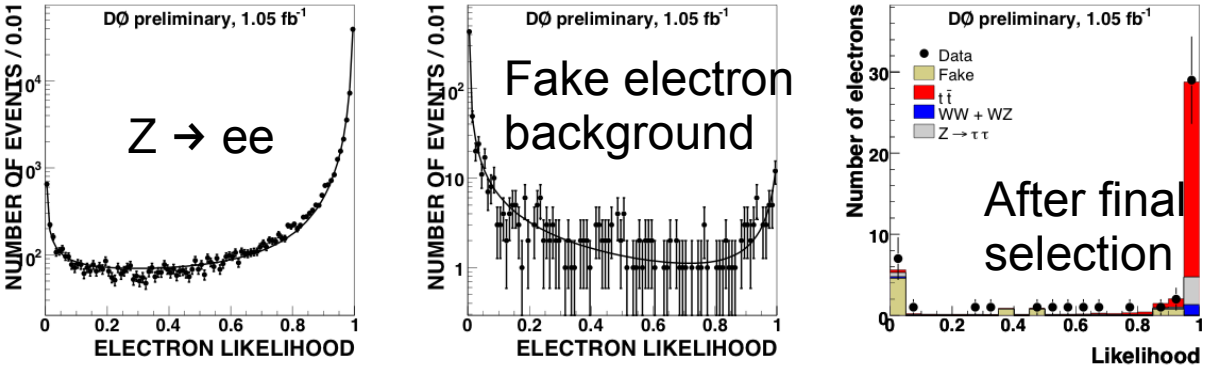
isolated leptons passing quality cuts, $p_T > 15$ GeV

Background Processes

- ee channel:
  - Z->ee + ≥2jets + $\not\!\!E_T$, (WW, WZ, ZZ)->ee + ≥2jets + $\not\!\!E_T$
  - Veto events with $M_{ee} \leq 15$ GeV and 80 GeV < M_{ee} < 100 GeV
  - Cut on $\not\!\!E_T$ depending on M_{ee}
- eμ channel:
  - Z->$\tau\tau$ + ≥2jets ->eμ + ≥2jets + $\not\!\!E_T$, (WW,WZ)->eμ + ≥2jets + $\not\!\!E_T$
  - Cut on $H_T = p_T$(leading lepton) + p_T(2 leading jets)
- $\mu\mu$ channel:
  - Z->$\mu\mu$ + ≥2jets + $\not\!\!E_T$, (WW, WZ, ZZ)->$\mu\mu$ + ≥2jets + $\not\!\!E_T$
  - χ^2 test of Z->$\mu\mu$ hypthesis
  - Contour cut in the $\not\!\!E_T$ vs. $\Delta\phi$(leading μ, $\not\!\!E_T$) plane

Instrumental Backgrounds

- Fake electron background (ee, eμ):
  Jet misidentified as an electron, or a non-isolated electron (b-decay)
  Estimation of background: Fit to electron likelihood



- Fake muon background (eμ, $\mu\mu$):
  Non-isolated muon misidentified as being isolated
  Background estimated from data

- Fake $\not\!\!E_T$ background (ee):
  Z/γ^* + jets events do not produce real $\not\!\!E_T$ (no ν); fake $\not\!\!E_T$ can appear due to instrumental effects
  Estimated from γ+jets sample ($\not\!\!E_T$ fake rate) and Z/γ^* → ee selection in low $\not\!\!E_T$ region (reversed $\not\!\!E_T$ cut)

Event Yields

- Signal expectation for $\sigma_{t\bar{t}}$ = 7 pb
- Signal efficiency for m_{Top} = 175 GeV

S/B

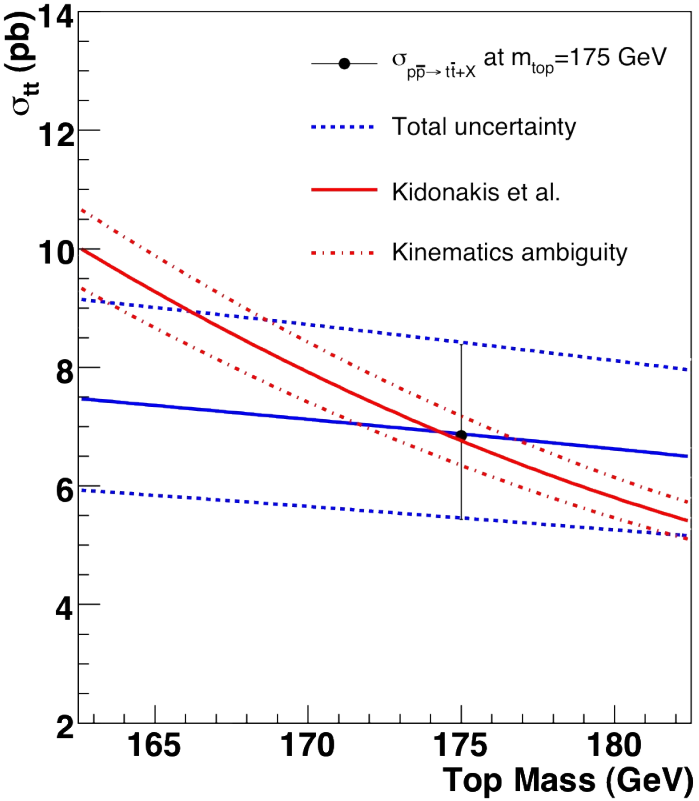
Channel	S/B
ee	3.2
eμ (1 jet)	0.6
eμ (≥2 jets)	4.3
μμ	1.6

