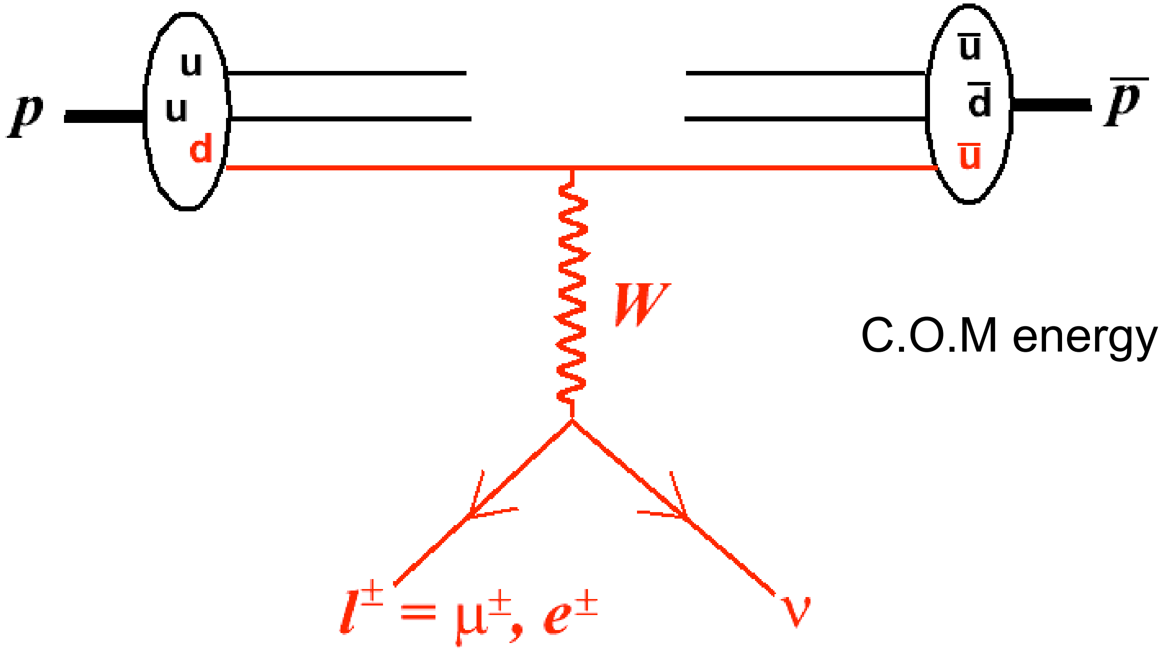
W Boson production and properties at CDF

EPS, Manchester, July 2007

W production at the Tevatron



C.O.M energy = 1.96 TeV

The electron and muon channels are used to measure W properties, due to their clean experimental signature.
The large mass (~80 GeV) of W bosons gives their decay products large p_T.

W events can be used to:

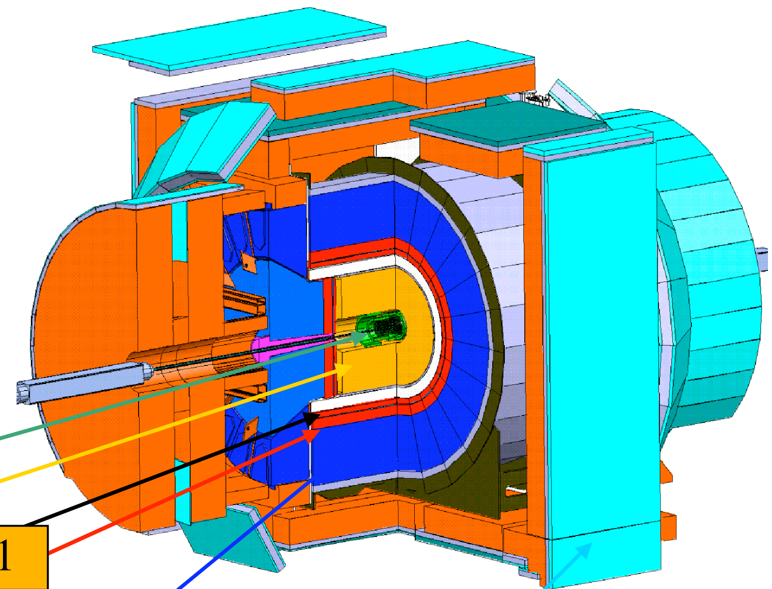
- constrain the QCD part of the production mechanism: W charge asymmetry.
- measure W properties: W mass (see talk by Oliver Steltzer-Chilton) and W width.

Detecting W decay particles at CDF

Electrons: detected in central trackers (p measurement) and EM calorimeter (E measurement).

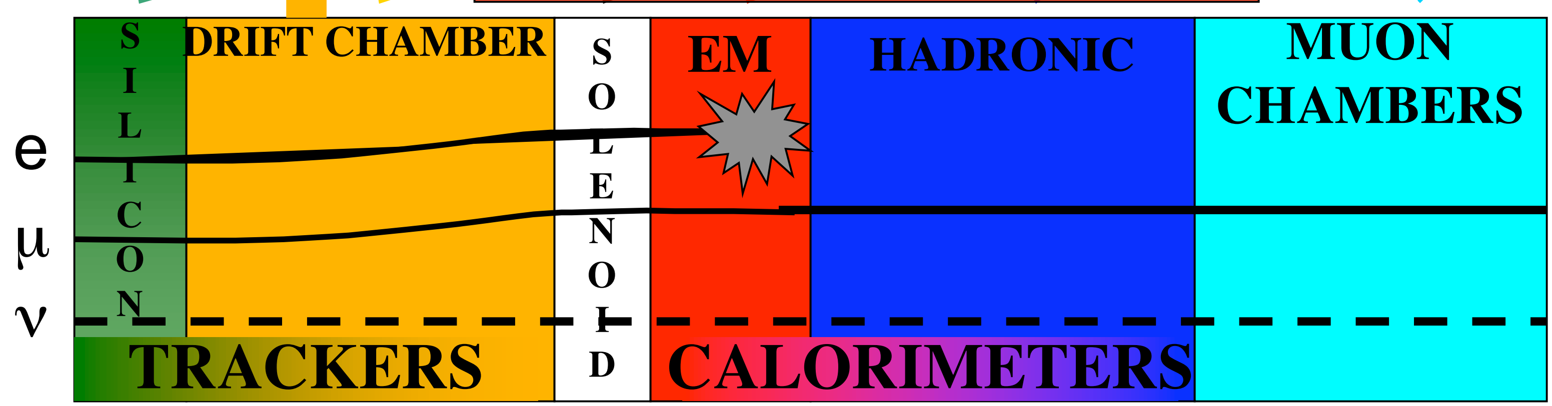
Muons: detected in central trackers (p measurement), calorimeter (MIP signal) and muon chambers.

