Top Quark Pair Production Cross Section at Tevatron

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Rencontres de Moriond
QCD and High Energy Interactions
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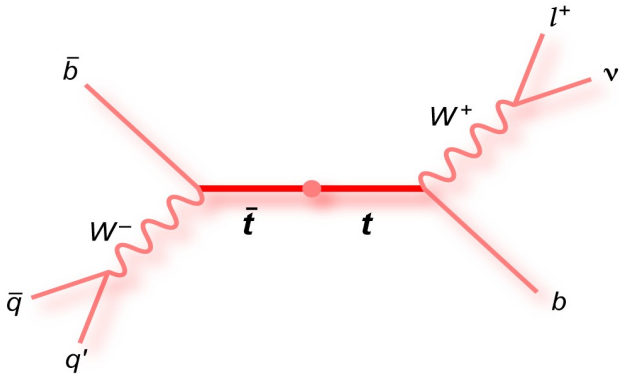
Why Cross-section?

- Comparison with a theoretical calculations: SM test, probe of the new production mechanism (e.g. resonance production)
  - N. Kidonakis and R. Vogt, arXiv:hep-ph/0805.3844, PRD 78, 074005 (2008): NLO + NNLO soft gluon correction, $\sigma = 7.27^{+0.76}_{-0.85}\,pb$, m_t = 172.5 GeV
  - S. Moch and P. Uwer, arXive:hep-ph/0804.1476, PRD 78, 034003 (2008): NNLO (approx), $\sigma = 7.45^{+0.50}_{-0.70}\,pb$, m_t = 172.5 GeV
  - M. Cacciari, S. Frixione, M. M. Mangano, P. Nason and G. Ridolfi, arXiv:hep-ph/0804.2800, JHEP 09, 127 (2008): NLO + next-to-leading threshold logarithm correction, $\sigma = 7.14^{+0.76}_{-0.86}\,pb$, m_t = 172.5 GeV
  - Errors ~ 7 – 10 %, depends how the scale uncertainty is defined
  - Run I, 2E = 1.80 TeV, L ~ 100 pb^{-1}: $\delta\sigma/\sigma$ ~ 25%
- Sample definition for the properties measurements
- Important background for the new phenomena and Higgs search
- Allow to extract the top mass from the cross-section dependence with a "clean" definition of a top mass from the theoretical point of view.

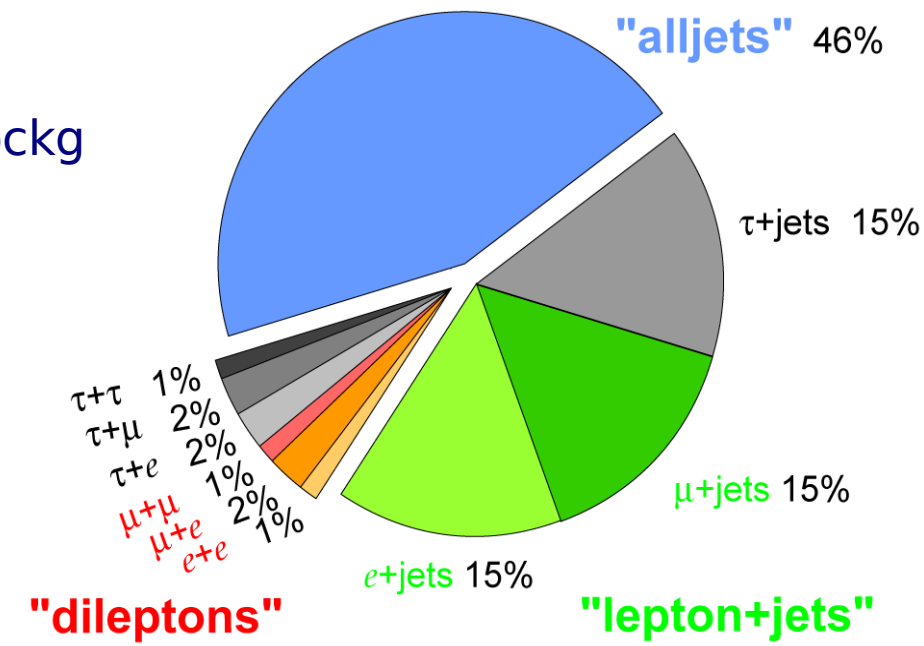
Top Quark Decays

- Top quark has a very short life-time ~ 10^{-25} sec ⇒ decay before hadronisation
- In SM $|V_{tb}|$~1 ⇒ Br(t→Wb) ~ 100%

