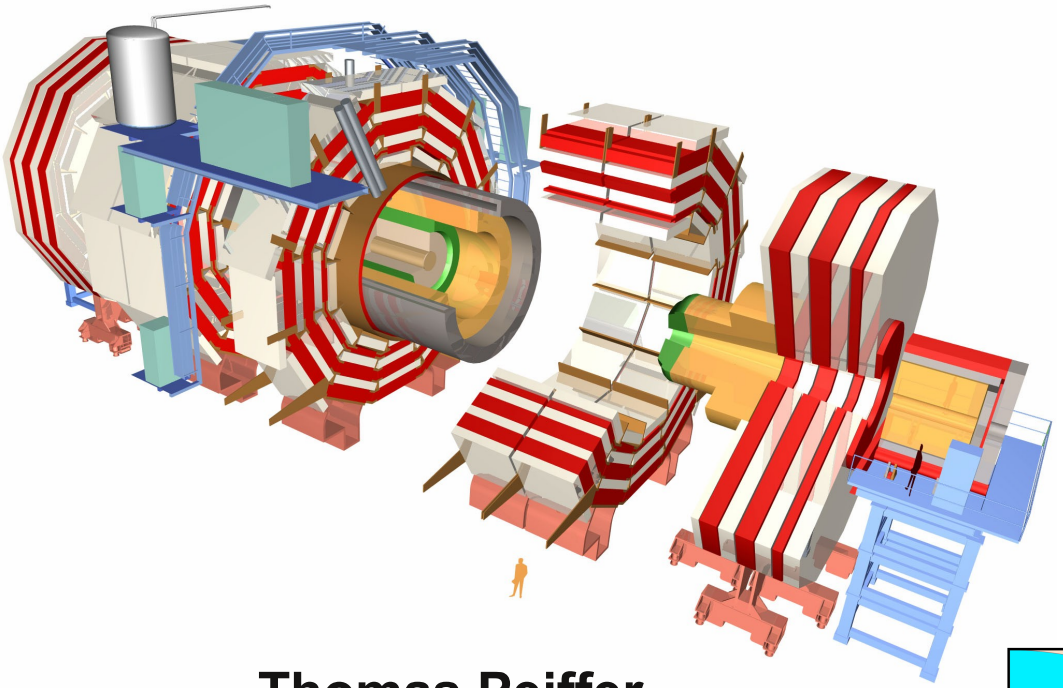
# Prospects for Top Quark Studies with CMS for up to 1fb$^{-1}$



**Thomas Peiffer**
on behalf of the CMS Collaboration

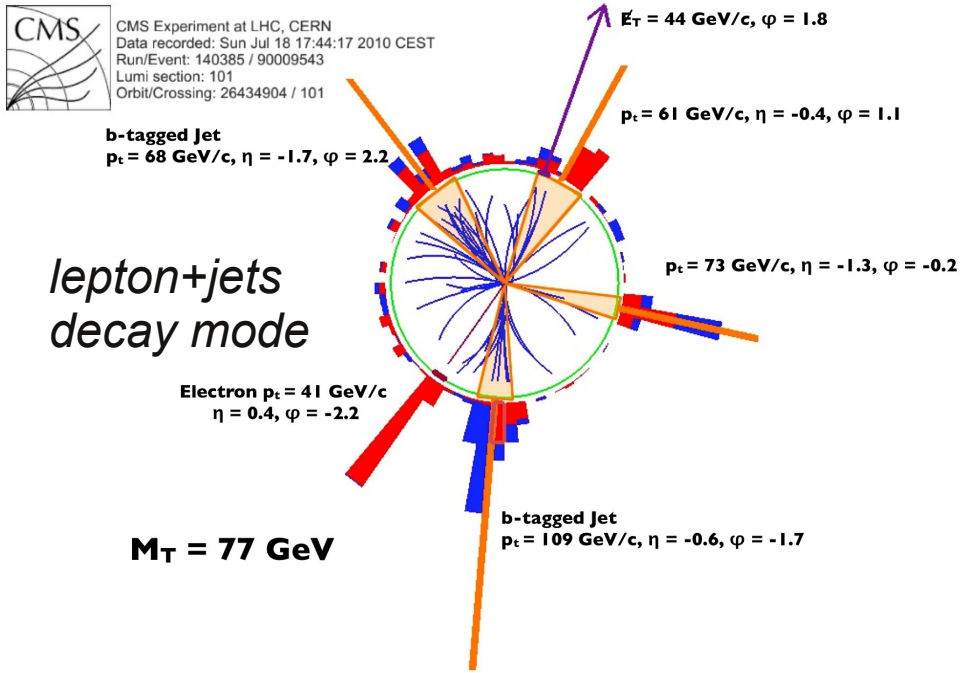
Institut für Experimentelle Kernphysik
Karlsruhe Institute of Technology

Karlsruhe Institute of Technology

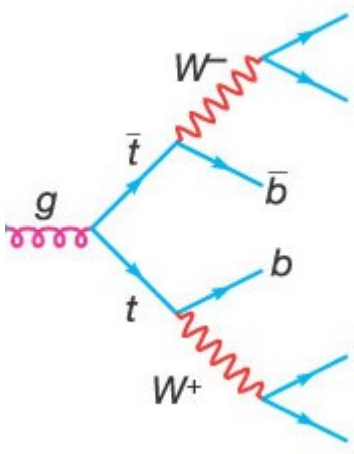
HQL 2010 Frascati
14.10.2010

# Introduction

First top-like events found with a few 100nb$^{-1}$ at CMS (see Talk from P. Q. Ribeiro)




*lepton+jets decay mode*

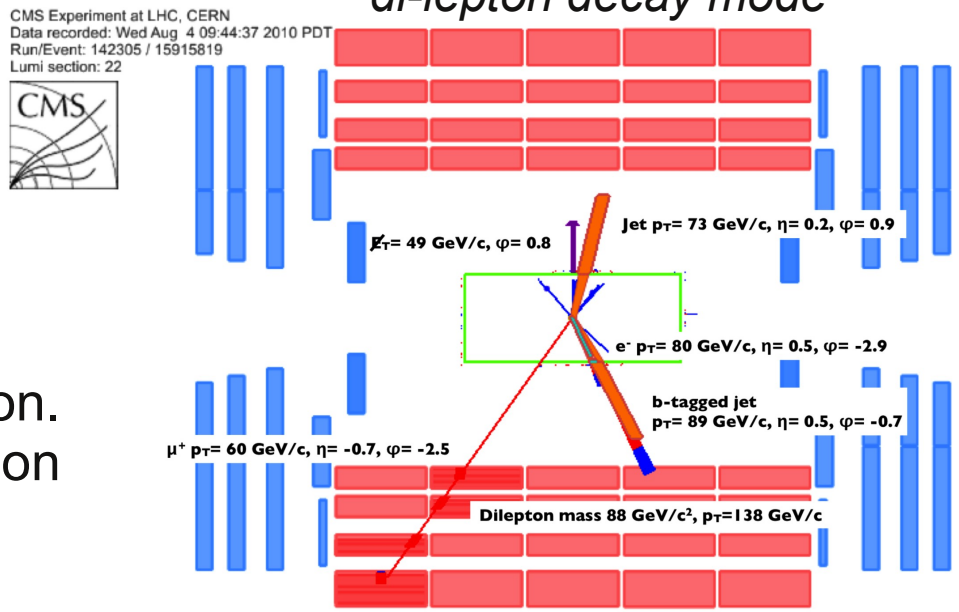



*2 x W→lν: di-lepton channel*

*1 W→lν, 1 W →qq': lepton+jets channel*

*2 x W→qq': full hadronic channel*

*di-lepton decay mode*




Next steps to come soon:

- Measure the top pair production cross section.
- Understand the details of top quark production at the LHC.

