Single Top Strategies and Potentials at CMS

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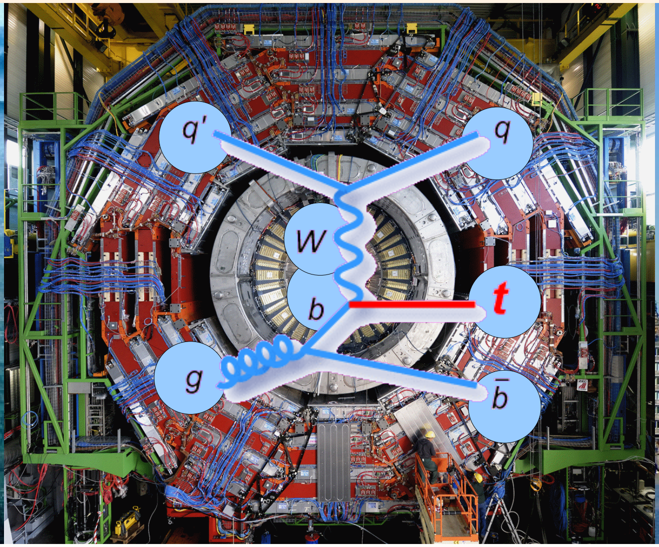
on behalf of the CMS Collaboration

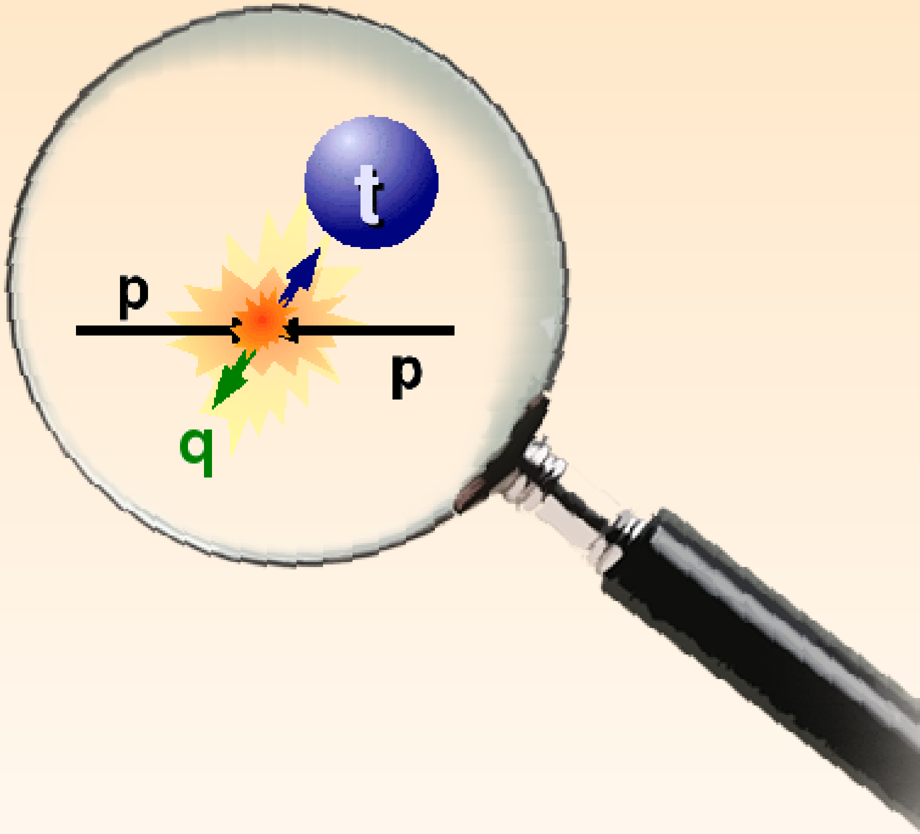
Workshop on single top physics and fourth generation quarks

DESY,14.9.2009



Overview

- Introduction
- t-channel modeling
- Early single top analysis
  - Event selection
  - QCD estimation
  - Robust sensitive variable
  - Prospects



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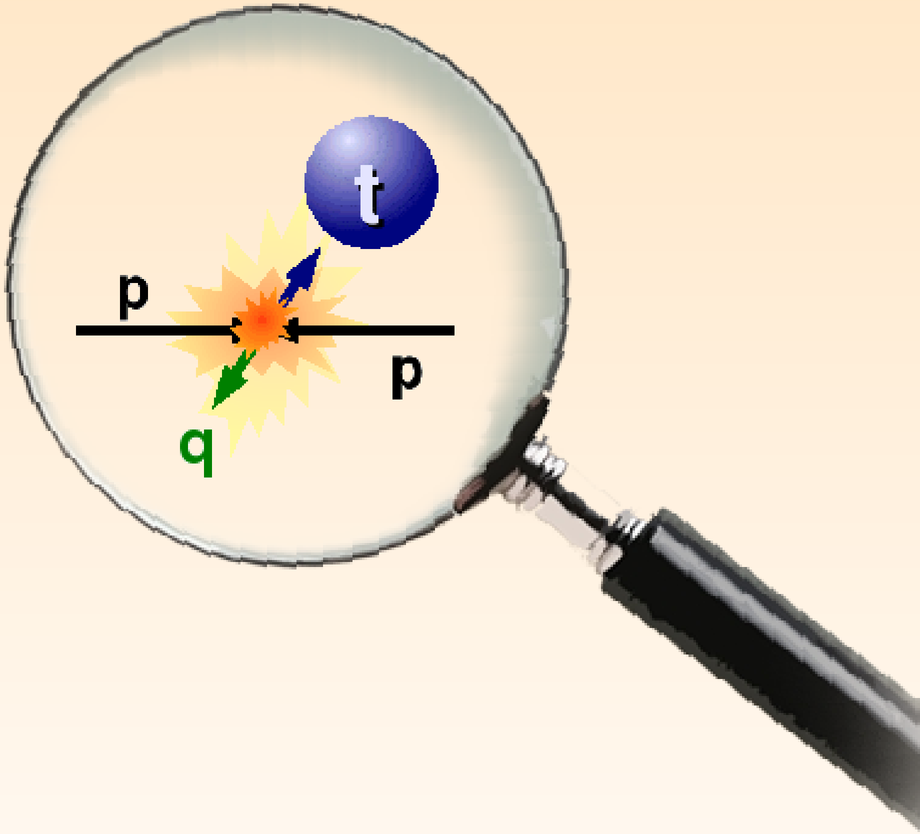
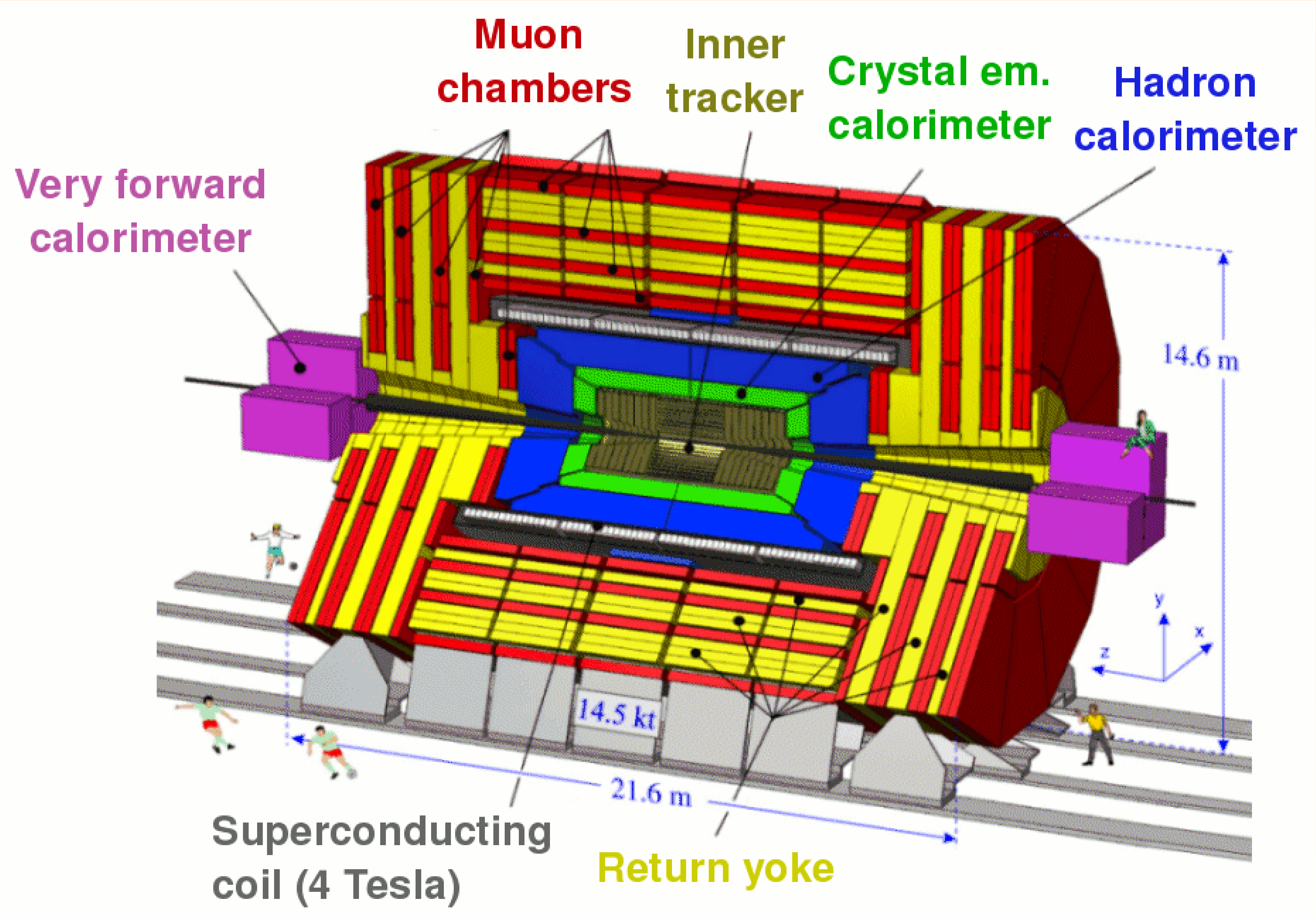
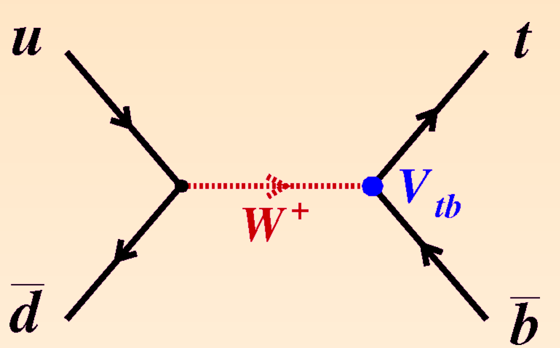


