Soft and Hard Interactions in $p\bar{p}$ Collisions at $\sqrt{s}$=1800 and 630 GeV

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Introduction: the issue of "soft" interactions

- We want to characterize soft interactions
- At CDF the greatest part of $\sigma_{inelastic}$ is due to "soft" interactions
- We have no theory such as pQCD in high E_T jet production
  Some models extrapolate pQCD to very low Q^2 (<1GeV)
  …but → are there "collective" processes ???
- We have many experimental data (ISR, UA5, E730) but often not comparable because of different experimental conditions
- Our knowledge rely on phenomenological models empirically connected to "MB" data (every expt. has its own MB trigger).

The Analysis

- Collect MB samples @ $\sqrt{s}$ = 1800 and 630 GeV

  - apply minimum possible event selection
  - contain any kind of interaction
  - sample events proportionally to their production rate

- Isolate a sample of pure *soft* interactions...this is largely arbitrary !

- Compare some variables at the two energies:
  - inclusive p_T distributions
  - "global" event variables (charged multiplicity, $\langle p_T \rangle_{ev}$)
  - final state correlations (p_T vs n_{ch})

☛ Observation: all properties of the soft subsample are invariant with E_{cms} for events with same multiplicity

Data Set

MB trigger : beam crossing + coincident hits in BBC ($3.2<|\eta|<5.9$)

Events : 1800 GeV Run1A = 1.7 M
Run1B = 1.5 M
Run1C = 0.1 M
630 GeV Run1C = 2.6 M

Event Selection
- cosmics in time with crossing
- events with no reconstructed tracks
- events with known CAL problems
- events with $\geq$1 tracks but no CAL towers > 100 MeV
- events with >1 primary vertices ← dominant !
- primary vertex > 60cm from CDF center

Selected events: 2,079,668 @ 1800 + 1,963,157 @ 630

Track Selection

- minimum number of CTC layers
- minimum number of hits in each layer

} CTCSEL

- $| D_{track} | < 0.5$ cm from beam axis
- $| Z_{vertex} - Z_{track} | < 5$ cm
- Full CTC efficiency and acceptance:

$p_T \geq 400$ MeV
$|\eta| < 1.0$

Efficiency Corrections

- Full-event tracking efficiency with Pythia + QFL

  (NB: this is a counting efficiency, not a track-finding efficiency!)

- 2.6 M events generated @ 1800 GeV (+ 320 K @ 630)

- A correction is computed for each distribution (p_T,n_{ch}, etc):

$$\varepsilon = \frac{\text{Distribution of tracks traced through the apparatus}}{\text{Pythia generated distribution}}$$

$\varepsilon(p_T)$ ~ 98% (dropping to ~92% for $p_T \gtrsim 2$ GeV)

$\varepsilon(\eta)$ ~ 98% (constant)

$\varepsilon(n_{ch})$ ~ 95% (dropping to ~85% for $n_{ch} \gtrsim 20$)

Backgrounds

By the same MC method we estimate:

- photon conversions
- particle decays
- particle interactions

An overall (efficiency+background) correction factor is finally computed as : CF = (1-background)/efficiency

Residual contamination of diffractive events:

5% - 0% in $0 < n_{ch} \leq 4$

1% - 0% for $0.4 < p_T < 0.8$ GeV

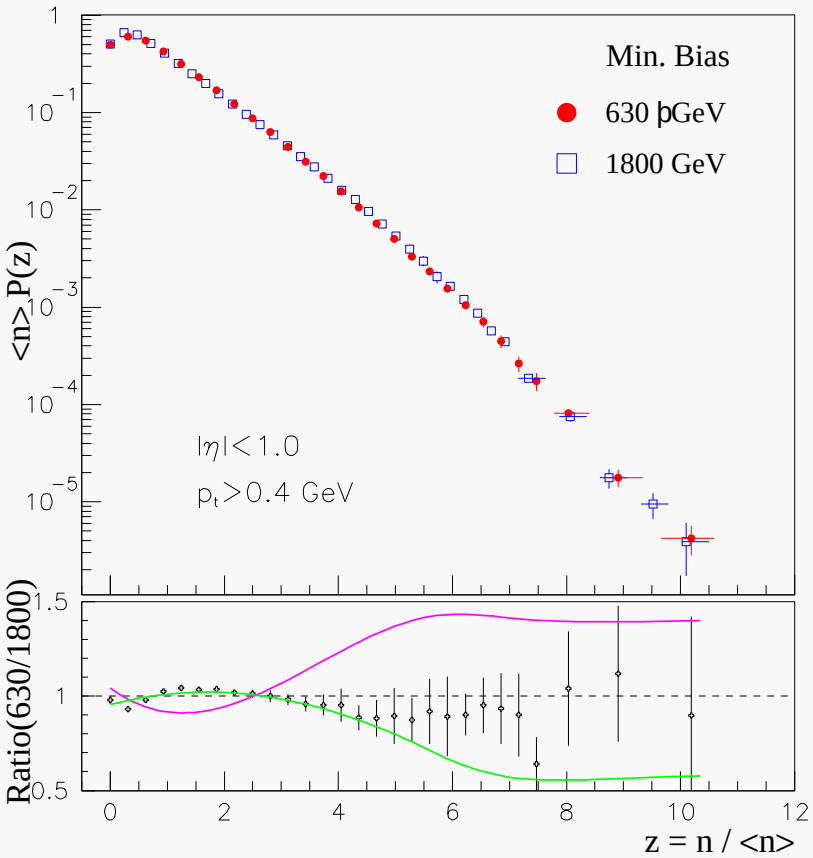
Systematic uncertainties

- Misclassified primary vertices strongly influence n_{ch} distributions (from 5% to 40% effect on the distribution ratios; function of n_{ch}) ← dominates
- Unresolved multiple interactions (from 2% to 30% on the distributions)
- The rejection of events with known calorimeter problems ($\lesssim$1%) introduces no appreciable effect on the ratios
- Efficiency corrections computed with different techniques may differ as much as 10% (low p_T region), but the effect on the ratios is negligible
- The uncertainty from γ conversions, secondary interactions and particle decays is $\approx$ 1%, but the effect on the ratios is negligible
- The uncertainty from the correction of diffractive contamination is negligible

→ Systematics tend to cancel in the distribution ratios

The full MB sample…

- Start with charged multiplicity distribution.
- Define n_{ch}: "*only particles from the primary vertex are included, and not, for example, the decay products of K^0_s and Λ^0*"…



- n_{ch} distribution in KNO form: $P(n) \rightarrow P(n/\langle n \rangle)$
- Small KNO violation (known since UA5 data)
- Distribution ratio: "quantify" the deviation from 1
- Systematics tend to cancel in the ratio.. only statistical uncertainties here.

