Parton distributions at 14 TeV with ATLAS

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(on behalf of the ATLAS collaboration)

QCD 2003

Montpellier, 2nd – 9th July 2003

Outline

- LHC and ATLAS.
- Precision tests & measurements in unexplored kinematic region.
- Jet physics.
- Direct photon production ($f_g(x)$, parton dynamics).
- Drell-Yan and W/Z production.
- Heavy quark production.
- Conclusions.

LHC (Large Hadron Collider):

- p-p collisions at $\sqrt{s} = 14\text{TeV}$
- bunch crossing every 25 ns (40 MHz)
- low-luminosity: $L \approx 2 \times 10^{33}\text{cm}^{-2}\text{s}^{-1}$
($\mathcal{L} \approx 20\text{fb}^{-1}/\text{year}$)
- high-luminosity: $L \approx 10^{34}\text{cm}^{-2}\text{s}^{-1}$
($\mathcal{L} \approx 100\text{fb}^{-1}/\text{year}$)

Process	σ (nb)	Events/year ($\mathcal{L} = 10\text{fb}^{-1}$)
Inclusive $b\bar{b}$	5×10^5	$\sim 10^{13}$
Inclusive jet $p_T > 200\text{ GeV}$	100	$\sim 10^{10}$
Inclusive $t\bar{t}$	0.8	$\sim 10^7$
Inclusive jet $E_T > 2\text{ TeV}$	$\sim 10^{-8}$	$\sim 10^3$

large statistics: **small statistical error!**

Production cross section and **dynamics** are largely controlled by QCD.

Mass reach (E_T) up to **$\sim 5\text{ TeV}$**

Test **QCD predictions** and perform precision measurements.

ATLAS: A Toroidal LHC AparatuS

7,000 tons

- **Multi-purpose detector**
coverage up to $|\eta| = 5$;
design to operate at $L = 10^{34} \text{cm}^{-2}\text{s}^{-1}$

- **Inner Detector (tracker)**
Si pixel & strip detectors + TRT;
2 T magnetic field;
coverage up to $|\eta| < 2.5$.

- **Calorimetry**
highly granular LAr EM calorimeter
($|\eta| < 3.2$);
hadron calorimeter – scintillator tile
($|\eta| < 4.9$).

- **Muon Spectrometer**
air-core toroid system
($|\eta| < 2.7$).

Jet energy scale: precision of 1% ($W \rightarrow jj$; $Z(\ell\ell) + \text{jets}$)

Absolute luminosity: precision $\leq 5\%$ (machine, optical theorem, rate of known processes)

Most of the QCD related measurements are expected to be performed during the "low-luminosity" stage.

Likely to **limit** cross-section measurements.

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LHC Parton Kinematics

- Essentially all physics at LHC are connected to the interactions of quarks and gluons (small & large transferred momentum).
- **This requires a solid understanding of QCD.**
- Accurate measurements of SM cross sections and QCD related processes at the LHC will further constrain the pdf's.
- The kinematic acceptance of the LHC detectors allows a **large range of x and Q^2 to be probed** (ATLAS coverage: $|\eta| < 5$).

Jet physics

- Test of pQCD in an energy regime never probed!
(probing the smallest distance scales at the LHC → huge cross-section!)
- The measurement of the jet production cross-section is sensitive both to the **quark and gluon densities**.
- The measurement of di-jets and their properties (E_T and $\eta_{1,2}$) can be used to **constrain p.d.f.'s**.
 - reconstruct $\mathbf{x}_{1,2}$ & $\mathbf{Q}^2$ of the hard scattering (LO):

$$x_{1,2} = \frac{E_T}{\sqrt{s}} (e^{\pm\eta_1} + e^{\pm\eta_2})$$

$$Q^2 \approx 2E_T^2 \cosh^2 \eta^* (1 - \tanh \eta^*)$$

- **Systematic errors:** jet algorithm, calorimeter response (jet energy scale), jet trigger efficiency, luminosity (dominant uncertainty 5% -10%), the underlying event.
- At the LHC the **statistical uncertainties** on the jet cross-section will be **small**.

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- more studies are needed to quantify uncertainties;
- **combined channels** have also to be investigated!

$\mathcal{L} = 300 \text{ fb}^{-1}$

$E_T > 180 \text{ GeV}$ and $|\eta| < 3.2$

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Direct photon production

- direct production of photons: information on gluon density in the proton, $f_g(x)$. (requires good knowledge of α_s)

Production mechanism:

$qg \rightarrow \gamma q$ dominant (QCD Compton scattering)
 $q\bar{q} \rightarrow \gamma g$

Background: mainly related to fragmentation (non-perturbative QCD)

Isolation cut: reduces background from fragmentation (π^0) (cone isolation)

ATLAS: high granularity calorimeters ($|\eta| < 3.2$) allow good background rejection.

