Expectations for first measurements of top-antitop pair-production using early CMS data

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Main top interests at the LHC

The LHC is a top factory !

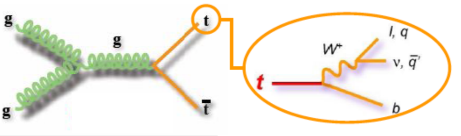
Main interests are :

- top rediscovery
- top as calibration tool :
  jet energy scale, b-tagging efficiency
- precision tests of the Standard Model
- new physics searches

The top quark is the heaviest quark of the SM : may have a particular coupling to new physics !

Top pair production @ LHC

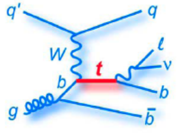
Strong production : $\approx$ 90% via gluon fusion @14 TeV



LHC vs Tevatron : $\sigma_{t\bar{t}} = 160$ pb @ 7 TeV
$\rightarrow \sigma_{t\bar{t}}$ 20 times higher than at Tevatron

Single top production @ LHC

Electroweak production

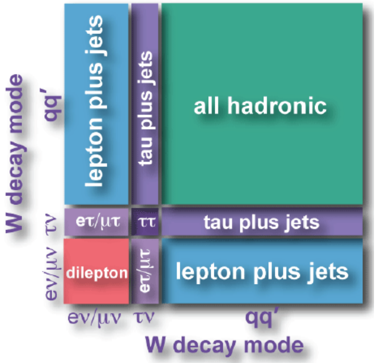


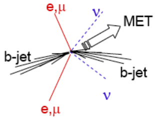
allows a direct measurement of the Wtb coupling
$\sigma_t \approx 1/3\sigma_{t\bar{t}}$

Top pair final states

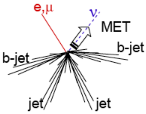
Top-antitop final states :

- di-leptonic channel (e/μ) :
  9% of total, low statistics,
  but clean signature with isolated leptons
- semi-leptonic channel :
  45% of total,
  reconstruction of top mass
- hadronic channel :
  46% of total,
  high multi-jet background, not for early data

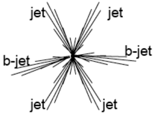




dileptons



lepton + jets



all hadronic

Analysis strategies for first measurements

Focus on di-leptonic and semi-leptonic channels

Analysis strategy :

- unprescaled single lepton triggers
- use of b-tag and MET with caution
- data driven background estimates
  $\longrightarrow$ multi-jets and W/Z+jets have large uncertainties @ LHC

Main backgrounds are :

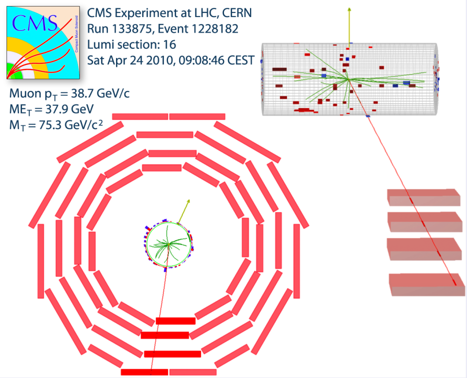
- multi-jet events
  $\longrightarrow$ jets faking leptons
- W+jets
  $\longrightarrow$ isolated lepton, MET, jets
- Z+jets, dibosons $\longrightarrow$ di-lepton channel
- single top

All results shown in the next slides are 10-14 TeV
$\longrightarrow$ strategy remains valid @ 7 TeV

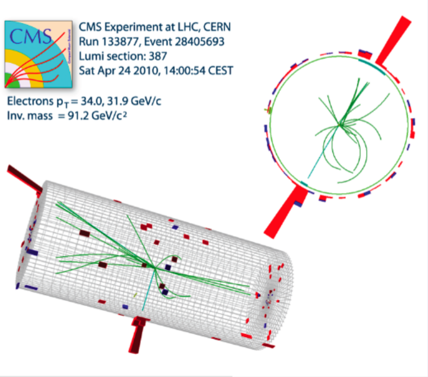
First leptons in 7 TeV collisions

First electron and muon candidates from electroweak processes in 7 TeV collision data !

$W^+ \to \mu^+ \nu_\mu$ candidate event !



$Z \to e^+ e^-$ candidate event !



$Z \to l^+ l^-$ events will be used to estimate trigger efficiencies and lepton id and isolation criteria with tag and probe methods

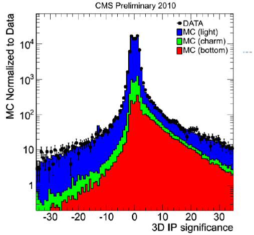
b-tagging in 7 TeV collisions

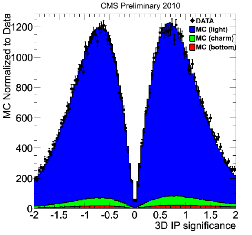
b-tagging is a key ingredient of top physics !

