Underlying Event Models

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TeV4LHC
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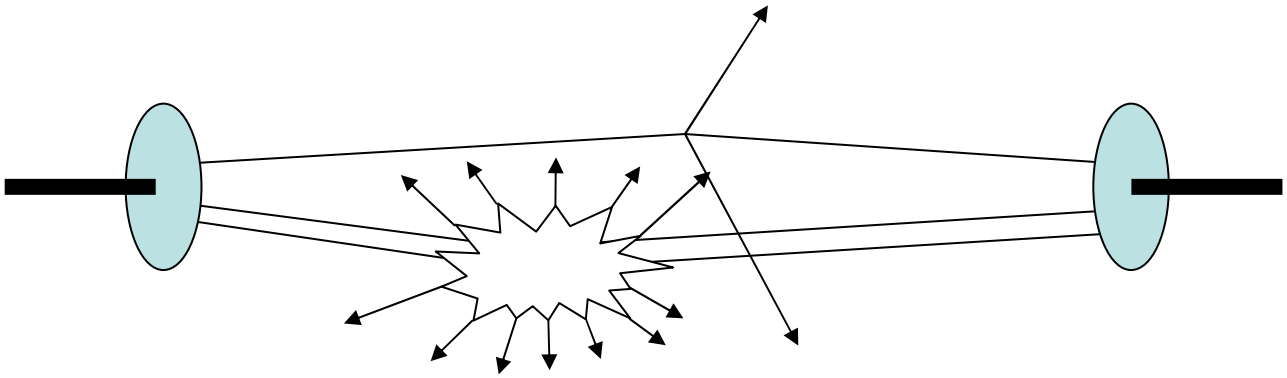
Underlying Event Models

1. What do mean by underlying event?
2. Why are we interested?
3. How do we model them?
4. Where are we heading?

What do we mean by the Underlying Event?

"Everything except the hard process"



but…

- initial state radiation
- factorization scale
- parton distribution functions
- parton evolution

→ underlying event model integral part of event model

Why should we be interested?

1. QCD

Connection with:

- diffraction
- saturation
- confinement
- total cross section

Can we predict/understand the properties of hadrons?

2. Experiments

- Occupancy
- Pile-up
- Backgrounds

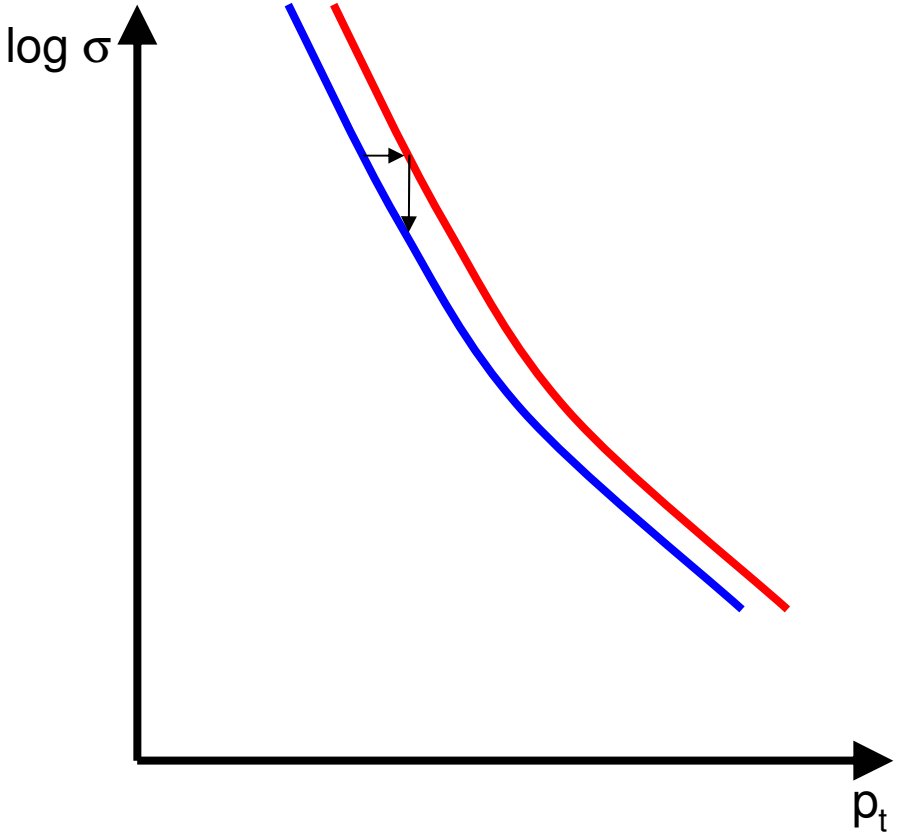
Why should we be interested?

2. Experiments
   - Occupancy
   - Pile-up
   - Backgrounds

3. Physics
   - Jet cross sections
   - Mass reconstruction
   - Rapidity gaps/jet vetoes
   - E_{miss} reconstruction
   - Photon/lepton isolation
   - ⋮

"Don't worry, we will measure and subtract it"
But… fluctuations and correlations crucial

Fluctuations and correlations



Steep distribution ⇒ small sideways shift = large vertical

Rare fluctuations can have a huge influence

⇒ corrections depend on physics process

How do we model the Underlying Event?

- Uncorrelated soft scatter – HERWIG/UA5 model

  Parameterization of data

  - Broad multiplicity distributions $\Rightarrow$ large fluctuations
  - Long range correlations

  But…

  - Energy-dependence?
  - Hard component?
  - Hard/soft correlation?

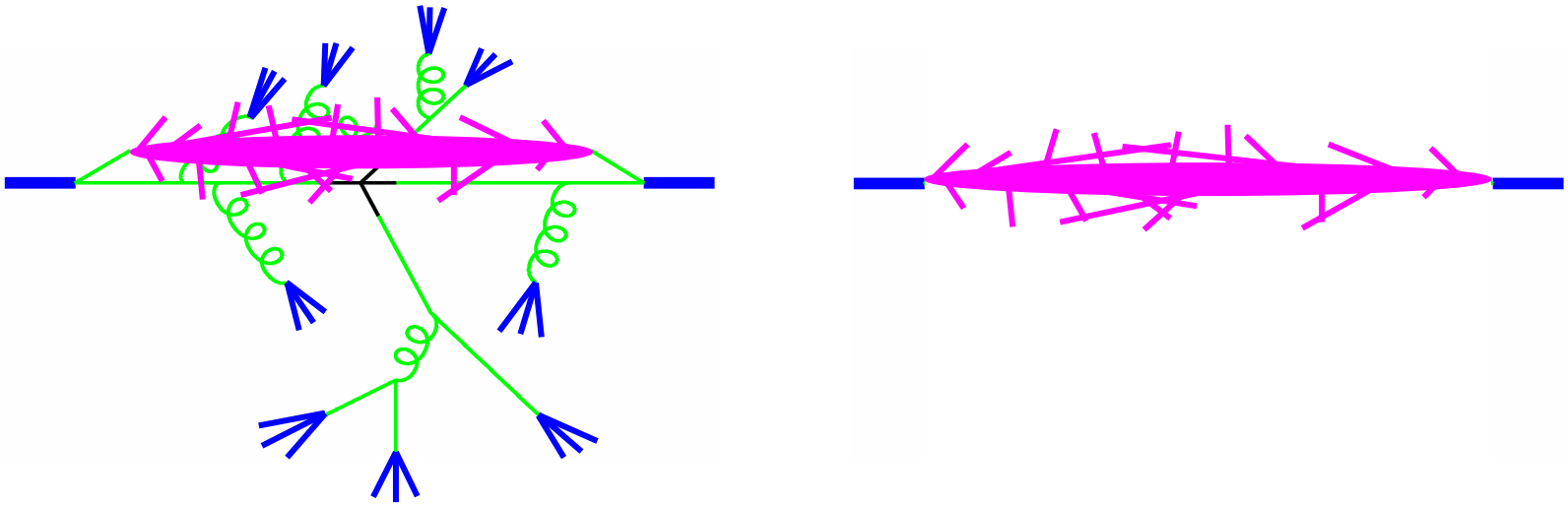
- Multiple interactions – hard and/or soft

