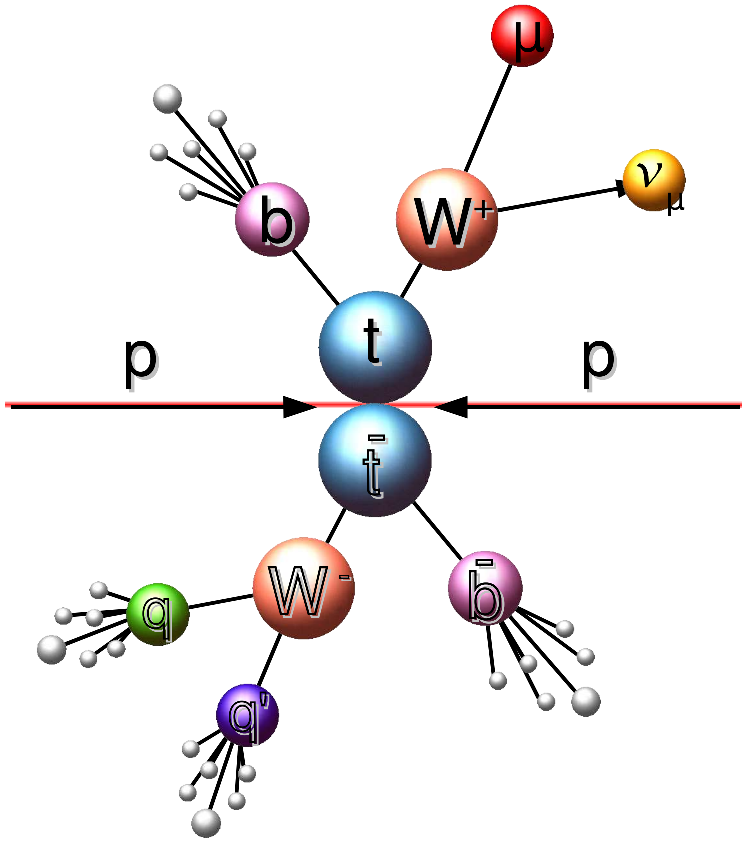
Measurement of the Top Quark Mass with the ATLAS Detector



Input from:

- **ATL-PHYS-2002-007**
- **hep-ex/0403021**
- **Presentations from**
  - **S. Bentvelsen**
  - **M. Cobal**
  - **D. Pallin**

- **using ATLFAST**

Tobias Golling – Friday Physics Session – April 1 2005

The Top-Quark in the Standard Model

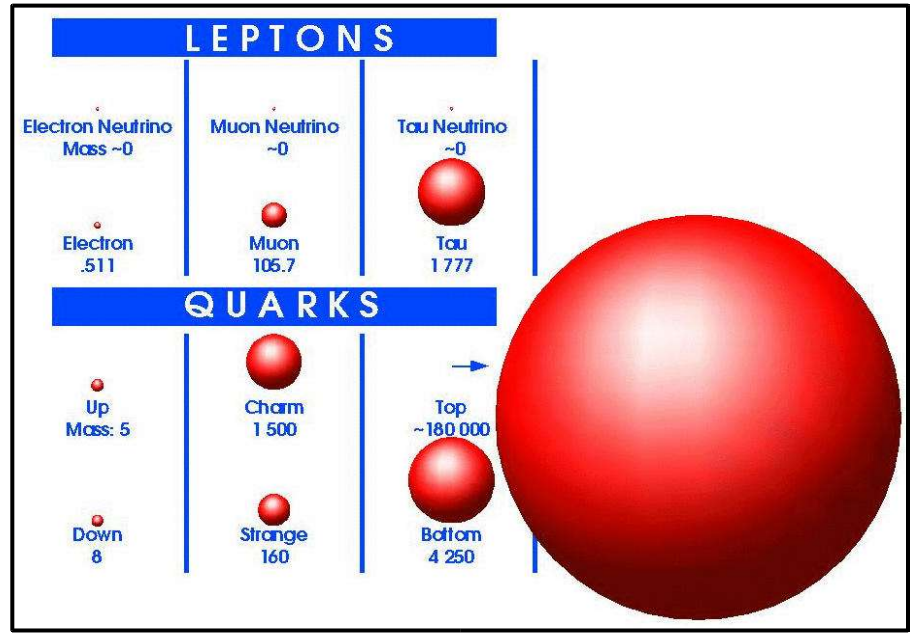
Why is the Top-Quark so interesting ?

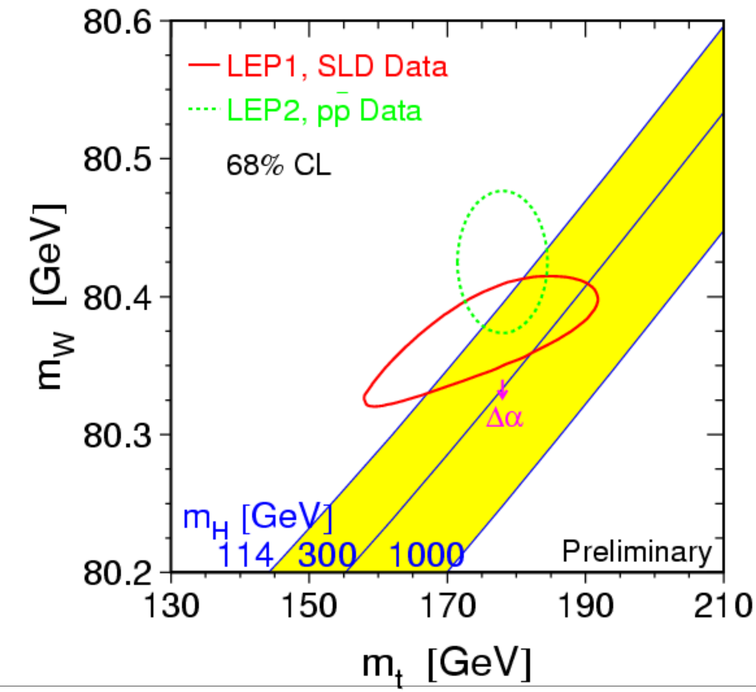
- **completes the quark sector**

- **large mass: m_{top} ~ 180 GeV**
  EW precision data + m_{top} + $m_W \Rightarrow m_{Higgs}$
- **m_W = 15 MeV $\Rightarrow$ m_{top} < 2 GeV**
- **Higgs+Top+W $\Rightarrow$ (SM) model consistency check**

- **short lifetime: $\tau \sim 5 \cdot 10^{-25}$ s**
  - **no bound states or hadronisation**
  - **spin information is conserved**

