Cross section Measurement of $pp \rightarrow Z+bb$, $Z\rightarrow \ell\ell$ process at CMS

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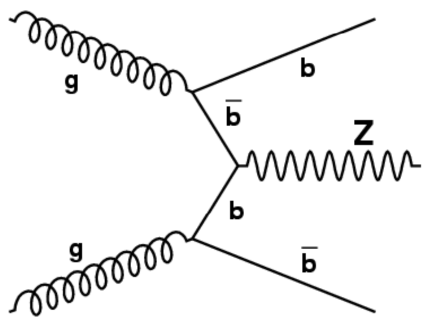
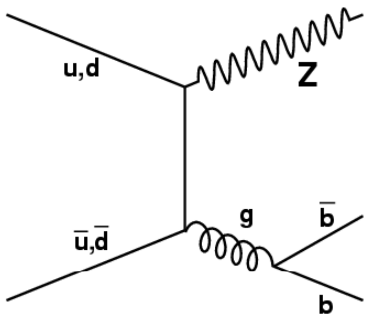
(On behalf of CMS Collaboration)

Introduction

- Measurement of Zbb production is an important test of QCD calculation
- Background to Higgs discovery channels at LHC, like SM $H \to ZZ \to 4\ell$,
  SUSY $bb\Phi$, $\Phi \to \tau\tau$ ($\mu\mu$)
- Z + 1 b-jet has been measured both at CDF & D0
- The possibility of observing and measuring the production of Z + 2 b-jet at LHC has been studied aiming at early 100 pb^{-1} of CMS data.



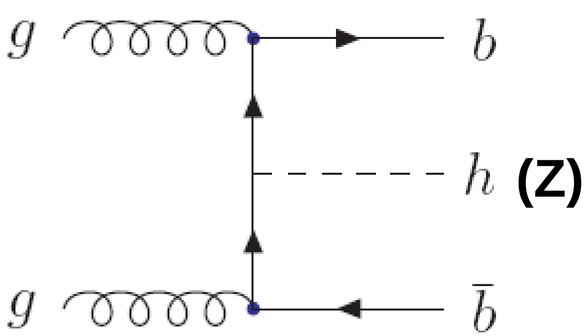
Dominant at LHC



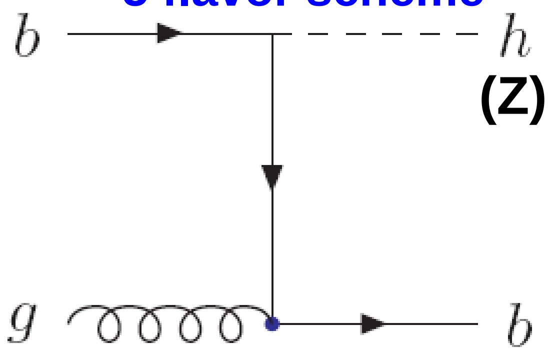
~ 15% of bbZ total σ

bbZ measurement can help reducing uncertainty of bbH cross-section calculation

4 flavor scheme



5 flavor scheme



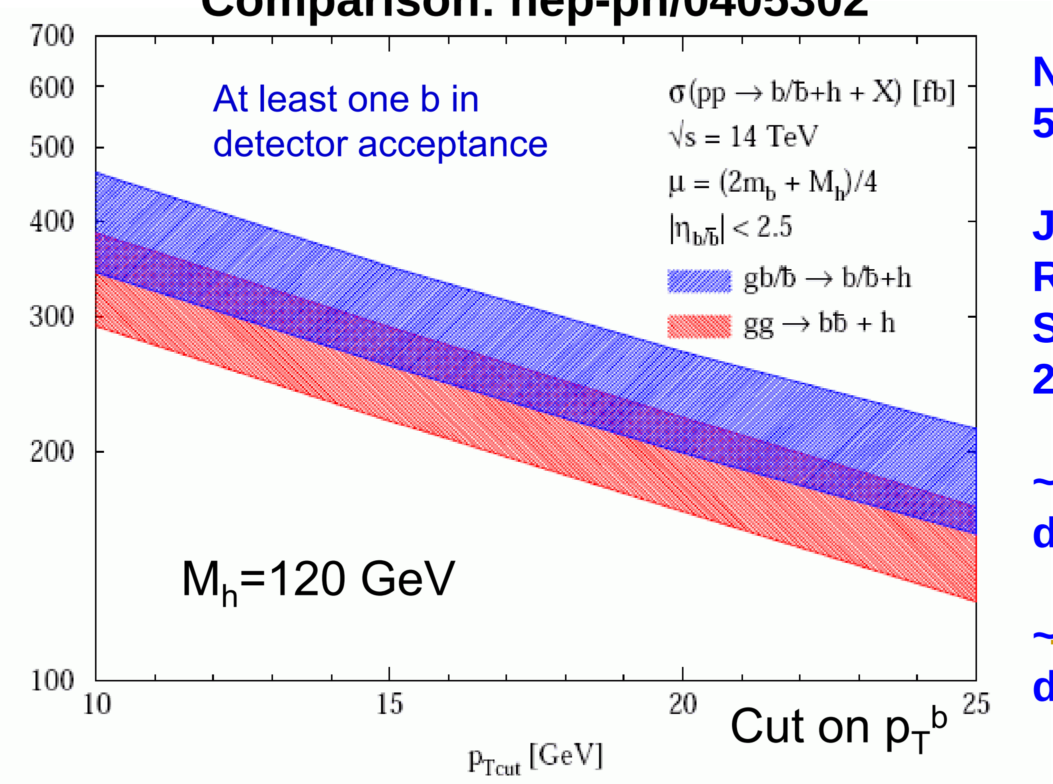
NLO in 4-flavour scheme:

S. Dittmaier,
M. Kramer,
M. Spira
2003

~ 20 % uncertainty due to scale

~10 % uncertainty due to PDF

Comparison: hep-ph/0405302



NLO in 5-flavour scheme:

J. Campbell,
R.K. Ellis, F. Maltoni,
S. Willenbrock
2003

~20% uncertainty due to scale

~10 % uncertainty due to PDF

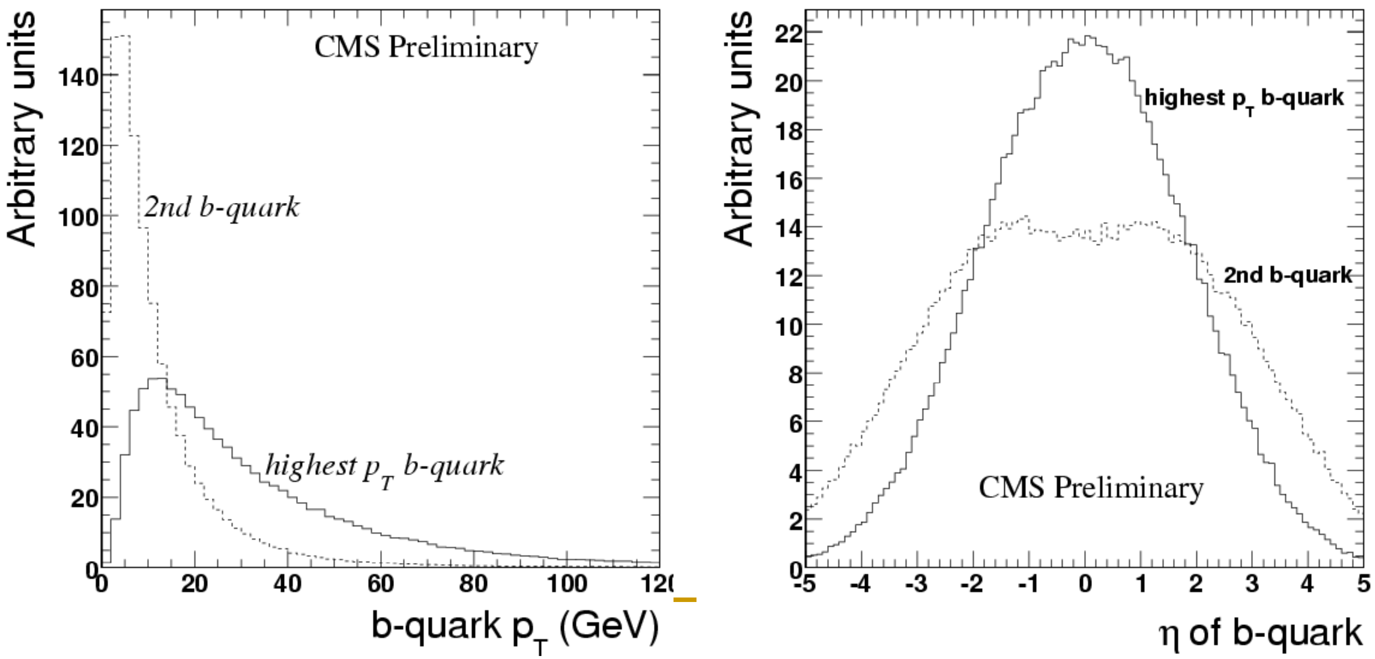
Cross section and Event generation

Signal $\ell\ell bb$ (Zbb) :

CompHEP events with $p_T(b) > 10$ GeV, $|\eta|(b) < 10$, $m_{\ell\ell} > 40$ GeV, $|\eta|(\ell) < 2.5$
were generated and fully simulated in CMS 100 pb^{-1} calibration and mis-alignment

Cross section calculated using MCFM, NLO σ ($\ell\ell bb$) = 45.9 pb , ℓ = e, μ, τ
PDF : CTEQ6M, scale $\mu_R = \mu_F = M_Z$

LO cross section calculated using PDF : CTEQ6L1 and same values for scale K (NLO) = 1.51



Cross section and Event generation

Backgrounds

tt~ + n jets, n >= 0 :
Generated using ALPGEN
Cross section normalized to NLO inclusive tt~ cross section 840 pb

$\ell\ell$cc + n Jets, n>= 0 (Zcc) :
Generated using ALPGEN
Normalized on NLO σ (using MCFM) 13.29 pb, K factor = 1.46 with cuts :
$p_T(c) > 20$ GeV, $|\eta|(c) < 5$, $m_{\ell\ell} > 40$ GeV

$\ell\ell$ + n Jets, n >= 2, (Zjj) :
Generated using ALPGEN
Normalized on NLO σ (using MCFM) 714 pb , K factor = 1.02 with cuts :
$p_T(j) > 20$ GeV, $|\eta|(j) < 5$, $m_{\ell\ell} > 40$ GeV

Initial Event selections:

Trigger selection : single isolated electron or muon

Level-1 threshold 12 GeV, 7 GeV & High-Level threshold 15 GeV, 11 GeV

Corresponds to low luminosity period L = $10^{32} cm^{-2} s^{-1}$

Lepton Selection :

