PROTON STRUCTURE FROM HARD SCATTERING PROBES AT THE LHC: FIRST STUDIES OF THE ATLAS AND CMS POTENTIAL

WALTER BONIVENTO [a]
European Laboratory for Particle Physics (CERN),
CH-1211 Geneva 23, Switzerland

One important ingredient to cross section calculations for signal and background processes at the LHC is the knowledge of the parton distribution functions (PDFs) of the proton. I discuss here the possibility of extracting informations on the PDFs from the study of some final states at the LHC itself.

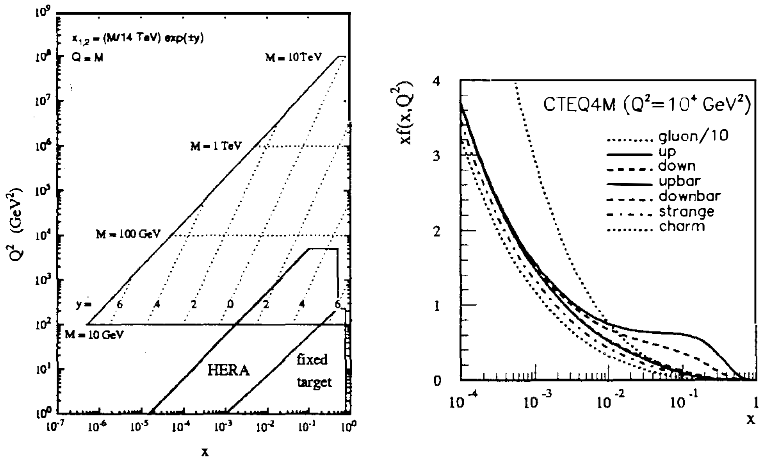
1 The LHC collider and detectors

The LHC is designed as a 7+7 TeV pp collider, with an instantaneous luminosity at the interaction points of $\mathcal{L} = 10^{34} cm^{-2} s^{-1}$, corresponding to an integrated luminosity of 100 fb^{-1}/year. For the first three years it is foreseen to run with the luminosity reduced by a factor ten.
The main purposes for which it is built are the search for Higgs boson, SUSY particles and, more generally, physics beyond the Standard Model. Many other studies will also be performed such as in QCD, Electro-Weak, b and t quark physics. Two multi-purpose detectors are being built: ATLAS and CMS. The main characteristics of the ATLAS detector, which I will mostly refer to, are photon and electron identification and measurements with high granularity, good energy and position resolution, muon identification and measurements and jet and E_T^{miss} measurements for $|\eta| < 2.5$. Calorimetric coverage is ensured up to $|\eta| = 5$.
Given the huge particle rates expected in the detectors, relatively high trigger thresholds in transverse energy E_T for single *objects* will be set: e.g. at high luminosity 30 GeV for electrons, 60 GeV for photons and 290 GeV for jets. Lower thresholds are envisaged with many particle triggers or with down-scaling.

[a] representing the ATLAS collaboration

2 Motivation

In the QCD improved parton model, for hard scattering processes, the cross section factorises into a hard core parton cross section, which is calculated in perturbative QCD, and the parton distribution functions (PDFs) of the two protons $f_{i,i=1,2}$, which are extracted from various measurements (usually at different Q^2) and evolved up to the Q^2 of the reaction under study using the DGLAP equation.
Of course the knowledge of cross sections for signal and background processes is an important pre-requisite for LHC phenomenology. Various systematic uncertainties affect the cross section predictions: PDFs, missing higher orders, efficiencies and luminosity (so far estimated in ATLAS to be measurable at the $\pm 5\%$ level; it is under study to improve over that). The statistical errors are often negligible.
Moreover there are studies for which the knowledge of PDFs is one of the most important systematic uncertainties, such as the W mass and the $sin^2\theta_W$ measurement from A_Z^{FB}.
Information on PDFs has been so far extracted from various measurements, in deep inelastic scattering (DIS), fix target Drell-Yan (DY) and $p\bar{p}$ data.
The kinematic range covered by the pp interactions at the LHC is shown in figure 1a) and an



(a) (b)

Figure 1: a) Kinematic range of the parton interactions at the LHC compared to that of Hera and fix-target experiments b) estimate of PDFs at $Q^2 = 10^4\ GeV^2$

example of estimate of PDFs at $Q^2 = 10^4\ GeV^2$ is shown in figure 1b).
In addition to improving the precision to which PDFs are known, measuring the PDFs directly at the LHC will allow to test the DGLAP evolution equation over a large Q^2 range, and possibly to perform measurement in x regions which are not accessible to DIS, if the measurement of jet and photons could be extended up to $|\eta| = 5$ (under study).

3 Light quarks DF

3.1 The present situation

The u and d DFs are determined from the measurement of $F_{2,3}$ in DIS to $\sim 3\%$ for $10^{-4} < x < 0.75$. The sea q and $\bar{q}$ DFs at low x are less precisely known.