The *soft* and *hard* samples

- Identification of "soft" and "hard" events is a matter of definition !!!
  → We classify a "hard" event as having some cluster (jet) structure
  → Remaining events are classified "soft"
- Jet reconstruction is experimentally ambiguous for $E_T(\text{jet}) \lesssim 3$ GeV

Definition of "cluster"

1) Apply JETCLU with R=0.7
→ **a cluster is at least 1seed+1 tower (1+0.1=1.1 GeV)**

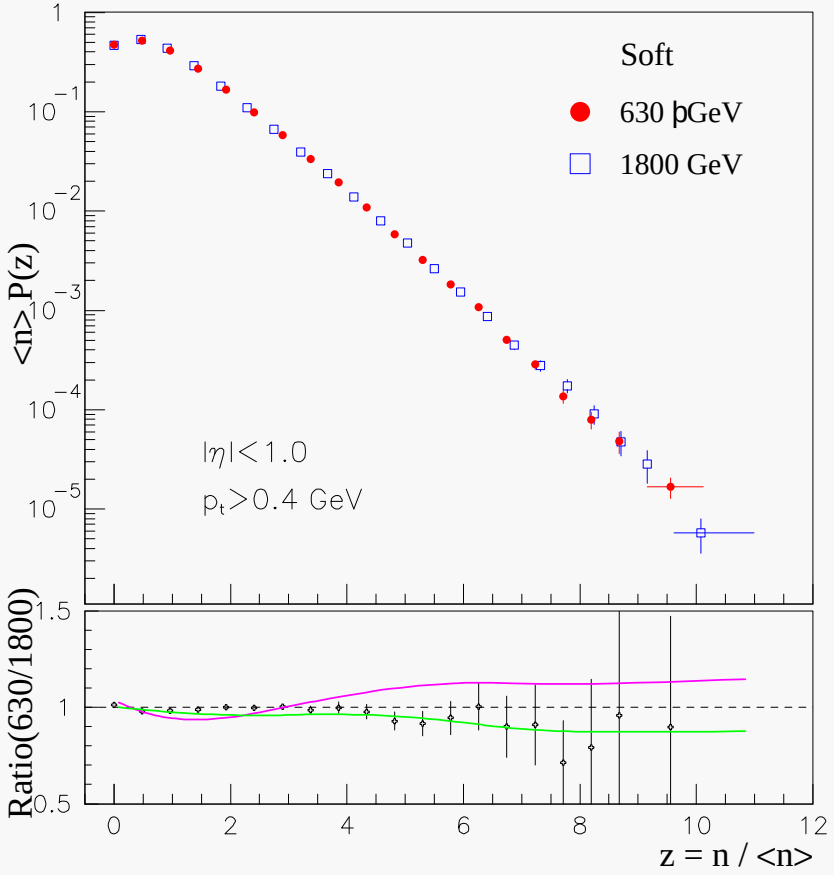
2) CAL cracks: use custom track clustering in $|\eta|<0.02$ $1.1<|\eta|<1.2$
→ **a cluster is 2 tracks of p_T=0.7+0.4 GeV/c in R=0.7**

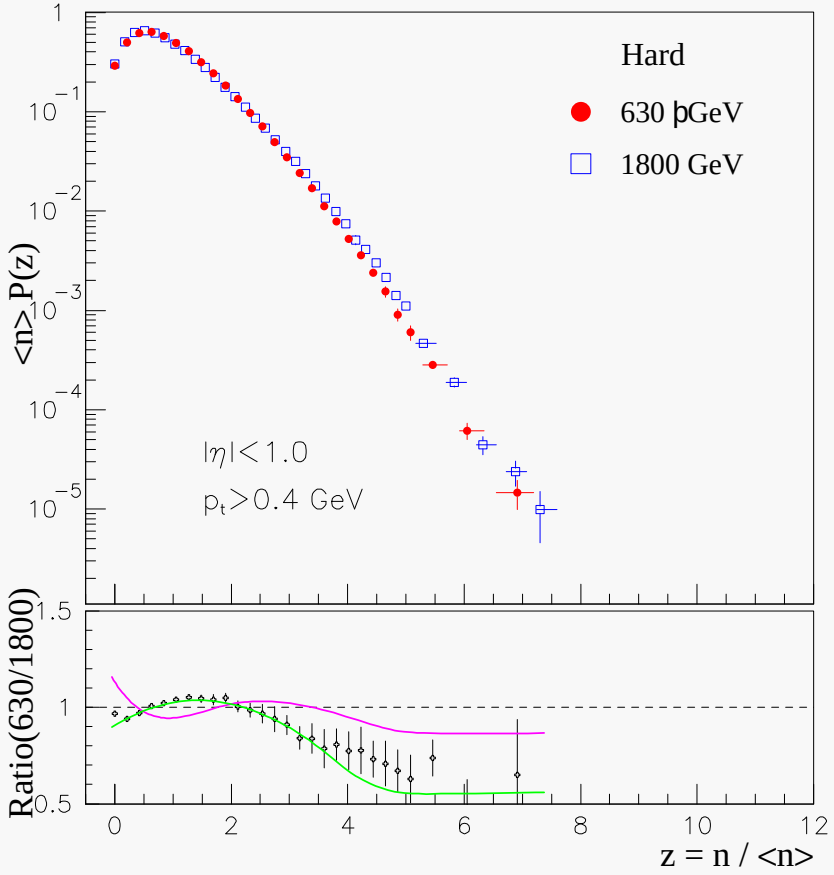
✓ The soft subsample is ~46%(1800) and ~58%(630)
✓ How well we recognize soft/hard events ?
...estimated with Pythia MC: ~ 70% overall (>80% in $|\eta|<0.8$)

Multiplicity distributions

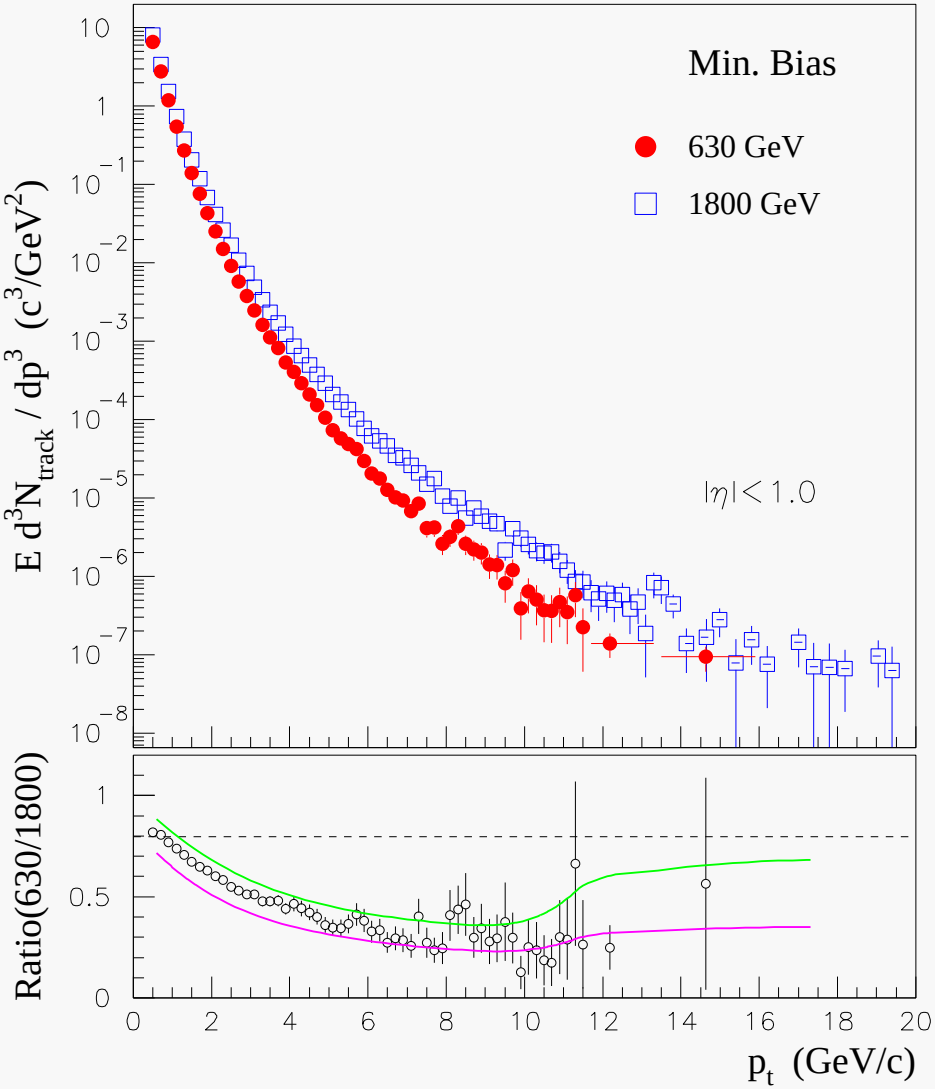
Compare soft and hard n_{ch} KNO distributions :

⇒ soft does *not* violate KNO scaling !!!

