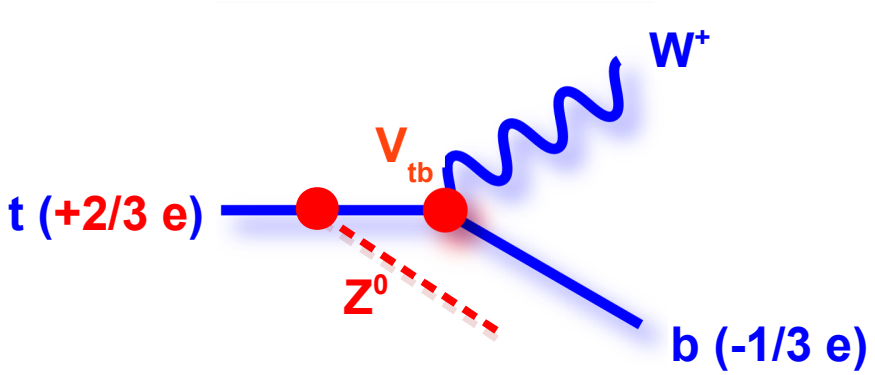

Other top quark properties at CMS

based on results from CMS Physics Analysis Summaries:
TOP-11-029, TOP-11-031, TOP-12-014

Yvonne Küssel for the CMS Collaboration

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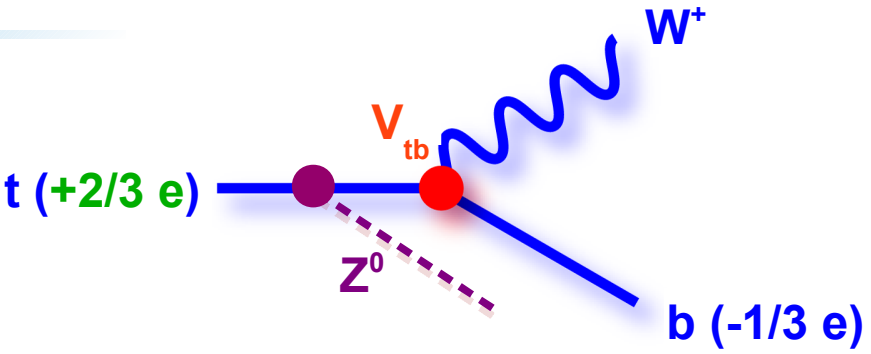
Content

- First measurement of $t\bar{t}V$:

$$\sigma(t\bar{t}V) = \sigma(t\bar{t}Z) + \sigma(t\bar{t}W)$$



- Measurement of R:

$$R = \frac{B(\mathrm{t}\to\mathrm{Wb})}{B(\mathrm{t}\to\mathrm{Wq})} = \frac{|V_{\mathrm{tb}}|^2}{|V_{\mathrm{td}}|^2+|V_{\mathrm{ts}}|^2+|V_{\mathrm{tb}}|^2} \approx 99.8 \ \text{(standard model)}$$

- Constraints on the top quark electric charge:

$$A = \frac{N_{+2/3\mathrm{e}} - N_{-4/3\mathrm{e}}}{N_{+2/3\mathrm{e}} + N_{-4/3\mathrm{e}}} = 1 \ \text{(standard model)}$$

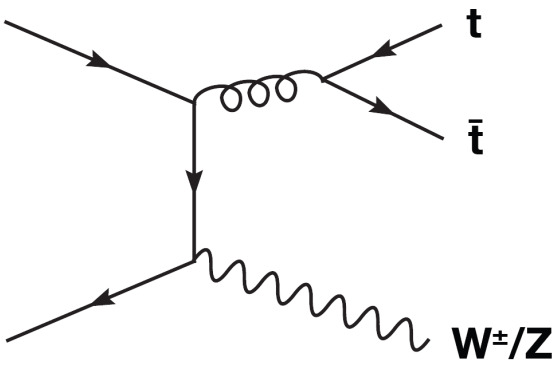
First Measurement of Vector Boson Production Associated with $t\bar{t}$

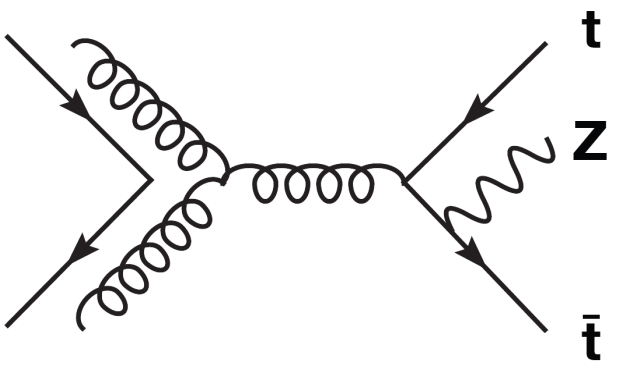
- $\mathcal{L}$ = 5 fb^{-1} at $\sqrt{s}$ = 7 TeV

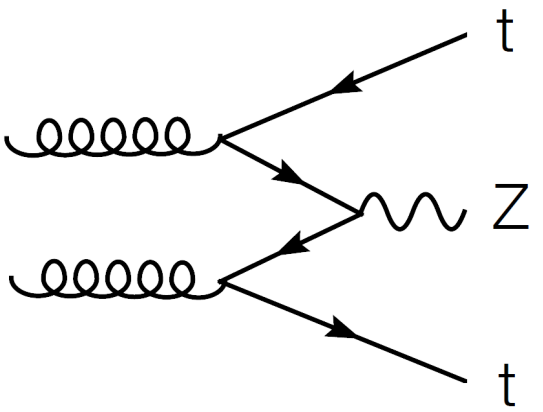
Trilepton channel: $\sigma\left(t\bar{t}\,Z \rightarrow l + \text{jets} + (Z \rightarrow l\,l)\right)$

Same-sign dilepton channel: $\sigma\left(t\bar{t}\,V \rightarrow l + \text{jets} + (W \rightarrow l\,\nu) \text{ or } (Z \rightarrow l\,l)\right)$