Two high p_T, isolated, opposite charged leptons

$|\eta|(e) < 2.5$, $|\eta|(\mu) < 2.0$,

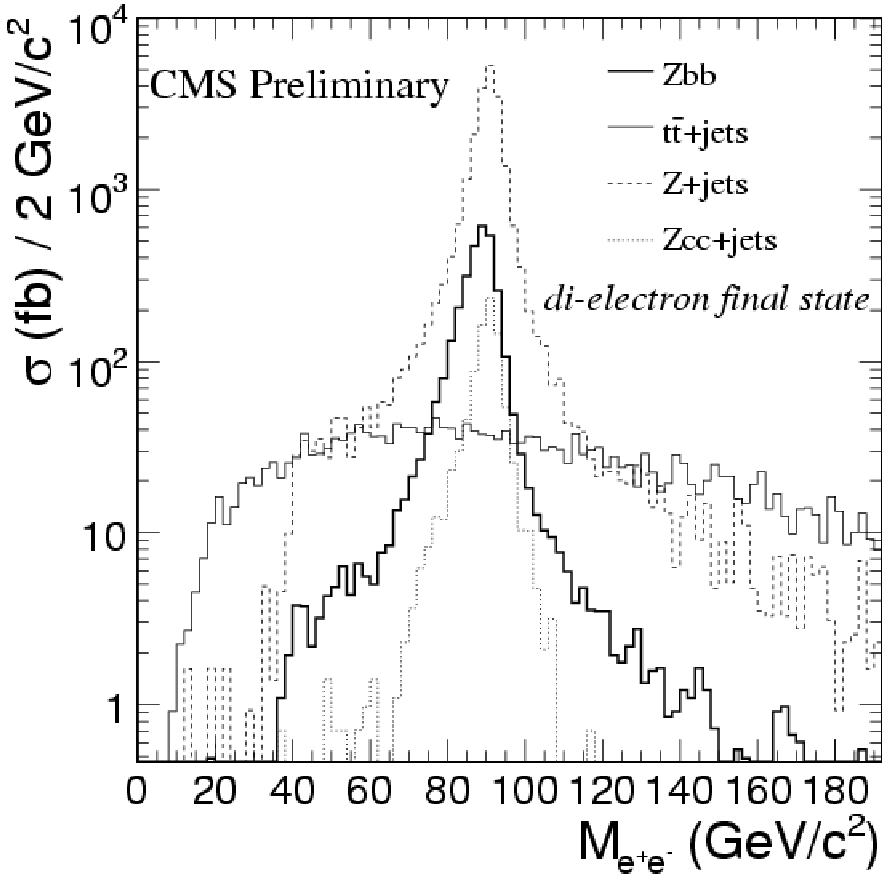
lepton p_T > 20 GeV

Jets Selection :

Two or more jets with corrected E_T > 30 GeV ,

$|\eta| < 2.4$

Jet corrected using Monte Carlo jet energy correction.

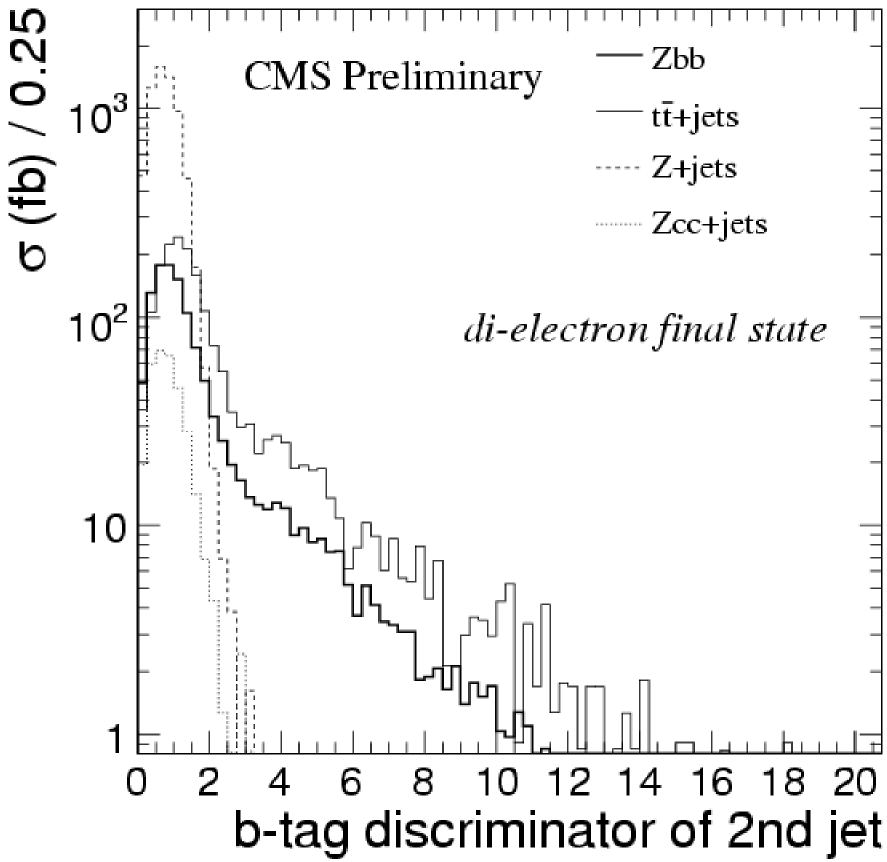


b-Jet Tagging

Lepton, jet selections + double b-tagging with b-discriminator > 0.