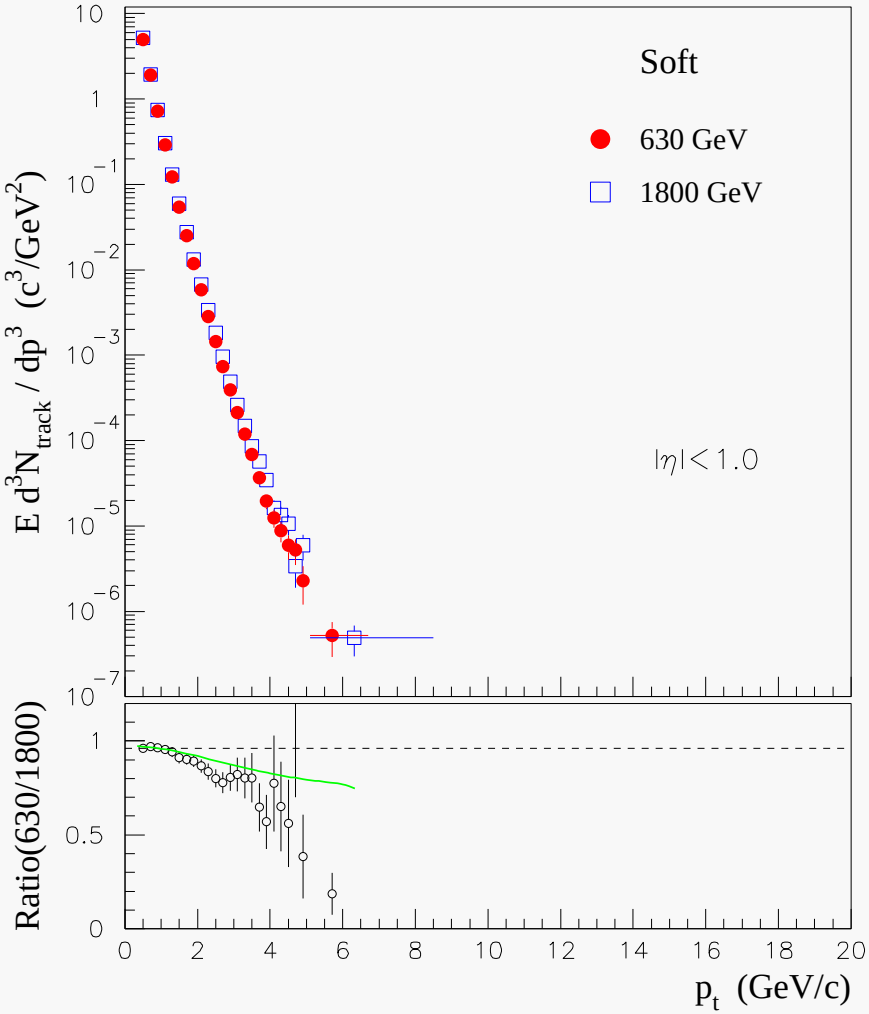


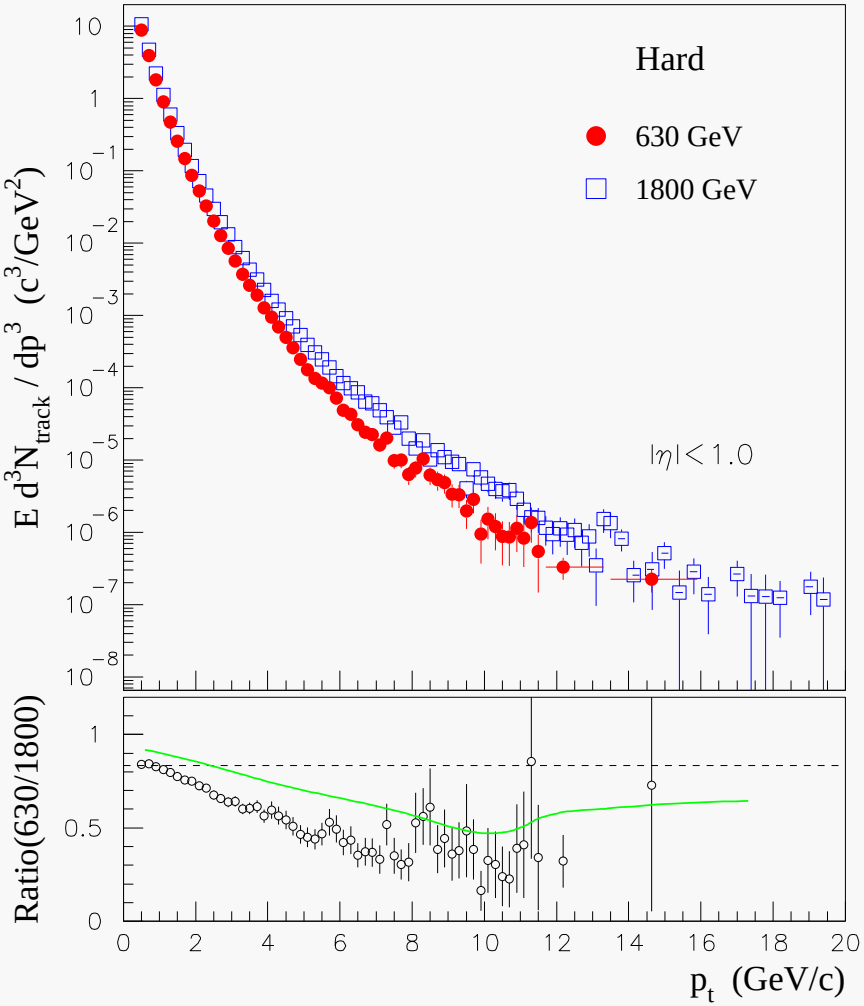


Inclusive p_T distributions (MB)

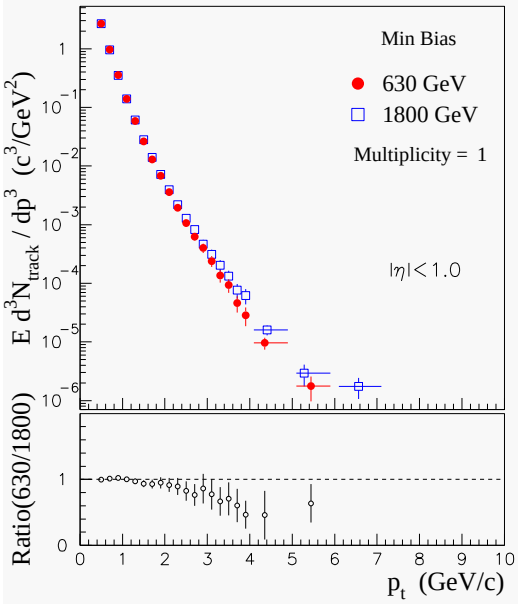


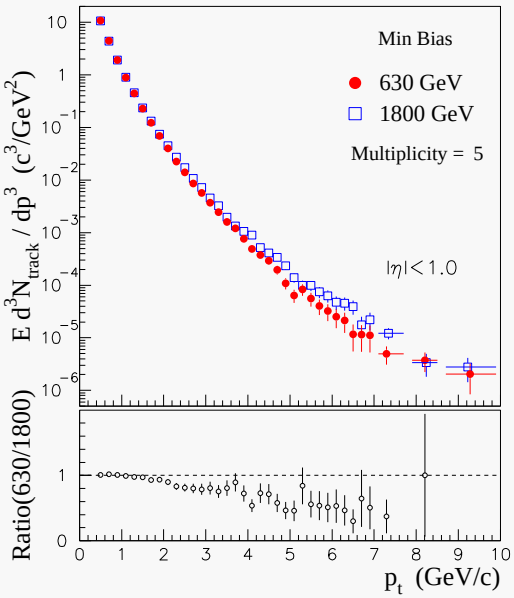
Inclusive p_T distributions (Soft+Hard)

