Electroweak Physics with CDF

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For the CDF Collaboration
EPS - Aachen
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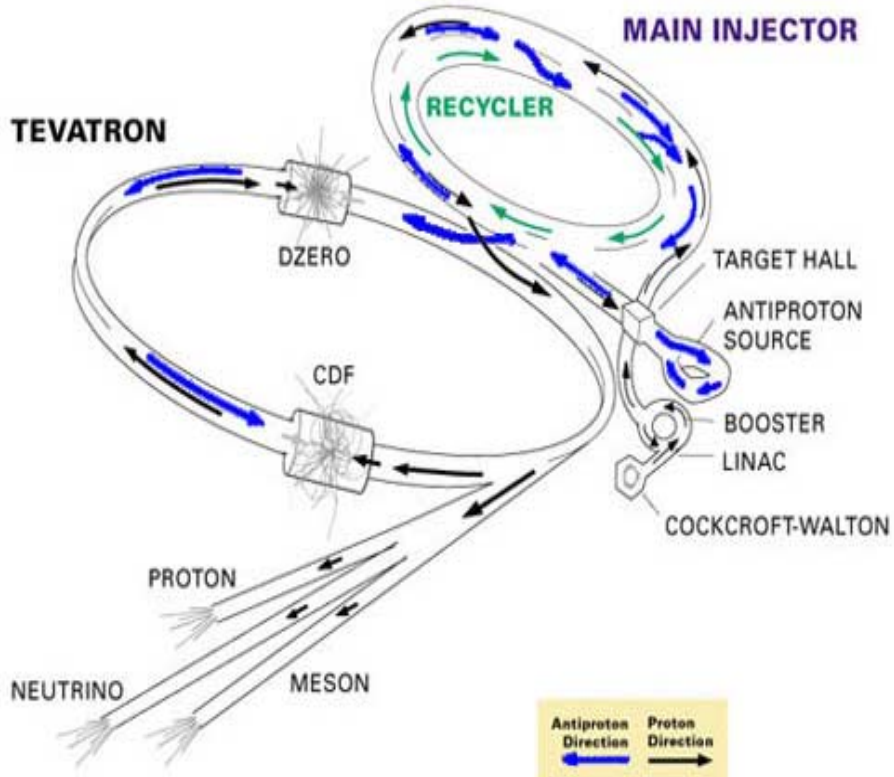
Outline:

- The Tevatron and CDF Upgrade
- Ewk Physics:
  - Baseline Measurements (W/Z)
  - Precision Measurements
- Perspectives

Fermilab Tevatron Upgrade (RunII)



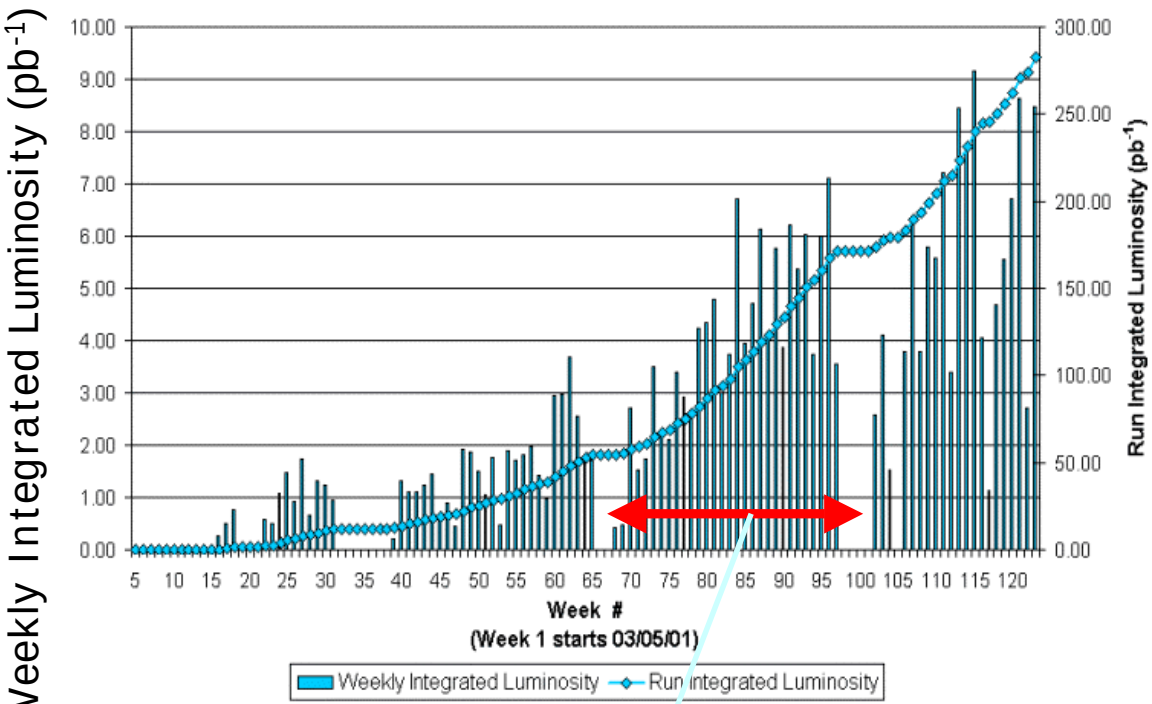
$\sqrt{s}_{\text{RunI}} = 1.8$ TeV

Now $\sqrt{s}_{\text{RunII}} = 1.96$ TeV

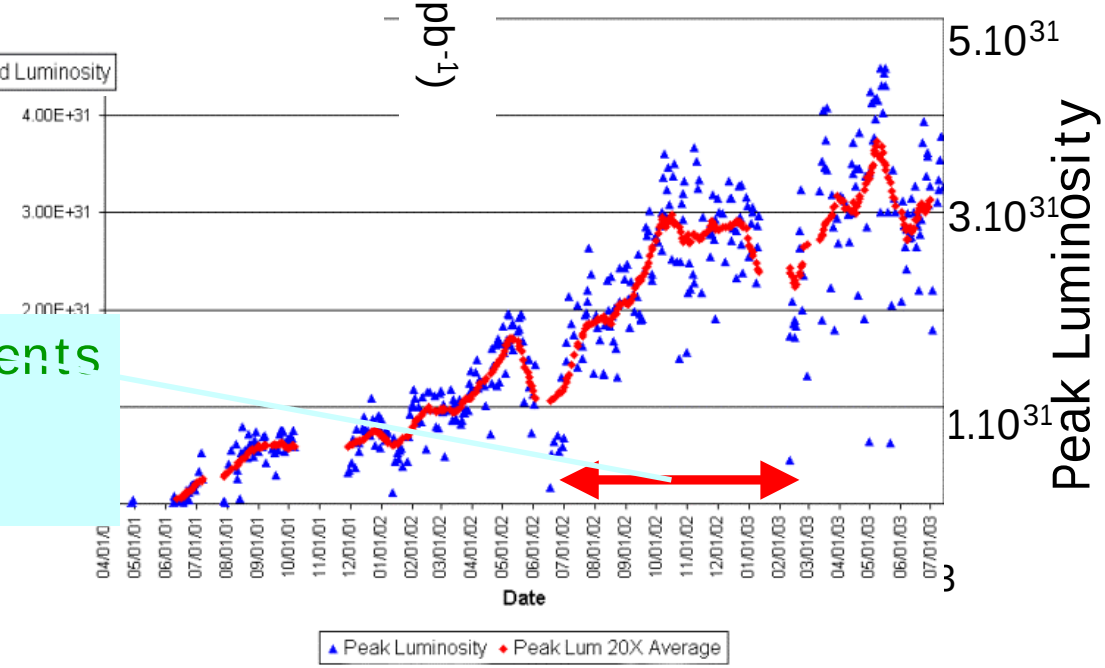
- **New Main Injector:**
  - **Improve p-bar production**
- **Recycler ring:**
  - **Reuse p-bars**

Not used yet!

Tevatron Performances



- Lum at RunI: 110 pb^{-1}
- 2003 Goals:
  - ~200 pb^{-1} for Fall
  - 10 pb^{-1}/week by the end of the year
- Achieved
  - ~9.2 pb^{-1} best week



Used for today's measurements

$$\int L dt \cong (50-70) pb^{-1}$$

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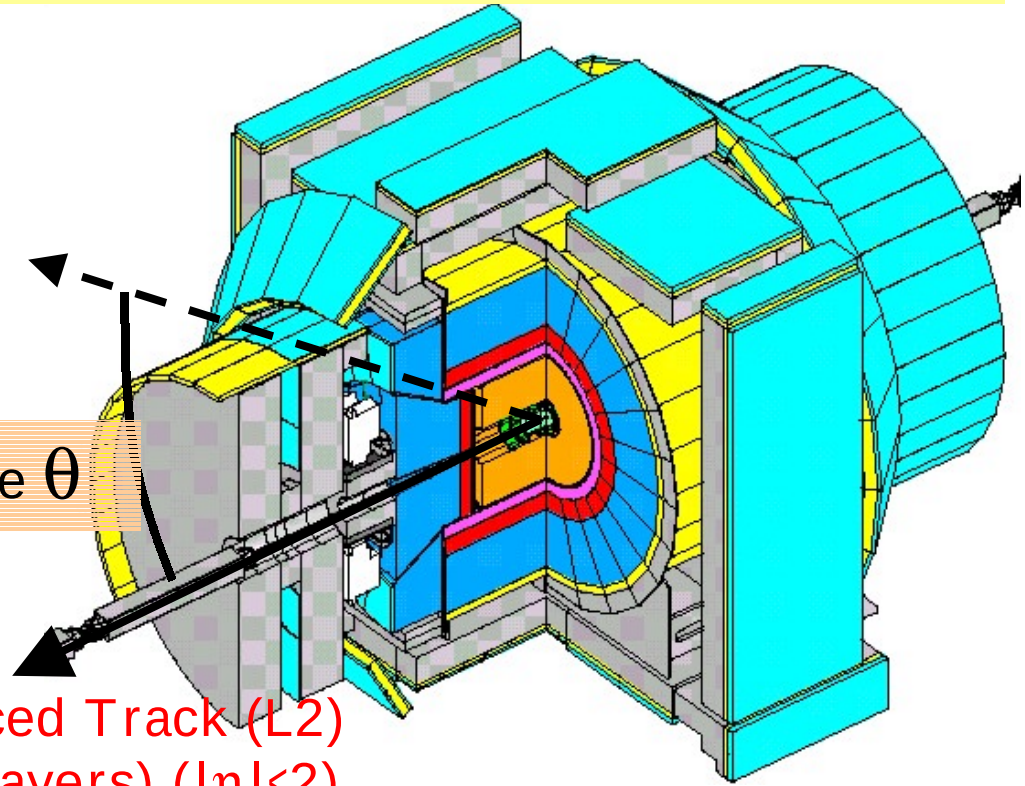
CDF RunII Detector

From RunI:
- Solenoid
- Muon system
- Central Calorimeter

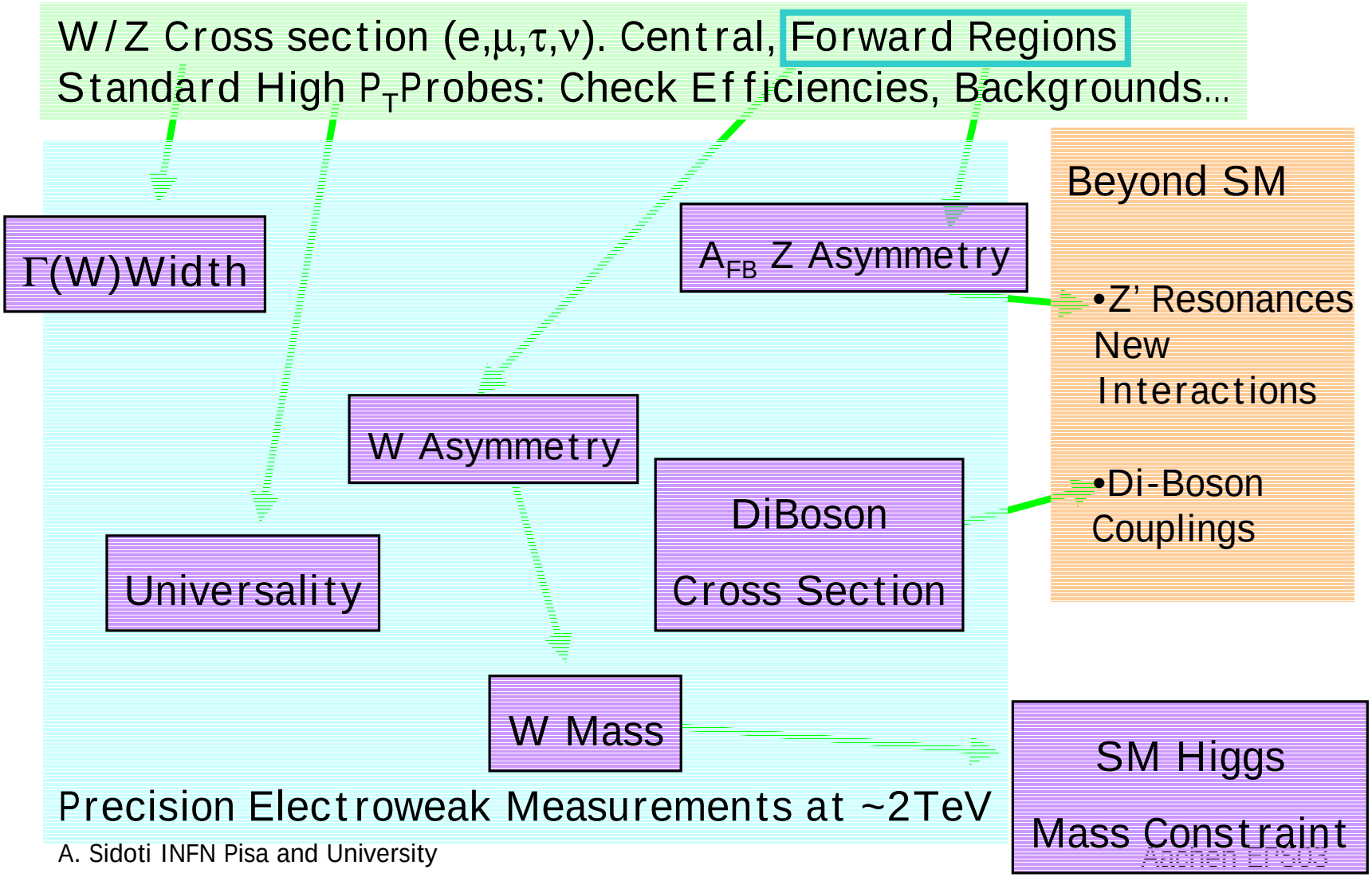


For RunII:
- Front-end DAQ
- Trigger
  Track (L1) and Displaced Track (L2)
- New Silicon Tracker (8 Layers) (|η|<2)
- Central Outer Tracker
- TOF
- Plug Calorimeters
- Extended Muon Coverage