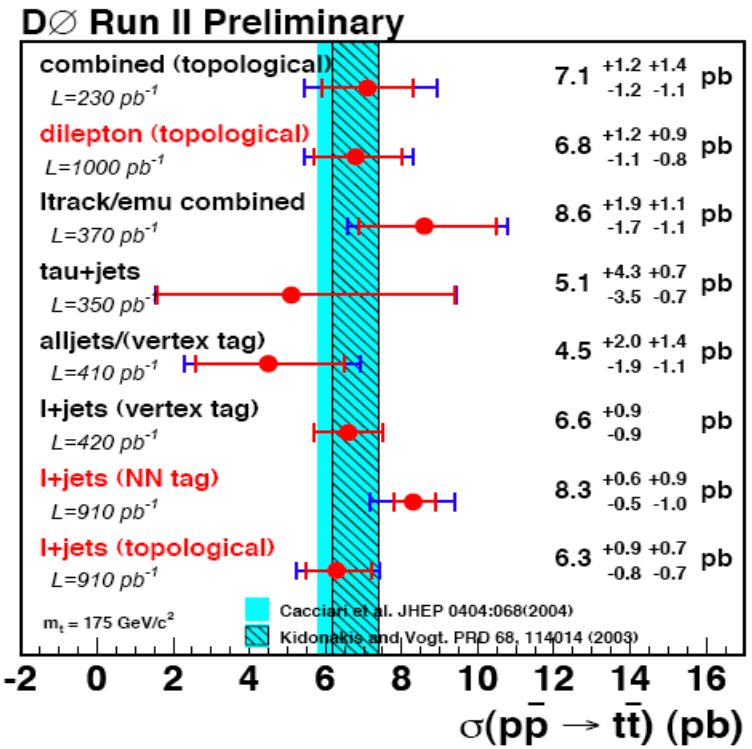
Category	ee	$\mu\mu$	$e\mu$ ($\geq$ 2 jets)	$e\mu$ (1 jet)
integrated luminosity (pb^{-1})	1036	1046	1046	1046
Z/γ^*	$2.4^{+0.4}_{-0.4}$	$2.7^{+0.4}_{-0.4}$	$3.6^{+0.7}_{-0.8}$	$5.5^{+0.8}_{-0.8}$
WW/WZ and other MC	$0.4^{+0.2}_{-0.2}$	$0.5^{+0.1}_{-0.1}$	$1.4^{+0.6}_{-0.6}$	$3.4^{+1.4}_{-1.4}$
Instrumental background	$0.2^{+0.2}_{-0.1}$	$0.4^{+0.2}_{-0.2}$	$1.8^{+0.6}_{-0.6}$	$1.2^{+0.4}_{-0.4}$
Total background	$3.0^{+0.5}_{-0.5}$	$3.6^{+0.5}_{-0.5}$	$6.7^{+1.2}_{-1.2}$	$10.2^{+1.8}_{-1.7}$
Signal efficiency (%)	$8.3^{+1.2}_{-1.2}$	$5.1^{+0.4}_{-0.4}$	$12.4^{+0.9}_{-1.0}$	$3.1^{+0.3}_{-0.3}$
Expected signal	$9.5^{+1.4}_{-1.4}$	$5.8^{+0.5}_{-0.5}$	$28.6^{+2.1}_{-2.4}$	$7.1^{+0.6}_{-0.7}$
Total Sig. + Bkg.	$12.5^{+1.5}_{-1.5}$	$9.4^{+0.7}_{-0.7}$	$35.3^{+2.8}_{-3.2}$	$17.2^{+2.0}_{-2.1}$
Selected events	16	9	32	16

$$\sigma(p\bar{p}\to t\bar{t}) = \frac{N_{observed} - N_{background}}{A_{tot}\int Ldt}$$

