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On behalf of
CDF and D0
Collaborations

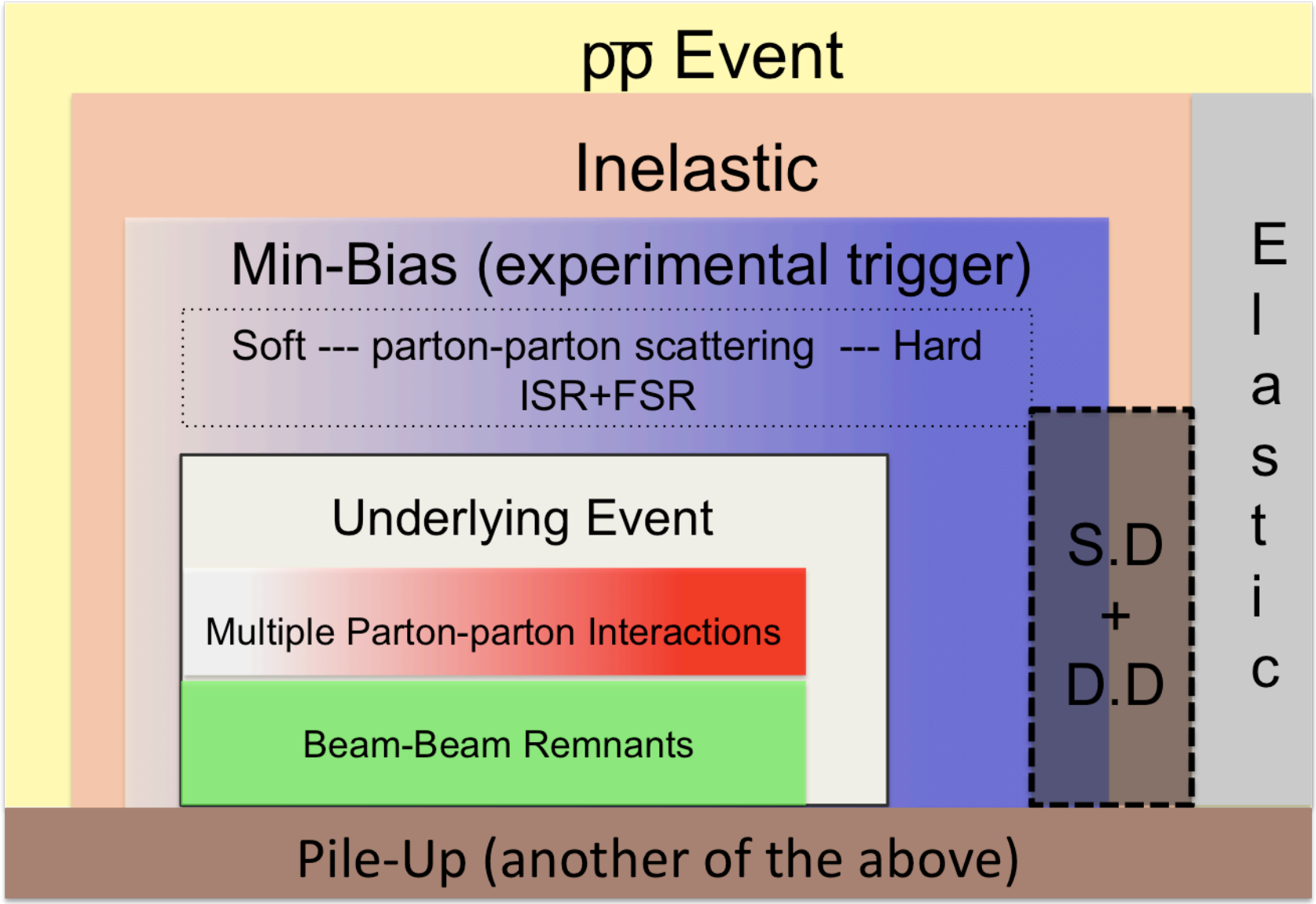
Soft QCD studies at the Tevatron

Les Rencontres de Physique de la Vallee d'Aoste
La Thuile - 03/03/2009

Motivations

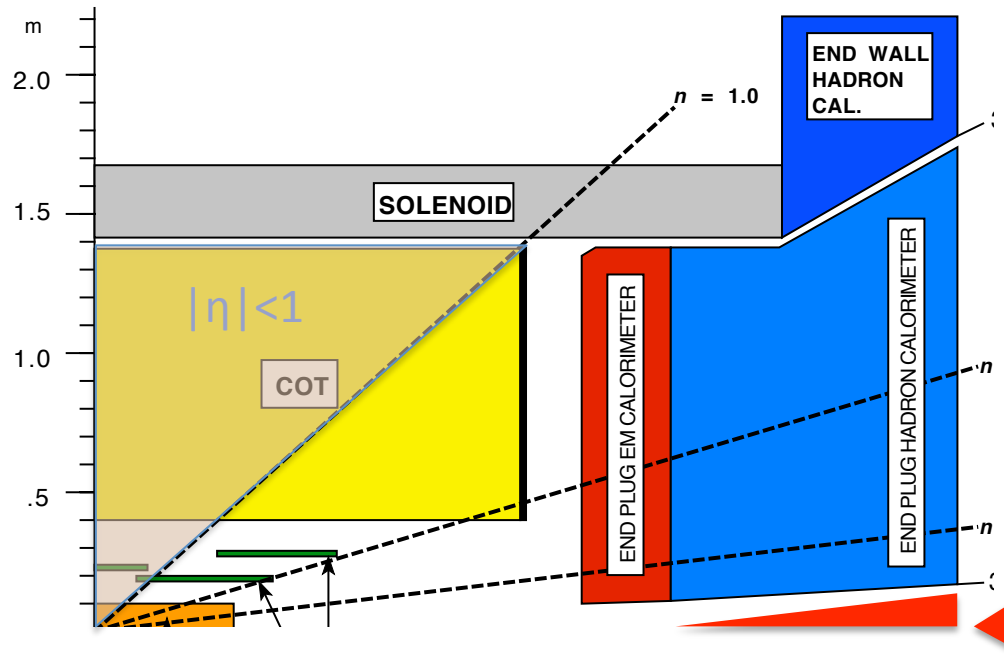
- "Soft" interactions are the largest – but most unknown – part of the inelastic Xs at colliders
- Understand the whole "event" (not just the pQCD part)
- Provide data to tune MC models of MB (in general) and of UE (specifically)
  - MB is a cocktail of hard (pQCD) and soft processes:
    - No MC generator can reproduce *all* MB observables *at the same time*
  - MB is important ("pile-up") in high luminosity environments
  - UE is a background to most collider high p_T observables

Terminology



A "small-bias" trigger

- "Minimum Bias" is defined by its trigger !

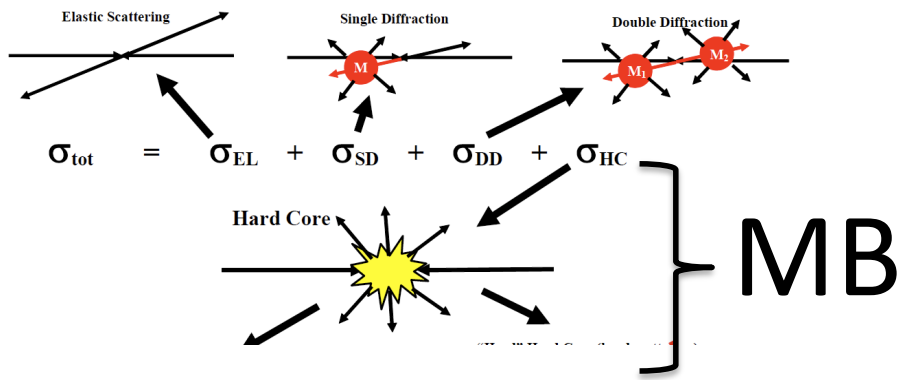


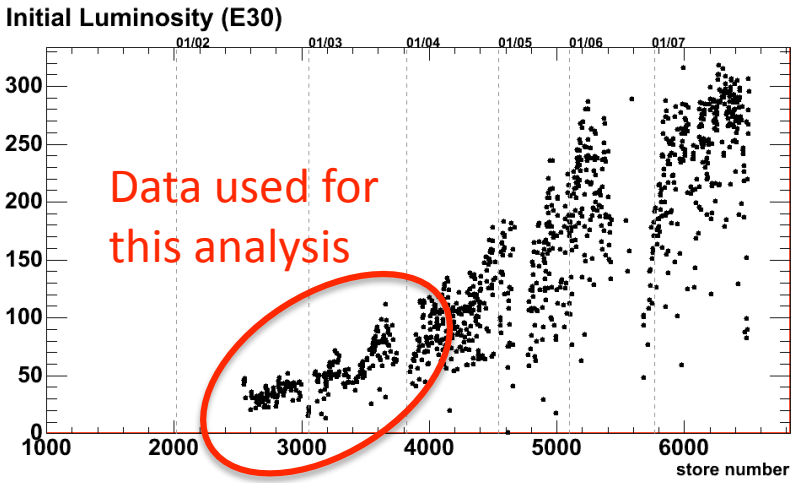
- CDF triggers MB with forward particles in 3.7<|η|<4.7 (<3deg)
- Requires coincidence of both sides (forw+backw)
- Implemented with Cerenkov counters (CLC)

