Minimum bias and underlying event studies at CDF

Niccolo' Moggi, INFN Bologna

for the CDF Collaboration

DIS 2010

Firenze – April 21th 2010

Outlook

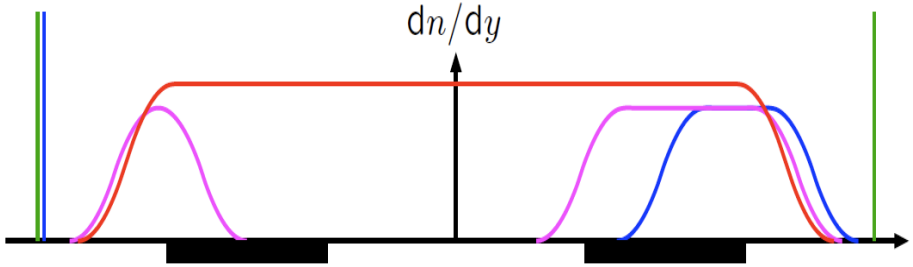
- Definition of terms
  - Minimum-bias
  - Underlying event
- The structure of minimum-bias
- Underlying event measurements at CDF
  - Evolution with jet p_T
  - Drell-Yan events
- Minimum-bias measurements at CDF

Definitions: MB & UE

"Minimum-bias" is the name of a trigger

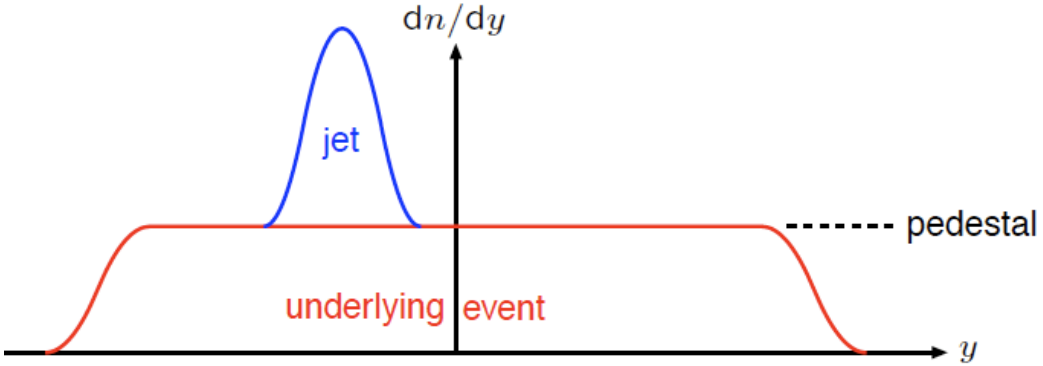
- trigger implementation → data sample
- selects events proportionally to their cross-section

$\sigma_{tot} = \sigma_{inel} + \sigma_{sd} + \sigma_{dd} + \sigma_{el}$



"Underlying Event" is defined event-by-event: **all** but 2→2 hard scatter (jets)

- Usually refers to σ_{inel}

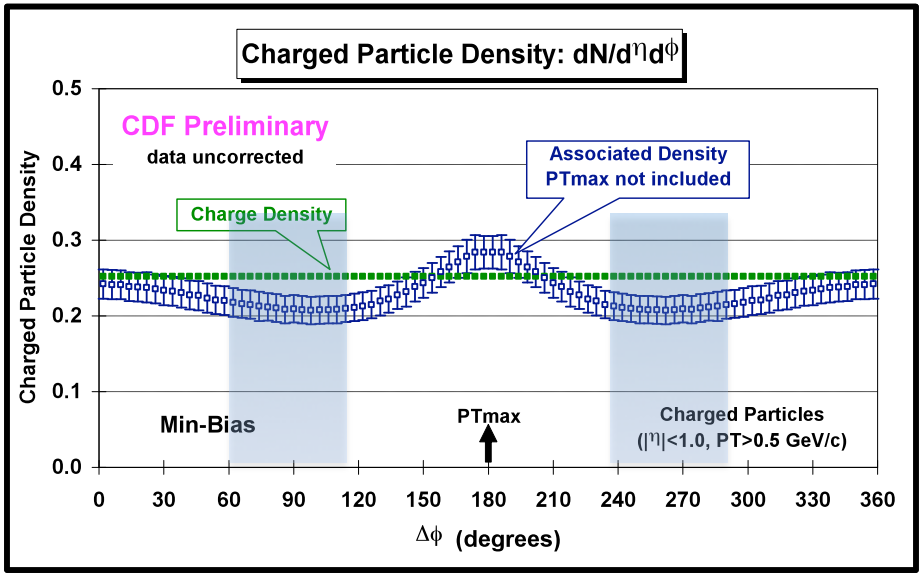


MB is background to high Lum (pile-up of events)

UE is background to high p_T observables (jets…)