  Hadron-hadron collision is incoherent sum of many parton-parton collisions

HERWIG's Soft Underlying Event model

G.Marchesini & B.R.Webber, PRD38(1988)3419

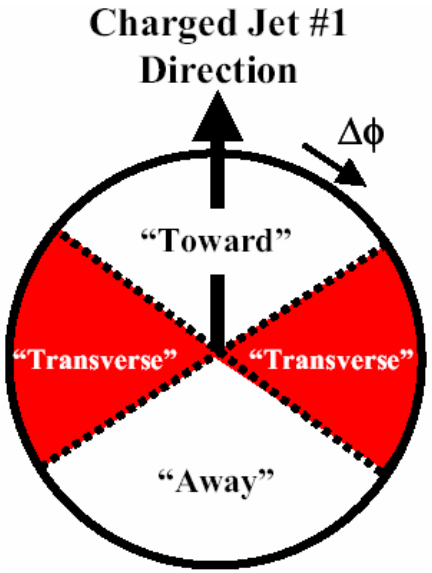
Compare underlying event with 'minimum bias' collision

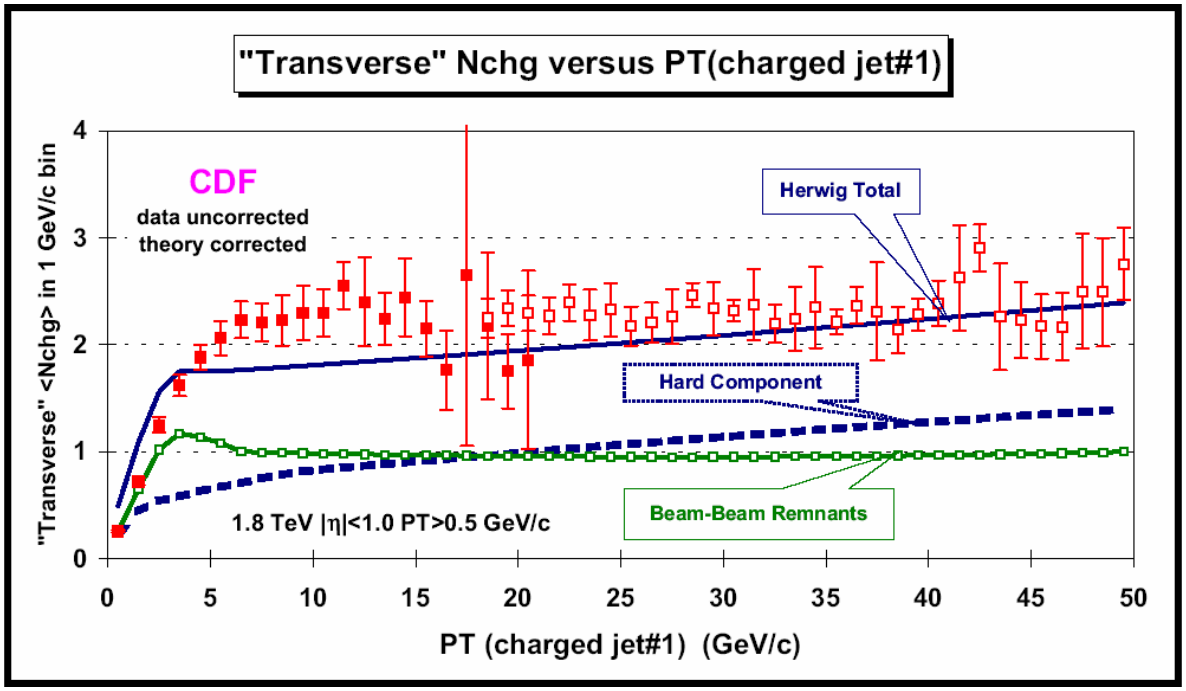


Parameterization of (UA5) data

+ model of energy-dependence

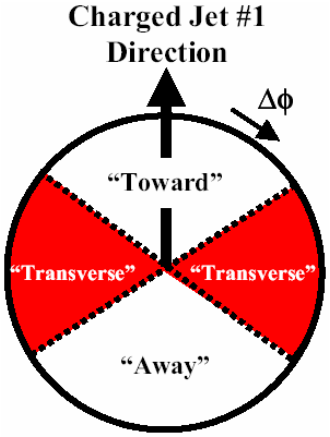
→ Pedestal Effect

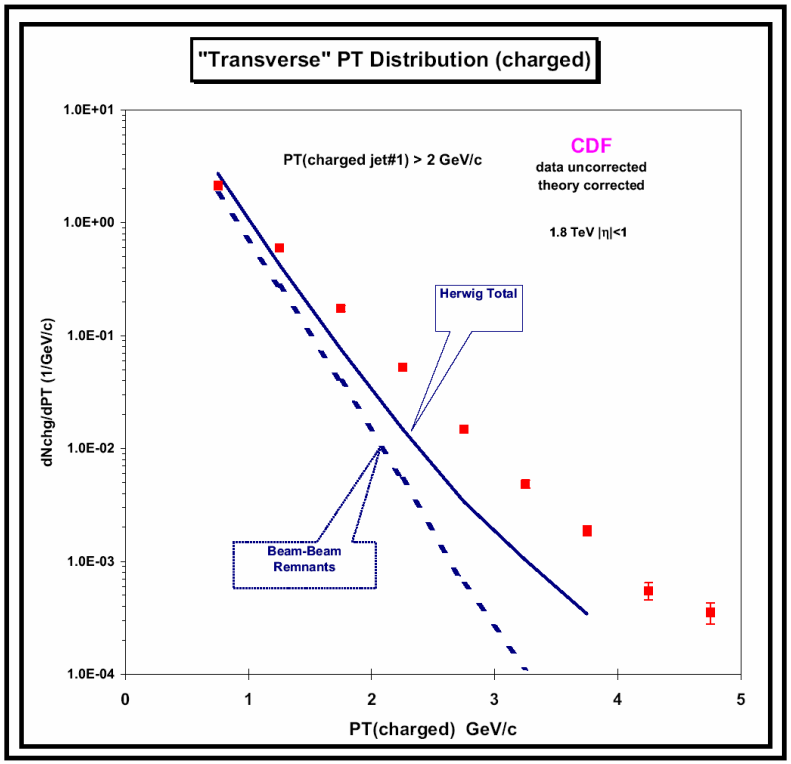




http://www.phys.ufl.edu/~rfield/cdf/chgjet/chgjet_intro.html

but suffers from lack of a hard component…

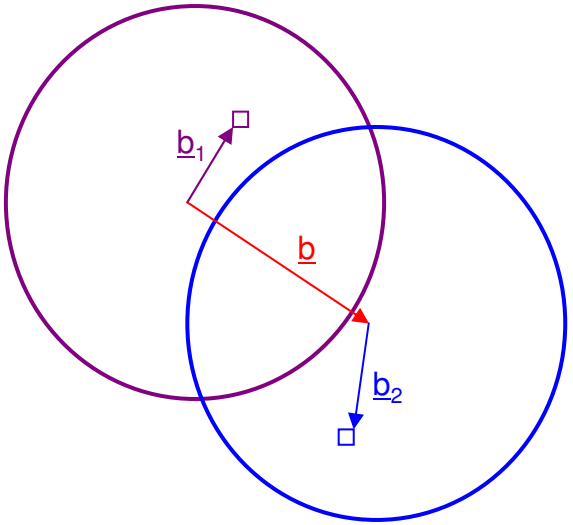




http://www.phys.ufl.edu/~rfield/cdf/chgjet/chgjet_intro.html

Multiple interactions – b-space picture

≈ instantaneous sampling of disk of partons



$$\sigma_{hh}(s) = \int d\underline{b} \int dx_1 d\underline{b}_1 \; dx_2 d\underline{b}_2 \; f_i(x_1, \underline{b}_1) f_j(x_2, \underline{b}_2) \times \sigma_{ij}(x_1 x_2 s) \times \delta(\underline{b}_1 - \underline{b}_2 - \underline{b})$$

Only need to know $f(x,\underline{b})$
and total parton-parton cross section σ_{ij}

Simplest possible model: $f(x,\underline{b})=f(x)G(\underline{b})$

Eikonal approximation: multiple scatters are independent of each other