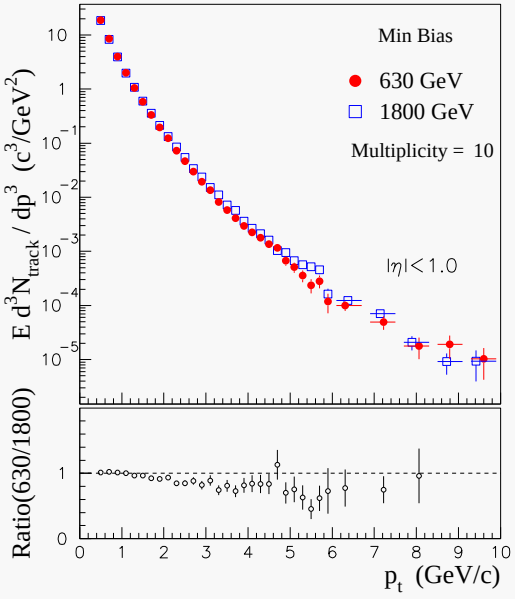


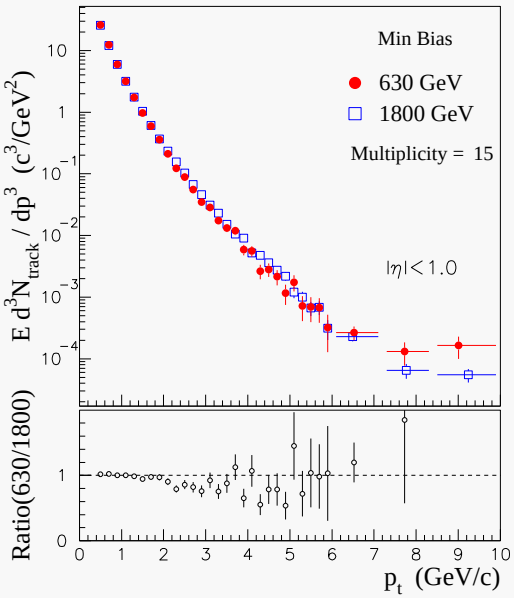


Inclusive p_T distributions (MB, fixed n_{ch})

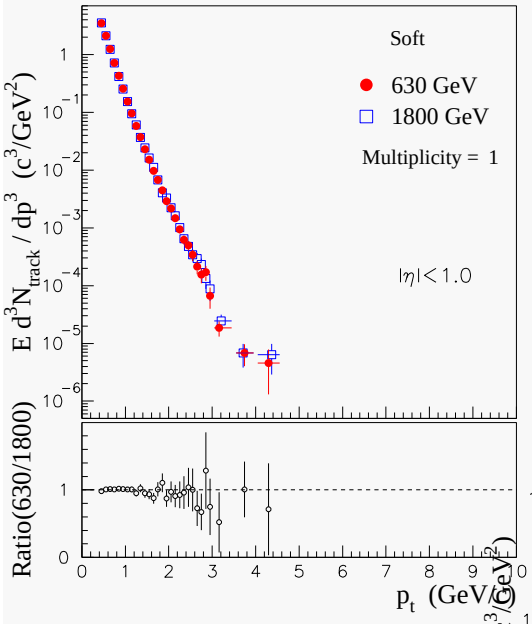


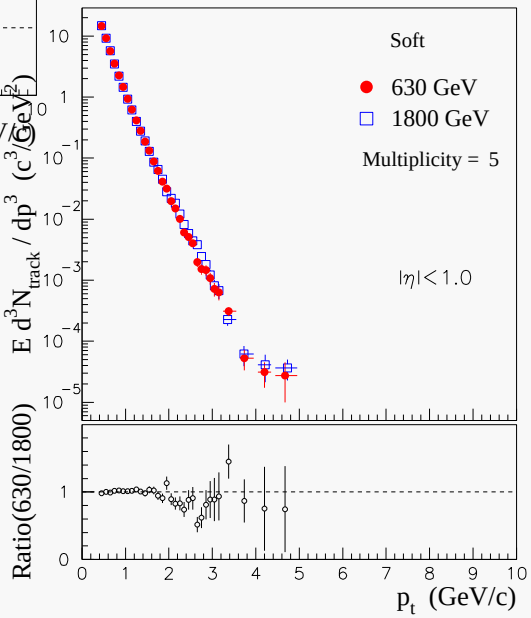


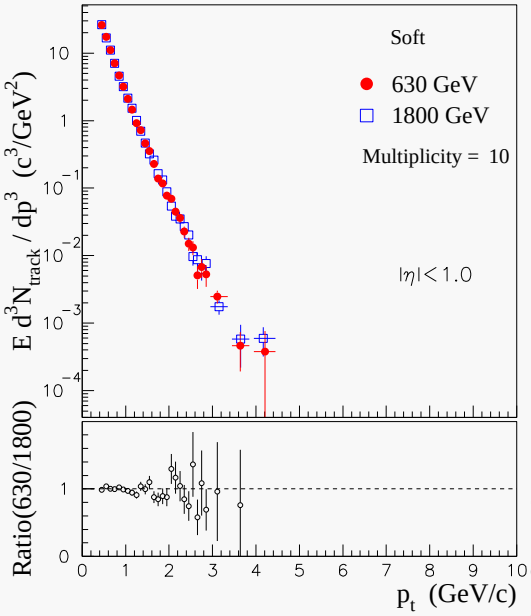


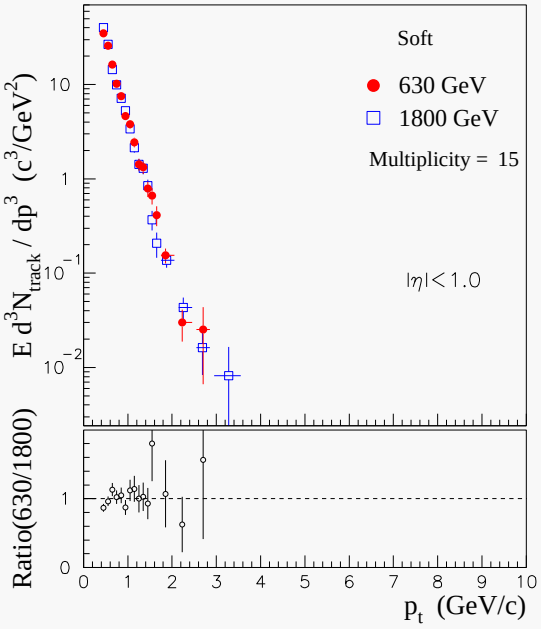


Inclusive p_T distributions (Soft, fixed n_{ch})

