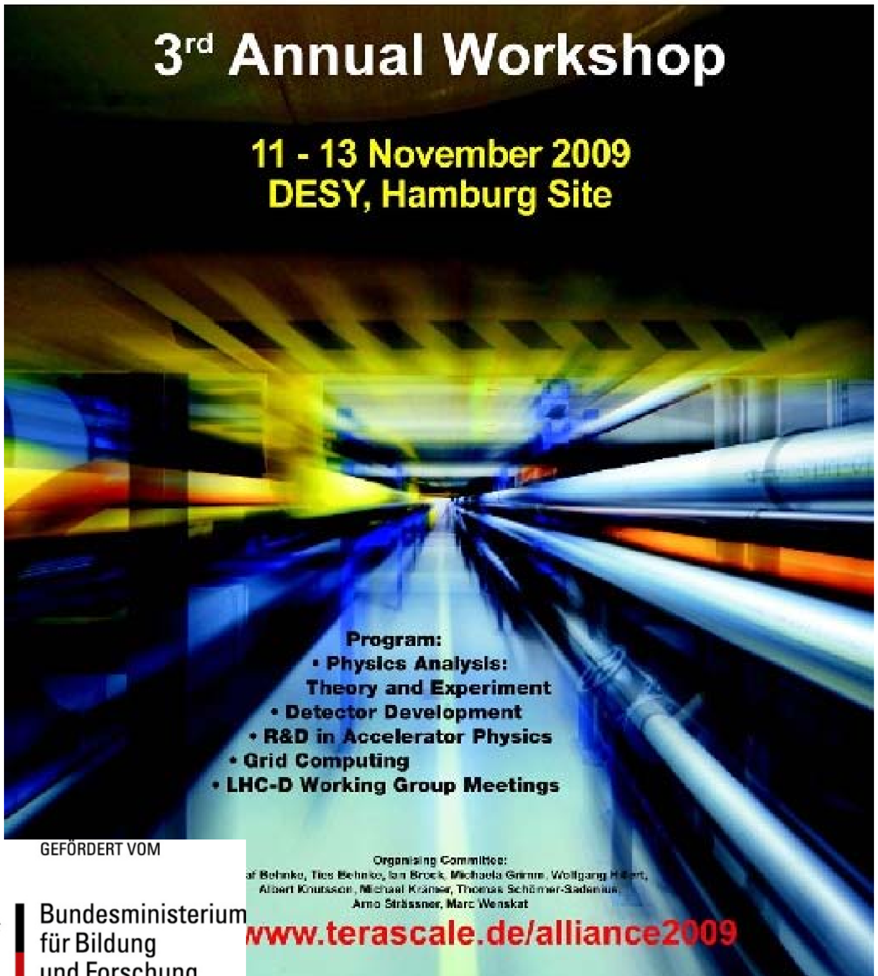
Top Quark Physics in LHC-D

Helmholtz Alliance
PHYSICS AT THE TERASCALE



GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

Frank-Peter Schilling

Karlsruhe Institute of Technology

with M. Cristinziani (ATLAS),

P. Uwer, W. Bernreuther (TH)

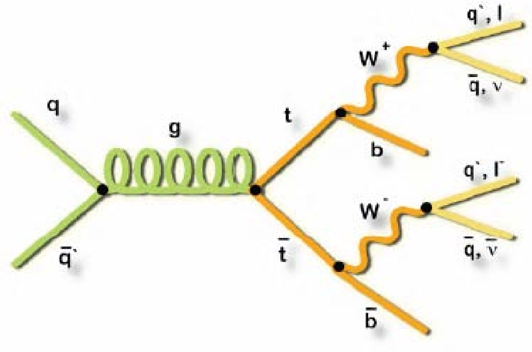
Terascale Alliance

3rd Annual Meeting

DESY, 13/11/2009

Introduction

- **Why Top Quark Physics at LHC?**
  - ❑ **Precise SM measurements**
    - o Heaviest known elementary particle (large Yukawa coupling)
    - o Top and W mass constrain Higgs mass
    - o Unique window on bare quarks due to short lifetime
  - ❑ **A window to new physics**
    - o New physics might couple preferentially to top
    - o Non-standard couplings
    - o New particles can produce / decay to top quarks
  - ❑ **In many new physics scenarios (e.g. SUSY) top is dominant BG**
  - ❑ **Tool to understand / calibrate detector**
    - o JES, b-eff.

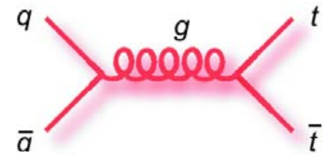


- **Early understanding of top physics @ LHC is cruical**

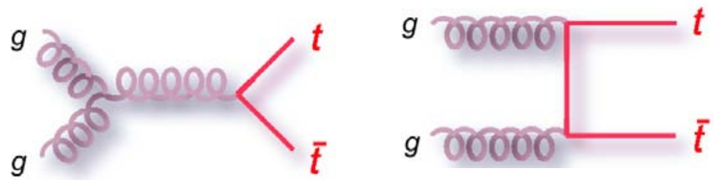
- **This talk: overview on Top Quark Physics activities in LHC-D**
  - ➢ **NOT a comprehensive summary of the field**

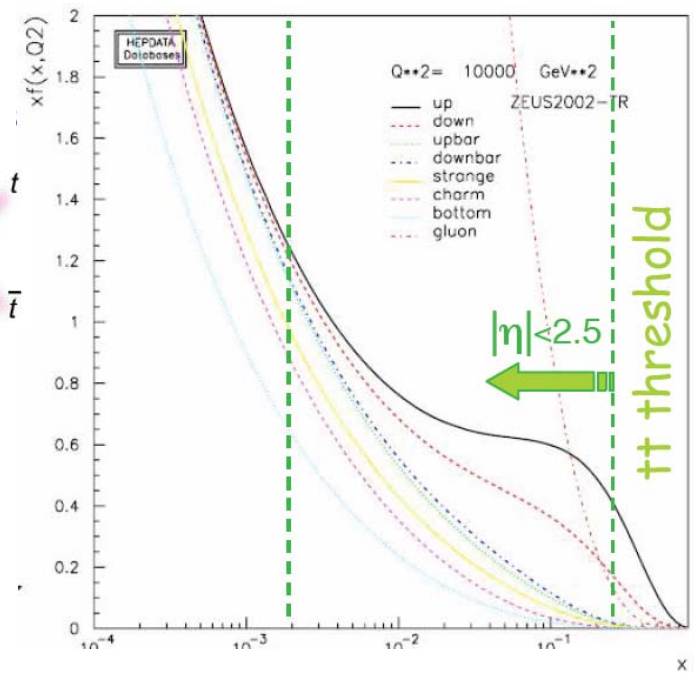
Ttbar pair production and decay

- **Pair production**
  - **~85% quark-induced at Tevatron**

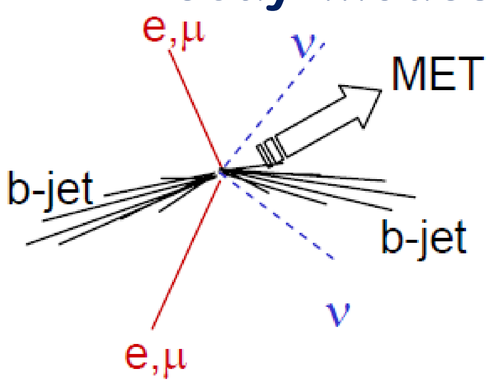


  - **~85% gluon-induced at LHC**

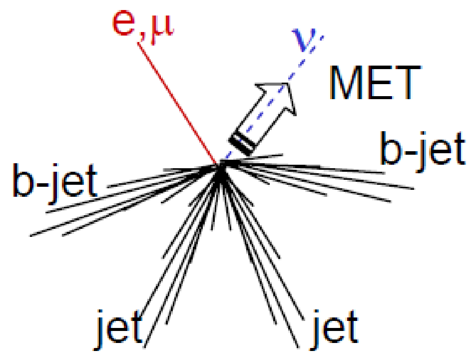




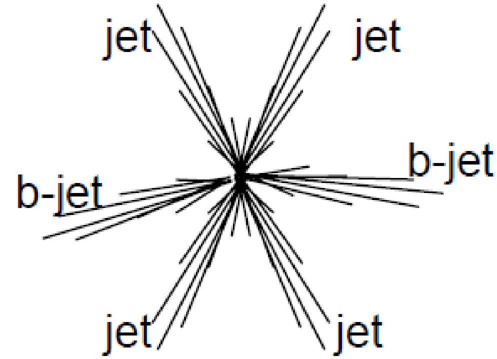
- **Decay modes**



dileptons
(BR~5%)



lepton + jets
(BR~30%)



all hadronic
(BR~46%)

Cross Sections at the LHC

	Cross Section [pb]		
Process	E(c.m.)=7 TeV	E(c.m.)=10 TeV	E(c.m.)=14 TeV
Ttbar	187 (x20)	414+/-40 +/-20 (x50)	908+/-83+/-30(x120)
Single-top s	1 (x1)	5+/- 0.5 (x5)	10.7 +/- 1.0 (x10)
Single-top t	65 (x30)	131+/- 7 (x60)	247 +/- 13 (x120)
Single-top tW	11 (x100)	29 +/- 3 (x290)	56 +/- 6 (x560)
QCD (LO, pt>80 GeV)	0.9*10^8	1.9*10^8	3.7*10^8
W->l+nu (LO)	24.000	40.000	60.000
Z->l+l (LO, m>50 GeV)	2.300	3.700	7.000

- Huge increase in signal cross sections w.r.t. Tevatron (red numbers)
- Cross section reduction with respect to nominal 14 TeV (ttbar, t, tW)
  - at 10 TeV, lose factor ~2 w.r.t. 14 TeV
  - at 7 TeV, lose factor ~4 w.r.t. 14 TeV
- **Expect 40.000 ttbar events in 2010 run (e.g. 200pb-1 @ 7 TeV)**

Experimental Challenges

- Signal cross section increases by factor ~50 at 10 TeV w.r.t. Tevatron, so what's the problem?
  - The dominant backgrounds increase a lot as well
    - Large phasespace for gluon emission at LHC energies
    - W+ 4 jets rate goes up much more (x100) than inclusive W cross section (x10)
    - Huge rate of QCD N-jet events, in which one jet may fake a lepton / has b-dec. lepton

- Good understanding of ~all physics objects required
  - Jets (jet energy scale)
  - Leptons (ID, momentum scale, isolation, efficiency and fake rate)
  - Missing ET (cleaning, scale, resolution)
  - B-tagging (efficiency and fake rate, applied to multi-jet environment)
  - Do all this in a data-driven way!

