Diffractive physics at ATLAS and DØ

Arnab K. Pal
Introduction

- Name: Arnab Kumar Pal
- Experiment: DØ
- Was graduate student at UTA from 2005-2011.
  - Went to CERN in 2007 for one year
  - Came back in 2008 and started work on thesis at Fermilab
  - Completed in Aug, 2011
Overview

- Central exclusive processes.
- Standard model exclusive Higgs at ATLAS.
- ATLAS forward proton detectors.
- Single diffractive differential cross at the Tevatron.
Central exclusive processes refer to the processes like \( pp \rightarrow p + \phi + p \), where ‘+’ refers to the presence of large rapidity gaps.

The final state contains the two outgoing protons and the decay products of the central system \( \phi \) and nothing else.

In the analysis the central decay product \( \phi \) is detected using the central detector and the final state protons are detected using the forward detectors located at 220m and 420m on both sides of the IP.

Rapidity gaps are not demanded because of the presence of large number of multiple interactions.

The forward detectors allow the study of many other exclusive processes both within and beyond the standard model.
Benefits of forward detectors

- There is significant reduction in the cross section in the exclusive process, but since the final state protons remain intact and scatter through small angles it means that the primary systems in $J_z = 0$, $C – even$ and $P – even$ state. ($J_z$ is the proton angular momentum along the beam axis).

- The discovery of a CEP Higgs would mean the measurement of its quantum number, which is $0^{++}$.

- The mass of the central resonance can be precisely (with a resolution of 2 to 3 GeV) using momentum loss of the outgoing protons, irrespective of the decay channel of the central system.
Production of Central Exclusive Higgs, Gluon is exchanged between the protons which conserves the color and the proton stays intact in the final state. The process can be written as 

\[ pp \rightarrow p + H^0 + p \]

- Missing mass method is used to reconstruct the mass of the central system.
- The proton with sufficient momentum loss are detected by the forward detectors located at 220m or 420m upstream and downstream of the ATLAS detector.
- Using the forward detectors calculate the fractional momentum loss

\[
\xi_1 = \frac{\Delta p_{1z}}{p_{1z}}
\]

\[
\xi_2 = \frac{\Delta p_{2z}}{p_{2z}}
\]

- Then the mass of the central system is

\[
\Delta M = \sqrt{\xi_1 \xi_2 \sqrt{s}}
\]

- 1% loss in the fractional momentum of the protons gives a central system of 140 GeV.
- Mass resolution of the Higgs depends only of the resolution of \( \xi_1 \) and \( \xi_2 \), which is expected to be in the 2 to 3 GeV range, far superior to that Obtainable using central detector.
Scenarios of production of Higgs

- Looked into the production and detection of standard model Higg’s boson of two different masses, 120GeV and 160GeV.
  - $M_H = 120$ GeV, decay channel is $H^0 \rightarrow b\bar{b}$.
  - $M_H = 160$ GeV, decay channel is $H^0 \rightarrow WW^* \rightarrow jjl\nu$. 
$H^0 \rightarrow b\bar{b}$ decay channel

- The cross section times branching ratio for the Exclusive Higgs of mass 120 GeV was predicted to be $3.0 \times 0.6 = 1.86 \text{ fb}$.
- The cut efficiencies must be included in order to get a correct estimate of the effective cross section.
- The main experimental signature in this decay channel are:
  - Two final state proton in the FP420 detector (note that a 120GeV particle is in the acceptance range of FP420 only).
  - Two b-Jets in the central detector, which are back to back.
  - Very little other activity outside the cone of the b-Jets.
$H^0 \rightarrow b\bar{b}$ \hspace{1cm} Backgrounds

- The most serious background for this channel is inclusive $b\bar{b}$ production + two single diffractive protons from other $pp$ interactions in the same bunch crossing.
- The cross section for $gg \rightarrow b\bar{b}$ is 500 $\mu$b.
- The effective pile-up cross section for the forward protons is given by

$$\sigma_{\text{eff}} = N(N - 1)P_i^2Q\sigma_{b\bar{b}}$$
Background

\[ \sigma_{\text{eff}} = N(N-1)P_i^2Q \sigma_{b\bar{b}} \]

- N = number of minimum bias events N \sim 35 at full luminosity.
- Q = rejection factor obtained using precision timing to reject events where the timing vertex is inconsistent with the central silicon vertex (Q=0.025).
- \( P_i \) = probability of an interaction giving a proton in the proton detector acceptance (\( P_i = 0.012 \) for 420 m detectors)
- \( \sigma_{b\bar{b}} \) is the input cross section for the hard scattering.
Exclusivity variables to beat down the background

- The background is extremely large as compared the signal cross section.
- Use the forward detectors in conjunction with the central detectors to maximize the signal.
- Based on the correlation of the forward track momentum and the central detector kinematics.
- There are four different variables: $R_j$, $Δy$, $N_T$ and $N_C$.

Some of the physics quantities before the definition of the variables

- Fractional momentum loss of the protons, $\xi_1 = \frac{△p_1}{p_1}$ and $\xi_2 = \frac{△p_2}{p_2}$ can be measured at the FPD ($0.002 < ξ < 0.015$).
- The mass of the central exclusive system is given by $\Delta M = \sqrt{ξ_1 ξ_2 s}$, where $\sqrt{s} = 14 GeV$. In the case of 1% fractional momentum loss the protons gives a central system of 140 GeV.
- $M_{jj}^2 = χ_1 χ_2 s$ Invariant mass of the b jet where

$$
χ_1 = \frac{1}{\sqrt{s}} \sum_{i=1,2} p_T^i e^{η} \text{ and }
χ_2 = \frac{1}{\sqrt{s}} \sum_{i=1,2} p_T^i e^{-η} s
$$
Definition of the variables

\[ R_j = \frac{2}{\Delta M} p_T \cosh (\eta - y) \quad y = 0.5 \ln \left( \frac{\xi_1}{\xi_2} \right) \]

\[ \Delta y = 0.5 \ln \left( \frac{\xi_1}{\xi_2} \right) - 0.5(\eta_1 + \eta_2) \]

\( N_T \) is the number of tracks outside the cone of \( R = 0.7 \) of the b-jet

\( N_C \) is the number of tracks outside the cone of \( R = 0.7 \) of the b-jet 60° away from the jet in \( \phi \) (\( \Delta \phi > 60° \))
Signal and background Monte Carlo

- The Signal processes were generated using EXHUME Monte Carlo generator.
- PYTHIA 6.3 was used to generate the background
- Kinematic cuts
  - Find the Combination of B-Jets Satisfying the Cuts.
  - Apply Cuts on $P_T$ (Transverse Momentum).
    - $P_T^1 > 45.0 \text{GeV}$ and $P_T^2 > 30 \text{GeV}$.
  - Apply Cuts on $\eta$ (Pseudo Rapidity).
    - $2.5 > \eta > -2.5$
  - Cuts on $\Delta \eta$.
    - $1.0 > \Delta \eta > -1.0$
    - Make sure that the Jets central and Back to Back in $\eta$.
  - Cuts on $\Delta \phi$.
    - $170 > \Delta \phi > 190 \text{ (deg)}$
    - Make sure that the Jets are Back to Back.
  - In the Analysis a Gaussian error of 1GeV for $\xi_1$ and $\xi_2$ is introduced to approximately simulate the detector response.
  - Calculate $\Delta M$ from the missing mass spectrum.
  - Use Acceptance cuts such that $0.002 < (\xi_1, \xi_2) < 0.015$
Signal and background separation

\[ R_j = \frac{2 p_T}{\Delta M} \cosh (\eta - y) \]
\[ y = 0.5 \ln \left( \frac{\xi_1}{\xi_2} \right) \]
(a)

\[ \Delta y = 0.5 \ln \left( \frac{\xi_1}{\xi_2} \right)^2 \Delta y^3 - 0.5 (\eta_1 + \eta_2) \]
(b)

(c)

(d)
Efficiencies of Cuts

- The cuts have been optimized manually.
- The correlation was removed by applying the cuts in different order.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Cuts</th>
<th>$H^0$</th>
<th>$b\bar{b}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinematic Cuts</td>
<td>(see text)</td>
<td>0.061</td>
<td>0.062</td>
</tr>
<tr>
<td>$R_j$</td>
<td>0.85 to 1.15</td>
<td>0.925</td>
<td>0.038</td>
</tr>
<tr>
<td>$\Delta y$</td>
<td>$&lt; 0.1$</td>
<td>0.905</td>
<td>0.060</td>
</tr>
<tr>
<td>$N_c$</td>
<td>$&lt; 2$</td>
<td>0.777</td>
<td>0.031</td>
</tr>
<tr>
<td>$N_T$</td>
<td>$&lt; 4$</td>
<td>0.810</td>
<td>0.010</td>
</tr>
<tr>
<td>$N_c$ and $N_T$</td>
<td>2 and 4</td>
<td>0.734</td>
<td>0.008</td>
</tr>
<tr>
<td>$\Delta M_{420+420}$</td>
<td>118.3, 121.7 GeV</td>
<td>0.723</td>
<td>0.014</td>
</tr>
</tbody>
</table>
## Results

- Very few signal events
- But the background is low as well!

<table>
<thead>
<tr>
<th>$\mathcal{L}$ (fb$^{-1}$)</th>
<th>$H^0$ (Signal)</th>
<th>$N$</th>
<th>$b\bar{b}$</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>2.3</td>
<td>3.5</td>
<td>1.12</td>
<td>2.15</td>
</tr>
<tr>
<td>60</td>
<td>4.5</td>
<td>3.5</td>
<td>2.24</td>
<td>3.0</td>
</tr>
<tr>
<td>60</td>
<td>4.5</td>
<td>7</td>
<td>10.8</td>
<td>1.35</td>
</tr>
<tr>
<td>150</td>
<td>11</td>
<td>18</td>
<td>184</td>
<td>0.85</td>
</tr>
<tr>
<td>300</td>
<td>23</td>
<td>35</td>
<td>1520</td>
<td>0.6</td>
</tr>
</tbody>
</table>
$H^0 \rightarrow WW^* \rightarrow jjl\nu$ decay channel

- For $H^0$ of Mass 160GeV we have acceptance in Forward proton detector at 420m as well as 220m.

Cross Section = 1.6fb

The main Decay channels

<table>
<thead>
<tr>
<th>Decay</th>
<th>Branching Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\mu\nu jj$</td>
<td>10.27%</td>
</tr>
<tr>
<td>$e\nu jj$</td>
<td>10.27%</td>
</tr>
<tr>
<td>$\tau\nu jj$</td>
<td>10.27%</td>
</tr>
<tr>
<td>$jjjj$</td>
<td>58.94%</td>
</tr>
<tr>
<td>$\ell\nu\ell\nu$</td>
<td>10.27%</td>
</tr>
</tbody>
</table>

Cross Sec × BR for this channel = 0.17fb

Signal Events were generated using EXHUME
$H^0 \rightarrow WW^* \rightarrow jjl\nu$ backgrounds

- $W + 2j$ production with one of the $W$’s decaying in the semi-leptonic mode along with 2 pile up protons at the forward detectors. (2.5 nb)
- Continuum production of $WW^*$, in which the $W$’s decay in semi-leptonic channel. (181 pb)
Preselection (Kinematic cuts)

- Jets
  - $P_T$ of jet1 & jet2 > 25 GeV.
  - $|\eta|$ of jet1 & jet2 < 3.2.

- Muon
  - $P_T$ > 20 GeV.
  - $|\eta|$ < 2.5.

- Missing $E_T$
  - $E_T$ > 25 GeV.

- Select Events with at least 2 jets, 1 Muon and Missing $E_T$
Exclusivity variables

- Ignore the rapidity of the leptonic W, and use the rapidity of the hadronic W as an estimate of the Higgs rapidity, rather than trying to account for the neutrino ambiguity.
- New variable $\Delta Y_M$ which takes into account both the mass difference and the rapidity difference.

**Ratio of cluster mass and missing mass, $r_{cm}$**

$$r_{cm} = \frac{m_c}{\Delta M}$$

Where $m_c = \sqrt{p_T^2(jj\ell) + m_{jj\ell}^2 + E_T}$, $\Delta M$ is the missing mass measured at the FPDs and is given by $\Delta M = \sqrt{\xi_1 \xi_2 \xi_3}$ and $m_{jj\ell}^2$ is invariant mass of the di-jets and the lepton.

**Difference in the rapidity and pseudorapidity, $\Delta y_{jj}$**

$$\Delta y_{jj} = \left| \frac{1}{2} (\eta_{j1} + \eta_{j2}) - \frac{1}{2} \log \left\{ \frac{\xi_1}{\xi_2} \right\} \right|$$

where $\frac{1}{2} \log \left\{ \frac{\xi_1}{\xi_2} \right\}$ is the rapidity measured by the proton detectors.

**Combined variable of rapidity and mass difference, $\Delta y M$**

$$\Delta y M = \cosh^{-1} \left\{ \frac{\Delta M}{2 (p_T^1 + p_T^2)} \right\} - 0.5 (\eta^1 + \eta^2) + 0.5 \log \left\{ \frac{\xi_1}{\xi_2} \right\}$$

$N_T$ is the number of tracks outside the cone of $R = 0.7$ of the b-jet.
Signal and background separation
## Cut efficiencies

<table>
<thead>
<tr>
<th>Variable</th>
<th>Cuts</th>
<th>$H^0$</th>
<th>$W + 2j$</th>
<th>$WW^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_{cm}$</td>
<td>0.6 to 1.3</td>
<td>1.0</td>
<td>0.020</td>
<td>0.025</td>
</tr>
<tr>
<td>$\Delta y_{jj}$</td>
<td>&lt; 0.4</td>
<td>0.98</td>
<td>0.0045</td>
<td>0.0041</td>
</tr>
<tr>
<td>$\Delta y: M$</td>
<td>0 to 1.3</td>
<td>0.95</td>
<td>0.0032</td>
<td>0.0026</td>
</tr>
<tr>
<td>$N_T$</td>
<td>8</td>
<td>0.94</td>
<td>0.0003</td>
<td>0.0002</td>
</tr>
<tr>
<td>$\Delta M_{420+420}$</td>
<td>156.5 to 163.5 GeV</td>
<td>0.68</td>
<td>$2.9 \times 10^{-5}$</td>
<td>$1.5 \times 10^{-5}$</td>
</tr>
<tr>
<td>$\Delta M_{420+220}$</td>
<td>154.5 to 165.5 GeV</td>
<td>0.81</td>
<td>$4.6 \times 10^{-5}$</td>
<td>$2.5 \times 10^{-5}$</td>
</tr>
<tr>
<td>RP Acc. (420+420)</td>
<td>0.002 to 0.015</td>
<td>0.12</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>RP Acc. (220+420)</td>
<td>-</td>
<td>0.57</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cuts</th>
<th>$H^0$</th>
<th>$W + 2j$</th>
<th>$WW^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>kinematical cuts + BR</td>
<td>0.01924</td>
<td>0.0313</td>
<td>0.1421</td>
</tr>
<tr>
<td>Exclusivity Cuts + $\Delta M(420+420)$</td>
<td>0.00175</td>
<td>$8.92 \times 10^{-7}$</td>
<td>$2.06 \times 10^{-6}$</td>
</tr>
<tr>
<td>Exclusivity Cuts + $\Delta M(420+220)$</td>
<td>0.0062</td>
<td>$1.43 \times 10^{-6}$</td>
<td>$3.59 \times 10^{-6}$</td>
</tr>
</tbody>
</table>
Results

<table>
<thead>
<tr>
<th>$\mathcal{L}$ (fb$^{-1}$)</th>
<th>$H^0$ (Signal)</th>
<th>N</th>
<th>$W + 2j$</th>
<th>$WW^*$</th>
<th>Total BG</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>0.061</td>
<td>3.5</td>
<td>$2.8 \times 10^{-3}$</td>
<td>$3.5 \times 10^{-4}$</td>
<td>$3.15 \times 10^{-3}$</td>
<td>1.23</td>
</tr>
<tr>
<td>60</td>
<td>0.122</td>
<td>7</td>
<td>$2.0 \times 10^{-2}$</td>
<td>$3.4 \times 10^{-3}$</td>
<td>$2.34 \times 10^{-2}$</td>
<td>0.78</td>
</tr>
<tr>
<td>150</td>
<td>0.306</td>
<td>17.5</td>
<td>0.348</td>
<td>0.060</td>
<td>0.408</td>
<td>0.48</td>
</tr>
<tr>
<td>300</td>
<td>0.611</td>
<td>35</td>
<td>2.864</td>
<td>3.344</td>
<td>6.208</td>
<td>0.33</td>
</tr>
</tbody>
</table>

420m + 420m

<table>
<thead>
<tr>
<th>$\mathcal{L}$ (fb$^{-1}$)</th>
<th>$H^0$ (Signal)</th>
<th>N</th>
<th>$W + 2j$</th>
<th>$WW^*$</th>
<th>Total BG</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>0.217</td>
<td>3.5</td>
<td>0.160</td>
<td>0.028</td>
<td>0.188</td>
<td>0.498</td>
</tr>
<tr>
<td>60</td>
<td>0.433</td>
<td>7</td>
<td>1.536</td>
<td>0.280</td>
<td>1.816</td>
<td>0.321</td>
</tr>
<tr>
<td>150</td>
<td>1.083</td>
<td>17.5</td>
<td>26.44</td>
<td>4.820</td>
<td>31.26</td>
<td>0.193</td>
</tr>
<tr>
<td>300</td>
<td>2.165</td>
<td>35</td>
<td>217.936</td>
<td>39.73</td>
<td>257.67</td>
<td>0.134</td>
</tr>
</tbody>
</table>

420m + 220m
Things related to exclusive Higgs

- The pile up with one forward proton is single diffraction which is the main source of background for the exclusive Higgs
  - Studies of the single diffraction was required on real data
  - Tevatron (D0) had forward detector data, next step was to study the single diffraction and possible “Double-pomeron” exchange
- Worked on forward jet triggers needed to isolate the single diffraction.
- Worked on Soft QCD studies e.g. color singlet exchange.
- Working on b-Jet studies at D0.
Measurement of Single Diffractive differential cross section using the DØ Forward Proton Detectors.
Definition of variables used in the analysis

- $\sqrt{s}$ : Total center of mass energy of the collision.
  - For the Run II this is 1.96 TeV.

- $|t|$ : Standard four momentum transfer.
  - This is defined as: $|t| = (p_f - p_i)^2 = 2K^2(1 - \cos \theta)$. 
  - $|t| = \theta^2$ (For small angles).

- $\xi$ : Fractional momentum loss.
  - $\xi = 1 - x_f = 1 - \frac{p_f}{p_i}$

- $M_X$ : Maximum Diffractive Mass
  - $M_X = \sqrt{\xi, s} \sim 400 \text{ GeV}$

Diffractive cross sections are defined as $\frac{d\sigma}{dt \ dM_X}$, we integrate over the mass $dM_X$ to get $\frac{d\sigma}{dt}$.
Experimental Signatures of Diffraction

- A diffractive reaction is characterized by the presence of a large rapidity gap in the final state and a leading beam particle carrying most of the beam momentum.
There are eight quadrupole spectrometers (Up, Down, In, Out) on the outgoing proton (P) and anti-proton (A) sides each comprised of two detectors (1, 2).

Use Tevatron lattice and scintillating fiber hits to reconstruct $\xi$ and $|t|$ of scattered protons (anti-protons).

The acceptance for $|t| > |t_{\text{min}}|$ where $t_{\text{min}}$ is a function of pot position: for standard operating conditions $|t| > 0.8 \text{ GeV}^2$. 
Goals of analysis

Measure the differential cross section, $\frac{d\sigma}{dt}$, of single diffractive scattering over a large $|t|$ range.

Previously there have been measurements of the single diffractive cross section

- **CDF**, $\sqrt{s} = 1.8$ TeV: low $|t|$, high $\xi > 0.035$. Phys. Rev.Lett.78 (1997) 2698

- **The DØ measurement**
  - Consists of multiple independent measurements of protons and anti-protons, allowing reduction of systematic errors
  - Is unique in that it covers a large $|t|$ range (0.2 to 1.2 GeV$^2$) and $\xi$ range (0 to 0.1).
  - At $\sqrt{s} = 1.96$ TeV (UA4 and UA8 covered parts only low $|t|$ and high $|t|$), respectively, while CDF only measured large $\xi$ anti-protons
Data used in this analysis is taken in a special high $\beta^*$ (1.6 m, the injection tune) in February 2006.

Optimized for alignment and physics of the DØ FPD

The beam consisted of only one proton and anti-proton bunch (electrostatic separators were off), and extra scraping was done so that the FPD detectors could be positioned closer to the beam axis than during the normal running of the experiment.

Initial instantaneous luminosity was $0.5 \times 10^{30}$ cm$^{-2}$ s$^{-1}$

20 Million triggers/integrated luminosity 30 nb$^{-1}$
Event selection

- Select events with SD_PRO or SD_PBAR triggers.
- Choose hits based on the single diffractive track trajectory (detector correlation cuts)
- Demand a valid track in the FPD spectrometer.
- Select high mass single diffractive events demanding a hit in opposite side luminosity monitor.
- Choose events that have tracks inside the good fiducial region of the spectrometers.
- Reject halo tracks
High and low mass diffraction

- Low mass SD will have a large halo contamination
- We can select high mass SD by demanding hits in the opposite side luminosity monitors.
- Analysis is on high mass SD
We want to go from:
\[
\frac{dN}{dt} \rightarrow \frac{d\sigma}{dt}
\]

Need to calculate the following:

- **Efficiency** (Trigger and Track reconstruction efficiency)
- **Acceptance** (Due to the incomplete coverage and the alignment of the detector)
- **Background subtraction** (Due to residual halo and overlap events)

\[
\frac{d\sigma}{dt} = \left( \frac{1}{\varepsilon \times A \times L} \right) \frac{dN}{dt}
\]

- Efficiency
- Acceptance
- Luminosity
Since the detectors don’t cover the whole ϕ region, the data has to be corrected for the geometrical acceptance.

The acceptance is a function of the detector position with respect to the beam and their alignment only.

To calculate the acceptances of the detector we perform the following steps.

- Generate uniform random distributions of |t|, ξ and ϕ for the proton and anti-proton.
- This gives us the values at the collision point, then use the tevatron transport matrix to get the positions of the protons and anti-proton at the detector positions. (x and y)
- Then use the FPD reconstruction program to find if there is a track and calculate the |t|, ξ and ϕ variables at the detector.

φ acceptance: Only a fraction of each t bin is accepted by the detector
Acceptance functions

Acceptance calculation using single diffractive Monte Carlo.

- $p(|t|) \sim e^{-4.02 |t|}$.
- $p(\xi) \sim \xi^{-1.11}$.
- $\phi$ distributed uniformly
- Corrected for the beam smearing and detector resolution effects.
- Used three functions to calculate acceptances
  - $e^{-4.02 |t|}$
  - $e^{-3.00 |t|}$
  - $e^{-5.00 |t|}$
- $A_{\text{GEO}}$ also accounts for the bin smearing correction

\[
A_{\text{GEO}} = \frac{N(\text{Reconstructed})}{N(\text{Generated})}
\]
Detector efficiency calculation

- Use ELAS2 (XTXT or TXTX) triggers to calculate trigger efficiencies.
- Demand a track on opposite side, now have 3 hits and sample is dominated by elastic events.
- The efficiency of the detector in question is the ratio of 4-detector hit to 3-detector hit.
- Use the opposite side track to look at t dependence of efficiencies.
- Gives combined hit, trigger and selection efficiencies.
- Increased statistics in the efficiency calculation method by requiring a looser opposite side track and verifying that this yielded consistent results.
Detector efficiencies

- Efficiency does not show $|t|$ dependence.
- At high $|t|$ fluctuation due to low statistics.
- Use single values as efficiencies as in table.
- Efficiencies are higher than what is calculated in elastic analysis because of different hit finding and selection.

<table>
<thead>
<tr>
<th>Detector</th>
<th>Efficiencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1U</td>
<td>0.704 ± 0.009</td>
</tr>
<tr>
<td>A1D</td>
<td>0.615 ± 0.032</td>
</tr>
<tr>
<td>P1U</td>
<td>0.572 ± 0.023</td>
</tr>
<tr>
<td>P1D</td>
<td>0.683 ± 0.004</td>
</tr>
<tr>
<td>A2U</td>
<td>0.366 ± 0.004</td>
</tr>
<tr>
<td>A2D</td>
<td>0.377 ± 0.016</td>
</tr>
<tr>
<td>P2U</td>
<td>0.571 ± 0.016</td>
</tr>
<tr>
<td>P2D</td>
<td>0.579 ± 0.004</td>
</tr>
</tbody>
</table>
Main background in untagged halo events.

Due to efficiency of the trigger scintillators in the diagonally opposite side detectors.

Efficiency of tagging halo is given by the logical OR of the scintillator efficiency of two detectors:

\[
\epsilon(A1U) \text{ OR } \epsilon(A2U) = \epsilon(A1U) + \epsilon(A2U) - \epsilon(A1U) \cdot \epsilon(A2U)
\]

The inefficiency of tagging halo is: 1 – Efficiency(Halo).

Untagged halo background is given by:

\[
\sigma_{bg} = (1 - \mathcal{E}_{Halo}) \cdot \sigma_{halo}
\]
- High efficiencies for the scintillators.
- P2D has very low efficiency.
- This is well known

- Cross section distribution of tagged halo events.
- The effective background is a fraction of this distribution given by (~ 1% and 0.1% P and A -side):
  \[ \sigma_{bg} = (1 - \varepsilon_{Halo}) \cdot \sigma_{halo} \]
Single diffractive differential cross section

- Single diffractive differential cross section obtained for protons and anti-protons after applying the correction factors.
- The signal is weighted according to the acceptance and the efficiencies.
- The dashed line shows the average of the proton and anti-proton cross section.
Sources of systematic uncertainty

- Luminosity measurement.
- Detector efficiency measurement.
- Luminosity monitor efficiency.
- Luminosity monitor acceptance.
- Choice of ansatz function in acceptance calculation.
- Beam smearing
- Pot position uncertainty
Total systematic errors

- The main sources of systematic are Luminosity and detector efficiencies.
- Rest of them are negligible.

<table>
<thead>
<tr>
<th>Syst. source</th>
<th>Value($X$)</th>
<th>$\frac{\delta X}{X}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminosity</td>
<td>$12.6 \pm 1.6$ nb$^{-1}$</td>
<td>0.126</td>
</tr>
<tr>
<td>LM efficiency (N)</td>
<td>0.968</td>
<td>0.004</td>
</tr>
<tr>
<td>LM efficiency (S)</td>
<td>0.935</td>
<td>0.004</td>
</tr>
<tr>
<td>LM acceptance</td>
<td>0.218</td>
<td>0.006</td>
</tr>
<tr>
<td>Trigger efficiencies (syst.)</td>
<td></td>
<td>0.050</td>
</tr>
<tr>
<td>Trigger efficiencies (stat.)</td>
<td></td>
<td>bin-wise</td>
</tr>
</tbody>
</table>
Single diffractive differential cross section in bins of $|t|$.

- Fitted to polynomial function.
- Includes statistical and systematic errors.
- Shaded region shows uncertainty in normalization (12.6%)
Comparison with theory and experiments

<table>
<thead>
<tr>
<th>Experiment</th>
<th>$\sqrt{s}$</th>
<th>$\sigma_{sd}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>UA4</td>
<td>546 GeV</td>
<td>9.4 ± 0.7 mb</td>
</tr>
<tr>
<td>CDF</td>
<td>546 GeV</td>
<td>7.89 ± 0.33 mb</td>
</tr>
<tr>
<td>E710</td>
<td>1.8 TeV</td>
<td>8.1 ± 1.7 mb</td>
</tr>
<tr>
<td>CDF</td>
<td>1.8 TeV</td>
<td>9.46 ± 0.44 mb</td>
</tr>
<tr>
<td>DØ Data fit + extrapolation</td>
<td>1.96 TeV</td>
<td>7.950 ± 0.324 (stat.) ± 1.007 (syst.) mb</td>
</tr>
<tr>
<td>DØ + UA4</td>
<td>1.96 TeV</td>
<td>9.681 ± 0.048 (stat.) ± 1.219 (syst.) mb</td>
</tr>
</tbody>
</table>

Theoretical fluxes are compared with experimental data from various experiments. The renormalized flux shows a significant deviation from the standard flux, with a "knee" at 22 GeV. The differential cross section $\frac{d\sigma}{dt}$ is plotted for different experiments and energies, illustrating the trends and differences in the data.
Conclusions

- Measurement of single diffractive differential cross section at $\sqrt{s} = 1.96$ TeV.
- Data can be fitted with an equation of the form:

$$A \cdot e^{(B \cdot |t| + C \cdot |t|^2)}$$

- Total single diffractive cross section using low $|t|$ UA4 data and a PYTHIA normalization is found to be
  - $9.682 \pm 0.048$ (stat.) $\pm 1.219$ (syst.) mb.
  - In addition to it, there is Monte Carlo uncertainty of 10%, difference between PYTHIA and PHOJET.
- Cross section is in good agreement with other experiments.
Backup
Systematic due to trigger efficiencies

- Use the bin by bin efficiency values to calculate the cross section.
- There is systematic shift of 5% form the cross section calculated by using const efficiency.
Cross section using efficiency fits
Cross section using efficiency fits
Cross section using efficiency fits
Systematic due to choice of ansatz function

- Take three ansatz function to calculate acceptances and evaluate cross sections using them.
- Difference of 1 GeV in slope of the ansatz function is overestimate.
- Still there is no need to add extra systematic from the choice of ansatz function.

Shows the combined effect of ansatz function and bin smearing.
Systematic due to beam smearing

- Use the smeared and un-smeared acceptances to calculate the cross section.
- There is no need to add extra systematic due to beam smearing.
Detector correlation

- Evaluate the single diffractive band cuts based on generic single diffractive Monte Carlo.
- The proton $\xi$ and $t$ are selected according to POMWIG parameterization function.
- The interaction point value is smeared by a Gaussian distribution to account for $z$-vertex distribution.
- The generated protons and anti-proton are propagated to forward detectors using the Tevatron transport matrix.
- The location of the hits from the detectors are passed to track reconstruction program.
The black points are SD Monte Carlo and red points are elastic data.

The band cut equation are evaluated using the SD Monte Carlo.