Using Drell-Yan to Probe the Underlying Event in Run 2 at CDF

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(On behalf of the CDF Collaboration)

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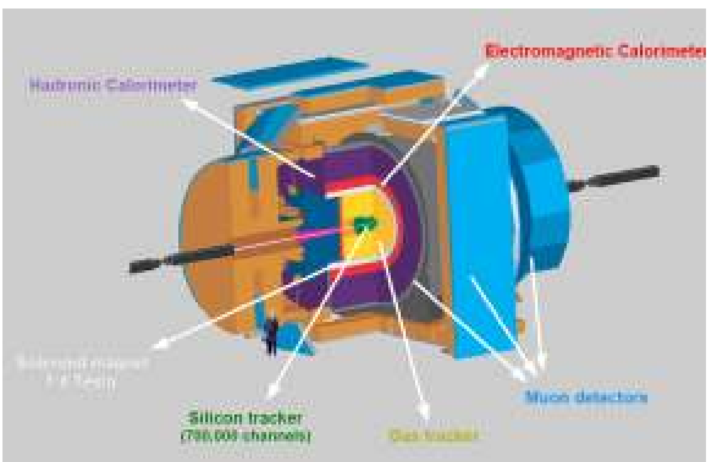
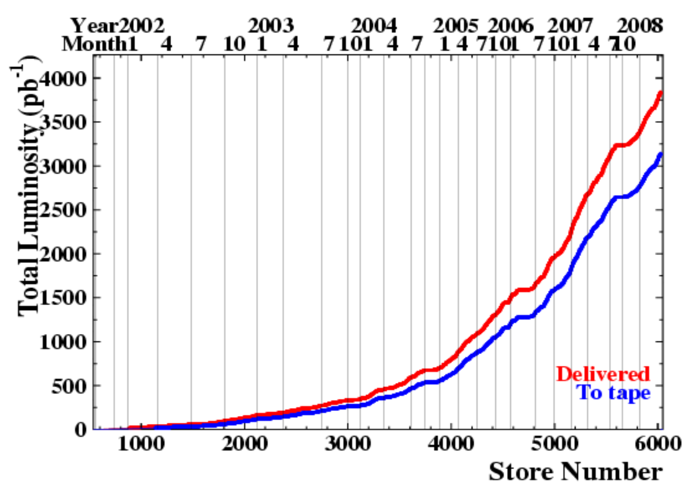
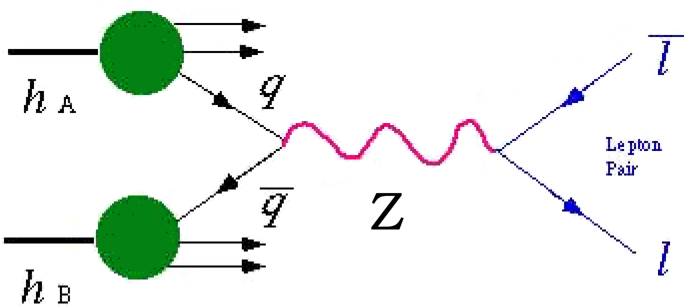
Madison, Wisconsin.

Collider Detector at Fermilab (CDF)

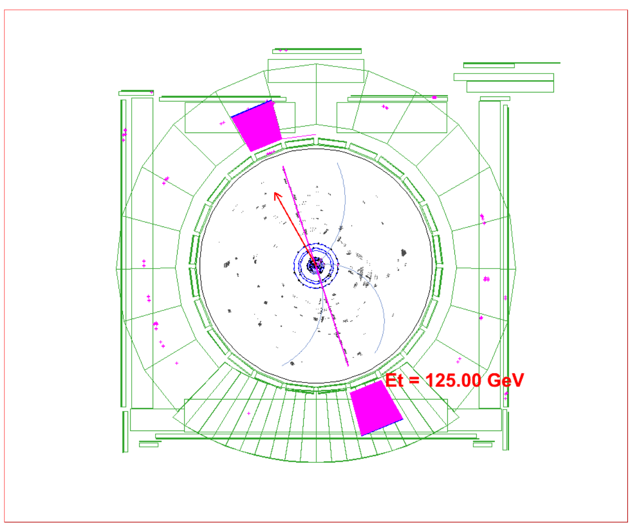


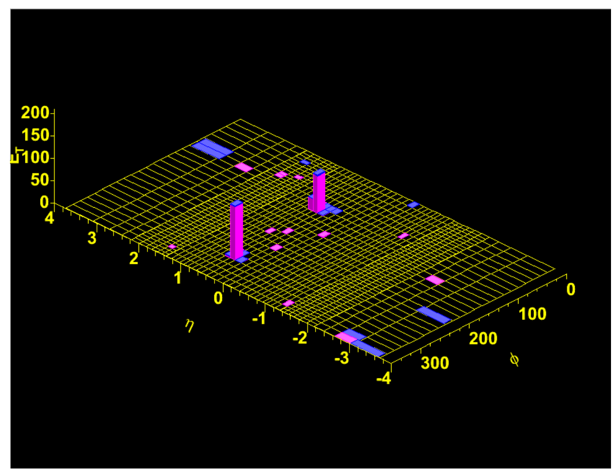


Drell Yan Process



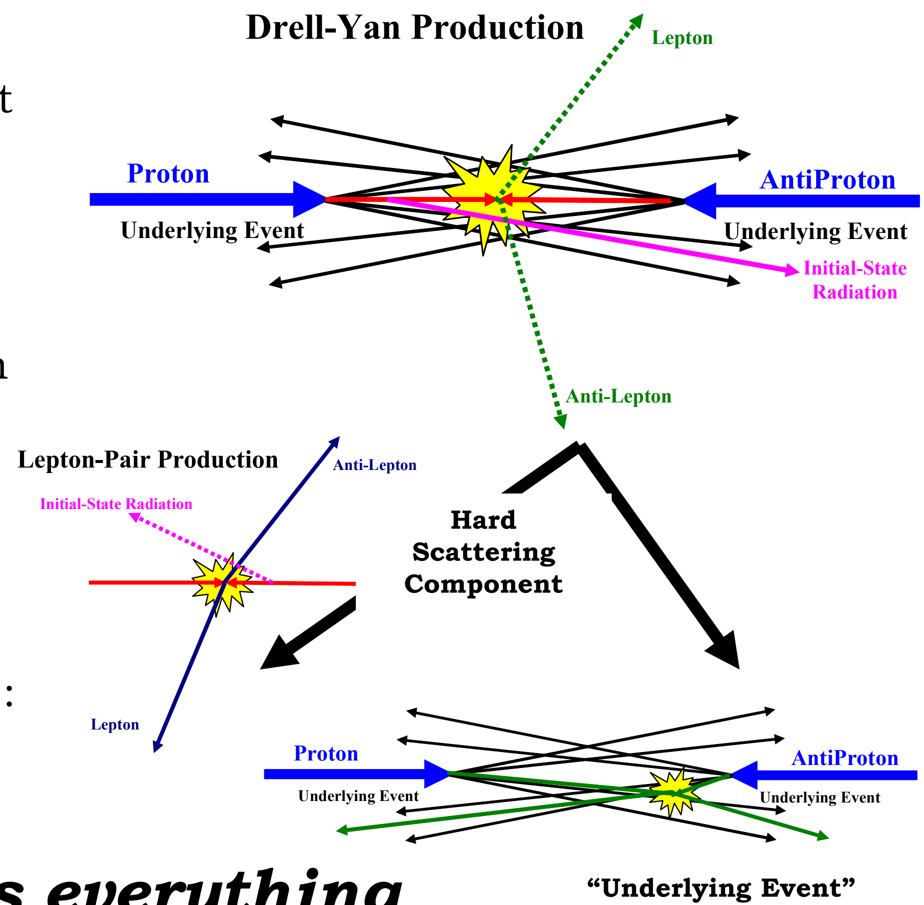
Quarks and Antiquarks annihilate to produce a virtual photon or Z^o , which then decays into a lepton pair ($\mu^+\mu^-$ or e^+e^-).