with $l = e$ or μ

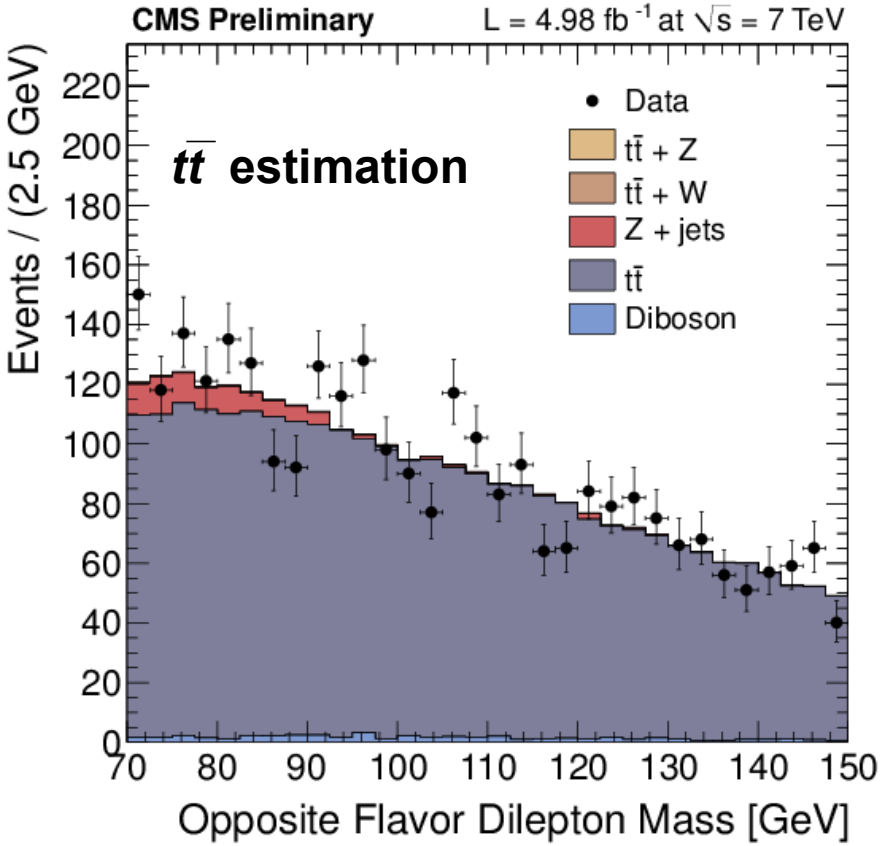


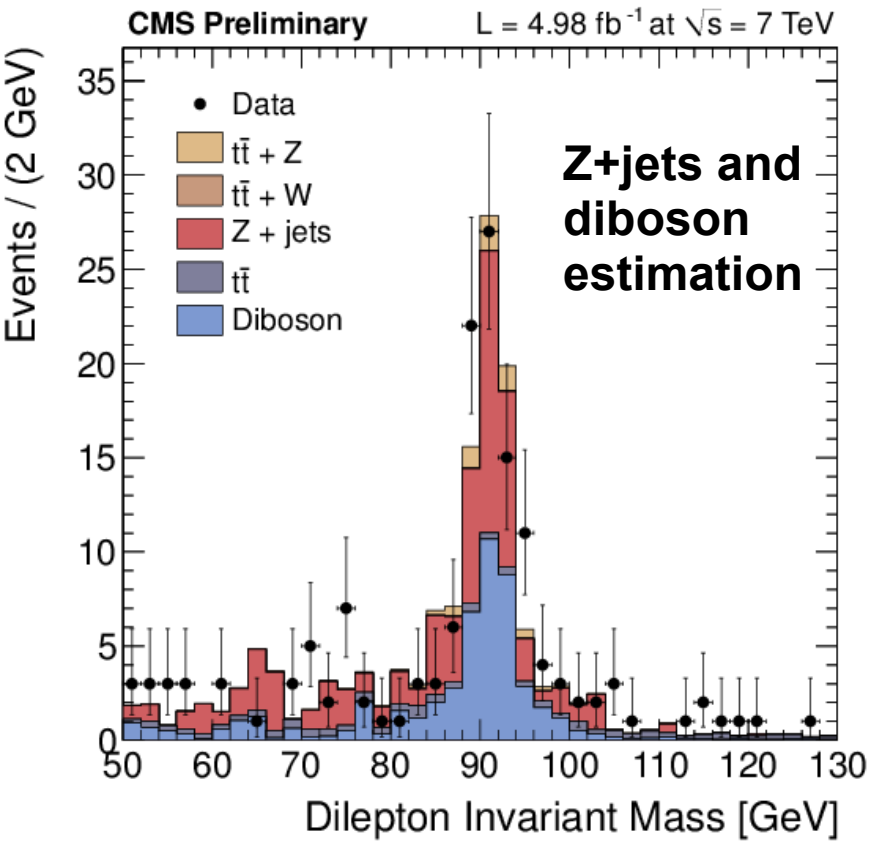




Trilepton Channel: σ($t\bar{t}Z$)

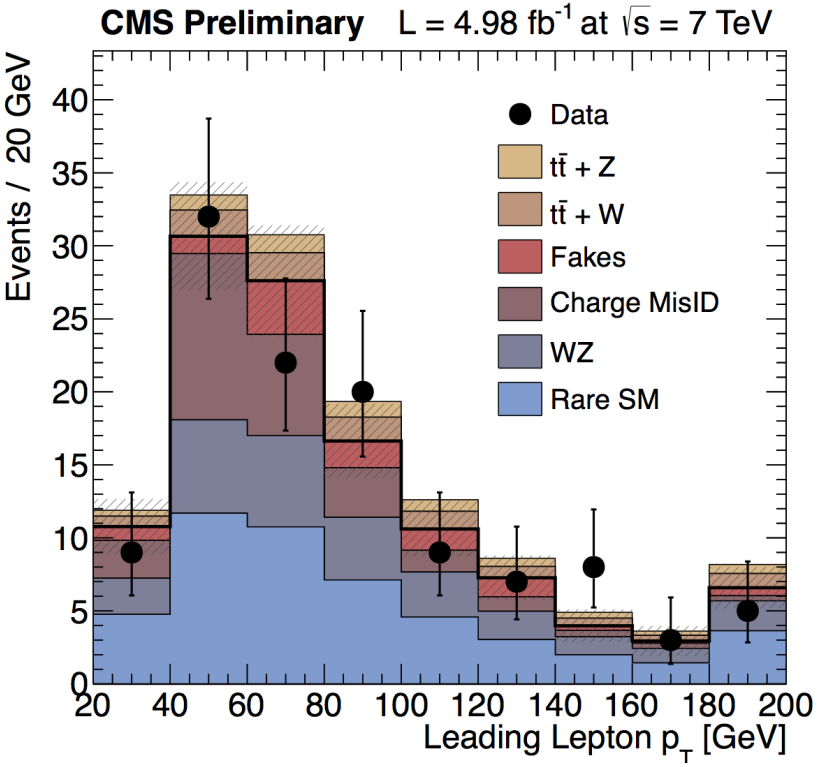
- Selection:
  - ➔ 3 leptons: 2 opposite-charge and same-flavor leptons (Z^{cand})
  - ➔ 3 jets (2 *b* tagged), H_T > 120 GeV
- Background estimation from data:
  - ➔ $t\bar{t}$: cross-flavor dilepton events
  - ➔ *Z*+jets and diboson: trilepton, no *b* tag events





Same-Sign Dilepton Channel: σ($t\bar{t}V$)

- Selection:
  - ➔ 2 same-sign leptons
  - ➔ 3 jets (1 *b* tagged), H_T > 100 GeV
  - ➔ Veto trilepton selection



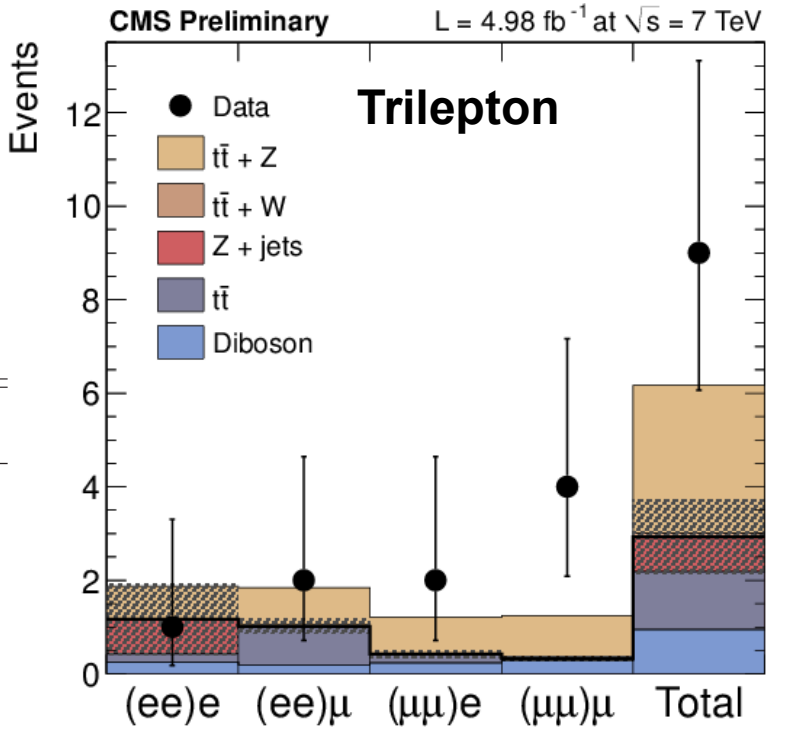
- Background estimation from data:
  - ➔ fake/non-prompt leptons: loose leptons passing tight criteria in QCD events
  - ➔ charge mis-identified electrons: fraction of same-signed electrons in *Z* decays
  - ➔ *WZ* cross section from CMS measurement
  - ➔ rare SM processes from MC prediction

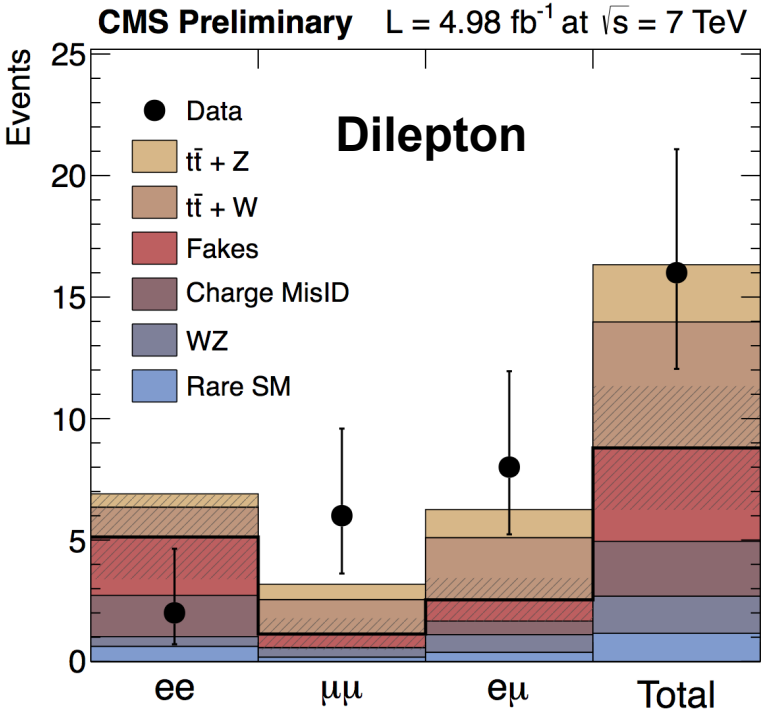
Combined Results

taking into account $t\bar{t}+W$

	$\sigma(t\bar{t}Z)$ [pb]	$\sigma(t\bar{t}W)$ [pb]	$\sigma(t\bar{t}V)$ [pb]
Trilepton Analysis	$\mathbf{0.30}\ ^{+0.14}_{-0.11}\ ^{+0.04}_{-0.02}$	-	$0.66\ ^{+0.32}_{-0.25}\ ^{+0.09}_{-0.05}$
Dilepton Analysis	-	$0.28\ ^{+0.14}_{-0.12} \pm 0.04$	$\mathbf{0.45}\ ^{+0.17}_{-0.15}\ ^{+0.06}_{-0.05}$
Combined	-	-	$0.51\ ^{+0.15}_{-0.13}\ ^{+0.05}_{-0.04}$
NLO Calculation	0.1387	$0.169\ ^{+0.029}_{-0.051}$	0.308

subtracting $t\bar{t}+Z$ yield





- Result combining all 7 channels:

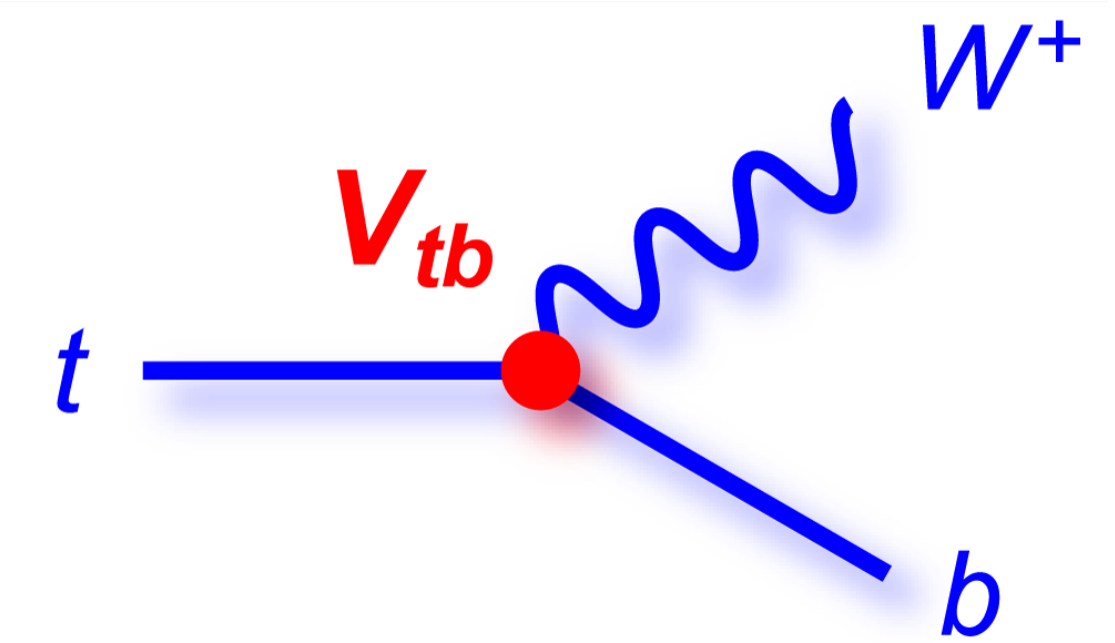
  ➔ signal established at a significance of 4.67 σ

$$\sigma(t\bar{t}V) = 0.51^{+0.15}_{-0.13}(\text{stat.})^{+0.05}_{-0.04}(\text{syst.})\ \text{pb}$$

Measurement of *R*

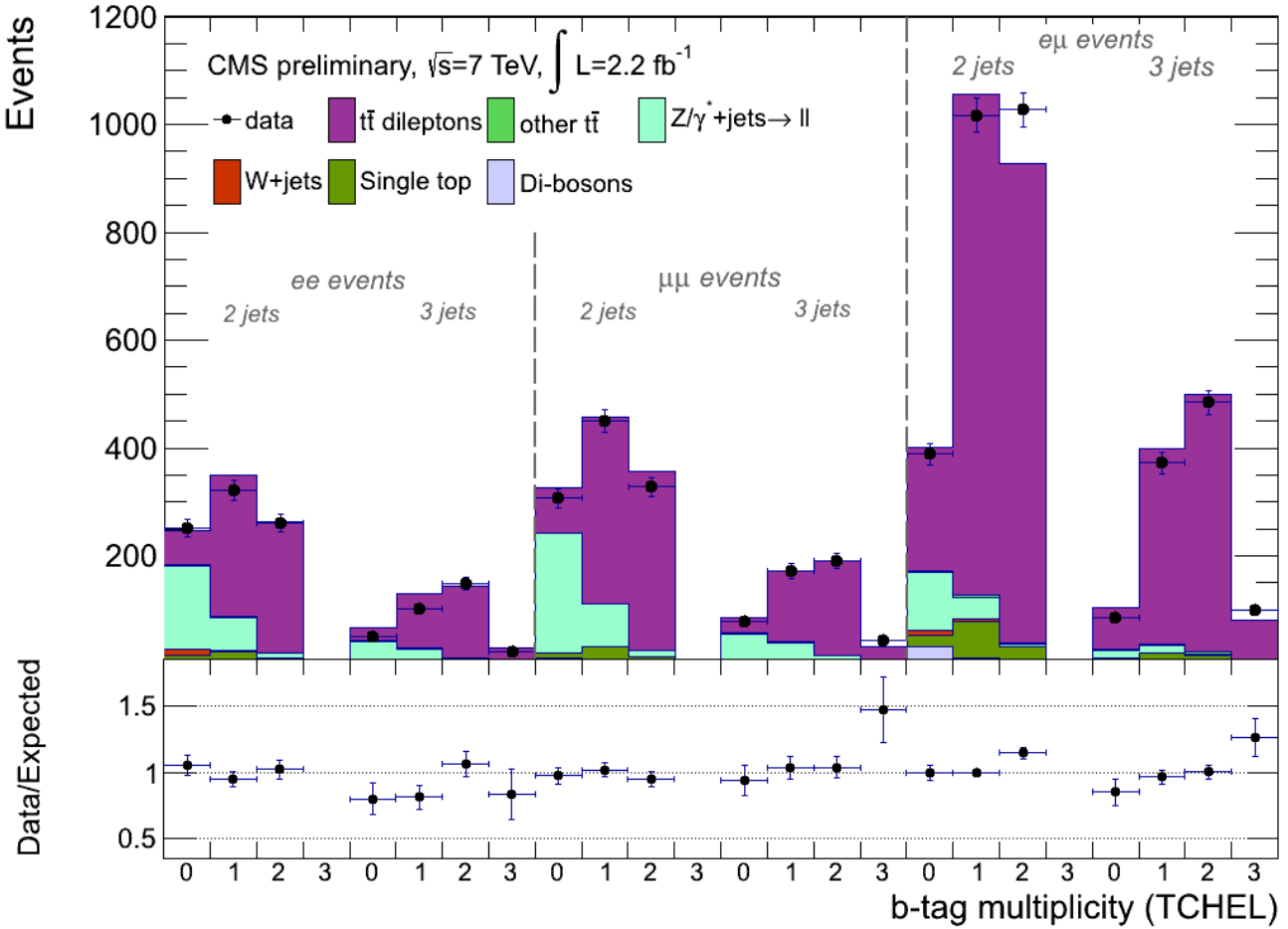
- Dileptonic $t\bar{t}$ in $\mathcal{L}$ = 2.2 fb^{-1} at $\sqrt{s}$ = 7 TeV
- Observable: *b*-tagged jet multiplicity

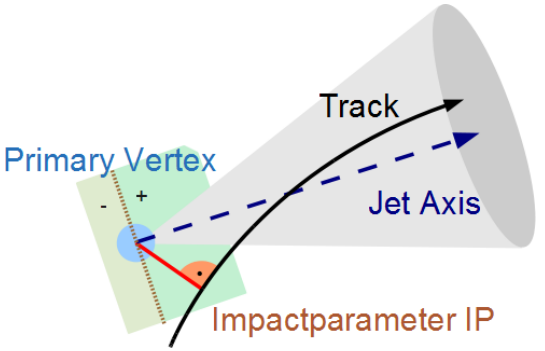
$$R = \frac{B(t \to Wb)}{B(t \to Wq)} = \frac{|V_{tb}|^2}{|V_{td}|^2 + |V_{ts}|^2 + |V_{tb}|^2}$$



b-Tagging Multiplicity N_{btag}

- *b* jet := tagged with Track Counting High Efficiency Loose (TCHEL)
- Fairly good agreement with $R = 1$



