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PRECISION MEASUREMENTS (?) WITH ATLAS

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Many physical quantities (masses, asymmetries, couplings) can be accessed at the LHC with unprecedented statistical precision. Most often however, uncertainties related to the initial state of the reaction and to the absolute scale of the measured particle momenta severely restrict the physical interpretation of the results. This contribution breifly reviews the current situation, and outlines a few recent ideas that may improve the situation.

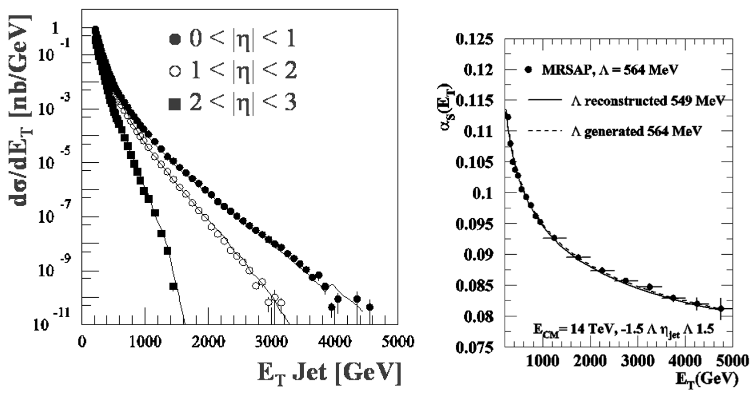
1 Precision measurements menu

The ATLAS experiment at the LHC will provide precise data on many subjects, including electroweak measurements and properties of the strong interaction. A few of them are mentioned below (all results are taken from [1]).

Jets and the strong coupling constant - Events with QCD jets will be produced copiously. The inclusive jet cross-section with $E_T > 200$ GeV is $\sim$10 nb. The dijet cross-section is $\sim$15 pb above $E_T >$1 TeV, providing 4×10^5 events per year; still 40 events are expected when $E_T > 3$ TeV. The triple differential dijet cross-section, $d\sigma/dE_T d\eta_1 d\eta_2$, can be measured with high precision for E_T ranging from $\sim$40 GeV to 4 TeV, and allows to extract the strong coupling constant, α_s. Over this range, the running of α_s reaches 30% and can be observed accurately, as illustrated in Figure 1. The scope of an absolute measurement of α_s is however limited by the knowledge of the jet energy scale and unknown higher order effects, and will not compete with the measurements performed in deep inelastic scattering or e^+e^- collisions.

Heavy quark production (including the top quark) - The inclusive c and b quark cross-sections are about 10^5 nb, providing of the order 10^{12} events per year, which can be selected using soft muons or displaced vertices. The process gQ$\rightarrow \gamma$Q (where Q = b, c) allows to probe the heavy quark content of the proton, in the range $10^{-4} < x < 10^{-1}$, with high statistics. The precision on the pdf's extracted from the heavy quark sample is however again limited by the knowledge of the jet energy scale.
About 10^7 top quark pairs will be produced per year. The semi-leptonic decays will be used to measure the top quark mass mass, with an expected precision of about 1.5 GeV. The final uncertainty comes mainly from the imperfect description of final state radiation and from the jet energy scale.
Because of its high mass (hence the relatively small value of the strong coupling),

Figure 1. *Left* : Inclusive jet differential cross-section. *Right* : Running of the strong coupling constant, as extracted from the triple differential dijet cross-section $d\sigma/dE_T d\eta_1 d\eta_2$.



the top quark pair production cross-section, dominated by $gg \to t\bar{t}$, is a well predicted observable. Its measurement thus provides an important test of perturbative QCD. The size of the sample allows a very good statistical precision; however, the uncertainty on the integrated luminosity (optimistically 5%, using standard methods) degrades the result.

W-mass measurement - The selection of leptonic W events relies on the detection of isolated leptons (electrons or muons), satisfying $p_T > 25$ GeV, and $|\eta| < 2.5$, large missing transverse energy ($E_T > 25$ GeV), and the absence of high energy jets. The signal efficiency is about 20%, and considering an inclusive W cross-section of $\sim$140 nb, about 60×10^6 events are expected per year at low luminosity. This sample is about a hundred times larger than what can be expected from the Tevatron Run II. The W mass can be extracted from the W transverse mass spectrum, and from a number of other methods, all of which are familiar from the Tevatron. A target precision for the LHC is $\Delta M_W = 20$ MeV, where the most important uncertainties are the lepton momentum scale and the theoretical knowledge of final state radiation.

2 Systematic effects.

As discussed above, the experimental results are almost invariably dominated by systematics (this is illustrated in Table 1 for a few observables). Indeed, the statistical precision on the measurements are most often a factor 10 below the systematic uncertainties. This situation is somewhat frustrating, but the numbers also indicate what could be gained from improved theroretical predictions and precise experimental calibrations.