# Motivation

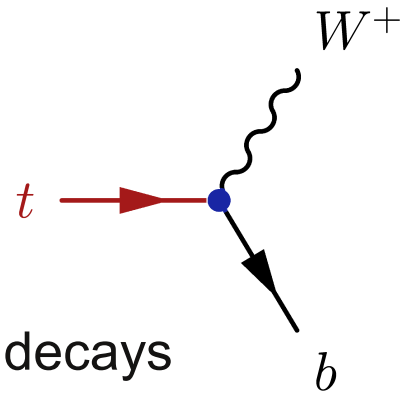
Studying top quark properties is an important test of the Standard Model.

Understanding the top quark production is important in New Physics searches.

Many studies are actually ongoing at CMS:

- cross section measurements in all channels
- top properties: mass determination, spin correlation, etc.

will focus on a few topics here:

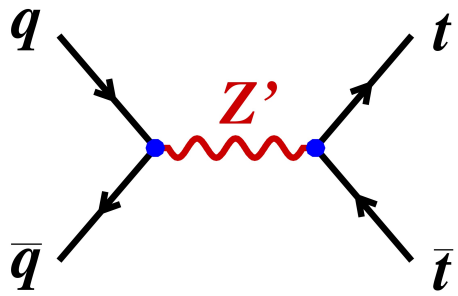


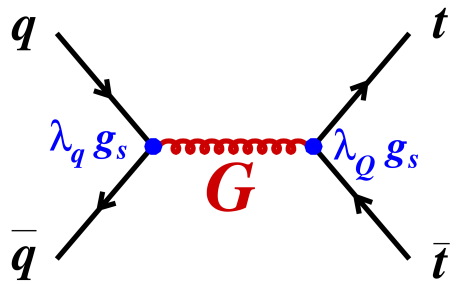

**Determination of $V_{tb}$:**

- Direct: measurement of electroweak single top quark production
- Indirect: determination of the ratio $R=B(t\to Wb)/B(t\to Wq)$ in top quark decays (top pair production)

**Direct searches for New Physics:**

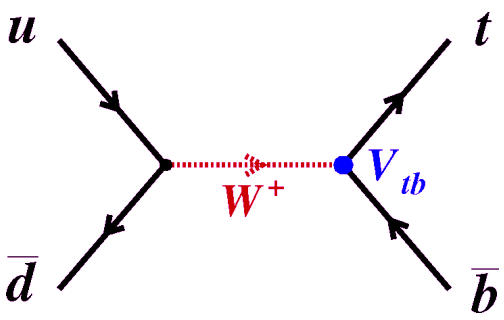
- Search for resonances in top pair production



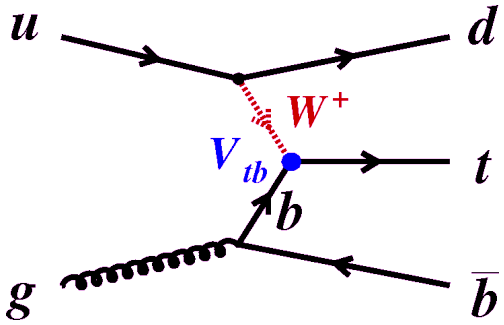



# Single Top at LHC

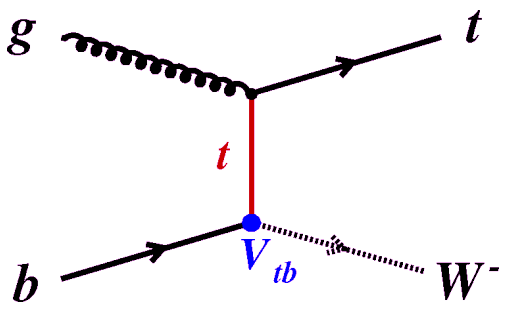
Single top quarks are produced in electroweak reactions:




**s-channel**
**σ=5 pb @ 10TeV**
**σ=4 pb @ 7TeV**




**t-channel**
**σ=134 pb @ 10TeV**
**σ=65 pb @ 7TeV**




**tW-channel**
**σ=29 pb @ 10TeV**
**σ=11 pb @ 7TeV**

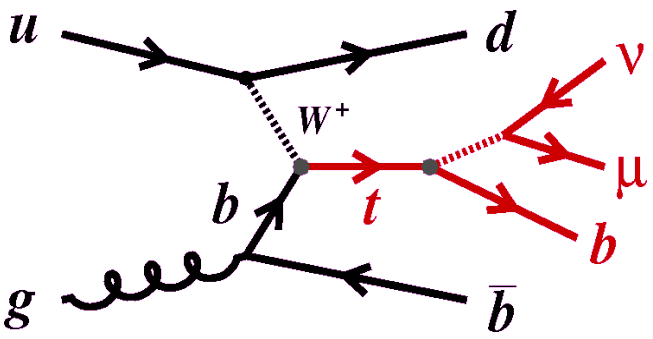
At LHC the t-channel will be the most abundant channel to discover single top quarks.

Single top quark production was first discovered last year at CDF and D0.

Single top quark cross section is a direct measurement of the CKM matrix element $|V_{tb}|$.

# Single Top

√s=10 TeV



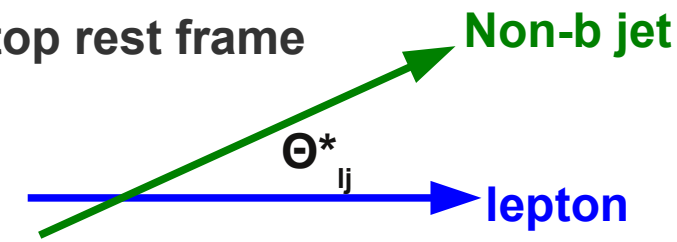

Search for single top in the t→bW→bμν channel

Event selection:

- Exactly one isolated muon with $P_T$>20 GeV/c
- Exactly 2 jets with $P_T$>30 GeV/c
- One b-tag (track counting algorithm using $IP/\sigma_{IP}$)
- $M_T(W)$>50 GeV/$c^2$