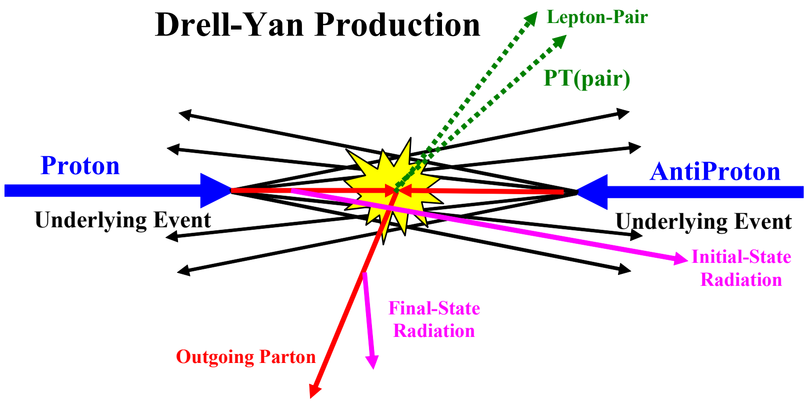
The Underlying Event in Drell-Yan Production

- 2-to-2 hard scattering results in two outgoing leptons which do not fragment into jets and can easily be removed.
- Initial state radiation (ISR) can produce additional jets, but there is no (colored) final state radiation (FSR).
- Beam-Beam Remnants (BBR) - particles that come from the breakup of the proton and antiproton.
- Multiple Parton Interactions (MPI): additional 2-to-2 scatterings within the same event.

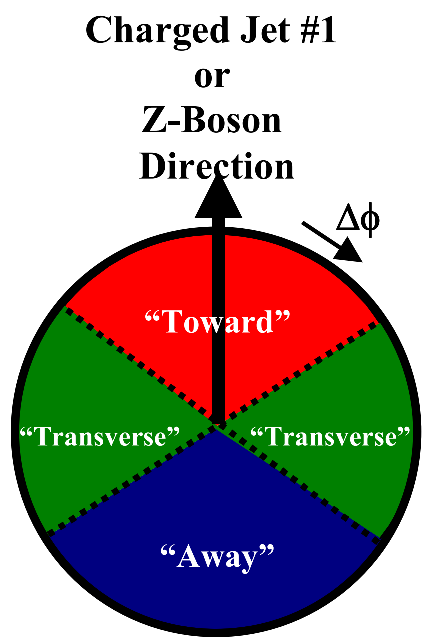


The underlying event is everything except the hard scattered components.

For High P_T Drell-Yan Production



Dividing up the Central Region



PT > 0.5 GeV $|\eta| < 1$

Azimuthal angle $\Delta\phi$ relative to the leading jet or Z boson.

We define -

$|\Delta\phi| < 60^o$ as "Toward"

$60^o < |\Delta\phi| < 120^o$ as "Transverse" and

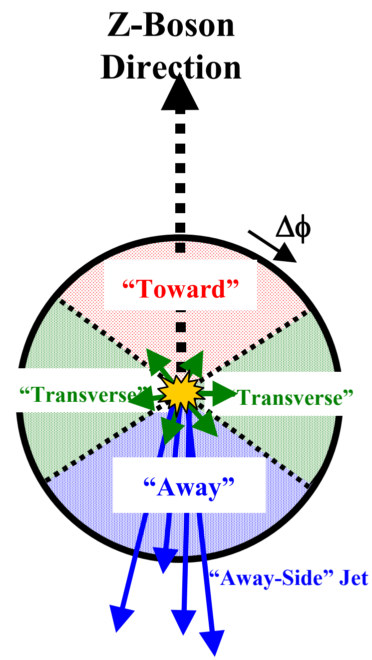
$|\Delta\phi| > 120^o$ as "Away"

Z-Boson Production at Tevatron

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

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

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

Observables

Observable	Particle Level	Detector Level
Lepton Pair P_T	P_T of the Lepton Pair.	P_T of the Lepton Pair, formed by at least one “Tight” Lepton.
No of Charged	Number of charged particles ($P_T > 0.5$ GeV/c, $\vert\eta\vert < 1$)	Number of “good” charged tracks ($P_T > 0.5$ GeV/c, $\vert\eta\vert < 1$)
P_T Sum	Scalar P_T sum of charged particles ($P_T > 0.5$ GeV/c, $\vert\eta\vert < 1$)	Scalar P_T sum of “good” charged tracks ($P_T > 0.5$ GeV/c, $\vert\eta\vert < 1$)
$< P_T >$	Average P_T of charged particles ($P_T > 0.5$ GeV/c, $\vert\eta\vert < 1$) Require at least 1 charged particle	Average P_T of “good” charged tracks ($P_T > 0.5$ GeV/c, $\vert\eta\vert < 1$) Require at least 1 charged particle
P_T Max	Maximum P_T of charged particle ($P_T > 0.5$ GeV/c, $\vert\eta\vert < 1$) Require at least 1 charged particle	Maximum P_T of “good” charged tracks ($P_T > 0.5$ GeV/c, $\vert\eta\vert < 1$) Require at least 1 “good” charged track

CDF Run 1 Tune

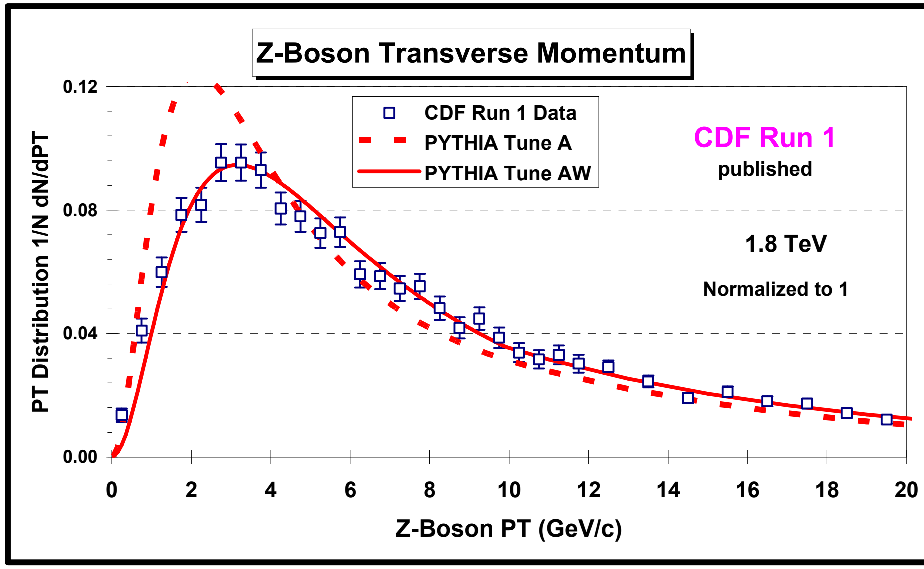
(PYTHIA 6.2 CTEQ5L)

UE Parameters

ISR Parameters

Intrensic KT

Parameter	Tune A	Tune AW
MSTP(81)	1	1
MSTP(82)	4	4
PARP(82)	2.0 GeV	2.0 GeV
PARP(83)	0.5	0.5
PARP(84)	0.4	0.4
PARP(85)	0.9	0.9
PARP(86)	0.95	0.95
PARP(89)	1.8 TeV	1.8 TeV
PARP(90)	0.25	0.25
PARP(62)	1.0	1.25
PARP(64)	1.0	0.2
PARP(67)	4.0	4.0
MSTP(91)	1	1
PARP(91)	1.0	2.1
PARP(93)	5.0	15.0



Shows the Run 1 Z-boson p_T distribution compared with PYTHIA Tune A and PYTHIA Tune AW.

Both tunes reveal a remarkably good agreement of the data and PYTHIA for underlying events.

