Soft QCD and Underlying Event at CDF

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Outline

➔ Event Shapes

- What are they and why?
- How to measure ?
- Latest results

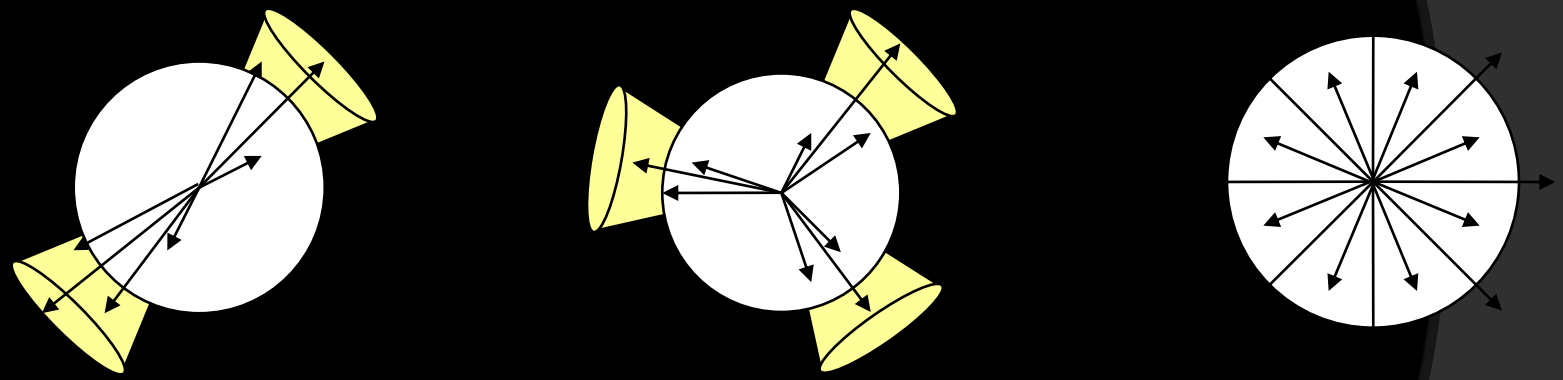
➔ Underlying Event

- Why UE?
- Latest measurements in Z boson events

Introduction

In most general terms event shapes measure geometric properties of the energy flow in QCD final states

Similar to jet finding algorithms which characterize the topology of an event (approach fails to capture the continuous nature of the variability of events)



In contrast, an event shape encodes in a continuous fashion particular aspects of how energy is distributed in an event

Free of arbitrariness associated with the jet definition (i.e. cone or cluster)

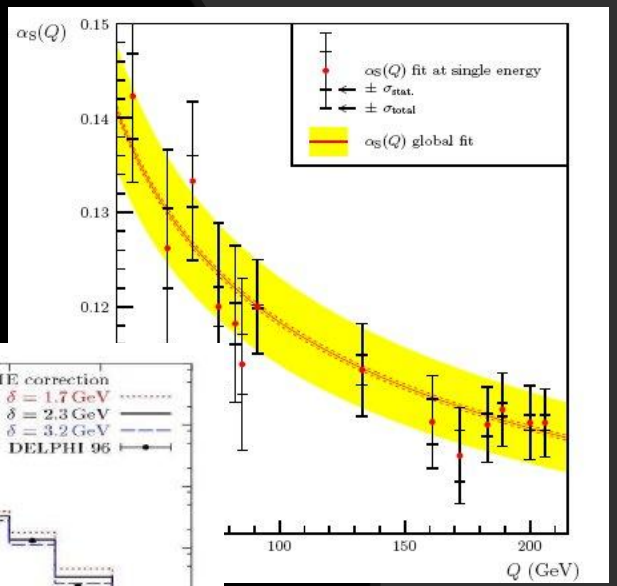
Why ES?

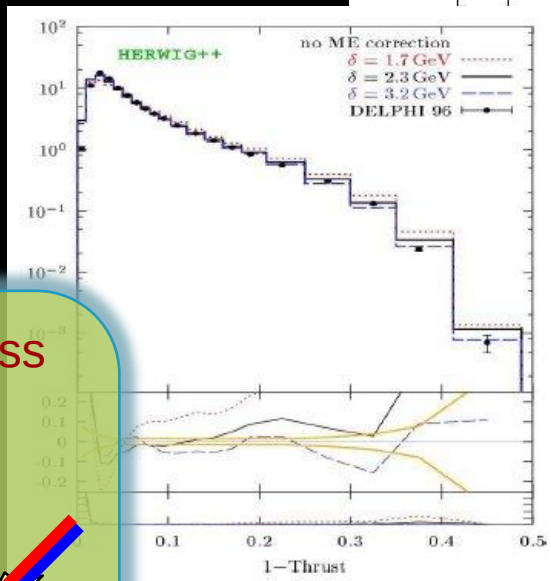
Studies of event shapes allow to probe:

Fixed order pQCD (measurement of the α_s)

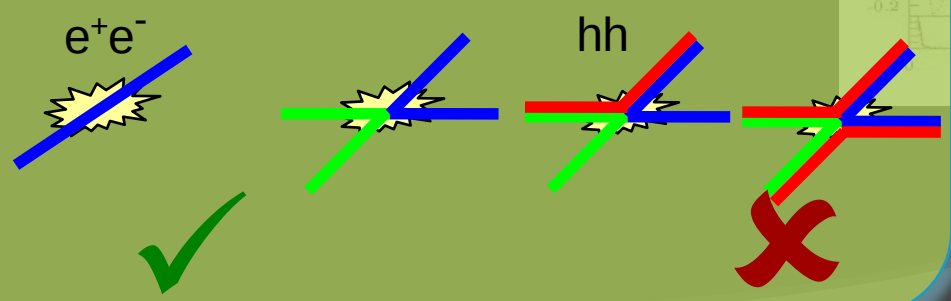
Soft gluon resummations (details of fragmentation)

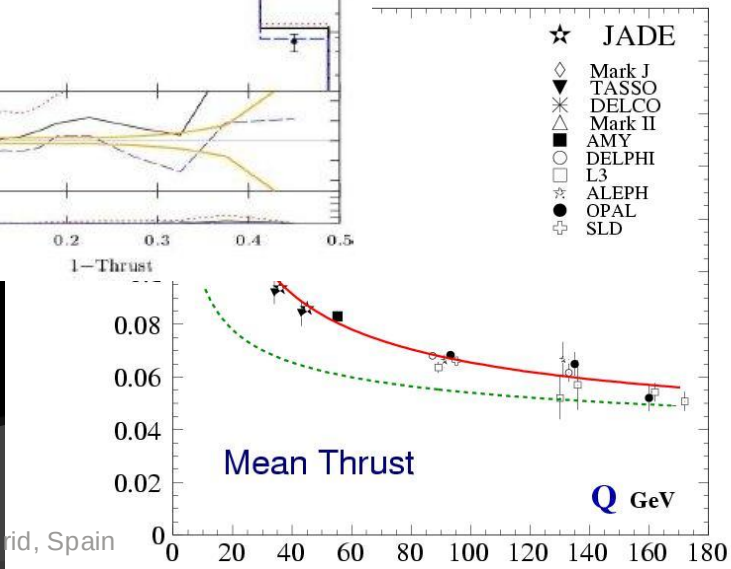
Soft QCD (hadronization models)





Studied extensively at LEP but by far less at hadron colliders





Present State of Theory

pQCD

✓ Hard scattering
Soft QCD radiation

NLOJet++

(matched)

CAESAR (NLL)

Underlying Event

✗ Beam remnants
Multiple parton interactions

Theorists still unable to incorporate phenomenological model into their calculations

Presence of the underlying event casts some doubts as to whether event shapes at hadron colliders can be used to study hadronization effects or even pQCD

Proposed Observables

The event shapes observables chosen for this study are defined as linear sums over the transverse momentum of all particles in the final state

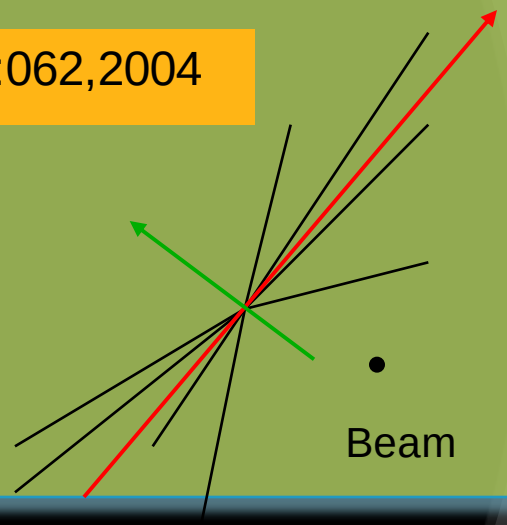
$$\tau \equiv 1 - \max_{\vec{n}_T} \frac{\sum \left| \vec{n}_T \cdot \vec{p}_\perp \right|}{\sum \left| \vec{p}_\perp \right|}$$

$$T_{\min} \equiv \frac{\sum \left| \vec{n}_m \cdot \vec{p}_\perp \right|}{\sum \left| \vec{p}_\perp \right|}$$