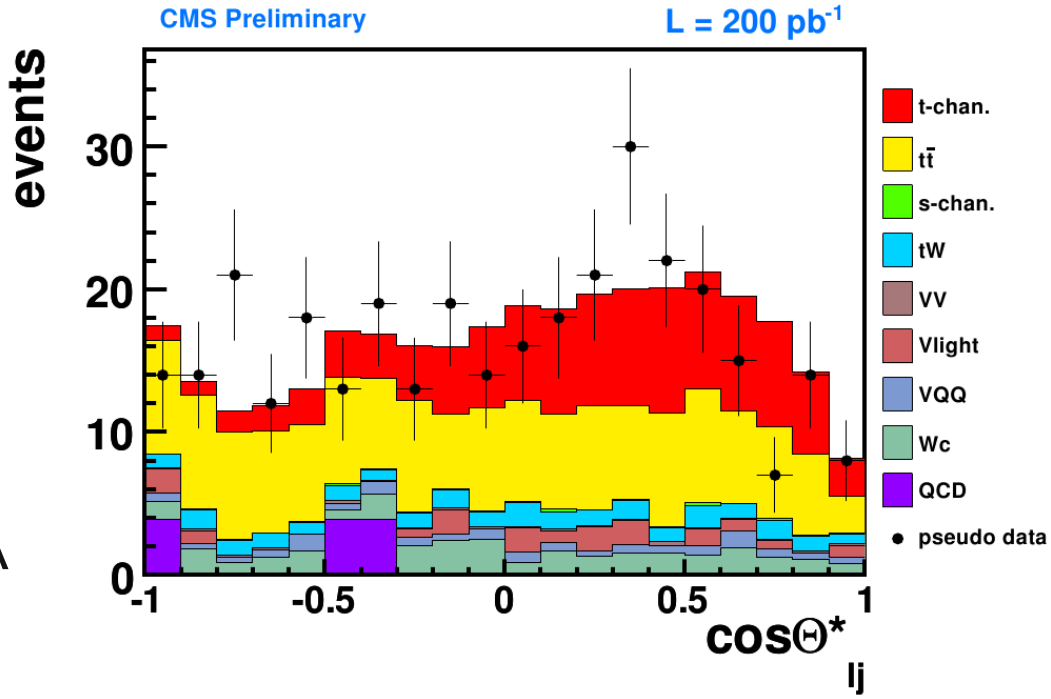
Need discriminating variables to extract single top cross section:

$\cos\Theta^*_{lj}$:




Signal: ~linear dependence due to V-A structure at Wtb vertex

Background: flat distribution

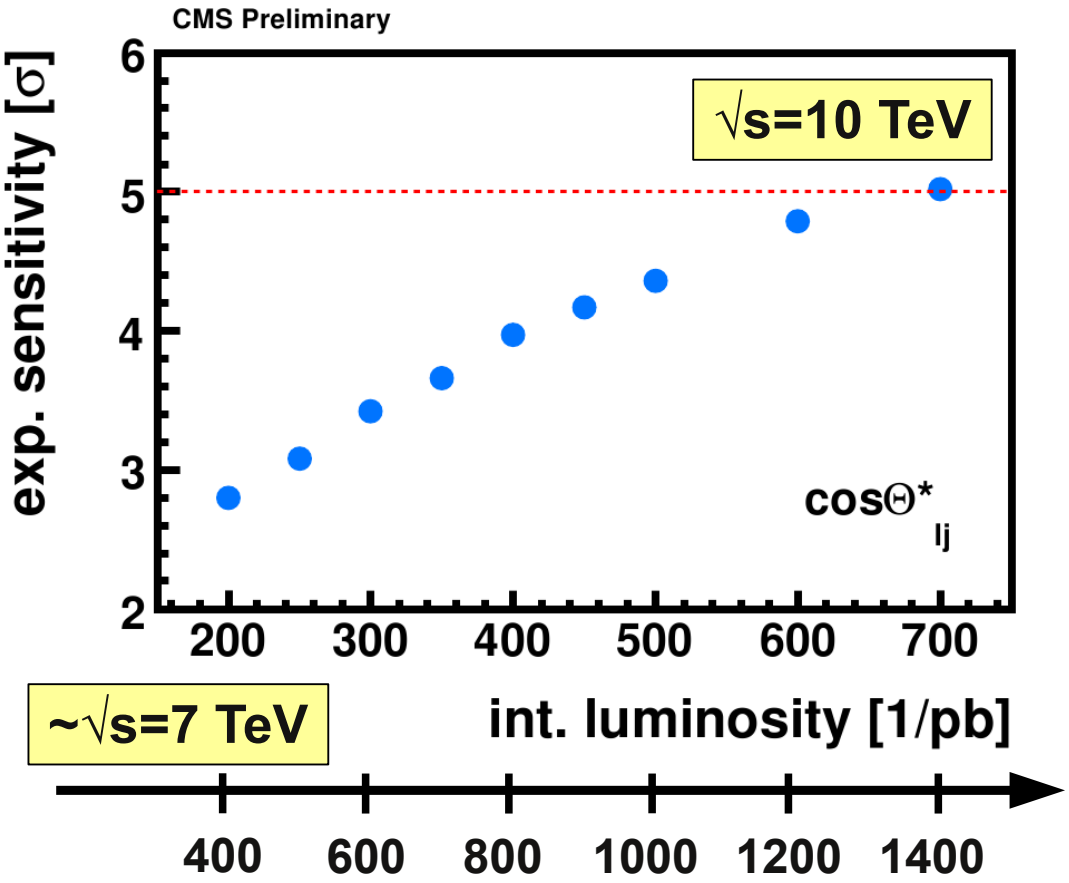


# Single Top Results

Single top (re-) discovery potential is estimated in likelihood fit of $\cos\Theta^*_{lj}$:

- Perform ensemble test to estimate sensitivity:
  expect ~3σ evidence with ~250pb$^{-1}$
- Fitting $\cos\Theta^*_{lj}$ is robust against systematic uncertainties.
- Sensitivity will scale down with a factor of about 2 going from 10 to 7 TeV.

| Source of uncertainty | $\Delta\sigma$ [%] | Expected sensitivity |
|---|---|---|
| statistical | $\pm$ 35 | $2.8\sigma$ |
| $b$ tagging | $\pm$ 7.3 | $2.7\sigma$ |
| mistag | $\pm$ 0.4 | $2.7\sigma$ |
| JES | $\pm$ 5.5 | $2.7\sigma$ |
| MET | $\pm$ 9.9 | $2.7\sigma$ |
| PDF | $\pm$ 5.5 | $2.7\sigma$ |
| total | $\pm$ 39 | $2.7\sigma$ |




With ongoing improvements a rediscovery of single top production at 1/fb @7 TeV seems to be likely.

# R Ratio

$V_{tb}$ can also be measured in top quark pair production:

- In Standard Model ($V_{tb}$=1) the top quark decays to ~100% to W+b
- $R=|V_{tb}|^2/(|V_{td}|^2+|V_{ts}|^2+|V_{tb}|^2)$ is sensitive to $V_{tb}$.