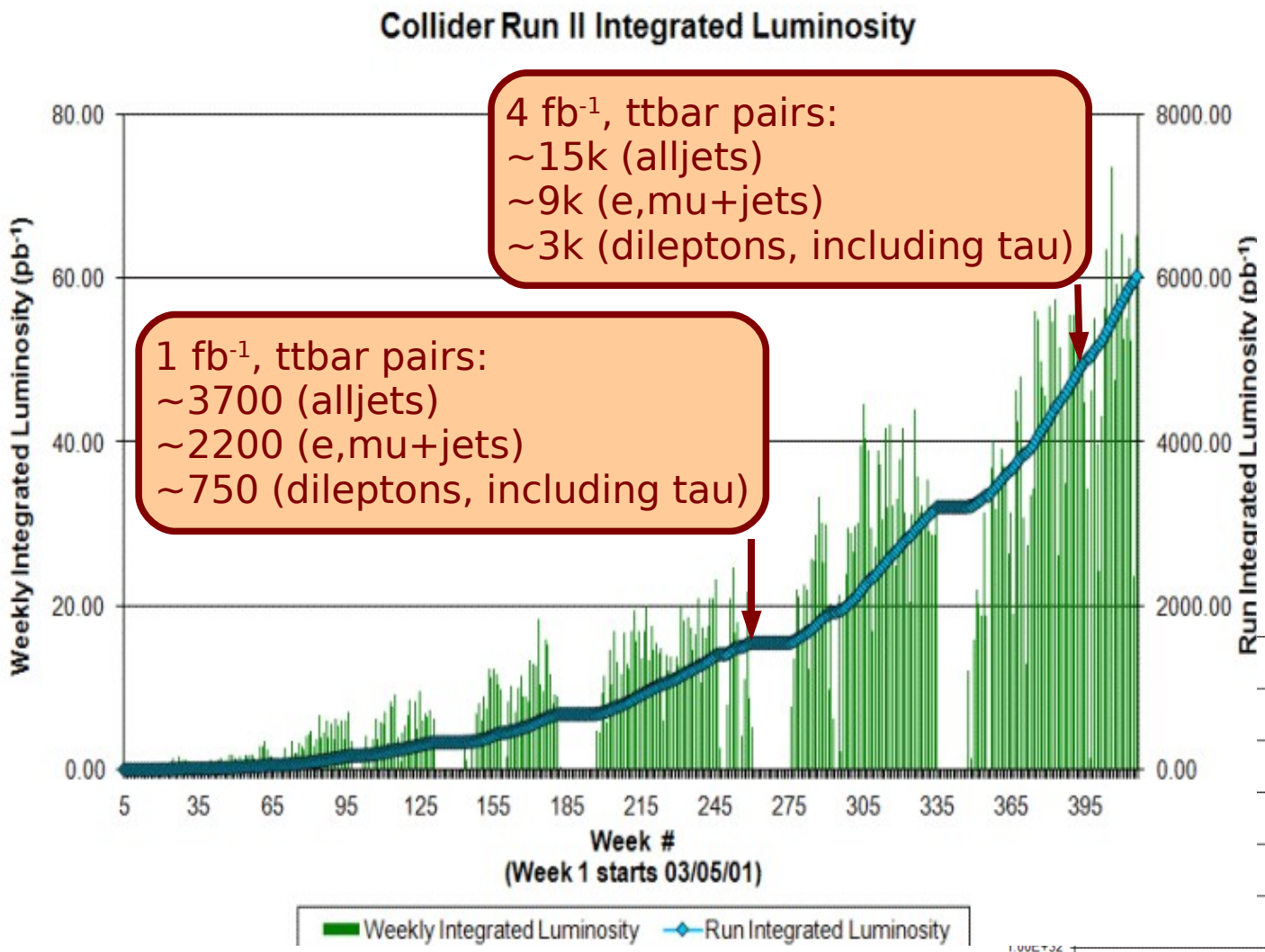


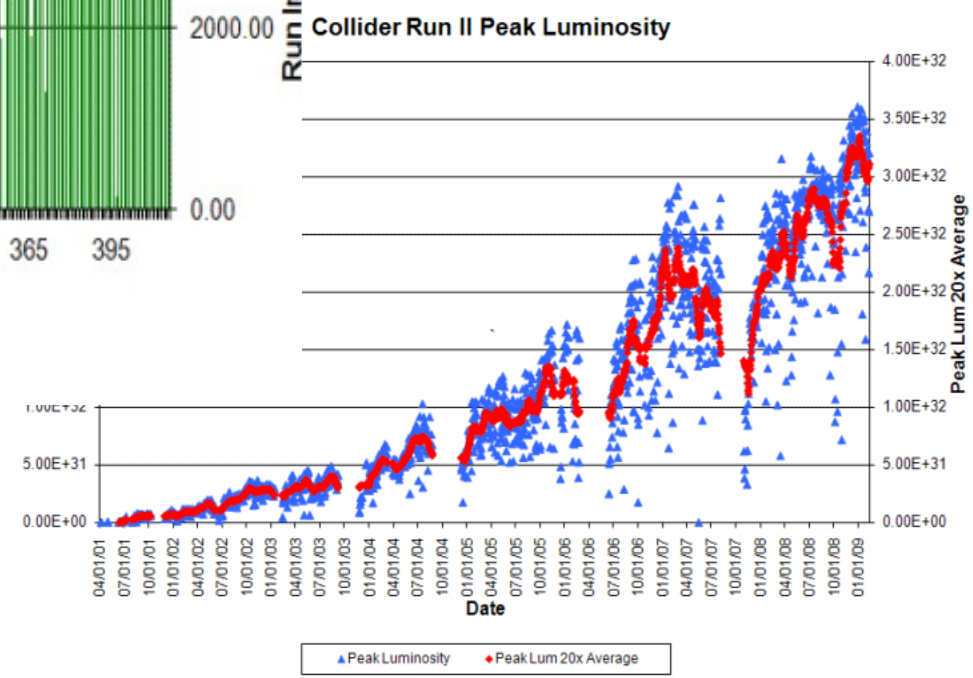
- Dileptons:
  - e, μ, τ → e (μ) : ~ 6.5%, low background
  - τ → had + e (μ) : ~ 3.6%, reasonable bckg
- Leptons + jets,
  - e, μ, τ → e (μ) + jets ~ 35%, reasonable bckg
  - τ → had + jets ~ 9.5%, high background
- All jets ~ 46%, high bckg

Top Pair Branching Fractions

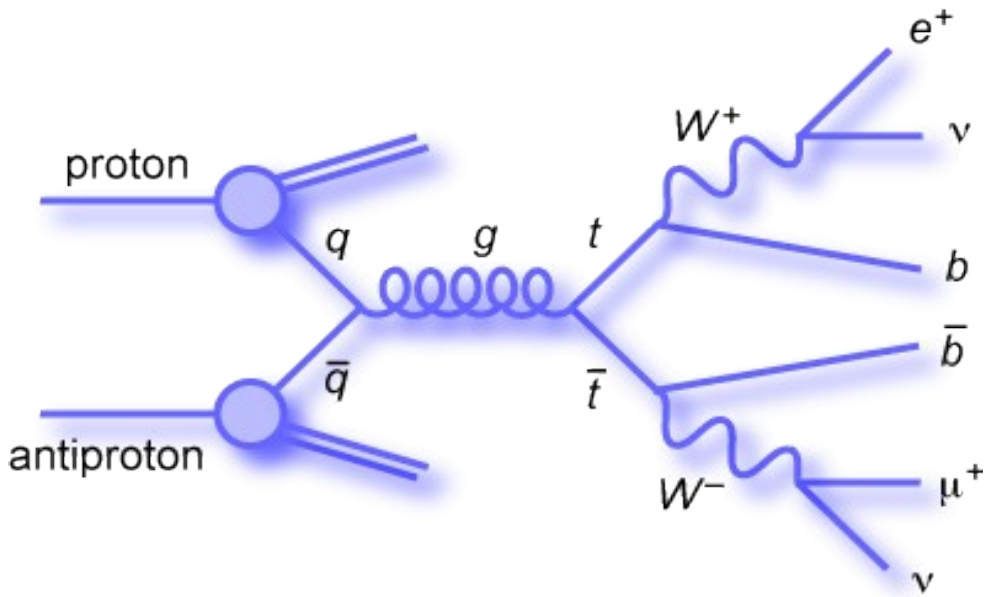


Tevatron Status





Dileptons



EXPERIMENTAL SIGNATURE:

2 high p_T leptons
2 b-quark jets
Missing transverse energy

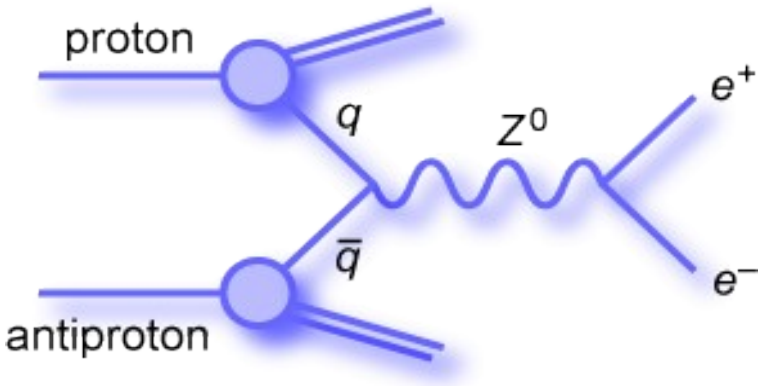
D0: topological selection to separate signal and background

CDF: topological selection and selection with b-quark jet identification (b-tag)

- An independent cross-check for the high statistics l+jets channel.
- Very high signal-to-background ratio
- Search for the BSM signal

Backgrounds

- $$\sigma = \frac{N_{observed} - N_{background}}{\varepsilon(m_t)\int Ldt}$$



- Z/γ^*, WW, WZ, ZZ: efficiencies from MC simulation, normalized to integrated luminosity:
  - Need to reweight the Z p_T distribution or apply the jet multiplicity depended scale factors (see, e.g. Sabine Lammer's Physics at LHC08 presentation)
- Instrumental background: misidentified leptons and leptons from semileptonic b quark jet decays. Estimated from data.
  - CDF: use the sample where both leptons have the same charge
  - D0: use samples with inverted quality on lepton identification parameters + samples where both leptons have the same charge.

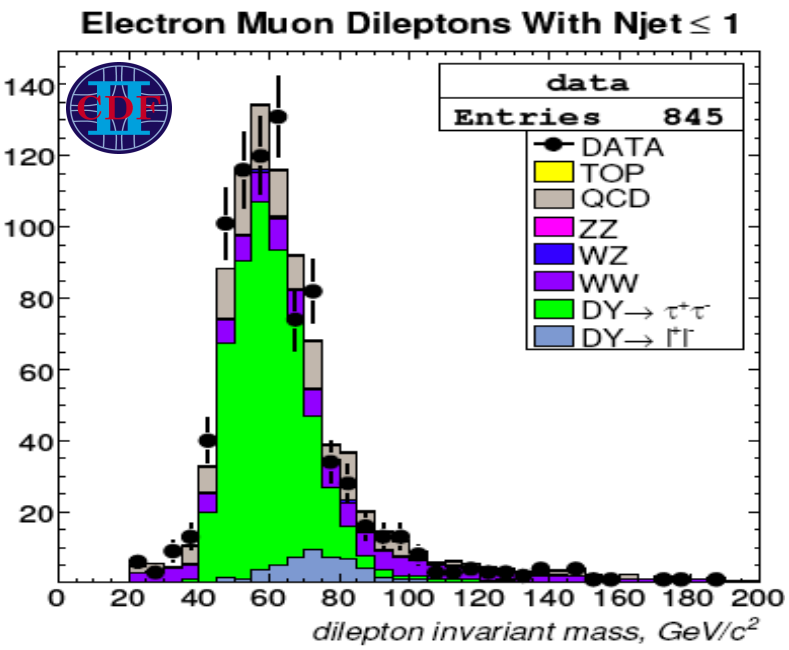
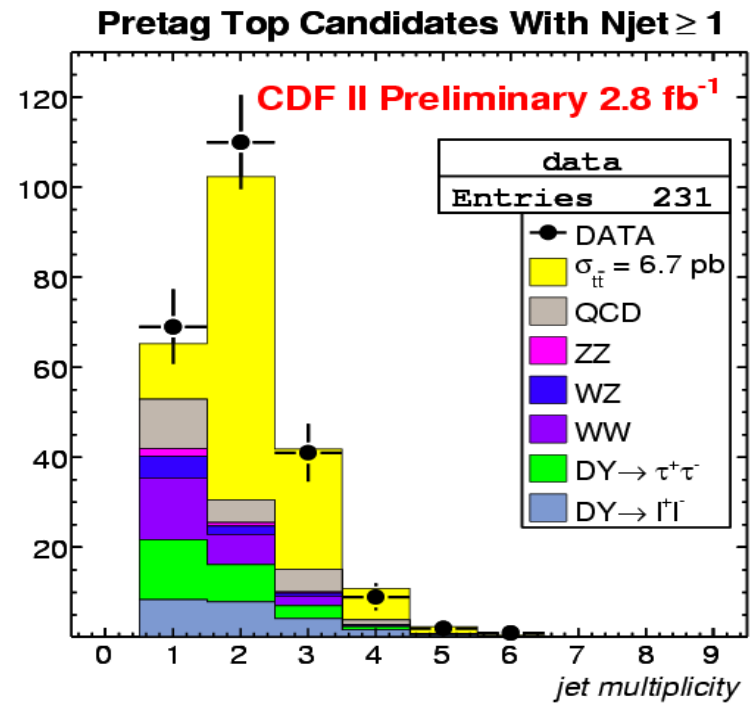
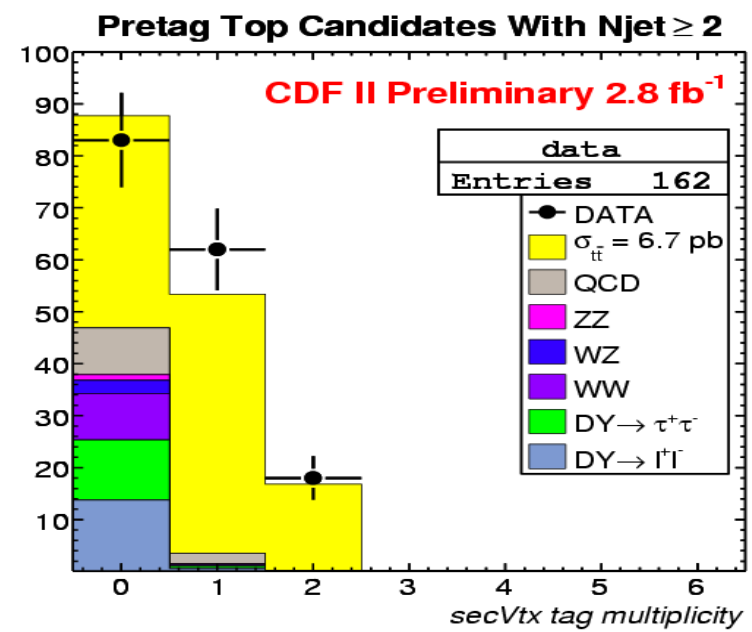