$$\eta = -\log(\tanh(\theta/2))$$

Electron Id up to |η|~2.8
Muon Id up to |η|~1.5

Electroweak Physics at CDF: RoadMap

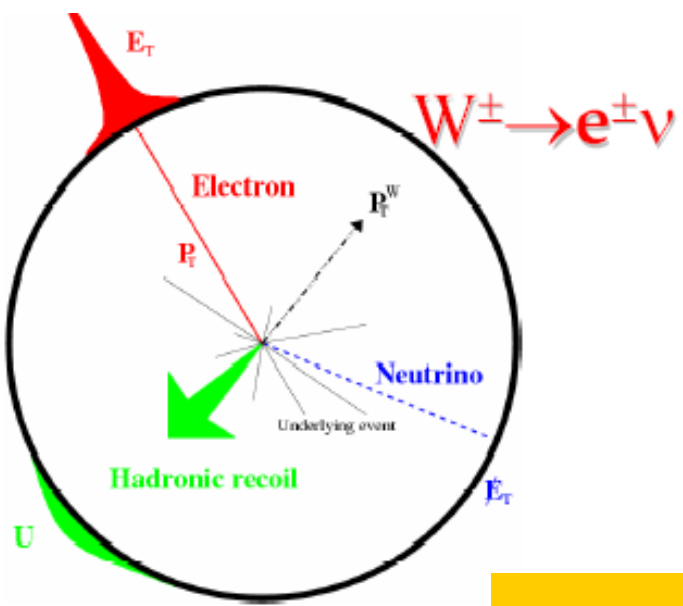


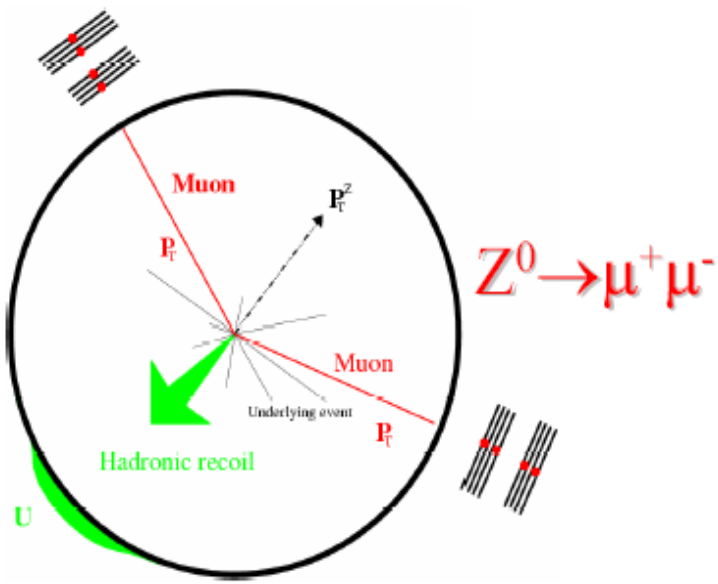
Boson Signatures at CDF

Electron:
EM Calorimeters
High Pt (Track)
Isolated

Muons:
Muon Detectors
High P_T
Isolated

Neutrinos:
Large Missing Energy
Only Transverse ($\not{E}_T$ or Met)





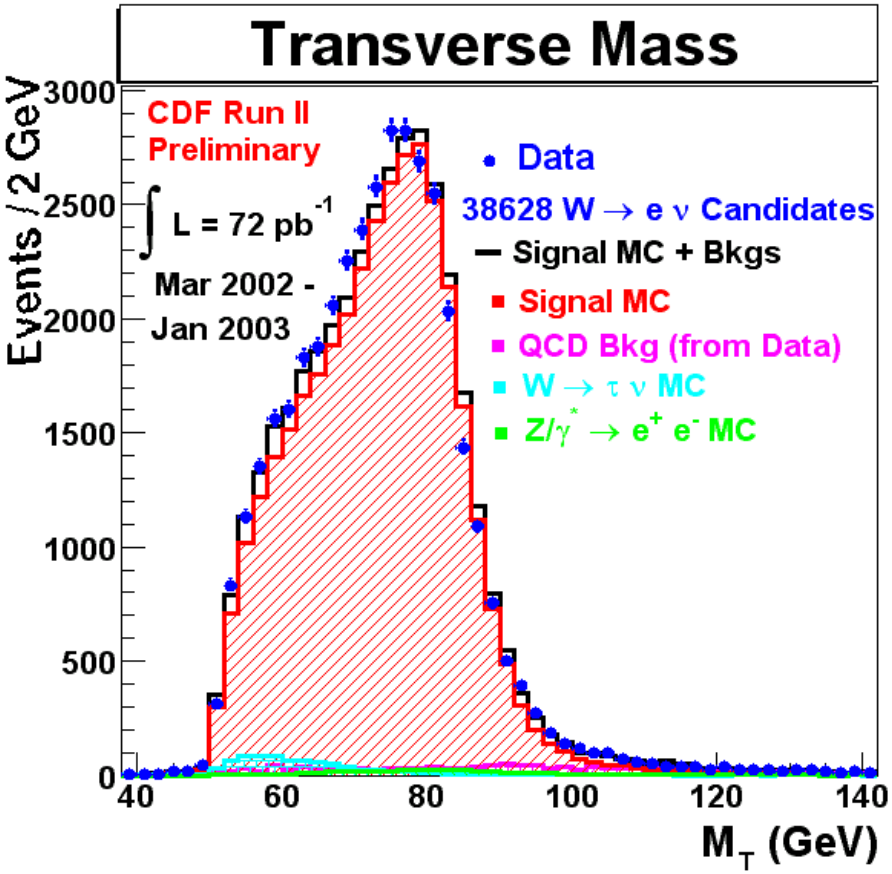
Z Signature: Two Isolated Leptons (diff charge)

W Signature: Isolated Lepton and $\not{E}_T$

W Cross Sections(e,μ)

$$M_T = \sqrt{2E_T E_\nu (1-\cos(\Delta\phi_{(e,\nu)}))}$$

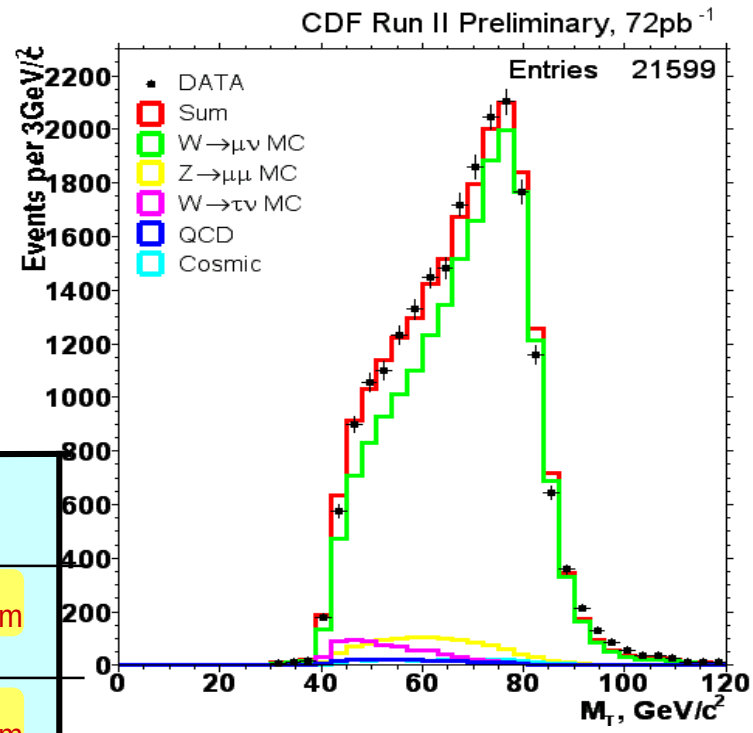
Electron-Channel



- **Clean Signature**
  - High E_T
  - Isolated lepton
  - Missing E_T
- High σ & S/B

$$\int Ldt = 72.0 \pm 4.3 pb^{-1}$$

Muon-Channel

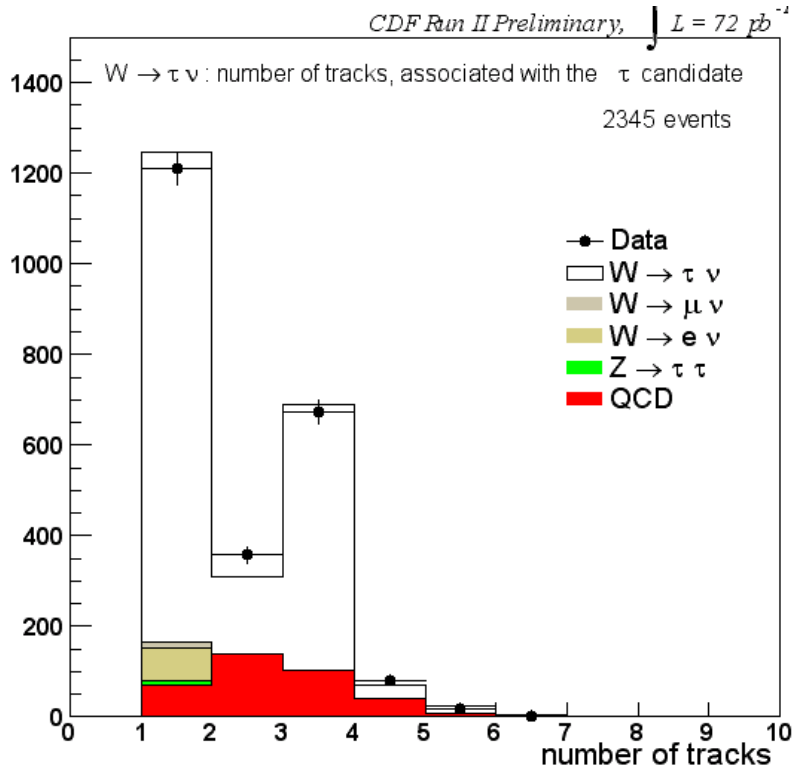


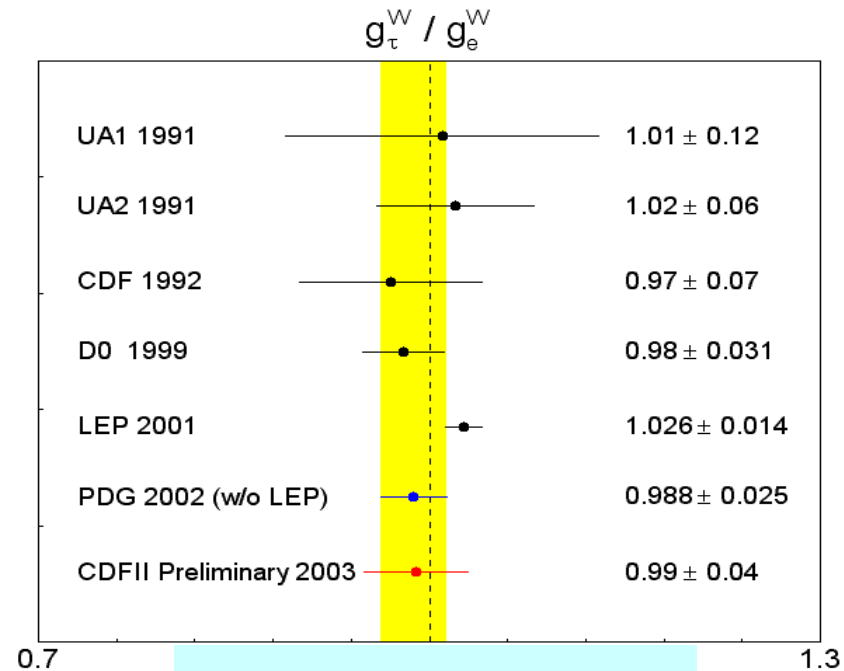
	Events	Back.	σ•B(W-->lν$_l$) (nb)
e	38625	6%	**2.64**±0.01$_{stat}$±0.09$_{sys}$±0.16$_{lum}$
μ	21599	11%	**2.64**±0.02$_{stat}$±0.12$_{sys}$±0.16$_{lum}$

W Cross Sections (τ)

Hadronic tau decays

τ_h = narrow isol. jet
+ low trk mult. (1 or 3)
+ M(vis)<M_τ





Lepton Universality

σ.BF(W->$\tau\nu$)=$2.62 \pm 0.07_{(stat)} \pm 0.21_{(syst)} \pm 0.16_{(lum)}$nb

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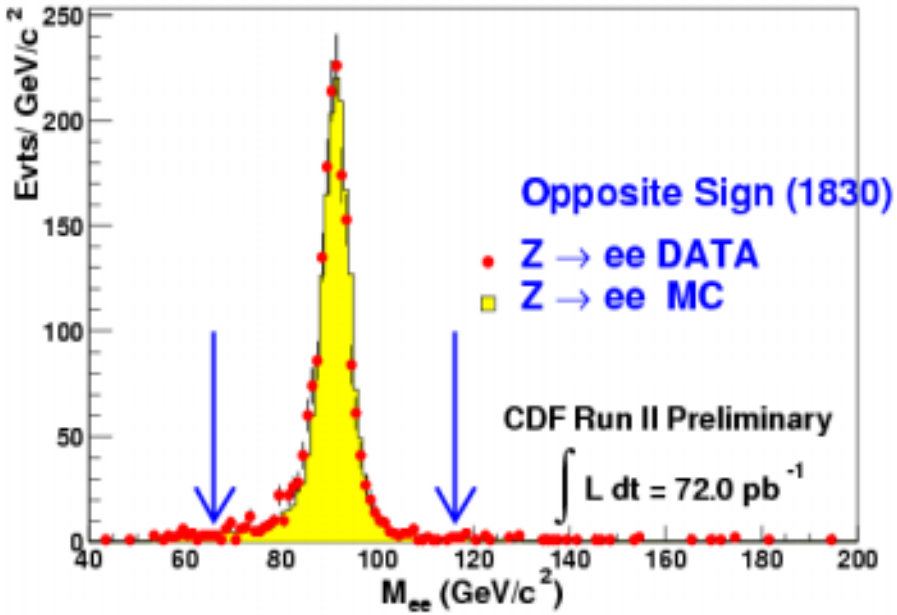
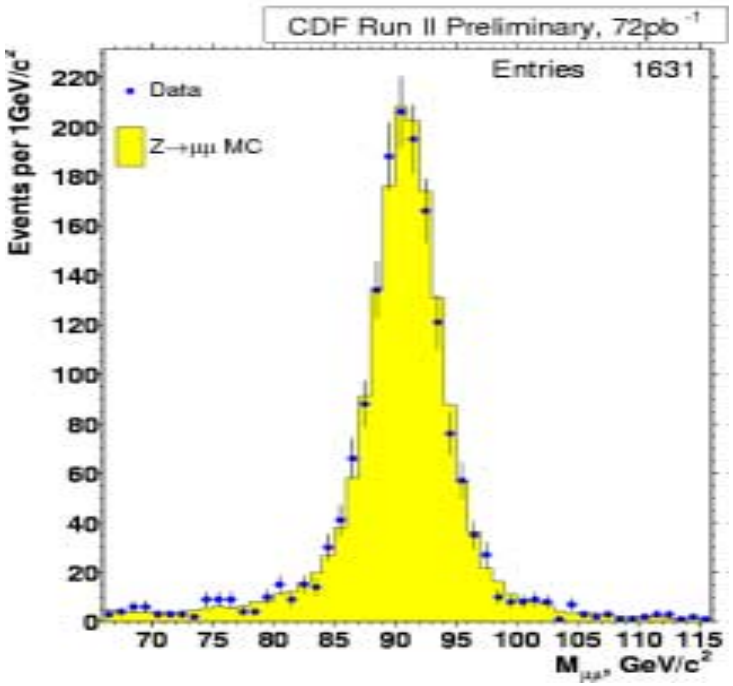
Z Cross Sections(e,μ)

