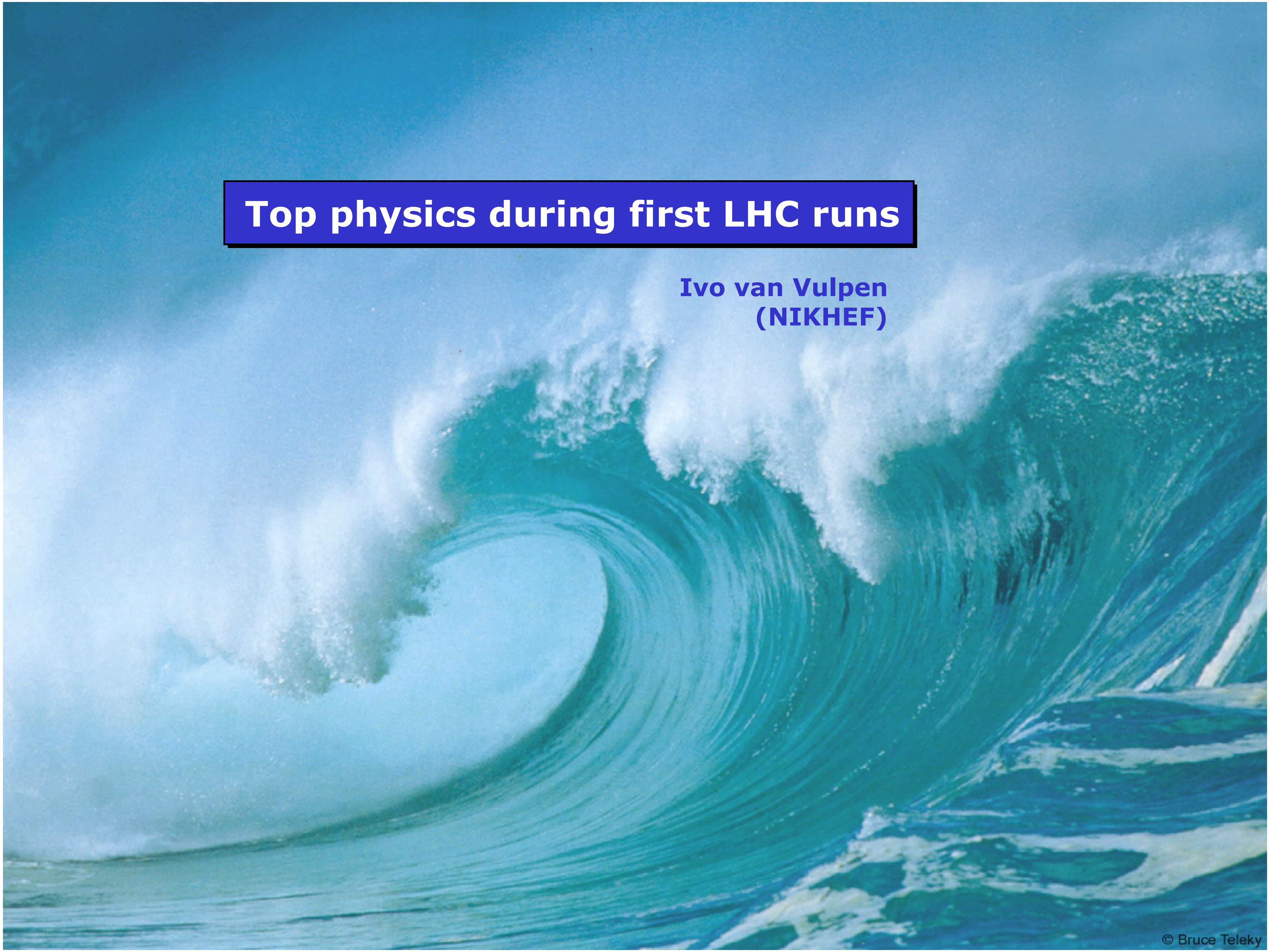
Top physics during first LHC runs

Ivo van Vulpen
(NIKHEF)



Conclusions:

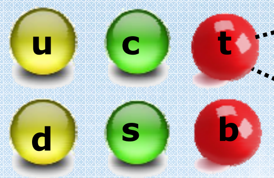
1) Top quarks are produced by the millions at the LHC:
→ Almost no background: measure top quark properties

2) Top quarks are THE calibration signal for complex topologies:
→ Most complex SM candle at the LHC
→ Vital inputs for detector operation and SUSY background

3) Top quarks pair-like events … window to new physics:
→ FCNC, SUSY, MSSM Higgses, Resonances, …

Discovered more than 10 years ago

We still know little about the top quark



- Mass	Precision <2% (see next talk on CMS' potential)
- Top width ~1.5 GeV	?
- Electric charge ⅔	-4/3 excluded @ 94% C.L. (preliminary)
- Spin ½	Not really tested – spin correlations
- BR(t→Wb) ~ 100%	At 20% level in 3 generations case
	FCNC: probed at the 10% level

The LHC offers opportunity for **precision measurements**

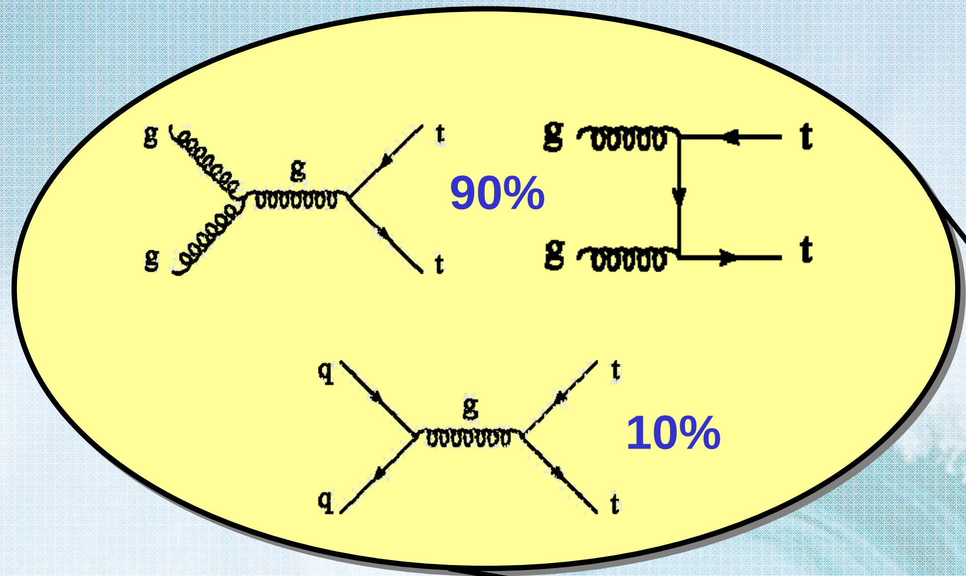
This talk: "What can we do with 1-10 fb^{-1} of high-energy data ?"

