Universiteit Twente
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Top Quark Physics at ATLAS

NIKHEF

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on behalf of the ATLAS Top Physics WG

Overview

- General properties of the top quark
- Mass measurements in QCD ttbar production
- Mass measurements in EW single top production
- Spin correlation in top pair production
- Detector effects
- Non-SM studies
- Conclusions

Top Mass

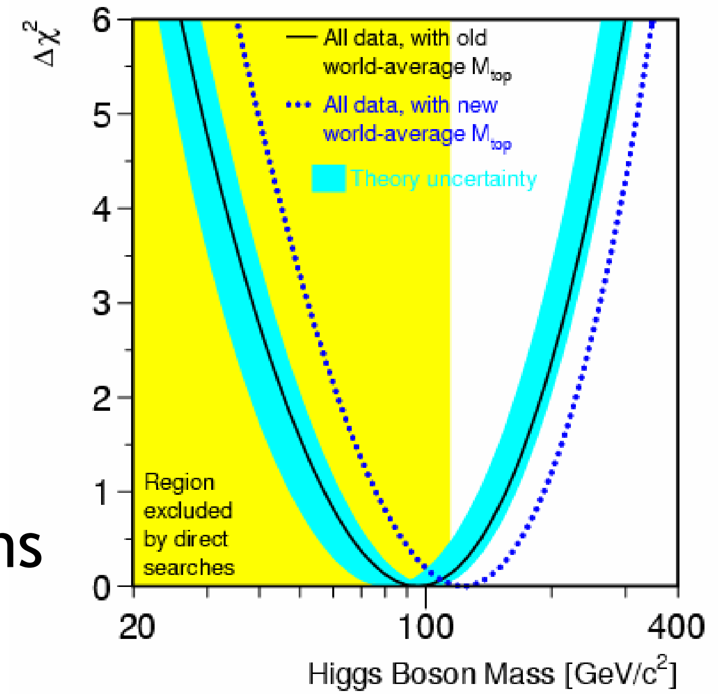
- Largest fermion mass in Standard Model
  $\longrightarrow$ large coupling to the Higgs boson
- Electroweak parameter with worst experimental resolution
- Constraint on the Higgs mass via loop diagrams
- Latest Tevatron average for the top mass:

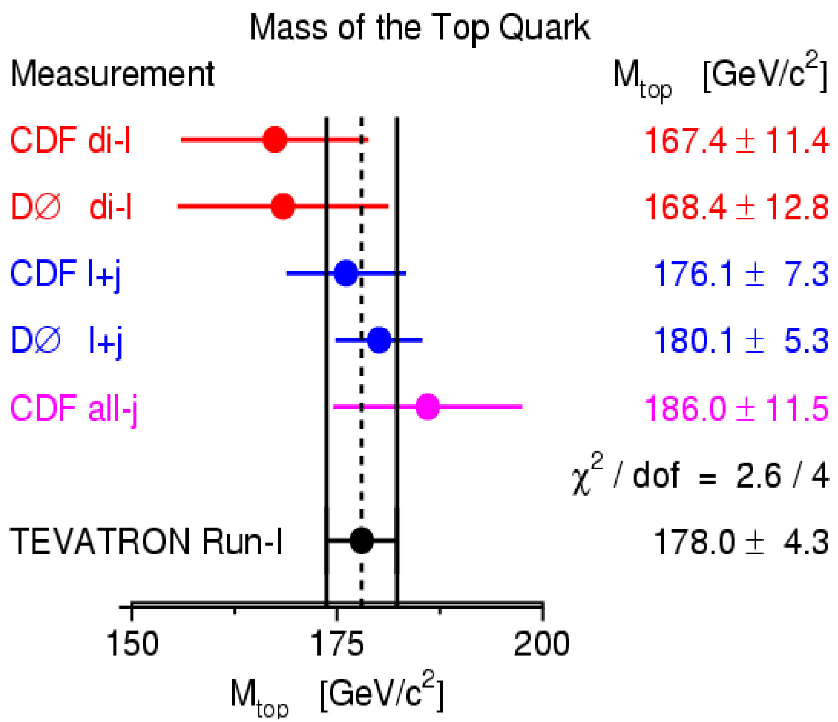
$$M_t = 178.0 \pm 4.3 \mathrm{GeV}$$

results in a Higgs mass prediction of:

$$M_H = 126^{+73}_{-48} \mathrm{GeV}$$

- Better top mass resolution
  $\longrightarrow$ more precise prediction of M_H





Classification of top decays

- In the Standard Model, the top quark decays (BR~99.9%) into Wb (evaluated from the CKM matrix) and the remainder into other down-type quarks (d,s)
- The W decays either into a lepton and a neutrino (BR~33%) or into a $q\bar{q}'$ pair (BR~66%)
- The top quark is then called “leptonic” or “hadronic” accordingly with the decay mode of its daughter W.

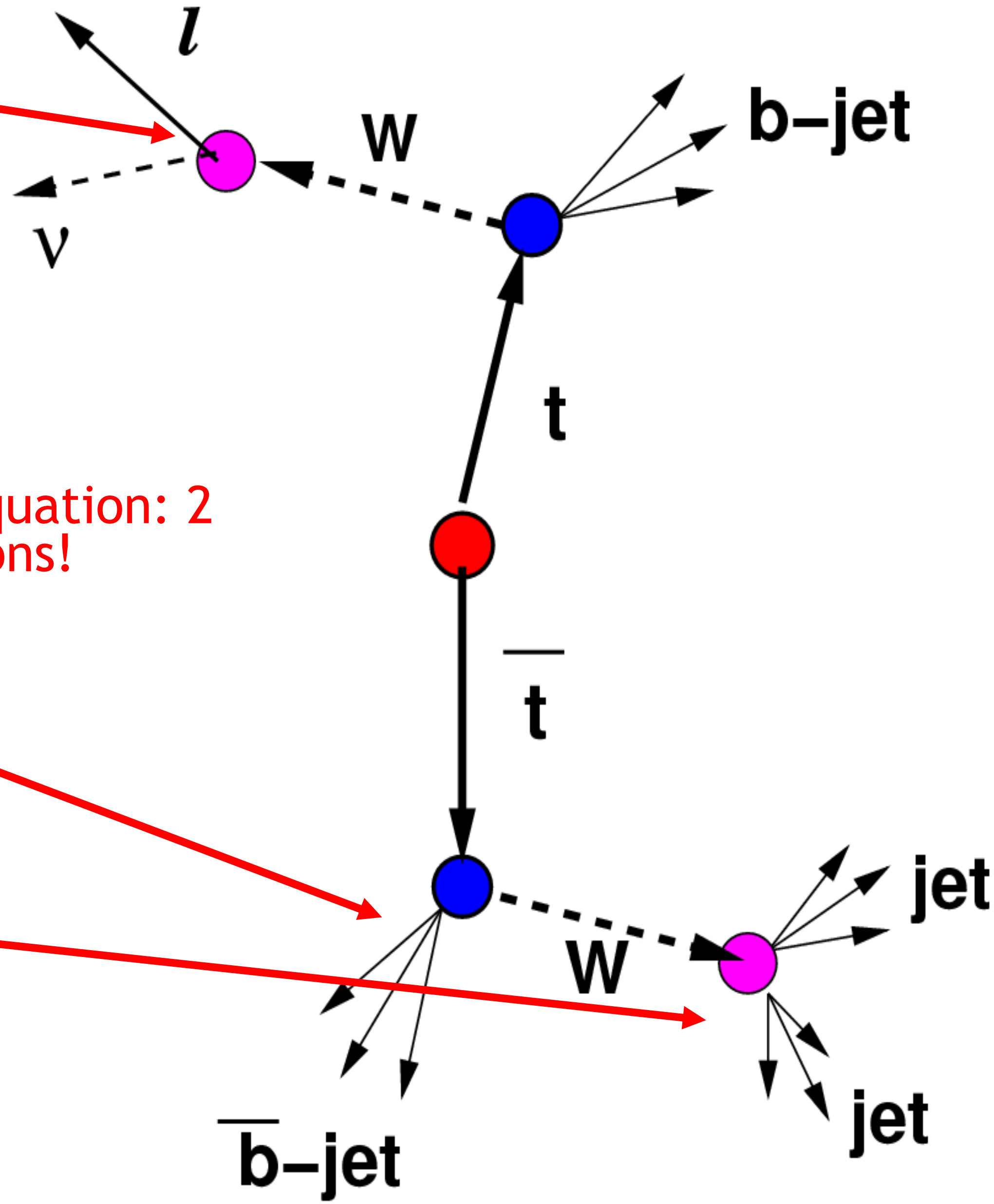
Reconstructing the top from decay products

- Leptonic W reconstructed by combining lepton and missing energy, which approximates the neutrino.
- The p_z of the neutrino can be evaluated using momentum conservation:

$$M_W^2 = 2(E_l \cdot E_\nu - \vec{P}_l \cdot \vec{P}_\nu)$$

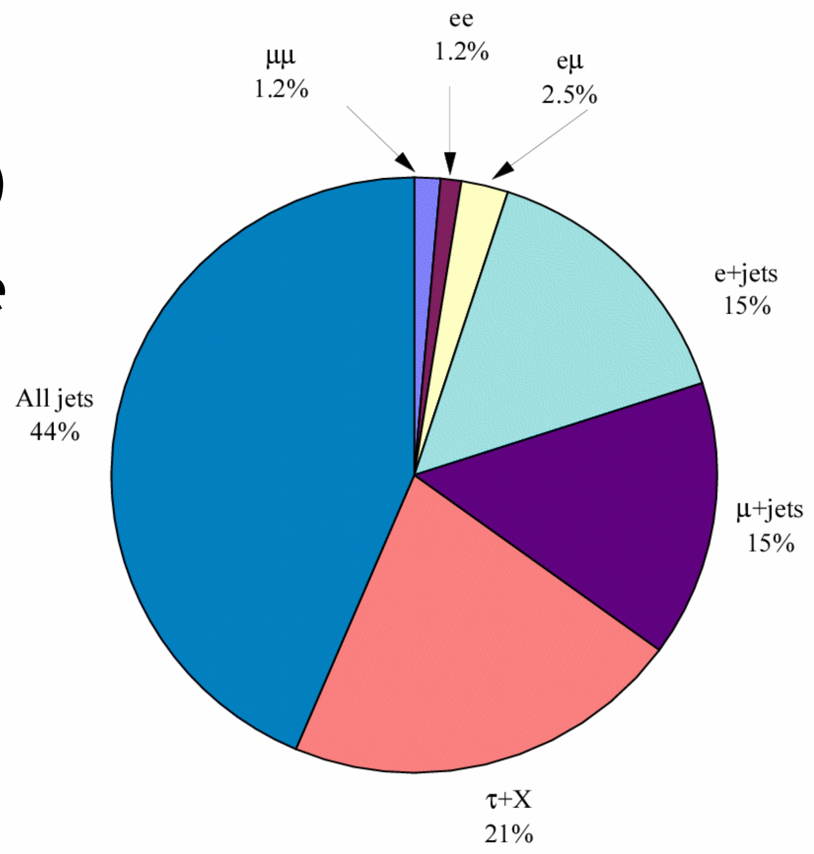
quadratic equation: 2 solutions!

