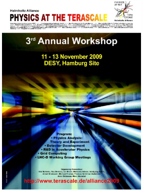
Top-quark pair-production cross-section measurement using early CMS data at 10 TeV

Jasmin Gruschke

Institut für Experimentelle Kernphysik,
Karlsruher Institut für Technologie (KIT)

Helmholtz Allianz Workshop
November, 12th 2009



Introduction

Theoretical prediction ($\sqrt{s} = 10$ TeV):

$$\sigma(t\bar{t}) = 414\text{pb} \pm 40(\text{scale}) \pm 20(\text{PDF})$$

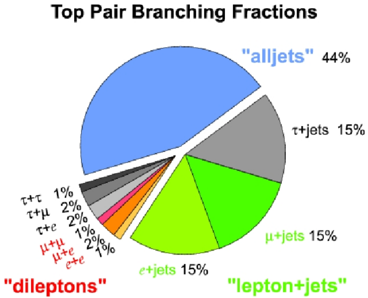
Cacciari *et al.*, JHEP **09** (2008) 127

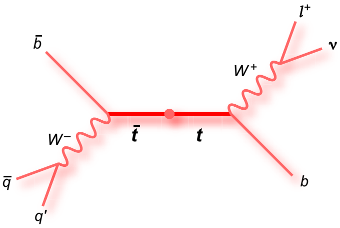
Signatures:

- 6 Jets (2 b-Jets)
- Lepton, 4 Jets (2 b-Jets), $\not{E}_T$
- Two opp. charged leptons, 2 b-Jets, $\not{E}_T$

Objective:

- Robust analyses of first/early CMS data at a center-of-mass energy of 10 TeV





Prospects for the first measurements of the top-quark pair-production cross-section in the muon+jets and electron+jets channels within 20/pb accumulated CMS data at $\sqrt{s}$ =10 TeV.

Summary of approved analyses:

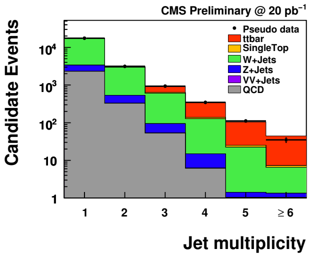
- CMS PAS TOP-09-003:
  http://cms-physics.web.cern.ch/cms-physics/public/TOP-09-003-pas.pdf
- CMS PAS TOP-09-004:
  http://cms-physics.web.cern.ch/cms-physics/public/TOP-09-004-pas.pdf

(with significant contributions from Karlsruhe by Th. Chwalek, J. Gruschke, Th. Müller, M. Renz and F. P. Schilling)

Event selection - semileptonic $t\bar{t}$ channel

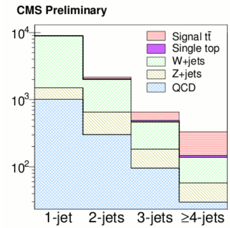
- Trigger: High level single electron/muon trigger
- Lepton: Exactly one isolated lepton
  - Muon: combined information from tracker and muon system; $p_T > 20$ GeV/c, $|\eta| < 2.1$ and certain quality criteria
  - Electron: combined information from tracker and ECAL; $E_T > 30$ GeV, $|\eta| < 2.5$ and certain quality criteria
- Jets: ≥ 4 jets with $p_T > 30$ GeV/c, $|\eta| < 2.4$ (SisCone; R=0.5)

Muon+jets channel



320 signal and 171 bkg events.

Electron+jets channel



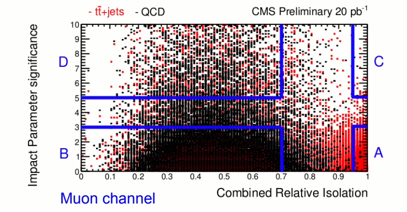
172 signal and 108 bkg events.

Data-driven estimation of QCD background

ABCD-Method:

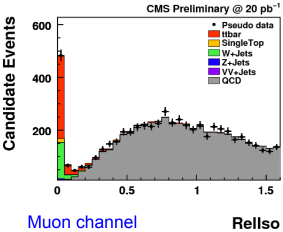
- Divide into 4 phase-space regions (3 dominated by QCD)
- Estimate QCD contribution in the signal region via:

$$N_A = N_B \cdot \frac{N_C}{N_D}$$



RelIso Extrapolation Method:

- Side-band region fit to an isolation distribution (RelIso includes tracker and calorimeter information)
- Integral of extrapolated function as estimate for the QCD contribution