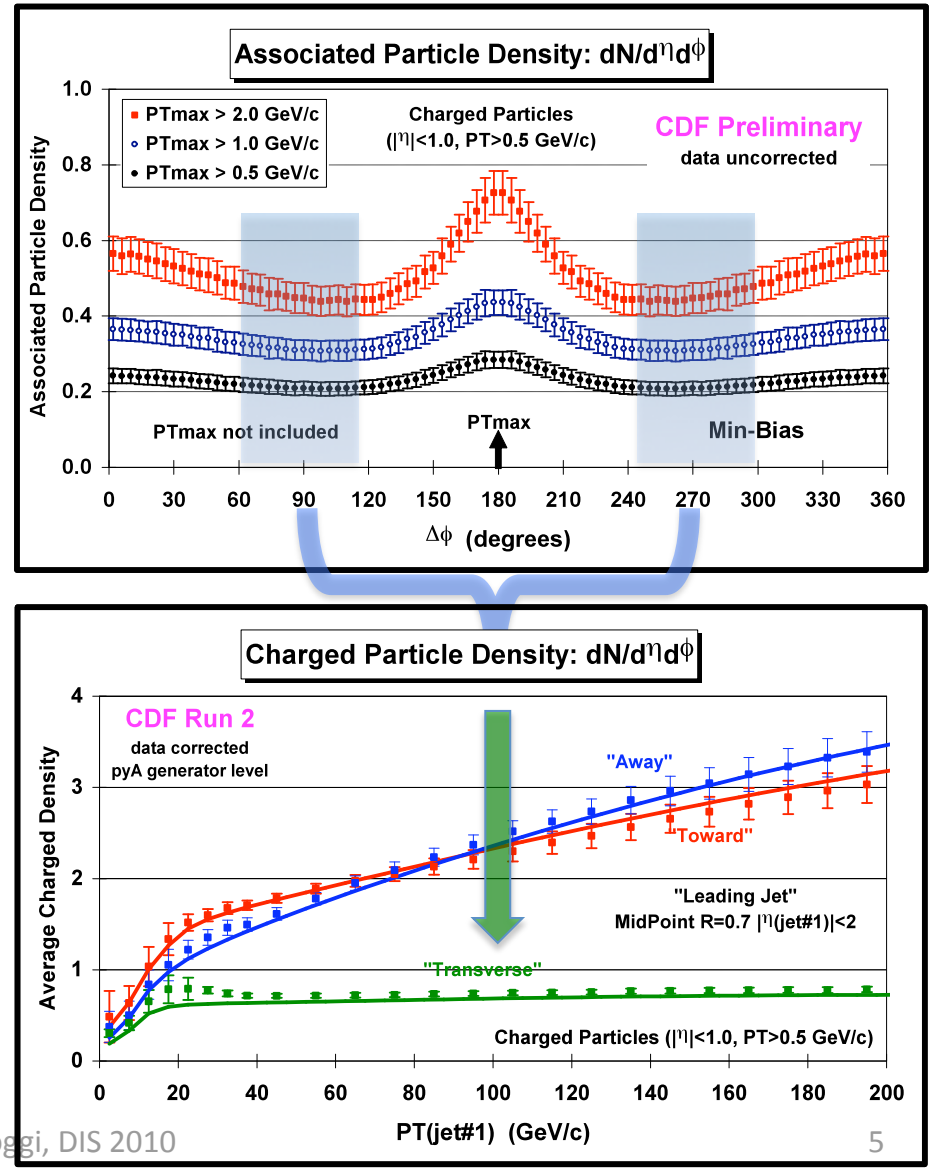
Structure of MB

- At CDF minbias is mostly (but not only) soft:
- Jet structure (RunI)
- Has an underlying event → transverse region
- Study evolution of UE with Q^2



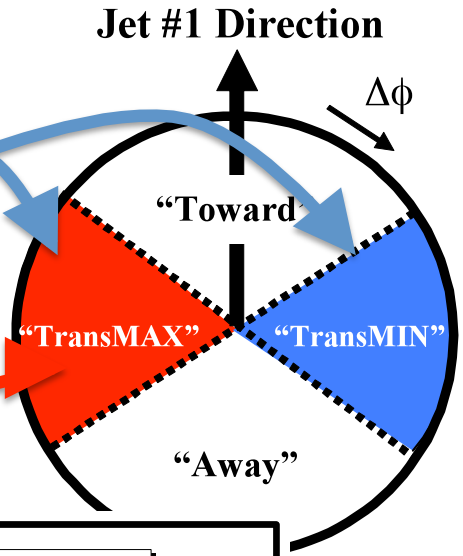
Structure of MB

- At CDF minbias is mostly (but not only) soft
- Jet structure (RunI)
- Has an underlying event → transverse region
- Study evolution of UE with Q^2 (p_T of jet)
- Higher Q^2 → harder UE



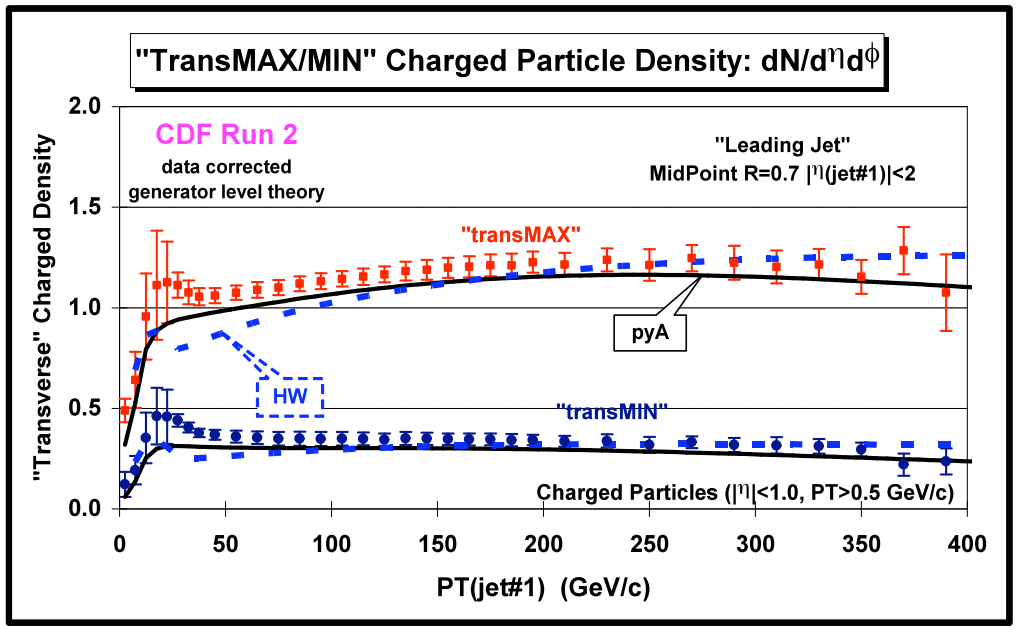
The Underlying Event

UE =
- BBR (beam-beam remnants)
- FSR, ISR (gluon radiation)
- MPI (>2 parton interactions)



