Minimum Bias Studies at CDF and Comparison with MonteCarlo

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This talk

- Set of measurements of inelastic non-diffractive particle production in $p\bar{p}$ interactions collected with a MB trigger:
  - Charged particle p_T differential cross section
    - Previous measurements (CDF 1988) extended in range and precision
  - Correlation of charged particle $\langle p_T \rangle$ with their multiplicity in the event
  - ΣE_T differential cross section
- Systematic comparison with MC at hadron level
- One example of possible outcome (top mass)
- Point out experimental issues and problems

Introduction

- MB data contains (in principle) all type of interactions proportionally to their natural production rate.
- At 2 TeV is a mixture of soft and hard interactions.
  - ~1% events with jet of E_T>10 GeV,   ~25% jet E_T>3 GeV
- It is the most suitable sample to study at the same time:
  - Non-perturbative contributions
    - Low-Q^2 parton interctions
    - beam-beam remnants
    - MPI

    $\left.\begin{array}{l}\text{beam-beam remnants}\\ \text{MPI}\end{array}\right\}$ U.E.
  - Other mechanisms (correlations?)
  - Interplay of soft and hard
- Important in itself and for precision measures of hard scattering processes (subtraction of soft effects)

By comparison to future LHC measurements, we will gather information on the energy dependence of the MPI process

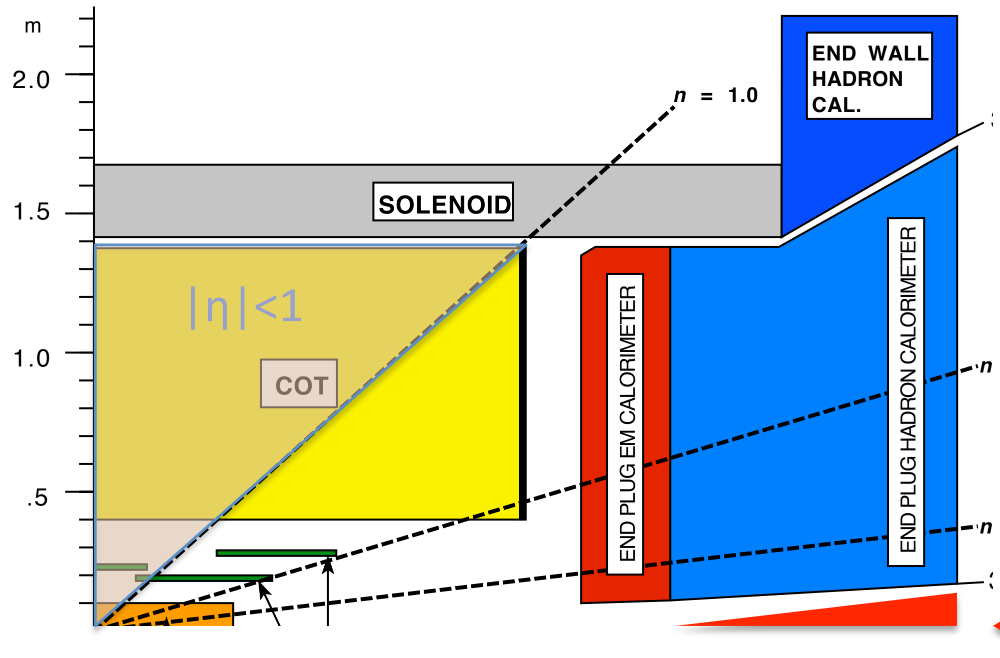
Especially at LHC because of huge pile-up !

MB and MC

- No generator correctly reproduces all the observables at the same time, but most may be tuned to be ok on each *single* one.
- In Pythia the description of MB rely on a $\hat{p}_T$ cut-off that :
  - Regulates the 2-2 parton perturbative Xs at low momenta, but also…
  - …the additional parton-parton scatterings (MPI)
  - Plus all the stuff we'll see in other presentations…
- Pythia tries to describe the largest possible set of MB distributions

A “small-bias” trigger

- “Minimum Bias” is defined by its trigger !