Correlations and fluctuations

- Simple b-space correlation

  Small cross section process has occurred

  $\Rightarrow$ bias to large overlap

  $\Rightarrow$ underlying event $\gg$ minimum bias

- More b-space correlation

  Expect high-momentum partons to be more central?

- Energy-momentum conservation

  Backward evolution $\Rightarrow$ even soft scatters consume a lot of energy $\sim$ 10%

  Scatters cannot be independent

  (Multiple scatters within evolution chain? → Sjöstrand and Skands)

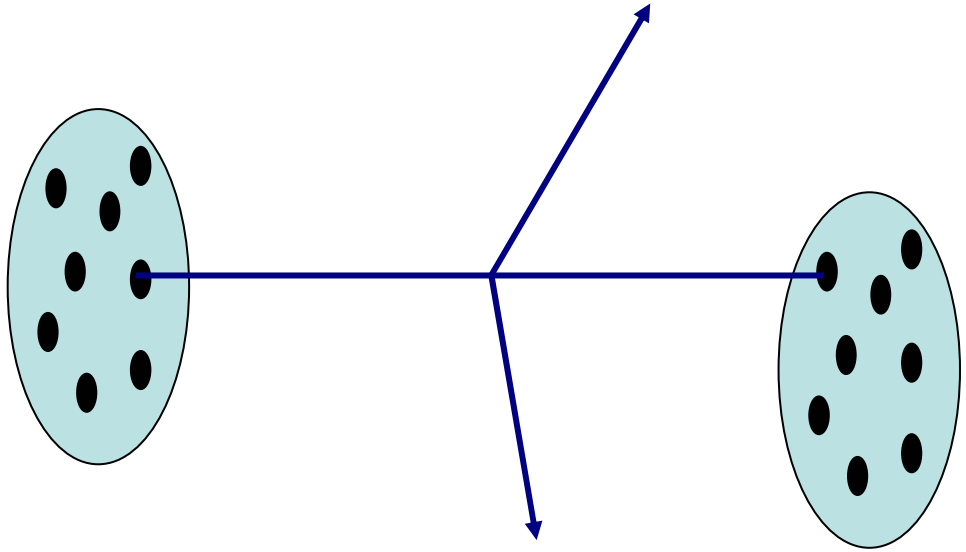
- Colour connections

  Each parton scattering hadronizes independently?

  Colour connections? Reconnections? → Sjöstrand and Skands

Jimmy – Multiparton Interactions in HERWIG

J.M.Butterworth, J.R.Forshaw & MHS, ZPC72(1996)637

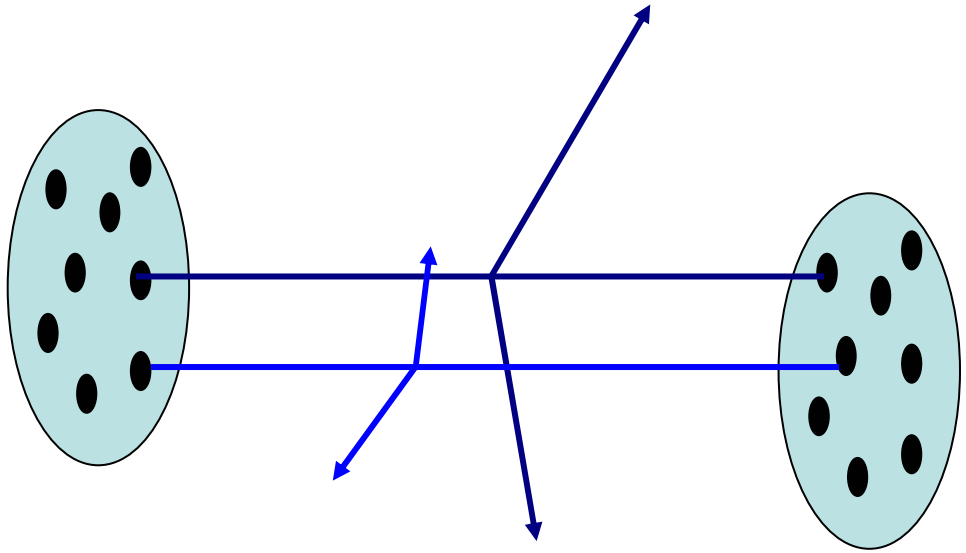


Starting point: $$\frac{dn_i}{d^2b\,dx} = f_i(x)G(b) \qquad \int d^2b\; G(b) = 1$$

eg (EM form factor) $$G_p(\mathbf{b}) = \int \frac{d^2\mathbf{k}}{(2\pi)^2} \frac{\exp(\mathbf{k}\cdot\mathbf{b})}{(1+\mathbf{k}^2/\mu^2)^2} \qquad \mu^2 = 0.71\ \mathrm{GeV}^2$$

$$\sigma^{inc}(s) = \int dx_1\; dx_2 \sum_{i,j} f_i(x_1)\; f_j(x_2)\; \hat{\sigma}_{ij}(x_1 x_2 s)$$