Figure 1: Dilepton invariant mass spectrum for electron muon events.

CDF Dileptons Results 2.8 fb^{-1} (ee, $\mu\mu$, $e\mu$)

Process	Topological	B-tag
$t\bar{t}$, $\sigma = 6.7$ pb	110.6	65.2
$Z/\gamma^* \to \ell^+\ell^-$	14.6	0.78
$Z/\gamma^* \to \tau^+\tau^-$	12.0	0.60
$WW \to \ell^+\ell^-$	10.2	0.44
$WZ \to \ell^+\ell^-$	2.91	0.09
$ZZ \to \ell^+\ell^-$	1.46	0.10
Monte Carlo	151.7	67.2
Data SS	10.8	2.00
Sum	162.5 ± 4.5	69.2 ±1.7
Data OS	162	80





σ = 6.7± 0.8 (stat) ± 0.4 (syst) ± 0.4 (lumi) pb

relative error : $\delta\sigma/\sigma$ ~14% m_t= 175 GeV

σ = 7.8± 0.9 (stat) ± 0.7 (syst) ± 0.4 (lumi) pb

relative error : $\delta\sigma/\sigma$ ~16% m_t= 175 GeV

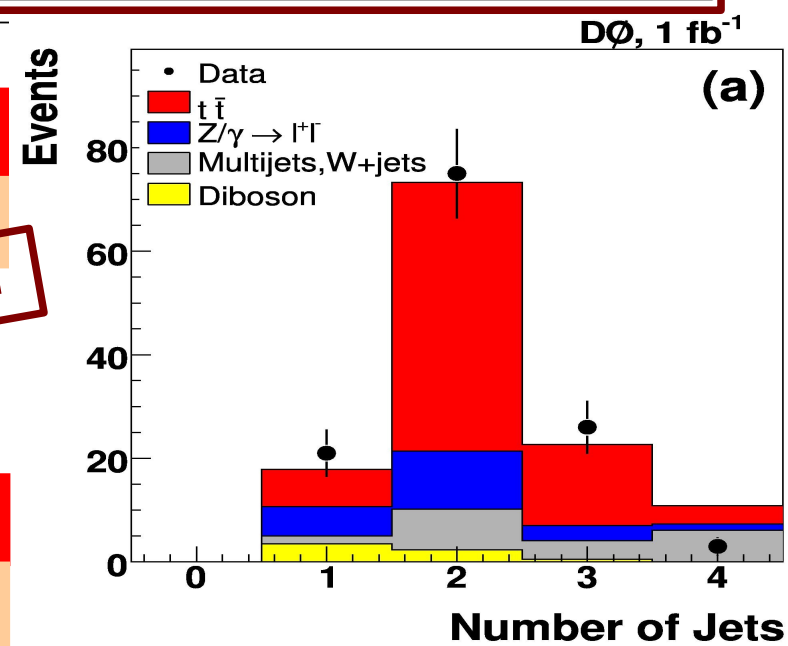
D0 Dileptons Result, 1 fb^{-1} (ee, $\mu\mu$, $e\mu$, $e\tau$, $\mu\tau$)

Channel	ee	$e\mu$ (1 jet)	$e\mu$ ($\geq$ 2 jets)	$\mu\mu$	$e\tau$	$\mu\tau$
Luminosity (pb^{-1})	1074	1070	1070	1009	1038	996
Z/γ^*	$2.4^{+0.6}_{-0.5}$	$5.5^{+0.7}_{-0.8}$	$5.4^{+0.9}_{-1.0}$	$5.6^{+1.0}_{-1.2}$	$0.6^{+0.1}_{-0.1}$	$1.2^{+0.3}_{-0.2}$
$WW/WZ/ZZ$	$0.5^{+0.1}_{-0.1}$	$3.1^{+0.7}_{-0.7}$	$1.4^{+0.4}_{-0.4}$	$0.6^{+0.1}_{-0.1}$	$0.2^{+0.0}_{-0.0}$	$0.2^{+0.0}_{-0.0}$
Multijet/W+jets	$0.6^{+0.4}_{-0.4}$	$0.9^{+0.3}_{-0.2}$	$2.6^{+0.6}_{-0.5}$	$0.2^{+0.2}_{-0.2}$	$3.6^{+1.8}_{-1.8}$	$8.8^{+2.8}_{-2.8}$
Total background	$3.4^{+0.7}_{-0.6}$	$9.5^{+1.0}_{-1.1}$	$9.4^{+1.2}_{-1.2}$	$6.4^{+1.9}_{-1.1}$	$4.4^{+1.8}_{-1.8}$	$10.2^{+2.9}_{-2.9}$
Signal efficiency (%)	$1.3^{+0.1}_{-0.1}$	$1.0^{+0.0}_{-0.0}$	$3.9^{+0.0}_{-0.0}$	$1.1^{+0.0}_{-0.0}$	$0.23^{+0.1}_{-0.1}$	$0.28^{+0.1}_{-0.1}$
Expected signal	$11.2^{+0.8}_{-0.8}$	$8.6^{+1.1}_{-1.1}$	$35.2^{+2.6}_{-2.7}$	$8.8^{+0.8}_{-0.8}$	$10.3^{+1.1}_{-1.1}$	$12.2^{+1.1}_{-1.1}$
Total expected	$14.6^{+1.0}_{-1.0}$	$18.0^{+1.4}_{-1.6}$	$44.6^{+3.4}_{-3.6}$	$15.1^{+1.5}_{-1.6}$	$14.7^{+2.0}_{-2.0}$	$22.3^{+3.1}_{-3.1}$
Data	17	21	39	12	16	20

$\sigma = 7.5 \pm 1.0\,(stat)\,^{+0.7}_{-0.6}\,(syst) \pm 0.6\,(lumi)$ pb

relative error : $\delta\sigma/\sigma$ ~18% $m_t = 170$ GeV

Submitted to PLB!

