Multiple Scattering, Underlying Event and Minimum Bias

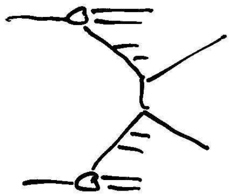
G. Gustafson, HERA-LHC March '07

Outline

- Multiple hard subcollisions
- Underlying event and correlations
- AGK cutting rules and PYTHIA MC
- Relation $E_\perp - n_{ch}$
- Dipole cascade models and pomeron loops

Minijet cross section

Collinear factorization



1 subcollision = 2 jets

$$\frac{d\sigma^{\text{subcoll}}}{dp_\perp^2} \sim \int dx_1\, dx_2\, f(x_1, p_\perp^2)\, f(x_2, p_\perp^2)\, \underbrace{\frac{d\hat{\sigma}(\hat{s}=x_1 x_2 s, p_\perp^2)}{dp_\perp^2}}_{\sim \frac{1}{p_\perp^4}}$$

Cutoff needed: $p_{\perp\min}$

Total subcollision cross section $\propto \frac{1}{p_{\perp\min}^2}$

Sjöstrand - Skands

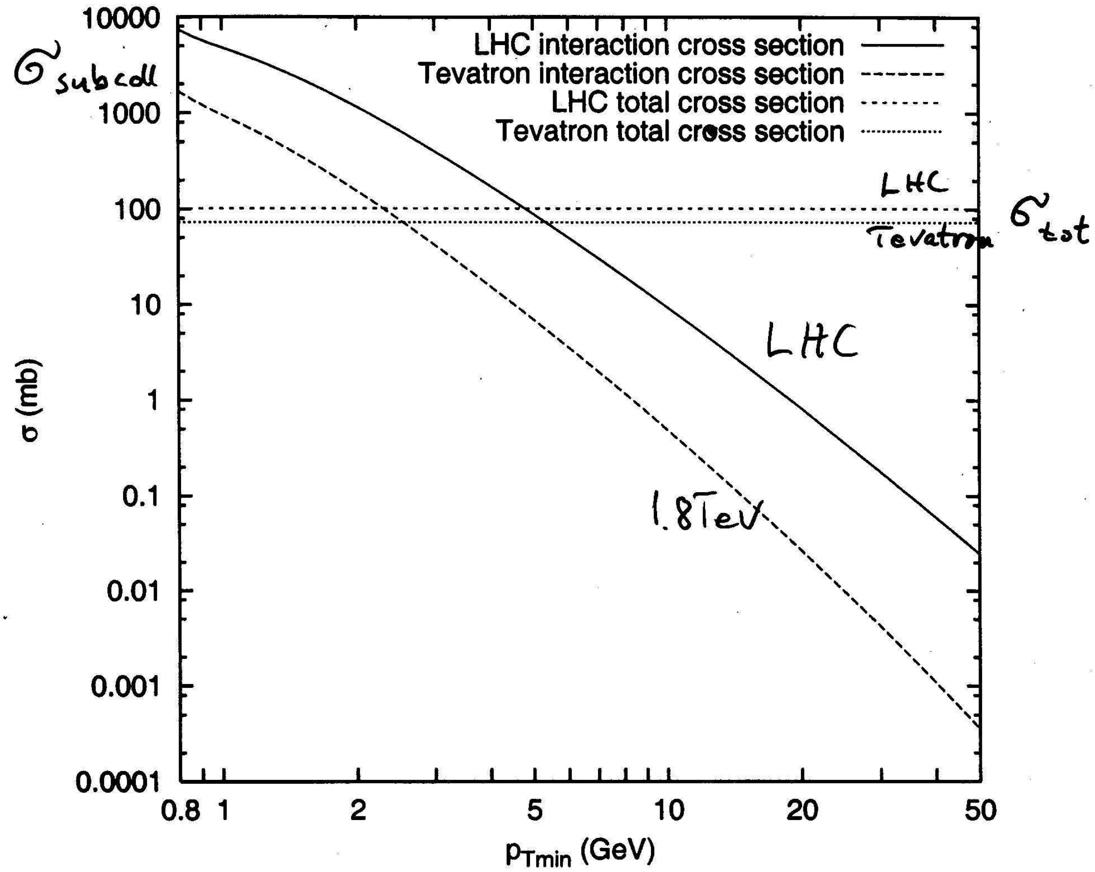
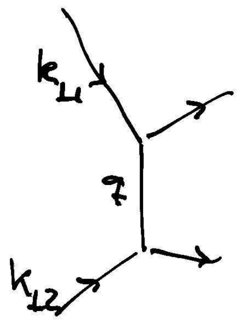


Figure 2: The integrated interaction cross section σ_{int} above $p_{\perp\text{min}}$ for the Tevatron, with 1.8 TeV $p\overline{p}$ collisions, and the LHC, with 14 TeV pp ones. For comparison, the flat lines represent the respective total cross section.

Fit to data : $p_{\perp min} \sim 2$ GeV at the Tevatron

Slowly growing with energy (Sjöstrand - v. Zijl)

<u>$k_\perp$ - factorization</u>



Dynamic cutoff when

$q_\perp < k_{\perp 1}, k_{\perp 2}$

(G.G. - G. Miu '01)

Similar effect

Result : $\sigma_{subcoll} >> \sigma_{tot}$

=> On average several subcoll. / event

Early suggestion : The increase in σ_{tot} is driven by hard parton - parton subcollisions

UA1

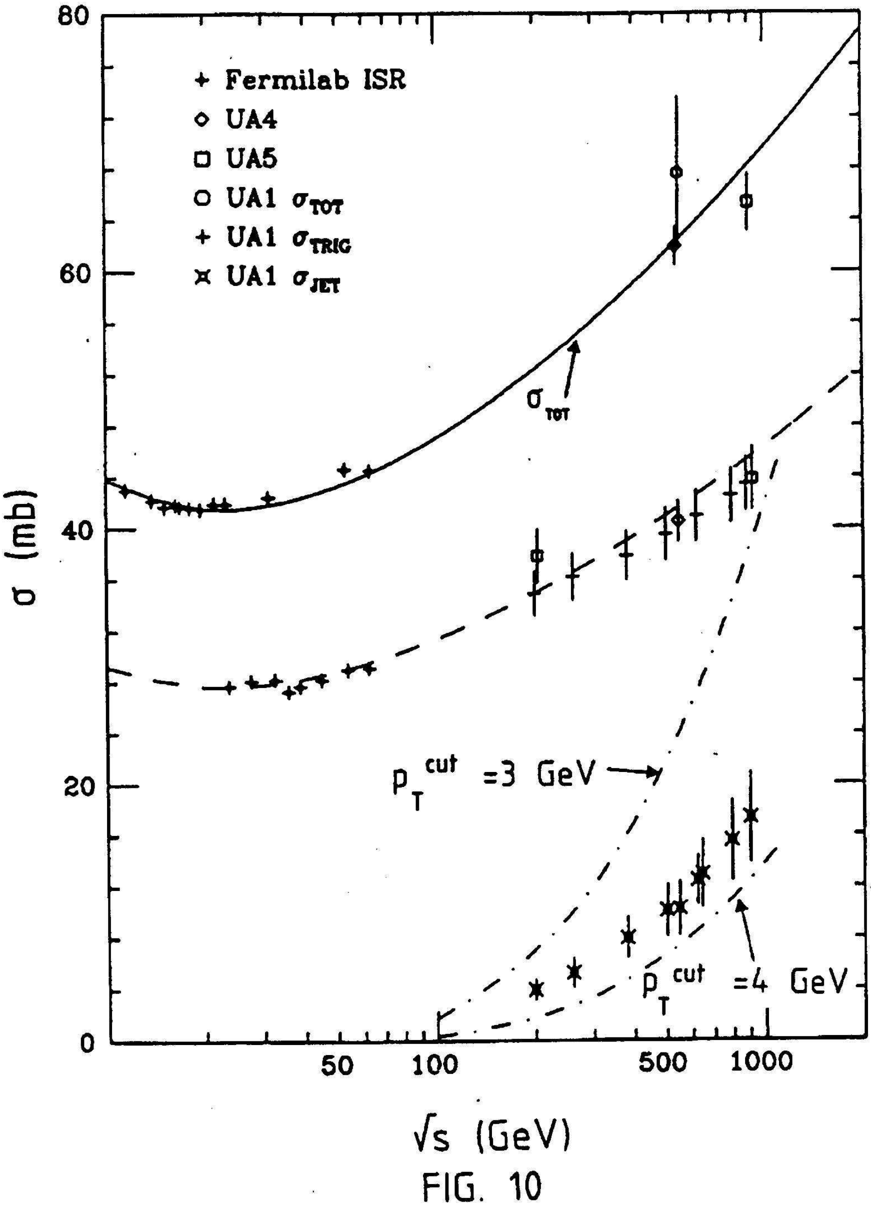
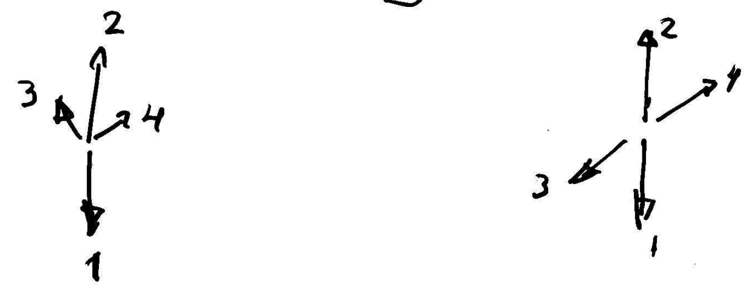