**Analysis strategy:**

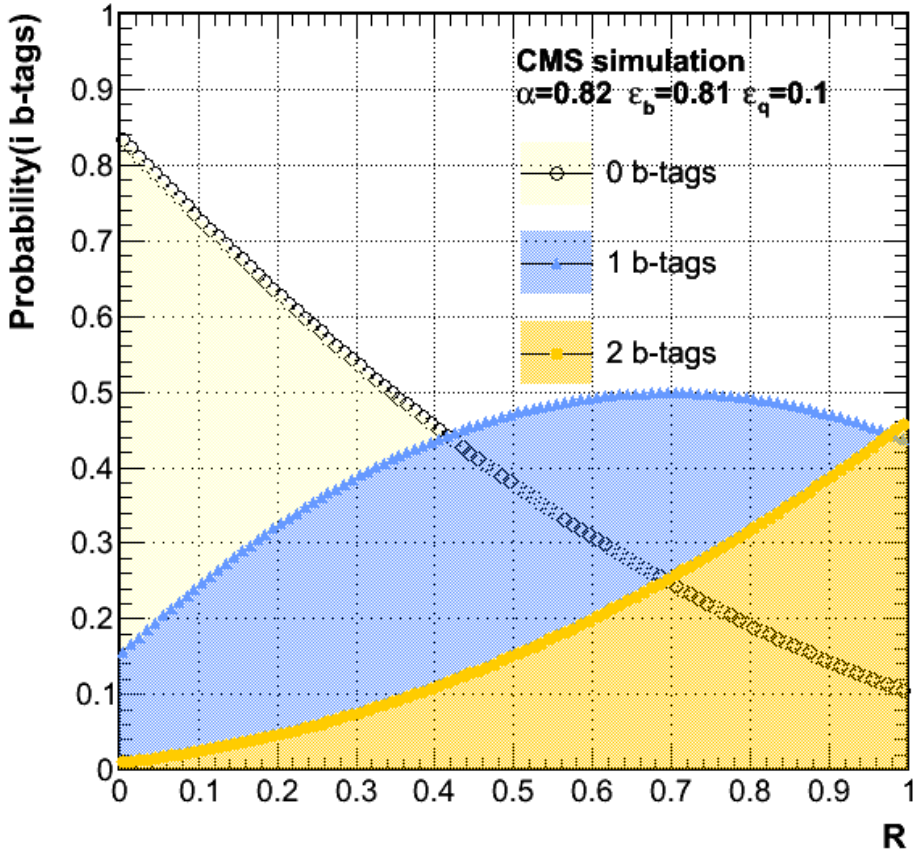
- Select a highly ttbar enriched sample without applying b-tagging cuts
- Estimate $R$ from the $N_{btag}$ distribution.

**Main challenges:**

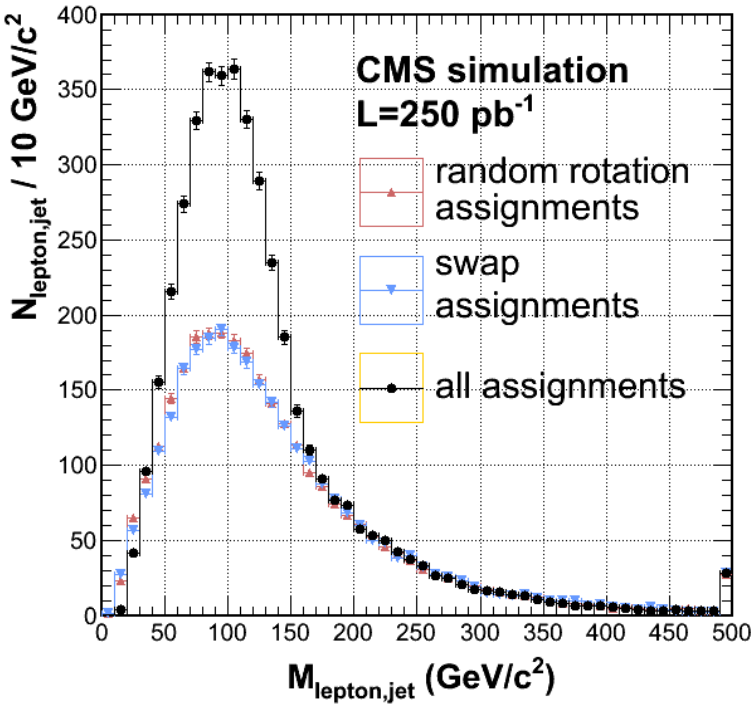
- Identify b jets originating from top decays
- Estimate the fraction of b jets wrongly assigned to top decays

Two MC studies are presented here:

- dilepton channel with eμ final state (very pure ttbar sample, S/B~10)
- muon+jets final state (S/B~5)



# R Ratio in Dilepton Events




**Dilepton event signature: 2 jets, electron + muon**

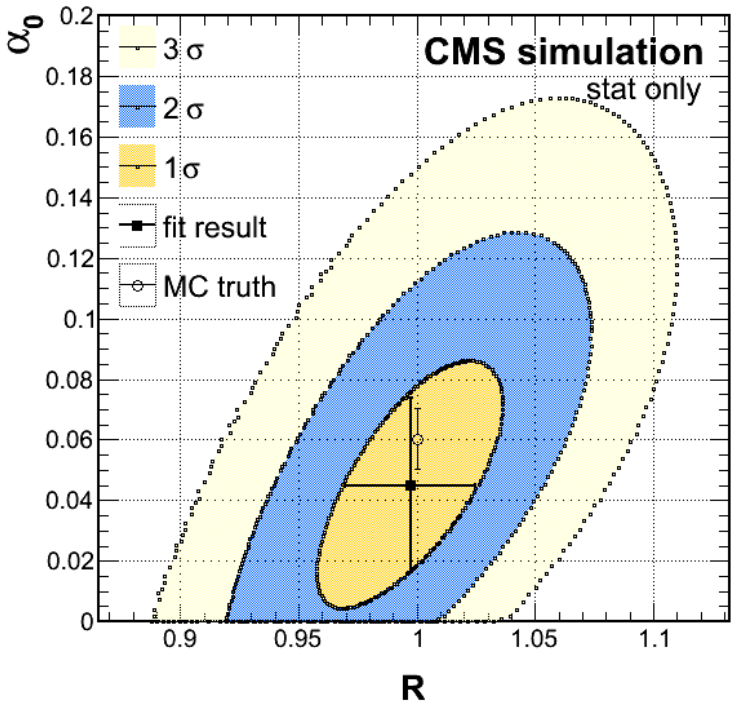
Assign one jet and one lepton to each top quark.

**Misassignment modelling:**

Correct assignments: $M_{lj} < \sqrt{(m_t^2 - m_W^2)} = 156$ GeV/c$^2$

→ misassignment rate $\alpha_0$ from fitting $M_{lj}$ distribution with shape taken from:

- "swapping": pair lepton with jet from other event
- "rotating": rotate lepton momentum randomly




Fit simultaneously R and $\alpha_0$ using b tag multiplicity from jet probability tagger.

Take b tagging efficiency $\varepsilon_b$ as input from an independent measurement.

Main systematic is assumption on $\varepsilon_b$.