CMS Detector

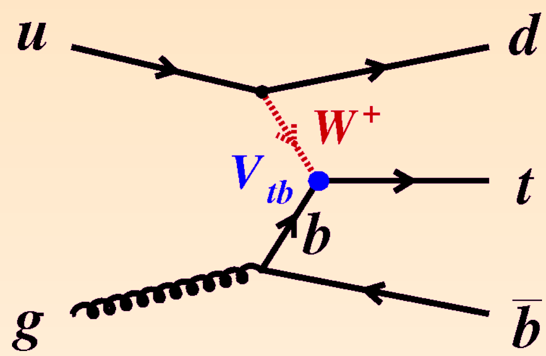


Single Top @ LHC

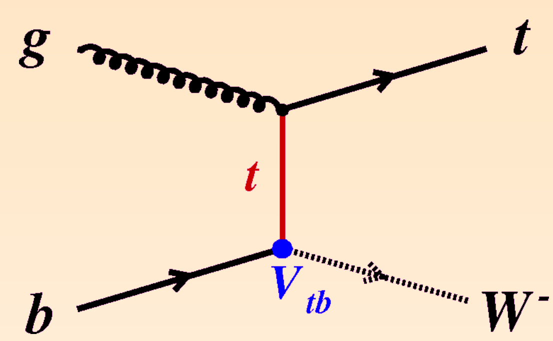
s-channel



t-channel



associated production



	Tevatron [pb] $\sqrt{s}$ = 1.96 TeV	LHC [pb] $\sqrt{s}$ = 14 TeV		LHC [pb] $\sqrt{s}$ = 10 TeV	
s-channel	0.88	10.7	(· 12)	**5**	(· 6)
t-channel	1.98	247	(· 125)	**130**	(· 65)
associated production	0.094	56	(· 600)	**29**	(· 310)

T.Tait Phys. Rev. D61, 034001 (2001); N. Kidonakis et al. Phsy. Rev. D75, 071501 (2007); B.W. Harris et. al. Phys. Rev. D66, 054024 (2002); MCFM calculations by Maxim Perfilov

- **Rise of t-channel x-section ~13 times larger than rise of W+jets x-section**
- **t-channel is most interesting channel for the first LHC data**

Single Top Group @ CMS

Louvain, Belgium:
Andrea Giammanco

Tehran, Iran:
Nadjieh Jafari
Mojtaba Mohammadi Najafabadi

Aachen, Germany:
Martin Erdmann
Dennis Klingebiel
Jan Steggemann *(joined recently)*

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Charge asymmetry

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Early analysis with 200/pb at $\sqrt{s}$=10TeV
(PAS TOP-09-005)

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MC generators:

MadEvent **SINGLETOP**

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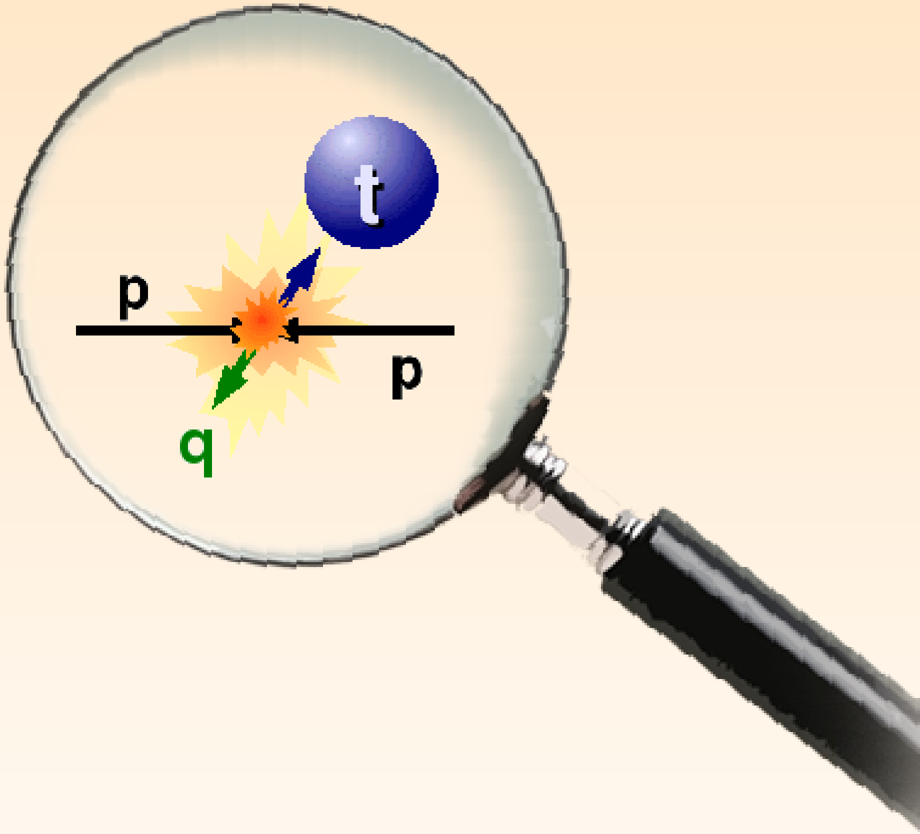
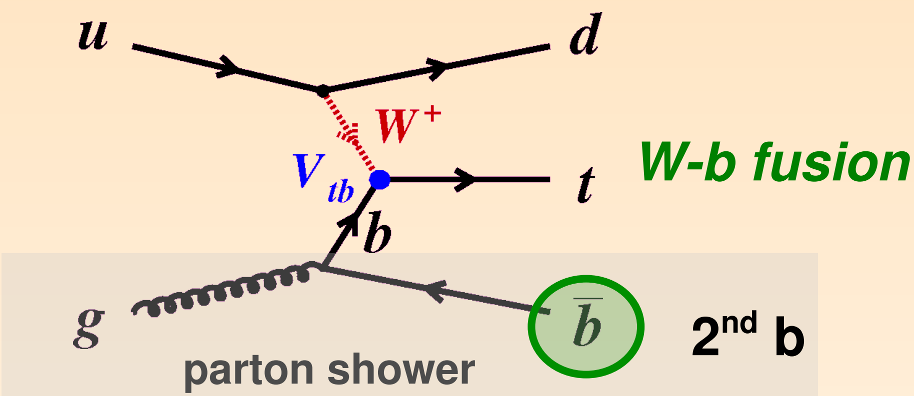
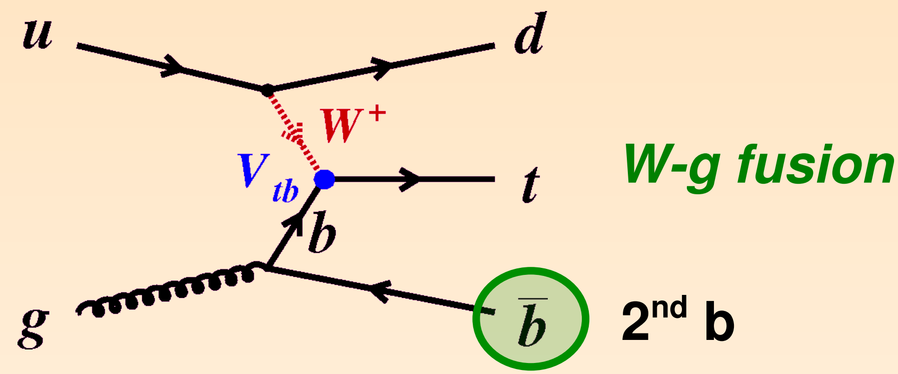


t-Channel Modeling

LO process (2→2)

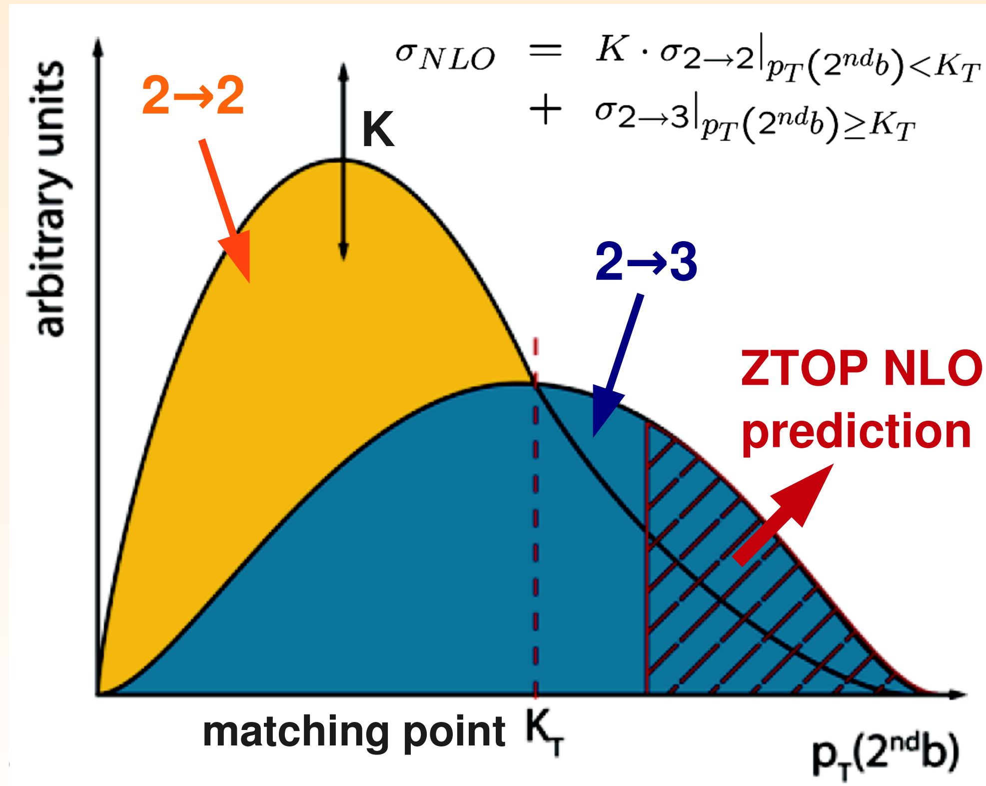


NLO contribution (2→3)