- Understand background-dominated control regions first
  - E.g. at low jet multiplicities
- Monte Carlo
  - Need to use advanced tools (MC@NLO, MADGRAPH, ALPGEN,…) CPU!
  - Tune simulations with early data

Parallel Session Overview

16:00->*18:40* LHC-D Top: Parallel Session I (Convener: Werner Bernreuther (*RWTH Aachen*) , Markus Cristinziani (*Uni Bonn*) , Peter Uwer (*Humboldt-Universität zu Berlin*) , Frank-Peter Schilling (*KIT / University of Karlsruhe*)) (Location: Lecture Hall)

16:00	MS bar mass extraction of the top quark (20')	Ulrich Langenfeld (*HU Berlin*)
16:20	W+jets background for ttbar (ATLAS) (20')	Sascha Mehlhase (*DESY*)
16:40	Ttbar cross section measurement in l+jets with topological likelihoods (ATLAS) (20')	Stefan Guindon (*Goettingen*) , Anna Henrichs (*Goettingen*)
17:00	Ttbar spin correlations (CMS) (20')	Martina Davids (*III. Phys. Intitut B, RWTH Aachen*)
17:20	Report from Alliance Workshop: Fourth Generation (20')	Heiko Lacker (*Humboldt University of Berlin*)
17:40	QCD radiation in ttbar events (CMS) (20')	Alexander Flossdorf (*DESY*)
18:00	Top for Calibration (CMS) (20')	Sebastian Naumann-Emme (*Uni Hamburg*)
18:20	Top event reconstruction with KLfitter (ATLAS) (20')	Johannes Erdmann (*Georg-August-Universität Göttingen, II.*

09:00->*12:35* LHC-D Top: Parallel Session II (Convener: Werner Bernreuther (*RWTH Aachen*) Markus Cristinziani (*Uni Bonn*) , Peter Uwer (*Humboldt-Universität zu Berlin*) , Frank-Peter Schilling (*KIT / University of Karlsruhe*)) (Location: Lecture Hall)

09:00	Top properties (mass and W-helicity in l+jets) with template and Matrix-Element analyses (ATLAS) (20')	Andrea Knue (*CMS Desy*)
	...op reconstruction with patterns in jet substructure (ATLAS)	Peter Kovesarki (*PhD student*)
	...tbar decays / boosted top (CMS) (20')	Thomas Peiffer (*University of Karlsruhe*)
	...nces in the ttbar invariant mass spectrum (ATLAS) (20')	Markus Mechtel (*Wuppertal*)
	Coffee break	
	...ss section at 10TeV (CMS) (20')	Jasmin Gruschke (*Universität Karlsruhe / KIT*)
	...om Alliance Workshop: Single Top (20')	Martin zur Nedden (*Humboldt-Universitaet zu Berlin*)
	...p (CMS) (20')	Jeannine Wagner-Kuhr (*University of Karlsruhe*)
11:40	Stand der Studien zu Single-Top bei 10 TeV und 200 pb-1 (ATLAS) (20')	Philipp Sturm (*Wuppertal*)
12:00	Discussion on Common Projects in LHC-D Top Group (30')	

- **Topics discussed**
  - **Ttbar cross section**
  - **Top properties**
  - **Single top**
  - **New physics in M(ttbar)**
  - **And more …**

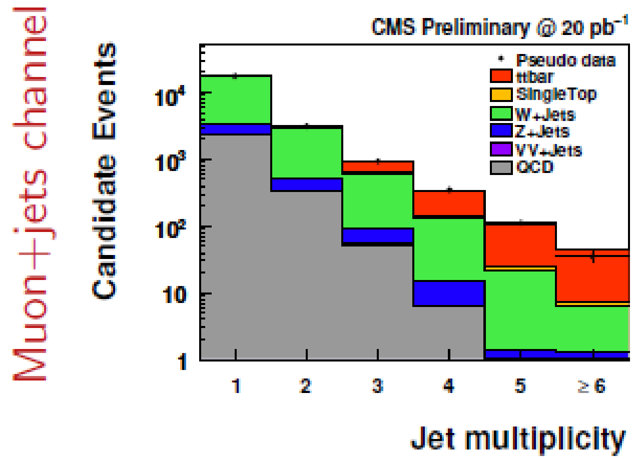
Cross section in lepton+jets @ 10 TeV

J. Gruschke (KIT)

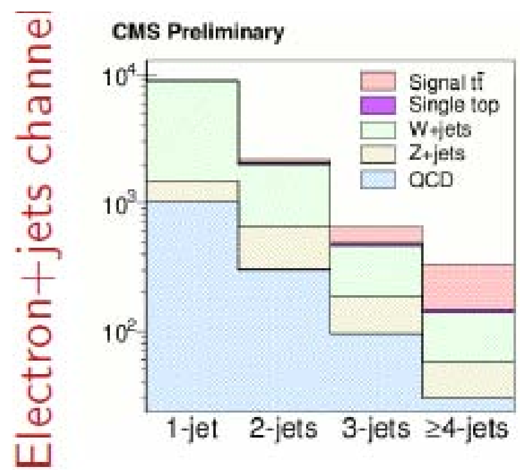
- **Muon+jets PAS TOP-09-003**
- **Electron+jets: PAS TOP-09-004**

- **Focus on early cross section measurement with first 20pb-1 of data**
  - ❑ **Robust selection (no MET, no b-tagging) for early data**
  - ❑ **Data driven backgrounds**
  - ❑ **Systematic uncertainties**

- **Event selection**
  - ❑ **Single lepton trigger**
  - ❑ **One isolated muon (Pt>20) or electron (Et>30)**
  - ❑ **>= 4 SisCone jets, Et>30 GeV**



320 signal and 171 bkg events.



172 signal and 108 bkg events.

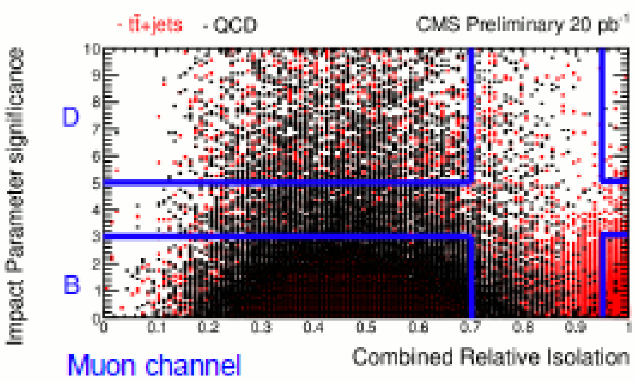
Data driven QCD background estimates

J. Gruschke (KIT)

ABCD-Method:

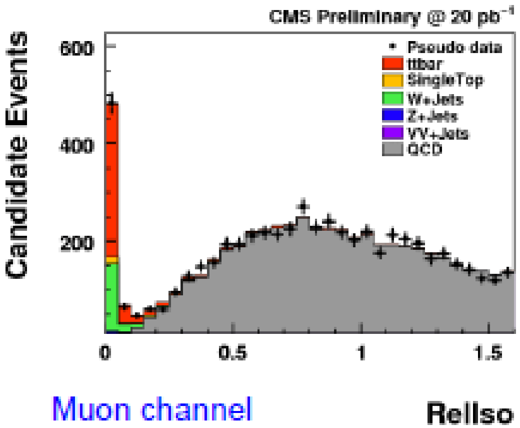
- Divide into 4 phase-space regions (3 dominated by QCD)
- Estimate QCD contribution in the signal region via:

$$N_A = N_B \cdot \frac{N_C}{N_D}$$



RelIso Extrapolation Method:

- Side-band region fit to an isolation distribution (RelIso includes tracker and calorimeter information)
- Integral of extrapolated function as estimate for the QCD contribution



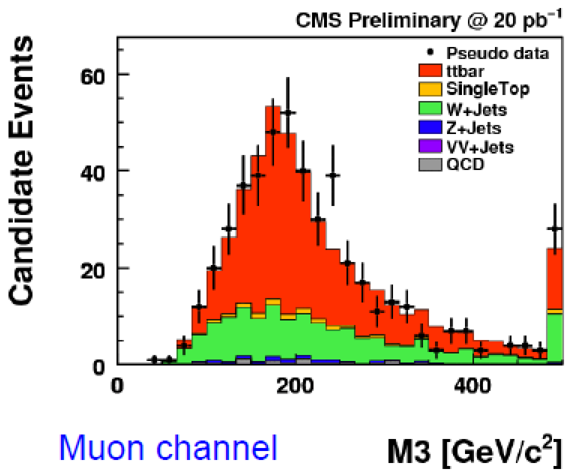
All methods yield ~50% uncertainty (OK if BG is small)

Cross section in lepton+jets @ 10 TeV

J. Gruschke (KIT)

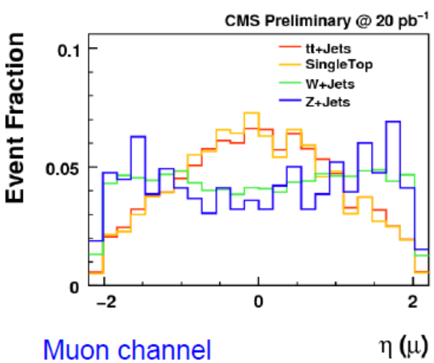
$$\sigma(t\bar{t}) = \frac{N_{t\bar{t}}}{A \cdot \varepsilon \cdot \mathcal{L}}$$

- **Extract cross section via template fits to discriminating variable**

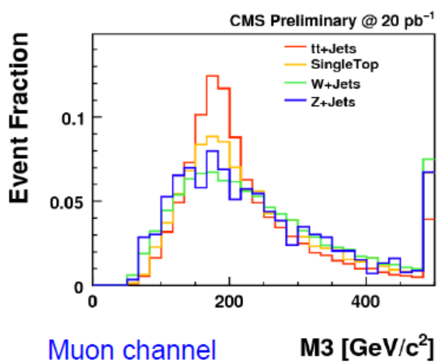


Muon channel

Comparison of shapes:



Muon channel



Muon channel

- **Systematic errors**
  - **for each 5k pseudo experiments performed**

Muon+jets channel:

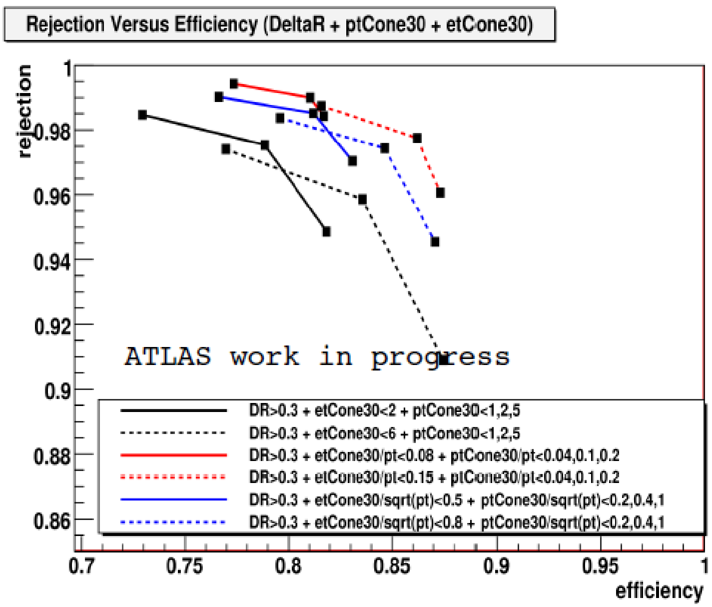
Source	Uncertainty [%]		
	Fit to $\eta(\mu)$	Fit to M3	Fit to M3′
Statistical Uncertainty (20 pb^{-1})	17.7	16.3	11.5
Jet Energy Scale	16.7	15.1	19
$t\bar{t}$ MC Generator	1.9	14.9	14
$t\bar{t}$ ISR/FSR	3.3	7.7	2
W+jets Factorization scale	4.4	4.7	4
W+jets Matching threshold	5.5	2.8	4
Single Top Shape	0.1	0.8	1
PDF Uncertainty	5.0	5.0	5.0
Total Systematic Error	19.2	23.8	25.0
Luminosity Error	10.0	10.0	10.0

- **Result for 20pb-1:**
  - **Muon+jets**
    - o **12-18% (stat.) ; 20-25% (syst.)**
  - **Electron+jets**
    - o **23% (stat.); 20% (syst.)**

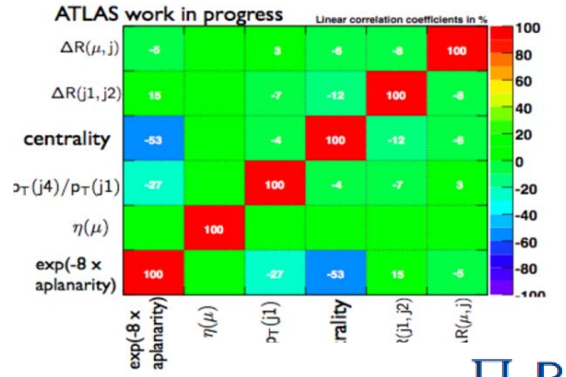
lepton+jets cross section

S. Guindon (Goettingen)

- Studies towards l+jets cross section, using
  - >=4 cone jets, Et>40/40/40/20 GeV
  - MET>20 GeV
  - electron or muon, Pt>20 GeV
- Isolation improvements
  - Use relative isolation
  - Combine tracker and calo

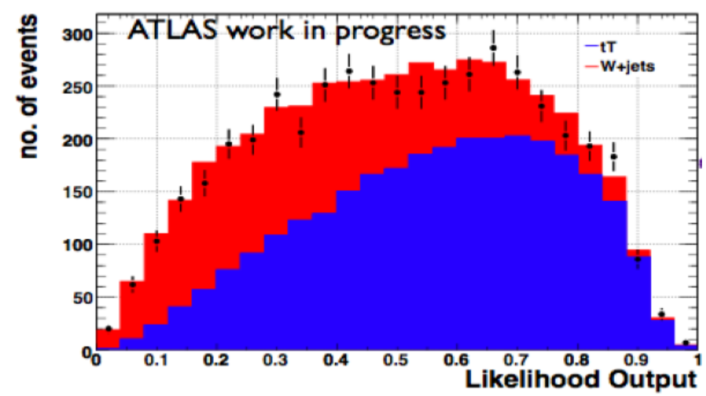


- Cross section extraction using likelihood ratio



$$L = \frac{\prod_i P(x_i|S)}{\prod_i P(x_i|S) + \prod_i P(x_i|B)}$$

- Signal fraction from template fit to LR discriminant



W+jets background from data

S. Mehlhase (DESY Zeuthen)

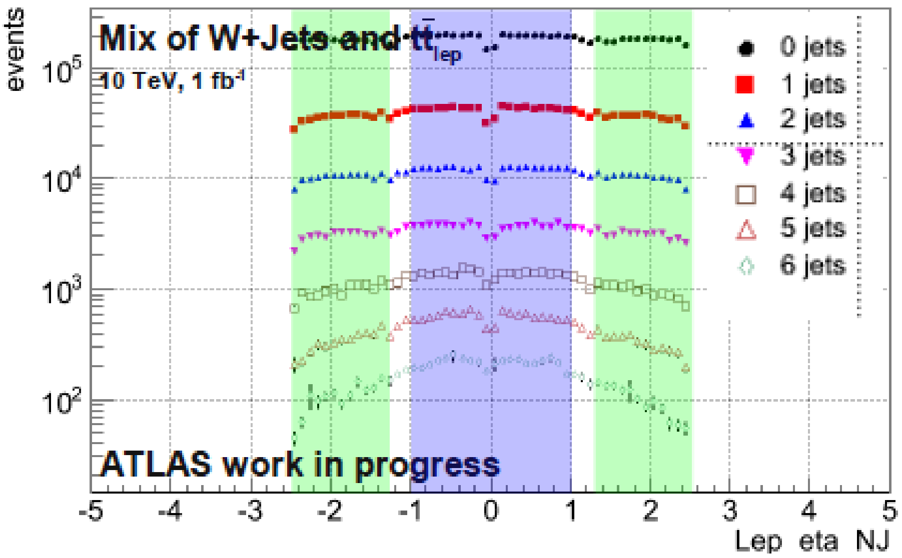
- Idea based on D. Stuart, V.Pavlunin
  - Phys.Rev. D78 (2008) 035012 [arXiv:0806.2338]
- Exploit W+jets and ttbar topologies
  - Signal (ttbar): high n-jet, small |eta|
  - Background (W+jets): low n-jet, all |eta|
  - Extrapolate W+jets from low n-jet and large |eta| to high n-jet and central |eta|

Method walk-through

- Determine $R_{N^{jet}} \equiv Y^{central}_{N^{jet}} / (Y^{central}_{N^{jet}} + Y^{forward}_{N^{jet}})$

$$Y^{central}_{N^{jet}} \equiv N^{|\eta_{lepton}| \le 1}_{events}$$

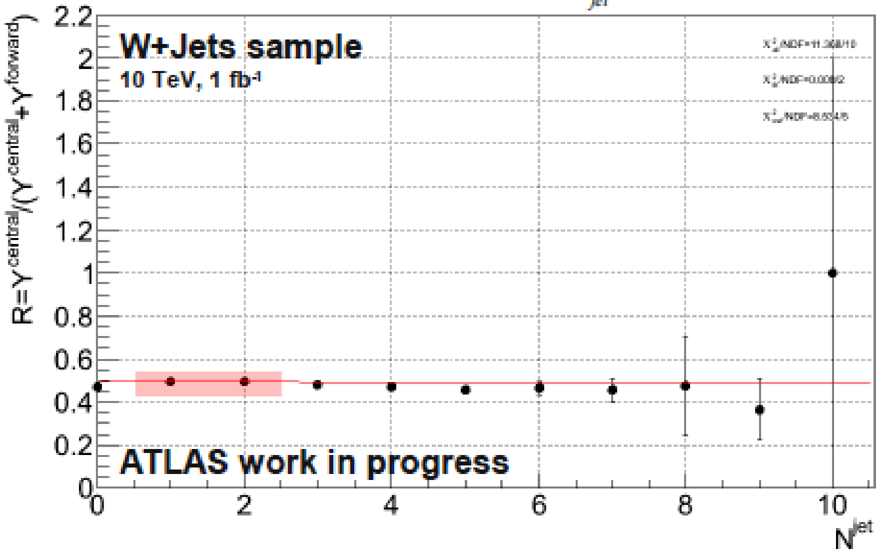
$$Y^{forward}_{N^{jet}} \equiv N^{1.3 \le |\eta_{lepton}| \le 2.5}_{events}$$

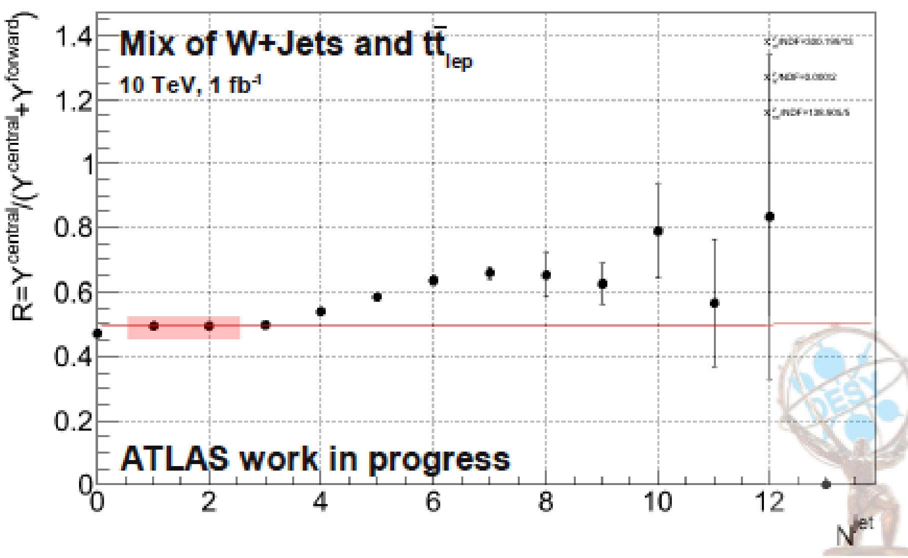


W+jets background from data

S. Mehlhase (DESY Zeuthen)

- Fit $R=R(N^{jet})$ with linear function at low multiplicities $1 \leq N^{jet} \leq 2$
- Extract $Y^{central,\,est}_{N^{jet}} = \frac{R_{N_{jet}}}{1-R_{N_{jet}}} Y^{forward}_{N^{jet}}$ at high multiplicities $4 \leq N^{jet} \leq 8$





- **However:** **must take signal and background overlap into account**
- **Modified method developed**
- **First results encouraging**

MSbar determination of m(top)