Electron Channel



Muon Channel



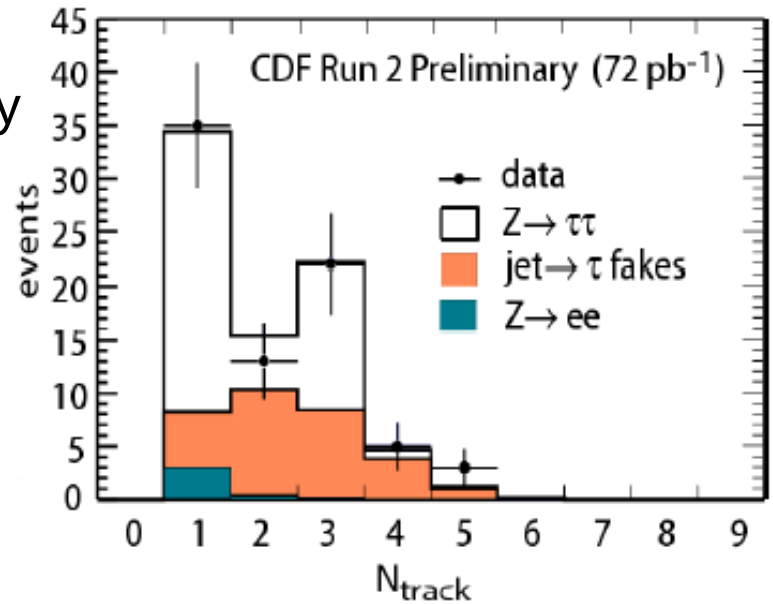
- **Clean Signature**
- Two High E_T Isolated lepton
- Opposite Charge
- High σ & S/B

$\int Ldt = 72.0 \pm 4.3 pb^{-1}$

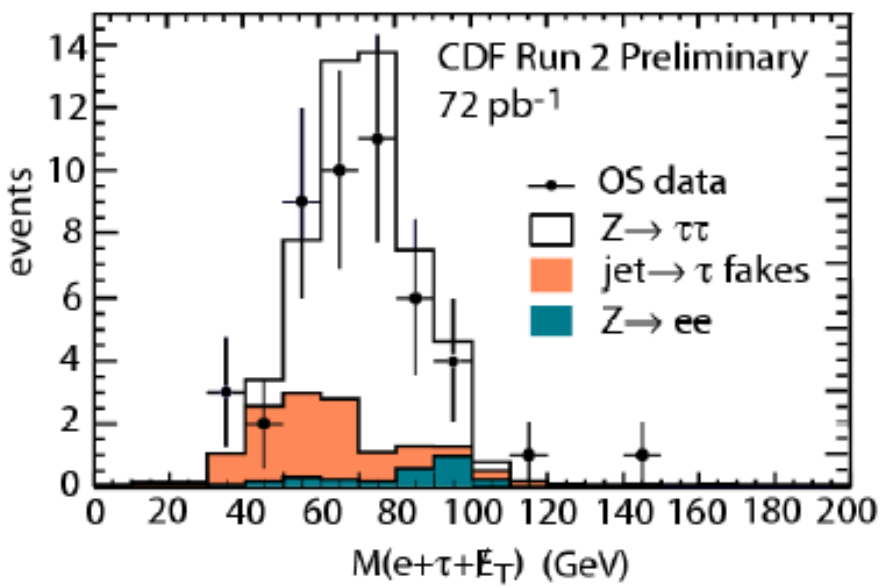
	Events	Back.	σ•B(Z-->ll) (pb)
e	1830	0.6%	$\mathbf{267} \pm 6_{stat} \pm 15_{sys} \pm 16_{lum}$
μ	1631	0.9%	$\mathbf{246} \pm 6_{stat} \pm 12_{sys} \pm 15_{lum}$

Z Cross Section (τ)

Triggering on τ from hadronic decay



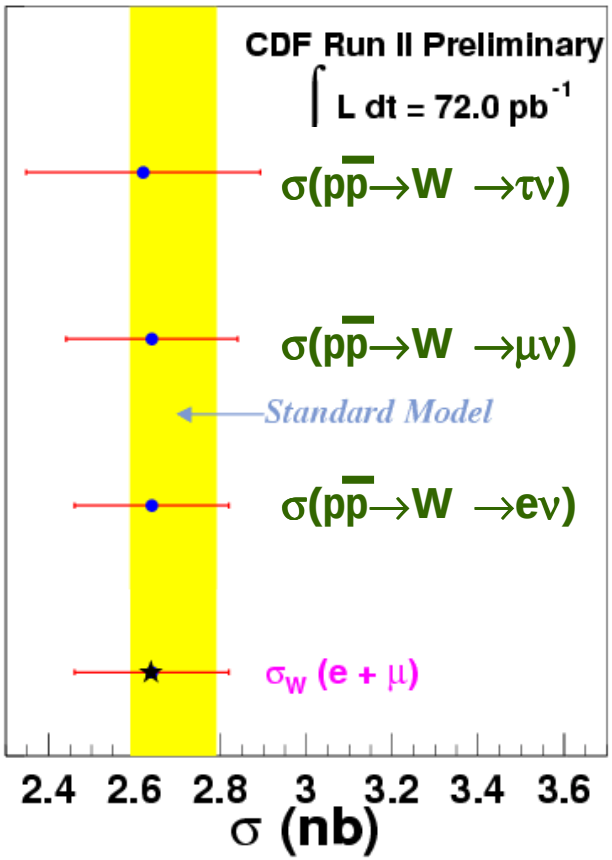
Clear $Z \rightarrow \tau_e \tau_h$ signal



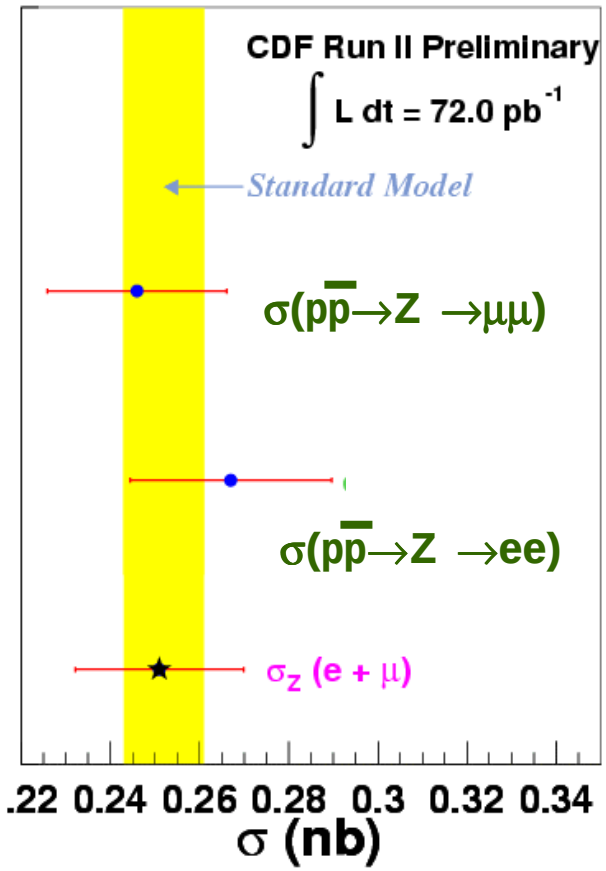
Can be our calibration sample

Work in Progress for Cross Section Measurement

W Cross Section Measurements



Z Cross Section Measurements



combined $\sigma_W \times B(W \to l\nu) = 2.640 \pm 0.012_{stat} \pm 0.093_{syst} \pm 0.158_{lum}$ nb

combined $\sigma_Z \times B(Z \to ll) = 251.5 \pm 4.3_{stat} \pm 10.6_{syst} \pm 15.1_{lum}$ pb

$\sigma(pp\text{->}W)_{Th}$@$\sqrt{}$1.96 TeV=2.731 $\pm 0.002_{(Th)}$ nb(NNLO),

Stirling et al, Phys Lett **B531**, (2002)

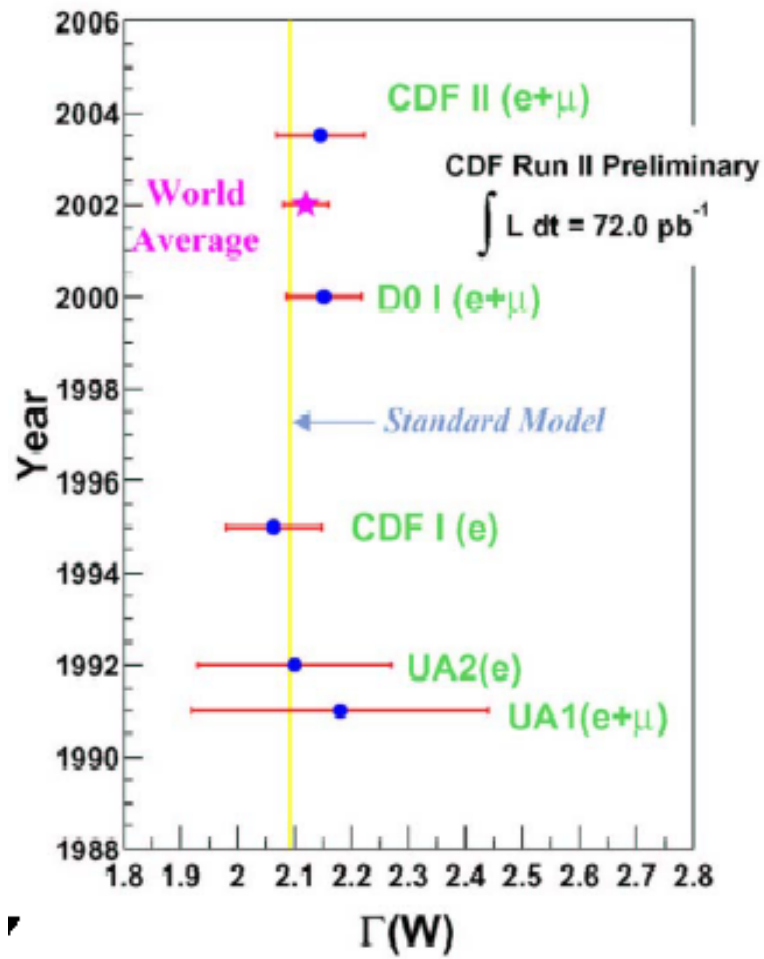
$\sigma(pp\text{->}Z)_{Th}$@$\sqrt{}$1.96 TeV=252.1 $\pm 8.8_{(Th)}$ pb(NNLO)

CDF Γ(W) Measurement

From R → to Γ(W)

$$R = \frac{\sigma.BF(W \to l\nu_l)}{\sigma.BF(Z \to ll)}$$

$$R = \frac{\sigma(pp \to W)}{\sigma(pp \to Z)} \; \frac{\Gamma(Z)}{\Gamma(Z \to ll)} \; \frac{\Gamma(W \to l\nu_l)}{\Gamma(W)}$$



Larger systematic uncertainties:

- Detector Simulation (e)
- Background Estimates(e-μ)
- Lepton ID (e-μ)

CDF (e): $9.88 \pm 0.24_{(stat)} \pm 0.44_{(syst)}$

CDF(μ): $10.69 \pm 0.28_{(stat)} \pm 0.31_{(syst)}$

CDF(e+μ): $10.69 \pm 0.28_{(stat)} \pm 0.31_{(syst)}$ →

$\Gamma(W)_{CDF} = 2146 \pm 78$ MeV

$\Gamma(W)_{SM} = 2092.1 \pm 2.5$ MeV

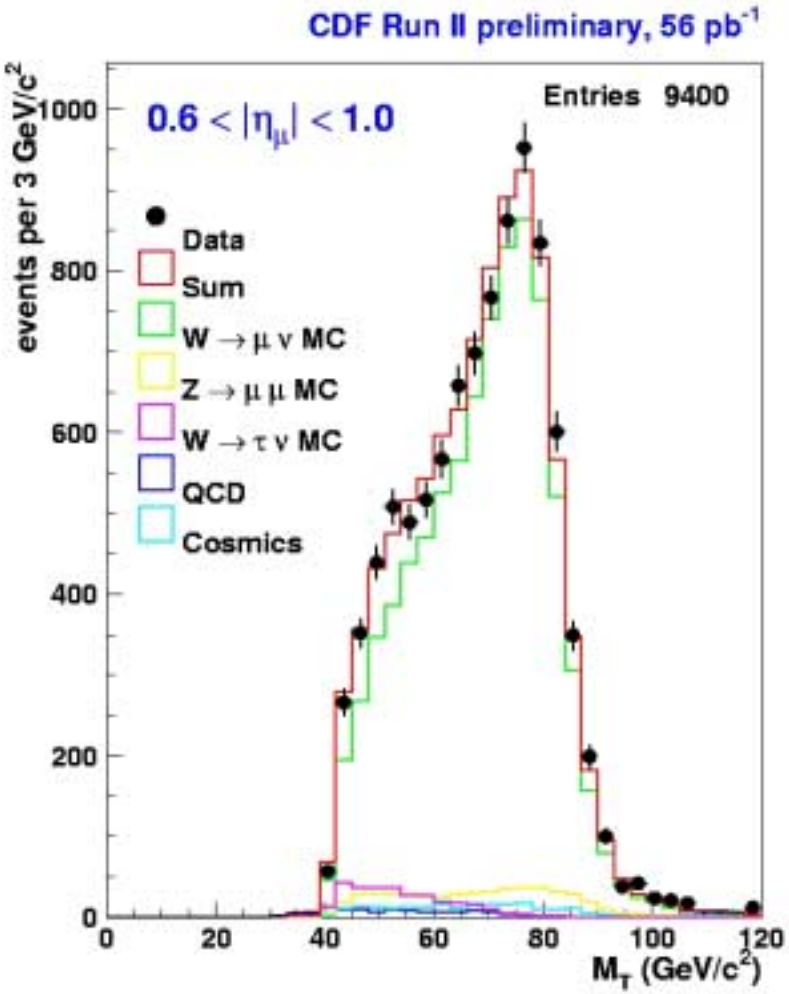
Extending Detector Acceptance

Muon Channel(~0.6<|η|<1.0)

- Extending geometric acceptance of Leptons.