Different regions are sensitive to different processes

MIN to BBR+MPI
MAX to BBR+MPI +radiations

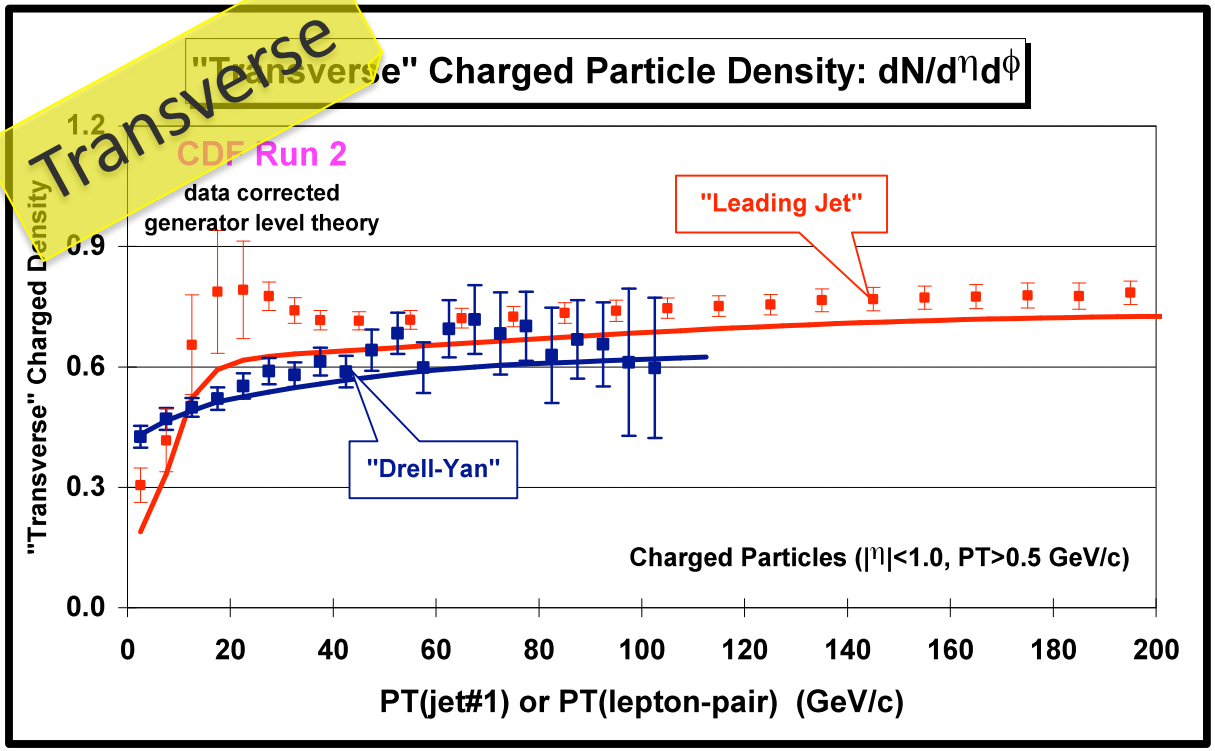


Data corrected to particle level
Tracks $p_T > 0.5$ GeV/c
$|\eta| < 1.0$
Jets in $|\eta| < 2.0$

UE in Drell-Yan events

Event topologies:

- Leading jet
- Back-to-back jets (suppress 3rd jet)
- Drell-Yan



Drell-Yan:
less gluon radiation
easier reconstruct.

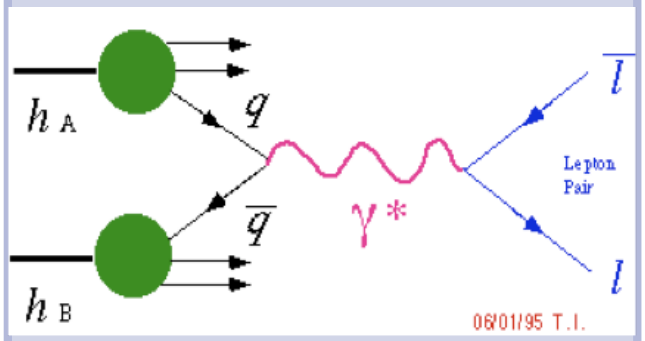
$\ell\ell$ = ee, μμ

$p_T > 20$ GeV/c

$|\eta| < 1$

$70 < M_{pair} < 110$ GeV

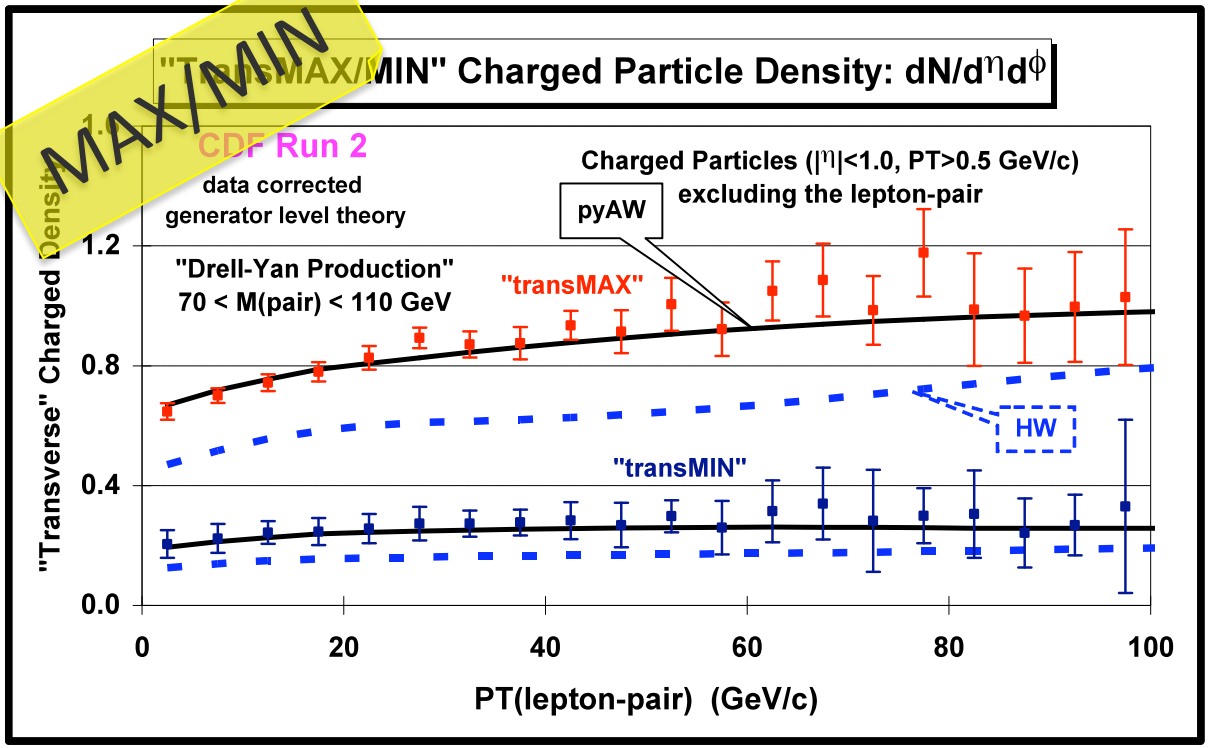
$|\eta_{pair}| < 6$



UE in Drell-Yan events

Event topologies:
- Leading jet
- Back-to-back jets (suppress 3rd jet)
- Drell-Yan

MAX/MIN



Drell-Yan:
less gluon radiation
easier reconstruct.

