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Top quark pair cross-section measurements @ D0

(1 fb^{-1} results)

- Introduction
- Dilepton
- Tau final state
- Lepton + jets
- Mass determination using cross-section measurement

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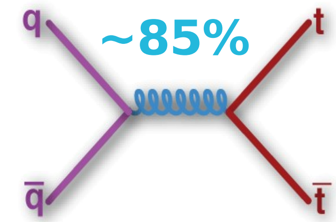
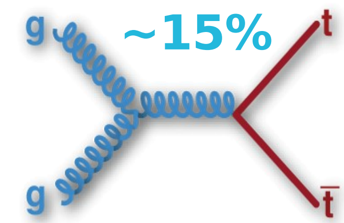
Why Measure the Top Quark Cross-Section?

- Comparison with a theoretical calculations: SM test, probe of the new production mechanism (e.g. resonance production)
  - Kidonakis et al., PRD 68 114014: 6.8±0.6 pb m_t = 175 GeV
  - Cacciari et al., *hep-th* 0804:2800: 7.6 ±0.6 pb m_t = 171 GeV
  - Run I, 2E = 1.85 TeV, L ~ 100 pb^{-1}: $\delta\sigma/\sigma$ ~ 25%
  - Run II, 2E = 1.96 TeV, L ~ 1000 pb^{-1}: $\delta\sigma/\sigma$ ~ 10%

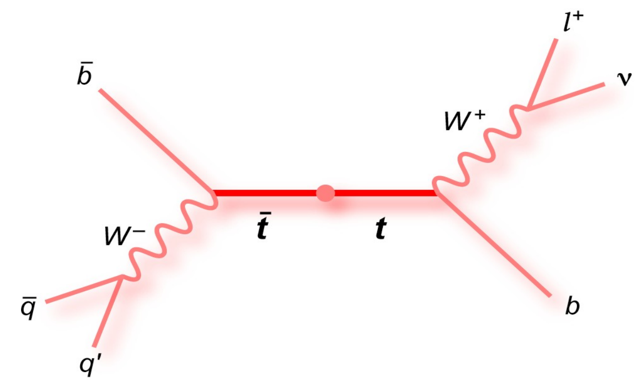




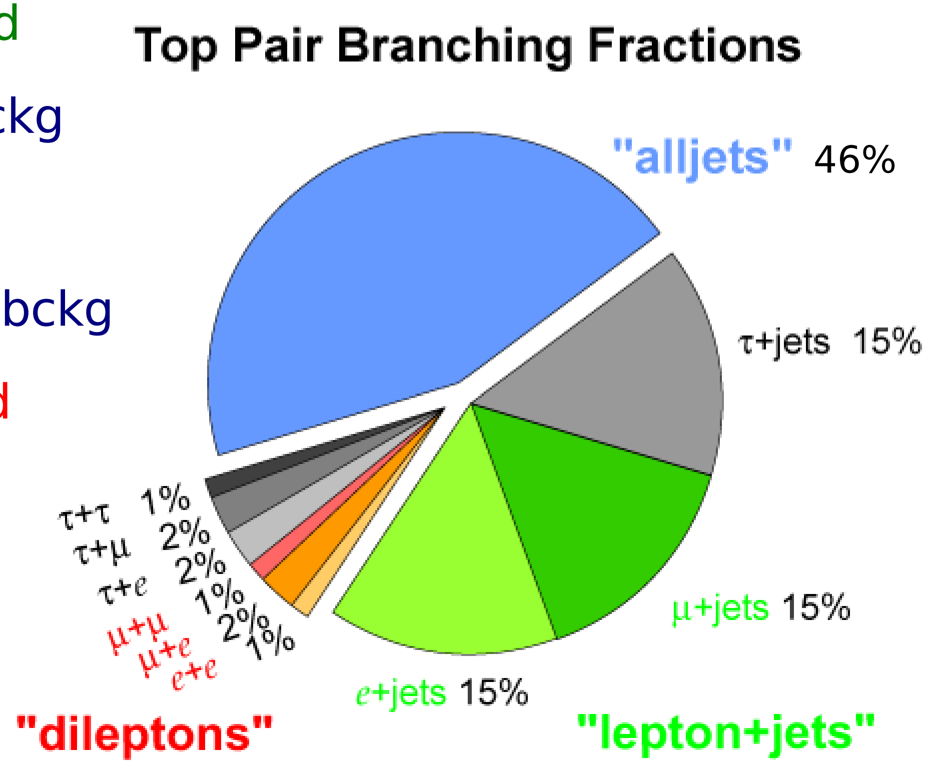
- Sample definition for the properties measurements
- Important background for the new phenomena and Higgs search
- Allow to extract the top mass from the cross-section dependence with a “clean” definition of a top mass from the theoretical point of view.

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

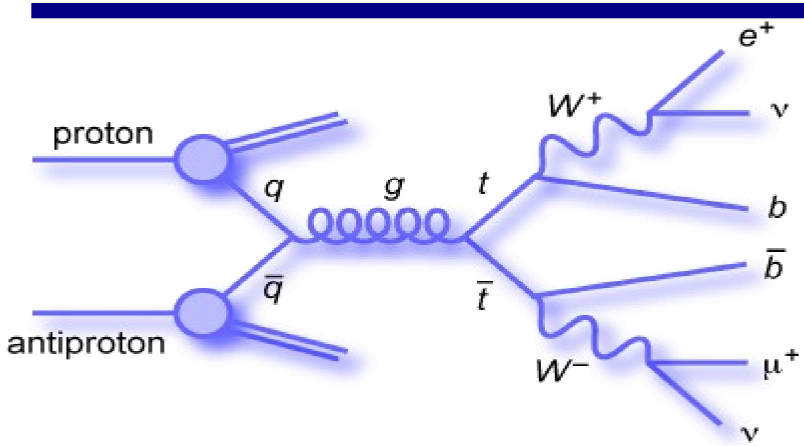


Cross-section Measurement

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

- Efficiency for all physics processes estimated from MC: Pythia or Alpgen (generator) + Pythia (showering). In the second case a matching algorithm avoids double counting of final states.
- Real “zero bias” events are superposed on detector simulation to reproduce all detector effects, including luminosity dependence.
- Available statistics = (delivered luminosity *x* cross-section - poor quality data) *x* trigger efficiency (channel dependent)
- Selection optimized for each individual channel in order to obtain the best possible precision.
- $N_{observed}$ - $N_{background}$ is calculated with event counting techniques or using signal/ background fit of the discriminating variable shape.
- The final result is a combination of several channels.