JHEP 0408:062,2004

where

$$\vec{n}_m \cdot \vec{n}_T = 0$$



Other proposed observables (Broadening, Hemisphere masses, etc..) were found to be very sensitive to detector mismeasurements in the forward region

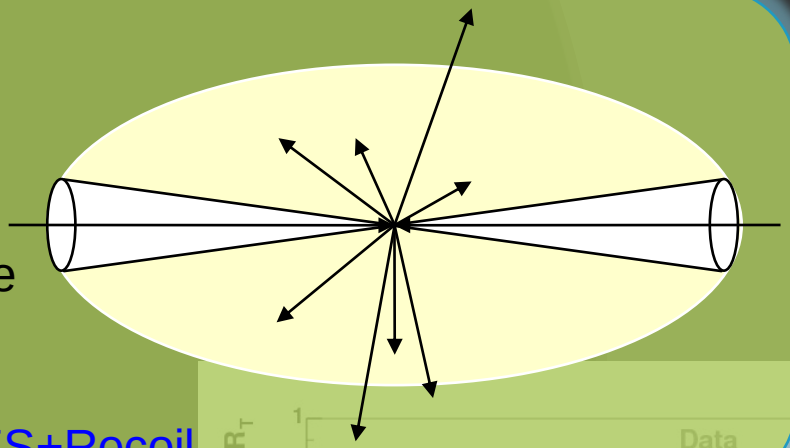
Recoil Term???

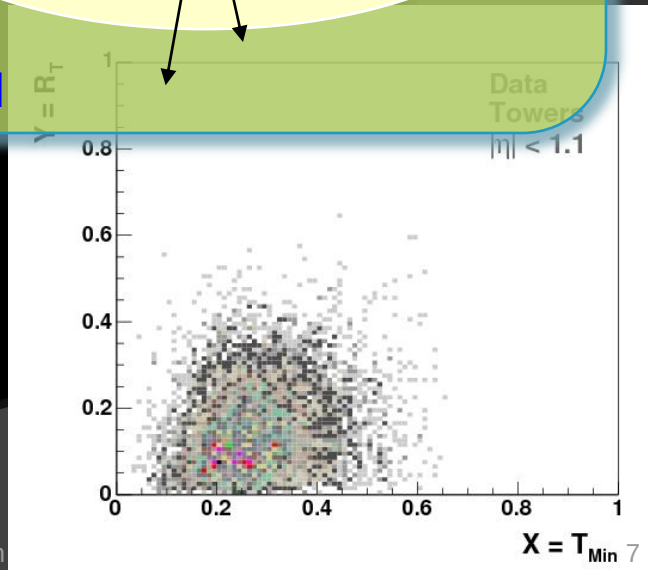
Theory imposes a significant constrain – observable must be GLOBAL (i.e. sensitive to emissions in all directions)
This is in direct conflict with the experimental reality where the detector has limited coverage in the forward region

Indirectly Global Event Shapes
Define ES in the reduced central region

Introduce Recoil Term defined in the same central region but sensitive to the emissions outside

Add on the event-by-event basis I.G.O.= ES+Recoil

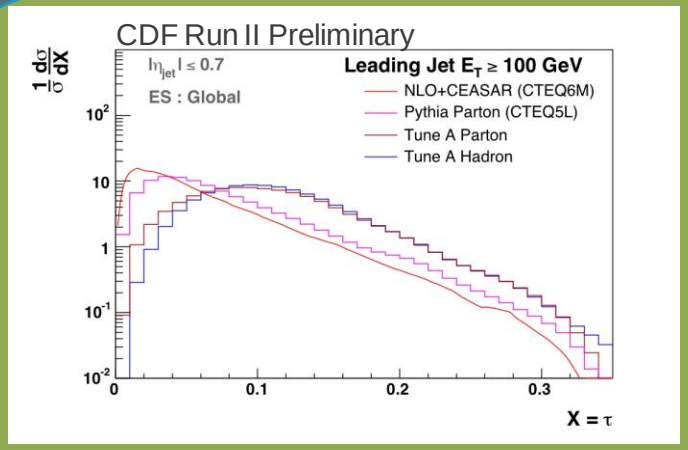


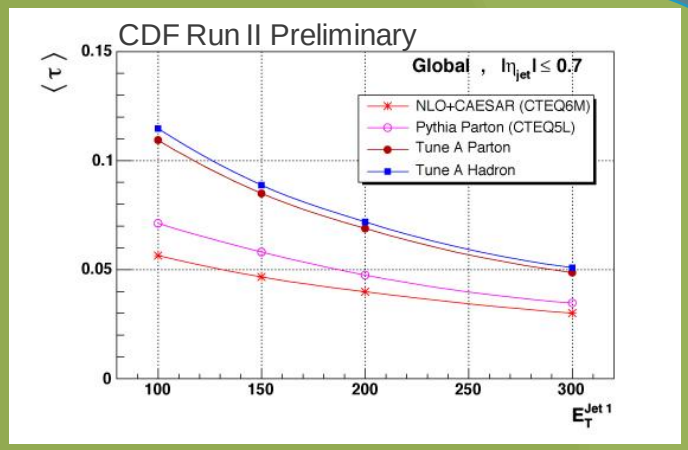


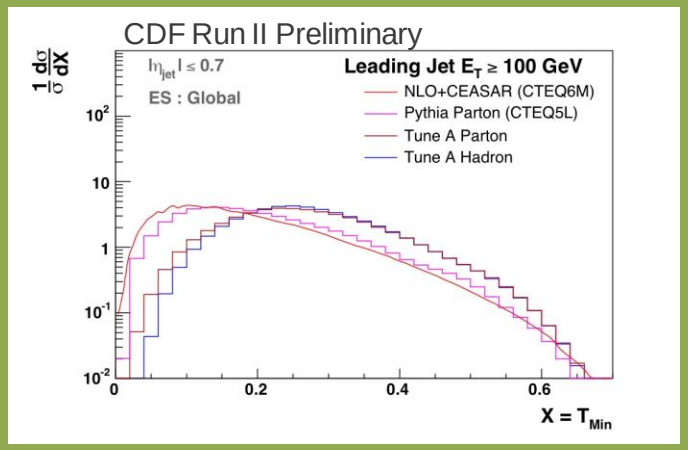
- Studies revealed small correlation b/w ES and Recoil
- Best shot of comparing with theory is to measure as much of an event as possible
- Effect of limited coverage $|\eta|<3.5$ is negligible

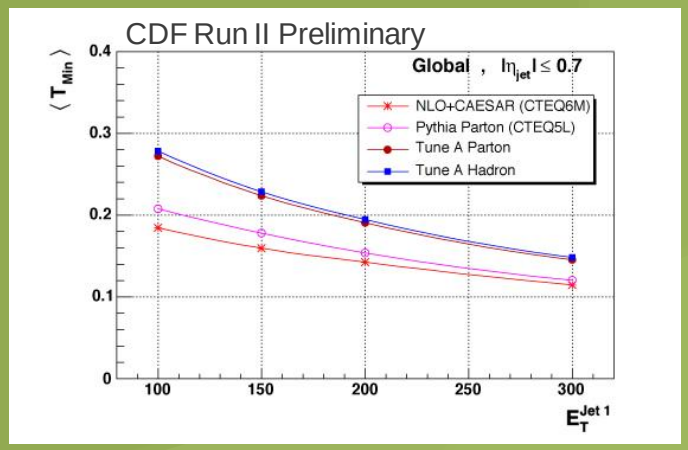
Role of the Underlying Event

NLO+CAESAR(NLL) ➔ Pythia 6.216 w/o MPI ➔ Pythia Tune A ➔ Hadronization









Underlying Event significantly changes means and shapes of the distributions

Treatment of the Underlying Event

Can we subtract contribution of the UE on average from our measurement?