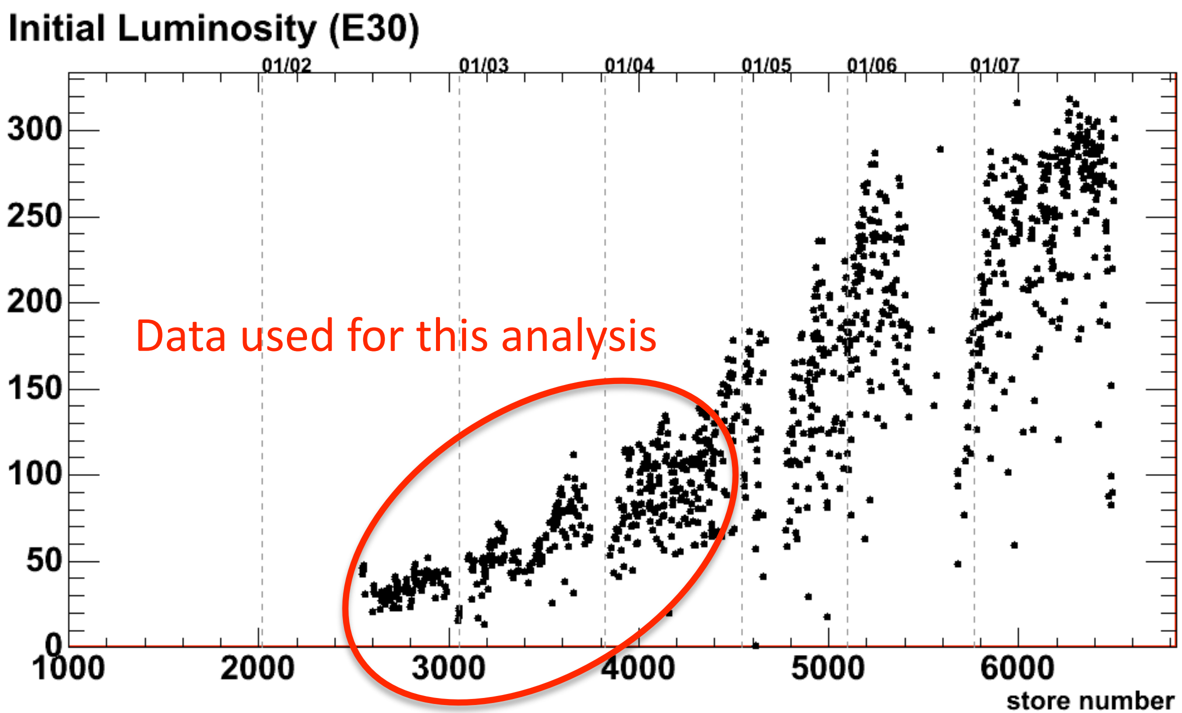


- CDF triggers MB with forward particles in $3.7<|\eta|<4.7$ (<3deg)
- Requires coincidence of both sides (forw+backw)
- Implemented with Cerenkov counters (CLC)

- The trigger is biased so to favor high p_T interactions
- Will affect the *shape* of inclusive distributions
- Note that the observables studied are in the central region ($|\eta|<1.0$)

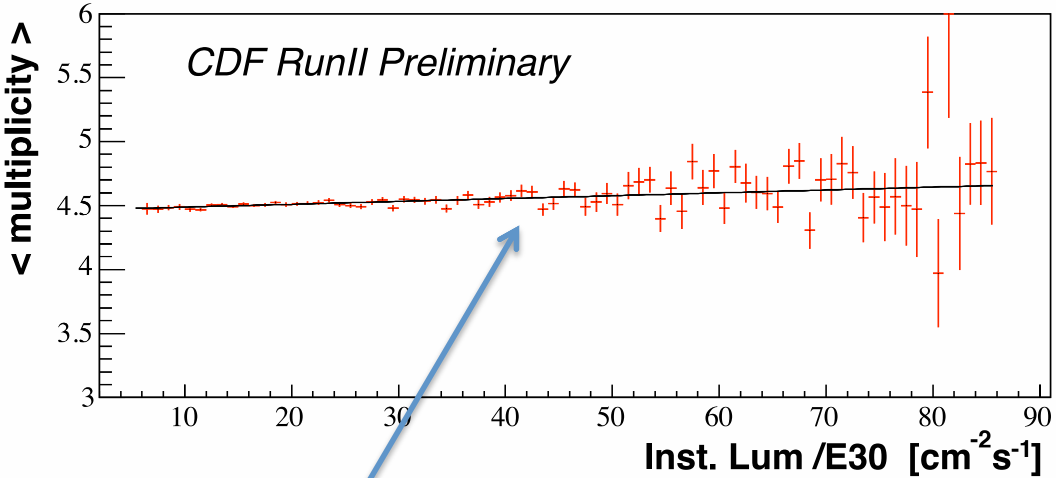
The data Sample

- 506 pb^{-1} (Tevatron runs during 2002 to 2004)
- Max inst. Lum: 90 $x10^{30}$ $cm^{-2}s^{-1}$ (<50 for ΣE_T)
- Average inst. Lum: 20 $x10^{30}$ $cm^{-2}s^{-1}$ (<17 for ΣE_T)