- The trigger is biased so to favor high p_T interactions
- Will affect also the *shape* of inclusive distributions
- This presentation → only observables in the central region (|η|<1.0)

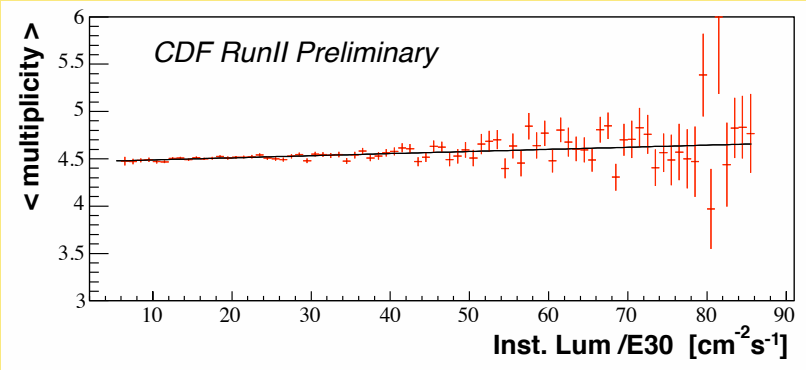
The MB data Sample

This talk is only about non-diffractive collisions





- 506 pb-1
- Max Inst. $\mathcal{L}$=90x10^{30} cm^{-2}s^{-1}
- Average Inst. $\mathcal{L}$=20x10^{30}
- Select crossings with only 1 primary (pp) vertex.
- Background from undetected primary vertices ~ 3% ("PileUp")

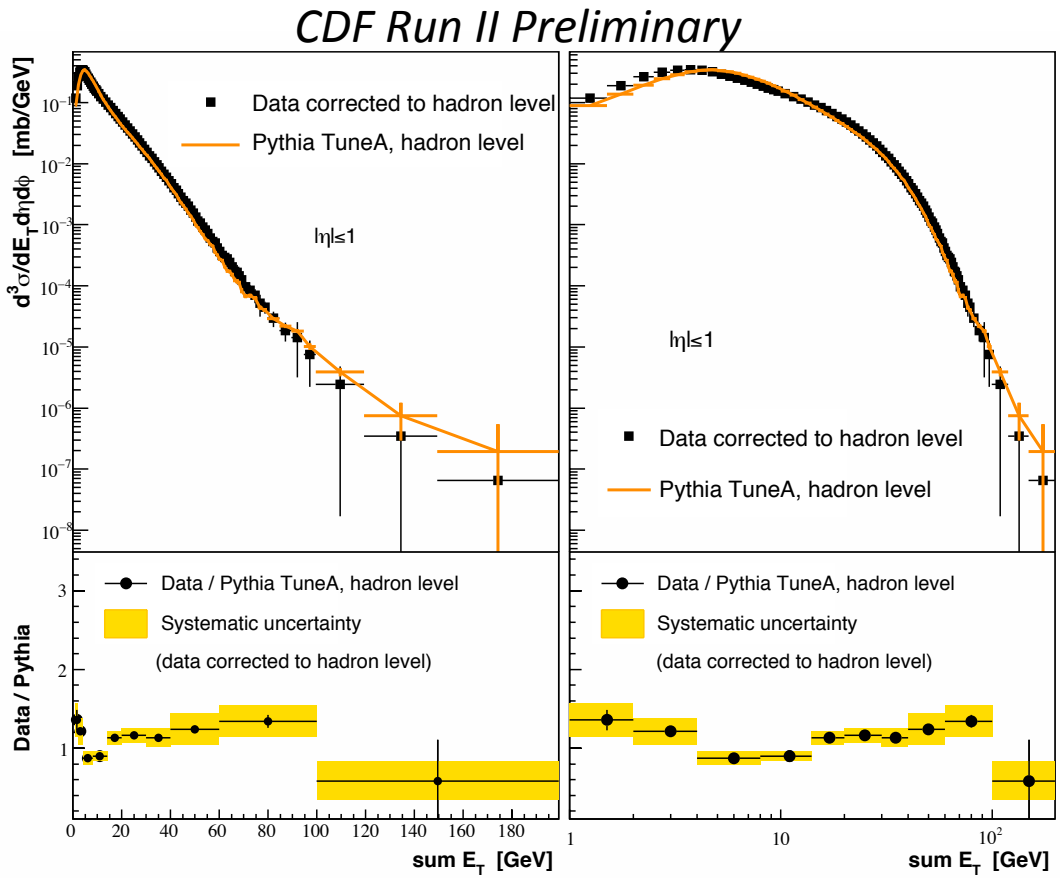


Primary vertex Z resolution ~3cm

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
- Calorimeter response is very sensitive to the MC model
- Large total systematic (~15% + 6%): comparison with MC little significant



