Lecture 2: first physics with ATLAS

Giacomo Polesello

INFN, Sezione di Pavia

Physics with early data

Realistic approach: assume low selection efficiency for interesting events

Process	$\sigma \times BR$		Events selected for 100 pb^{-1}
$W \to \ell\nu$	20 nb	$\sim 20\%$	~ 400000
$Z \to \mu\mu$	2 nb	$\sim 20\%$	~ 40000
$\bar{t}t$ (semileptonic)	370 pb	$\sim 1.5\%$	< 1000

Jets and minimum bias statistics only limited by allocated trigger bandwidth

Even from pilot run expect significant statistics from interesting physics processes

Many possible uses for early physics events:

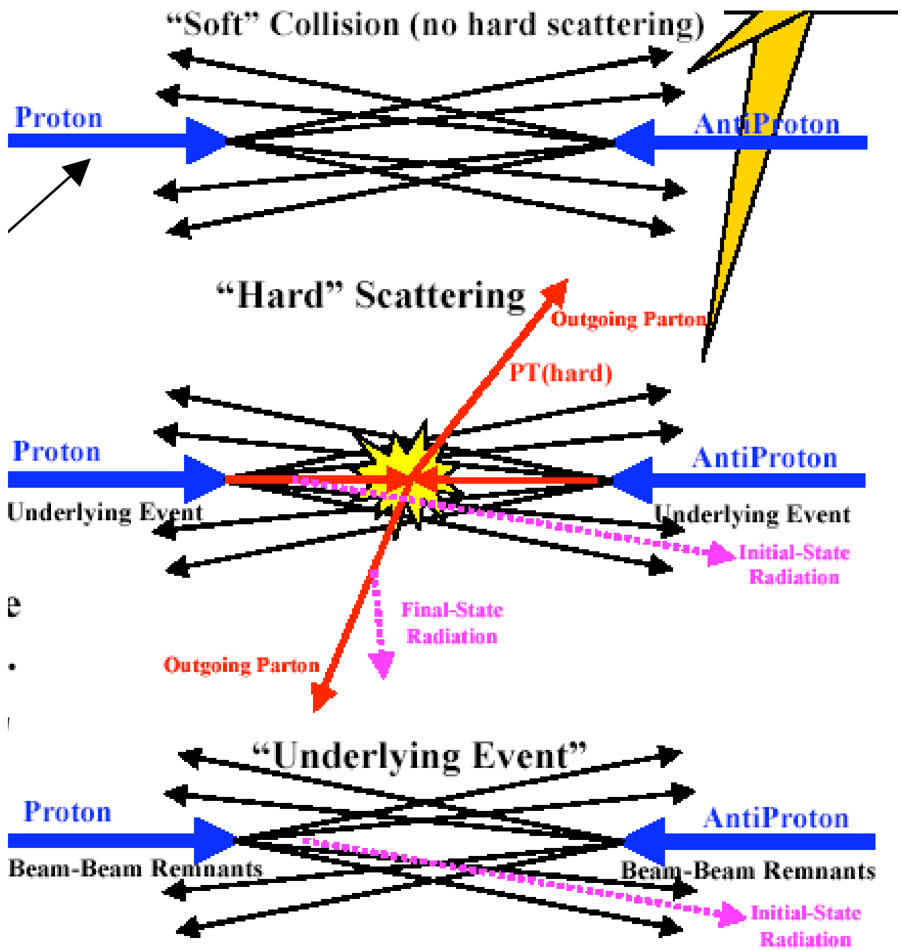
- Calibrate/understand the detector
- Perform SM physics measurements
- Start understanding SM processes as background for new physics

Show in some detail how we plan to use the different samples. Caveat: all preliminary work mostly not yet documented

Minimum bias and Underlying Event studies

Hadronic interactions:

- Hard processes (high p_T): well described by PQCD
- Soft interactions (low p_T): require non-perturbative phenomenological models:
  - Minimum bias: non single-diffractive events: $\sigma \sim 60 - 70$ mb
  - Underlying event: everything except two outgoing hard scattered jets



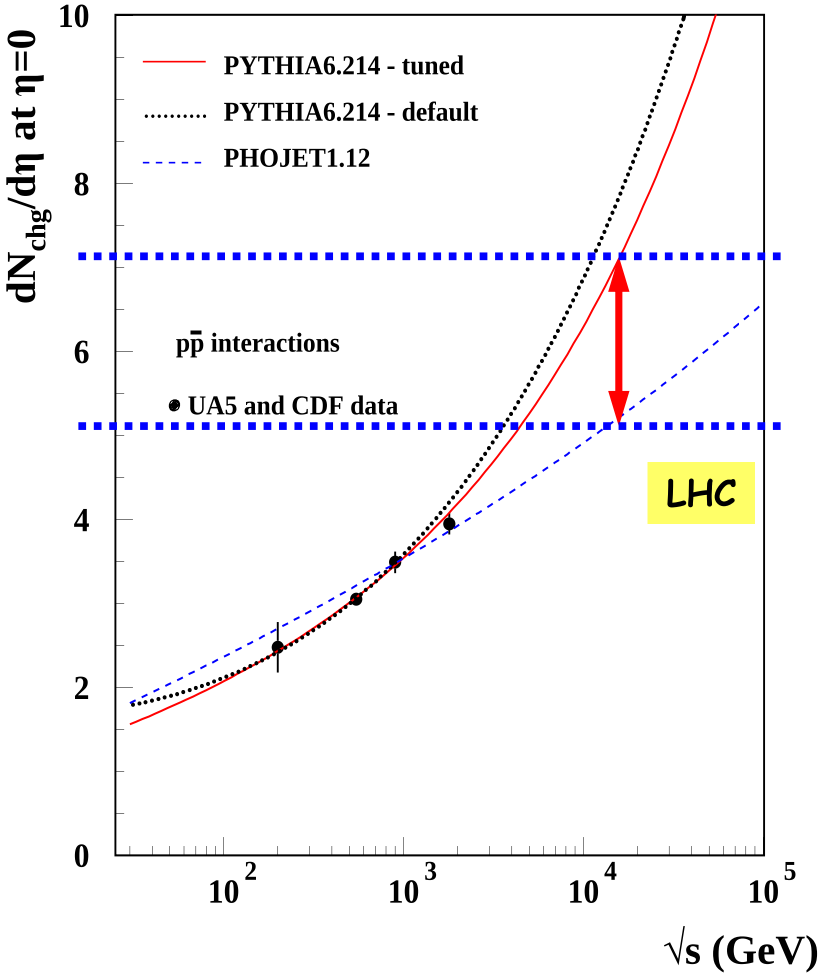
First physics available at the LHC

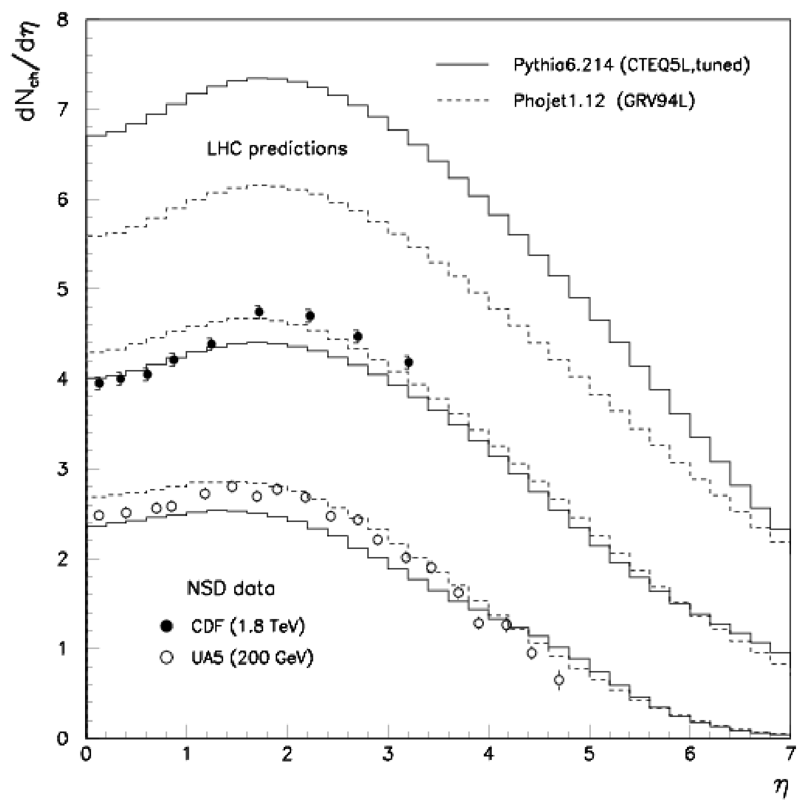
Interesting *per se*

Modeling of minimum bias pile-up and underlying event necessary tool for high P_T physics

Extrapolation to LHC from Tevatron

Dependence on $\sqrt{s}$ of charged particle density at $\eta = 0$





- PYTHIA models favour $\ln^2(s)$;
- PHOJET suggests a $\ln(s)$ dependence.

Measuring minimum bias with early data (ATLAS preliminary)

Number of charged tracks N_{ch} as a function of η ($dN_{ch}/d\eta$) and p_T ($dN_{ch}/d\eta$)

On fully simulated events compare reconstructed to generated distributions

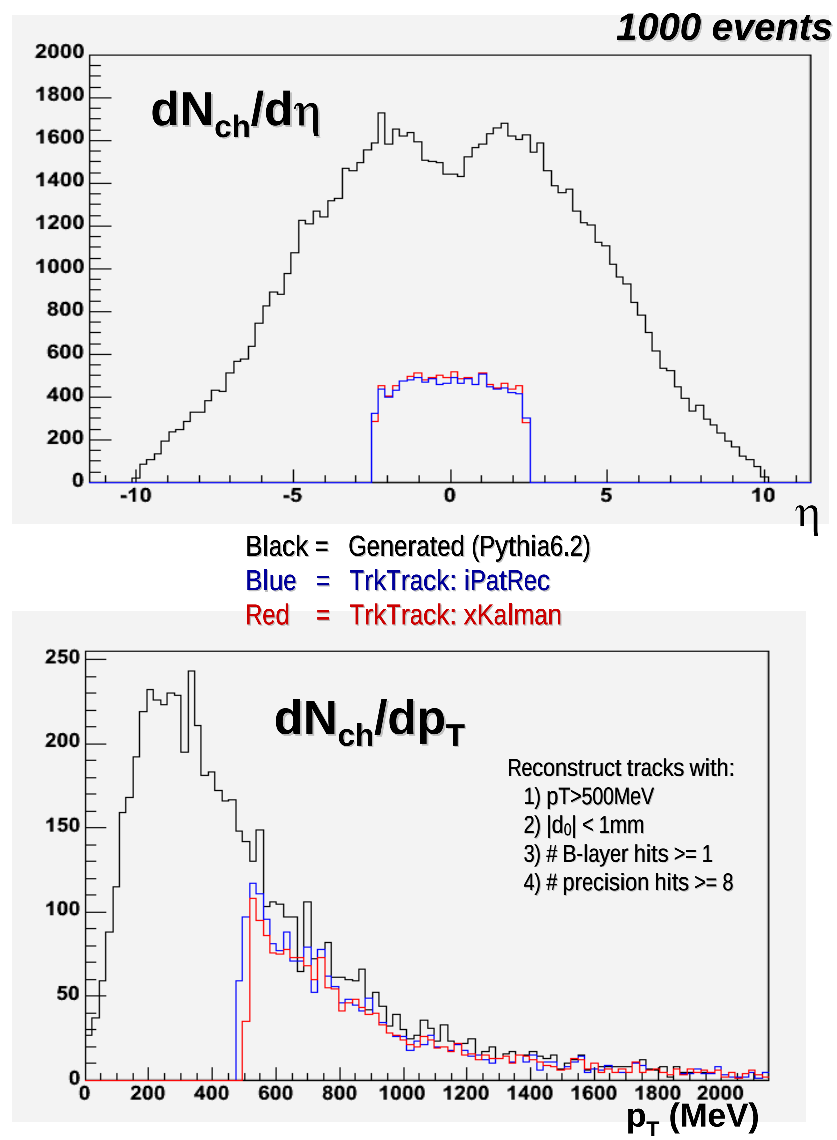
Very few events required

Only a fraction of tracks reconstructed:

- Limited rapidity coverage
- Can only reconstruct track p_T with good efficiency down to ∼500 MeV

Need to apply correction factor from MonteCarlo to subtract minimum bias: systematic uncertainty