- The b-jet is short-lived and produces a secondary vertex (b-tagging)
- Hadronic W reconstructed by combining two hadronic jets (usually highly energetic)
- Stumbling blocks: b-tag efficiency, missing E_T, combinatorics



QCD ttbar production

- Large cross section: σ~825±100 pb
- 90% gg$\rightarrow t\bar{t}$, 10% $q\bar{q} \rightarrow t\bar{t}$ (unlike Tevatron)
- Several experimental signatures from the decay of the two top quarks:
  - Di-lepton (low BR, good S/B)
  - Lepton+Jets (good BR, combinatorics)
  - All Jets (largest BR, troublesome BKG)
- Background: W+jets, Z+jets, single top

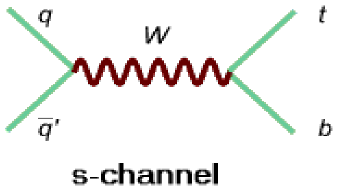


Selection cuts Lepton + Jets:
1 isolated lepton p_T>20 GeV, $|\eta|$<2.5
≥ 4 jets p_T>30 GeV, $|\eta|$<2.5
≥ 1 b-tagged jet
p_T^{Miss}>20 GeV

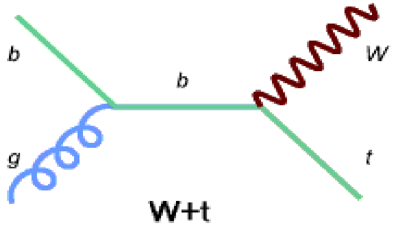
Selection cuts Di-lepton:
2 opposite charged leptons with p_T>20 GeV, $|\eta|$<2.5
≥ 2 jets p_T>20 GeV, $|\eta|$<2.5
≥ 1 b-tagged jet
p_T^{Miss}>40 GeV

Electroweak single top production

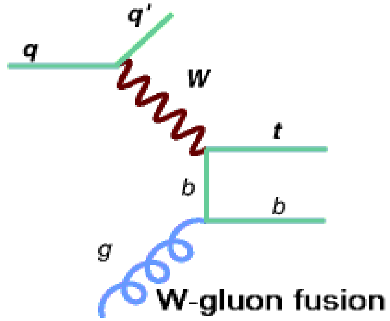
- Three different processes:
  - s-channel
  - W-t production
  - W-gluon fusion



σ~11±1 pb



σ~60±?? pb
(No NLO)



σ~247±8 pb

- Cross section measurement allows direct measurement of V_{tb} in CKM
- Single top is 100% polarized: sensibility to anomalous couplings
- Same background as ttbar production, but with smaller cross section
- ttbar is a background too!
- W-gluon fusion channel has a sizeable cross section: mass measurements are competitive with ttbar's

Selection cuts W-gluon:
1 isolated lepton p_T>20 GeV, $|\eta|$<2.5
1 b-jet p_T>50 GeV, $|\eta|$<2.5
1 light jet p_T>50 GeV, $|\eta|$>2.5

Top mass measurements at ATLAS

- Present results from two analyses:
  - ttbar:
    - Lepton + Jets sample (m_{top}=175 GeV)
    - 200k Full Simulation data
    - Effect of combinatorics
    - Top mass bias
  - Single top:
    - W-gluon channel (m_{top}=175 GeV)
    - 100k Fast Simulation data
    - Cut efficiency
    - Selection strategies
- Prospects for top mass measurements:
  Published in SN-ATLAS-2004-040

ttbar: purity of W-b assignment

- Assignment of the two b-jets to the hadronic W by using a combination of topological and kinematical variables:

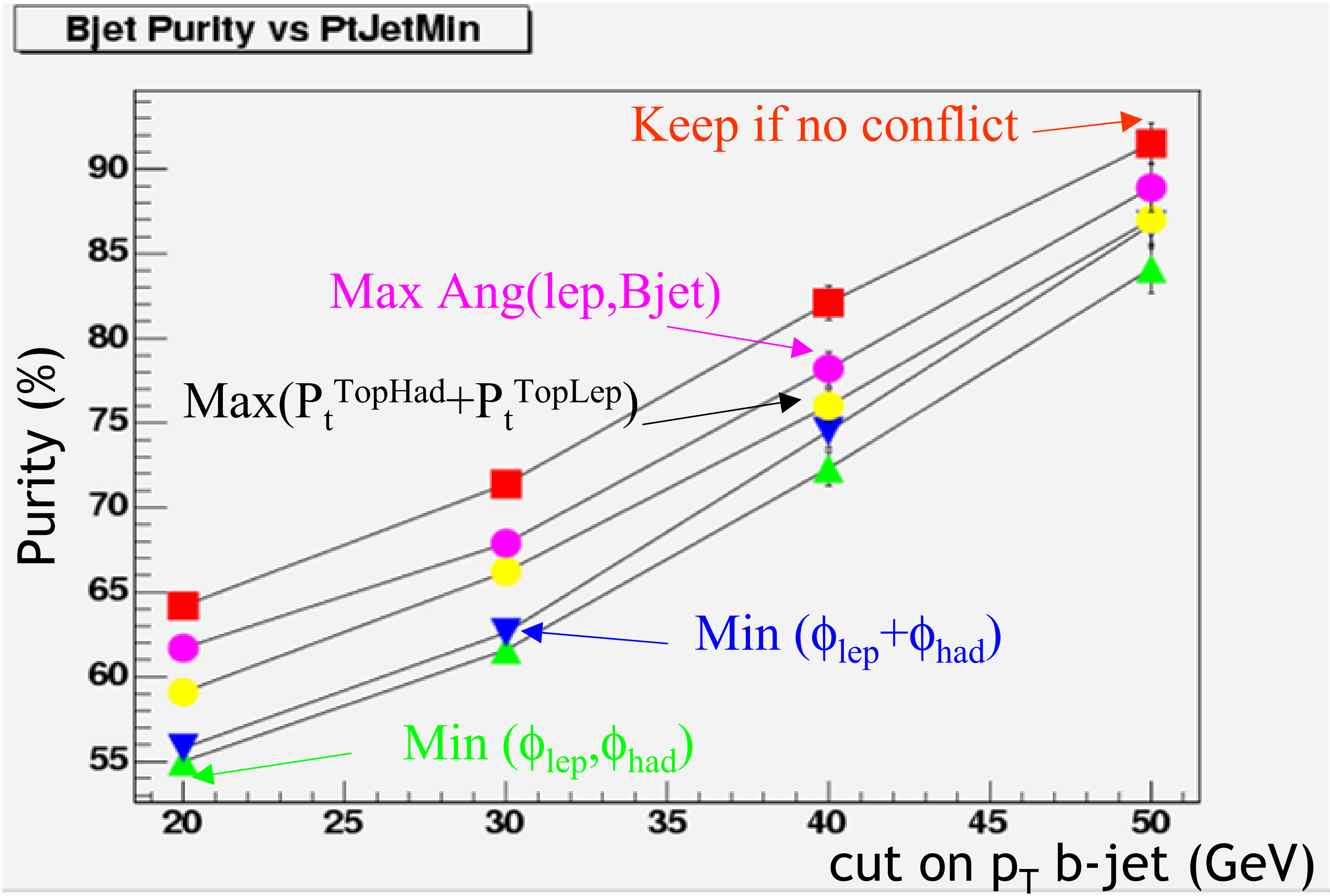
- Variable 1 (always used):
  - Minimum distance between hadronic W and bjet

- Variable 2 - one of the following:
  - Maximum distance between bjet and lepton
  - Maximize (p_T^{TopHad}+p_T^{TopLep})
  - Minimize (Φ_{lep}+ Φ_{had})

  (Φ_i = opening angle between W_i and assigned b-jet)
  - Minimize Φ_{lep} or Φ_{had}