Concerning theoretical uncertainties, recent progress has been made in improv-

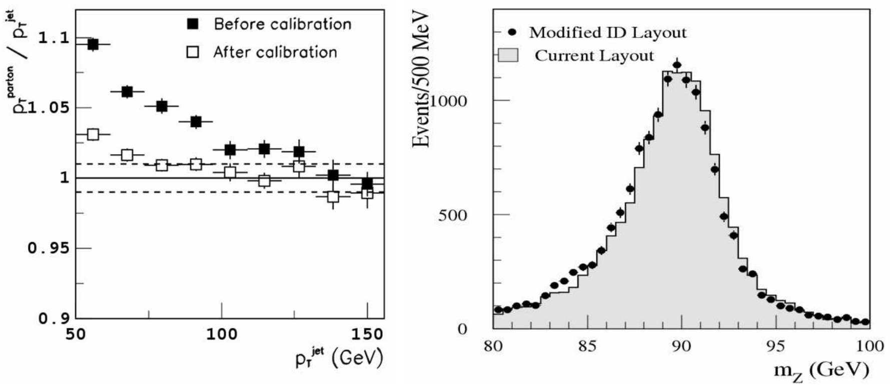
Table 1. Overview of a few measurements : expected statistical and systematic uncertainties.

Observable	Stat. unc.	Syst. unc.	Main contribution
M_W	1 MeV	20 MeV	Lepton p scale $\pm$ 0.02% ($\rightarrow$ 15 MeV)
M_t	0.1 GeV	1.5 GeV	FSR $\pm$ 10% ($\rightarrow\sim$1 GeV), Jet scale $\pm$ 1% ($\rightarrow\sim$0.7 GeV)
$\sigma_{t\bar{t}}$	$<$ 1%	6%	Luminosity $\pm$ 5% ($\rightarrow$ 5%)
α_s	$<$ 1%	10%	pdf's and ren. scale ($\rightarrow$ 7%)

ing the description of final state radiation. On the QCD side, it is now possible to interface parton shower algorithms with next-to-leading order matrix elements [2], and with higher order tree level processes [3]. Concerning QED, multiple photon emission in vector boson decays has recently been implemented [4]. Thus, 10% uncertainty on this effect now appears as a conservative estimate.

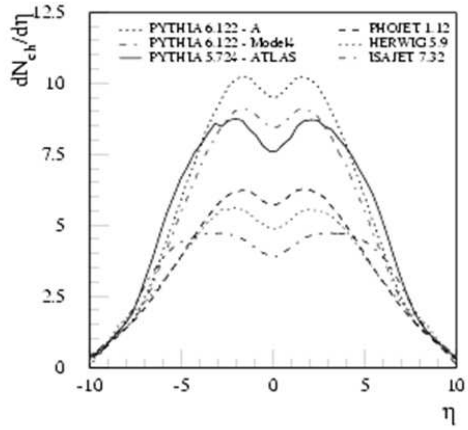
Energy scale determination is a matter that requires excellent understanding of the experimental setup. The jet energy scale is anticipated to be extracted from hadronic W decays in $t\bar{t}$ events, where the W mass is used as a constraint (see Figure 2). It is however crucial to dispose of independent processes, like Z+jet production, where the jet p_T is correlated to that of the Z, to verify that a consistent jet scale can be defined and used in independent measurements. Similarly, the lepton momentum scale can be extracted from leptonic Z decays, using the Z mass as a constraint (see again Figure 2).

Figure 2. *Left* : Ratio of the jet energy to the underlying parton energy, before and after calibration using hadronic W decays. *Right* : Impact of varying the amount of passive material in front of the calorimeter on the reconstructed Z resonance lineshape. The position of the peak is very weakly affected.



Another ingredient of jet energy scale determination is good knowledge of the pedestal above which the signal is observed, i.e the amount of spectator energy that fills the detector and has to be subtracted from a measured jet. As Figure 3 indicates, the theoretical predictions differ significantly, and only data taken *in situ* will constrain the models. ATLAS currently prepares an interaction trigger which will be included in its start-up configuration [5]. This system will allow ATLAS to trigger on low-momentum tracks as soon as the LHC provides the first collisions, so this question can be solved early.

Figure 3. Different predictions for the charged particle multiplicity vs. η, for minimum bias events.



Finally, another contribution to this conference describes an dedicated luminosity measurement program recently proposed by ATLAS [6]. The method to measure the delivered luminosity exploits elastic *pp* scattering in the Coulomb region. The goal is a precision better than 2%, significantly improving cross-section measurements.

3 Summary

With current understanding, the measurements that will be provided by the LHC experiments have uncertainties that are dominated by systematic effects, from both theoretical and experimental origin. Recent progress however suggests that the situation may be improved in the future, and that the accuracy could be better than what is generally quoted.

References

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