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Extracting σ_{eff} from the CDF measurement of γ+3 jets

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Outline

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- Transition from exclusive to inclusive σ_{eff}
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Motivation

- In 1997, CDF measured DPS in γ+3 jets production
  [Phys. Rev. D 56 (1997) 3811]
  - Measured inclusive DPS event fraction

$$f_{DP} = 0.526 \pm 0.025(\mathrm{stat}) \pm 0.009(\mathrm{syst})$$

  - Estimated exclusive TPS event fraction out of inclusive DPS

$$f_{TP} = 17^{+4}_{-8}\%$$

  - Effective cross section was defined for exclusive DPS

$$\sigma^{ex}_{ab;2} = \frac{\sigma_a \sigma_b}{\sigma_{eff(CDF)}}$$

Motivation

- Possible correction reflects:
  - Standard definition of σ_{eff} is in the inclusive manner

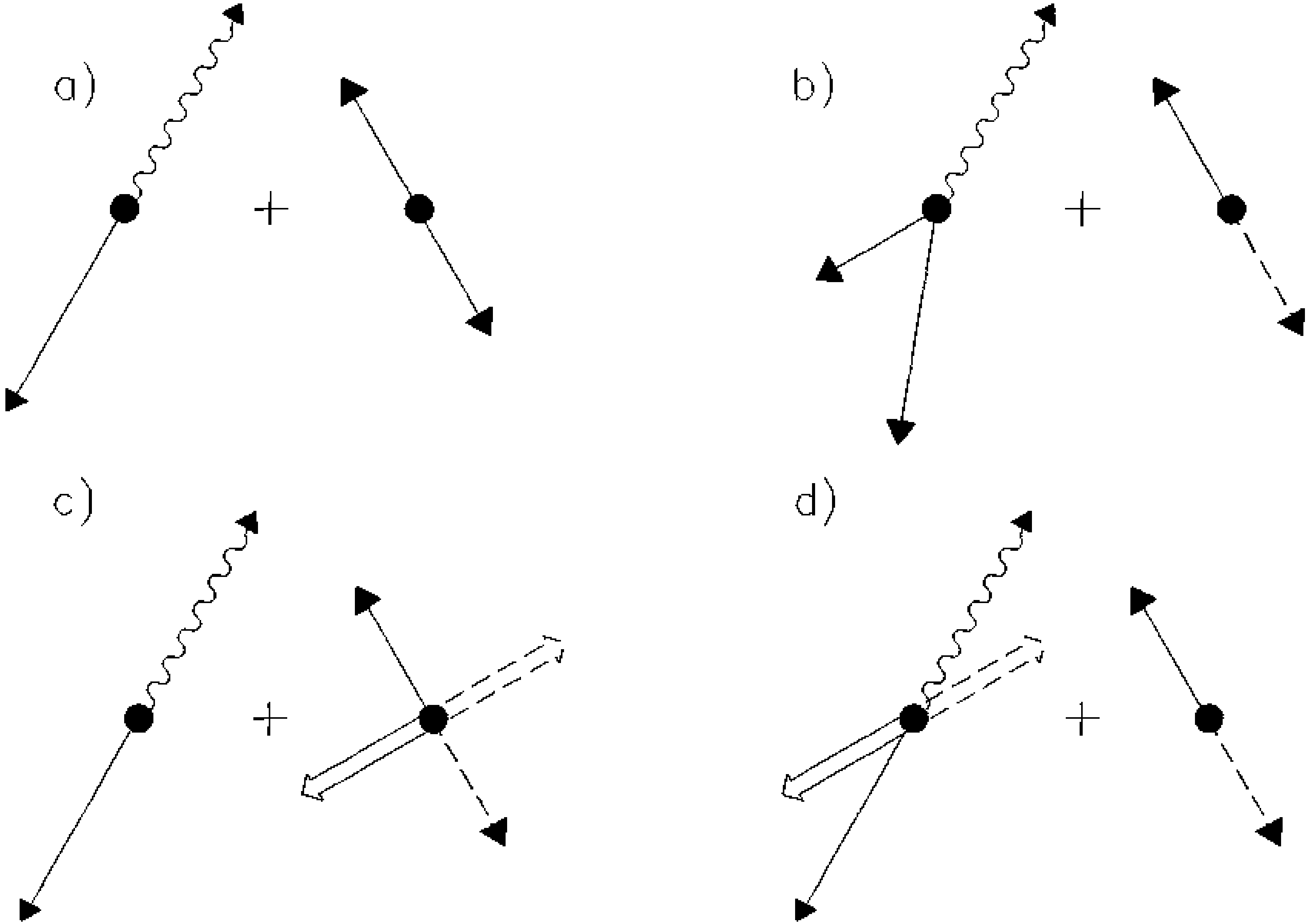
$$\sigma^{ex}_{ab;2} = \frac{\sigma_a \sigma_b}{\sigma_{eff(CDF)}} \Rightarrow \sigma^{in}_{ab;2} = \frac{\sigma_a \sigma_b}{\sigma_{eff}}$$