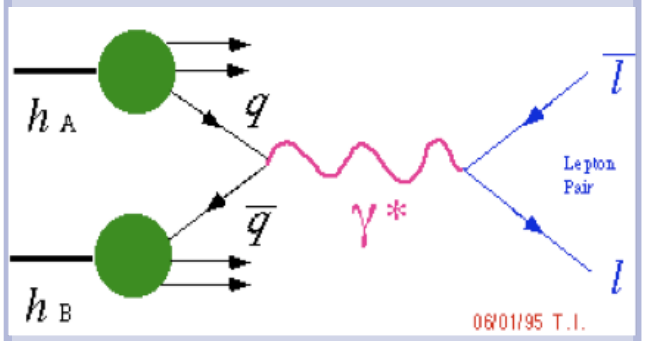
$\ell\ell$ = ee, μμ

$p_T > 20$ GeV/c

$|\eta| < 1$

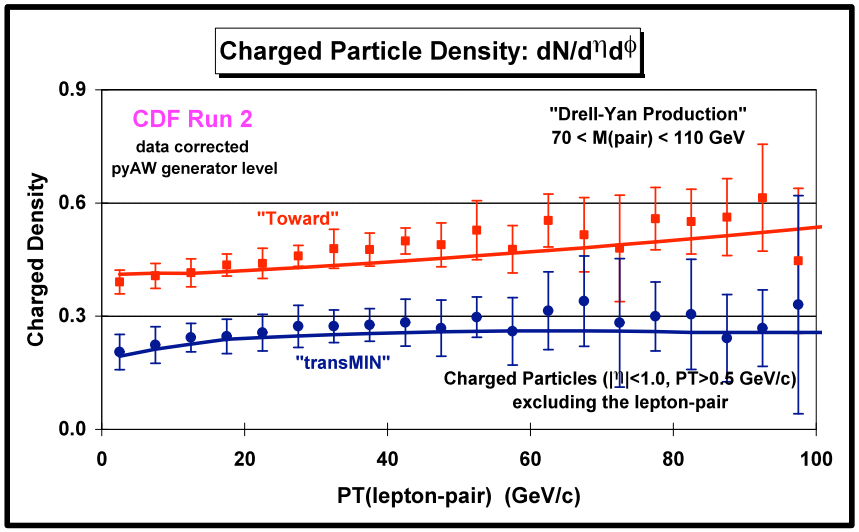
$70 < M_{pair} < 110$ GeV

$|\eta_{pair}| < 6$

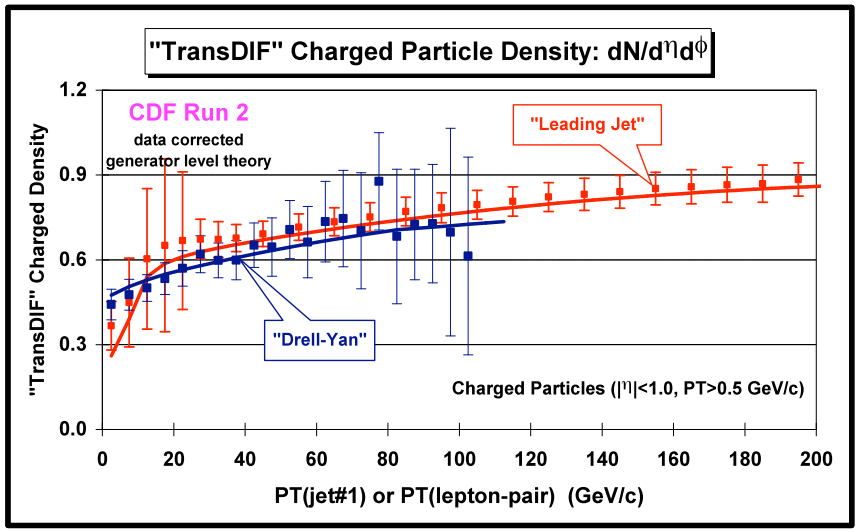


UE in Drell-Yan events

Toward and MIN are the most sensitive to UE (BBR and MPI)

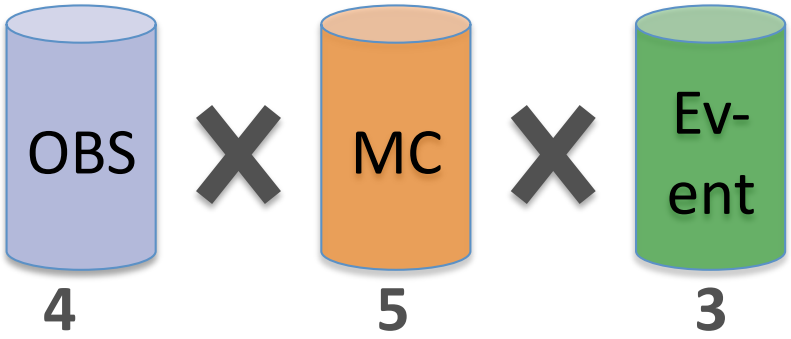


Define a new "DIF" region:
DIF = MAX – MIN
sensitive to radiation similar in Jets and DY



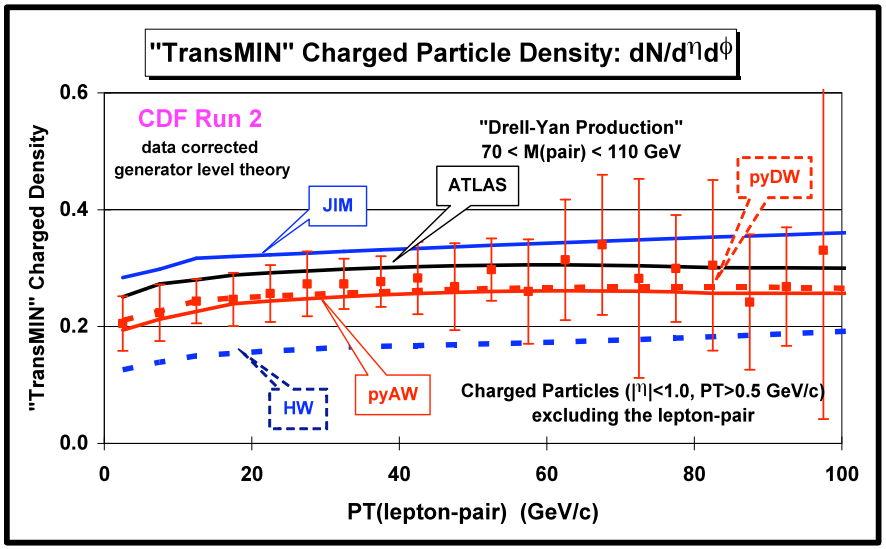
UE in Drell-Yan events

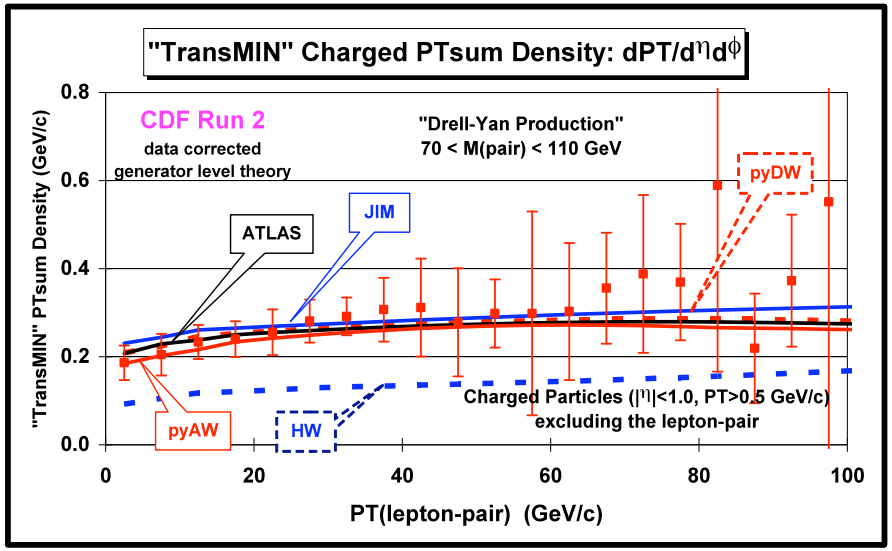
Systematic study to tune MonteCarlo models:



Tuning uses all combinations.
Not possible to show all !