3.2 The role of the LHC

For the determination of light q and $\bar{q}$ DFs the study of $W^+(W^-)$ production, which mainly proceeds through $u\bar{d}(d\bar{u})$ annihilation, was envisaged. Since $M_W^2 = sx_1x_2$, where s is the C.M. energy and $x_{i,i=1,2}$ the parton momentum fractions, then $x_1x_2 \sim 3.3 \cdot 10^{-5}$. The rapidity of the produced Ws is $y_W = 1/2 \cdot ln(x_1/x_2)$; therefore, as can be seen from figure 1b), for small y_W similar rates for W^+ and W^- are expected, while for large y_W the W^+ is expected to be more likely. Since the Ws decay weakly, the y_l distribution of their decay charged lepton maintain the same charge asymmetry. Therefore a measurement of the ratio of W^+ and W^- events as a function of y_l will be sensitive to the light q and $\bar{q}$ DFs in the range $3 \cdot 10^{-4} < x < 0.1$ for $Q^2 \sim 6 \cdot 10^3\ GeV^2$.
The similarity between single W production and W pair production has lead to the idea of using the single W process as a parton luminosity monitor for the other one. In this way one would get rid of the determination of the pp luminosity and the other uncertainties from missing higher orders and PDFs will also be reduced. A precision of $\pm 1\%$ on the WW cross section prediction might be achievable.

4 Gluon DF

4.1 The present situation

From data collected so far the uncertainty on $g(x, Q^2)$ was estimated to $< 15\%(10\%)$ at low (high) Q, except for $x < 10^{-4}$ and $x > 0.2$. One important issue at large x is the interpretation of inclusive jet cross-section measurements at the Tevatron, which might hint to a composite structure of the quarks.

4.2 Expected improvements before the LHC start-up

For the determination of $g(x, Q^2)$ at high x two main sources of information will be:

- di-jet, direct photons and DY cross sections at Tevatron Run II (2 fb^{-1}) and possible upgrades
- scaling violations of F_2 at HERA (150 pb^{-1}/year), possibly leading to $\Delta g/g \sim 3\%$ for $10^{-4} < x < 10^{-1}$

4.3 The role of the LHC

Various measurements have been envisaged to extract information on the gluon DF:

a) inclusive jet production, sensitive to both quark and gluon densities, the gluon contribution decreasing with increasing E_T

b) di-jet production, with the advantage with respect to a) of determining x and Q^2 event-by-event, since $x_{1,2} = E_T/\sqrt{s}(e^{\pm\eta_1} + e^{\pm\eta_2})$ and $Q^2 = 2E_T^2 cosh^2\eta^*(1 - tanh\eta^*)$ at leading order, with $\eta^* = 0.5|\eta_1 - \eta_2|$ and $\eta_{i,i=1,2}$ being the pseudorapidities of the two final state partons.

The accessible range is $0.01 < x < 0.6$ for $10^5 < Q^2 < 10^6\ GeV^2$.
The main tool for jet measurements is calorimetry, both electromagnetic and hadronic. Both ATLAS and CMS are going to build high performance calorimeters. The main issue in jet measurements at the LHC is the determination of the energy scale. Calibration of the calorimeters is foreseen in beam tests with electron and pions beams. Moreover *in situ* calibration with $W \rightarrow$ jet-jet and Z-jet processes is envisaged, aiming at $\pm 1\%$ up to $E_T \sim 500\ GeV$. For larger E_T, extrapolations will be used and this will become the dominant systematic uncertainty

c) processes with photons in the final state:

   1) direct single photons, for which $gq \rightarrow g\gamma$ is the dominant production mechanism. The accessible kinematic range, with $p_T^\gamma > 40 GeV$ (trigger at low $\mathcal{L}$) is $5 \cdot 10^{-4} < x < 0.2$ for $Q^2 = (p_T^\gamma)^2 > 10^3\ GeV^2$. This process is affected by a huge jet (π^0) background, since $\sigma(\gamma + X)/\sigma(jets) \sim 1.5 \cdot 10^{-3}$ for 100 GeV$< p_T^\gamma <$ 500 GeV. After isolation and γ/jet identification cuts, the background level can be reduced in ATLAS by a factor 4000 for 80% signal efficiency, with the residual π^0 fraction measurable on a statistical basis.
   The energy scale will be known to $< 0.1\%$ from *in situ* calibration with $Z \rightarrow e^+e^-$.

   2) photon pair production: the gg annihilation process is dominant for low $m_{\gamma\gamma}$ (50-70 GeV)

   3) γ-jet process, is dominated by $qg \rightarrow \gamma q$

d) Z-jet process, dominated by $qg \rightarrow Zq$.
Final state selection for the processes c3) and d) proceeds through similar cuts. Already with one year at low luminosity there is enough statistical precision to allow distinction between different PDFs.

5 Heavy quarks DF

The processes $cg \rightarrow \gamma c(\rightarrow \mu)$ of $\sigma \sim 1.7nb$ and $bg \rightarrow \gamma b(\rightarrow \mu)$ of $\sigma \sim 0.3nb$ have been investigated. The heavy quark component in the selected sample can be extracted by fitting the p_t spectrum of the decay muon. The b-quark content can be enhanced with respect to the c one by using the b-tagging capabilities offered by the ATLAS and CMS inner detectors.
The measurements of the heavy quarks DFs will be systematically limited to 5-10% by the knowledge of the corresponding fragmentation functions.

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