

# Study of $pp \rightarrow Z^0 b \bar{b}$ , $Z^0 \rightarrow \mu^+ \mu^-$ at LHC with CMS detector

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- Motivation
- Comparison MC with Data
- Event & Efficiency Selection
- Conclusions and Outlook

# Motivation

## Standard Model process:

- Confirm or constrain theoretical NLO cross-section (1 and 2 b-tags)

## Background process to:

- SUSY (MSSM) Higgs discovery channels  $b\bar{b}\Phi$  where  $\Phi$  is  $h^0, H^0, A^0$
- SM Higgs discovery channel  $H^0 \rightarrow Z^0 Z^0 \rightarrow 4\ell$
- SM Higgs production  $Z^0 H^0 \rightarrow Z^0 b\bar{b}$

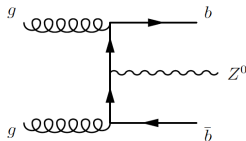
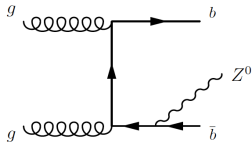
## Previous Studies:

- $Z^0 + 1$  b jet first observed and measured
  - **CDF with  $2 \text{ fb}^{-1}$ :**  $\sigma(p\bar{p} \rightarrow Z^0 + b)/\sigma(p\bar{p} \rightarrow Z^0 + j) = 2.08 \pm 0.33(\text{stat}) \pm 0.34(\text{syst})\%$
  - **DØ with  $4.2 \text{ fb}^{-1}$ :**  $\sigma(p\bar{p} \rightarrow Z^0 + b)/\sigma(p\bar{p} \rightarrow Z^0 + j) = 1.76 \pm 0.24(\text{stat}) \pm 0.24(\text{syst})\%$

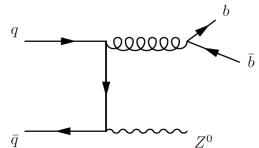
# $Z^0 b \bar{b}$ production at the LHC

- Tree-level Feynman diagrams (subsequently  $Z \rightarrow \mu^+ \mu^-$ )
- Gluon fusion dominant at LHC
- Quark fusion  $\sim 15\%$  total  $Z^0 b \bar{b}$
- Ongoing calculation for at least 1 b-tagged jet @ 7 TeV

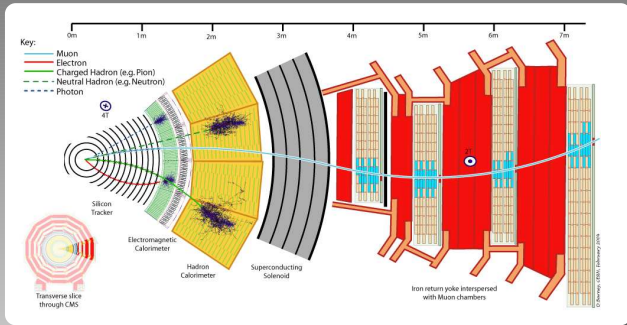
## $gg \rightarrow Z^0 b \bar{b}$



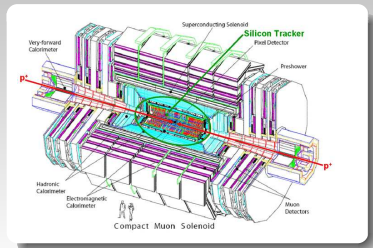
## $q\bar{q} \rightarrow Z^0 b \bar{b}$



# The CMS Detector



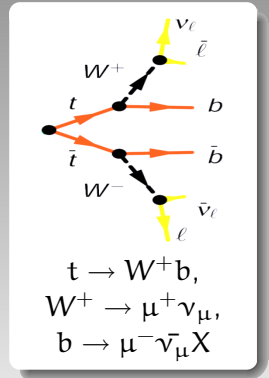
- Tracker - track parameters
- Muon Detection System - muon identification
- Calorimeter - jets and missing transverse energy (MET)



# Background processes

- **Top pair production:**  $t\bar{t}$
- **Drell-Yan  $Z^0/\gamma^* \rightarrow \mu^+\mu^-$  in association with:**
  - $Z^0 q\bar{q}$  ( $q = u, d, s$ )
  - $Z^0 c\bar{c}$
- **Other Backgrounds:**
  - $Z \rightarrow \tau\tau$ ,
  - $W \rightarrow \mu\nu$ ,
  - $WW, WZ, ZZ$
  - and QCD

Needed for Lepton Selection  
After b-tagging selection  
 $\Rightarrow$  negligible contribution



# Tools and Monte Carlo Samples

## Data:

- Used  $\int \mathcal{L} dt \approx 35 \text{ pb}^{-1}$  (CMS validated runs)