Expected precision of both methods in both channels about 50%

Data-driven estimation of W+jets background

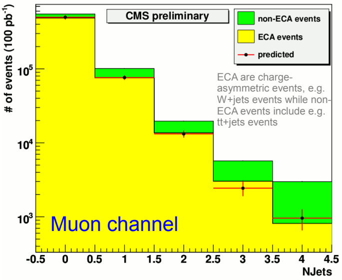
Utilize charge asymmetry:

- Measure the number-difference of leptons to anti-leptons in candidate events
- Estimate the number of charge-asymmetric background events (e.g. W+jets) via:

$$\left(N^{+}+N^{-}\right)_{\mathrm{data}} = \mathrm{R}_{\pm}\cdot\left(N^{+}-N^{-}\right)_{\mathrm{data}}$$

$$\mathrm{R}_{\pm} = \frac{N_{W^{+}}+N_{W^{-}}}{N_{W^{+}}-N_{W^{-}}} = \frac{A_{+}\sigma_{W^{+}}+A_{-}\sigma_{W^{-}}}{A_{+}\sigma_{W^{+}}-A_{-}\sigma_{W^{-}}}$$

Jet multiplicity with prediction for events leading to charge asymmetry (ECA) scaled to 100/pb



Expected precision of the estimation is 30% within 100/pb

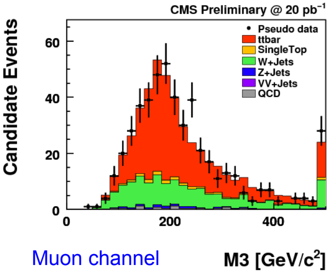
Determination of the $t\bar{t}$ cross section

- From experimental point of view, the cross-section is given by:

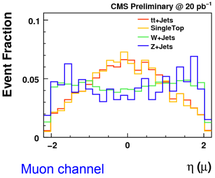
$$\sigma(t\bar{t}) = \frac{N_{t\bar{t}}}{A \cdot \varepsilon \cdot \mathcal{L}}$$

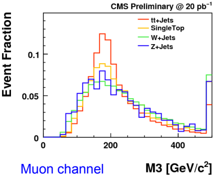
- Extraction of $N_{t\bar{t}}$ via a template fit to a discriminating variable utilizing a standard binned likelihood procedure.

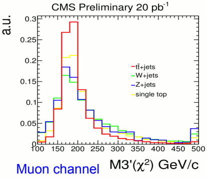
Invariant mass of three jets with the highest vectorial-summed p_{T}:

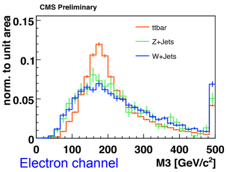


Comparison of shapes:









Results

- Estimation of sensitivity and systematic uncertainties employing ensemble test (i.e. sets of 5k pseudo experiments)
- Total uncertainty is obtained by quadratic sum of individual uncertainties; luminosity is treated separately

Muon+jets channel:

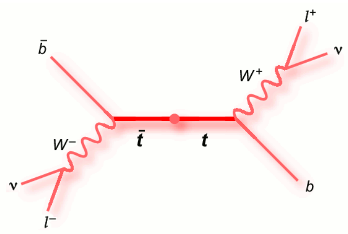
Source	Uncertainty [%]		
	Fit to $\eta(\mu)$	Fit to M3	Fit to M3′
Statistical Uncertainty (20 pb^{-1})	17.7	16.3	11.5
Jet Energy Scale	16.7	15.1	19
$t\bar{t}$ MC Generator	1.9	14.9	14
$t\bar{t}$ ISR/FSR	3.3	7.7	2
W+jets Factorization scale	4.4	4.7	4
W+jets Matching threshold	5.5	2.8	4
Single Top Shape	0.1	0.8	1
PDF Uncertainty	5.0	5.0	5.0
Total Systematic Error	19.2	23.8	25.0
Luminosity Error	10.0	10.0	10.0

Stat. uncertainty: 12-18%
System. uncertainty: 20-25%

Electron+jets channel:

	Relative Systematic Uncertainty
Jet Energy Scale	15%
$t\bar{t}$ MC Generator	10%
$t\bar{t}$ ISR/FSR uncertainty	3%
W+jets MC Factorization Scale	1%
W+jets MC Matching threshold	5%
Shape uncertainty of Single Top	1%
Shape uncertainty of QCD	2%
PDF uncertainty	5%
Total	20%

Stat. uncertainty: 23%
System. uncertainty: 20%



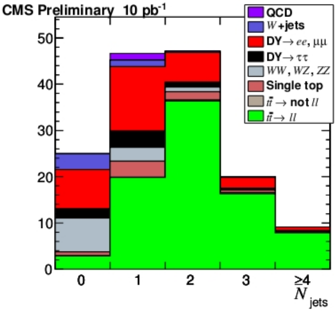
Expectations for observation of top-quark pair-production in the dilepton final state with the early CMS data at $\sqrt{s}$ =10 TeV