Multiparton Interactions



Assume: n-parton distributions uncorrelated:

$$\frac{dn_{i,j}}{d^2b_i\,dx_i\;d^2b_i\,dx_i} = f_i(x_i)G(b_i)\;\; f_j(x_j)G(b_j)$$

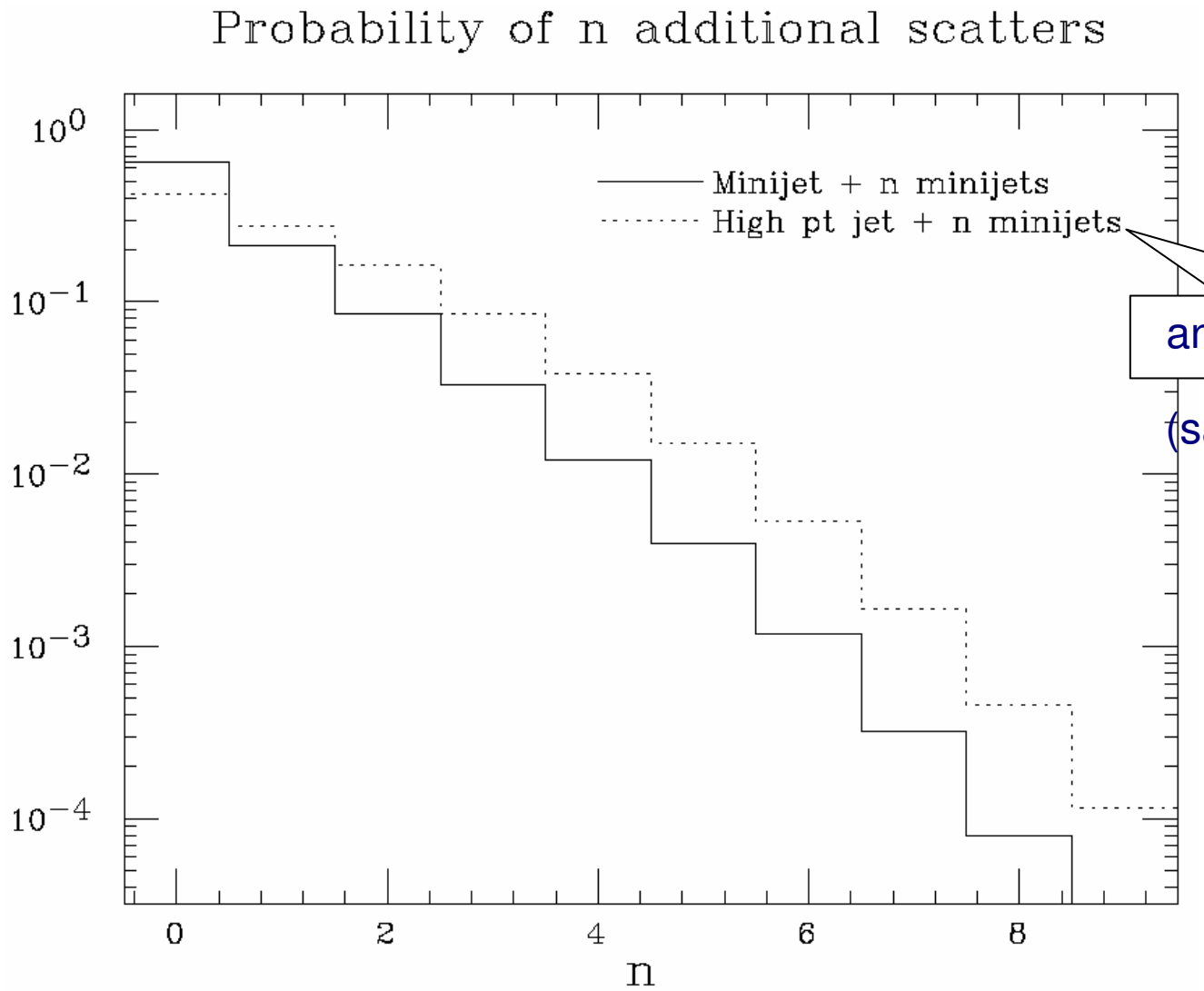
→ Poisson distribution at fixed impact parameter