Corrected to hadron level
Finite E_T resolution unfolding included

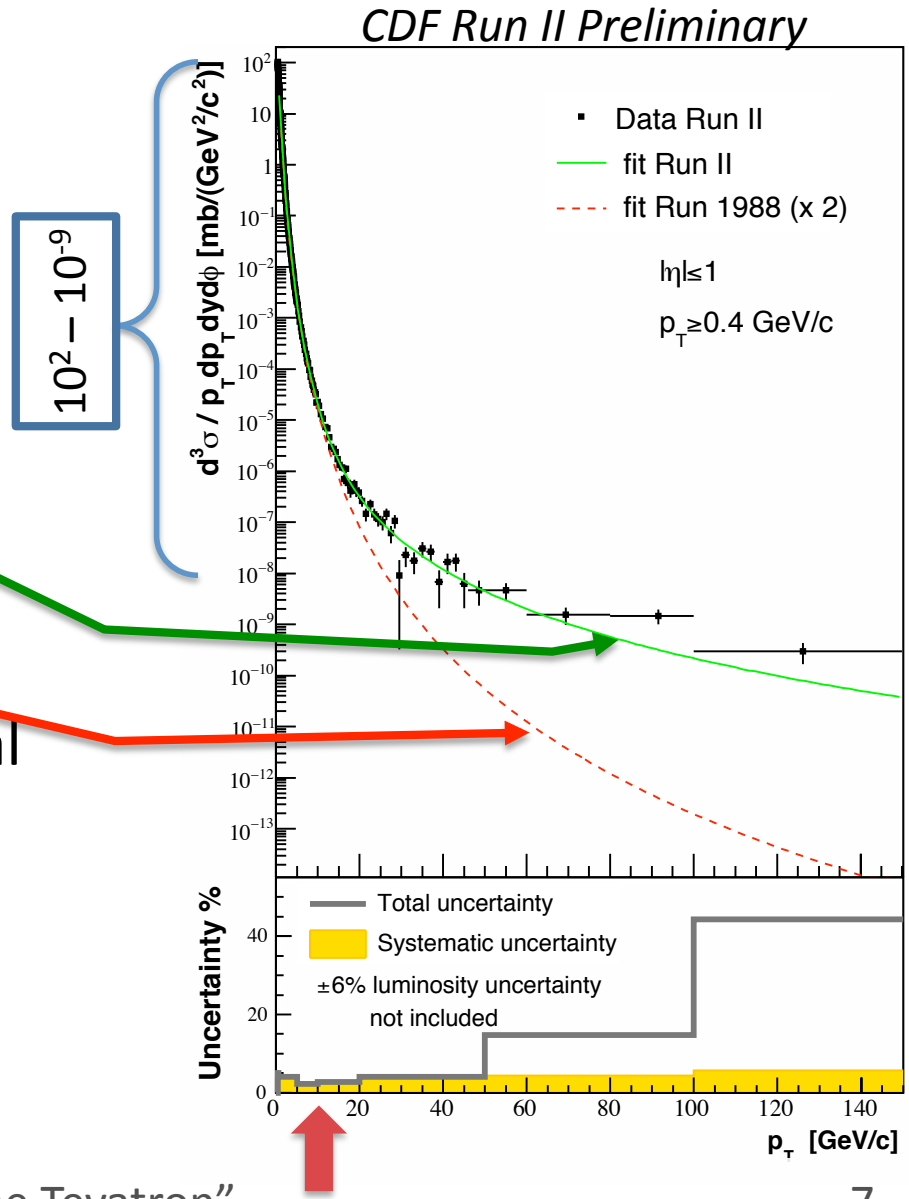
Single Particle p_T Spectrum

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

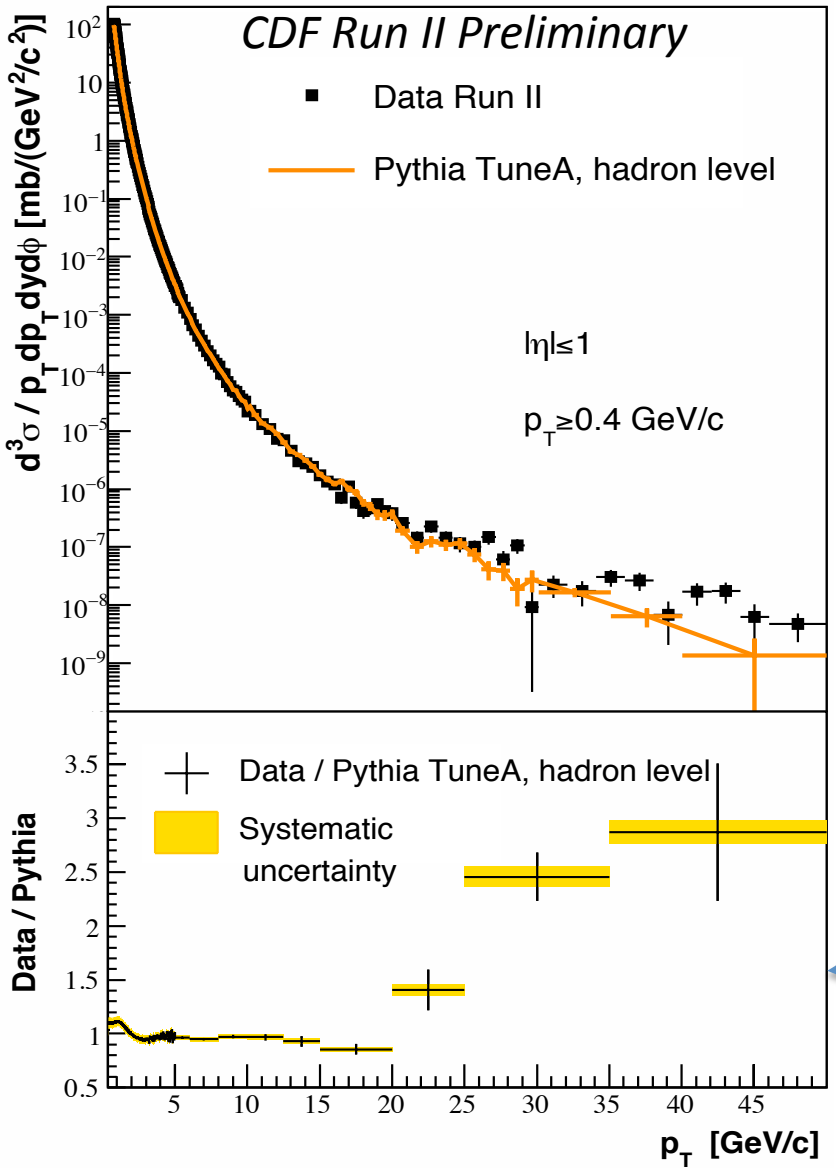
- Modeling of the distribution:

$$f = A\left(\frac{p_0}{p_T+p_0}\right)^n + B\left(\frac{1}{p_T}\right)^s$$

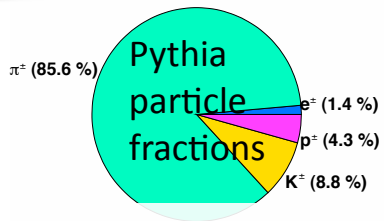
- Fits are good, but merely empirical
- Xs(2 TeV) ~ 1.04 Xs(1.8 TeV)
- Extends previous measurement (CDF 1988) from 10 to 150 GeV/c



Compare to Pythia



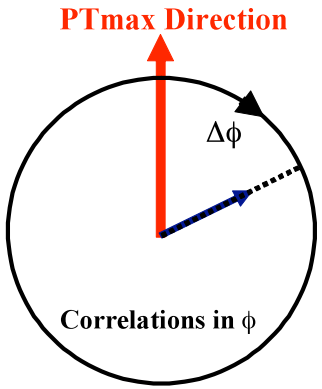
- Pythia v6.2. MB description relies on a p_T cutoff parameter that regulates both:
  - 2-to-2 parton perturbative Xs at low p_T
  - Additional parton-parton scatterings (MPI)
- Data has much more particle production in p_T>20 GeV
- TuneA produces no particles at all above ~50 GeV/c

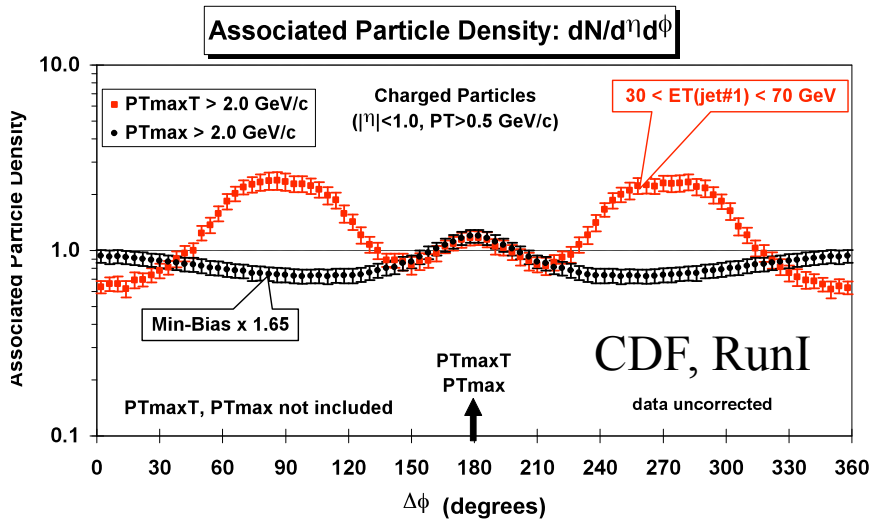


All tracks are assumed to be π

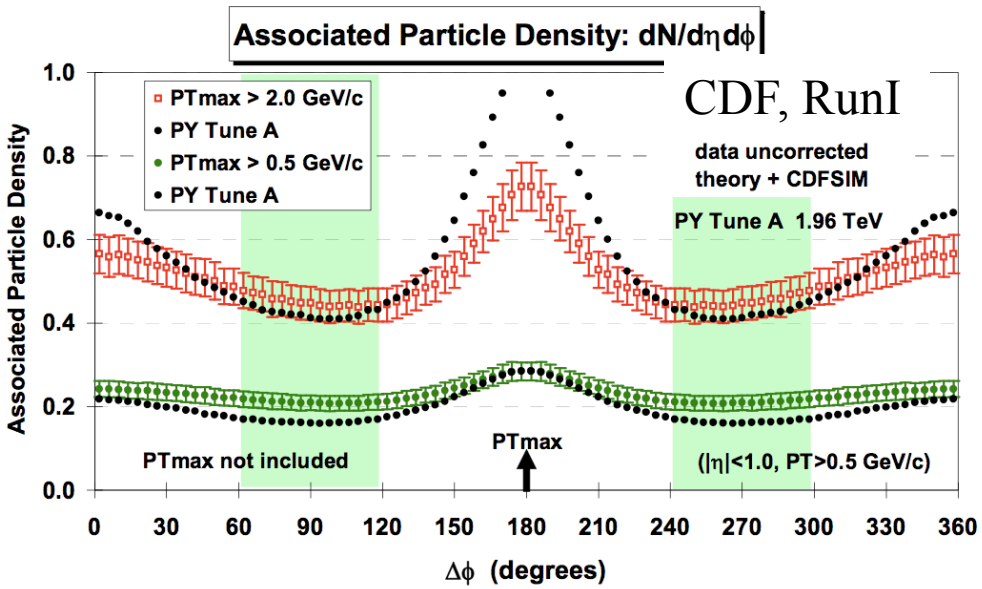
Structure of MB

- Correlations among charged particle indicate a jet structure in MB as low as ~1 GeV





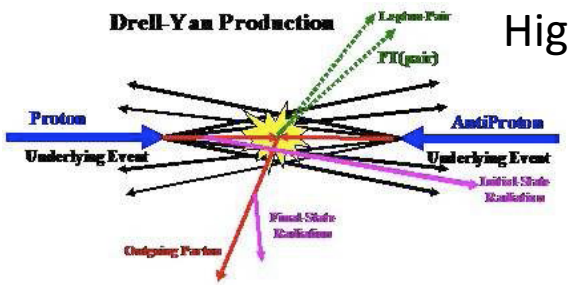
- Very similar to that in back-to-back jet transverse region
- Pythia more "jetty" than data



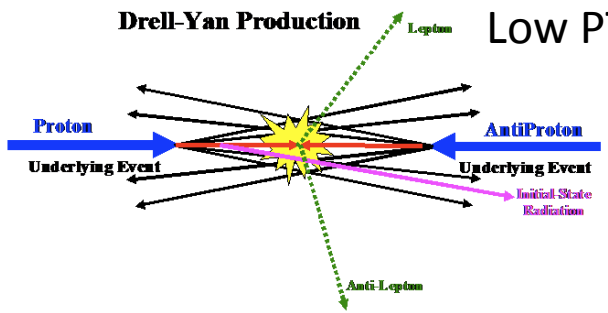
Studies dedicated to the UE

UE and ISR/FSR particles cannot be resolved experimentally
Use specific event topologies where ISR/FSR effects can be dumped or enhanced