Summary of (focus on $t\bar{t}$ $\rightarrow$ll+jets in 10/pb using calorimeter jets):

- PAS TOP-09-002: http://cms-physics.web.cern.ch/cms-physics/public/TOP-09-002-pas.pdf

Event selection - dileptonic $t\bar{t}$ channel

- Final states: e^+e^-, $\mu^+\mu^-$ and $e^\pm\mu^\mp$
- Trigger: High level single electron or single muon trigger
- Lepton: At least two isolated leptons with opposite-sign charge, p_T >20 GeV/c, $|\eta|$ <2.4 and certain quality criteria
  - Z-boson veto (ee & $\mu\mu$ channel): reject events with $|M_{ll} - M_Z|$ <15 GeV/c^2
- Jets: $\geq$2 jets with p_T >30 GeV/c, $|\eta|$ <2.4 (SisCone; R=0.5)
- MET: $\not{E}_T$ >30 GeV (ee & $\mu\mu$ channel); $\not{E}_T$ >20 GeV (eμ channel)



Data sample	e^+e^-	$\mu^+\mu^-$	$e^\pm\mu^\mp$
$t\bar{t} \to \ell\ell$	11.6 ± 0.2	13.2 ± 0.2	35.6 ± 0.4
other $t\bar{t}$	0.21 ± 0.03	0.04 ± 0.01	0.46 ± 0.04
Single top	0.46 ± 0.03	0.56 ± 0.03	1.40 ± 0.06
$WW/WZ/ZZ$	0.26 ± 0.02	0.33 ± 0.03	0.71 ± 0.05
DY$\to \tau\tau +$jets	0.3 ± 0.1	0.3 ± 0.1	0.7 ± 0.2
DY$\to ee/\mu\mu +$jets	4.1 ± 0.4	5.3 ± 0.4	0.08 ± 0.05
$W +$jets	0.2 ± 0.1	< 0.1	0.3 ± 0.1
QCD	< 1	< 0.4	< 0.4
Total backgrounds	5.5 ± 0.4	6.6 ± 0.4	3.7 ± 0.2
Data driven fakes	1.1 ± 0.6	0.8 ± 0.4	2.5 ± 1.2
Data driven DY	4.0 ± 1.3	5.1 ± 1.6	

Data-driven estimation of background events

Estimation of DY+jets background

- Number of events $\mathrm{N}^{\mathrm{data}}_{\mathrm{DY,in}}$ within $|M_{ll} - M_{\mathrm{Z}}| <$15 GeV/c^2 to estimate the number of events passing the Z-boson veto:

$$\mathrm{N}^{\mathrm{data}}_{\mathrm{DY,out}} = \mathrm{R}_{\mathrm{out/in}} \cdot \mathrm{N}^{\mathrm{data}}_{\mathrm{DY,in}}$$

- where $\mathrm{R}_{\mathrm{out/in}}$ taken from γ^*/Z-simulations

Method yields 30% systematic uncertainty.

Data-driven estimation of background events

Estimation of DY+jets background

- Number of events $\mathrm{N}^{\mathrm{data}}_{\mathrm{DY,in}}$ within $|M_{ll} - M_{\mathrm{Z}}| < 15$ GeV/c^2 to estimate the number of events passing the Z-boson veto:

$$\mathrm{N}^{\mathrm{data}}_{\mathrm{DY,out}} = \mathrm{R}_{\mathrm{out/in}} \cdot \mathrm{N}^{\mathrm{data}}_{\mathrm{DY,in}}$$

- where $\mathrm{R}_{\mathrm{out/in}}$ taken from γ^*/Z-simulations

Method yields 30% systematic uncertainty.

Estimation of fake leptons

- Fakes: Misidentified jets as leptons
- "Fake Ratio" (FR) from e.g. multi-jet events:

$$FR = \frac{FO_{\mathrm{pass\ full\ selection}}}{FO}$$

FO is an object with looser requirements.

- Estimation of fakes via:

$$N_{\mathrm{fake}} = N_{\mathrm{l,FO}} \cdot FR(1 - FR)$$

where in $\mathrm{N}_{\mathrm{l,FO}}$ events both leptons fulfill FO requirements but only one pass the full selection.

Method yields 50% systematic uncertainty.