Tuning PYTHIA

Technically, PYTHIA parameters can be varied independently of each other, but the physical requirement of a sensible description of a set of data leads to correlations and anticorrelations between the parameters. Hence the need to produce tunes, not of one parameter at a time, but simultaneously for a group of them.

To bring PYTHIA in good agreement with the data -

- The initial state radiation had to be significantly intensified.
- The dependence of the probability of multi-parton (secondary) interactions on the impact parameter had to be smoothed out.
- Probability of di-gluon production in multi-parton secondary interactions had to be substantially enhanced over di-quark production.
- The probability of color connections of products of secondary interactions with p¯p-remnants had to be increased.

Soft QCD phenomena in events with high-ET jets at tevatron - Andrey Korytov, Eur Phys J C 33, s01, s425–s426 (2004)

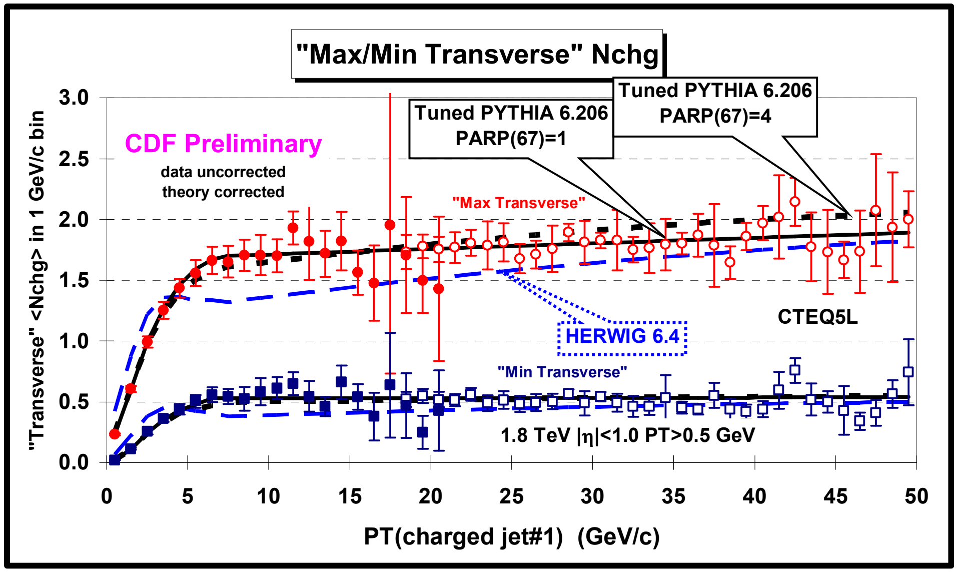
Goal of the Analysis

The goal of the analysis is 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).

Steps Are …

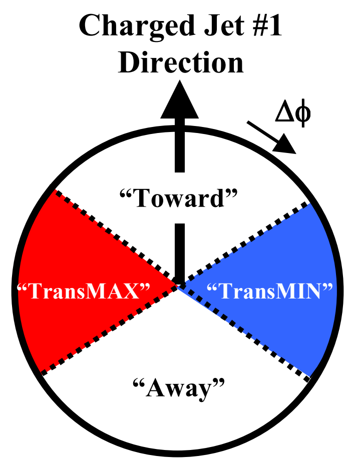
1. Calculate the observables by Monte Carlo event generator in particle level and in (by running through CDFSIM) detector level.
2. Correct the observables back to particle level in real data by calculating the correction factor from Monte Carlo.
3. Compare with different Monte Carlo event generators (PYTHIA, HERWIG …).

CDF Run 2 Leading Jet "Underlying Event" Results



Two "Transverse" regions: "transMAX", "transMIN".

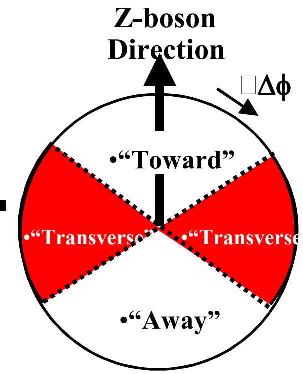
PYTHIA Tune A does a fairly good job fitting the PTsum density in the "transverse" region. HERWIG (without MPI) does a poor job.

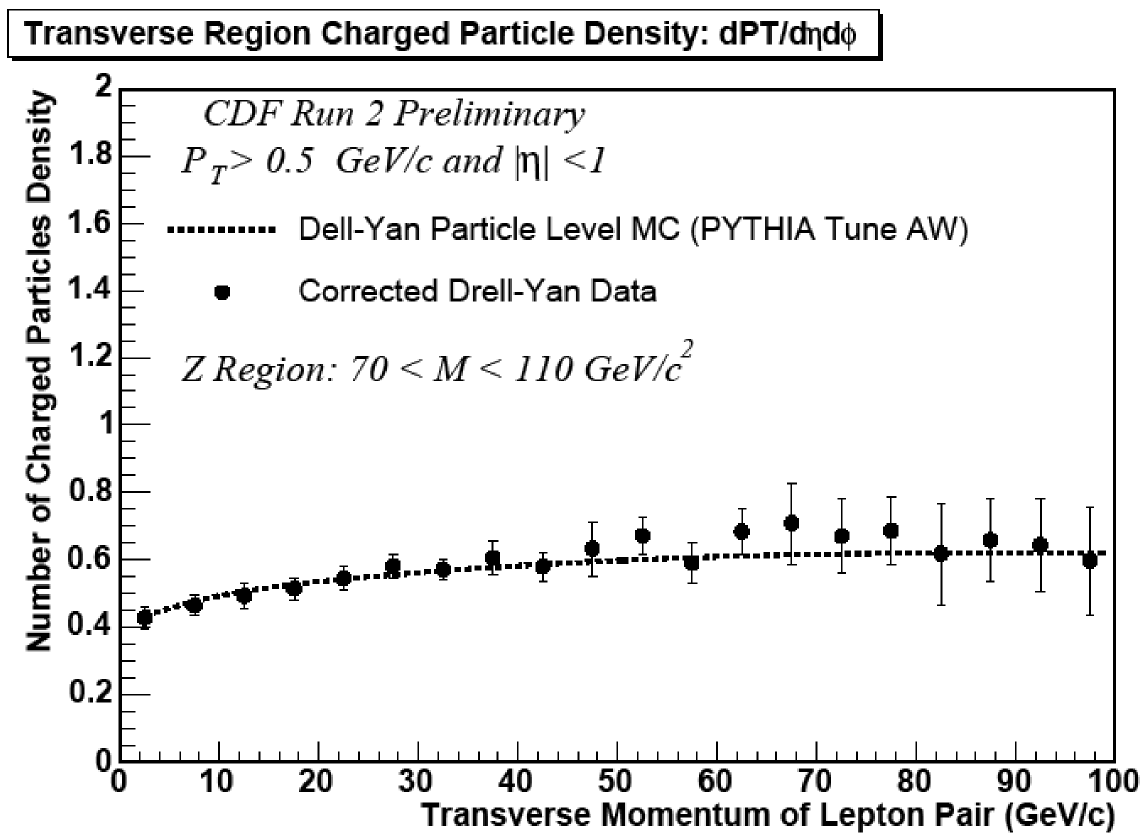


Our Analysis

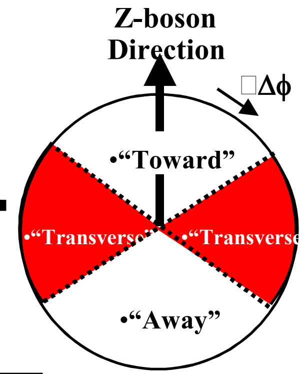
- High P_T Electron and Muon Data, yielding ~50,000 electron and muon (oppositely charged) pairs each, passing all selection cuts.
- Charged Particles with P_T > 0.5 GeV/c and $|\eta| < 1$
- Using events with the lepton pair invariant mass in the Z region: 70 GeV/c^2 < M(ll) < 110 GeV/c^2
- Errors coming both from statistical and systematic (due to lepton selection and charged particle selection) sources.