LHC

$p_T^\gamma > 40 \text{ GeV} \rightarrow Q^2 > 10^3 \text{ GeV}^2$

$5 \cdot 10^{-4} < x < 0.2$ (statistics)

HERA

$Q^2 > 10^3 \text{ GeV}^2$

$x > 0.01$

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Drell-Yan processes

(e, μ channels!)

- **W** and **Z** production at the LHC: **huge statistical samples** & **clean** experimental channel.

W and Z production:

$\sim 10^5$ events containing W ($p_T^W > 400$ GeV) for $\mathcal{L} = 30\text{fb}^{-1}$

$\sim 10^4$ events containing Z ($p_T^Z > 400$ GeV) for $\mathcal{L} = 30\text{fb}^{-1}$

LHC

$Q^2 \approx 6(8) 10^3 \text{ GeV}^2$

$3 \cdot 10^{-4} < x < 0.1$ ($|\eta| > 2.5$)

HERA

$Q^2 > 10^4 \text{ GeV}^2$

$x > 0.1$

DY production of muon pairs:

$m_{\mu\mu} > 400 \text{ GeV}$: 10^4 events for $\mathcal{L} = 30\text{fb}^{-1}$

($|\eta| > 2.5$)

$Q^2 > 1.6 \cdot 10^5 \text{ GeV}^2$

$2.3 \cdot 10^{-3} < x < 0.34$

- **W⁺ and W⁻ production:** different y^W distributions (differences in parton distributions leading to W production: **u** and **d**)
- It can be used to **constrain quark** and **anti-quark densities** in the proton.

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Determination of $\sin^2\theta_{\text{eff}}^{\text{lept}}(M_Z^2)$

- $\sin^2\theta_{\text{eff}}^{\text{lept}}$ is one of the **fundamental parameters of the SM** (constrain the Higgs mass and check consistency of the SM) !
- Main systematic effect: **uncertainty on the p.d.f.'s**, lepton acceptance ($\sim 0.1\%$), radiative correction calculations.
- $\sin^2\theta_{\text{eff}}^{\text{lept}}$ will be determined at the LHC by measuring A_{FB} in **dilepton production** near the Z pole.

$$A_{\text{FB}} = b \{ a - \sin^2\theta_{\text{eff}}^{\text{lept}}(M_Z^2) \}$$

a and **b** calculated to **NLO** in QED and QCD.

y cuts – e^+e^- ($ y(Z) > 1$)	ΔA_{FB} (statistical)	$\Delta \sin^2\theta_{\text{eff}}^{\text{lept}}$ (statistical)
$ y(l_{1,2}) < 2.5$	3.03×10^{-4}	4.0×10^{-4}
$ y(l_1) < 2.5$; $ y(l_2) < 4.9$	2.29×10^{-4}	1.41×10^{-4}

$$\mathcal{L} = 100 \text{ fb}^{-1}$$

$$\sigma(Z \rightarrow l^+l^-) \sim 1.5 \text{ nb} \text{ (for either e or } \mu)$$

$$\sin^2\theta_{\text{eff}}^{\text{lept}}(M_Z^2) = 0.23126 \pm 1.7 \times 10^{-4} \text{ (global fit PDG)}$$

Can be further improved:
combine channels/experiments.

Heavy flavour production

- The **dominant production** mechanism for heavy quarks (b and t) at the LHC is **gluon-gluon interaction**.
- Measurements of **heavy quark production** will provide constraints on the **gluon density**.

Process	σ (nb)	Events/year ($\mathcal{L} = 10 \text{ fb}^{-1}$)
$b\bar{b}$	5×10^5	$\sim 10^{12}$
$t\bar{t}$	0.8	$\sim 10^7$

LHC: Heavy quarks factory!

c and b quarks

- c and b can be measured by quark flavour tagged sub-sample of **photon-jet final states**;
- dominant production: $c(b) g \rightarrow c(b) \gamma$
- jet flavour is identified as a c or b jet by using **inclusive high- p_T muons & b tagging**

$$p_T^\gamma > 40 \text{ GeV}$$

$$0.001 < x_c (x_b) < 0.1$$

$$p_T^\mu \sim 5 - 10 \text{ GeV}$$

$$(\mathcal{L} = 10 \text{ fb}^{-1})$$

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Conclusions:

- LHC will probe QCD to unexplored kinematic limits;
- Jet studies (test of pQCD, constrain p.d.f.'s, physics studies);
- Prompt-photon production will lead to improved knowledge of $f_g(x)$ and parton dynamics;
- Drell-Yan processes will provide information that can be used to constrain quark and anti-quark densities (W and Z decays, muon pairs, W^+ and W^- production);
- Heavy quark production (provide constraints for the gluon density & c and b densities).