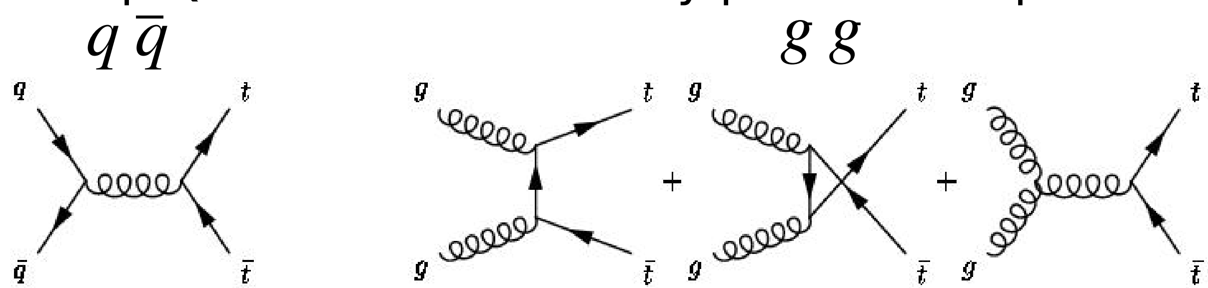
- **Higgs-Boson coupling to fermions:**
  $\lambda_f \sim m_f \;\Rightarrow\; \lambda_t \sim 1$