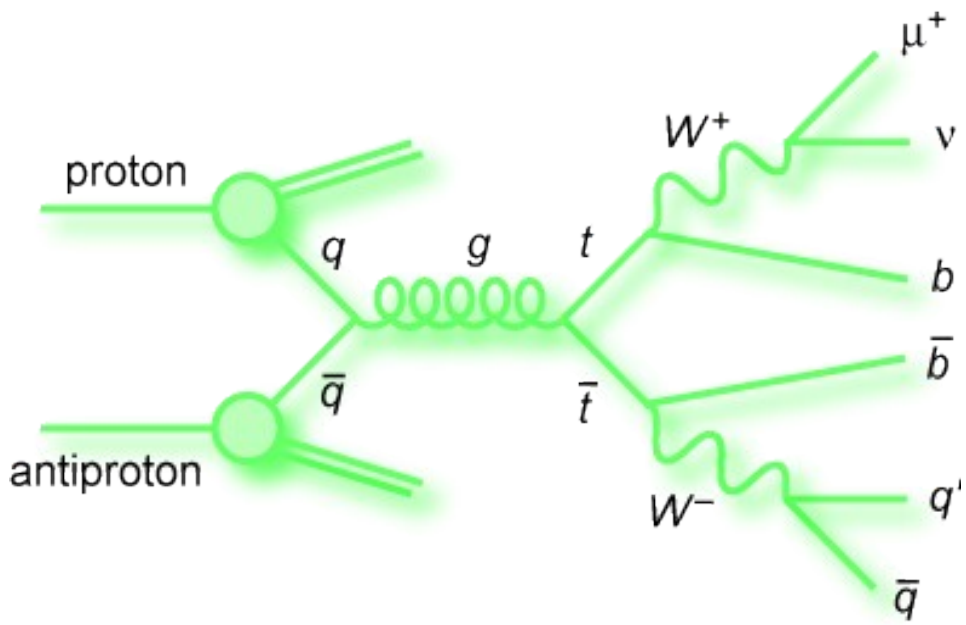


τ+lepton, 2.2 fb^{-1}

$\sigma = 7.3^{+1.3}_{-1.2}\,(stat)\,^{+1.2}_{-1.1}\,(syst) \pm 0.45\,(lumi)$ pb

relative error : $\delta\sigma/\sigma$ ~23% $m_t = 170$ GeV

Lepton + Jets Final State



EXPERIMENTAL SIGNATURE:

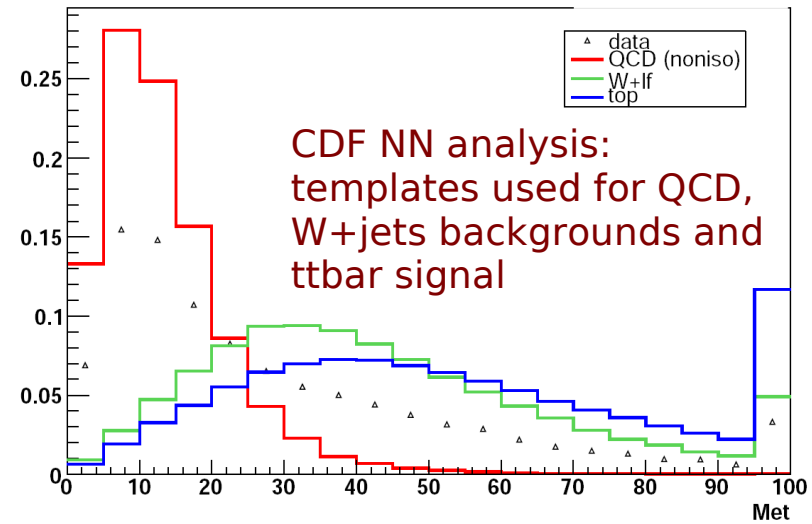
1 high p_T lepton
2 b-quark jets
2 light quark jets
Missing transverse energy

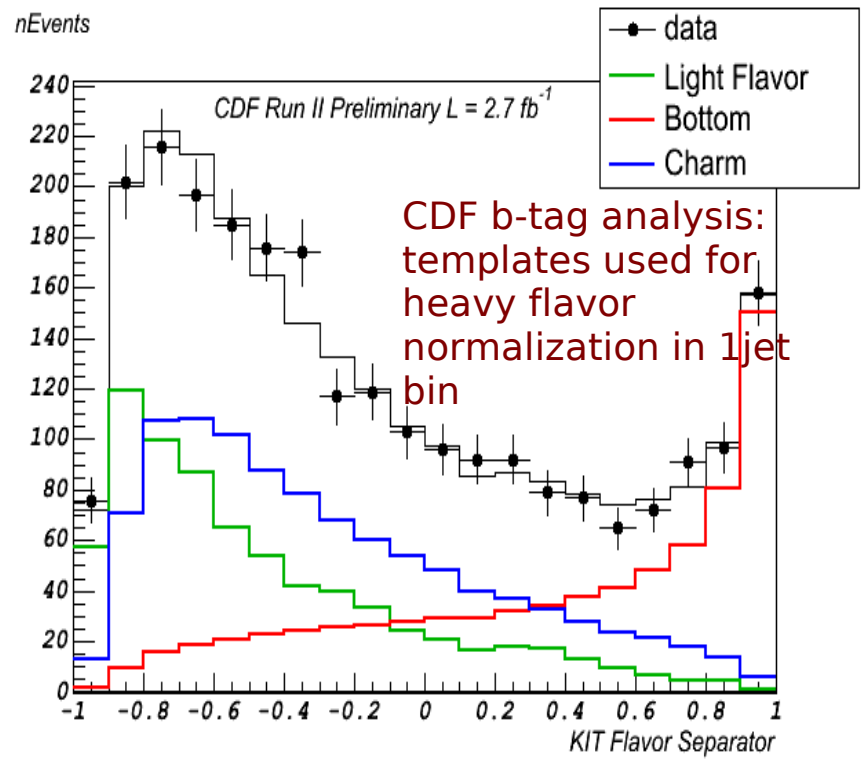
D0: topological (likelihood discriminant) and b-tagging analyses

CDF: topological (neural network) and b-tagging analyses

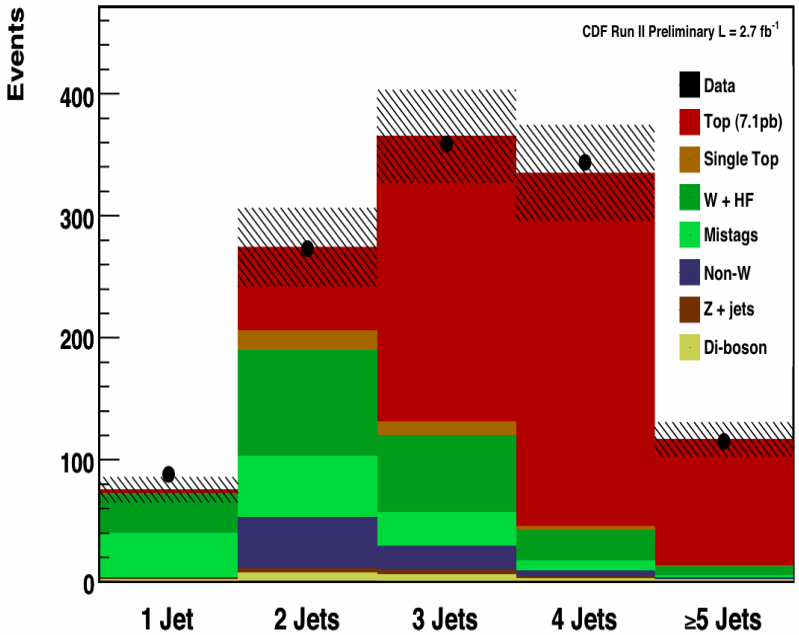
Background

- Multijet background: estimated from the QCD enhanced sample (loose lepton identification criteria, low MET to remove W background).
- W+jets background simulated with Matrix Element generator
  - Simulation : Alpgen (ME) + Pythia (showering)
  - Separately simulate different light parton bins: W+0lp, W+1lp, W+3lp, ...
  - Sum them together according to the alpgen cross-sections
  - Normalize the total W cross-section to data in each jet multiplicity bin
  - If b-tagging is used, separately simulate W +bb+#lp, W+cc+#lp and adjusted corresponding cross-section by data / MC comparison (e.g. in 1 jet bin) ⇒ an important source of systematics uncertainty





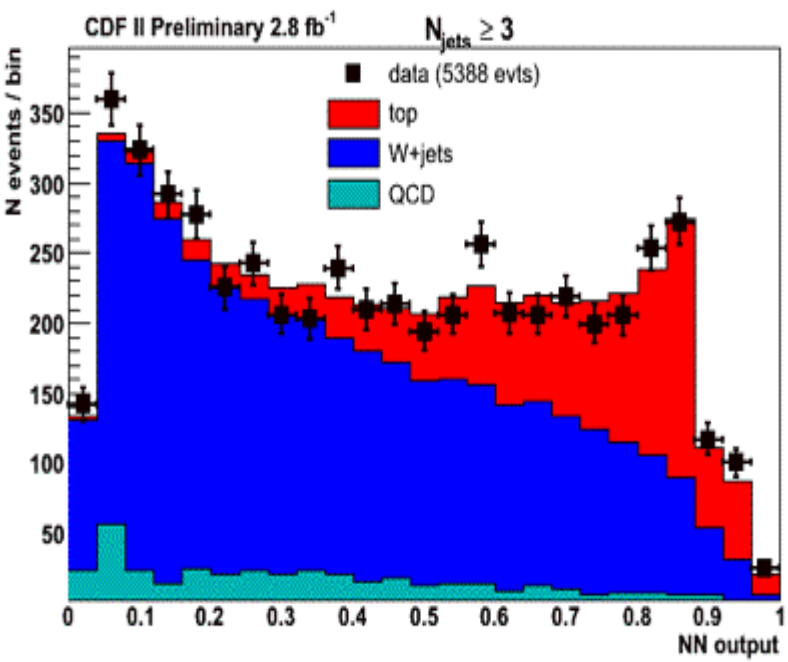
CDF l+jets Results



b-tag analysis (2.7 fb^{-1}):