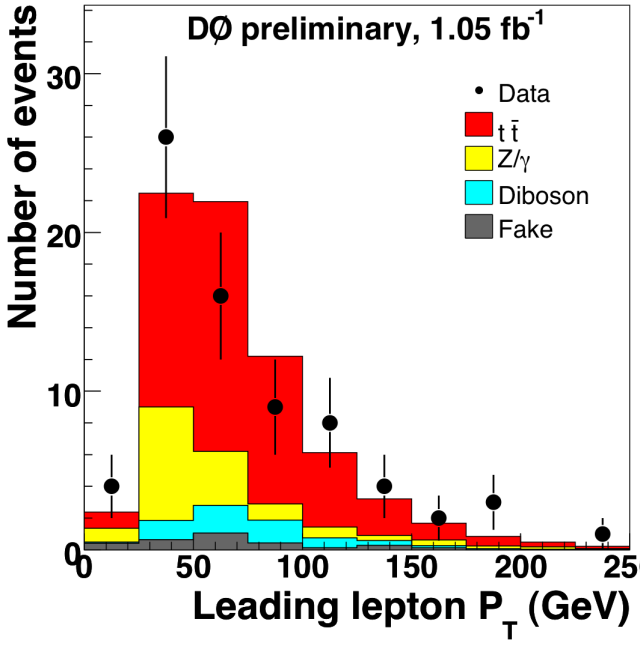
Cross Section Results

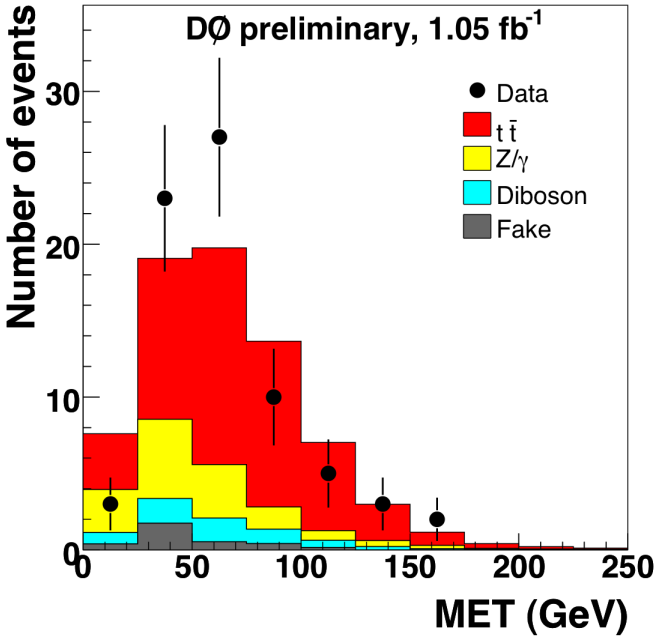
$$
\begin{aligned}
\text{ee} &: \quad \sigma_{t\bar{t}} = 9.6^{+3.2}_{-2.7}\,(\text{stat})\,^{+1.9}_{-1.6}\,(\text{syst}) \pm 0.6\,(\text{lumi})\,\text{pb} \\
\text{e}\mu &: \quad \sigma_{t\bar{t}} = 6.1^{+1.4}_{-1.2}\,(\text{stat})\,^{+0.8}_{-0.7}\,(\text{syst}) \pm 0.4\,(\text{lumi})\,\text{pb} \\
\mu\mu &: \quad \sigma_{t\bar{t}} = 6.5^{+4.0}_{-3.2}\,(\text{stat})\,^{+1.1}_{-0.9}\,(\text{syst}) \pm 0.4\,(\text{lumi})\,\text{pb} \\
\text{dilepton} &: \quad \sigma_{t\bar{t}} = 6.8^{+1.2}_{-1.1}\,(\text{stat})\,^{+0.9}_{-0.8}\,(\text{syst}) \pm 0.4\,(\text{lumi})\,\text{pb}
\end{aligned}
$$

