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Vrije Universiteit Brussel

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Search for Single top tW associated production in the dilepton decay channel at CMS

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Introduction

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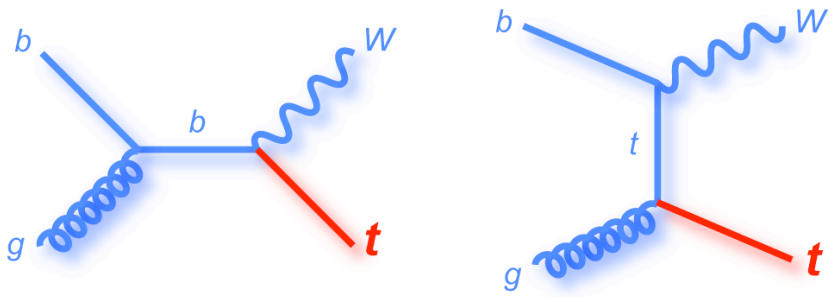
- The first step towards the experimental study of the tW associated Single Top quark at CMS:
  - Too difficult at the **Tevatron**, with no results from **CDF** and **D0**
  - At the **LHC**, **ATLAS** has public results with **2010 and 2011** data (upper limits in the cross-section)

- Has a very interesting signature:
  - important background to **Higgs searches** (H→WW)
- The observation of the process leads to more physics:
  - Measuring EW properties of the top-quark:

    $\mathbf{V_{tb}}$ CKM matrix element, Wtb vertex
  - Sensitive to **BSM** processes, can be used to constrain the Standard Model rate assuming lepton universality, etc.

tW dilepton topology

- The tW leptonic final states (**ee/eμ/μμ**) are studied:

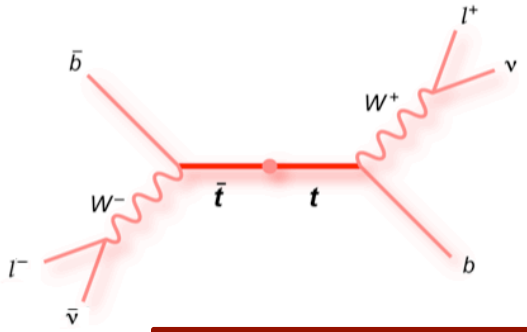


Signal Signature:

2 opposite sign isolated leptons
Missing E_T (2 neutrinos)
1 jet (from a b-decay)

- All the processes able to produce similar signatures are background sources:
  - **ttbar** (dominant background), **Z+jets** **(ee/μμ)**, EWK di-boson production (**WW**, **WZ**, **ZZ**), **W+jets**, other **single top** processes (**s** & **t** channel) and **QCD**

Process	Cross-section
tW	15.6±0.4+1.0-1.2 pb (app. NNLO)
tt	163±14 pb (app. NNLO)
Z+jets	3048±132 pb (NNLO)



B.R. (t→Wb) ≈ 1

Analysis Flow I

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- **HLT Triggers: 2.1 fb^{-1}** of data passing dilepton triggers
  - collected before September 2011
- **Primary Vertex cut:** Minimum of 1 primary vertex with 4+ tracks, within 24 cm of detector center
- **Lepton Selection:** exactly two isolated leptons with opposite charge
- **Invariant Mass and MET cuts:**
  - **All** final states: $m_{ll} > 20$ GeV
  - Events inside the Z-mass window [81, 101] rejected (**ee/μμ**)
  - Missing $E_T > 30$ GeV (**ee/μμ**)

Drell-Yan background
(also other Z processes and QCD)