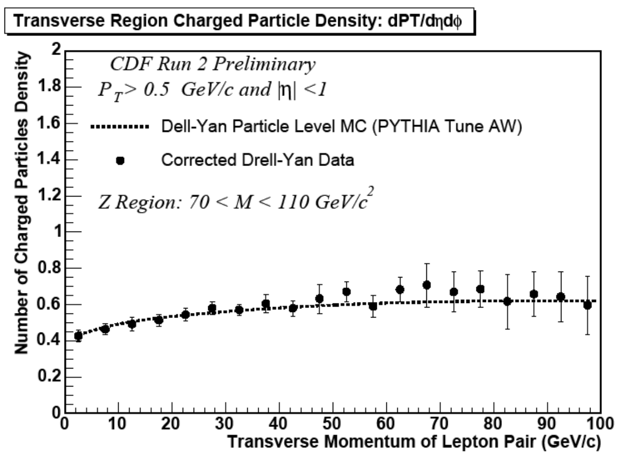
Transverse Region

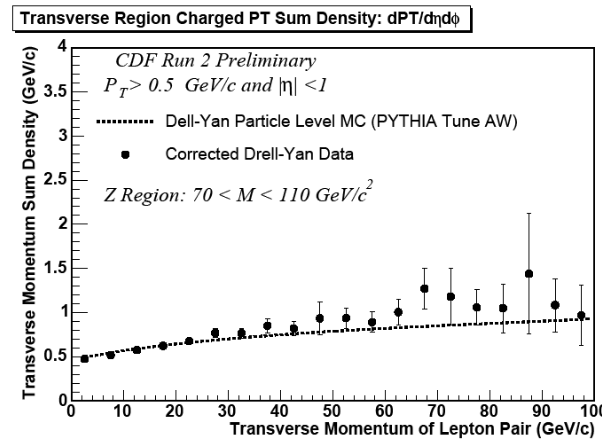


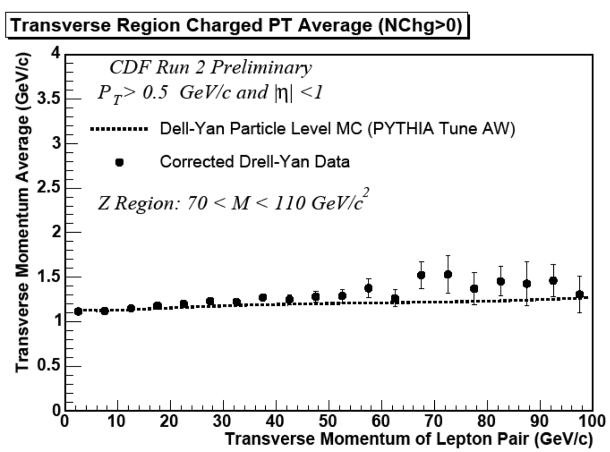


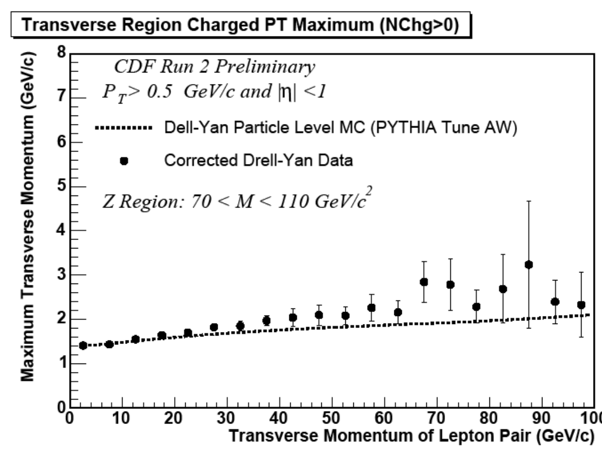
Transverse Region



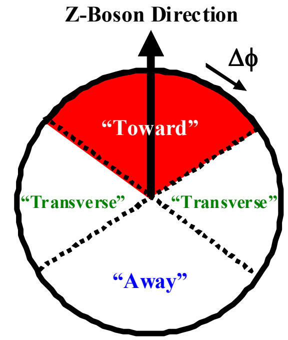


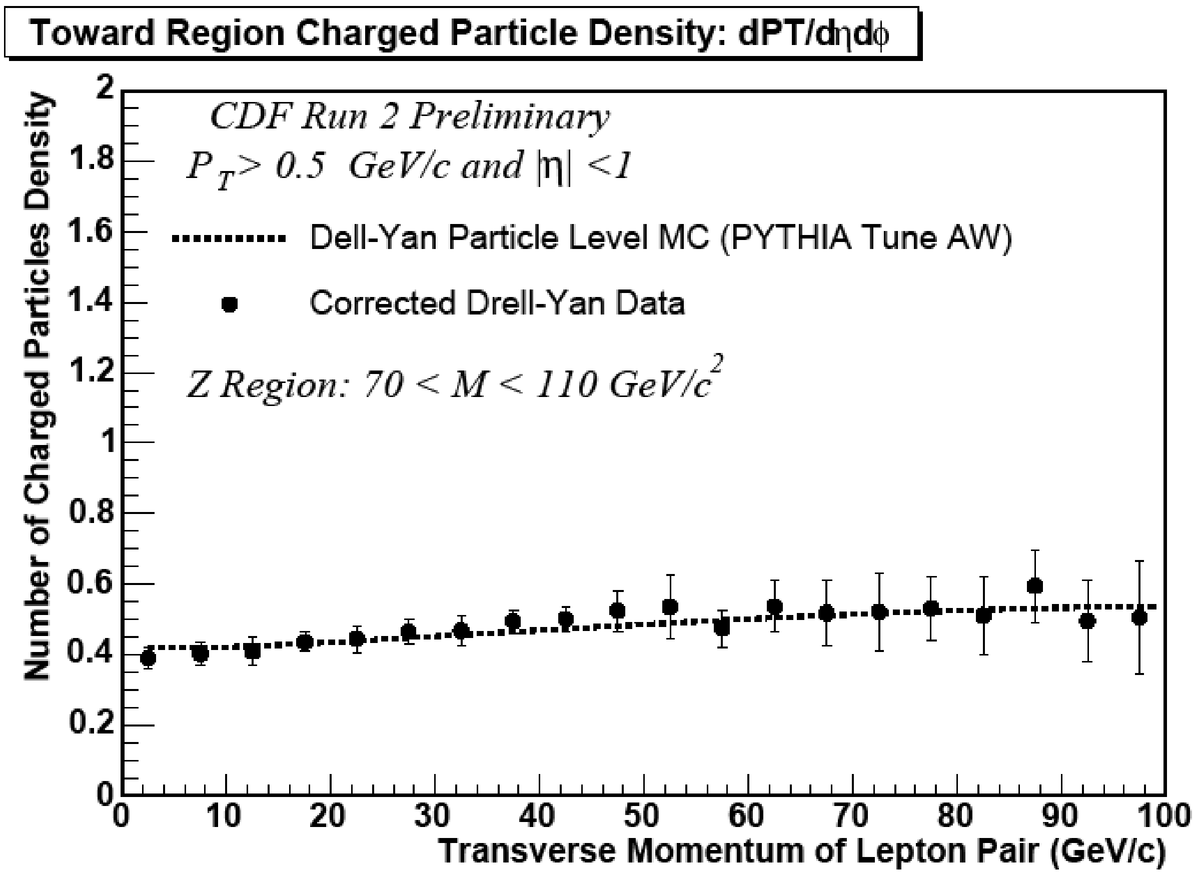




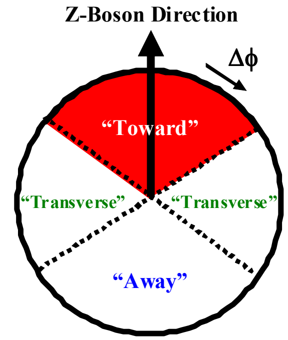


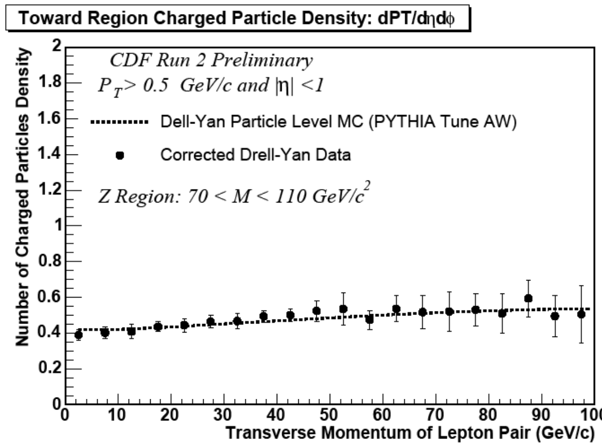
Toward Region

