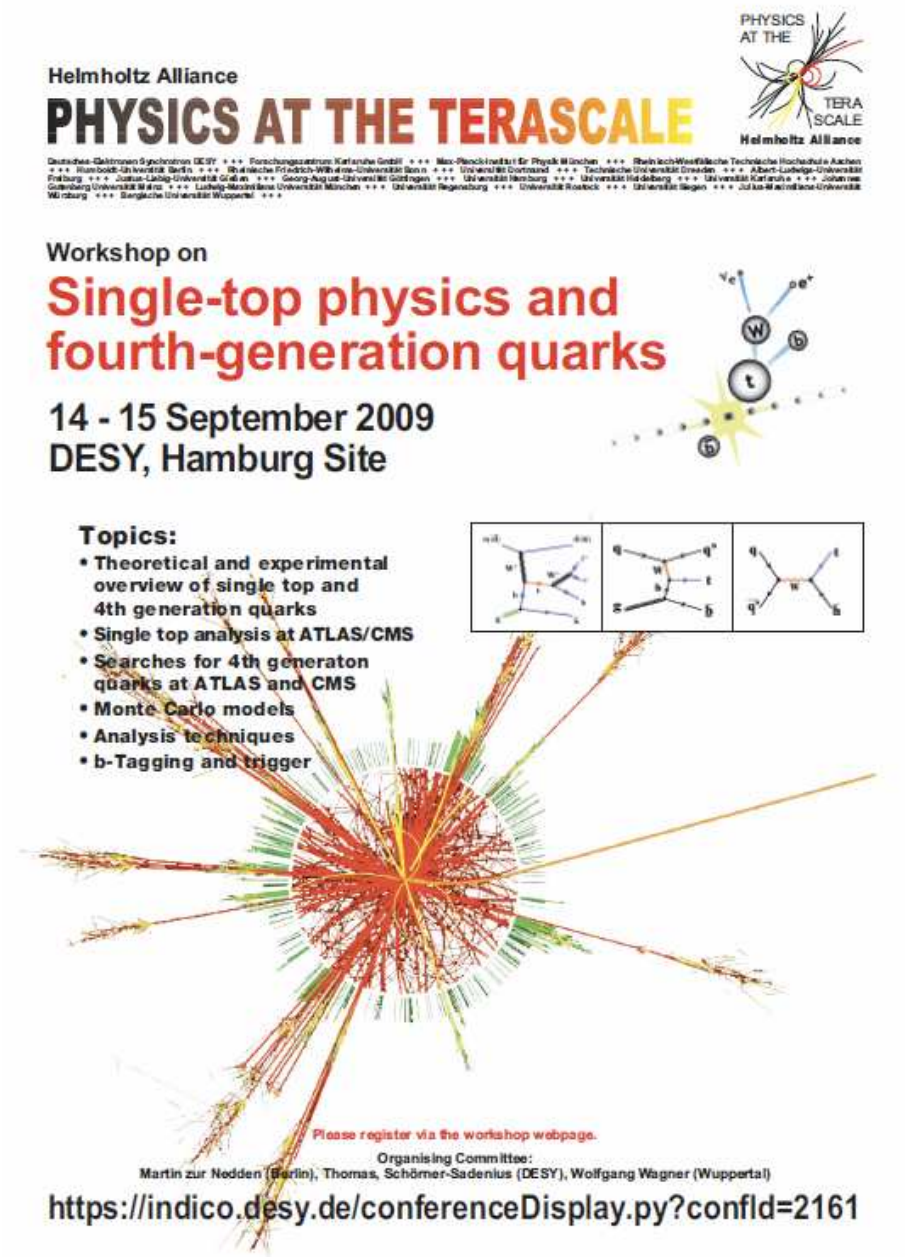
Single Top and 4th generation quarks Workshop Summary

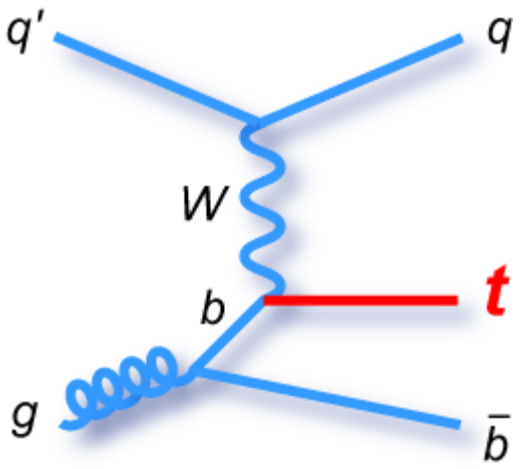


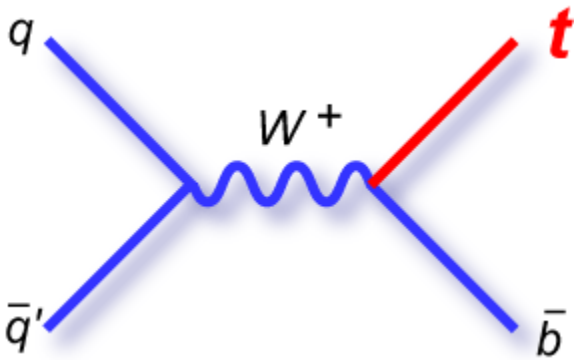
Anual Meeting of the Helmholtz-Alliance „Physics at the Terascale“ 11th to 13th November 2009

Martin zur Nedden

Humboldt-Universität zu Berlin

We have learned and discussed a lot ...