- **Jet Selection:** Require exactly 1 jet, which is b-tagged

Analysis Flow II

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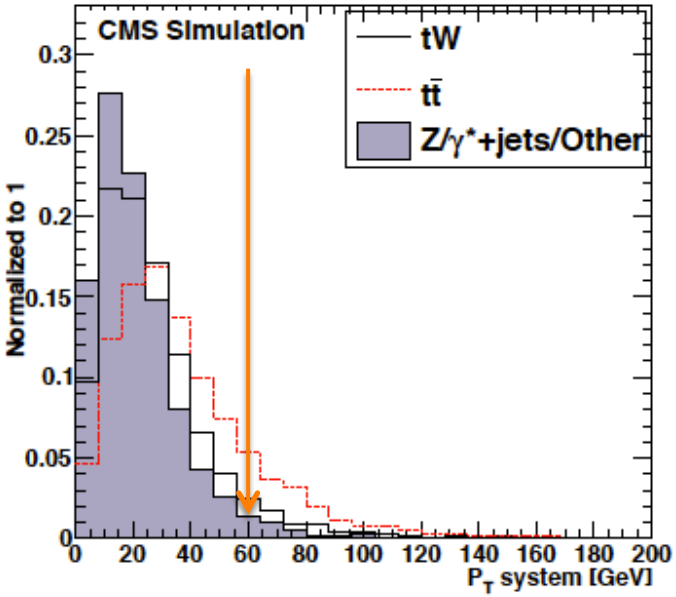
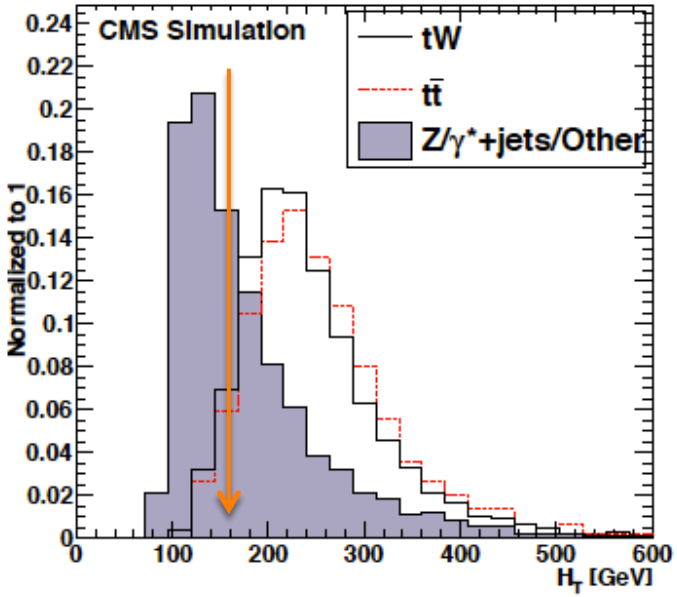
- **Extra kinematical cuts:** applied to maximize the signal significance after b-tagging, applied in:
  - P_T of the system (leptons + jet + MET) < 60 GeV
  - H_T (**eμ** only) > 160 GeV





Normalised kinematic distributions in the signal region eμ final state

DY Background estimation

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- **WW, WZ, ZZ, W+jets, QCD** and other **single top** contributions **taken from Monte Carlo**

- In the **signal region**, **Drell-Yan** is a main background (**ee/μμ**), and is estimated from events in/out of the Z-mass window in data:

$$N_{ll,out}^{estimated} = \frac{N_{ll,out}^{MC}}{N_{ll,in}^{MC}} \left(N_{ll,in}^{observed} - \frac{1}{2} k \cdot N_{e\mu,in}^{observed} \right)$$

- The calculated estimates and MC yields are as:

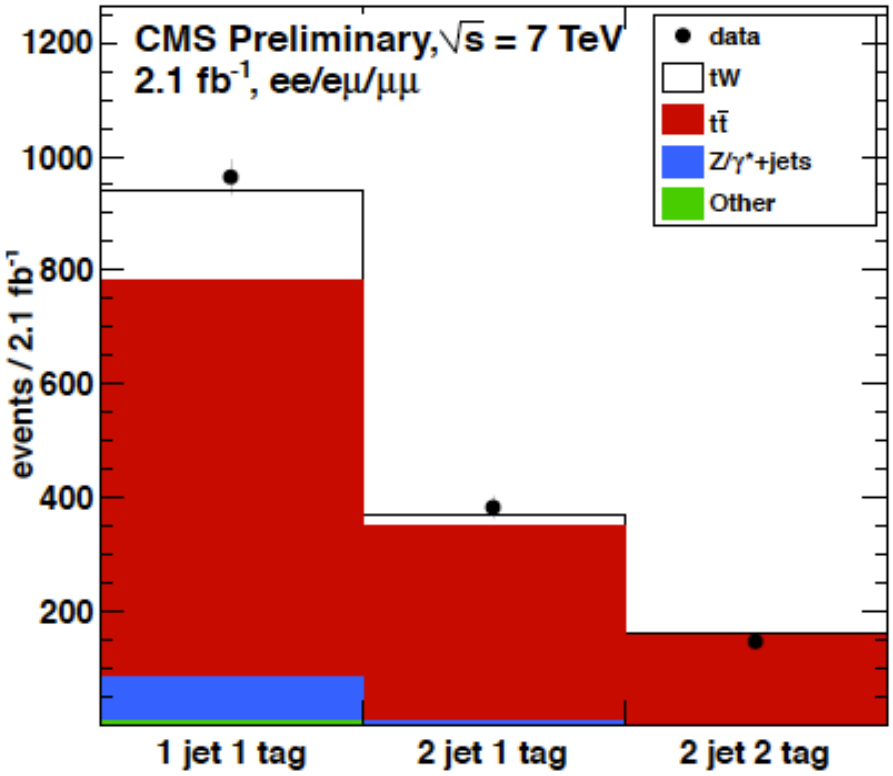
	ee channel	*μμ* channel
Data-driven estimate	20.7 ± 3.9	45.7 ± 6.1
Estimated from simulation	12 ± 2	26 ± 3

Uncertainty associated 50% (conservative)

- For the eμ final state, the simulation yield is scaled to match the data by a factor derived from the ee and μμ final states:
  - 10.4 ± 2.2 events (6.0 ± 1.3 in simulation)

TT control regions

- Two tt enriched control regions considered **in the statistical fit**
  - 2 jets and 1 b-tag
  - 2 jets and 2 b-tags
- Constrain tt contamination and b-tagging efficiency
- Drell-Yan in ee/μμ from data-driven estimate
- tt contribution scaled to statistical fit outcome



"Other" = WW, WZ, ZZ, single top t/s channel, W+jets and QCD

Systematics

Rate systematic uncertainties for the three final states in the signal region, presented in percentage

Systematic uncertainty ($ee/e\mu/\mu\mu$) [%]	signal tW	$t\bar{t}$	$Z/\gamma^{\star}$	other
Luminosity	4.5	4.5	-	4.5
Pile-up multiplicity	0.48/0.55/0.73	$\star$	-	$\star$
Trigger Efficiency	1.5	1.5	-	1.5
Muon reconstruction and identification	- /1/1	- /1/1	-	- /1/1
Electron reconstruction and identification	2/2/ -	2/2/ -	-	2/2/ -
JES	$^{-2.5}_{+1.6}$ / $^{-2.4}_{+0.1}$ / $^{-0.6}_{+1.0}$	$^{-5.6}_{+4.4}$ / $^{-6.0}_{+4.7}$ / $^{-5.9}_{+2.3}$	-	$\star$
JER	1.1/0.5/0.4	3.1/3.9/4.4	-	$\star$
B-tagging	$^{-9.5}_{+10}$ / $^{-9.8}_{+9.8}$ / $^{-9.5}_{+10}$	$^{-8.5}_{+10}$ / $^{-11}_{+10}$ / $^{-9.1}_{+11}$	-	$\star$
Factorization/Normalization Scale (Q^2)	7.7/6/10	7.7/11/12	-	$\star$
ME/PS matching thresholds	-	5.7/0.7/2.3	-	$\star$
ISR/FSR	-	8.9/7.3/7.3	-	$\star$
DR/DS scheme	8.2/9.1/6.6	-	-	$\star$
$E_{\mathrm{T}}^{\mathrm{miss}}$ modeling	2.3/0.9/0.9	$\star$	-	$\star$
PDF uncertainties	4.5/4.5/4.5	$\star$	-	$\star$
Background Normalization	-	15/15/15	50/ 50/ 50	$\star$
Simulation statistics	3.5/1.9/2.7	-	-	17/21/11

("-" doesn't apply and "★" for negligible contributions)

Statistical Interpretation & Result

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- Evaluation uses a statistical model of Poisson event counts in the three final states (ee/eμ/μμ)
- Systematic uncertainties included as nuisance parameters
  - as in other multi-channel counting experiments
- tt contribution estimated simultaneously, by including tt enriched regions in the model
- Significance calculated using background-only distribution of the likelihood ratio, and the 68% confidence level interval evaluated using the profile likelihood method