- begin by separating event into hard and soft components:

$$\tau \approx \frac{\sum\left|q_\perp^{hard}\right| - \max\sum q_\perp^{hard}\left|\cos\phi\right|}{\sum\left|q_\perp^{hard}\right| + \sum\left|q_\perp^{UE}\right|} + \frac{\sum q_\perp^{UE}\left|1-\cos\phi\right|}{\sum\left|q_\perp^{hard}\right| + \sum\left|q_\perp^{UE}\right|}$$

$$T_{\min} = \frac{\sum q_\perp^{hard}\left|\sin\phi\right|}{\sum\left|q_\perp^{hard}\right| + \sum\left|q_\perp^{UE}\right|} + \frac{\sum q_\perp^{UE}\left|\sin\phi\right|}{\sum\left|q_\perp^{hard}\right| + \sum\left|q_\perp^{UE}\right|}$$

- introduce a new observable

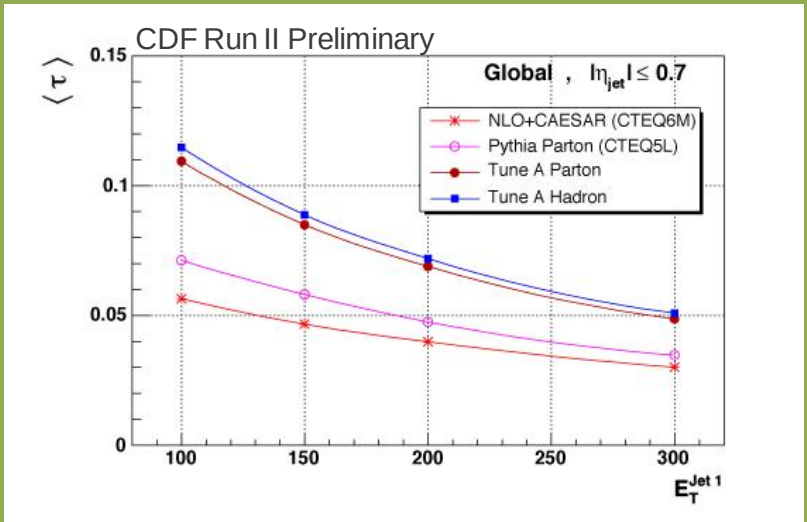
$$C\left(\langle\tau\rangle,\langle T_{\min}\rangle\right) \equiv \left(\alpha\langle\tau\rangle - \beta\langle T_{\min}\rangle\right)\cdot\gamma_{MC}$$

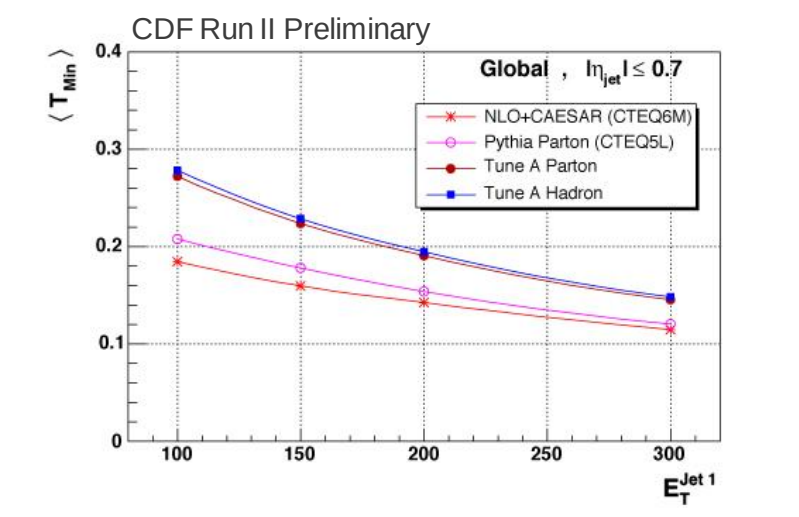
which is independent of the UE part

where $\alpha = 1 - 2/\pi$, $\beta = 2/\pi$, and

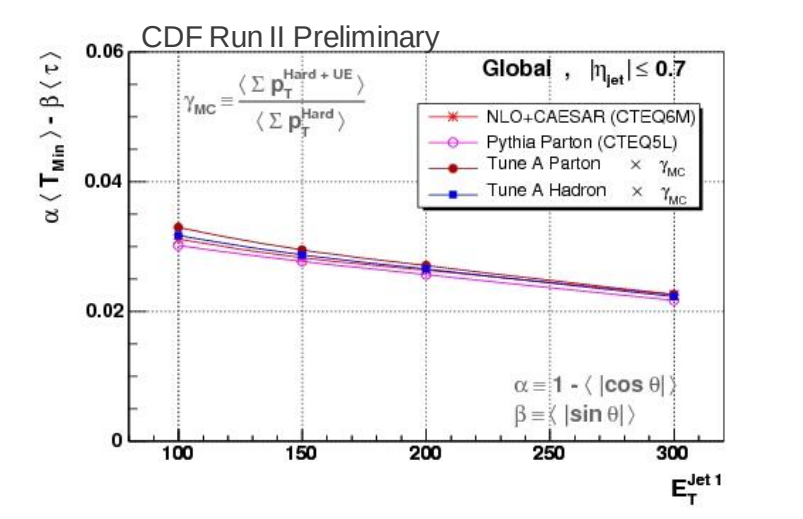
$$\gamma_{MC} \equiv \frac{\sum\left|q_\perp^{hard}\right| + \sum\left|q_\perp^{UE}\right|}{\sum\left|q_\perp^{hard}\right|}$$

Treatment of the Underlying Event





(NLO+CAESAR) vs Tune A



Converges well

Instrumentation Effects

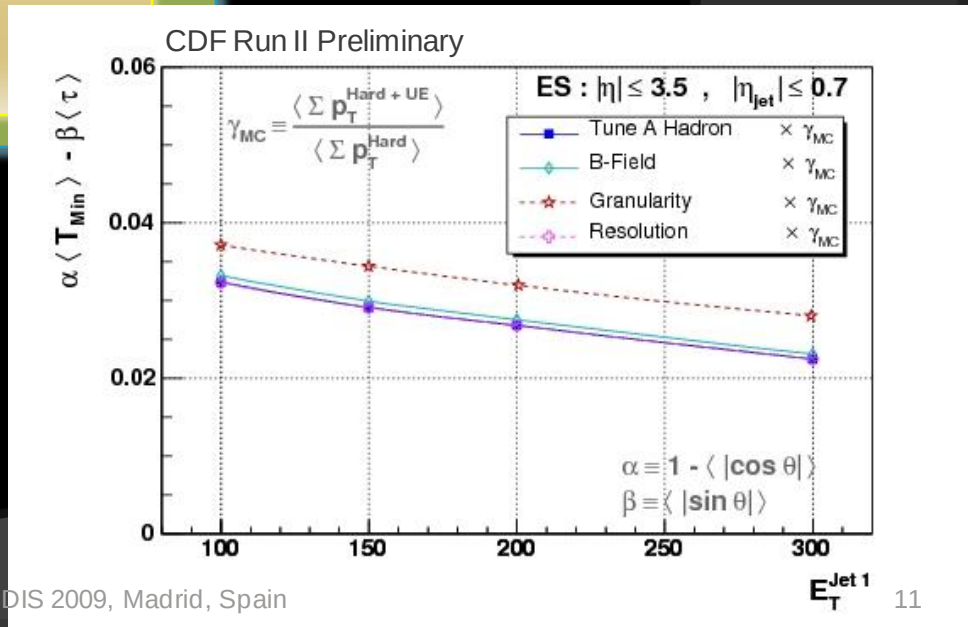
Instrumentation effects studied individually:

a) B-field on charged particles

b) Calorimeter resolution

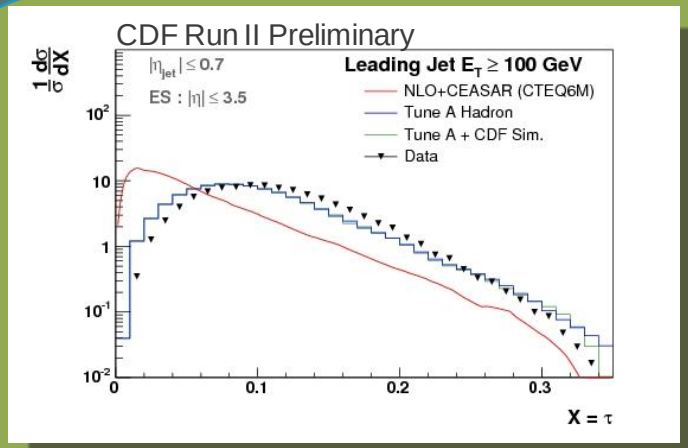
c) Calorimeter granularity

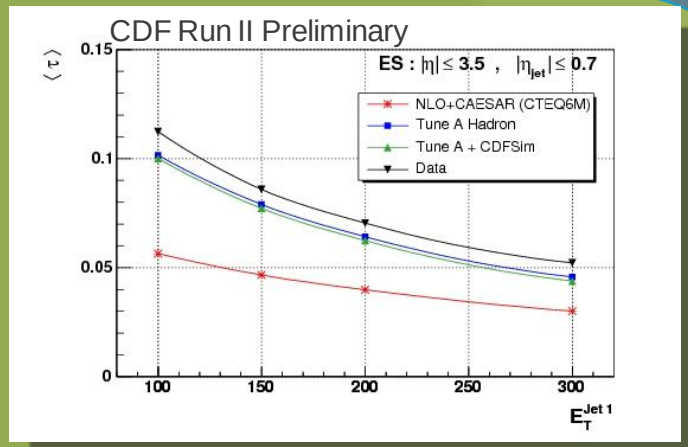
$\Delta\eta = 0.1$, $\Delta\Phi = 15^o$ Central
$\Delta\eta = 0.2\text{-}0.6$, $\Delta\Phi = 15^o$ Forward