σ = 7.2± 0.4 (stat) ± 0.5 (syst) ± 0.4 (lumi) pb

relative error : $\delta\sigma/\sigma$ ~10% m_t= 175 GeV



NN analysis (2.8 fb^{-1}):

σ = 7.1± 0.4 (stat) ± 0.4 (syst) ± 0.4 (lumi) pb

relative error : $\delta\sigma/\sigma$ ~9% m_t= 175 GeV

D0: PRL 100, 192004 (2008), 1fb^{-1}

7.62± 0.85 pb, m_t=172.6 GeV

CDF l+jets Systematics

NN analysis (2.8 fb^{-1}):

Effect	$\Delta\sigma_{t\bar{t}}$ (%)
Statistical	5.7
Jet E_T Scale	3.1
W+jets Q^2 Scale	2.2
Z Q^2 Scale	-
$t\bar{t}$ generator	2.9
$t\bar{t}$ IFSR	0.8
PDF	0.4
QCD shape	0.9
QCD fraction	1.3
Other EWK	1.0
Background	-
MC Statistics	-
N_{jet} Scale Factor	-
Lepton Scale	-
Track ID	-
Lepton ID/trigger	0.6
Zvtx SF	0.2
Systematic before Lumi	5.1
Luminosity	5.8
Total Systematic	7.7
Total (stat and sys)	9.4

b-tag analysis (2.7 fb^{-1}):

SYSTEMATIC	$\Delta\ \sigma$ pb	$\Delta\ \sigma\ /\sigma$ %
JET ENERGY SCALE	0.16	2.2
BOTTOM TAGGING	0.38	5.2
CHARM TAGGING	0.08	1.1
MIS-TAGS	0.15	2.1
HEAVY FLAVOR CORRECTION	0.23	3.2
LUMINOSITY	0.42	5.8
QCD FRACTION	0.02	0.2
PARTON SHOWER MODELING	0.13	1.8
INITIAL/FINAL STATE RADIATION	0.04	0.6
TRIGGER EFFICIENCY	0.05	0.6
PDF	0.06	1.0
TOTAL	0.67	9.3

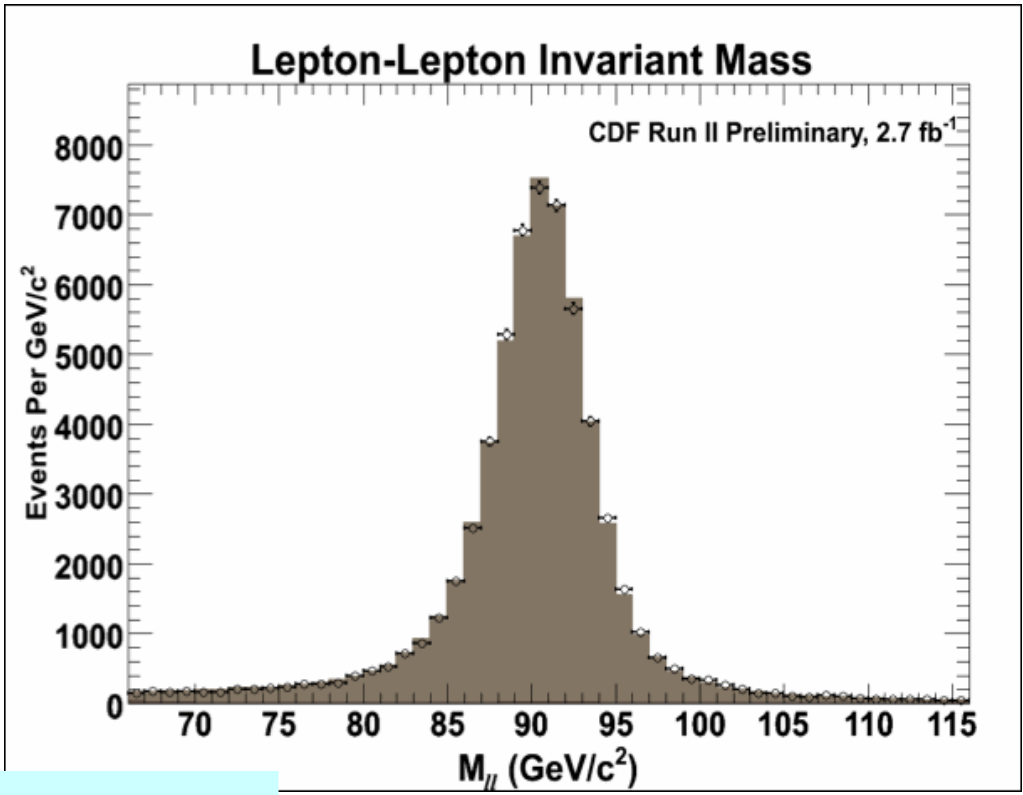
CDF Run II Preliminary L=2.7 fb^{-1}

ttbar / Z Cross-sections Ratio

- Luminosity is the largest systematics uncertainty ⇒ cancel it by calculating the ratio to Z cross-section

$$\sigma^{\text{theory}}_{\gamma^*/Z} = 251.3 \pm 5.0_{\text{scales/pdf}} \ \text{pb}$$

J. Phys. G: Nucl. Part. Phys. **34** (2007) 2457–2544



b-tag analysis (2.7 fb^{-1}):

σ = 7.0± 0.4 (stat) ± 0.6 (syst) ± 0.1 (Z theory) pb

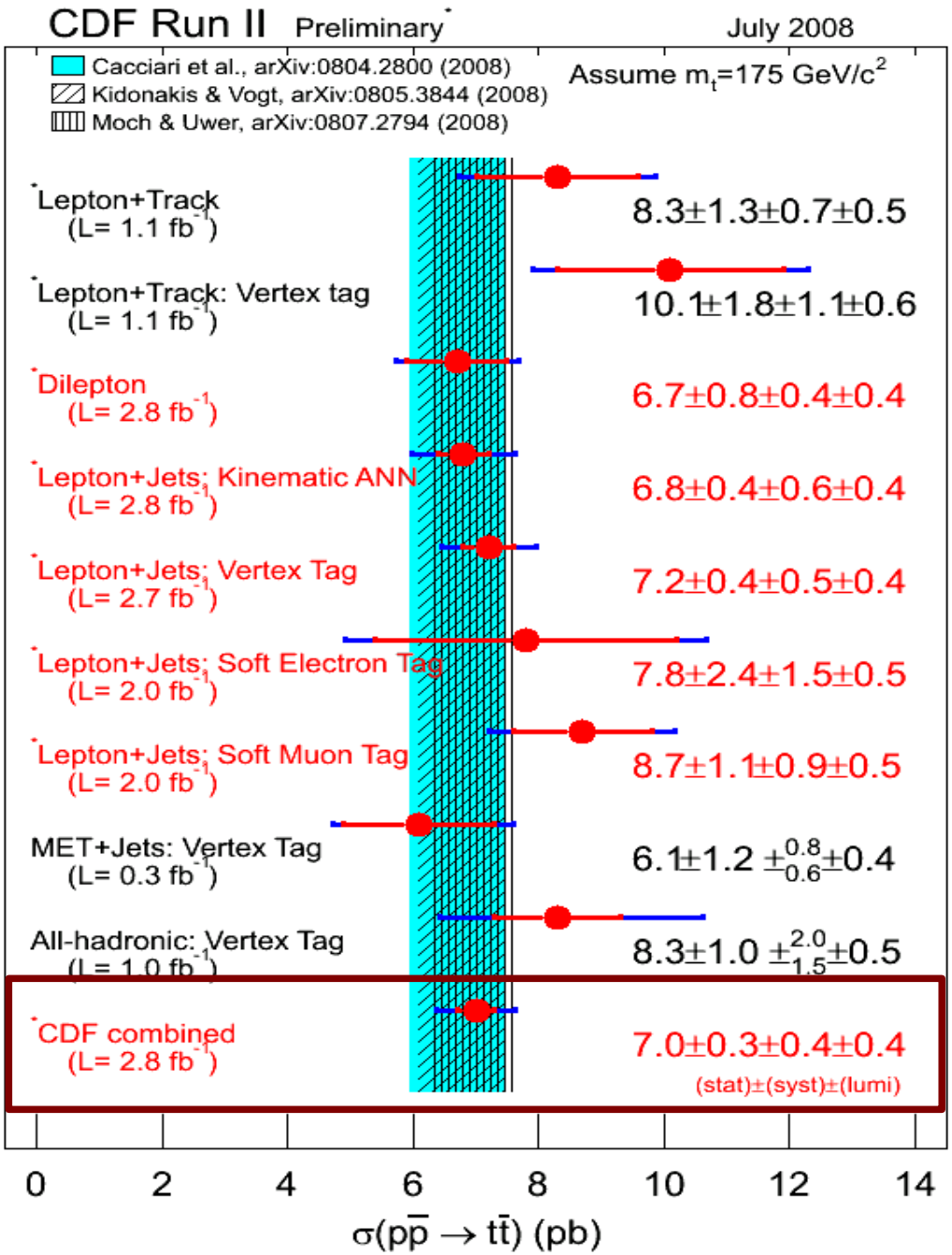
relative error : $\delta\sigma/\sigma$ ~10% m_t= 175 GeV