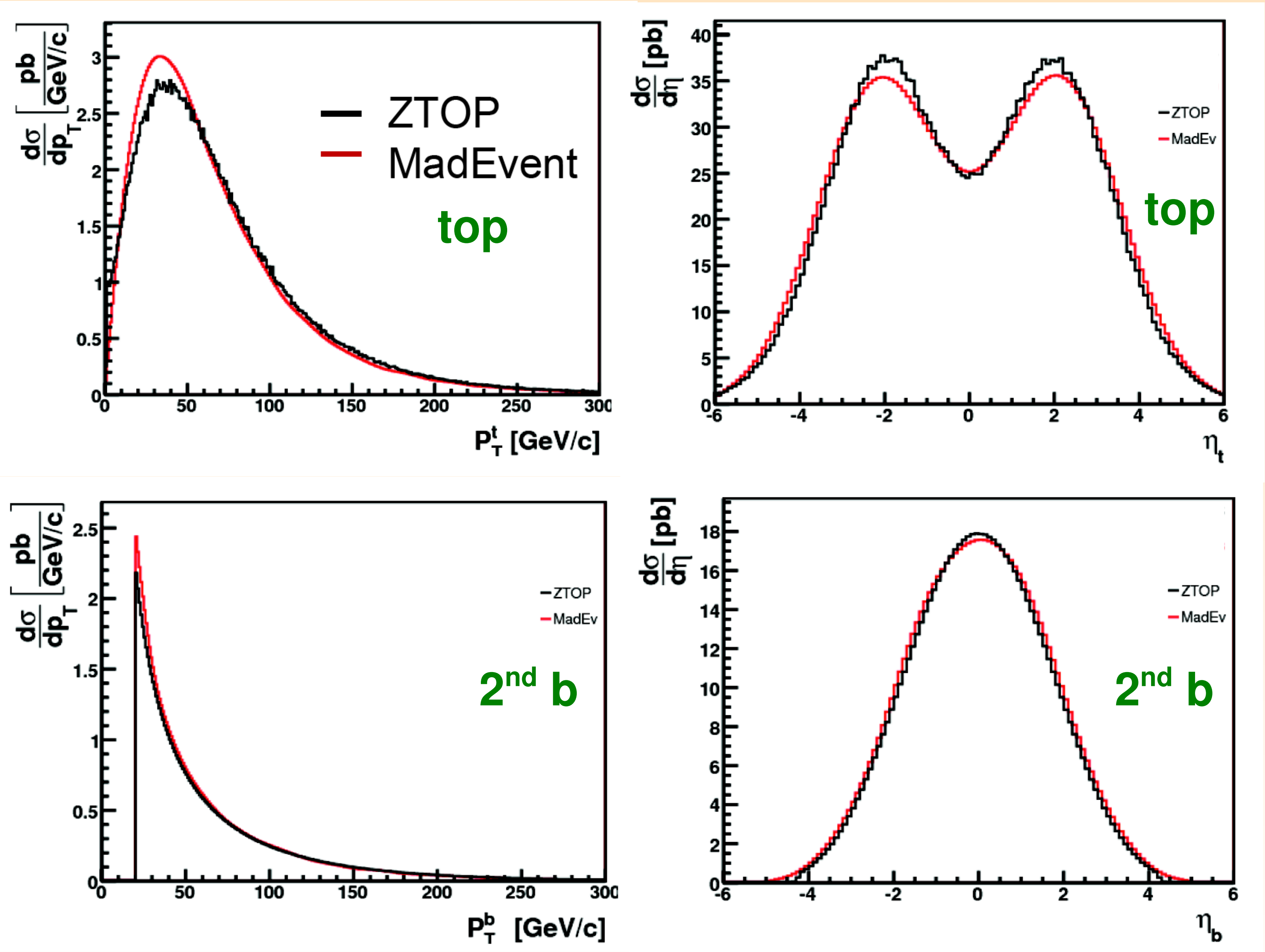
Modeling:

- MadEvent + PYTHIA for showering
- W-b and W-g fusion processes generated separately and matched in p_T of 2nd b to match ZTOP NLO calc.
  (total x-section and rate of events with a hard 2nd b)



ZTOP: PRD66,054024 (2002); MadEvent: JHEP 0709:028 (2007)

Comparison: MadEvent - ZTOP



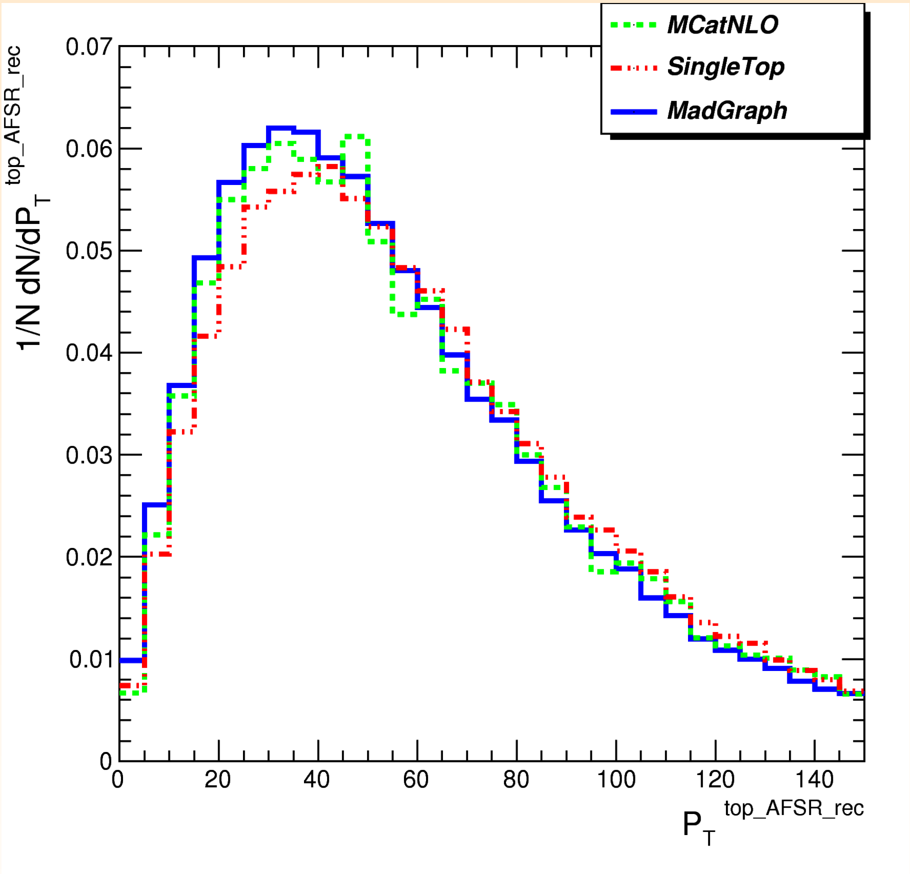
√s=14TeV

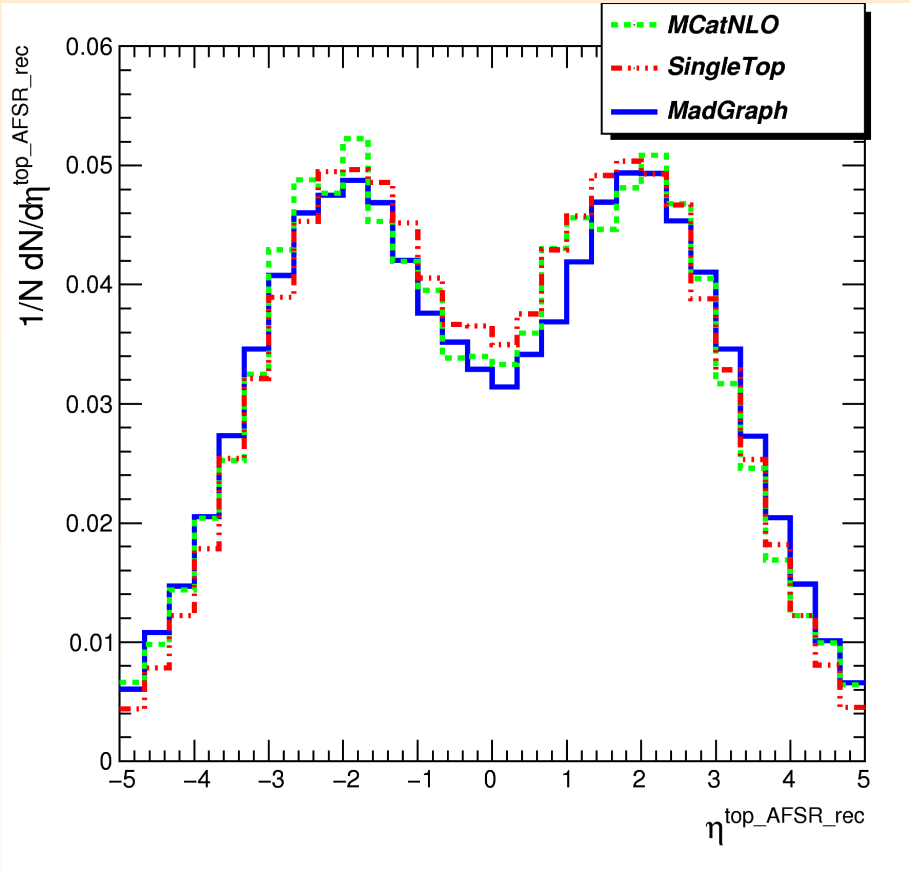
Matched MadEvent sample reproduces kinematics of NLO ZTOP calculation well

Generator Comparison – Top Quark

- MadEvent: Matched 2->2 and 2->3 process *(Default, $m_b \neq 0$)*
- MC@NLO: NLO MC, based on Herwig *(m_b=0 in ME, $m_b \neq 0$ in showering)*
- SINGLETOP: Matched 2->2 and 2->3 process *($m_b \neq 0$)*