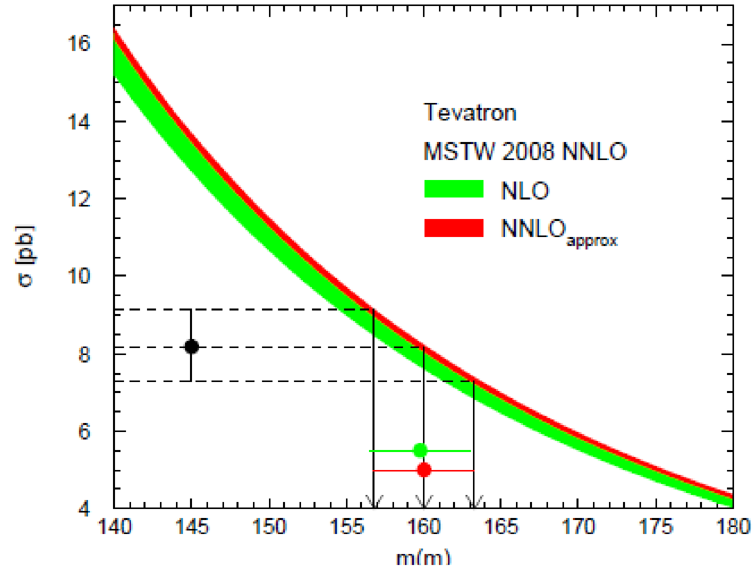
U. Langenfeld (HU Berlin)

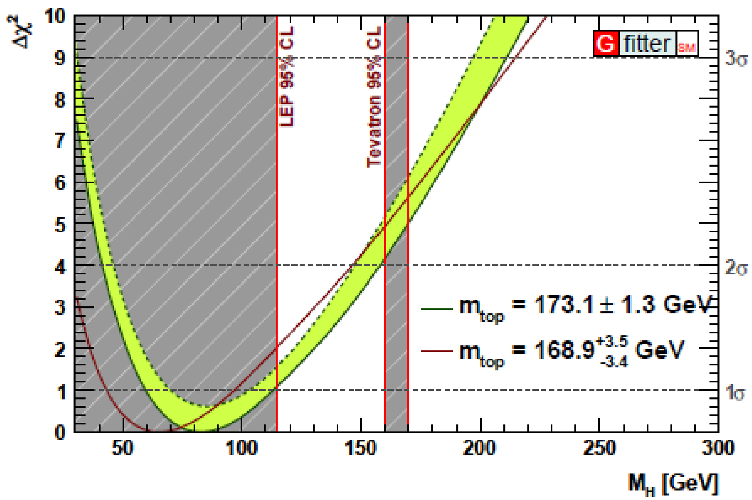
- **Work in collaboration with S. Moch, P. Uwer**
  - Phys.Rev.D80 (2009) 054009 [arXiv:0906.5273]
- **m(top) measured at Tevatron as "pole mass" (PYTHIA parameter)**
- **Here: extract m(top) in MSbar scheme by comparing sigma(ttbar) measured at Tevatron with theory predicion (approx. NNLO)**
  - **Result:** $\overline{m} = 160.0^{+3.3}_{-3.2}$ GeV

convert $\overline{\text{MS}}$ mass $\overline{m}$ into pole mass m_t

Our Analysis: $m_t = 168.9^{+3.5}_{-3.4}$ GeV

world average: $m_t = 173.1^{+1.3}_{-1.3}$ GeV





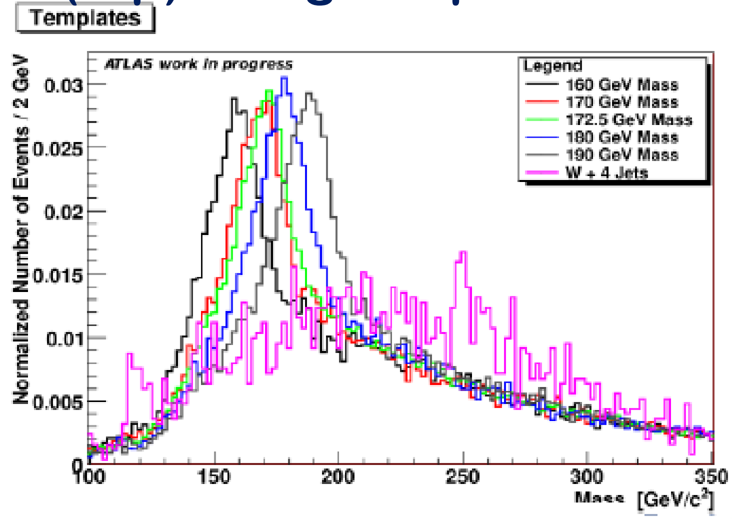
m(top) and W-helicity in l+jets

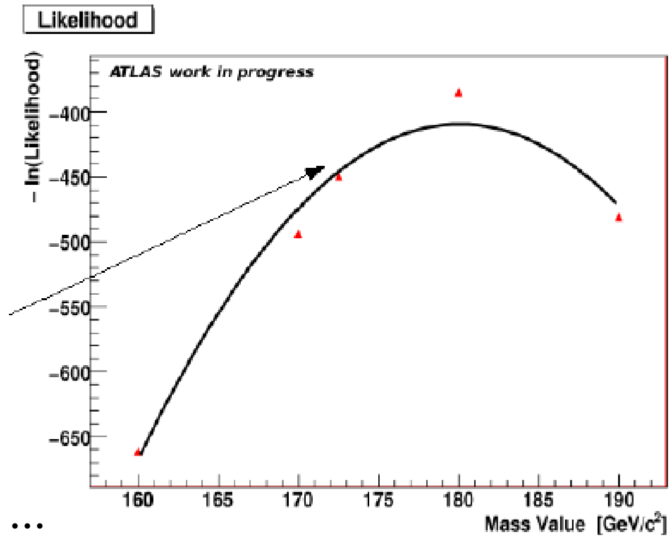
A. Knue, J. Erdmann (Goettingen)

- **Preparation for**
  - **Top mass measurement**
    - Using template method
    - Using matrix element method
  - **W helicity measurement**
    - Using template method

- **Application of statistical tools**
  - **BAT (Bayesian Analysis Toolkit)** [arXiv:0808.2552]
  - **KLFitter (Kinematic Likelihood Fit)** ATL-COM-PHYS-2009-551

- **m(top) using templates**





Need more / parameterized templates …

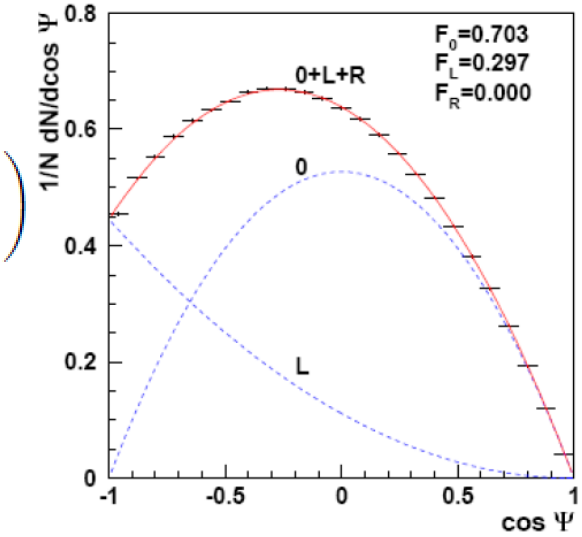
m(top) and W-helicity in l+jets

A. Knue, J. Erdmann (Goettingen)

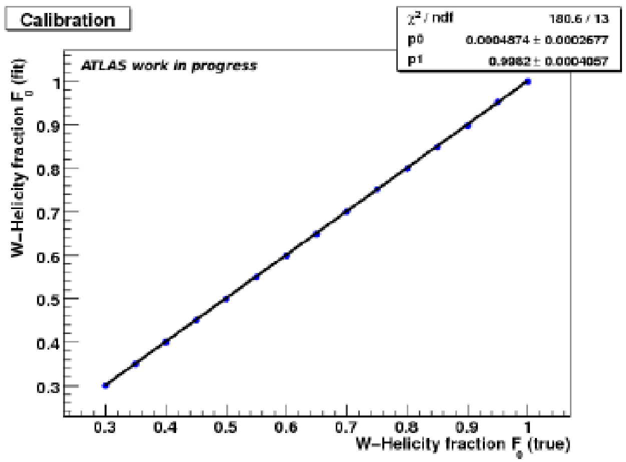
- **W-helicity using templates**
  - **Use cos(theta*) = angle(b,l) in W rest frame**

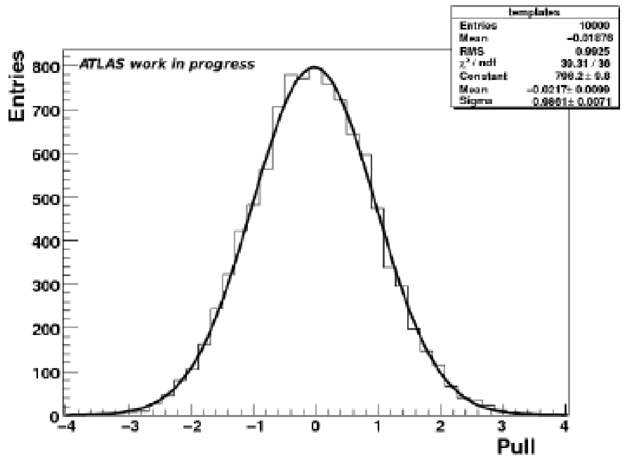
$$\frac{dN}{d\cos\theta^*} = \frac{3}{2}\left(F_0\left(\frac{\sin\theta^*}{\sqrt{2}}\right)^2 + F_L\left(\frac{1-\cos\theta^*}{2}\right)^2 + F_R\left(\frac{1+\cos\theta^*}{2}\right)^2\right)$$

  - **Use templates obtained from reweighting**



- 15 templates produced
  $\Rightarrow F_R = 0$
- 10,000 ensembles used
- Gaussian fit to distributions





- more templates used
  $\Rightarrow$ Pull only small

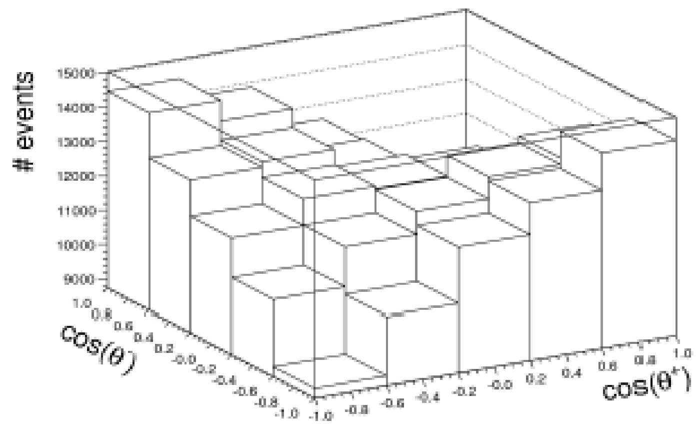
- **Add BG templates**
- **Multi-dim fit**
- **Also use ME method**