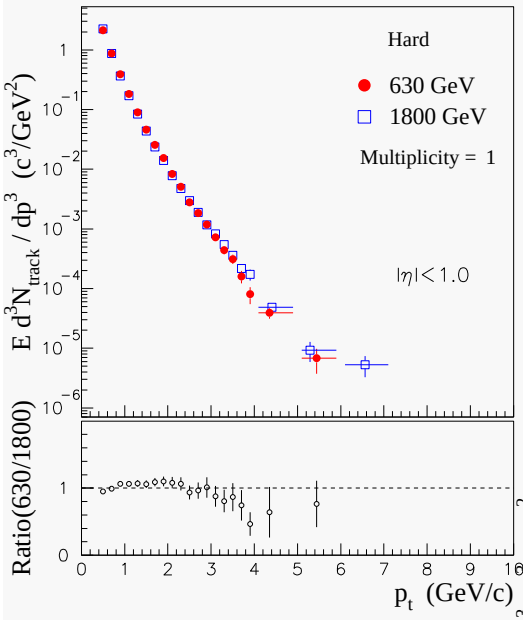


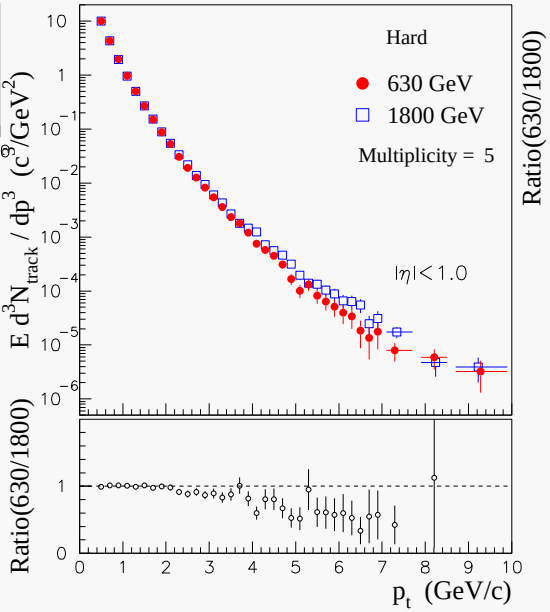


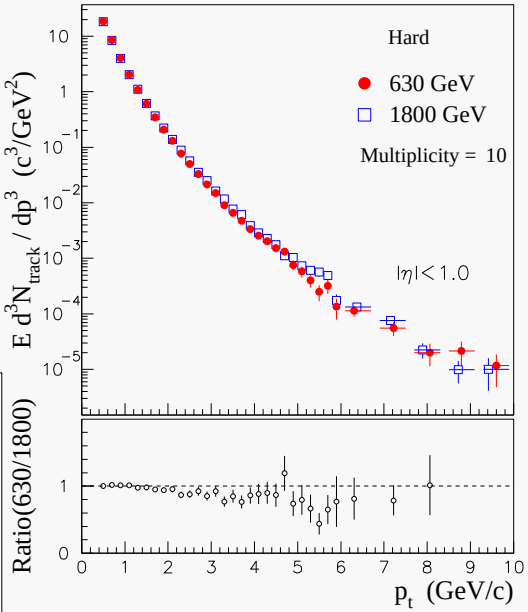


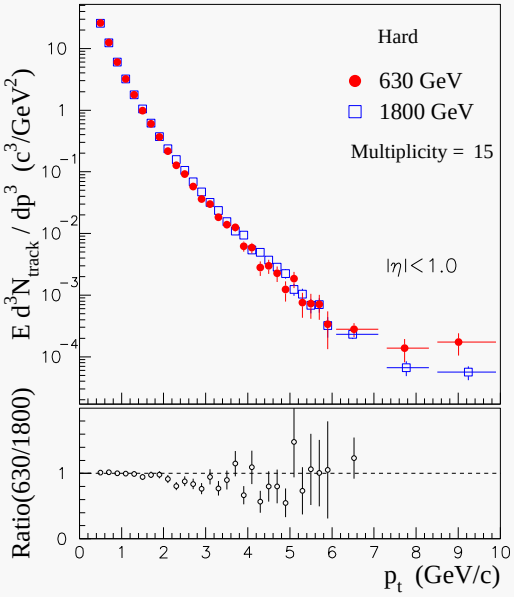


Inclusive p_T distributions (Hard, fixed n_{ch})







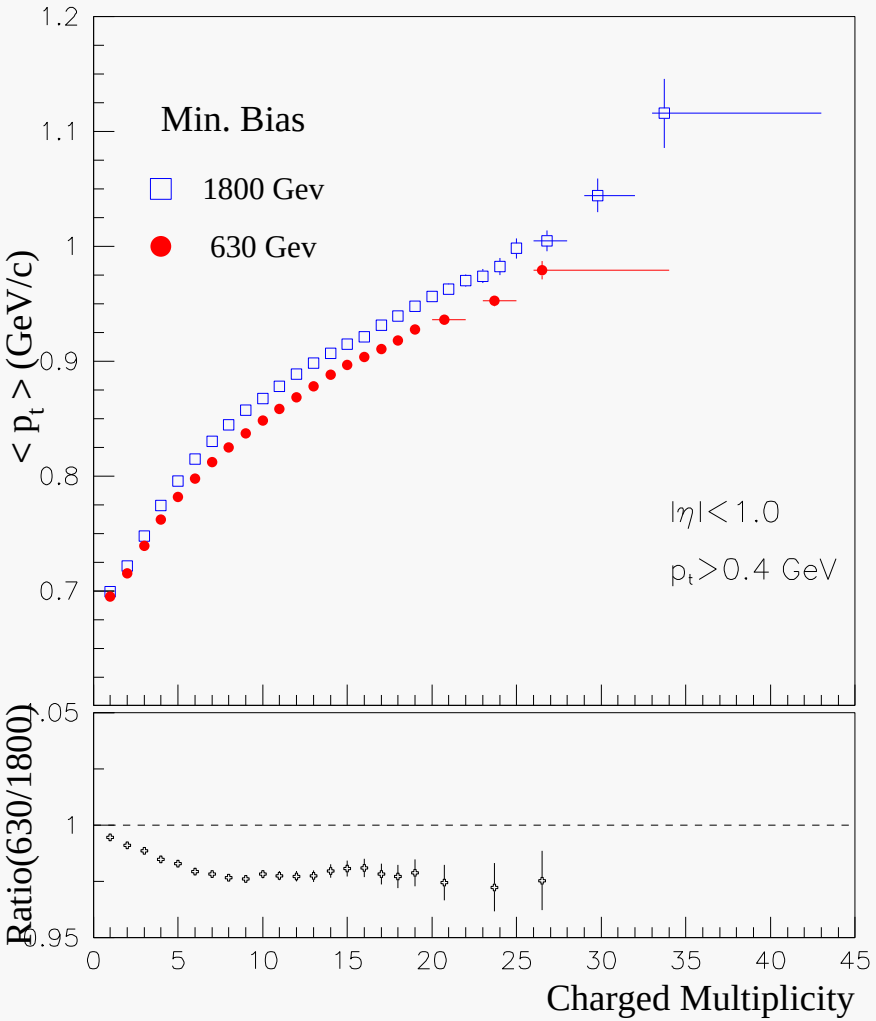


Some observations

- In soft interactions the p_T distributions for a given n_{ch} are CM energy invariant
  → n_{ch} is the only global event variable changing with $\sqrt{s}$!!!