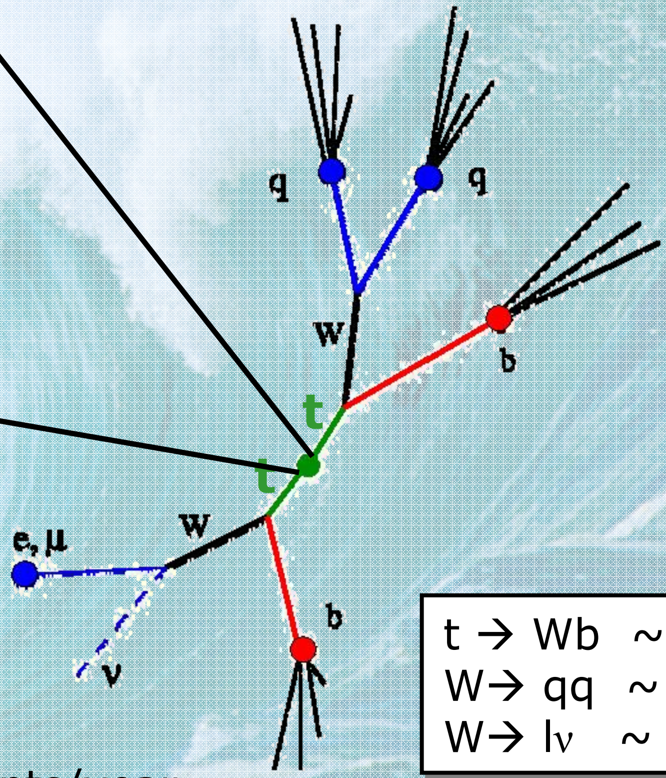
Top quark production at the LHC

<u>Production</u>: σ_{tt}(LHC) ~ 830 ± 100 pb

→ 1 tt-event per second

Cross section LHC = 100 x Tevatron
Background LHC = 10 x Tevatron





<u>Final states</u>:

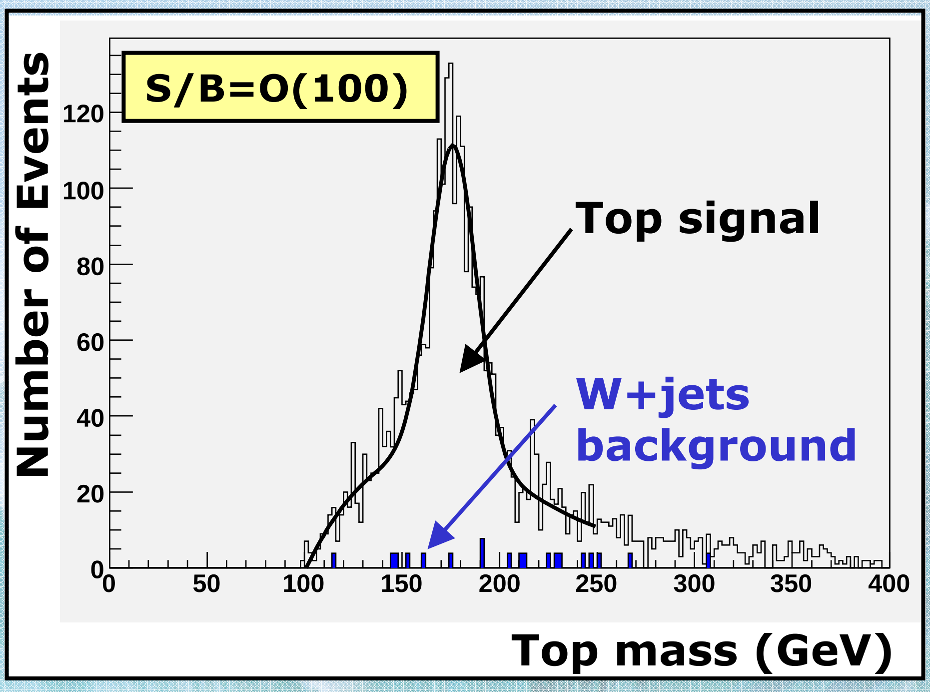
1) Fully-hadronic (4/9) 6 jets
2) Semi-leptonic (4/9): 1l + 1ν + 4 jets
3) Fully-leptonic (1/9): 2l + 2ν + 2 jets

→ *Golden channel* (l=e,μ)→ 2.5 million events/year

t → Wb	~ 1
W→ qq	~ 2/3
W→ lν	~ 1/3

Top quark physics with b-tag information

Top physics is 'easy' at the LHC:



Selection: Lepton
Missing E_T
4 (high-P_T)-jets (2 b-jets)

→ signal efficiency few %
→ *very* small SM background

- 'Standard' Top physics at the LHC:
  - b-tag is important in selection
  - Most measurements limited by systematic uncertainties
- 'Early' top physics at the LHC:
  - Cross-section measurement (~ 20%)
  - Decay properties

- Robust selection cuts:

Missing	E_T > 20 GeV
1 lepton	P_T > 20 GeV
4 jets(R=0.4)	P_T > 40 GeV

Selection efficiency = 5.3%

Still 1500 events/day

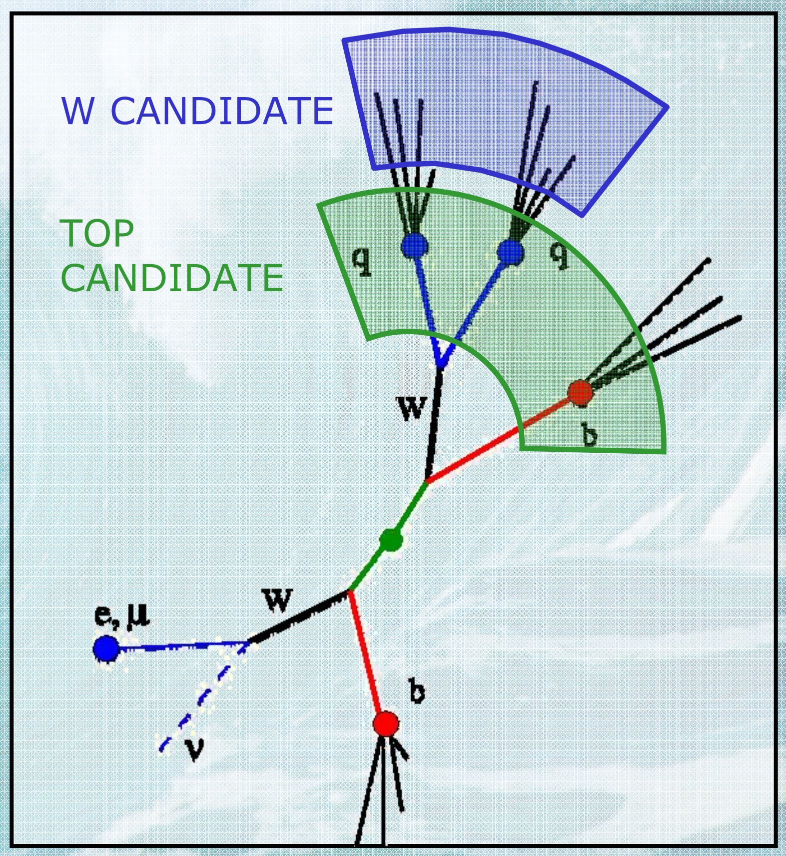
- Assign jets to W-boson and top-quark:

1) Hadronic top:

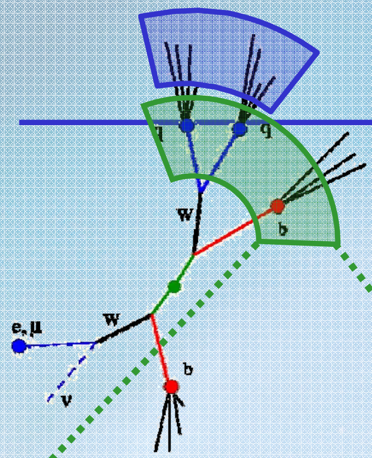
Three jets with highest vector-sum p_T as the decay products of the top