- Purity varies according to cut on pT of b-jets

Purity of W-bjet pairing



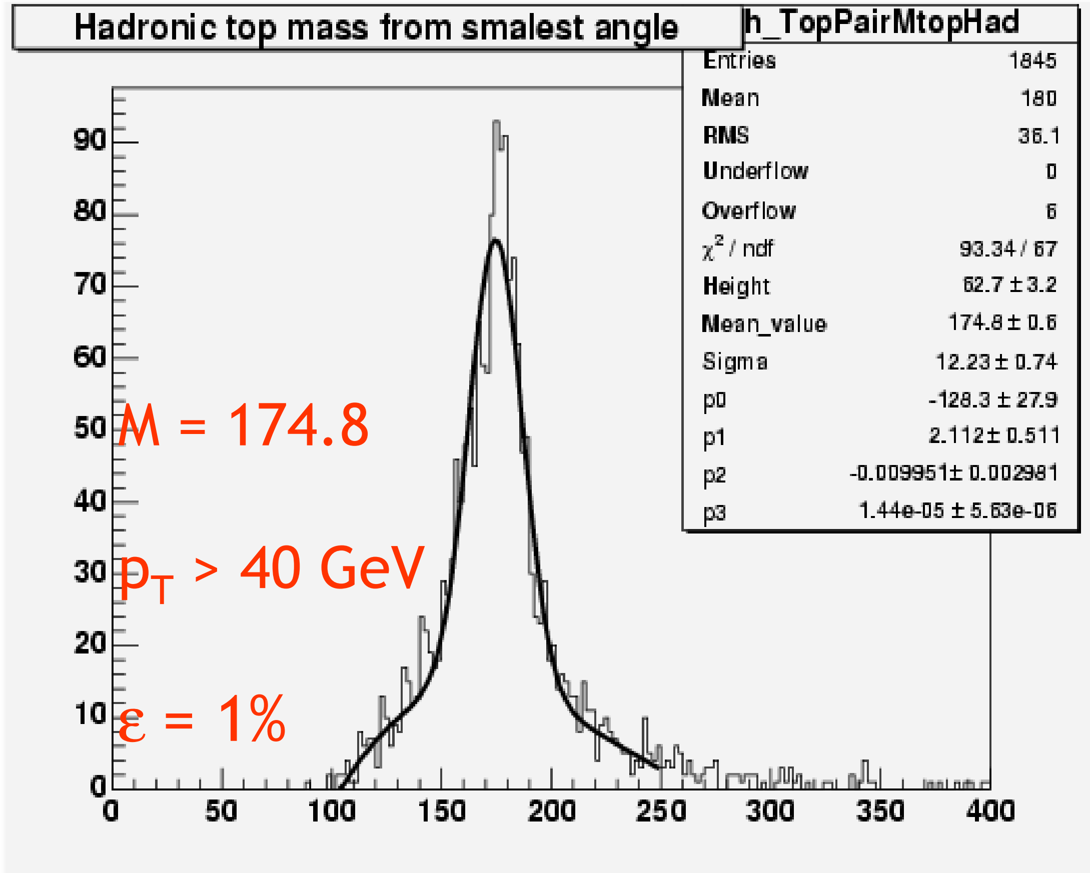
Results

- Top mass peaks from hadronic and leptonic branch in separate histograms

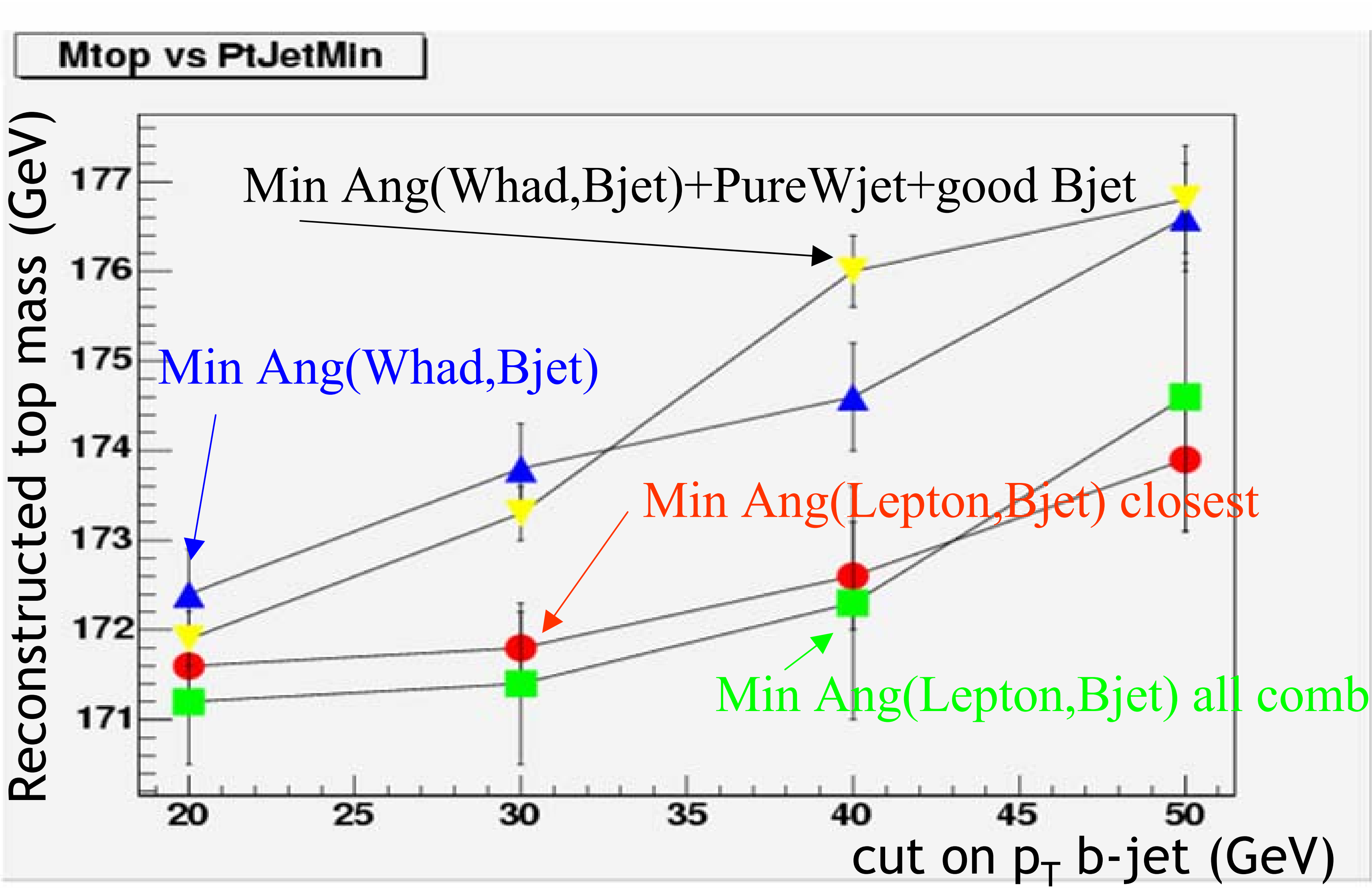
- Leptonic top peak lower than hadronic top (missing E_T calibration missing)

- Top mass biased by cut on bjet pt (see following slide)

- Analysis ongoing, with improved b-tagging algorithm

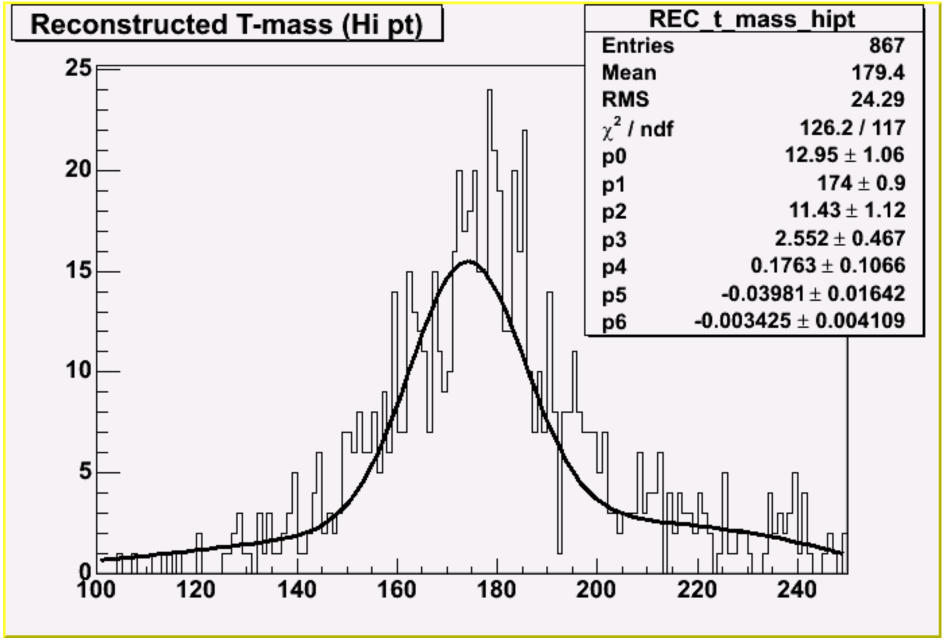


Top mass bias from bjet pt cut



Single top mass measurement in W-gluon

- 100k events Fast Simulation
- M_W reconstructed from lepton + missing E_T
- No combinatorics (W-b assignment unique)
- Two solutions for $p_z\nu$: currently highest top p_T chosen, other selections under study



Method	High p_T top	Δφ(W,b)	Best Mass
Top Mass	174.0±11.4	173.4±12.1	175.7±8.9

- Single top mass resolution competitive with ttbar's
- **Same data** soon to be processed into Full Simulation