√s=14TeV



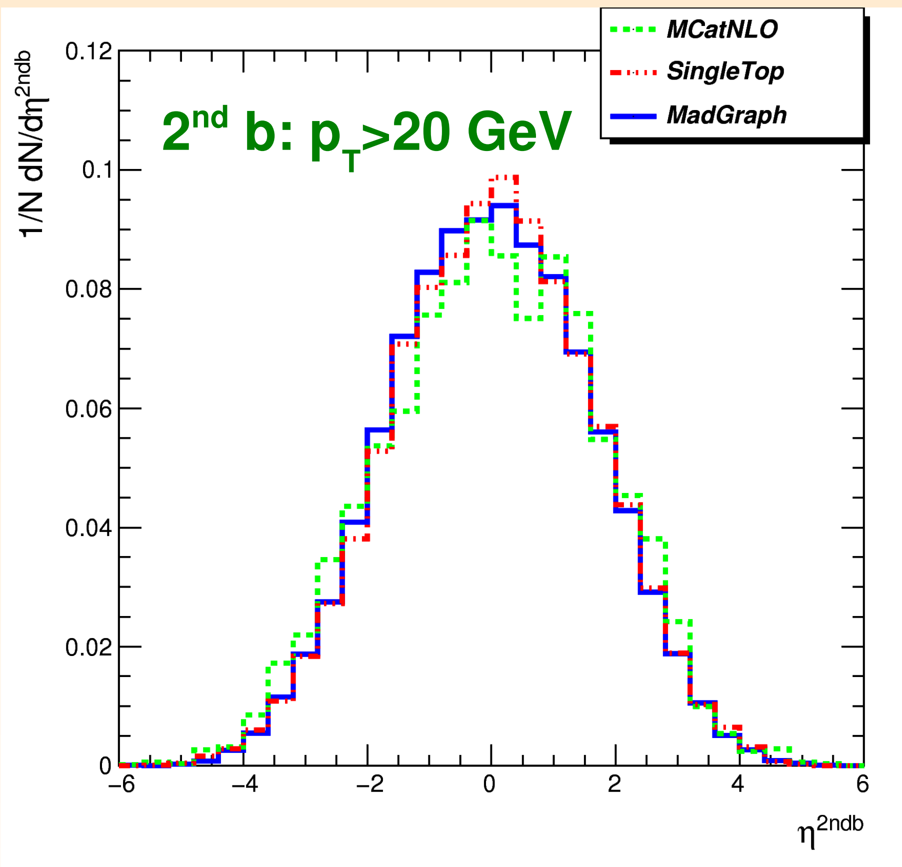


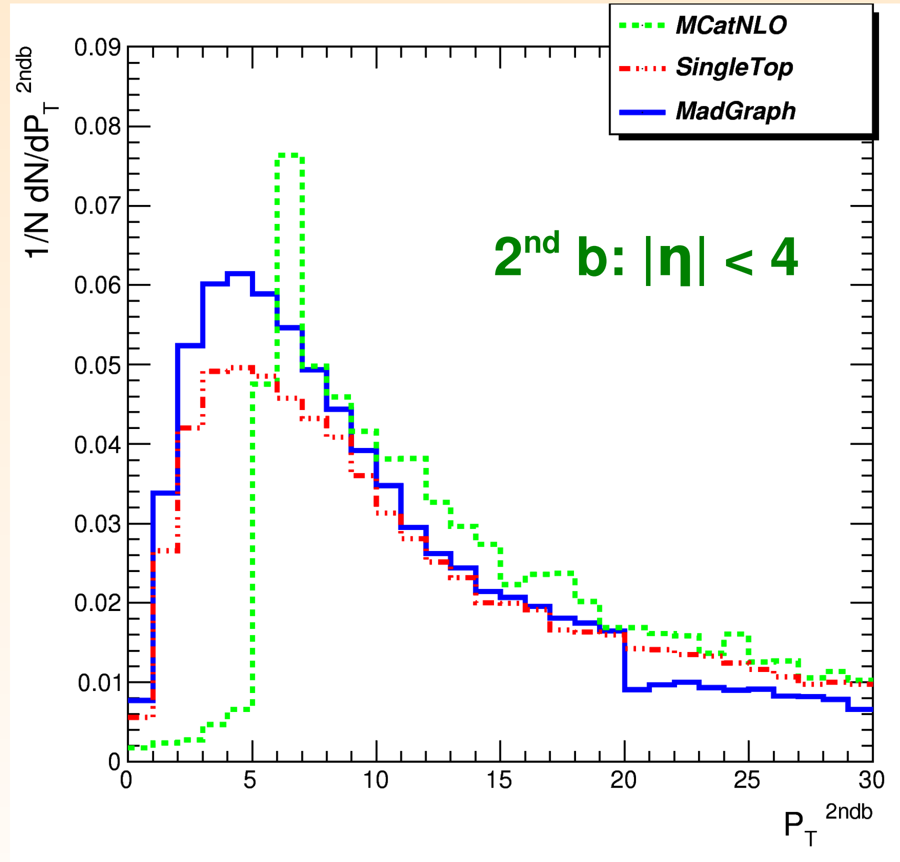
Good agreement between all three generators

Generator Comparison – Top Quark

- **MadEvent: Matched 2->2 and 2->3 process** *(Default, $m_b \neq 0$)*
- **MC@NLO: NLO MC, based on Herwig** *(m_b=0 in ME, $m_b \neq 0$ in showering)*
- **SINGLETOP: Matched 2->2 and 2->3 process** *($m_b \neq 0$)*

√s=14TeV





Largest differences visible in variables of 2nd b

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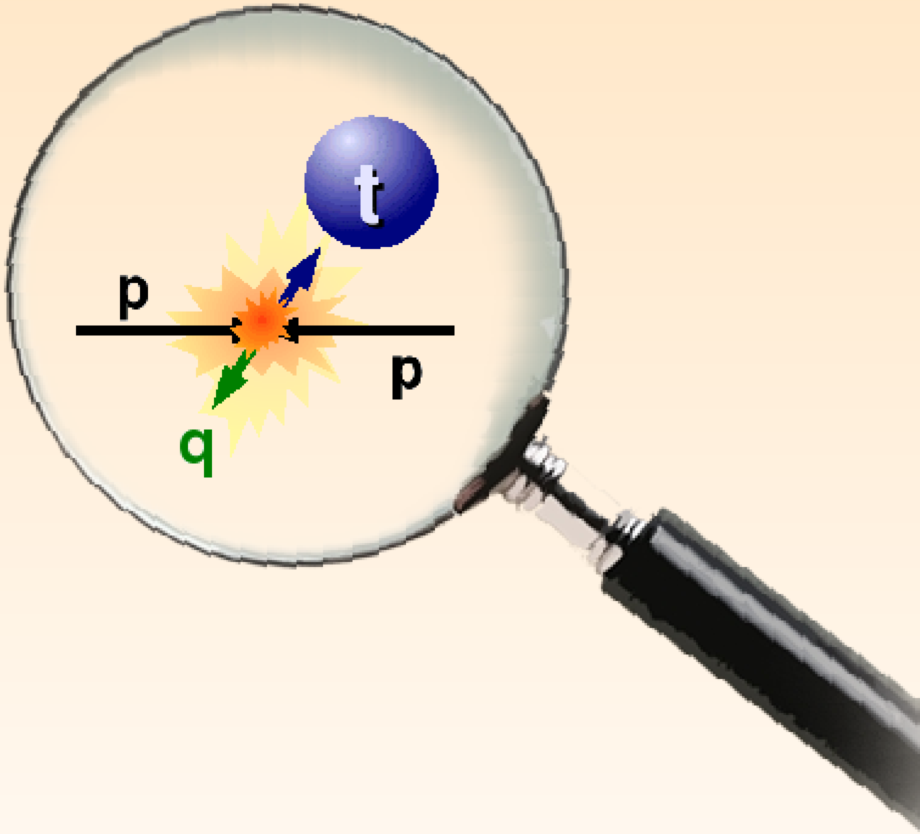
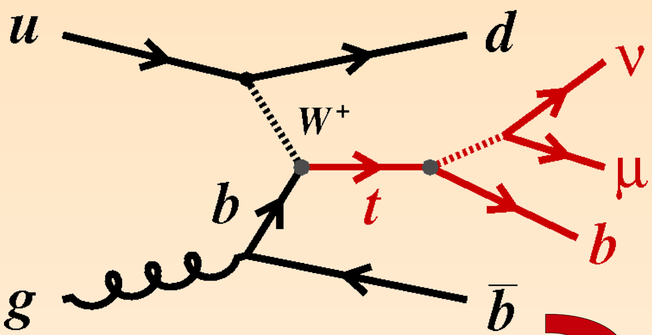


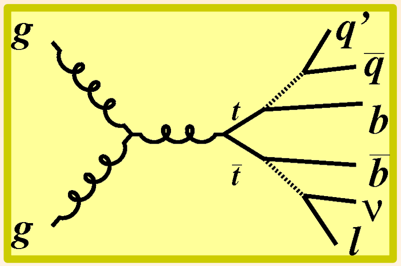
Considered Processes

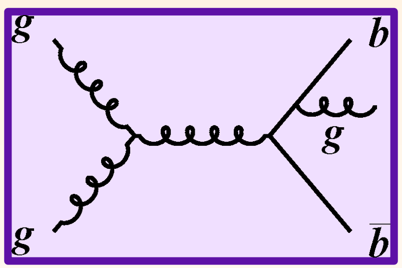


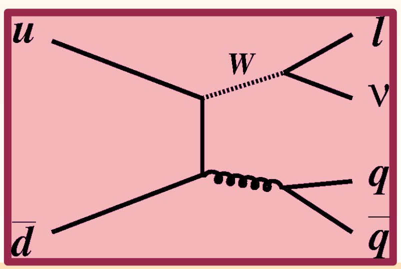
Signal: Single top t-channel events, where the W decays leptonically into a muon and a neutrino

√s=10TeV

Important backgrounds:







Process	$\sigma \times$ BR[pb]
single top, t channel $(W \to l\nu, l = e, \mu, \tau)$	42.9 (NLO)
single top, s channel $(W \to l\nu, l = e, \mu, \tau)$	1.6 (NLO)
single top, tW	29 (NLO)
$t\bar{t}$	414 (NLO+NLL)
QCD multi-jet (μ-enriched)	121675 (LO)
Wc $(W \to l\nu, l = e, \mu, \tau)$	1 490 (LO)
$Wb\bar{b}$ $(W \to l\nu, l = e, \mu, \tau)$	54.2 (LO)
$Wc\bar{c}$ $(W \to l\nu, l = e, \mu, \tau)$	118.8 (LO)
$W+$ light partons $(W \to l\nu, l = e, \mu, \tau)$	40 000 (LO)
$Zb\bar{b}$ $(Z \to ll, l = e, \mu, \tau)$	44.4 (LO)
$Zc\bar{c}$ $(Z \to ll, l = e, \mu, \tau)$	71.7 (LO)
$Z+$ light partons $(Z \to ll, l = e, \mu, \tau)$	3 700 (LO)
Diboson WW	74 (LO)
Diboson WZ	32 (LO)
Diboson ZZ	10.5 (LO)

Event Selection – Muon, Jets

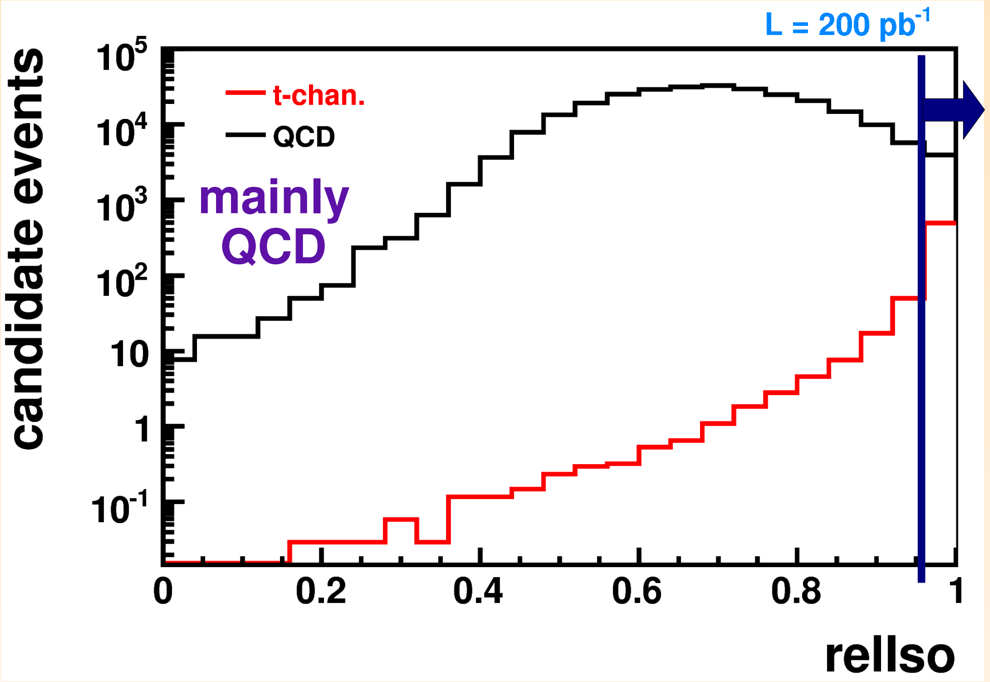
- **Trigger: muon trigger (pT> 15 GeV)**
- **Single isolated muon, di-lepton veto**