Ttbar Spin Correlations

- Spin configuration depends on production mechanism
- Top quarks decay before hadronising ⇒ spin information from decay products
- Best top spin analyser: charged lepton from W decay ($\kappa_f = \pm 1$) ⇒dilepton channel
- Observable for tt spin correlations: angular distribution of charged leptons:

$$\frac{1}{N}\frac{d^2N}{d\cos\theta^*_{l+}\,d\cos\theta^*_{l-}} = \frac{1}{4}(1 - A\kappa_1\kappa_2\cos\theta^*_{l+}\cos\theta^*_{l-} + p_+\cos\theta^*_{l+} + p_-\cos\theta^*_{l-})$$

($\theta^*_{l+/-}$: angle between p(l) in t rest frame and p(t) in tt pair rest frame)

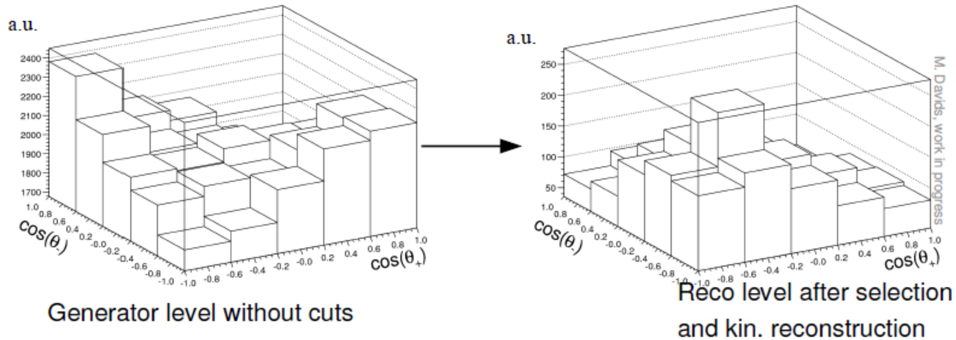


- Prediction for LHC: A ≈ 0.326 (14 TeV, e. g. Hep-ph/0410197, Bernreuther et al.),
  A ≈ 0.315 (10 TeV)

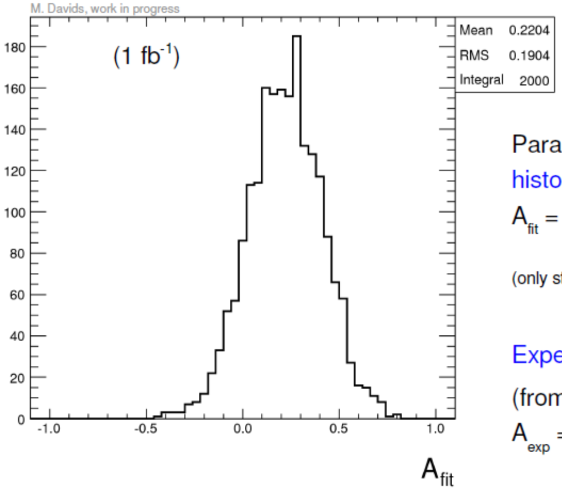
Ttbar Spin Correlations

M. Davids (Aachen)

- Kinematic reconstruction (in dilepton channel)
- Angular distributions distorted due to selection cuts



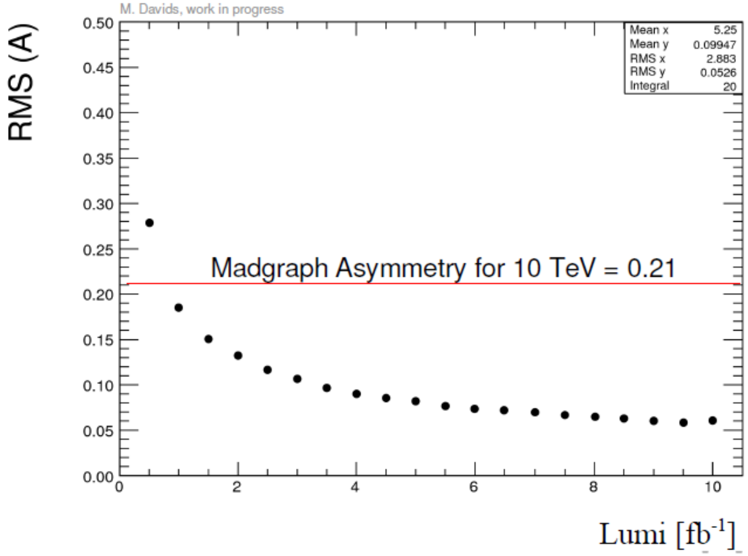
- Fit basis histos plus background templates to data



Parameters from
histogram fit (1 fb^{-1}):
$A_{fit} = 0.22 \pm 0.19$

(only statistical errors)

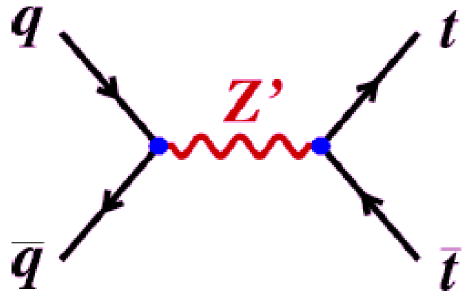
Expectation
(from generator fit)
$A_{exp} = 0.21$

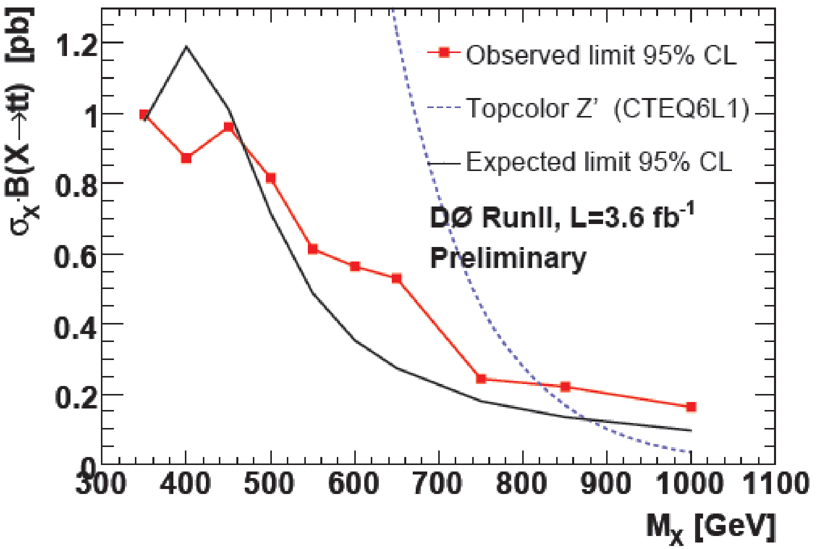


- Outlook:
  - ❑ Add further backgrounds, study systematics

New physics in M(ttbar)

- Several new physics scenarios predict heavy particles decaying into ttbar pairs
  - e.g. Axigluons, Technicolor Z', KK excitations of extra ED gravitons
- In all cases leads to distortion of M(ttbar) spectrum
- Tevatron has excluded narrow Z' for M<820 GeV
- Experimental challenges
  - At high mass, top decay products are boosted (close together)
    - Leptons fail isolation requirement
    - Jets merge with other jets / leptons
    - B-tagging at high Pt difficult / impossible (dense tracks)



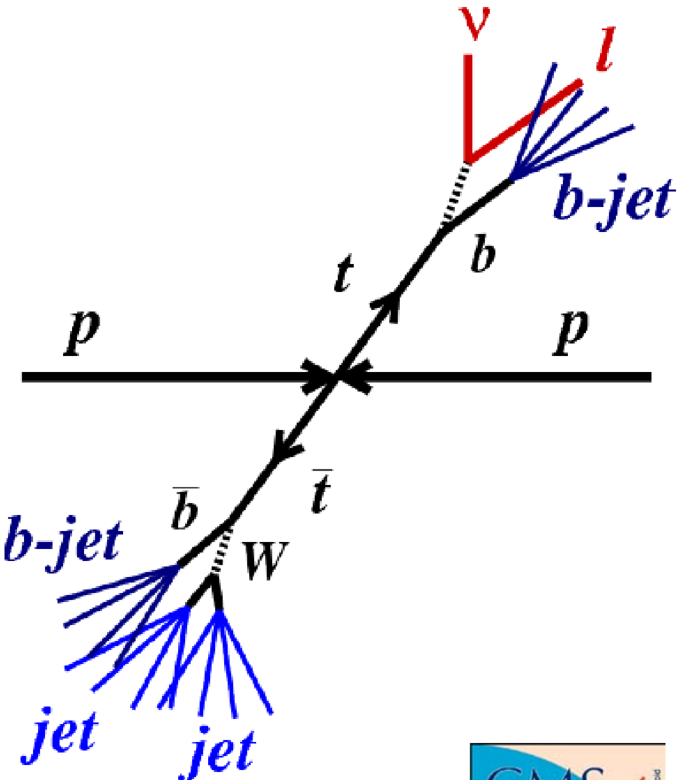


Boosted Top

T. Peiffer (KIT)

- Two recent CMS approvals with german contribution
  - Low-mass: PAS TOP-09-009 (Aachen)
  - High-mass: PAS EXO-09-008 (Karlsruhe)
- Scenario studied: 10 TeV, 100-200pb -1, narrow Z' resonance in muon plus jets channel

- Low mass scenario:
  - Similar topology as SM ttbar, >=4 jets
- High mass scenario:
  - Top quarks boosted, decay products closeby: jets merge (njet>=2), lepton not isolated
- Need event reconstruction to obtain m(ttbar)

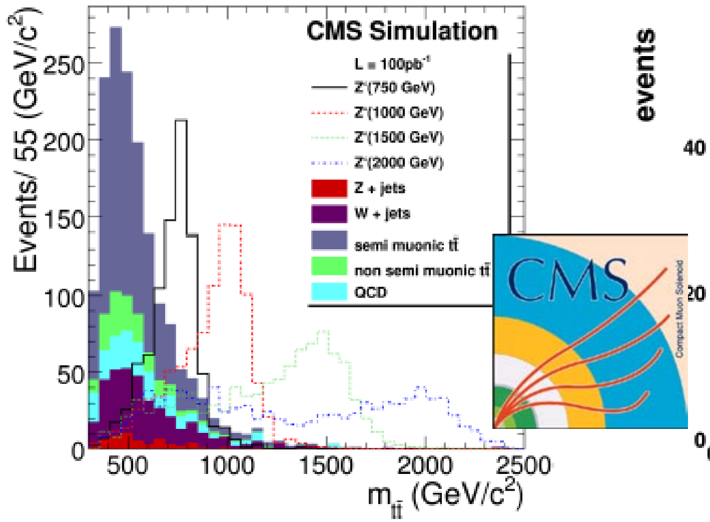


Boosted Top

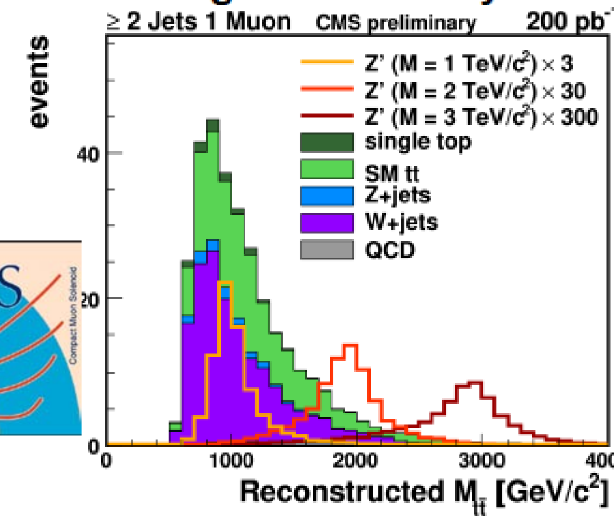
T. Peiffer (KIT)