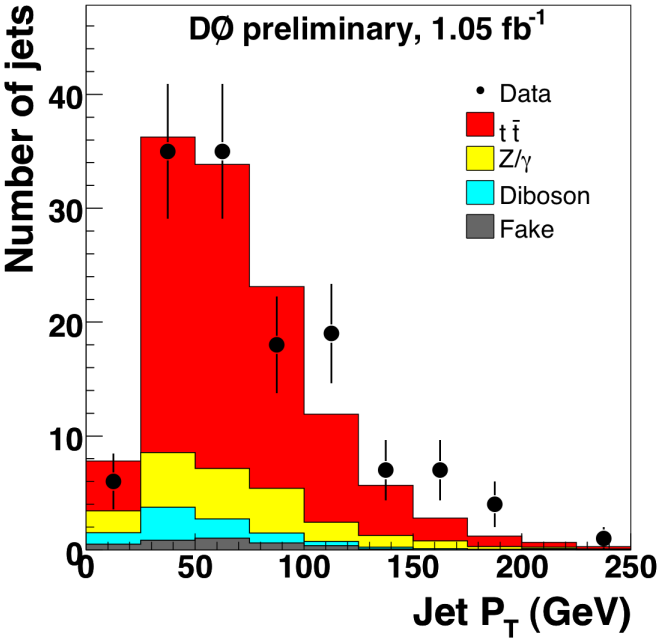


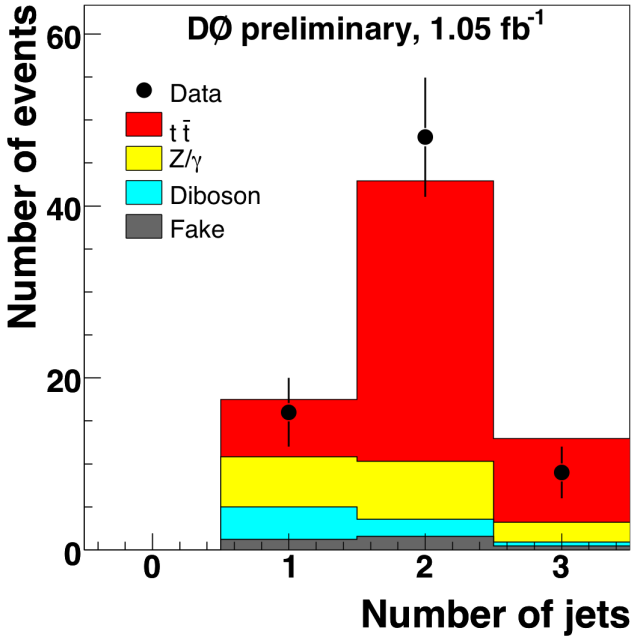


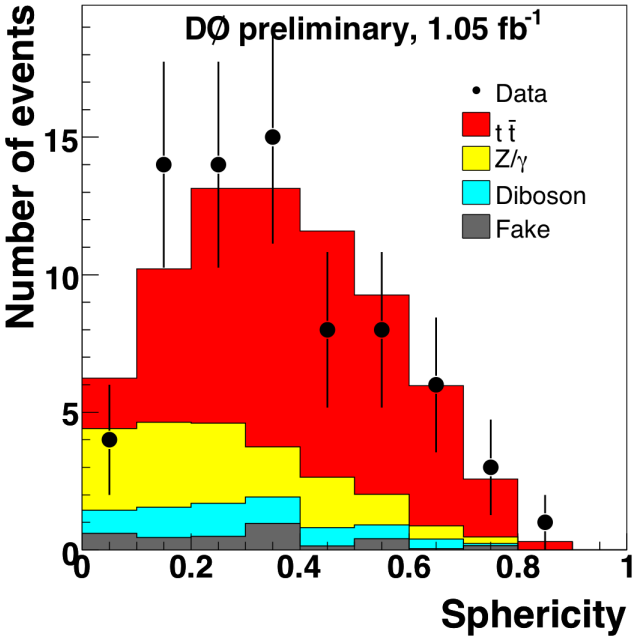
After Final Selection Cuts

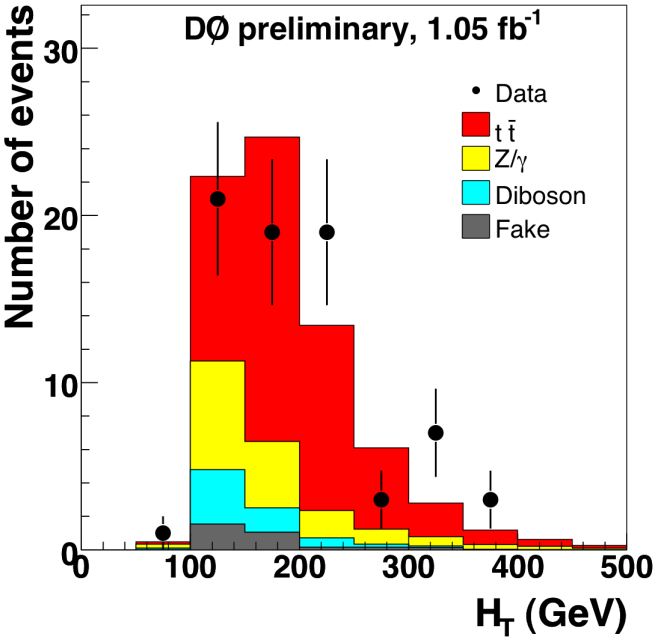












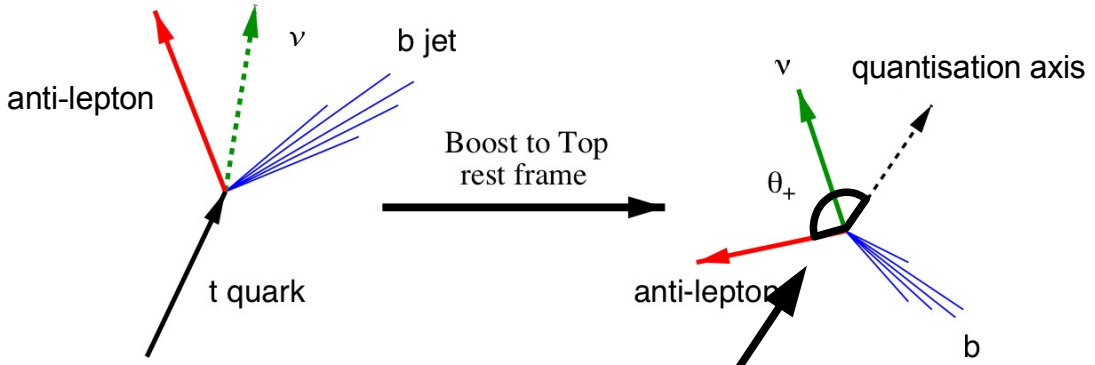
Systematic Uncertainties

•Jet energy scale, MC normalization and lepton identification give largest contribution

Systematic Uncertainty Source (pb)	$\ell\ell$
Jet energy calibration	$+0.3-0.3$
Jet identification	$+0.1-0.1$
Primary vertex identification	$+0.3-0.2$
Muon identification	$+0.2-0.2$
Electron identification	$+0.6-0.5$
Trigger	$+0.2-0.2$
Fake background	$+0.2-0.2$
MC normalization	$+0.3-0.3$
Other	$+0.2-0.2$
Total	$+0.9-0.8$

Spin Correlation

- Top has a very short lifetime: $\tau \sim 10^{-25}$ s $\Rightarrow$ decay before hadronisation
- Top spin is not diluted by hadronisation but passed on to decay products

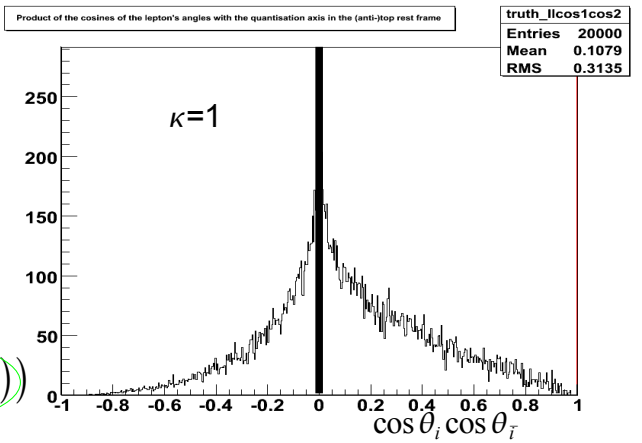


- Allows to test top production and decay:

$$\kappa \propto \frac{N_{\text{like spin}} - N_{\text{unlike spin}}}{N_{\text{like spin}} + N_{\text{unlike spin}}}$$

$$\frac{1}{\sigma}\frac{d^2\sigma}{d(\cos\theta_{\bar{i}})\,d(\cos\theta_i)} = \frac{1+\kappa\cos\theta_{\bar{i}}\cos\theta_i}{4}$$

