The ATLAS Forward Physics Program DIS 2009

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ATLAS-The Forward System

See talk by Laura Fabbri for details of ATLAS Forward Detectors
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THE AFP PROJECT aims to create a precise forward proton spectrometer using Si trackers and fast-timing detectors deployed close to the beam at 220m & 420m from the IP.

- Moveable beam pipe are used to locate detectors

See talk by Laura Fabbri for details of ATLAS Forward Detectors
INSTRUMENTATION OF THE FORWARD REGION opens up a new window on QCD physics at the LHC - Diffractive and Elastic - 40% of total p-p cross-section ($\sigma_{\text{tot}} \sim 100 \text{ mb}$)

- **Elastic**
  (25% of $\sigma_{\text{tot}}$)

- **Single diffractive**
  (10% of $\sigma_{\text{tot}}$)

- **Double diffractive**
  (~1% if $\sigma_{\text{tot}}$)

- **Central diffractive**
  DPE (~1% if $\sigma_{\text{tot}}$)

- **Inelastic**
  (non diffractive)
  (60% of $\sigma_{\text{tot}}$)
Absolute Lumi & $\sigma_{tot}$

- **USE ALFA TO STUDY ELASTIC SCATTERING** in the Coulomb Nuclear Interference CNI region: $L \sim 10^{27} \text{ cm}^{-2}\text{s}^{-1}$, large $\beta^*$ optics (beam div. $\sim 0.2 \mu \text{rad}$)

  Fit of data gives $\rightarrow \sigma_{tot}, L, \rho, b (\Delta L/L \sim 3\%)$

\[
\frac{dN}{dt} \bigg|_{t=CNI} = L_{\pi} |f_C + f_N|^2 \approx L_{\pi} \left( \frac{2\alpha_{EM}}{t} \right) + \sigma_{tot} (i + \rho)e^{\frac{b(t)}{2}}
\]

- **USE THE OPTICAL THEOREM** as a complementary solution

\[
L = \frac{(1 + \rho^2)}{16\pi} \frac{N_{tot}^2}{\frac{dN_{el}}{dt} \bigg|_{t=0}}
\]

\[
\sigma_{tot} = \frac{N_{tot}}{L}
\]

- **Provide high precision (2-3%) LUCID CALIBRATION**

- **QCD Physics**
  - Low lumi
  - $\gamma/\gamma p$ Physics
  - Low lumi

- **ZDC physics**

- **QCD High lumi**

- **$\gamma/\gamma p$ Physics**
  - High lumi
• **HARD DIFFRACTION:** $X = \text{jets, Ws, Zs, Higgs, etc:}$
  - Hard processes calculable in pQCD
  - Info on proton structure: dPDFs and GPDs
  - Discovery physics (!)

• **SOFT DIFFRACTION:** $X = \text{anything, dominated by soft physics, Important insights on npQCD:}$
  - Gap survival probability,
  - Multi-parton interactions
  - Pile-up contributions at high-luminosity.
Diffraction - Detector Inputs

- FORWARDED PROTON TAG in special runs with ALFA
  - Elastic + SD measurement

- FORWARD RAPIDITY GAP requirement in FCAL (3.2<|η|<4.9), LUCID (5.6<|η|<6.0) and ZDC (|η|>8.3).

- CENTRAL RAPIDITY GAP in hadronic/EM calorimeters (|η|<3.2) and inner detector (|η|<2.5).

- ☒ PILE-UP will kill rapidity gaps
Soft SD with ALFA

- ALFA has good acceptance (in special runs) for single diffractive (SD) events.
  - Measure forward proton spectrum in region $6.3 \text{ TeV} < E_{\text{prot.}} < 6.993 \text{ TeV}$
  - SD measurement for $\xi < 0.01$.
  - Non-diffractive forward proton spectrum measurement for $0.01 < \xi < 0.1$.
- Expect 1.2-1.8M events in 100hrs at $L = 10^{27} \text{ cm}^{-2} \text{ s}^{-1}$. 
Hard Single Diffraction

- Look for hard scatter event with gap on one side of the detector.
- Compare gap/non-gap ratio to determine soft-survival.
- Gap defined by LUCID/ZDC + FCAL

**FCAL gap needed to restrict event to diffractive region** ($x_{pom}<0.01$). E.g. di-jet production

<table>
<thead>
<tr>
<th>$p_T$ (GeV)</th>
<th>$x_{pom}$</th>
<th>$\sigma$ (pb)</th>
<th>gap type</th>
<th>efficiency</th>
<th>Events in 100 pb$^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>&lt; 0.01</td>
<td>$7.2 \times 10^5$</td>
<td>FCAL</td>
<td>0.4</td>
<td>$2.9 \times 10^7$</td>
</tr>
<tr>
<td>20</td>
<td>&lt; 0.1</td>
<td>$3.6 \times 10^6$</td>
<td>FCAL</td>
<td>0.08</td>
<td>$2.9 \times 10^7$</td>
</tr>
<tr>
<td>40</td>
<td>&lt; 0.1</td>
<td>$2.1 \times 10^5$</td>
<td>FCAL</td>
<td>0.05</td>
<td>$1.0 \times 10^6$</td>
</tr>
<tr>
<td>40</td>
<td>&lt; 0.1</td>
<td>$2.1 \times 10^5$</td>
<td>LUCID,ZDC</td>
<td>0.44</td>
<td>$9 \times 10^5$</td>
</tr>
</tbody>
</table>

- Approximately 5000 (8000) SD di-jet events in 100 pb$^{-1}$ with jet transverse energy > 20 (40) GeV after trigger pre-scale.
• Two central jets with $|\eta| < 2.5$.

• Gap imposed on both sides of IP in FCAL, LUCID, ZDC.

• Expect CEP cross section to be 50 times larger than DPE for these criteria.

• Measurement of CEP dijet production at 14TeV. Compare with CDF measurement to constrain theoretical model.

• CDF has already observed DPE/ CEP production of photon-photon, di-jet and $\chi_c$
Gaps Between Jets

- **Di-jet production via colour singlet exchange**
  - (background from single gluon exchange process).
- **Require two jets, one in each forward calorimeter.**
- **Require gap in central calorimeter.**
- **ATLAS can make an improved measurement with increased** $E_{cm}$ **and available phase space.**
- **D0 performed similar measurements at the Tevatron-PLB 440, 189 (1998).**
**Photon Induced Muon Pairs**

- **EXCLUSIVE Dileptons**
  - Two isolated leptons back-to-back in $\phi$, balanced in $P_T$
  - Leptons derive from an exclusive vertex (no other tracks can join)
  - Protons remain intact not other activity in the detector (use FCAL, LUCID, ZDC)

- **PROCESSES:**
  - Two photon production $\rightarrow$ non-resonant lepton pairs from $\gamma\gamma \rightarrow l^+l^-$
  - Photoproduction - lepton pairs through $J/\psi$ & upsilon resonances $-\gamma IP \rightarrow J/\psi, Y \rightarrow l^+l^-$
Photon Induced Muon Pairs

• In MC, several hundred two-photon and Upsilon events pass the final selection in the dimuon channel, for 100 pb⁻¹:
  
  709 ± 27 (stat) elastic events
  223 ± 15 (stat) ± 42 (model) singly inelastic events

• QED process - minimal uncertainties on the cross-section, highly constrained 4-body final state

• Startup applications - candidate for:
  – Luminosity calibration
  – Low \( p_T \) lepton ID studies

• High-luminosity applications:
  – Alignment sample for forward proton taggers
  – “Standard candle” for BSM physics in high energy interactions: \( \gamma \gamma \rightarrow \gamma \gamma \), \( \gamma \gamma \rightarrow \) slepton pairs, Higgs pairs, W-pairs etc.
**ZDC - Physics**

- **HEAVY-ION PHYSICS:**
  - Count spectator neutrons
  - Determine the event centrality
  - Trigger for ultra-peripheral collisions

- **VERY FORWARD CROSS-SECTIONS**
  - New energy range explored
  - Input for high energy cosmic ray MCs (Modeling air showers)
  - Improve hermiticity
QCD at Hi Lumi - the AFP Project

- AFP - Forward Proton Spectrometers to tag protons at 220m & 420m.
- Use fast timing to reduce pile-up background at high luminosity
- Good acceptance and mass resolution for the DPE Higgs
Higgs Production

- SM h→WW*, 140 < M_h < 180 GeV
- Higgs boson studies - Higgs mass, quantum numbers, discovery in certain regions of MSSM/NMSSM:
  - Standard Model h→WW*, for M_h > 140GeV.
  - MSSM h,H→bb and h,H→τ+τ- for M_h/H < 240GeV.
  - NMSSM h→aa→4τ, 90GeV < M_h < 110GeV.
- Slepton pair production.
- Gluino pair production for split-SUSY models.
Rich $\gamma p + \gamma \gamma$ Physics via $p$-Tagging
Summary & Conclusions

- **LUMINOSITY:**
  - LUCID and ALFA will provide the luminosity to ATLAS to better than 5% accuracy.

- **FORWARD PARTICLE SPECTRUM:**
  - ZDC (and LHCf experiment) will measure forward particle production for MC tuning.
  - ZDC will measure forward spectators for heavy ion collisions; provide trigger, luminosity and centrality measurements.

- **LOW LUMINOSITY PHYSICS:**
  - Elastic scattering and $\sigma_{\text{tot}}$ using ALFA
  - Single diffractive forward proton spectrum (ALFA).
  - Single diffractive di-jet and W production, DPE and CEP of di-jets (with rapidity gap veto in FCAL, LUCID, ZDC).
  - Gaps between jets as a probe of colour singlet exchange.

- **POSSIBLE HIGH LUMI UPGRADE AT 220M and 420M:**
  - Proton tagging gives access to CEP Higgs production and SUSY physics as well as $\gamma-\gamma$ and $\gamma$-IP physics, at high luminosity

- **THE LHC WILL BE 4 COLLIDERS IN 1: p-p, IP-IP, $\gamma$-IP,$\gamma-\gamma$!**