The Event Selection and Background

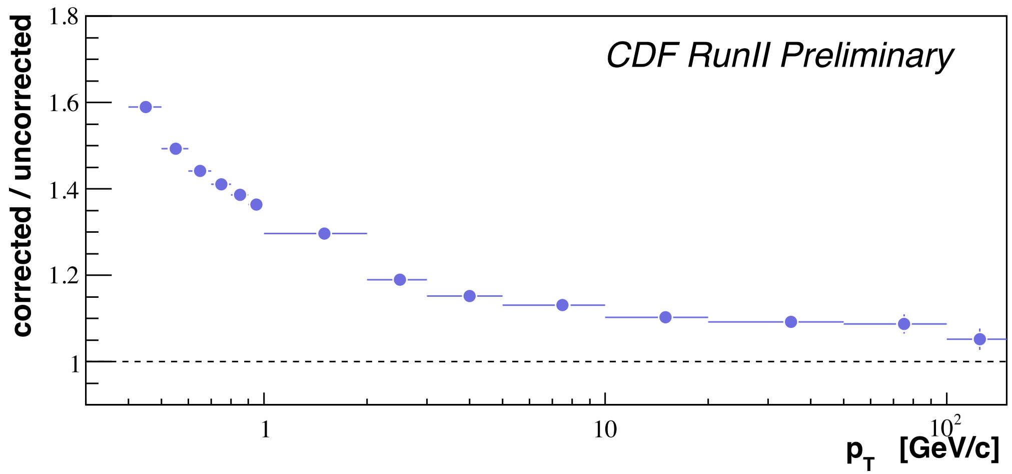
- Event cuts:
  - $|Z_{vertex}|<40$ cm
  - Limited vertex asymmetries in η
  - No pile-up detected
- Vertex acceptance is function of the total activity in the crossing
- Backgrounds:
  - Pile-Up (~3% of MB)
  - Diffractive interactions (~3.5% of MB)



The average particle multiplicity grows with the Inst.Lum. because of undetected pile-up events. The resolution for separating primary vertices in Z is ~3 cm

Tracking efficiency

- ε is function of p_T, N_{ch}, # of jets…
  - In the same event the probability for a particle to be observed depends whether is inside a jet or not (and on the jet E_T)
  - Cannot analyze as function of all kinematic variables, must rely on MC for most
- Overall correction computed with MC:
  - ε is the largest contribution: (~70% at p_T=0.4, ~92% at p_T=5 GeV/c)
  - includes correction for
    - Contamination of second.
    - Particle decays, conversions..
    - Trigger + event acceptance



- Full detector simulation and event reconstruction
- Accepted region: p_T>0.4 GeV/c and |η|<1.0

Single Particle p_T differential Xs

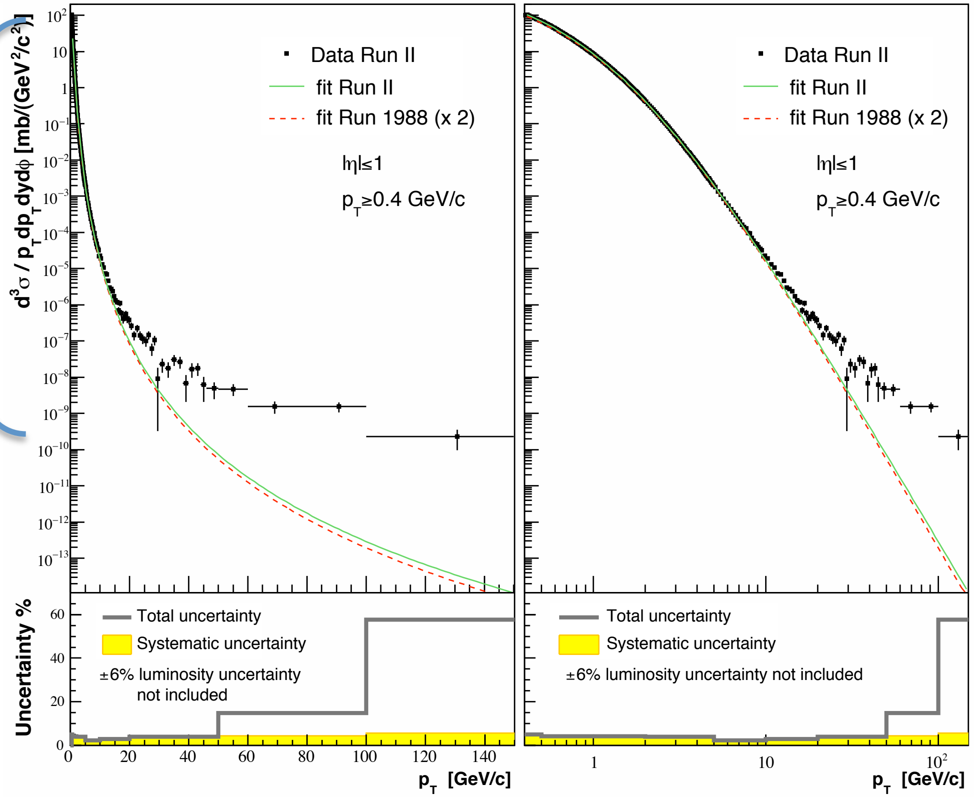
$$E\frac{d^3\sigma}{dp^3} = \frac{d^3\sigma}{p_T\,\Delta\phi\,\Delta y\,dp_T} = \frac{N_{ch}/(\varepsilon \times A)}{L\,p_T\,\Delta\phi\,\Delta y\,dp_T}$$