- κ is 0.806 at NLO for the Tevatron using the beamline as quantisation axis



Asymmetry

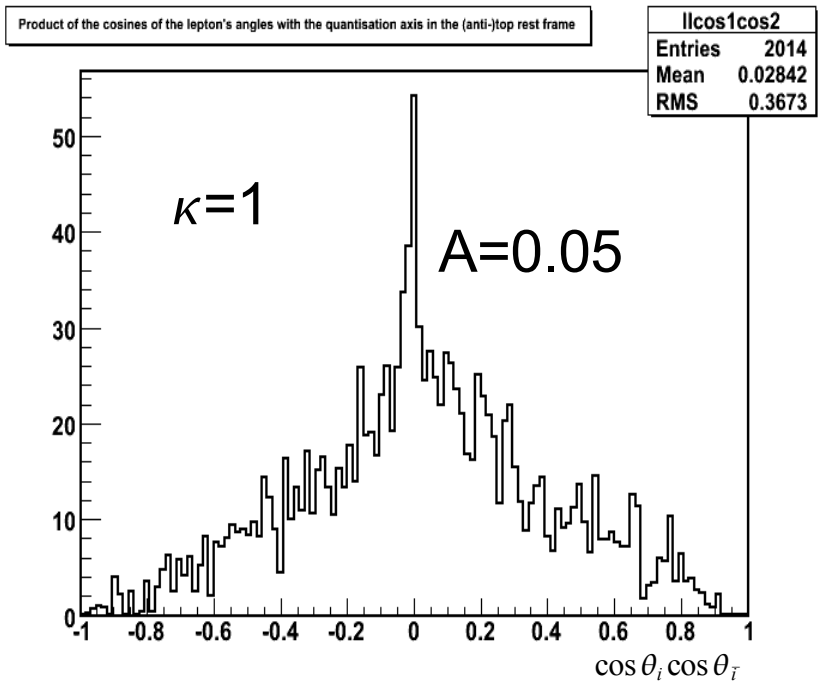
$$\frac{\kappa}{4} = \frac{1}{\sigma}\left(\int_0^1 \frac{d\sigma}{d(\cos\theta_i\cos\theta_{\bar{i}})}\,d(\cos\theta_i\cos\theta_{\bar{i}}) - \int_{-1}^0 \frac{d\sigma}{d(\cos\theta_i\cos\theta_{\bar{i}})}\,d(\cos\theta_i\cos\theta_{\bar{i}})\right)$$

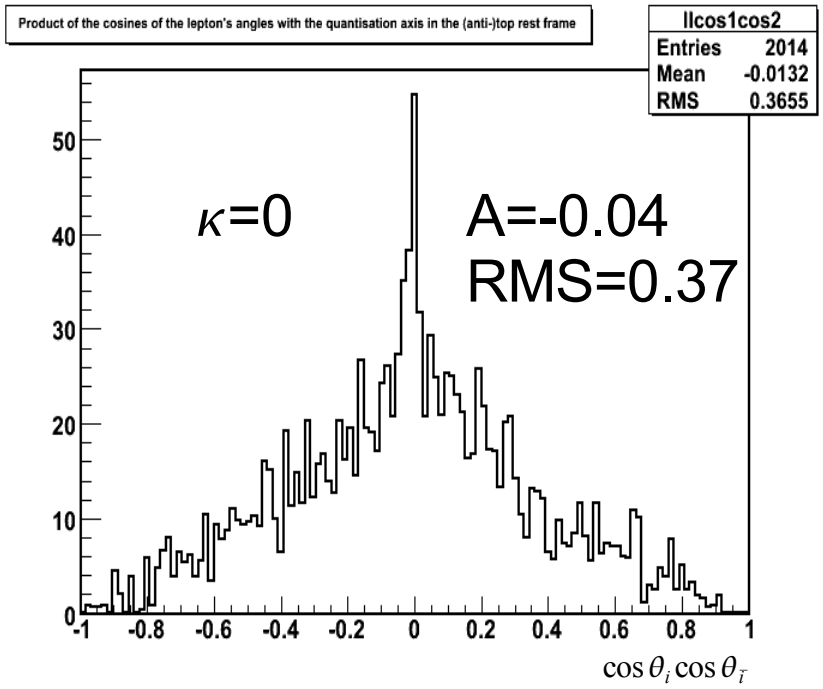
Kinematic Reconstruction of Dilepton Events

- Equations describing dilepton kinematics can be solved analytically: Phys.Rev.D 73, 54015 (2006)
- Neutrino four-vectors are unknown ⇒ underconstrained system of equations
- Zero, two or four solutions per event
- Twofold ambiguity: b (anti-)quark ⇔ jet assignment

Estimating the Sensitivity

$$Sensitivity = 4\,\frac{Asymmetry(\kappa=1) - Asymmetry(\kappa=0)}{\sigma_{Asymmetry}(\kappa=0)}$$