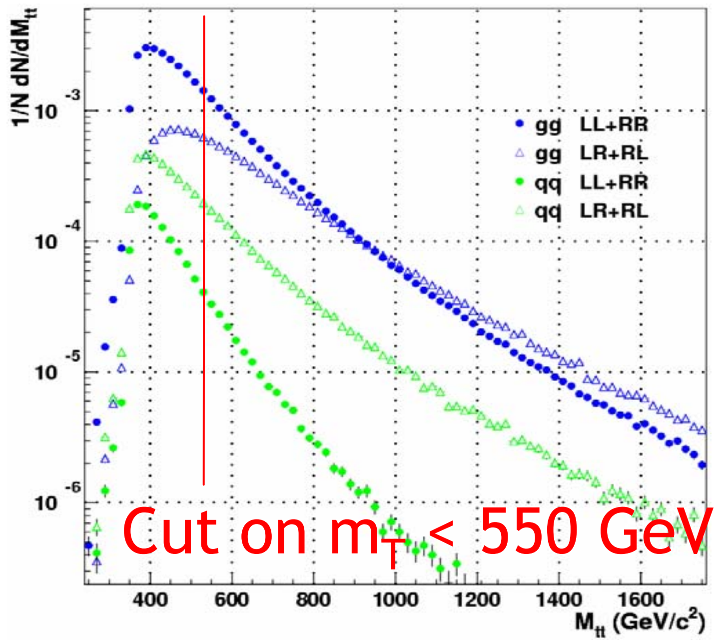
Top mass measurements - conclusions

- Systematics for top mass measurements being explored
- ttbar:
  - Study of combinatorial effects
  - Mass bias from selection cuts
- Single top:
  - Selection strategies for neutrino solutions
  - Increase efficiency of cuts
- Both QCD and EW production processes give compatible mass measurements

Spin correlation in top pair production

- Top quarks produced in QCD process are not polarized
- However, theory predicts asymmetry in favour of same-helicity pairs:

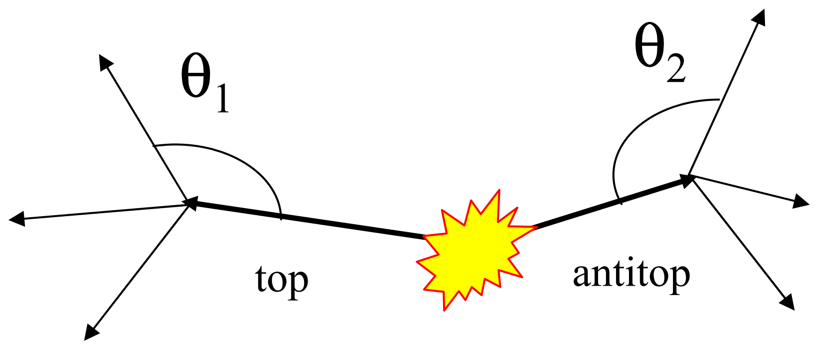
$$A = 0.326^{+0.003}_{-0.002}(\mu_{r,f})^{+0.013}_{-0.001}(PDF)$$



- Asymmetry decreases with increasing invariant mass of the ttbar pair. Need to introduce additional quality cut $m_T < 550$ GeV
- Probe on non-SM phenomena (anomalous coupling, new interactions)

Spin analyzers

The asymmetry can be evaluated by studing the differential distributions of the top decay chain products (spin analyzers):



$$\frac{1}{N}\frac{d^2N}{d(\cos\theta_1)d(\cos\theta_2)}=\frac{1}{4}(1-C\cos\theta_1\cos\theta_2)$$

$$\frac{1}{N}\frac{dN}{d(\cos\phi)}=\frac{1}{2}(1-D\cos\phi)$$

θ_i = angle between the spin analyzer *i* and the top (antitop) in the top (antitop) frame of reference

ϕ = opening angle between the two spin analyzers

e.g.: $C \sim A\,|\alpha_1\alpha_2|$ (hep-ph/0403035)

Analysing power α_i

$$\frac{dN}{d\cos\theta_i} \sim 1+\alpha_i\cos\theta_i$$

The lepton from the leptonic W decay and the L.E. jet are the best spin analyzers:

An. power	Leptons	d,s jets	u,c jets	Least energy jet
LO	1	1	-0,31	0,51
NLO	0,998	0,93	-0,31	0,47

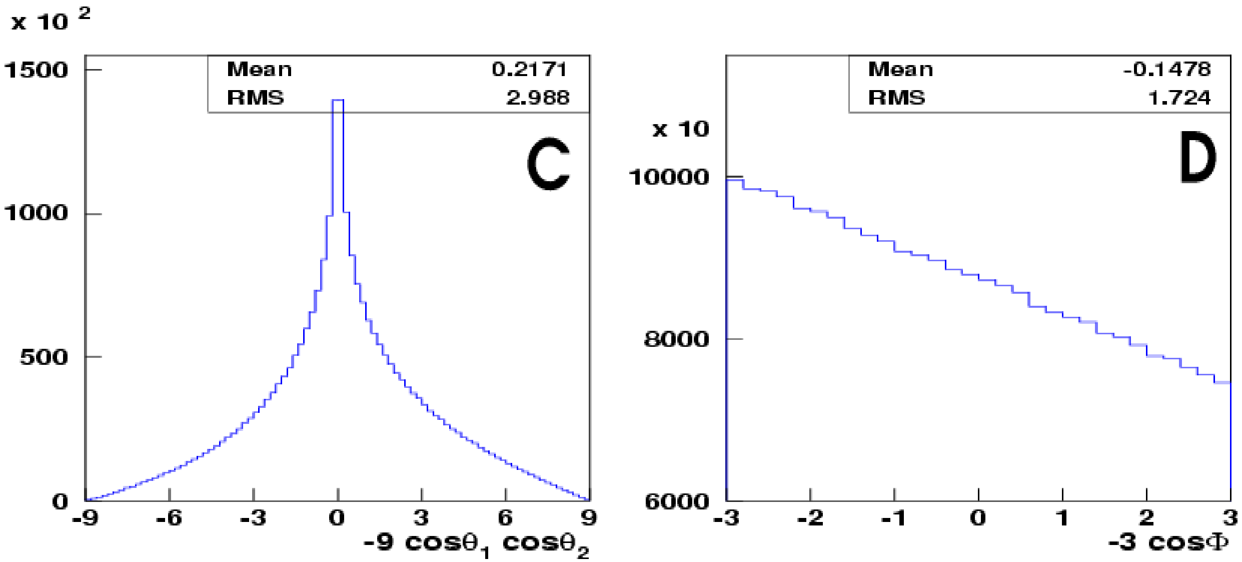
Experimentally identical!

Spin correlation parameters

The best unbiased estimators for the correlation parameters:

$$C = -9\langle \cos\theta_1 \cos\theta_2 \rangle$$

$$D = -3\langle \cos \phi \rangle$$

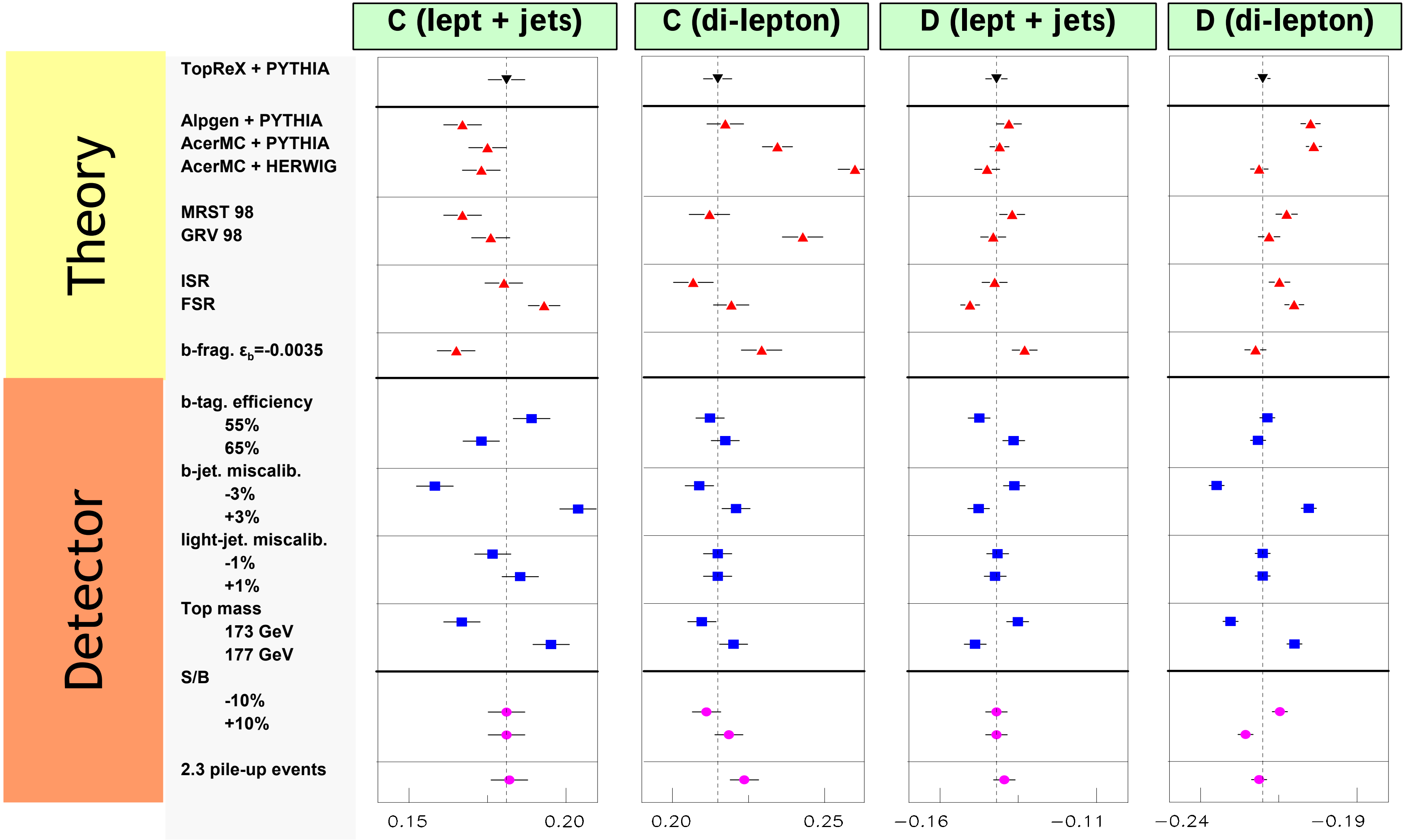


Two analyses in ttbar channel: di-lepton and lepton+jets

Lepton + jets:
ATL-PHYS-PUB-2005-008
Spin analyzers:
•Lepton from W decay
•Least energetic jet

Di-lepton:
ATL-PHYS-2003-012
Spin analyzers:
•Leptons from W+W- decays

Spin Correlation - Systematics



Spin Correlation - Results

Results for 10 fb^{-1} of data (signal + background)
Generation: TopReX 4.05 + Pythia 6.220 (CTEQ5L)
Detector Simulation: ATLFAST 2.60
(statistics, systematics)

Parameter	Di-lepton	Lepton+jets
C (theory)	0.46 ±0.04	0.22±0.02
C (MC)	0.22±0.02±0.06	0.18 ±0.01±0.04
Precision	30%	23%
D (theory)	-0.31±0.03	-0.15±0.01
D (MC)	-0.22±0.01±0.03	-0.14±0.006 ±0.02
Precision	16%	13%

The parameter **D** offers the best prospects for studying the spin correlation

Physics Note in preparation

Detector effects

- The top pair production process is valuable for the in-situ calibration of ATLAS in the early stages:
  - Large cross section $\longrightarrow$ sufficient statistics in short time
  - Good S/B ratio $\longrightarrow$ pure calibration samples

- Top analyses are strongly dependent on b-tagging.
- Precise alignment of the Inner Detector can be reached only after few months of data taking.
- Can we observe the top without b-tagging?