Neutrinos : not detected! Vector sum the total *transverse energy* ($E_T = E\sin\theta$) in calorimeters. "Missing E_T" inferred as neutrino p_T.



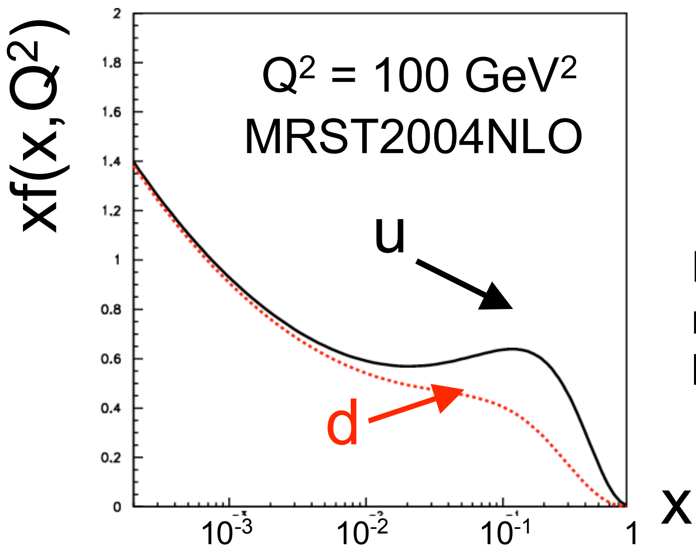
$\delta p_T / p_T \approx 0.0005 \times p_T$ [GeV/c; beam constrained]; $|\eta| < 1$

$\delta E_T / E_T \approx 13.5\% / \sqrt{E_T} \oplus 1\%$ $|\eta| < 1.1$

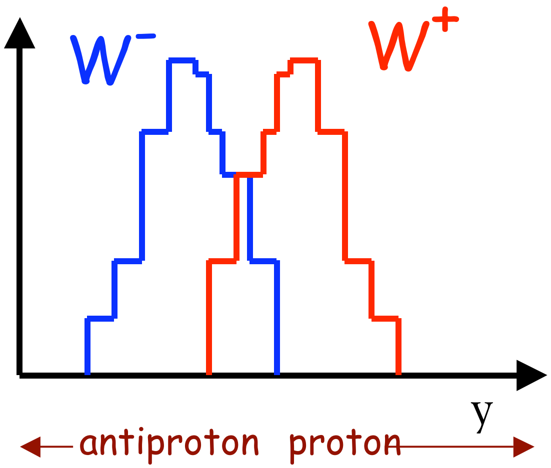


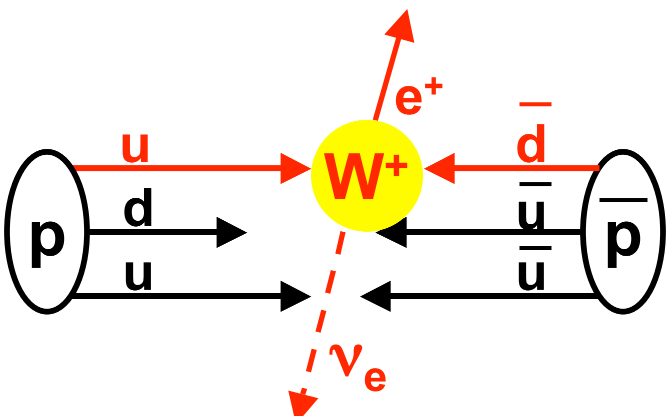
W charge asymmetry: introduction

Parton Distribution Functions describe the momentum distribution of partons in the (anti-)proton. They are constrained by fits to data.



Fraction of proton momentum carried by quark





$$rapidity = y = \frac{1}{2} \ln \frac{E + p_L}{E - p_L}$$

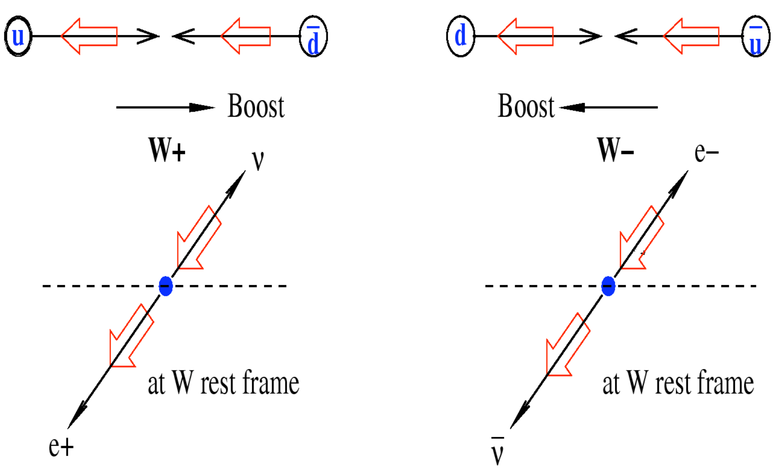
$$A(y_W) = \frac{d\sigma_+/dy_W - d\sigma_-/dy_W}{d\sigma_+/dy_W + d\sigma_-/dy_W}$$

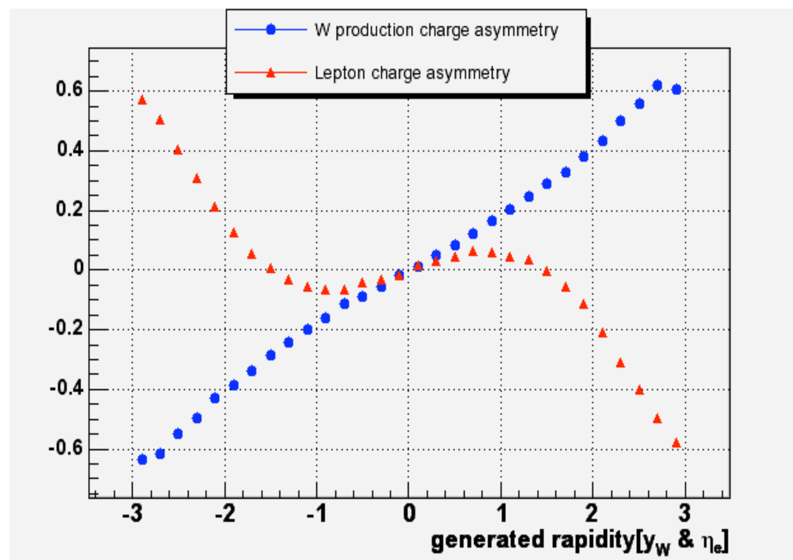
(helps constrain PDFs!)