Fermilab ISR
UA4
UA5
UA1 σ_TOT
UA1 σ_TRIG
UA1 σ_JET
σ_TOT
p_T^cut =3 GeV
p_T^cut =4 GeV
σ (mb)
0
20
40
60
80
50
100
500
1000
√s (GeV)

FIG. 10

Experimental evidence for multiple subcollisions

1. Multijet events

Cf. double bremsstrahlung – double parton scatt.



Imbalance parameter

$$J = \frac{1}{2}\left[(\bar{p}_{\perp 1} + \bar{p}_{\perp 2})^2 + (\bar{p}_{\perp 3} + \bar{p}_{\perp 4})^2\right]$$

fig

AFS

Also CDF, DØ 4jet ev.

CDF $3j + \gamma$ fig

Zeus photoprod.

ISR

AFS at ISR
63 GeV

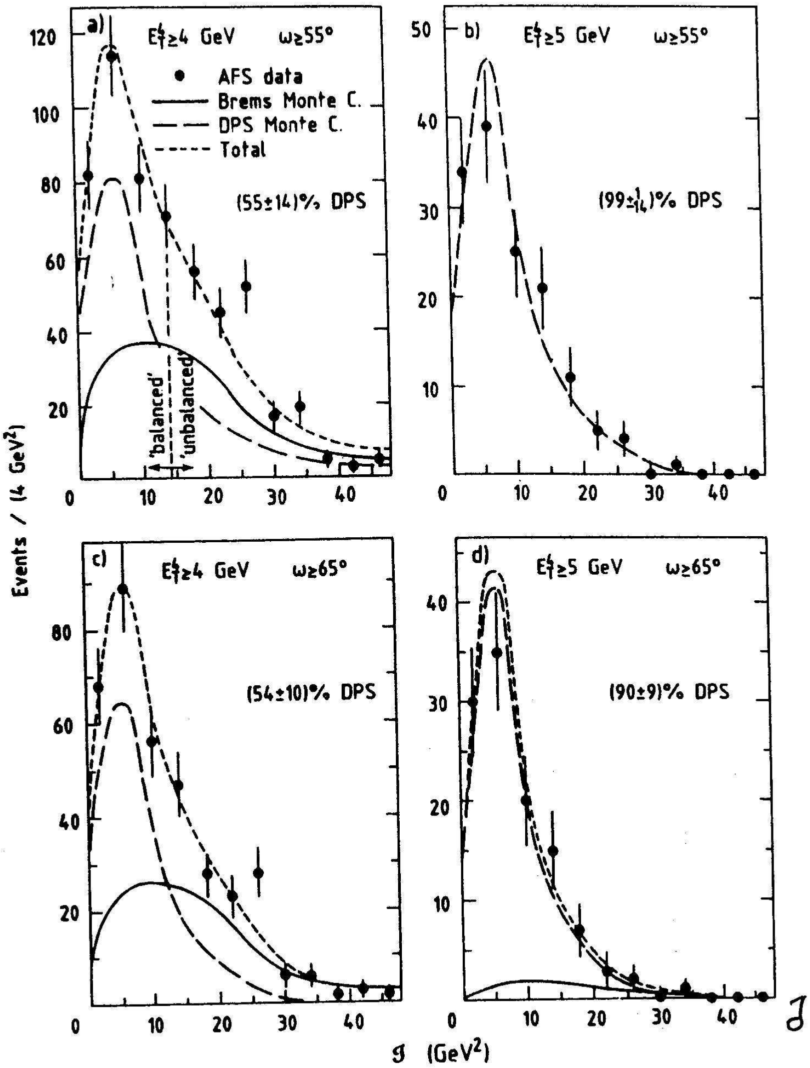
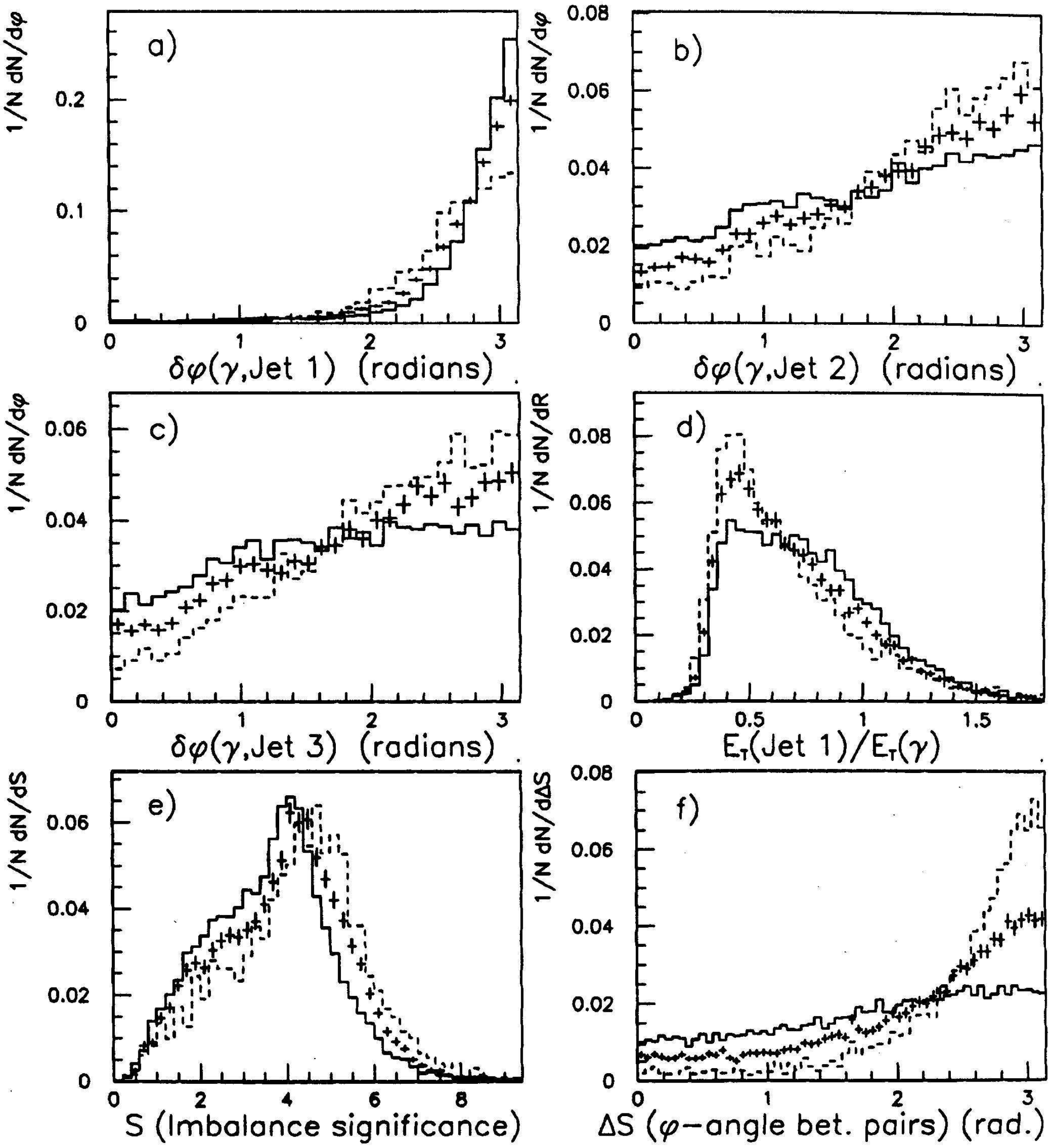