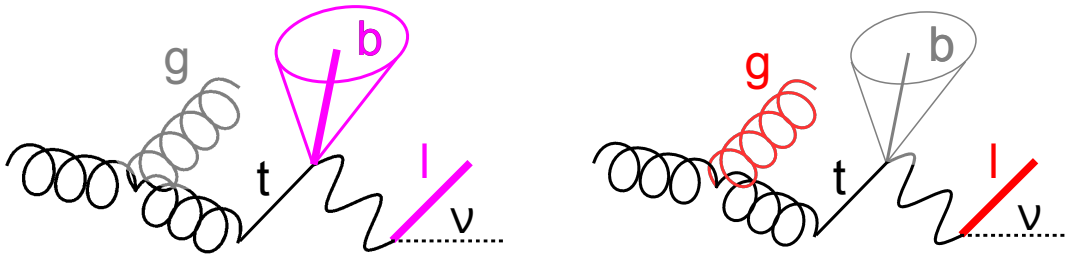


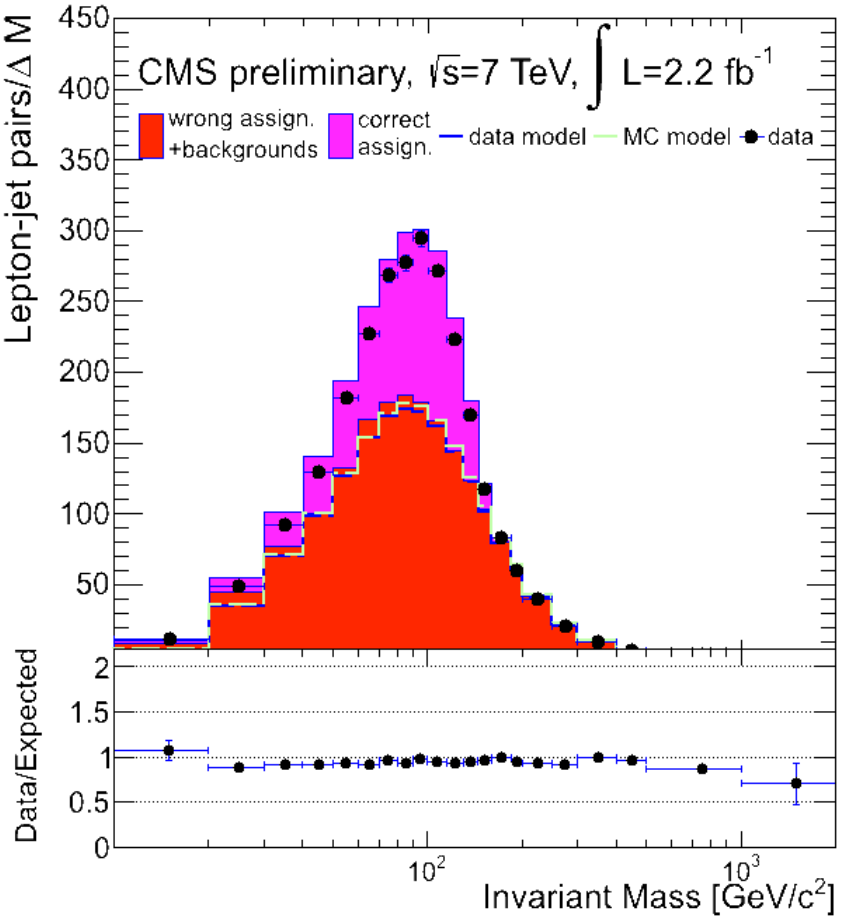
Jet-Assignment Estimate f_{correct}

- **Correctly assigned jets from $t\bar{t}$:**

$$m^{\text{inv}}(\text{lep., jet}) \leq \sqrt{m_t^2 - m_W^2} = 156 \text{ GeV}$$

- **Other jet assignments** lead to large tail:
  - ➔ averaged template from data:
    - ➔ swapping jet from different event
    - ➔ from randomly rotating $\vec{p}_{\text{lep}}$

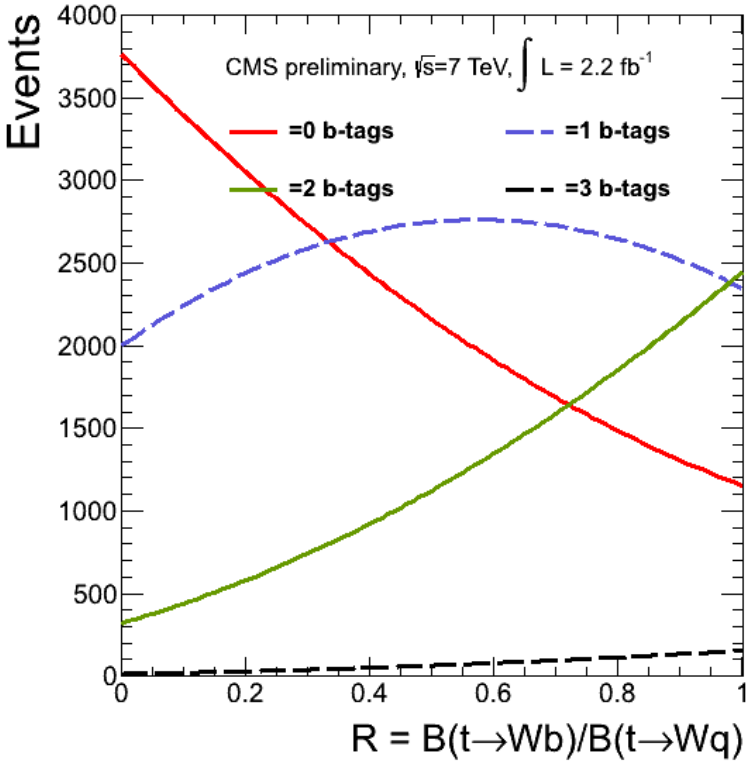


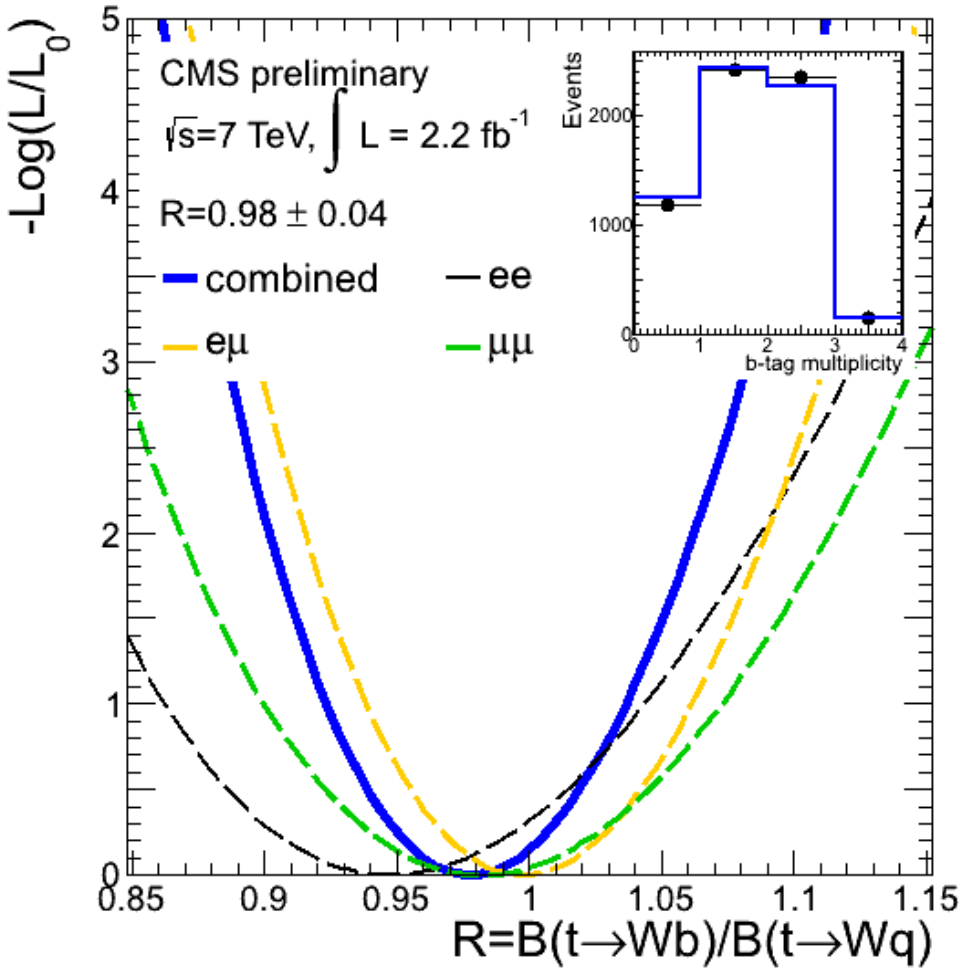


$$f_{\text{correct}}^{\text{data}}(e\mu, 2 \text{ jets}) = 0.388 \pm 0.011 \text{ (stat. + sys.)}$$

Model and Fit of $N_{btag}(R)$

- Binned maximum likelihood fit with $N_{btag}(R)$-model that depends on:
  - ➔ *b*-tag and mistag efficiencies (from data)
  - ➔ fraction of top events (from data)
  - ➔ fraction of jets from top (from data)