Observed significance: **2.7 σ**
Expected significance: **1.8 ± 0.9 σ**

Cross section value and 68% C.L. interval: **22 +9/-7 (stat + syst) pb**

Summary

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- First indications of the **tW production in CMS in the dilepton channel** (ee, eμ and μμ final states) using **2.1fb^{-1}**
- Main background: **tt**
- also important **Drell-Yan** (data-driven)
  - Minor contribution from other backgrounds (WW/WZ/ZZ, W+jets, QCD etc)
- All the sources of systematic uncertainties addressed

Observed (expected) significance: **2.7 σ (1.8 ± 0.9 σ)**

- Cross-section measured at the same time, value and 68% C.L. interval:

22 +9/-7 (stat + syst) pb

CMS-TOP-11-022

The Future…

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- Follow-up analysis using full 2011 data set almost complete – **4.9 fb^{-1}**
- Multivariate techniques being implemented to improve the significance of the result
  - Boosted Decision Tree method to be published with revised cut & count as a cross check
  - Linear Likelihood analysis presented as an internal cross check
- A new 8 TeV integral cross-section analysis is to be made using 2012 data

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Backup slides

Leptons, Jets and MET

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- Leptons, jets and missing ET reconstructed by the Particle Flow (PF) algorithm:

  a global event reconstruction identifying particles as electrons, muons, charged and neutral hadrons or photons

Muons:
- Reconstructed from Track and Muon Chambers
- $P_T > 20$ GeV
- $|\eta| < 2.4$
- Standard CMS requirements on number of hits, isolation & quality of reconstructed track

Electrons:
- Reconstructed from ECAL energy deposits matched to tracker hits
- $E_T > 20$ GeV
- $|\eta| < 2.5$
- shower shape and track-cluster matching used to reject fakes
- Further quality cuts on the impact parameter, isolation, etc

Jets:
- Anti-kt jets (0.5)
- Corrected $P_T > 30$ GeV
- $|\eta| < 2.4$
- Standard Jet ID criteria applied
- $\Delta R_{\text{jet-lepton}} < 0.3$

B-tagging:
- Algorithm reconstructs decay vertex and requires a minimum # of tracks: Simple Secondary Vertex

MC/data distributions

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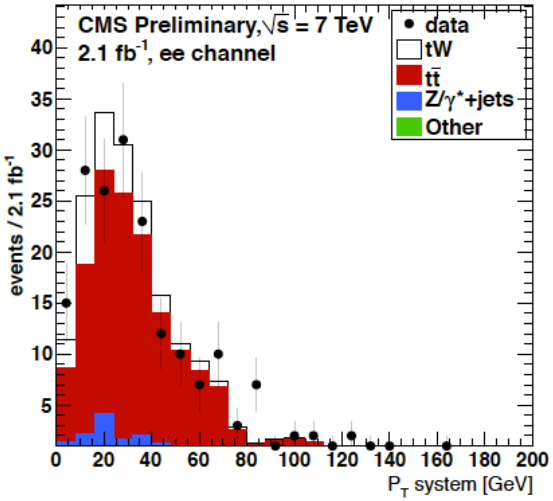