→ Looking in the Forward regions (High |η|).

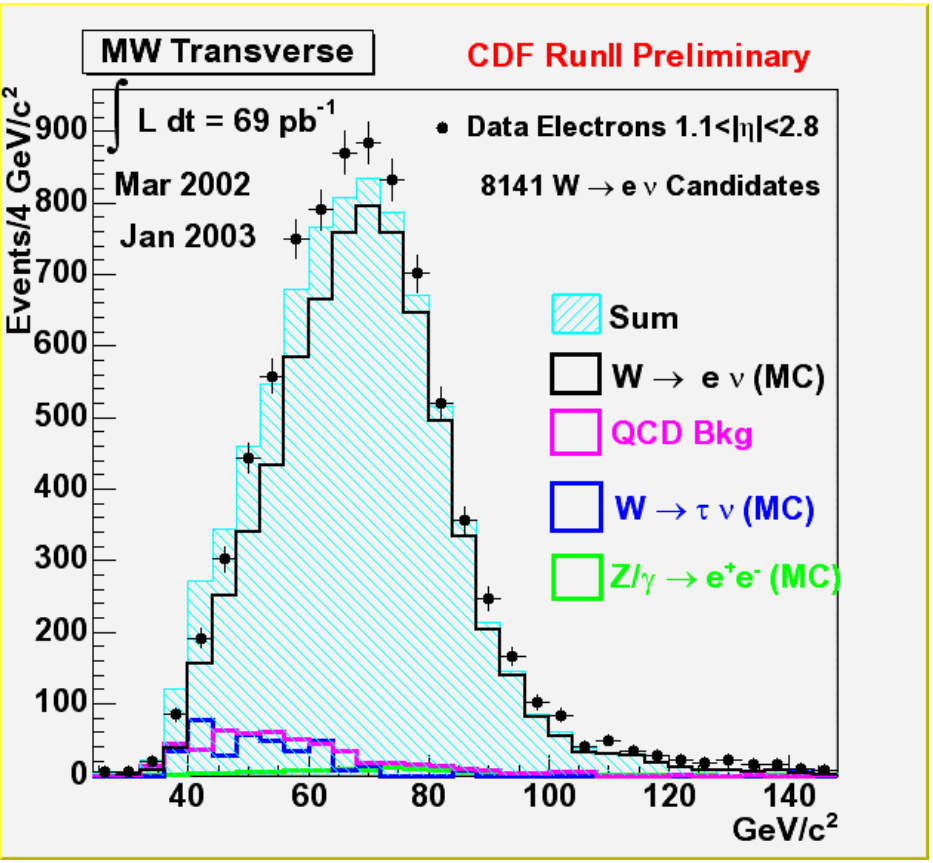
- Towards Cross Section Measurements:
- Establishing Baseline Selection
- Trigger and ID efficiencies
- Background Studies



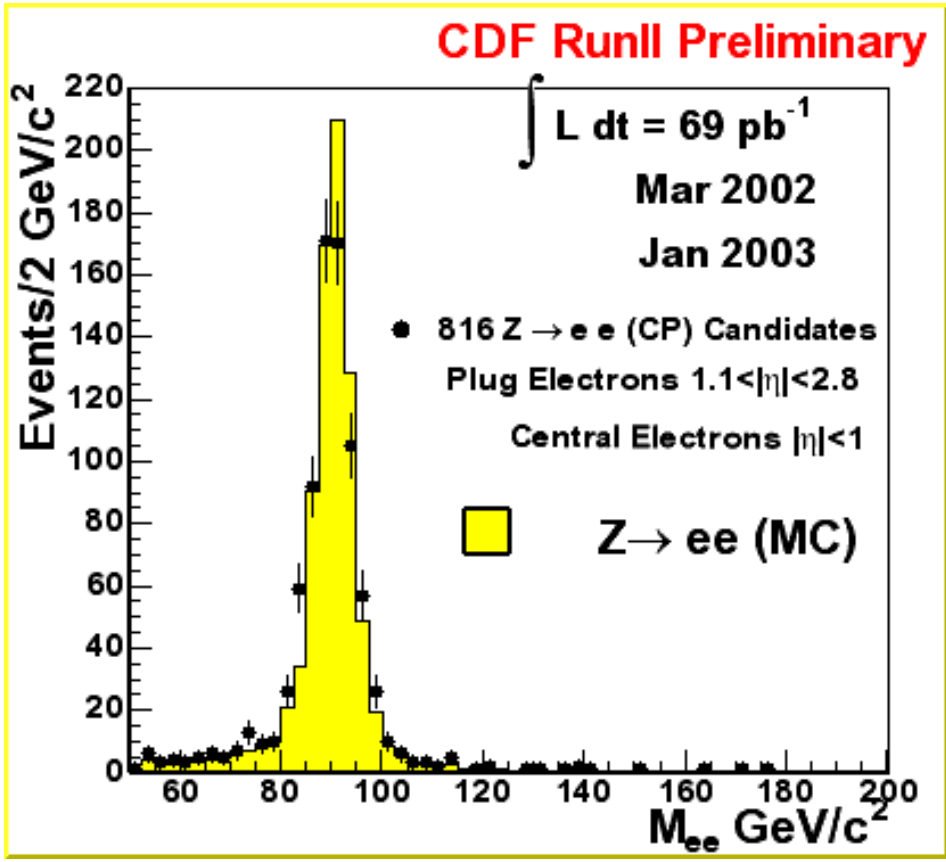
i.e. "How to increase sample without increasing Luminosity"

Electron Channel
1.1<|η|<2.8
Combining Plug Calorimetry and Forward Tracking

W Boson



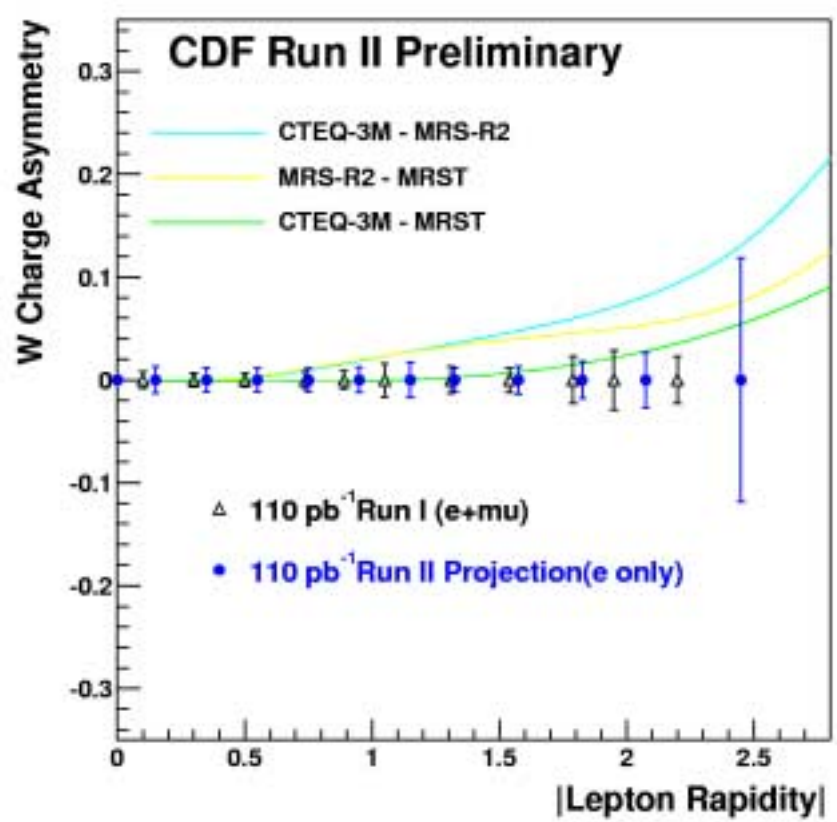
Z Boson



Towards W Charge Asymmetry

$$A(\eta) = \frac{d\sigma(e^+)/d\eta - d\sigma(e^-)/d\eta}{d\sigma(e^+)/d\eta + d\sigma(e^-)/d\eta}$$

PDF Sensitivity



- Charge ID and high |η| coverage

- Sensitivity to u/d fraction in proton

Constraints on PDF

→ Smaller Uncertainty from PDF

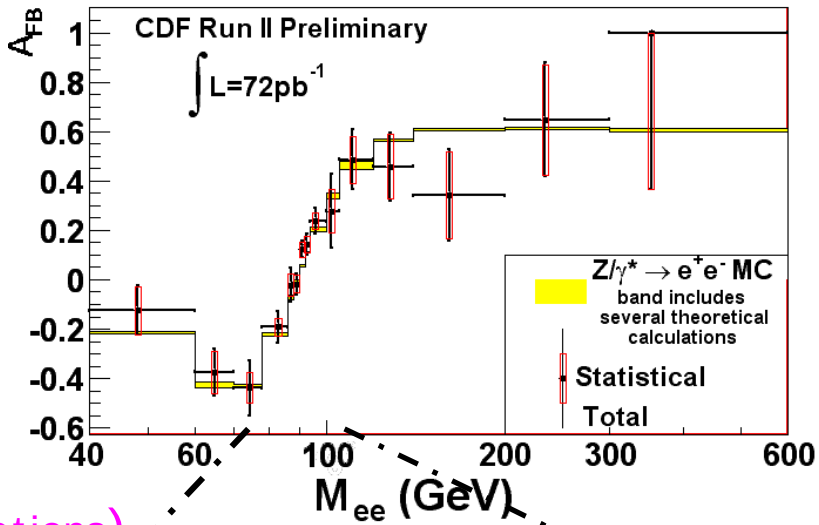
in highP_T EWK and Top Physics

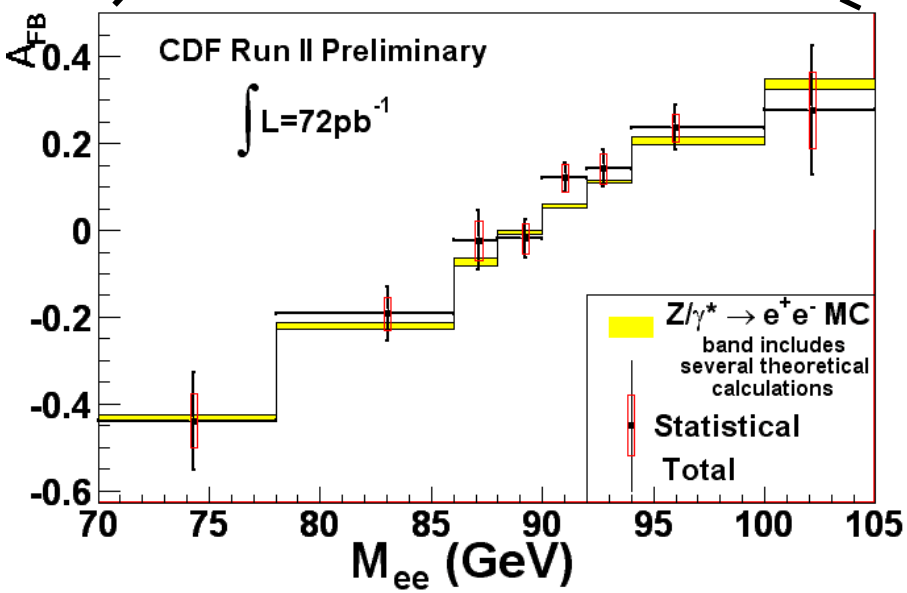
Work in Progress

Z Forward Backward Asymmetry

$$A_{FB} = \frac{d\sigma(\cos\theta > 0) - d\sigma(\cos\theta < 0)}{d\sigma(\cos\theta > 0) + d\sigma(\cos\theta < 0)}$$

$$= \underbrace{A(1+\cos^2\theta) + B\cos\theta}_{\text{SM Contributions}} + \underbrace{\ldots}_{\text{Beyond SM (Z', New Interactions)}}$$





Probing (Unique at Tevatron):

- Z/γ^* Interference in High Invariant Mass Region (far from Z-pole)