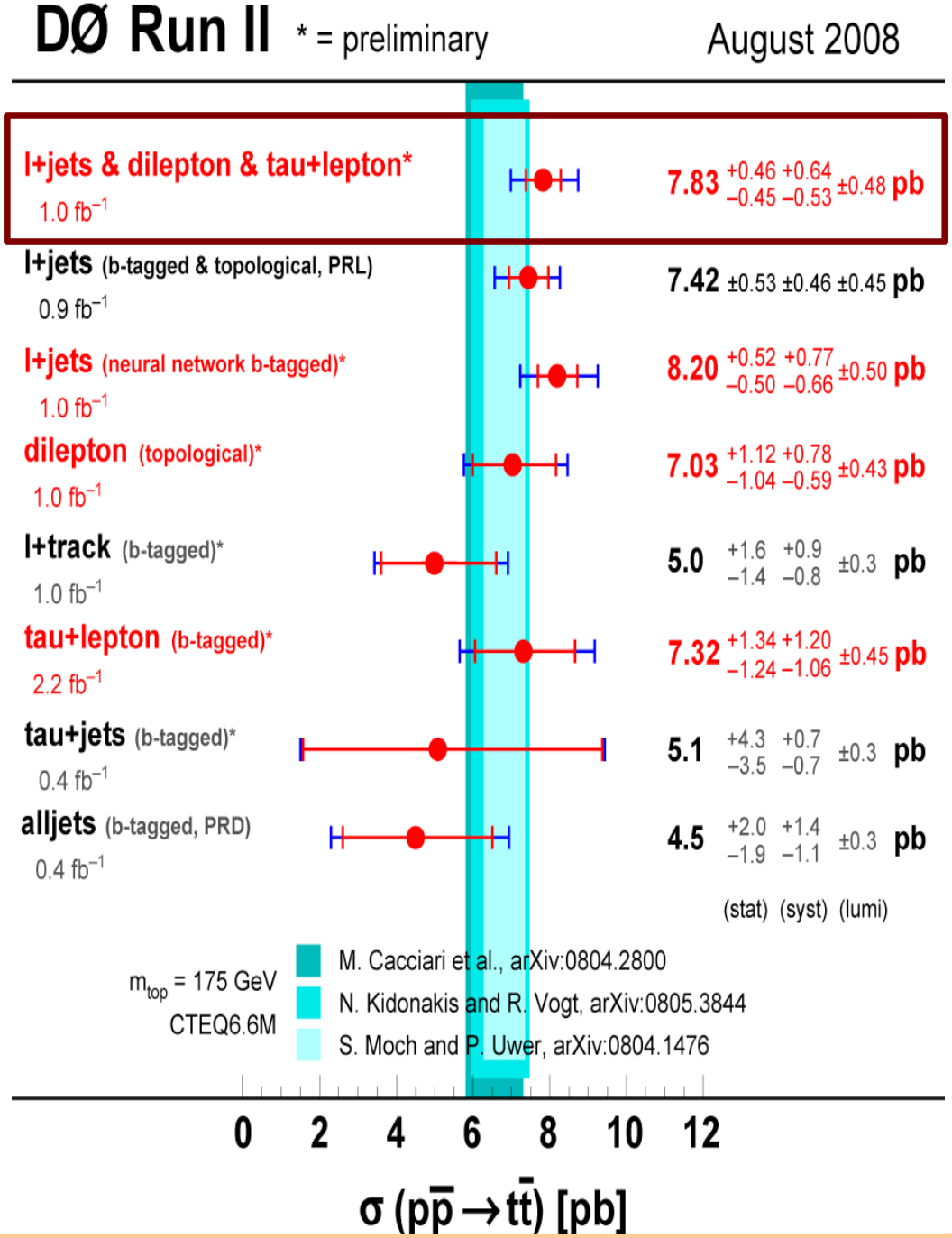
NN analysis (2.8 fb^{-1}):

σ = 6.9± 0.4 (stat) ± 0.4 (syst) ± 0.1 (Z theory) pb

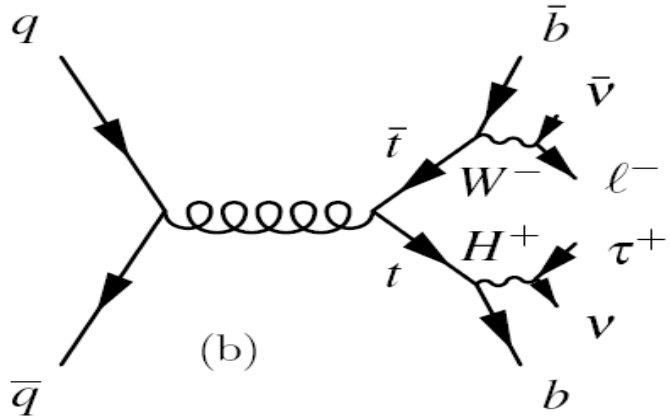
relative error : $\delta\sigma/\sigma$ ~8% m_t= 175 GeV