  - Individual scatters can not be identified and counted
  - The systematic uncertainty decreases by not-rejecting the exclusive triple parton scattering events

CDF σ_{eff} extraction method

- no dependence on Monte Carlo
- Fine vertex resolution and low luminosity allowed reasonable determination of single- and double- proton-antiproton interaction per bunch crossing
- 1 VTX data for inclusive gamma production were combined with 1 VTX minimum bias data to model the inclusive DPS

$$\sigma^{ex}_{\gamma+3jets;2} = \frac{(\sigma_{\gamma+0jet}\sigma_{3jets}) + \sigma_{\gamma+1jet}\sigma_{2jets} + \sigma_{\gamma+2jets}\sigma_{1jet}}{\sigma_{eff(CDF)}}$$


a)
b)
c)
d)

Transition from exclusive to inclusive σ_{eff}

- Exclusive measurement by CDF:

$$\sigma_{eff(CDF)} = (14.5 \pm 1.7^{+1.7}_{-2.3})\ \text{mb}\,, \qquad \frac{\sigma^{ex}_{ab;3}}{\sigma^{ex}_{ab;2}} = \frac{17}{83}$$

- Treleani: **[Phys. Rev. D 76 (2007) 076006]**

$$\sigma^{in}_{ab;2} \simeq [\sigma^{ex}_{\gamma+3jets;2}]_{CDF} + 2\frac{17}{83}[\sigma^{ex}_{\gamma+3jets;2}]_{CDF}$$

$$\sigma_{eff} \approx \frac{\sigma_{eff(CDF)}}{1.41} = 10.3\ \text{mb}$$

Transition from exclusive to inclusive σ_{eff}

- Inclusive DPS cross section for processes a and b:

$$\sigma^{in}_{ab;2} = \sigma_a \sigma_b \int d^2\beta \, (A(\beta))^2 = \frac{\sigma_a \sigma_b}{\sigma_{eff}}$$

- Exclusive DPS cross section:

$$\sigma^{ex}_{ab;2} = \sigma_a \sigma_b \int d^2\beta \, (A(\beta))^2 \, e^{-(\sigma_a + \sigma_b) A(\beta)} = \frac{\sigma_a \sigma_b}{\sigma_{eff(CDF)}}$$

- Exclusive TPS cross section:

$$\sigma^{ex}_{ab;3} = \frac{1}{2!} \sigma_a \sigma_b^2 \int d^2\beta (A(\beta))^3 e^{-(\sigma_a + \sigma_b) A(\beta)}$$