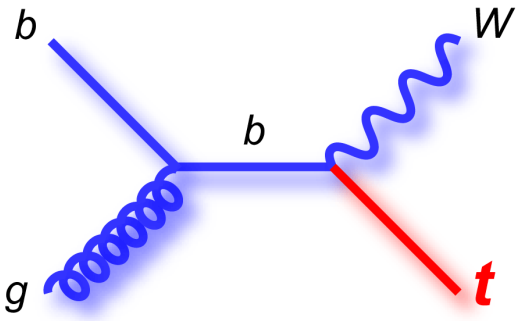


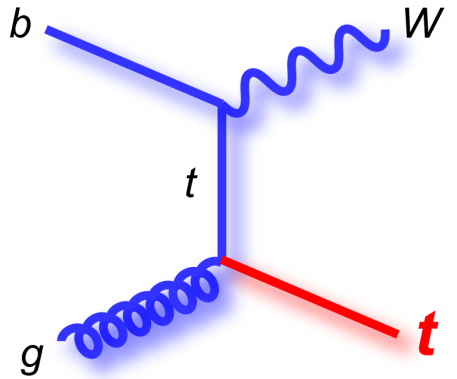
- **single top** predictions and simulations
- **Single top** potentials and strategies at ATLAS / CMS

- **b-quark distribution** in nucleons
- angular correlations in **t-channel**
- cross section studies and background estimations (**W+jets**)

- search for **4th generation** quarks
- **4th generation** and Higgs
- bounds on a **4th generation**

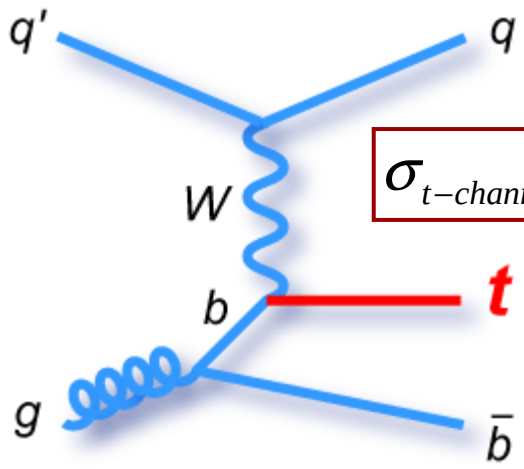
- trigger and **b-tagging**
- strategies for **first data**





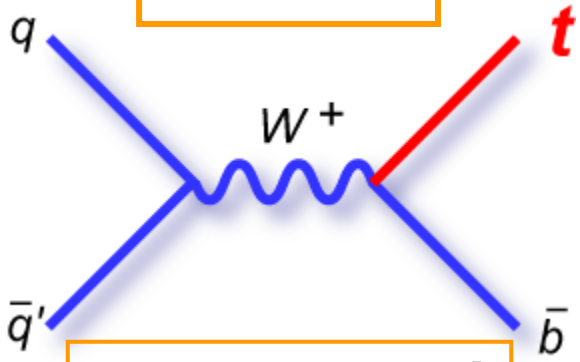
Single Top Production at LHC

W-gluon-fusion: **t-channel**



$\sigma_{t-channel} \approx 246 \pm 12\text{pb}$

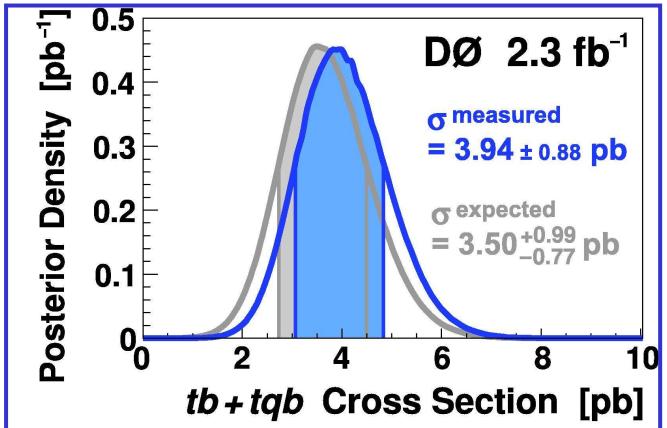
W*-process
s-channel



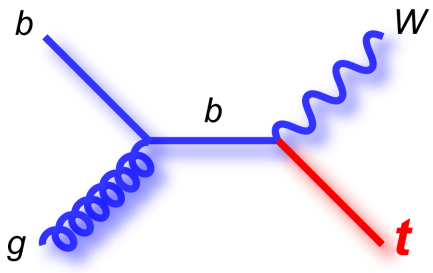
$\sigma_{s-channel} \approx 11 \pm 1\text{pb}$

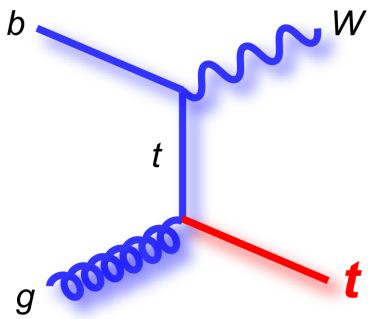
single top production:
electro weak process: Wtb - vertex
3 different contributions