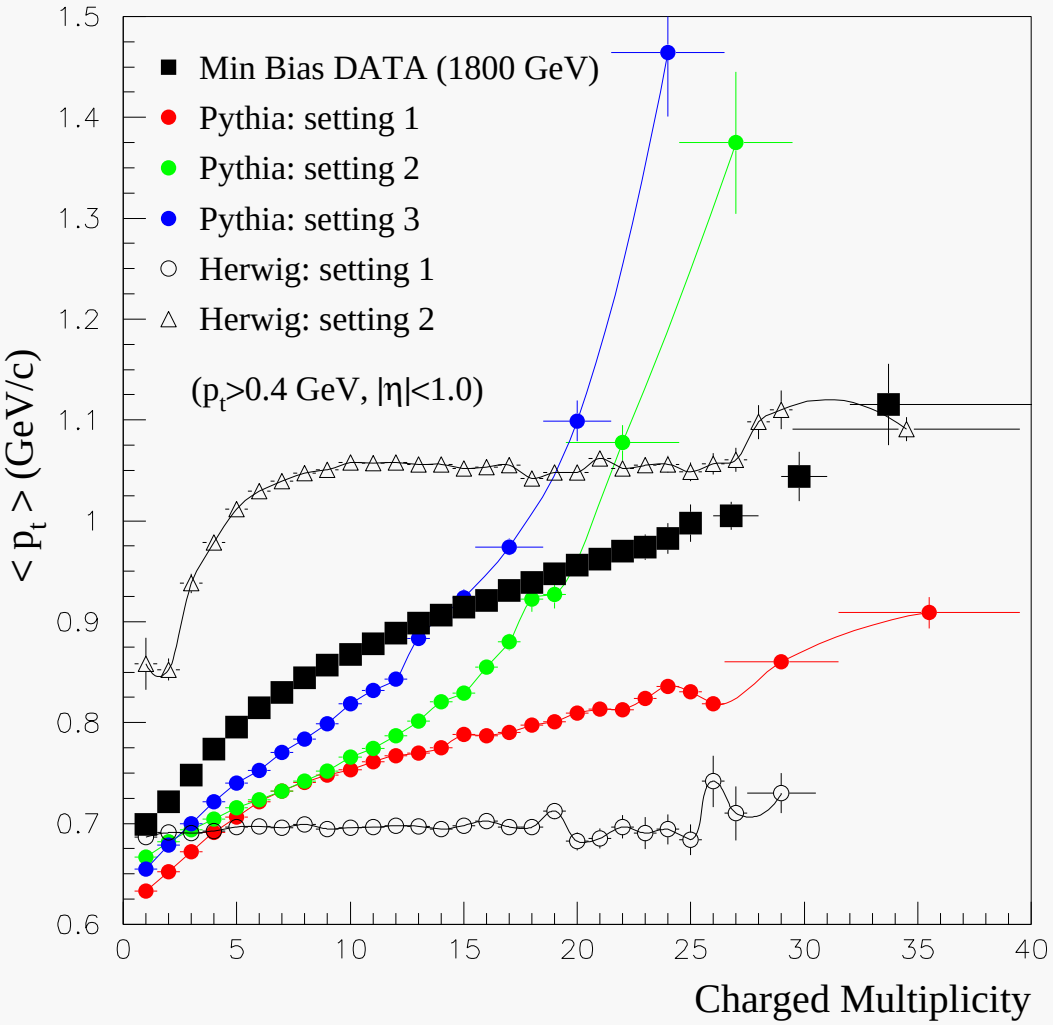
- The increasing slope with $\sqrt{s}$ of inclusive p_T distributions in the soft sample is due entirely to the change in n_{ch}
  → The more pronounced change in the slope of MB p_T distribution is caused also by the increasing jet cross-section.

The mean track p_T vs n_{ch}...



- Compute track <pT> from events with same n_{ch}
- Somehow describes the evolution of the scattering process
- MB: non-linear growth
- No satisfactory models for such correlation, but many measures published (including at Tevatron)

…and its simulation



A few simulations with Pythia and Herwig:

Pythia 1) MB our settings

Pythia 2) MB with p_{Tmin}=1.4 GeV

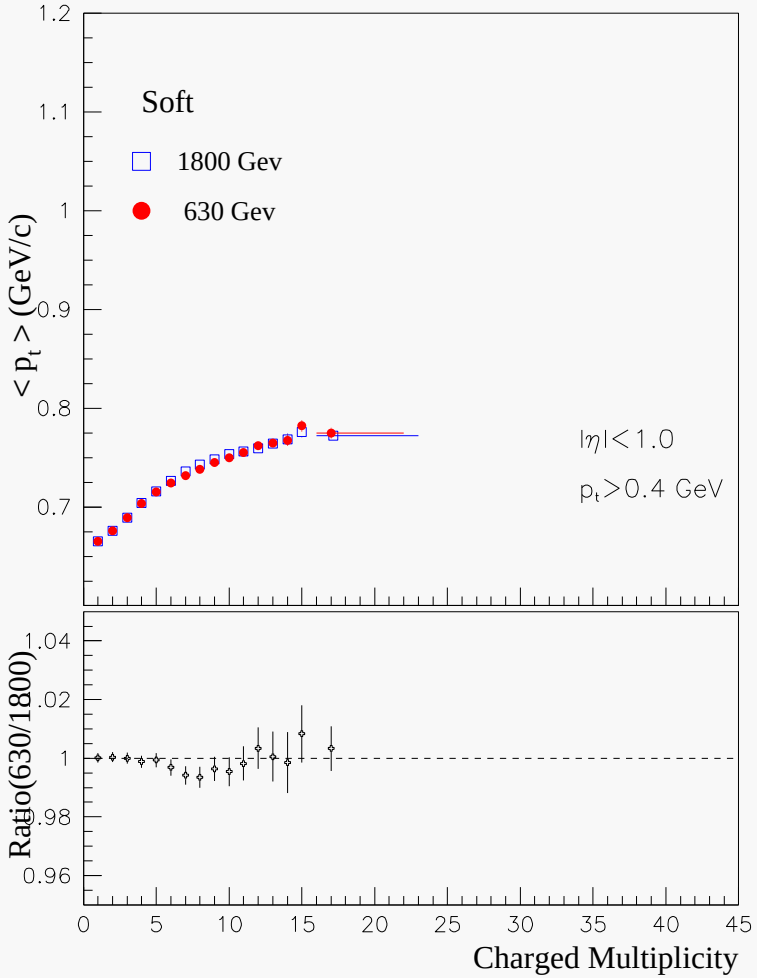
Pythia 3) MB with p_{Tmin}=1.9 GeV

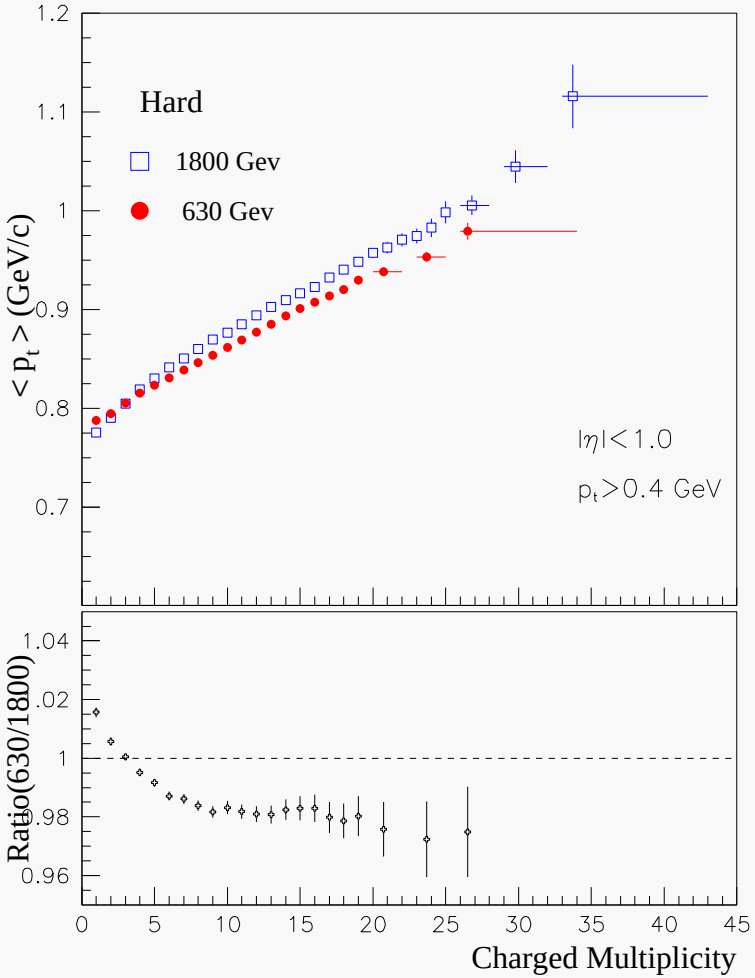
Herwig 1) MB soft production

Herwig 2) QCD 2→2 + underlying event

The mean track p_T vs n_{ch} (Soft and Hard)

This is a consequence of the previous results...