A(Z_{vertex}, PileUp)

- Modeling of the distribution:

$$f = A\left(\frac{p_0}{p_T+p_0}\right)^n$$

$10^2 - 10^{-9}$



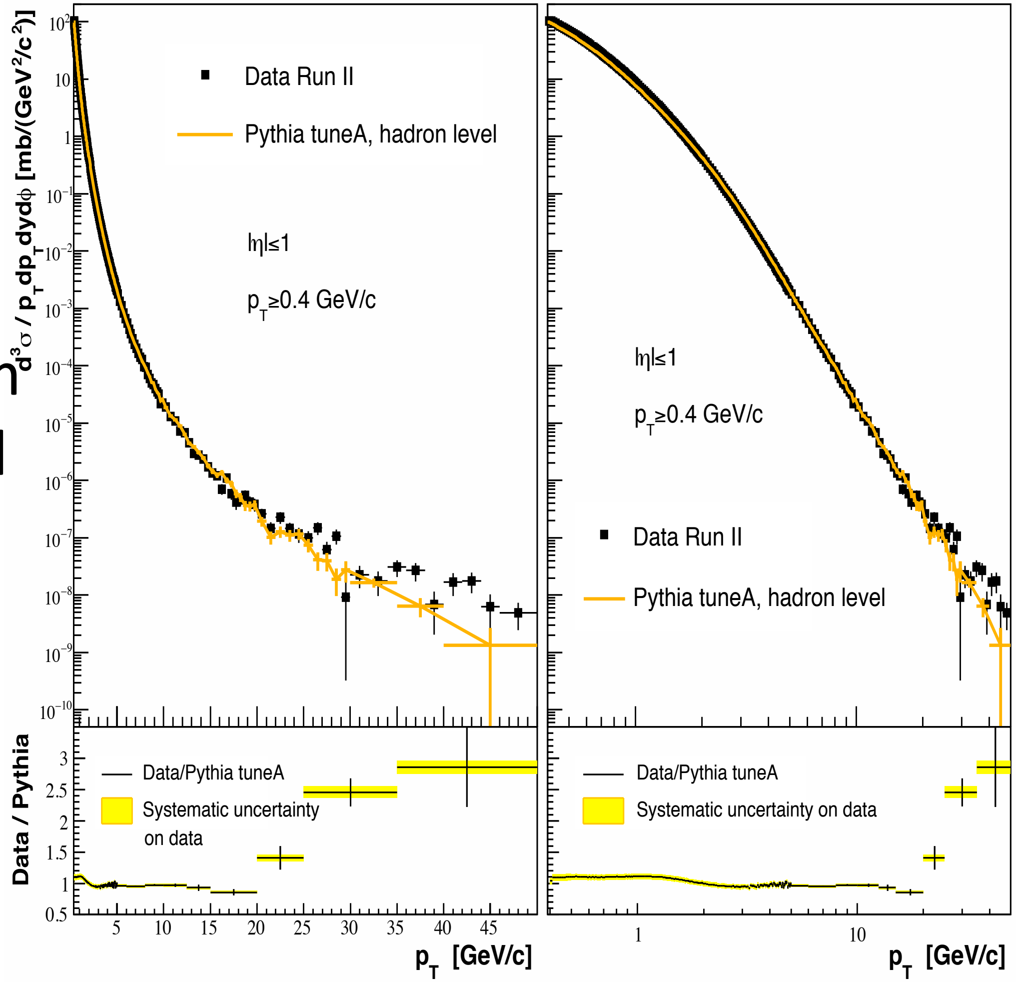
- High p_T tail orders of magnitude higher than fit extrapolation
- Same fit as with 1800 GeV
- New parameterization ?

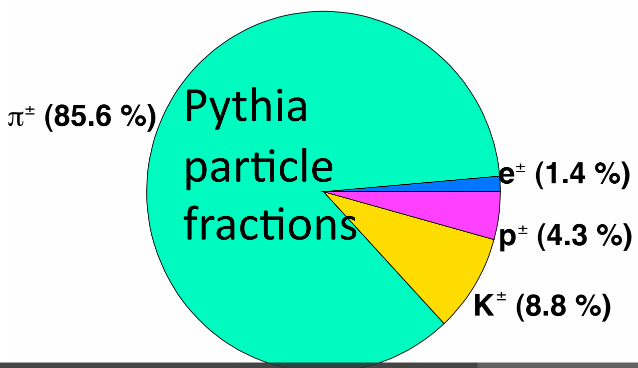
	p_0	n	p_T range (GeV/c)	χ^2/dof
Run 0, 1800 GeV	1.29±0.02	8.26±0.08	0.4 - 10.	102/64
Run 0, 1800 GeV	1.3 fixed	8.28±0.02	0.4 - 10.	103/65
Run II, 1960 GeV	1.230±0.004	8.13±0.01	0.4 - 10.	352/192