W charge asymmetry: from $e^{+(-)}$ asymmetry

- Since p_L^{ν} is not known the $W^{\pm}$ rapidity cannot be reconstructed ∴ traditionally the *electron charge asymmetry* is measured.
- The V-A structure of the $W^{+(-)}$ decay favours a backward (forward) $e^{+(-)}$ "diluting" the W charge asymmetry.

$$A(\eta_l) = \frac{d\sigma_+/d\eta_l - d\sigma_-/d\eta_l}{d\sigma_+/d\eta_l + d\sigma_-/d\eta_l}$$





W charge asymmetry: direct measurement

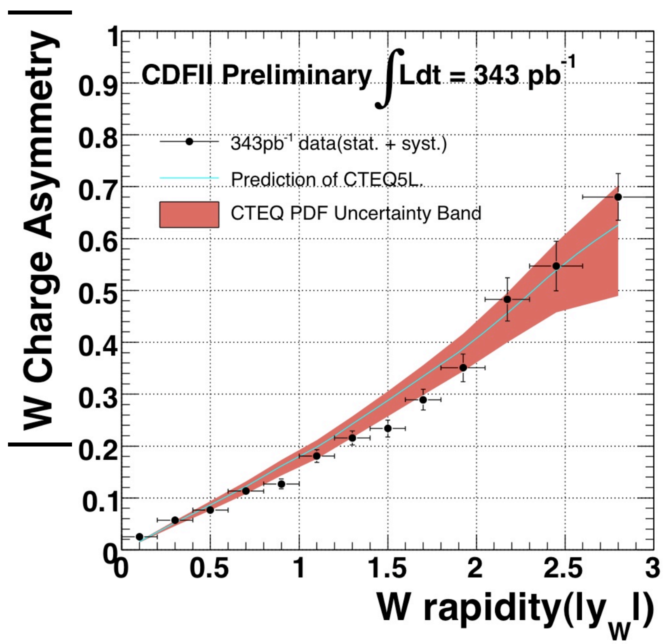
This CDF measurement (performed in $W \rightarrow e\nu$ channel):

p_L^{ν} determined by constraining M_W = 80.4 GeV→ two possible y_W solutions. Each solution receives a weight probability according to:

a) V-A decay structure

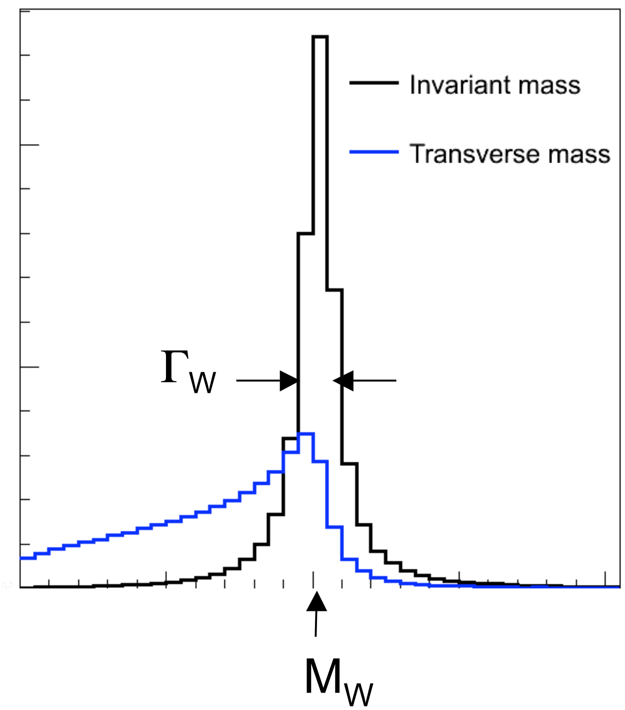
b) W cross-section: $\sigma(y_W)$

(Process iterated since $\sigma(y_W)$ depends on asymmetry)



W width : introduction

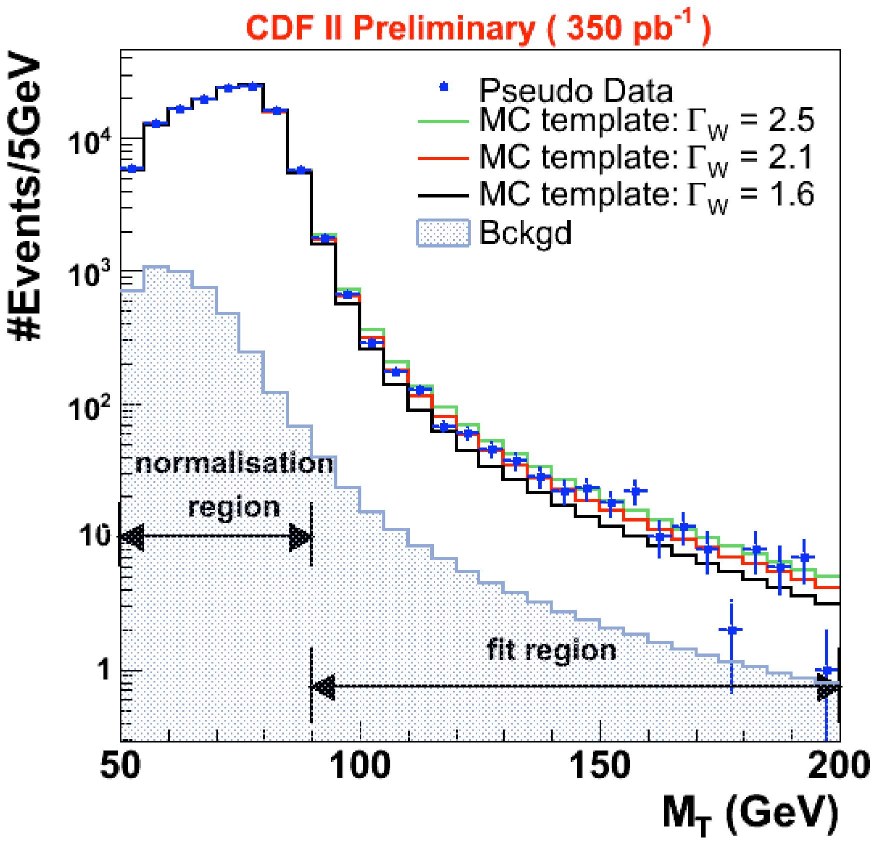
- Predicted very precisely within the Standard Model by summing the leptonic and hadronic partial widths: Γ_W^{SM} = 2091 ± 2 MeV **[PDG:** J. Phys. G **33,** 1]
- Deviations from this prediction suggest non-SM decay modes.
- Γ_W is an input to the W mass measurement: $\Delta M_W \sim \Delta\Gamma_W / 7$