Fig. 3a–d. The distribution of the imbalance variable $\mathcal{J}$ for our (uncorrected) data and the predictions of the two model calculations including full detector simulation etc. Figures **a–d** correspond to various cuts on the E_T of jet $4(E_T^4)$ and interjet angle (ω) as indicated. The data are fitted to a sum of the two components. The results of the fit are the fractions of DPS indicated, and the model curves

8 CDF 4
γ + 3 jet

CDF : 3 jets + γ
– – – with mult. int.
——— without "



Underlying event

Is a high $p_\perp$ event = 2 jets + min. bias ?

Correlations

Uncorrelated subcollisions $\Rightarrow$

Prob. (n subcollisions) = Poisson distrib.

$$\therefore \quad P(2) = \frac{1}{2} P^2(1)$$

double counting

$$P(2) = \frac{\sigma_2}{\sigma_{\mathrm{inel,nd}}} \quad ; \quad P(1) = \frac{\sigma_1}{\sigma_{\mathrm{inel,nd}}}$$

$$\therefore \quad \sigma_2 = \frac{1}{2} \frac{\sigma_1^2}{\sigma_{\mathrm{inel,nd}}}$$

Exp. notation: $\quad \sigma_2 = \frac{1}{2} \frac{\sigma_1^2}{\sigma_{\mathrm{eff}}}$

ISR: $\sigma_{\mathrm{eff}} \sim 5\,\mathrm{mb}$ $(p_\perp > 4\,\mathrm{GeV})$ $\quad \sigma_{\mathrm{nd}} \sim 30\,\mathrm{mb}$

CDF: $\sigma_{\mathrm{eff}} \sim 12\,\mathrm{mb}$ $(p_\perp > 25\,\mathrm{GeV})$ $\quad \sigma_{\mathrm{nd}} \sim 50\,\mathrm{mb}$

CDF $3j+\gamma$ $\quad \sigma_{\mathrm{eff}} \sim 14\,\mathrm{mb}$

$\sigma_{\mathrm{eff}} \ll \sigma_{\mathrm{nd}} \Rightarrow$ Correlated mult. coll.

1 hard coll. => more likely to have another one.

Interpretation:

$\begin{cases} \text{Central coll.} \Rightarrow \text{many hard sub coll.} \\ \text{Peripheral coll.} \Rightarrow \text{few} \quad - \text{''} - \end{cases}$

Pedestal effect

High $p_\perp$ jets ⇒ Undelying event grows

UA1 (fig)