Xs (2TeV) ~ 1.04 Xs (1.8 TeV)

P_T Xs, compare to Pythia

- Data has much more particle production in p_T>20 GeV
- TuneA produces no particles at all above ~50 GeV/c
- Note that Δy is computed from Δη assuming the π mass for all tracks
- Bias ~5% at p_T=0.4 GeV/c dependent on the (unknown) fractions of particle species



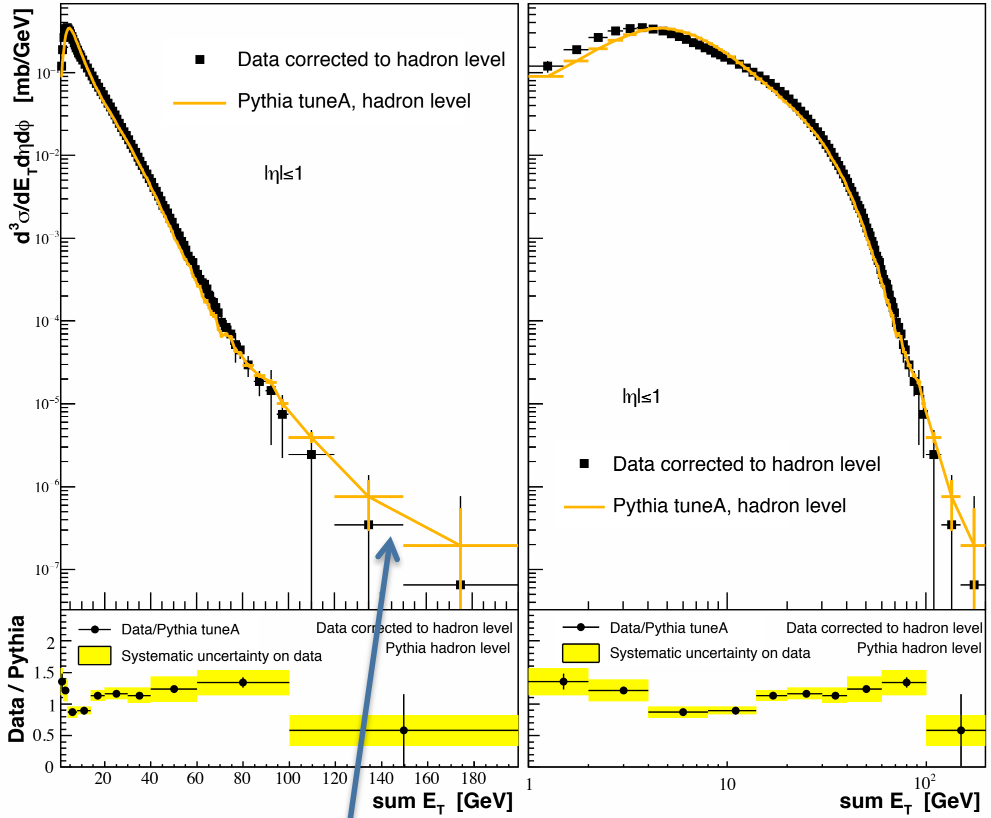


Overall 6% systematic from Luminosity measurement

Sum E_T differential Xs

$$\frac{d\sigma}{\Delta\phi\,\Delta\eta\,dE_T} = \frac{N_{ev}}{Lum\,\Delta\phi\,\Delta\eta\,dE_T}$$

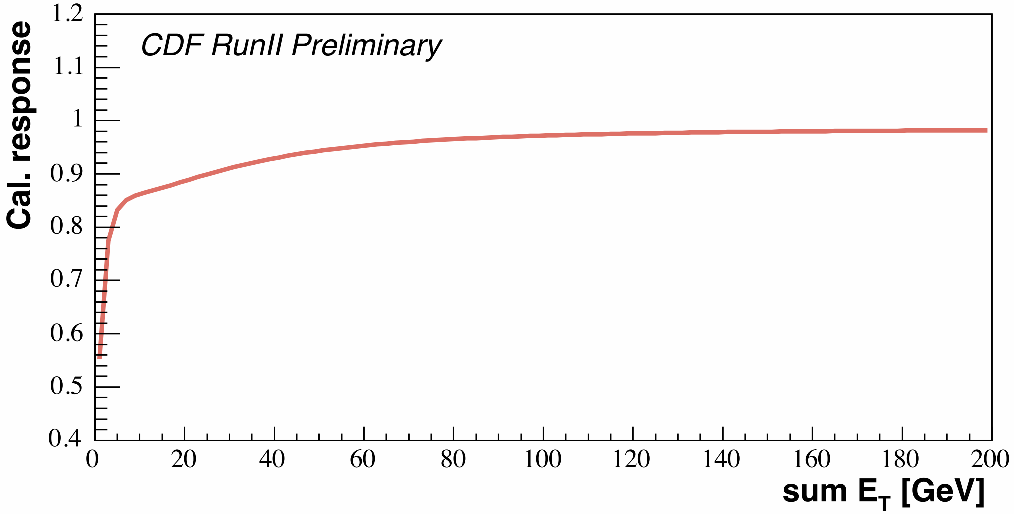
- First attempt of really inclusive measure with neutral particles
- ΣEt integrates all undetected pile-up: large systematic also at low lum (~3%)
- Different Pythia tunings (A,DW) give different cal responses: systematic ~5 to 15%
- + overall systematic 6% due to luminosity measurement