Consistent with SM

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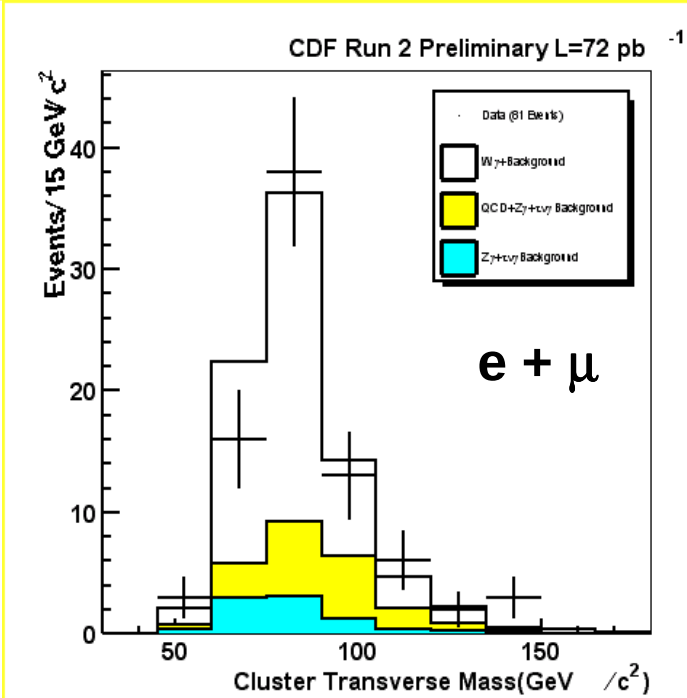
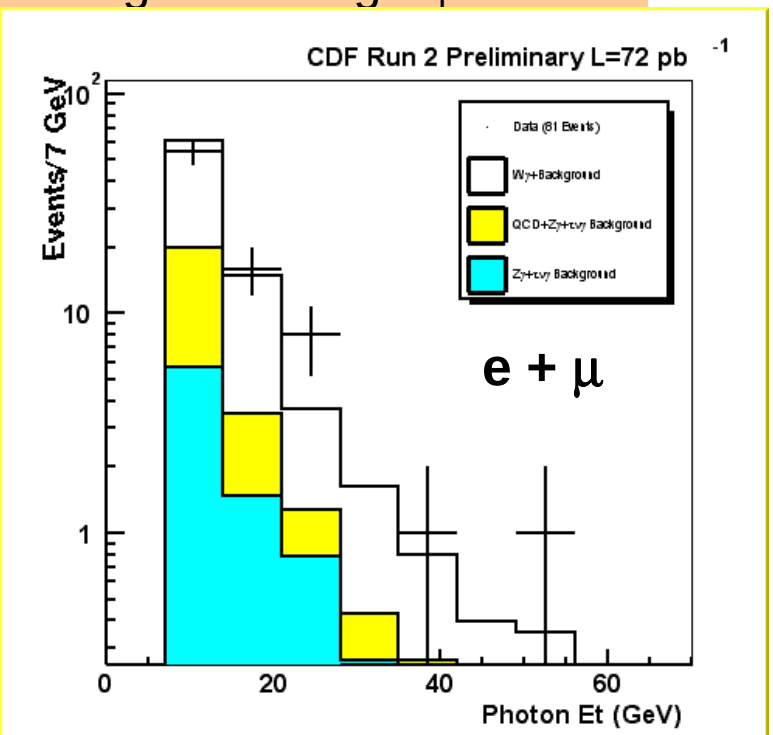
DiBoson Production:Wγ

- DiBoson Coupling Measurements:
- Probe ewk boson self-coupling
- Sensitivity to physics BSM(Anomalous Couplings)
- Statistically Limited

Process:
$p\bar{p}$->Wγ->$l\nu_l\gamma$

- One High-P_T lepton(e,μ)
- One Photon($\Delta R_{(\gamma,l)}$>0.7)
- Large Missing E_T





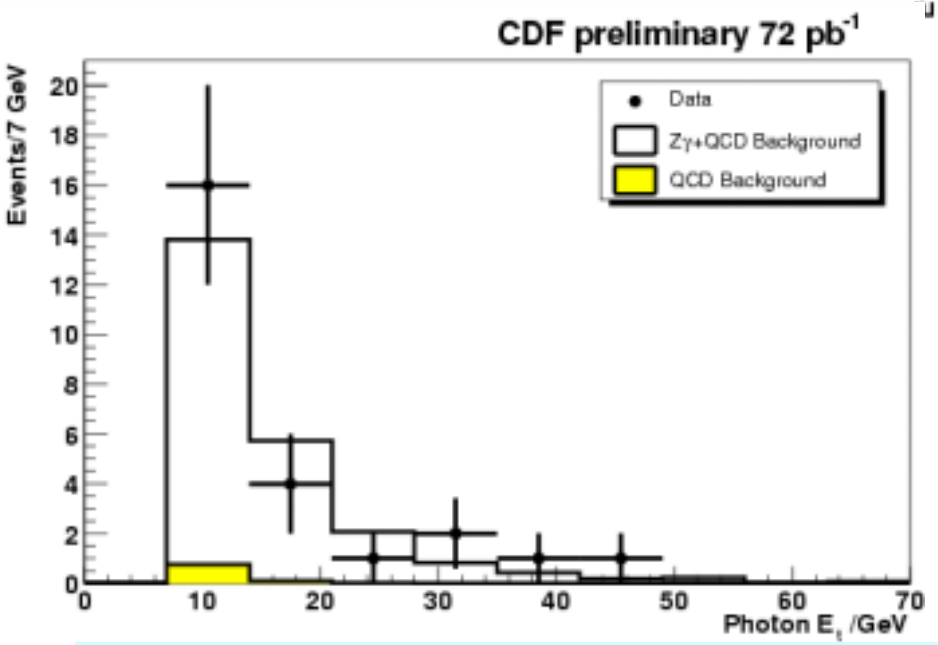
	Events	Back	σ•B(Wγ→lνγ) (pb)
e	43	33%	**17.2**±3.8$_{stat}$±2.8$_{sys}$±1.0$_{lum}$
μ	38	29%	**19.8**±4.5$_{stat}$±2.4$_{sys}$±1.2$_{lum}$
SM @√s=1.96TeV			18.7 ± 1.3

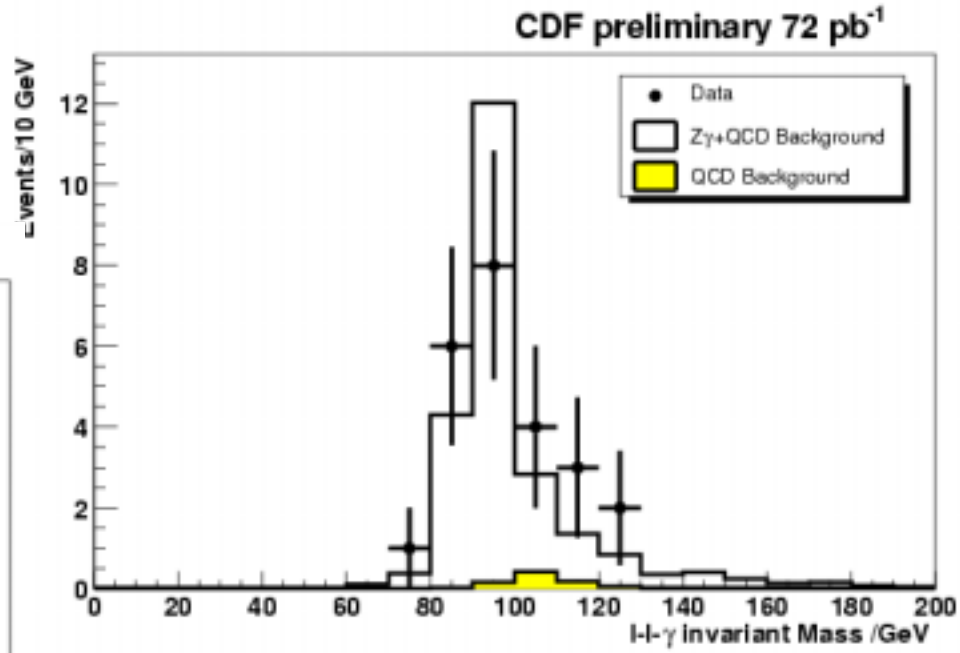
Consistent with SM

DiBoson Production:Zγ

Process:

$\bar{p}p \to Z\gamma \to ll\gamma$





- Two High-P_T Leptons(Opposite sign)
- One Photon ($\Delta R_{(l,\gamma)}$ >0.7)

	Events	Back.	$\sigma \cdot B(Z\gamma \to ll\gamma)$ (pb)
e	11	4.6%	$\mathbf{5.5} \pm 1.7_{stat} \pm 0.6_{sys} \pm 0.3_{lum}$
μ	14	4.0%	$\mathbf{6.0} \pm 1.6_{stat} \pm 0.7_{sys} \pm 0.4_{lum}$

$\sigma \cdot B(Z\gamma \to ll\gamma)_{SM} = 5.4 \pm 0.4$pb

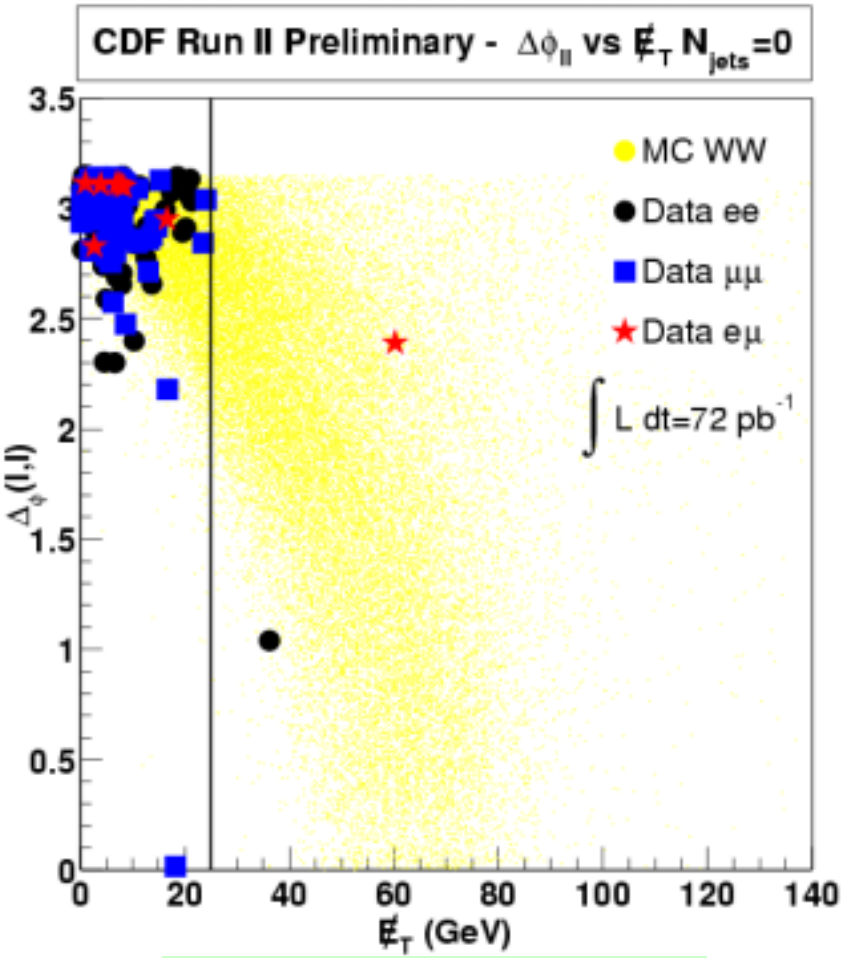
Consistent with SM

Diboson Cross Sections: WW

$p\bar{p}$->WW->ll'νν' (l=e,μ)

Statistics Limited

Step for SM Higgs Searches



Selection:
- Two High-Pt Isolated Central Leptons(Opposite Charge)
- Large Missing E_T
- Veto Z production and Jets

Main Backgrounds: DY, tt,WZ,Fakes

Bkg	1.53±0.64
WW->Dil	2.79±0.62
2 Events observed	

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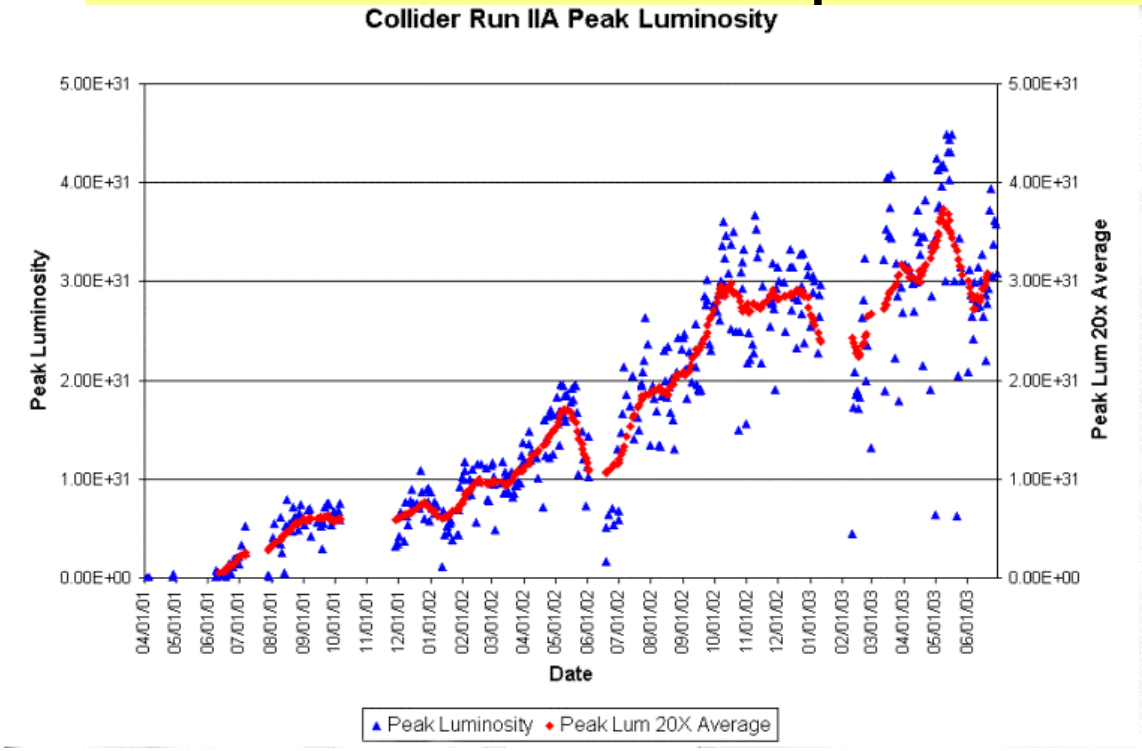
Conclusions

- Baseline Electroweak Measurements Re-established → Consistent with SM
- Electroweak Precision Measurement Program
- Exploiting larger detector acceptance
- Work in progress on dataset with the largest (beyond RunI) integrated luminosity datasets

Backup Tevatron



.um at Run I ~110 pb^{-1}

$\sqrt{s}_{Run I}$ = 1.8 TeV

Now $\sqrt{s}_{Run II}$ = 1.96 TeV

	Run 1B	Run IIa	Run IIb
Energy/beam	900 GeV	980 GeV	980 GeV
Peak Luminosity	1.6×10^{31}	2.0×10^{32}	5.0×10^{32}
Number of bunches	6	36/108	~ 108
Bunch spacing	3500 nsec	396/132 nsec	132 nsec
Interactions/crossing	2.8	5.8/1.9	4.9
Run period	1992-96	2001-03	2004-07
Integral Luminosity	118 pb^{-1}	2 fb^{-1}	13 fb^{-1}