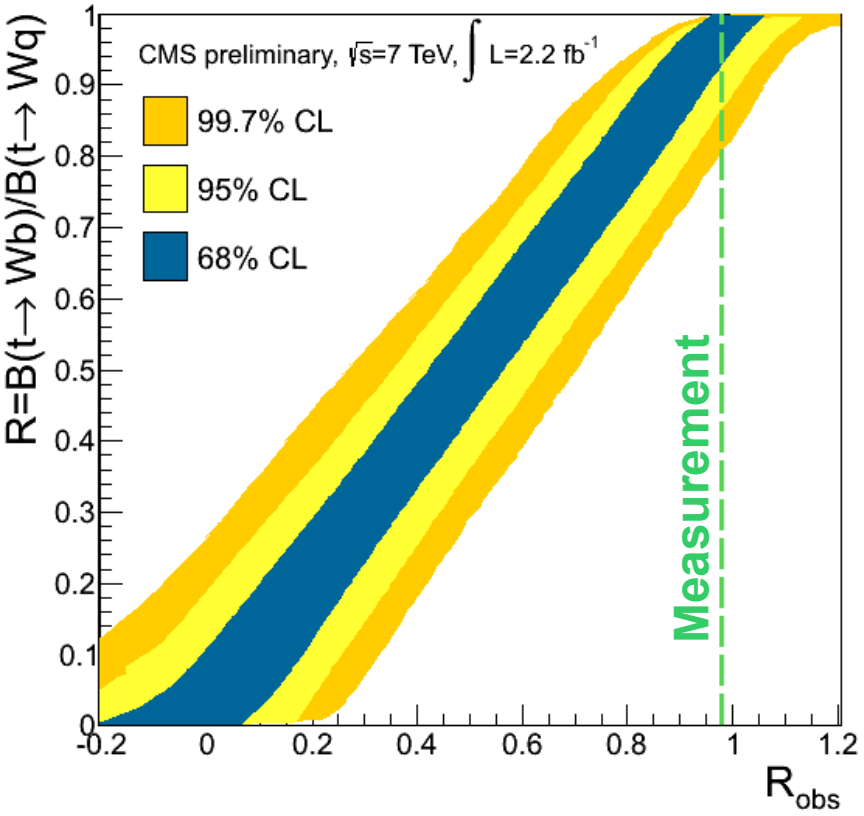


Results of *R* Measurement

$R = 0.98 \pm 0.04$ (syst.+stat.)

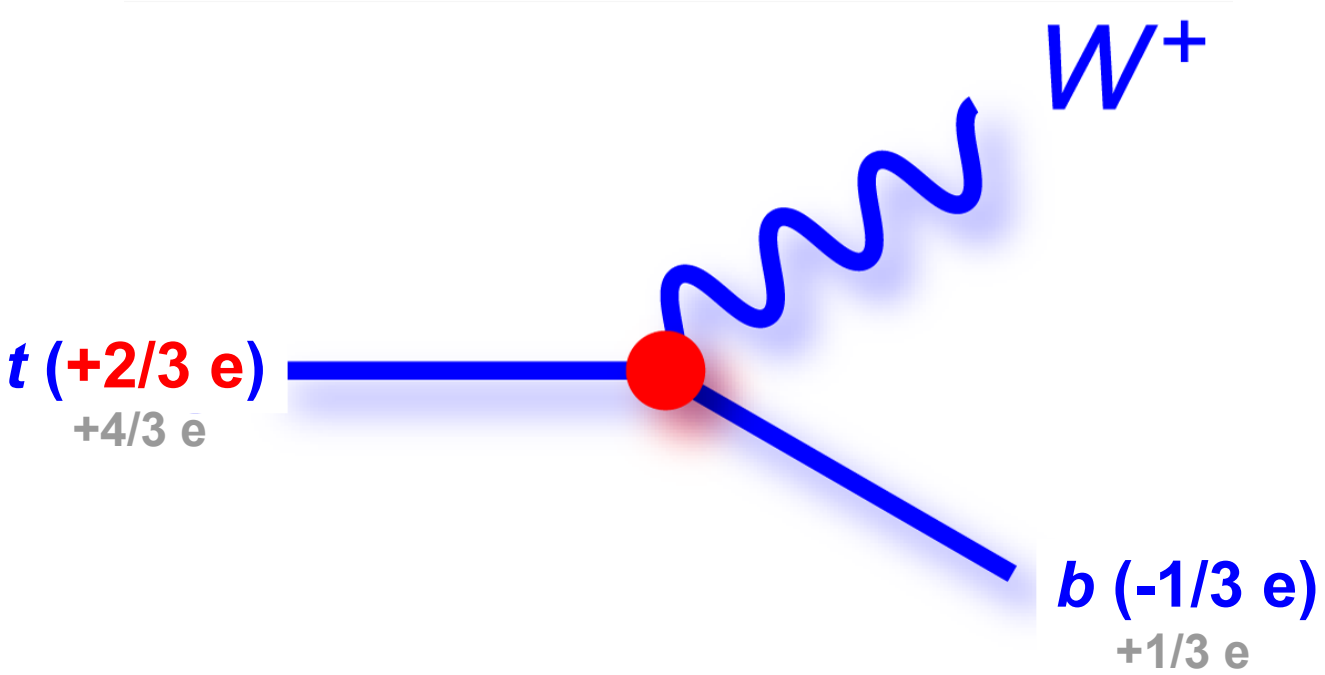
- Dominated by systematic uncertainties
- Feldman-Cousins frequentist approach: $R > 0.85$ at 95 % C.L.

Source	Uncertainty
ε_b	0.031
ε_q	0.011
Jet energy scale	0.002
Jet energy resolution	0.004
Pile-up	0.006
Q^2	0.023
Jet-parton matching scale	0.011
DY contamination	0.012
$t\bar{t}$ contribution	0.002
Total	0.044



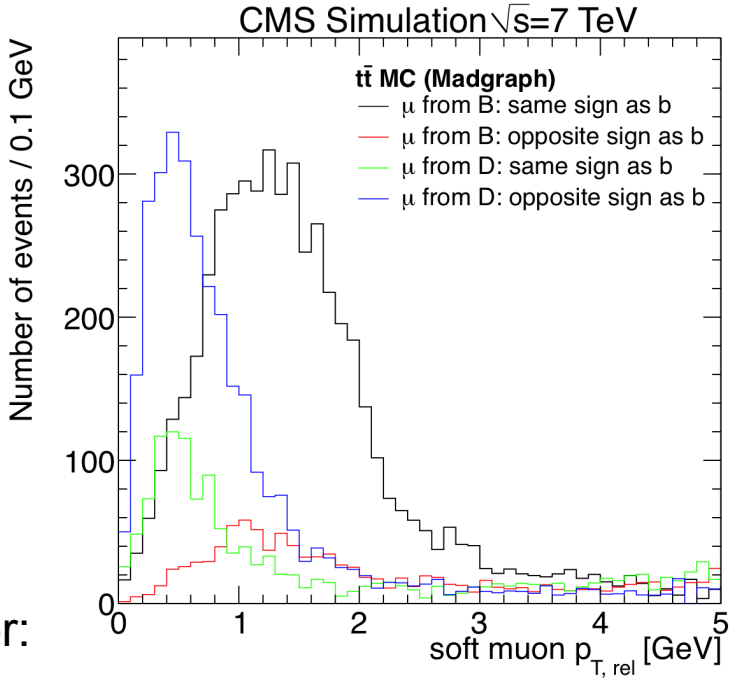
Constraints on Top Quark Charge

- Determine *b* charge and combine with *W* charge
- Discriminate +2/3 e against -4/3 e top charge scenario
- $t\bar{t} \rightarrow \mu$ + Jets in $\mathcal{L}$ = 5 fb^{-1} at $\sqrt{s}$ = 7 TeV

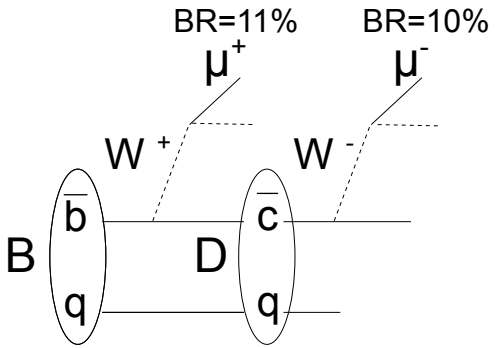


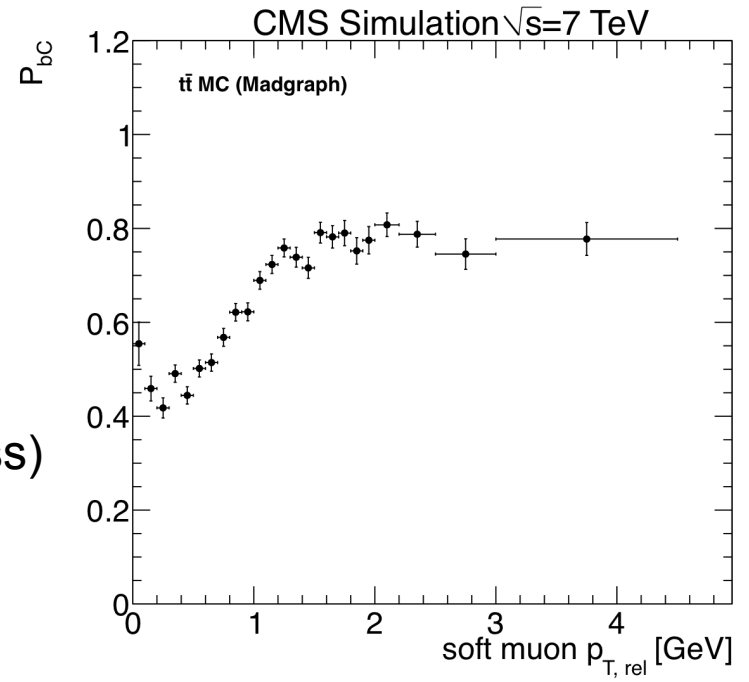
Charge Tagging of *b* Jet

- Charge of *b* quark:
  - ➔ diluted in hadronization process
  - ➔ transmitted to decay products