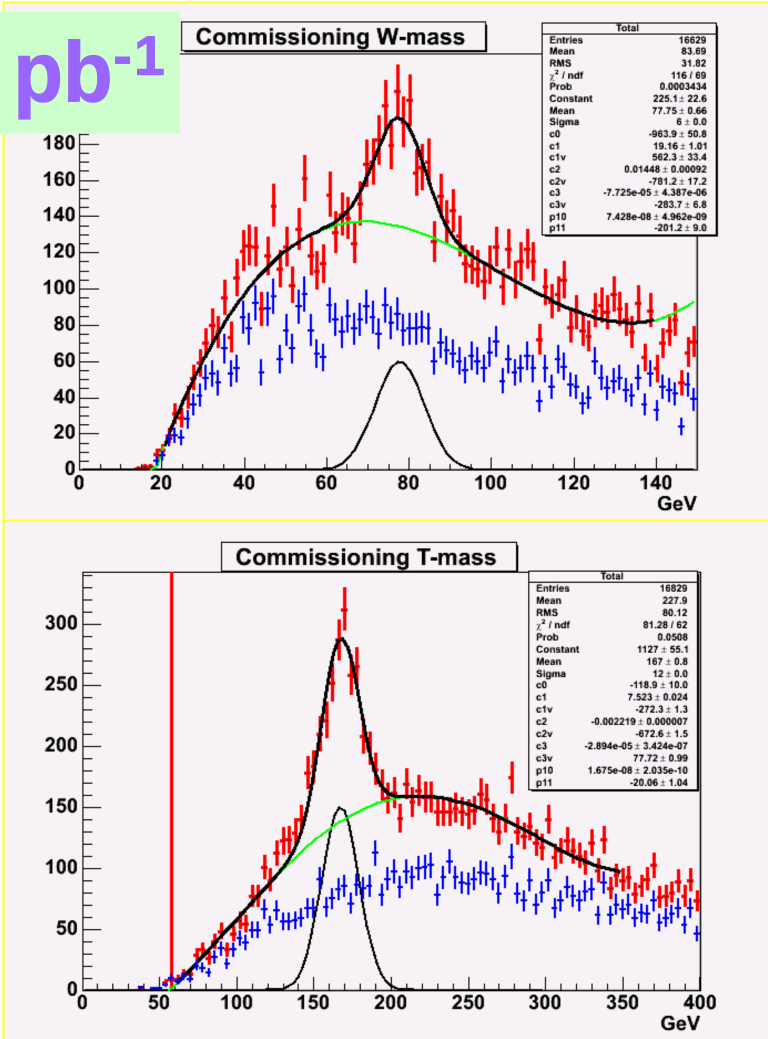
- Precision measurements of mass need absolute jet energy scale
- Miscalibrations arise from detector effects, physics effects, cone algorithms effects
- Use W from lepton + jets ttbar sample to obtain calibration factor

Top mass without b-tagging

- Selection:
  - Isolated lepton with P_T>20 GeV
  - Exactly 4 jets (ΔR=0.4) with P_T>40 GeV
- Reconstruction:
  - Select 3 jets with maximal resulting P_T (vector sum)
  - The 2 jets with highest resulting P_T give the W mass
- Background:
  - W+4 jets (leptonic decay of W, with 4 extra 'light' jets)
- Fit:
  - Gaussian signal + 4th order polynomal background

NLO +Fast Sim.

150 pb^{-1}



150 pb^{-1}	mean	σ(stat)
ε in peak	3.0%	0.15%
Mtop	167.0	0.8
Mw	77.8	0.7

Jet calibration using hadronic W

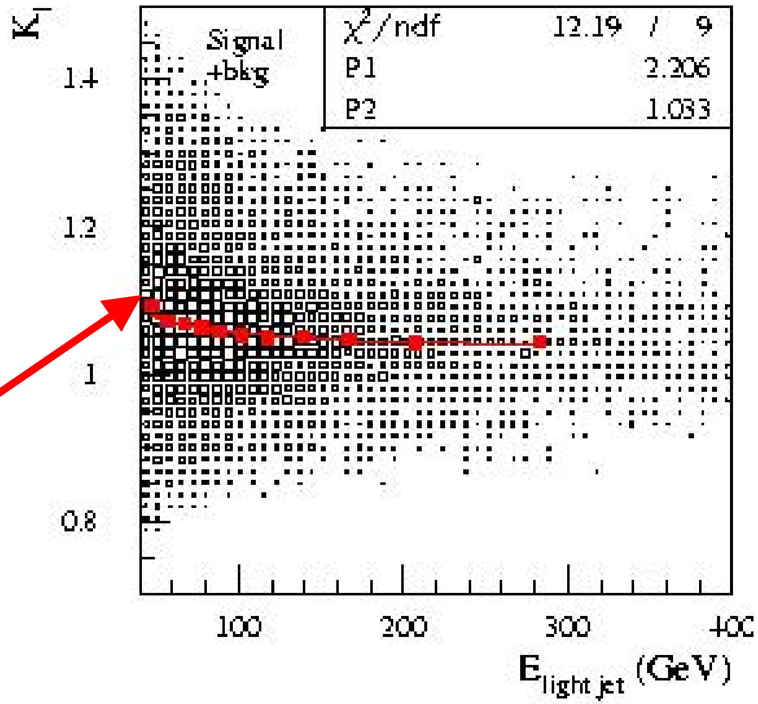
- W mass from the $j_1 j_2$ system: $M_W^2 = 2E_{j_1} E_{j_2} (1 - \cos\theta_{j_1 j_2})$
- Mass shift from jet cone algorithm ΔR=0.4 in presence of FSR but also due to $\cos\theta_{jj}$ measurement:

  jj opening angle ≠ partons' opening angle

- Constrained fit to the W mass:

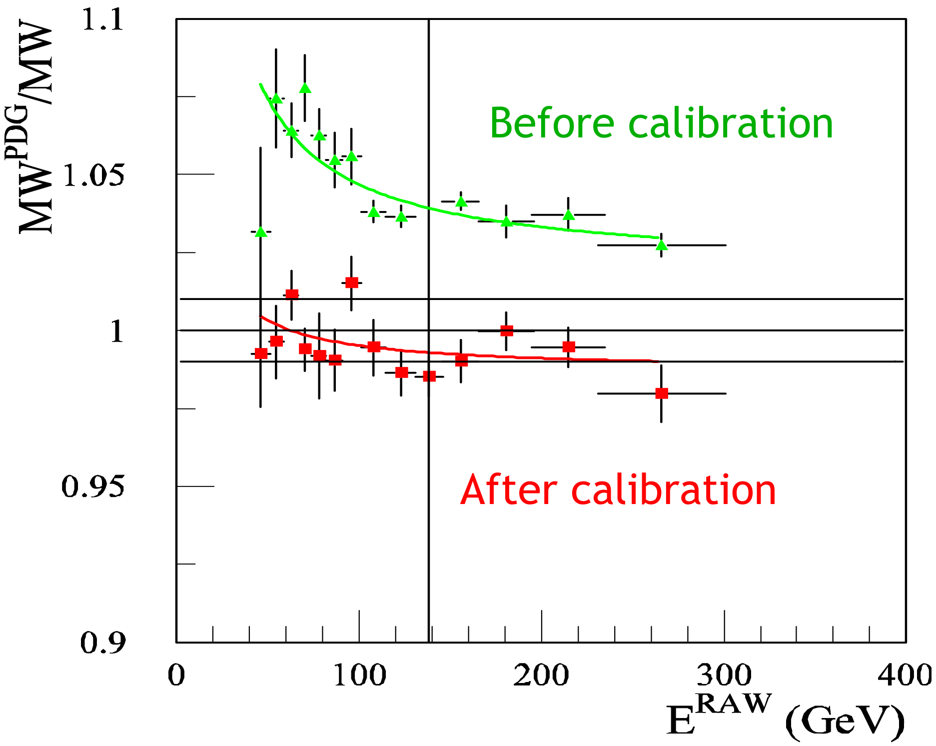
$$\chi^2 = \left(\frac{m_{jj} - M_W}{\sigma_{M_W}} \right)^2 + \sum \left[\frac{X_i - \alpha_E^i X_i}{\sigma_X} \right]^2 \quad X = E,\ \eta,\ \phi$$

- Extract factor α as function of jet energy



Jet calibration results

- Jet calibration with at least 3000 jets to obtain a M_W precision of 3%
- At initial luminosity ($10^{33}cm^{-1}/s$):
  - 5/10 days of data taking at ($\varepsilon_{b\text{-}tag}$=0.6)
  - 10/20 days of data taking at ($\varepsilon_{b\text{-}tag}$=0.3)
- Code validated for Fast Simulation
- Still to be done for Full Simulation