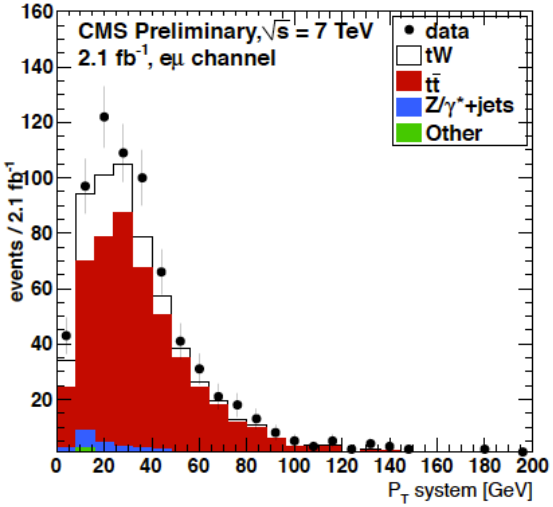

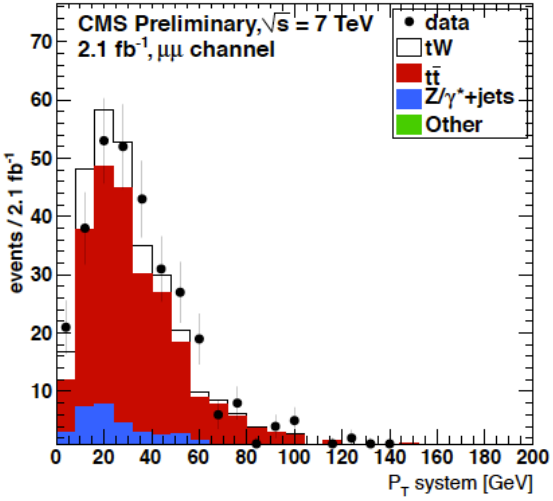

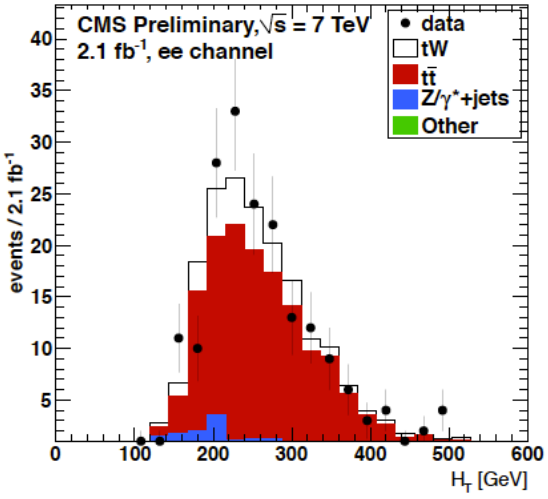

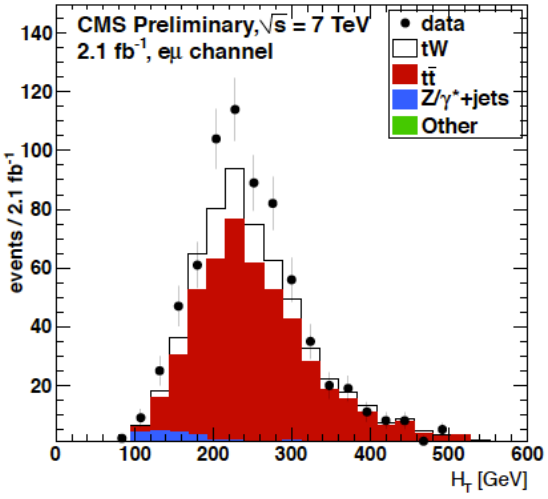

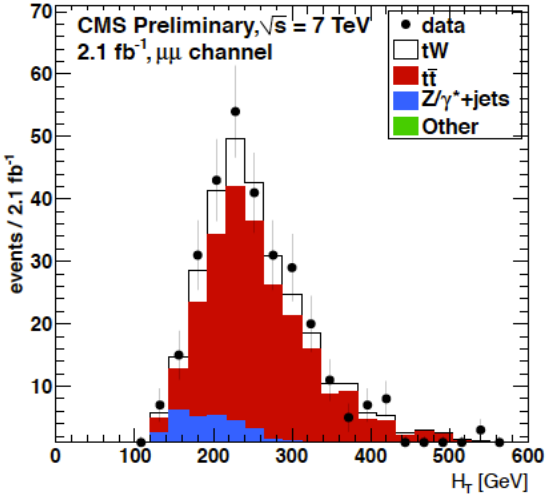

Systematics I

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The main sources of systematic errors, and methods used to estimate them:

- **Luminosity:** Luminosity measurement at CMS (4.5%)
- **Pile Up multiplicity:** Official Pile-up reweighting applied to the Monte Carlo, shifted by ±0.6 to estimate the systematic
- **Trigger Efficiency/Lepton reconstruction and identification efficiency:** Systematic taken directly from other dilepton analysis with similar selections (TOP-11-005/HIG-11-003)
- **MET modeling:** Scaling ±10% the un-clustered components of the MET
- **Jet multiplicity and jet energy scale (JES):** Shifting the jet energy correction (JEC) one standard deviation up/down, including the MET