Signed 3D impact parameter significance for all tracks selected for b-tagging for jets with $p_T > 40 GeV$ and $|\eta| < 1.5$

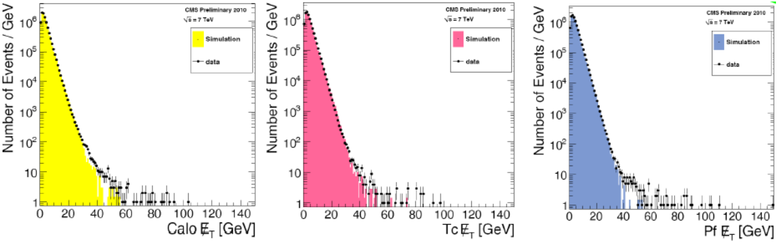
Data : $\approx$ 0.9 nb^{-1} @ $\sqrt{s} = 7 TeV$

Simulation : combination of minimum bias data and QCD samples

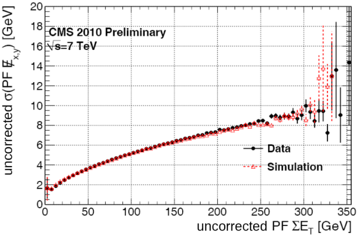




Good agreement seen for b-tagging observables between data and simulation : b-tagging might be used in early data !



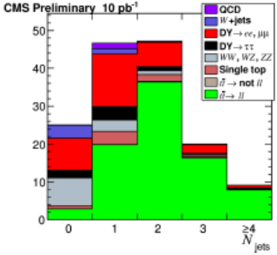
Core of MET is well described.
Noise cleaning expected to improve in future.



All CMS results : https://twiki.cern.ch/twiki/bin/view/CMS/PublicPhysicsResults

Dilepton cross-section measurement

- **Robust event selection :**
  2 opposite charged isolated leptons $p_T > 20 GeV$
  Z mass veto, > 2 jets $p_T > 30 GeV$
  MET > 20 (30) GeV
- **Alternative selection :** b-tagging, use of track-jets
- **Prospects to measure cross-section ratio :**
  $\sigma(t\bar{t})/\sigma(Z+X) = N(t\bar{t})\epsilon(Z)/N(Z)\epsilon(t\bar{t})$
  $\rightarrow$ luminosity uncertainty cancellation



	Main selection		
Data sample	e^+e^-	$\mu^+\mu^-$	$e^\pm\mu^\mp$
$t\bar{t} \rightarrow \ell\ell$	11.6 ± 0.2	13.2 ± 0.2	35.6 ± 0.4
Single top	0.46 ± 0.03	0.56 ± 0.03	1.40 ± 0.06
DY+jets	4.4 ± 0.4	5.6 ± 0.4	0.8 ± 0.2
Others	0.67 ± 0.11	0.37 ± 0.03	1.5 ± 0.1
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	

Expected cross-section precision, 10 pb^{-1}, $\sqrt{s} = 10 TeV$:
$\Delta\sigma/\sigma = \pm 15\%(stat) \pm 10\%(sys) \pm 10\%(lumi)$

Lepton isolation and fake rate

- **10 pb^{-1} :** use multi-jet sample dominated by fake leptons. Select leptons with relaxed lepton id and isolation. Apply the tight selection and define a fake rate. Estimated uncertainty $\approx$ 30 %
- **100 pb^{-1} :** Matrix method :
  Define 3 sub-samples for each level of lepton isolation (loose, medium, tight)
  - N_s events containing 2 real leptons (signal like)
  - N_W events containing 1 real lepton (W+jets like)
  - N_{QCD} events containing 2 fake isolated leptons (QCD like)

  System of three equation allows to solve the three unknowns N_s^l, N_W^l, N_{QCD}^l

$$\boxed{\begin{aligned} N^t &= \varepsilon_S^{l\to t} N_S^l + \varepsilon_W^{l\to t} N_W^l + \varepsilon_{QCD}^{l\to t} N_{QCD}^l, \\ N^m &= \varepsilon_S^{l\to m} N_S^l + \varepsilon_W^{l\to m} N_W^l + \varepsilon_{QCD}^{l\to m} N_{QCD}^l, \\ N^l &= N_S^l + N_W^l + N_{QCD}^l. \end{aligned}}$$