Dilepton signatures



tt⇒e track bb νν

tt⇒μ track bb νν

tt⇒ee bb νν

tt⇒eμ bb νν

tt⇒μμ bb νν

tt⇒eτ bb νν

tt⇒μτ bb νν

electron: isolated cluster in EM calo, p_T>15 GeV, track match, $|\eta| \in$ 0 – 1.1, 1.5 – 2.5

muon: track in muon system, track in central tracker isolated in calo and tracker p_T>15 GeV, $|\eta| < 2$

jet: dR=0.5 cone, JES corrected for muons from b-quark decays, p_T > 20 GeV (at least), $|\eta| < 2.5$

MET: corrected for electrons, muons, jets

- Explore all channels to maximize acceptance
- Explicitly remove overlaps by vetoes

ee, eμ, μμ

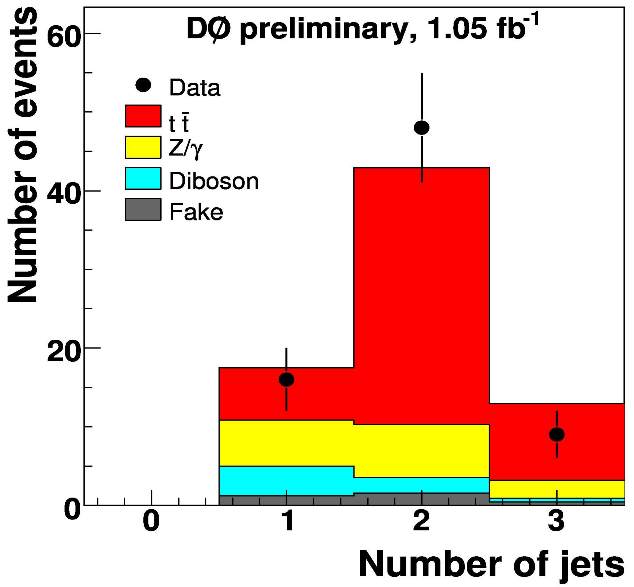
- Physics background estimated from MC: $Z\to ee$, $Z\to \mu\mu$, $Z\to \tau\tau$ + jets, WW, WZ, ZZ + jets
- Instrumental background is estimated from data: jets misidentified as electrons, muons from the semileptonic b-quark decays, large missing E_T due-to detector resolution

ee: veto event in Z-peak
MET > 35 (45) GeV
sphericity > 0.15

eμ: p_T(jets) + p_T (leading lept) >115 GeV

μμ: MET > 35 GeV
muon p_T and MET vector must be separated in azimuth
χ^2 of $Z\to\mu\mu$ hypothesis >8

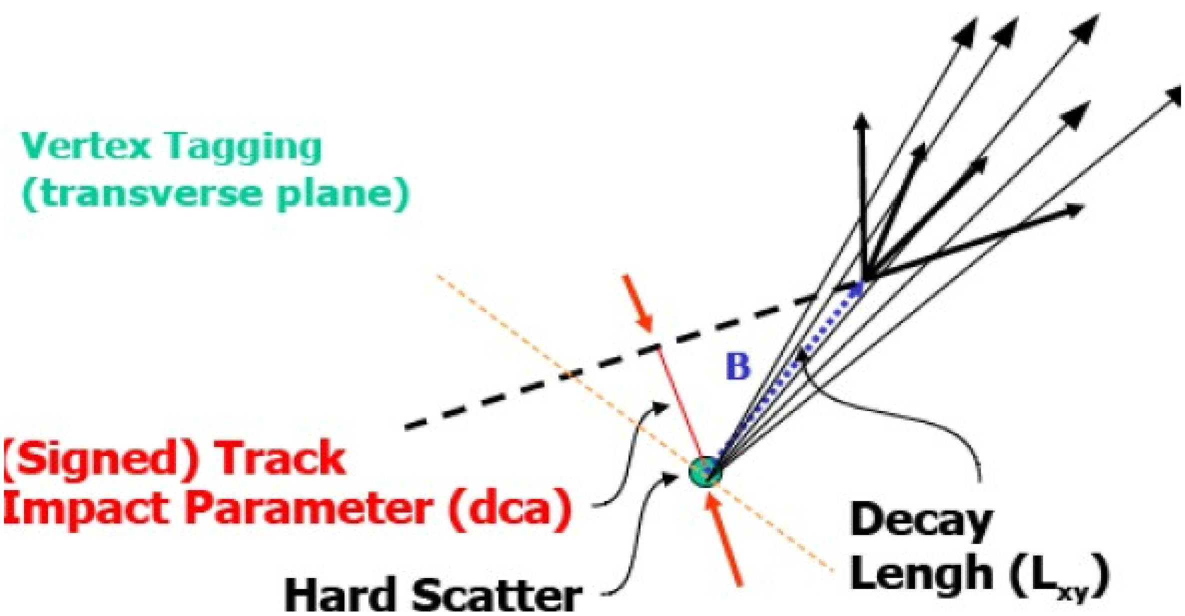
channel	Observed	N^{bkg}	BR	$\mathcal{L}$ (pb^{-1})	ε
ee	16	3.0	0.01584	1036	8.3 %
$e\mu$ nj=1	16	10.2	0.03155	1046	3.1%
$e\mu$ nj≥2	32	6.7	0.03155	1046	12.4%
$\mu\mu$	9	3.6	0.01571	1046	5.1%