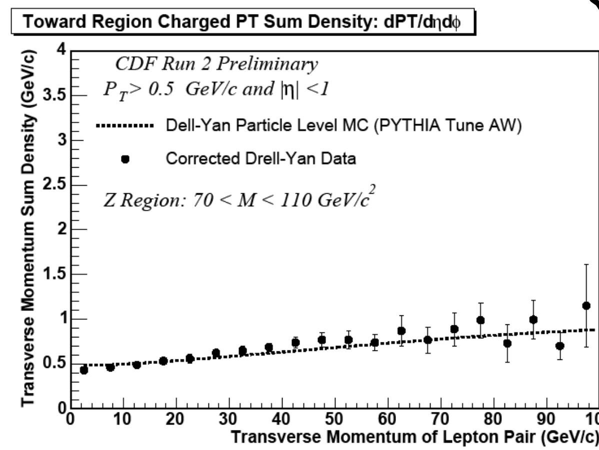


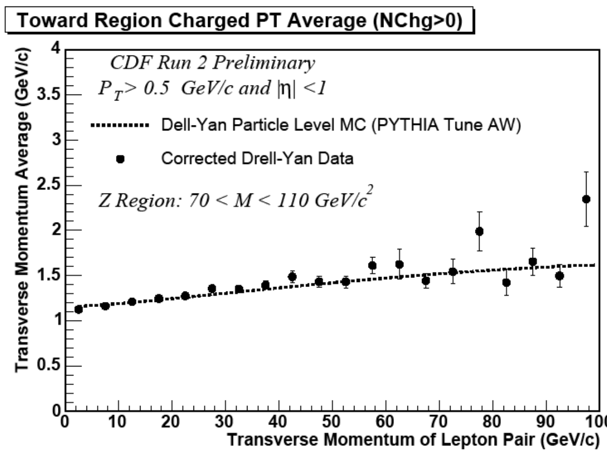


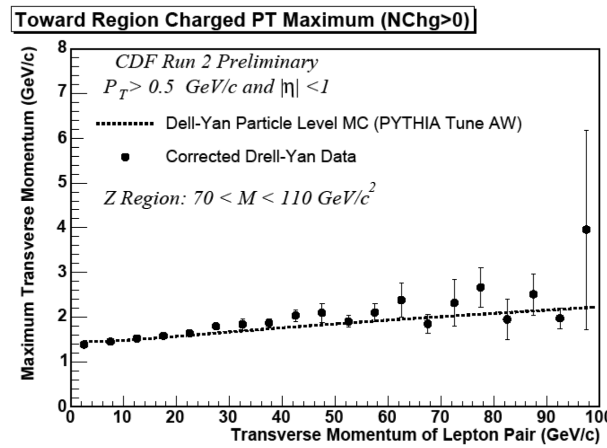
Toward Region











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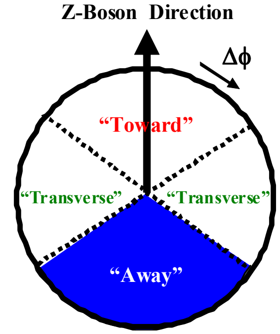
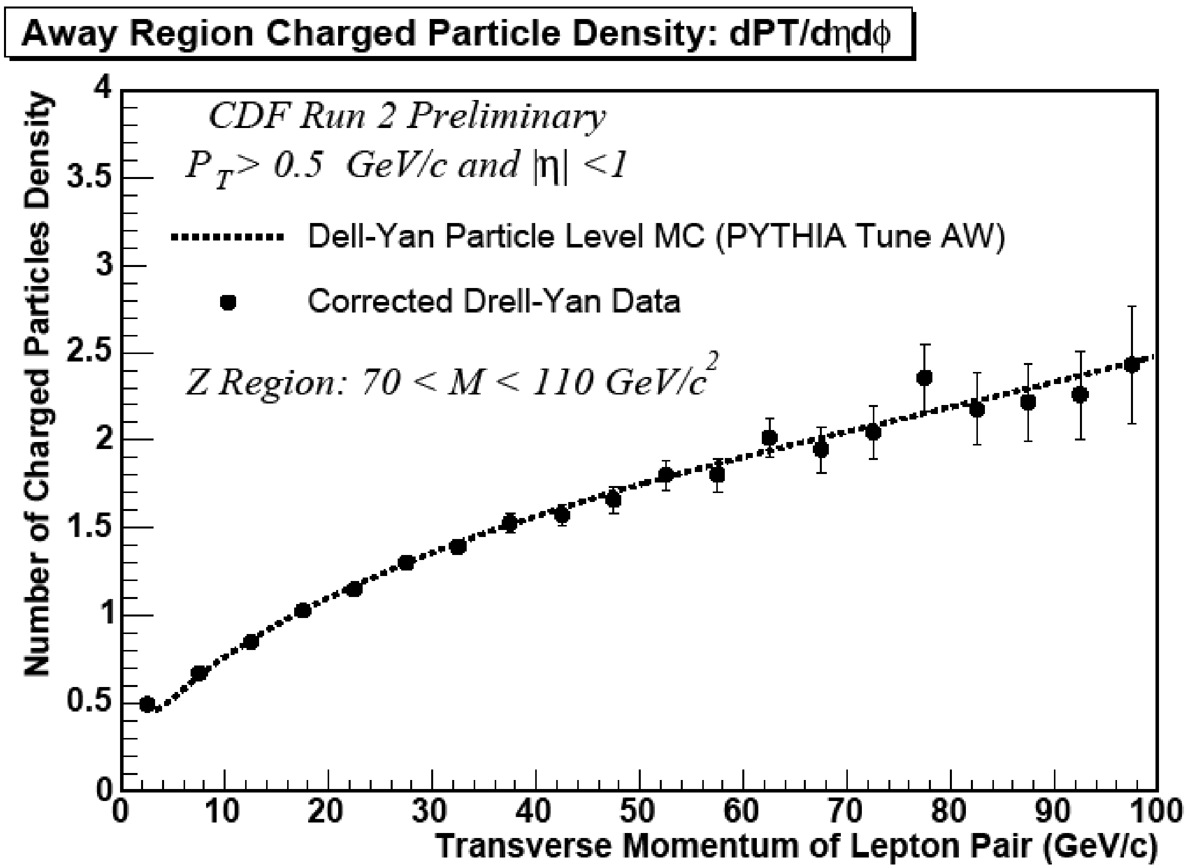
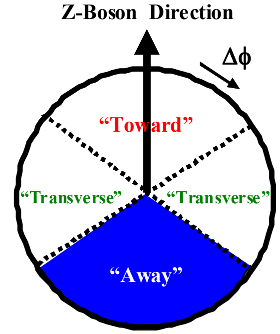
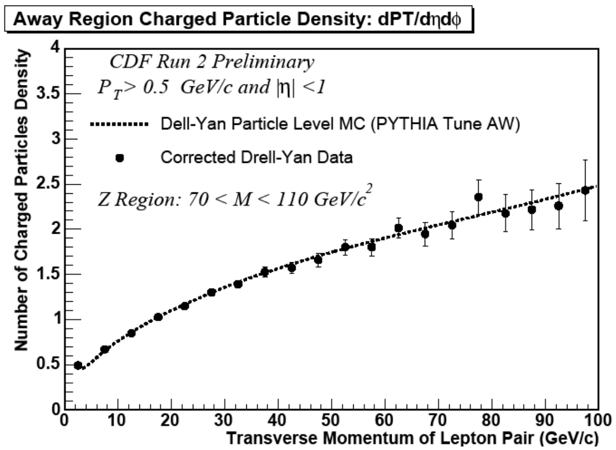
Away Region