2) W boson:

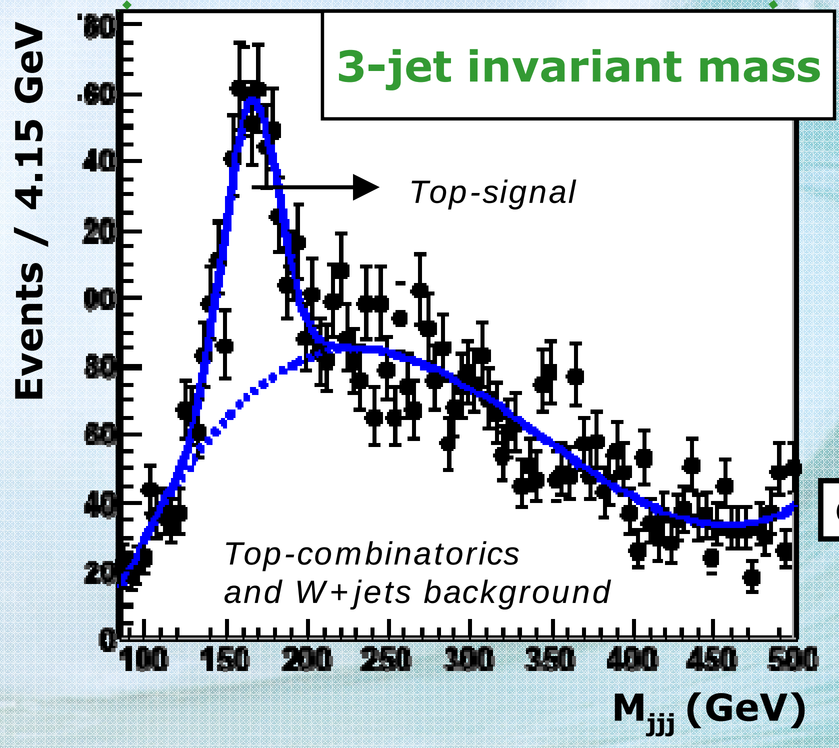
Two jets in hadronic top with highest momentum. in reconstructed jjj C.M. frame.



Results for a 'no-b-tag' analysis: 100 pb^{-1}

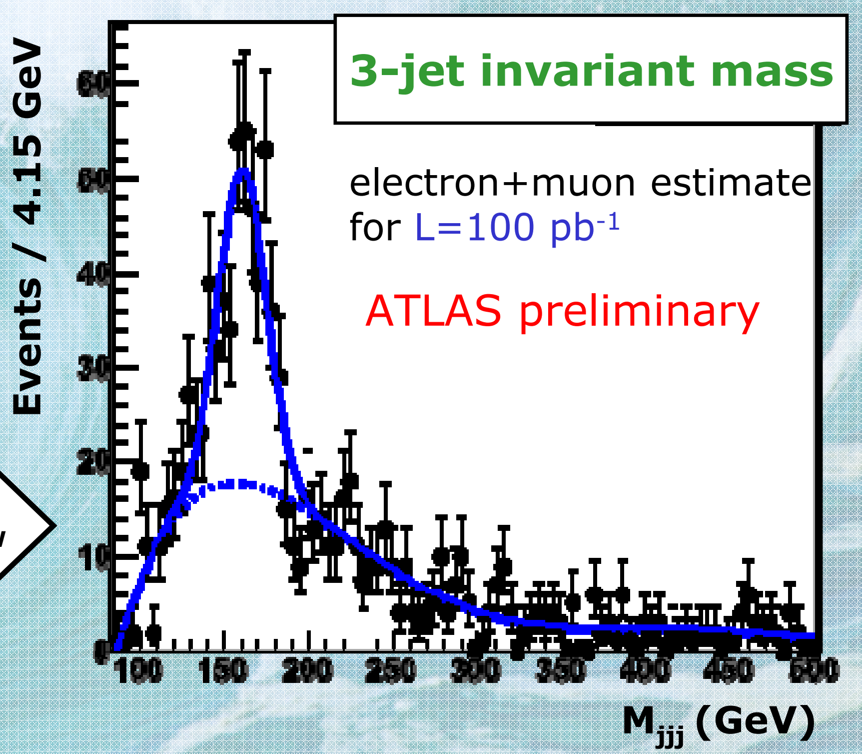


100 pb^{-1} is a few days of nominal low-luminosity LHC operation



Cut on M_W

We can easily see top peak without b-tag requirement



Top quarks form an 'oasis' in our search for new physics

First year at the LHC:

A new detector **AND** *a new energy regime*

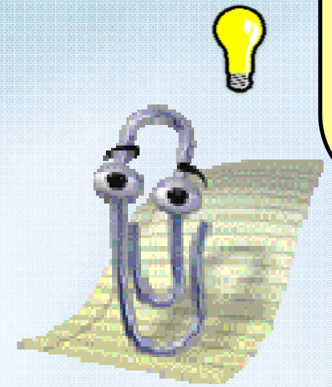
1. Understand ATLAS/CMS using *cosmics*
2. Understand SM+ATLAS/CMS in *simple topologies*
3. Understand SM+ATLAS/CMS in *complex topologies*
4. Look for *new physics* in ATLAS at 14 TeV

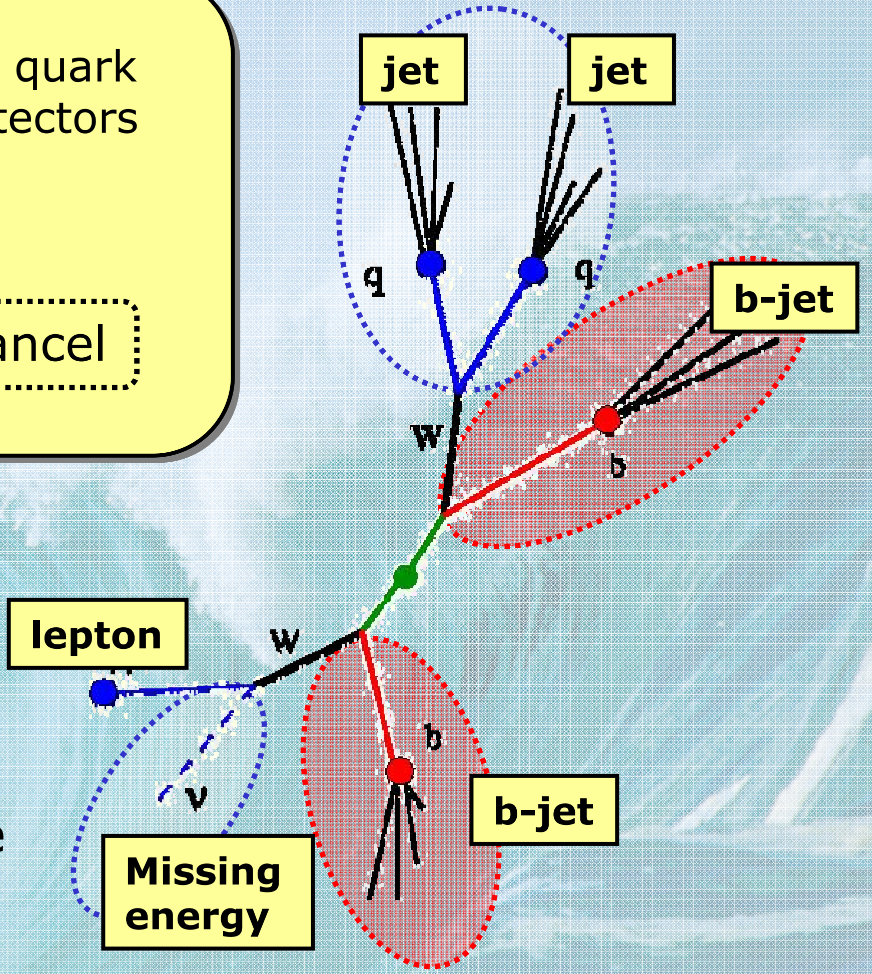
Process	#events 10 fb^{-1}
$b\bar{b}$	10^{12}
$W \rightarrow e\nu$ (2)	10^{8}
$Z \rightarrow e^+e^-/\mu^+\mu^-$	10^{7}
$t\bar{t}$ (3)	10^{7}
Min. bias	10^{7}
QCD jets $P_T > 150$ GeV	10^{7}
h (m_h = 130 GeV)	10^{5}
$\tilde{g}\tilde{g}$ ($m_{\tilde{g}}$ = 1 TeV) (4)	10^{4}