$$\sigma_n = \int d^2b\,\frac{(A(b)\sigma^{inc})^n}{n!}\exp(-A(b)\sigma^{inc})$$

$$A(b) = \int d^2b_1 G(b_1)\,d^2b_2 G(b_2)\,\delta(b - b_1 + b_2)$$

→ Non-Poissonian Distribution

~ Geometric Distribution



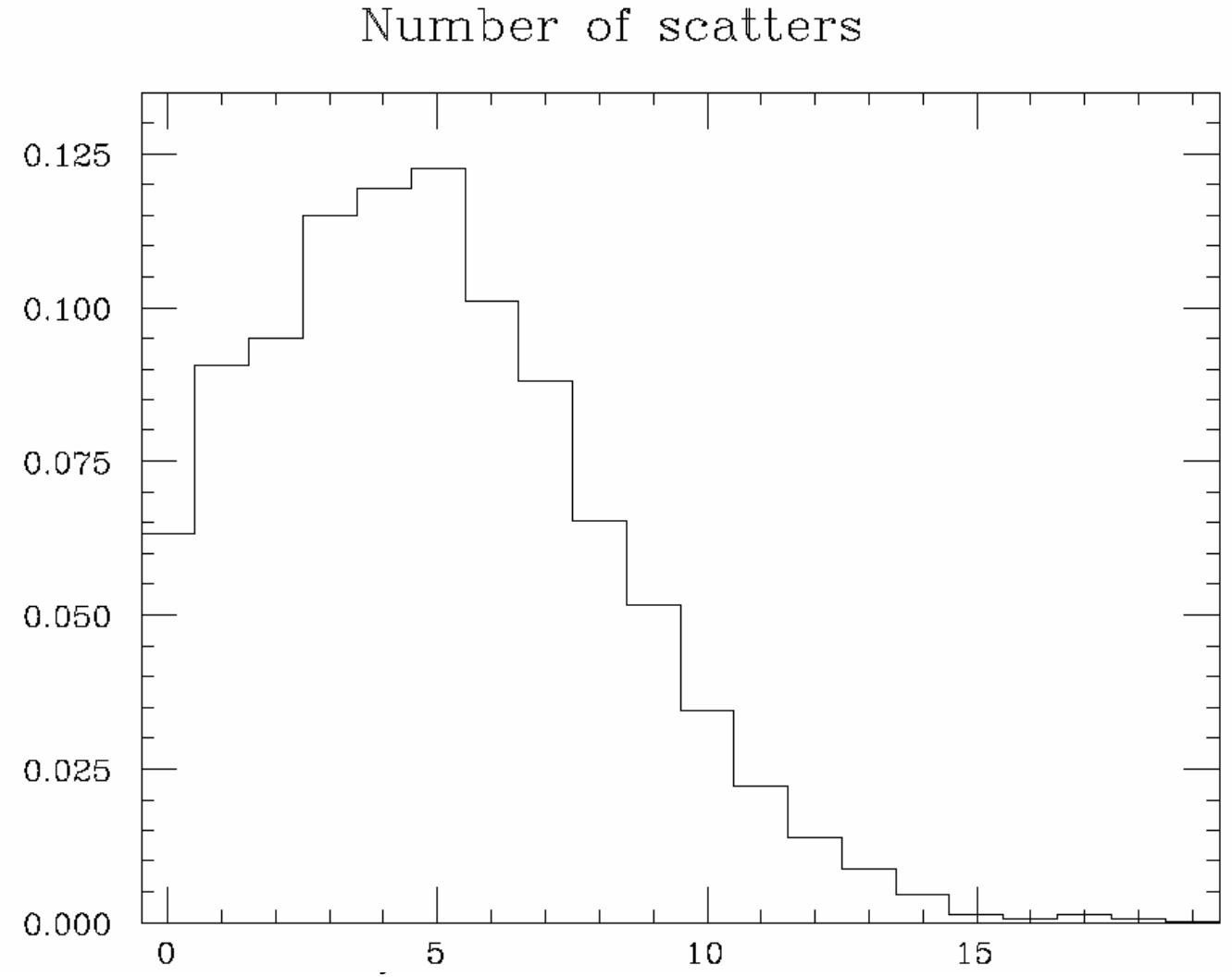
and b-space correlations

(saturates at pt~10 GeV)

Energy Conservation

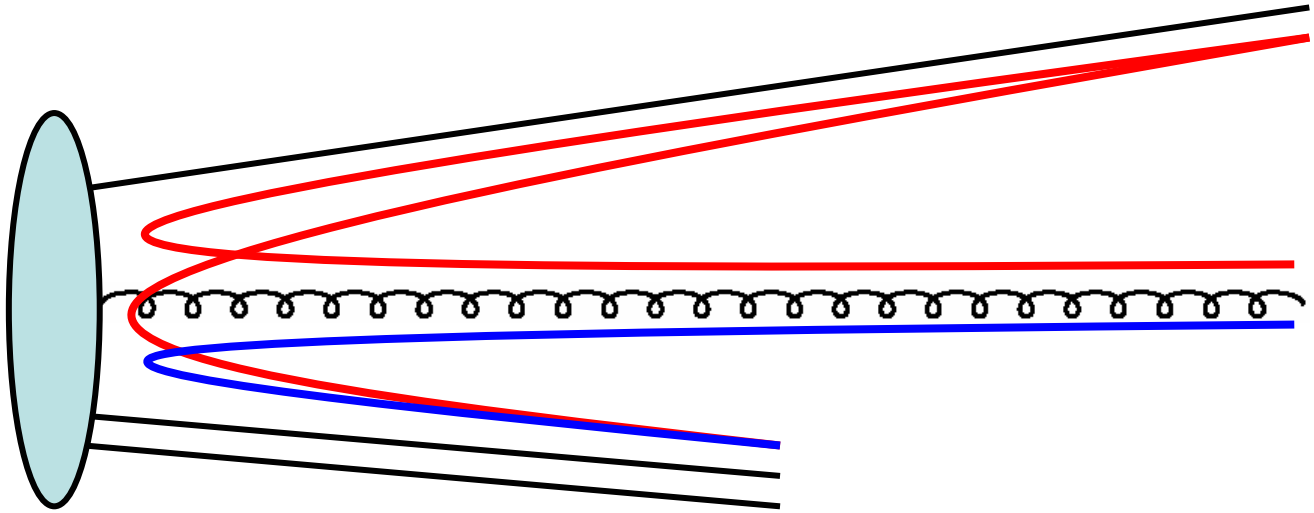
Narrows distribution.

Ask for infinite number of extra scatters. How many do you get?

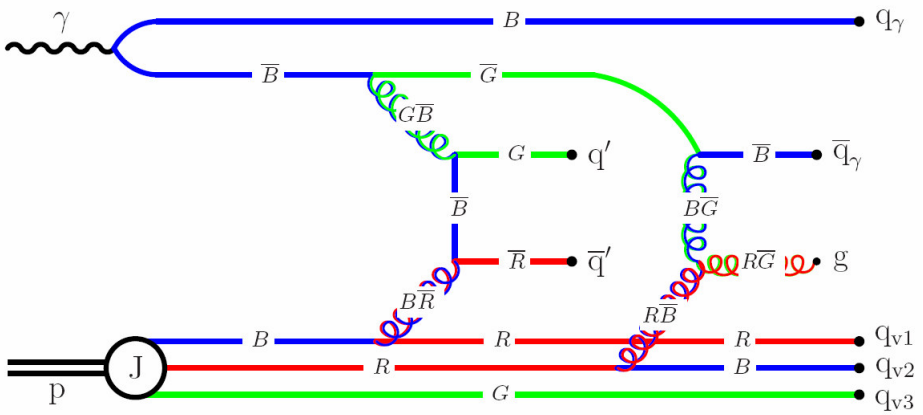


+ Many other choices…

- Scattering cross sections calculated with standard pdfs
- But initial state shower/remnant model gluon only
- Colour connections between scatters