  Leading to the number of signal, W+jets and QCD events :

$$N_S^t = \epsilon_l^{l\to t} N_S^l,\ N_W^t = \epsilon_l^{l\to t} N_W^l,\ N_{QCD}^t = \epsilon_l^{l\to t} N_{QCD}^l$$

  Estimated uncertainty for W+jets events : 20% with 100 pb^{-1}

Z+jet background

Use the ratio of events inside/outside the Z mass window :

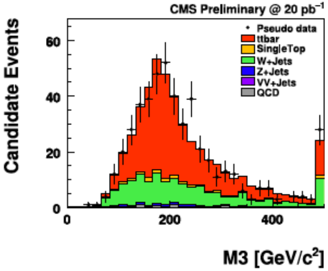
- Select events with low MET<20 GeV
- Assume dominated by Z+jets events
- Count the number of events outside the Z window : N_{tails}
- Rescale N_{tails} :
  - fit M_{ll} (MET>50 GeV) by a Breit-Wigner + polynomial
  - use maximum of Breit-Wigner to determine the scale factor

Estimated uncertainty $\approx$ 30%

Lepton + jets cross-section measurement

- **Simple event selection :**
  Exactly one isolated lepton $p_T(\mu/e) > 20/30 GeV$,
  $>=$ 4 jets,
  no MET, no b-tag !
- **Cross-section measurement :**
  Fit discriminating variables M3, M3' or $\eta(\mu)$
  3 templates : $t\bar{t}$, single-top, W+jets

  M3 : inv. mass of 3 jets with highest Σp_T
  $\approx$ *hadronic top mass*
  M3' : χ^2 *sorted M3 using W mass and MET*
  $\eta(\mu)$ *: smallest sys, less sensitive to JES*
- **Prospects to measure cross-section ratio :**
  $\sigma(t\bar{t})/\sigma(W+X) = N(t\bar{t})\epsilon(W)/N(W)\epsilon(t\bar{t})$

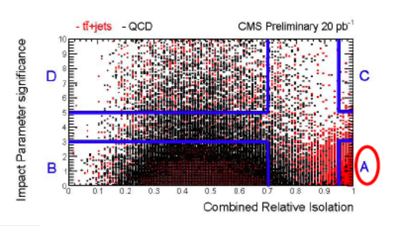


e+jet channel : larger level of multi-jet bkg (photon conversions)
Possible options : conversion removal, MET cut, central electron

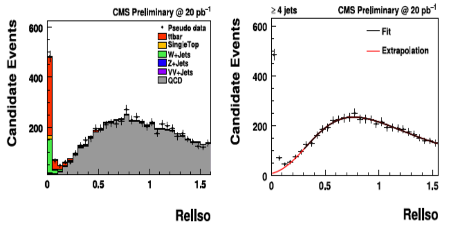
Expected cross-section precision, 20 pb^{-1}, $\sqrt{s} = 10 TeV$:
$\Delta\sigma/\sigma(\mu + jets) = \pm 12 - 18\%(stat) \pm 20 - 25\%(sys)$
$\Delta\sigma/\sigma(e + jets) = \pm 23\%(stat) \pm 20\%(sys)$ (main sys=JES)

Multi-jet background

Quadrant method :
$\sigma(IP_\mu)$ and μ isolation are two independent discriminating variables
Number of QCD events in signal region A :
$N_A = N_B N_C / N_D$



Extrapolation of relative isolation variable :
Sideband region fit to combined (tracker + calo) lepton isolation variable



50 % uncertainty conservatively assumed for both methods

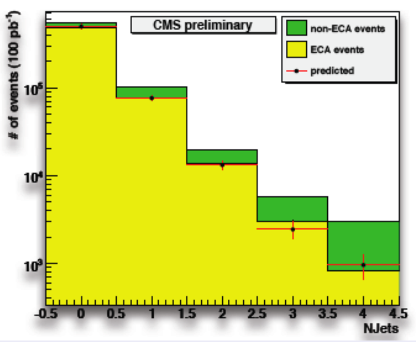
Use the W charge asymmetry (> 100 pb^{-1}):

- Measure the difference of lepton to anti-lepton in candidate events
- Estimate the number of W+jet events

$$N^+ + N^- = R_\pm (N^+ - N^-)$$

$$R_\pm = (N_{W^+} - N_{W^-})/(N_{W^+} + N_{W^-})$$

$R_\pm$ *is taken from simulation*



Jet mutiplicity with prediction of events leading to charge asymmetry (ECA)

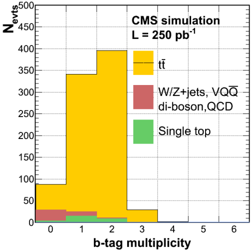
Estimated precision is 30 % in 100 pb^{-1}, error mostly statistical, PDF systematics to be evaluated