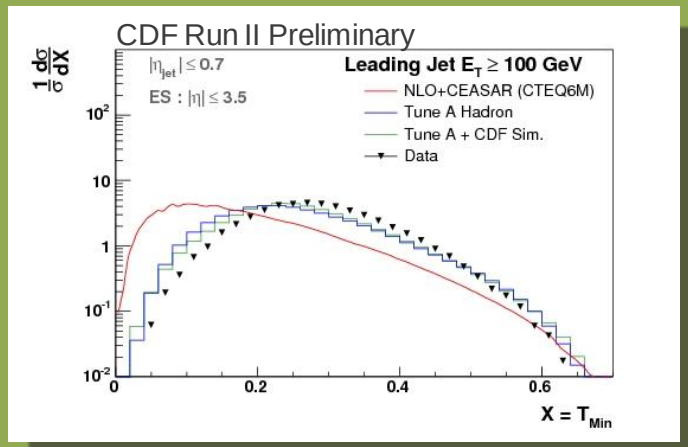


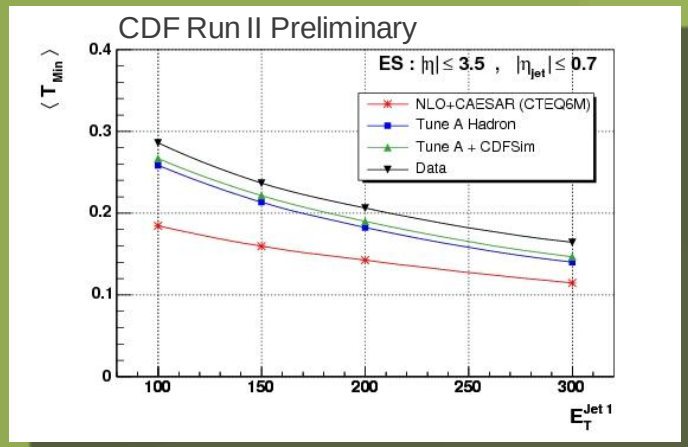
Results

Look at the τ and T_{min} first…



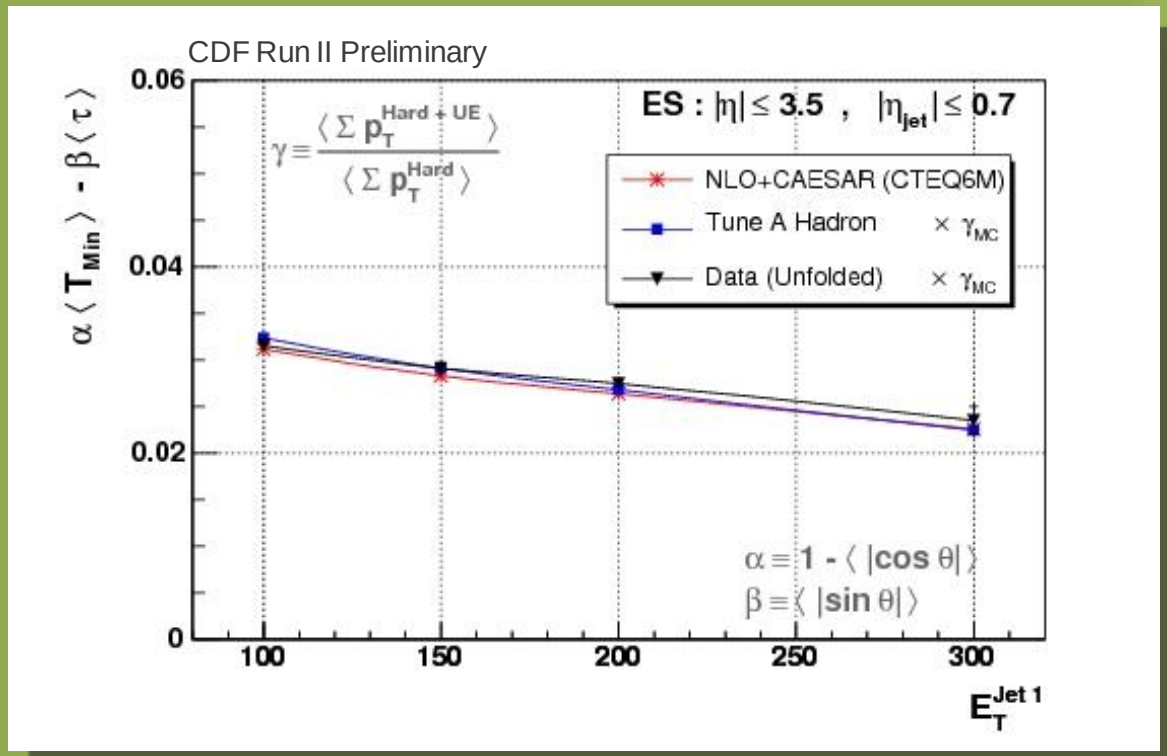






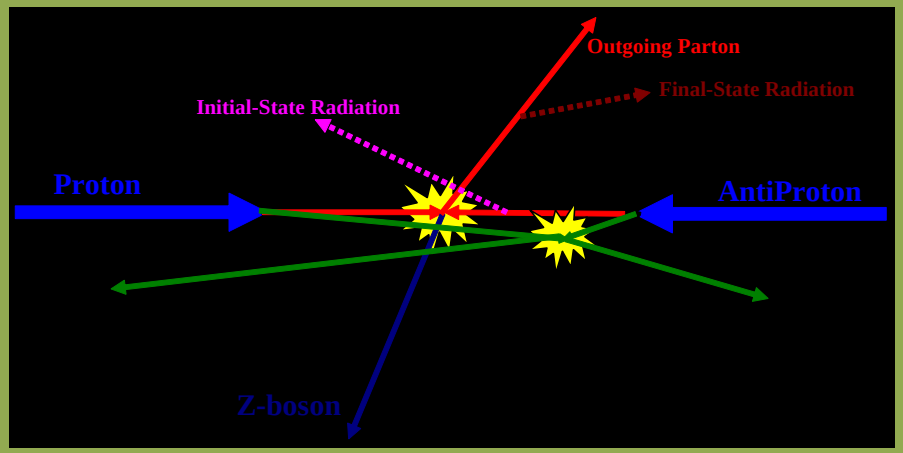
Results

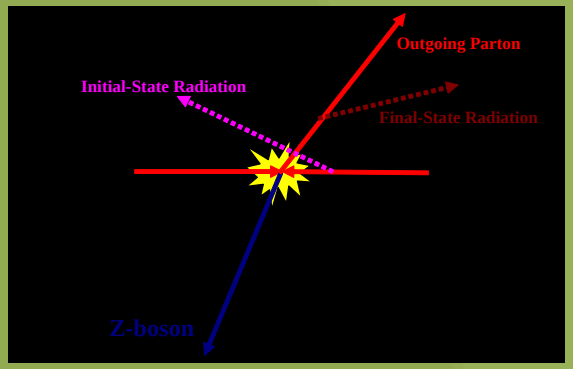
And now at our observable…

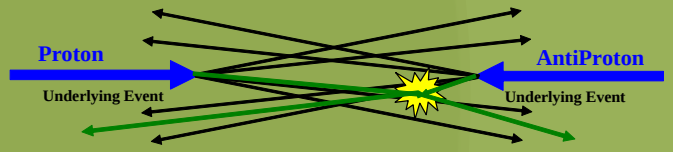


After accounting for the effect of calorimeter granularity observe excellent agreement between Data and Theory

Underlying Event

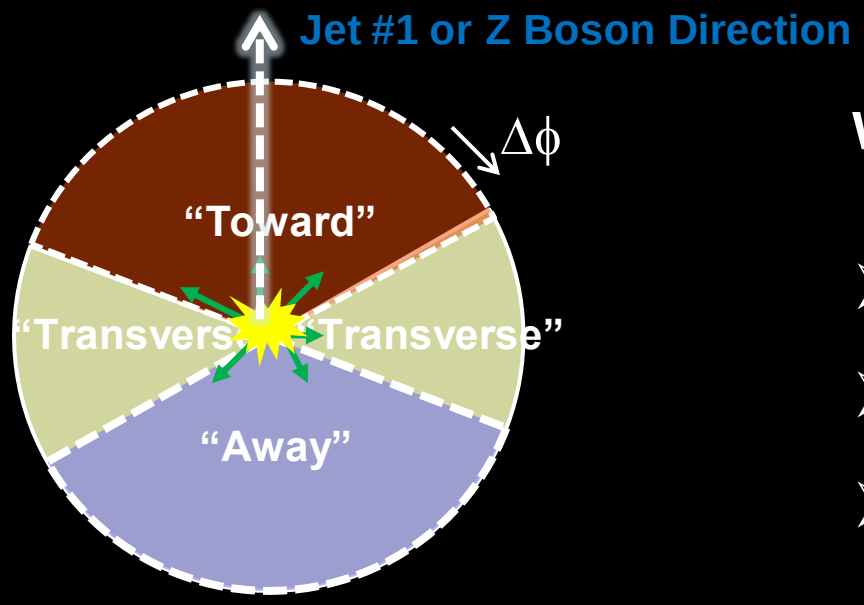






- Start with the perturbative Drell-Yan muon pair production and add initial-state gluon radiation (in the leading log approximation or modified leading log approximation).
- The "underlying event" consists of the "beam-beam remnants" and from particles arising from soft or semi-soft multiple parton interactions (MPI).
- Of course the outgoing colored partons fragment into hadron "jet" and inevitably "underlying event" observables receive contributions from initial-state radiation.