Detector effects - Conclusions

- Top quark detectable already in the first weeks of data taking
- b-tagging not strictly necessary in the commissioning phase
- Hadronic decays of W from ttbar events useful for jet energy calibration
- W mass resolution under 3% after max. 3 weeks

Non-SM physics

- The ATLAS Top Physics group is also involved in several studies of non-SM phenomena
- Heavy particles decaying to ttbar pairs
- Flavour Changing Neutral Currents:
  - Single top production + decay $t \rightarrow Z + q$
  - Single top production + decay $t \rightarrow \gamma + q$
- Single top production via charged SUSY Higgs

Conclusions and Outlook

- Accurate top mass measurements are necessary before we can start thinking about the Higgs

- ATLAS Top Physics WG very active in the study of systematics which can affect the mass measurement

- ttbar events are an important tool to understand our detector:
- "independence" from b-tagging $\longrightarrow$ visible from Day 1
- W from top decay useful for jet scale calibration

- But! Most studies are still performed at LO, with Fast Simulation
- Sizeable set of MC samples with Full Simulation available from May
- MC@NLO available for ttbar right now, available for single top in Summer 2005

Backup Slides

W sample selection

- W sample with 2 b-tags:
- No cuts on mjj (unlike standard top mass measurement)
- W reconstructed from jj pair with highest p_T
- The b-jet closer (ΔR) to the W is assigned to the W.
- No jet calibration applied yet
- W sample with 1 b-tag:
- same as 2 btag but:
- keep event only if the b is closer to the W than to the lepton(cut2) or if the b very close to the W (cut1)
- higher physical background (mainly Z+jets,W+X)
- Reconstructed W purity:
  (including combinatorial + physical background)

Sample	Eff btag=0.3	Eff btag=0.6
$\geq$1 btag (cut1)	78%	83%
$\geq$1 btag (cut2)	73%	79%
$\geq$2 btag	83%	87%

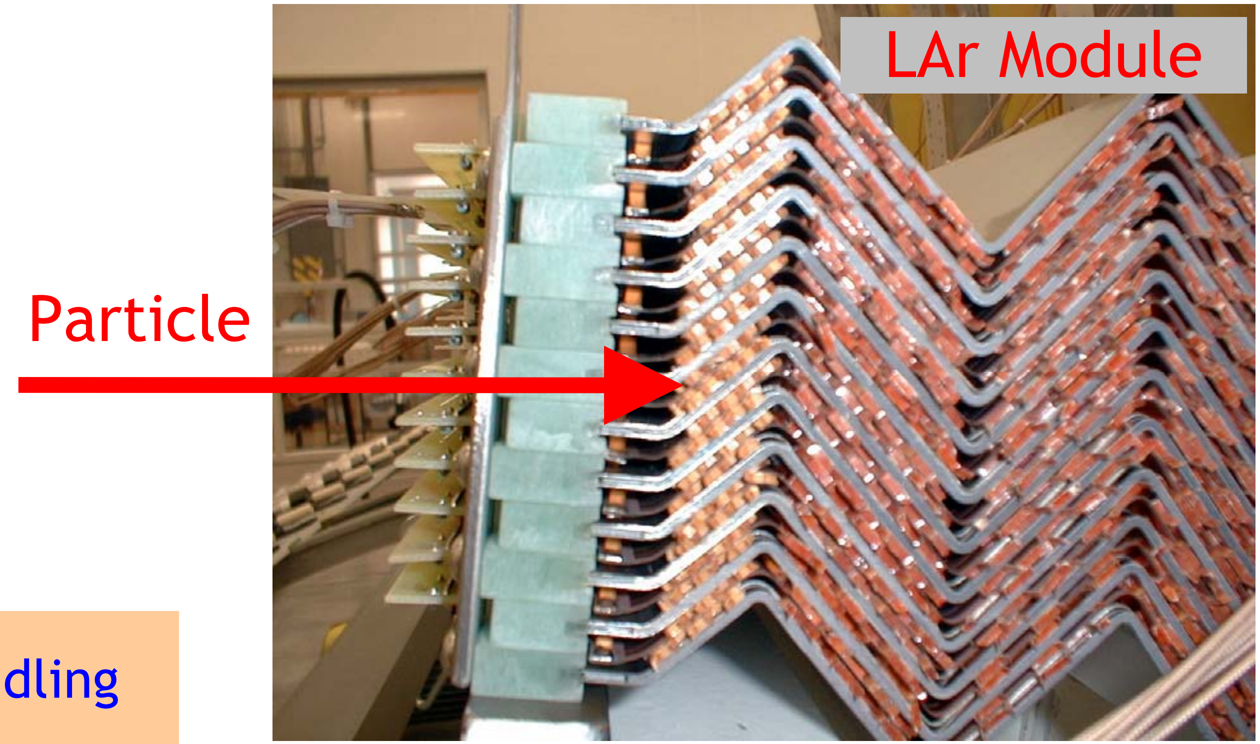
10 fb^{-1} ATLFAST data
Estimated rate at low lumi:
~130-300 events/day

Mass measurements – ttbar -> lepton + jets

- 200000 ttbar PYTHIA events with Mtop = 175 GeV
- Full simulation (GEANT3)
- Standard selection cuts, 2 b-tags required
- Lepton isolation: reject lepton with distance from closest jet $\Delta R<0.2$
- No b-tagging in reconstruction sw, "homemade" solution adopted:
  - Distance of b quark (MC Truth) to closest jet < 0.2
  - p_T of closest jet > 20 GeV
- Study of jet calibration effects, cuts on jet energy
- Strategies to reduce effect of combinatorics

Detector effects: dead Calorimeter cells

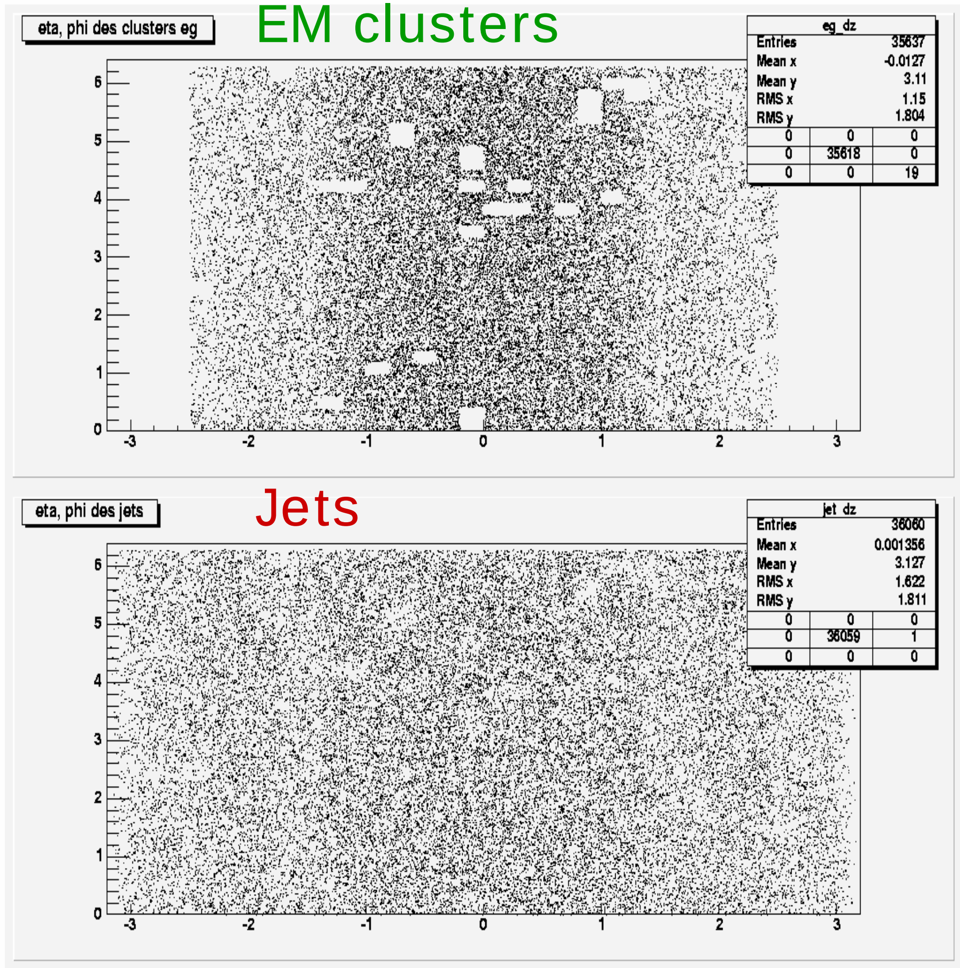
- Effects of dead EM cells on M_{top}
  - ATLAS Lar Calorimter: Argon gap (width ~ 4 mm) is split in two half gaps by the readout electrode
  - There are ~ 33 / 1024 sectors where we may be able to set the HV on one half gap only
  - Energy multiplied by 2 to recover
  - What if no HV at all?