Top quark pair production as calibration tool

You can use production of top quark pairs to help calibrate LHC detectors in complex event-topologies

Yes   No   Cancel





→ <u>A candle for complex topologies</u>:

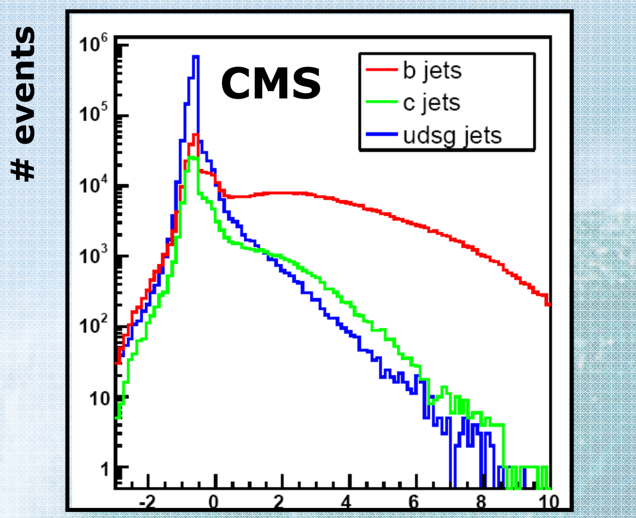
- Calibrate light jet energy scale
- Calibrate missing E_T
- Obtain enriched b-jet sample
- Leptons and trigger

Note candles: 2 W-bosons
2 top quarks

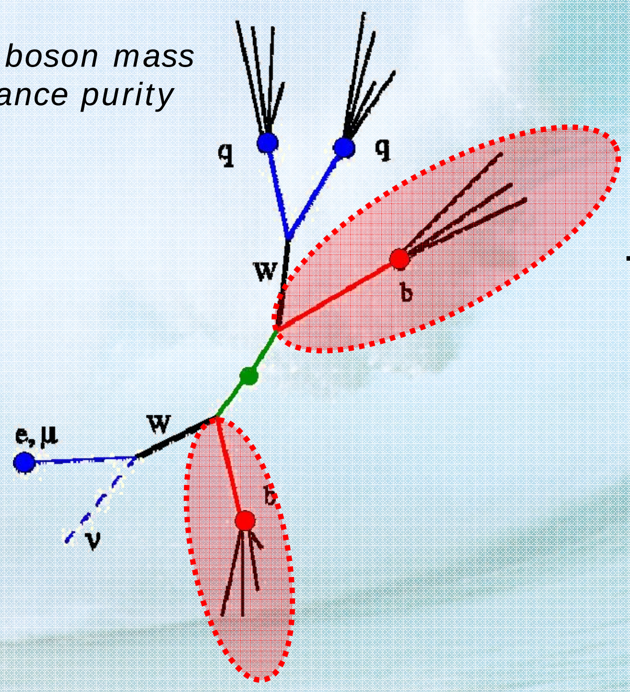
Calibrating the b-jet identification efficiency

- B-jet identification efficiency:
  Important in cross-section determination
  and many new physics searches (like H, ttH)

- A clean sample of b-jets from top events
  2 out of 4 jets in event are b-jets (*a-priori*)



Use W boson mass to enhance purity



B-jet sample from top quark pairs:

- Calibrate b-tagging efficiency **from data** (~ 5%)
  Dominant systematic uncertainty: ISR/FSR jets

- Study b-tag (performance) **in complex events**

Note: Can also use di-lepton events

Calibrating the light jet energy scale

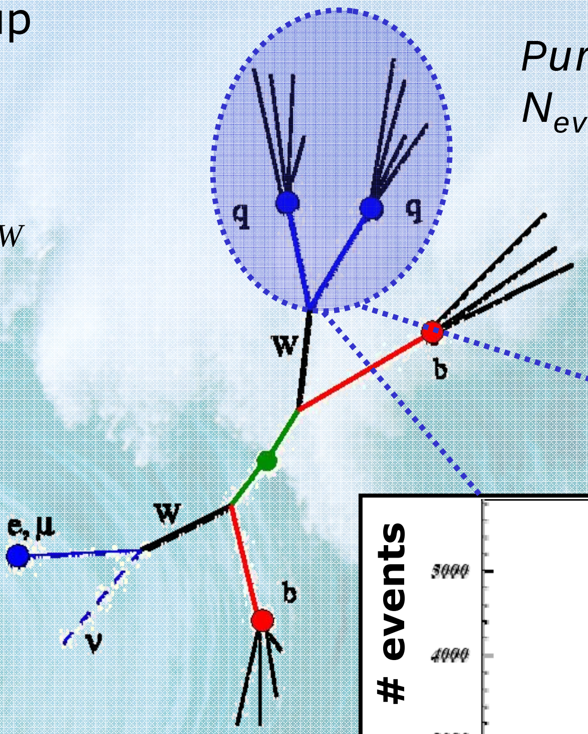
- Light jet energy scale calibration (target ~1%)

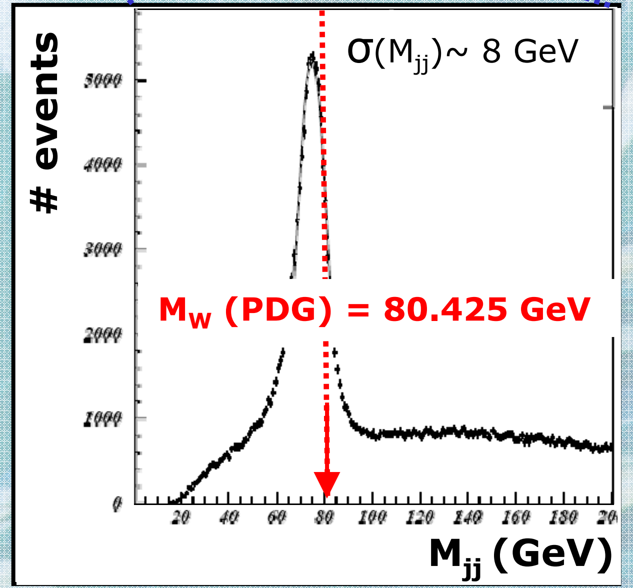
Invariant mass of jets should add up to well known W mass (80.4 GeV)

$$M_{jj} = \sqrt{2E_{j1}E_{j2}(1-\cos\theta_{j1j2})} = M_W$$

Rescale jet energies:
E_{parton} = (1+ α) E_{jet}, with $\alpha = \alpha(P_T, \eta)$

