

**POSTCARDS FROM**

# **THE ENERGY FRONTIER**

**BATAVIA, ILL.**



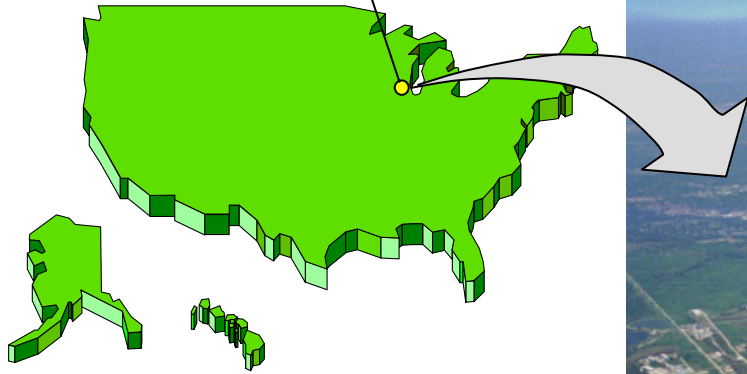
**Tevatron – Part Deux**  
**John M. Butler**  
*Boston University*



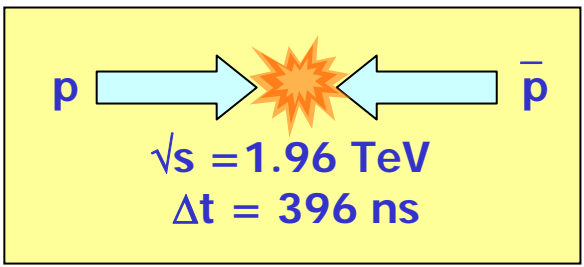
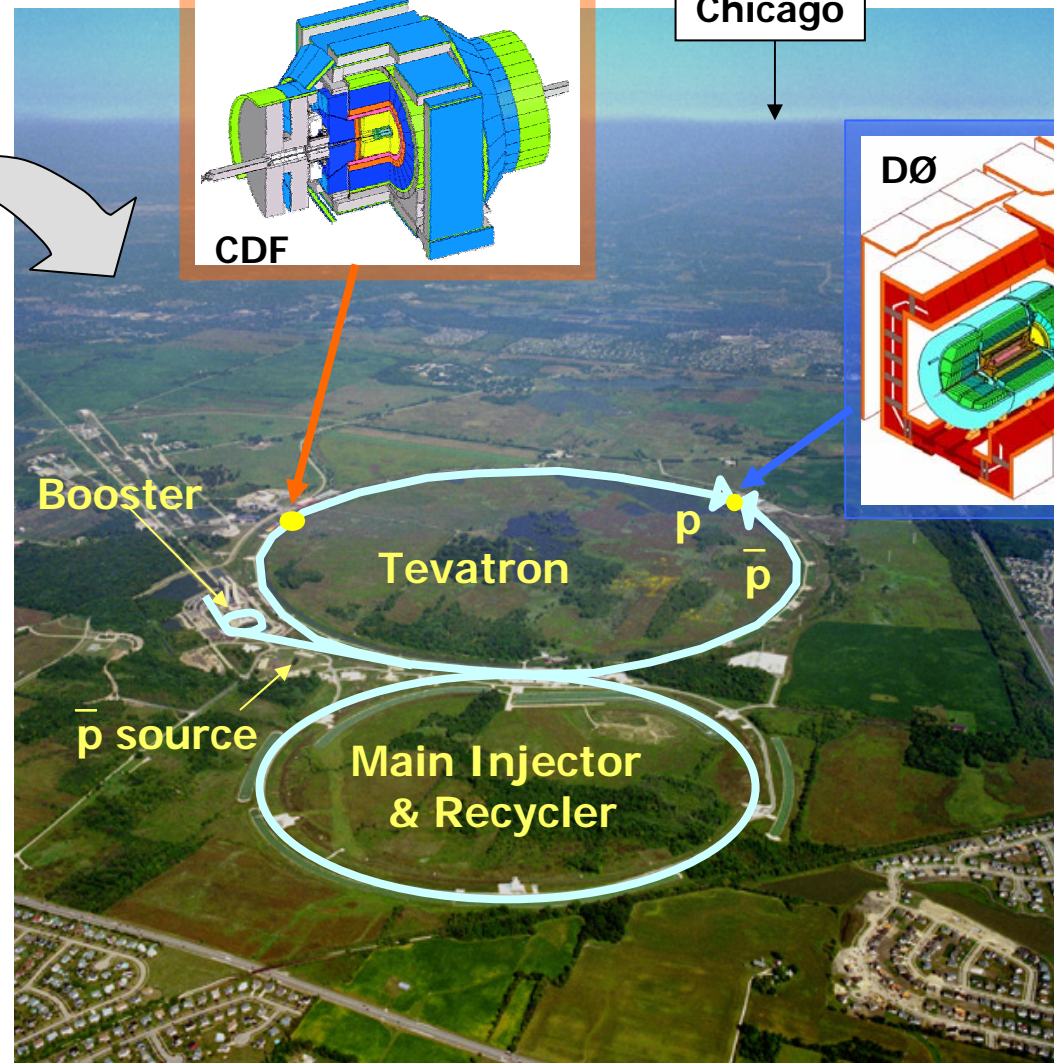
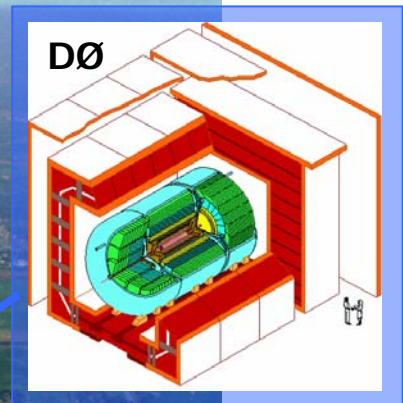
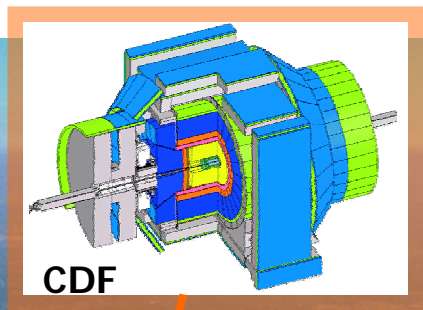
# Fermilab