Dividing up the Central Region



We define –

- $|\Delta\phi| < 60^o$ as **Toward**
- $60^o < |\Delta\phi| < 120^o$ as **Transverse**
- $|\Delta\phi| > 120^o$ as **Away**

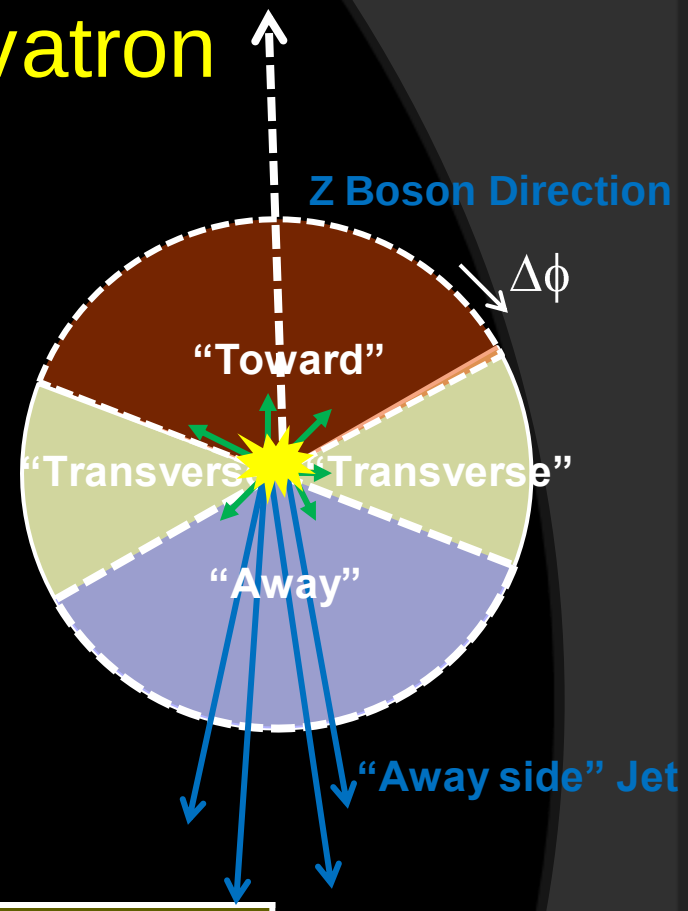
Azimuthal angle $\Delta\phi$ relative to the leading calorimeter jet (or the Z-boson)

Z-Boson Production at the Tevatron

Single Z Bosons are produced with large p_T via the ordinary QCD sub processes:

$$qg \rightarrow Zq,\ q\bar{q} \rightarrow Zg,\ \bar{q}g \rightarrow Z\bar{q}$$

They generate additional gluons via bremsstrahlung – resulting in multi-parton final states **fragmenting into hadrons** and forming **away-side jets**.



	CDF (pb)	NNLO (pb)
$\sigma(Z \rightarrow l^+l^-)$	254.9±3.3(stat)±4.6(sys)±15.2(lum)	252.3±5.0

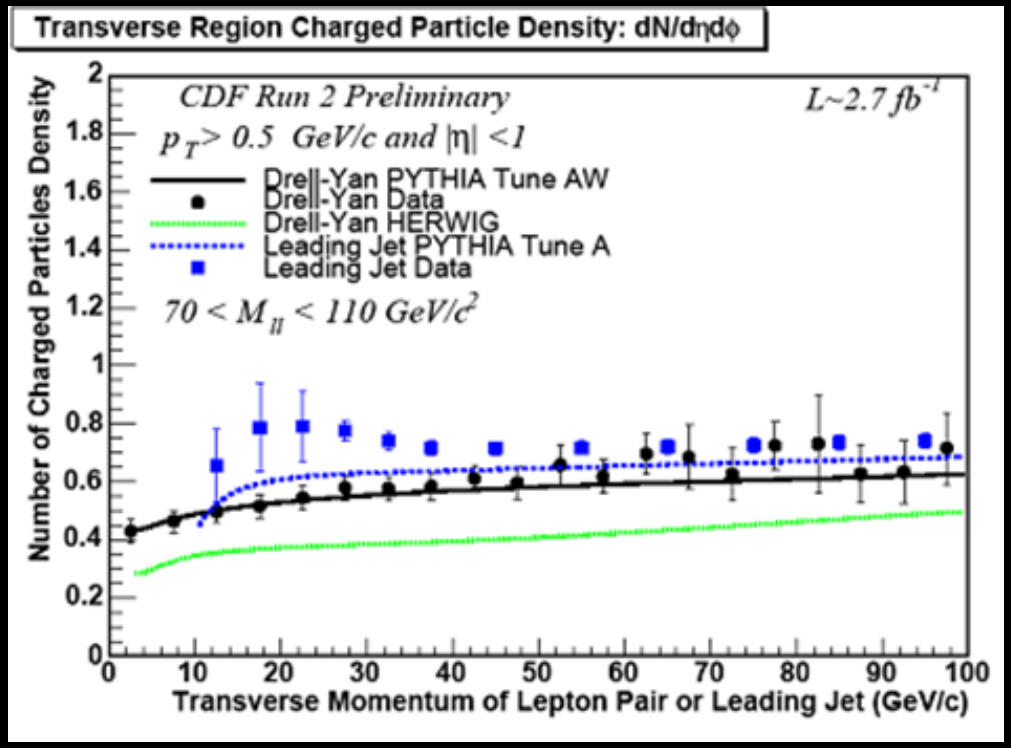
CDF: Phys. Rev. Lett. 94, 091803 (2005)
NNLO Theory: Stirling, Van Neerven

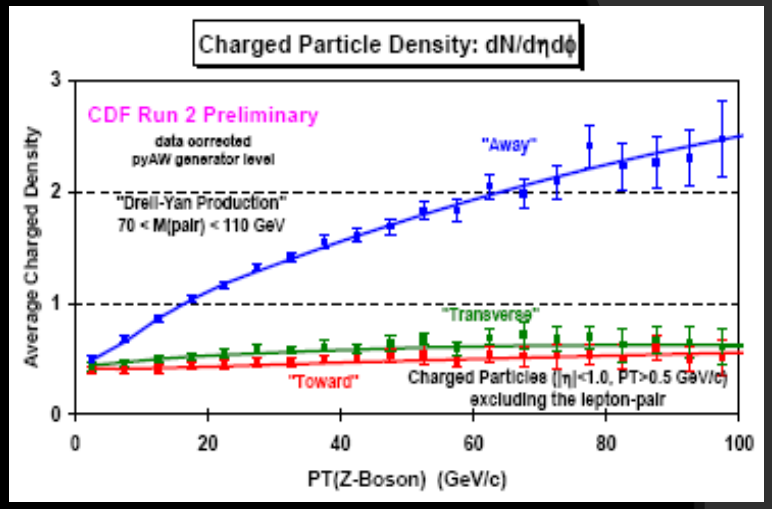
Our Analysis

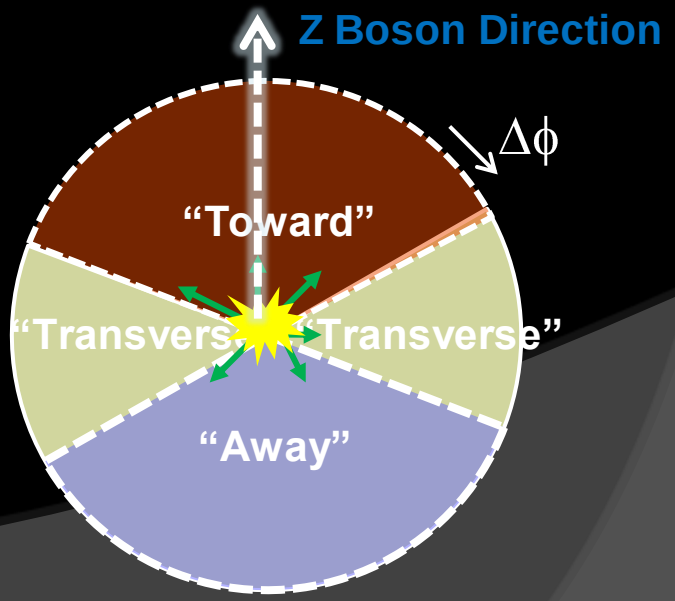
- The goal of the analysis was to produce data on the **underlying event** that is **corrected** to the particle level so that it can be used to **tune** the QCD Monte-Carlo models without requiring CDF detector simulation (i.e. CDFSIM).

- Also by looking at the measurements sensitive to the underlying event, we would be able to **better constrain** our underlying event models.