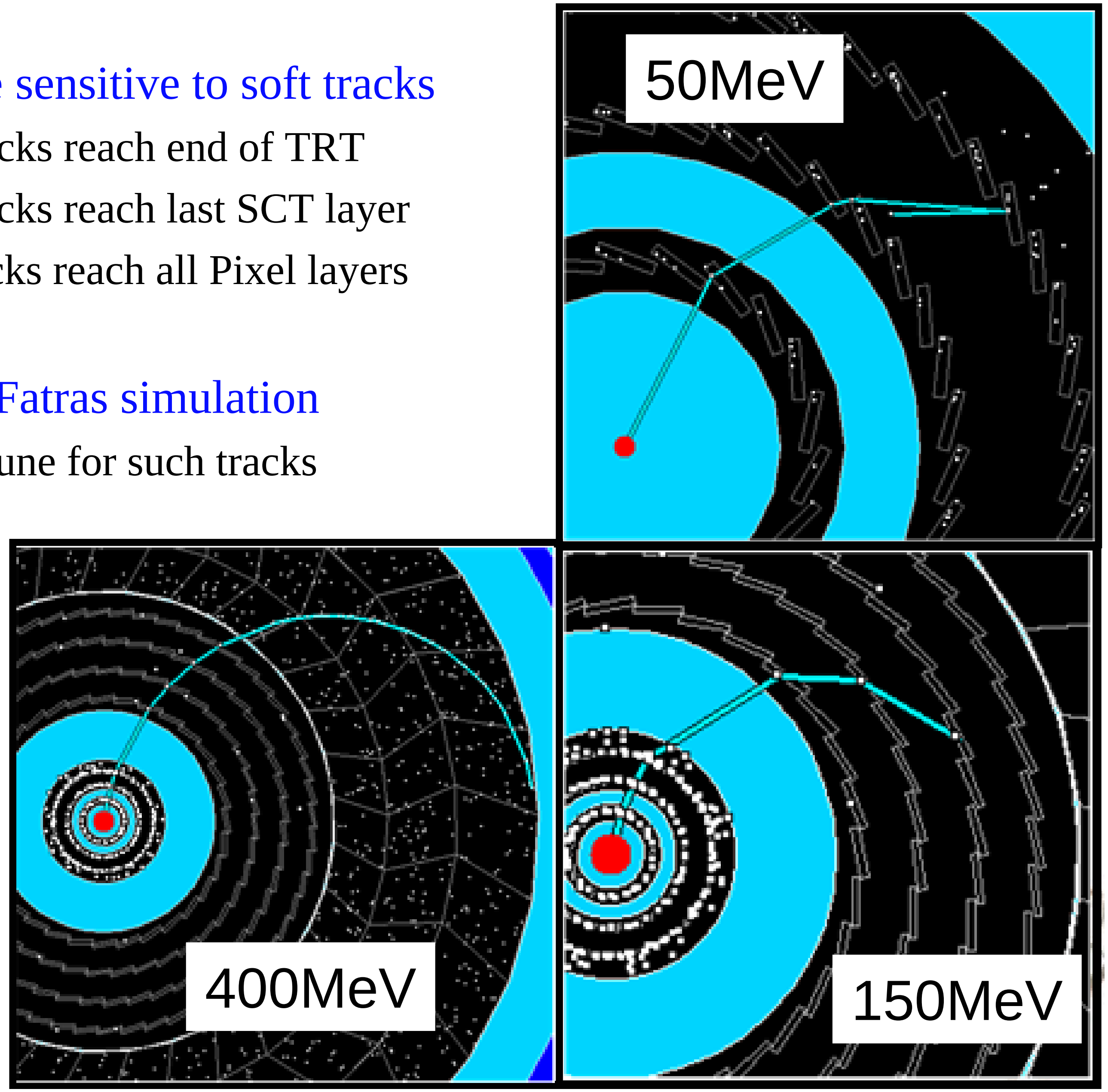
Explore extending tracking down to lower p_T



Preliminary exploration of low-pt track reconstruction in ATLAS ID

- Tracker is in principle sensitive to soft tracks
  - Pt = 400 MeV - tracks reach end of TRT
  - Pt = 150 MeV - tracks reach last SCT layer
  - Pt = 50 MeV - tracks reach all Pixel layers

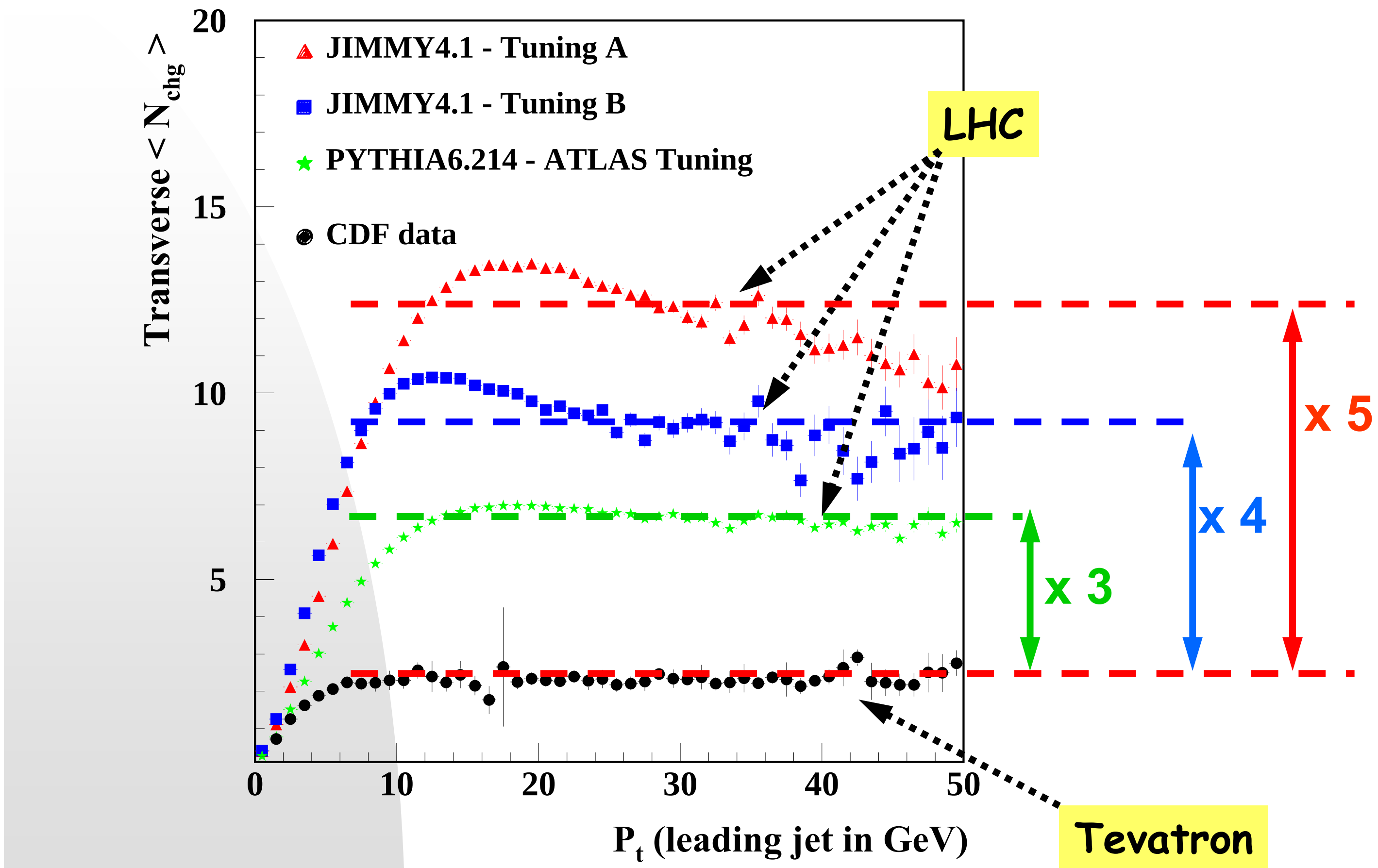
- Event graphics using Fatras simulation
  - Tools are there to tune for such tracks



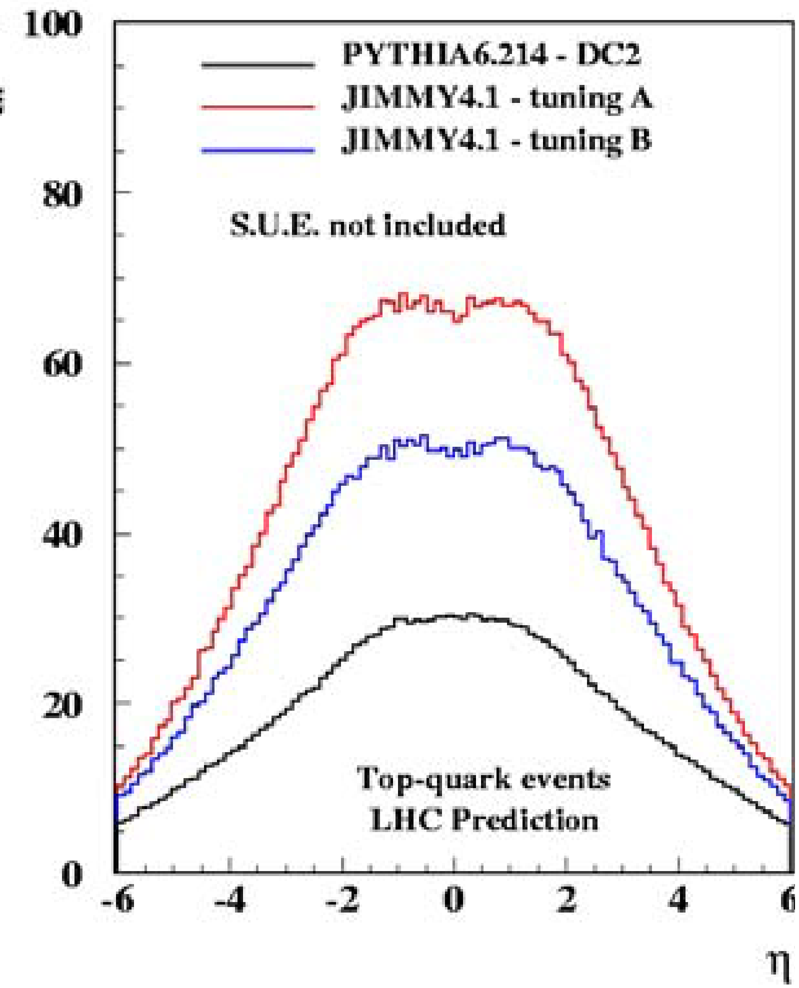
A.Salzburger

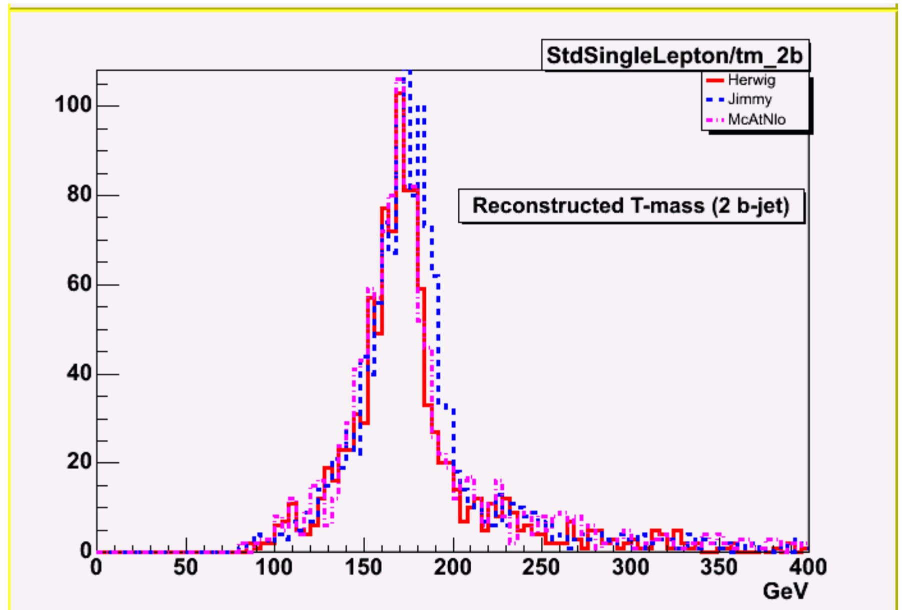
Underlying event LHC predictions for different generators

Consider PYTHIA and JIMMY underlying events tuned to the Tevatron data



Example: Impact on top mass measurement

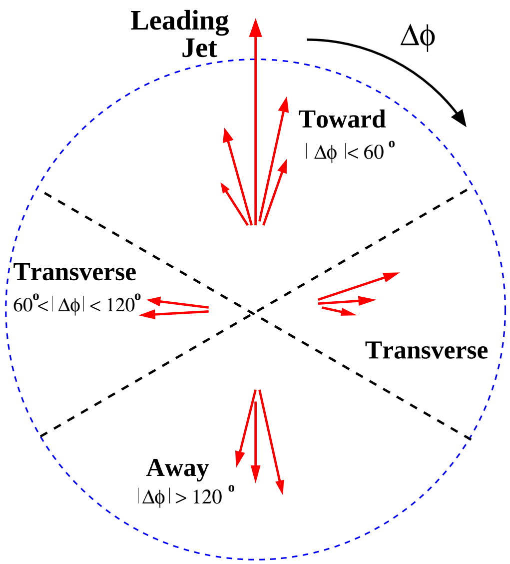




Different UE models can shift top mass by up to 5 GeV

Need excellent UE modeling to perform subtraction

Measuring Underlying Event at the LHC



Perform measurement by looking at tracks in the "transverse" region with respect to jet activity

On fully simulated events compare reconstructed and generated multiplicity

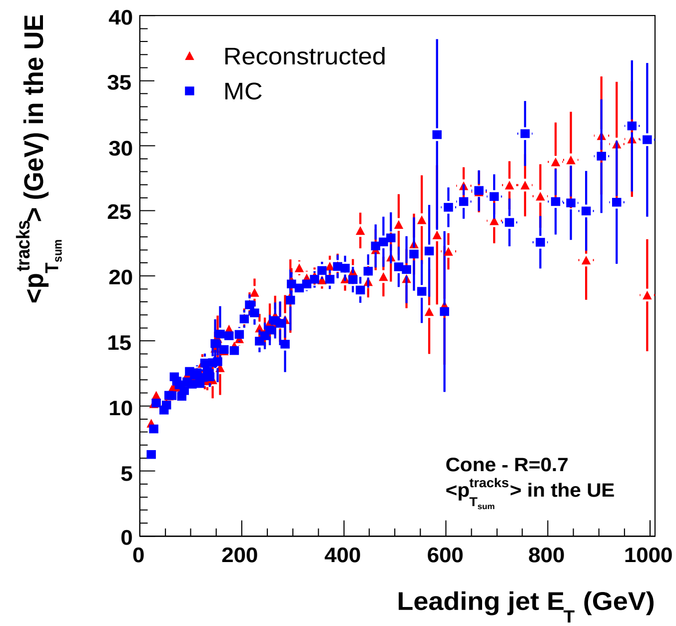
Select:

$N_{jet} > 1 \quad p_T^{jet} > 10 \text{ GeV} \quad |\eta_{jet}| < 2.5$

$p_T^{track} > 1.0 \text{ GeV} \quad |\eta_{track}| < 2.5$

Good agreement reconstructed/generated

Can use to tune MonteCarlo

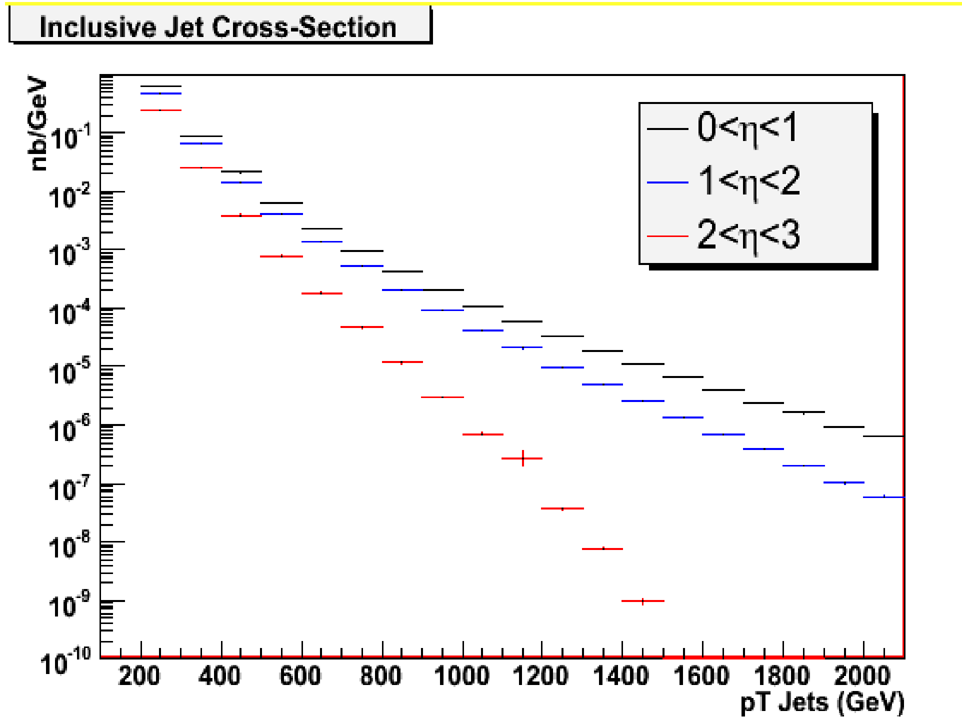


Inclusive Jet cross-section measurement

Concerns all events containing jets, the bulk of high p_T events at the LHC

Measurement provides test of QCD

Study of high P_T tails of X-section sensitive to any type of new physics manifesting itself as contact interactions



Cross-sections calculated using NLOJET with jet k_T algorithm

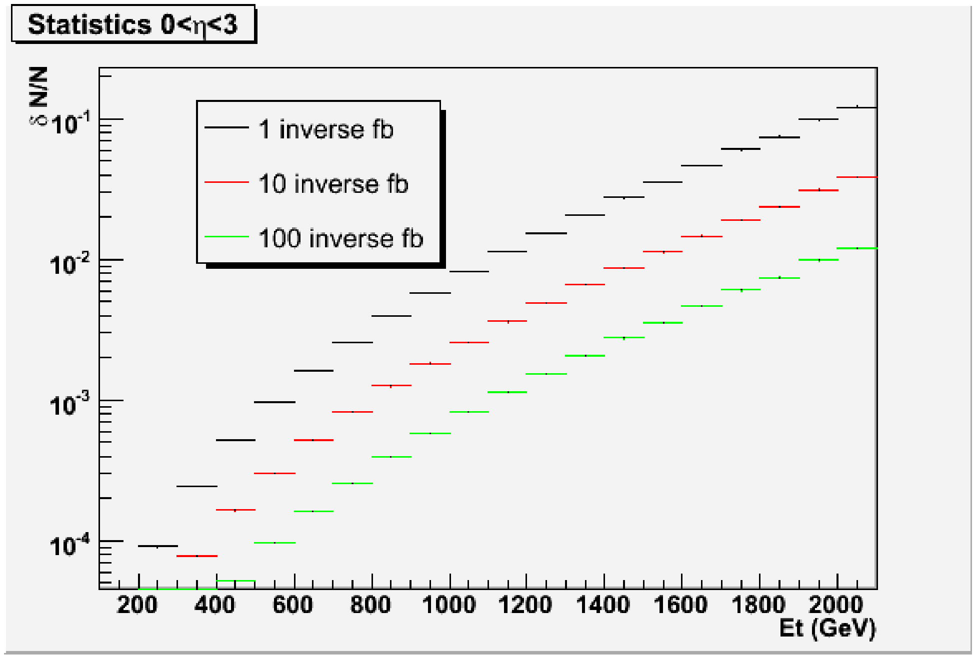
Detailed evaluation of errors on QCD predictions and and on experimental measurements necessary, as they can both fake and mask new physics

Show a preliminary exercise from the ATLAS Glasgow group to evaluate relative size of different sources of error

Statistical errors

Naive estimate: take error as $\sqrt{N}$, with N number of events from cross-section for a given integrated luminosity

Plot relative error $\sqrt{N}/N$



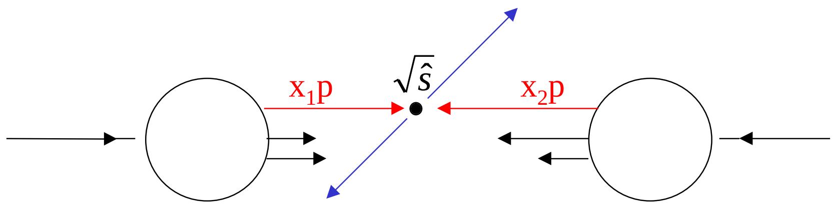
For 1 fb^{-1} 1% error for $P_T(jet) \sim 1$ TeV

For 100 pb^{-1} 1% error for $P_T(jet) \sim 0.8$ TeV

Larger error if restricting to high $|\eta|$ bins: 10% for 1 fb^{-1} and 1 TeV p_T

Theoretical errors

Jet cross section convolution of hard scattering process, and momentum distribution of partons in proton



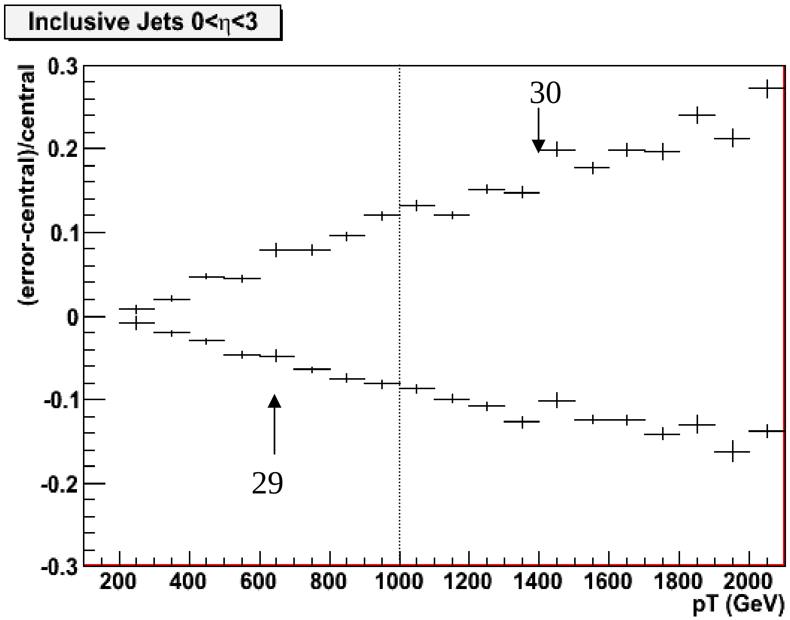
$$\sigma = \sum_{a,b} \int dx_1 dx_2 f_a(x_1, \mu_F) f_b(x_2, \mu_F) \hat{\sigma}_{a,b}(x_a, x_b, \mu_R)$$

μ_F and μ_R arbitrary energy scales

Two main sources of theoretical uncertainty:

- Parton Distribution functions (PDFs): phenomenological parametrisation from fitting of DIS data: experimental uncertainty on input data and on parametrisation shape
- Renormalisation/Factorisation scale, arising from perturbative calculation being carried out at fixed order. Uncertainty decreases as one goes to higher orders

Theoretical errors II



Cross-sections now come with a 'best value' and estimate of errors (LHAPDF) in standard format

Study relative change of NLOJET X-S for the extreme sets of the CTEQ6 PDF

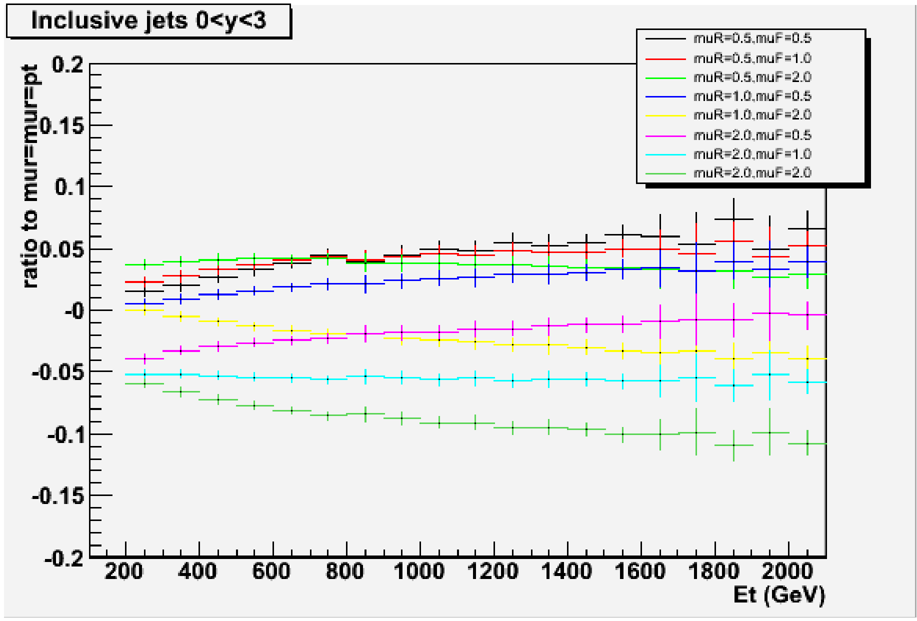
For a jet p_T of 1 TeV errors are approx 10 to 15%

Dominated by high-x gluon uncertainty

Vary renormalisation (μ_R) and factorisation scale (μ_F) between $0.5E_T$ and $2E_T$

Relatively small variation due to use of NLO cross-sections, need to go to NNLO to achieve smaller sensitivity

Uncertainty of 5 to 10% on inclusive jet cross-section for jet p_T of 1 TeV



Experimental errors

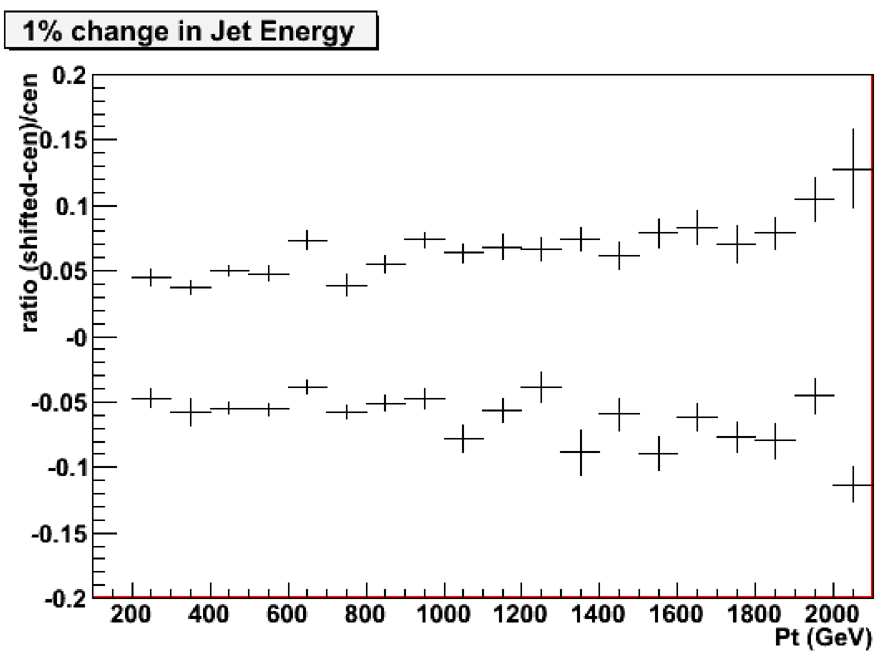
Many possible sources of experimental errors:

- Jet energy scale,
- Linearity of calo response
- Jet resolution, UE subtraction, trigger efficiency....
- Luminosity determination

Focus on jet energy scale, dominant in Tevatron analyses

Uncertainty on jet scale of 1% yields error on σ(jet) X-s of 6%

Uncertainty on jet scale of 5% yields error on jet σ(jet) of 30%



Conclusions on early jet cross-section

From the early days cover with high statistics large range of p_T, up to ~TeV region

Early sensitivity to new physics effects, if adequate control of systematics. Main issues:

- Theoretical predictions: study ways of constraining the PDF's in the relevant region from the LHC data themselves without flattening out signals for new physics
- Experimental measurements: Most difficult issue: jet scale must be known to $\sim 1\%$ in the TeV region: control of linearity to carry to high energy scale established at 100 GeV.

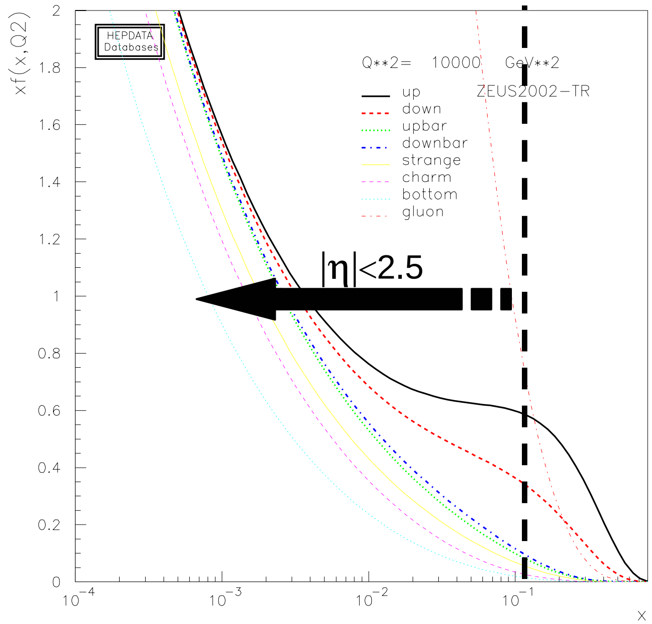
  Requires concentrated studies with many control samples, likely to be the dominant factor in determining the time of publication

Studies of W and Z production

W and Z production cross-section precisely predicted by QCD

Measuring them is one of first basic physics checks at the LHC

Eventually can be used as a luminosity measuring device if theoretical and experimental uncertainties down to ~3%



Main theoretical uncertainty: PDF parametrisation

For W and Z production at the LHC:

- Dominant sea-sea parton interactions at low x
- At $Q^2 = M_Z^2$ sea distributions driven by gluon
- Low x gluon has large uncertainty

Studying W and Z production can increase our knowledge of gluon SF

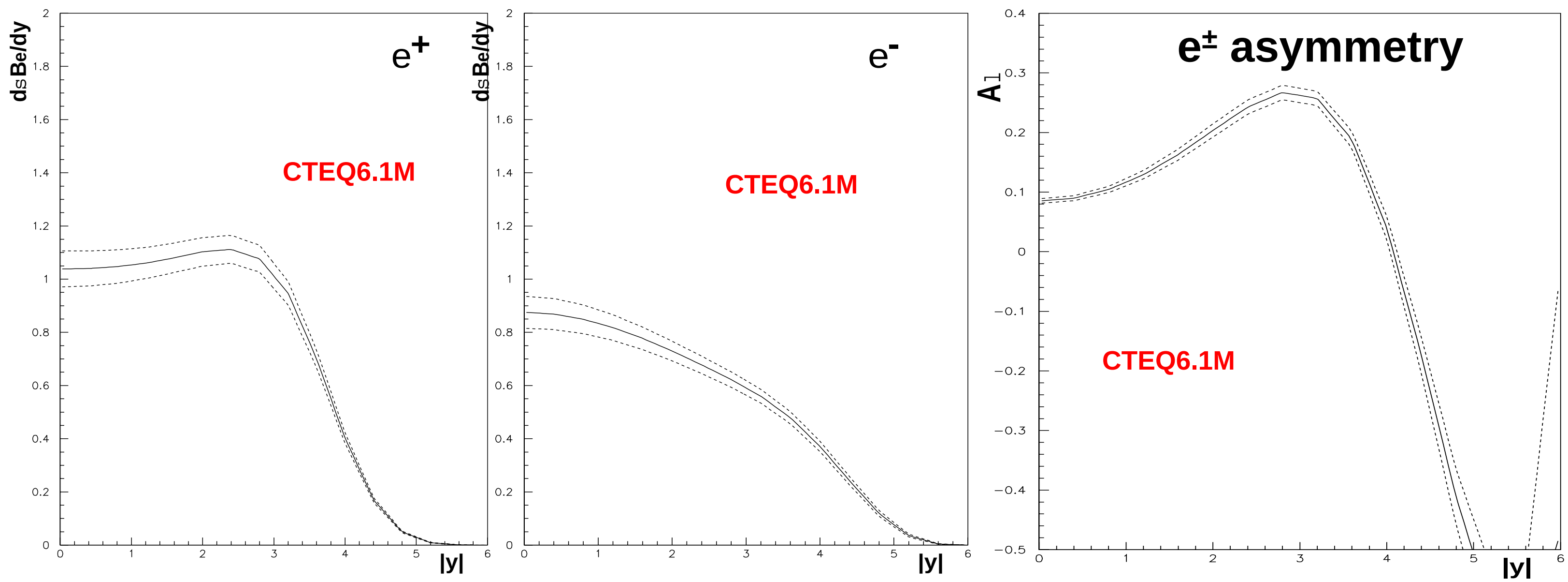
Show study performed by ATLAS Oxford group

Rapidity distributions

Shape of W y distributions particularly sensitive to PDF errors:

At y=0 total W PDF uncertainty order 8-10%, sum of uncertainty of single PDF (5-8%) and spread among paramtrisations (4-5%)

Observe lepton from W decays: sensitivity to gluon parameters similar to the W

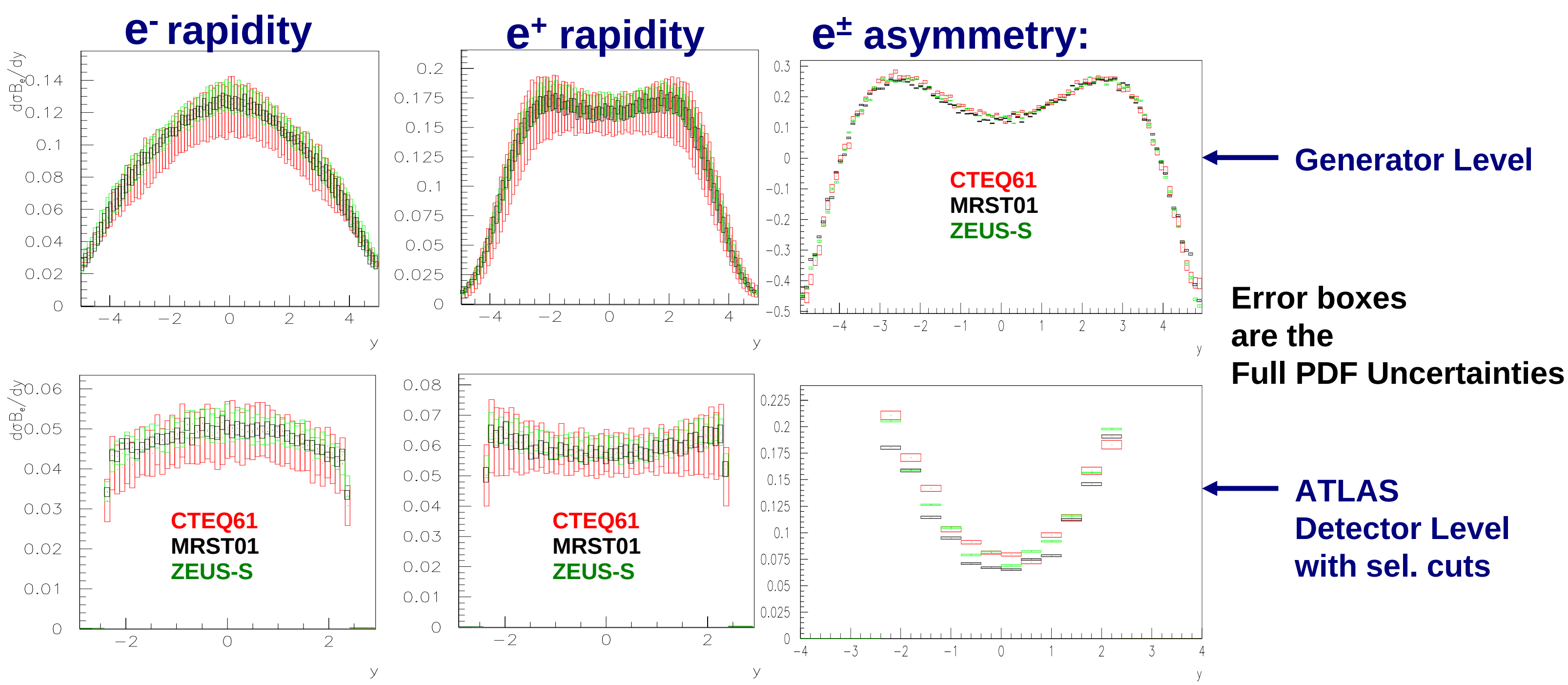


Uncertainties mostly canceled if asymmetry considered: SM benchmark

Detector level distributions

Events produced with HERWIG, reweighted for MCNLO, PDF's CTEQ6.1

Pass through fast simulation of ATLAS



PDF spread reproduced at detector level, as well as cancellation for asymmetry

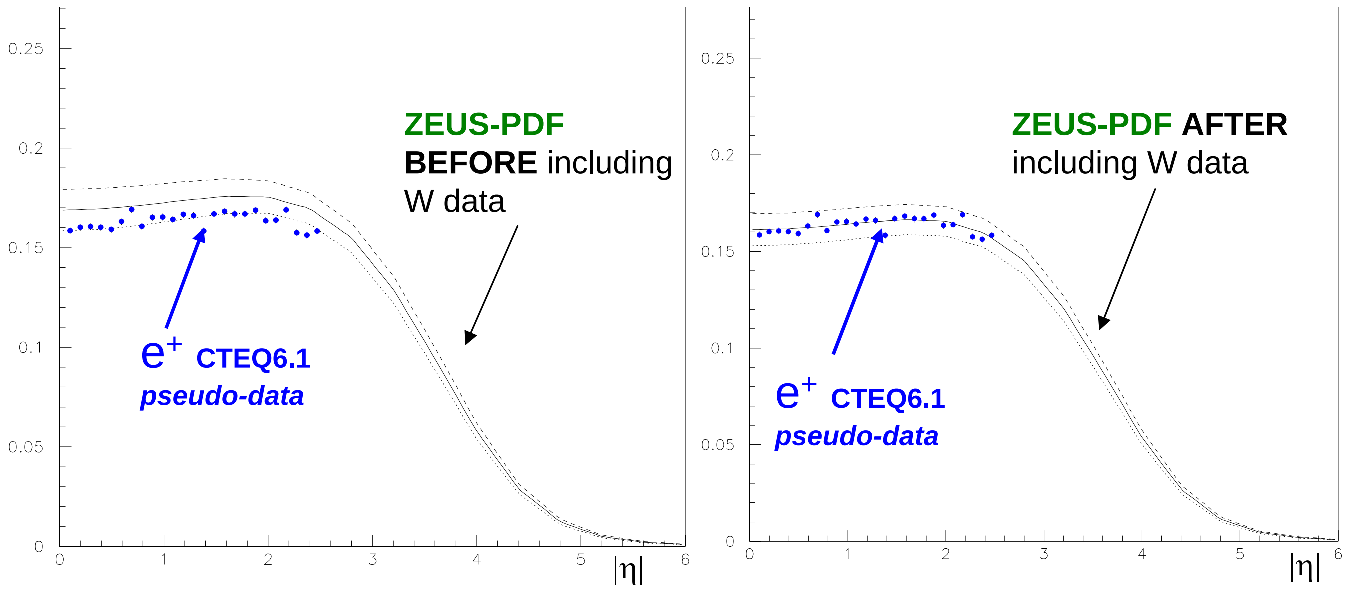
- Background contribution studied, negligible after cuts
- Effect of charge misidentification studied with full simulation Z events:

0.3-0.5% effects observed which can be corrected for using data

PDF constraining potential of ATLAS

Exercise: generate 1M ATLAS pseudo-data (ATLFAST) with CTEQ6.1 PDF's, correct back for acceptance effects, and include in ZEUS PDF fit

Statistics corresponds to $\sim$100-200 pb^{-1}



To simulate experimental uncertainties impose a 4% random error on data points

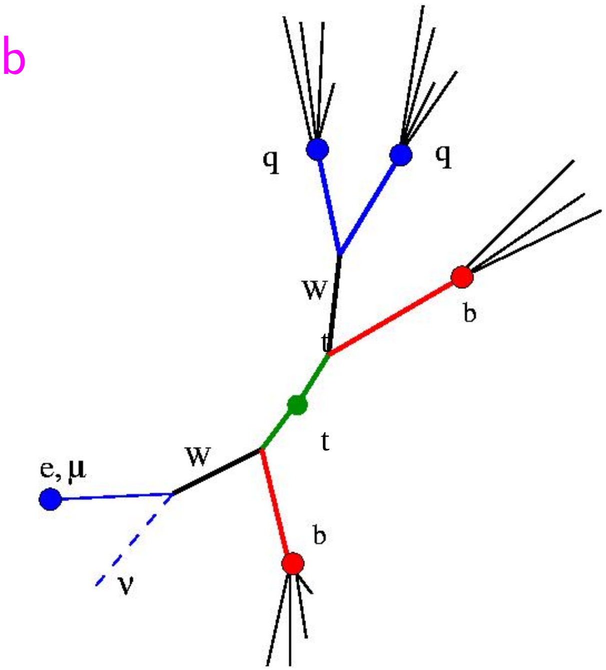
Low-x gluon distribution determined by shape parameter λ $(xg(x) \sim x^{-\lambda})$

Observe 35% error reduction λ when ATLAS pseudo-data included in fit

Early top physics in ATLAS

Top production is ideal laboratory for initial studies

Very high cross-section at the LHC: $\sigma_{\bar{t}t} = 830$ pb



Semi-leptonic signature: $\bar{t}t \rightarrow b\ell\nu bqq$:

Easy to trigger on and to extract

involves many detector signatures:

lepton-id, $\not{E}_T$, Jet reconstruction and calibration, b-tagging

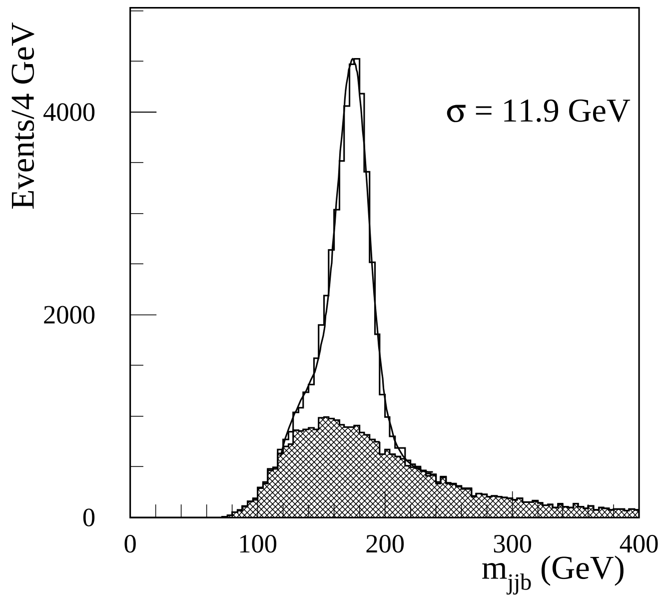
Three main aspects of early top studies:

- Initial measurements of mass, σ_{tt}, possible deviations due to new physics
- Use as a calibration tool
- Learn how to control top as a background

Statistical uncertainties on σ and mass

Standard ATLAS TDR analysis: require:

- $P_t(lep) > 20$ GeV
- $\not{E}_T > 20$ GeV
- ≥ 4 jets with $P_T > 40$ GeV
- ≥ 2 b-tagged jets
- $|m_{jjb} - < m_{jjb} > | < 20$GeV



For initial run:

$\mathcal{L} = 10^{33}$ cm^{-2}s^{-1}

Time	Events	dM_{top} (stat)	$\delta\sigma/\sigma$ (stat)
1 year	3×10^5	0.1 GeV	0.2%
$\sim$ month	7×10^4	0.2 GeV	0.4%
$\sim$ week	2×10^3	0.4 GeV	2.5%

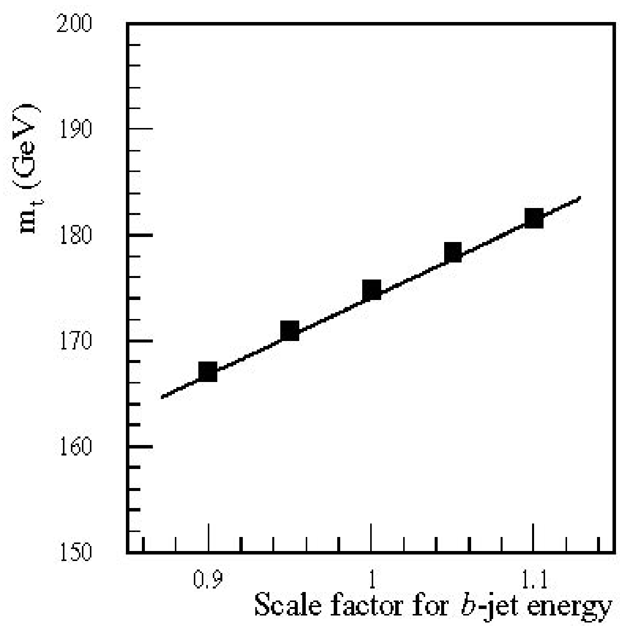
Systematic error on M_{top} (TDR performance, 10 fb^{-1})

Source of uncertainty	Hadronic part δM_{Top} (GeV)	Kinematic fit δM_{Top} (GeV)	Comments
Light jet energy scale	0.9	0.2	1% error
b−jet energy scale	0.7	0.7	1% error
b−quark frag.	0.1	0.1	(ε_b=−0.006)−(ε_b=−0.035)
ISR	0.1	0.1	20%(ON−OFF)
FSR	1.9	0.5	20%(ON−OFF)
Combinatorial Bkg	0.4	0.1	
Total	2.3	0.9	

Initial performance: uncertainty on b-jet scale dominate

cfr: 10% on q-jet scale → 3 GeV om M_{top}

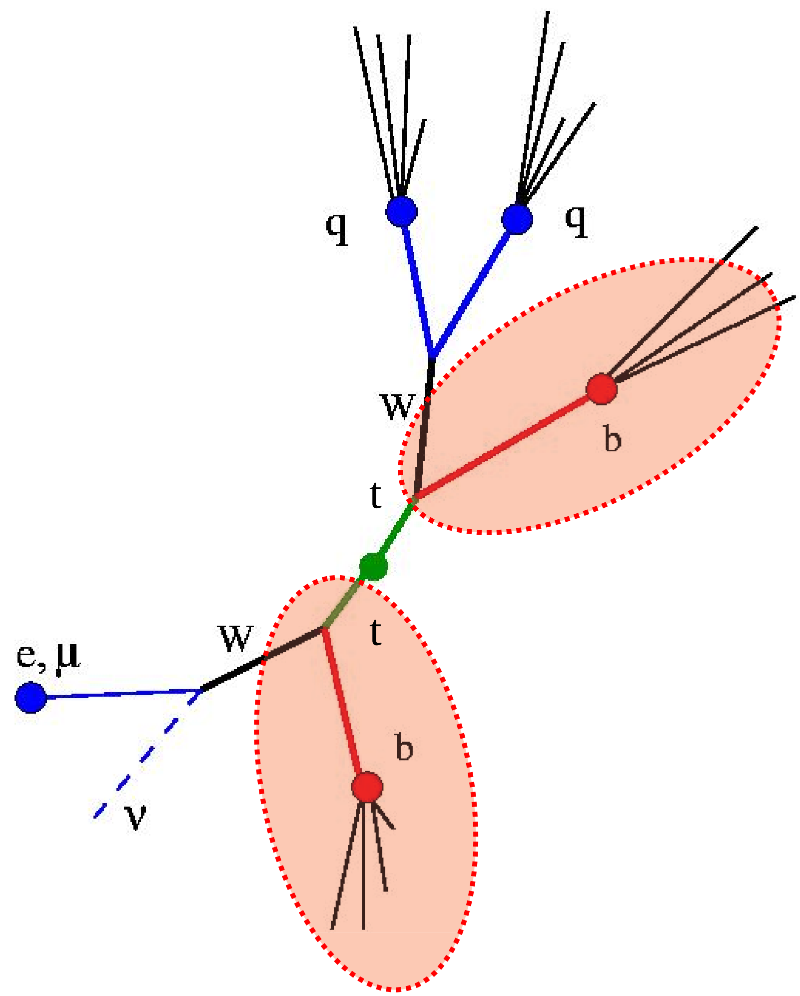
b-jet scale uncertainty	dM_{top}
1%	0.5 GeV
5%	3.5 GeV
10%	7 GeV



What can we learn from $t\bar{t}$ production (1)

Abundant clean source of of b jets

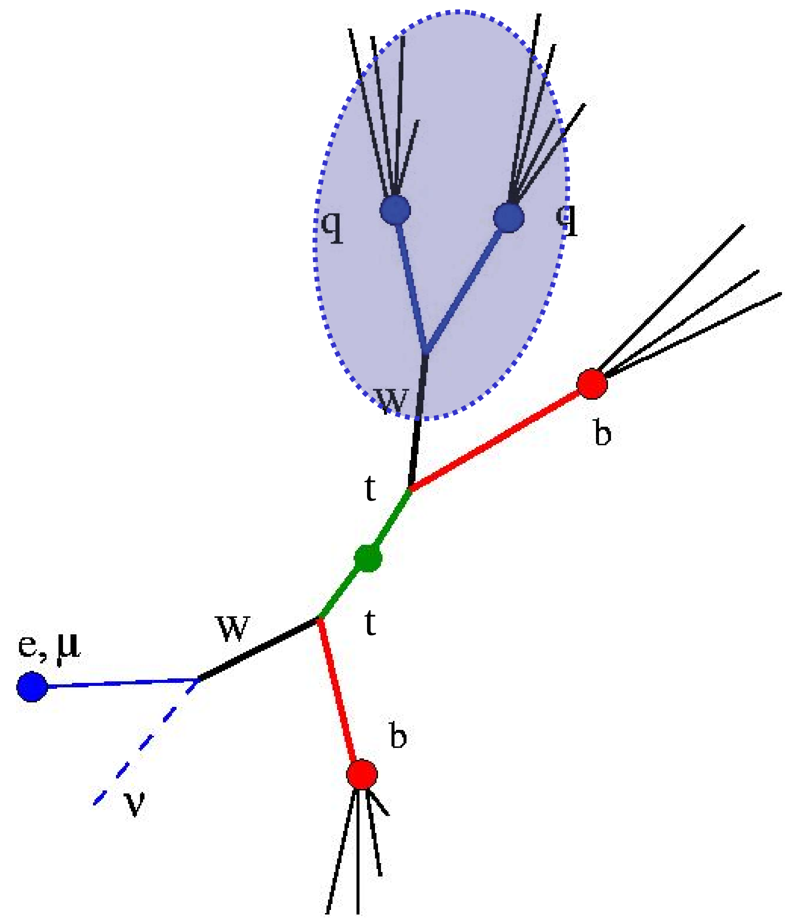
- 2 out of 4 jets in events are b jets $\Rightarrow$ O(50%) a priori purity (need to be careful with ISR and jet reconstruction)
- Remaining two jets can be kinematically identified (should form W mass) $\Rightarrow$ possibility for further purification



What can we learn from $t\bar{t}$ production (2)

Abundant source of W decays into light jets

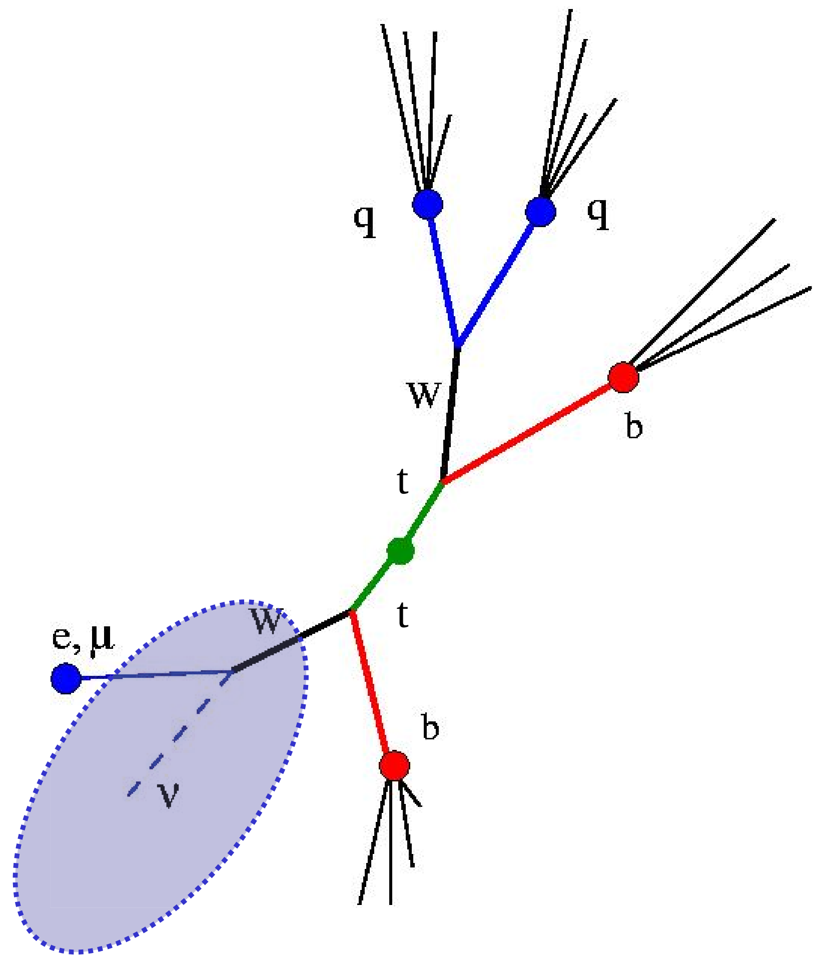
- Invariant mass of jets should add up to well known W mass
- Suitable for light jet energy scale calibration (target 1%)
- Need some level of b-tagging to reduce combinatorial to W jet assignment
- Only decay of a high mass resonance in jet jet easily selectable with good purity at the LHC



What can we learn from $t\bar{t}$ production (3)

Known amount of missing energy

- 4-momentum of single neutrino in each event can be constrained from event kinematics
- Inputs to calculation:
  - $m(top)$
  - b-jet energy scale
  - lepton energy scale



Commissioning scenarios

Nominal performance of b-tagging only can be achieved for an alignment of the pixel system of order 5 μm

Several months required to achieve this level of alignment

Top events can be used to monitor the efficiency of b-tagging: study whether a clean sample of top events can be isolated from background without requiring b-tagging

- Base analysis on simple cuts
- Use high multiplicity in final state
- hard p_T cuts to clean sample and minimize contribution of additional jets

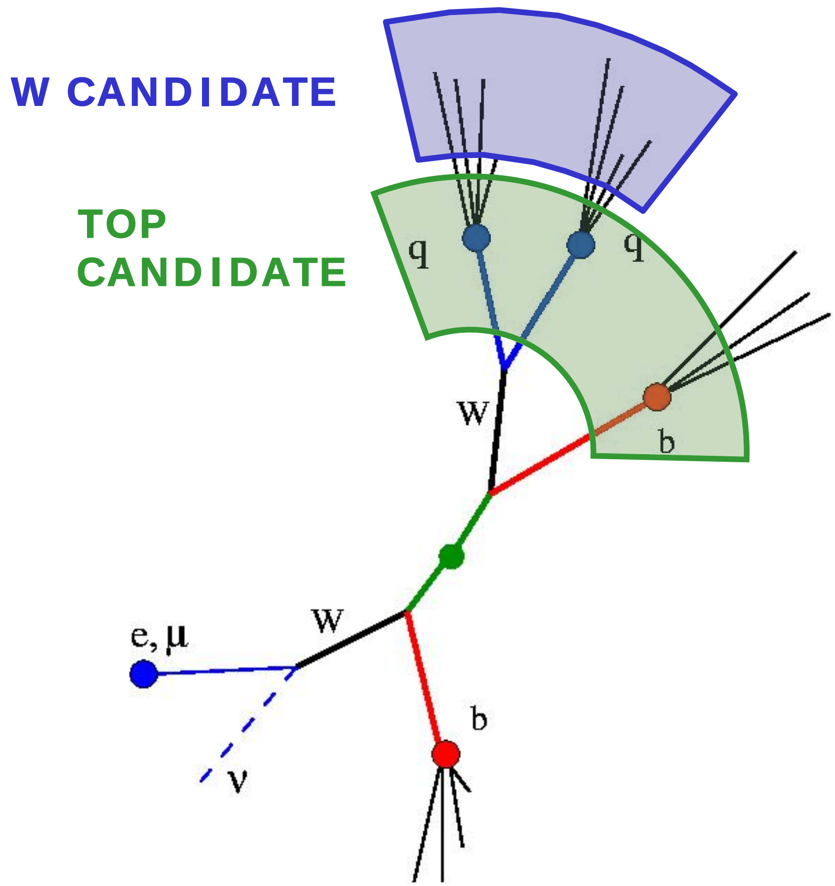
Possible because of high production rate: event with a 5% selection efficiency still have ∼10 events/hour at 10^{33}

Full simulation study by the ATLAS NIKHEF group

Analysis without b-tagging

Selection criteria:

- $\not{E}_T > 20$ GeV
- 1 lepton with $p_T > 20$ GeV
- 4 jets ($\Delta R = 0.4$) with $p_T > 40$ GeV



Assign jets top W, top decays

Hadronic top:

Three jets with highest $\Sigma \vec{p}_T$ as top decay products

W boson:

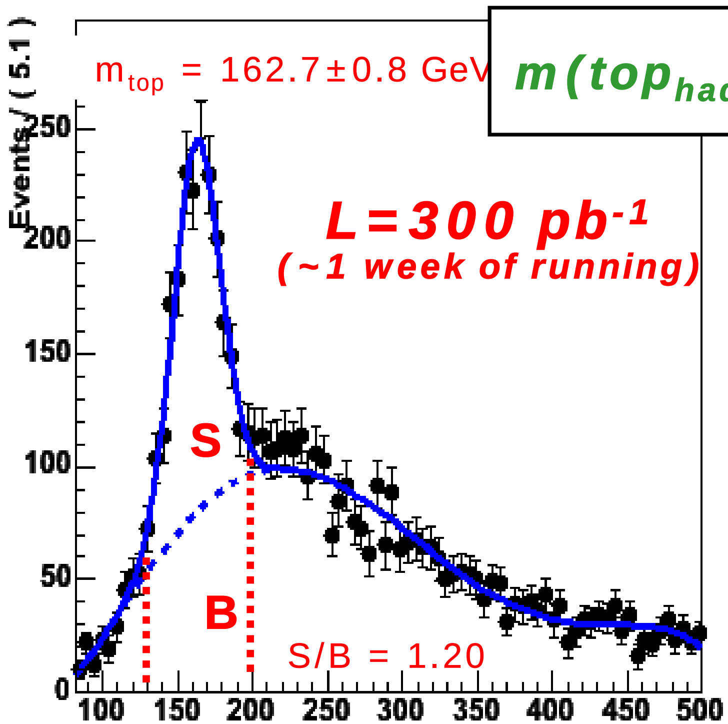
Two jets in hadronic top with highest momentum in reconstructed jjj C.M. frame

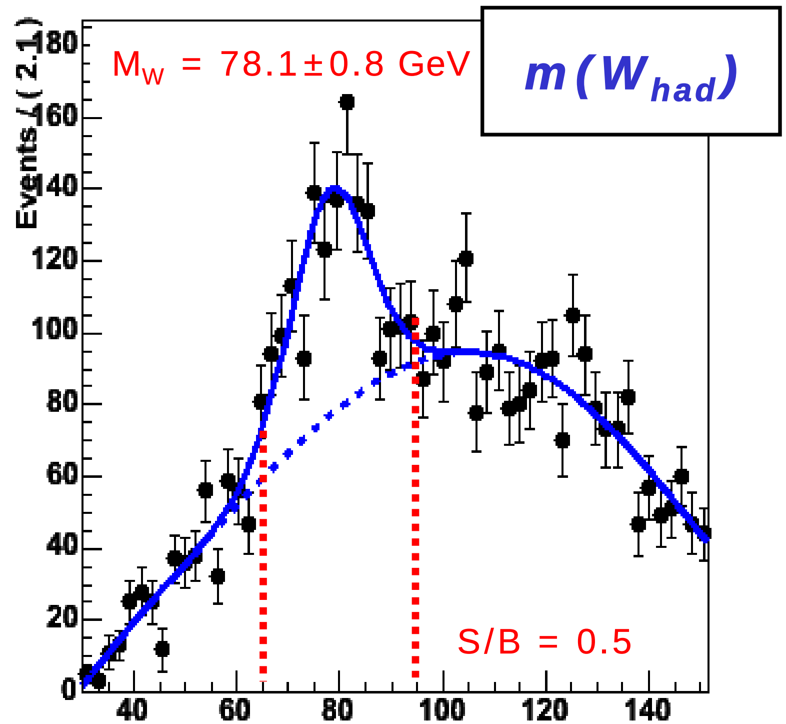
Signal-only distributions

Clear top, W mass peaks visible

Background due to mis-assignment: easier to get top than W assignment right

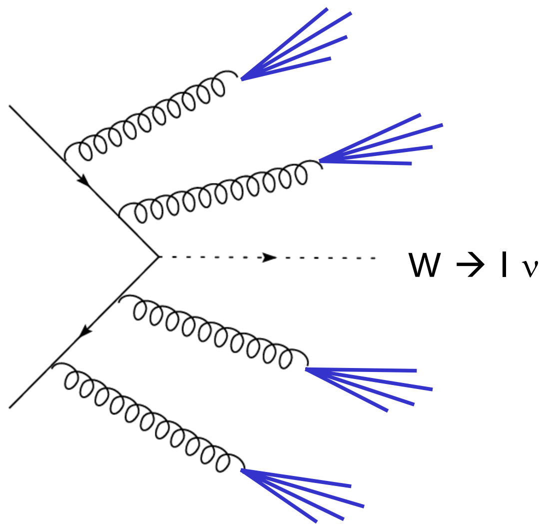
Masses shifted somewhat low: effect of imperfect energy calibration





Background sources

W+4jets (largest bkg)

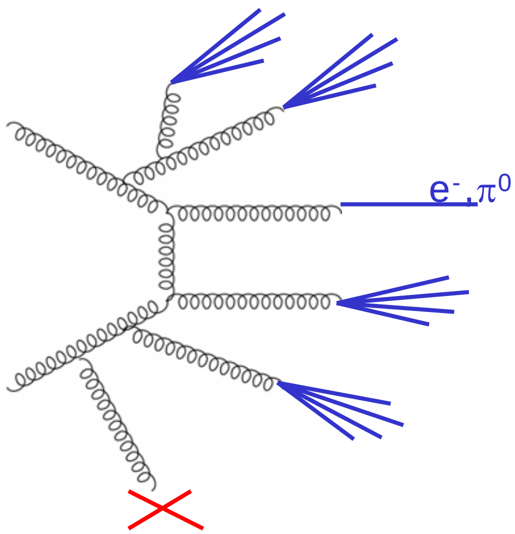


High multiplicity of hard jets

Not reliably simulated by PS generators (PYTHIA+Herwig)

Use ALPGEN generator

QCD multi-jet events



Can simulate signal if one jet mismeasured or lost ($\not\!\!E_T$) and one jets mimics electron

Cross-section large and not well known

Rely on good lepton-id and good $\not\!\!E_T$ measurement to suppress. Not further considered in analysis

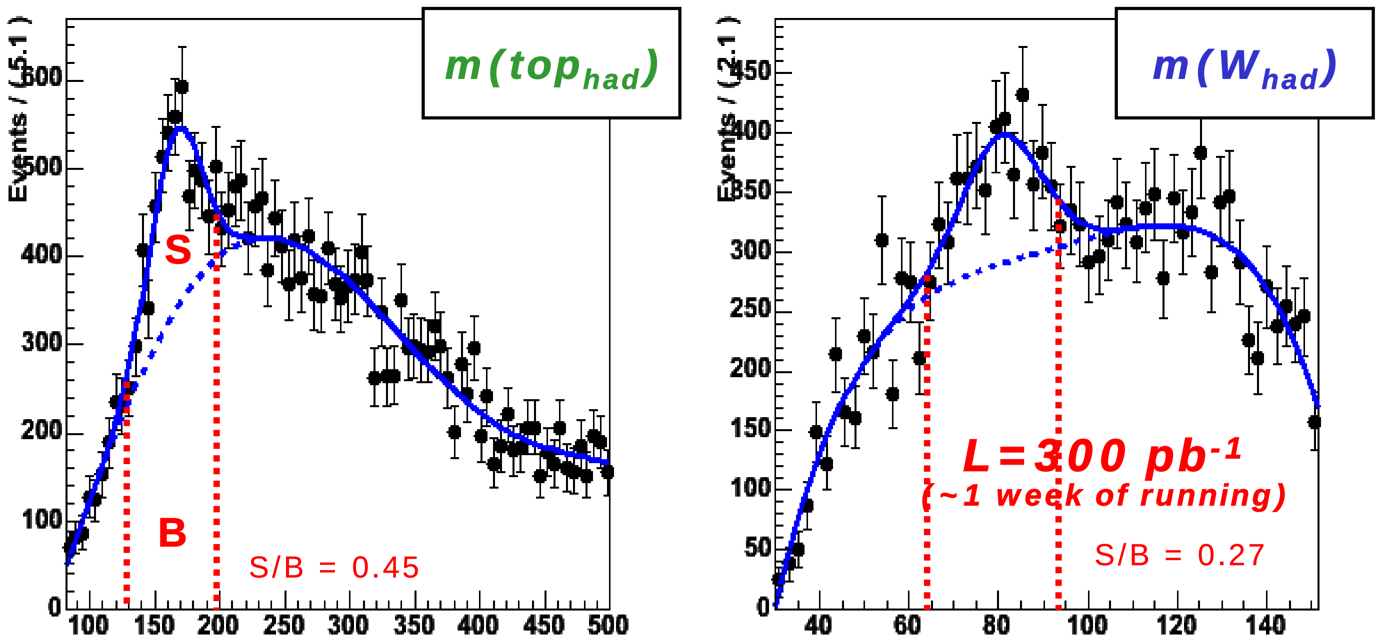
Signal + W+jets background

Preliminary plot:

background too high by factor two (norm. mistake), $W+$ n-jet matching not included

Signal still well visible, large theoretical uncertainty on background

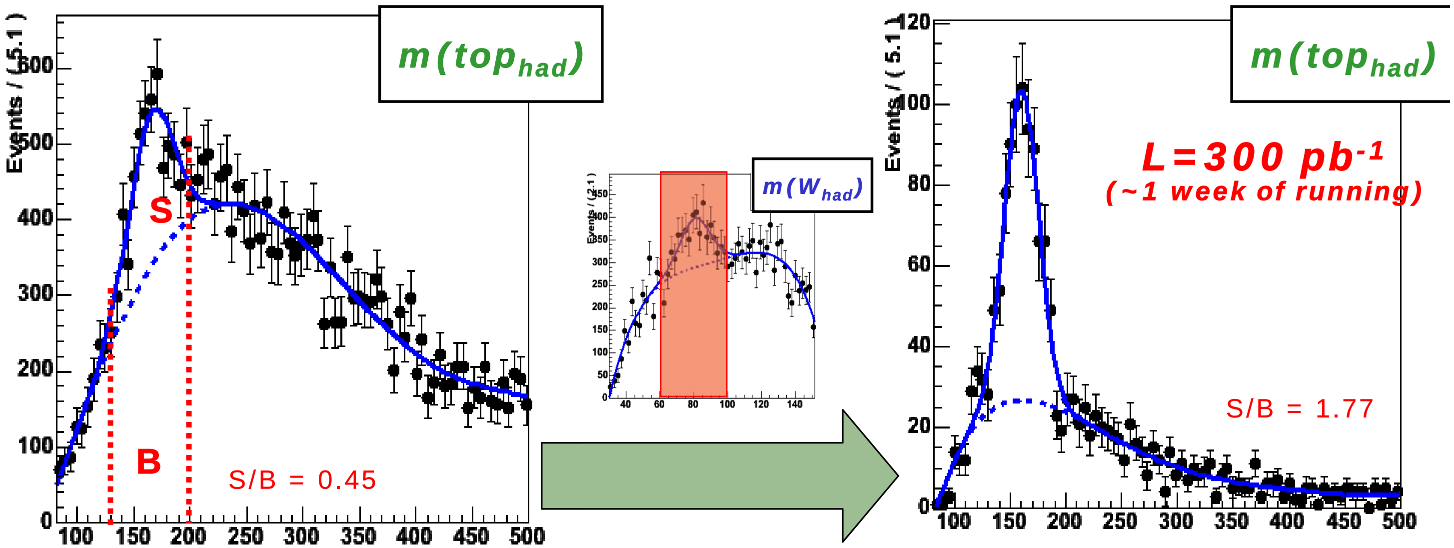
Will need to use data (esp. $Z+$jets) for background normalisation



Signal + W+jets background

Exploit correlation between $m(top_{had})$ and $m(W_{had})$ to clean top signal

Show $m(top_{had})$ only for events with $|m(jj) - m(W)| < 10$ GeV



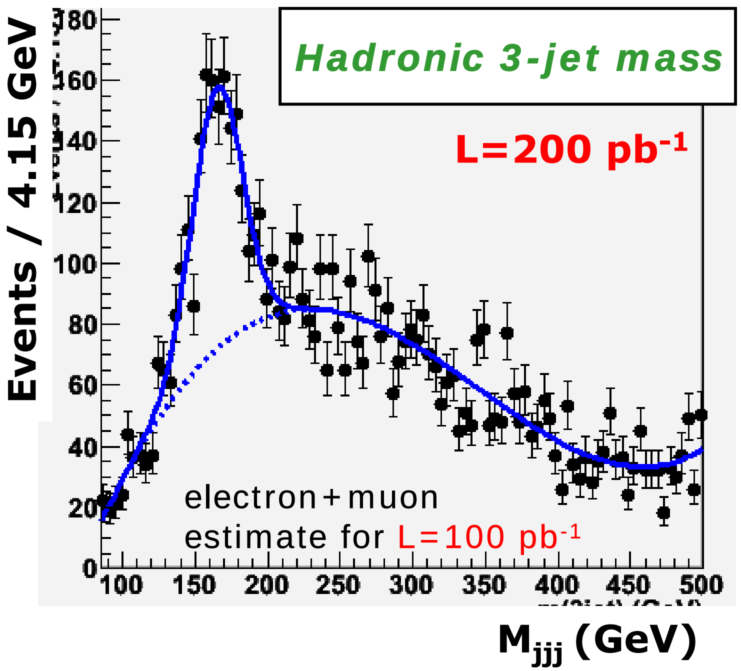
Expect a statistical error on cross-section between 5 and 10%, depending on cuts

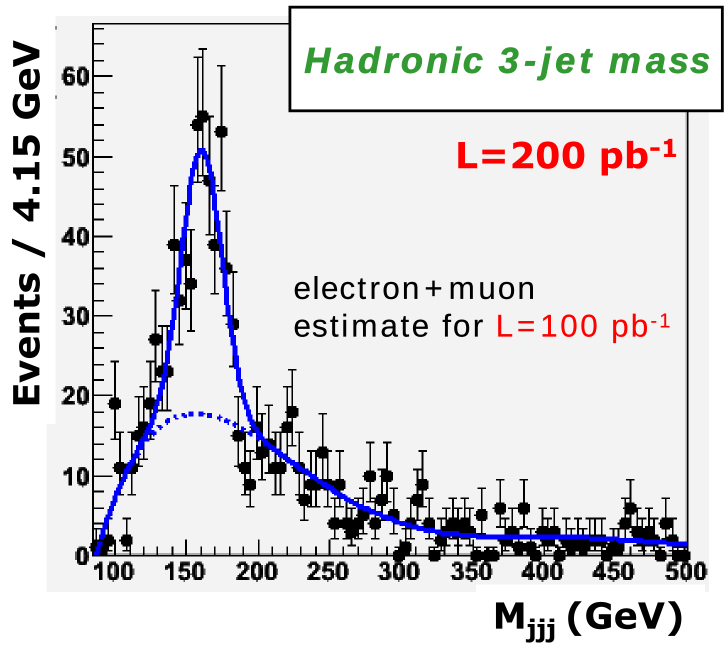
Error on $m(top)$ already dominated by systematic effects

Lower statistics?

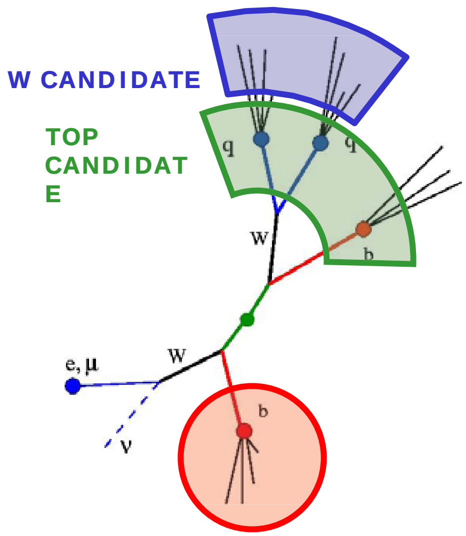
Same as previous slide only for 100 pb^{-1} (2007?)

For these plots background correctly normalised (factor $\sim$2 smaller), and jet matching procedure applied on ALPGEN (+10%)





Still clear top signal with reasonable statistics



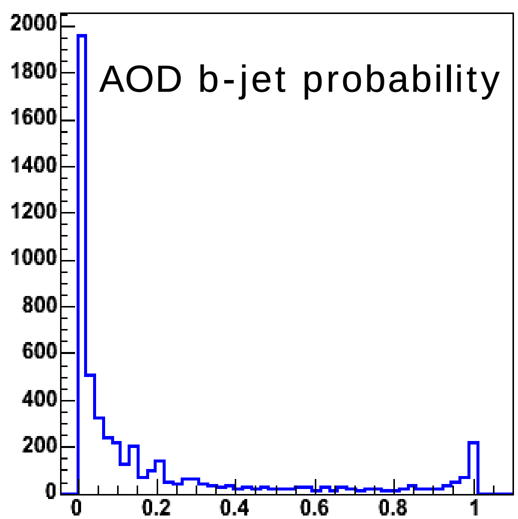
Using ttbar events: b-jet selection

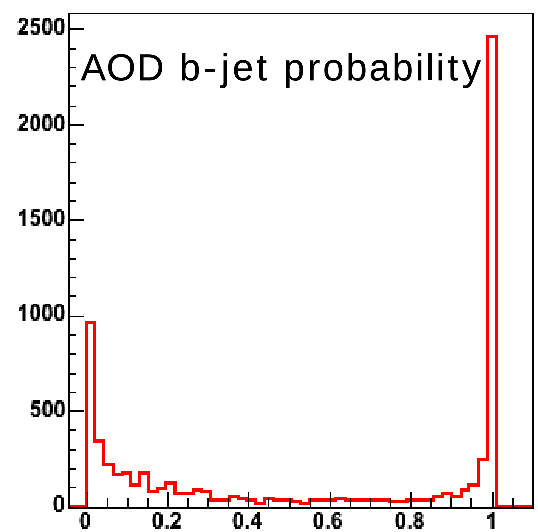
Simple exercise to verify enrichment of b jet sample:

Cut on $m(W_{had})$ and $m(top_{had})$ masses

Look at b-jet probability for 4^{th} jet

(Must be b-jet if all assigmments correct)





Left: random jet from $W+$ jets bg, Right: 4^{th} jet in ttbar

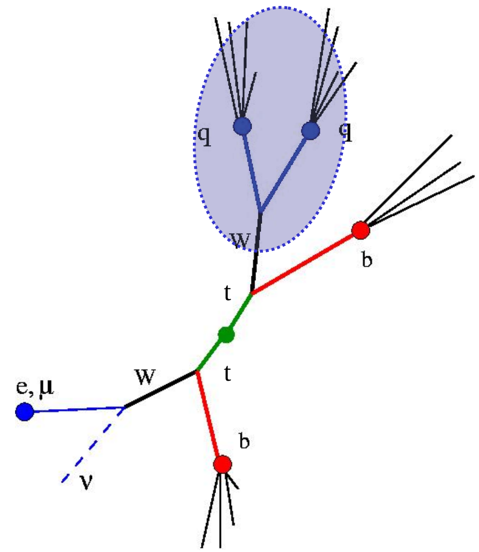
Clear enhancement observed

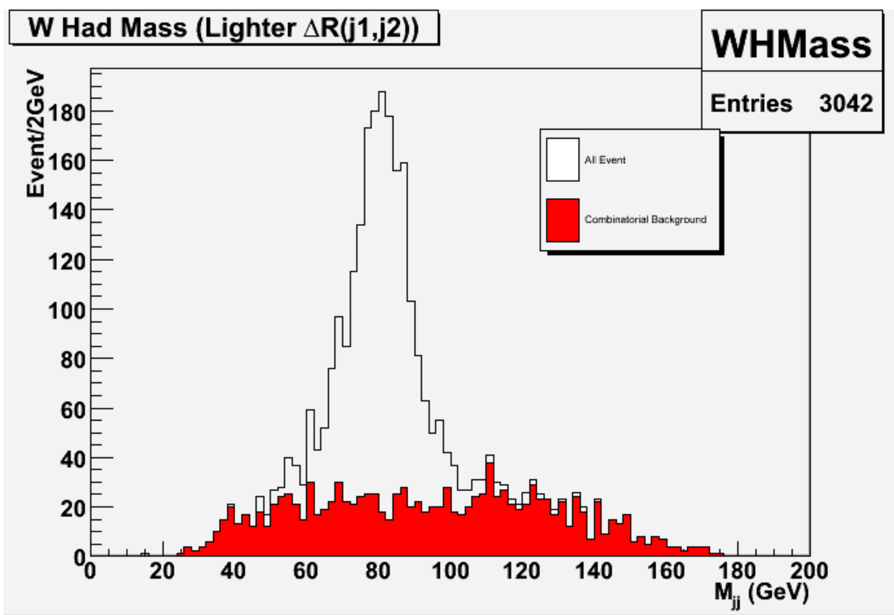
Using ttbar events: jet energy scale from W

Preliminary exercise on ATLAS full simulation (D. Pallin)

Use top semileptonic decay: select two light jets from W decay, and calibrate to W mass

Selection with 1 or 2 b tags Typically 3000(6000) W/fb^{-1} for 2(1) b-tag, $\epsilon_{btag} = 60\%$





Using both b-tagging and kinematic constraints achieve purity of 80-90%

W mass distribution ATLAS full simulation, 500 pb^{-1} stats.

Cover jet energies fro 40 to 400 GeV

Naive approach

Correction factor as a function of jet energy: $\frac{E^{parton}}{E^{jet}} = \alpha(E^{jet})$

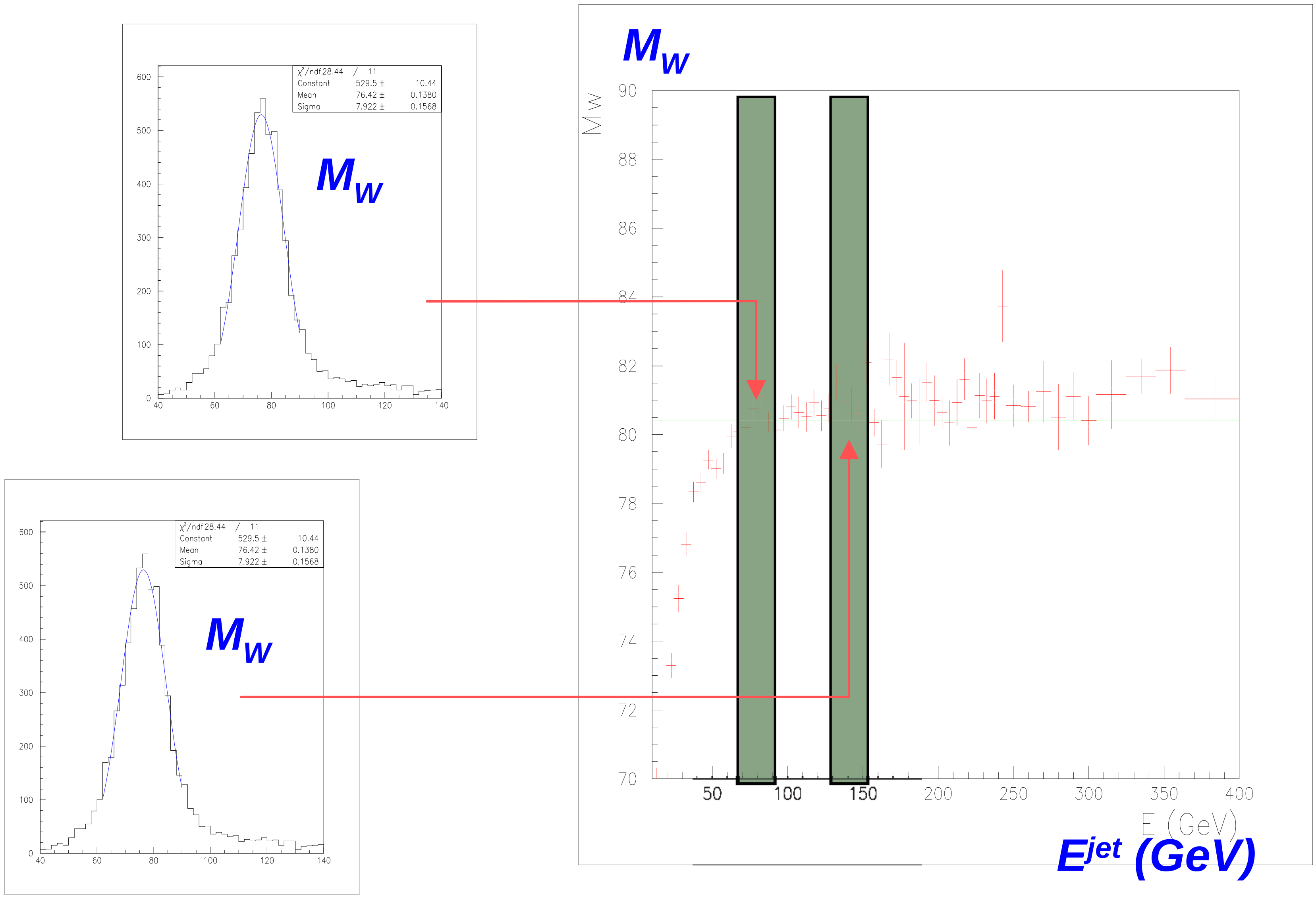
$$M_W^2 = 2E_{j1}E_{j2}(1 - \cos\theta_{j1j2})$$

Assume $\cos\theta_{j1j2}$ measured correctly, take $E_i = \alpha(E_i)E_{ji}$ with E_i partonic energy

The master formula becomes:

$$M_W^{PDG} = \sqrt{\alpha_1\alpha_2}M_W$$

- No hypothesis on function α, no MC
- Build W mass distributions in bins of jet energy
- Extract peak values for each bin
- Deduce $\alpha(E)$ from $M_W(E)$



χ^2/ndf 28.44 / 11
Constant 529.5 ± 10.44
Mean 76.42 ± 0.1380
Sigma 7.922 ± 0.1568
M_W
χ^2/ndf 28.44 / 11
Constant 529.5 ± 10.44
Mean 76.42 ± 0.1380
Sigma 7.922 ± 0.1568
M_W
M_W
Mw
E (GeV)
E^{jet} (GeV)

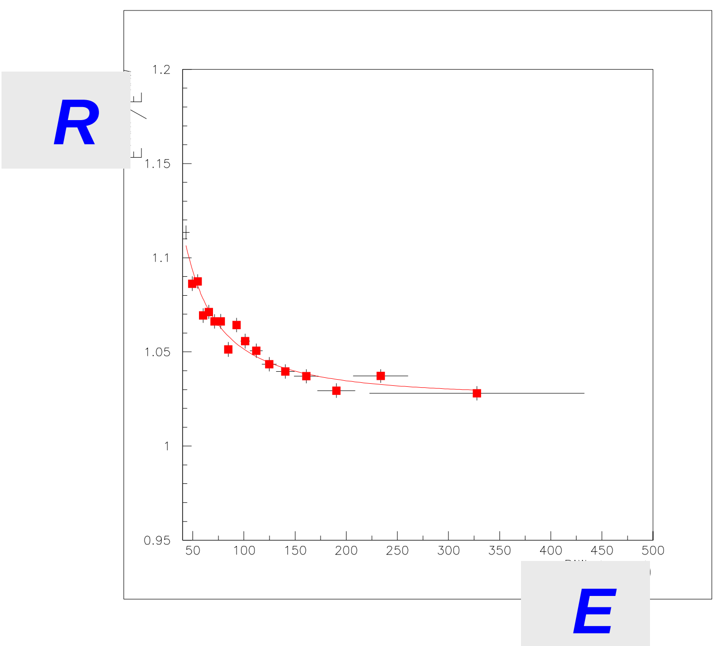
Implementation

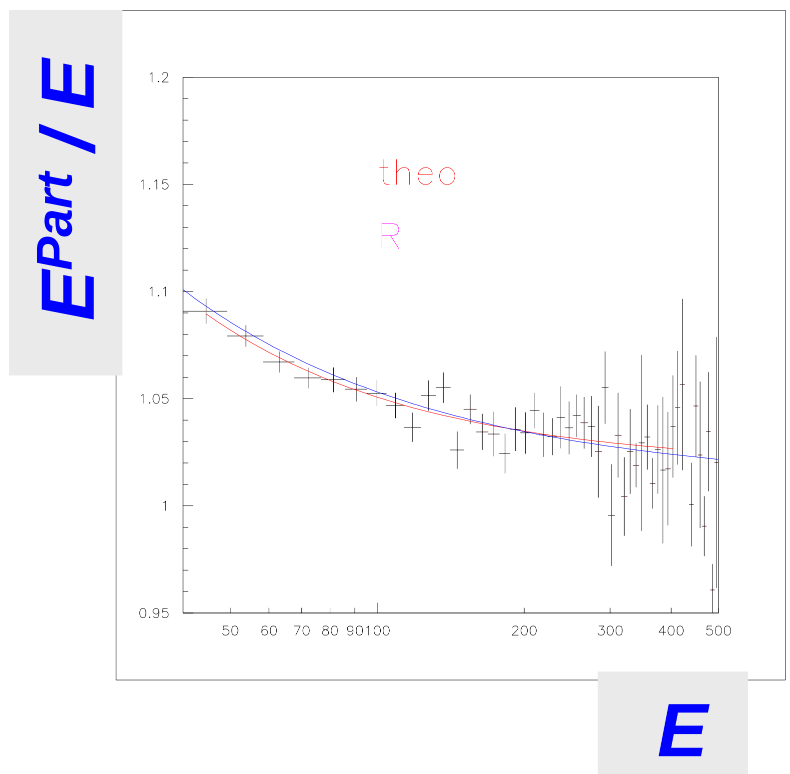
Need to correct effect of up to 10% for low jet energies

Various possible approaches to extract α:

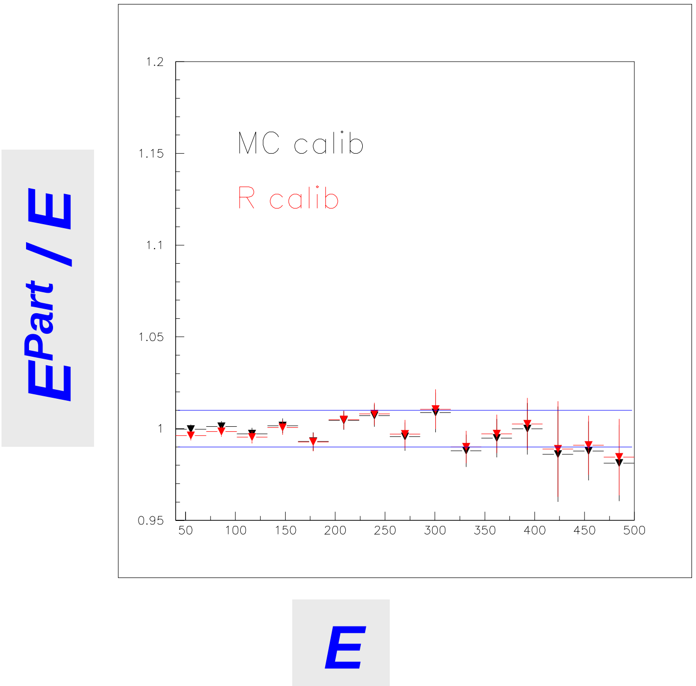
- Iterative procedure on $\alpha = < \alpha_1 \alpha_2 >$
- Full χ^2 fit to α_1, α_2

Similar results: build a calibration function which reproduces the input function calculated from truth (theo)





Results

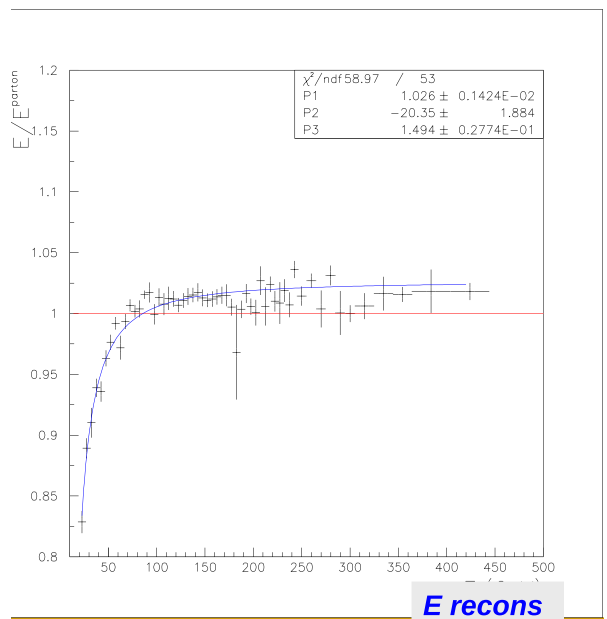


Calibration with W has potential of achieving calibration at the level of 1% for a statistics of 1 fb^{-1}

Need to study dependence on calibration on procedure

Observe biases when E_{jet}/E_{part} studied as a function of reconstructed jet energy assuming perfect calibration

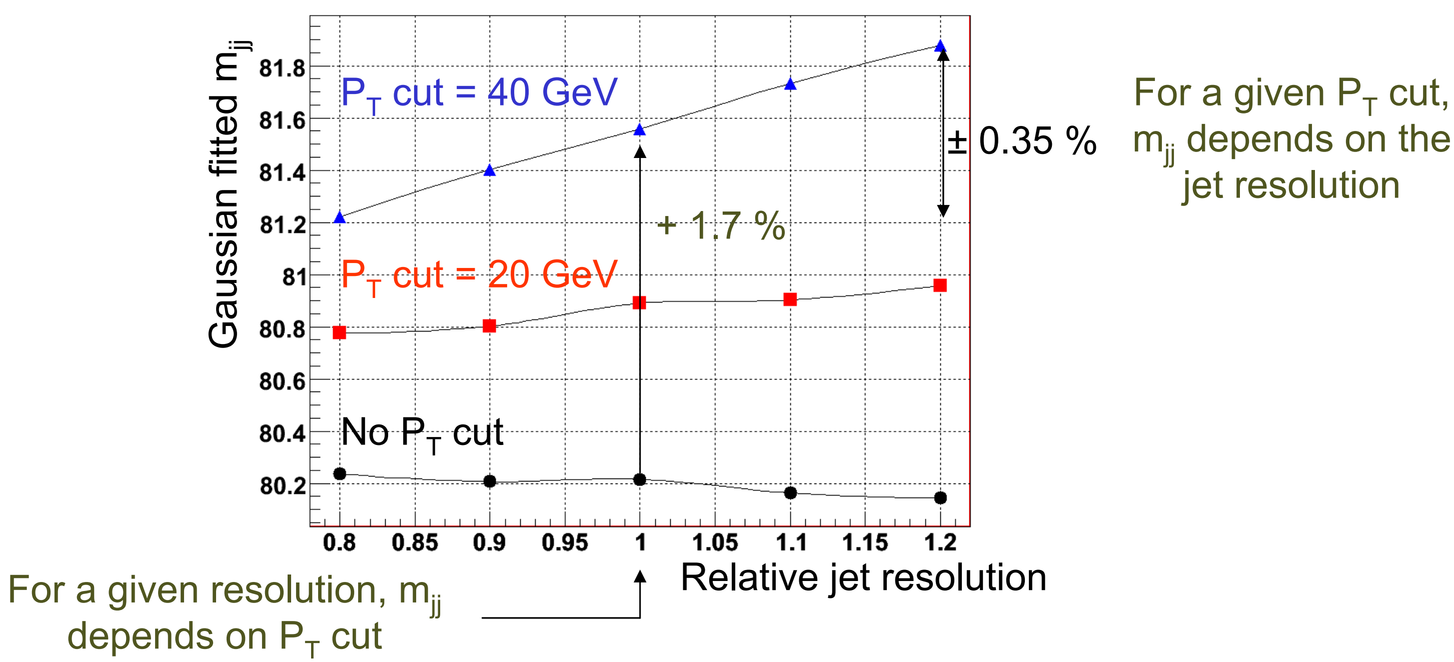
Effect caused by binning in energy: can be corrected if excellent understanding of jet resolution



Systematic effects

Two main sources of systematics being studied (Saclay group):

- Dependence on selection cuts applied to define the W sample
- Dependence on assumed jet resolution, skewing the lower energy jets



More sophisticated methods being developed to take into account these effects

Conclusions

LHC startup will require a long period of development and understanding for both machine and detectors

Detailed commissioning plan for detectors: plan to achieve baseline 'reasonable' calibration and alignment before collisions using cosmics and machine development periods

As soon as interactions at 14 TeV happen, interesting physics available in data

Parallel processes of using data to further 'technical' detector understanding and to perform benchmark SM physics measurements

Goal is to arrive at high statistics (few fb^{-1}) data-taking ready to go for early discovery physics

Main opportunity: SUSY searches. Tomorrow's seminars