Excess of energy in the UE in high p_T jets wrt data ?

Corrections to Sum E_T Xs

- Many step correction:
  - Single tower relative cal response f(η, Z_{vertex})
  - Absolute response to ΣE_T
  - Acceptance vs Z_{vertex}
  - Pile-Up
  - Undetected low-p_T charged particles
  - Trigger and vertex acceptance
  - Unfolding (spread of events due to finite energy resolution)



Cut at p_T~0.3 GeV/c at CDF
1 to 2 GeV/c at
CMS and Atlas

$$N_{ev}^{corrected} = N_{ev}^{raw}\left(\frac{\sum E_T}{C_{tower-\eta}\, C_{absolute}\, A_{vertex-Z}} + C_{low-p_T}\right)\frac{C_{pile-up}\times C_{unfolding}}{A_{trigger\ and\ vertex}}$$

Charged particle $\langle p_T \rangle$ vs Multiplicity

$$\langle p_T \rangle (N_{ch}) = \frac{\sum_{ev} \sum_{i}^{N_{ch}} p_T^i}{N_{ev}^{N_{ch}} \times N_{ch}}$$

- Sensitive to the various components of MB:
  - Measure of the amount of hard vs soft
  - Sensitive to the modeling of MPI, eg . 'Color Reconnections'
  - Most poorly reproduced by MC
  - Probably best current model is Pythia tuneA, but new tunings with ad-hoc CR + much more are being studied

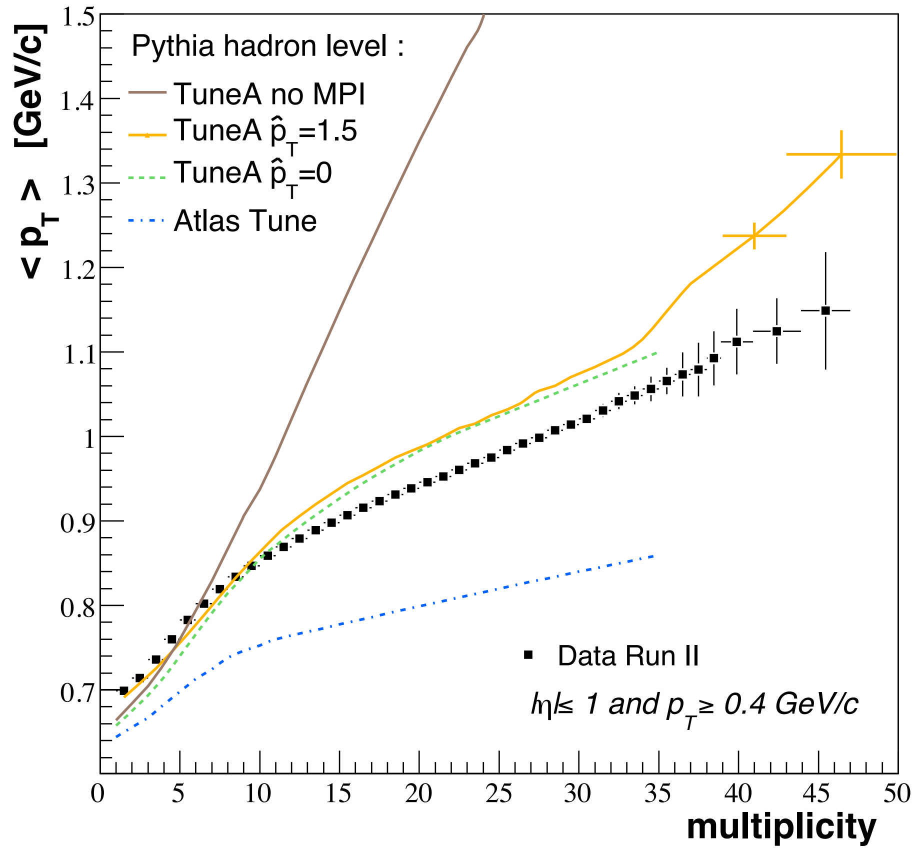
P.Skands and D.Wicke, 2007:

"…models which successfully describe the <pT>(Nch) distribution such as R.Field 'TuneA' … do so by incorporating very strong ad hoc correlations between final state partons from different interactions...