Purity = 83%
N_{evt} ~ 2400 (1 fb^{-1})





Pro:
- Complex topology, hadronic W
- Large statistics

Con:
- Only light quark jets
- Limited P_T-range (50-200 GeV)

Precision: < 1% for 0.5 fb^{-1}

Alternative: P_T-balance in Z/γ+jet (6% b-jets)

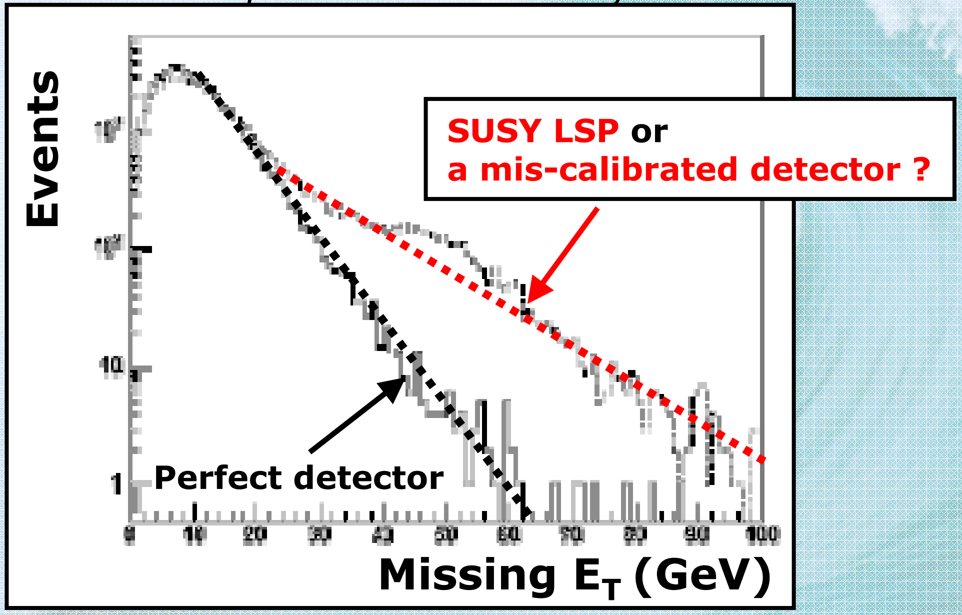
- Calibrate missing energy

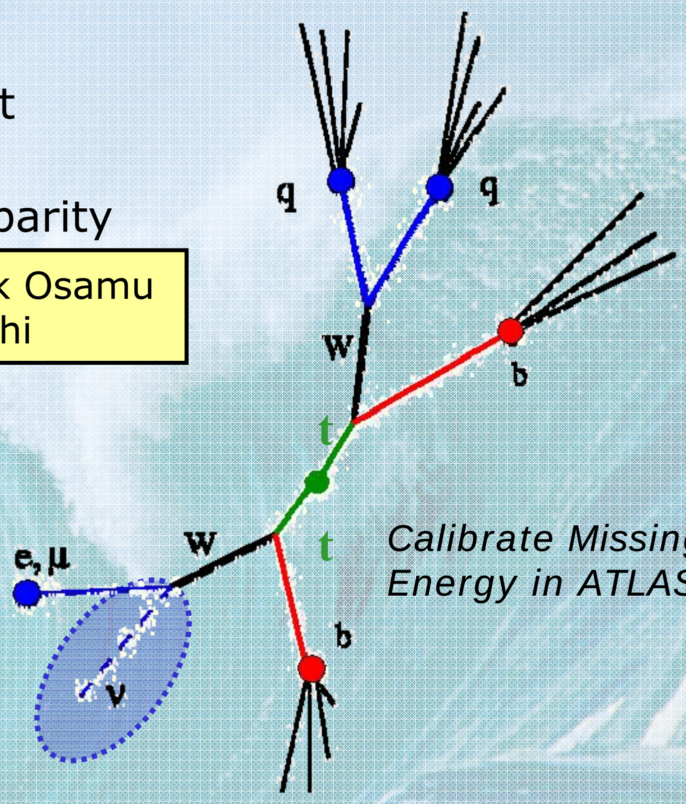
- P_μ(neutrino) constrained from kinematics: M_W
  → known amount of missing energy per event

- Calibration of missing energy **vital** for **all** (R-parity conserving) SUSY and most exotics!

See talk Osamu Jinnouchi

Example from SUSY analysis





Calibrate Missing Energy in ATLAS

Range: $50 < P_T < 200$ GeV

1) Top properties:

- Estimate of $\sigma_{top}(M_{top})$ ~ 20% accuracy
  One of LHC's first physics results ?
- Top decay, …

2) Calibrating complex event topologies:

- Light jet energy scale (< 1%)
- b-tag efficiency (~ 5%)
- Missing energy and lepton reconstruction/trigger eff.

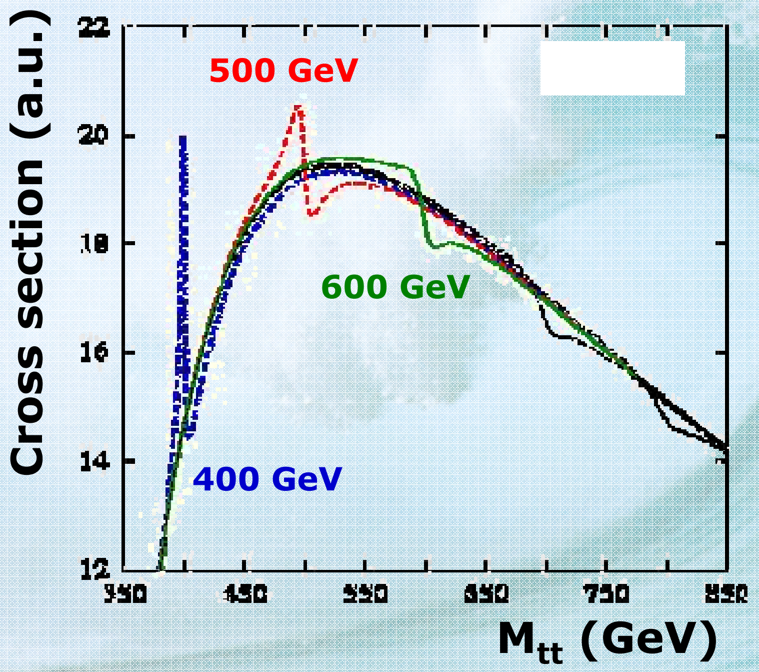
3) Window to new physics ?