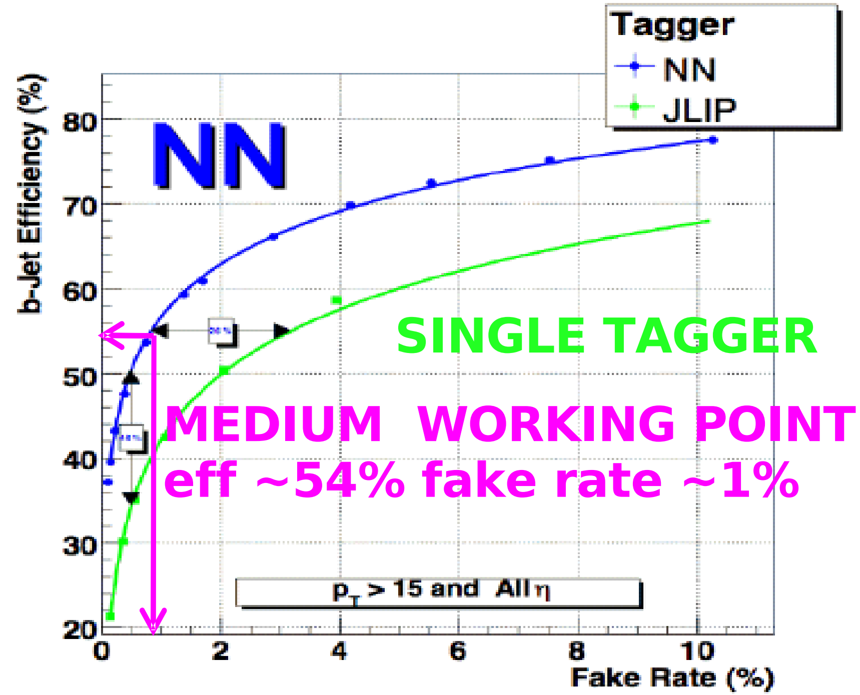


$\sigma = 6.8^{+1.2}_{-1.1}$ (stat) $^{+0.9}_{-0.8}$ (syst) ± 0.4 (lumi) pb

relative error : $\delta\sigma/\sigma$ ~22% m_t= 175 GeV

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

Lepton + track

- estimate rate of the events with track not from the lepton
- Use b-tagging to reduce background (at least 1 b-tagged jet)

Veto for other dilepton channels is applied

channel	Observed	N^{bkg}	BR	$\mathcal{L}$ (pb^{-1})	ε
e+track, nj=1	4	1.58	0.1066	1035	0.25%
e+track, nj≥2	8	1.83	0.1066	1035	1.31%
μ+track, nj=1	1	1.38	0.1066	994	0.18%
μ+track, nj≥2	8	1.36	0.1066	994	1.08%

$\sigma = 5.1^{+1.6}_{-1.4}$ (stat) $^{+0.9}_{-0.8}$ (syst) ± 0.3 (lumi) pb

relative error : $\delta\sigma/\sigma$ ~34% m_t = 175 GeV

COMBINED WITH DILEPTONS

$\sigma = 6.2 \pm 0.9$ (stat) $^{+0.8}_{-0.7}$ (syst) ± 0.4 (lumi) pb

relative error : $\delta\sigma/\sigma$ ~19% m_t = 175 GeV

1 e or μ: p_T > 15 GeV

track: p_T>15 GeV, $|\eta|$ < 2, isolated and separated in dR from jets and leptons

MET
μ+track: correct MET for track > 25 GeV (35 GeV)
e+track: > 20 GeV (25 GeV) outside (inside) Z peak

MET in Z-event hypothesis:
μ+track: > 25 GeV (35 GeV)
e+track: > 20 GeV (25 GeV) outside (inside) Z peak