..Simultaneous agreement with <pT>(Nch) is only obtained from the models incorporating non-trivial color correlations…"

$<p_T> (N_{ch})$

- Merged data at high N_{ch} from a dedicated "high-multiplicity" trigger
  - ToF at L1
  - Track reconstruction at L3
  - Double the stat in $N_{ch}>24$
  - Total uncertainty ~2% (6% for Nch>40)



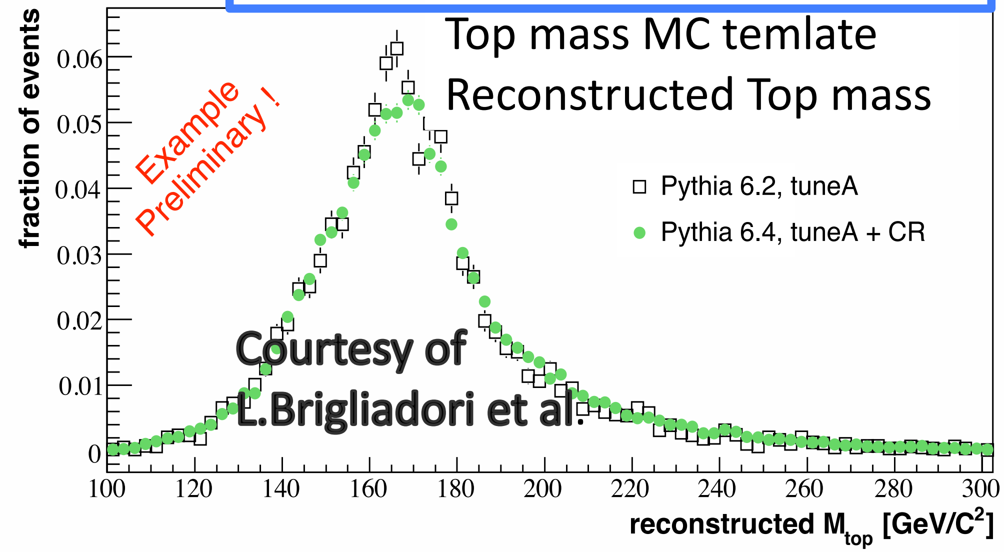
- TuneA: fairly good
  TuneA no MPI: too hard
  Atlas tune: too soft
  (tunes by courtesy of R.Field)
- MPI mechanism necessary to reproduce $<p_T>(N_{ch})$
- $<p_T>(N_{ch})$ useful to tune MPI

Outcomes: an example

- New Pythia tuning based on these data
  - New parton shower and ISR/FRS models
  - Ad hoc 'color reconnection' model
- Effect on the had TOP mass measure
  - Produce a sample of tt→Wb+Wb→6 jets
  - Compare to previous tuneA
  - M_{top} variation ~0.6 to 0.8 GeV
- But first we need to disentangle perturbative effects (jet shapes should be sensible to parton shower) and check the effect on
  - other top channels
  - dijets
  - JES…

All-hadronic TOP:

- Many templates produced with varying M_{top}
- Background is added
- Templates are parameterized
- Parameters studied vs M_{top}, compared to data best set chosen



Experimental issues: caveats for LHC

- By the experience gained at CDF, some effects affect the analyses of MB:
  - Undetected pile-up becomes systematic uncertainty
    - Need excellent separating resolution of PV (timing may be a good handle)
    - Watch for biases introduced by the selection of the PV (no algorithm can be totally unbiased)
  - MB triggers like CDF are actually biased to favour hard interactions (eg, Atlas may incur in the same problem)
  - Low-p_T particle reconstruction usually neglected (~1 GeV/c ?)
    - At LHC the high B fields will hide a large part of the spectrum !
  - Care needed in tracking inside/outside jet cones
  - Do not forget the rest of the world (neutrals) and P.ID.
- MB is (also) useful to the understanding of the detector and to calibrate tools of high-p_T analyses (eg. JES, ME_T ...)