- Soft muon from *b* decay chosen as *b*-charge discriminator:



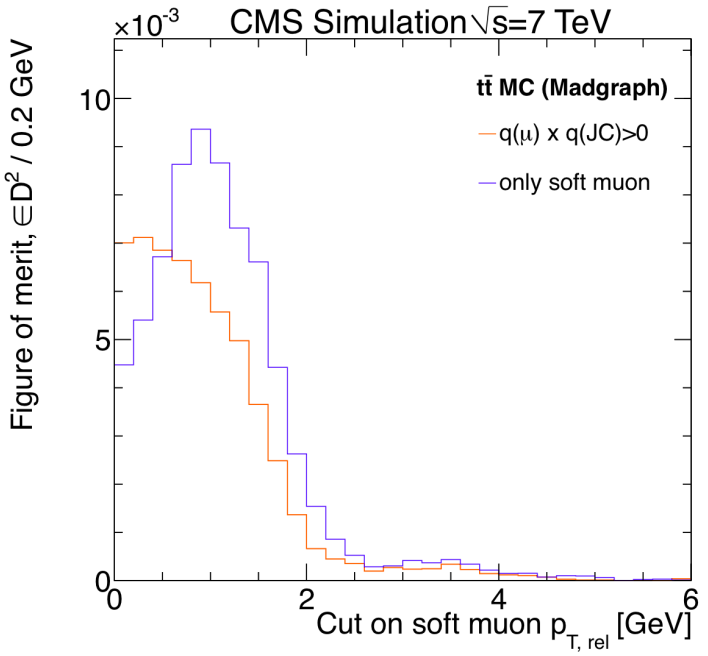


- ➔ increase performance with $p_{T,rel}$ to jet axis (*B* mass)
- ➔ global muon (p_T > 4 GeV) inside *b* jet (ΔR < 0.4)

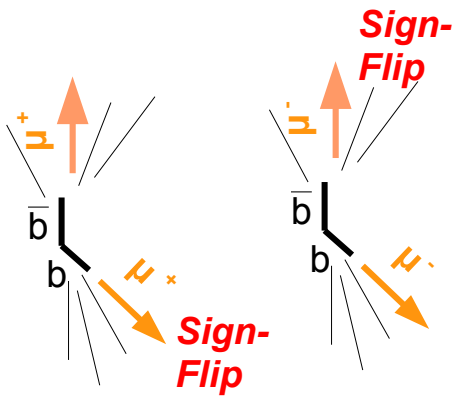
Charge Tagging of *b* Jet

- Optimization of soft muon charge discriminator:
  - ➔ maximal statistical significance: εD^2
  - ➔ muon $p_{T,rel} > 0.85$ GeV
- Probability of correct *b* charge:

$$P_{bC} = [74.5 \pm 0.8\ (stat.) \pm 2.6\ (syst.)]\ \%$$



- Estimate from data:
  - ➔ fraction of same sign muons in enriched $b\bar{b}$ sample
  - ➔ data and simulation agrees within stat. uncertainty of 2.5%
  - ➔ taken as syst. uncertainty for $t\bar{t}$



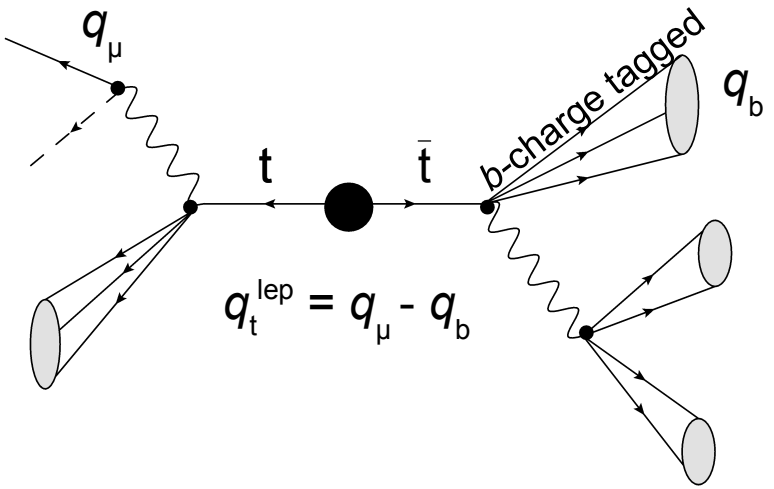
- Additional systematic study: comparison of two different fragmentation models

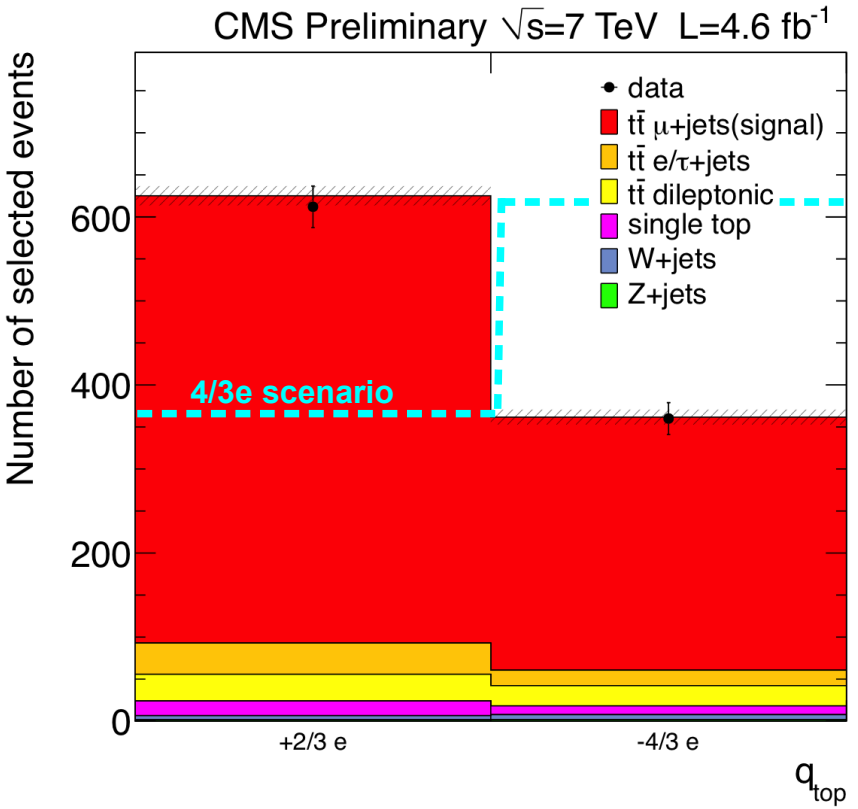
Event Categorization

- Choose the combination with m_{inv}(one *b* jet, two non-*b* jets) closest to top mass
  - ➔ assign to hadronic side
  - ➔ quality cut on $m_{inv}(\mu, b_{lep.}) < 150$ GeV
- Correct assignment of charge tagged b jet:

$$P_{pair} = [80.2 \pm 0.8\ (stat.) \pm 3.8\ (syst.)]\ \%$$

- Combine *b* charge with high-p_T muon charge
- Example:





Results of Top Charge Analysis

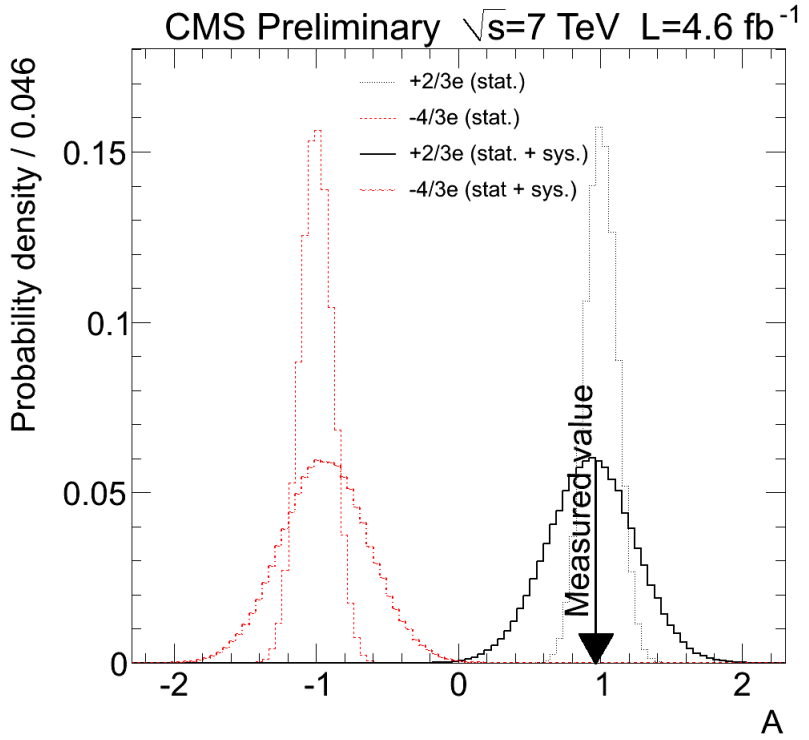
- Test statistics: asymmetry between +2/3 e and -4/3 e categorized events