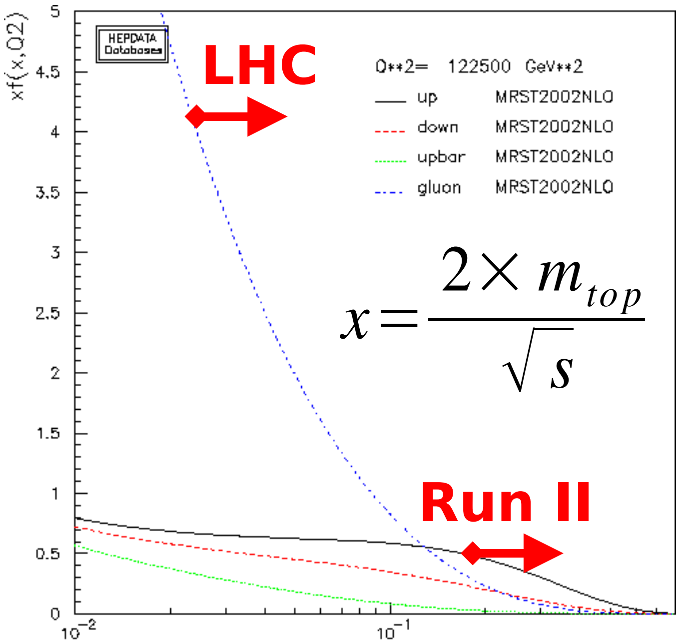




Top-Quark Production

Top-Quarks are dominantly produced in pairs both at the Tevatron and at the LHC

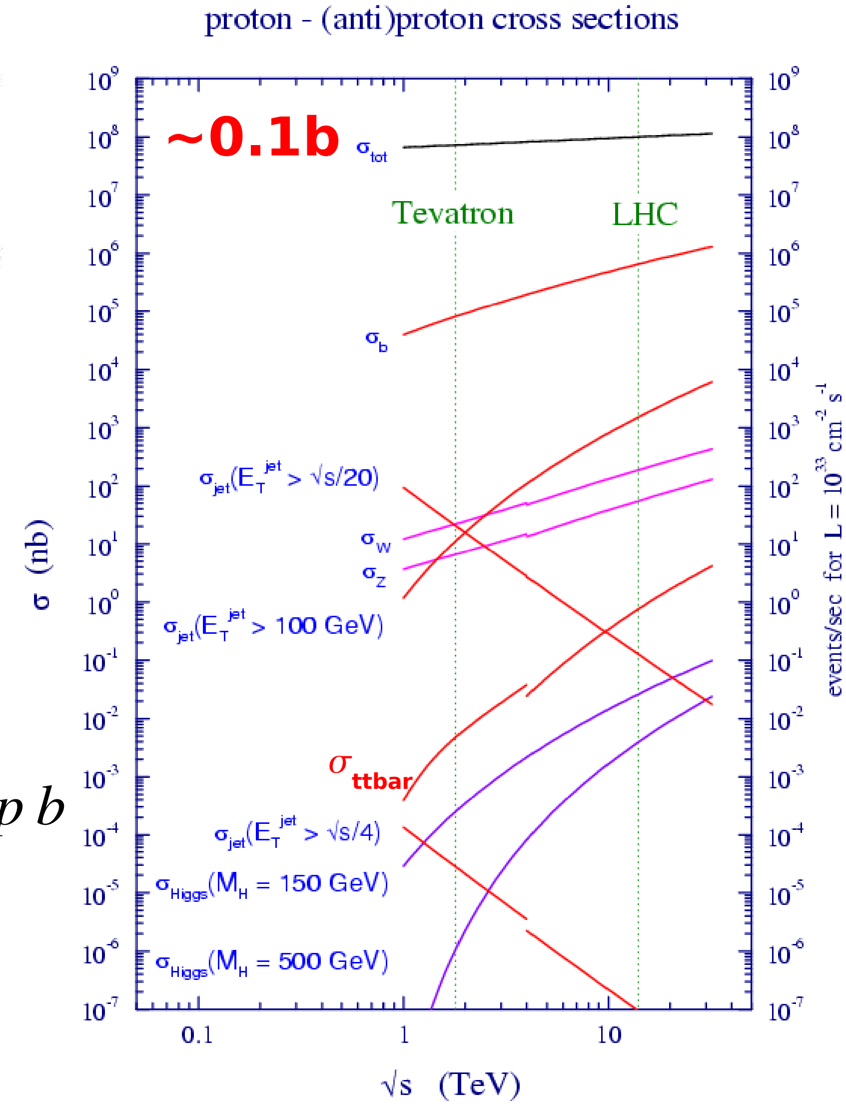




$$x = \frac{2 \times m_{top}}{\sqrt{s}}$$

$$\sigma^{Run\,I}_{p\bar{p} \to t\bar{t}+X} = 5.7 \pm 1.6\,pb$$

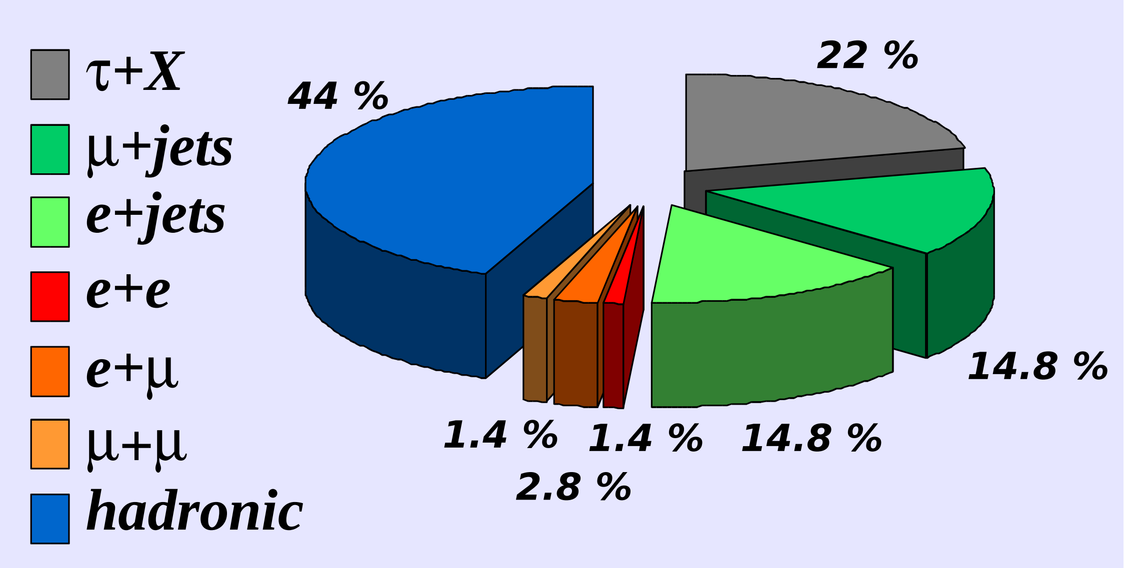
(limited by statistics)



	σ_{ttbar}^{NLO} (pb)	qq->tt	gg->tt
Run I (1.8 TeV)	**4.87±10%**	**90%**	**10%**
Run II (2.0 TeV)	**6.70±10%**	**85%**	**15%**
LHC (14 TeV)	**830±12%**	**10%**	**90%**

	Tevatron	LHC
typical S/B:	1-10	10-100

Top Quark Decay

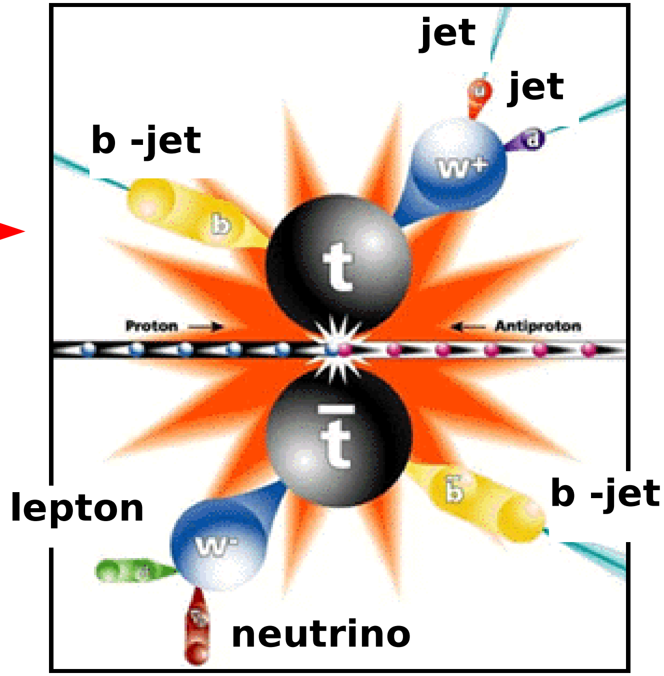


Top quarks decay predominantly (~100%) to a W-Boson and a b-quark

Top-Antitop Signatures determined by the W decay modes:

`dilepton channel'
~5% : 2 jets, 2 charged leptons, 2 neutrinos

`lepton+jets channel'
~30%: 4 jets, 1 charged lepton, 1 neutrino
- Large statistics compared to dilepton channel
- Clear signature compared to all-jets channel



`all-jets channel'
~40%: 6 jets

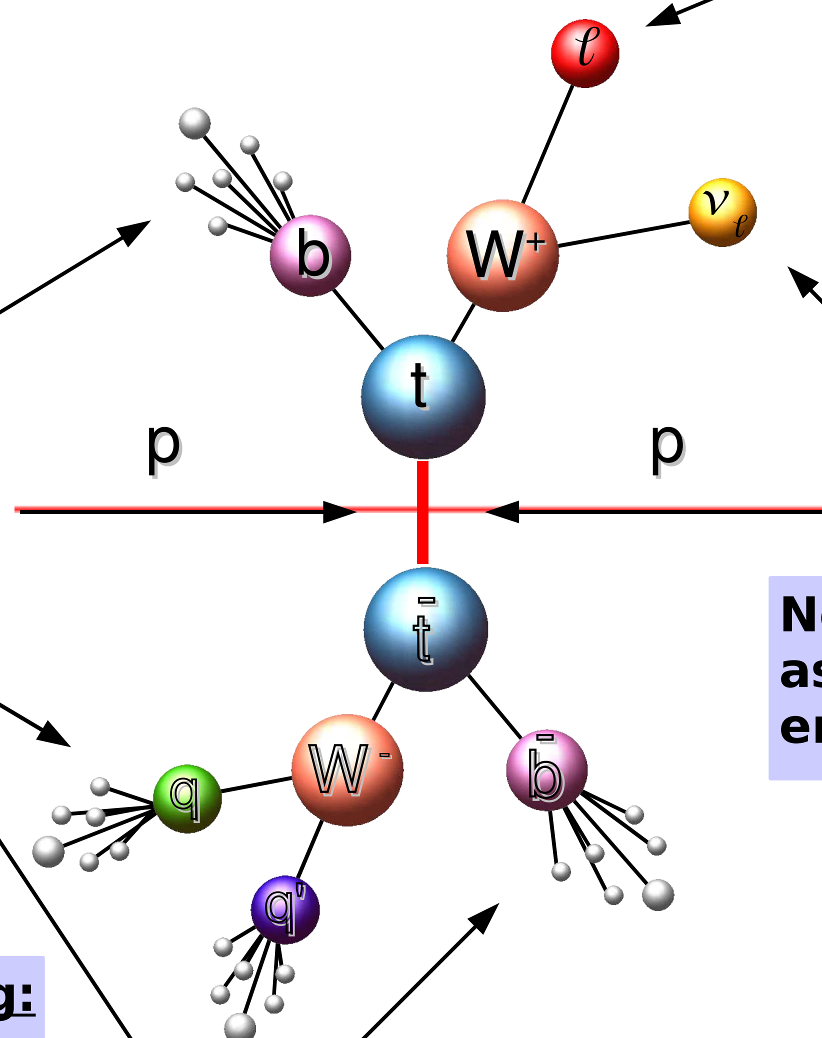
always 2 jets are b-jets

Preselection "W+Jets Selection"