Compare to simulation:
MPI best to fit the data





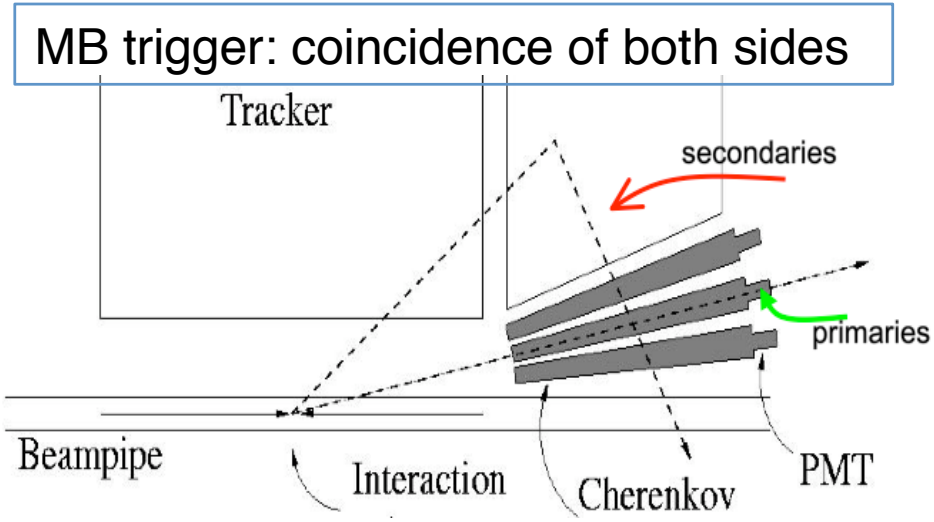
Minimum-Bias measurements

- ***Here we see all models at work together***
- Need to input the correct mixing of soft/hard
- Hard to find a model that fits all observables at the same time
  - Uncertainties from:
    - Parton PDFs
    - Gluon radiation
    - MPI models
  - predictions for LHC

CDF measurements:

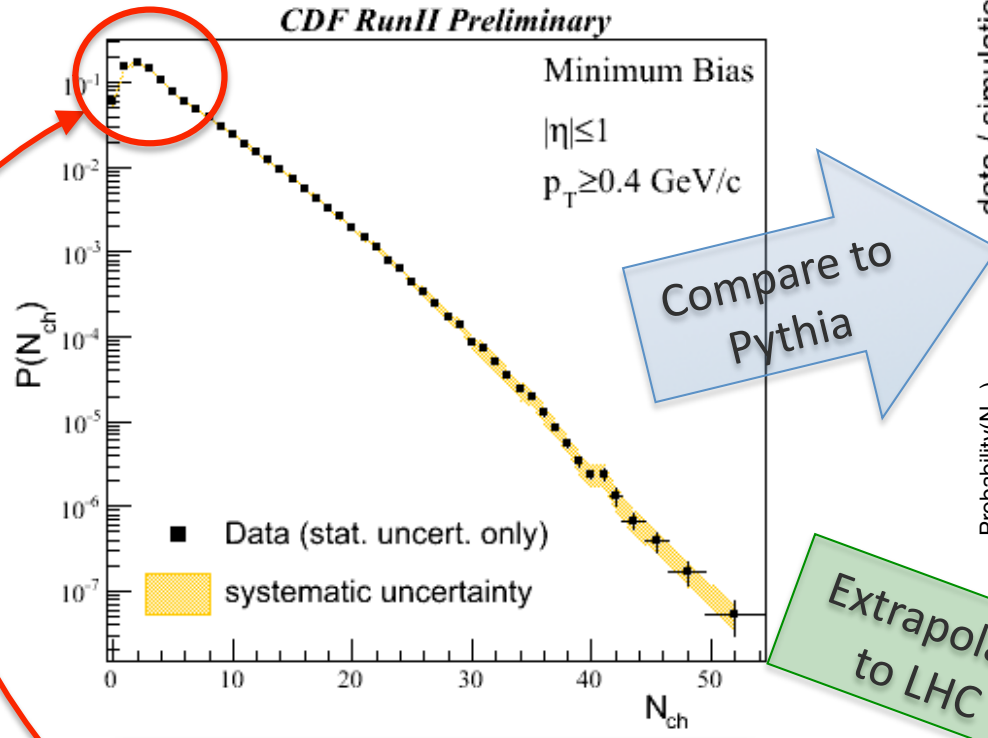
- trigger efficiency = $f(N_{ch})$
- event pile-up ($<N_{pp}>\sim 1.7$)
- 506 pb^{-1}