New physics: Resonances in M_{tt}

- Structure in M_{tt}

  - Interference from MSSM Higgses $H,A \rightarrow tt$ (can be up to 6-7% effect)

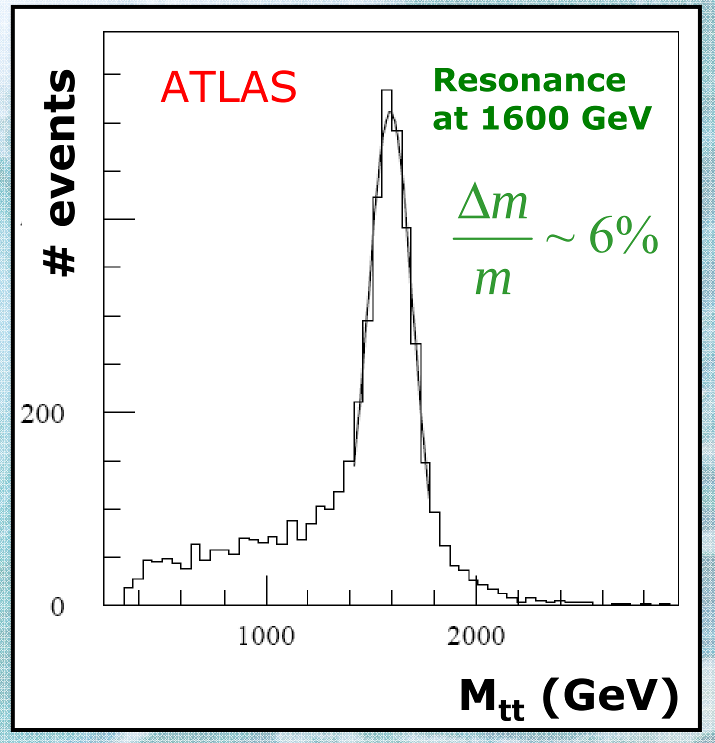
Gaemers, Hoogeveen (1984)



- Resonances in M_{tt}

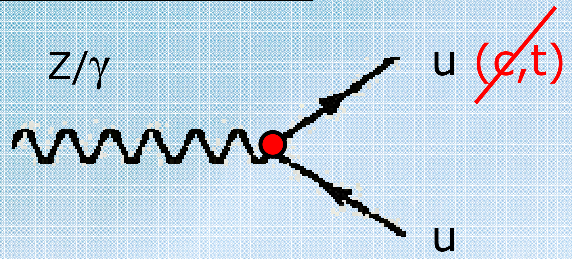
$$pp \rightarrow X \rightarrow t\bar{t}$$

Z′, Z_H, $G^{(1)}$, SUSY, ?



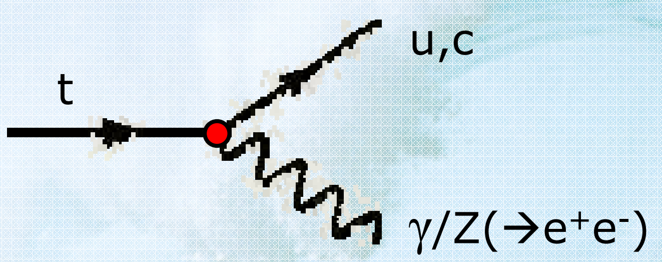
New physics: Flavour changing neutral currents

- No FCNC in SM:

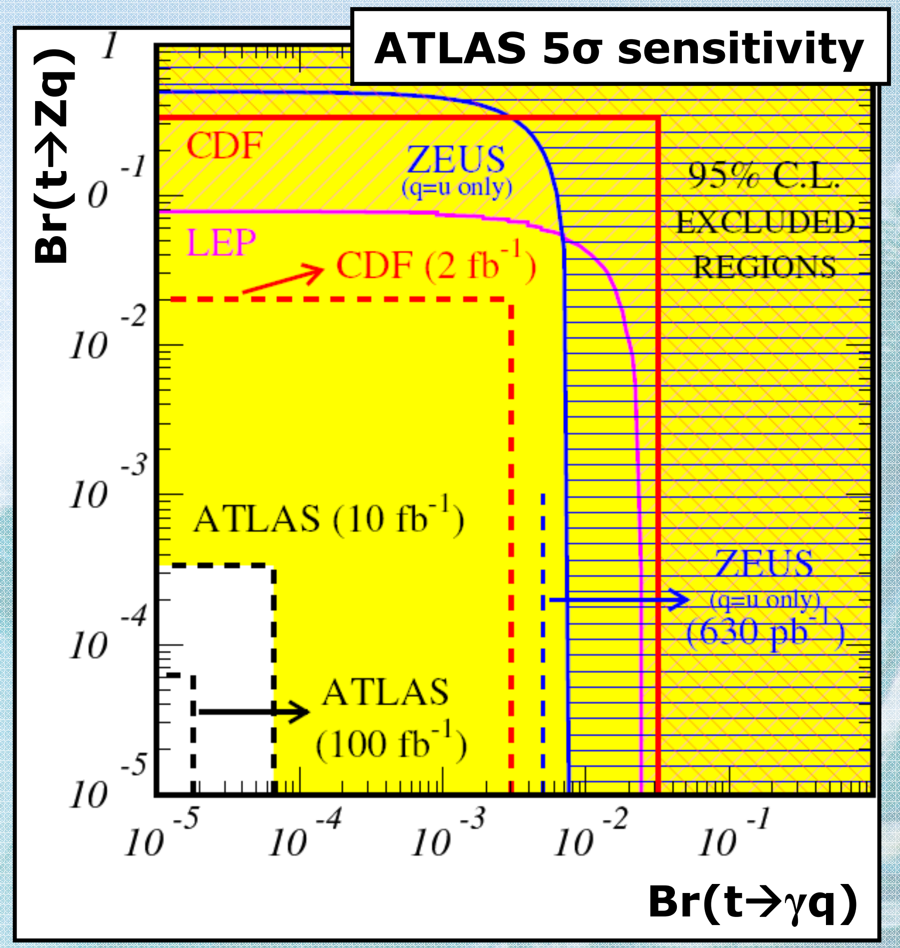


SM: 10^{-13}, other models up to 10^{-4}

- Look for FCNC in top decays:



Mass peak in je^+e^- or $j\gamma$



→ With 10 fb^{-1} already 2 orders of magnitude better than LEP/HERA

Summary on early top quark physics at the LHC

Conclusions:

1) Top quarks are produced by the millions at the LHC:
   → Almost no background: measure top quark properties

2) Top quarks are THE calibration signal for complex topologies:
   → Most complex SM candle at the LHC
   → Vital inputs for detector operation
   and SUSY background

3) Top quarks pair-like events … window to
   new physics:
   → FCNC, SUSY, MSSM Higgses,
   Resonances, …