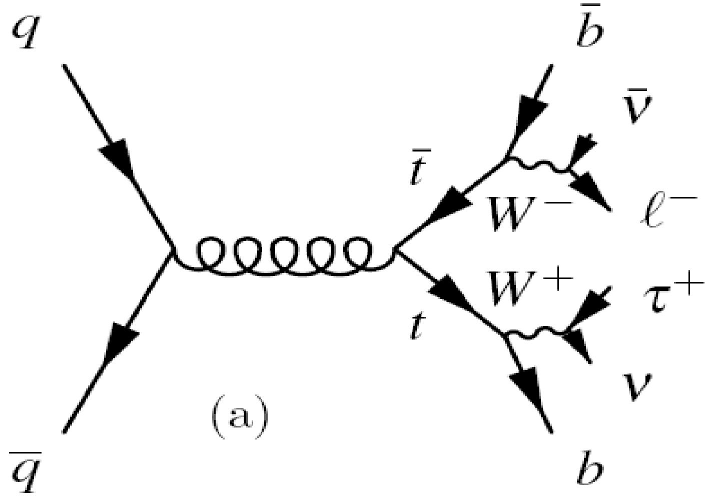
Dilepton Systematics

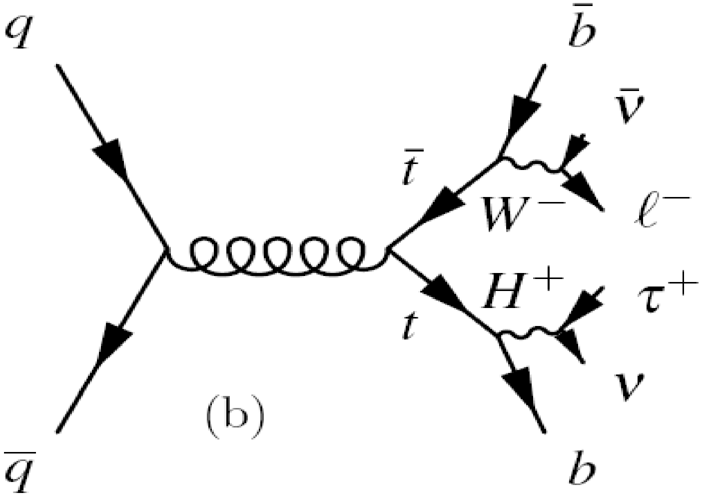
Source	$\ell\ell$	ℓ+track	combined
Jet energy calibration	$+0.3-0.3$	$+0.1-0.1$	$+0.3-0.2$
Jet identification	$+0.1-0.1$	$+0.02-0.03$	$+0.04-0.04$
PV identification	$+0.3-0.2$	$+0.2-0.1$	$+0.3-0.2$
Muon identification	$+0.2-0.2$	$+0.06-0.05$	$+0.2-0.1$
Electron identification	$+0.6-0.5$	$+0.2-0.2$	$+0.4-0.4$
Track identification	N/A	$+0.7-0.6$	$+0.3-0.3$
Trigger	$+0.2-0.2$	$+0.3-0.2$	$+0.2-0.2$
Fakes	$+0.2-0.2$	$+0.3-0.2$	$+0.1-0.1$
b-tagging	N/A	$+0.3-0.3$	$+0.1-0.1$
MC normalization	$+0.3-0.3$	$+0.2-0.2$	$+0.2-0.2$
Other	$+0.2-0.2$	$+0.1-0.1$	$+0.2-0.2$
Subtotal	$+0.9-0.8$	$+0.9-0.8$	$+0.8-0.7$
Luminosity	± 0.4	± 0.3	± 0.4
Total	$+1.0-0.9$	$+1.0-0.9$	$+0.9-0.8$

- There is no “main” systematics which is driving the total error. Further improvement is possible, but require laborious work on each source of systematics

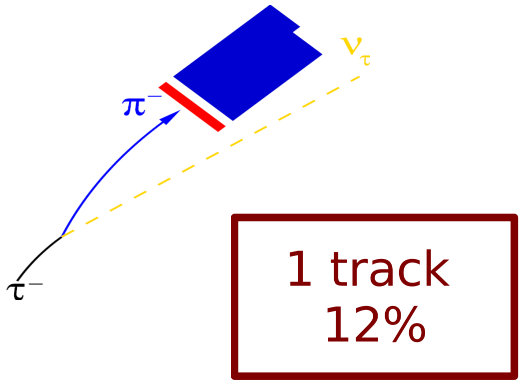
Finals states with tau

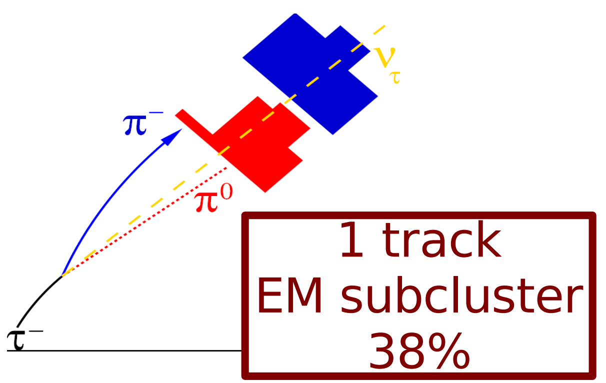
- Sizable branching fraction, but tau-lepton identification is not simple. Tau looks like a narrow jet or like a muon.
- Why measure the cross-section with this channel?
- Tau is a heaviest lepton and hence tau final states are the most sensitive to the new physics including higgs.
- If the mass of charged higgs in MSSM scenario is low enough the $t \rightarrow H^{+}b$ decay will be allowed and will enhance the tau final states.

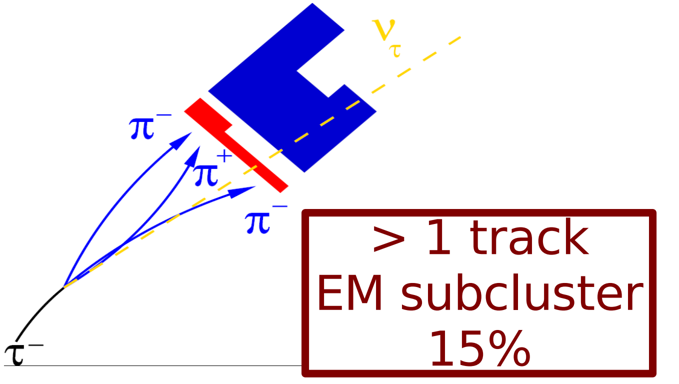




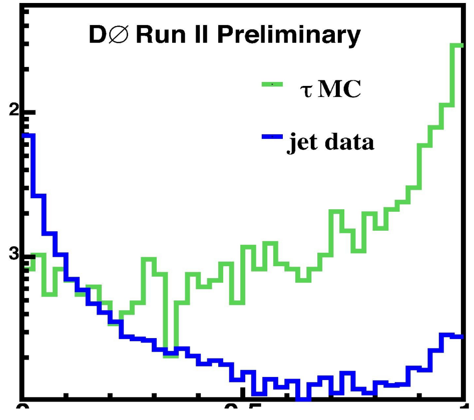
Tau Lepton identification

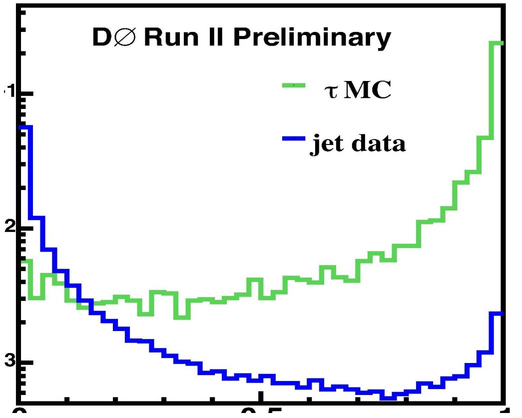


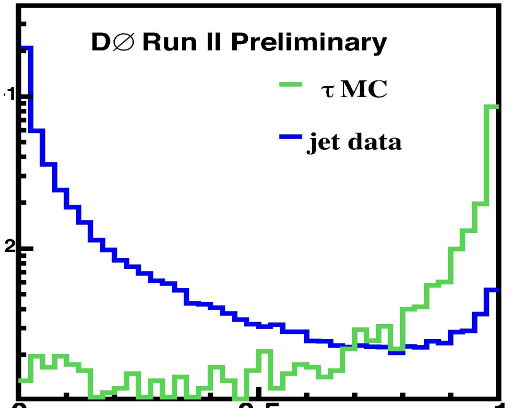




- Tau candidates is a narrow jets (dR = 0.3) + one or more tracks
- For each tau type a neural network has been trained to distinguish between true taus (from MC) and from fakes (from data).
- NN inputs: isolation, energy deposition profiles, track / calorimeter correlation variables. NN performance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