Ideally we would reconstruct the invariant mass of the decay products to measure Γ_W, since ν isn't detected we reconstruct the transverse mass:

$$m_T = \sqrt{2 p_T^{\,l} p_T^{\,\nu} (1 - \cos\phi_{l\nu})}$$

W width : Analysis strategy



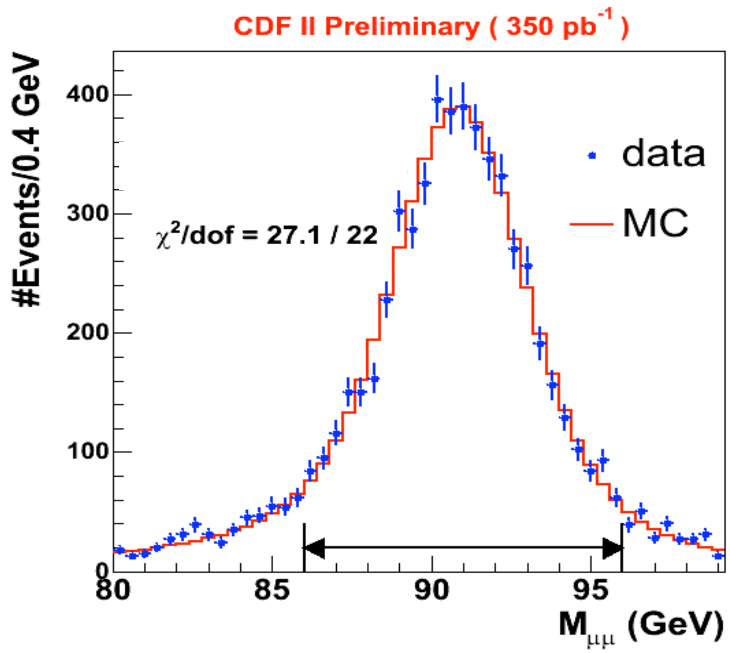
- Simulate m_T distribution with a dedicated *fast* parameterised MC (using a Breit-Wigner lineshape).
- MC simulates QCD (RESBOS Balazs et.al. PRD56, 5558) and QED (Berends & Kleiss Berends et.al. ZPhys. C27, 155) corrections.
- Utilise $Z \to ll$ (and $W \to l\nu$) data to calibrate the detector to a high precision.
- Fit m_T templates (with Γ_W varying) to the data, fit range: 90-200 GeV

optimised to reduce total uncertainty

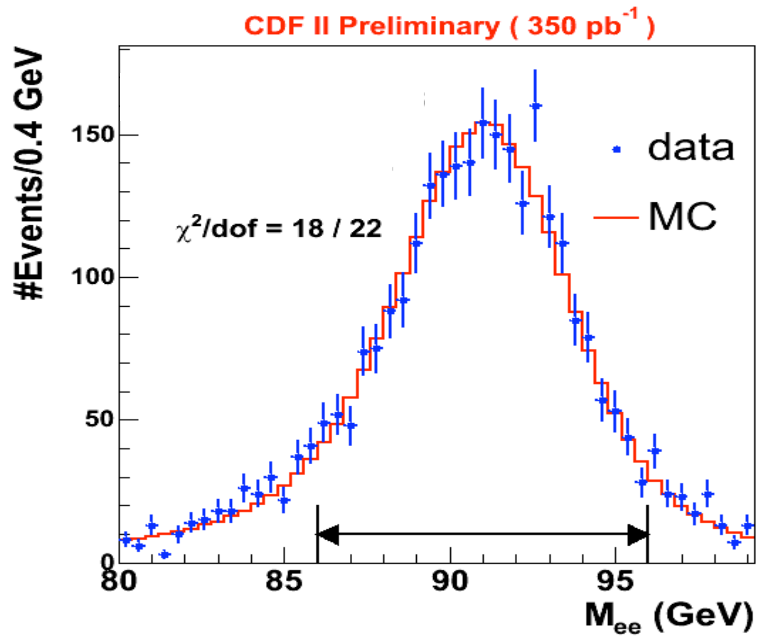
$$m_T = \sqrt{2 p_T^{\,l} p_T^{\,\nu} (1 - \cos\phi_{l\nu})}$$

W width : Lepton p_T

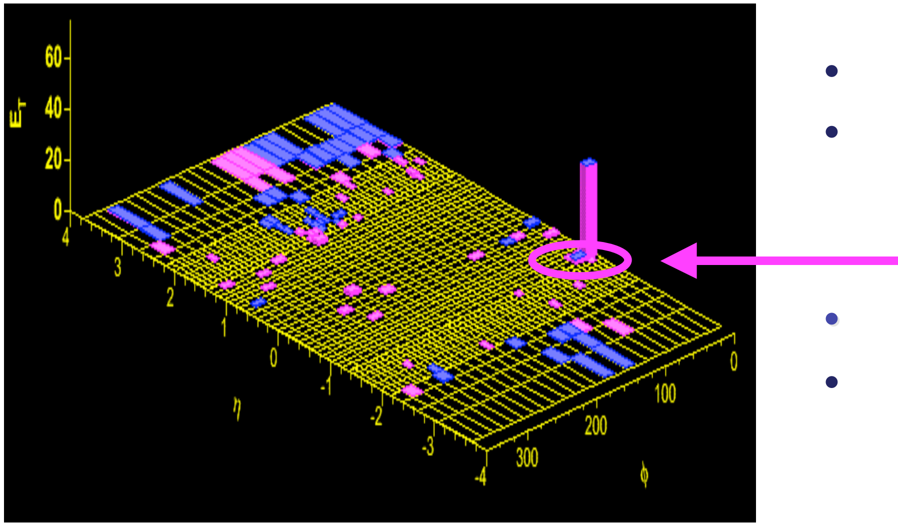
$\mu^{\pm}$ momentum measured in central tracker - scale and resolution calibrated using $Z \rightarrow \mu\mu$ resonance.