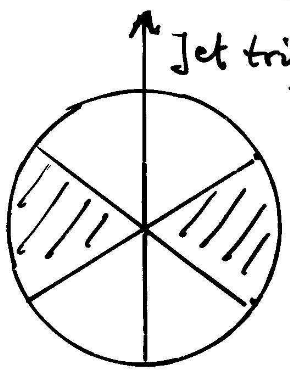
H1 resolved γ-prod

CDF Rick Field

Tuned PYTHIA MC to CDF data

Tune A, tune AW

give good fits to "all" data



$E_\perp$ & charged mult. in transverse region

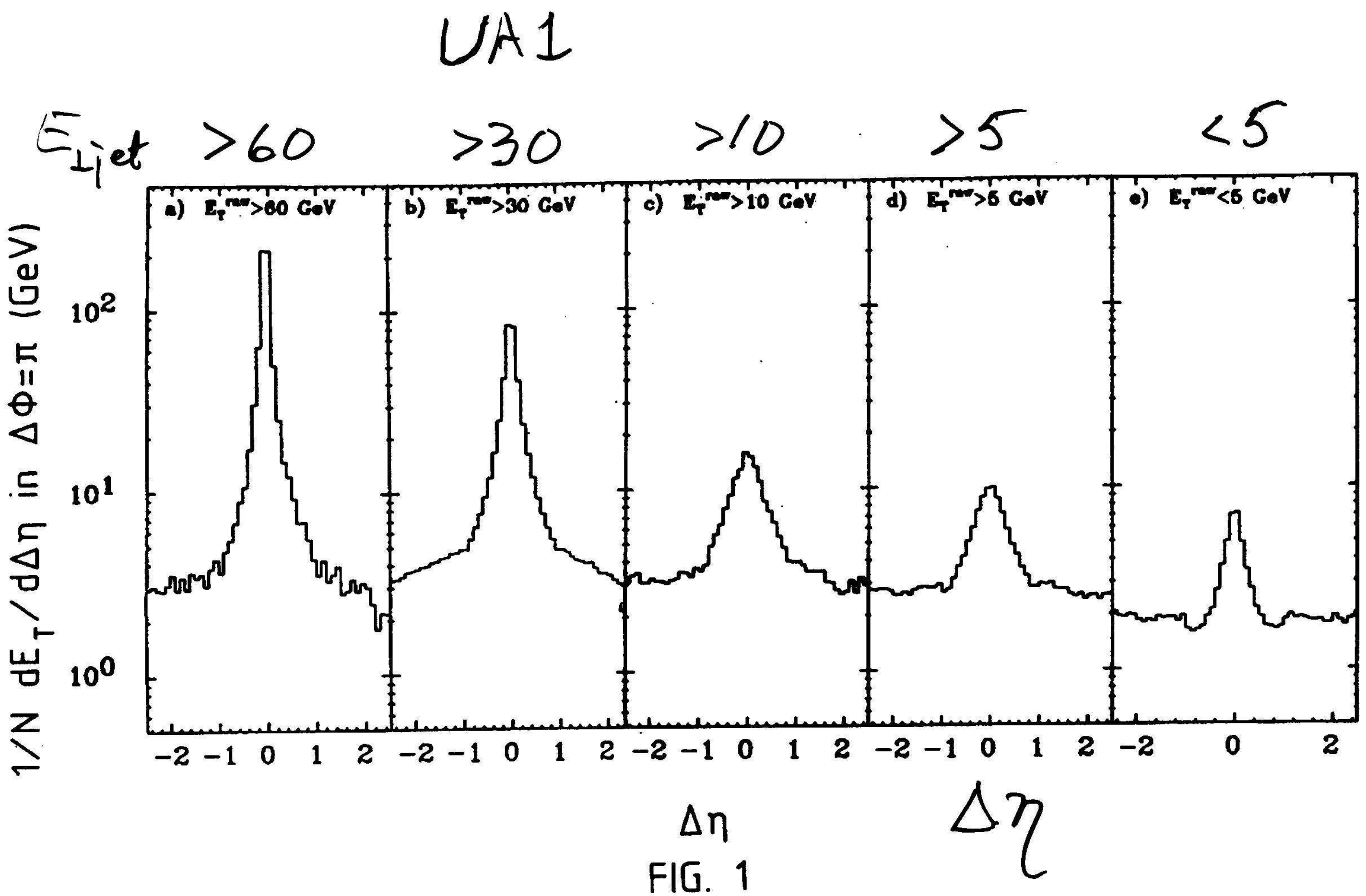

UA1
$E_{\perp jet}$ >60 >30 >10 >5 <5
a) E_T^{raw}>60 GeV
b) E_T^{raw}>30 GeV
c) E_T^{raw}>10 GeV
d) E_T^{raw}>5 GeV
e) E_T^{raw}<5 GeV
$1/N\ dE_T/d\Delta\eta$ in $\Delta\Phi=\pi$ (GeV)
10^2
10^1
10^0
−2 −1 0 1 2
$\Delta\eta$
$\Delta\eta$

FIG. 1

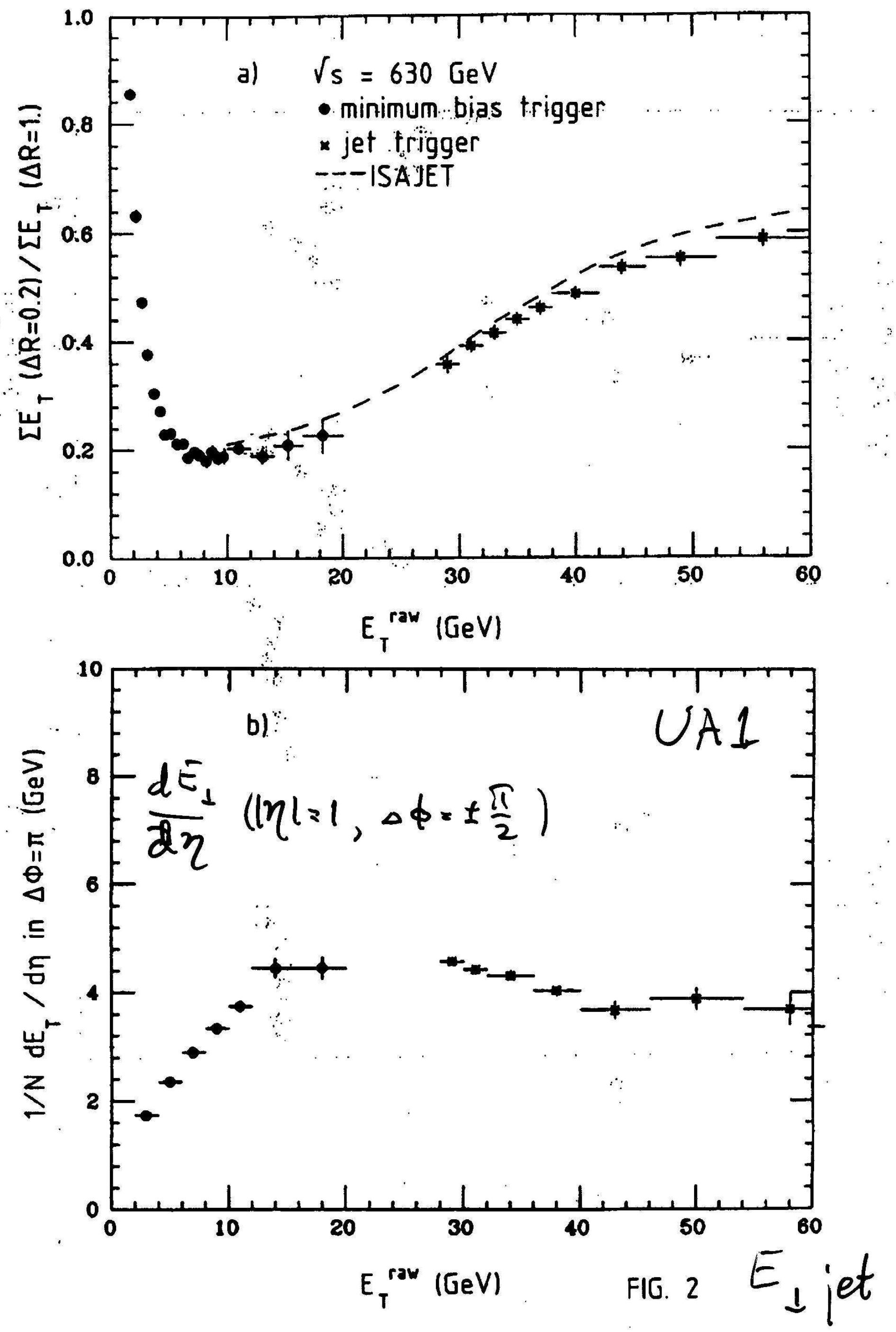
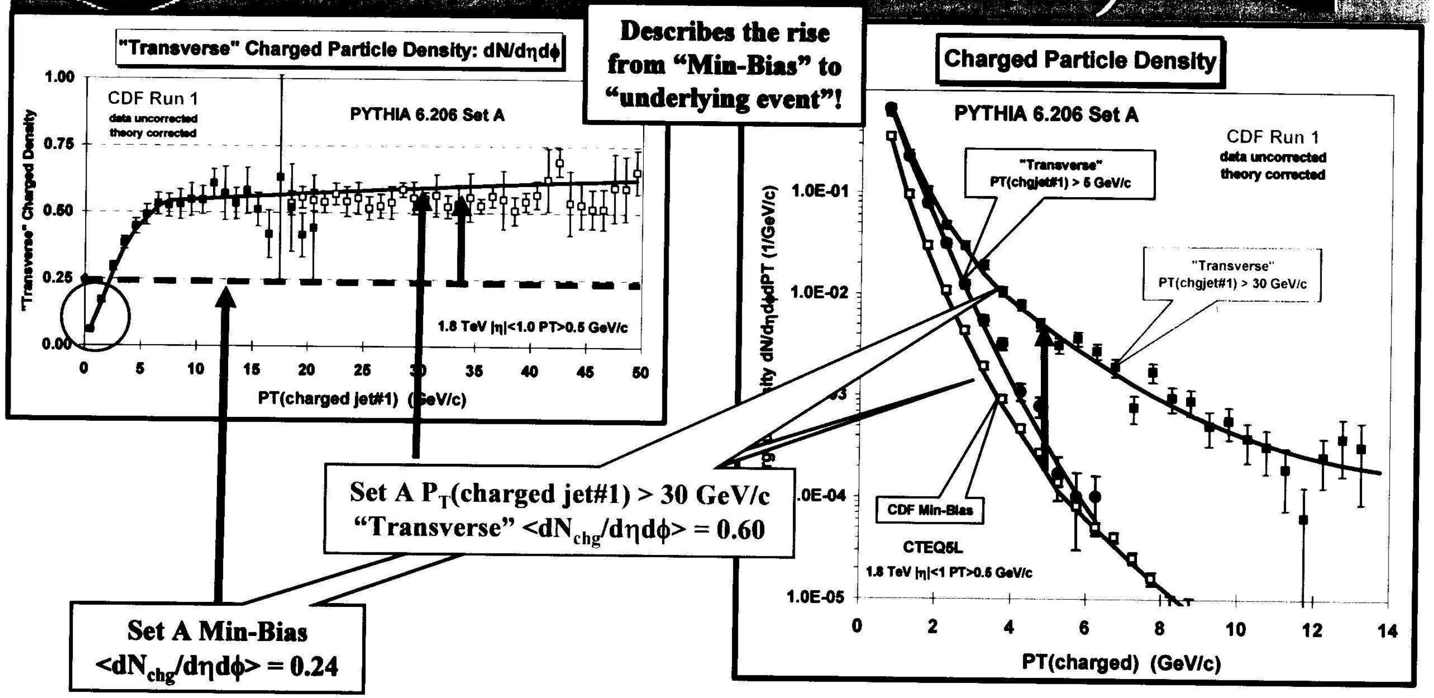