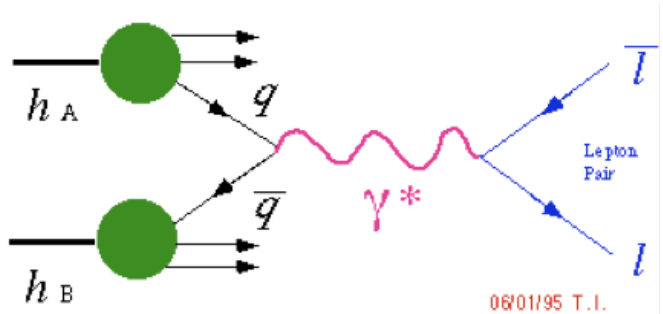
- <u>Leading Jet: 2.2 fb-1</u>
  - High p_T jet in $|\eta|<2$
  - MidPoint, R=0.7 f_{merge}=0.75
- Back-to-back Jet (not shown)
  - Third jet suppression
- <u>Drell Yan: 2.7 fb-1</u>
  - $\varepsilon^{\pm},\mu^{\pm}$ E_T>20 GeV, $|\eta|<1$, Iso>0.4
  - $70<|M_{pair}|<110$ GeV
  - $|\eta_{pair}|<6$



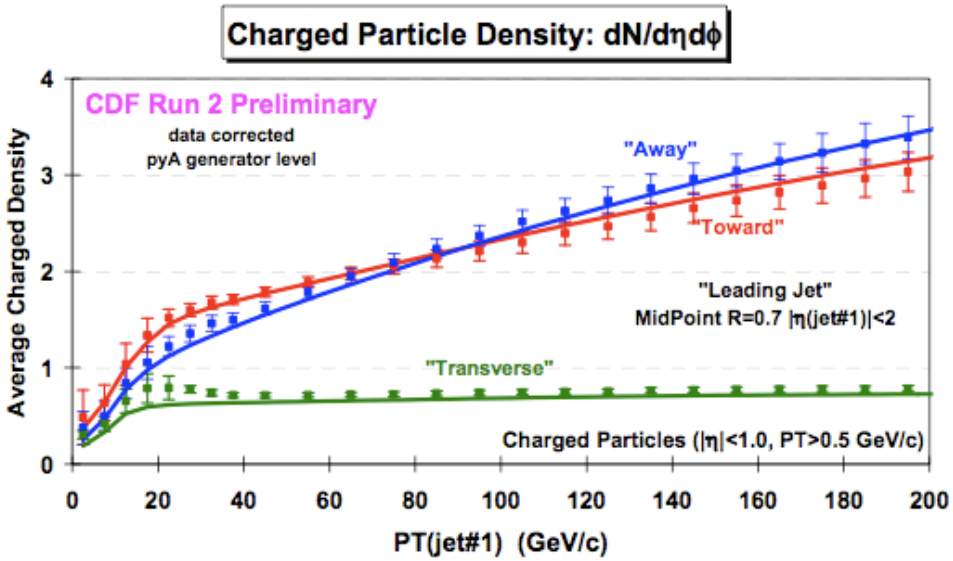
High PT

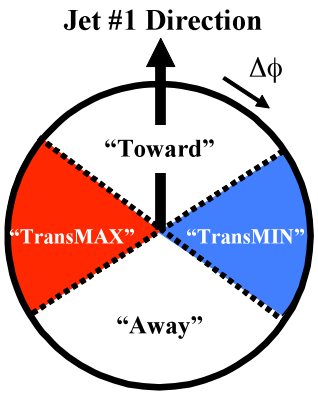


Low PT



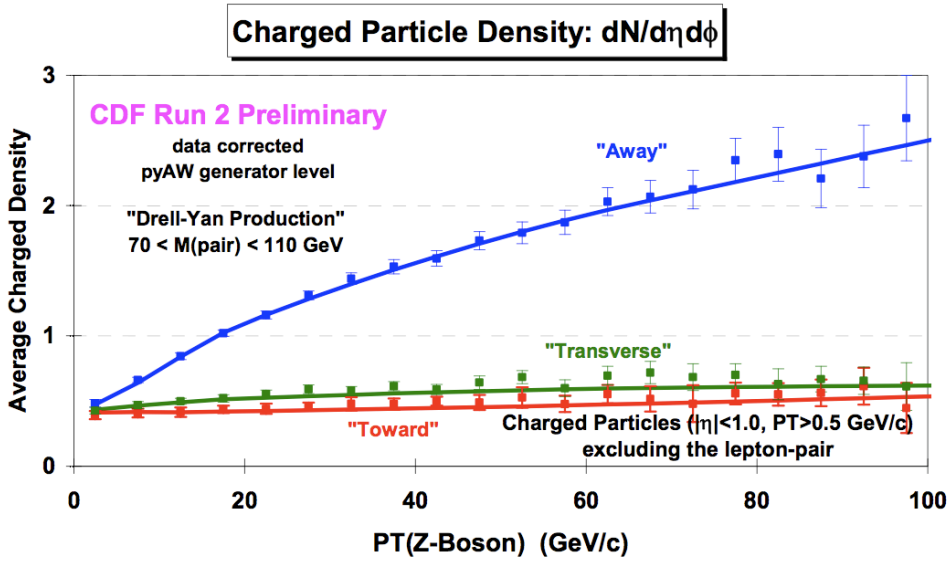
The transverse regions

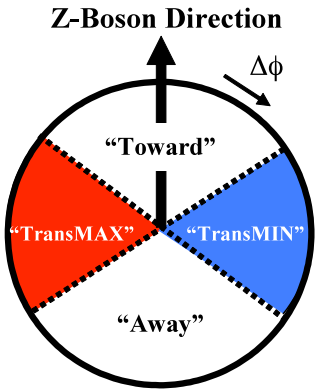




Leading Jet:

- **TransMAX** = BBR + ISR/FSR
- TransMIN = BBR
- MAX-MIN = ISR/FSR





Drell-Yan:

- No FSR !
- Exclude leptons
- Toward = Trans

The GOAL

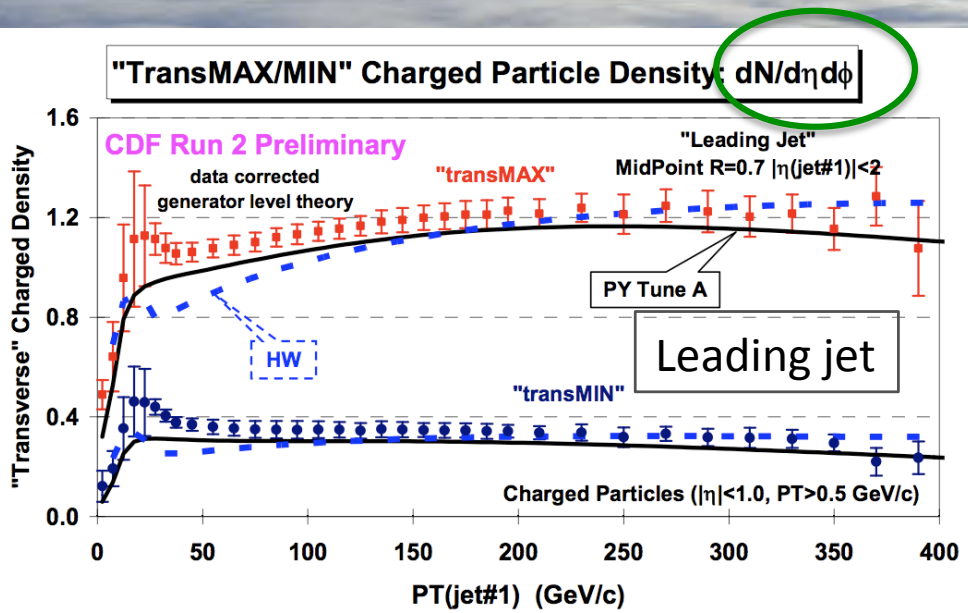
Systematic study of many observables to tune and improve QCD MonteCarlo models of the underlying event

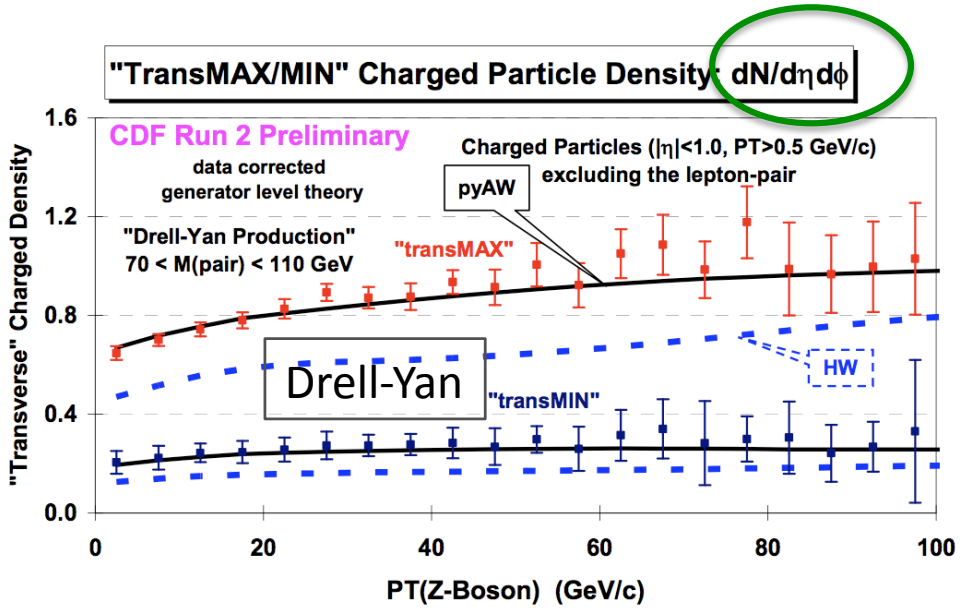
- Observables
  - Charged particle density
  - PTsum density
  - Average particle PT
  - Max particle PT
  - Others

- MC generators
  - Pythia TuneA
    - Fit to CDF UE (Run1)
  - Pythia Tune AW
    - A+Fit to pT(Z)
  - Pythia Tune DW
    - AW+Fit dijet Dphi (D0)
  - Herwig (noMPI)
    - Fit to pT(Z)
  - Herwig+JIM
  - Others

X 3 event topologies !