Results Overview

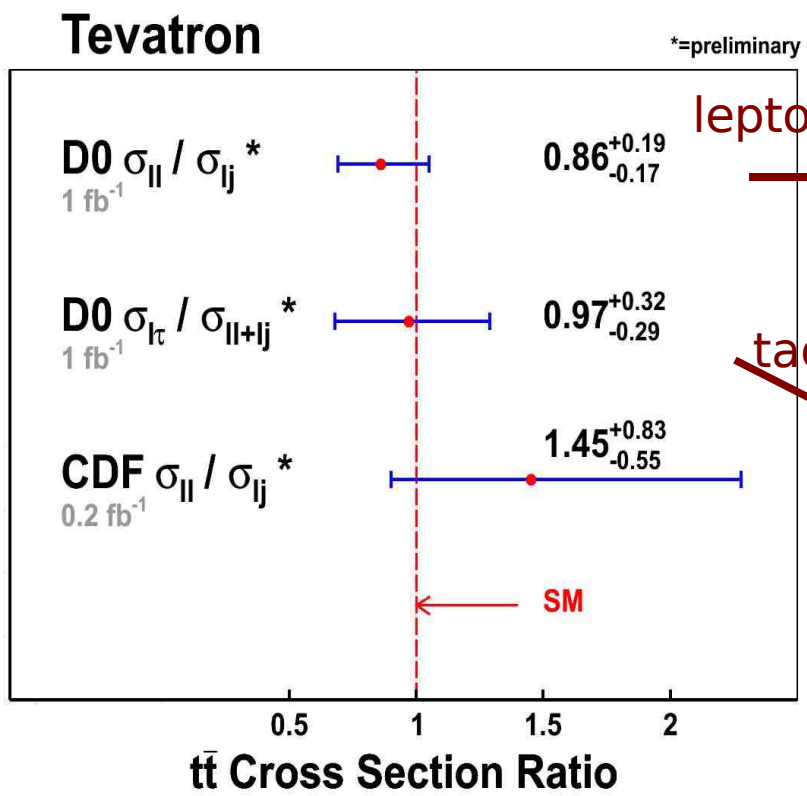




D0: cross-section ratios

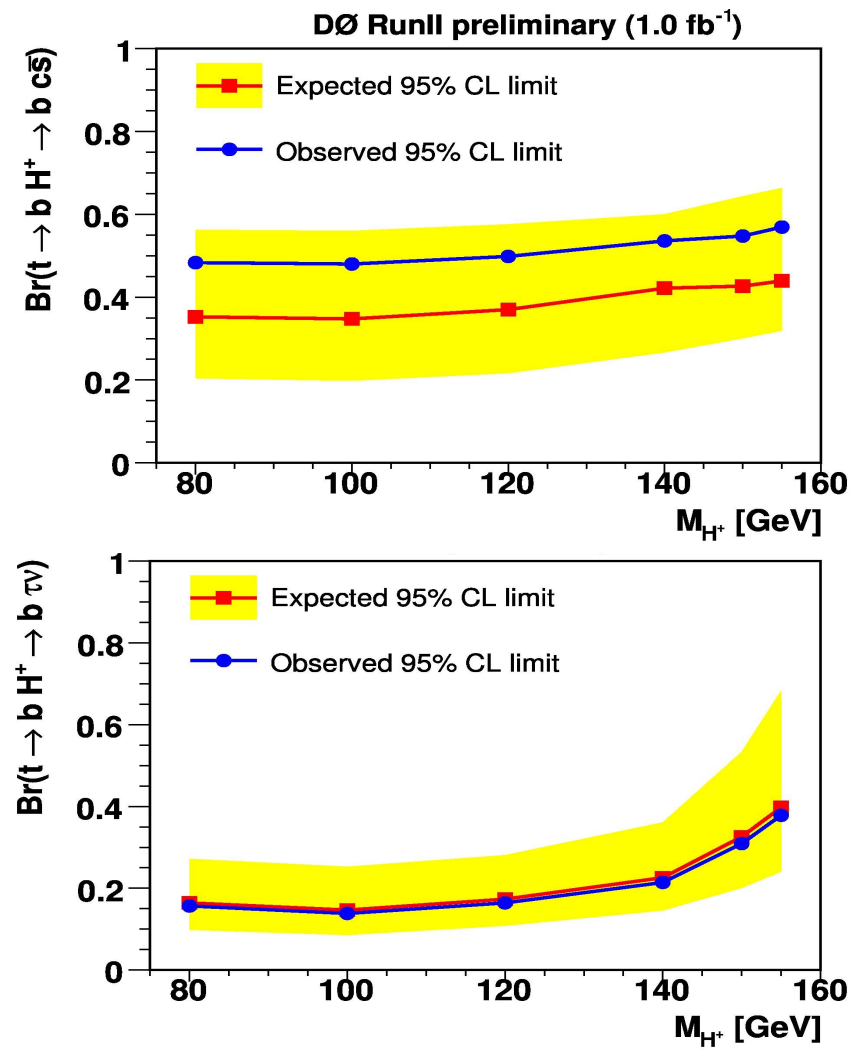


Many systematics uncertainties are canceled in the ratio ⇒ sensitive to BSM physics.
E.g. If the mass of charged higgs in MSSM scenario is low enough the $t \to H^+ b$ decay will be allowed and will enhance the tau final states.



leptophobic mode

taounic model



D0 : Top Mass from Cross-Section

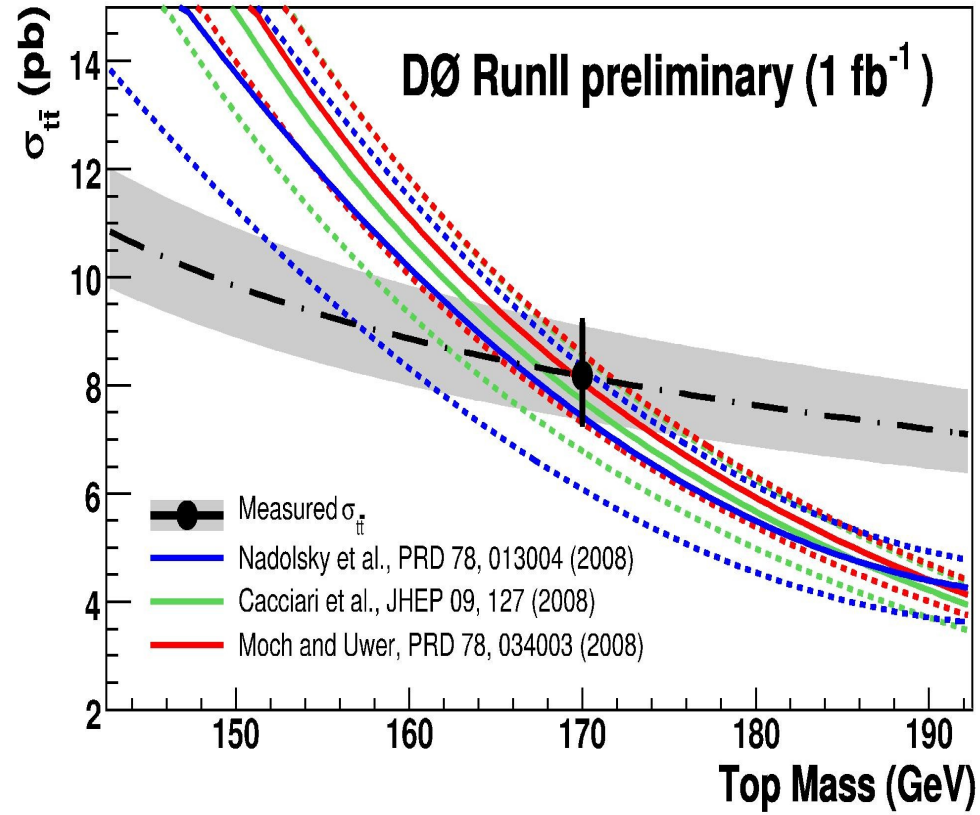
- Motivation: complementary measurement to the direct top mass measurement. Less sensitive to the non-perturbative QCD effects.
- Define theory likelihood according to PDF and scales uncertainties from

  (1) P. M. Nadolsky et al., Phys. Rev. D 78 013004 (2008); W. Beenakker et al., Phys. Rev. D 40, 54 (1989).

  (2) M. Cacciari et al., JHEP 09, 127 (2008);

  (3) S. Moch and P. Uwer, Phys. Rev. D 78, 034003 (2008);

  (4) N. Kidonakis and R. Vogt, Phys. Rev. D 78, 074005 (2008);
- Construct likelihood with measurements: Gauss(σ,$\delta\sigma$). Multiply the theory and measurement likelihoods to obtain a joint likelihood. Integrate over the cross section to get a likelihood function that depends only on the top-quark mass and calculate 68% C.L.



Theoretical computation	m_t (GeV)
NLO [1]	$165.5^{+6.1}_{-5.9}$
NLO+NLL [2]	$167.5^{+5.8}_{-5.6}$
approximate NNLO [3]	$169.1^{+5.9}_{-5.2}$
approximate NNLO [4]	$168.2^{+5.9}_{-5.4}$