Isolated lepton (e,μ) with p_T > 20 GeV and $|\eta|$ < 2.5

≥ 4 jets with p_T > 40 GeV and $|\eta|$ < 2.5

+ jets from ISR/FSR



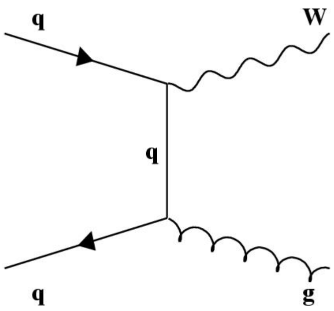
Neutrino reconstructed as missing transverse energy (MET)

<u>with working b-tagging:</u>
identify two jets as b-jets

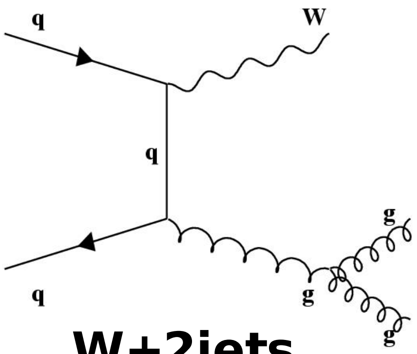
Backgrounds

Physics Background:

- **Electroweak W production**
  W → $\ell+\nu_\ell$ in association with ≥ 4 jets
- **Z+jets**
- **WW, WZ, ZZ**
- **Single top**



W+1jet



W+2jets

...

Instrumental Background (fake lepton, fake MET):

QCD multijet production

Electron Fakes:

Electrons faked by (electromagnetic) jets

Muon Fakes:

Muon-fakes are real muons which are fakely isolated (muons from semileptonic b-decays, where the b-jet is not reconstructed)

MET Fakes:

Misreconstructed calorimeter energy

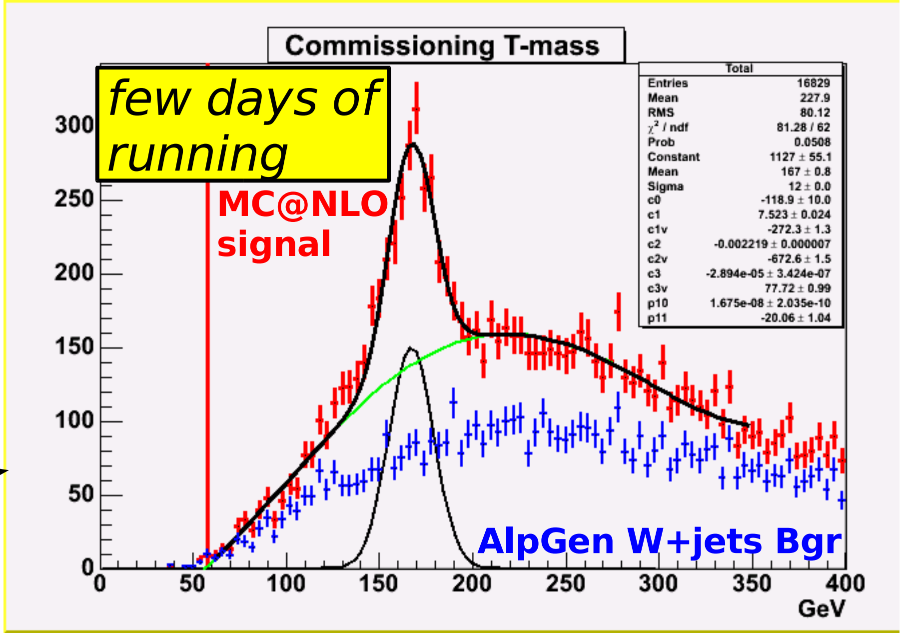
Numbers & Plots

1 in 10^8 events is a ttbar event

1 year running with low luminosity (10 fb^{-1}) produces $8 \cdot 10^6$ ttbar events

⇒ $2.5 \cdot 10^6$ ttbar events with the "lepton+jet" final state

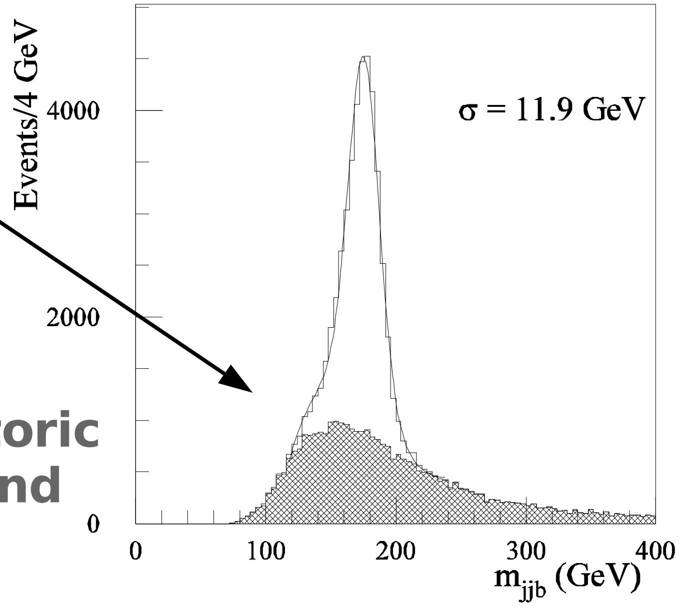
no b-tagging: S/B = ~1



assuming (optimistically!) 60% b-jet tagging efficiency:

single b-tag: S/B = ~30

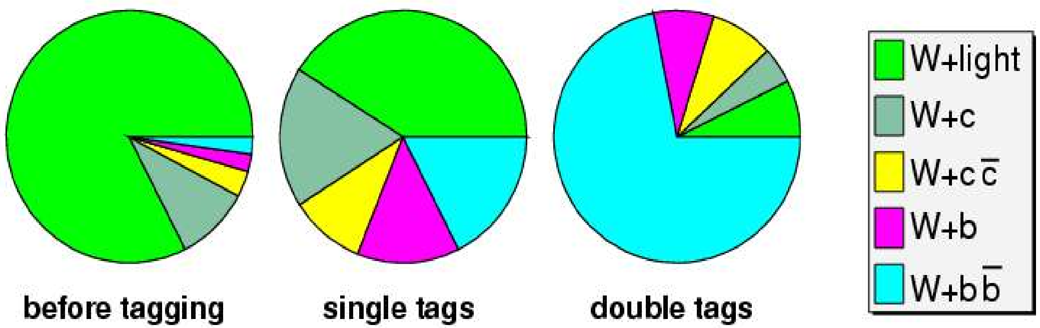
double b-tag: S/B = ~80 ≙ 87000 events selected