First example





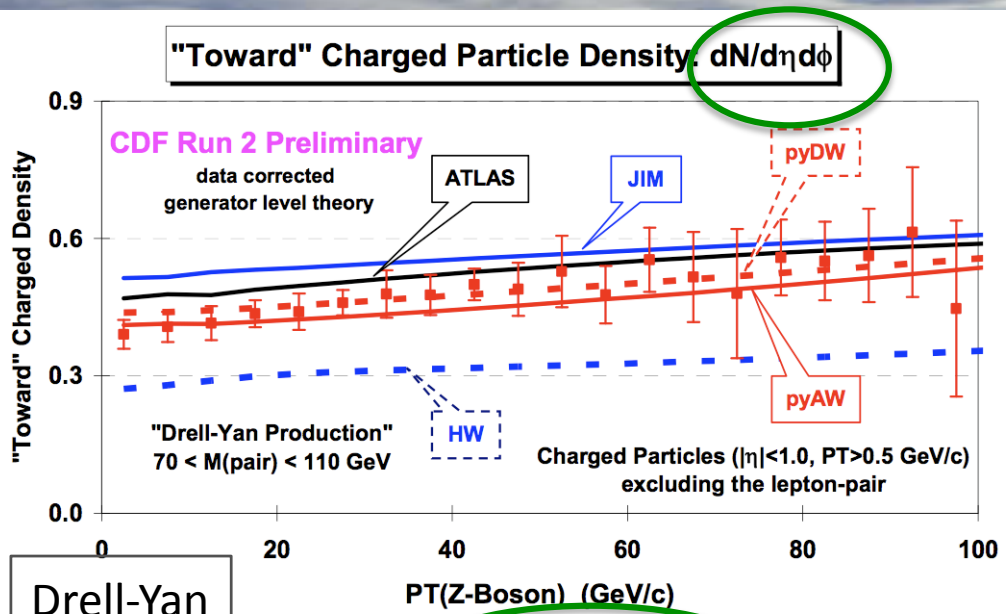
MAX receives BBR+ISR+FSR
MIN receives BBR
and less of ISR+FSR

Herwig no MPI:

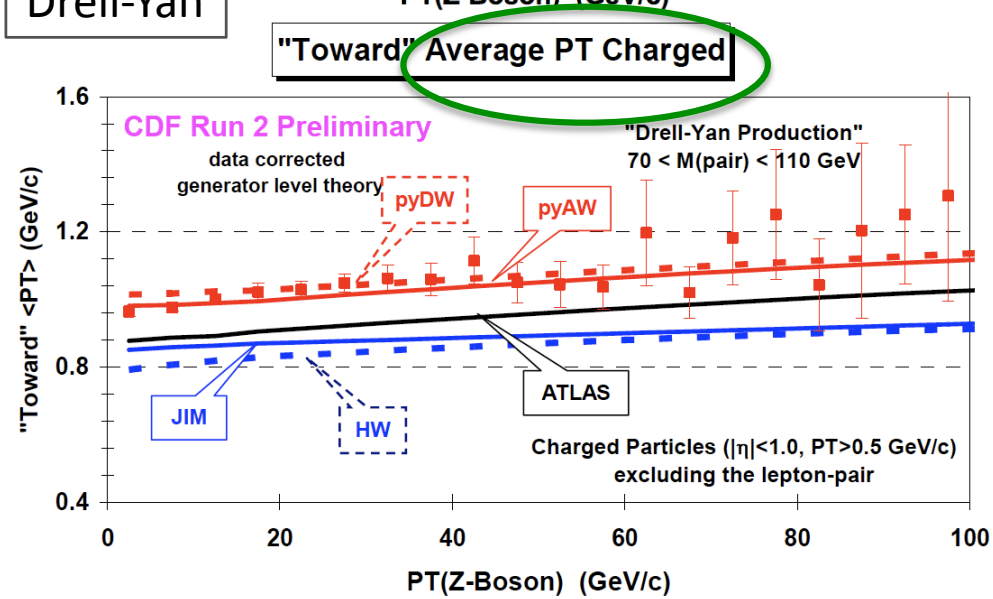
- not enough particles
- in DY more disagreement because the lack of MPI is more evident in absence of FSR

Pythia A/AW ~ ok

Second example (DY)



Drell-Yan



Toward and TransMIN regions in Drell-Yan events are more sensitive to UE since are less likely to receive contributions from ISR

Pythia DW ~ ok

Herwig no MPI

- too few particles
- too soft

Herwig+JIM

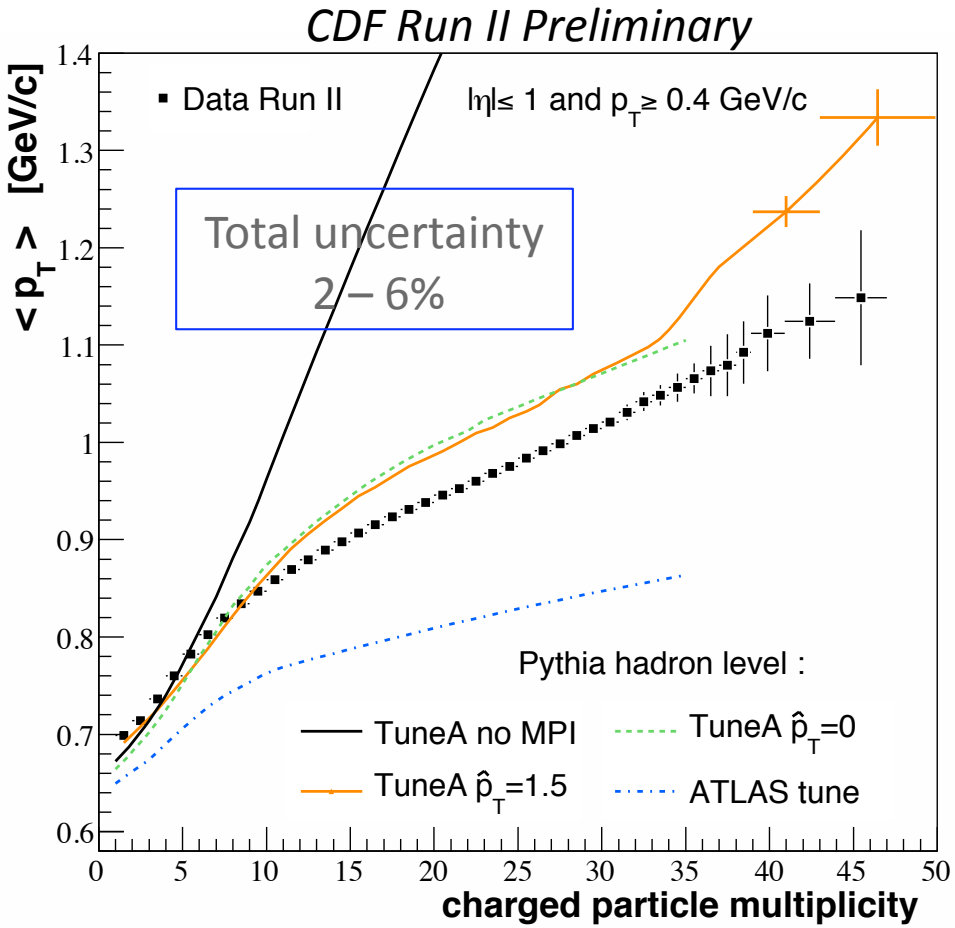
- too many particles
- too soft

$<P_T>$ Vs N_{ch} correlation in MB

Most poorly reproduced by MC.