a) $\sqrt{s}$ = 630 GeV
● minimum bias trigger
× jet trigger
--- ISAJET
$\Sigma E_T\ (\Delta R=0.2)/\Sigma E_T\ (\Delta R=1.)$
E_T^{raw} (GeV)
b)
UA1
$\frac{dE_\perp}{d\eta}$ ($|\eta|=1$, $\Delta\phi=\pm\frac{\pi}{2}$)
$1/N\ dE_T\,/\,d\eta$ in $\Delta\Phi=\pi$ (GeV)
E_T^{raw} (GeV)
$E_\perp$ jet

FIG. 2

Rick Field

PYTHIA 6.206 Tune A (CDF Default)



- **Compares the average "transverse" charge particle density ($|\eta|<1$, $P_T>0.5$ GeV) versus P_T(charged jet#1) and the P_T distribution of the "transverse" and "Min-Bias" densities with the QCD Monte-Carlo predictions of a tuned version of PYTHIA 6.206 (P_T(hard) > 0, CTEQ5L, Set A). Describes "Min-Bias" collisions! Describes the "underlying event"!**

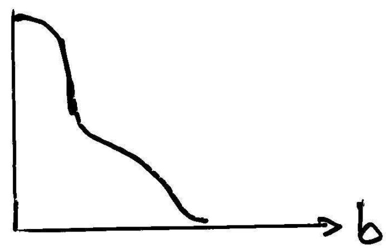
Early <u>Sjöstrand - v. Zijl model</u>
implemented in <u>PYTHIA</u>

Assume: High energy collisions are dominated by parton-parton subcoll.

Min. bias: At least one parton-parton subcoll.

Parton distrib: ~ Double Gaussian

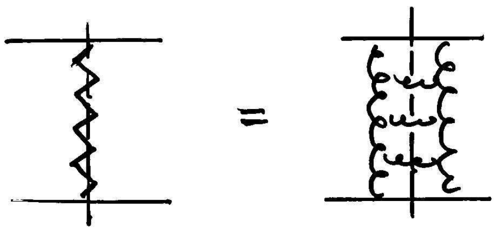
Fixed b: Poisson distrib.
< # subcoll. > $\propto$ overlap



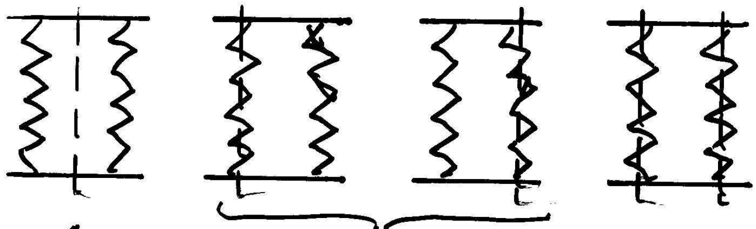
$\Rightarrow$ P(n) $\approx$ Geometric distrib.
Wider than Poisson

AGK cutting rules

$\mathbb{P}$ = gluon ladder

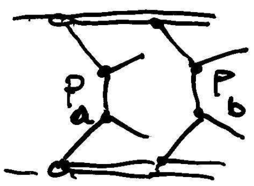


Double $\mathbb{P}$ exch.



$$1 \;:\; \underbrace{-4}_{} \;:\; 2$$

PYTHIA: Fixed b, double scatt.



Uncorrelated $\Rightarrow$

$$P_1 = P_a(1-P_b) + P_b(1-P_a) =$$
$$= P_a + P_b - 2\,P_a \cdot P_b$$

$$\begin{cases} \text{Contrib. to } P_1 \text{ from double } \mathbb{P} \text{ exch.} = -2P_aP_b \\ \quad \text{"} \quad P_2 \qquad\quad \text{— " —} \qquad\quad = P_a \cdot P_b \end{cases}$$

Agrees with AGK

Multi $\mathbb{P}$ exch

AGK: $\nu\,\mathbb{P}$, μ cuts (no color complications)

$$F_\mu^\nu = (-1)^{\nu-\mu}\binom{\nu}{\mu}\,\Sigma^\nu$$

↑ contrib from single $\mathbb{P}$

$$\Rightarrow\quad P_\mu = \sum_{\nu=\mu}^{\infty} F_\mu^\nu = \frac{1}{1+\Sigma}\left(\frac{\Sigma}{1+\Sigma}\right)^\mu$$

Geometric series!

Agrees with PYTHIA, when PYTHIA is fit to data

Relation $E_\perp - n_{ch}$

Rick's tune A fits both $E_\perp$ flow and particle flow, but pays a price.

Relation $E_\perp - n_{ch}$ is <u>not</u> as expected

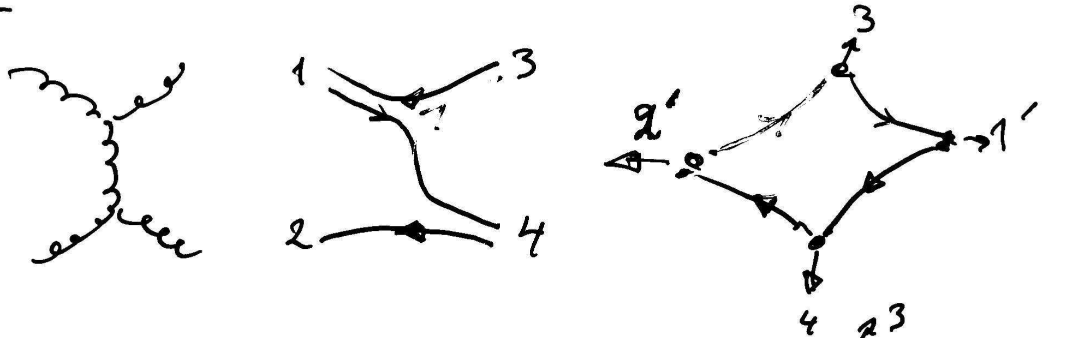
1 cut $\mathbb{P}$: 

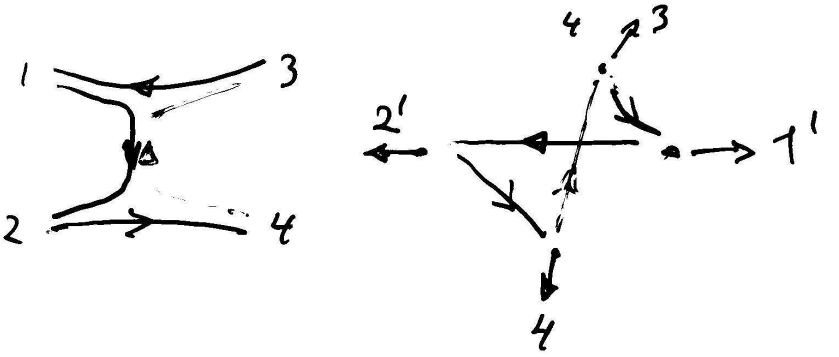
2 cut $\mathbb{P}$: 