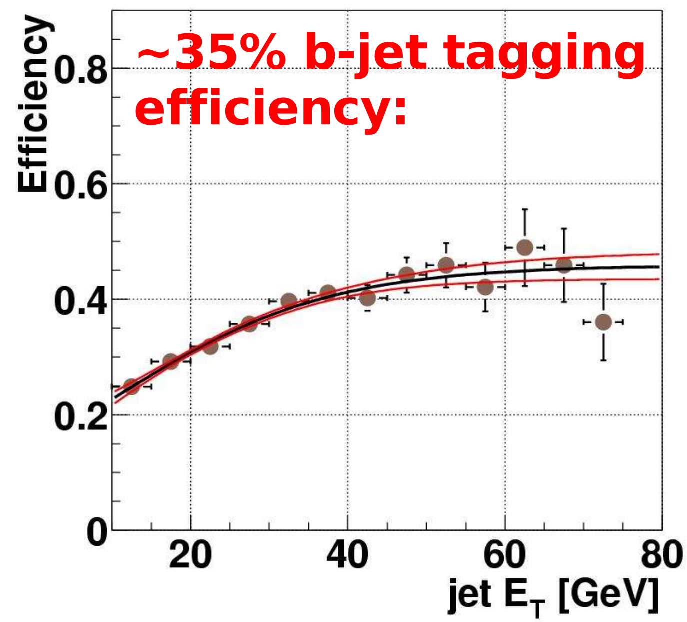


Combinatoric background

Dominant Background: W+Jets

- W+light (light=u, d, s, gluon)
- W+c
- W+cc
- W+b
- W+bb





$$P^{singletag}_{W+jjjj} = 1\% \qquad \Leftrightarrow \qquad P^{singletag}_{t\bar{t}} = 45\%$$

$$P^{doubletag}_{W+jjjj} < 0.01\% \qquad \qquad P^{doubletag}_{t\bar{t}} = 14\%$$

⇒ **B-Tagging:** **Keep ~60% tt, eliminate ~95% background!**

Top Mass Reconstruction

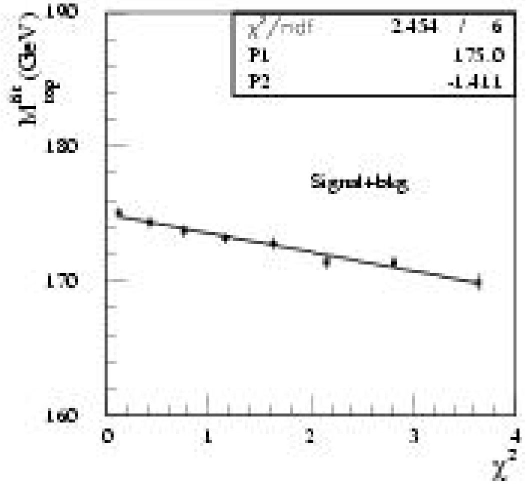
From now on assume always 2 b-jets identified (2 "b-tags")

1.) *Three jets invariant mass of the hadronic top decay:*

- **2 light-jets with highest p_T** ***(ISR/FSR is infrared divergent)***
- **b-jet which makes the highest p_T for the top**
  (how often correct assignment?)

2.) *Kinematic fit:*

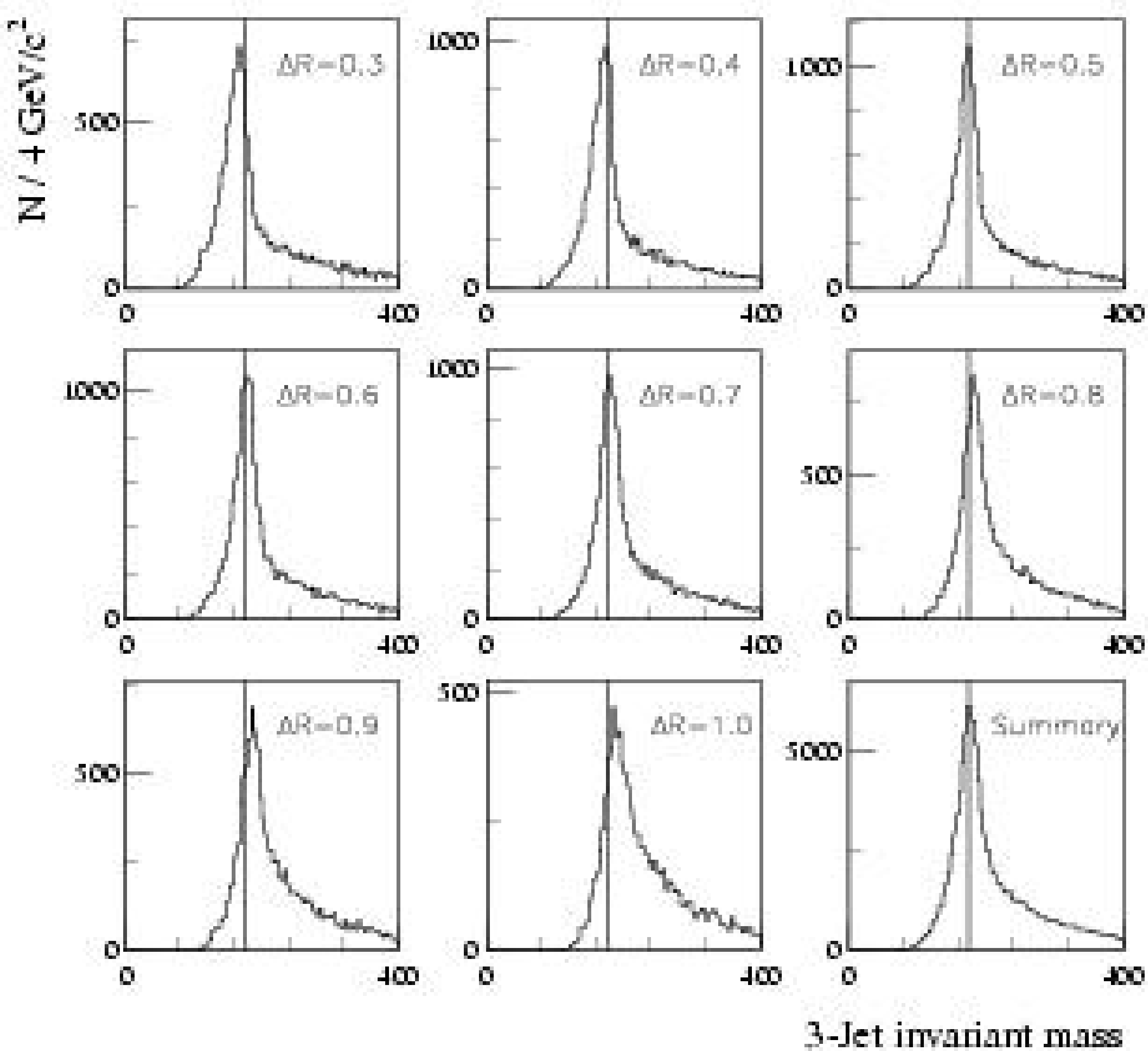
- **let lepton & jet four momenta vary within their corresponding resolutions**
- **constrains: $m_{jj} = m_{l\nu} = m_W$ and $m_{jjb} = m_{l\nu b} = m_{top}^{fit}$**
- **minimize χ^2 event by event, select m_{top}^{fit} with lowest χ^2**
- **$m_{top} = m_{top}^{fit}(\chi^2 \rightarrow 0)$**