Batavia, Illinois



Chicago



Run I 1992-96  
Run II 2001-09

50 × larger dataset  
at increased energy

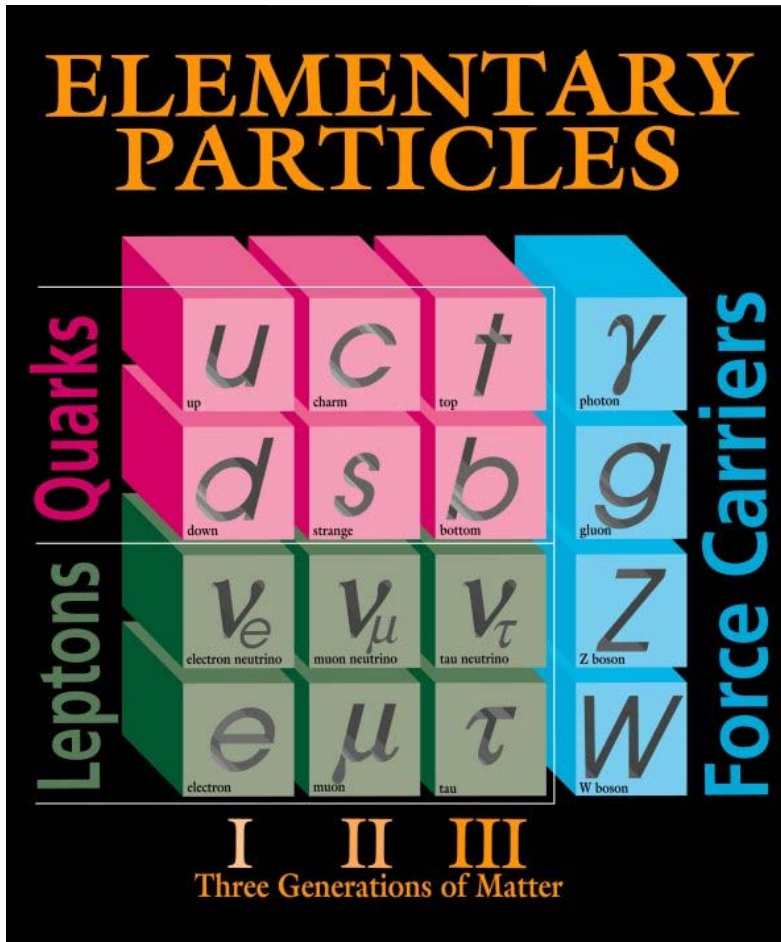




# Motivation



- ❖ The Standard Model of particle physics is a highly successful description of Nature
- ❖ Aesthetically appealing in its elegance and simplicity
- ❖ No measurement is in significant disagreement with the SM
- ❖ Nobody believes it is the whole story



Fermilab 95-759



# “The analysis finally agrees with the SM, let’s publish...”



- ❖ Not our job to validate the Standard Model (SM) but to find out how nature works. Much more fun to make the discovery that breaks the SM!
- ❖ The Tevatron confronts the SM with a rich\* program of physics
- ❖ Measurements from a broad range of topics
  - Top quark properties
  - Strong interaction – QCD
  - CKM or “Heavy Flavor” – b and c quark studies
  - Electroweak (EW) physics
  - Searches for the Higgs boson
- ❖ Actively pursuing signs of new physics beyond the SM
  - Mechanism of EWSB – SUSY or technicolor or little Higgs or ...?
  - Large extra dimensions
  - Leptoquarks
  - Excited leptons, monopoles, ...
  - “Who ordered that?”

\*Beware! When physicists say “rich” they often mean “vastly complicated” or “really hard” or “impossible to get a sensible result”