Ev-by-Ev $\langle p_T \rangle_{ev}$ fluctuations

Study Ev-by-Ev fluctuations of event mean p_T

$$\langle p_T \rangle_{ev} = \frac{1}{N_{tracks}} \sum_N p_{Ti}$$

For every n_{ch} compute the dispersion:

$$D_n = \frac{\langle\langle p_T \rangle_{ev}^2 \rangle_n - \langle\langle p_T \rangle_{ev} \rangle_n^2}{\langle p_T \rangle_{MinBias}}$$

normalization factor

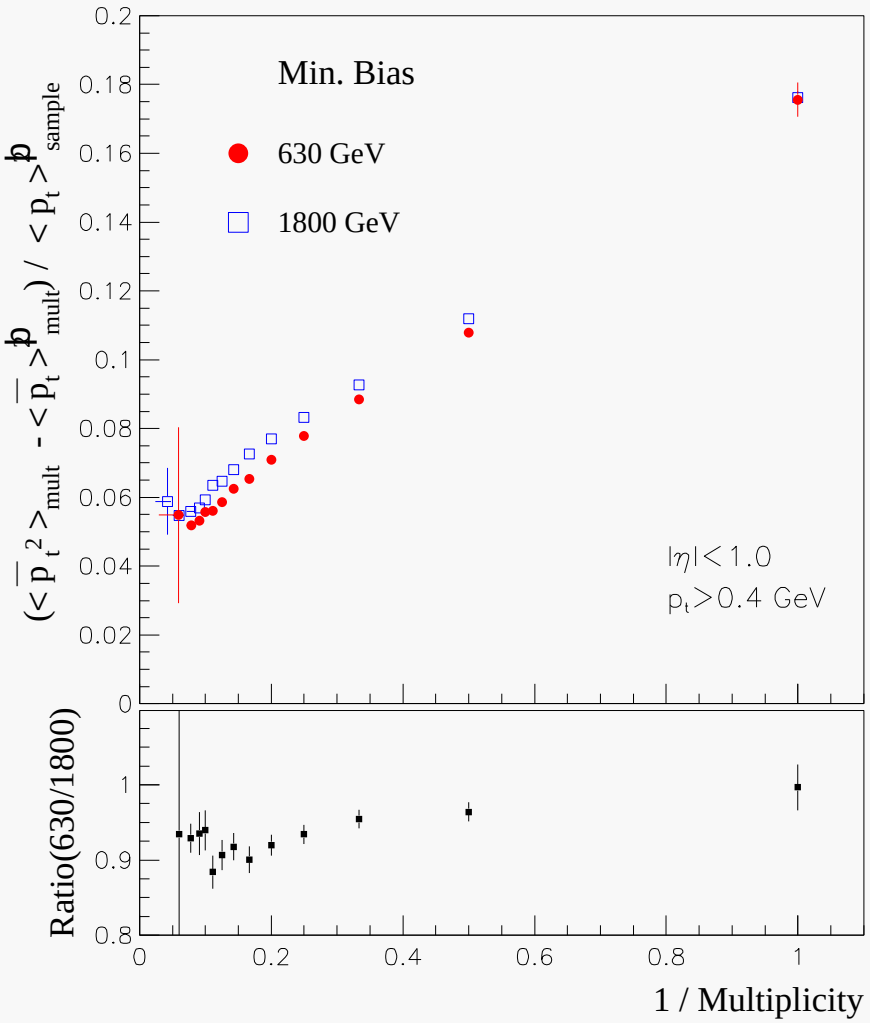
where $\langle ... \rangle_n$ implies an average over all events of equal multiplicity **n**

As a function of $1/n_{ch}$ we have for $n_{ch} \to \infty$

Stat. ONLY fluctuations → $D \to 0$

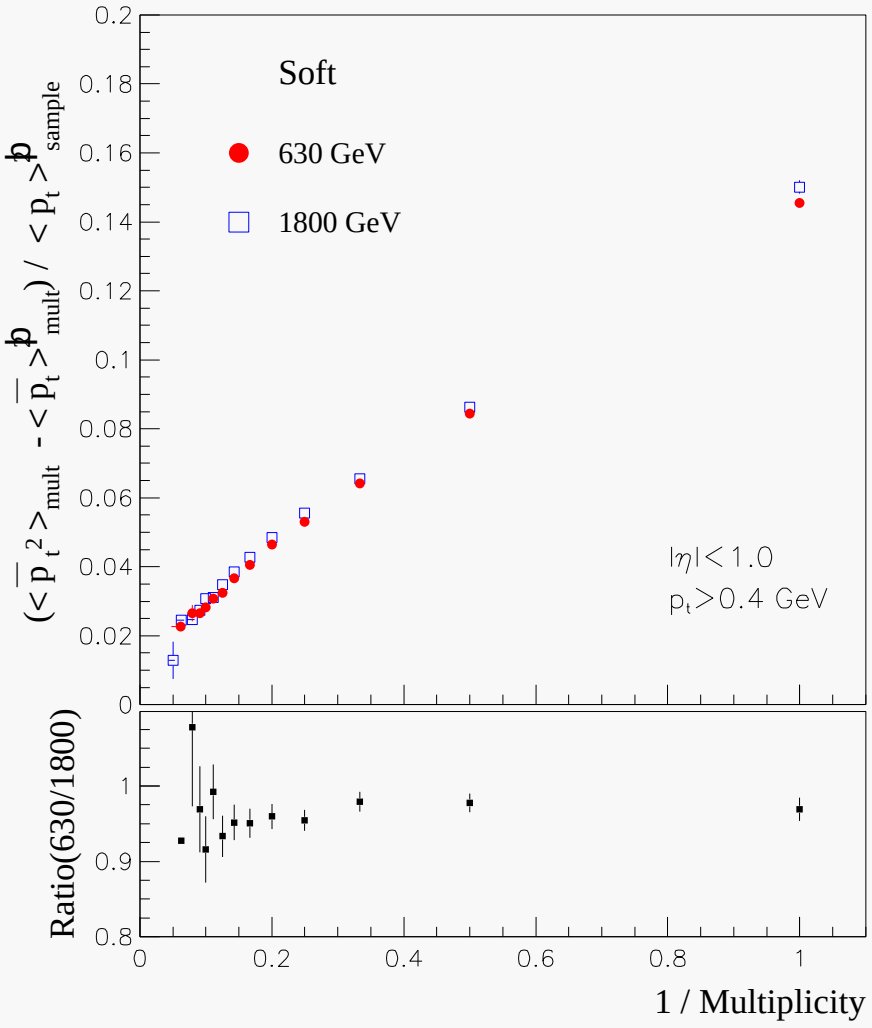
Fluctuations NOT ONLY statistical → $D \to > 0$