3.) *Jet reconstruction with a continuous algorithm (0.3 < ΔR < 1.0, 0.1 steps):*

- **Idea: position of accumulation is more robust estimator w.r.t. single mass per event**

Continuous Jet Algorithm



Uncertainties

Statistical uncertainties (1 year low luminosity):
negligible (0.1 GeV)

Dominant systematic uncertainties:
- **FSR (dependent on top mass reconstruction technique)**
  1 GeV → 0.5 GeV → 0.2 GeV for 1.) → 2.) → 3.)
- **Light-jet energy scale**
- **b-jet energy scale**

Rest of the talk: Jet Energy Scale (JES) calibration
Prior to data taking: **ΔJES = 5-10% ⇒ Δm_{top} > 5GeV (!!!)**

Data makes you smarter !

Use known physics processes to measure the JES more precisely, e.g.
- **Z+jet (or photon+jet, J/Ψ+jet, Υ+jet,...)**
- **W → jj**

Jet Energy Scale (JES)

Miscalibration arises from

Calorimeter detector characteristics & performances
- calorimeter response to charged & neutrals, non-compensation
- calorimeter granularity, non linearities, cracks,dead/non instrumentet zones

} *calorimeter response R*

- electronic noise

physics effects
- parton fragmentation, ISR, FSR, leakage
- underlying & MB events

} *energy offset O*

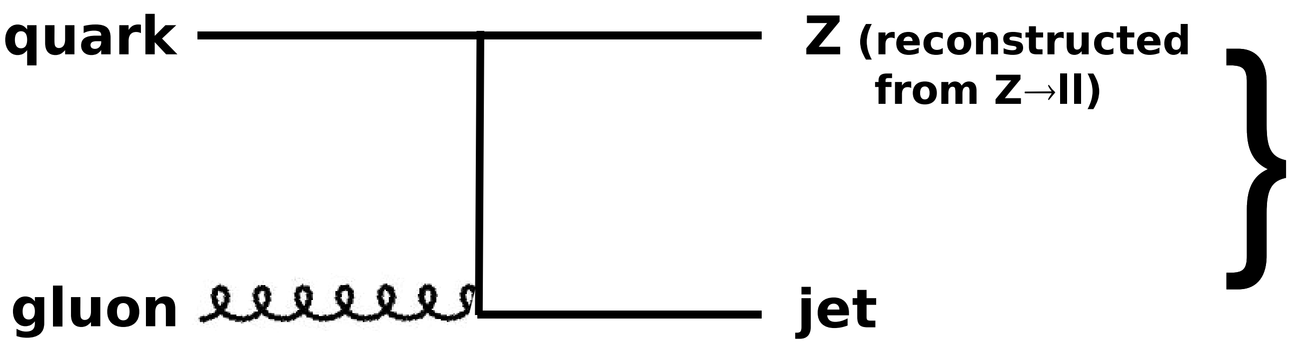
Jet energy reconstruction effects
- jets overlap
- cone effects

} *showering correction S*

$\Rightarrow E_{parton} = (E_{jet} - O) / (R \cdot S)$

JES: Rescale jet to parton energy: $\alpha(E_{jet}) = E_{parton} / E_{jet}$

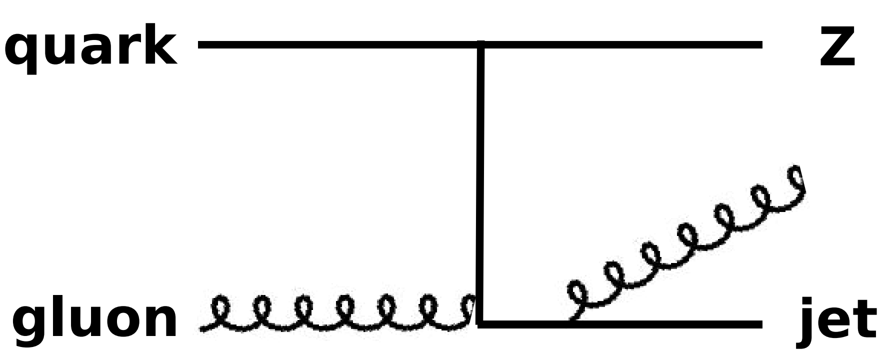
Z+Jet JES Calibration

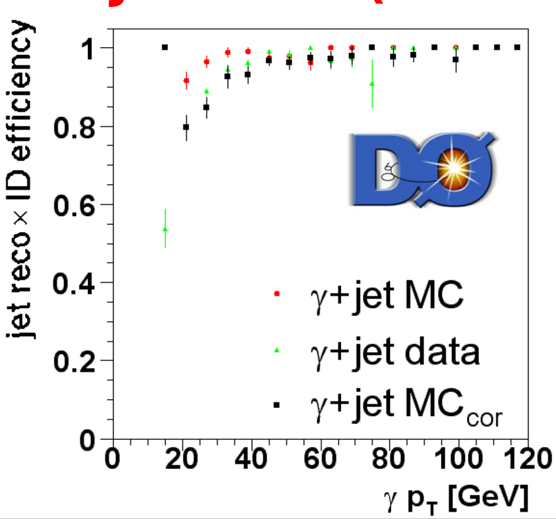


jet and Z:
- **back-to-back in ϕ**
- **balanced in p_T**
- **not balanced in η due to *z*-boost**