$\tau + e,\mu$

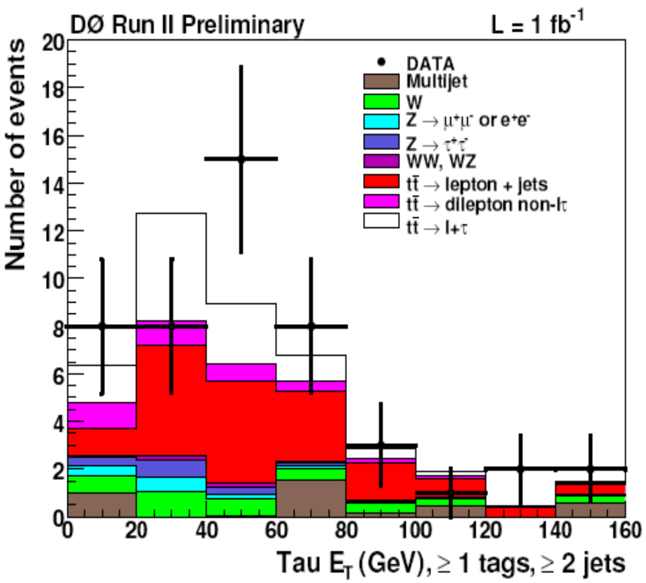
- Use b-tagging to suppress backgrounds (at least 1 jet tagged)
- Physics backgrounds: W+jets, Z+jets, dibosons estimated from MC
- Multijet background is estimated from same-sign data

1 τ candidate + 1 e $p_T > 15$ GeV or μ $p_T > 20$ GeV

2 jets: $p_T > 20$ GeV,
leading jet $p_T > 30$ GeV
dR(jet, tau) > 0.5

15 GeV < MET < 200 GeV
lepton p_T and MET vector must be separated in azimuth

rejects events with 2 muons and invariant mass ~ Z peak



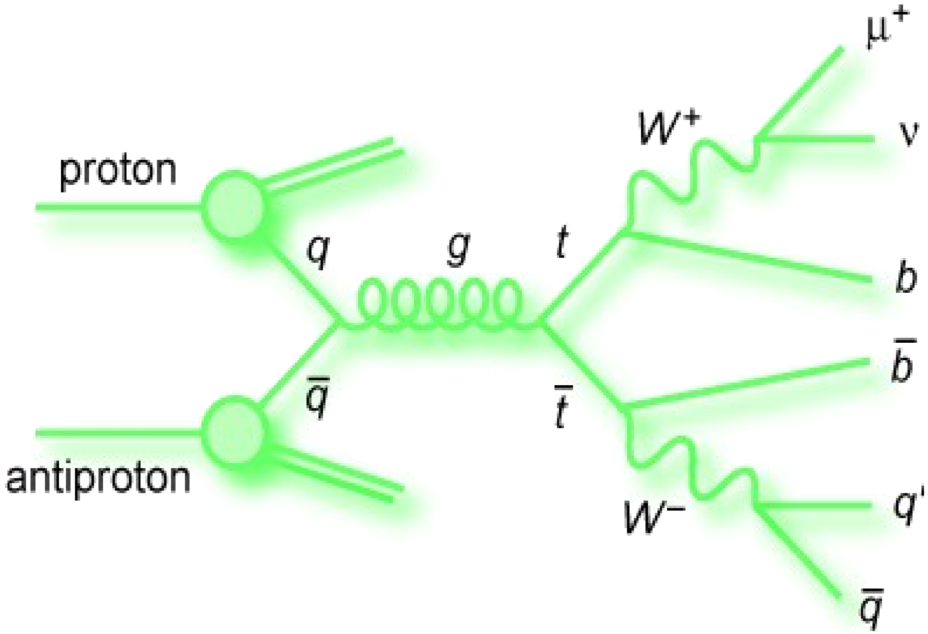
$\sigma = 8.3^{+2.0}_{-1.8}\,(\text{stat})\,^{+1.4}_{-1.2}\,(\text{syst}) \pm 0.5\,(\text{lumi})$ pb

$\delta\sigma/\sigma \sim 30\%$ $m_t = 175$ GeV all ttbar finals states are used

$\sigma(tt) \times BR(tt \to l + \tau + 2\nu + 2b) = 0.19 \pm 0.08(\text{stat}) \pm 0.07(\text{syst}) \pm 0.01\,(\text{lumi})$ pb

SM: 0.128 (e), 0.125(μ) only $l+\tau$ is used

Lepton + jets



INCLUSIVE SAMPLE

electron: p_T>20 GeV, $|\eta| \in$ 0 – 1.1

muon: p_T>20 GeV, $|\eta| < 2$

jet: at least 3 jets with p_T > 20 GeV, $|\eta| < 2.5$
leading jet p_T > 40 GeV

MET: e+jets > 20 GeV, μ+jet>25 GeV
lepton p_T and MET vector must be separated in azimuth

- Use 2 approaches to analysis: kinematic likelihood and b-tagging.
- Dominant background is W+jets: use normalization from data.
- Instrumental background is estimated from data (sample with the loose electron identification or the muon isolation).