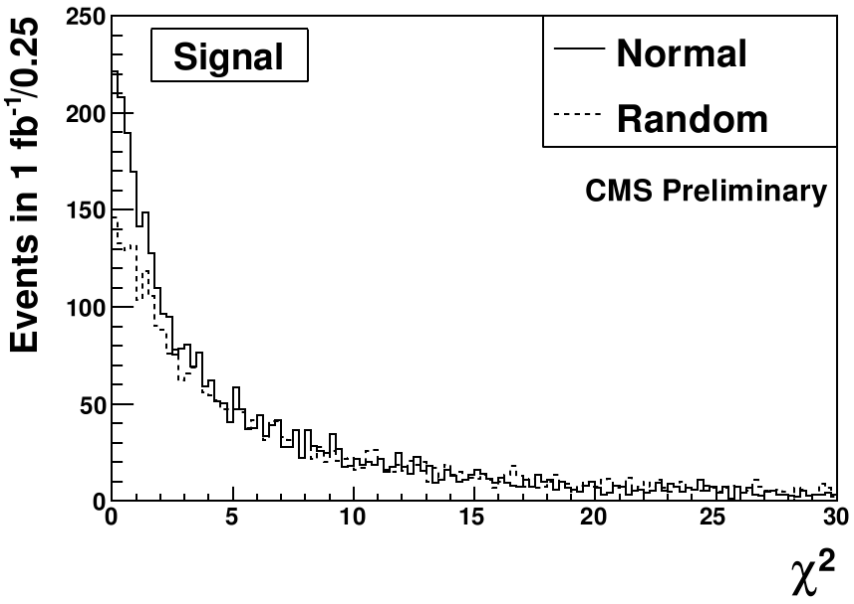
# R Ratio in μ+Jets Events

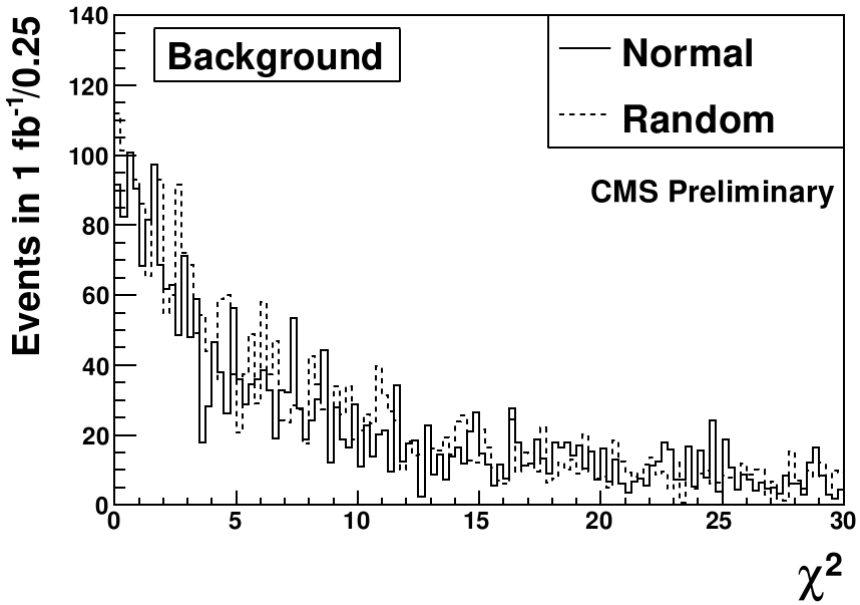
**Event signature: one muon + 4jets**

Correct assignment of jets to top quark is more difficult (one jet to leptonically decaying t, 3 jets to hadronically decaying t):

Choose assignment with smallest $\chi^2$:

$$\chi^2 = \left(\frac{m_{ijk} - m_{tHad}}{\sigma(m_{tHad})}\right)^2 + \left(\frac{m_{lvp} - m_{tLep}}{\sigma(m_{tLep})}\right)^2$$



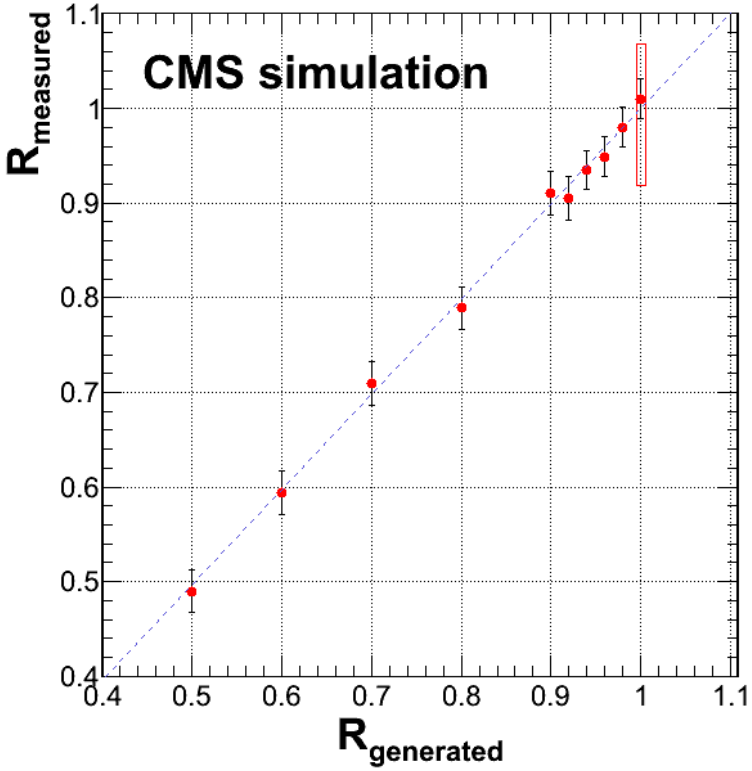

Background and incorrectly reconstructed top events:

- Construct a random $\chi^2$ distribution from data by randomly rotating jets in η and φ.
- Take this distribution to model background and misassignments.
- Fit *R* to the background subtracted b tagging multiplicity.

# R Ratio Summary

Evaluate expected uncertainties on R measurement in toy Monte Carlos.

**dilepton analysis**

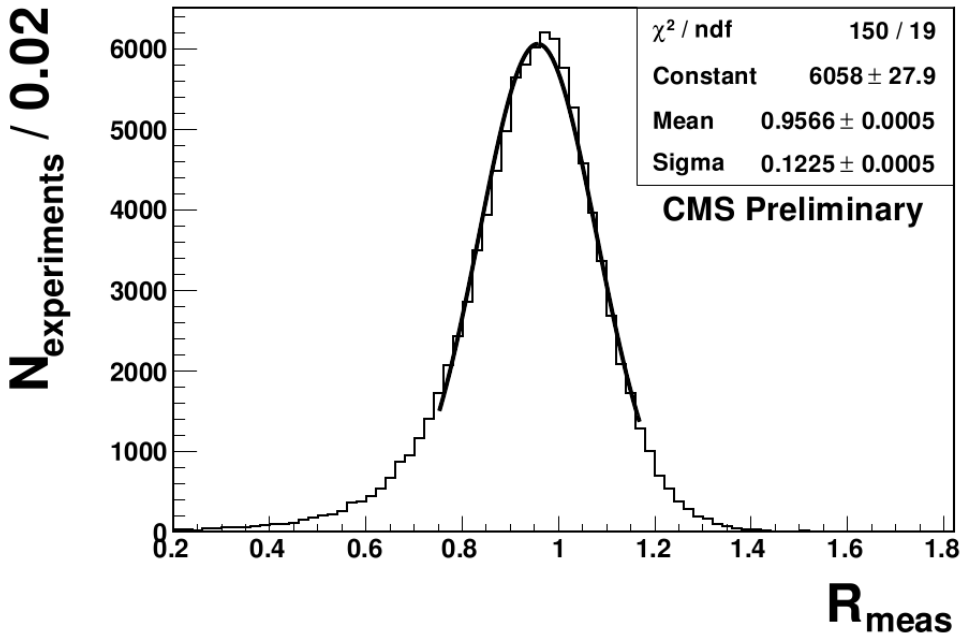



Expected uncertainty:

$\sigma_R$(stat+syst)=9%

at $\sqrt{s}$=10 TeV, L=250 pb$^{-1}$

**muon+jets analysis**



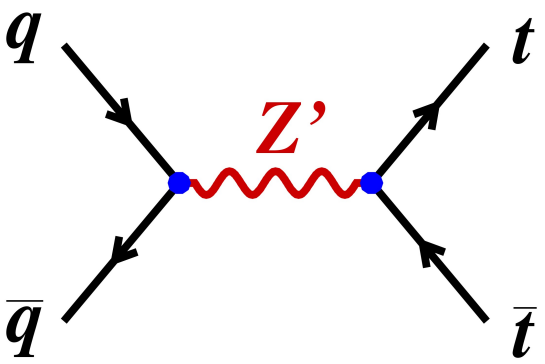

Expected uncertainty:

$\sigma_R$(stat)=12%, $\sigma_R$(syst)=11%

at $\sqrt{s}$=10 TeV, L=1 fb$^{-1}$

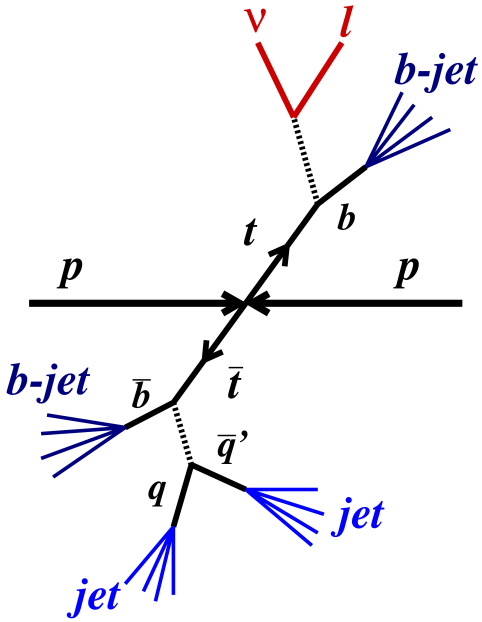
# $M_{t\bar{t}}$ Resonances

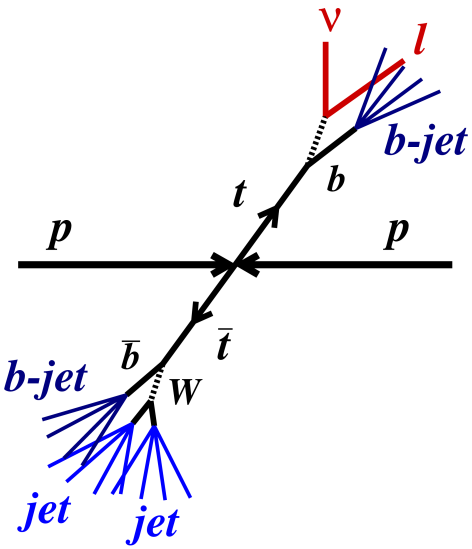
The top quark pair might be produced in the exchange of a unknown heavy particle at the LHC.




Several models include such resonances:

- Axigluons
- Extra Dimensions
- Kaluza-Klein states
- Z'
- …



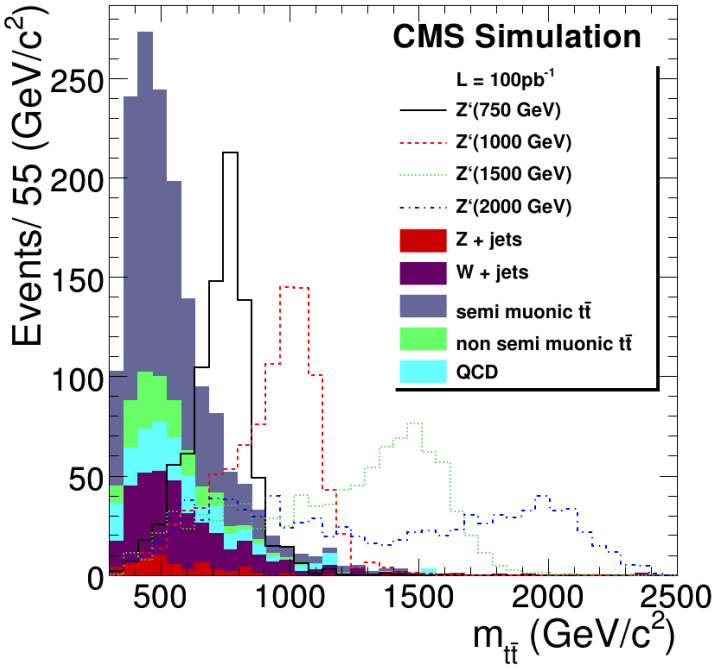

If the new exchange particle is heavy and narrow, the distribution of the invariant mass of the top quark pair system will show resonances.

Top quarks originating from a decay of a high mass resonance are boosted → *different event topology than in SM.*

# Muon+Jets

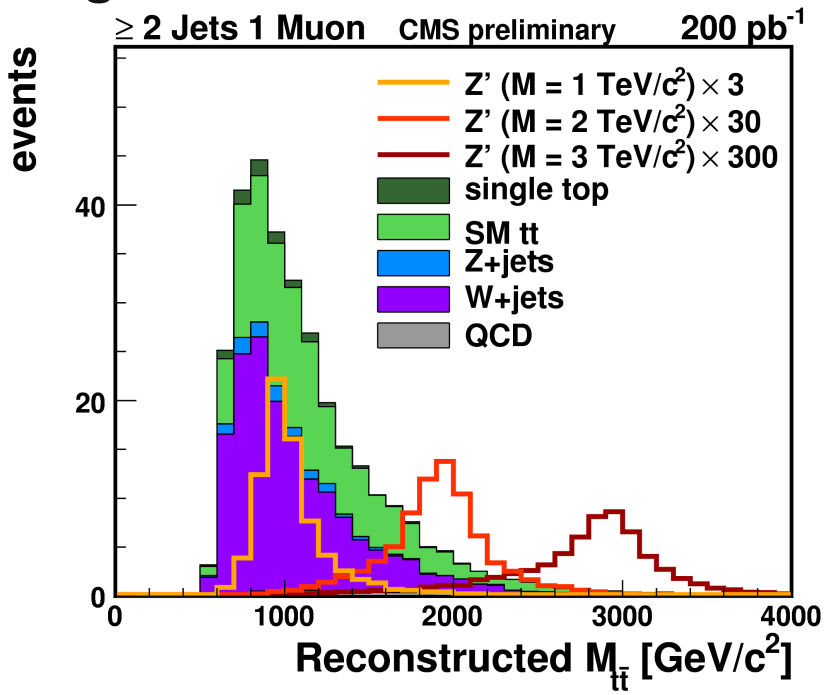
Two analyses in the muon+jets decay channel optimized for low and high mass resonances:

**low mass:**




- Select events with 4 jets and one muon
- Estimate backgrounds from sideband with $H_T$<350 GeV
- Full reconstruction of top 4-momenta and top decay products possible with a kinematic fit.

**high mass:**




*topcolor Z' as reference*

- Select events with 2 jets and one muon
- Estimate backgrounds from sideband with $P_T(\mu)$+MET<200 GeV
- Exploit the boosted event topology to re-construct the top 4-momenta.