b-discriminator of 2nd highest discriminator jet

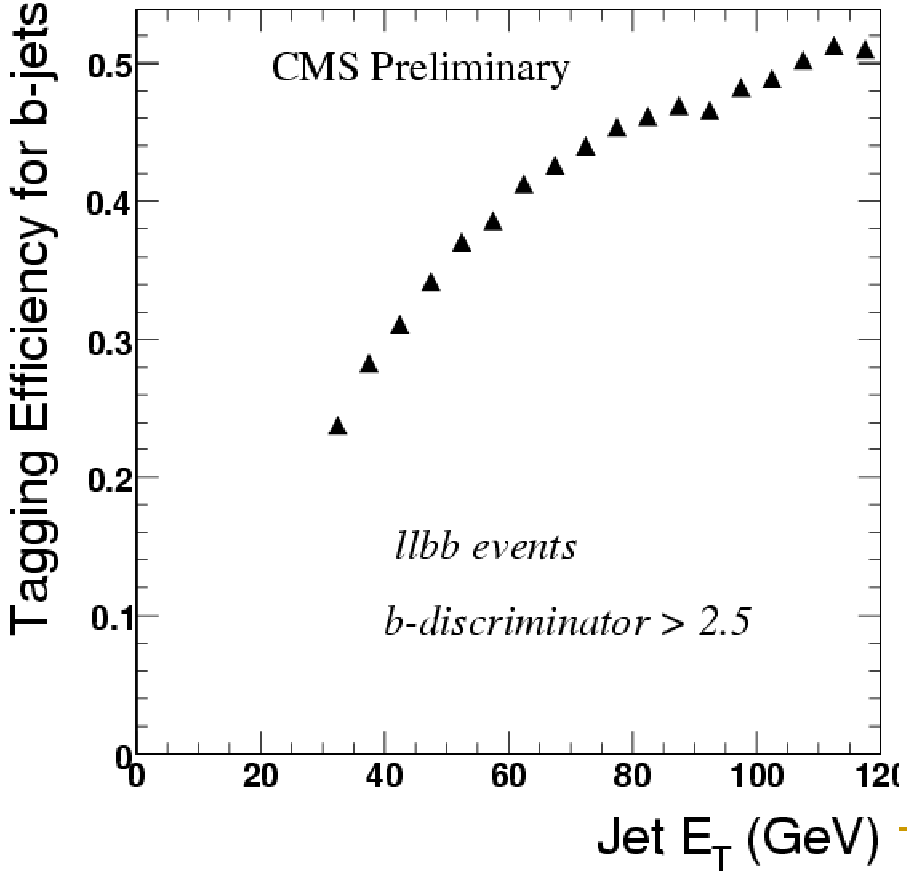
Jets are tagged using
"Track Counting b-tagging"
Which uses the 3-dimentional impact parameter significance , of 3rd highest significance track, as the b-tagging discriminator

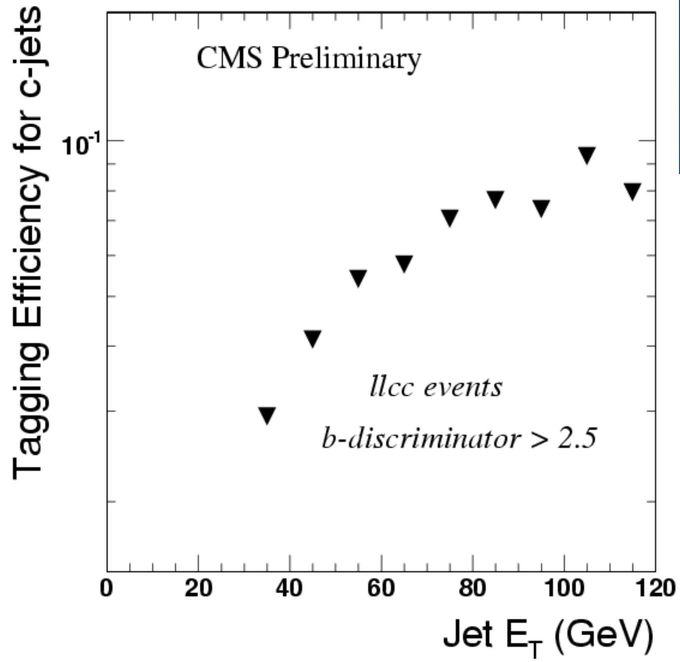


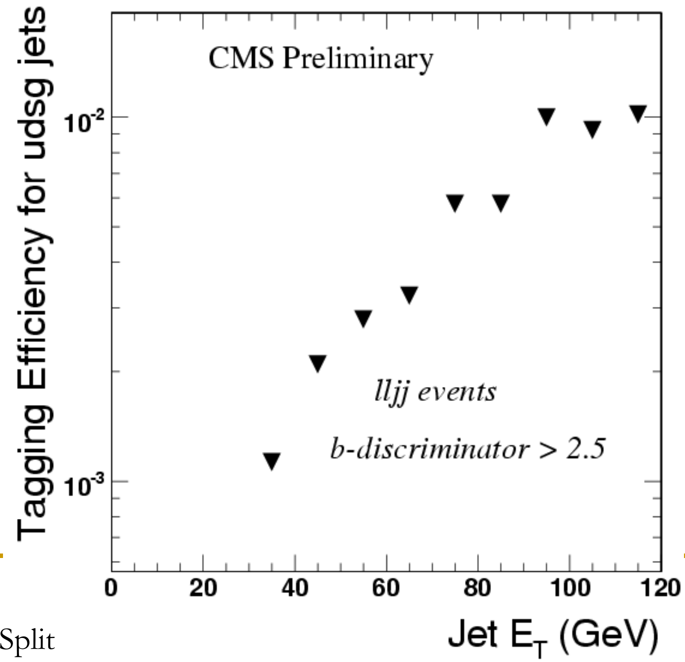
Effective to supress the Z+jets backgrounds.

b-tag efficiency

b-tagging efficiency for b, c, light jets
after applying cut on b-discriminator > 2.5