# Abundance of Physics at 2 TeV



Abstracts Submitted to ICHEP'04

Abstract Title	Session	EB
<b>B Physics (10)</b>		
Pub* Measurement of B hadron lifetimes using final states containing J/ψ	CP violation and CKM	EB027
Pub B hadron lifetime ratios in semileptonic mode	CP violation and CKM	EB006
A study of Bd oscillations	CP violation and CKM	EB017
Search for Bs oscillations	CP violation and CKM	EB017
Pub X(3872) state	Hadron spectroscopy and exotics	EB007
Upsilon (1S) bottomonium production	Heavy quark mesons and baryons	EB007
Observation of L=1 B <sub>c</sub> J* states at the DØ experiment	Heavy quark mesons and baryons	EB028
Observation of semileptonic B decays into orbitally excited D final states	Heavy quark mesons and baryons	EB023
A study of the B <sub>c</sub> meson	Heavy quark mesons and baryons	EB028
Pub* A study of rare B meson decays using the DØ detector	Beyond standard model	EB023
<b>Electroweak (5)</b>		
Pub Measurement of the W and Z production cross sections times the leptonic branching ratios...	Electroweak	EB003
Measurement of the width of the W boson at the Fermilab Tevatron	Electroweak	EB026
Measurement of the forward-backward charge asymmetry in Drell-Yan events	Electroweak	EB021
Pub* Measurements of the production of photons in association with a W or a Z boson...	Electroweak	EB016
Pub Associated production of W and Z bosons	Electroweak	EB003
<b>Higgs (9)</b>		
Pub* Measurement of the Wbb production cross section and search for the Higgs in WH...	Electroweak	EB004
Pub Search for Higgs decays to WW at DØ	Electroweak	EB005
Measurement of the W-pair production cross section at DØ	Electroweak	EB005
Search for technicolor particle at DØ	Beyond standard model	EB029
Search for Fermiophobic and topcolor Higgs in the diphoton final states at DØ	Beyond standard model	EB013
Pub Search for doubly charged Higgs pair production in the muon decay channel at DØ	Beyond standard model	EB005
Pub* Z+j production cross section and cross section ratios of Z+b/Z+j at DØ	Electroweak	EB004/5
Search for Z to bbar decay at DØ	Electroweak	EB018
A search for neutral Higgs bosons at high tanβ with the DØ Detector	Beyond standard model	EB018
<b>New Phenomena (10)</b>		
Pub* Searches for first and second generation leptoquarks	Beyond standard model	EB015
Search for anomalous heavy-flavor jet production in association with W bosons	Beyond standard model	EB029
Search for heavy stable charged particles	Beyond standard model	EB020
Search for RPV SUSY in multilepton final states	Beyond standard model	EB014
Search for the associated production of charginos/neutralinos in the final states with three leptons	Beyond standard model	EB014
Pub Search for GMSB SUSY in diphoton events with large missing ET	Beyond standard model	EB013
Search for heavy dilepton resonances with the DØ detector	Beyond standard model	EB012
Search for large extra spatial dimensions in jets + missing ET topologies	Beyond standard model	EB019
Search for squarks and gluinos in the jets + missing ET topology	Beyond standard model	EB019
Pub Search for extra dimensions in the dilepton and diphoton channels	Beyond standard model	EB012

Last Updated on 5/28/2004

Jianming Qian



# ...and more and more...

## Abstracts Submitted to ICHEP'04

### Quantum Chromodynamics (8)

Pub	Measurement of dijet azimuthal decorrelations at central rapidities at DØ Run II	QCD hard interactions	EB002
	Measurement of the elastic slope with the DØ Detector in Run II	QCD soft interactions	EB001
	Diffractive Z measurement at DØ Run II	QCD soft interactions	EB001
	Forward proton detector status and diffractive jet production at DØ Run II	QCD soft interactions	EB001
Pub	Measurement of the inclusive jet cross section by the DØ Collaboration in Run II	QCD hard interactions	EB002
Pub	Measurement of the dijet cross section using the DØ detector in Run II	QCD hard interactions	EB002
	Measurement of the inclusive b-jet cross section using the DØ detector in Run II	QCD hard interactions	EB025
	Measurement of the dijet angular distribution using the DØ detector in Run II	QCD hard interactions	EB002

### Top Physics (7)

Pub*	Measurement of the top quark pair production cross section in l+jets and ll+jets final state	QCD hard interactions	EB008/9
Pub	Measurement of the top quark pair production cross section with lifetime b tagging at DØ	QCD hard interactions	EB030
	Search for single top quark production at DØ	Electroweak	EB024
	Measurement of the top quark mass in lepton+jets channel at DØ	Electroweak	EB011
	Measurement of the top quark mass in dilepton+jets channel at DØ	Electroweak	EB011
	Measurement of the W boson helicity in top quark decays at DØ	Electroweak	EB022
	Measurement of $Br(t \rightarrow Wb)/Br(t \rightarrow Wq)$ at DØ	Electroweak	EB022

Note      \*: the abstract in question combines several analyses, aiming to publish a subset  
 Yellow indicates the existence of preliminary results while blue is for those submitted for publication.



# Approach for this talk



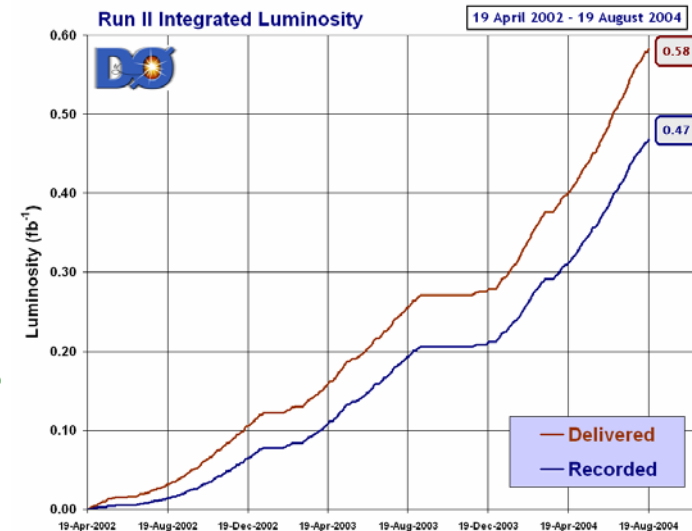
- ❖ No attempt to give a comprehensive review of latest results from CDF and DØ
- ❖ Rather, I'll present some representative measurements from the main physics areas studied at the Tevatron
  - What the data looks like and what you can do with it
- ❖ Physics Topics – my own idiosyncratic selections
  - Top quark properties – see Darien Wood's talk from Monday
  - QCD: inclusive jet cross section
  - Heavy flavor:  $B_s$  and  $\Lambda_b$
  - Electroweak: W mass
  - Searches for the Higgs boson
  - Searches for new physics
    - SUSY in trileptons
    - The virtues of recycling - dileptons



# Some Obvious Observations



- ❖ High energy and luminosity are good, higher is better
  - Energy Frontier: high E allows to probe shortest distance scales and directly produce new heavy states of matter
  - High L allows to observe rare processes with small cross sections
- ❖ Corollary - when LHC is running, the Tevatron is toast
- ❖ Corollary – lots of data is good, more is better
  - Now measuring integrated L in  $\text{fb}^{-1}$
- ❖ Hadron machines are quickest, path to high E and L
  - “Discovery Machines” that also can make precision measurements
  - Dirty environment or “rich” environment?