$e^{\pm}$ energy measured in EM calorimeter - scale and resolution calibrated using $Z \rightarrow ee$ resonance and E/p in $W \rightarrow e\nu$ data.

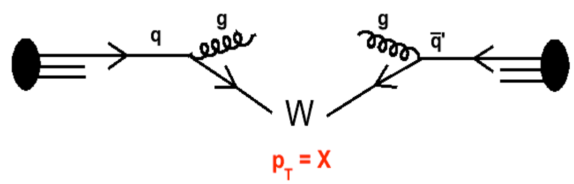


W width : Neutrino p_T



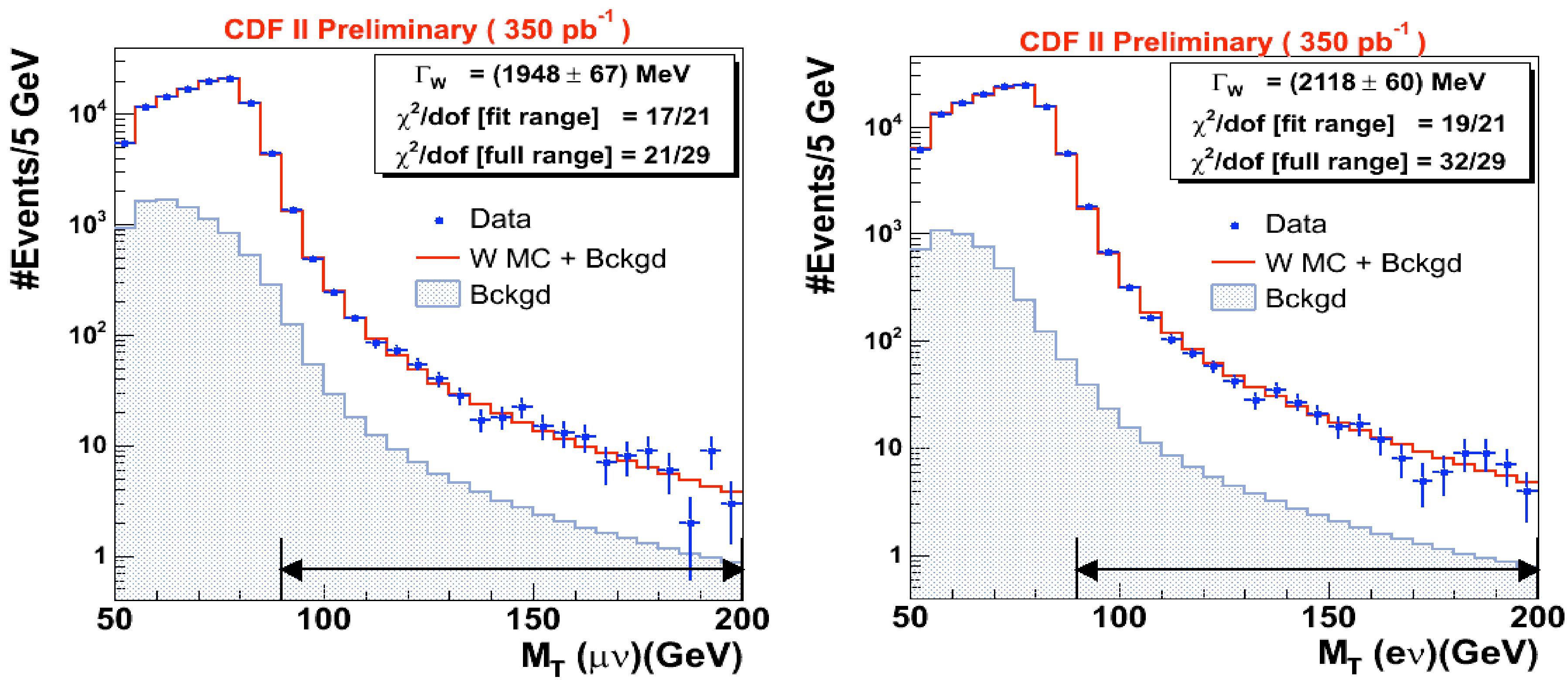
- p_T^{ν} inferred from E_T^{miss}
- $U=(U_x, U_y)=\sum_{towers} E\sin\theta\ (\cos\varnothing, \sin\varnothing)$ vector sum over calorimeter towers

  Excluding those surrounding lepton
- **$p_T^{\nu} = E_T^{miss} = -(U + p_T^{lep})$**
- U mostly comes from gluon radiation from incoming quarks (also Underlying Event (UE), photons from bremsstrahlung).



- Accurate predictions of U (QCD radiation, UE, hadronisation and detector response to hadrons) is difficult (and slow) from first principles.
- Devise an ad-hoc parameterised model of the recoil in terms of the boson p_T, tuned to the recoil in $Z \rightarrow ll$ events (where the Z p_T can be reconstructed).