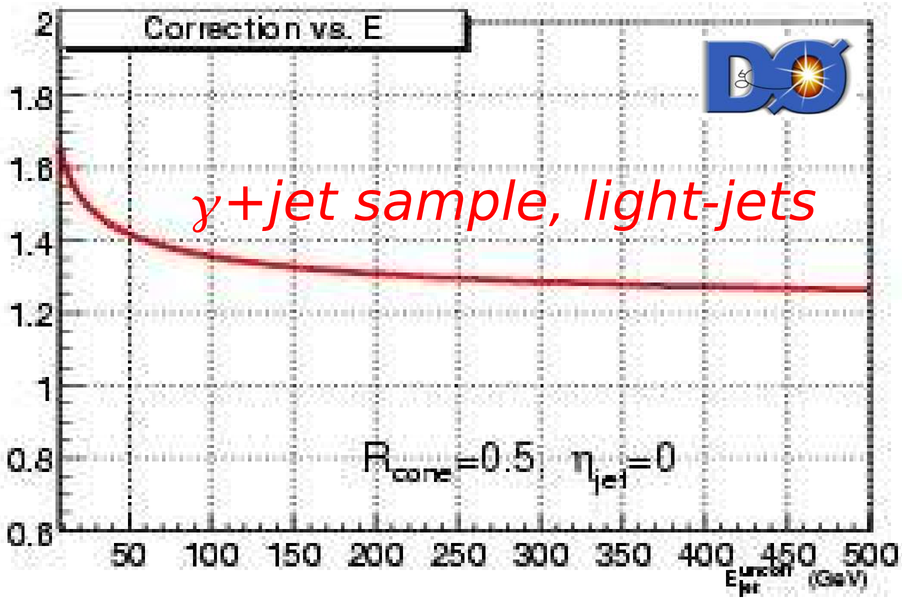
Problems of Z+jet JES calibration:
- **Additional jets from ISR/FSR**
- **Probe "low p_T"**
- **Probe gluon and quark jets** (may have different JES)
- **Probe jets w/o color-connection & energy sharing**

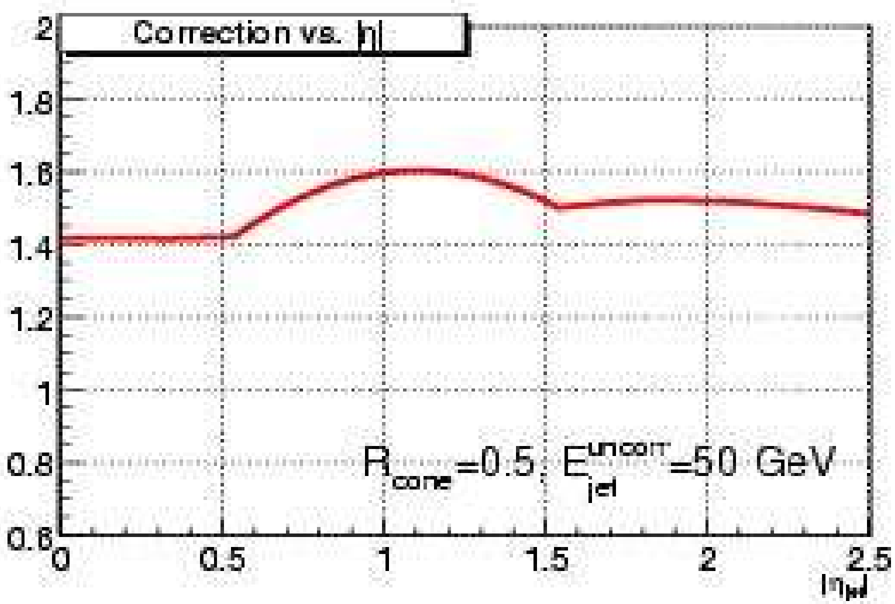
Jet veto not 100% efficient
⇒ JES overestimated
⇒ ΔJES > 1% (biased)



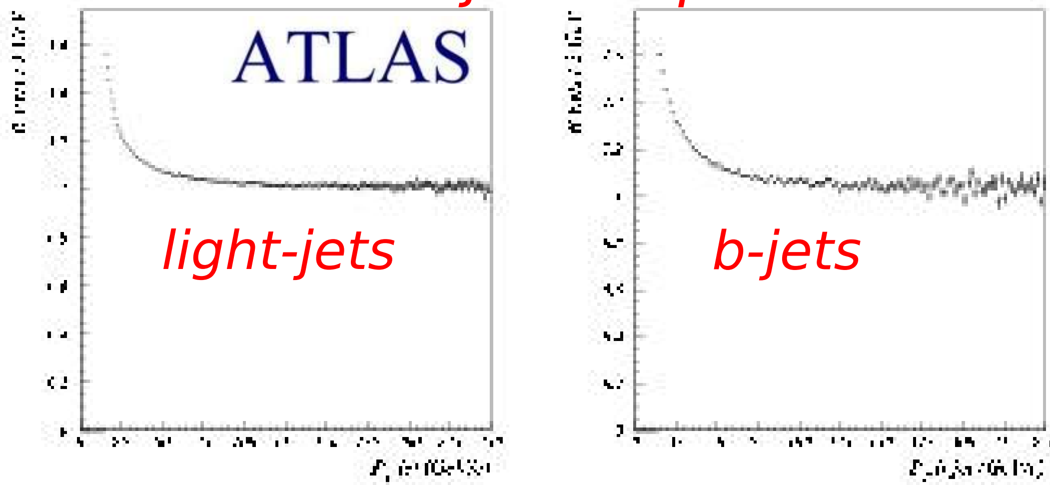


JES & Uncertainty





Z+jet sample



ATLAS

Correction for b-jets is higher than for light-jets (semilep. b-decays)

Prior to data taking:

ΔJES = 5-10% ⇒ Δm_{top} > 5GeV (!!!)

After Z+jet JES calibration:

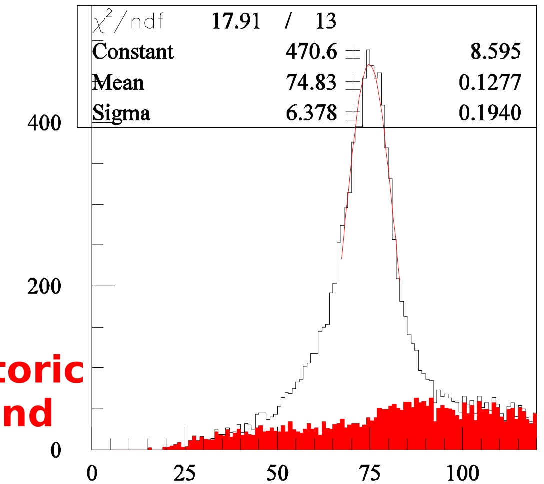
ΔJES = 1% ⇒ Δm_{top} = 1.6 GeV (still large)

In-situ W → jj JES Calibration

Extract absolute energy and direction calibration from W → jj in ttbar events:

- **preselection (page 5)**
- **$|m_{jj} - m_{peak}| < 20$ GeV**
- **$|m_{jjb} - m_{peak}| < 15$ GeV**