  1μ with: p_T>20 GeV, |η|<2.1

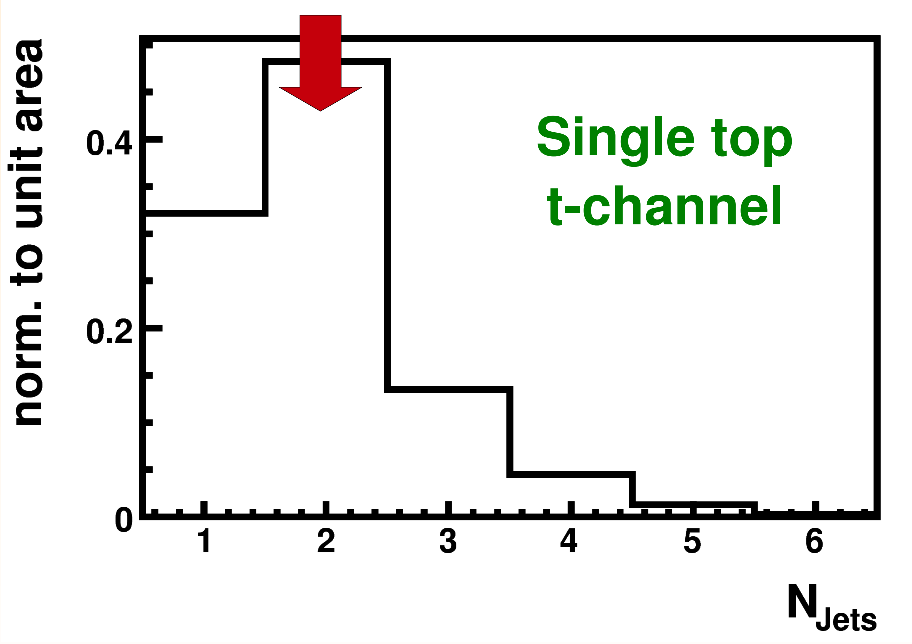
  0e with: p_T>20 GeV, |η|<2.4

$$relIso = \frac{p_{T,\mu}}{p_{T,\mu} + tkIso + caloIso} > 0.95$$

TkIso (caloIso): Scalar sum of p_T (E_T) of tracks (cal. deposits) in a cone of ΔR=0.3 around μ



Strong reduction of QCD



- **Exactly 2 jets, far from the muon**

  Iterative Cone algorithm (R=0.5),

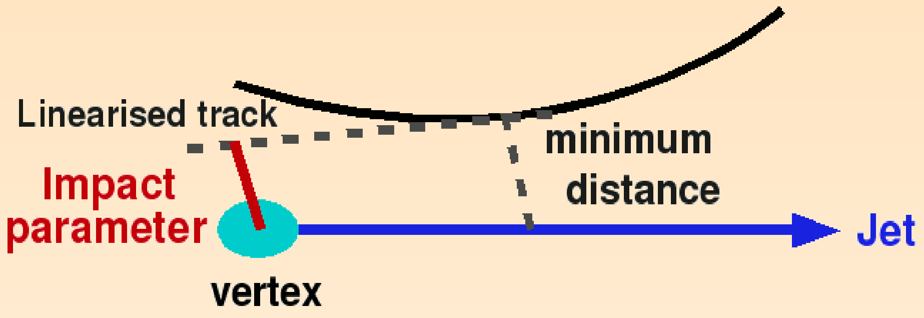
  p_T^{calib}>30 GeV, |η|<5, ΔR(μ, jets)>0.3

Calib: calibrated jets; scaled with factor that describes detector response depending on jet E_T and η

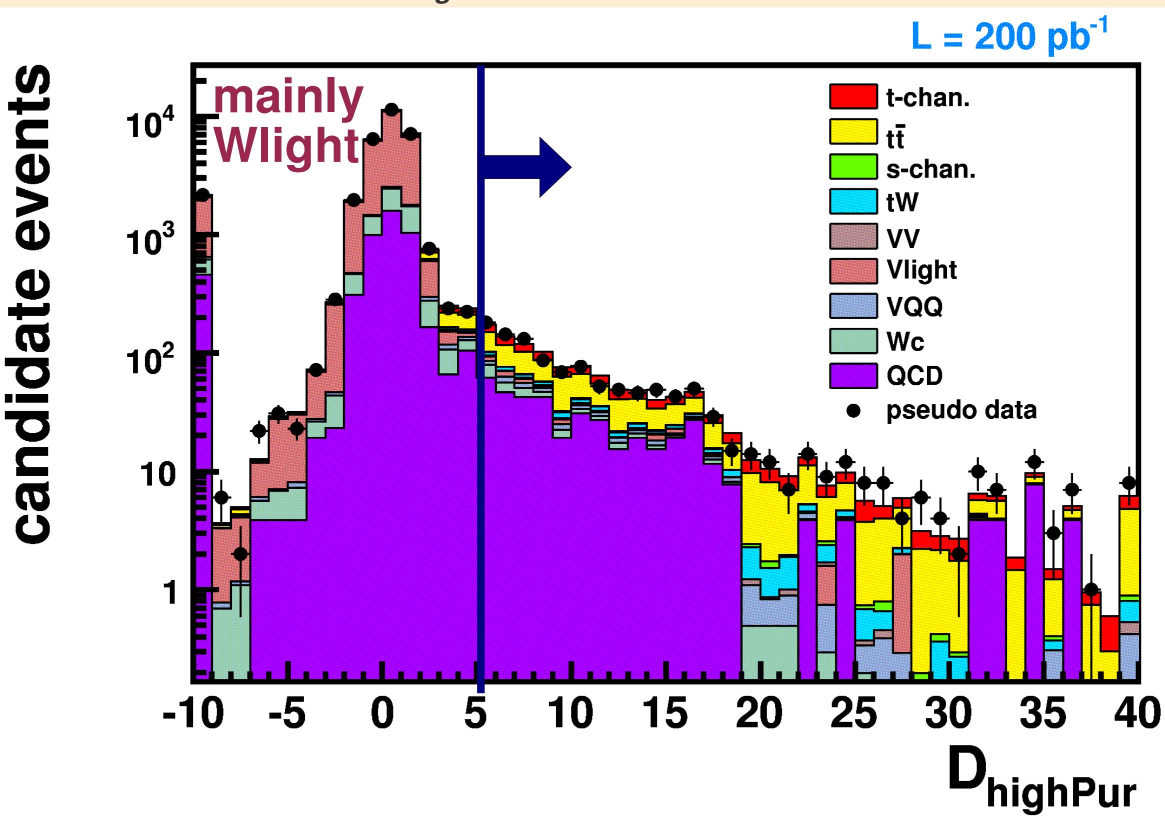
Cut to Reduce Wlight

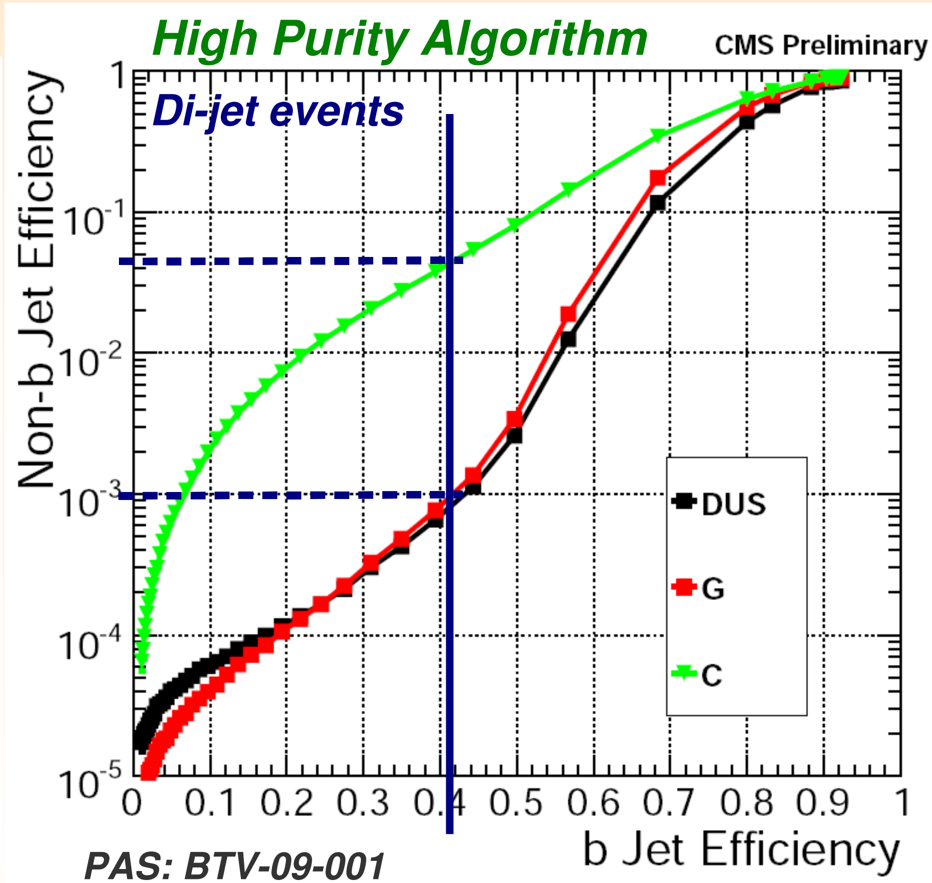
- One b jet

Track counting High Purity Algorithm:
$D_{highPur}$: impact par. significance (IPsig) of track in jet with third highest IPsig