To reproduce this, we need the correct recipe to mix:

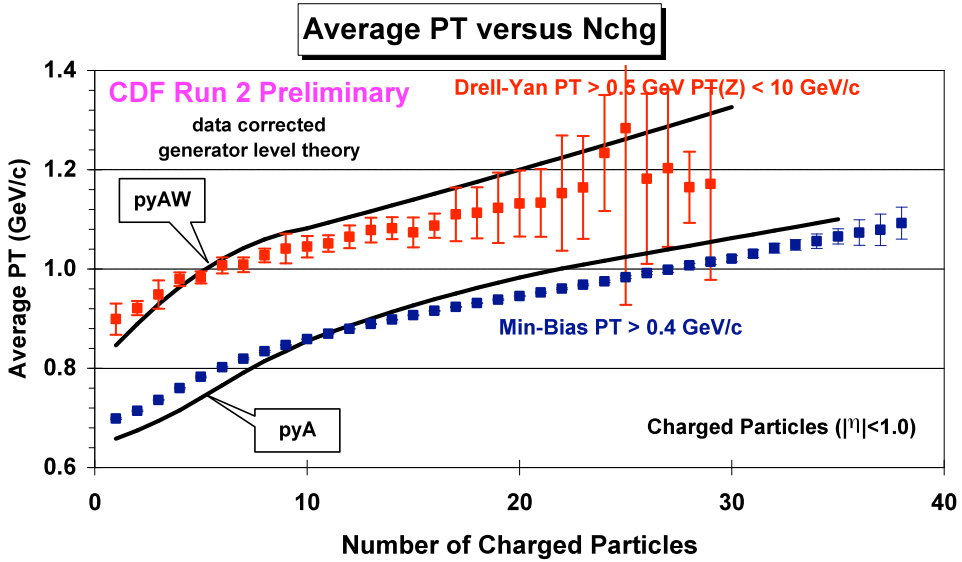
- soft and hard collisions + soft and hard components of single collisions
- With only soft and hard 2-to-2 scatterings, large N_{ch} would give too high $<p_T>$
- MPI provide a mechanism to produce larger N_{ch} with $<p_T>$ softer than in the primary parton-parton interaction

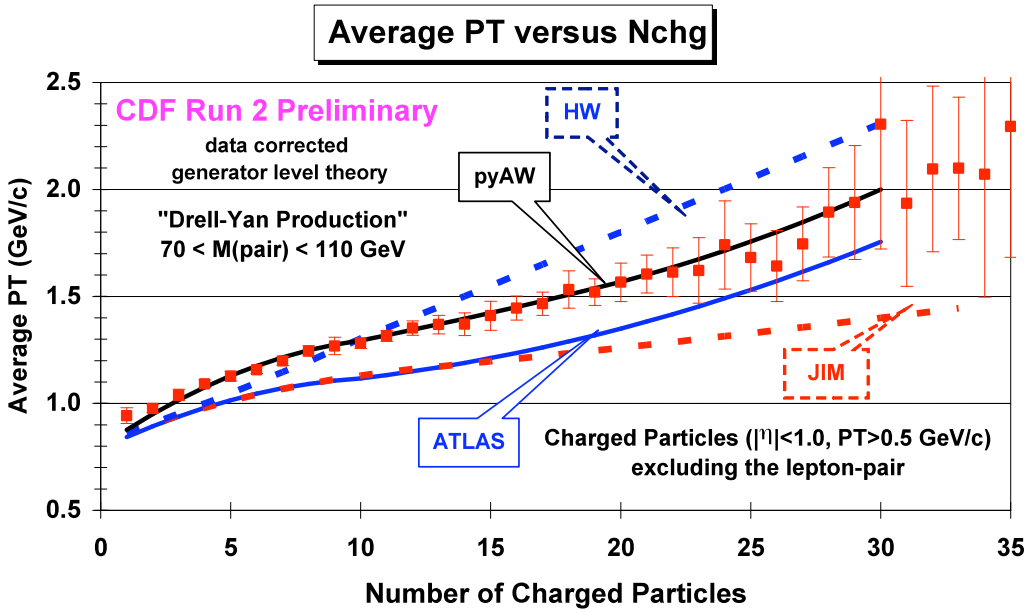


Sample = MB + dedicated "high multiplicity" trigger in Nch>22 particles

$\langle P_T \rangle$ Vs N_{ch} in Drell-Yan Events

- Same structure as in MB
  - Confirmed MPI importance
  - Universality of MPI ?
- Pythia A/AW ~ok but not perfect
- Herwig noMPI too hard
- Herwig+JIM too soft
- Herwig can't be compared to MB as Xs diverges when p_T(hard)→0





Color correlations in UE ?

- Pythia v > 6.3 introduces new MPI model with ad hoc color correlations between the hard process and MPI.

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…"

- Top mass measurement may be sensitive to CR:

  +-0.5 GeV from non-pQCD effects ?

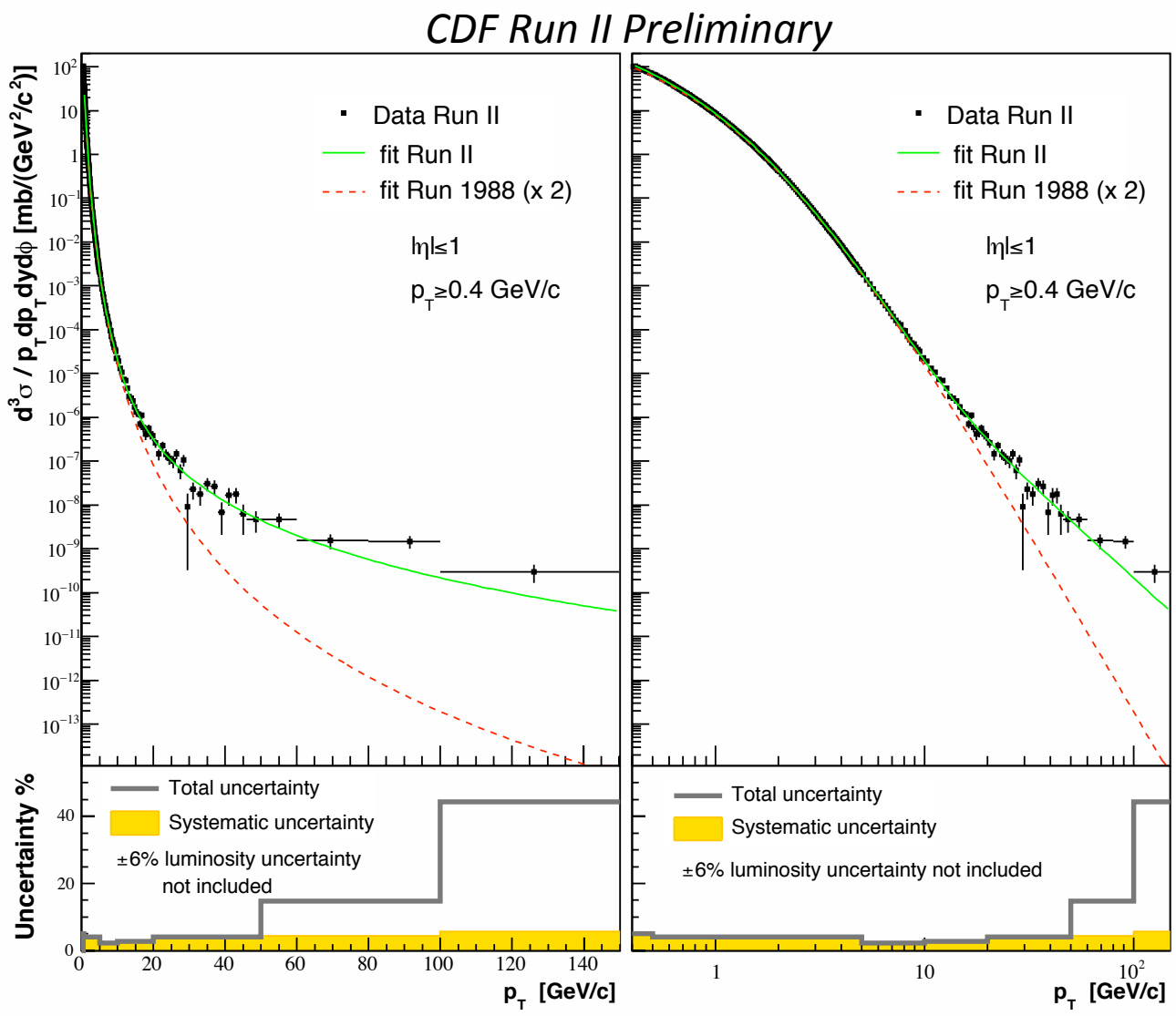
- Preliminary D0 & CDF estimates with tuneA v6.4 confirm?

Conclusions

- We have provided a set of precision measurements of MB and of UE to tune MC models
- All data distributions studied:
  - favor models with MPI
  - show continuous soft/hard transition
- Pythia tunes A/AW ~ Ok for inclusive distributions
- No model reproduces correctly the final-state correlations
- For LHC: Pythia predicts a more active UE than at the Tevatron, Herwig predicts roughly same activity
- Understanding of MB and UE is becoming important for precision high PT measurements

BACKUP SLIDES

log-log P_T spectrum



Pythia tunes

Parameter	Tune A	Tune AW	Tune DW	Tune DWT	ATLAS
PDF	CTEQ5 L	CTEQ5 L	CTEQ5 L	CTEQ5 L	CTEQ5 L
MSTP(81)	1	1	1	1	1
MSTP(82)	4	4	4	4	4
PARP(82)	2.0	2.0	1.9	1.9409	1.8
PARP(83)	0.5	0.5	0.5	0.5	0.5
PARP(84)	0.4	0.4	0.4	0.4	0.5
PARP(85)	0.9	0.9	1.0	1.0	0.33
PARP(86)	0.95	0.95	1.0	1.0	0.66
PARP(89)	1800	1800	1800	1960	1000
PARP(90)	0.25	0.25	0.25	0.16	0.16
PARP(62)	1.0	1.25	1.25	1.25	1.0
PARP(64)	1.0	0.2	0.2	0.2	1.0
PARP(67)	4.0	4.0	2.5	2.5	1.0
MSTP(91)	1	1	1	1	1
PARP(91)	1.0	2.1	2.1	2.1	1.0
PARP(93)	5.0	15.0	15.0	15.0	5.0