T. Sjöstrand and P.Z. Skands (JHEP 0403:053,2004)



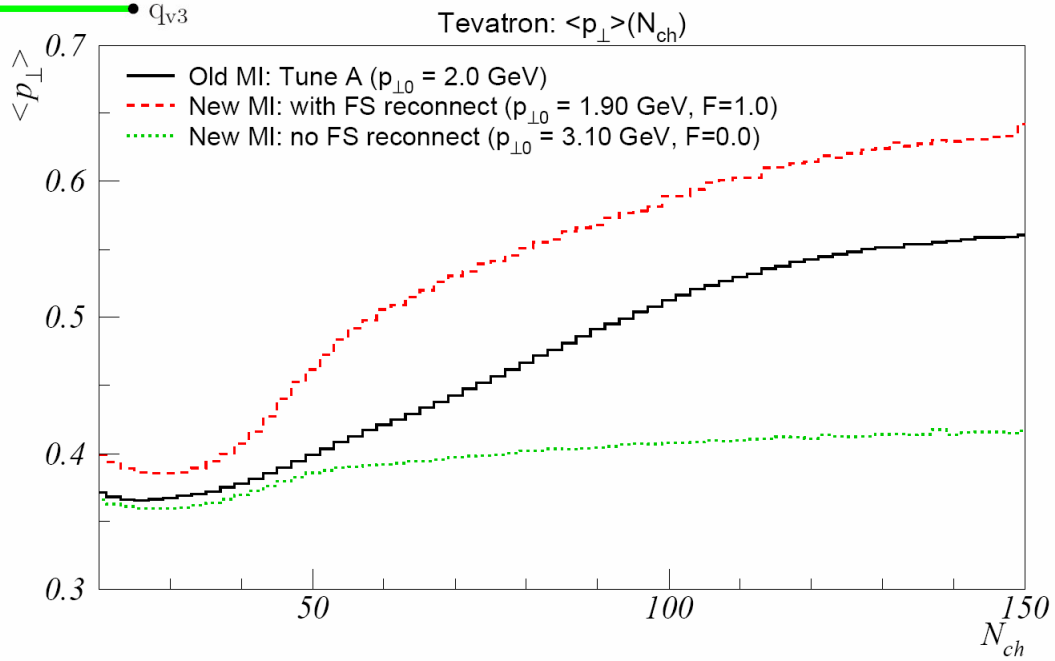


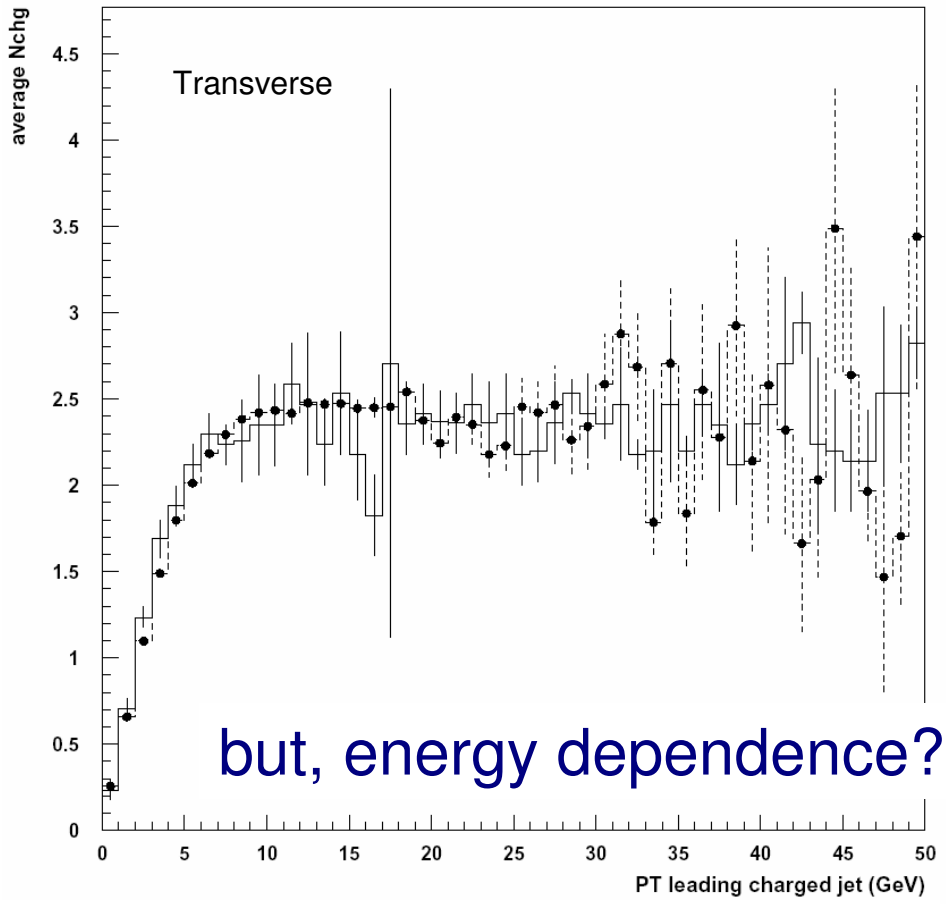
Figure 21: $\langle p_\perp \rangle$ vs. $n_{\rm ch}$ at the Tevatron for Tune A (solid line), and for the new model with (dashed line) and without (dotted line) final-state reconnections allowed. Both of the new models use rapidity ordering of the colour lines in the initial state and give the same average charged multiplicity as Tune A, with the same impact parameter dependence as Tune A.

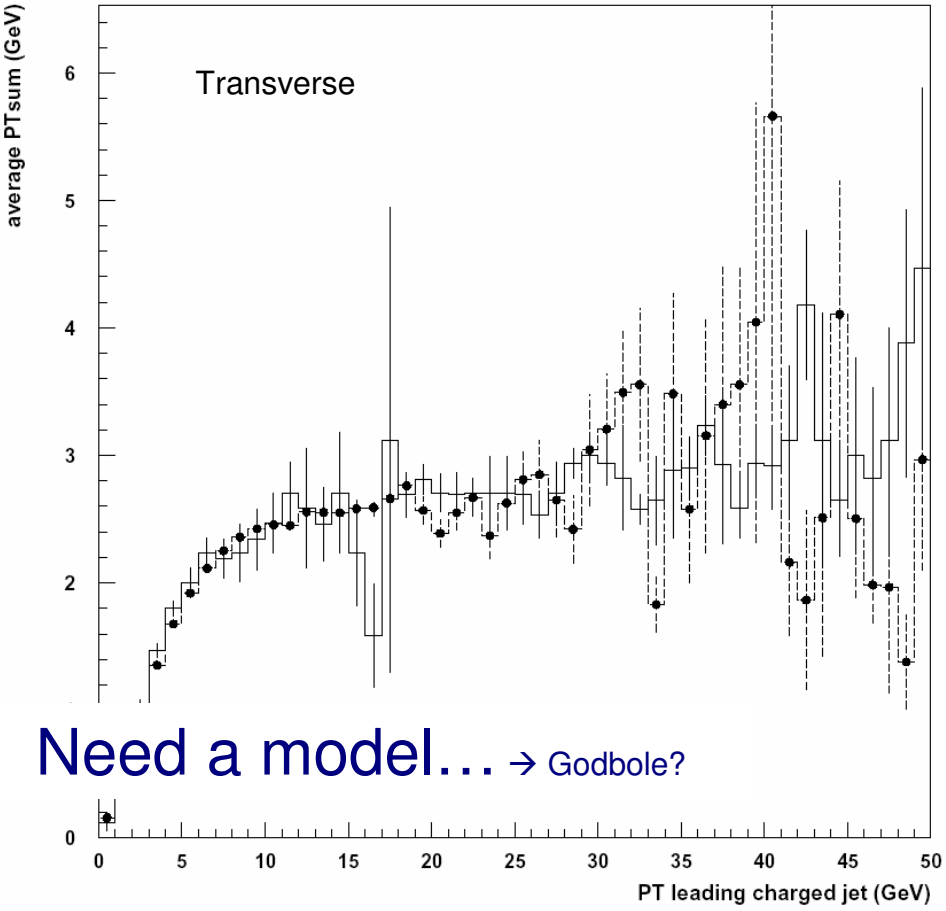
Proton Radius parameter within Jimmy

I.Borozan, PhD thesis, unpublished

- Increasing μ^2 to 2 GeV^2 (i.e. decreasing proton radius by 40%) with ptmin=3 GeV gives