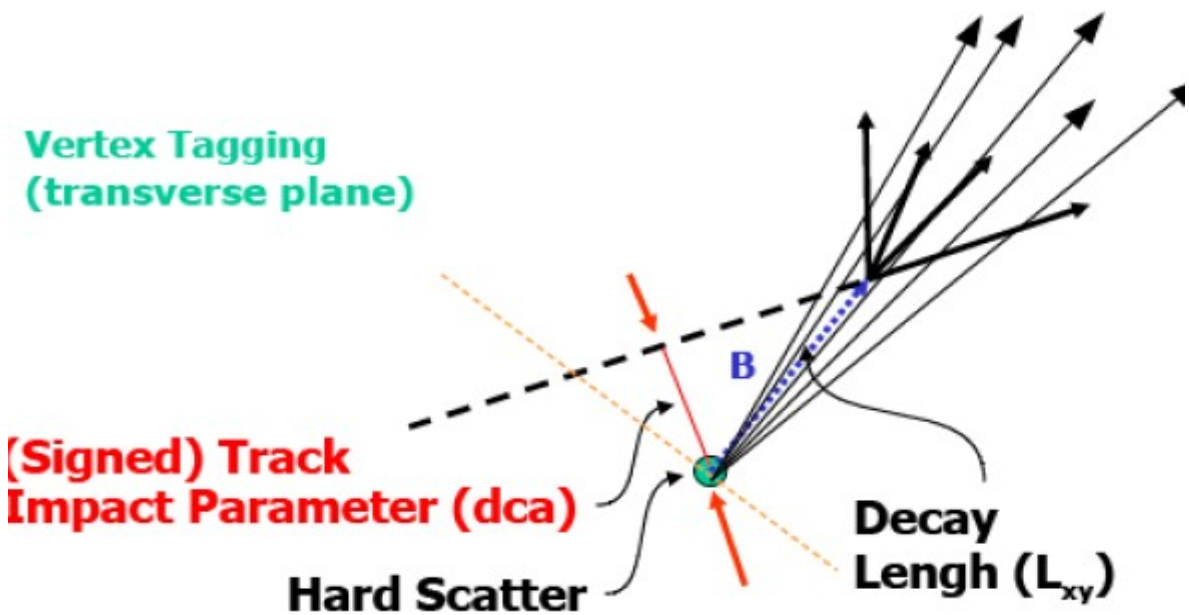
Conclusion

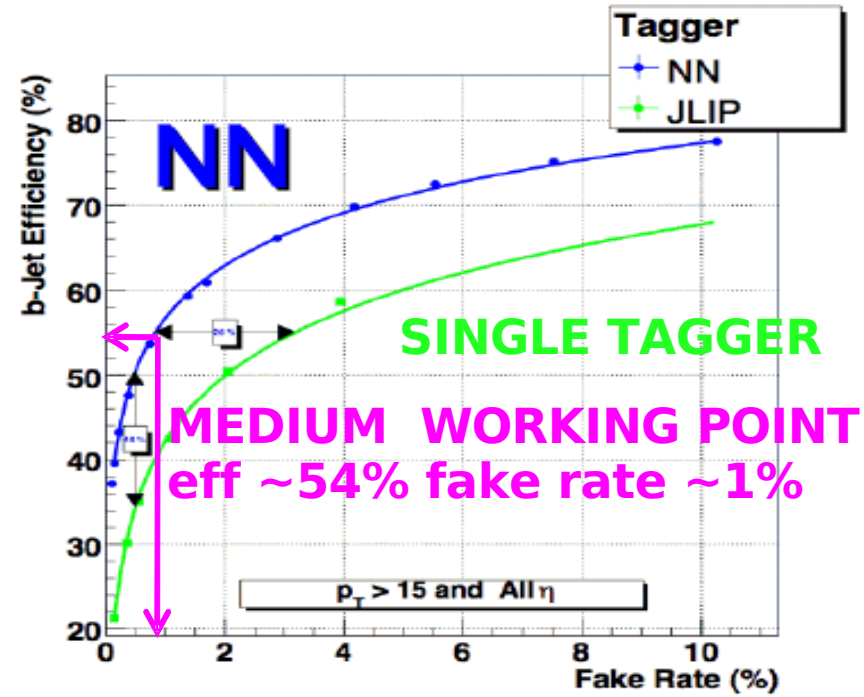
- Current experimental precision of ttbar cross-section determination~9% reach the level uncertainty of approximate NNLO calculation.
- Using ttbar to Z cross-sections ratio one can cancel out the luminosity uncertainty and decrease the uncertainty to 8% and open the way for further improvement in systematics uncertainties.
- All available final states are under investigation, including final states with tau. This allow to make an extensive test of the SM and search for the new physics (for example, charged higgs)
- Current cross-section results are used to determine the top mass with well defined mass definition from theoretical point of view.
- D0 and CDF experiments start the discussion about merging cross-section results together.
- For more information and the latest results, see
  - D0: *http://www-d0.fnal.gov/Run2Physics/top/top_public_web_pages/top_public.html*
  - CDF: *http://www-cdf.fnal.gov/physics/new/top/public_xsection.html*

BACK-UP

b-tagging: D0 example

b-Jet Tagging





Several mature algorithms used:

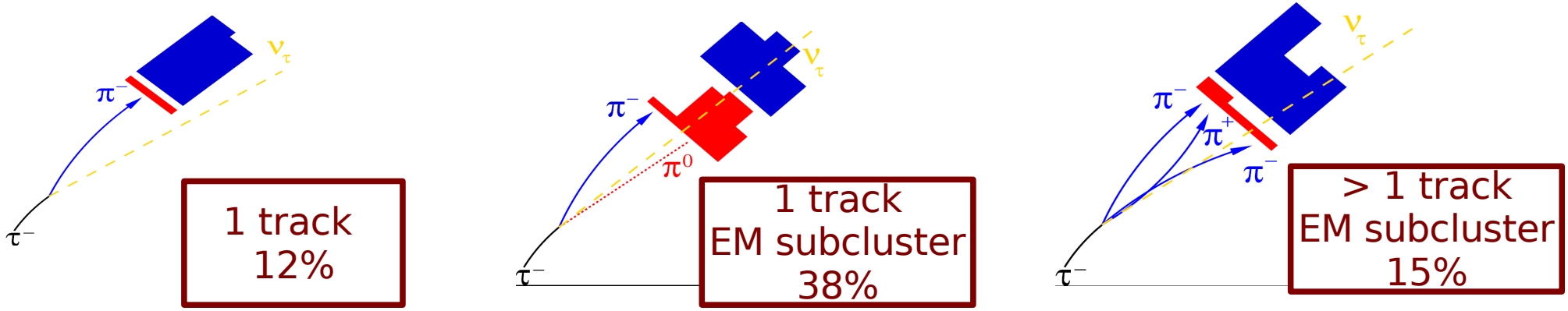
3 main categories:

- Soft-lepton tagging
- Impact Parameter based
- Secondary Vertex reconstruction

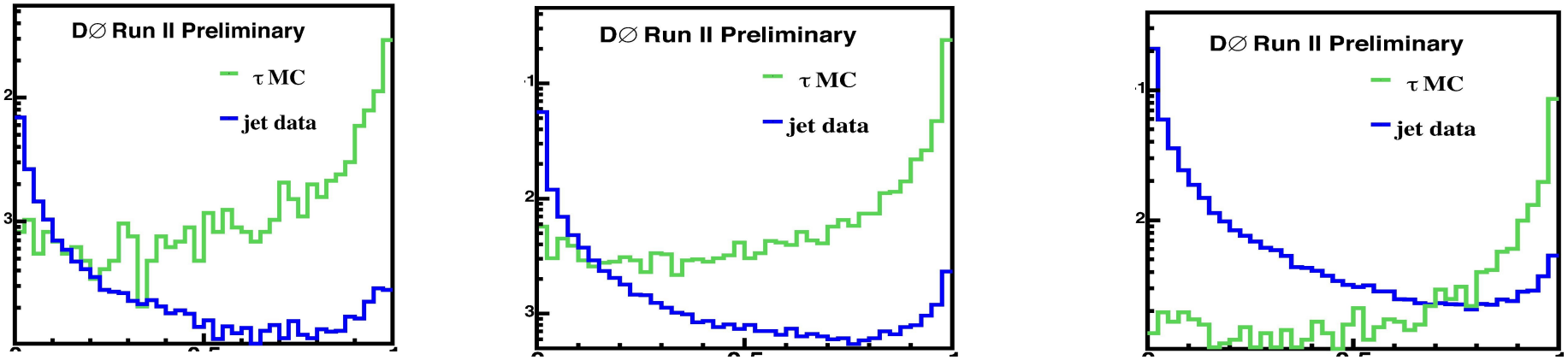
Combine in Neural Network:

- vertex mass
- vertex number of tracks
- vertex decay length significance
- chi2/DOF of vertex
- number of vertices
- two methods of combined track impact parameter significances

D0: Tau Lepton identification



- Tau candidates is a narrow jets (dR = 0.3) + one or more tracks
- For each tau type a neural network has been trained to distinguish between true taus (from MC) and from fakes (from data).
- NN inputs: isolation, energy deposition profiles, track / calorimeter correlation variables. NN performance has been verified with $Z \Rightarrow \tau\tau$ data



Multijet background ("matrix" method): D0

N_{SIGNAL} includes W+jets and ttbar

Loose Isolated Data $N_{LOOSE} = N_{QCD} + N_{SIGNAL}$

Tight Isolated Data $N_{TIGHT} = \varepsilon_{QCD} N_{QCD} + \varepsilon_{SIGNAL} N_{SIGNAL}$

From QCD dominated sample (MET < 10 GeV)

From MC corrected by efficiency measured in $Z \to ee$ ($Z \to \mu\mu$) events

$$N_{QCD} = \frac{\varepsilon_{SIGNAL} N_{LOOSE} - N_{TIGHT}}{\varepsilon_{SIGNAL} - \varepsilon_{QCD}}$$

Dileptons Selections

	D0	CDF
electron:	isolated cluster in EM calo, p_T>15 GeV, track match, $\|\eta\| \in$ 0 – 1.1, 1.5 – 2.5	isolated cluster in EM calo, p_T>20 GeV, track match,
muon:	track in muon system, track in central tracker isolated in calo and tracker p_T>15 GeV, $\|\eta\|$ < 2	track in muon system and in central tracker isolated in calo and tracker p_T>20 GeV,
jet:	dR=0.5 cone, JES corrected for muons from b-quark decays, p_T > 30, 20 GeV, $\|\eta\|$ < 2.5	dR=0.4 cone, JES corrected, p_T > 30, 15 GeV, $\|\eta\|$ < 2.5
MET:	corrected for electrons, muons, jets, MET > 0, 35, 45 GeV	corrected for electrons, muons, jets, MET > 25 GeV
Final:	topological	topological, with b-tagging

lepton +jets Selections

	D0	CDF
electron:	isolated cluster in EM calo, p_T>20 GeV, track match, $\|\eta\| \in$ 0 – 1.1	isolated cluster in EM calo, p_T>20 GeV, track match,
muon:	track in muon system, track in central tracker isolated in calo and tracker p_T>20 GeV, $\|\eta\|$ < 2	track in muon system, trak in central tracker isolated in calo and tracker p_T>20 GeV
jet:	dR=0.5 cone, JES corrected for muons from b-quark decays, at least 2 jets with p_T > 40 (leading), 20 GeV, $\|\eta\|$ < 2.5	dR=0.4 cone, JES corrected, at least 3 jets with p_T > 30 (leading), 20 GeV, $\|\eta\|$ < 2.5
MET:	corrected for electrons, muons, jets. MET >20 (e+jets), 25 (μ+jets) GeV. MET vector and lepton p_T separted in azimuth	corrected for electrons, muons, jets, MET > 35 GeV
Final:	topological, with b-tagging	topological (neural network), with b-tagging