Results

The signal-to-noise ratio is about 4 to 1 in the combination of all channels and about 9 to 1 in the $e^{\pm}\mu^{\mp}$ channel alone

Source	e^+e^- and $\mu^+\mu^-$	$e^{\pm}\mu^{\mp}$
Statistical	25	18
Lepton ID	5	5
Lepton isolation	3	3
Jet energy scale	8	5
Theory	4	4
DY$\rightarrow ee, \mu\mu$ method	10	
Fake leptons method	4	4
Residual background	5	4
Integrated luminosity	10	10

Stat. uncertainty: 15%
System. uncertainty: 10%

The analysis can be extended by (see Ref. for details):

- Using jets reconstructed by the tracker and omitting the MET requirement
- Utilize the identification of $b-$jets

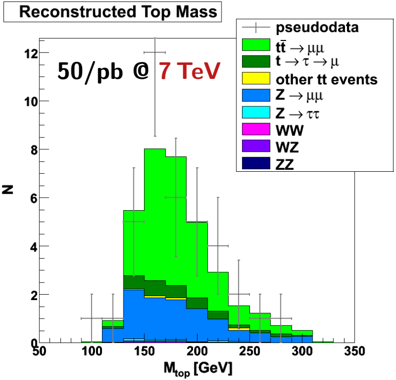
Disclaimer:
The following results do not represent official material released by CMS but are results recently obtained.

Work in progress . . .

Thanks to D. Dammann and D. Tornier for their slides/material!

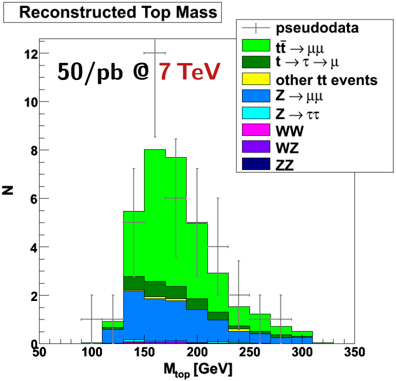
$t\bar{t}$ dilepton activities at DESY

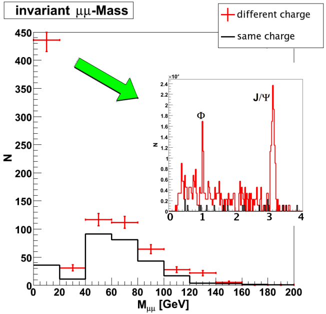
- Determination of $t\bar{t}$ cross section in 7 TeV and 10 TeV data in 2010
- Event selection without b-tagging
- In addition a $\mu\mu$ analysis is planned within 50/pb at 7 TeV



$t\bar{t}$ dilepton activities at DESY

- Determination of $t\bar{t}$ cross section in 7 TeV and 10 TeV data in 2010
- Event selection without b-tagging
- In addition a $\mu\mu$ analysis is planned within 50/pb at 7 TeV





Estimation of QCD and fake muon background using the wrong charge method.

$t\bar{t}$ dilepton activities in Aachen

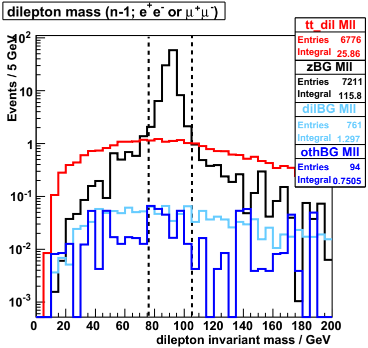
Cross-section measurement via counting experiment within early data

- High level single electron or muon trigger
- ≥ 2 opposite-sign charged isolated leptons with $p_{\mathrm{T}} > 20$ GeV/c
- No $b-$jet identification applied

$t\bar{t}$ dilepton activities in Aachen

Cross-section measurement via counting experiment within early data

- High level single electron or muon trigger
- ≥ 2 opposite-sign charged isolated leptons with $p_{\mathrm{T}} > 20$ GeV/c
- No $b-$jet identification applied



Estimation of Drell-Yan background in data via:

$$\mathrm{N}^{\mathrm{data}}_{\mathrm{DY,out}} = \mathrm{R}_{\mathrm{out/in}} \cdot \mathrm{N}^{\mathrm{data}}_{\mathrm{DY,in}}$$

after correction of $\mathrm{N}^{\mathrm{data}}_{\mathrm{DY,in}}$ using opposite-flavour events

Conclusion

- Three feasibility studies for early $t\bar{t}$ cross-section measurement

channel	$\int \mathcal{L}\, dt$	stat. uncertainty	system. uncertainty
e+jets	20	23 %	20 %
μ+jets	20	12-18 %	20-25 %
ll+jets	10	15 %	10 %

- Employ data-driven techniques for the estimation of background contributions
- Currently the analyses change for a center-of-mass energy of $\sqrt{s} = 7$ TeV
- We are ready and eager to analyze first data ... and will hopefully be able to claim the discovery of the top quark in Europe!

Backup

$t\bar{t}$ dilepton channel