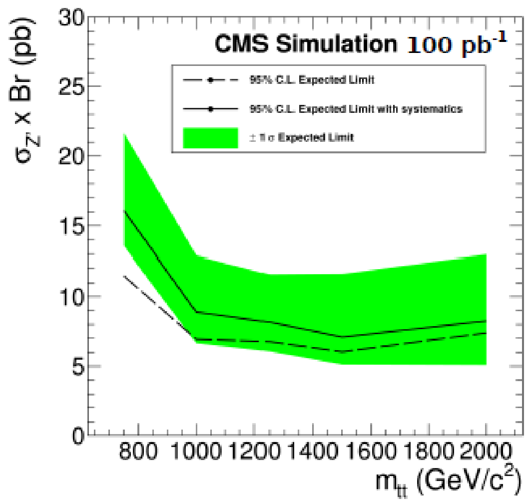
- Low mass scenario
  - ❑ Kinematic fit for jet assignment
- High mass scenario
  - ❑ Full reco not possible
  - ❑ Neutrino from MET, W-mass constraint
  - ❑ Assign jets such that top and tbar are back-to-back
  - ❑ Data-driven BG estimates
  - ❑ Limits from template fits including systematics
  - ❑ Limits in pb range in one year of data taking

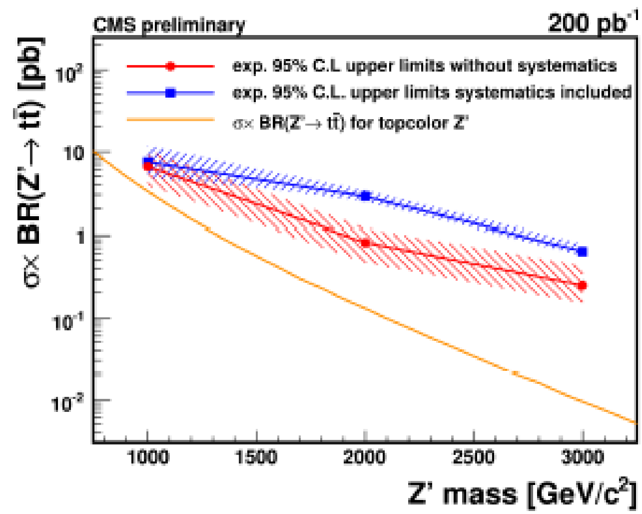
low mass analysis



high mass analysis



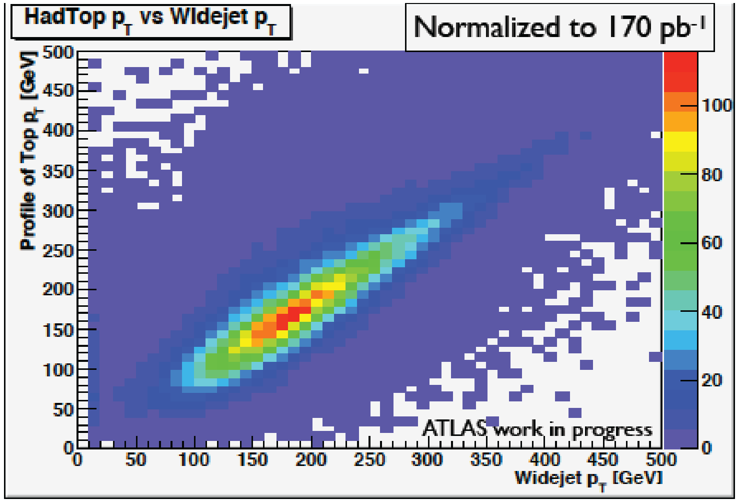




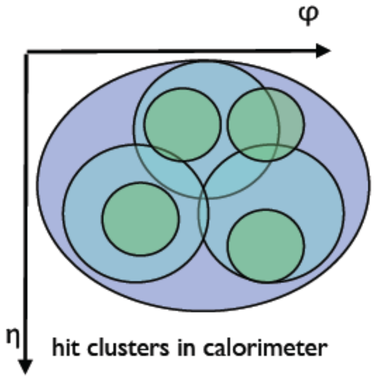
High pt top reco using substructure

P. Kovesarki (Bonn)

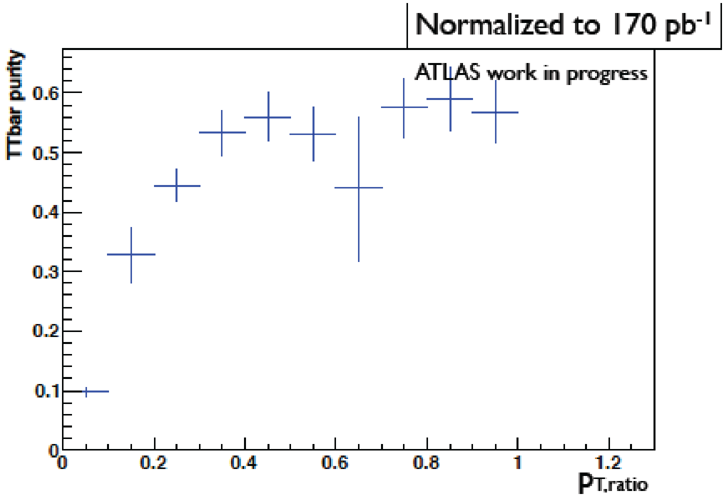
- Cluster jets with large dR=1.5
- Pt correlation with hadronic top visible for pt>100 GeV



- Selection:
  - ❑ Wide jet, Pt>300 GeV
  - ❑ Isol. Electron, Pt>50 GeV



- Reduce cone size
  - ❑ Find “split levels”
  - ❑ Define pt-ratio of 2 jets at first splitting



Interference Effects in m(ttbar)

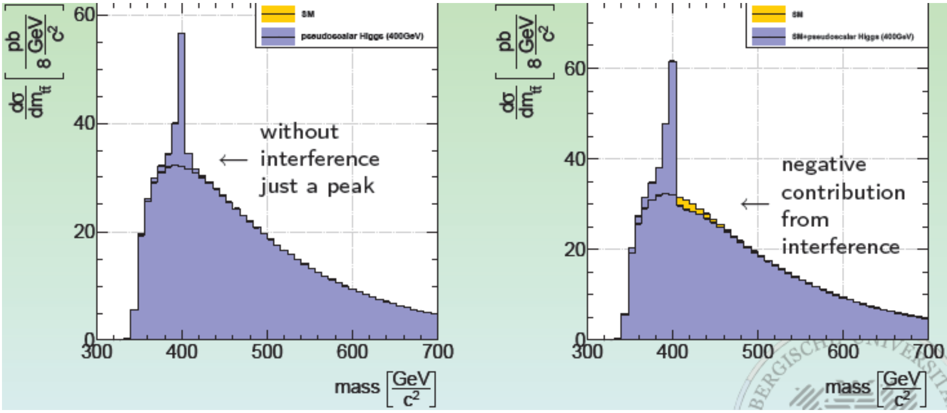
M. Mechtel (Wuppertal)

- **Many models predict interference between signal and SM background**
  - ❑ **Affects m(ttbar) shape**

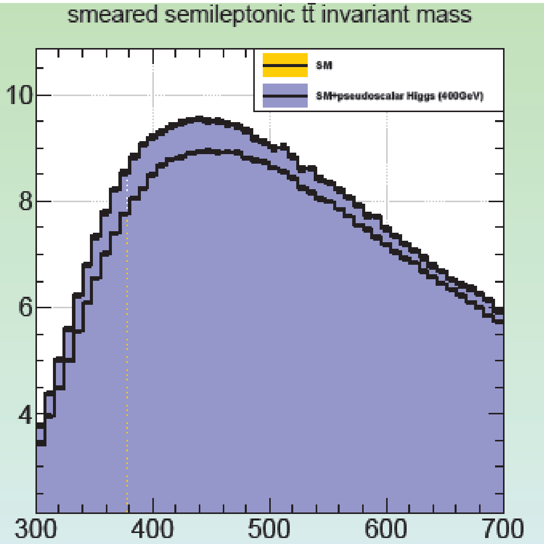
Spin	color	parity $(1,\gamma_5)$	some examples	Interf.
0	0	(1,0)	SM, MSSM, 2HDM	×
0	0	(0,1)	MSSM, 2HDM	✓
0	8	(1,0), (0,1)	techni-π^0	×
1	0	(SM,SM)	Z'	×
1	0	(1,0), (0,1), $(1,\pm 1)$	vector	✓
1	8	(1,0)	coloron, KK gluon	✓
1	8	(0,1)	axigluon	×
2	0	–	KK graviton	✓

[Frederix, Maltoni: JHEP01(2009)047]

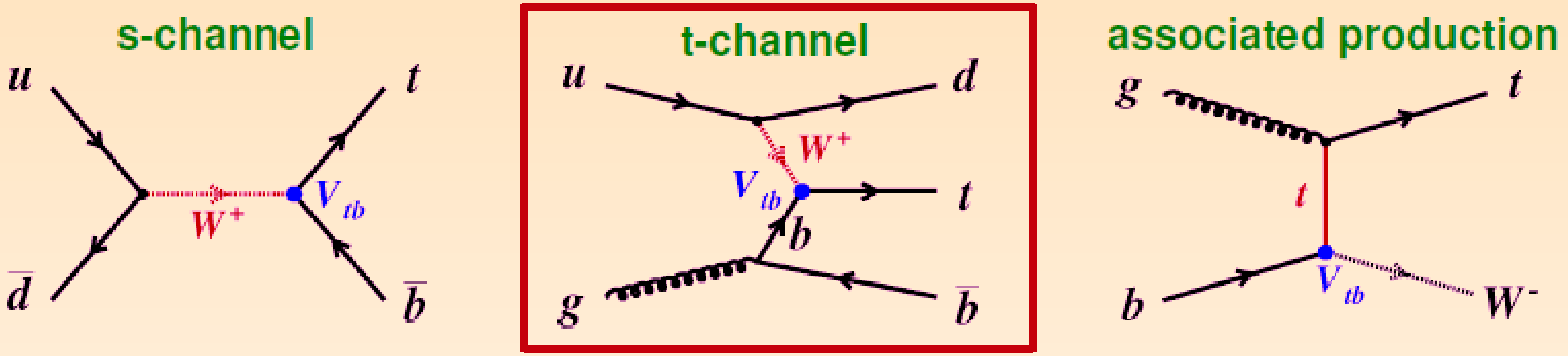
- **Example: pseudoscalar Higgs, 400 GeV, parton level**



- **Simulate detector by 4-vector smearing:**
- **Effect mostly washed out …**



Single Top



PRD 74, 114012 (2006); PRD 70, 114012 (2004); Nucl. Phys. B726, 109 (2005); JHEP 0910, 042 (2009)	Tevatron [pb] √s=1.96 TeV	LHC [pb] √s=7 TeV	LHC [pb] √s=10 TeV
s-channel	0.88	1	**5**
t-channel	1.98	65	**124**
associated production	0.26	11	**29**

Physics motivation:

- **Direct measurement of $|V_{tb}|^2$**
- **Test of Wtb coupling**
- **Search for new physics**
  (4th gen., H+, W' ...)