E_T^{miss} selection

Lepton, jet selections + double b-tagging with b-discriminator > 0

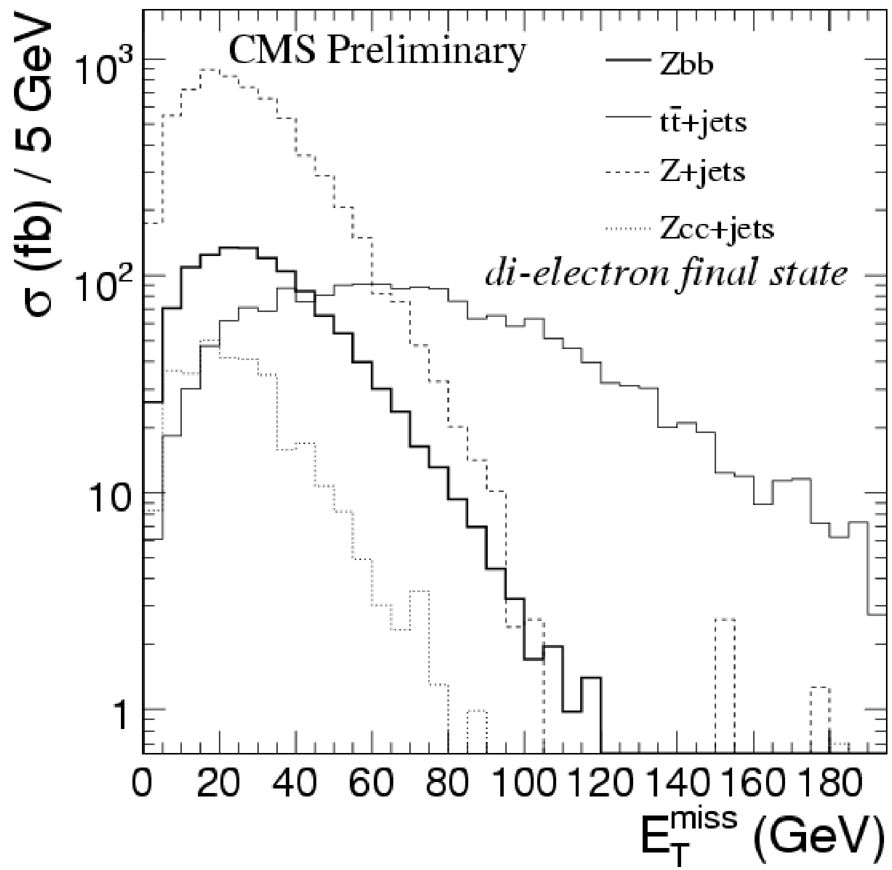
Missing E_T reconstructed from calorimeter and corrected for Jet Energy scale and muons.

Type-1 $E_{Tx,y}^{miss} = -(E_{Tx,y}^{calo} + \Sigma_{jets}(E_{Tx,y}^{corr} - E_{Tx,y}^{raw}))$

Muon corr. $= -(\Sigma_{muons}(p_{x,y} - E_{x,y\ (calo.\ deposit)}))$

Effective to supress the tt~+jets backgrounds

Cut E_T^{miss} < 50 GeV



Event Selection details

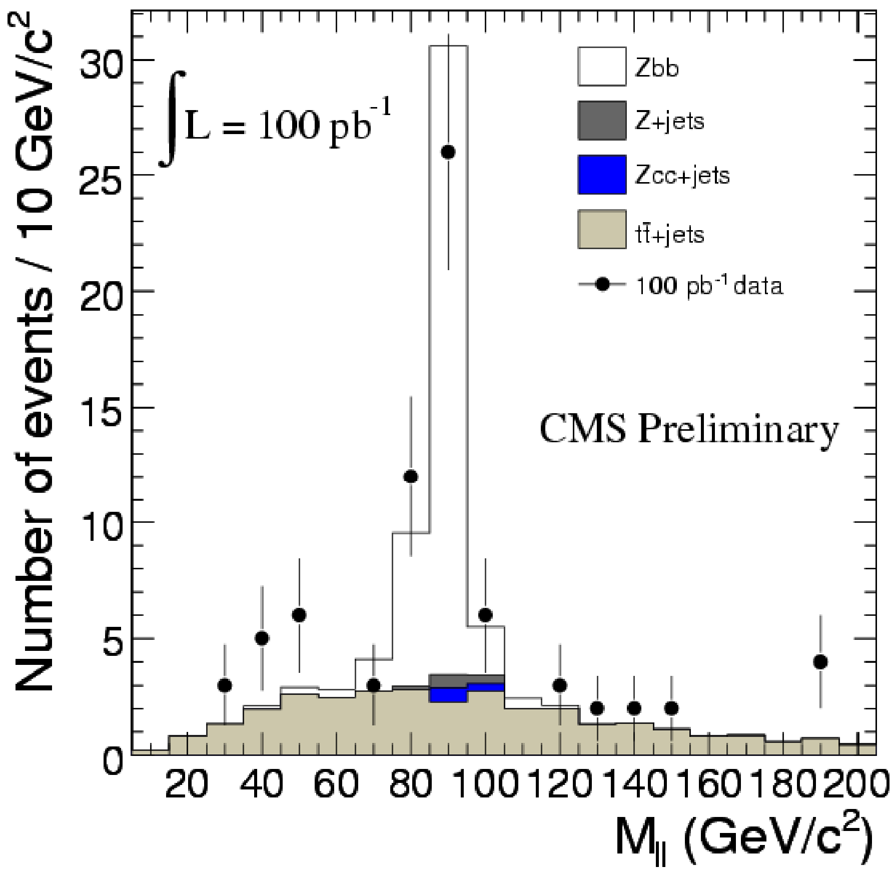
Two Leptons, $p_T > 20$ GeV, $|\eta|(e) < 2.5$, $|\eta|(\mu) < 2.0$
Two or more Jets , $E_T > 30$ GeV , $|\eta| < 2.4$
Two b-tagged Jets
Missing E_T < 50 GeV