Charged Particle Multiplicity

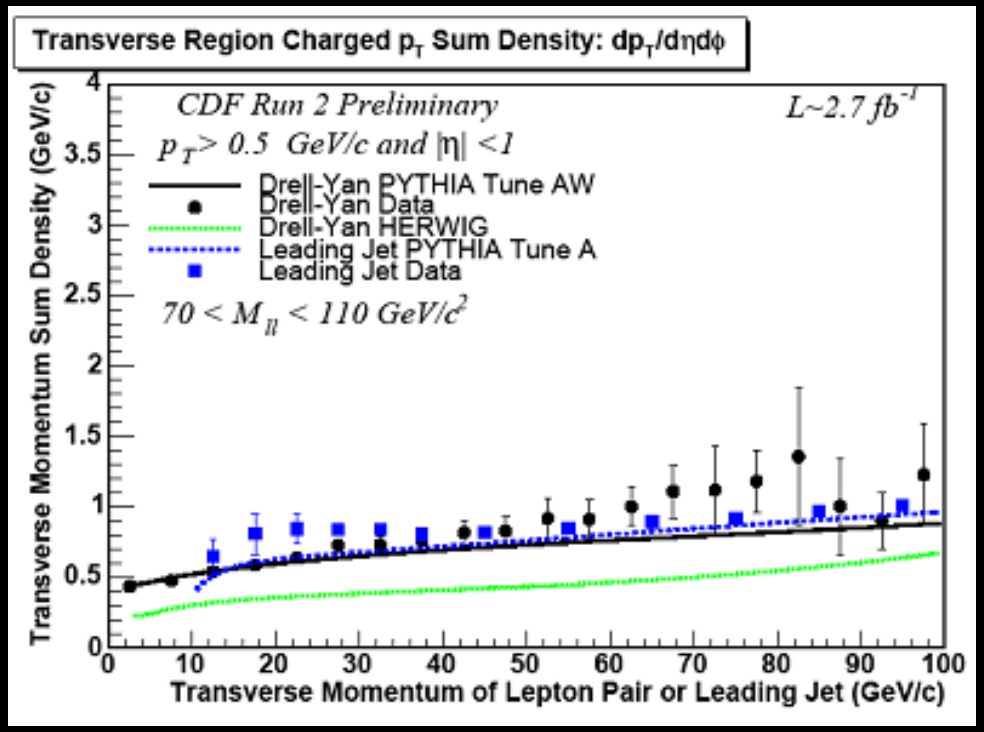


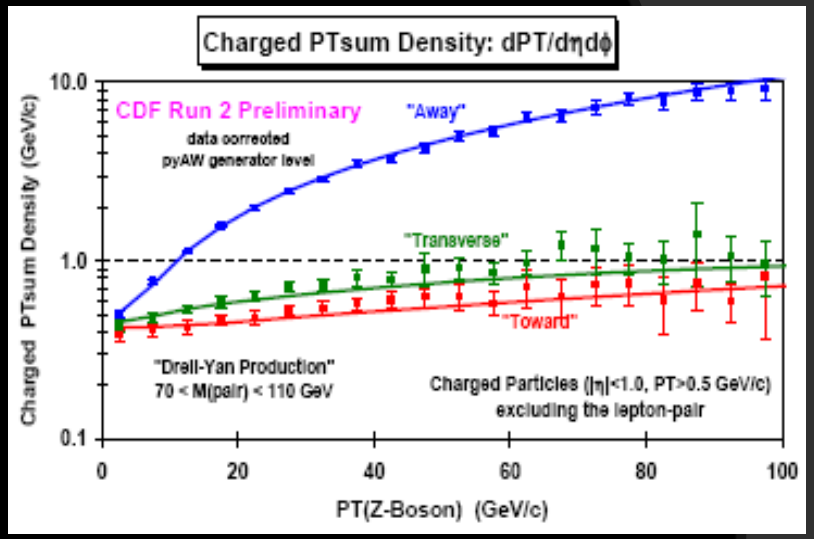


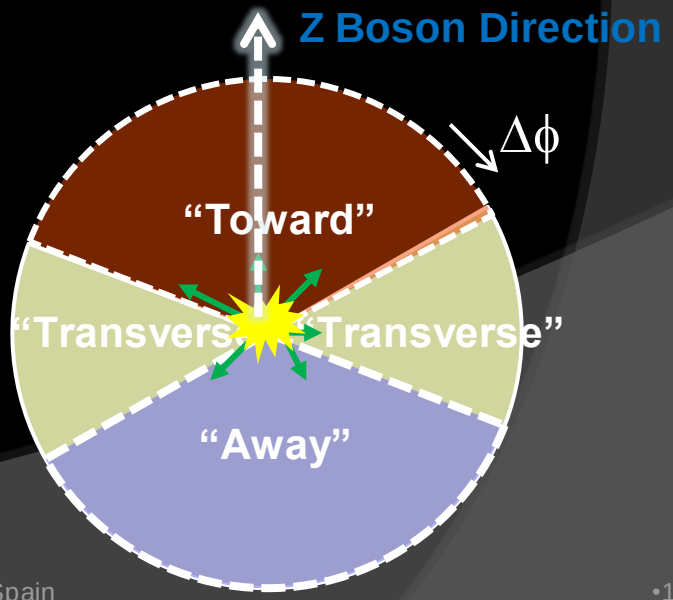


no FSR!
exclude leptons
"towards"="Trans"

Charged Transverse Momentum Sum



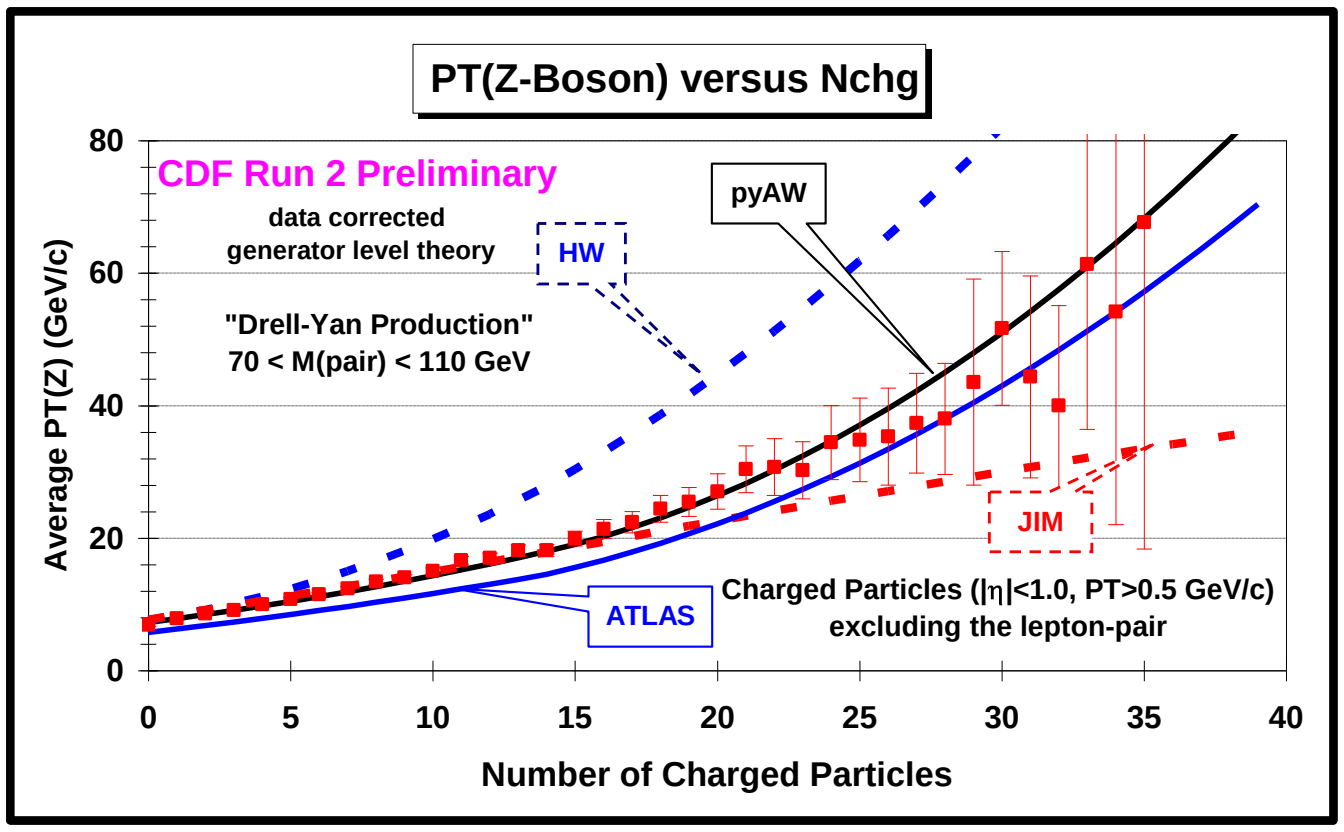




Mean p_T vs Charged Multiplicity

$\langle p_T \rangle$ versus N_{chg} is a measure of the amount of **hard versus soft** processes contributing and it is **sensitive** to the modeling of the multiple-parton interactions.