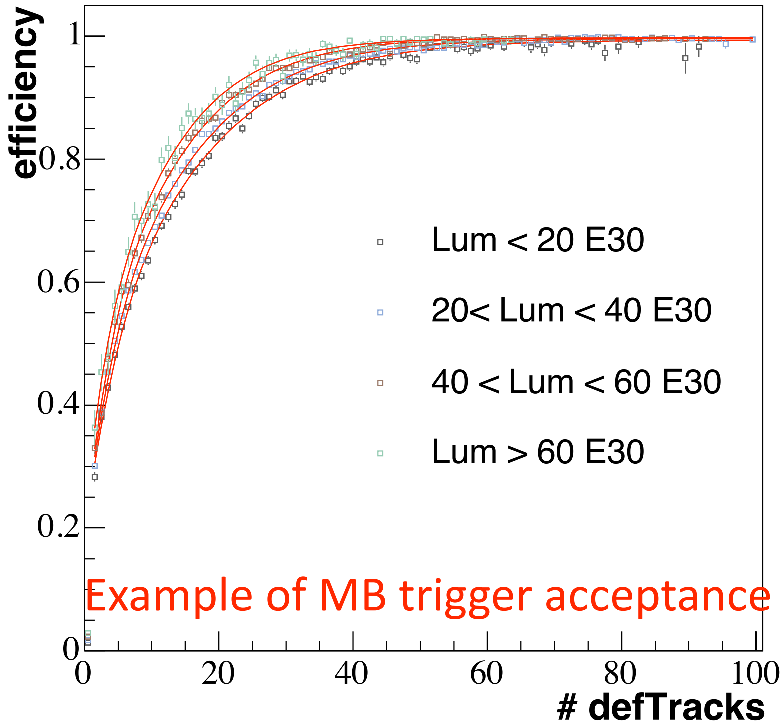
Conclusions

- MB is a mixture of different processes:
  - It's difficult to simulate, but…
  - It's ***the*** sample where is possible to understand how all the processes involved overlap and interact
- We have provided a set of high precision measurements of the MB final state at 2 TeV
- Few immediate observations:
  - Pythia reproduces the particle p_T spectrum within 10% only at p_T<20 GeV/c
  - $\langle p_T \rangle (N_{ch})$ strongly favors models with MPI and put constraints on the MPI model itself
- Hopefully these data will lead to improved models in time for the first LHC data

BACKUP SLIDES

CDF Vertex & Trigger acceptance

- Trigger: acceptance is function of many variables
  - # primary detected vertices, Luminosity, # tracks, CLC calibration…
  - In short, acceptance increases with the total activity in the *crossing*. Plateau at ~98%
  - Measurable with 0-Bias sample

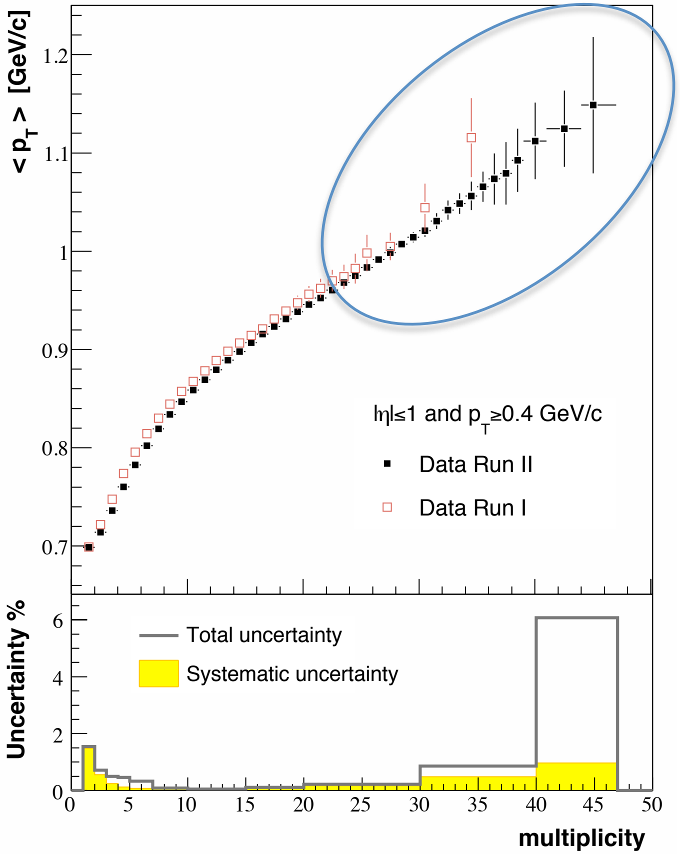


Example of MB trigger acceptance

- Primary Vertex (after trigger):
  - Clustered by the tracking system
  - Flat in $|Z_{vertex}|<40$ cm, outside affected by tracking inefficiencies
  - Depends on #PV, # tracks, Luminosity

$<p_T>$ (N_{ch}) – comparison to Run I

- This measurement was published by CDF in 2002 (PRD D65 072005)



Correction procedure

1. Tracking efficiency: correct the $<p_T>$ for each reconstructed N_{ch}
2. Smearing: generate matrix of P(Nr,Ng) Then apply this unfolding factor bin by bin

$$\langle p_T \rangle_{n_r=m} = \sum_i^{n_g} (\langle p_T \rangle_{n_r=i} \times P_{n_r=m}^{n_g=i})$$

$<p_T>$ at Nr

$<p_T>$ at Ng

(.. works as long as $<p_T>$ at N_{ch}=gen is the same that at N_{ch}=rec)