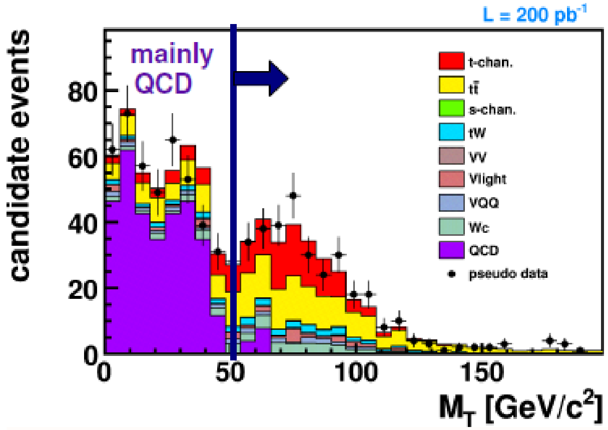
t-channel:

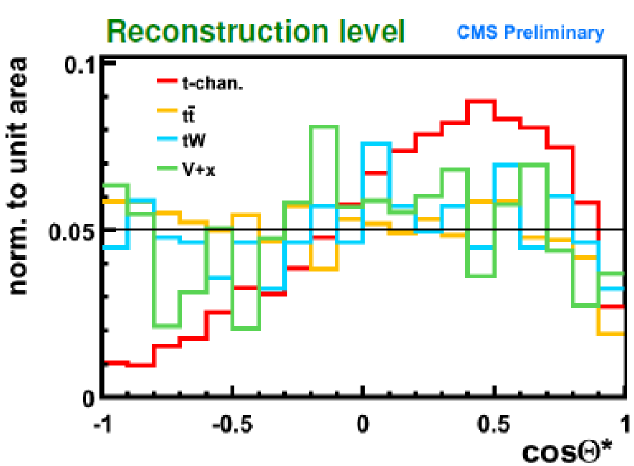
- **Improved S/B ratio compared to Tevatron**
- **Most promising for re-discovery**

Single Top in CMS

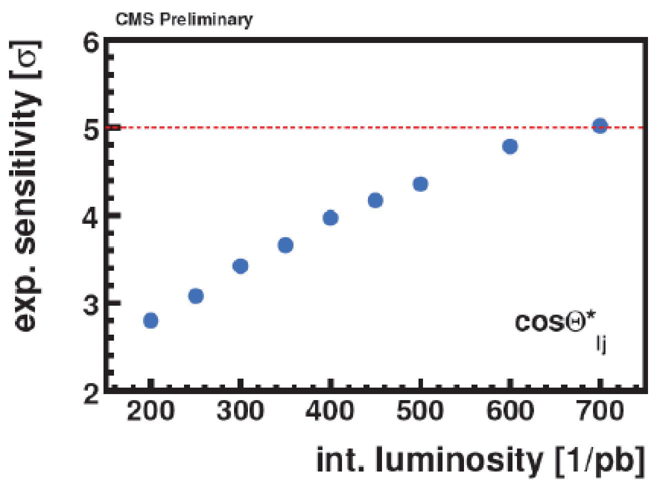
J. Wagner-Kuhr (KIT)

- Approved CMS analysis PAS TOP-09-005
  - t-channel, muonic W decay, 10 TeV, 200pb-1
- Event selection
  - 1 muon, Pt>20 GeV
  - ==2 jets, Et>30 GeV, |eta|<5.0
  - ==1 b-tag, veto on second (loose) b
  - Mt(W)>50 GeV
- Yields S/B = 1 / 2.3
  - Use template fit to cos(theta*)[l,q]





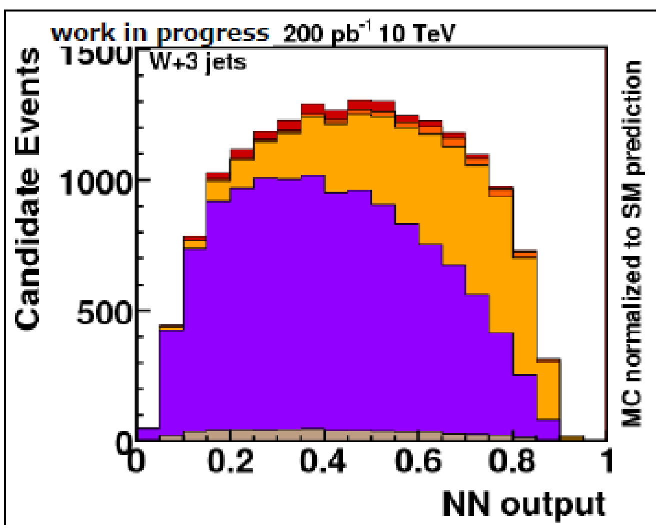
- Sensitivity (incl. systematics):
  - ~3sigma with 200pb-1

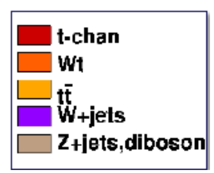


Single Top in ATLAS

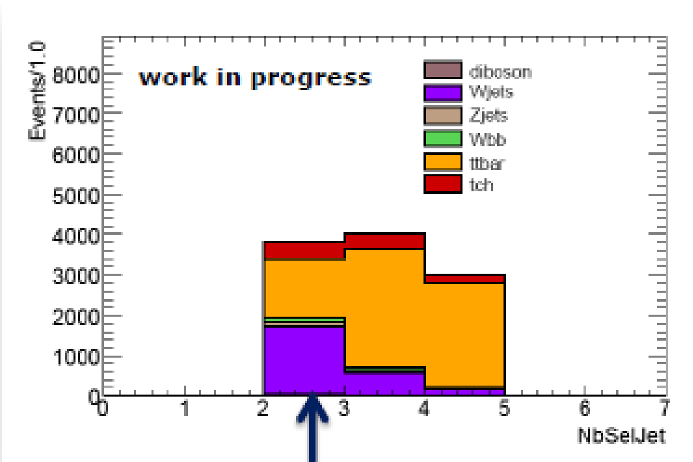
P. Sturm (Wuppertal)

- **t-channel selection**
  - **1 electron or muon, Pt>20 GeV**
  - **2 or 3 jets, Et>30, |eta|<5.0**
  - **1 b-tag, MET>20 GeV**
- **Determine ttbar and W+jets BG in 3-jet pretag sample using Neural Net**





- **Measure cross section in 2-jet tagged sample using Neural Net**
- **Study systematics**

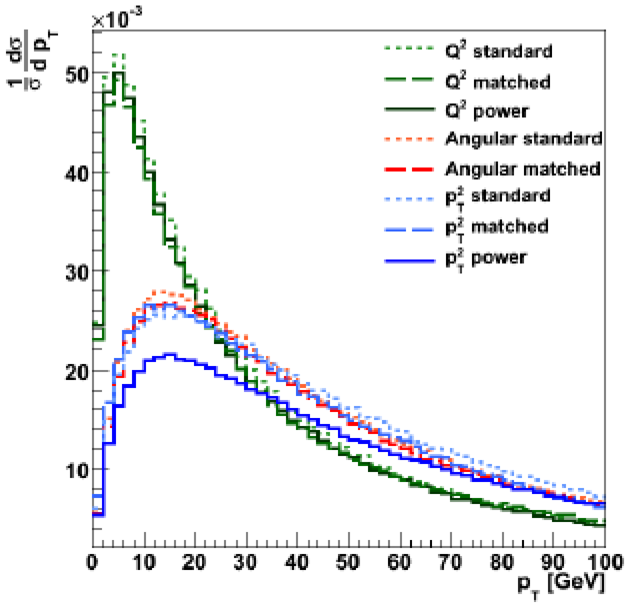


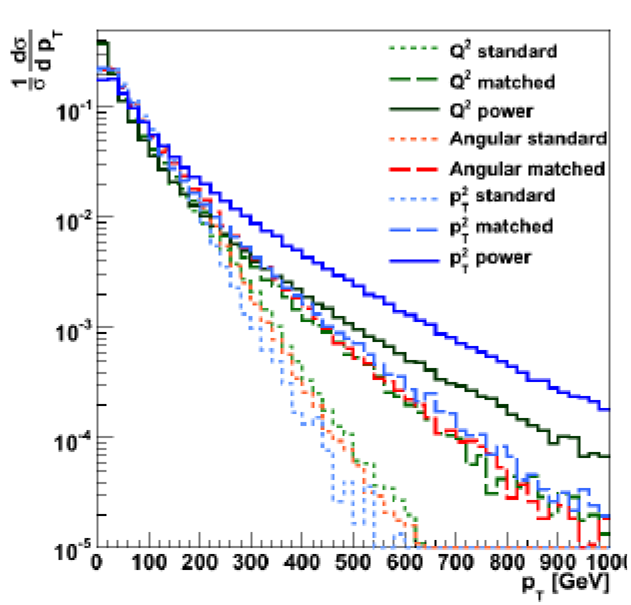
Use events with 2 jets and one b-tagged jet