- track $p_T > 0.4$ GeV/c
- $|\eta| < 1$



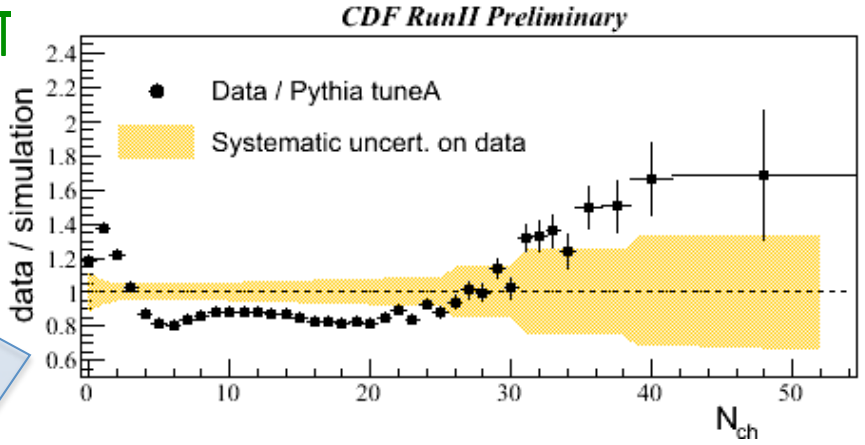
MB : charged multiplicity

$\sigma_{MB} = \sigma_{inel} + \sigma_{sd} + \sigma_{dd} + \sigma_{el}$

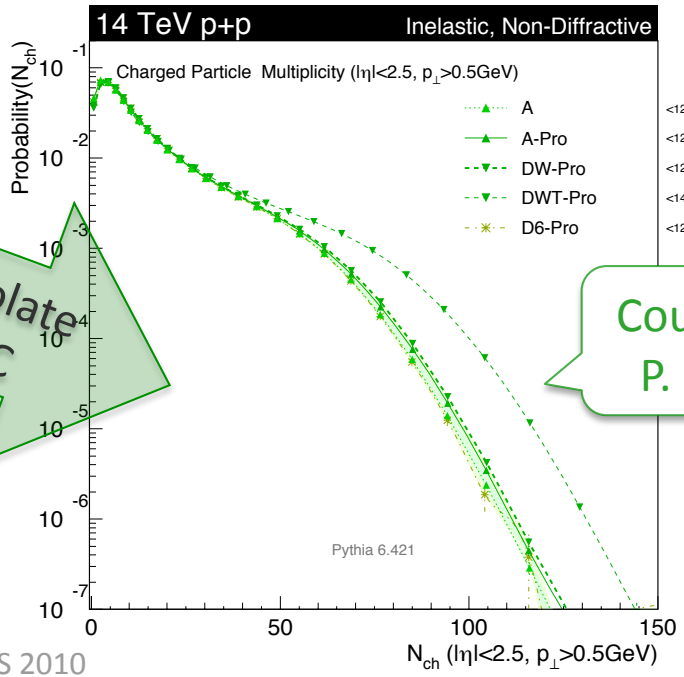


- Trigger inefficiency
- Diffractive bkg subtraction

Compare to Pythia



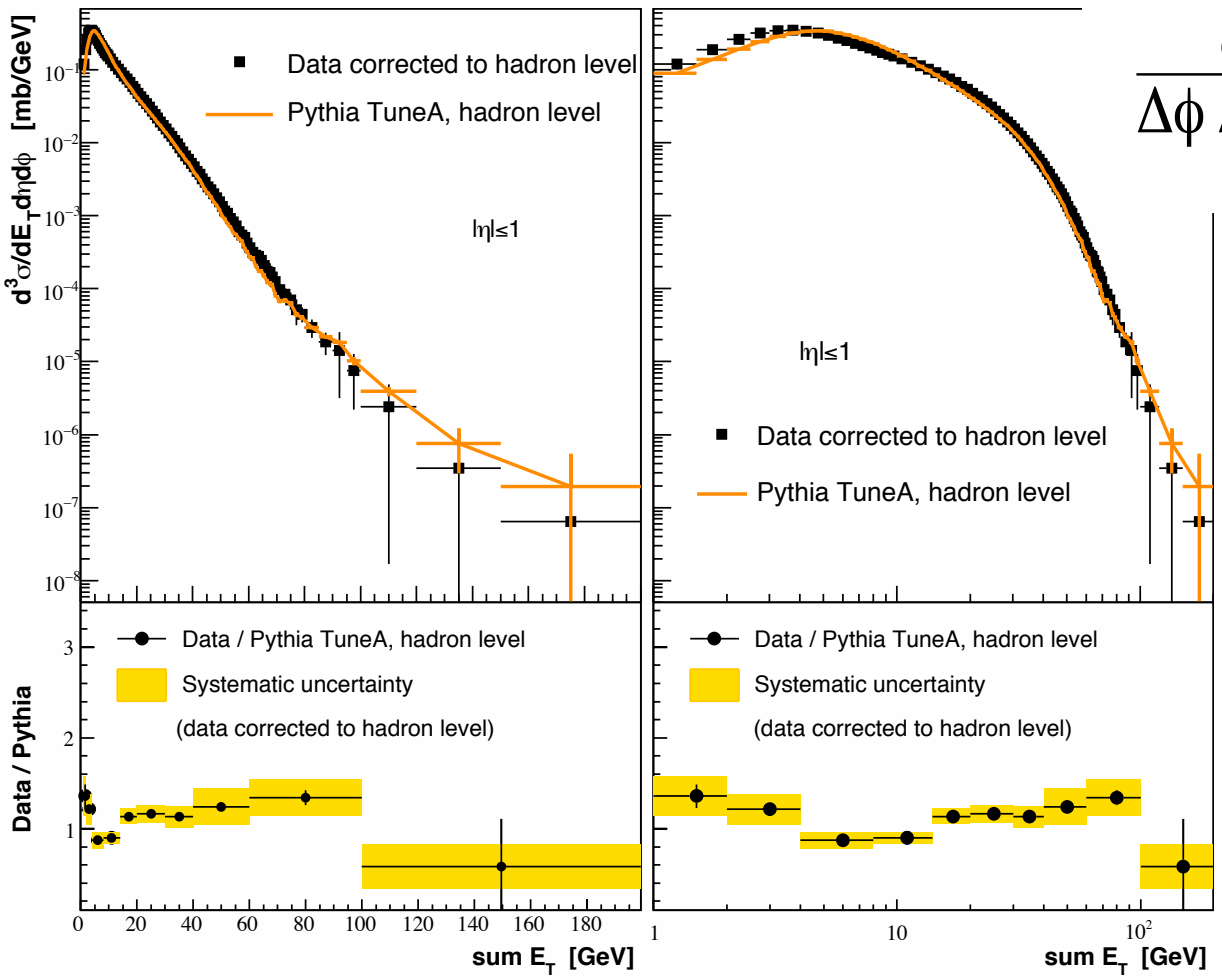
Extrapolate to LHC



Courtesy of P. Skands

MB : charged + neutral Et

$\sigma_{MB} = \sigma_{inel} + \sigma_{sd} + \sigma_{dd} + \sigma_{el}$



$$\frac{d^3\sigma}{\Delta\phi\,\Delta\eta\,dE_T} = \frac{N_{ev}/(\varepsilon \times A)}{Lum\,\Delta\phi\,\Delta\eta\,dE_T}$$

ΣE_T from CAL

Reasonable agreement with Pythia TuneA

Conclusions

- *CDF has a very large and complete set of measurements both of minimum-bias and underlying event*

- More measurements hopefully are on the way
  - Final state correlations
  - Heavy flavors in MB (lower p_T now accessible)

- Fundamental to extrapolate MC models to LHC energies…
- ..but also to evaluate backgrounds to high p_T

- Still we're not able to model and accommodate all soft(er) components, but CDF has greatly contributed at least in clarifying the topic of soft interactions

Backup slides

UE observables

Table 1.1. Observables examined in this analysis as they are defined at the particle level and the detector level. Charged tracks are considered good if they pass the track selection criterion given in Section III(5). The mean charged-particle $\langle p_T \rangle$ is constructed on an event-by-event basis and then averaged over the events. For the average p_T and the PTmax, we require that there is at least one charged particle present. Particles are considered stable if $c\tau > 10$ mm (K_s, Λ, Σ, Ξ, and Ω are kept stable) .