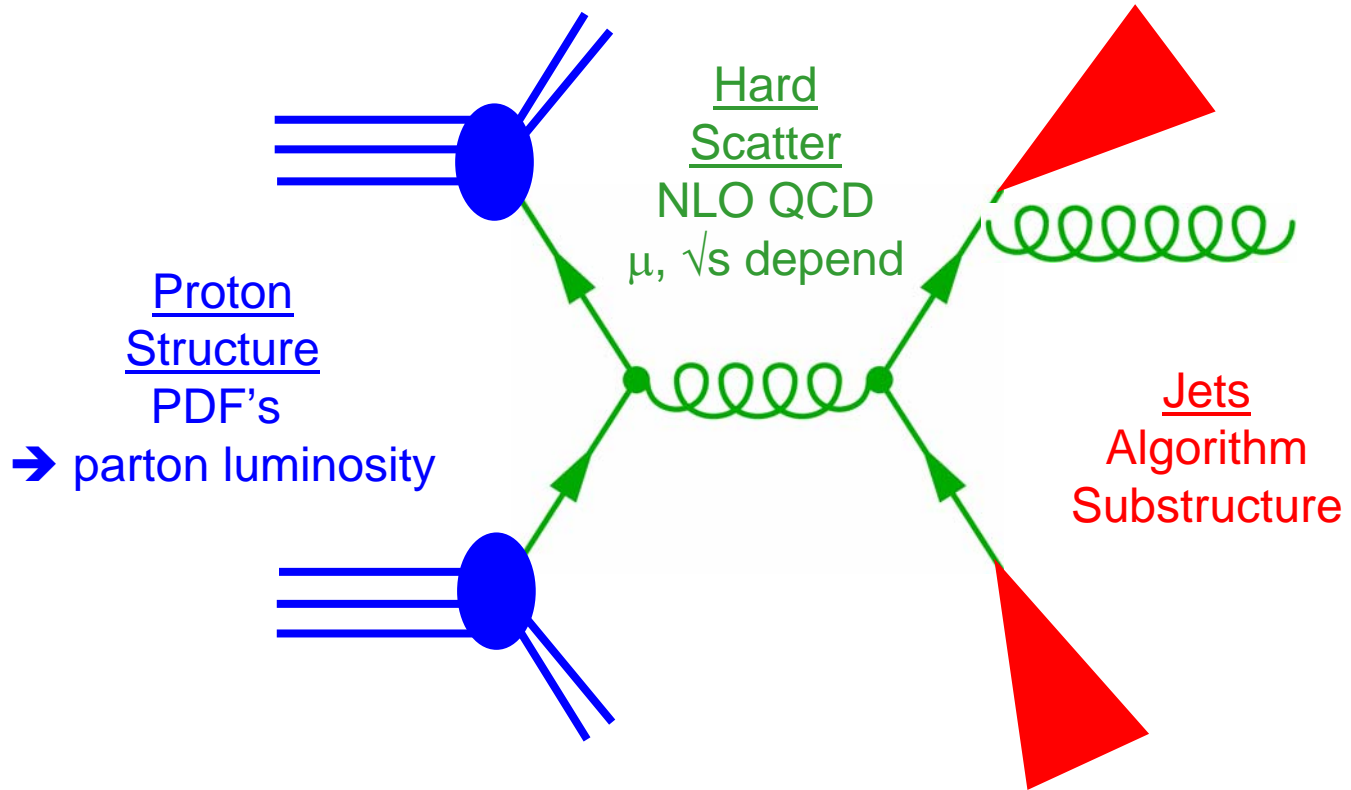




QCD



# Studying Strong Interactions at the Tevatron

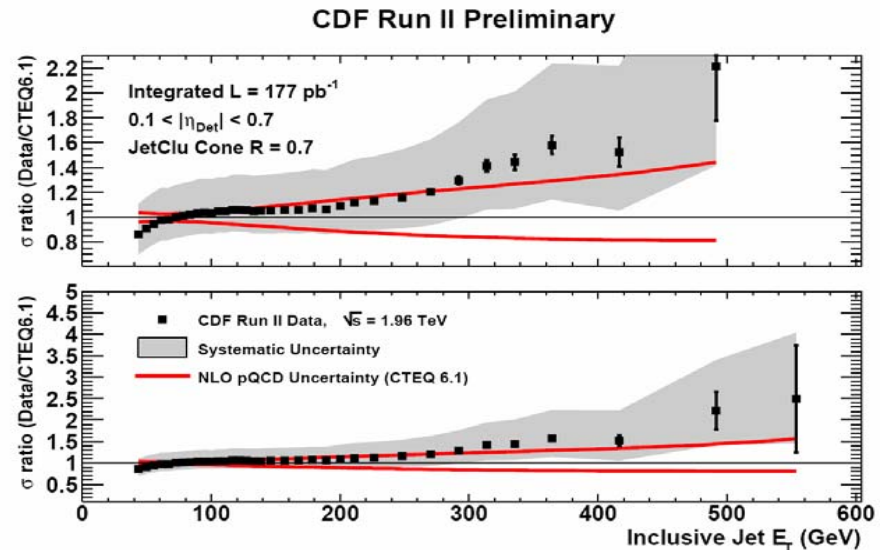
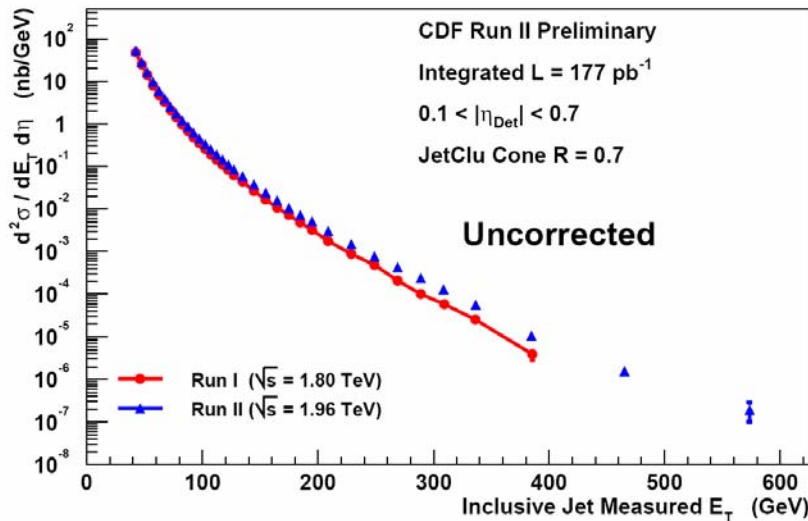
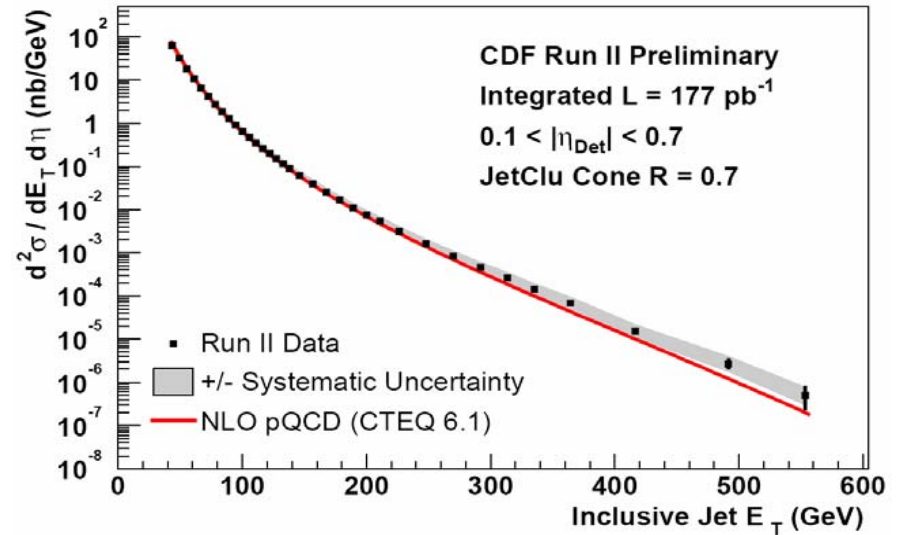




# Inclusive Jets



- ❖ Inclusive jet production tests pQCD and structure