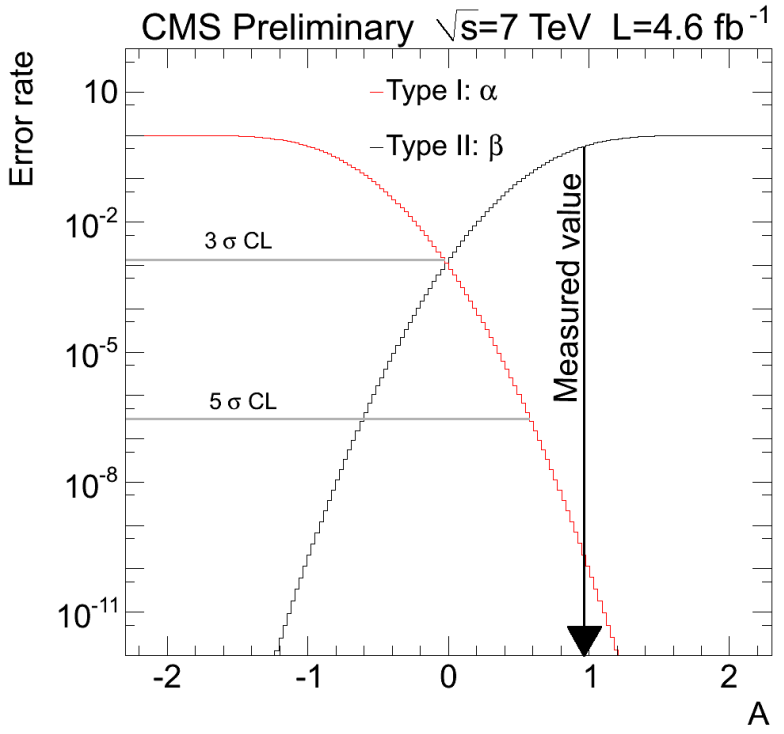
$$A = \frac{N_{+2/3e} - N_{-4/3e}}{N_{+2/3e} + N_{-4/3e}}$$

➔ probability density of A: pseudo experiments of $N_{+2/3e}$ and $N_{-4/3e}$

A_{meas} = 0.97 ± 0.12 (stat.) ± 0.31(syst.)

- Dominant syst. uncertainty: limited statistics in systematic samples





Summary

- First measurement of $t\bar{t}V$:
  - ➔ signal established at a significance of 4.67 σ

$$\sigma(t\bar{t}V) = 0.51^{+0.15}_{-0.13}(\text{stat.})^{+0.05}_{-0.04}(\text{syst.})\ \text{pb}$$

- Measurement of *R*:

$$R = 0.98 \pm 0.04\ (\text{syst.+stat.})$$

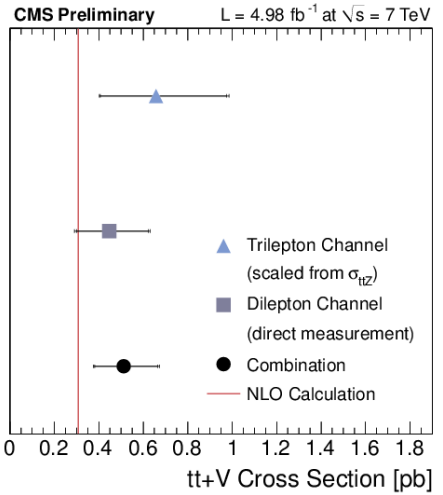
  - ➔ A limit is set to $R > 0.85$ at 95 % C.L. .

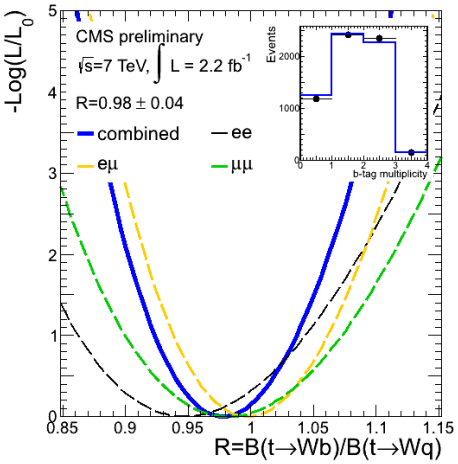
- Constraints on the top quark electric charge:

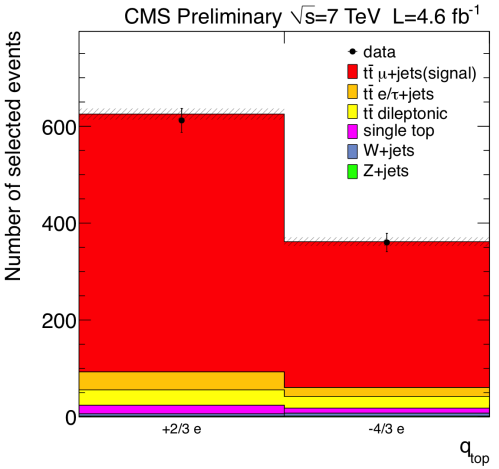
$$A_{\text{meas}} = 0.97 \pm 0.12\ (\text{stat.}) \pm 0.31\ (\text{syst.})$$

  - ➔ 4/3 e charged top scenario ($A = -1$) excluded.

Top quark properties measured by CMS agree nicely with SM!







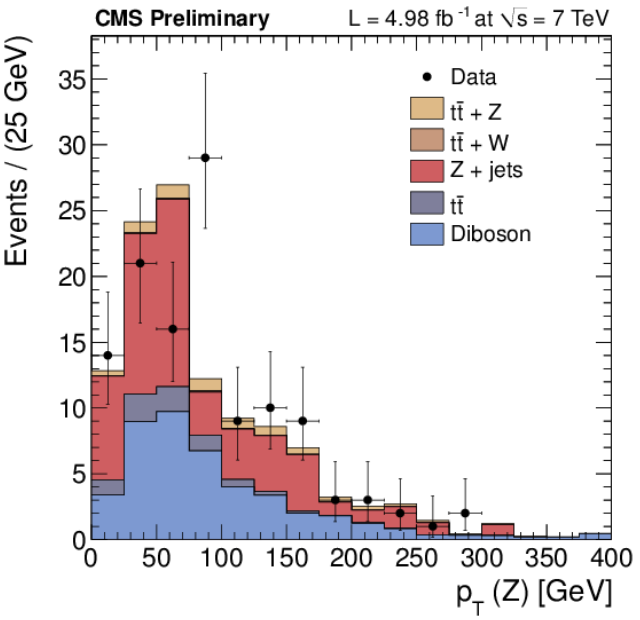

BACKUP

Selection of Trilepton Channel

$\sigma(t\bar{t}V)$

- Full selection optimized for signal significance:
  - Z_{cand}: 2 opposite-charge, same-flavor leptons with $p_T > 20$ GeV
  - $p_T(Z_{cand}) > 35$ GeV and $m_{inv}(Z_{cand}) \in [81,101]$ GeV
  - third lepton with $p_T > 10$ GeV
  - at least 3 jets ($p_T > 20$ GeV, $|\eta| < 2.4$) (1 lose, 1 medium *b* tagged), $H_T > 120$ GeV
- Loosened selection (background from data):
  - 2 opposite-charge leptons ($p_T > 20$ GeV)

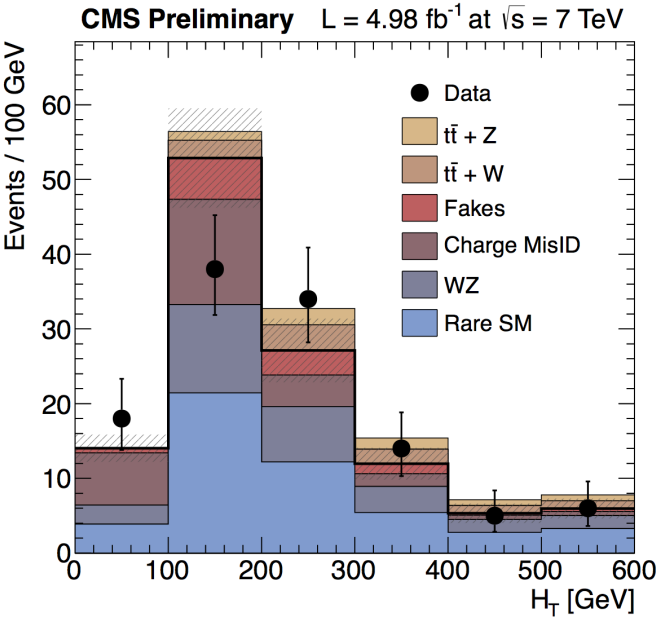
    with $m_{inv}(Z_{cand}) > 50$ GeV,no same-flavor: $t\bar{t}$ estimation
  - at least 3 jets ($p_T > 20$ GeV, $|\eta| < 2.4$)
  - third lepton with $p_T > 10$ GeV (Z+jets and diboson)