Sensitivity = 0.26

Expected 1σ stat. Error: 1/Sensitivity / $\sqrt{N}$

50 dilepton Events: $\delta\kappa$ = 0.55

Summary & Outlook

- Dilepton cross sections have been measured with the full Run IIa dataset

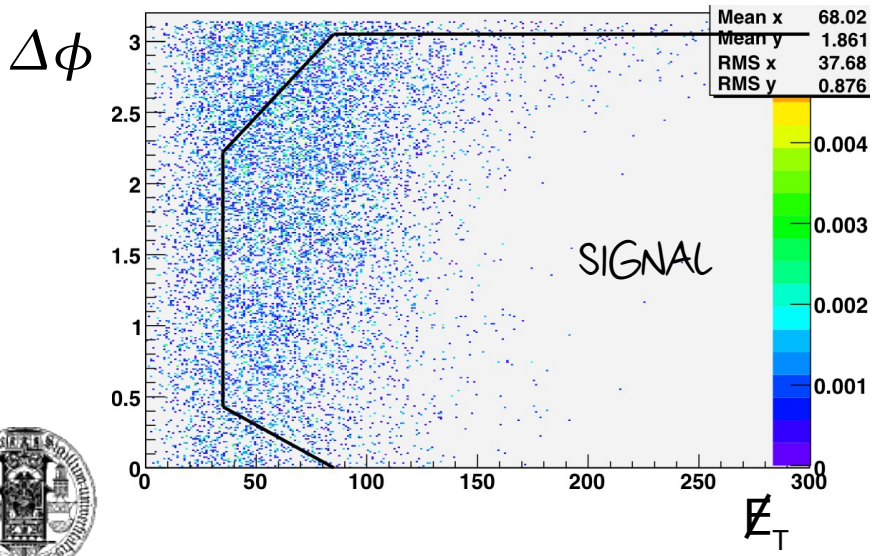
$$\sigma_{t\bar{t}} = 6.8^{+1.2}_{-1.1}\,(\text{stat})\,^{+0.9}_{-0.8}\,(\text{syst}) \pm 0.4\,(\text{lumi})\,\text{pb}$$

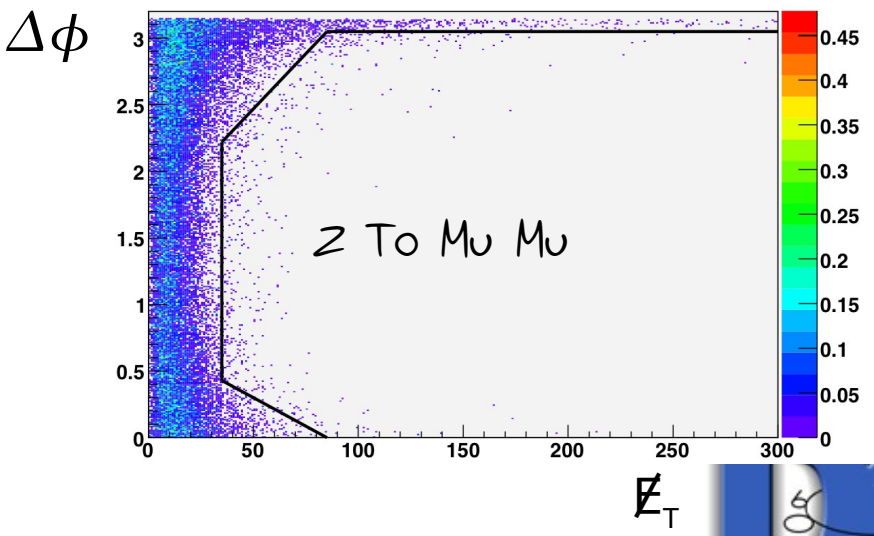
- The dilepton event selections are ready for top properties analyses
- Finalize cross section analyses for publication
- Improve kinematic reconstruction & measure spin correlation

Backup Slides

Dimuon Selection

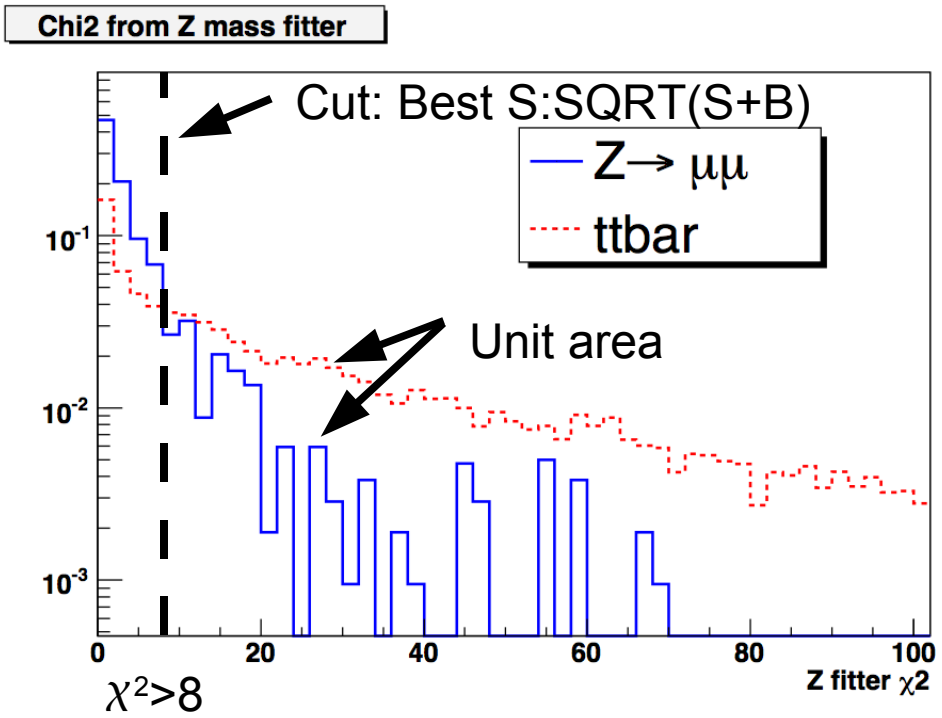
- Contour cut: $\not\!\!E_T$ vs. $\Delta\phi$(leading $\not\!\!E_T$)
  - 2 neutrinos ⇒ a first cut is set: $\not\!\!E_T$ > 35 GeV
  - To prevent from misreconstructed muon momenta: $\Delta\phi$(leading $\not\!\!E_T$) < 175°
  - To further reduce background, $\not\!\!E_T$ cut is increased for $\Delta\phi$(leading $\not\!\!E_T$) close to 0° or 180°