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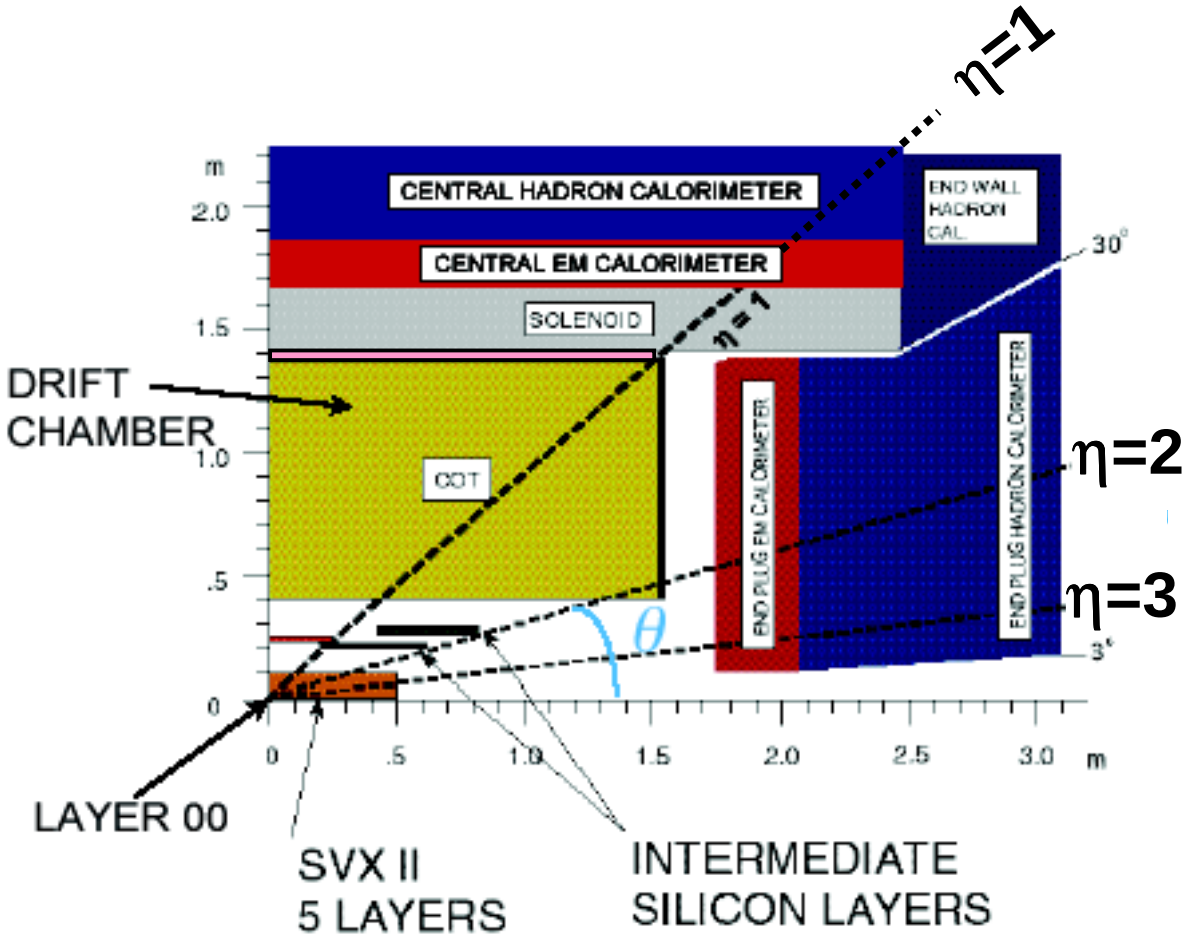
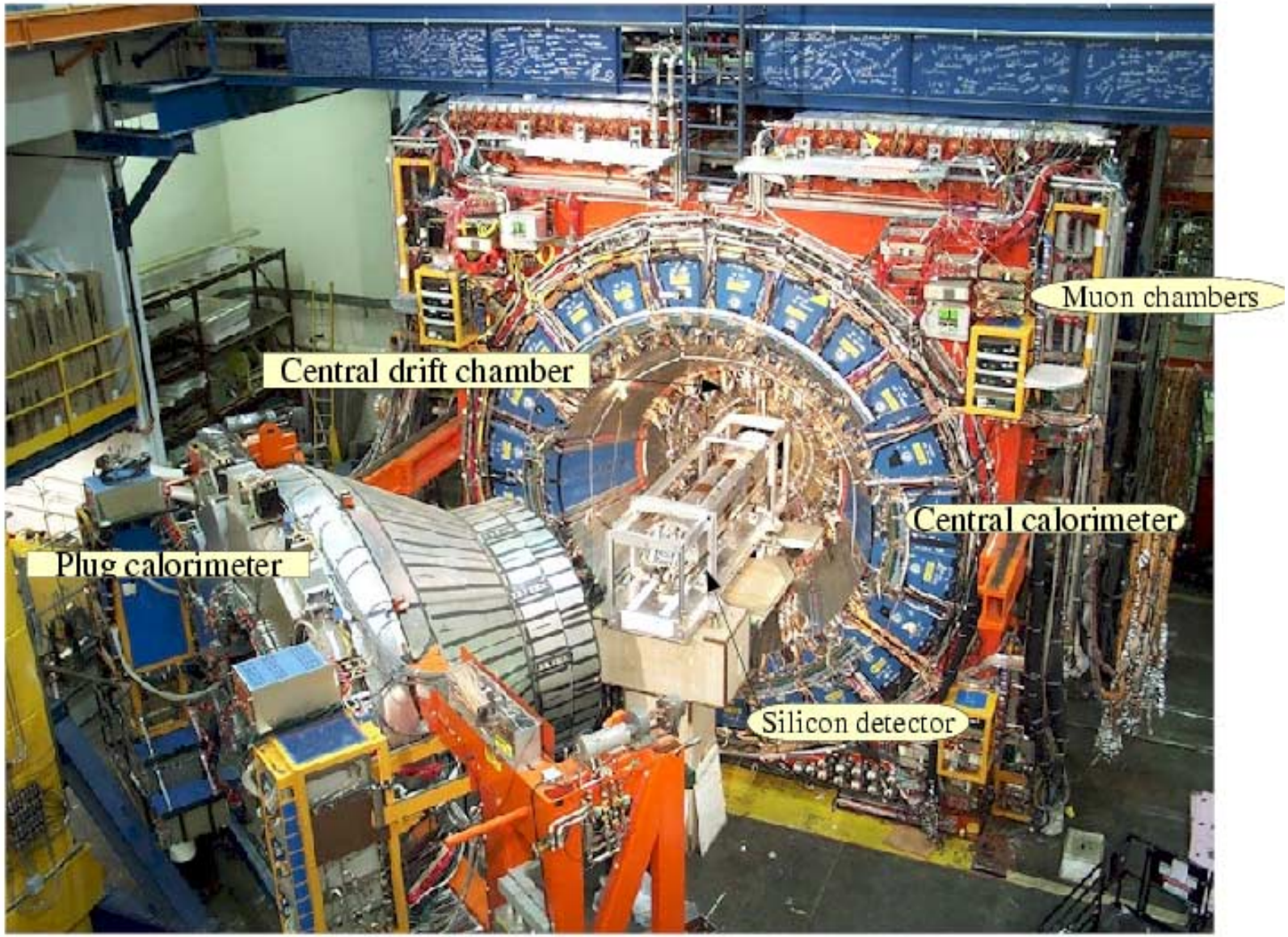
CDF Detector




Muon chambers
Central drift chamber
Central calorimeter
Plug calorimeter
Silicon detector

Luminosity Measurement at CDF

Luminosity (L) from CLC (Cherenkov Luminosity Counters):

- Discriminating primary (from ppbar)-secondary particles
- Time resolution

Well adapted for high-L collider

$$\mu_\alpha \cdot f_{BC} = \sigma_{pp} \cdot \varepsilon_\alpha^{clc} \cdot L$$

α: selection criteria for pp coll.

μ_α: #int/Bunch Crossing (BC)

f_{BC}: BC Frequency

σ_{pp}: $p\bar{p}$ inelastic cross section

ε_α^{clc} :Efficiency of CLC

Increasing Lum.

"0" hits $\mu_{clc} = -\ln\left(\frac{N_{zeroBC}}{N_{totalBC}}\right)$

#hits $\mu_{clc} = \frac{\langle N_{Hits/BC} \rangle}{\langle N_{Hits/p\bar{p}} \rangle}$

#part $\mu_{clc} = \frac{\sum A_i}{\langle A_{p\bar{p}} \rangle}$

Uncertainty manly from:

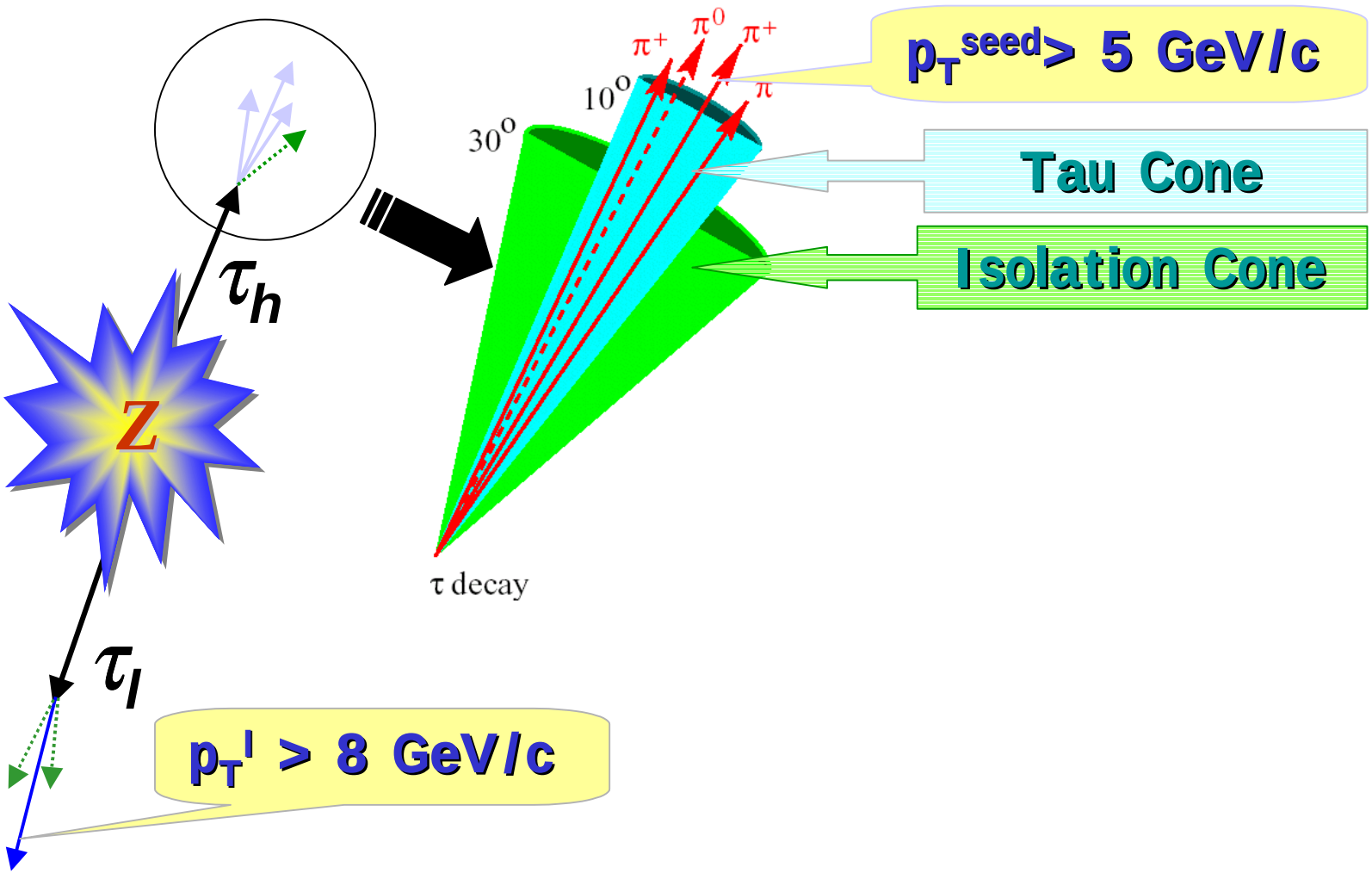
ε_α= MC simulation.

σ_{pp} = 60.4±1.4 mb (measured by CDF)

μ_{clc}: Different definitions

Systematic uncertainty ~5%

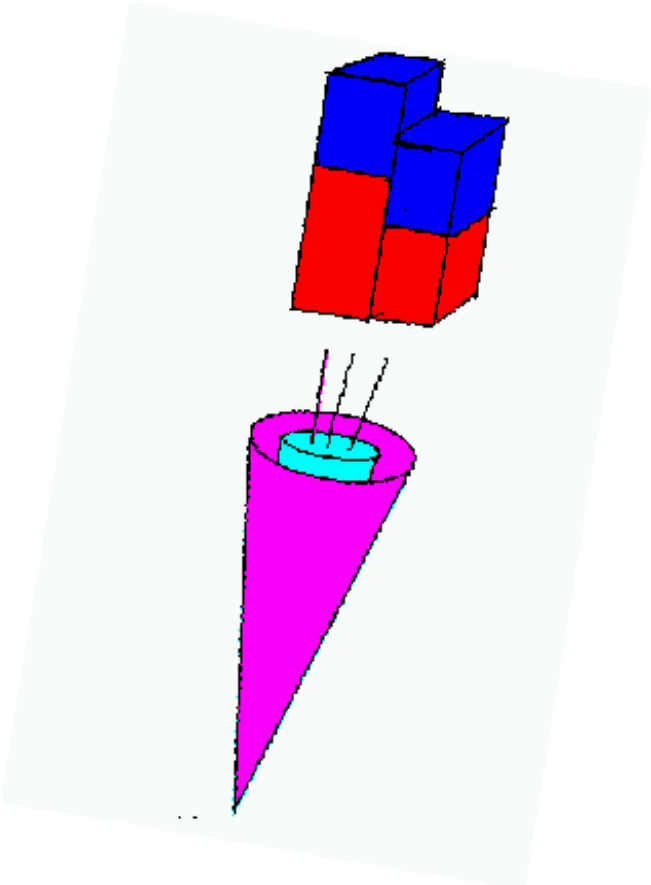
Triggering on Taus (hadronic)