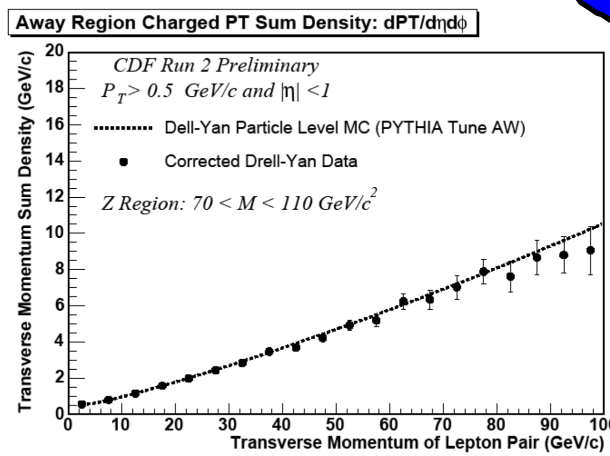

Z-Boson Direction
Δϕ
"Toward"
"Transverse"
"Transverse"
"Away"

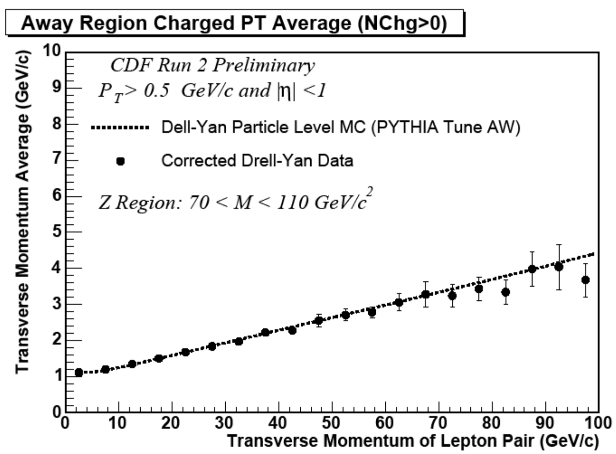

Away Region Charged Particle Density: dPT/dηdϕ
CDF Run 2 Preliminary
P_T > 0.5 GeV/c and |η| < 1
Dell-Yan Particle Level MC (PYTHIA Tune AW)
Corrected Drell-Yan Data
Z Region: 70 < M < 110 GeV/c²
Number of Charged Particles Density
Transverse Momentum of Lepton Pair (GeV/c)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
10
20
30
40
50
60
70
80
90
100

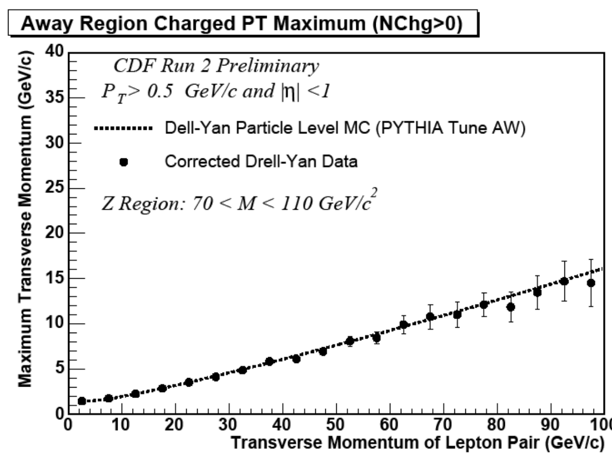
Away Region


Z-Boson Direction
Δϕ
“Toward”
“Transverse”
“Transverse”
“Away”

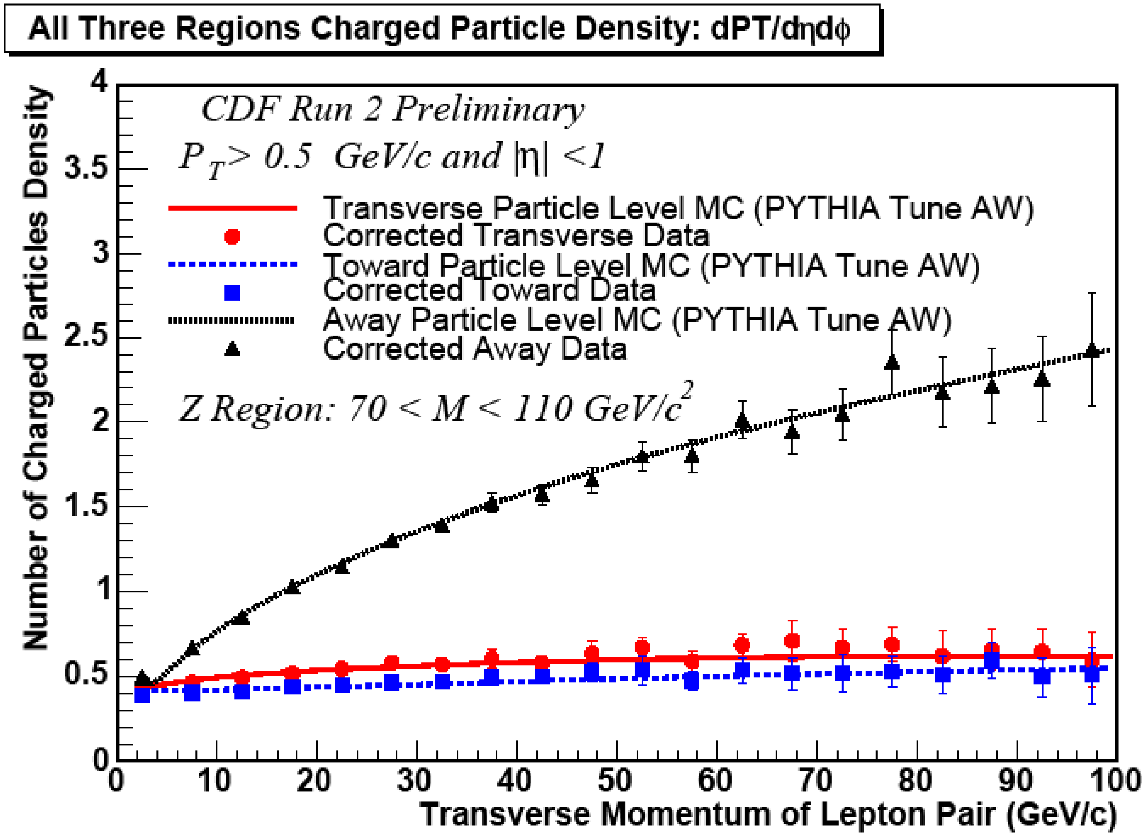

Away Region Charged Particle Density: dPT/dηdϕ
CDF Run 2 Preliminary
P_T > 0.5 GeV/c and |η| <1
Dell-Yan Particle Level MC (PYTHIA Tune AW)
Corrected Drell-Yan Data
Z Region: 70 < M < 110 GeV/c^2
Number of Charged Particles Density
Transverse Momentum of Lepton Pair (GeV/c)