## Full Simulation:

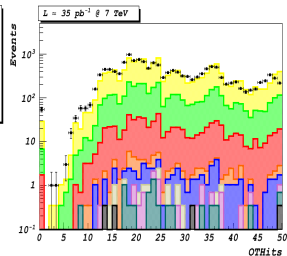
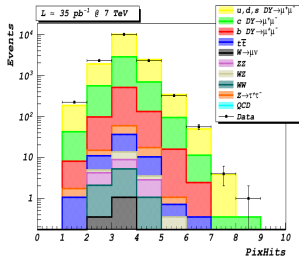
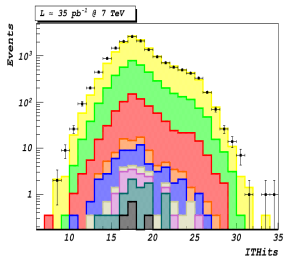
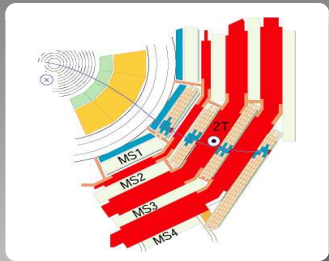
- Monte Carlo Events generated for  $\sqrt{s} = 7 \text{ TeV}$  using CMS production software
- Number of Events corresponding to  $\int \mathcal{L} dt \approx 100 \text{ pb}^{-1}$
- Drell-Yan:  
POWHEG&PYTHIA6 with  $M_{\mu\mu} > 20 \text{ GeV}$ ,  
 $\Rightarrow \sigma_{\text{NLO}} = 1614 \text{ pb}$
- $\sigma_{\text{NLO}}^{b\bar{b}Z} = 52 \text{ pb}$ ,  $\sigma_{\text{NLO}}^{c\bar{c}Z} = 382 \text{ pb}$ ,  $\sigma_{\text{NLO}}^{q\bar{q}Z} = 1180 \text{ pb}$
- $t\bar{t} \rightarrow 2l2\nu2b$   
POWHEG&PYTHIA6  $\Rightarrow \sigma_{\text{NLO}} = 15.86 \text{ pb}$

# Physics Objects Reconstruction: Muons

Only **Muons** with segments in the Muon System matched to the correct track segments in the Tracker considered

**Good quality muon track:** Number of Hits in Pixels, Strip tracker, Muon System

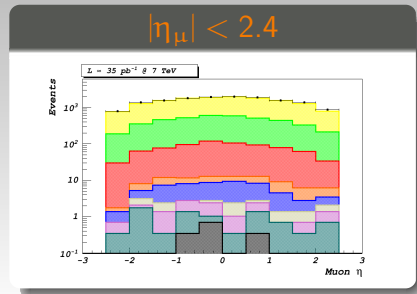
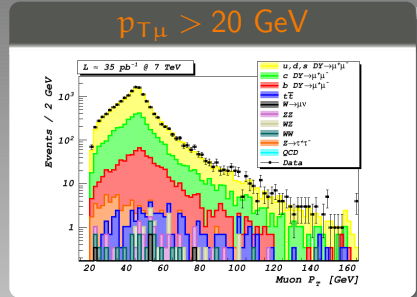
**Triggers:** Events with muons with  $p_T > 9, 11, 15$  GeV



# Muon Selection

## Selection Criteria:

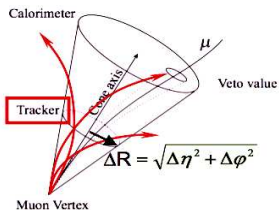
- $Q_{\mu_1} \cdot Q_{\mu_2} < 0$
- $|d_{xy}| < 0.2$  cm, Avoid cosmics
- **Kinematics:**
  - Two muons with highest  $p_T$
  - $p_{T\mu} > 20$  GeV,  
Reduce backgrounds with fake muons (e.g. QCD)
  - $|\eta_{\mu}| < 2.4$ ,  
Best Tracker acceptance





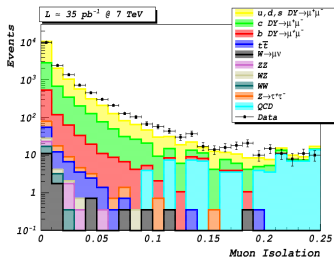
# Muon Isolation

## Track&Calo-based

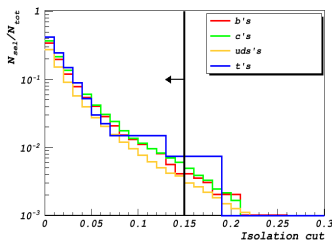


- Consider tracks within cone around muon candidate
- Relative Isolation  
 $(\text{ISO}_{\text{TRK}} + \text{ISO}_{\text{ECAL}} + \text{ISO}_{\text{HCAL}}) / p_{T\mu} < 0.15$

## Isolation



## Efficiency vs Isolation



# Finding the Z peak

## Candidates

- $Z^0 \rightarrow \mu^+ \mu^-$ :

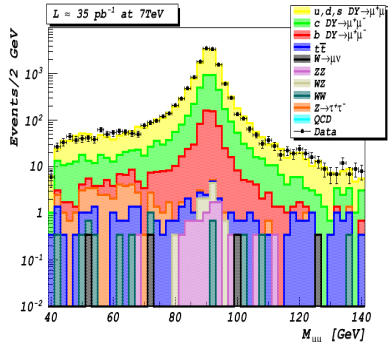
Mass window:

$$60 \text{ GeV} < M_{\mu\mu} < 120 \text{ GeV}$$

Observed:  $14315 \pm 120$ ,

MC:  $14017 \pm 118$

## Invariant Mass



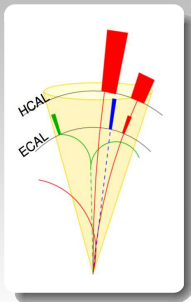
## Efficiency:

$b(\bar{b})\text{DY}$ : **81.1%**,  $c(\bar{c})\text{DY}$ : **83.3%**,  $q(\bar{q})\text{DY}$ : **85.2%**,  $t\bar{t}$ : **39.3%**

# Physics Objects Reconstruction: Jets

## Particle Flow:

- Information from all subdetectors
- Identify all particle candidates (4-vectors)
- Create a list of particles
- Input of jet clustering & MET reconstruction

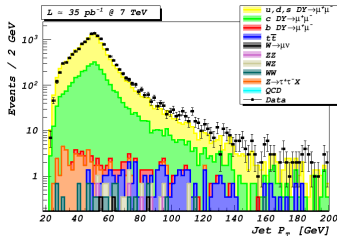


## Selection Criteria:

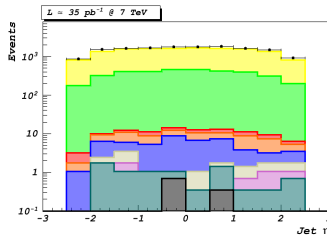
Anti- $k_T$  Algorithm:  
( $\Delta R = 0.5$ )

- at least one jet
- $p_{T,jet} > 25$  GeV
- $|\eta_{jet}| < 2.5$
- MET < 40 GeV

$p_T > 20$  GeV



$|\eta| < 2.4$

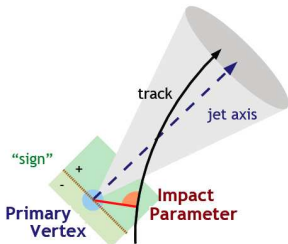


# b-jet Identification

## b-jets:

- different properties from those of lighter flavour quarks (large lifetime & mass, high decay multiplicity etc)

## Several algorithms exploiting different b-quarks features



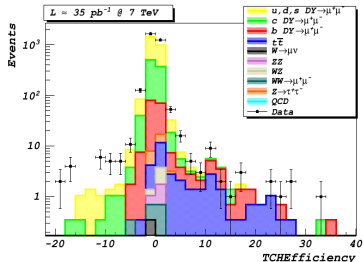
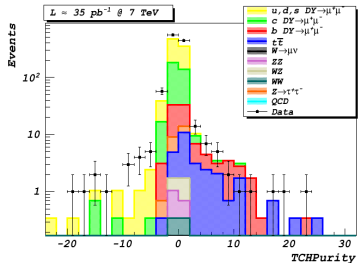
## "TrackCounting" algorithm:

- Sort tracks in jet by descending Significance of the Signed Impact Parameter (SIP)
- Select  $n^{\text{th}}$  track:
  - $2^{\text{nd}}$  track  $\rightarrow$  "high efficiency" tag
  - $3^{\text{rd}}$  track  $\rightarrow$  "high purity" tag

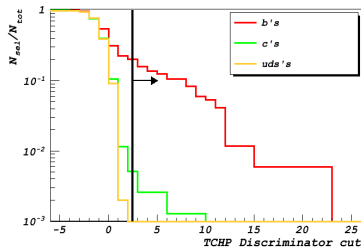
Discriminator = SIP Significance of chosen track

# Including the Discriminator

## TCHP & TCHE



## Efficiency vs Discriminator



- $b\&t$ – jets have larger tails towards higher values
- Discriminator  $> 2.5$ : helps removing light quark bkg

# Final Invariant Mass

Invariant Mass ( $\int \mathcal{L} dt \approx 35 \text{ pb}^{-1}$ )

First to be  
approved by CMS

Selection	Processes [%]			
	$Zbb$	$Zcc$	$Zuds$	$tt$
Charge	98.6	99.8	87.9	84.6
$p_{T_\mu} > 20 \text{ GeV}$	97.6	98.9	98.7	83.7
$iso_\mu: < 0.15$	81.1	83.3	85.2	39.3
$p_{T_{jet}} > 25 \text{ GeV},  \eta_{jet}  < 2.5$	80.7	83.1	85.0	37.6
TCHP Discriminator $> 2.5$	1.45	0.04	0.00	4.27

## Number of Candidates

$b(\bar{b})DY$ : 11,  $c(\bar{c})DY$ : 1,  $q(\bar{q})DY$ : 0,  $t\bar{t}$ : 1, ██████████

# Conclusions and Outlook

- $Z^0 b \bar{b}$  analysis for the first  $35 \text{ pb}^{-1}$  LHC data was presented
- Cross section of  $Z^0 + 1 \text{ b-jet}$  in preparation
- Agreement between Data and MC for various variables and Invariant Mass
- Systematic errors under study
- Ongoing study of the data driven methods for bkg estimation