Multijet background ("matrix" method)

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 $Z \rightarrow ee$ ($Z \rightarrow \mu\mu$) events

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

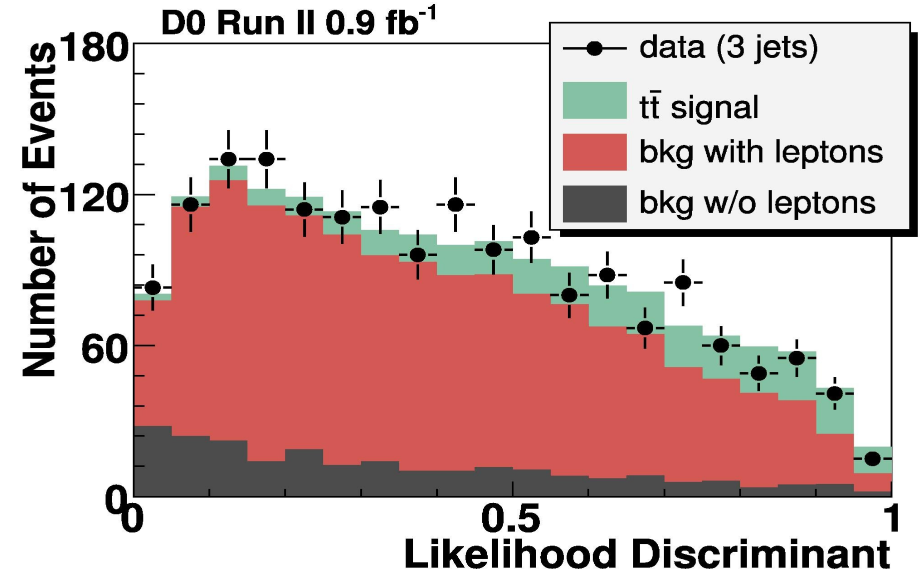
Kinematic Likelihood analysis

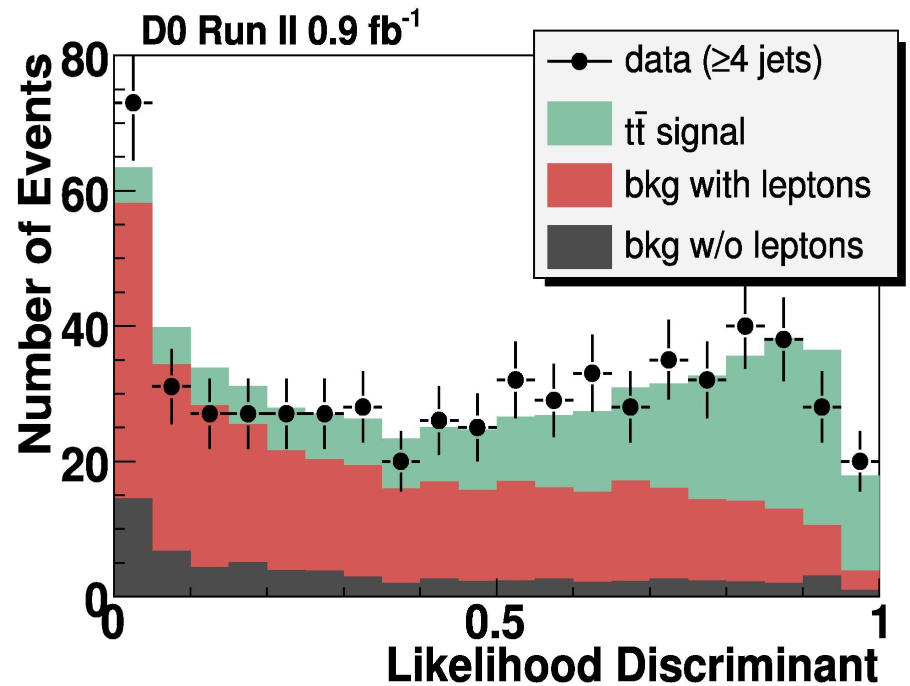
- Inclusive sample + $\sum_{i=1}^{N_j} p_T(i) > 120$ GeV
- Construct likelihood discriminant from 5—6 kinematic variable in each channel (2 lepton flavors *x* 2 jet multiplicities)
- Fit simultaneously all channels and extract ttbar contribution. Use templates for the top signal and W+jets from MC and for multijets backgrounds from data.

	3 jets	$\geq$4 jets
$N_{\rm data}$	1760	626
$N_{t\bar{t}}$	245±20	233±19
$N_{W\rm jets}+N_{\rm other}$	1294±48	321±30
$N_{\rm jj}$	227±28	70±12