direct production:
Wt-process



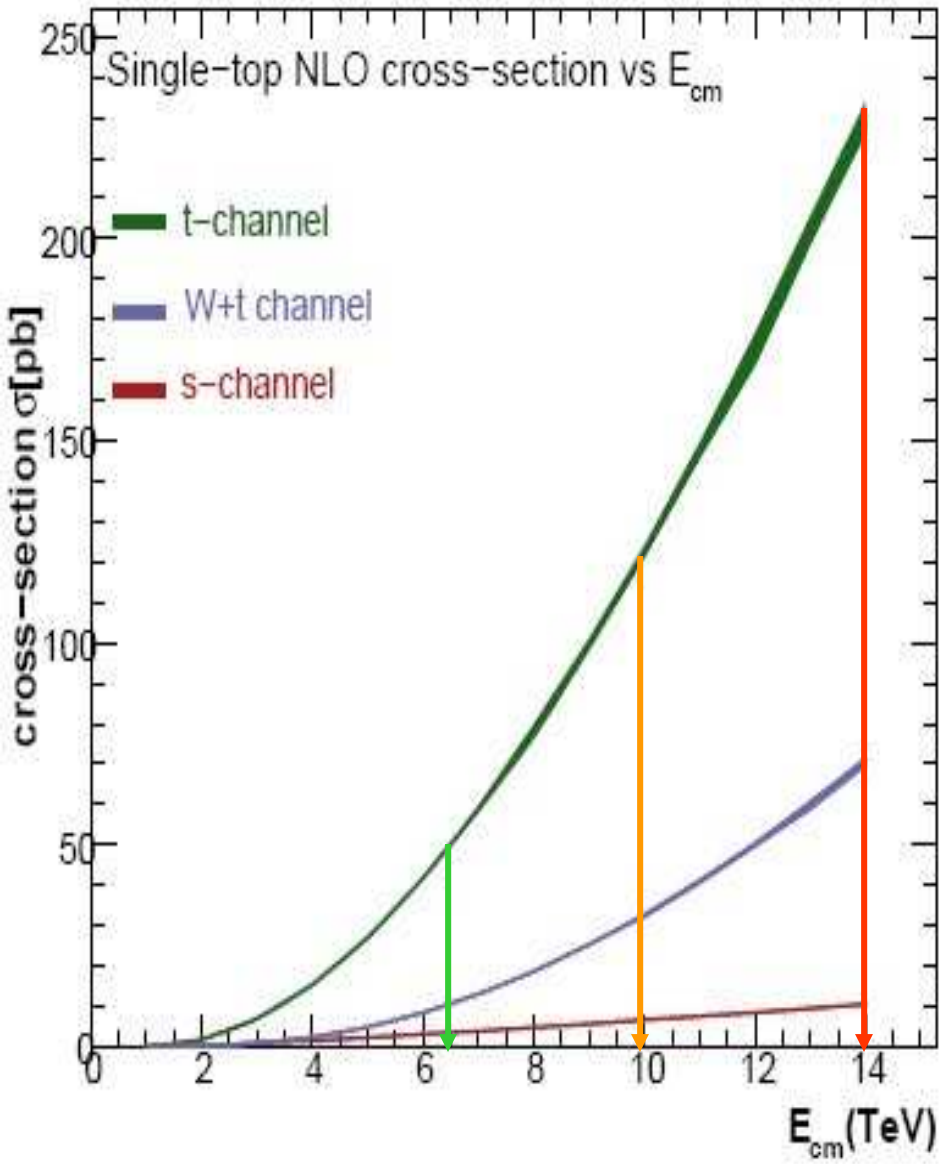
first measurement of single top production at TEVATRON in 2009





$\sigma_{W+t} \approx 62 \pm 2\text{pb}$

Single Top Cross Section Dependence



E_{cm} (TeV)	s-channel (NLO) $t\bar{b}$ (fb)	$\bar{t}b$ (fb)	t-channel (NLO) $tq(b)$(fb)	$\bar{t}q(b)$ (fb)	W+t channel (NLO) $tW^- + \bar{t}W^+$ (fb)
1 TeV	23	6.6	77	21	3.4
2 TeV	251	89.9	1396	503	168
3 TeV	621	260.6	4939	2,032	888
4 TeV	1,063	489	10,695	4,789	2,450
5 TeV	1,538	760	18,408	8,716	4,982
6 TeV	2,047	1,054	27,938	13,776	8,532
7 TeV	2,562	1,375	38,767	19,956	13,102
8 TeV	3,095	1,710	50,945	26,918	18,704
9 TeV	3,641	2,059	64,202	34,936	25,308
10 TeV	4,205	2,437	78,340	43,751	32,750
11 TeV	4,764	2,808	93,699	52,811	41,100
12 TeV	5,321	3,203	109,540	63,114	50,260
13 TeV	5,898	3,598	125,718	73,746	60,404
14 TeV	6,481	4,012	143,224	85,553	71,194

Strategies for first data:

-Depending on E_{cm} and integrated luminosity

- **10 TeV / 200 pb^{-1}:**
  ~100 event expected in **t-channel** with S/B ~ 0.5
  → **measurement possible**
- **7 TeV: 4 times more luminosity would be needed**

Talks (Single Top) I

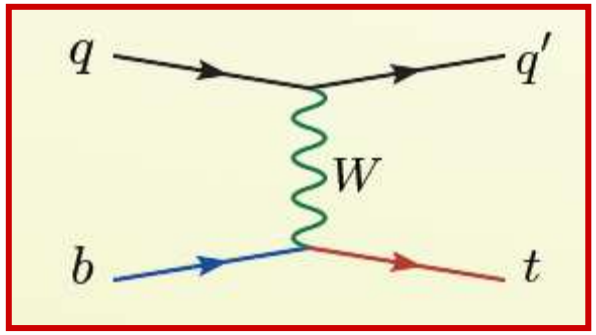
- **Fabio Maltoni** (U Louvain)
  - **Progress in single top predictions and simulations**
- **Dominic Hirschbühl** (U Wuppertal)
  - **Prosepcts of the measurement of single top quark production with ATLAS**
- **Jeannine Wagner-Kuhr** (KIT Karlsruhe)
  - **Single Top Strategies and Potentials at CMS**
- **Sergei Alekhin** (IHEP Protvino)
  - **The b-Quark Distributions in the Nucleon**
- **Patrick Motylinski** (U Freiburg)
  - **Angular correlations in t-channel single top production at the LHC**

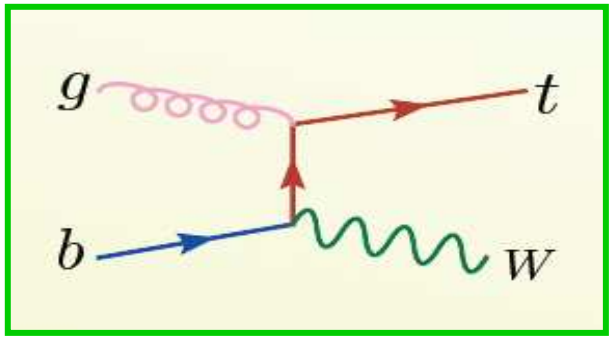
Talks (Single Top) II

- **Gia Korihauli** (U Bonn)
  - **Single-top t-channel cross section studies at 200 pb^{-1} for ATLAS**
- **Muhammad Alrhoob** (U Bonn)
  - **Estimating the W+jets background in single-top selections by a fraction fitting method**
- **Martha Felcini** (U Dublin)
  - **Trigger Strategies for top and 4^{th} Generation Quarks**
- **Clemens Lange** (DESY Zeuthen)
  - **Prospects for b-tagging techniques at the LHC experiments**
- **Julien Donini** (U Grenoble)
  - **Strategies for First Data**