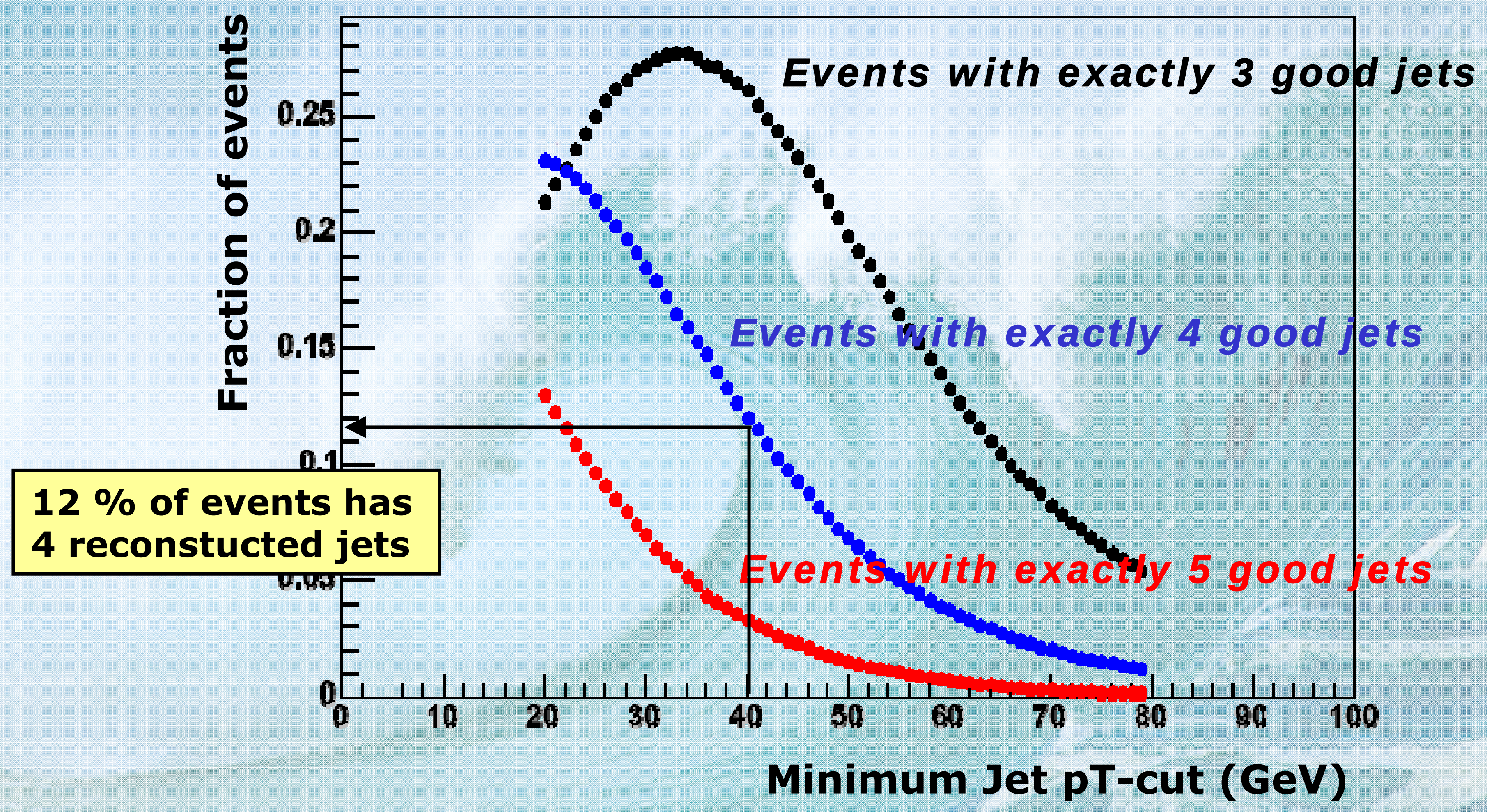
DAY-2 top physics:

- Single top production
- Top charge, spin(-correlations), mass

BACKUP

Influence of Jet $p_{T\text{-}min}$ cut on number of selected events

Note: require 4 good jets, with ***Good jet:*** $P_T > P_T(\text{min})$ and $|\eta| < 2.5$



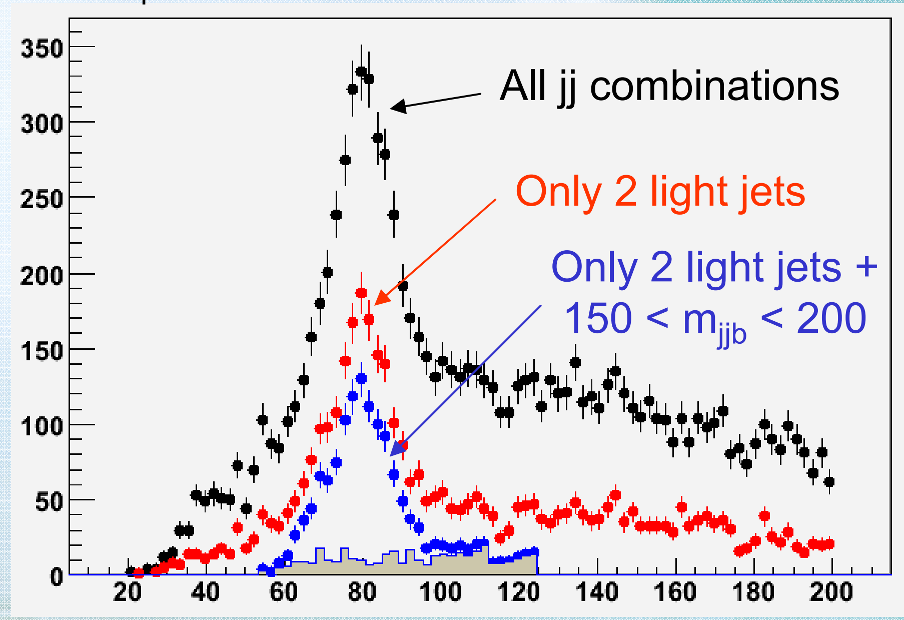
Using t → W → jj to calibrate the light JES

- Standard tt → lνb jjb selection cuts
- Improve W → jj purity by requiring:
  - 2 light jets only
  - 150 < m_{jjb} < 200 GeV