QCD radiation effects in ttbar

- **Impact of various parton shower models on Pt(ttbar) distribution**

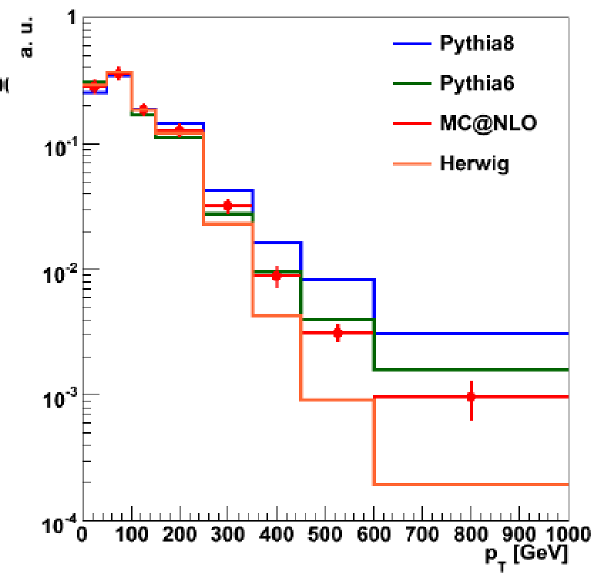
A. Flossdorf (DESY)





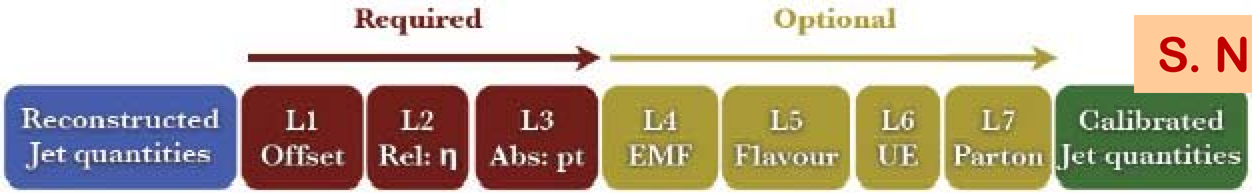
Generator level

Detector Level, 7fb-1

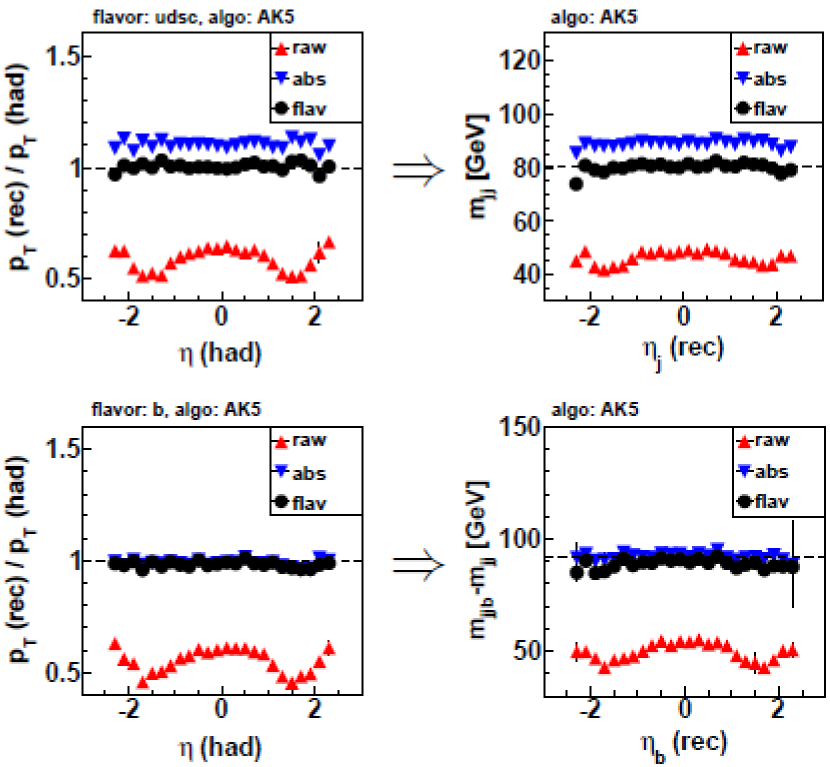


Ttbar events as JES calibration candles

S. Naumann-Emme (Hamburg)



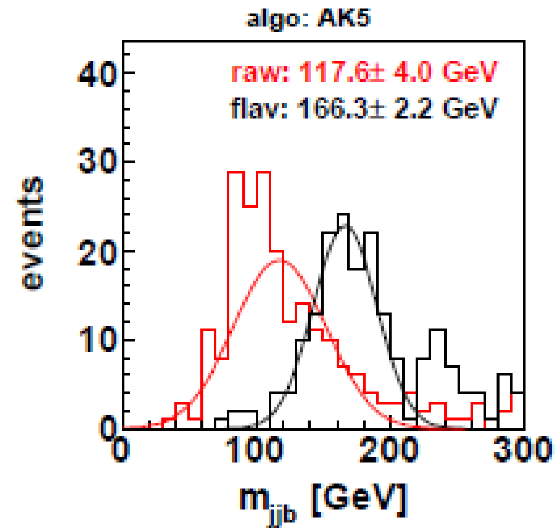
- **Use ttbar events to monitor the jet response**
  - ❑ **m(jj) and m(jjb) in lepton+jet events**
  - ❑ **Data-driven jet assignment**



use the reconstructed m_{jj} to monitor the light jet response

use the reconstructed m_{jjb}-m_{jj} to monitor the b jet response

50pb-1 data, 10 TeV, 220 events



2% level monitoring possible

Other Topics

- **Summaries talks from workshop on single top and fourth generation physics (Sept 2009, DESY)**
  - **Single top (M. Zur Nedden, HU Berlin) https://indico.desy.de/getFile.py/access?contribId=90&sessionId=41&resId=0&materialId=slides&confId=2154**
  - **4th generation (H. Lacker, HU Berlin) https://indico.desy.de/getFile.py/access?contribId=82&sessionId=36&resId=0&materialId=slides&confId=2154**

- **Discussion session on common projects in LHC-D TOP group**
  - **At interface between theory and experiment**
  - **Penomenological studies, NLO codes and tools, etc.**

Conclusions

- 5th workshop of the LHC-D top group
  - Key measurements well covered by German ATLAS, CMS groups
  - Theory not well represented this time
  - Plan: strenghen common activities

- Ttbar physics program at the LHC
  - 900 GeV collisions
    - None ;-)
  - 20 (50) pb-1 @ 10 (7) TeV:
    - “rediscover” top quark
    - first ross section and mass measurements
  - ~200 pb-1 @ 10 TeV:
    - first statement on single top
    - limits on new physics in m(ttbar) in 1-3 TeV range
  - several fb-1:
    - Precision measurements of top quark properties

Backup

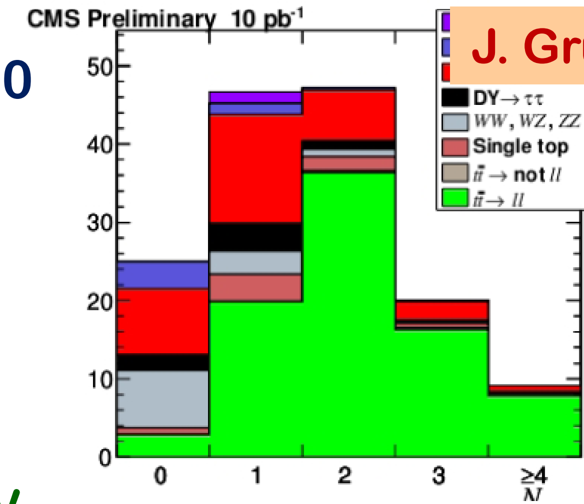
TOPics discussed

- Cross section measurements
  - Cross section measurements at 10 TeV (J. Gruschke, KIT, CMS)
  - Lepton+jets with Likelihood (S. Guindon, Goettingen, ATLAS)
  - W+jets background (S. Mehlhase, DESY, ATLAS)
- Top properties
  - MSBAR mass extraction (U. Langenfeld, Berlin, Theory)
  - Spin Correlations (M. Davids, Aachen, CMS)
  - Mass and W-helicity (A. Knue, Goettingen, ATLAS)
- Ttbar resonances / boosted Top
  - High pt top reconstruction / jet substructure (P. Kovesarki, Bonn, ATLAS)
  - Boosted top (T. Peiffer, KIT, CMS)
  - Interferences in M(ttbar) (M. Mechtel, Wuppertal, ATLAS)
- Single top
  - Single top in CMS (J. Wagner-Kuhr, KIT, CMS)
  - Single top in ATLAS (P. Sturm, Wuppertal, ATLAS)
  - Report from alliance WS: Single top (M. zur Nedden, HU Berlin, Gen)
  - Report from alliance WS: Fourth generation (H. Lacker, HU Berlin, Gen)
- Other topics
  - QCD radiation effects (A. Flossdorf, DESY, CMS)
  - Top for calibration (S. Naumann-Emme, Hamburg, CMS)
  - Event reconstruction with Klfitter (J. Erdmann, Goettingen, ATLAS)
- Discussion session on common projects

Cross section in dilepton (CMS)

J. Gruschke (KIT)

- **Early measurement in 10pb-1 at 10 TeV (ee, mumu, emu)**
  - PAS TOP-09-002
- **Event selection**
  - Single lepton trigger
  - 2 leptons, opp. Charge, Pt>20 GeV
  - Z-veto in ee,mumu
  - >=2 jets, Et>30 GeV
  - MET> 20 (30) GeV
- **Result for 10pb-1**
  - Stat. error 15%
  - Syst. Error 10%



Data sample	e^+e^-	$\mu^+\mu^-$	$e^\pm\mu^\mp$
$t\bar{t} \to \ell\ell$	11.6 ± 0.2	13.2 ± 0.2	35.6 ± 0.4
other $t\bar{t}$	0.21 ± 0.03	0.04 ± 0.01	0.46 ± 0.04
Single top	0.46 ± 0.03	0.56 ± 0.03	1.40 ± 0.06
$WW/WZ/ZZ$	0.26 ± 0.02	0.33 ± 0.03	0.71 ± 0.05
DY$\to \tau\tau$ + jets	0.3 ± 0.1	0.3 ± 0.1	0.7 ± 0.2
DY$\to ee/\mu\mu$ + jets	4.1 ± 0.4	5.3 ± 0.4	0.08 ± 0.05
W + jets	0.2 ± 0.1	< 0.1	0.3 ± 0.1
QCD	< 1	< 0.4	< 0.4
Total backgrounds	5.5 ± 0.4	6.6 ± 0.4	3.7 ± 0.2
Data driven fakes	1.1 ± 0.6	0.8 ± 0.4	2.5 ± 1.2
Data driven DY	4.0 ± 1.3	5.1 ± 1.6	

- **Variations studied**
  - Use track-jets and no MET
  - Use b-tagging
  - Track-corrected MET