Double particle density expected

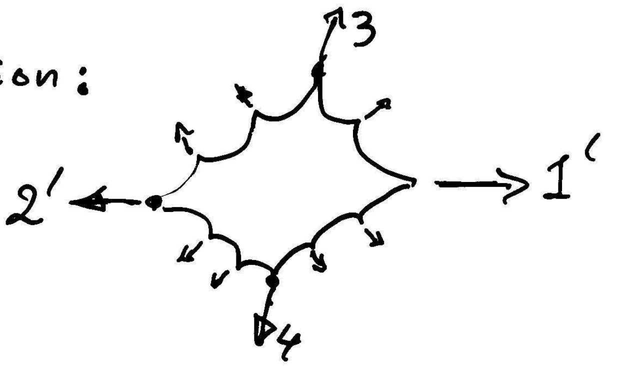
<u>CDF data</u>: $E_\perp$ grows more than the multiplicity

Pythia : 1 hard collision



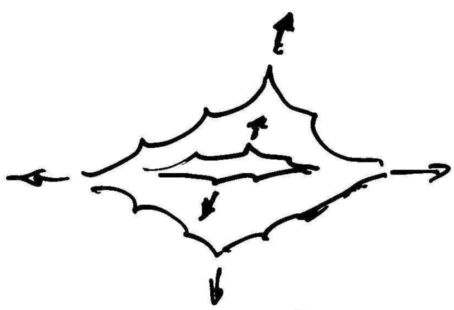


+ initial state radiation:



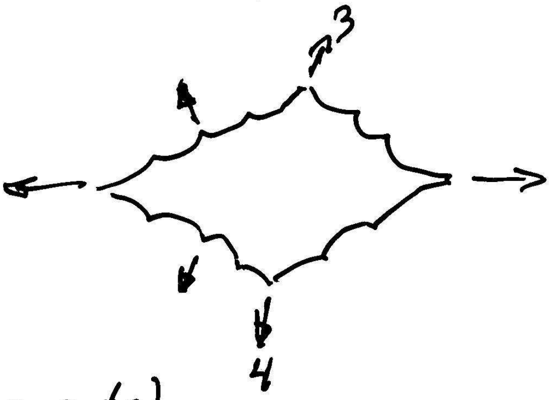
2nd hard subcoll.

à la AGK



Tune A

Inserted as extra kink (90% of the events)



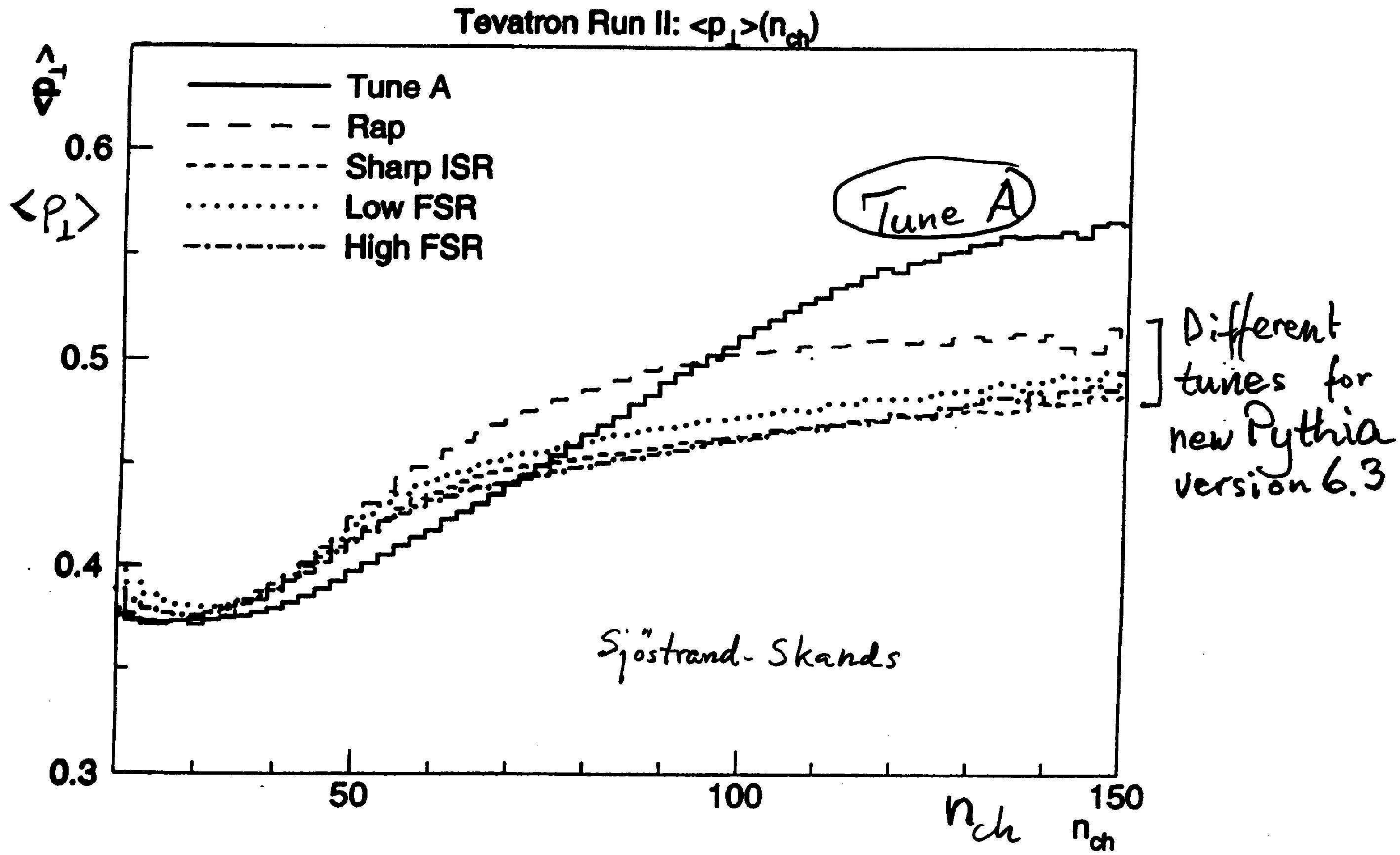


Figure 6: Average $p_\perp$ as a function of charged multiplicity, $\langle p_\perp \rangle(n_{ch})$, for 1.96 TeV $p\bar{p}$ minimum-bias events. Note that the origo of the plot is *not* at (0,0).

Tune A: Multiple coll. adjusted to $E_\perp$-flow

Hadron multiplicity "artificially" suppressed.

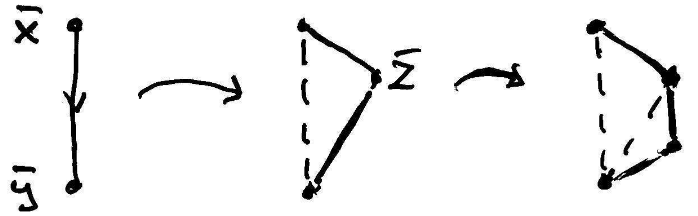
Question: Would it be more relevant to adjust multiple coll. to the hadron mult., and have some mechanism, which enhances the $E_\perp$-flow?

A "rope"?

Dipole cascade models and $\mathbb{P}$ loops

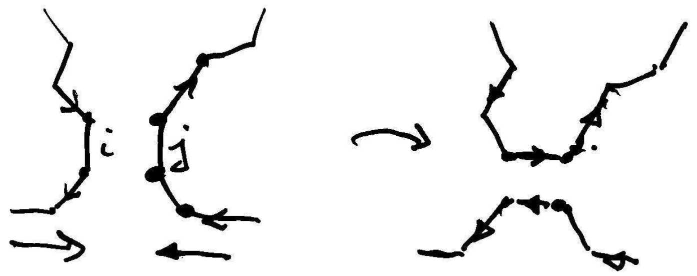
Mult. scatt. and rescattering more easily treated in transverse coord. space.