1 jet with $D_{highPur}$>5.4

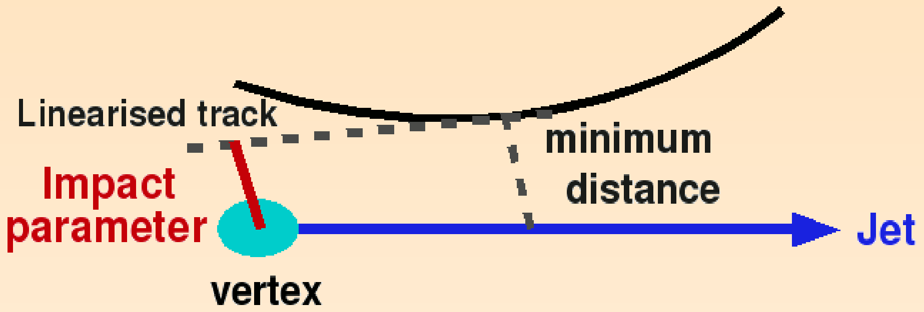




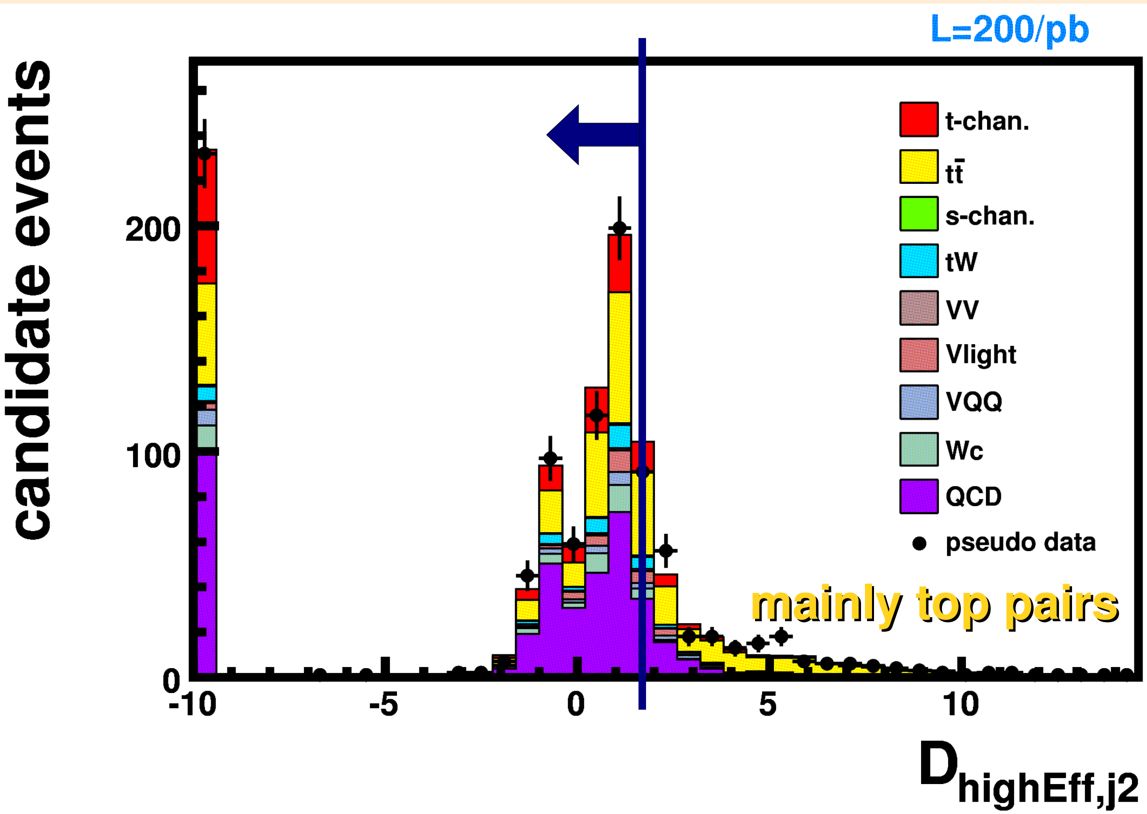
Cut to Reduce Top Pairs

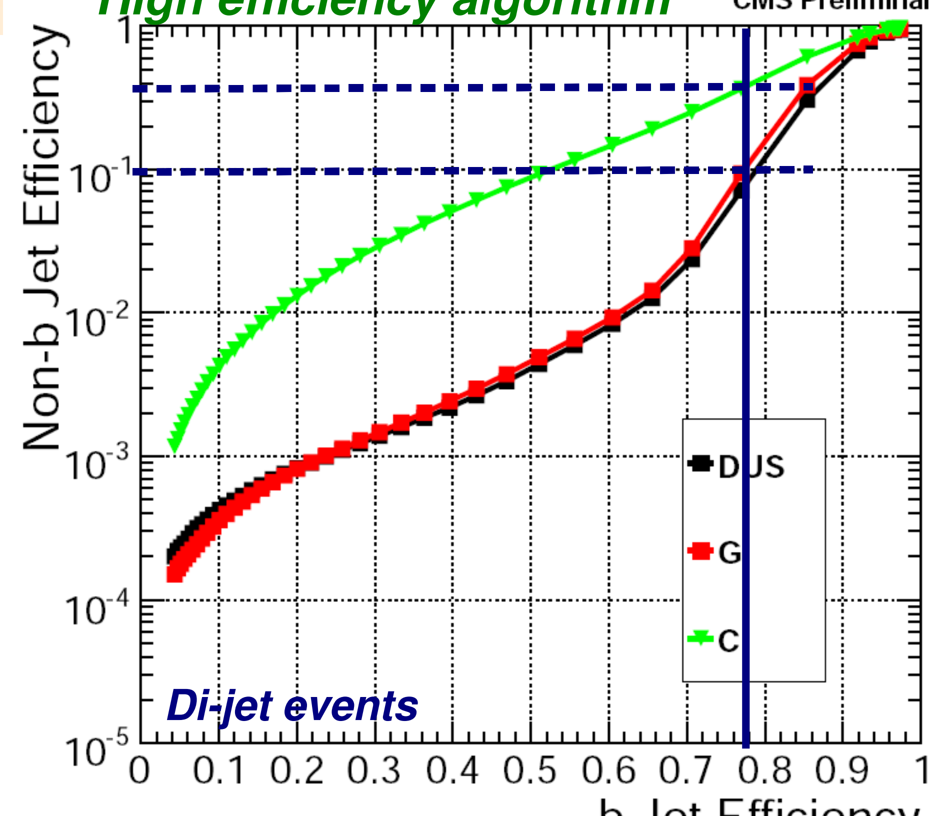
- 2^{nd} b veto

Track counting High Efficiency Algorithm:
$D_{highEff}$: impact par. significance (IPsig) of track in jet with second highest IPsig



2^{nd} jet with $D_{highEff}$<1.5



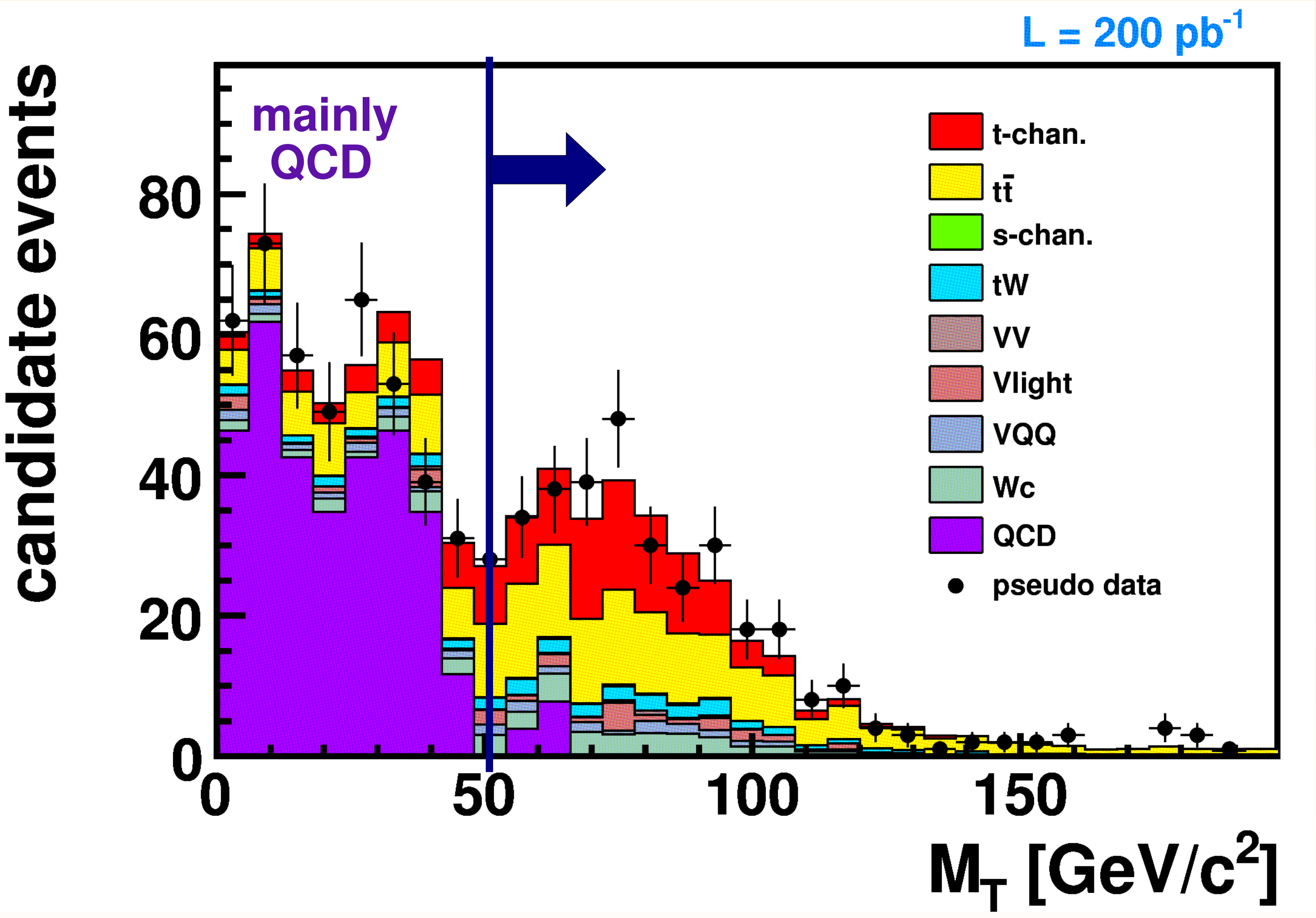


PAS: BTV-09-001

Cut to Further Reduce QCD

- Transverse mass of W boson (t→Wb)

$$M_T = \sqrt{(p_{T,\mu} + p_{T,\nu})^2 - (p_{x,\mu} + p_{x,\nu})^2 - (p_{y,\mu} + p_{y,\nu})^2} > 50\mathrm{GeV/c^2}$$



Event Yield

Process	N_{evt} in 200 pb^{-1}
single top, t channel ($W \to l\nu, l = e, \mu, \tau$)	102±1.8
single top, s channel ($W \to l\nu, l = e, \mu, \tau$)	1.8±0.2
single top, tW	22.3± 0.9
$t\bar{t}$	136.0±3.5
QCD multi-jet (μ-enriched)	12±6.7
Wc ($W \to l\nu, l = e, \mu, \tau$)	29±1.7
$Wb\bar{b}$ ($W \to l\nu, l = e, \mu, \tau$)	8.0±0.7
$Wc\bar{c}$ ($W \to l\nu, l = e, \mu, \tau$)	1.2±0.2
$W+$ light partons ($W \to l\nu, l = e, \mu, \tau$)	12±2.6
$Zb\bar{b}$ ($Z \to ll, l = e, \mu, \tau$)	2.7±0.4
$Zc\bar{c}$ ($Z \to ll, l = e, \mu, \tau$)	0.2±0.1
$Z+$ light partons ($Z \to ll, l = e, \mu, \tau$)	2±1.2
WW	0.9±0.3
WZ	1.2±0.2
ZZ	0.17±0.04
Total Background	229±8.4