W width: results



Γ_W = 2032 ± 71 (stat + syst) MeV

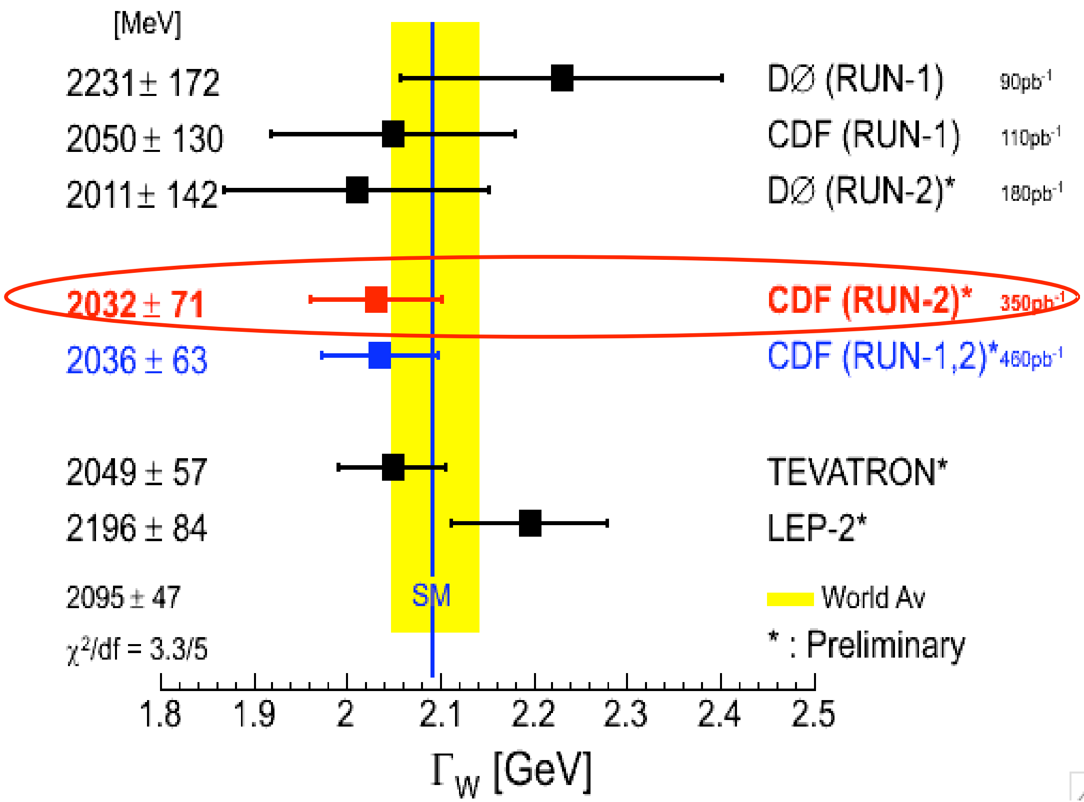
W width: systematic uncertainties

CDF Run II Preliminary (350 pb^{-1})

	$\Delta\Gamma_W$ [MeV]		
	Electrons	Muons	Common
Lepton Scale	21	17	12
Lepton Resolution	31	26	0
Simulation	13	0	0
Recoil	54	49	0
Lepton ID	10	7	0
Backgrounds	32	33	0
$p_T(W)$	7	7	7
PDF	16	17	16
QED	8	1	1
W mass	9	9	9
Total systematic	78	70	23
Statistical	60	67	0
Total	98	97	23

W width: world average

World's most precise single measurement!



Central value decreases by 44 MeV:
2139 → 2095 MeV

Uncertainty reduced by 22%:
60 → 47 MeV

Indirect Width Measurement

$$R_{exp} = \frac{\sigma \cdot BR\,(W \rightarrow l\nu)}{\sigma \cdot BR\,(Z \rightarrow ll)}$$

Precision LEP Measurements

SM Calculation

NNLO Calculation

$$R = \frac{\sigma_W}{\sigma_Z} \times \frac{\Gamma(W \rightarrow l\nu)}{\Gamma(W)} \times \frac{\Gamma(Z)}{\Gamma(Z \rightarrow ll)}$$