Mueller: Color dipole cascade



Large N_c. Prob $\propto \bar{\alpha} = \frac{N_c \alpha_s}{\pi}$

Onium-onium scattering



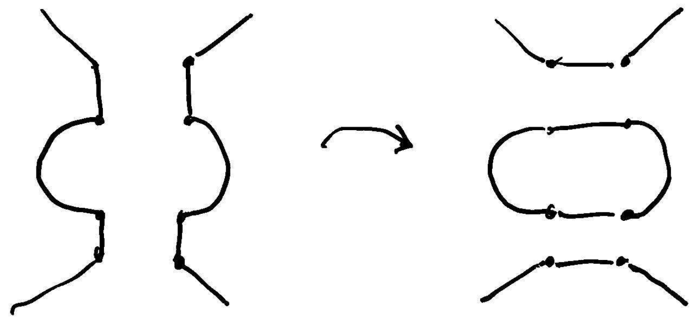
Dipole-dipole scattering $f_{ij} \sim \alpha_s^2 = \frac{\pi^2 \bar{\alpha}^2}{N_c^2}$

Formally color suppressed

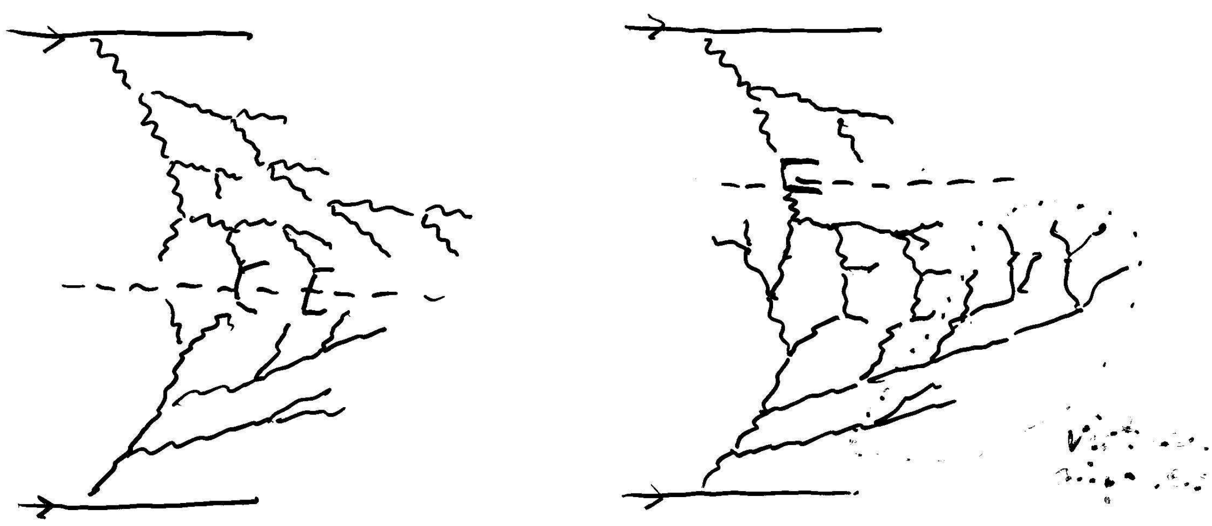
Eikonal approx. $1 - \prod_{ij} (1 - f_{ij})$

$\Rightarrow$ Unitarity. Scattering prob. ≤ 1

Mult. coll. ⇒ Color loops ~ $\mathbb{P}$ loops



Frame independence



cms

different frame
gluons join

Different approaches:

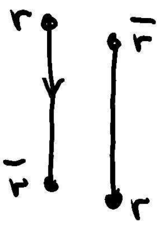
1. Express the evolution in terms of interacting dipoles ⇒ # dipoles can be reduced.
   2 dipoles → 1 dipole. Evol. dep. on target.

2. Eliminate noninteracting dipoles afterwards. Evol. independent of target. No need to reduce # dipoles in the evol.. Color loops ($\mathbb{P}$ loops) formed by "swing".

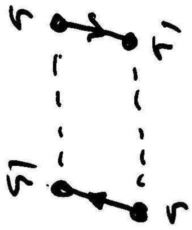
Dipole swing

Finite N_c corrections

- Identical colors. → color multiplets



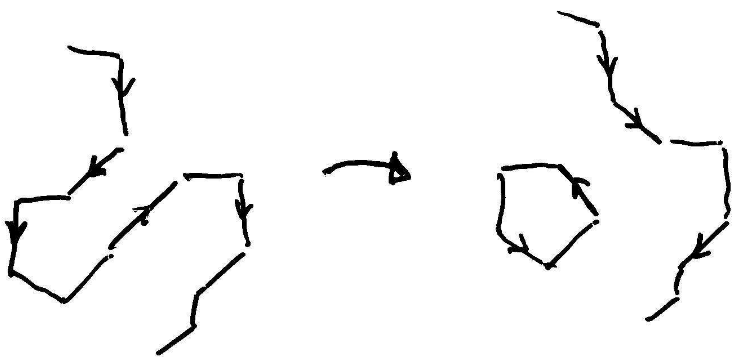
Quadrupole better approximated by recoupled dipoles



- Gluon exchange. Color suppressed $\sim \alpha_s^2 \sim \dfrac{\bar{\alpha}^2}{N_c^2}$

  like the dipole scatt. f_{ij}

Both mechanisms described by "swing"

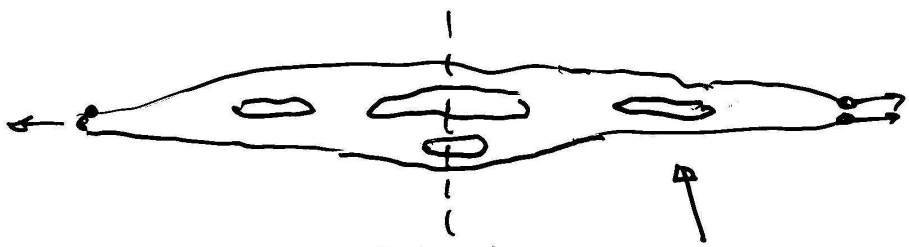


Prob. $\sim \dfrac{1}{N_c^2}$

Inserted in MC ⇒ Approximately frame indep.

E. Avsar - G.G. - L. Lönnblad
JHEP 0701:012, 2007; hep-ph/0601?

Describes F_2 and pp cross section



Color Loops from mult. coll. in cms

color loop in cascade evol. from "swing"