of the proton through the Parton Distribution Functions (PDFs)
- ❖ Highest  $E_T = E \sin\theta$  jets probe distance scale of order  $10^{-19} \text{ m}$
- ❖ Sensitive to new physics, e.g. quark compositeness

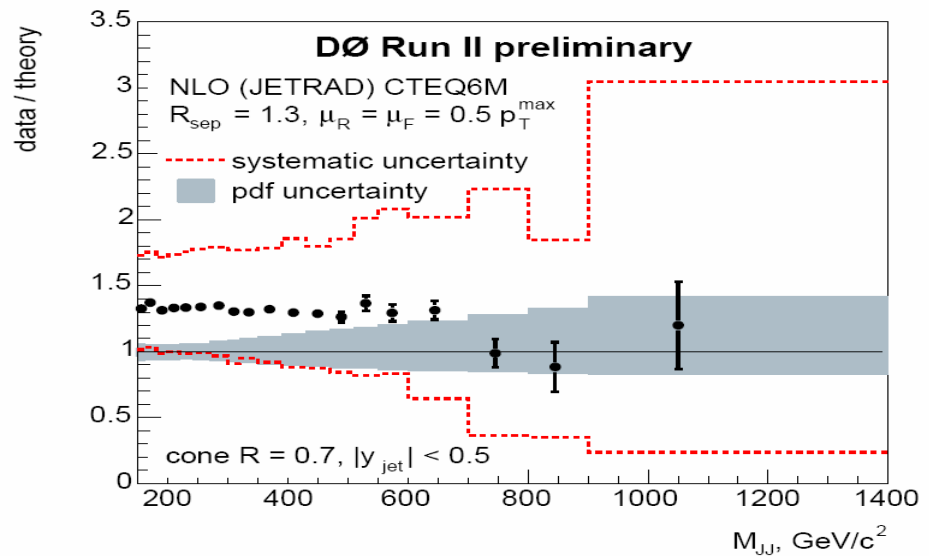
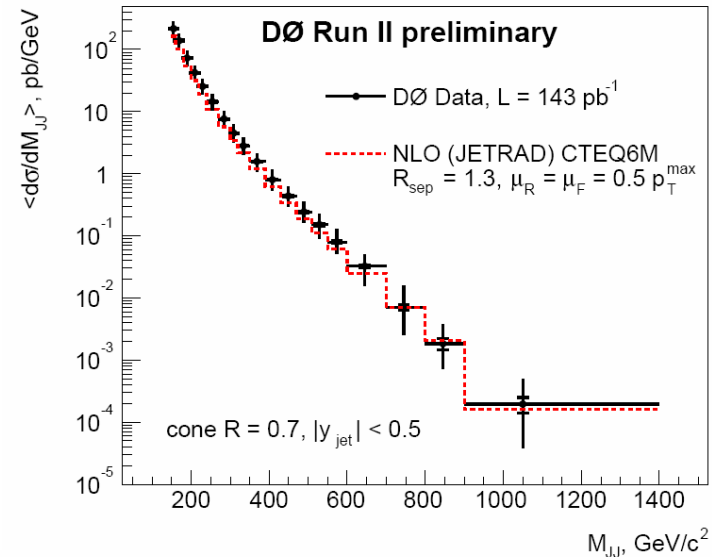