A=fits UE
W=fits Drell-Yan
D=fits $\Delta\phi$(dijet)

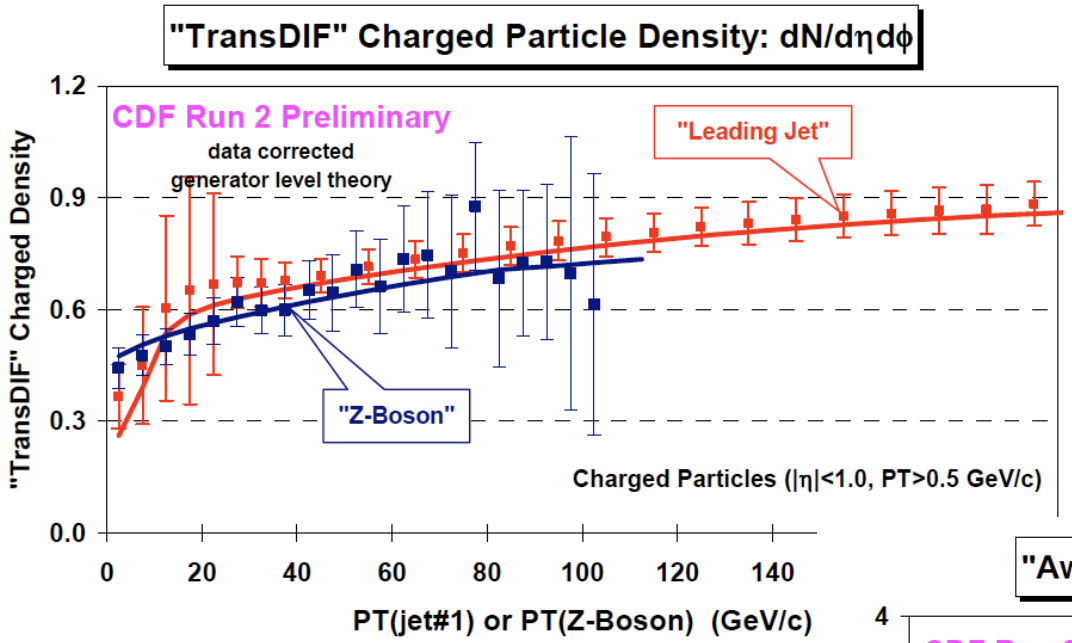
MPI

ISR

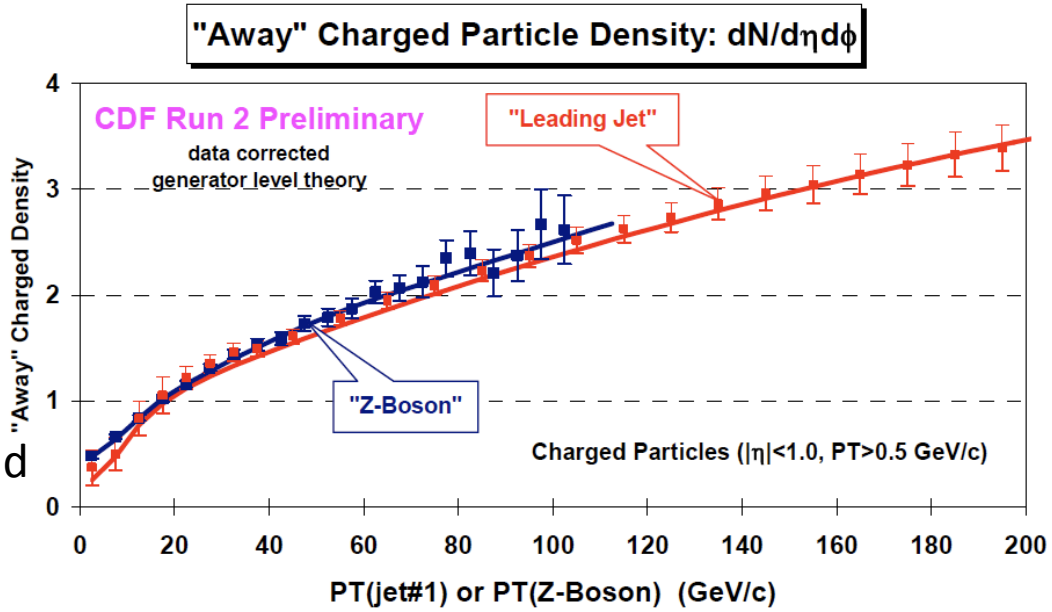
BBR

Parton k_T

Trans-DIF and Away region

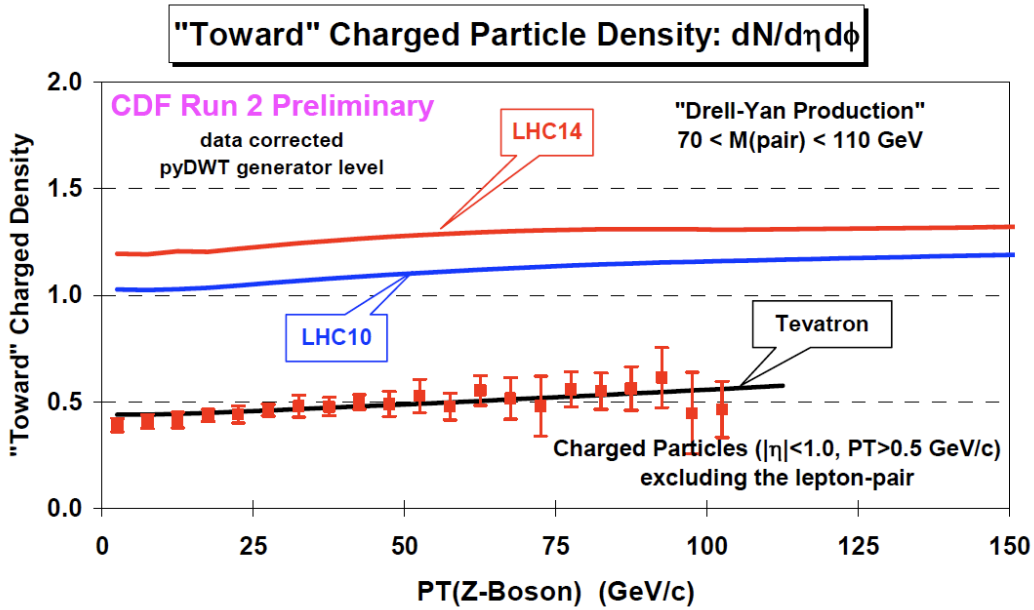


Most sensitive to ISR(+FSR)



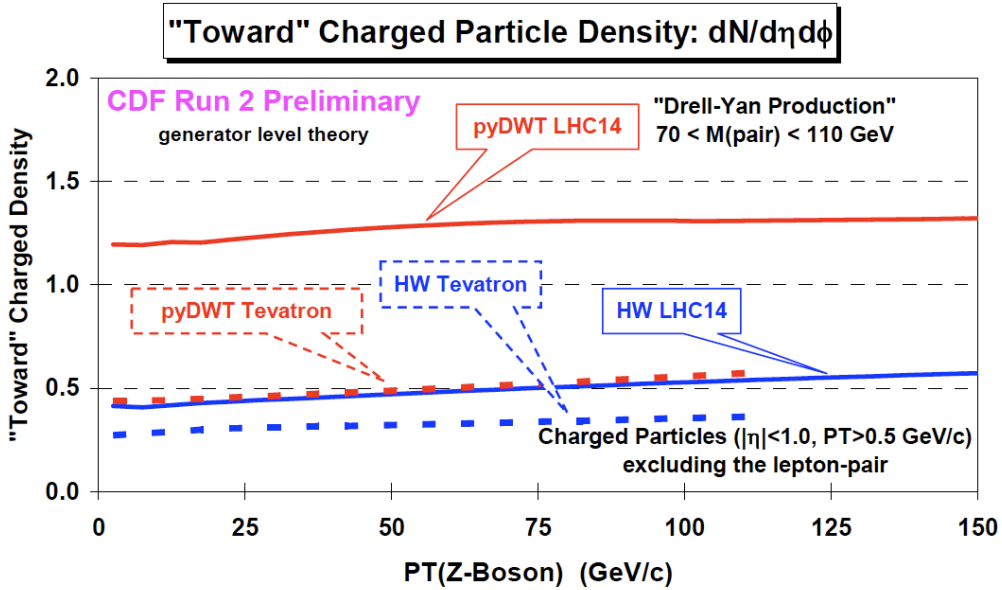
Similar in Leading-jet and Drell-Yan events