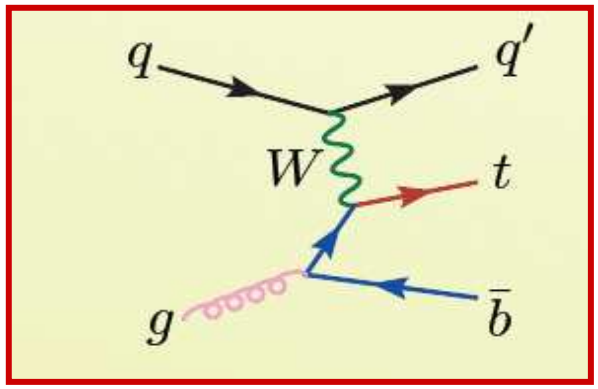
Progress in theoretical Predictions and Simulations

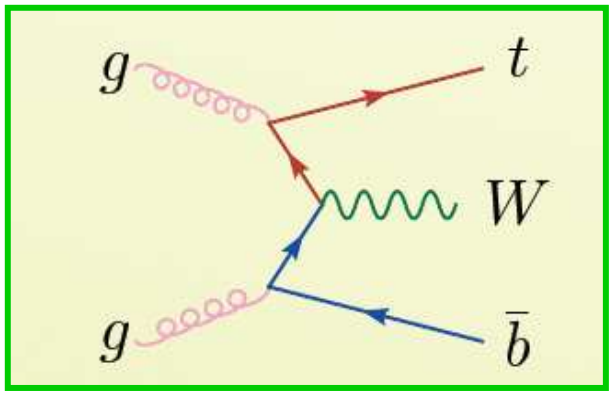
t-channel and **Wt associated** production have a b-quark in the IS





equivalent description with a **gluon splitting** to b-quark pairs





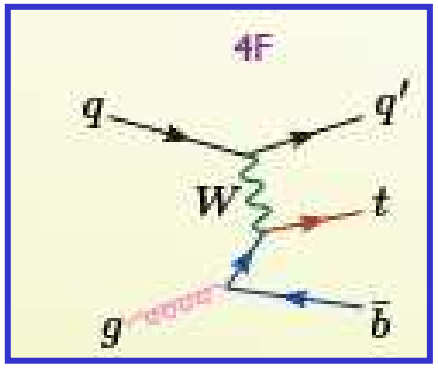
t-channel and Wt production enhanced by a collinear logarithm; resummation into PDF

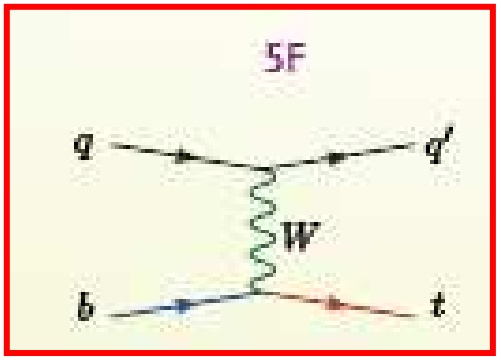
at all orders both descriptions should agree; otherwise differ by

- evolution of logarithms in PDF: they are resumed
- ranges of integration
- approximation by large logarithm

Schemes / t-channel cross section Prediction

Two different ways of computing the same quantities:



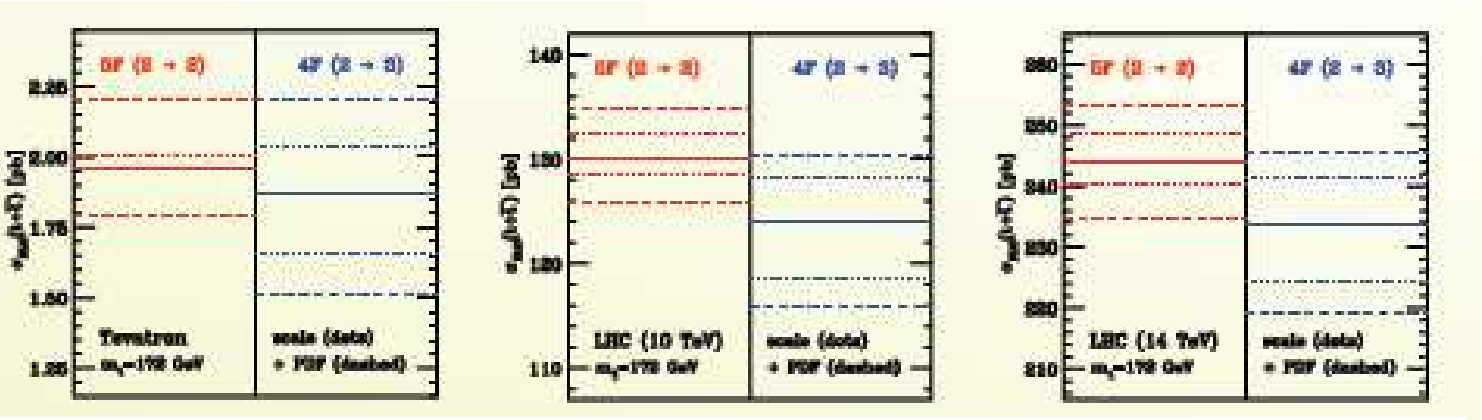


ACOT formalism: use the **b-PDF** (**"5 flavor scheme", 2 → 2**) when the spectator b is not important, otherwise keep it explicit ("**4 flavor scheme", 2 → 3**)

all higher order calculations performed in 5F scheme

terms from 4F enter at NLO

properties of spectator b are only LO



$\sigma^{\rm NLO}_{\rm t-ch}(t+\bar{t})$	$2 \to 2$ (pb)				$2 \to 3$ (pb)			
Tevatron Run II	$1.96\ ^{+0.05}_{-0.01}$	$^{+0.20}_{-0.16}$	$^{+0.06}_{-0.06}$	$^{+0.05}_{-0.05}$	$1.87\ ^{+0.16}_{-0.21}$	$^{+0.18}_{-0.15}$	$^{+0.06}_{-0.06}$	$^{+0.04}_{-0.04}$
LHC (10 TeV)	$130\ ^{+2}_{-2}$	$^{+3}_{-3}$	$^{+2}_{-2}$	$^{+2}_{-2}$	$124\ ^{+4}_{-5}$	$^{+2}_{-3}$	$^{+2}_{-2}$	$^{+2}_{-2}$
LHC (14 TeV)	$244\ ^{+5}_{-4}$	$^{+5}_{-6}$	$^{+3}_{-3}$	$^{+4}_{-4}$	$234\ ^{+7}_{-9}$	$^{+5}_{-5}$	$^{+3}_{-3}$	$^{+4}_{-4}$