# Inclusive Dijets

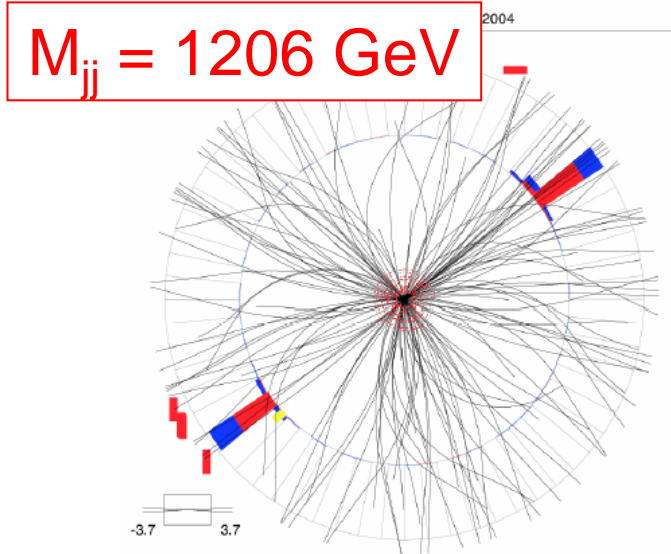
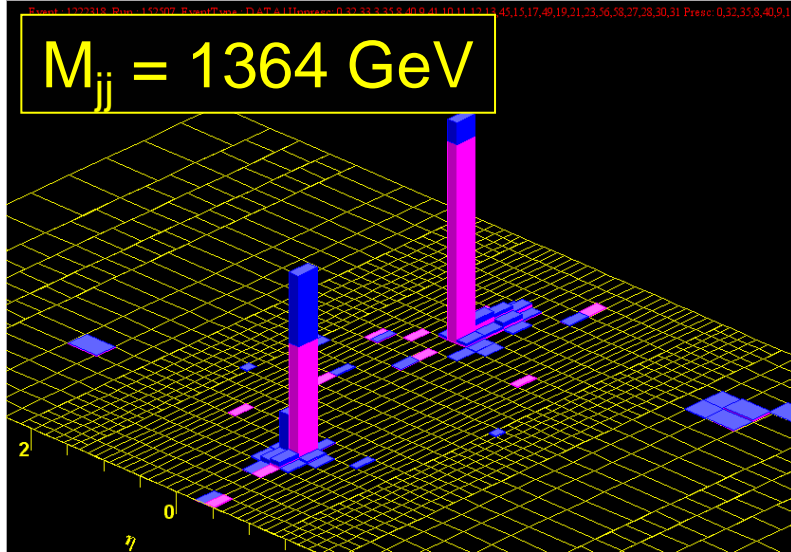


- ❖ Again sensitive probe of PDFs
- ❖ Look for excess or “bump hunting” at high  $M_{jj}$ 
  - Very hard to see  $W, Z \rightarrow jj$
- ❖ Energy scale systematic uncertainty dominates the experimental error
  - Careful! A case where the errors are nearly 100% correlated point-to-point
  - Requires a detailed understanding of your detector