Drell-Yan extrapolation to LHC



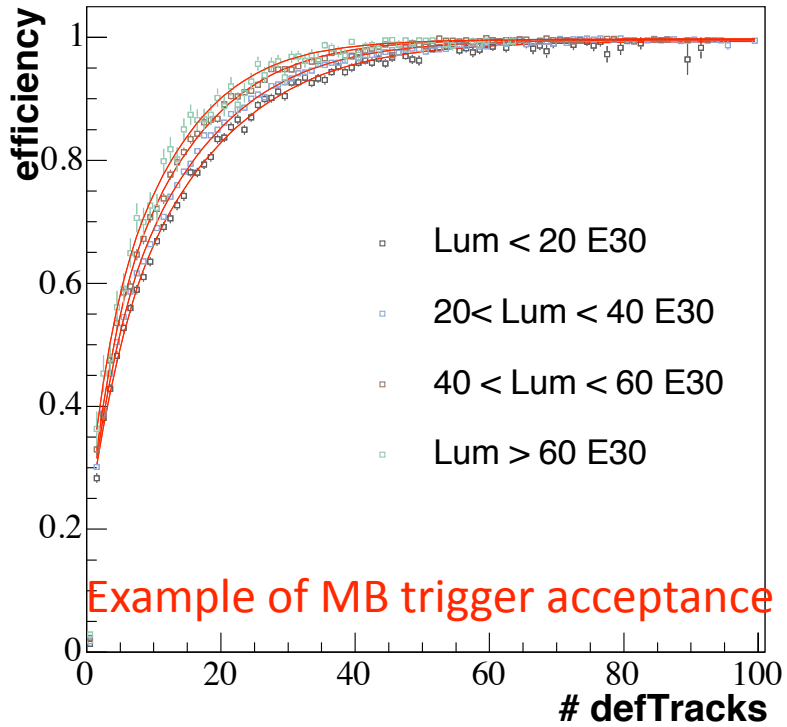
Data CDF, Pythia 2,10 and 14 TeV

Pythia 2 and 14 TeV
Herwig 2 and 14 TeV



CDF Vertex & Trigger acceptance

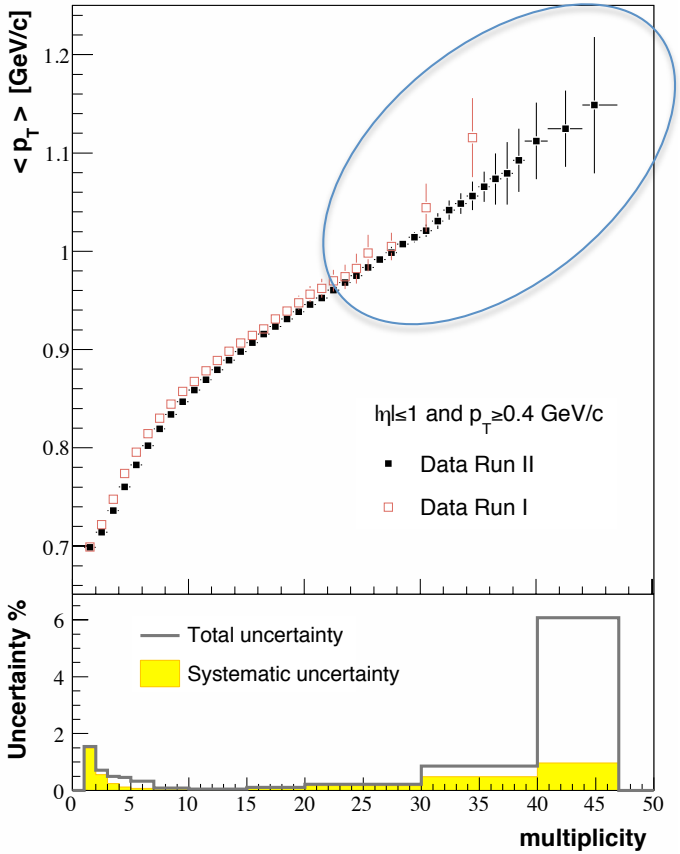
- Trigger: acceptance is function of many variables
  - # primary detected vertices, Luminosity, # tracks, CLC calibration…
  - In short, acceptance increases with the total activity in the *crossing*. Plateau at ~98%
  - Measurable with 0-Bias sample



- 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

$<P_T>$ Vs N_{ch} comparison to Run I

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



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

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

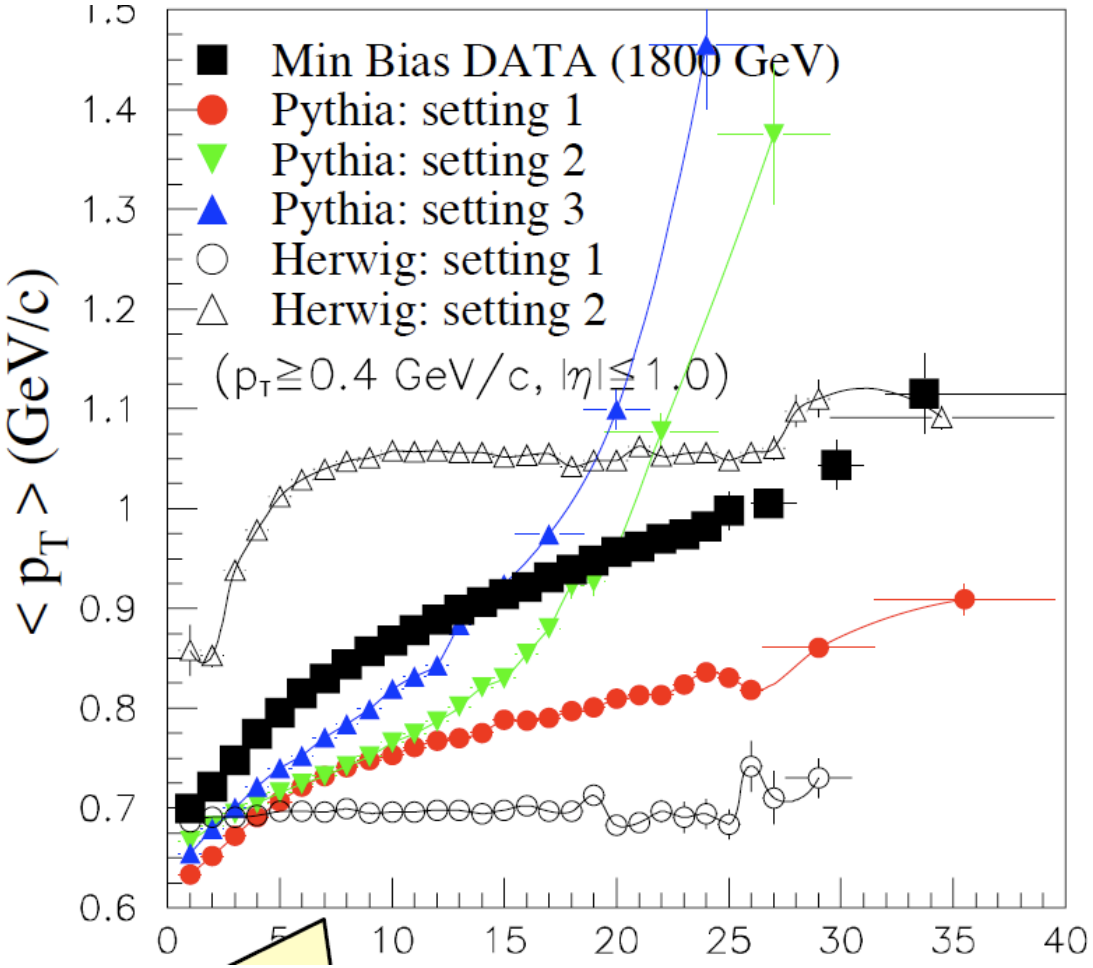
$$\langle p_T \rangle_{n_r=m} = \sum_i^{n_g} (\langle p_T \rangle_{n_r=i} \times P_{n_r=m}^{n_g=i})$$

$<p_T>$ at Nr

$<p_T>$ at Ng

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

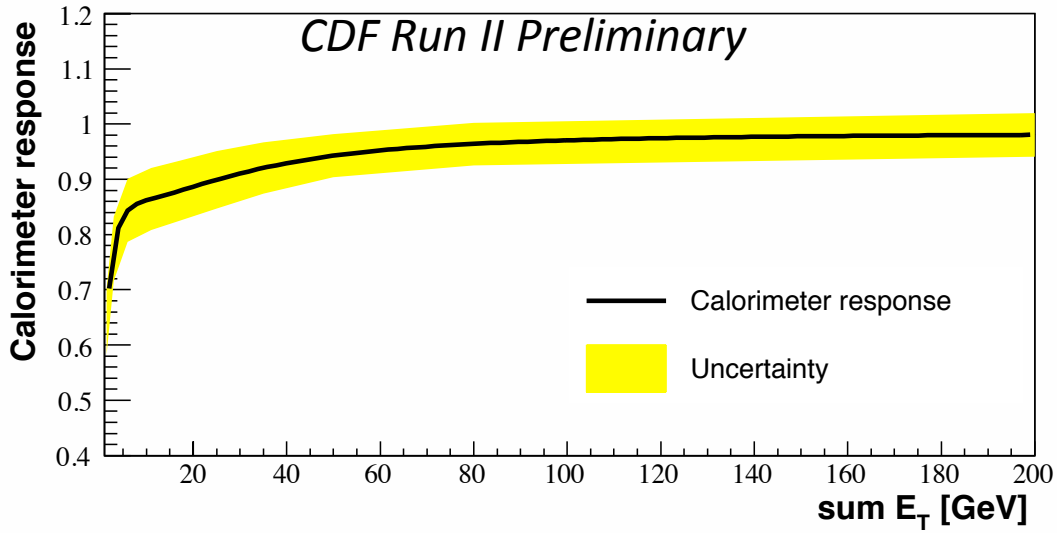
Pre TuneA



CDF Run I

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

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