Away Region Charged PT Sum Density: dPT/dηdϕ
CDF Run 2 Preliminary
P_T > 0.5 GeV/c and |η| <1
Dell-Yan Particle Level MC (PYTHIA Tune AW)
Corrected Drell-Yan Data
Z Region: 70 < M < 110 GeV/c^2
Transverse Momentum Sum Density (GeV/c)
Transverse Momentum of Lepton Pair (GeV/c)

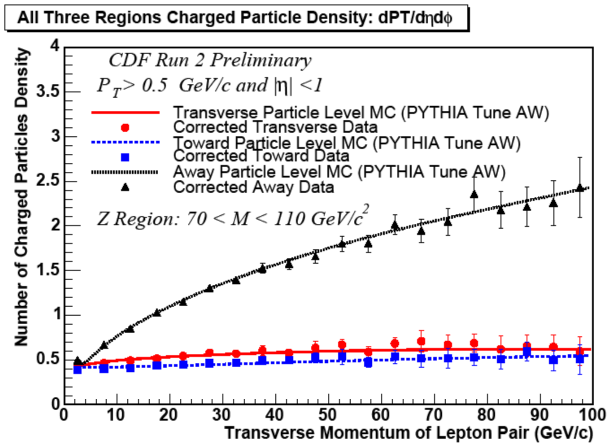

Away Region Charged PT Average (NChg>0)
CDF Run 2 Preliminary
P_T > 0.5 GeV/c and |η| <1
Dell-Yan Particle Level MC (PYTHIA Tune AW)
Corrected Drell-Yan Data
Z Region: 70 < M < 110 GeV/c^2
Transverse Momentum Average (GeV/c)
Transverse Momentum of Lepton Pair (GeV/c)

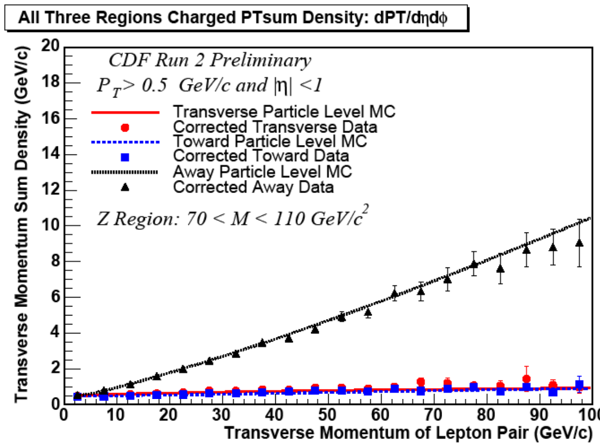

Away Region Charged PT Maximum (NChg>0)
CDF Run 2 Preliminary
P_T > 0.5 GeV/c and |η| <1
Dell-Yan Particle Level MC (PYTHIA Tune AW)
Corrected Drell-Yan Data
Z Region: 70 < M < 110 GeV/c^2
Maximum Transverse Momentum (GeV/c)
Transverse Momentum of Lepton Pair (GeV/c)