Stated uncertainties reflect stat. uncertainty of MC

√s=10TeV
L=200pb^{-1}

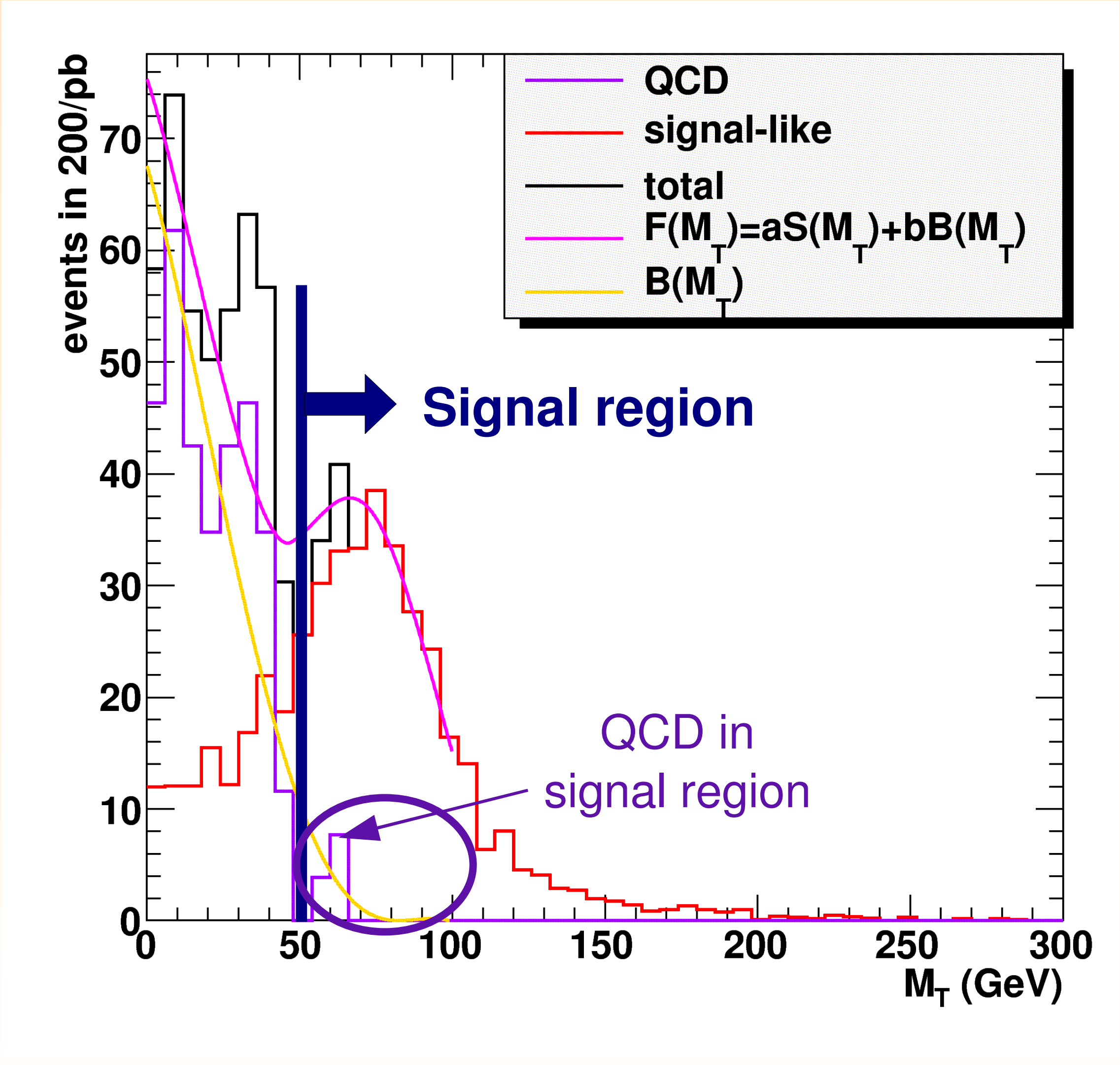
Expect only a small contribution of QCD events, but we prefer not to rely on predictions from MC

Expected back-ground uncertain-ties at the level of (30-50)%

→ Simple counting experiment not possible

QCD Background Estimation

QCD rate: Determine number of QCD events in signal region by performing a fit to the M_T distribution *(data-driven method)*



Signal-like (S):

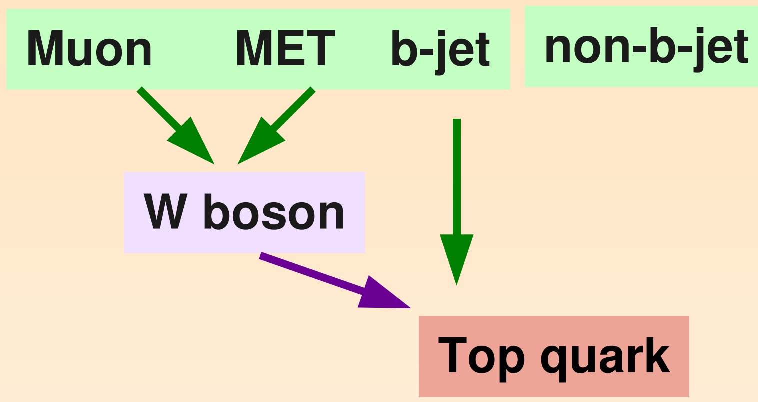
- Use either Z+jets sample *(+ M_W/M_Z- rescaling, take one μ as ν)*, MC signal-like prediction or W-enriched sample
- Parametrize samples with Crystal Ball functions

QCD background (B):

- Use sample without b-tag requirement and anti-isolation cut
- Parametrize sample with a polynominal of rank 4

Uncertainty (syst.+stat.): ± 45%

Reconstruction of Single Top Events



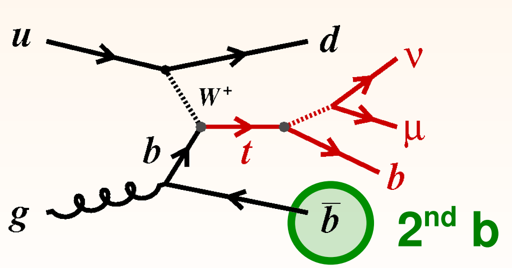
W boson reconstruction:

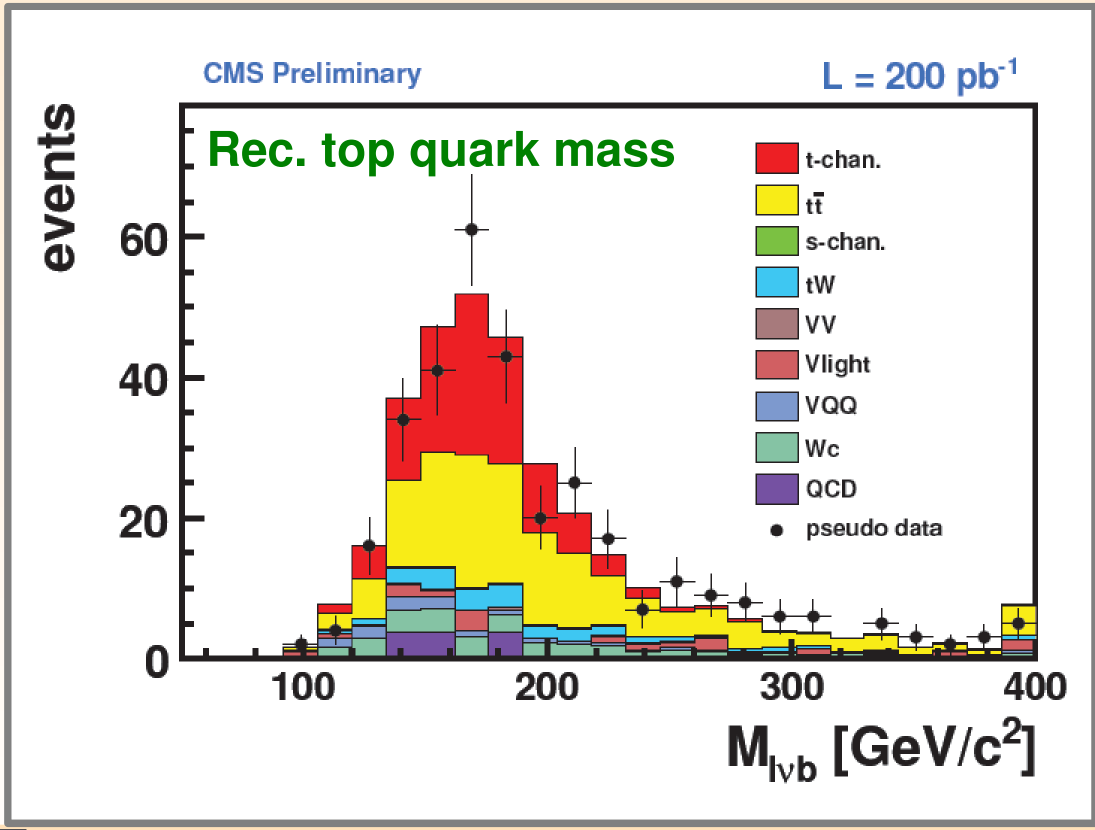
W mass constraint → 2nd order equation in $p_{z,\nu}$

- Complex solutions (36%)
  → Varying $p_{x,\nu}$, $p_{y,\nu}$ so that $M_T = M_W$ → $\mathrm{Img}(p_{z,\nu}) = 0$
- Two real solutions (64%)
  → Pick the one with smallest $|p_{z,\nu}|$

Assigning the b quark from the top quark decay:

Take the b-tagged jet
→ Correct in 92.2%, only in 4% the 2nd b is chosen





Polarization of the Top Quark

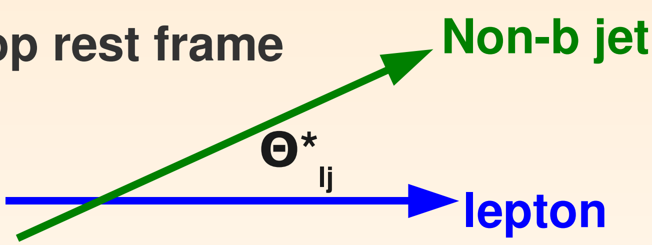
Single top s- and t-channel events:

Polarization of the top quark
(due to V-A nature of Wtb coupling)