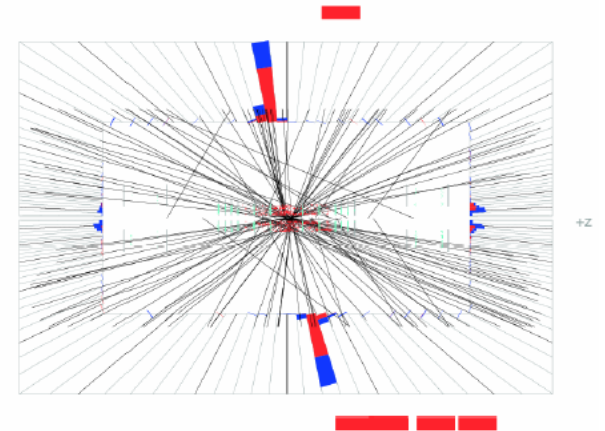


# Highest ET Events

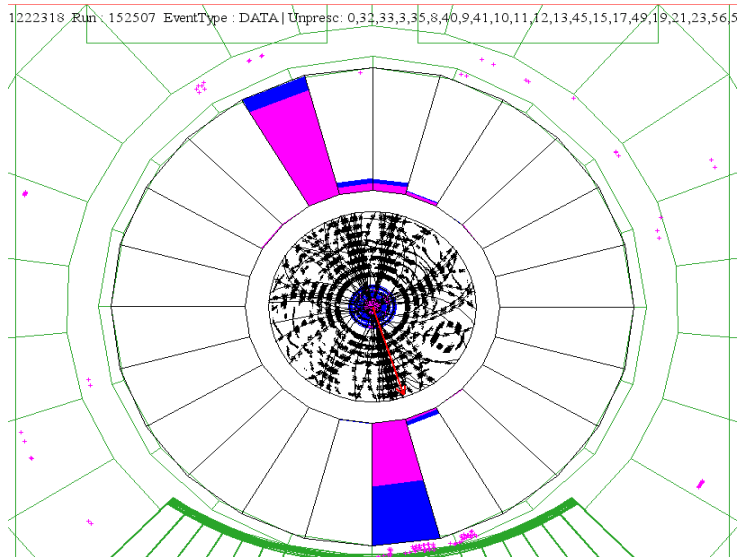


x-y view

E scale: 431 GeV



r-z view





# Heavy Flavor



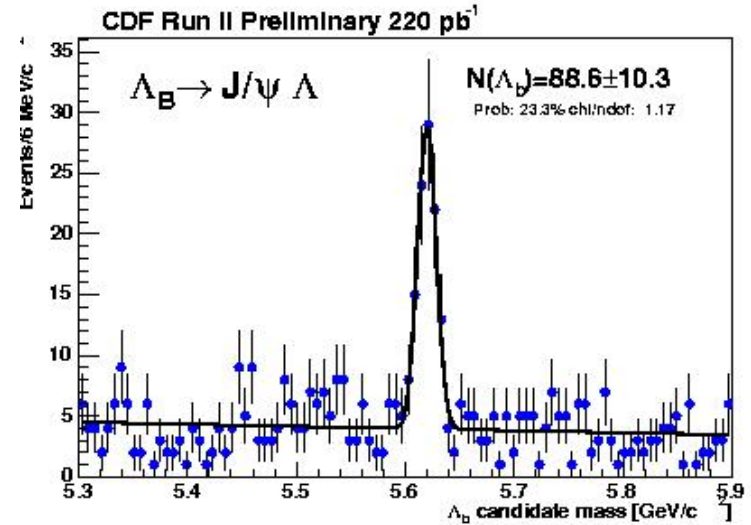
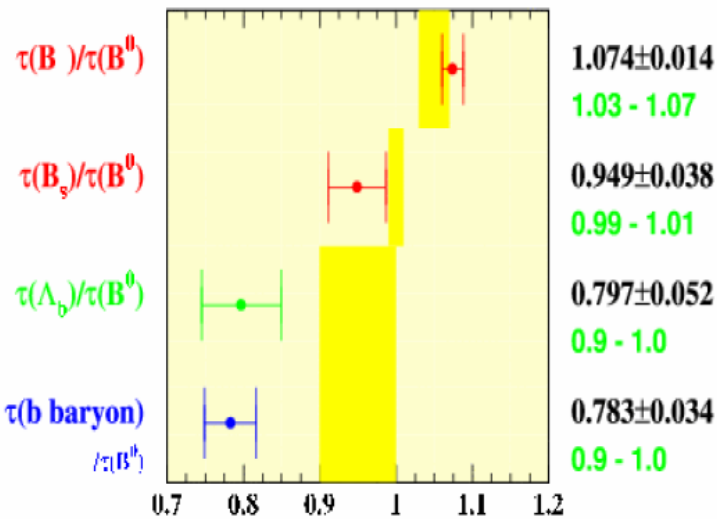
# B Physics at the Tevatron



- ❖ Complementary to the  $e^+e^-$  B Factories (Dallapiccola & Morii – Friday)
- ❖ Hadron colliders have some advantages...
  - Lots of b quarks produced  $\sigma(b\bar{b}) \sim 100 \mu\text{b}$ 
    - 10,000 Hz @  $L = 10^{32}$
    - More b's than tape
  - All species produced  $B_u, B_d, B_s, B_c, \Lambda_b, \dots$
- ❖ ...and some disadvantages
  - $\sigma(b\bar{b}) \ll \sigma(p\bar{p})$   
➔ must trigger on b's
  - “Rich” environment
  - Limits the final states that are accessible for study
- ❖ Topics include
  - Masses
  - Lifetimes
  - Oscillations
  - CP violation
  - Rare decays



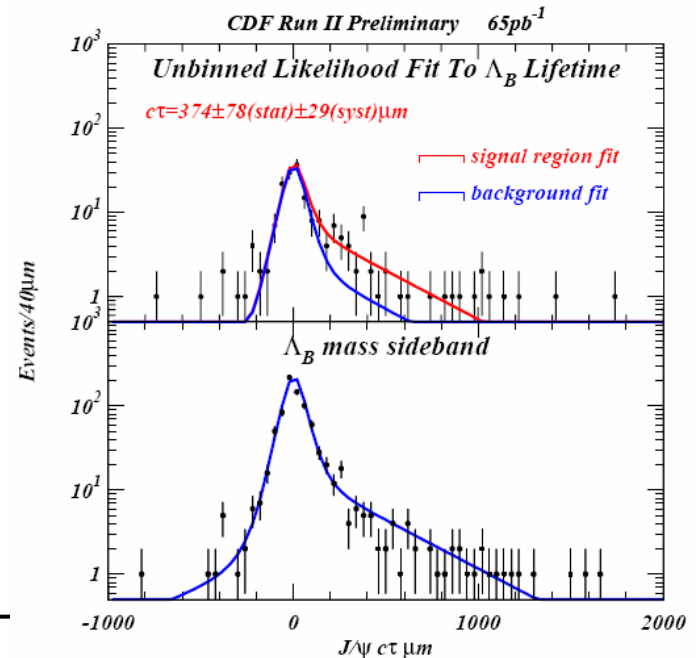
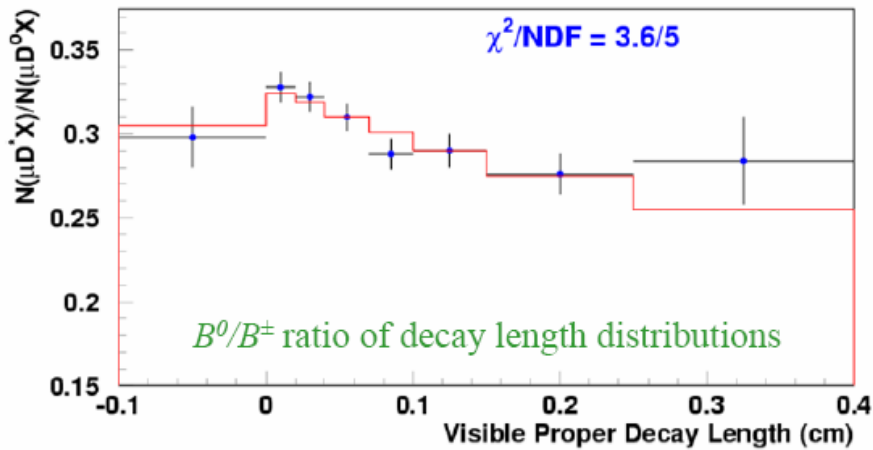
# Masses and Lifetimes