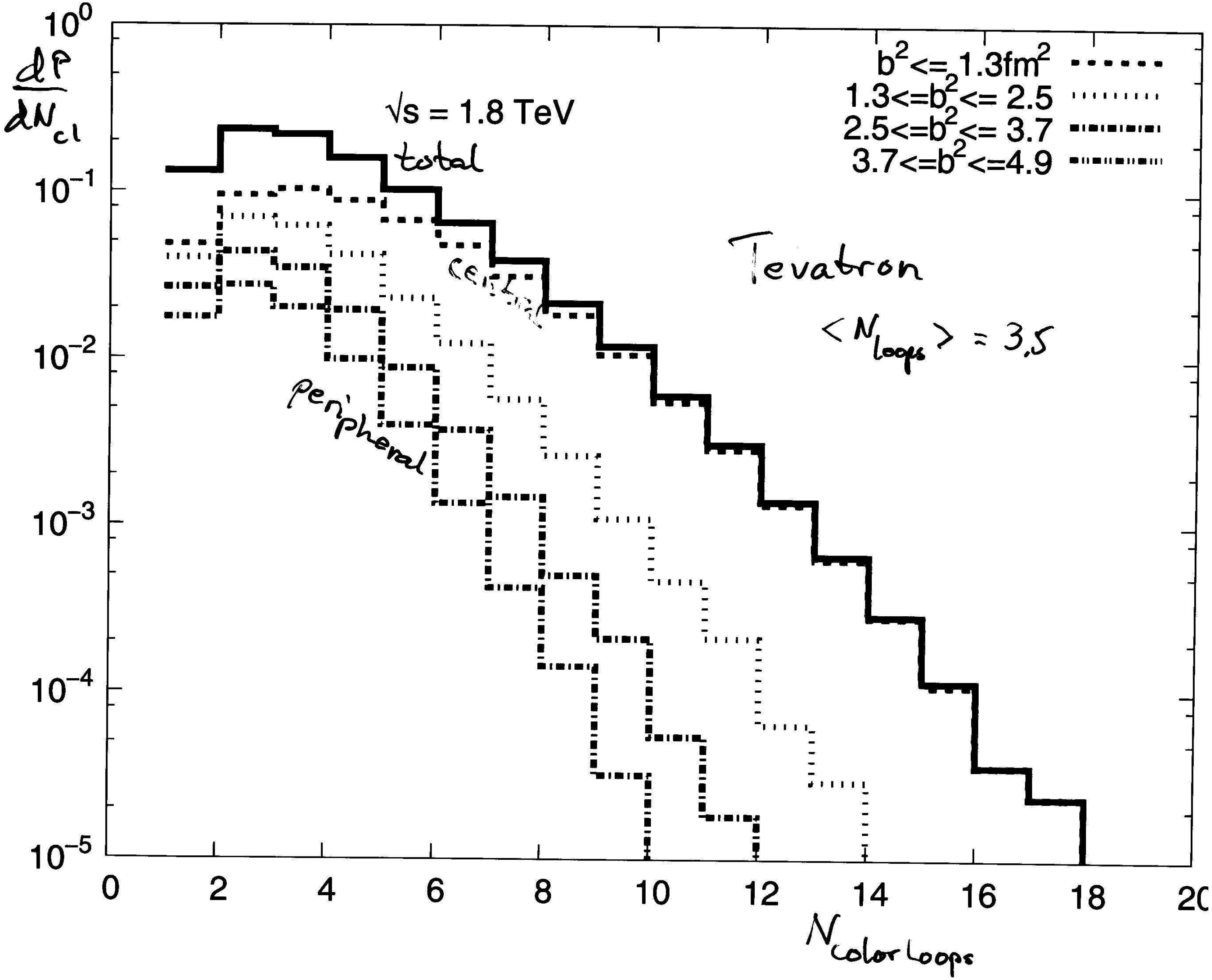
Tevatron

$\langle N_{loops} \rangle$ cms: $0.65 + 2.2 + 0.65 = 3.5$

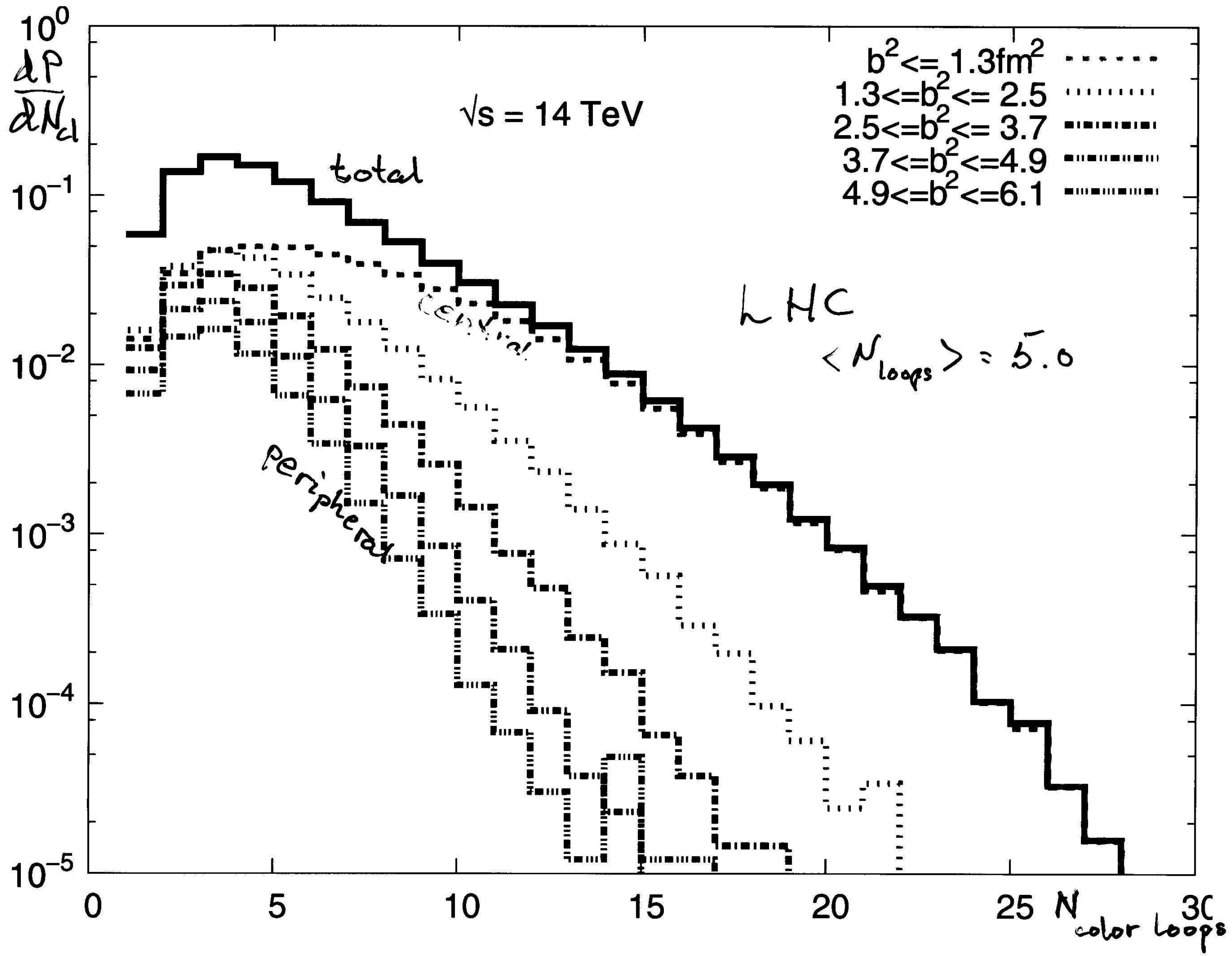
Asymmetric frame

$Y = 4.5 + 10.5$ $\quad 0.15 + 2 + 1.35 = 3.5$

LHC $\langle N_{loops} \rangle = 5.0$



dP/dN_cl
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
0
2
4
6
8
10
12
14
16
18
20
N_color Loops
√s = 1.8 TeV
total
central
peripheral
Tevatron
<N_loops> = 3,5
b^2<=1.3fm^2
1.3<=b^2<= 2.5
2.5<=b^2<= 3.7
3.7<=b^2<=4.9


$\sqrt{s}$ = 14 TeV
b^2<=1.3fm^2
1.3<=b^2<= 2.5
2.5<=b^2<= 3.7
3.7<=b^2<=4.9
4.9<=b^2<=6.1
total
central
peripheral
LHC
$\langle N_{loops} \rangle$ = 5.0
$\frac{dP}{dN_{cl}}$
$N_{color\ loops}$

Conclusions

- Mult. coll. present in data
- Hard subcoll. correlated:

  Underlying event $\neq$ min. bias
- Simplest AGK rules (with no color)

  $\Rightarrow$ Geom. distr. for mult. inter.

  Agrees with PYTHIA fits

  Is this fundamental?
- Relation $E_\perp - n_{ch}$ is a serious problem
- Dipole cascade models describe F_2 and σ_{tot}^{pp}

  $\mathbb{P}$ loops obtained from dipole swing
- Future: Final states