CDF Run II **INDIRECT width (72 pb^{-1}):**

2092 ± 42 MeV

PRL 94, 091803

CDF Run II **DIRECT width (350 pb^{-1}):**

2032 ± 71 MeV

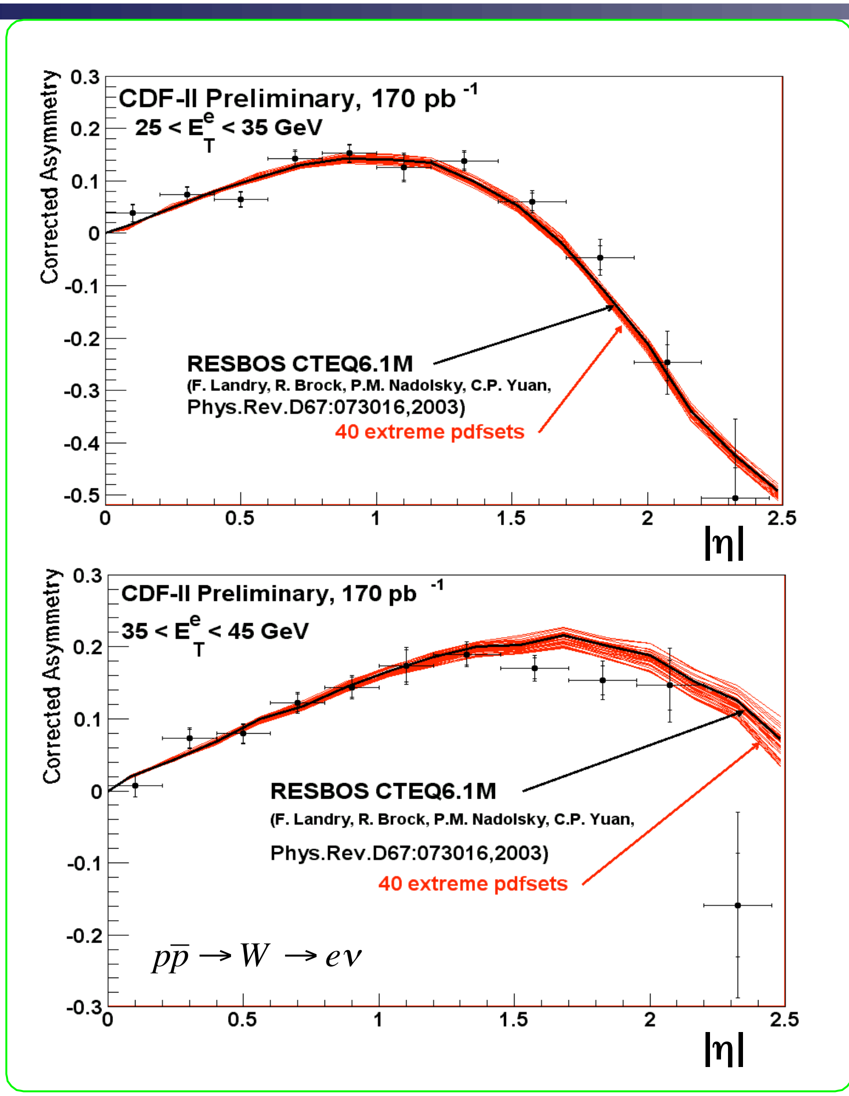
preliminary

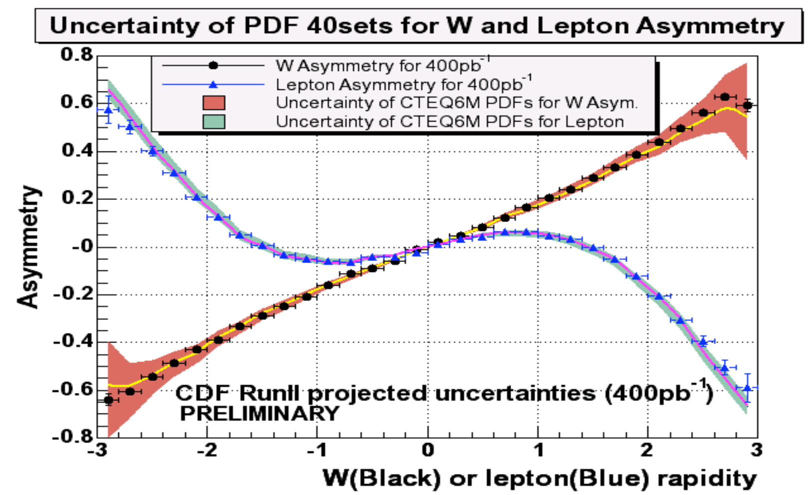
Summary

- W charge asymmetry measurement - will help constrain PDFs (due to be updated this summer).
- W width measurement (world's most precise measurement!) - consistent with the Standard Model prediction and indirect measurement.

Back-up slides

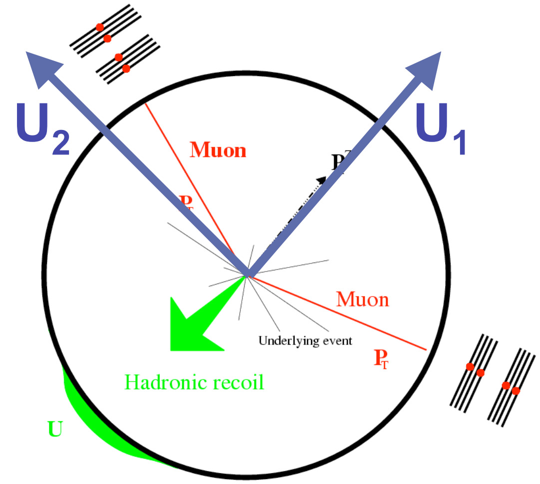
e asymmetry

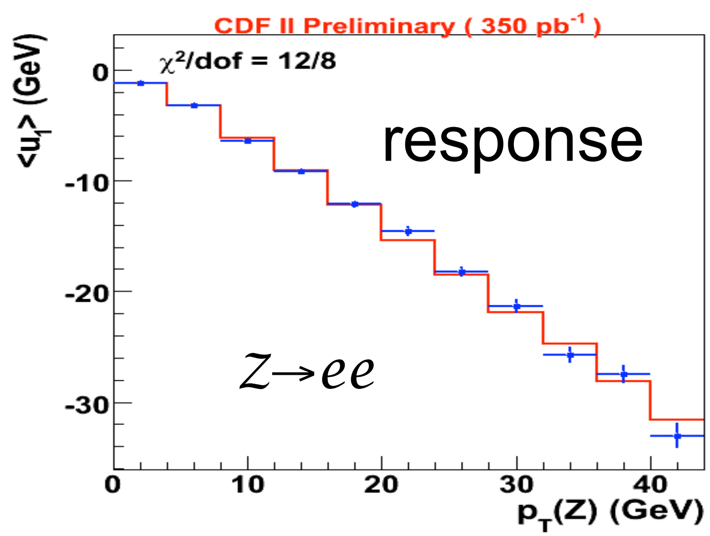

CDF-II Preliminary, 170 pb -1
25 < E e T < 35 GeV
Corrected Asymmetry
RESBOS CTEQ6.1M
(F. Landry, R. Brock, P.M. Nadolsky, C.P. Yuan,
Phys.Rev.D67:073016,2003)
40 extreme pdfsets
|η|
CDF-II Preliminary, 170 pb -1
35 < E e T < 45 GeV
Corrected Asymmetry
RESBOS CTEQ6.1M
(F. Landry, R. Brock, P.M. Nadolsky, C.P. Yuan,
Phys.Rev.D67:073016,2003)
40 extreme pdfsets
$p\bar{p} \rightarrow W \rightarrow e\nu$
|η|


Uncertainty of PDF 40sets for W and Lepton Asymmetry
W Asymmetry for 400pb-1
Lepton Asymmetry for 400pb-1
Uncertainty of CTEQ6M PDFs for W Asym.
Uncertainty of CTEQ6M PDFs for Lepton
Asymmetry
CDF RunII projected uncertainties (400pb-1)
PRELIMINARY
W(Black) or lepton(Blue) rapidity

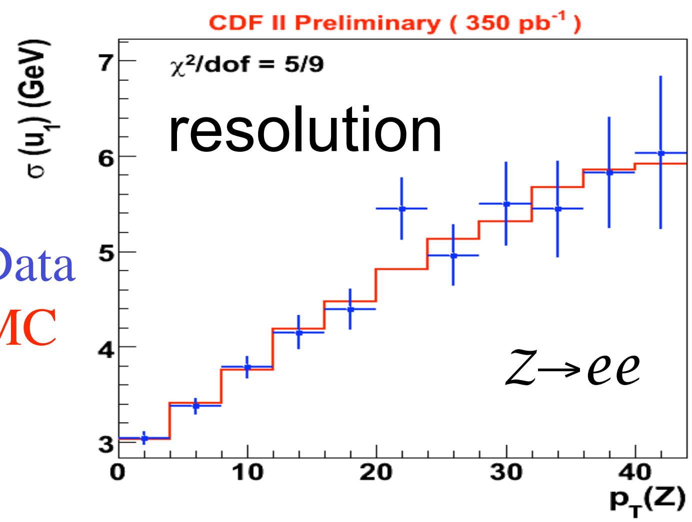
Hadronic Recoil: U

- Accurate predictions of U is difficult (and slow) from first principles.
- U simulated with ad-hoc parameterised model, tuned on $Z \rightarrow \ell\ell$ data.
- U split into components parallel (U_1) and perpendicular (U_2) to Z p_T
- 7 parameter model describes the response and resolution in the U_1 and U_2 directions as a function of the Z p_T.
- Systematic comes from parameter uncertainties (limited Z stats).