A.I.Etienvre, J.P.Meyer, J.Schwindling

Dead EM cells

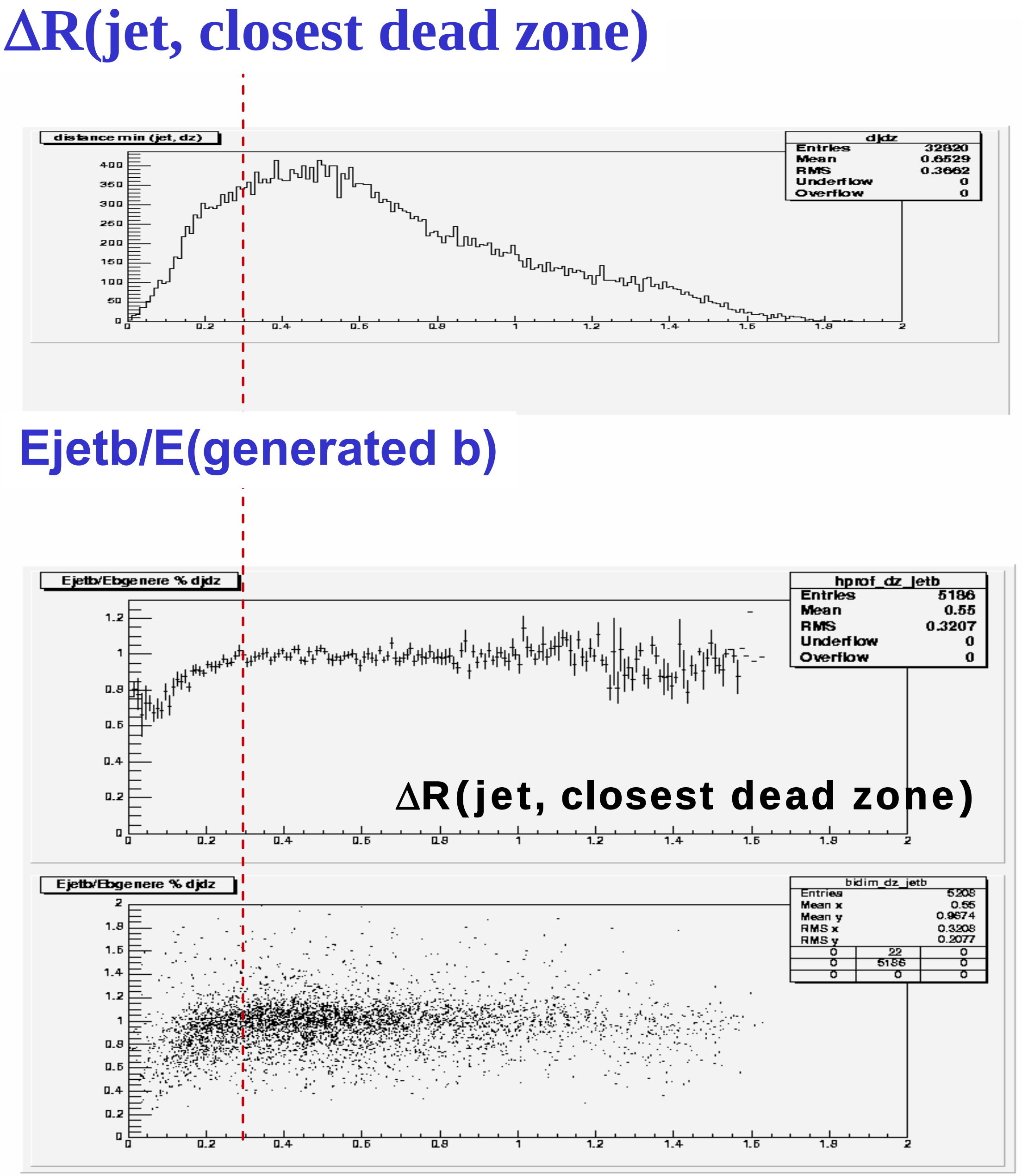
- 100k ttbar events (~1.5 days LHC at low L)
- Generator: PYTHIA
- Full simulation: ATLSIM + GEANT3 (initial detector, $|\eta| < 3.2$)
- Reconstructed using ATHENA 7.0.0
- Jet algorithm: cone with $\Delta R < 0.4$
- No electronic noise
- Preselection of events:
  - At least one recontructed e or μ with $P_T > 20$ GeV and $|\eta| < 2.5$
  - $E_{Tmiss} > 20$ GeV
  - 4 jets with $P_T > 20$ GeV and $|\eta| < 2.5$



Dead EM Cells

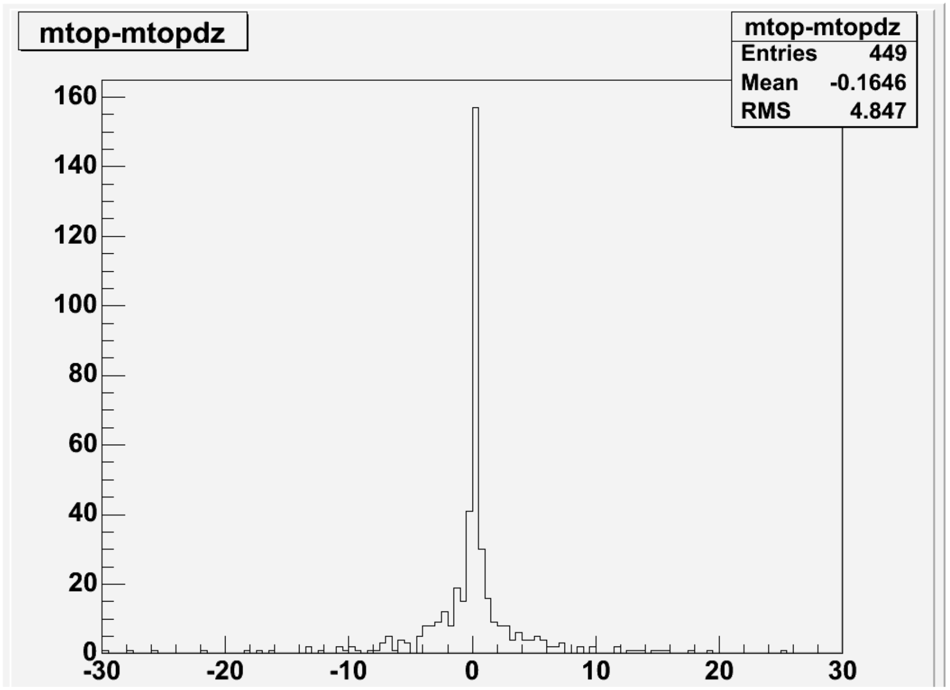
- Energy measurement is affected when ΔR(jet – closest dead region) is less than 0.3
- Affects ~ 20% of the jets ≤ $\pi \times 0.3^2 * 33 / (5 \times 2\pi)$

→ 50% of the events have at least one jet affected



Dead EM cells: results

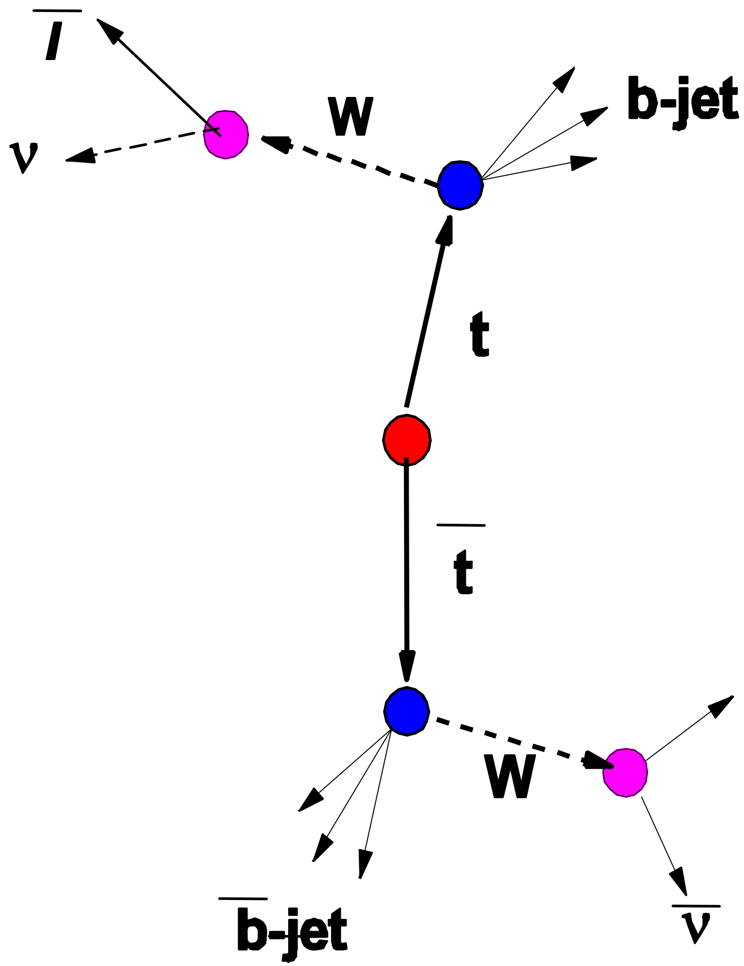
- Jet affected if ΔR(jet-dead cell) < 0.3
- 20% of jets are affected
- 50% of events with > 1 "bad" jet
- Energy recalibration as function of ΔR
- If all 33 HV sectors die (very pessimistic), the effects on the top mass measurement, after recalibration, are:
  - Loss of signal: < 8 %
  - Increase in background: not studied
  - Displacement of the peak of the mass distribution: -0.2 GeV



Mtop (perfect Calo) – Mtop (with dead regions)