Observable	Particle Level	Detector level
$dN/d\eta d\phi$	Number of stable charged particles per unit η-ϕ ($p_T > 0.5$ GeV/c, $\lvert\eta\rvert < 1$)	Number of good tracks per unit η-ϕ ($p_T > 0.5$ GeV/c, $\lvert\eta\rvert < 1$)
$dPT/d\eta d\phi$	Scalar p_T sum of stable charged particles per unit η-ϕ ($p_T > 0.5$ GeV/c, $\lvert\eta\rvert < 1$)	Scalar p_T sum of good tracks per unit η-ϕ ($p_T > 0.5$ GeV/c, $\lvert\eta\rvert < 1$)
$\langle p_T \rangle$	Average p_T of stable charged particles ($p_T > 0.5$ GeV/c, $\lvert\eta\rvert < 1$) Require at least 1 charged particle	Average p_T of good tracks ($p_T > 0.5$ GeV/c, $\lvert\eta\rvert < 1$) Require at least 1 good track
PTmax	Maximum p_T stable charged particle ($p_T > 0.5$ GeV/c, $\lvert\eta\rvert < 1$) Require at least 1 charged particle	Maximum p_T good charged tracks ($p_T > 0.5$ GeV/c, $\lvert\eta\rvert < 1$) Require at least 1 good track
Jet	MidPoint algorithm R = 0.7 f_{merge} = 0.75 applied to stable particles	MidPoint algorithm R = 0.7 f_{merge} = 0.75 applied to calorimeter cells

Pythia tunes

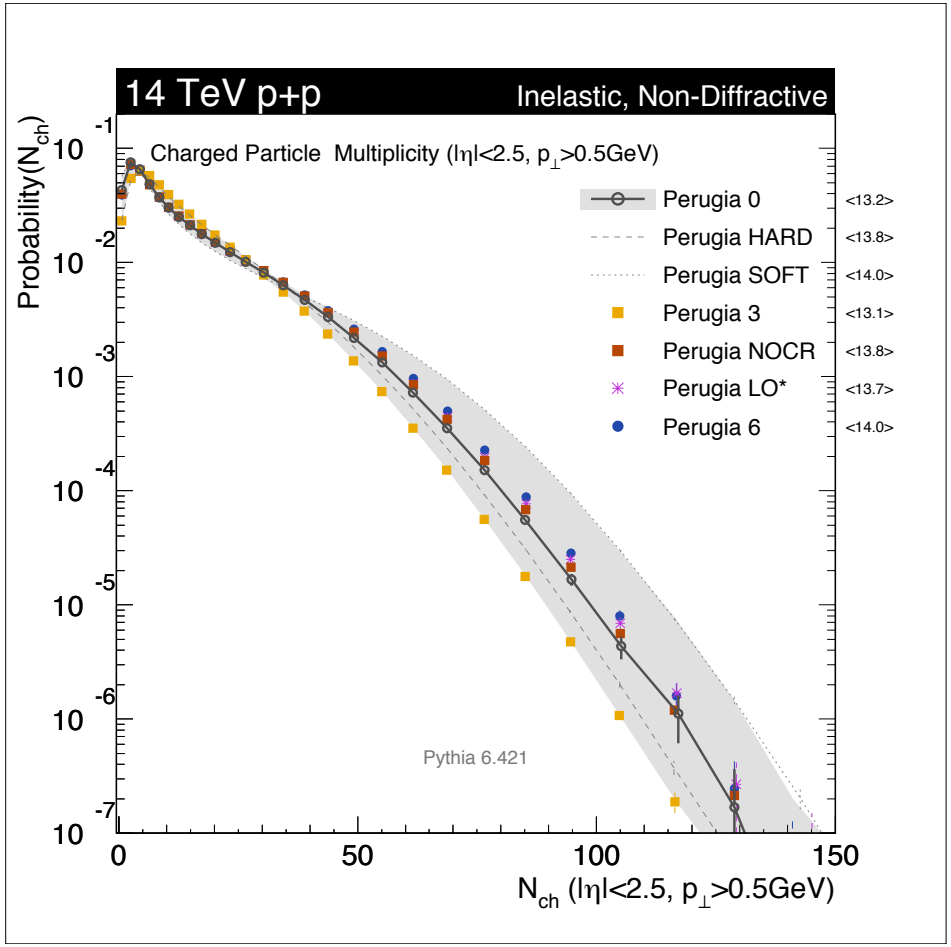
Parameter	Description	Tune A	Tune AW	Tune DW	Tune DWT	ATLAS
PDF	Parton Distribution Functions	CTEQ5L	CTEQ5L	CTEQ5L	CTEQ5L	CTEQ5L
MSTP(81)	MPI On	1	1	1	1	1
MSTP(82)	Double Gaussian Matter Distribution	4	4	4	4	4
PARP(82)	MPI Cut-Off	2.0	2.0	1.9	1.9409	1.8
PARP(83)	Fraction of matter within core	0.5	0.5	0.5	0.5	0.5
PARP(84)	Core Radius	0.4	0.4	0.4	0.4	0.5
PARP(85)	Color Connections	0.9	0.9	1.0	1.0	0.33
PARP(86)	Color Connections	0.95	0.95	1.0	1.0	0.66
PARP(89)	Reference Energy	1800	1800	1800	1960	1000
PARP(90)	MPI Energy Dependence	0.25	0.25	0.25	0.16	0.16
PARP(62)	Initial-state radiation Cut-Off	1.0	1.25	1.25	1.25	1.0
PARP(64)	Soft Initial-State Radiation Scale	1.0	0.2	0.2	0.2	1.0
PARP(67)	Hard Initial-State Radiation Scale	4.0	4.0	2.5	2.5	1.0
MSTP(91)	Gaussian Intrinsic k_T	1	1	1	1	1
PARP(91)	Intrinsic Gaussian Width, σ	1.0	2.1	2.1	2.1	1.0
PARP(93)	Intrinsic k_T Upper Cut-Off	5.0	15.0	15.0	15.0	5.0