σ = 6.6 ± 0.8 (stat) ± 0.4 (syst) ± 0.4 (lumi) pb

relative error : $\delta\sigma/\sigma$ ~15% m_t= 175 GeV





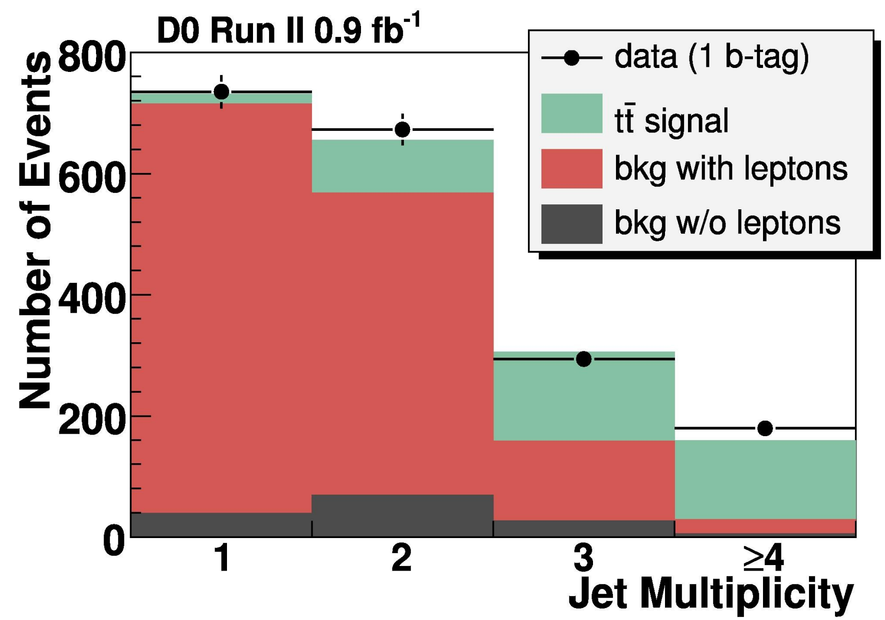
b-tagging analysis

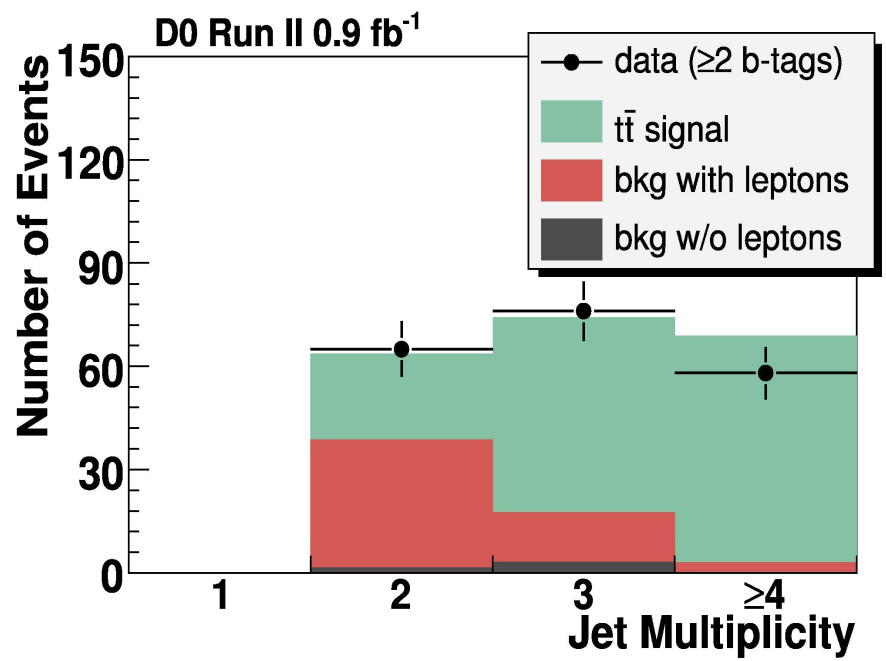
- Consider 8 channels: 2 lepton flavors *x* 2 jet multiplicities *x* 1 or 2 b-tags
- Fix the W+jet number of events from pre-tag samples, apply b-tagging, calculate ttbar cross-section, update the W+ jet normalization and iterate calculation until result will be stable.
- Instrumental background: N_{evt} in inclusive sample *x* b-tagging probability

	3jets,1tag	3jets,≥2tags	≥4jets,1tag	≥4jets,≥2tags
$N_{t\bar{t}}$	147±12	57±6	130±10	66±7
$N_{W\text{jets}}$	105±5	10±1	16±2	2±1
N_{other}	27±2	5±1	8±1	2±1
N_{jj}	27±6	3±2	6±3	0±2
total	306±14	74±6	159±11	69±7
N_{data}	294	76	179	58