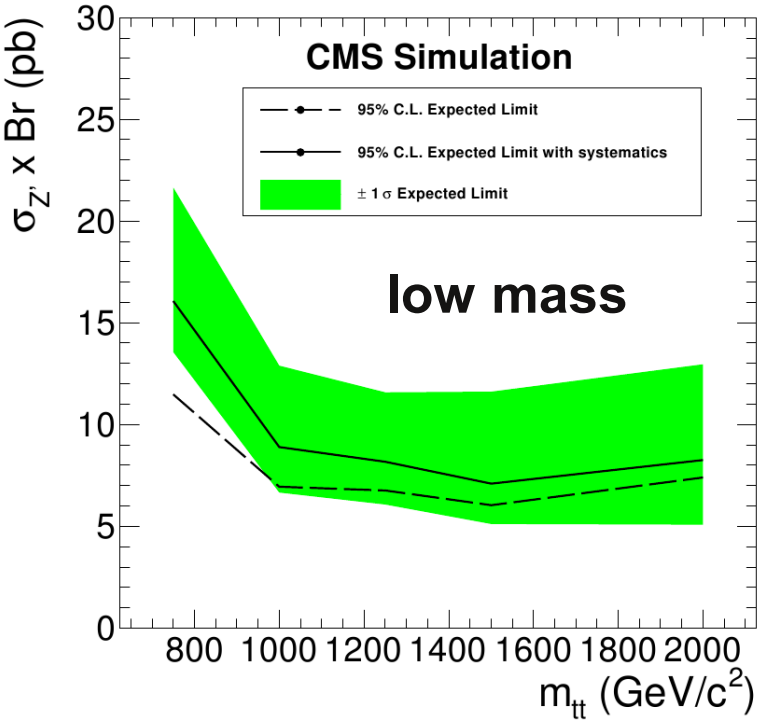
# Muon+Jets Results

Exclusion limits are determined in likelihood fits to the $M_{tt}$ distribution in pseudo experiments.

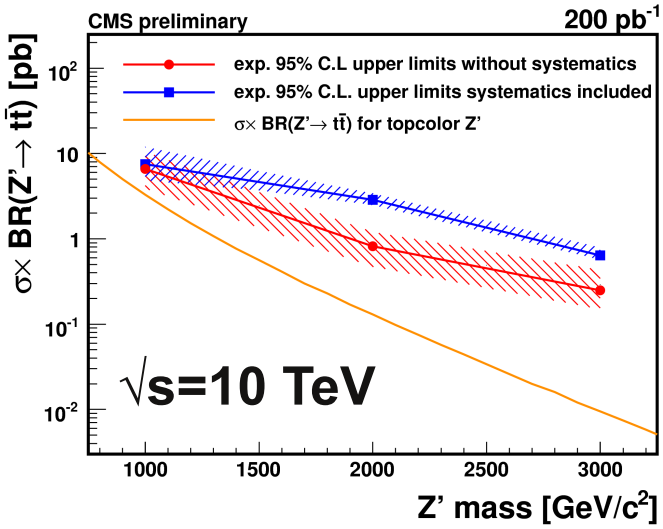
Systematic uncertainties are incorporated into the fit.

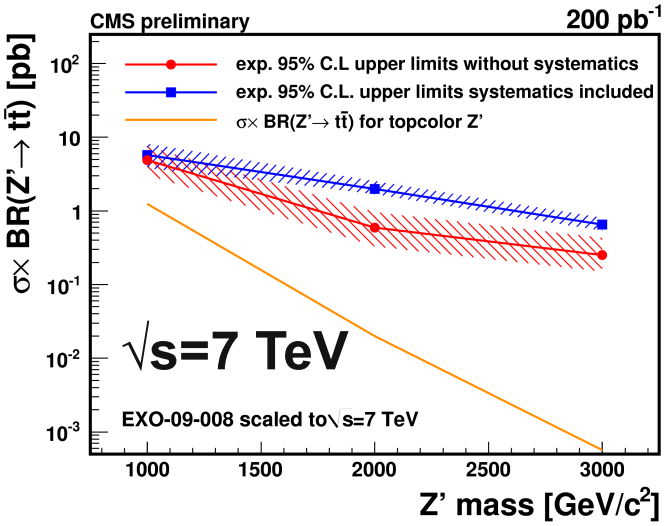
Limits in reach are of the order of a few pb.

For the first time limits on heavy resonances decaying to top pairs can be given in the multi-TeV range.




**high mass**

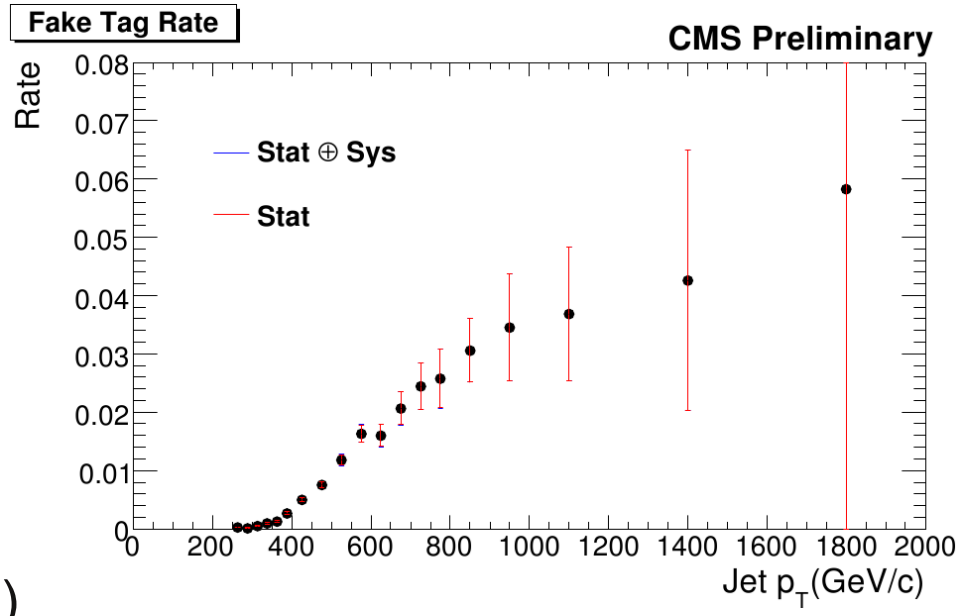


# Top Tagging

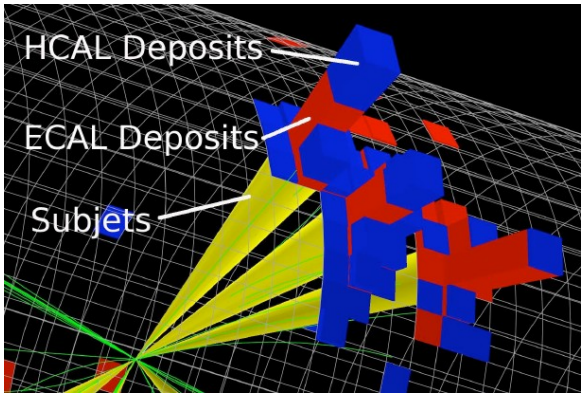
**Full hadronic decay channel (t→bqq') :**