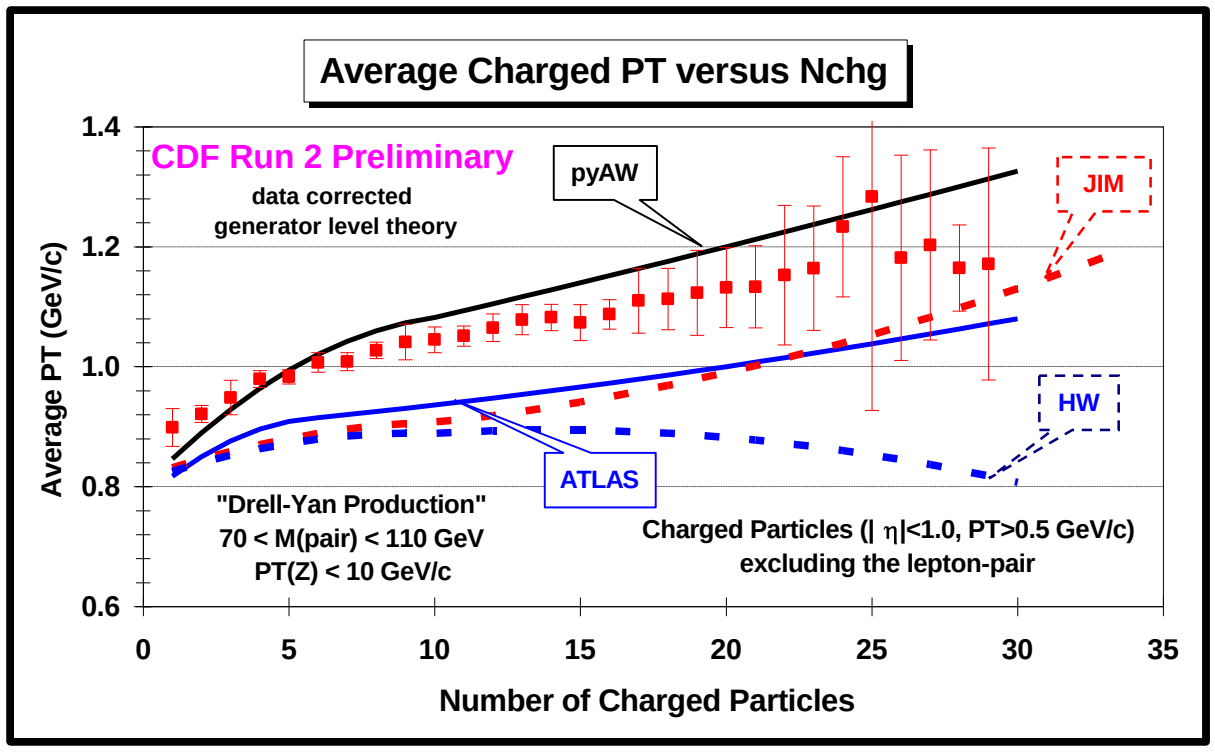
Mean p_T vs Charged Multiplicity



Large N_{chg} implies high p_T jets (i.e. hard 2→2 scattering). Without MPI the only way to get large N_{chg} is to have a very hard 2→2 scattering.

Mean p_T vs Charged Multiplicity

$P_T(Z) < 10$ GeV/c

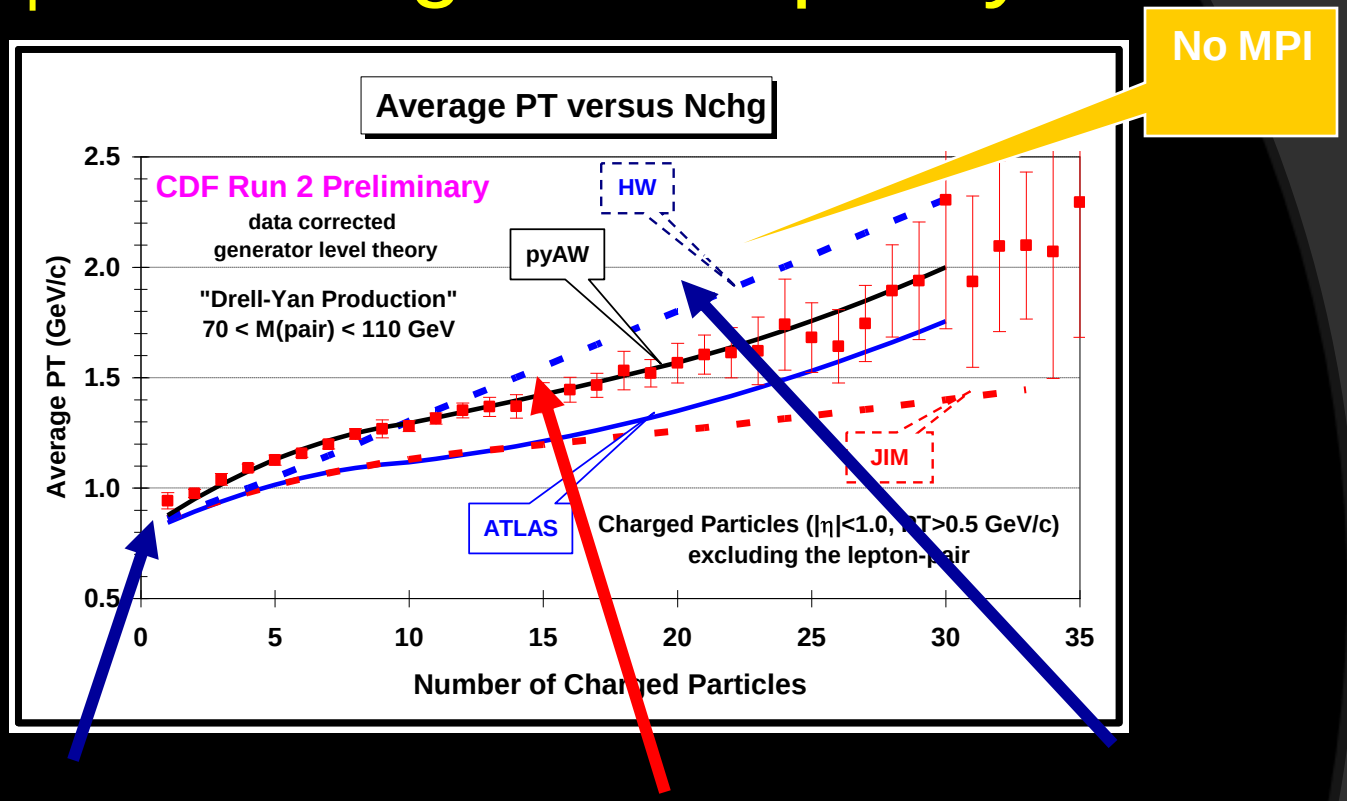


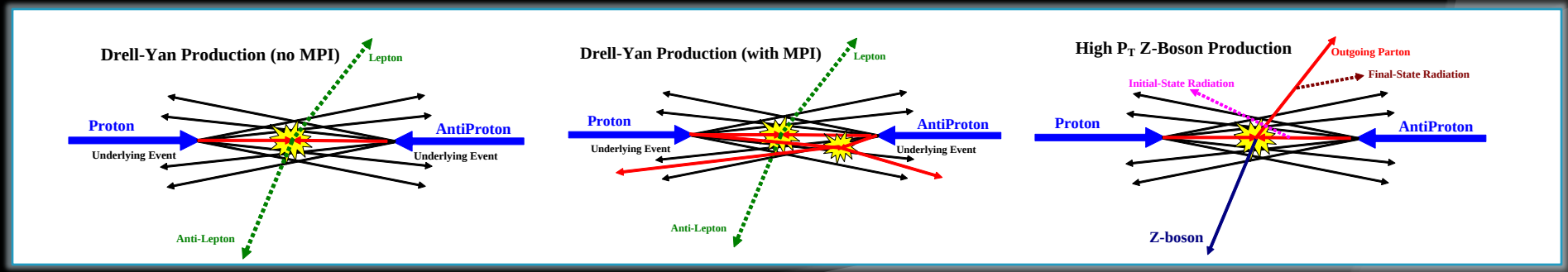
Multiple-parton interactions provides another mechanism for producing large multiplicities that are harder than the beam-beam remnants, but not as hard as the primary Z +jet hard scattering.

Moving Forward to LHC

- The UE measurement plan at the LHC benefits from the solid experience of the CDF studies.
- Predictions on the amount of activity in transverse region at the LHC are based on extrapolations from lower energy data (mostly from the Tevatron).
- All the UE models have to be tested and adjusted at the LHC, in particular we know very little about the energy dependents of MPI in going from the Tevatron to the LHC.

