# Measurement of the top-quark mass using $J/\psi$ -in-jet candidates at the CMS experiment

Maria Giulia Ratti Università degli Studi di Milano

Supervisors: Maria Aldaya and Sebastian Naumann

September 6<sup>th</sup>, 2012

• The most precise value of the **top-quark mass** now available (Tevatron, June 2012):

 $m_t = 173.18 \pm 0.94$  GeV

- At the LHC several methods are being used, most of them requiring the full reconstruction of the top event
- An alternative method was suggested (Kharchilava, 1999) and studied for CMS at simulation level (CMS Physics TDR, 2006) but not used in data yet
- It would use final states of  $t\overline{t}$  with  $J/\psi$ -in-jet candidates

#### very CLEAN (appealing) but extremely RARE (challenging)

- Simulation studies suggest small systematic uncertainties
- Given the clean signature, the approach is interesting for **high-luminosity** scenarios (increased pile-up)

3

(日本) (日本) (日本)

## $t\overline{t}$ production and decay

At the LHC  $t\bar{t}$  pairs are **produced** in pp collisions ( $\sigma_{t\bar{t}} \approx$ 165 pb at 7 TeV) via:

- gluon gluon fusion (pprox 85%)
- q ar q annihilation (pprox 15%)



In the Standard Model, the top quark decays almost exclusively into W + b  $\rightarrow$  the W **decay** modes define the  $t\bar{t}$  final states:

- All-hadronic (6 jets)
- Semileptonic (1 lepton + 4 jets)
- Dileptonic (2 leptons + 2 jets)



## ${\sf J}/\psi$ final states in dilepton channel

- In the **dilepton channel** of  $t\bar{t}$ , consider the following final state:
- Two hard isolated leptons
- Two neutrinos
   => missing E<sub>T</sub>
- Two b quarks => two **b-jets** => one of them  $J/\psi \rightarrow \mu^+\mu^-$



- The invariant mass of the two muons + isolated lepton (from the same top) =  $m_{J/\psi L}$  is correlated with the top mass
- Generate distributions of  $m_{J/\psi L}$  for different values of  $m_t$  and compare them to data ==>Template method
- In principle  $J/\psi \to e^+e^-$  could also be considered and the semileptonic  $t\bar{t}$  channel investigated





Silicon tracker, EM calorimeter, hadronic calorimeter, muon chambers

э

・ 何 ト ・ ヨ ト ・ ヨ ト

## Data Samples and Event Selection

- Data: CMS 2011, 4.9 fb<sup>-1</sup>, 7 TeV
- Monte Carlo: Fall11 MadGraph + Pythia tt sample (64M events)
- Preselection close to standard reference selection for dileptons in CMS
  - Dileptonic triggers
  - Two hard isolated leptons (ee, e $\mu,~\mu\mu$ ),  $p_T>20$  GeV,  $|\eta|<2.4$
- Look for opposite-sign dimuon candidates in jets
  - Particle-flow jets, anti- $k_T$ , R=0.5,  $p_T > 30$  GeV,  $|\eta| < 2.4$

• Dimuons in the jet is like requiring b-tagging

## Data Samples and Event Selection

- Data: CMS 2011, 4.9 fb<sup>-1</sup>, 7 TeV
- Monte Carlo: Fall11 MadGraph + Pythia tt sample (64M events)
- Preselection close to standard reference selection for dileptons in CMS
  - Dileptonic triggers
  - Two hard isolated leptons (ee, e $\mu$ ,  $\mu\mu$ ),  $p_T$  > 20 GeV,  $|\eta|$  < 2.4
- Look for opposite-sign dimuon candidates in jets

• Particle-flow jets, anti- $k_T$ , R=0.5,  $p_T > 30$  GeV,  $|\eta| < 2.4$ 

	Data	tīt sig (MC)	tīt bkg (MC)	$t\overline{t}$ fraction
Preselection	3462315	21613	142	1%

• Dimuons in the jet is like requiring b-tagging

## Data Samples and Event Selection

- Data: CMS 2011, 4.9 fb<sup>-1</sup>, 7 TeV
- Monte Carlo: Fall11 MadGraph + Pythia *t*t sample (64M events)
- Preselection close to standard reference selection for dileptons in CMS
  - Dileptonic triggers
  - Two hard isolated leptons (ee, e $\mu$ ,  $\mu\mu$ ),  $p_{T}$  > 20 GeV,  $|\eta|$  < 2.4
- Look for opposite-sign dimuon candidates in jets
  - Particle-flow jets, anti- $k_{T}$ , R=0.5,  $p_{T}$  > 30 GeV,  $|\eta|$  < 2.4

	Data	tīt sig (MC)	tīt bkg (MC)	$t\overline{t}$ fraction
Preselection	3462315	21613	142	1%
Dimu-in-jet	525	206	1	39%