Etienvre, Schwindling

→ Purity ~ 83 %, ~ 1200 W selected for 500 pb^{-1}

P_T cut = 40 GeV

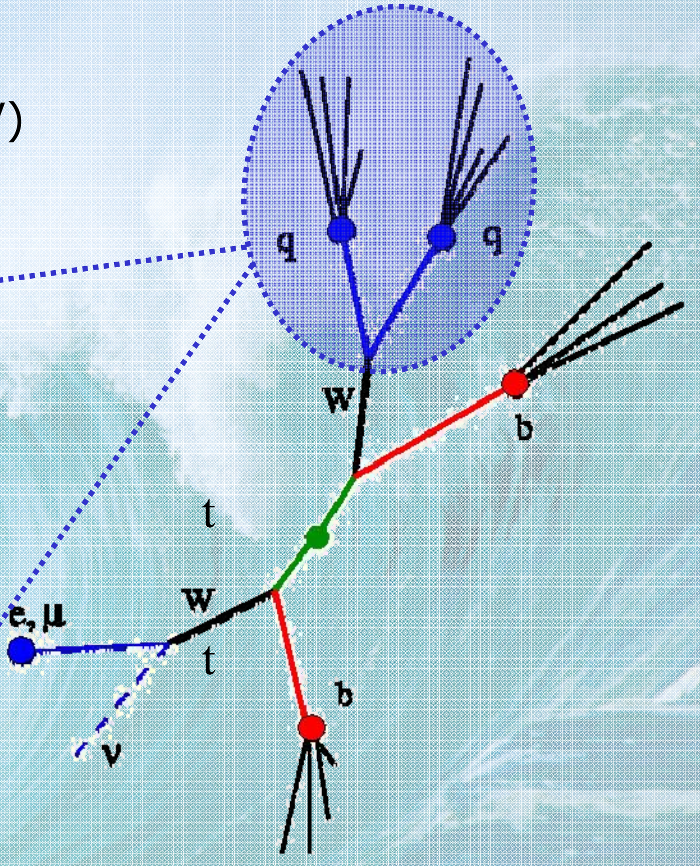


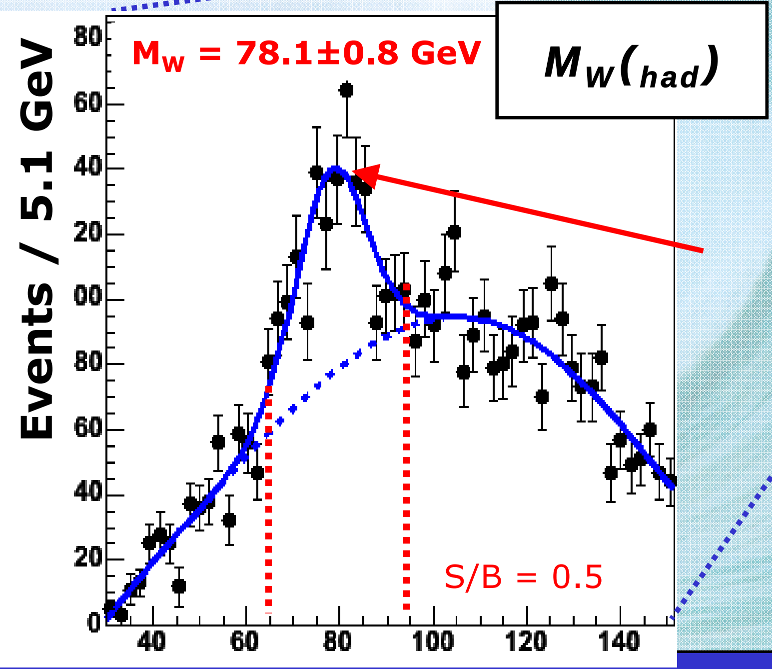
Number of jj for 491 pb^{-1}:
(% purity as fraction of cases with 2 jets at ΔR < 0.25 from 2 W quarks)

	all	60 < m_{jj} < 100
Standard selection	15833 16.1 ± 0.3 %	4001 56.7 ± 0.8 %
+ only 2 light jets	3558 41.0 ± 0.8 %	1903 69.0 ± 1.1 %
+ m_{top} in 150 - 200	1401 73.5 ± 1.2 %	1205 82.6 ± 1.1 %

- (1) Abundant source of W decays into light jets
  - Invariant mass of jets should add up to well known W mass (80.4 GeV)
  - W-boson decays to light jets only
    → Light jet energy scale calibration (target precision 1%)

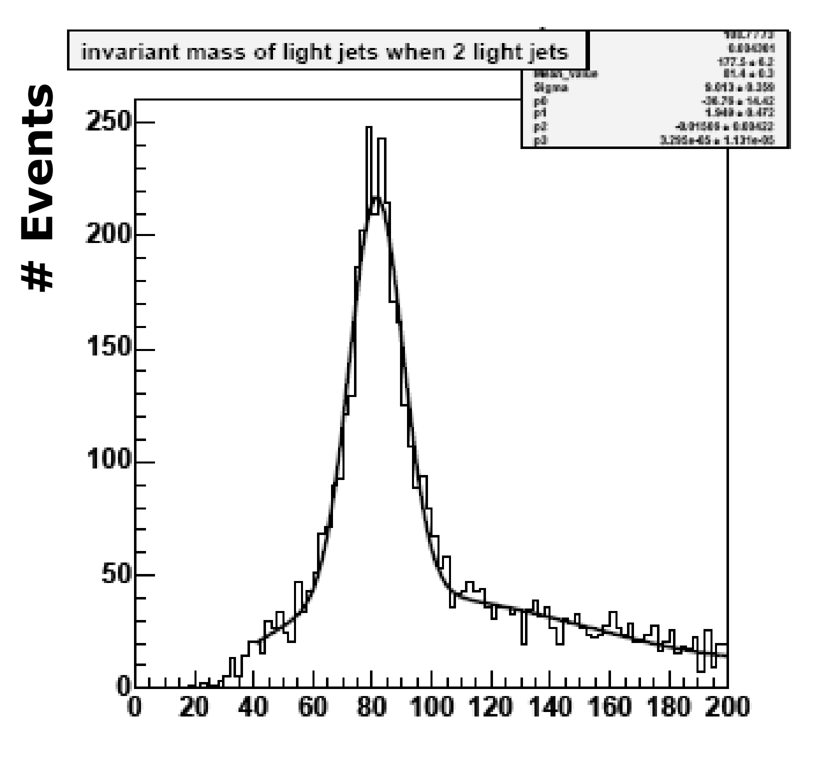
Determine Light-Jet energy scale





Translate jet 4-vectors to parton 4-vectors

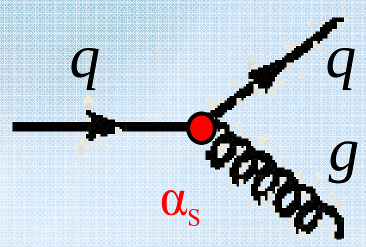
Full Simulation

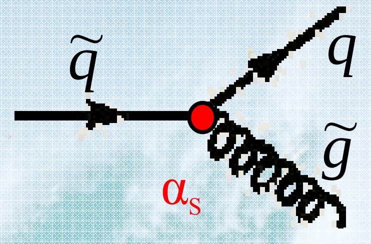


M_{jj} (GeV)

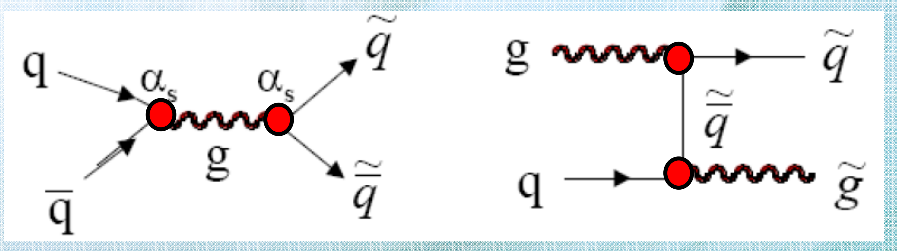
ATLAS note:
ATLAS-PHYS-INT-2005-002

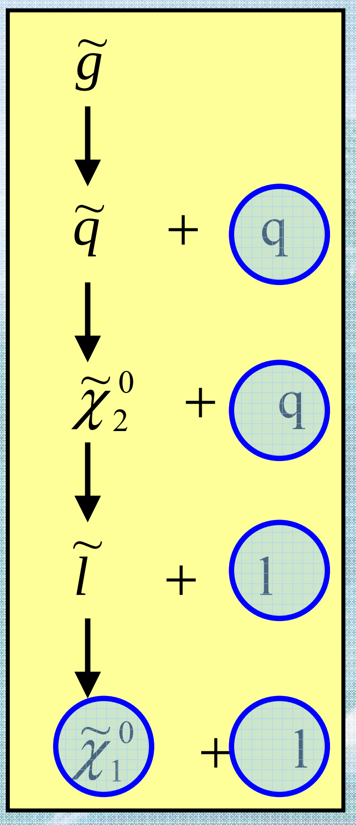
- Superpartners have same gauge quantum numbers as SM particles → interactions have same couplings





Gluino's / squarks are produced copiously
(rest SUSY particles in decay chain)





In this example:
Gluino → 2 jets + 2 leptons
+ LSP (missing energy)