Uncertainties: scales, PDF, m_t (1%), m_b(5%)

Summary / Conclusion from Theory

- Single top (multivariate) analyses rely heavily on the MC for the expected signal (and to a less extend background) distributions

- Theory and MC under continuous improvement to match the needs of experimental analyses
- Single top one of the most “influential” examples of processes that can be described with heavy quarks in IS
- Single top can also be thought as a template to other difficult searches at the LHC

b-PDF (Summary)

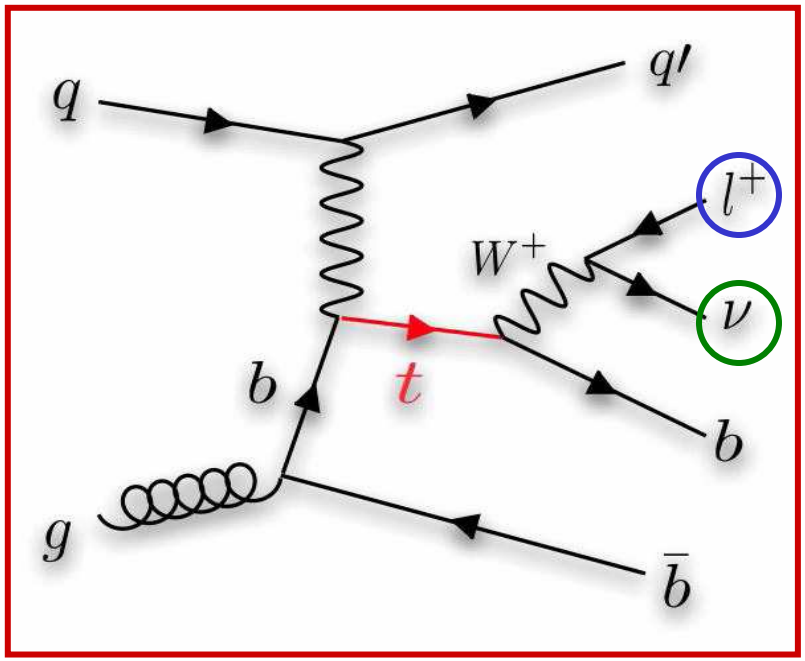
- **Uncertainty** in the **NNLO b-quark distribution** for the single-top production kinematics estimated to **be 3-7%**
  - dominating source at LHC is variation of

    b-quark mass by ±0.5 Gev
  - Dominate source at TEVATRON due to uncertainties in data, may be improved if new HERA and TEVATRON data are included into the PDF-fit
  - Uncertainty due to high-order correction is within ~ 1-8%, will be improved with NNLO corrections
- Differences between the NNLO b-quark distributions ABLM09 and MSTW08 sets is ~ 1-2σ

Strategies of ATLAS / CMS

- With first data (200 pb^{-1}), only a **t-channel analysis** would be feasible, 3σ precision expected
- Trigger on high **p_T leptons**
- **b-tagging important**, b-tag veto for second jet
- Further cuts on **E_T^{miss}**, **NJets**, **η**
- Dominating backgrounds are **top pairs**, **W+jets** and **QCD** (multi jets)
- Reconstruction via a **W boson and t-quark** mass reconstruction and **tagged b-jet**

t-channel with First Data

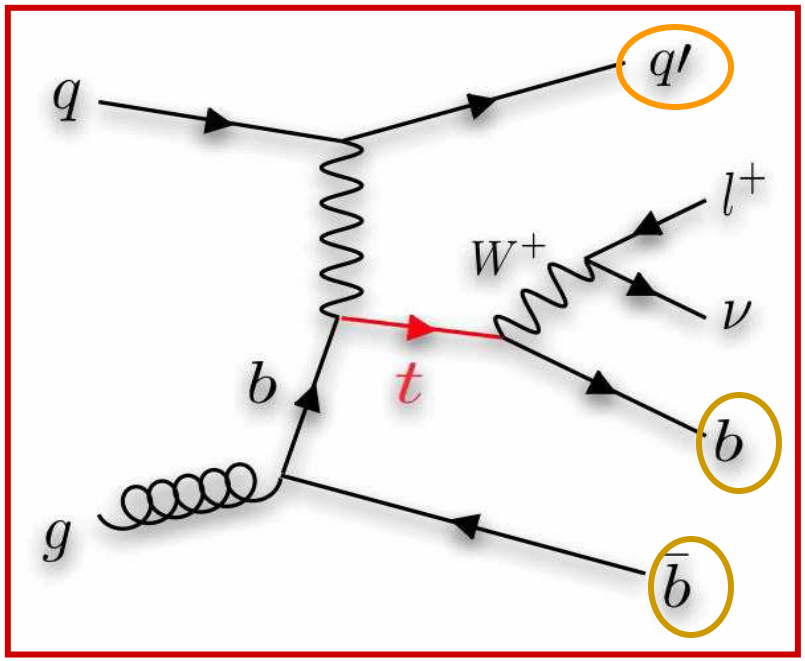


t-channel: dominant process, first cross section measurement

selection based on lepton + jets:
t → W b → l ν_l b

- **Trigger:**
  - **high pT inclusive lepton (e/μ)**
  - leptons + jets
  - missing ET (MET) + jets (not for early data)
- **Lepton ID:**
  - **one isolated lepton candidate**
  - loose and tight definitions (estimate of multi jet rates)
- **Missing ET:**
  - **large MET in the signal**
  - multi jet background can be reduced by MET cut
  - not to be used in commissioning phase