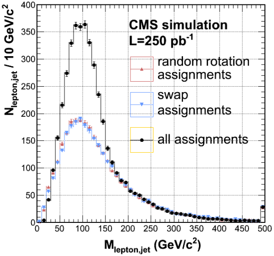
Measurement of $R = BR(t \to Wb)/BR(t \to Wq)$

Expect $R = BR(t \to Wb)/BR(t \to Wq) \approx 1$ (q = d, s, b)

Use eμ events : clean $t\bar{t}$ sample (bkg < 10 %)

The number of observed b-jets depends on R, b-tag efficiency ϵ_b and on jet misassignment
Jet misassignment : top events with missing and/or fake b-jets...
$\rightarrow$ extracted from data : $M_{lepton-jet}$ fit



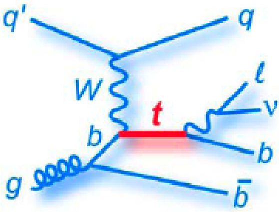


Fix ϵ_b or R and fit R or ϵ_b :

Expect R with $\pm 2\%(stat) \pm 9\%(sys\ from\ \epsilon_b) \pm 3\%$, 250 pb^{-1}, $\sqrt{s} = 10$ TeV
Or alternatively expect $\epsilon_b \approx \pm 2\%(stat) \pm 4\%(sys)$ assuming $R = 1$

Single top (t channel)

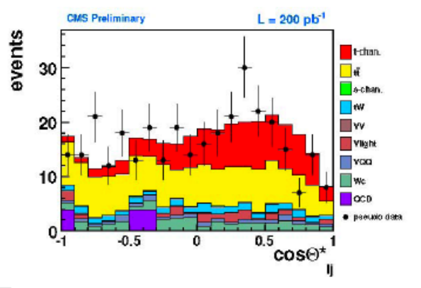
Analysis strategy :
One isolated μ and lepton veto
two jets far from μ
one b jet, 2nd jet must fail b-tag
$M_T > 50$ GeV (on-shell W, anti-QCD)
top reconstruction



Single top cross-section :
fit to polarization angle and/or charge asymmetry

Sensitivity : 2.7 σ for 200 pb^{-1}, $\sqrt{s} = 10\,TeV$

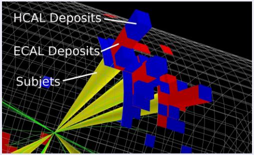
S/B=0.45 (t channel =102, ttbar=136, tW channel=22, QCD=12, W+x=50)



Boosted tops

Several BSM extensions predict contributions to top-pair production
$\rightarrow$ distorted $M_{t\bar{t}}$ spectrum w.r.t. SM

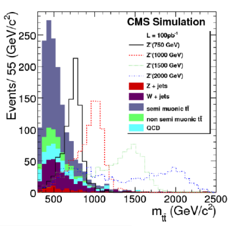
Search for boosted hadronic tops : decay products end up in monojets with substructure



Selection : 2 monojets with $p_T > 250$ GeV

100 pb^{-1}, 10 TeV:
$M_{t\bar{t}}$=2 (3) TeV
Discovery up to $\sigma\times$ BR = 4.0 (1.6) pb
Exclusion @ 95% CL up to 1.5 (0.7) pb

Search for $t\bar{t}$ resonances in semi-leptonic channel, 2 analyses : @ low and high masses



Standard analyses with specific cuts : relaxed isolation criteria, high p_T jets...
100 pb^{-1}, 10 TeV:
$M_{t\bar{t}}$=2 TeV
Exclusion @ 95% CL up to 9 pb

Summary & perspectives

Top ingredients (leptons, jets, b-tagging, MET) in good shape @ 7 TeV.

10 TeV cross-section measurement stategies remain valid @ 7 TeV.

Expect first cross-section measurement with 10 pb^{-1} @ 7 TeV :
Dilepton : $\approx 25\, t\bar{t}$
e + jets : $\approx 40\, t\bar{t}$
μ + jets : $\approx 70\, t\bar{t}$
$\rightarrow$ Concentrate on background estimates from data
$\rightarrow$ Possible use of b-tagging

Refined measurements with 50-500 pb^{-1} :
Fully hadronic channel and tau final states, observation of single-top, JES calibration and b-tag efficiencies, first mass measurements, high mass resonances...

Precision top-quark physics with >500 pb^{-1} :
Rare decays, helicity and spin correlations...

Exciting top physics program ahead of us !

References

- CMS PAS TOP-09-001
- CMS PAS TOP-09-002
- CMS PAS TOP-09-003
- CMS PAS TOP-09-004
- CMS PAS EXO-09-002
- CMS PAS EXO-09-008
- ...