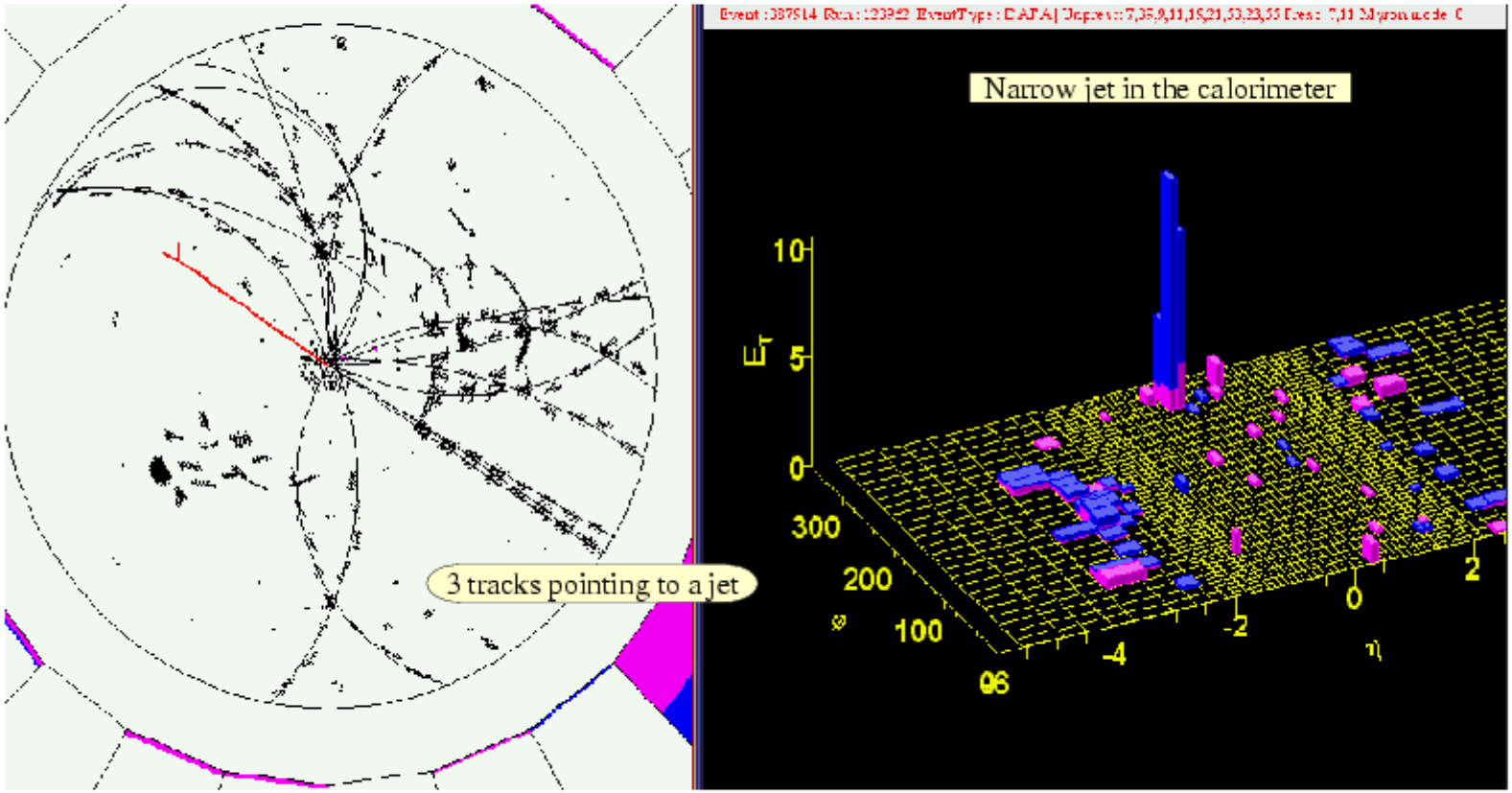
ee, $e\mu$, $\mu\mu$, $e\tau_h$, $\mu\tau_h$

Tau Reconstruction at CDF

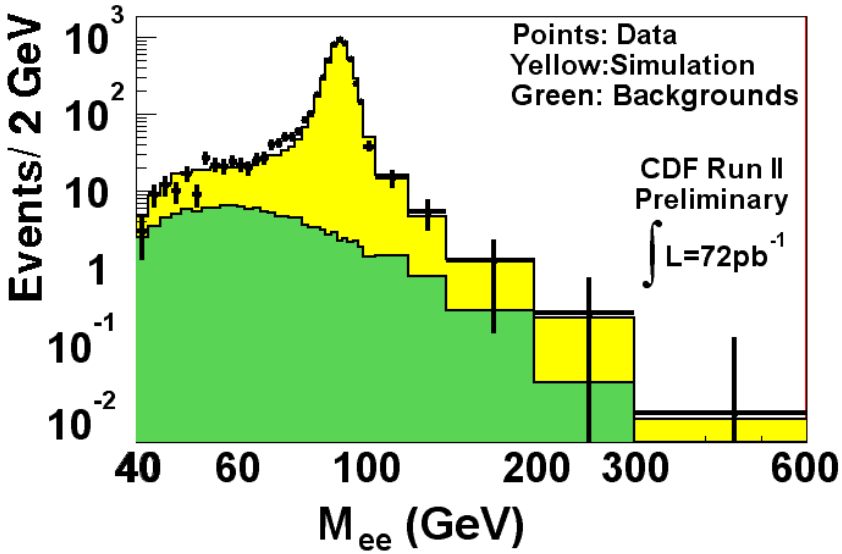
- Start from narrow cluster in the central calorimeter
- Search for an energetic track pointing to it
- Define 2 cones - 10 degrees (cyan) and 30 degrees (pink) - around the seed track
- Allow more tracks within cyan cone
- Disregard the candidate if there are tracks in between the pink and cyan cones
- Reconstruct energy clusters in shower max detector and make π^0 candidates out of them
- Require effective mass of all the tracks and π^0's inside the 10° cone to be < 1.8 GeV (tau mass plus resolution)
- Expect E(cal) = sum(P)(tracks+π^0)

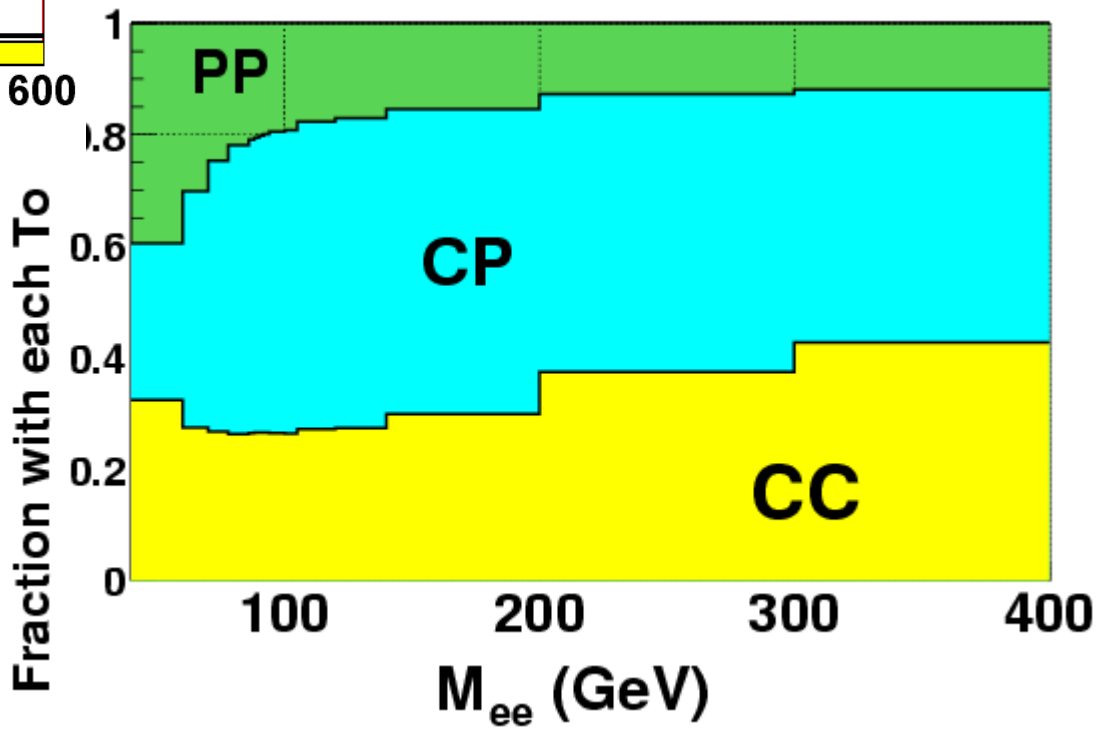


A typical W->τν candidate event



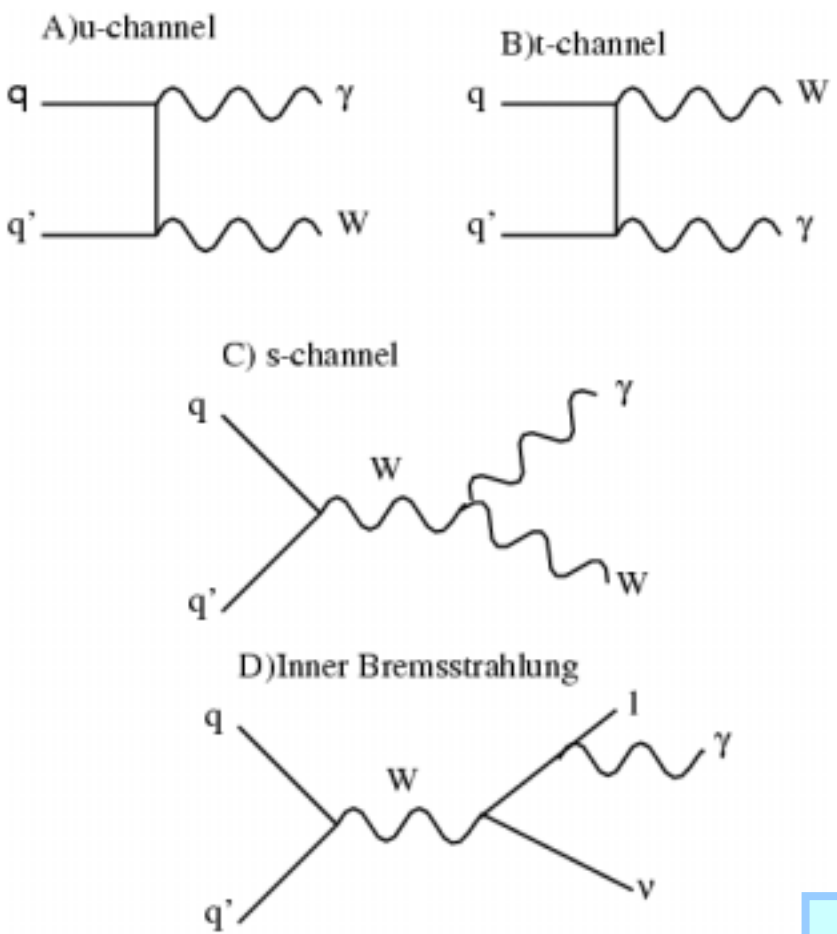
Backup AFB


Points: Data
Yellow:Simulation
Green: Backgrounds
CDF Run II
Preliminary
∫L=72pb-1
Events/ 2 GeV
10^3
10^2
10
1
10^-1
10^-2
40
60
100
200
300
600
M_ee (GeV)

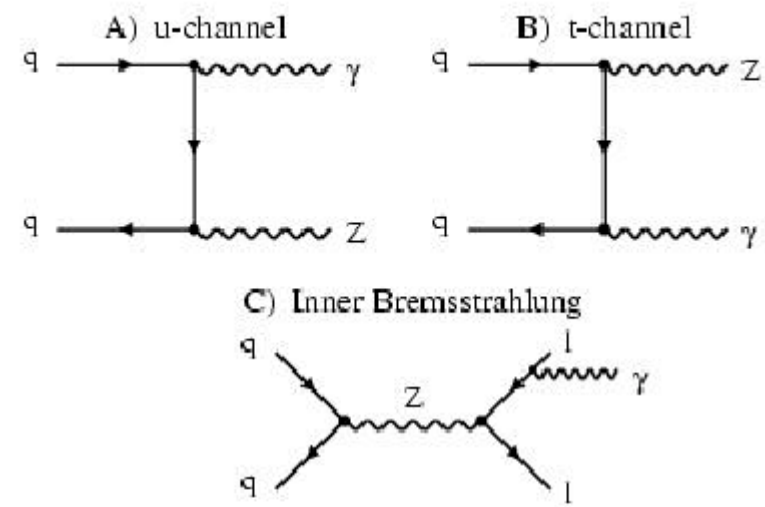

PP
CP
CC
Fraction with each To
1
0.8
0.6
0.4
0.2
0
100
200
300
400
M_ee (GeV)

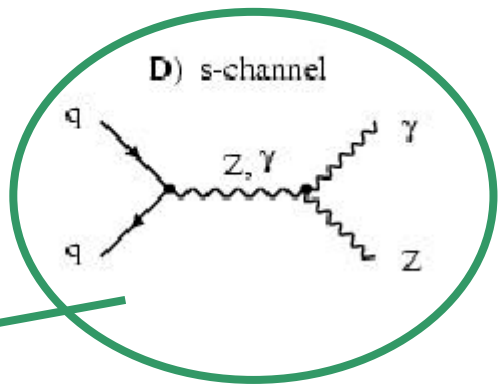
DiBoson(Wγ,Zγ)

Wgamma



Z gamma

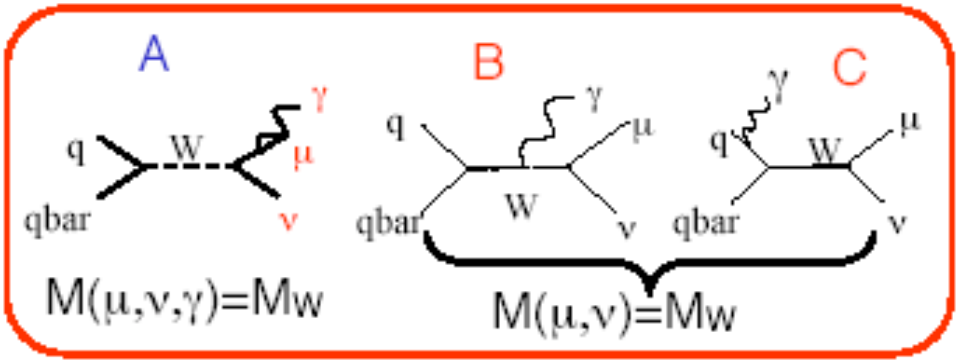




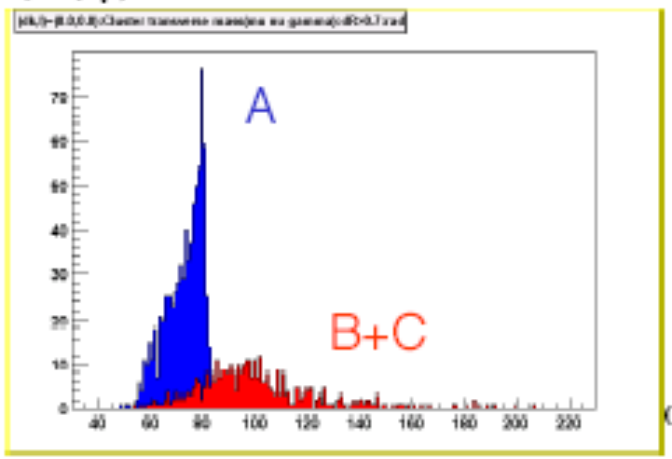
Non SM!