→ **passed to its decay particles**

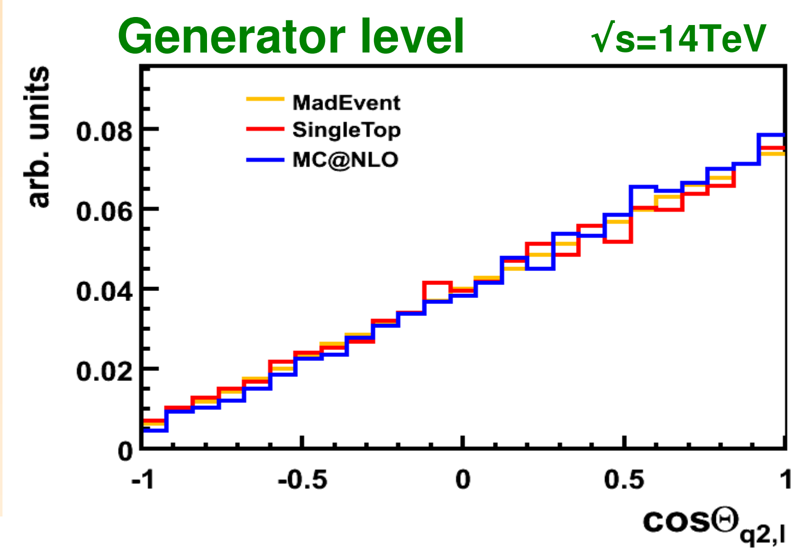
Sensitive variable: $\cos\Theta^*_{lj}$

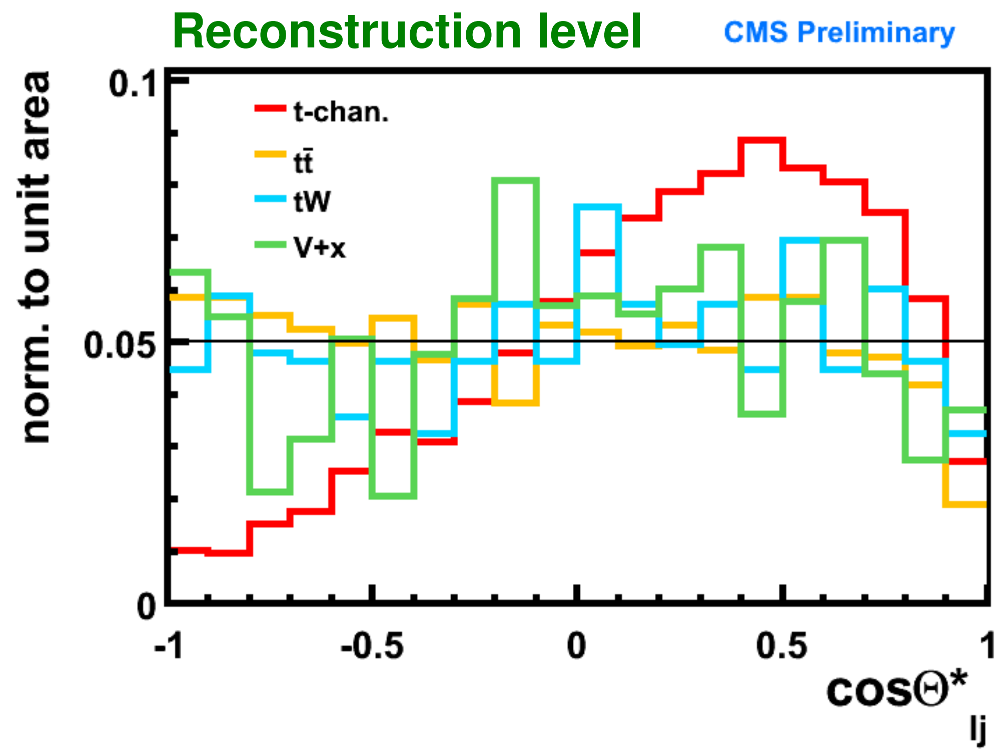
top rest frame



Signal: linear dependence on $\cos\Theta^*_{lj}$ *(gen. level)*

Backgrounds: flat in $\cos\Theta^*_{lj}$

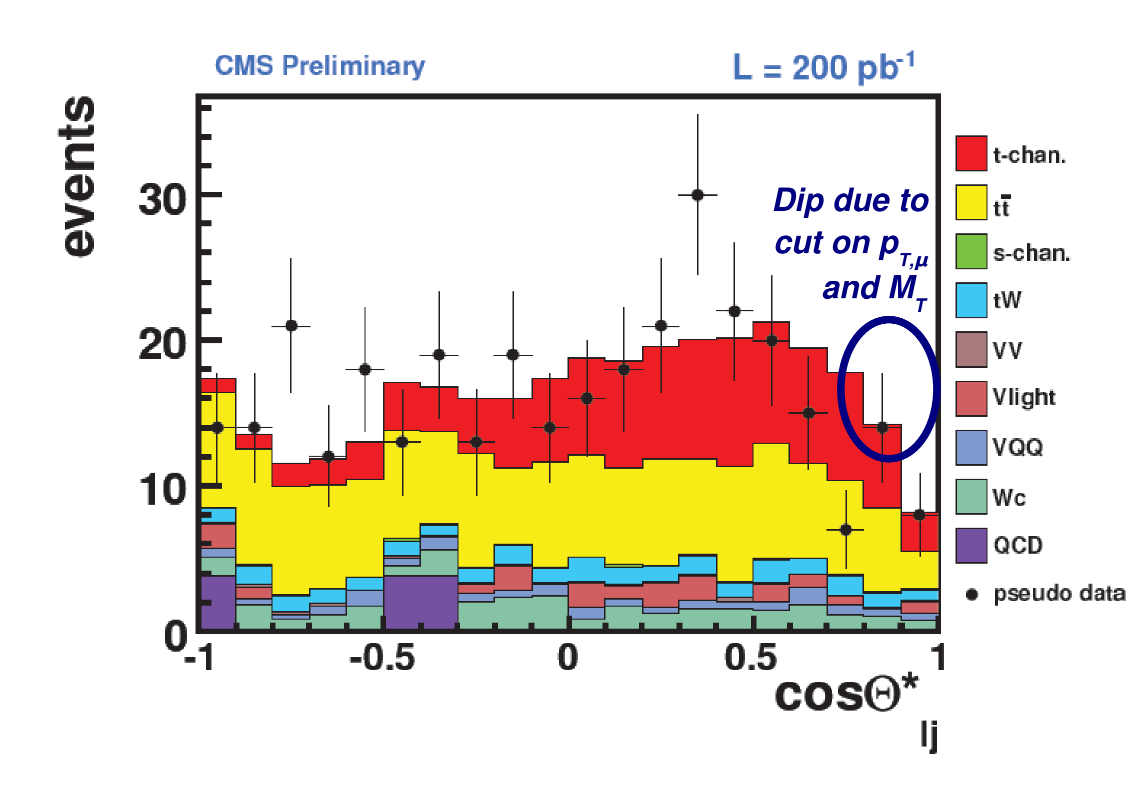




Single Top Prospects

Binned likelihood fit to $\cos\theta_{lj}^*$:

- Fit range: [-1,¾]
- Take single top template from MC, assume flat template for sum of backgrounds
- No assumption about background size



Ensemble tests:

- Determine uncertainty on cross section and expected sensitivity *(hypothesis test)*

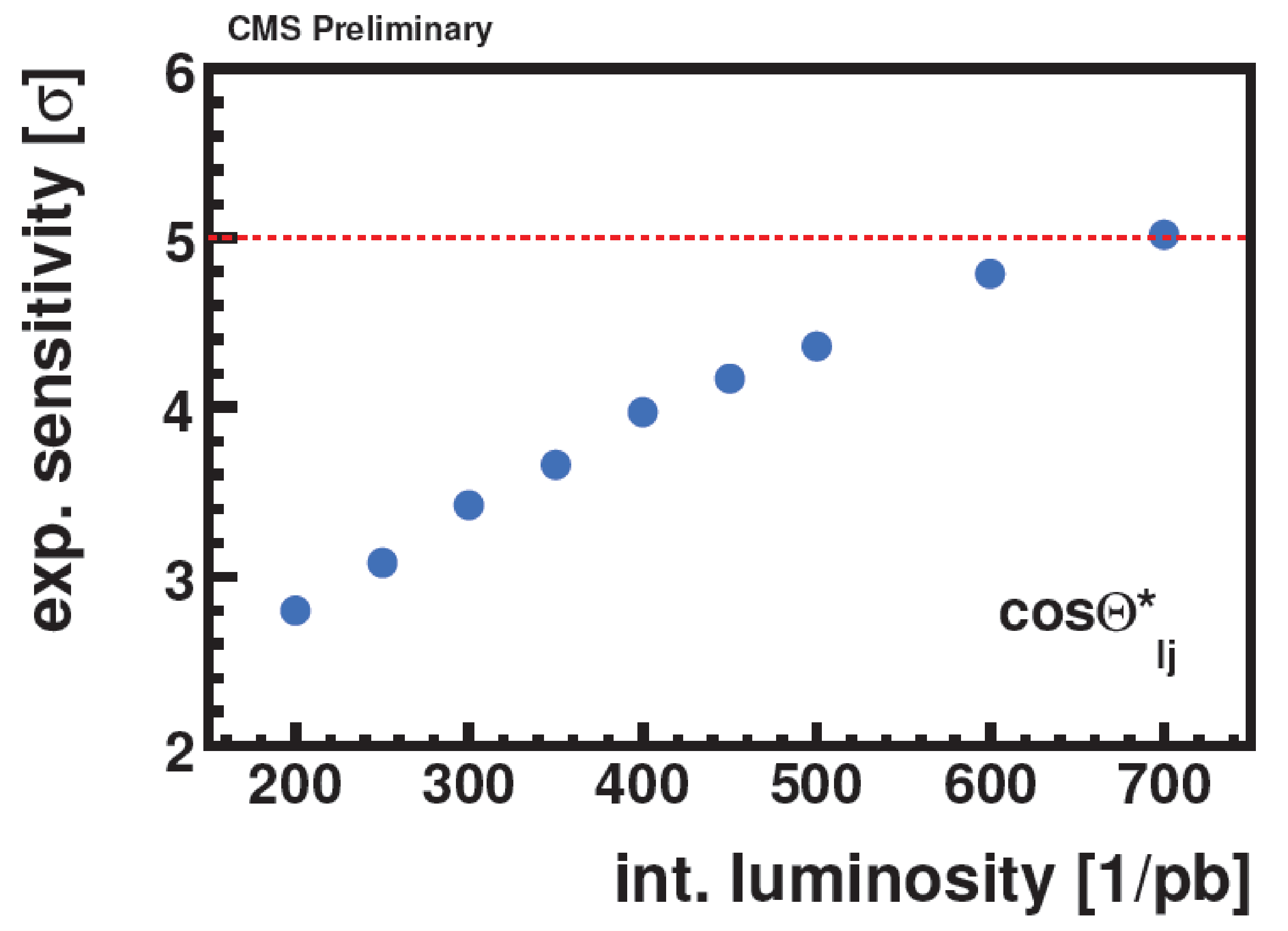
➡ **$\cos\theta_{lj}^*$ is very robust against sources of uncertainty**

(extreme bkg shapes: 2.7σ → 2.6σ)

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

Luminosity Projection

Expected sensitivity as a function of integrated luminosity:



stat. uncertainties only

√s=10TeV

- Method would need ~700/pb to manifest an observation
- There is a good chance to obtain an evidence with 200/pb

Summary

t-channel modeling:

- **Top kinematics of different generators** *(SINGLETOP,MadEvent, MC@NLO)* **agree well**
- **Some discrepancies visible in 2nd b variables** *(presumably m_b effects)*

Early single top analysis - fit $\cos\theta_{lj}$*:

(muon-jet angle in rec. top quark rest frame)

- **Robust against systematics and size of backgrounds**
- **Scenario: 200/pb @10 TeV:**
  → Exp. Uncertainty on x-section:
  ± 35% (stat.) ± 14% (syst.) ± 10% (lumi.)
  → Can realistically achieve ~3σ