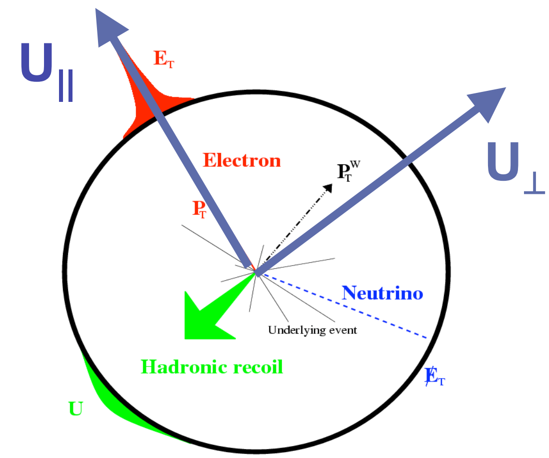
Data
MC



Hadronic Recoil: U (p_T^ν)

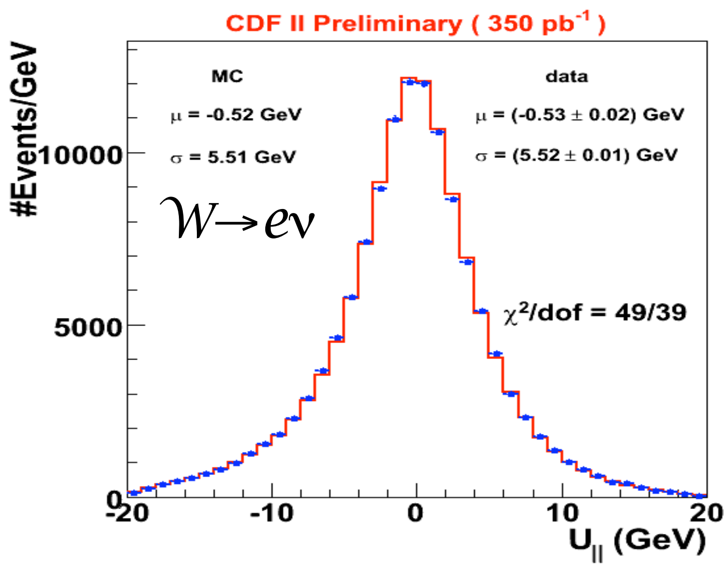
$$<u_1> = (P_1 + P_2 p_T) * (1 - e^{(-P_3 \times p_T)})$$

$$\sigma(u_1) = (P_4 + P_5 p^T) * M_1 \sum E_T^{M_2}$$

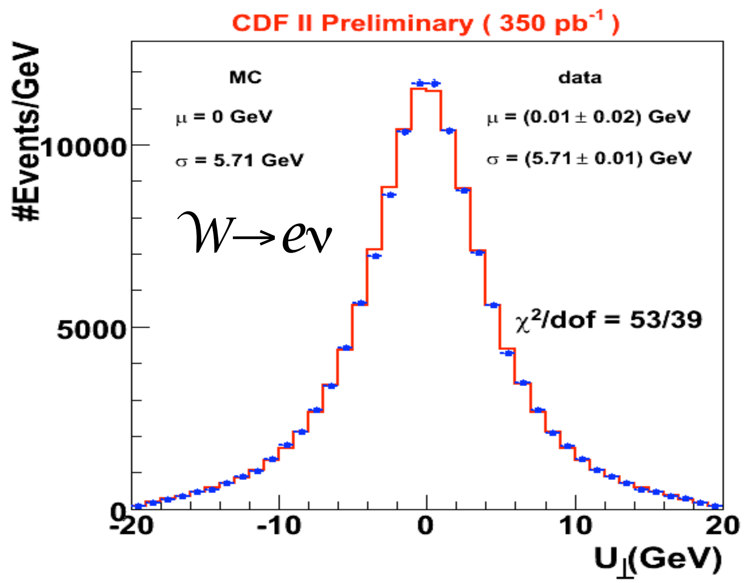


- U split into components parallel ($U_{||}$) and perpendicular ($U_\perp$) to charged lepton.

- Many distributions used to cross check the model in $W \to l\nu$ data:



Data
MC



Backgrounds

electron *and* muon channel:

$Z \rightarrow ll$

- One lepton lost
- E_T^{miss} from missing lepton

$W \rightarrow \tau\nu$

- τ decays to e/μ
- intrinsic E_T^{miss}

multijet

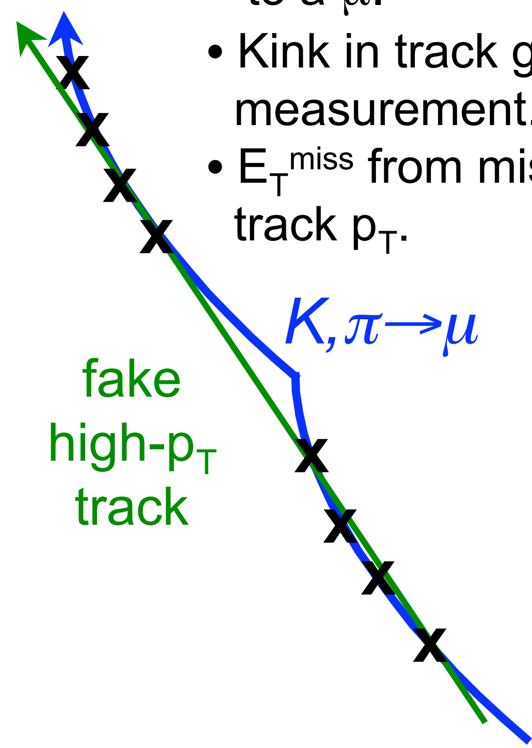
- Jet fakes/contains a lepton
- E_T^{miss} from misconstruction

Need the m_T distributions *and* the normalisations!

muon channel only:

Decay In-Flight

- Kaon/pion decays "In-Flight" to a μ.
- Kink in track gives high-p_T measurement.
- E_T^{miss} from mis-measured track p_T.



Backgrounds