• Dimuons in the jet is like requiring b-tagging

## ${\sf J}/\psi$ mass peak

- Fundamental ingredient is the  $J/\psi$  meson (=  $c\,\overline{c})$  produced in the b-hadronization

 $J/\psi \to \mu^+\mu^- => J/\psi$  reconstructed candidates from 2 opposite-sign muons in the same jet

• J/ $\psi$  mass (PDG, 2012): 3096.916  $\pm$  0.011 MeV



• 30.4 $\pm$  6.1  $J/\psi$  candidates, first time seen in  $t\bar{t}$  data

э

伺い イヨン イヨン

- Data: CMS 2011, 4.9 fb<sup>-1</sup>, 7 TeV
- Monte Carlo: Fall11 MadGraph + Pythia  $t\bar{t}$  sample (64M events)
- Preselection close to standard reference selection for dileptons in CMS
  - Dileptonic triggers
  - At least two hard isolated leptons (ee, e $\mu$ ,  $\mu\mu$ ),  $p_{T}$  > 20 GeV,  $|\eta|$  < 2.4
- Look for opposite-sign dimuon candidates in jets
  - Particle-flow jets, anti- $k_{T}$ , R=0.5,  $p_{T}$  > 30 GeV,  $|\eta|$  < 2.4
- Restrict to dimuon candidates in 2.8-3.2 GeV window

	Data	tt sig (MC)	tīt bkg (MC)	tt fraction
Preselection	3462315	21613	142	1%
Dimu-in-jet	525	206	1	39%
$J/\psi$ window	38	18	0	48%

3

A = 
 A = 
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A

## $m_{J/\psi L}$ distribution

- We need to **match** the selected dimuons with the isolated leptons for each event
- In principle we would like lepton and  ${\sf J}/\psi$  from the same top
- For statistical reasons we ignore this and consider both possible assignments Two entries per event: one "correct", one "wrong" 38 events → 76 entries

- Simulated mass: 172.5 GeV
- High statistic uncertainties on data
- Data and simulations agree within the uncertainties



## $m_{J/\psi L}$ distribution in simulation

- Generate the templates:
  - fit Monte Carlo with Gaussian distribution
  - extract the reconstructed value of  $m_{J/\psi L}$  as the mean of the Gaussian
  - repeat the same steps with different simulated top masses

 $m_t = 172.5 \,\, {
m GeV}$ 



- Simulated mass  $m_t = 172.5$  GeV
- Gaussian in range 20 120 GeV
- Unbinned, maximum likelihood

• 
$$m_{J/\psi L} = 67.21 \pm 0.66$$
 GeV

## $m_{J/\psi L}$ distribution in simulation

 $m_t = 161.5 \, GeV$ 

- Generate the templates:
  - fit Monte Carlo with Gaussian distribution
  - extract the reconstructed value of  $m_{J/\psi L}$  as the mean of the Gaussian

 $m_{t} = 184.5 GeV$ 

repeat the same steps with different simulated top masses



• Putting things together: correlation between simulated  $m_t$  and reconstructed  $m_{J/\psi L}$ 



Good linear correlation

$m_t$ (GeV)	$m_{J/\psi L}$ (GeV)
160.5	$63.40\pm0.75$
172.5	$67.21\pm0.66$
184.5	$73.39\pm0.77$

• The steeper the curve the better

→ < ∃→

э

## Comparison to data

• Fit the data with the same shape (Gaussian), extract mean value for  $m_{J/\psi L}$ , apply MC-based calibration



ightarrow Top mass: 166  $\pm$  11 (stat)  $\pm$  26 (calib) GeV

• Within the huge statistic uncertainty the measurement is compatible with 173.18  $\pm$  0.9 GeV (systematics not evaluated)

#### Best-lepton assignment

Methods to **choose one lepton** to pair with the  $J/\psi$ : lower angle wrt  $J/\psi$ 

Any lepton (two entries)







Lower angle lepton (one entry)







Measurement of the top-quark mass using  $J/\psi$ -in-jet candidates Maria Giulia Ratti - Desy SSP 2012

#### Best-lepton assignment: calibration and results

• Measured top mass in data: 168  $\pm$  28 (stat)  $\pm$  36 (calib) GeV



- First time seen  $J/\psi$ -in-jet candidates in CMS  $t\bar{t}$  data
- A preliminary calibration of the  $m_{J/\psi L}$  correlation with the top mass is given, without accounting for systematics
- A very preliminary measurement of the top mass is given:  $166 \pm 11$  (stat)  $\pm 26$  (calib) GeV. The precision is limited by lack of statistics, both in data and in simulations.
- $J/\psi$ -in-jet candidates could be **promising for other searches** and for b-tagging in particular  $(H \rightarrow b\bar{b} \rightarrow J/\psi J/\psi$ ?) at high luminosities

A = 
 A = 
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A
 A