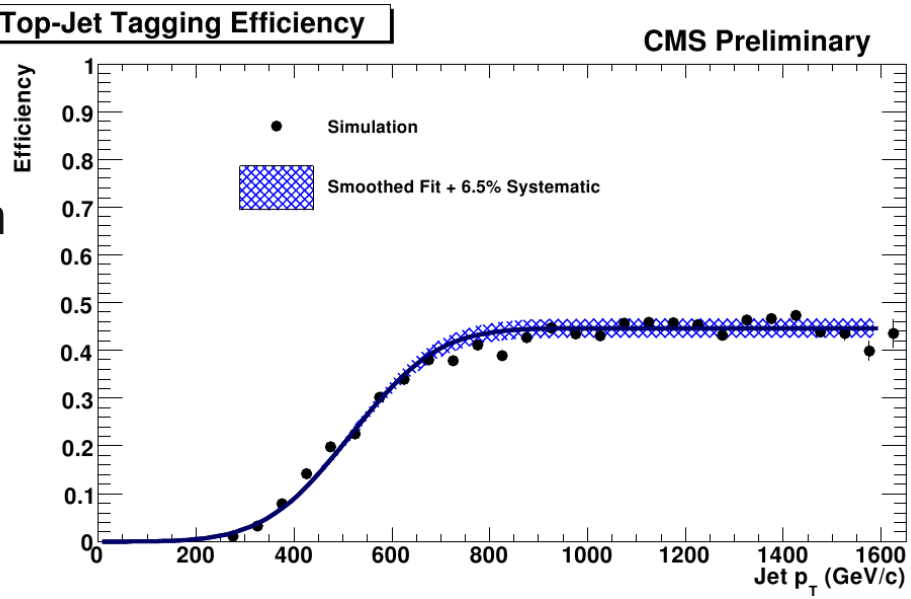
- For boosted tops all decay products of each top quark end up in one fat jet.
- Main background is QCD di-jet production.
- Jets from boosted tops can show sub-Structure → *top tagging*



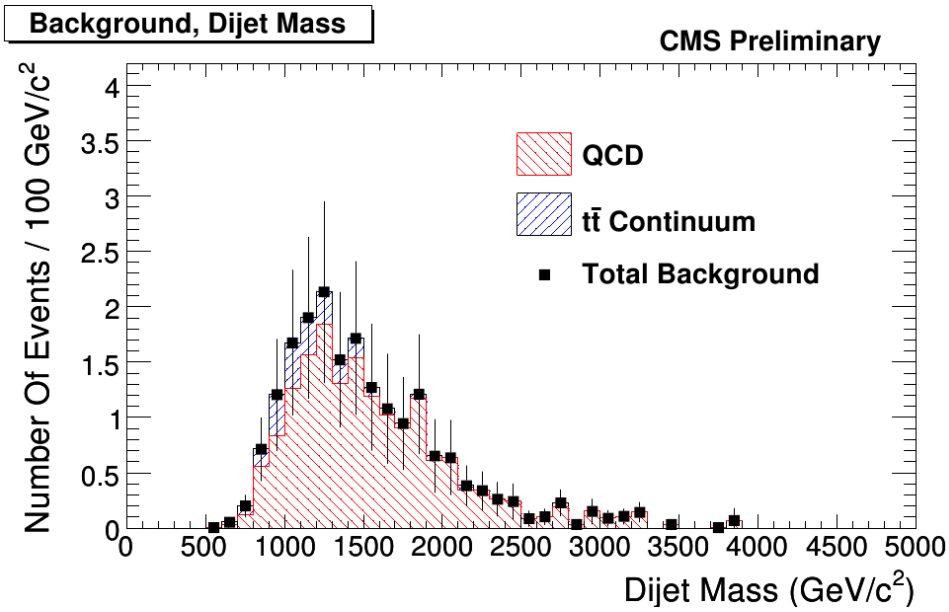

**Tagging algorithm:**

- Use Cambridge-Aachen jets ($P_T$>250 GeV/c)
- Undo the last jet clustering steps and search for high-$P_T$ subjets
- Apply cuts on di-subjet masses consistent with M(W) and jet masses consistent with M(top).



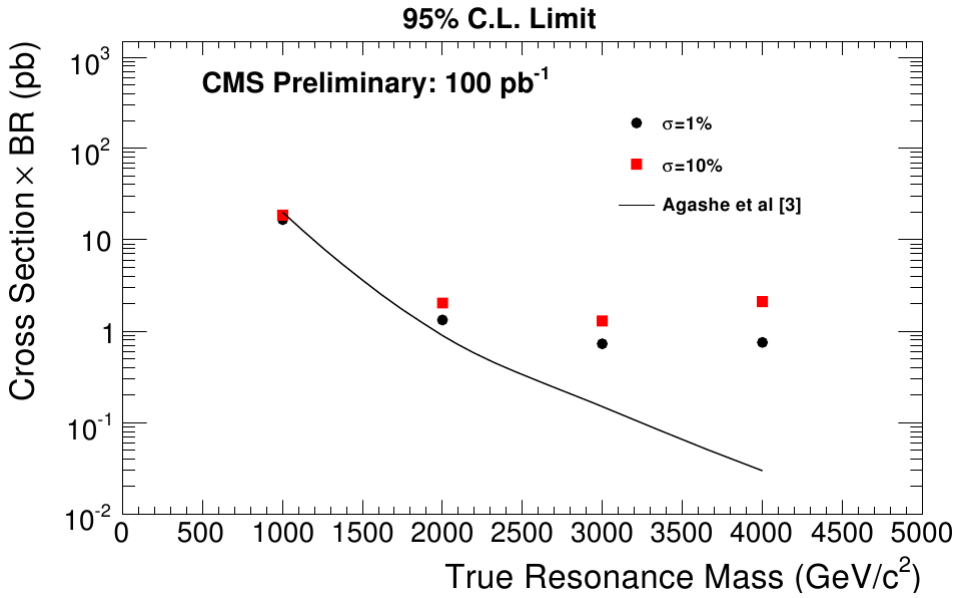
# Top Tagging Results




**Determination of exclusion limits:**

- Perform counting experiments in mass windows of the dijet mass distribution.
- Fold in systematic uncertainties into the likelihood function.
- Widths of 1% and 10% of the resonace are assumed.

*Kaluza Klein gluon for RS1 as reference*




Some new physics scenarios might be excluded with first data next year.

# Summary

Top quarks will provide broad spectrum of interesting measurements at LHC.

Presented measurements:

- Search for electroweak single top quarks,
  cross section is a direct measure for $|V_{tb}|$.
  Might be able to observe single top quarks with $1fb^{-1}$.

- Measurement of $R=B(t\rightarrow Wb)/B(t\rightarrow Wq)$ in top pair production.
  A precision of ~10% is expected.

- Search for resonances in the top-antitop mass spectrum;
  Special reconstruction and selection methods required for “boosted tops”.
  Might reach limits on resonance cross section of a few pb soon.

**References:**

Single top: CMS PAS TOP-09-005
R ratio: CMS PAS TOP-09-001, CMS PAS TOP-09-007
Top pair resonances: CMS PAS TOP-09-008, CMS PAS TOP-09-009, CMS PAS EXO-09-008
https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsTOP