Double Parton Scattering
in CDF
DPF
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Double Parton Scattering (DPS)

2 parton-parton hard scatters in 1 pp collision provides information on spatial distribution of partons in proton and possible parton-parton correlation - extension of proton pdf studies

Customary to write: M. Drees, T. Han

\[ \frac{d^2 \sigma}{d^2 \text{T} \text{eff}} = \frac{\sigma_\text{pp}}{2} \text{ where } A \text{ and } B \text{ are distinguished} \]

\[ \frac{d^2 \sigma}{d^2 \text{T} \text{eff}} \text{ of } B \text{ given } A \]

if parton distribution uniform, \( T_{\text{eff}} \) lar; \( \frac{d^2 \sigma}{d^2 \text{T} \text{eff}} \) sm

" clumpy, \( T_{\text{eff}} \) sm; \( \frac{d^2 \sigma}{d^2 \text{T} \text{eff}} \) lar
Treat protons as spheres with constant parton density

\[ \sigma_{\text{DP}} = \frac{\sigma_{\text{NSP}}}{4.6} = \frac{51 \text{ mb}}{4.6} \Rightarrow 11 \text{ mb} \]

Theoretical reasons to believe in DPS:
- In mini-jet model, this explains rising \( pp \) cross section

Previous measurements of DPS were with 4-jet final states \((m = 1)\):

- AFS: \( \sigma_{\text{eff}} \approx 5 \text{ mb} \)
- UA2: \( \sigma_{\text{eff}} > 8.3 \text{ mb} \)
- CDF: 1989 data

DP fraction = 5.4 \pm 1.6\% 
\( \sigma_{\text{eff}} = 12.1^{+10.7}_{-5.4} \text{ mb} \)

\[ \frac{\sigma_{(4 \rightarrow 4)} \text{ [DPS]}}{\sigma_{(2 \rightarrow 4)} \text{ [QCD]}} \downarrow \text{ as } p_T \uparrow \]

Want \( p_T \) as small as possible (and still be able to trigger)
In this analysis

"γ" + 3 jet final states

true isolated π°

Data Sample 16 pb^{-1} (1992-93)

γ trigger $E_T^γ > 16$ GeV/c

$|\eta^γ| < 0.9$

Isol $γ < 4$ GeV/c in cone R = 0.7 around $γ$

$|\eta^{jet 1}| < 4$

# of jets $\equiv 3 \Rightarrow n_{ψx}=1 \Rightarrow n_{ψx}=2 \Rightarrow$

$E_T^{jet 1} > 5$ GeV/c

5 GeV/c $< E_T^{jet 2}$, $E_T^{jet 3} < 7$ GeV/c

6 sensitive variables in analysis

$\delta \phi (γ, jet 1)$

$\delta \phi (γ, jet 2)$

$\delta \phi (γ, jet 3)$

$E_T^{jet 1}/E_T^γ$

transverse mom for $ψ$

$S = \frac{1}{12} \sqrt{\frac{|p_T(γ)|^2}{\Delta φ^2} + \frac{|p_T(γ)|^2}{\Delta φ^2}}$

$ΔS$ : Δφ between $p_T$ vectors of $γ + jet$, jet + jet pairs
CDF Detector

$\eta = 0$

$\eta = 0.9$

$\eta = 2.4$

$\eta = 4$

INTERACTION POINT

Silicon Vertex Detector

Central Tracking Chamber

Solenoid

CENTRAL EM

Forward (Not-To-Scale)
$\gamma + 3\text{ jet}$ Final states

(a) QCD

(b) DP Type 1

(c) DP Type 2

$\gamma$ + 1 jet
jet + jet

$\gamma$ + jet + jet
jet + jet
DI = double interaction, 2 hard scatters at separate vertices
Goal is to extract:
- $f_{pp}$: % of events from double parton scattering
- $f_{ef}$
- any evidence for parton correlations

Two approaches for measuring $f_{pp}$:
- Use Pythia to model QCD, fit 6 distributions for $f_{pp}$ and $f_{qcd}$
- Data driven; contrast 2 sets of data with different $f_{pp}$ values, determine $f_{qcd}$ and $f_{pp}$

Both give similar results
$f_{pp} = 0.270 \pm 0.017$
CDF Preliminary

CDF 16 GeV $\gamma/n^0 + 3$ Jets

- Data
- DP, QCD Admixture (52%/48%)
- 100% QCD (Pythia)
CDF Preliminary

CDF 16 GeV p/\bar{p} + 8 data

Data
- Data
- Di Model 0.75
- Di Model 0.05

Significance

Events between pairs:
FIG. 16. Distributions of (a) $S$ and (b) $\Delta S$ obtained using four-jet data with a cut on fifth jets of $p_{T5} < 15$ GeV/c overlaid on the QCD double bremsstrahlung distribution and a fitted admixture of double bremsstrahlung and double parton distributions. Also shown are the fitted values of $R$. The $\Delta S$ distribution is shown using a logarithmic scale for clarity. (76)
CDF Preliminary

CDF 16 GeV γ/π⁰ + 3 Jets

- Data
  Based on 1 event with δS<1
- Prediction
  Based on DP model
  Normalized to 52% for 5≤E<7 GeV
  ±14% Norm. Uncert. not shown
Determination of \( \Gamma_{\text{eff}} \)

Previous analyses:

\[
\Gamma_{\text{eff}} = \frac{\Gamma_{\text{pp}} \rightarrow \text{measured}}{\Gamma_{A} \Gamma_{B} \rightarrow \text{calculated}} \times \frac{1}{2} \cdot \text{Jet + Jet}
\]

This analysis:

- \# beam crossings with single \( pp \) collisions
- \( \Gamma_{\text{eff}} = \left( \frac{N_{\text{pp}}}{N_{\text{pp}}} \right) \left( \frac{N_{\text{NSD}}}{2 N_{\text{NSD}}} \right) \times N_{\text{NSD}} \left( \frac{m}{M} \right) \)
- \# beam crossings with \( 2 \) \( pp \) collisions

\[\text{IF } m=2 \text{, then } \Gamma_{\text{eff}} = 10 \text{ mb} \pm 1 \text{ mb}\]

\[\downarrow \text{ still under theoretical debate} \]

Parton Correlations:

- Look for \( x \)-dependence to \( \Gamma_{\text{eff}} \)
  - If proton has a hot core, then
  - If one parton at higher \( x \), same true at other parton.

- Measure \( x \) distribution for sample enriched in DPS
  - \( N_{\nu+\tau} = 1 \Rightarrow \Gamma_{pp} = 87 \%
  - \Delta s < 1.2

\[\Rightarrow \text{no systematic deviations of DPS rates vs } x \text{ for } x \text{ from } 0.002-0.20 \]
Other kinematic correlations?

- Use same "enriched" data sample as previous study.
  - 87% DP
  - 13% qCD

- Evaluate:
  - Invariant mass
  - P_T
  - P_T^*

...distributions agree with MC mixture of above.
Conclusions

- Strong signal for double parton scattering in $\pi/\pi^0 + 3$ jet
  - Factor of 10 increase in signal strength
  - Factor of 8 increase in statistics
  - $f_{pp} = 52.2 \pm 1.7\%$

- $T_{ext} = 10 \text{ mb} \ (\text{if } m=2)$

- No kinematic correlations observed

Future

- Determine $m$
- Extension to other processes
  - $K\pi\pi$
  - $\rho^0\pi$