→



Combinatoric background

m_{jj} [GeV]

$$m_W^2 = 2 E_{j1} E_{j2} (1 - \cos\theta_{j_1 j_2})$$

⇒ 1 constraint (equation) and 3 unknowns ☹

$$m_W^2 = 2 E_{j1}^2 (1 - \cos\theta_{j_1 j_2})$$

(pick events with $E_{j2}=E_{j1}$)

⇒ 1 constraint and 2 unknowns ☹

lose statistics (not yet done)

$$m_W^2 = 2 E_{j1}^2 (1 - (-1))$$

(pick events with $E_{j2}=E_{j1}$ & back-to-back)

⇒ 1 constraint and 1 unknown ☺

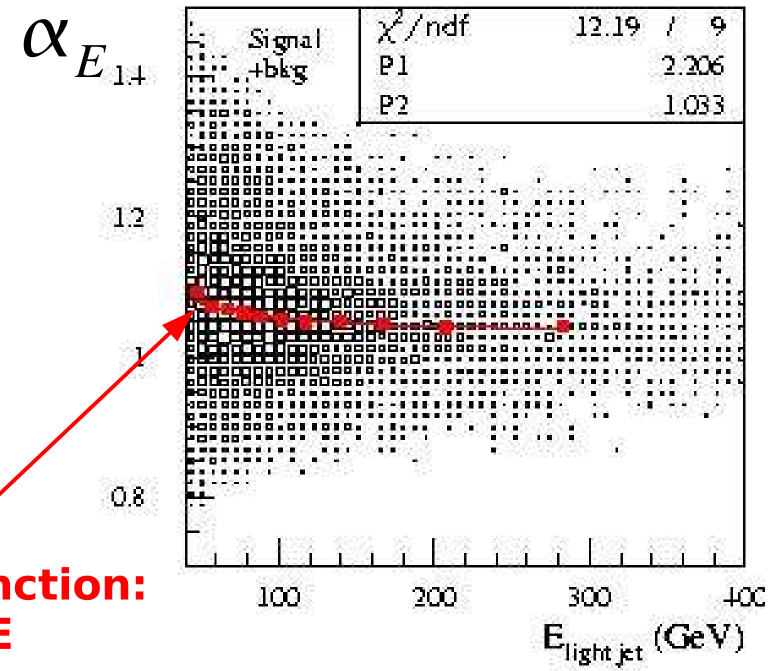
$\alpha(\cos\theta) = 1$ for $\cos\theta = -1$

⇒ calibration of energies and opening angle are correlated ☹

χ^2 minimization W → jj JES Calibration

χ^2 minimization constraining m_{jj} to m_W:

$$\chi^2 = \left(\frac{m_{jj} - M_W}{\sigma_W}\right)^2_{\alpha_E^i} + \sum_{1,2}^{X=E,\eta,\varphi} \left[\frac{X_i - \alpha_X^i X_i}{\sigma_X}\right]^2$$



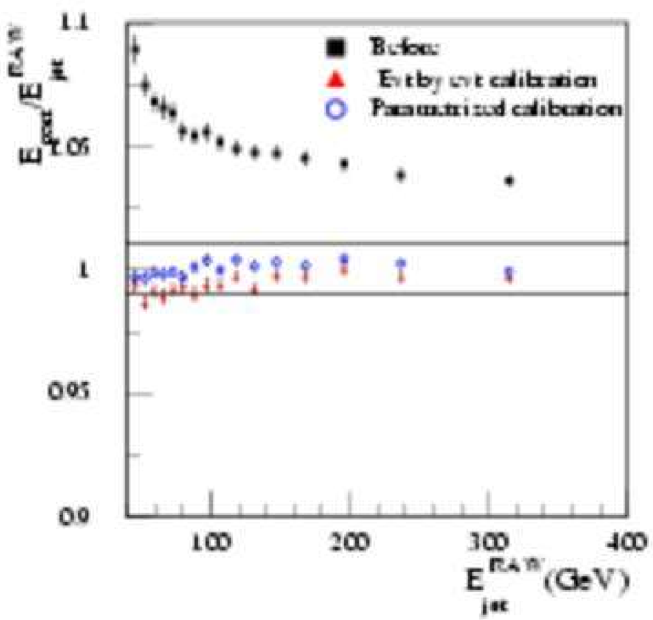
⇒ event by event compute α_E^1 & α_E^2
"do same for cos θ"

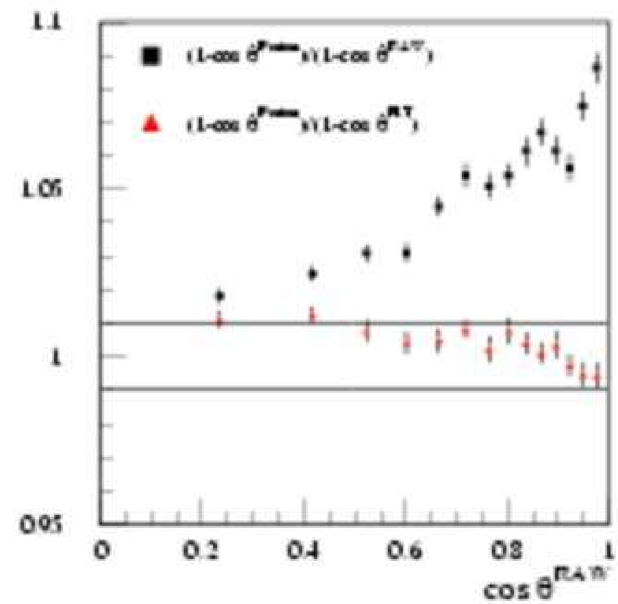
deduced function:
$\alpha(E) = a + b/E$

with:

$$m_{jj}^2 = 2\alpha_E^1 E_{j1} \alpha_E^2 E_{j2} (1 - \cos\theta_{j_1 j_2})$$

calibration factor α
mass, energy resolution σ





⇒ ΔJES ≤ 1%

ΔJES(DØ) = 5%

Summary & Conclusion

Prior to data taking:

ΔJES = 5-10% $\Rightarrow$ Δm_{top} > 5GeV (!!!)

After Z+jet JES calibration:

ΔJES = 1% $\Rightarrow$ Δm_{top} = 1.6 GeV (still large)

After W$\rightarrow$jj JES calibration:

ΔJES $\leq$ 1% $\Rightarrow$ Δm_{top} < 1 GeV

➔ **Limited by the knowledge of the energy resolution σ_E**

- **Alternative method (independent of σ_E):**
  - ➔ **knowing/assuming functional dependence α(E)**
  - ➔ **$\alpha(\cos\theta)$ = 1 for $\cos\theta$ = -1**

$$m_W^2 = 2 \times \alpha(E_{j1}) E_{j1} \times \alpha(E_{j2}) E_{j2} \times \alpha_\theta (1 - \cos\theta_{j_1 j_2})$$