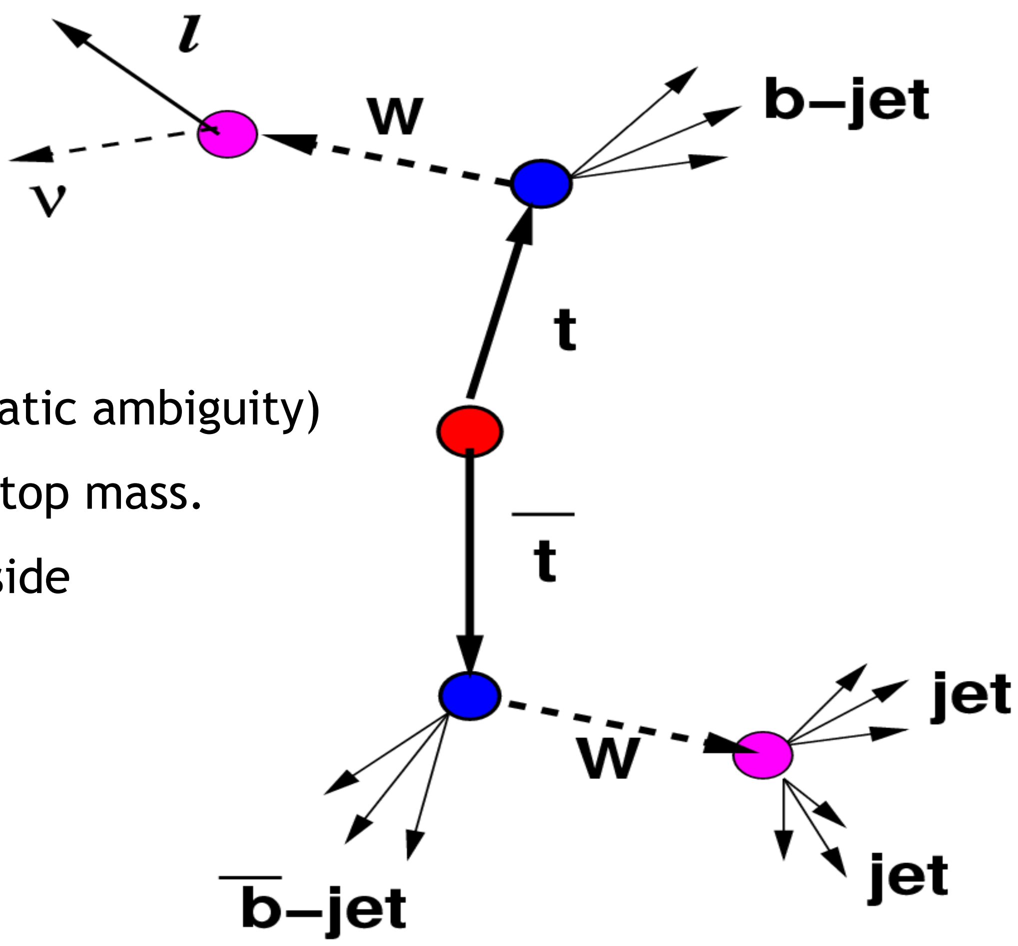
Spin Correlation – Dilepton Sample

- Selection cuts:
  - Two opposite charged leptons with p_t > 20 GeV, $|\eta|<2.5$
  - Two b-tagged jets with p_t > 20 *GeV*, p_t > 20 GeV
  - Missing transverse energy E_T^{MISS} > 40 GeV
  - Quality cut: M_{ttbar}< 550 GeV
- Selection efficiency= 4.4%   S/B=6.2
- Top/antitop reconstructed by set of non-linear equations using kinematic constraints. (described in ATL-PHYS-2001-018)



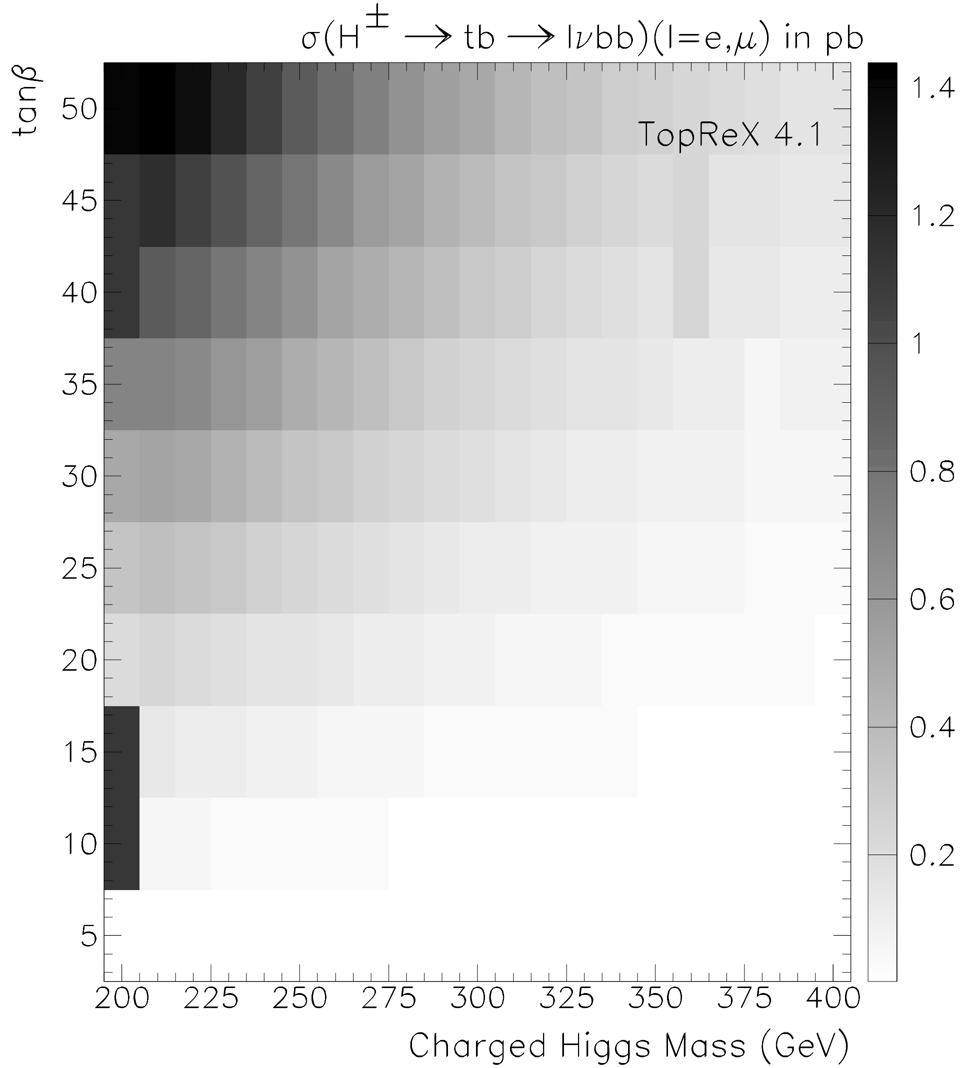
Spin Correlation – Lepton + Jets sample

- Selection cuts:
  - One isolated lepton with p_t > 20 GeV, $|\eta|<2.5$
  - At least four jets with p_t > 20 GeV, $|\eta|<2.5$
  - At least two out of four b-tagged jets
  - Missing momentum p_T^{MISS} > 20 GeV
  - Quality cut: M_{ttbar}< 550 GeV
- Reconstruction:
  - Lepton + missing p_T to reconstruct W (quadratic ambiguity)
  - Hadronic side: jjb combination to give best top mass.
- Least energetic jet best analyzer on hadronic side
- Results published in ATL-PHYS-PUB-2005-008



Single top production via SUSY Higgs

- Extended spectrum of 5 Higgs bosons
- 3 neutral : h, H, A & 2 charged : H±
- Mass Spectrum dependent by two parameters: tanβ , m_A
- Charged Higgs : $m_{H\pm}{}^2 = m^2{}_A + m^2{}_W$
- Cross-section dependent on tH±b coupling in (tanβ , mH±) plane



ttbar resonances

- The ttbar system can be a probe for new resonances or gauge bosons that are strongly coupled to the top
- ***Invariant mass of heavy resonances decaying to ttbar:***
  - ***SM :Higgs if mass above threshold***
  - ***SUSY: H,A large B.R. for tan$\beta \approx 1$***
  - ***Technicolor, Z', etc.***
- ***Study of a generic resonance with M_X from 350 GeV up to 5 TeV ; $\Gamma_X < \Gamma_{det}$ and $\Gamma_X > \Gamma_{det}$***

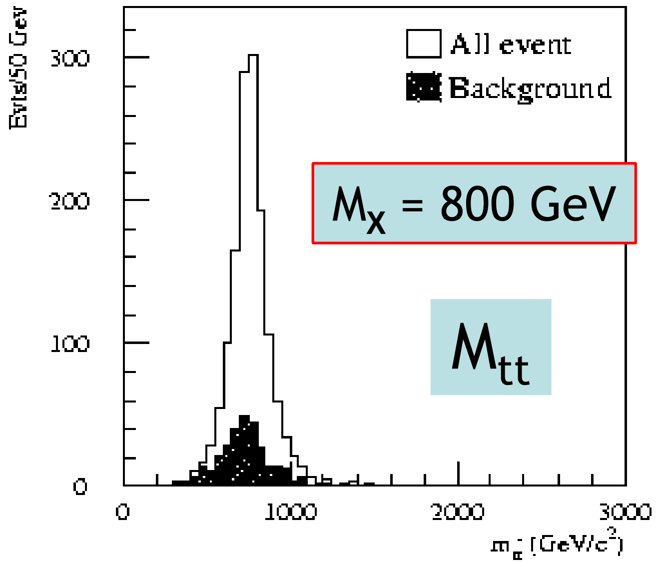
- Signal observation above continuum BKG within a $2\sigma_{det}$ mass window
- Preselection
  - E_T > 40 GeV
  - At least ONE muon, p_T >20 GeV, $|\eta|$ > 2.5
  - At least FOUR jets p_T >40 GeV , $|\eta|$ > 2.5, two b-tags
- Selection
  - Reconstruct Hadronic Top:
    - $|Mjj-M_W|$ < 20 GeV; $|Mjjb-M_t|$ < 40 GeV
  - Reconstruct Leptonic Top:
    - $|Mjj-M_W|$ < 20 GeV; $|Mjjb-M_t|$ < 40 GeV

E.Cogneras

ttbar resonances

Discovery potential for 300 fb^{-1}

- M_X = 500 GeV (σ x BR)>1500 fb
- M_X = 1 TeV (σ x BR)> 650 fb
- M_X > 3 TeV (σ x BR)> 11 fb



Combinatorial Background Only!