σ = 8.1 ± 0.5 (stat) ± 0.7 (syst) ± 0.5 (lumi) pb

relative error : $\delta\sigma/\sigma$ ~12% m_t = 175 GeV





Combining results

σ = 7.4 ± 0.5 (stat) ± 0.5 (syst) ± 0.5 (lumi) pb

relative error : $\delta\sigma/\sigma$ ~11% m_t= 175 GeV

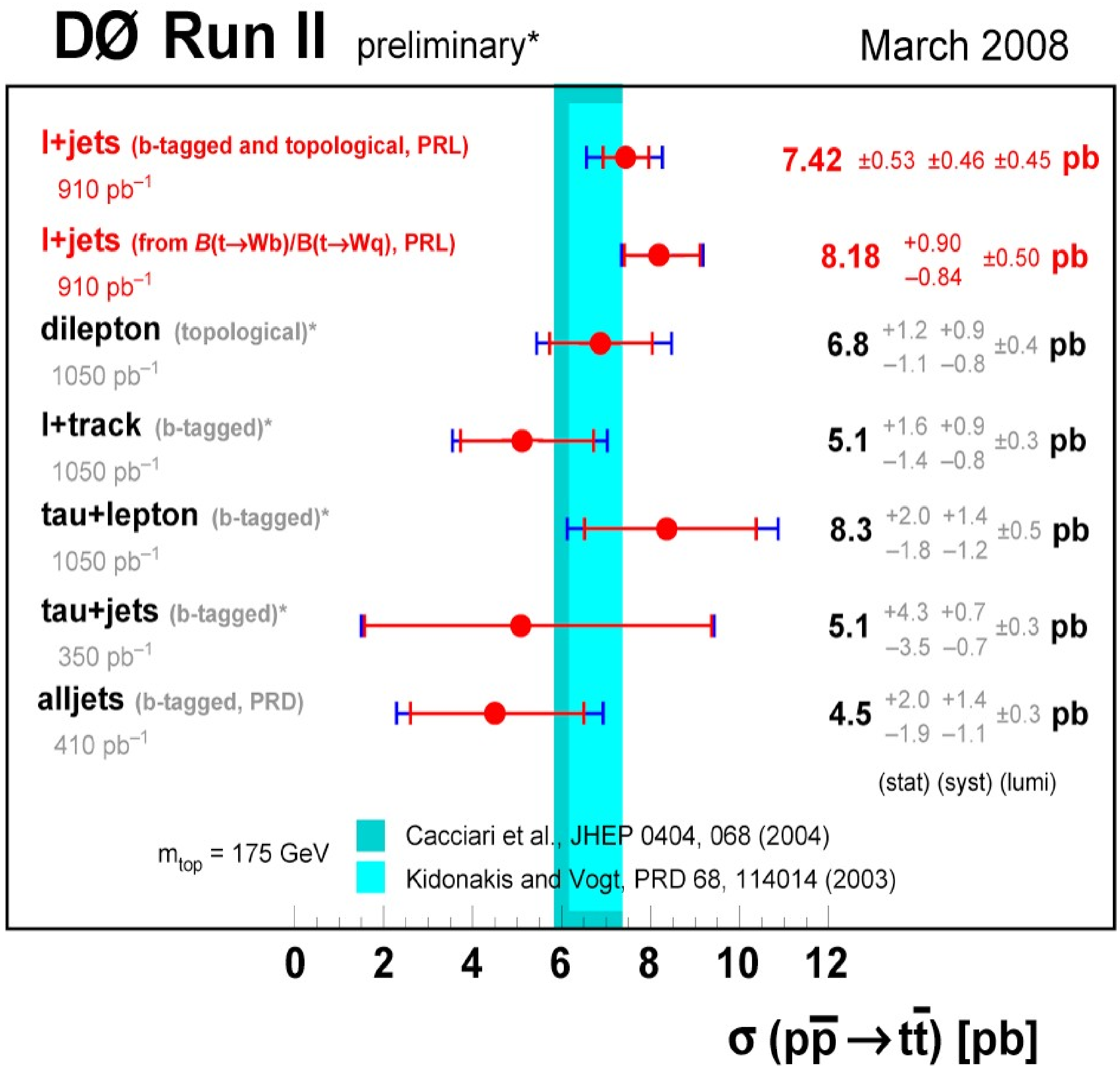
Statistical correlation factor 0.31

SYSTEMATICS

source	b-tag	likelihood	combined
selection efficiency	0.26 pb	0.25 pb	0.25 pb
jet energy calibration	0.30 pb	0.11 pb	0.20 pb
b-tagging	0.48 pb	—	0.24 pb
MC model	0.29 pb	0.11 pb	0.19 pb
N_{jj}	0.06 pb	0.10 pb	0.07 pb
likelihood fit	—	0.15 pb	0.08 pb

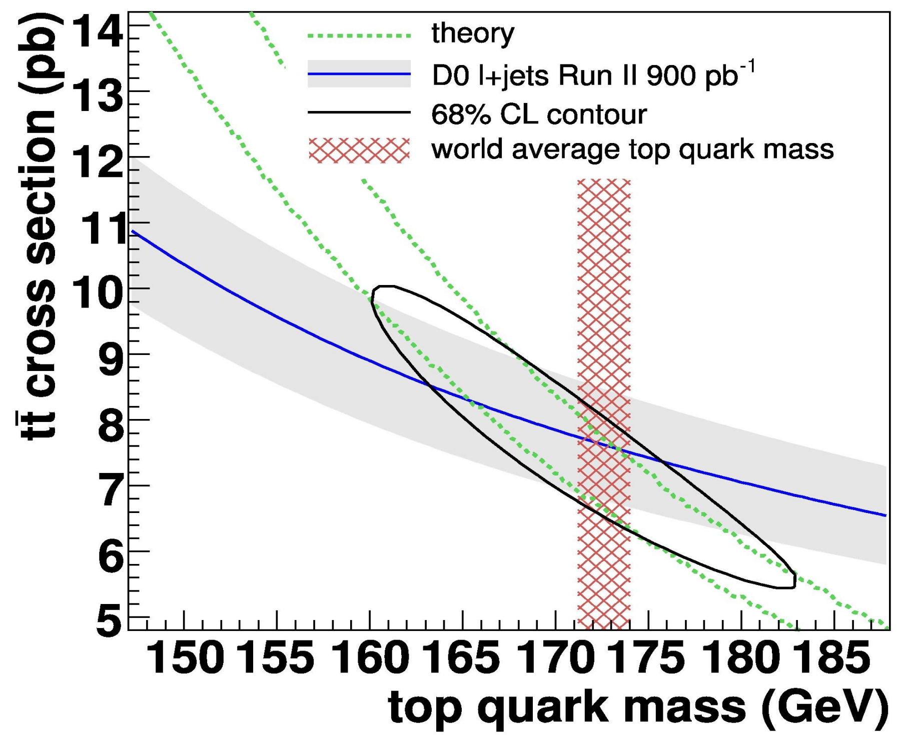
- B-tagging analysis is limited by systematics, while topological one is limited by statistics. With 8pb^{-1} one could expect to reach < 5% in statistical uncertainty, which will lead to the total error limited mainly by systematics and luminosity errors at 8% level. Farther improvement require reducing the systematics uncertainty.

Cross-Section Summary



Top Mass from Cross-Section

- Motivation:
  - not meant to compete in precision with direct measurement, but provides a complementary measurements
  - top mass definition (pole , running)
- Construct likelihood with measurements from lepton+jet and dilepton channels: Gauss(σ,$\delta\sigma$)
- Define theory likelihood according to PDF and scales uncertainties from
  - Kidonakis et al., PRD 68 114014
  - Cacciari et al., JHEP 0404:068



m_t = 170.0 ± 7 GeV @ 68% C.L.

D0 combined, 1 fb^{-1}: 172.1± 2.4 GeV

- 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.

Perspectives

- At the end of RunII one could expect to have a cross-section measurement at 6% level (systematics should be improved), limited mainly by the luminosity error.
  - Normalization with Z peak could be considered to improve the precision by 1 – 2 %, but it will introduce a dependence from theoretical calculation of the Z-boson cross-section.
- With larger statistics, the measurement of the cross-section ratio between different channels starts to be interesting, for example, *dilepton / lepton + jets*. Taking into account the common systematics (luminosity, jet energy scale, lepton IDs) this ratio could be measured with a precision of ~6% at the end of RunII, limited by the dilepton statistical uncertainty.

Conclusion

- Current experimental precision of cross-section determination reach the level of theoretical uncertainty ~10%.
- 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.