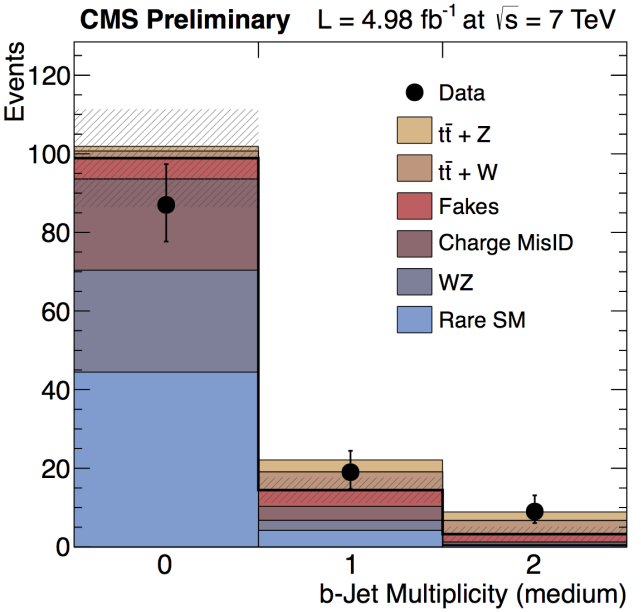


Selection of Same-Sign Dilepton Channel

$\sigma(t\bar{t}V)$

- Full selection optimized for signal significance:
  - ➔ 2 same-sign leptons with $p_{T1} > 55$ and $p_{T2} > 30$ GeV
  - ➔ at least 3 jets with $p_T > 20$ GeV (1 *b* tagged)
  - ➔ $H_T > 100$ GeV
- Loosened selection for validation:
  - ➔ 2 same-sign leptons with $p_T > 20$ GeV
  - ➔ $m_{inv}(ll) > 8$ GeV
  - ➔ 3 jets with $p_T > 20$ GeV and $|\eta| < 2.4$
- Rare SM: *ZZ*, *V*+gamma, same-sign *WW* production, triboson and multi-parton interaction leading to twice *W*+jets

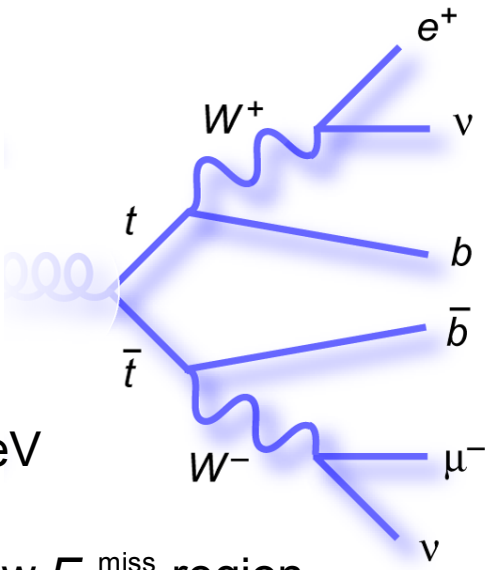




Dileptonic $t\bar{t}$ Selection in $\mathcal{L}$ = 2.2 fb^{-1} at $\sqrt{s}$ = 7 TeV

R

- Leptons (muons and *electrons*):
  - ➔ trigger: double lepton
  - ➔ at least 2 leptons with p_T > 20 GeV and isolation: particle flux$_{\Delta R < 0.3}$ < 17% (*20%*)
  - ➔ if more than 2 leptons: oppositely charged and highest $\Sigma\, p_T$
  - ➔ M_{ll} > 12 GeV
- Drell-Yan (DY) contribution:
  - ➔ same flavored leptons: | M_Z - M_{ll} | > 15 GeV and E_T^{miss} > 30 GeV
  - ➔ estimated from data: angle between leptons; template from low E_T^{miss} region
- Jets: E_T > 30 GeV, well separated from leptons
- Fraction of $t\bar{t}$ events after selection: 0.767 ± 0.052 (stat.+syst.)



Factorization of $N_{btag}(R)$

R

- Expected *b*-tagging multiplicity P_k to reconstruct and select 0, 1 or 2 jets from top decays

  ➔ e.g. two jets from top decays:

$$P_k = R^2\varepsilon_b^2 + 2R(1-R)\varepsilon_b\varepsilon_q + (1-R)^2\varepsilon_q^2$$

- P_k of the different event cases are combined using the probabilities α_i of having reconstructed *i* jets from top decays
- α_i can be expressed in terms of

  ➔ fractions of top pair and single top events

  ➔ fraction of correctly assigned *b* jets $f_{correct}$

- Likelihood using this model and observed *b*-tag multiplicity:

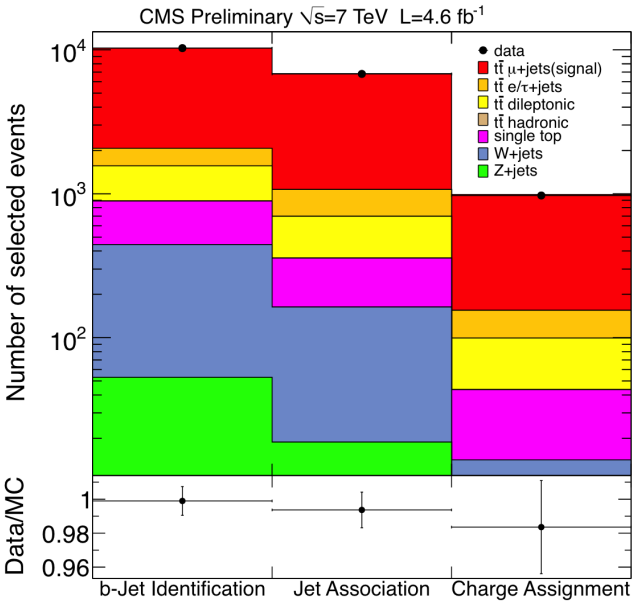
$$\mathcal{L} = \prod_{\ell\ell} \prod_{jets\geq 2} \prod_{k=0}^{jets} \mathcal{P}_{oisson}[N_{ev}^{\ell\ell,jets}(k), \hat{N}_{ev}^{\ell\ell,jets}(k)] \prod_x \mathcal{G}_{aus}(x, \bar{x}, \sigma_x)$$

Selection of $t\bar{t} \rightarrow \mu$ + Jets in $\mathcal{L}$ = 5 fb^{-1} at $\sqrt{s}$= 7 TeV

q_{top}

- Leptons:
  - ➔ trigger: single isolated muon
  - ➔ exactly 1 isolated muon p_T > 26 GeV (trigger plateau)
  - ➔ veto on second loose lepton

    (electron E_T > 15 GeV, muon with p_T > 10 GeV)
- Jets:
  - ➔ at least 4 jets with p_T > 30 GeV
  - ➔ at least 2 *b* jets with TCHE medium
  - ➔ *b*-tagging efficiencies and mistag rates corrected (event weight)
- Resulting background fraction (W, DY, QCD) ~ 2 %
- Top pairs and single top treated as signal



Factorization of *A*

q_{top}

- Probability to reconstruct a +2/3 e categorized event:

$$P = \frac{N_{2/3e}}{N_{2/3e} + N_{4/3e}}$$

➔ account for background events (f_{BG}: background fraction):

$$P = f_{BG} \cdot 0.5 + (1 - f_{BG}) \cdot P_{signal}$$

➔ Account for misidentification of *b* jet:

$$P_{signal} = (1 - P_{btag}) \cdot P_{!btag,\,bC} + P_{btag} \cdot P_{pair,bC}$$

	Summary of performance numbers
P_{btag}	$0.911 \pm 0.004(stat.) \pm 0.029(sys.)$
P_{bC}	$0.745 \pm 0.008(stat.) \pm 0.026(sys.)$
P_{pair}	$0.802 \pm 0.008(stat.) \pm 0.038(sys.)$
$P_{!btag,bC}$	$0.53 \pm 0.03(stat.) \pm 0.14(sys.)$
P_{signal}	$0.64 \pm 0.01(stat.)$
f_{BG}	$0.014 \pm 0.005(stat.)$
P_{BG}	0.5 ± 0.1

➔ Account for wrong *b* charge tagging and wrong association to lep. or had. side:

$$P_{pair,bC} = P_{pair} \cdot P_{bC} + (1 - P_{pair}) \cdot (1 - P_{bC})$$