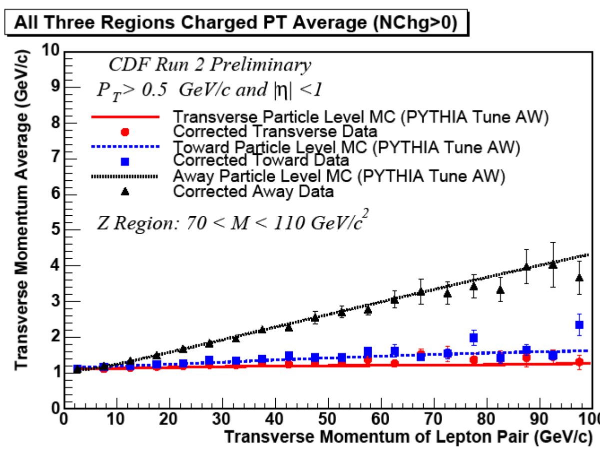
Overlaying All Regions

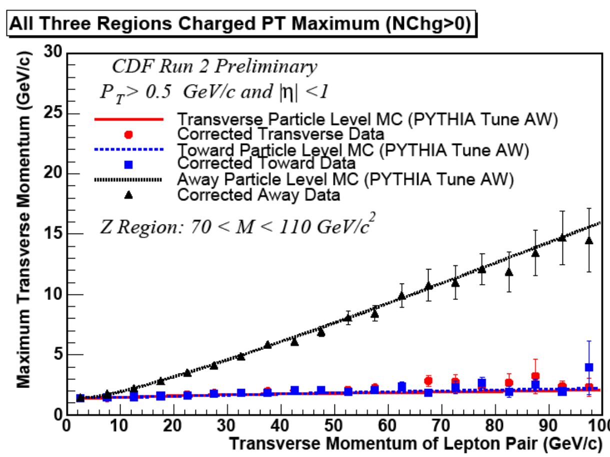


Overlaying All Regions

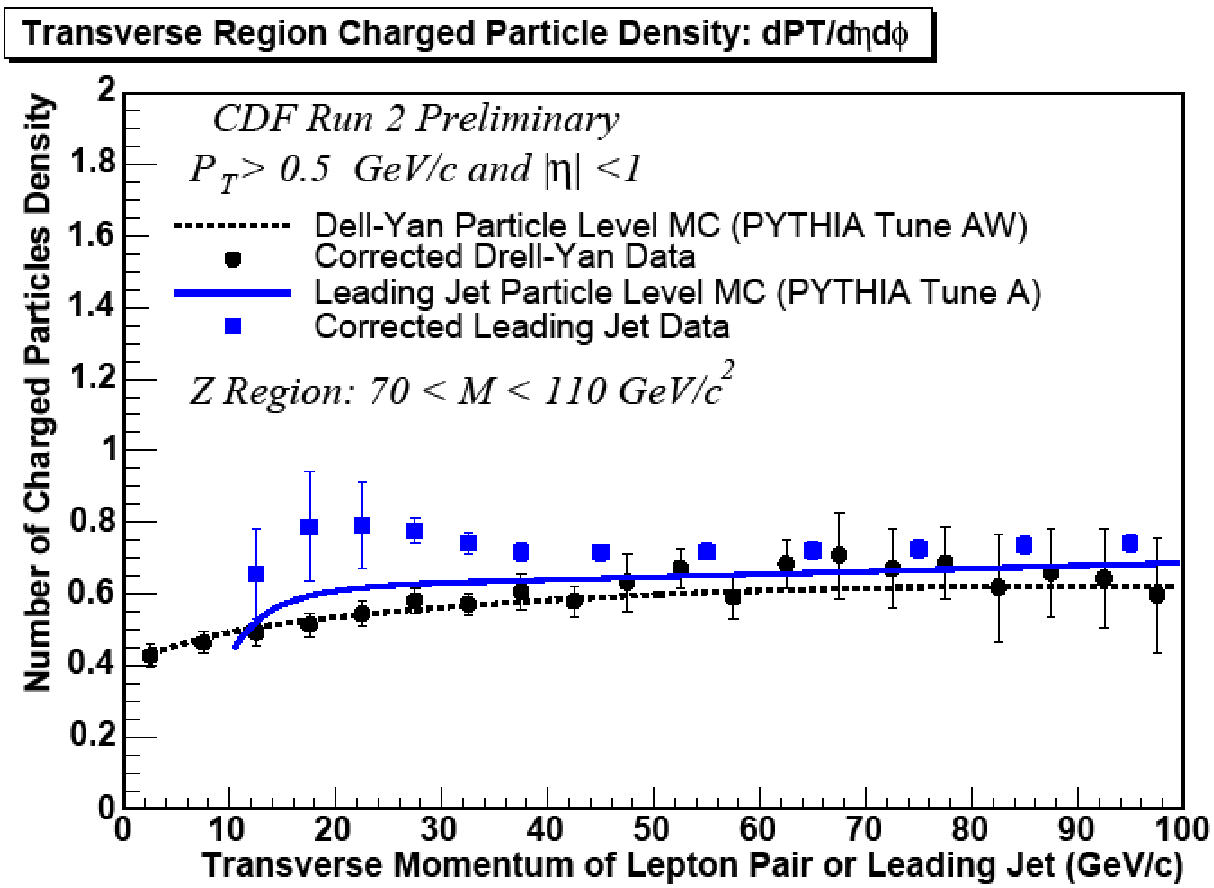




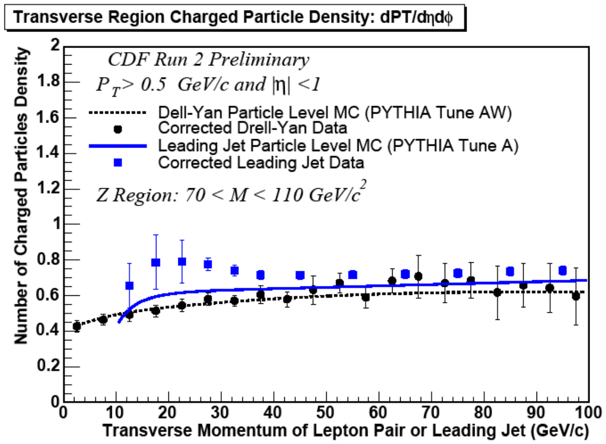


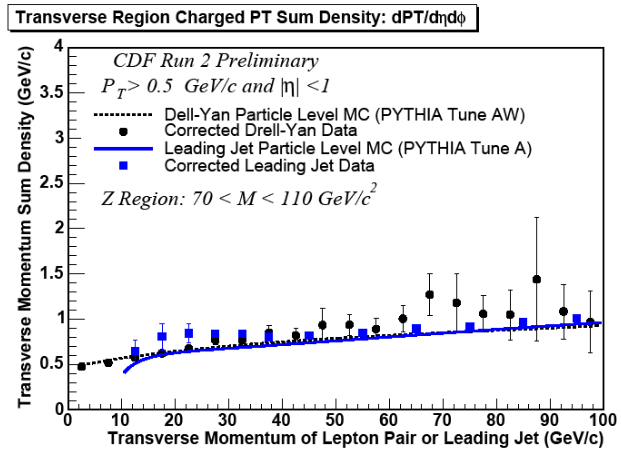


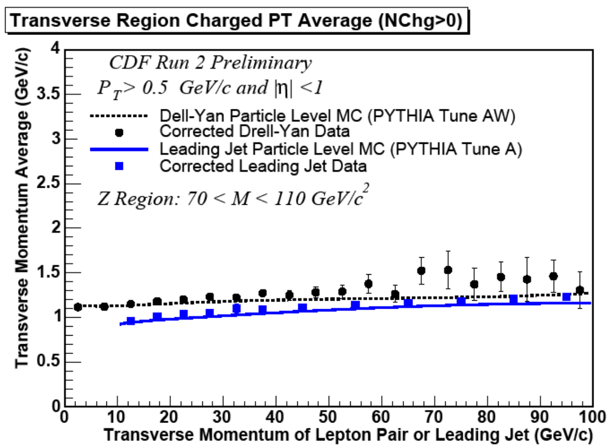
Comparison with Jet Transverse Region

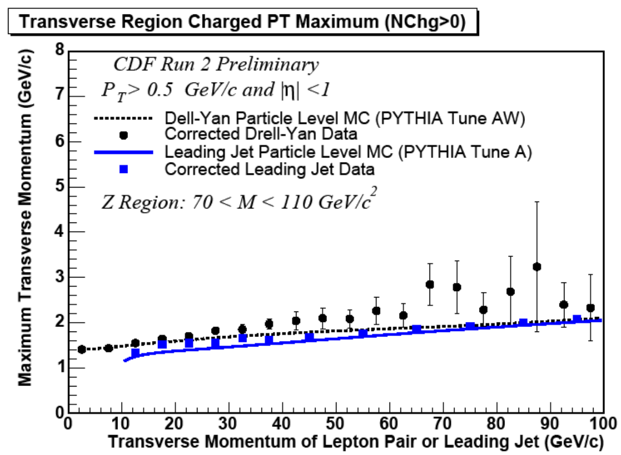


Comparison with Jet Transverse Region

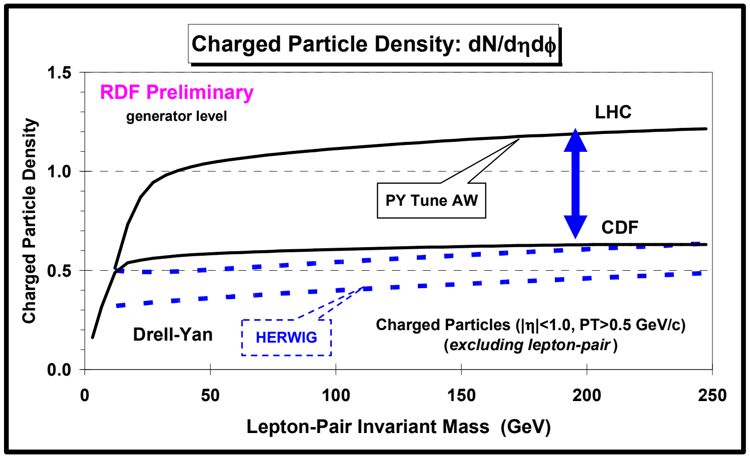


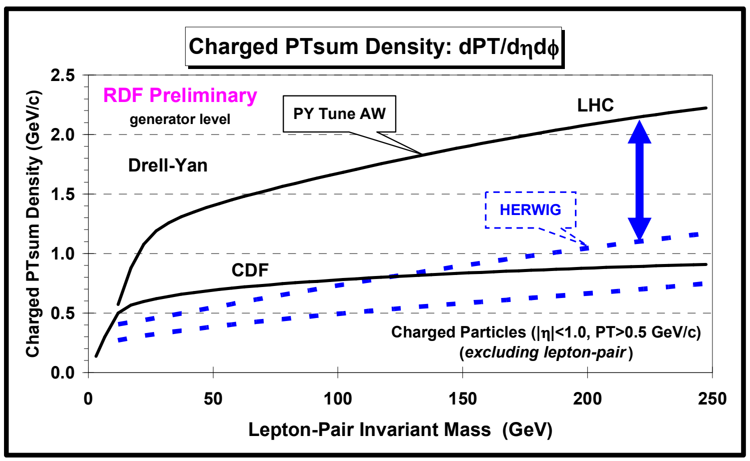






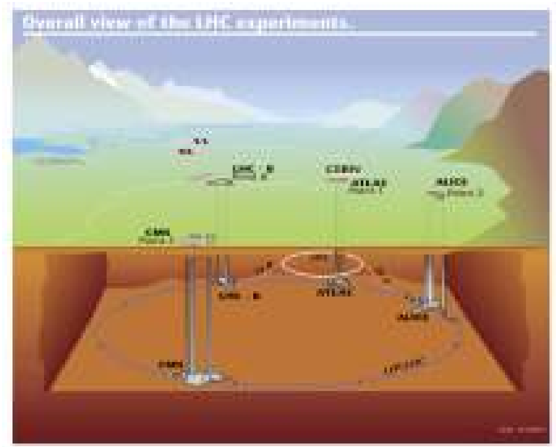
The “Underlying Event” in Drell-Yan Production in LHC





Charged particle density and Charged Ptsum density versus the lepton-pair invariant mass at at 1.96 TeV versus at 14 TeV for PYTHIA Tune AW and HERWIG (*without MPI*). (Generator Level)

“Underlying event” much more active at the LHC!



Summary

- Observed excellent agreement with PYTHIA Tune AW predictions.

- Close match with leading jet underlying event results – perhaps indicating an universality of hard scattering underlying event.

- One will learn a lot about the energy dependence of the “underlying event” (i.e. multiple parton interactions) by comparing the Tevatron results with the LHC. Early analyses in the LHC would be geared towards tuning the QCD Monte Carlo models.