Z Rejection

- Z->ll is the main background in the dileptonic decay channels
- Cut on M_{ee} to reject Z→ ee
- χ^2 test of Z->$\mu\mu$ hypothesis performas better than dimuon invariant mass cut



Object Selection

- Leptons:
  - Loose electrons Track matched calorimeter cluster with shower shape & isloation cuts, p_T > 15 GeV, $|\eta|$<1.1 or 1.4<$|\eta|$<3.6.
  - Tight electrons: additional likelihood cut
  - Muons: Cosmic veto, central track match, isolation cuts, p_T > 15 GeV, $|\eta|$<2.0
- Primary Vertex: $|z_{PV}|$<60 cm, $n_{Tracks} \geq 3$, Δz(PV, lepton) < 1 cm
- Jets: Apply JES, standard jet ID, no overlap with EM clusters
- $\not\!\!E_T$: Propagate JES corrections and muon p_T to $\not\!\!E_T$

Dielectron Selection

- Luminosity: 1.07 fb^{-1}
- Analysis cuts:
  - 2 tight electrons
  - ≥ 2 jets
  - $\not\!\!E_T$ depends on M_{ee}: $\not\!\!E_T$ > 40 GeV for 15 GeV < M_{ee} < 80 GeV
    and $\not\!\!E_T$ > 35 GeV for M_{ee} > 100 GeV
  - Sphericity > 0.15
- Trigger: ORing of all dielectron triggers; Signal efficiency ≈ 94%

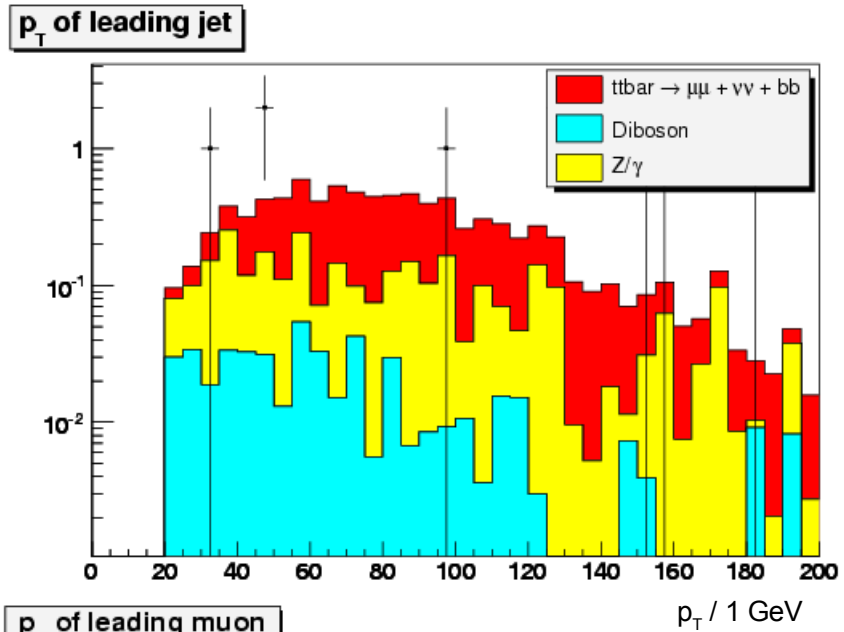
Electron-Muon Selection

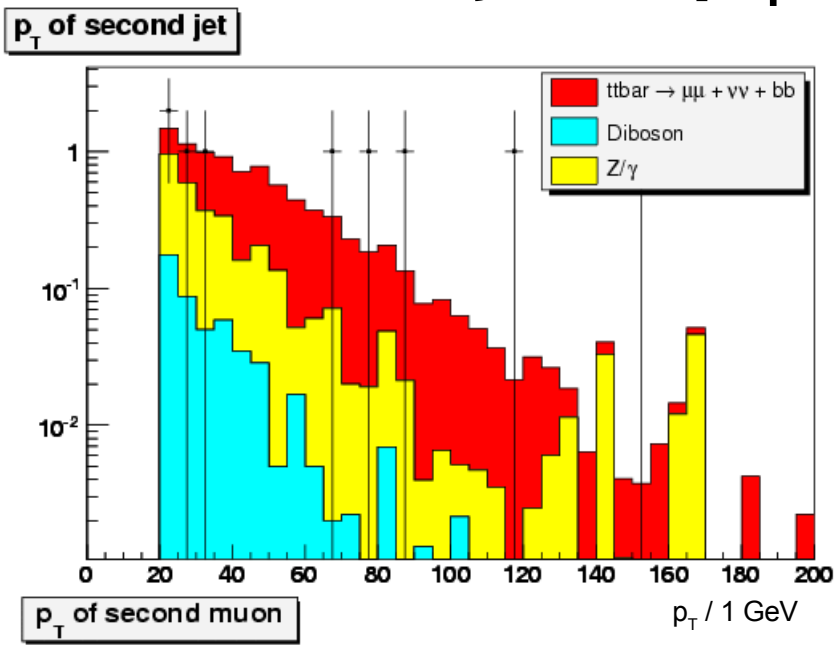
- Luminosity: 1.04 fb^{-1}
- Analysis cuts:
  - Exactly one loose electron
  - ≥ 1 medium muon
  - No common track between the electron and any loose trtack matched muons
  - ≥ 2 jets
  - ΔR(selected e, jet)>0.5 and ΔR(selected μ, jet)>0.5
  - $H_T = p_T$(leading lepton) + p_T (2 leading jets) > 115
- Trigger: Oring of e triggers + matching online/offline objects; Signal Efficiency ≈ 86%