t-channel with First Data

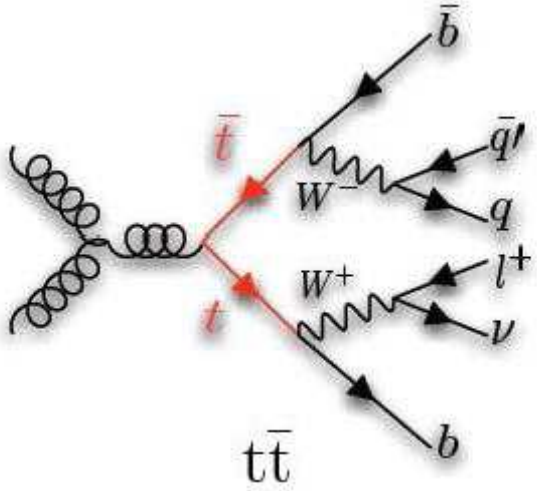


t-channel: dominant process, first cross section measurement

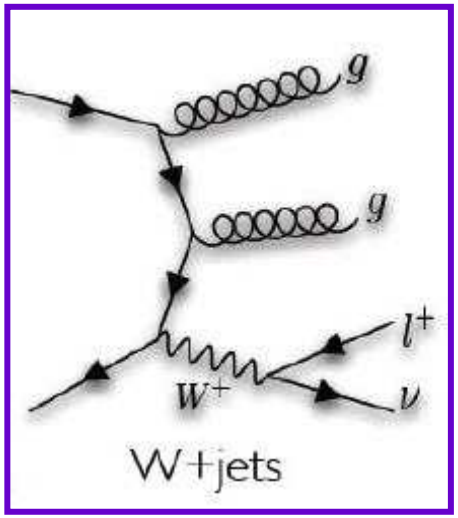
selection based on lepton + jets:
$t \rightarrow W\,b \rightarrow l\,\nu_l\,b$

- **Jets:**
  - **2 – 4 jet signature**
  - best S/B ratio for 2-jet events
- **b-Jets:**
  - **1 – 2 b-Jets in detector acceptance**
  - b-tagging is a crucial aspect of all single top analysis
  - commissioning of b-tagging algorithms with first data:
    efficiency: ε = (40-50 ± 5)%
    rejection factor: R ≈ 100 (± 10%)

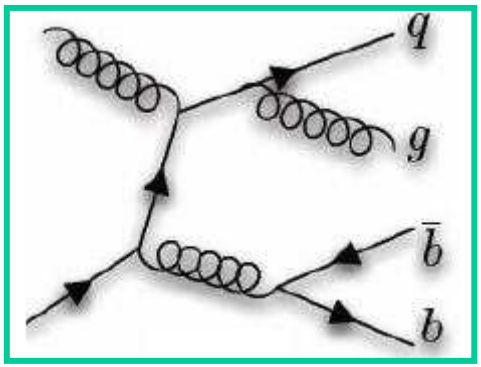
Background for t-channel



Top pair production,
generators: MC@NLO (ATLAS), MADGRAPH (CMS)
normalizing rate using data
most dominating physics back ground

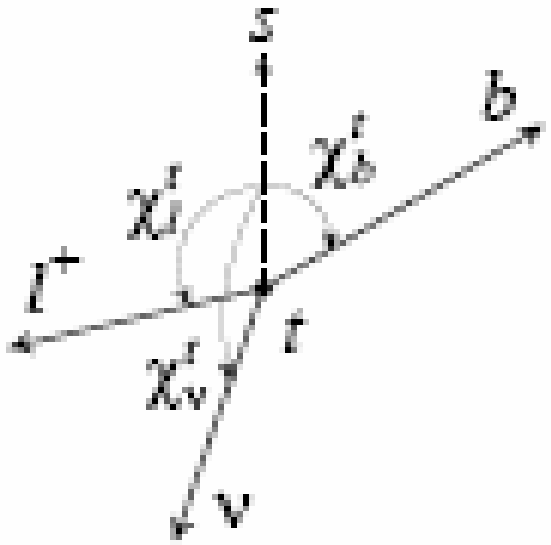


W+jets
generator: ALPGEN
separate Wjj, Wcc and Wbb processes
Wbb ad Wcc fraction underestimated in ALPGEN
normalize total rate using data



Multijet
model and normalize QCD background using data
before b-tagging in sideband regions
Define regions in two uncorrelated variables

Angular Correlations



to determine the **handed-ness of the EW coupling** of the top quark (SM: purely left-handed)

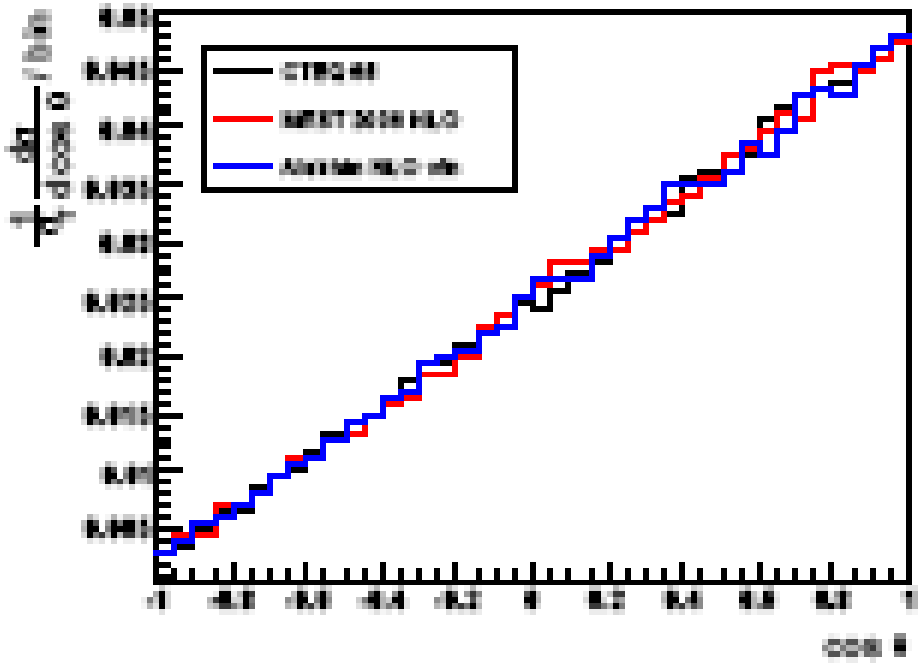
strong correlation with the decay products enable measurement of the coupling
(100% correlation between top-spin and lepton direction)