~ perfect description of Tevatron data…



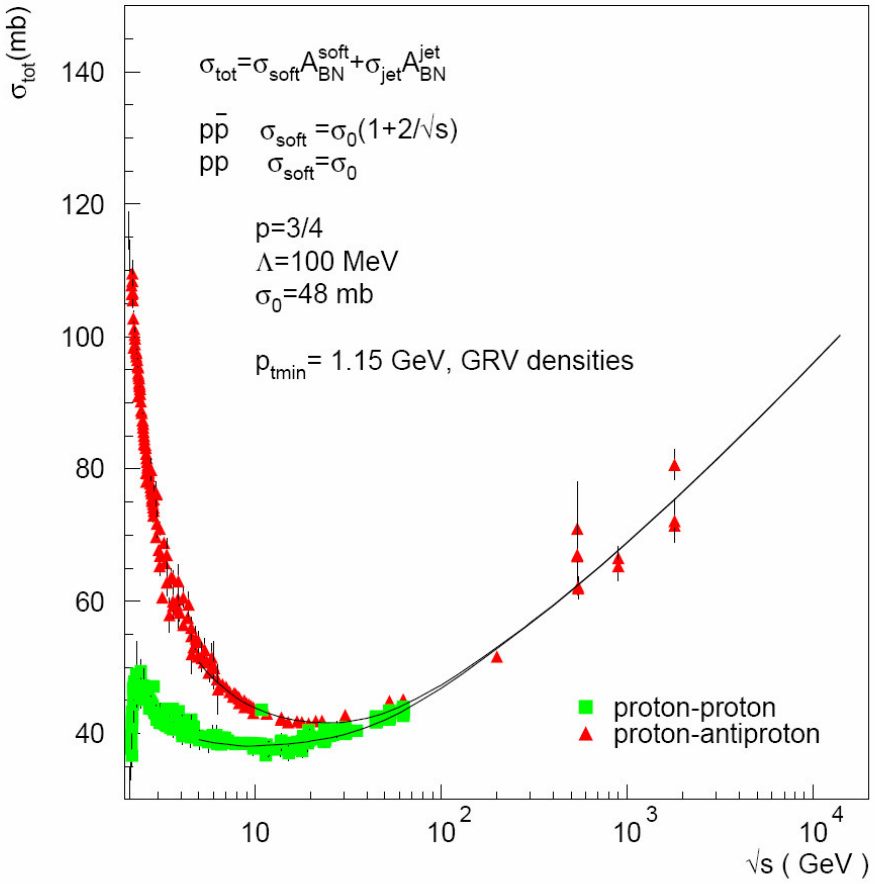


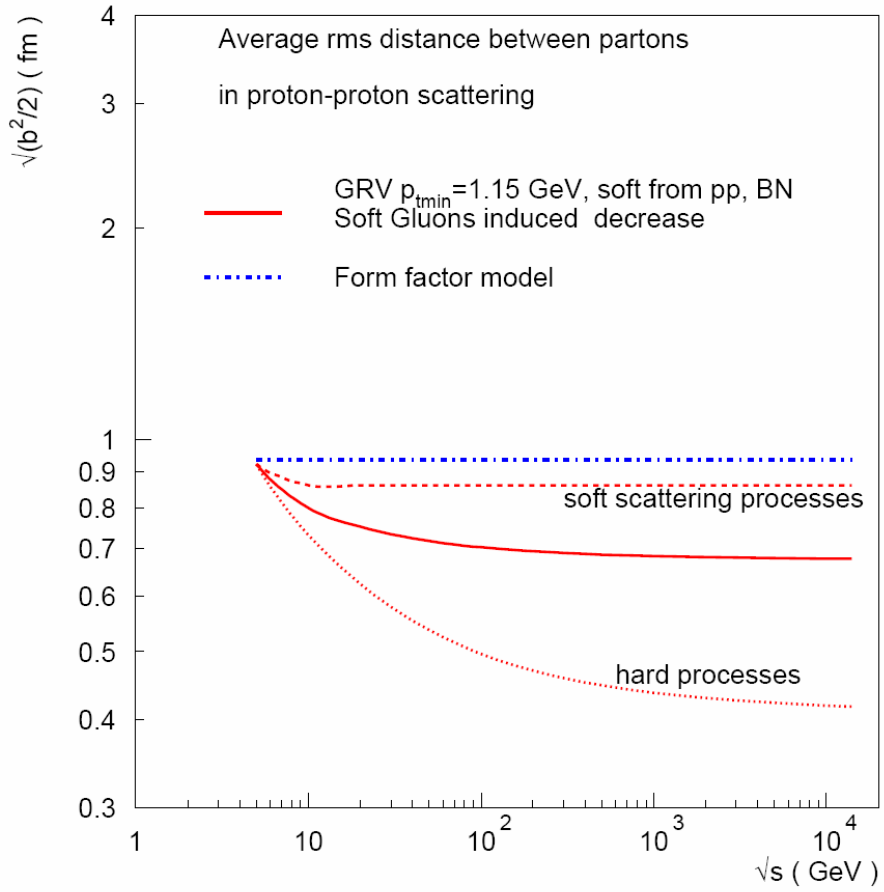
but, energy dependence? Need a model… → Godbole?

Proton Radius parameter in total cross section

R.Godbole et al, hep-ph/0408355

- Starting point ≅ Jimmy+Ivan
- Resum dynamical effects due to soft gluon emission





Recent Progress

- HERWIGv6.5 + Jimmy v4.1 (http://hepwww.rl.ac.uk/theory/seymour/herwig/)
  - Plug and play add-on to HERWIG
  - Simulates underlying event in high-E_t jet processes and any other hard process correctly (for first time!)
- Sjöstrand and Skands completely new model for multiple interactions in PYTHIA (JHEP 0403:053,2004 and hep-ph/0408302)
  - Includes completely new initial-state cascade model
  - Colour (re)connection within and between interactions
  - Multiple interactions within one parton-parton collision
- Borozan and MHS model of multi- hard and soft scatters
  - Proof of principle for possible future model…

Ivan – Multiple soft interactions in HERWIG

I.Borozan & MHS, JHEP0209(2002)015

- Partons still independent
- Soft scatters below PTMIN
- Gluon—gluon only: x g(x) = const
- 'Gaussian' distribution in pt
- Continuity at pt=PTMIN
- Take Eikonal seriously…

$$\sigma_{tot} = 2\pi \int_0^\infty db^2 \left[1 - e^{-\chi(b,s)}\right], \qquad \chi(b,s) = \chi_{QCD}(b,s) + \chi_{soft}(b,s),$$
$$\sigma_{ela} = \pi \int_0^\infty db^2 \left|\left[1 - e^{-\chi(b,s)}\right]\right|^2, \qquad \chi_{QCD}(b,s) = \tfrac{1}{2}\sigma^{inc}_{hard}(s)A(b),$$
$$\sigma_{inel} = \pi \int_0^\infty db^2 \left[1 - e^{-2\chi(b,s)}\right]. \qquad \chi_{soft}(b,s) = \tfrac{1}{2}\sigma^{inc}_{soft}(s)A(b).$$