Initial and final cross sections after all selections

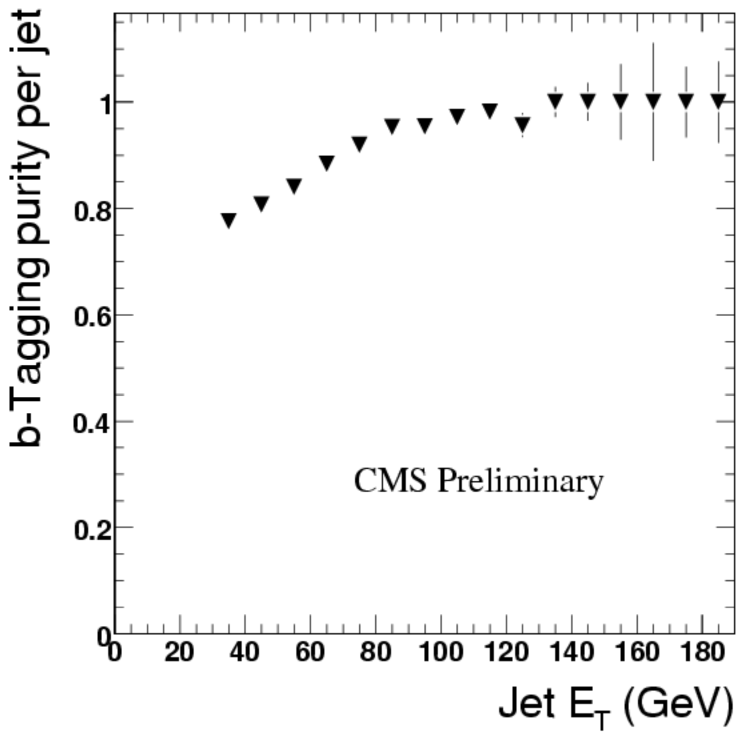
Process Name	σ NLO (pb)	Final σ (fb)	
		Electron	Muon
Zbb	46	176	212
tt~ + jets	840	173	178
Z+jets	714	5.5	5.5
Zcc+jets	13.3	4.3	5.1