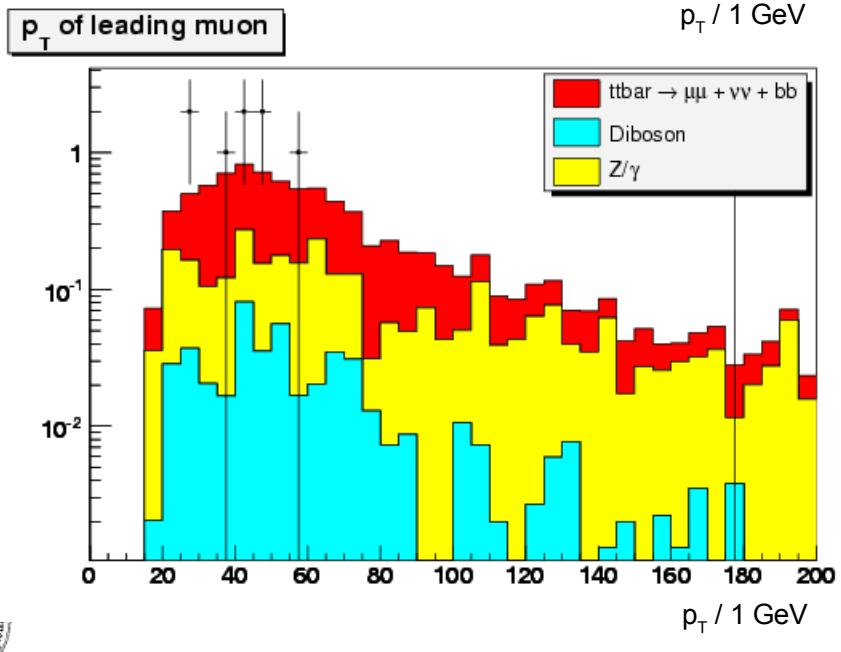
Dimuon Selection

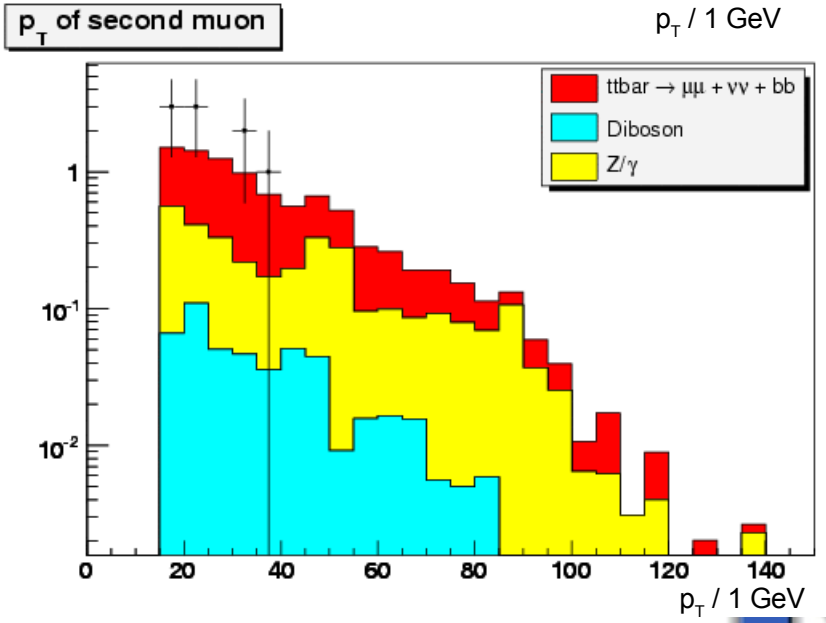
- Luminosity: 1.05 fb^{-1}
- Analysis cuts:
  - Veto any top_loose electron
  - ≥ 2 tight isolated muons
  - ≥ 2 jets
  - $M_{\mu\mu}$ > 30 GeV
  - Contour cut in the $\not\!\!E_T$ – $\Delta\phi$(leading $\not\!\!E_T$) plane
  - Z fitter χ^2>8
- Trigger: Oring of all single muon triggers & matching reco / trigger objects (tracks, muons); Signal efficiency ≈ 88%

After All Cuts: Jet & Myon p_T









After All Cuts: $\not{E}_T$, Invariant Mass, Z fit χ^2, $\Delta\phi$(leading μ, $\not{E}_T$)