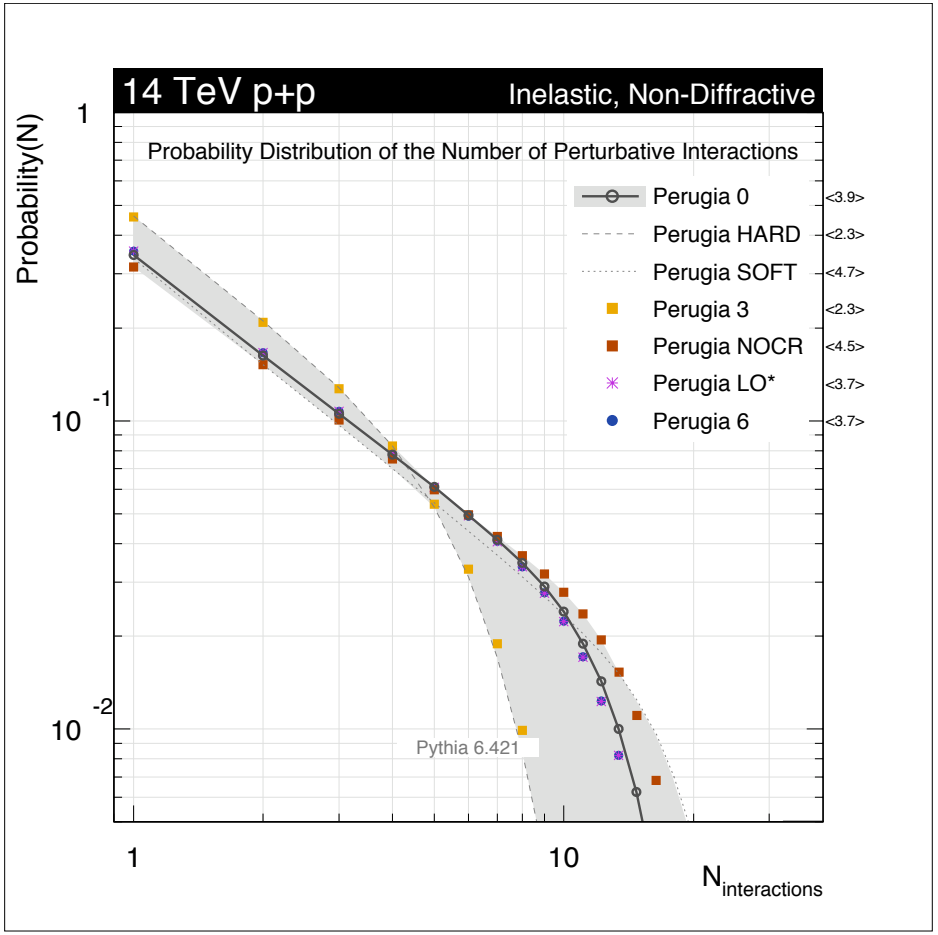
A fits UE
W fits DY
DW fits DW+jet $\Delta\phi$

MPI

ISR

Pythia at LHC

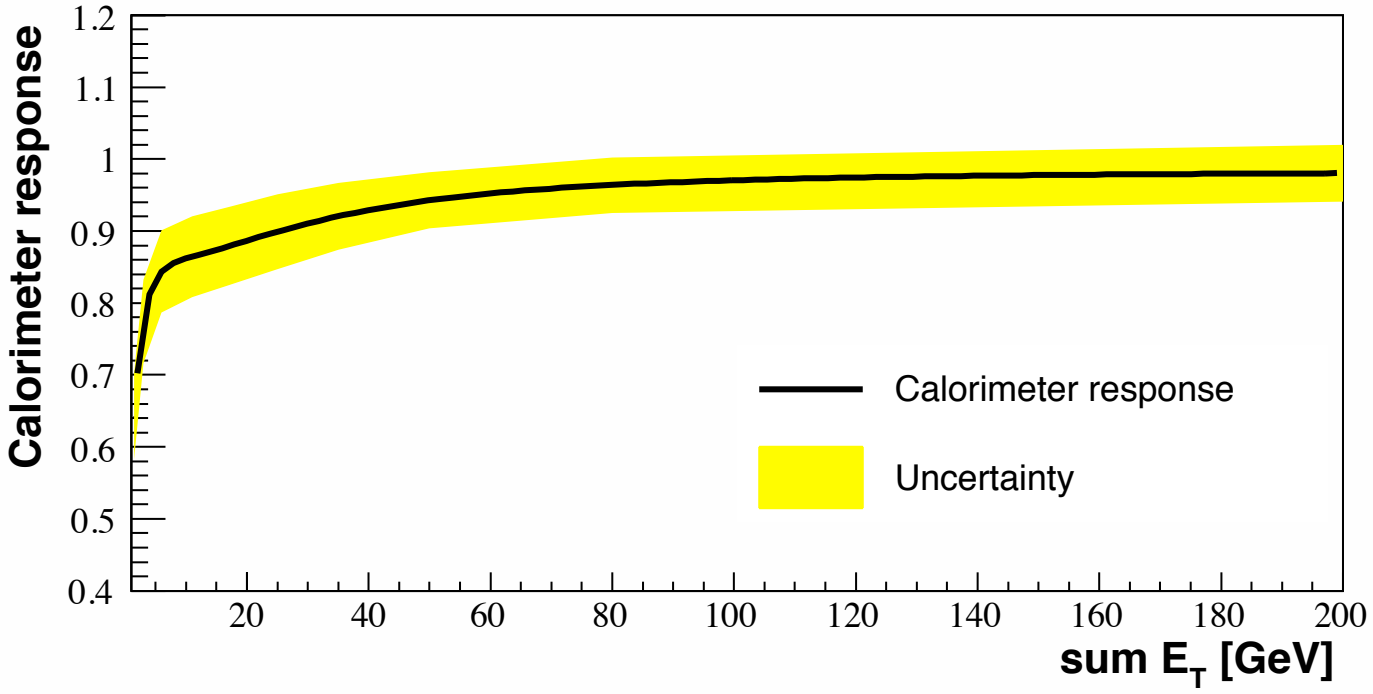




MB systematics

- Eight possible sources were evaluated:
  - Amount of undetected pile-up: 0.5%
  - Merging triggers 1.1%
  - Trigger efficiency correction: 4.4%
  - Vertex efficiency correction: 0.2% in $N_{ch}<3$
  - Diffractive background suppression: 13-0.1% in $N_{ch}<7$
  - Dependence on the MC generator up to 22% $f(N_{ch})$
  - Usage of dijet MC sample: 2% in 36-43
    4% in $N_{ch}>43$
  - Absolute correction of tail 10% in $N_{ch}>49$
- Total systematic 5 -34%

Calorimeter Response



N_{ch} *unfolding*

- Event by event correction C(N_{ch}) from MC
- Unfold corrected distribution

$$U = \frac{N_{ch}^{GEN}}{N_{ch}^{REC} \times C(N_{ch})}$$

- Reweigth MC unitl it follows the data
- Unfold again

Pythia MPI model

T. Sjöstrand et al. PRD 36 (1987) 2019

- The main parameter in Pythia (p_{Tmin}) affects *directly* (also) the multiplicity of particles:

Pythia uses only one parameter p_{Tmin} to regularize σ_{hard} at low p_T and determine the number of MPI

$$\sigma_{hard}(p_{T\,\min}) = \int_{p_{T\,\min}} \frac{d\sigma}{dp_T^{\,2}}$$

$$< N_{parton-parton} >= \frac{\sigma_{hard}(p_{T\,\min})}{\sigma_{inelastic}}$$

- Let $\sigma_{hard} > \sigma_{tot}$ and interpret the events in excess as MPI:
- p_{Tmin} smaller gives $<N_{parton\text{-}parton}>$ larger → larger multiplicities
  - p_{Tmin} must be >0 to avoid σ_{hard} divergence
  - Experimentlly $p_{Tmin} \approx$ 2GeV