Mean p_T vs Charged Multiplicity





Conclusions

➔ First look at Event Shapes in Run II, certainly first comparison to theoretical results

➔ Great agreement between Data and Theory for the introduced observable

➔ CDF tunes A and AW describe data quite well

➔ Still a lot can be done on both ends – theoretical and experimental…

Pythia Tunes

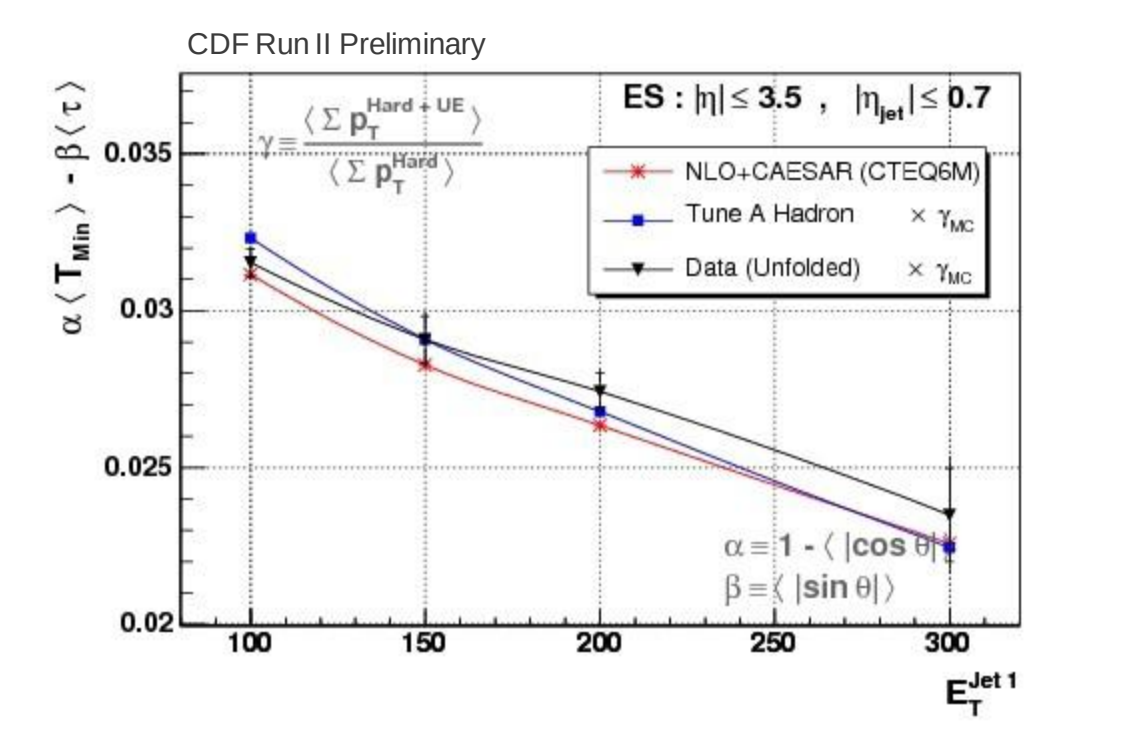
Parameter	Tune A	Tune AW	Tune DW	Tune DWT	ATLAS
PDF	CTEQ5 L	CTEQ5 L	CTEQ5 L	CTEQ5 L	CTEQ5 L
MSTP(81)	1	1	1	1	1
MSTP(82)	4	4	4	4	4
PARP(82)	2.0	2.0	1.9	1.9409	1.8
PARP(83)	0.5	0.5	0.5	0.5	0.5
PARP(84)	0.4	0.4	0.4	0.4	0.5
PARP(85)	0.9	0.9	1.0	1.0	0.33
PARP(86)	0.95	0.95	1.0	1.0	0.66
PARP(89)	1800	1800	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

MPI

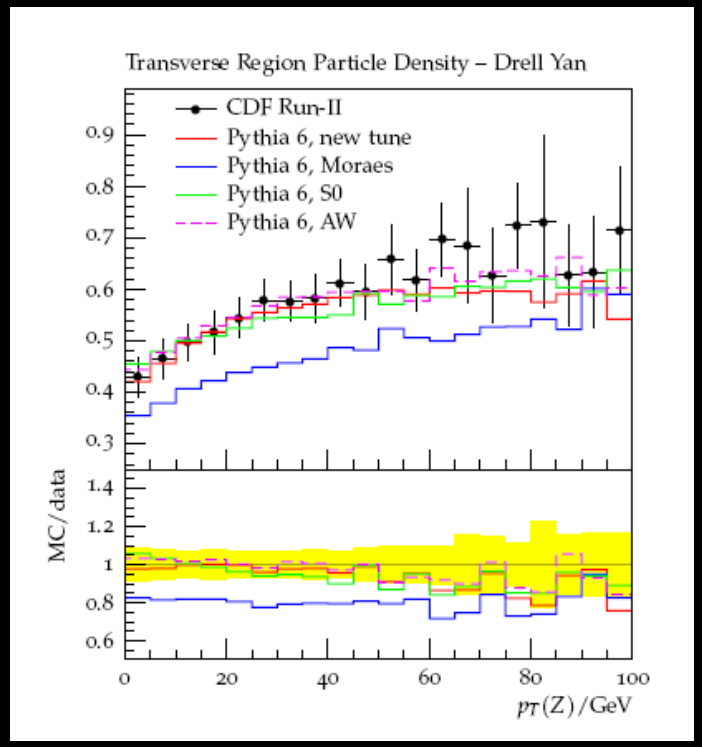
ISR

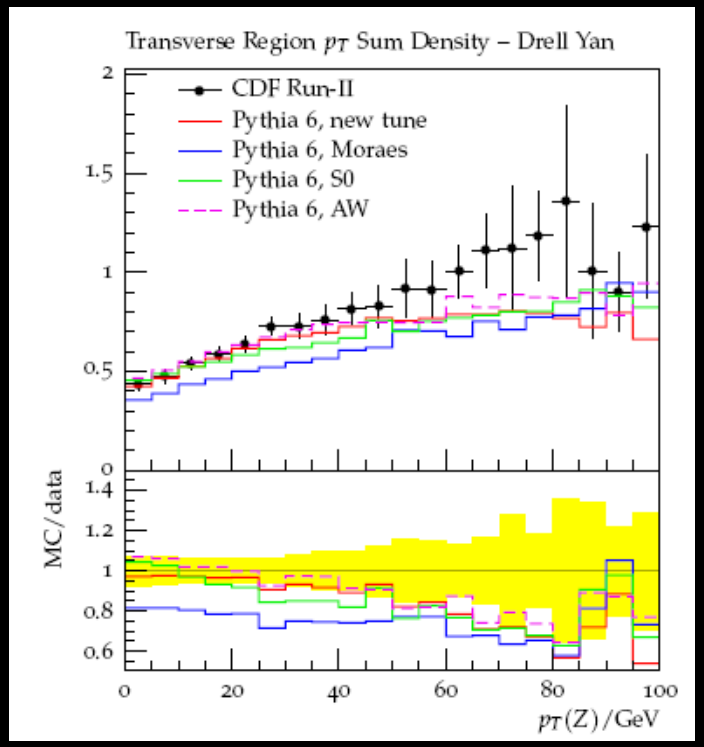
BBR

ES Results (zoomed)



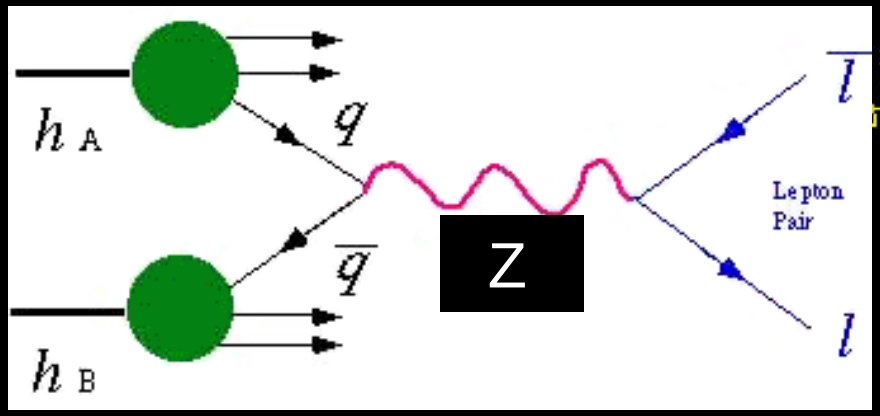
“Newer” Tunes
(From H. Hoeth, MPI@LHC 2008)

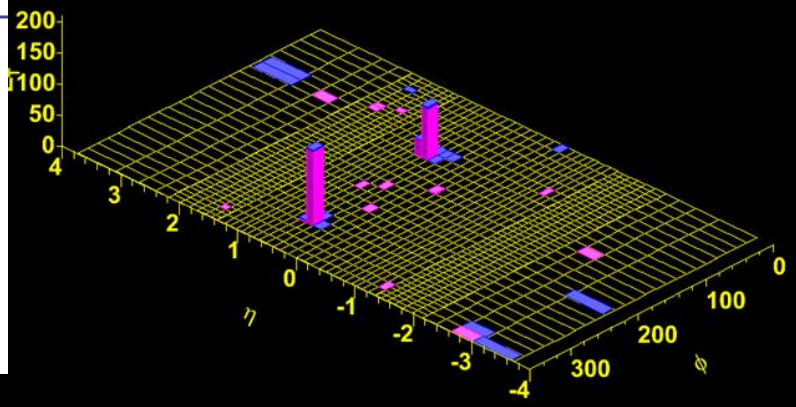




Data/MC comparisons show the features and problems of different generators and tunings.

Drell-Yan Process





Charged particles with: $p_T > 0.5$ GeV/c and $|\eta| < 1$

Using events with the lepton pair invariant mass in the Z region: $70 < M(ll) < 110$ GeV/c^2