Expected Measurement for 100 pb^{-1}

events scaled to 100 pb^{-1}

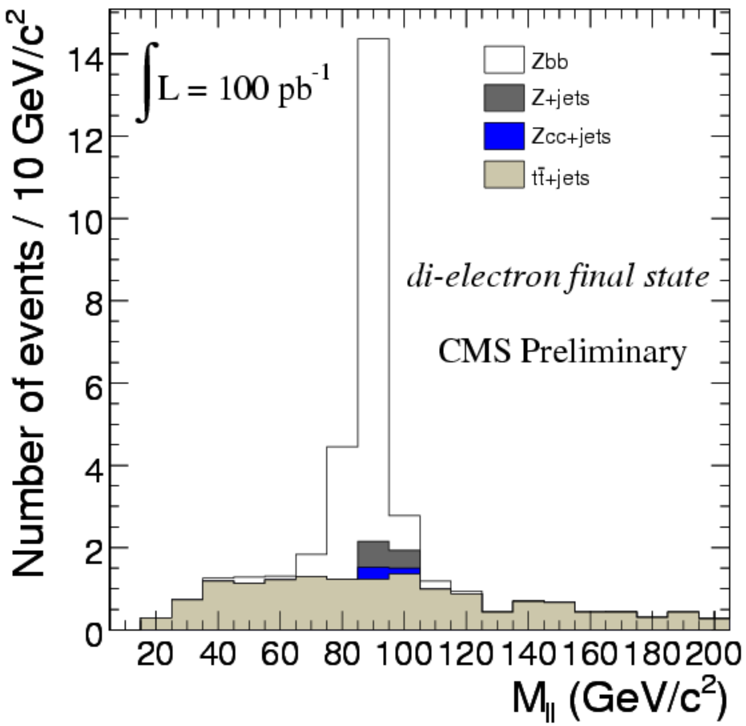


Purity of b-tagging in Zbb events

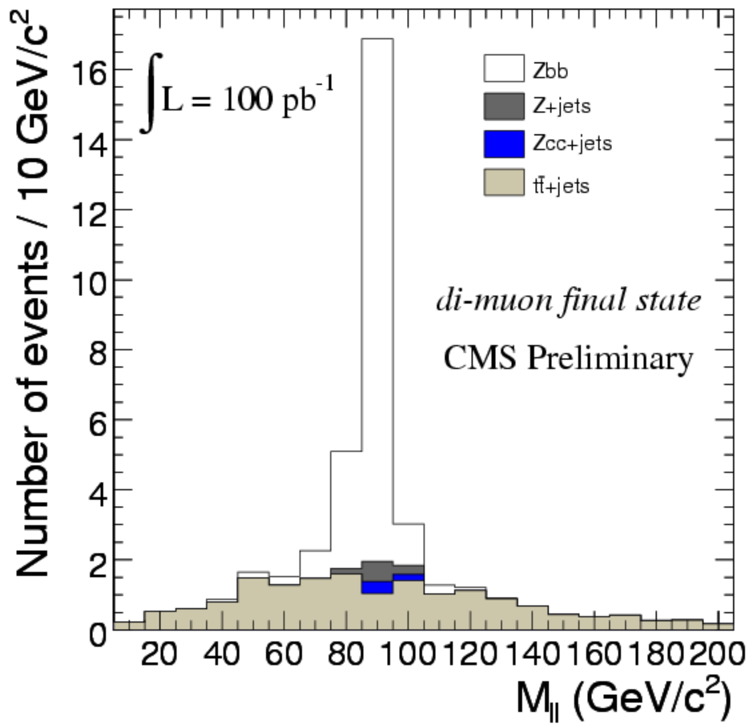


Expected Measurement for 100 pb^{-1}

$Z \rightarrow ee$ final state



$Z \rightarrow \mu\mu$ final state



tt~ background Estimation

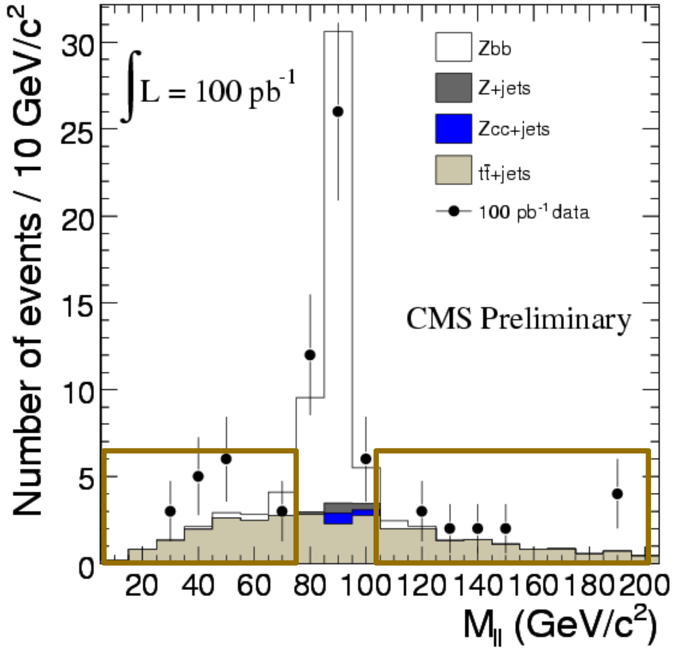
Dilepton mass region

Signal : **75-105 GeV** (Z)

Side band : **0-75 GeV & 105 – above** (no Z)

$$N_Z(tt) = (\varepsilon_Z(tt)/\varepsilon_{noZ}(tt)) \times N_{noZ}(tt)$$

$$\Delta N_Z(tt)/N_Z(tt) = 1/\sqrt{N_{noZ}(tt)}$$



$N_Z(tt)$ = expected no. of tt~ events in signal region

$N_{noZ}(tt)$ = measured no. of tt~ events out side signal region

$\varepsilon_Z(tt)$ = selection efficiency of tt~ in signal region

$\varepsilon_{noZ}(tt)$ = selection efficiency of tt~ outside signal region

$\Delta N_Z(tt)$ = uncertainty of the expected number of tt~ events in the signal region.

Uncertainty on $\varepsilon_Z(tt)/\varepsilon_{noZ}(tt)$ is negligible compared to the statistical uncertainty on N_{noZ}.

Systematics

Uncertainty due to Background and double b-tagging.

N_{Zbb} and ΔN_{Zbb} are determined as follows.

$$N_Z^{before\ b\text{-}tag} = N_{Zjj} + N_{Zcc} + N_{Zbb}$$

$$N_Z^{after\ b\text{-}tag} = \varepsilon_\ell \times N_{Zjj} + \varepsilon_c \times N_{Zcc} + \varepsilon_b \times N_{Zbb}$$

Where,

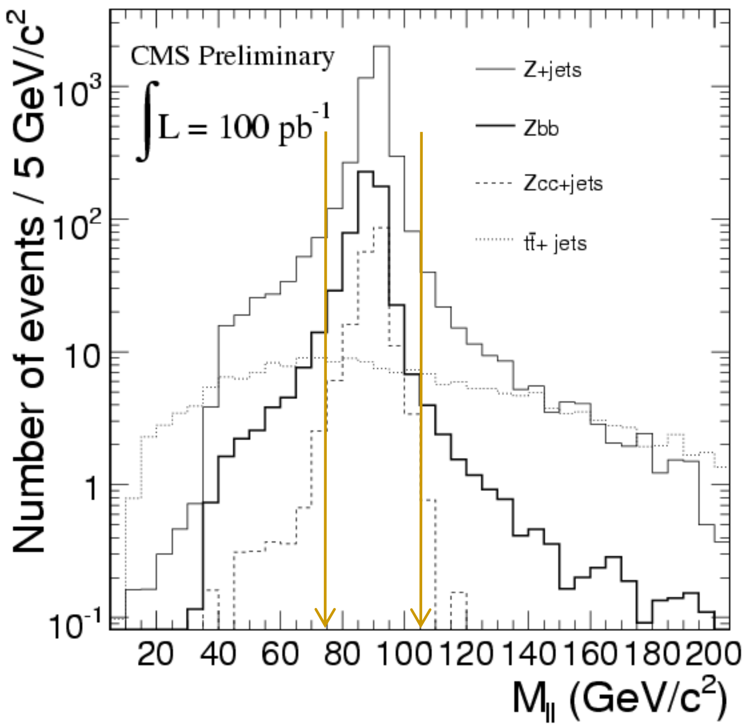
$N_Z^{before\ b\text{-}tag}$ = measured number of $Z/\gamma^* \rightarrow \ell\ell$ events after all selections except b-tagging under Z mass peak (75-105 GeV). Contribution of tt~ is negligible (~1%).

$N_Z^{after\ b\text{-}tag}$ = measured number of $Z/\gamma^* \rightarrow \ell\ell$ events after all selections including b-tagging with tt~ subtracted

N_{Zjj} is unknown number of $\ell\ell$+jets (u, d, s, g) events before double b-tagging.

N_{Zcc} is unknown number of Zcc events before double b-tagging.

N_{Zbb} is unknown number of Zbb events before double b-tagging.