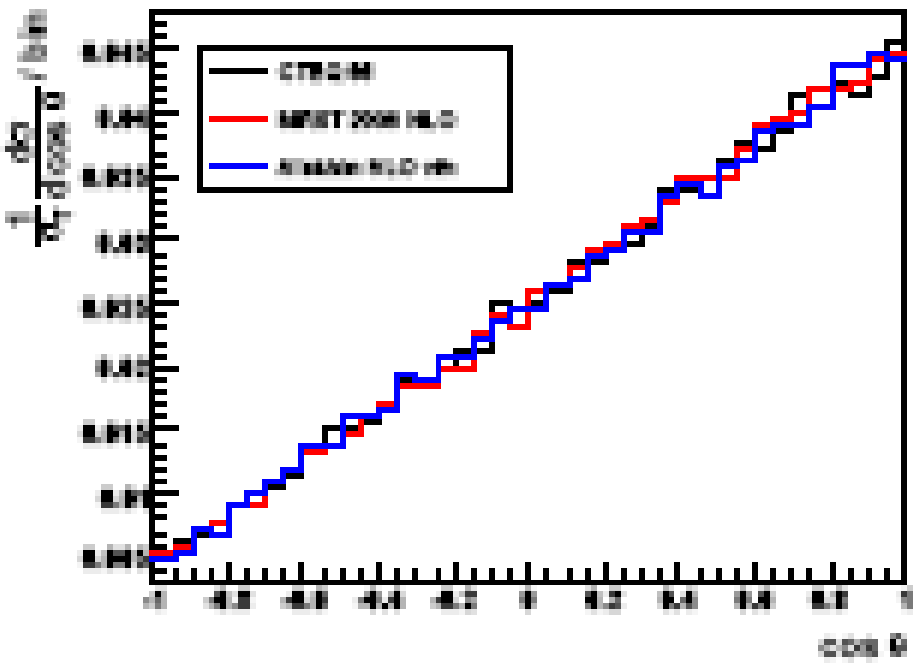
$$\frac{1}{\Gamma_t}\frac{d\Gamma_t}{d\cos\theta} = \frac{1}{2}\left(1 + s\cdot\cos\theta\right)$$

s: correlation factor (1 for isospin -½ particles)
θ: angle between the charged lepton/d-type quark and the orientation of the top quark spin

- polarization robust with respect to choice of PDF, PDF uncertainties play minor role
- correlations are practically stable with respect to varying the factorization scale
- correlation do not change behavior at lower energies
- effect of changing R-parameter is minor

Polarization studies: Changing PDFs



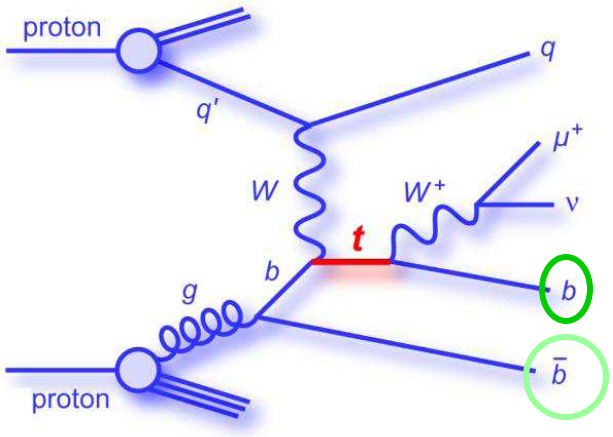


PDF set	Spectator basis	Beam line basis w. $\lvert\eta_l\rvert > 2.5$
CTEQ66	96.16% ± 0.30% †	91.15% ± 0.32% †
MSTW2008nlo	95.28% ± 0.38% †	91.01% ± 0.40% †
ALEKHIN vfn	95.81% ± 0.30% †	91.36% ± 0.32% †

Fraction fitting Method

- to estimate the **W+jets** and **Z+jets** background:
  - Robust method to measure **W+jets cross section**
  - Data driven estimate for the **W+jets BG** in single top
- technique to fit templates of various source in order to extract constituent fractions
  - data = $\varphi_1 M_1 + \varphi_2 M_2 + \ldots + \varphi_n M_n$
- taking into account both data and MC statistical uncertainties
- variables with higher correlations not used
- **method demonstrated to be working using MC mixed samples**

b-tagging Techniques



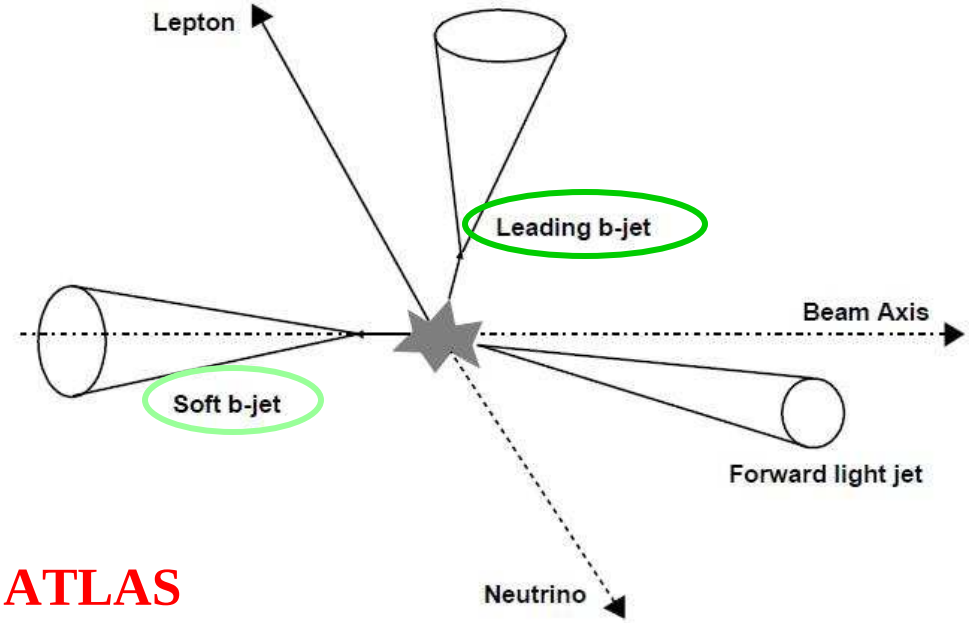
b-hadrons:

- **hard fragmentation**, b-hadron carries 70% of b-quark momentum
- **high mass** of b-quark: large p_T of decay products
- **long life time** ($c\tau \approx 450\ \mu m$): 3 mm for 50 GeV hadron

Need displaced tracks and/or secondary vertices
Good tracking (silicon pixel strip) detectors necessary

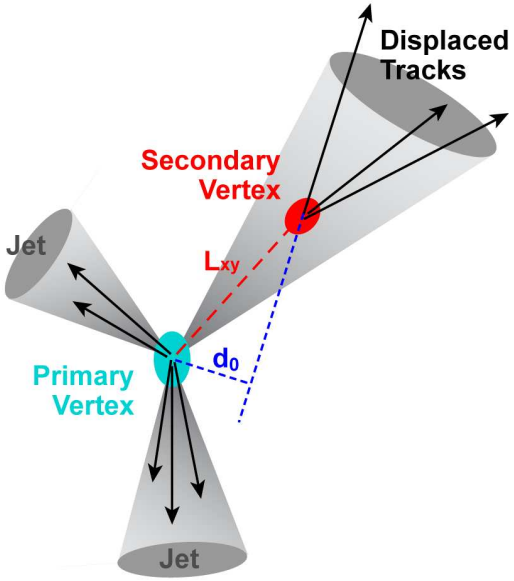
Sensitive to misalignment

E_T^{min}(jet) = 15 GeV, P_T^{min}(track) = 1 GeV



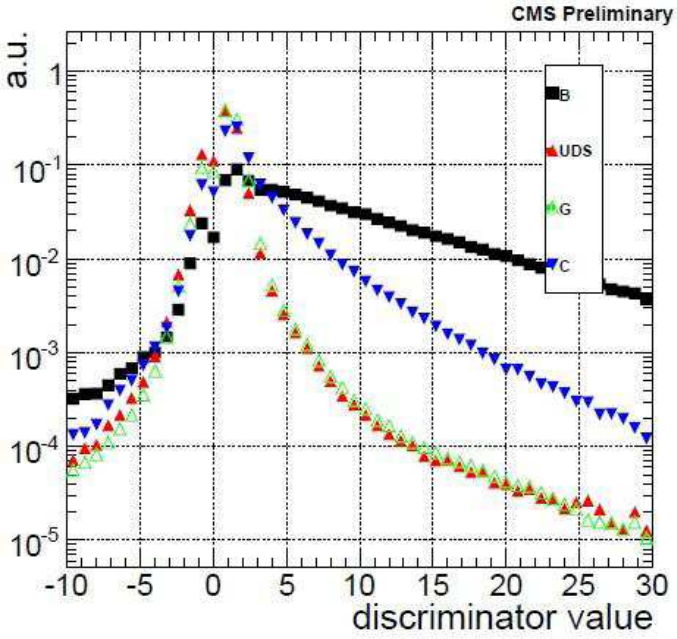
Similar techniques for CMS and ATLAS

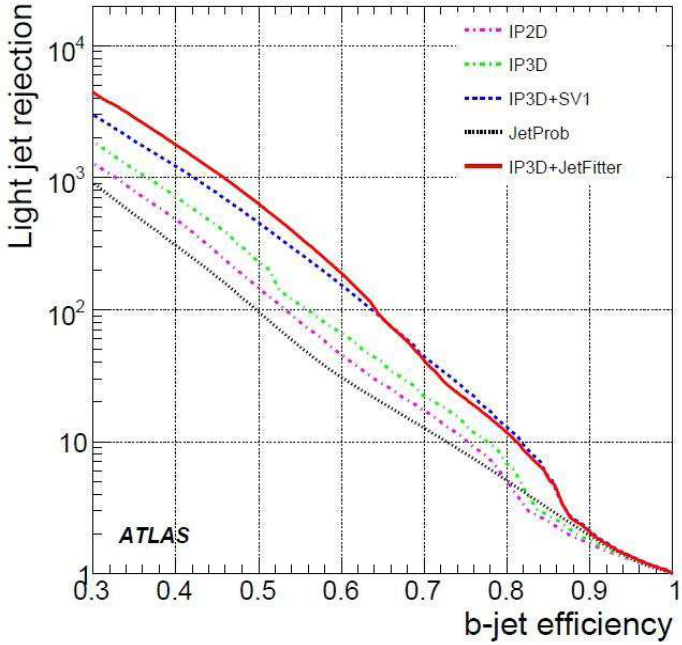
b-tagging Algorithms and Performance



Many algorithms, delivering **discriminator value** to cut on methods:

- **secondary vertex** displaced from primary
- track counting: with **large impact parameter** within a jet, calculate significance
- jet probability: **impact parameters** of all tracks in jet
- multidimensional likelihood taggers: likelihood rations from MC distributions (b and light quark hypothesis)





S/B ratio improved by t-tag by a factor of 5

high b-tag efficiency leads to low purity (or rejection)

Strategies for first Data

- depending much on beam energy and integrated luminosity
- **10 TeV collisions and 200 pb^{-1}**
  - **t-channel:** few 100 selected events in lepton+jets channel, **S/B ~ 0.5** and a signal significance (incl. systematics) of 2-3σ can be achieved
  - **Wt-channel:** excess in lepton+lepton and letpon+jet channels
  - **s-channel:** far out of reach
- **7 TeV collisions**
  - obtaining similar results require about **4 times more luminosity**
- need to reconstruct and identify precisely different type of objects: **leptons**, **jets**, **missing E_T**, **b-tagged jets**
- lot of effort needed to improve signal purity, control systematic
- single top analysis will be the **first user of b-tagging**

… so, how to continue?

- first workshop in the Helmholtz alliance on this topic
- the aim was to bring together the peoples working on this field from experiment and theory
- **we would like to continue on a informal basis**
  - keep the discussion forum
  - **next workshop: in about one year, when the first measurements are available**
  - keep contact in the framework of LHC-D and the top-groups from ATLAS / CMS
  - Wolfgang Wagner (Wuppertal) and Martin zur Nedden (Berlin) will act as contact persons an will organize the next workshop
- use the webpage as source of information:
  - **https://indico.desy.de/conferenceDisplay.py?confId=2161**