Transition from exclusive to inclusive σ_{eff}

- Assumptions:
  - $\sigma_a << \sigma_b$ (direct photon vs di-jet production)
  - Exponential factor is approximated by an appropriate sum
  - One can distinguish if there is one or two b processes

$$\sigma_{ab;2}^{ex} = \frac{\sigma_{eff(CDF)}}{\sigma_{eff}} \sigma_{ab;2}^{ex} - 2\sigma_{ab;3}^{ex}$$

$$\boxed{\sigma_{eff(CDF)} = \sigma_{eff} \left(1 + 2 \frac{\sigma_{ab;3}^{ex}}{\sigma_{ab;2}^{ex}} \right)}$$

Specification of the final state

- In the real case, one can not distinguish if the 2 jets originate in the same parton interaction or not
  → expansion of all possibilities is necessary

$$\sigma^{ex}_{\gamma+3jets;2} = \int d^2\beta \left[\left(\sigma_{\gamma+1jet} A(\beta)\right) \left(\sigma_{2jets} A(\beta)\right) + \right.$$

$$\left. + \left(\sigma_{\gamma+2jets} A(\beta)\right) \left(\sigma_{1jet} A(\beta)\right) \right] \left(1 - \sigma_{jets} A(\beta)\right)$$

$$\sigma^{ex}_{\gamma+3jets;3} = \frac{1}{2!} \int d^2\beta \left[\left(\sigma_{\gamma+1jet} A(\beta)\right) \left(\sigma_{1jet} A(\beta)\right) \left(\sigma_{1jet} A(\beta)\right) \right]$$

Specification of the final state

$$\sigma_{eff(CDF)} \approx \sigma_{eff}\left(1+2\frac{\sigma^{ex}_{\gamma+3jets;3}}{\sigma^{ex}_{\gamma+3jets;2}}\left(\frac{\sigma_{2jets}}{\sigma_{1jet}}+\frac{\sigma_{\gamma+2jets}}{\sigma_{\gamma+1jet}}\right)\frac{\sigma_{jets}}{\sigma_{1jet}}\right)$$

$$= \sigma_{eff}\left(1+2\frac{\sigma^{ex}_{\gamma+3jets;3}}{\sigma^{ex}_{\gamma+3jets;2}} f\right)$$

Treleani

$$\sigma_{eff(CDF)} = \sigma_{eff}\left(1+2\frac{\sigma^{ex}_{ab;3}}{\sigma^{ex}_{ab;2}}\right)$$

Analysis

- Correction factor $f = \left(\frac{\sigma_{\text{2jets}}}{\sigma_{\text{1jet}}} + \frac{\sigma_{\gamma+\text{2jets}}}{\sigma_{\gamma+\text{1jet}}} \right) \frac{\sigma_{\text{jets}}}{\sigma_{\text{1jet}}}$
- CDF final state definition:

$$E_T^\gamma > 16 \text{ GeV}, \quad E_T^j > 5 \text{ GeV}, \quad E_T^{j_2,j_3} < 7 \text{ GeV},$$
$$|\eta^\gamma| < 0.9, \quad \Delta R^{\gamma j} > 0.8,$$
$$|\eta^j| < 4.2, \quad \Delta R^{jj} > 0.7,$$

- Cross sections are for exactly one scatter (MPI OFF)
- Rivet analysis of direct γ and QCD di-jet processes

Analysis – results for default tune

	Herwig++			fHerwig			Pythia 6		
σ [mb]	Hard	Soft	Sum	Hard	Soft	Sum	Hard	Soft	Sum
σ_{1jet}	9.16	3.16	12.32	5.33	6.61	11.94	6.93	2.51	9.44
σ_{2jets}	0.62	0.15	0.77	0.54	0.70	1.24	0.72	0.00	0.72
σ_{jets}	13.87	3.70	17.57	8.72	8.31	17.03	10.54	2.52	13.06
σ [nb]									
$\sigma_{\gamma+1jet}$	5.66	0.03	5.69	3.41	0.16	3.57	4.47	0.08	4.55
$\sigma_{\gamma+2jets}$	1.46	0.01	1.47	1.02	0.04	1.06	1.05	0.07	1.22
$\frac{\sigma_{2jets}}{\sigma_{1jet}}$	0.063			0.103			0.076		
$\frac{\sigma_{jets}}{\sigma_{1jet}}$	1.426			1.426			1.383		
$\frac{\sigma_{\gamma+2jets}}{\sigma_{\gamma+1jet}}$	0.258			0.300			0.246		
f	0.458			0.575			0.445		
$f_{avg.}$	0.493								