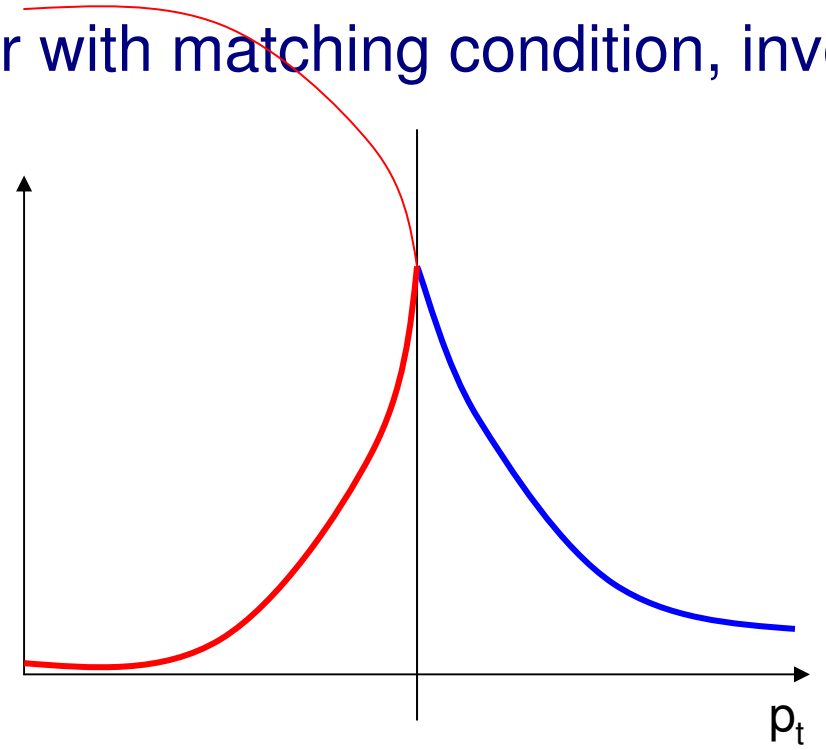
→ No new free parameters!

Jimmy doesn't leave much room for Ivan!

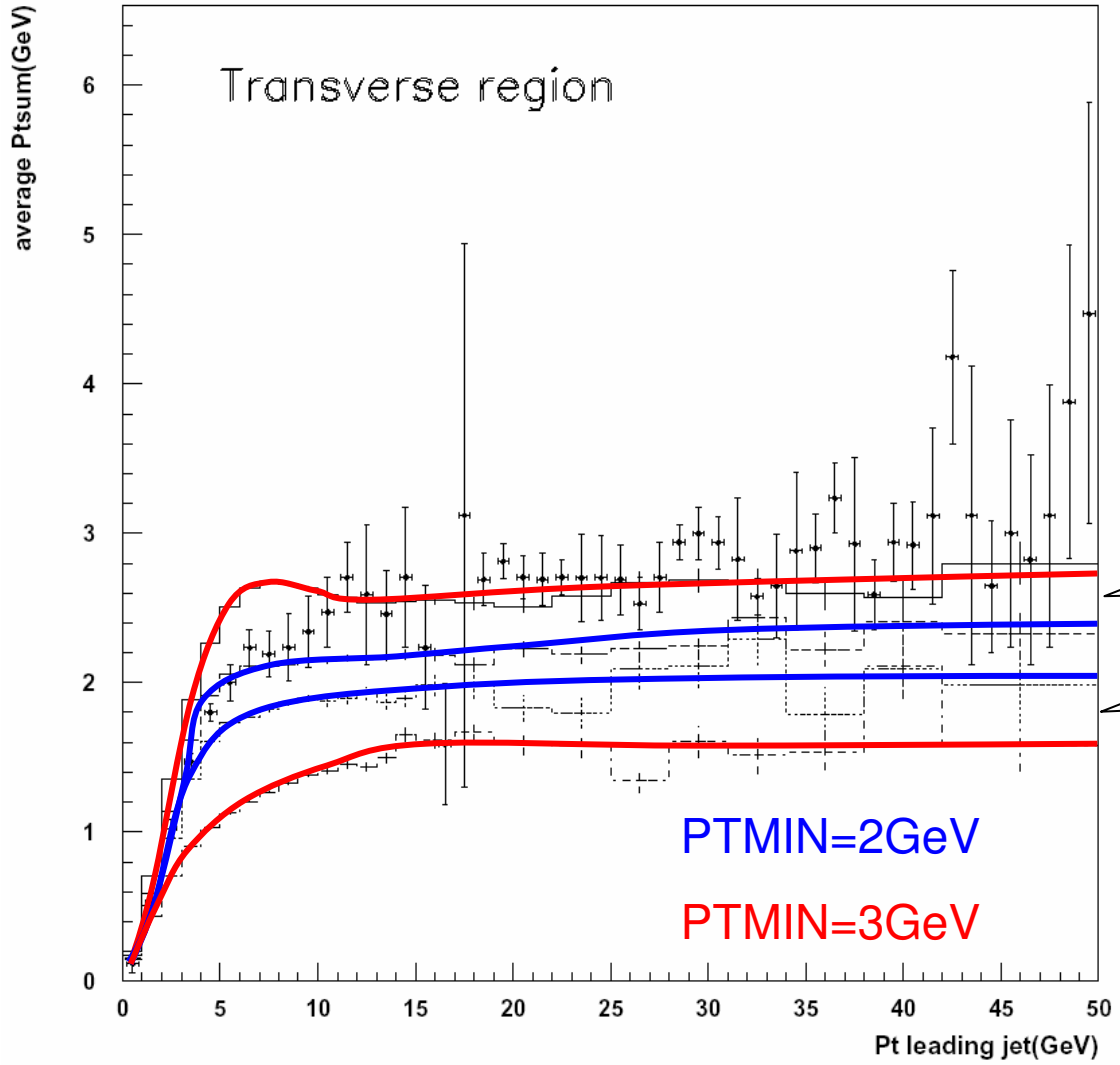
- For PTMIN<2 GeV, hard cross section saturates total…

$p_{tmin}(\mathrm{GeV})$	$\sigma^{inc}_{SOFT}(s_{p\bar{p}})(\mathrm{mb})$	$\sigma^{inc}_{H}(s_{p\bar{p}})(\mathrm{mb})$	$\langle n_{soft}\rangle$	$\langle n_{hard}\rangle$
2.0	39.7	99.2	0.7	1.7
2.5	85.6	51.3	1.5	0.9
3.0	109.7	28.7	1.9	0.5

- Together with matching condition, inverts Gaussian…



→ Similar to Jimmy with low PTMIN,
but smaller PTMIN dependence



Still needs study of radius dependence

Jimmy+Ivan

Jimmy

To Do List (July 2003)

- Upgrade Jimmy to HERWIG6.5 This month
- PTMIN(HW) > PTMIN(Jimmy) Real soon now
- Robust distribution of Jimmy within HERWIG This year…?
- Robust distribution of Ivan within HERWIG++ …?

Work in Progress

- Understanding Jimmy
  - small-x partons play a huge role
    - eg PTMIN=3 GeV @ LHC probes $x \sim 10^{-7}$
  - proton radius parameter from Godbole et al model?
- Understanding new PYTHIA
  - huge job! Need to tune
    - new initial state shower?
    - colour connection options?
    - matter distribution?
- New models
  - SHERPA (Frank Krauss et al)
  - Jimmy+Ivan → HERWIG++
  - Multiple interactions in the LDC model (Leif Lönnblad)

Summary

- Underlying events are important for almost all physics measurements at LHC, extremely important for some
- Theoretical activity is increasing

  $\sim$ 4 new models available now/soon
- HERA and Tevatron are excellent testing grounds
- Don't forget SPS data too
- Deeper theoretical understanding needed