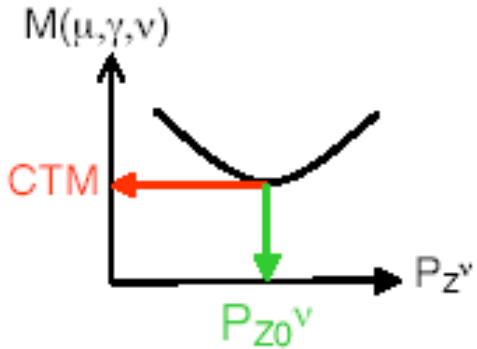
A. Sidoti INFN Pisa and University

DiBoson(Wγ)



- $dM(\mu,\nu,\gamma)/dP_Z^{\nu}=0$ at P_{Z0}^{ν}





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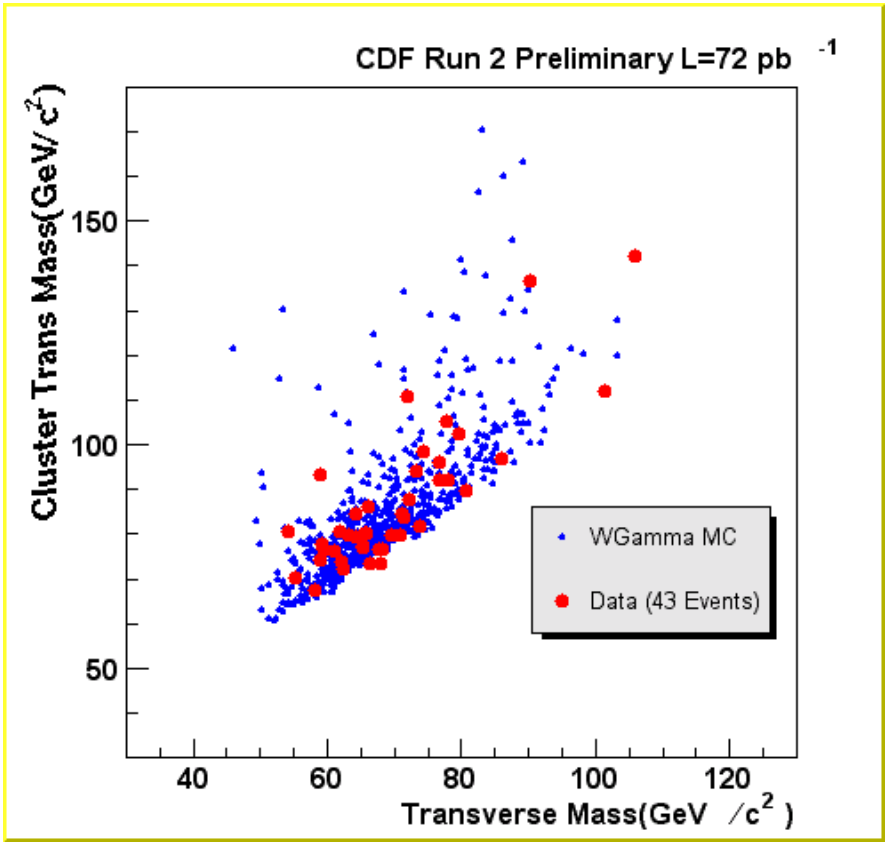
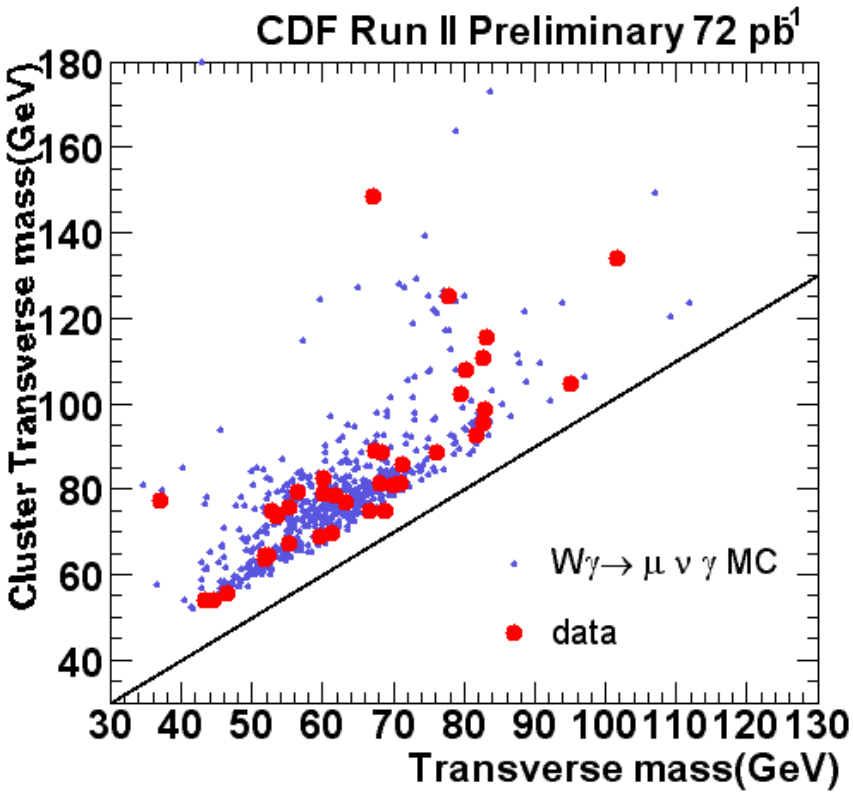
$$M_{CT}^2(l\gamma; \not{E}_t) = [(M_{l\gamma}^2 + |p_{T\gamma} + p_{Tl}|^2)^{1/2} + \not{E}_t]^2 - |p_{T\gamma} + p_{Tl} + \not{E}_t|^2, \qquad (1.1)$$

where P_{Tl} is the transverse momentum of the lepton and $M_{l\gamma}$ denotes the invariant mass of the $l\gamma$ pair.

DiBoson:Wgamma

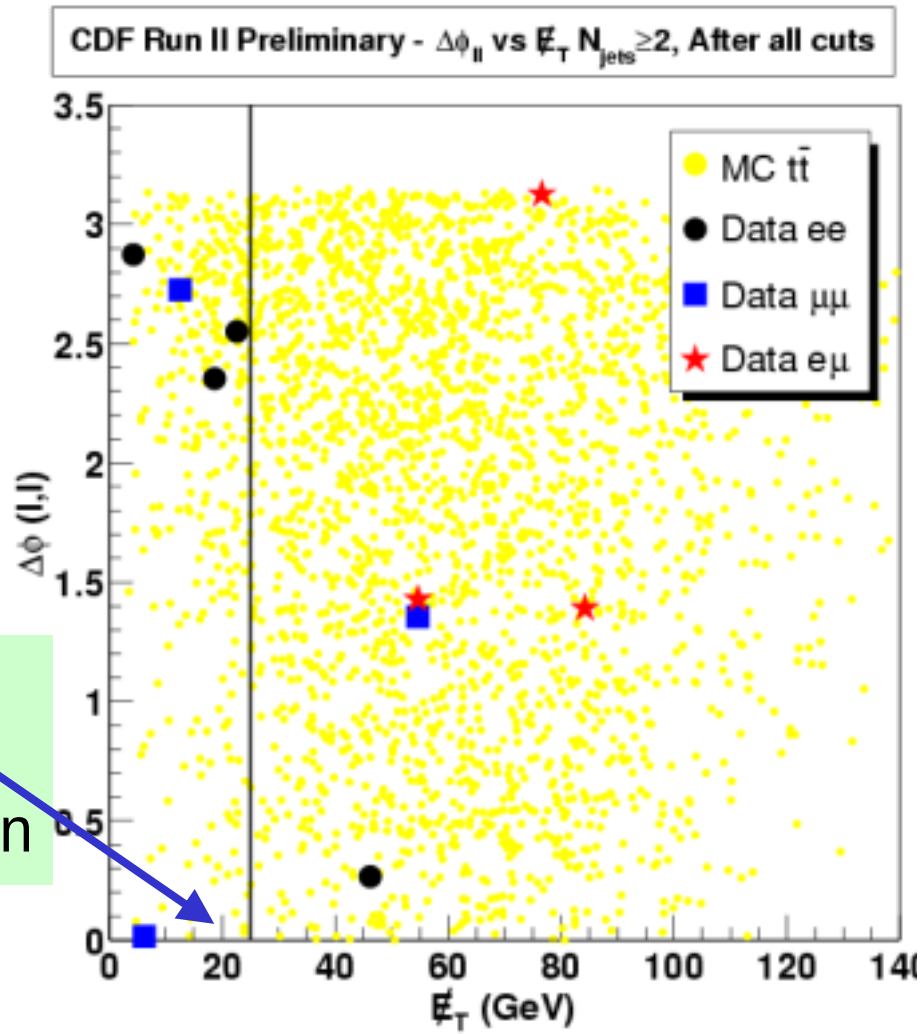


$W\gamma \to e\nu_e\gamma$



$W\gamma \to \mu\nu_\mu\gamma$

WW DiBoson



$\Delta\phi$~0 Events

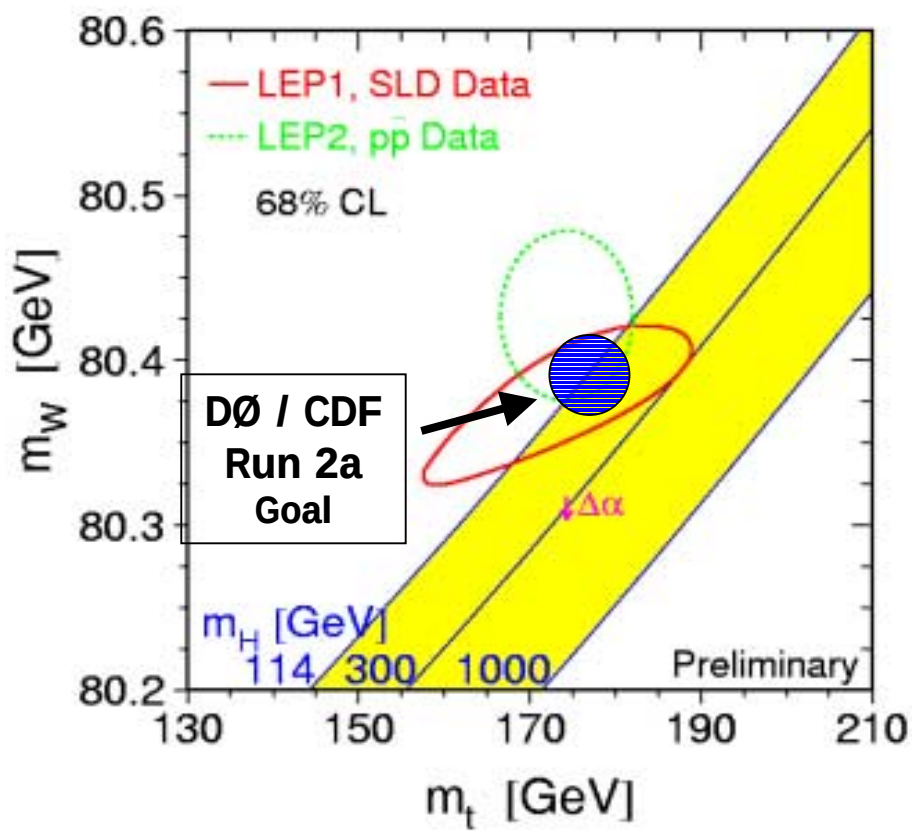
compatible with tt dilepton

W Mass(Perspectives for RunII)

Run II with 2 fb^{-1} will provide a chance to:

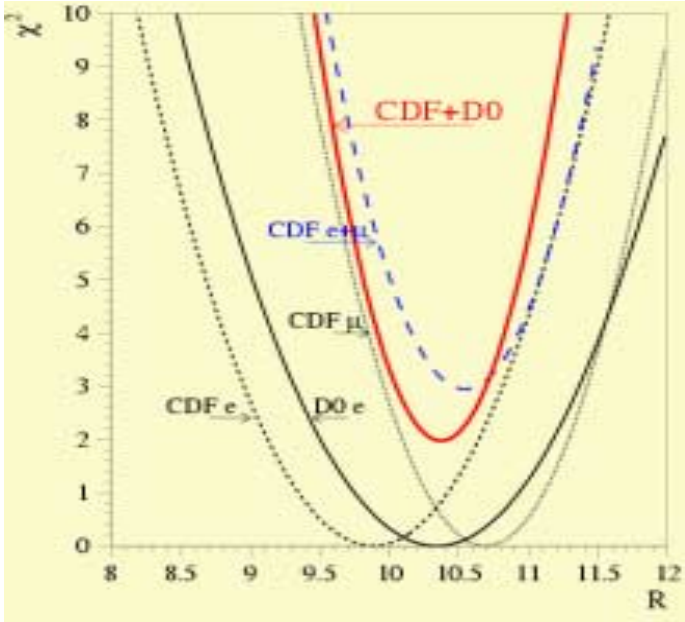
- –Measure M_w to ±40 MeV/c^2
- –Measure M_{top} to ±3 GeV/c^2

Constraints on SM Higgs Mass



From R Tevatron Combined Measurement...

First RunII Tevatron Combined (D0+CDF) Measurement



From Tevatron Combined R:

- DØ (e channel)
- CDF (e,μ channel)

$$R = \frac{\sigma.BF(W \to l\nu_l)}{\sigma.BF(Z \to ll)}$$

Larger systematic uncertainties dominated:

Detector Simulation (CDF e)

Background Estimates(CDF/DØ e)

Lepton ID (all channels)

CDF (e): $9.88 \pm 0.24_{(stat)} \pm 0.44_{(syst)}$

CDF(μ): $10.69 \pm 0.28_{(stat)} \pm 0.31_{(syst)}$

DØ(e) : $10.34 \pm 0.35_{(stat)} \pm 0.39_{(syst)}$

TeV : $10.37 \pm 0.16_{(stat)} \pm 0.28_{(syst)}$