- Ratios are more stable than cross sections itself, as expected

Hard QCD (direct γ) : $\hat{p}_t > 2$ GeV ($\hat{p}_t > 10$ GeV)

Soft : $0.5 < \hat{p}_t < 2$ GeV ($5.0 < \hat{p}_t < 10$ GeV)

Analysis – systematics

- Systematics studied for
  - 3 generators
    - Herwig++ 2.5.2, Pythia 6.4.26, fHerwig 6.510
  - 3 jet clustering algorithms (FastJet 2.4.2)
    - CDFJetClu, PxCone, anti-k_t; R = 0.7
  - 3 values of intrinsic parton k_t (0.0, 1.0, 2.0 GeV)
  - 3 parton distribution functions
    - CTEQ6L1, MRST98, MRST LO**
  - 1 loop vs 2 loops α_S
- Spread of predictions is consistent with crude estimation of uncertainty: $\alpha_s(5\ \mathrm{GeV}) \sim 0.2$

Analysis – systematics

- PDF and α_S

PDF	MRST98	CTEQ6L1	MRST LO**	α_S	1-loop	2-loops
f	0.477	0.447	0.458	f	0.476	0.458

- Jet clustering

Jet algorithm	CDFJetClu	PxCone	Anti-k_T
f	0.458	0.512	0.525

- Intrinsic k_t

f	$k_T = 0.0$ GeV	$k_T = 1.0$ GeV	$k_T = 2.0$ GeV
Herwig++	0.648	0.582	0.465
fHerwig	0.575	0.619	0.564
Pythia 6	0.620	0.590	0.445

Final factor :

$$f_{avg.} = 0.49 \pm 0.10$$

Analysis – results

- Final result $$\sigma_{eff} = \left(12.0 \pm 1.3^{+1.3}_{-1.5}\right)\ \text{mb}$$
- Treleani $$\sigma_{eff} \approx 10.3\ \text{mb}$$
- CDF value $$\sigma_{eff(CDF)} = (14.5 \pm 1.7^{+1.7}_{-2.3})\ \text{mb}$$

- Systematic uncertainty was significantly reduced!
  - Uncertainty caused by removal of triple parton scattering was avoided
  - Additional uncertainty of the correction factor f is negligible

Summary

- Final result $\sigma_{eff} = \left(12.0 \pm 1.3^{+1.3}_{-1.5}\right)$ mb
- Systematic uncertainty was significantly reduced
- The value is in the middle between the CDF result and correction suggested by Treleani
- The value of sigma effective is important for a comparison with other experimental values and theoretical considerations validation of MC MPI models (standard LHC tunes leads to $\sigma_{eff} > 25$ mb, see Mark Strikman's talk)
- Publication is planed to be ready soon.

Back up

CDF definition (TPS excluded)

$$\sigma_{eff(CDF)} = \left(\frac{N_{DI}}{N_{DP}}\right)\left(\frac{A_{DP}}{A_{DI}}\right) R_c \sigma_{NSD}$$

Re-definition, using all data sample

$$\hat{\sigma}_{eff(CDF)} = \frac{N_{DI}}{N_{DP+TP}}\left(\frac{A_{DP}}{A_{DI}}\right) R_c\, \sigma_{NSD}$$

=>

$$\hat{\sigma}_{eff(CDF)} = \sigma_{eff}\left(1 + \frac{\sigma^{ex}_{\gamma+3jets;3}}{\sigma^{ex}_{\gamma+3jets;2} + \sigma^{ex}_{\gamma+3jets;3}}\left[2\, f\, - 1\right]\right)$$