Systematics II

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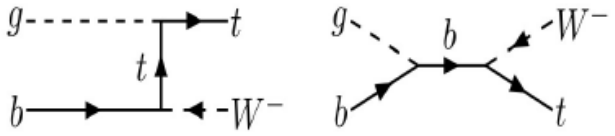
- **Jet energy resolution (JER):** The JER is worse in data, everything should be corrected by 10%, and to estimate the uncertainty, 0% for JER- and 20% for JER+ (small effect, taken as a systematic only)
- **B-tagging:** Varying the b-tagging scale factor 0.95 by ±10%
- **Background Normalization:** Depends on the background, for DY, 50% comes from the data-driven estimation, for the rest backgrounds come from theory (uncertainty in the cross-section)
- **PDF uncertainties:** alternate weights for each event are produced using different pdf sets
- **Factorization/Normalization Scale (Q2):** Dedicated Samples (Fall10 for tt/ Summer11 for signal)
- **ME/PS matching thresholds:** Dedicated Samples (Fall10 tt)
- **[Initial and final state radiation (ISR/FSR):** Dedicated Samples (Fall10 tt)**]**
- **DS/DR scheme:** Difference between the DR (default) and DS signal samples
- **Monte Carlo statistics:** Related to the size of the samples

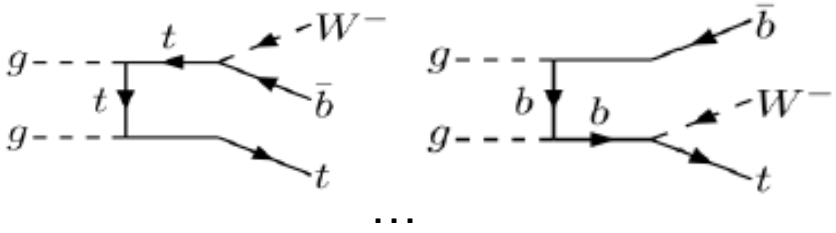
Diagram Removal and Subtraction

The definition of the tW process in perturbative QCD mixes with top-pair production (tt) at NLO, and poses conceptual problems

LO



NLO



Two different solutions

-**The "diagram removal" approach (DR):** all ambiguous diagrams at NLO are excluded from the definition of signal (*__chosen as default in the analysis)__

- **The "diagram subtraction" approach (DS):** subtracts a gauge-invariant term, cancelling locally the contribution of tt diagrams

* Although they don't behave in an identical way, the differences of using one or another Monte Carlo are small at the end of the analysis chain; taken as a **systematic**

Leptons, Jets and MET

Muons:
- Global Muon and Tracker Muon
- p_T > 20 GeV
- |η| < 2.4
- χ^2/ndof < 10
- number of tracker hits > 10
- |d0| < 0.02 cm
- PF iso (ΔR 0.3) < 0.15

Loose Muons:
- p_T > 10 GeV, |η| < 2.5
- PF iso (ΔR 0.3) < 0.2

Electrons:
- E_T > 20 GeV
- |η| < 2.5
- |d0| < 0.02 cm
- $|Z_e - Z_{PV}| < 1$
- WP70
- number of missed inner layers = 0
- partner track conversion veto (0.02,0.02)
- PF iso (ΔR 0.3) < 0.15

Loose Electrons:
- E_T > 15 GeV, |η| < 2.5
- WP95
- PF iso (ΔR 0.3) < 0.2

Data-driven scale factors for the lepton identification & isolation (PAS **TOP-11-005**): 0.947±0.002/0.968±0.003/0.990±0.001 in μμ, ee, and eμ final states

Jets:
- Anti kt 0.5 PF jets
- Corrected PT > 30 (20) GeV
- Jet ID applied
- $\Delta R_{jet\text{-}lepton}$ < 0.3

B-tagging *:
- SSVHEM (disc. > 1.74)

Missing Et:
- Particle Flow

*uncertainty on b-tagging SF (PAS **BTV-11-001**): 0.95±0.01(stat)±0.10(sys)