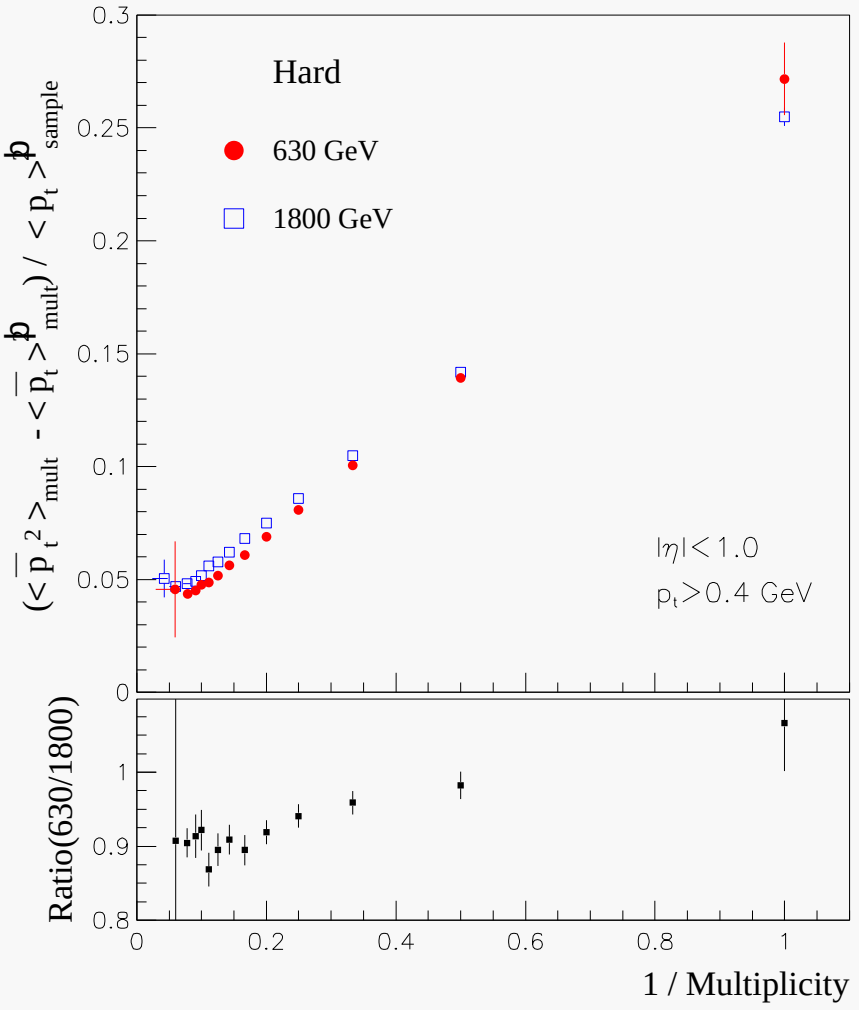
Ev-by-Ev $\langle p_T \rangle_{ev}$ fluctuations (MB)



- Previous measure at E_{cms} 63 GeV (ISR)
- There ARE non-statistical fluctuations (we knew…)
- They are produced by particle correlations in the final state
- The correlation slope changes (especially at high n_{ch}) : this was not observed at lower E_{cms}

Ev-by-Ev $\langle p_T \rangle_{ev}$ fluctuations (Soft and Hard)





Observations on Ev-by-Ev $\langle p_T \rangle_{ev}$ fluctuations

- In the soft sample the dispersion drops at high n_{ch}
  → particle correlations change with multiplicity

- Data points are consistent with an extrapolation to zero at $n_{ch} = \infty$
  → asymptotically soft interactions have no dynamical fluctuations ?

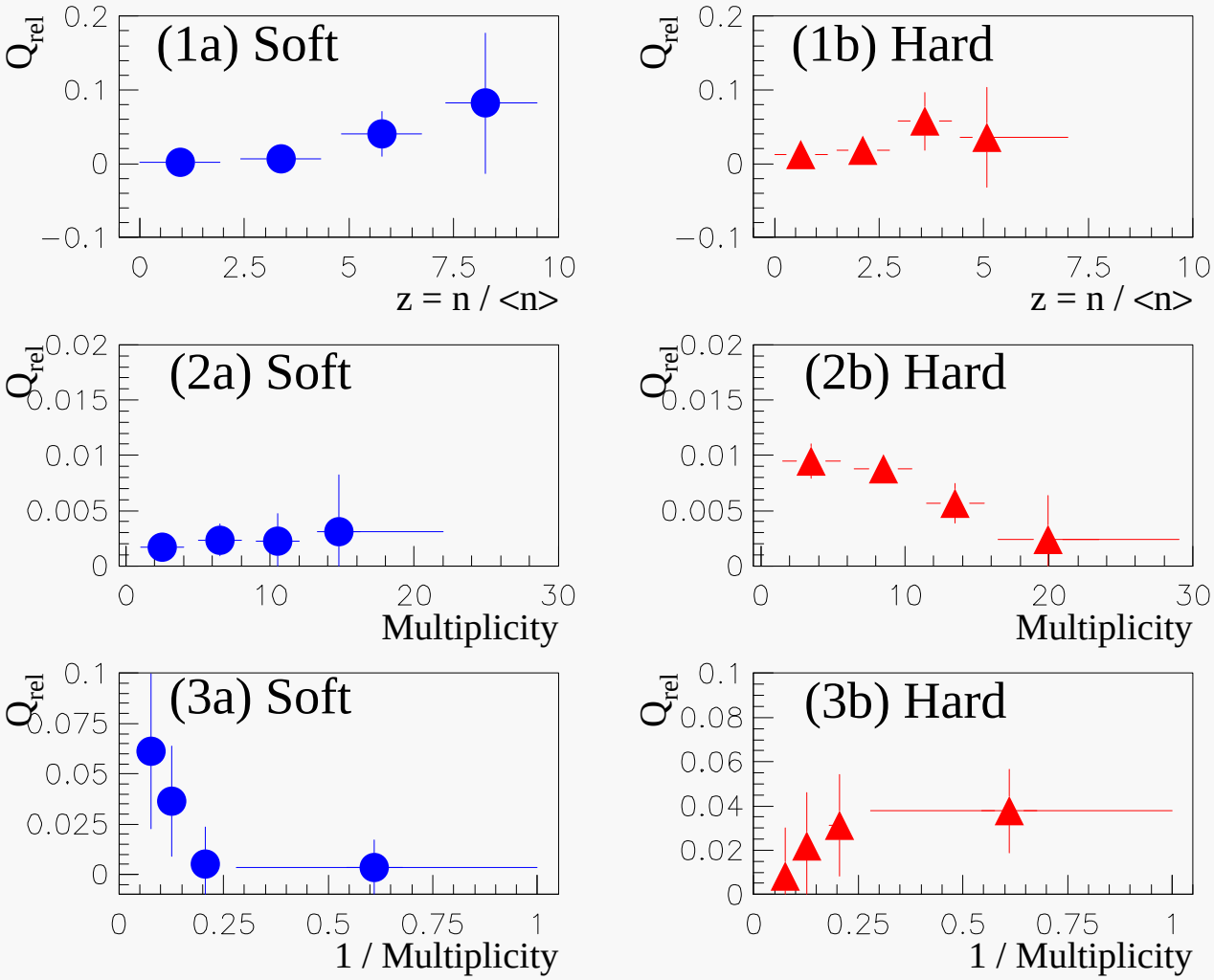
- In the hard sample the dispersion increases at high n_{ch}
  confirms that this effect is related to jet production

Dependence on E_T Threshold

All analyses were repeated with minimum cluster E_T = 3 GeV

Inclusive distributions change but invariance of soft sample is preserved (ratios do not change).

$$Q_{rel} = \frac{R_{(Et=3)} - R_{(Et=1.1)}}{R_{(Et=1.1)}}$$



Conclusions

Soft and Hard samples behave differently.

Concerning the Soft sample:

1) N_{ch} distribution follows KNO scaling
2) p_T distributions for fixed n_{ch} are energy invariant
3) (→) the mean p_T as a function of n_{ch} also scales with energy
   (notice the growth even if hard interactions are suppressed)
4) Dynamical fluctuations asymptotically tend to zero for high n_{ch}

All studies are compatible with the hypothesis of invariance with energy of soft interactions

→

The dynamical mechanism of soft multi-particle production is invariant with E_{cms} Final state properties are determined only by the number of (charged) particles.