(after all selections except b-tagging)

ε_b, ε_c, ε_ℓ are the efficiency of double b-tagging for Zbb, Zcc and Z+jets events
(Ratio of number of events before and after double b-tagging)

Contd ……

Using D0 analysis approach,
Use the Ratio

$$R = \frac{\sigma(Zcc)}{\sigma(Zjj)} \times \frac{\varepsilon^{sel}_{Zcc}}{\varepsilon^{sel}_{Zjj}} = 0.046 \pm 0.002 \quad (systematics)$$

where $\frac{\varepsilon^{sel}_{Zcc}}{\varepsilon^{sel}_{Zjj}}$ is ratio of selection efficiencies

Solving the equations

$$N_{Zbb} = \frac{N_Z^{after\ b-tag} + R \times N_Z^{after\ b-tag} - \varepsilon_\ell \times N_Z^{before\ b-tag} - \varepsilon_c \times R \times N_Z^{before\ b-tag}}{\varepsilon_b + \varepsilon_b \times R - \varepsilon_c \times R - \varepsilon_\ell}$$

The Uncertainties on N_{Zbb} is calculated from uncertainties of
$N_Z^{after\ b\text{-}tag}$ (uncertainty due to tt~ subtraction),
δR and uncertainties on ε_b, ε_c, ε_ℓ

Total Uncertainty on Measurement

Source of uncertainty	Value used (%)	$\delta(\sigma(Zbb))$ (%)
Jet energy scale (JES)	7	7.6
Type 1 missing E_T scale	10 (unclustered E_T^{miss}) + 7 (JES)	7.4
MC p_T^{jet}, η^{jet} dependence	-10, +0	-10, +0
b-tagging of b-jets ($\delta\varepsilon_b$)	8	16
mistagging of c-jets ($\delta\varepsilon_c$)	8	0.5
mistagging of light jets ($\delta\varepsilon_\ell$)	7.6	0.5
$N_Z^{after\ b\text{-}tag}$ due to tt~ subtraction	4	4.6
R (Zcc / Zjj)	5	0.4
lepton selections	0.5	0.5
luminosity	10	10

Total cross section is expected to be measured in 100 pb^{-1} of data with uncertainty

$\delta\sigma$ = +21%, - 25% (syst.) , +/- 15% (stat.)

Conclusion

- The possibilty to measure the bbZ, $Z \rightarrow \ell\ell$ process at CMS has been studied, aiming the early 100 pb^{-1} of data, with robust selection of leptons and jets.
- Possible methods to measure backgrounds from data has been discussed.
- The statistical and systematic uncertainties has been studied.

backup

Systematics due to JES and MET scale

Uncertainty due to JES :
Calculated by shifting
Jet Energy by 7%
Rel. Uncert. = $(\varepsilon_{max} - \varepsilon_{min})/2\varepsilon$

Uncertainty due to MET scale :
Calculated by shifting Raw MET
unclustered in jets 10% and
corrected Jet energy by 7%
Rel. Uncert. = $(\varepsilon_{max} - \varepsilon_{min})/2\varepsilon$

$$E_{T(x,y)}^{miss.corr} = \alpha_{calo} \times E_{T(x,y)}^{miss.calo} + \Sigma_{jets}(\alpha_{jet} \times E_{T(x,y)}^{jet.corr} - \alpha_{calo} \times E_{T(x,y)}^{jet.raw})$$

$\alpha_{calo} = \alpha_{jet} = 1$ in ideal calibrations.
α_{calo} was varied to 10% and α_{jet} was varied to 7% .

Total systematic uncertainty due to JES is 7.6%

Total systematic uncertainty due to Missing ET scale is 7.4%

Uncertainties due to lepton selections :

total efficiency for lepton $\varepsilon_{total} = \varepsilon^2_{off\text{-}line} \times \varepsilon_{trigger}$

with 10 pb-1 the syst. uncert. of ε_{total} on e^+e^- final state is 1% . (CMS PAS EWK-07-001)

for 100 pb-1 , rescaled by $\sqrt{10}$ => 0.3%

for $\mu^+\mu^-$ the systematic uncertainty is 0.5%

We use 0.5% for both ee and $\mu\mu$ final state.

Uncertainty due to MC p_T and η of jet dependence for signal events

It is defined from the comparison of ratio of LO and NLO MCFM cross sections for different set of cuts on p_T (jet) (10 and 30 GeV) and η (jet) (10 and 2.4).

p_T(jet) > 10 GeV, $|\eta|$(jet) < 10 : CompHEP generator level cuts

p_T(jet) > 30 GeV, $|\eta|$(jet) < 2.4 : experimental like selection cuts

The LO ratio is 10% bigger than the NLO ratio.

Statistical Uncertainty :

Defined as $\Delta N_{sel} / N_{sel} = 1 / \sqrt{N_{sel}}$, where N_{sel} = 46 , measured number of events after all selections.

=> δN_{sel} = 14.7%

$\varepsilon_b = 0.0654$, $\varepsilon_c = 0.0051$, $\varepsilon_\ell = 0.00025$

$N_{Zcc} = R \times N_{Zjj}$

The uncertainty on $\frac{\sigma(Zcc)}{\sigma(Zjj)}$ ratio is +/- 3% due to scale variation around the central value

$\mu_R = \mu_F = M_Z$ from $M_Z/2$ to $2M_Z$

The uncertainty on $\frac{\varepsilon^{sel}_{Zcc}}{\varepsilon^{sel}_{Zjj}}$ due to JES is +/- 1.6% and E_T^{miss} scale is +/- 3.6%

$\delta N_Z^{\text{after b-tag}} = 4\%$, uncertainty on $N_Z^{\text{after b-tag}}$ due to tt~ subtraction.

Uncertainties on $\varepsilon_{b,c,l}$ are approximated as 2X $\Delta\varepsilon_{b,c,\ell}$

$\delta\varepsilon_b = 8\%$ (per jet) (CMS PAS BTV-07-001)
$\delta\varepsilon_c = 8\%$ (per jet) used the same value as for b-jets.
$\delta\varepsilon_\ell = 7.6\%$ (per jet) (CMS PAS BTV-07-002)