B Lifetime Working Group  
CKM WKS February 2002

lifetime ratio

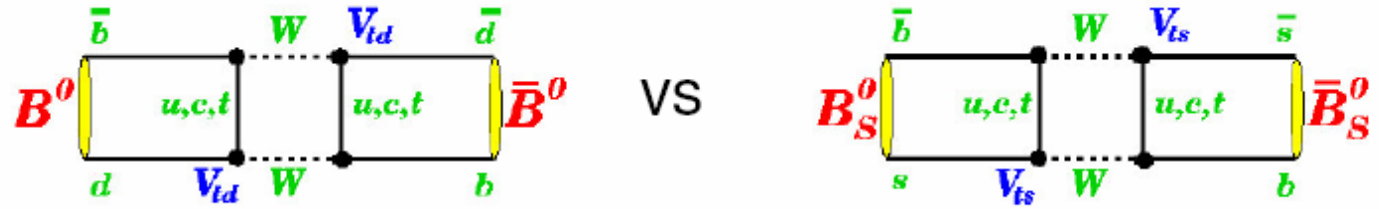
DØ RunII Preliminary, Luminosity = 250 pb<sup>-1</sup>





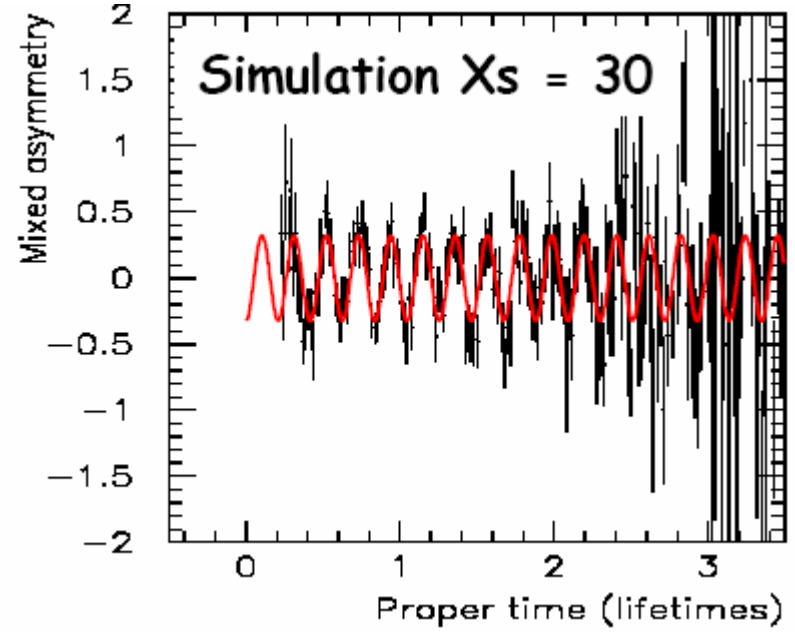
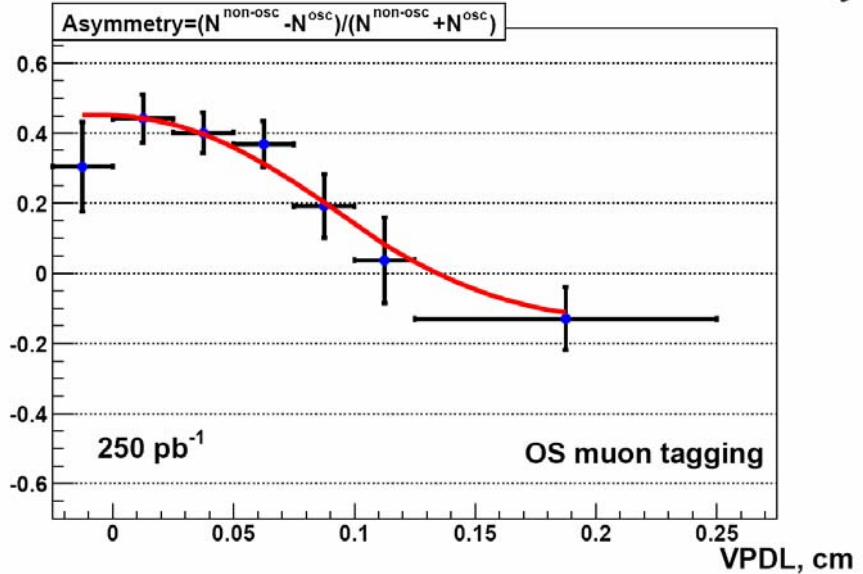


# $B_s$ Oscillations



$\Rightarrow B_s$  oscillates >25 times faster than  $B_d$

DØ Run II Preliminary



$B_d$  mixing is Tevatron proof of principle



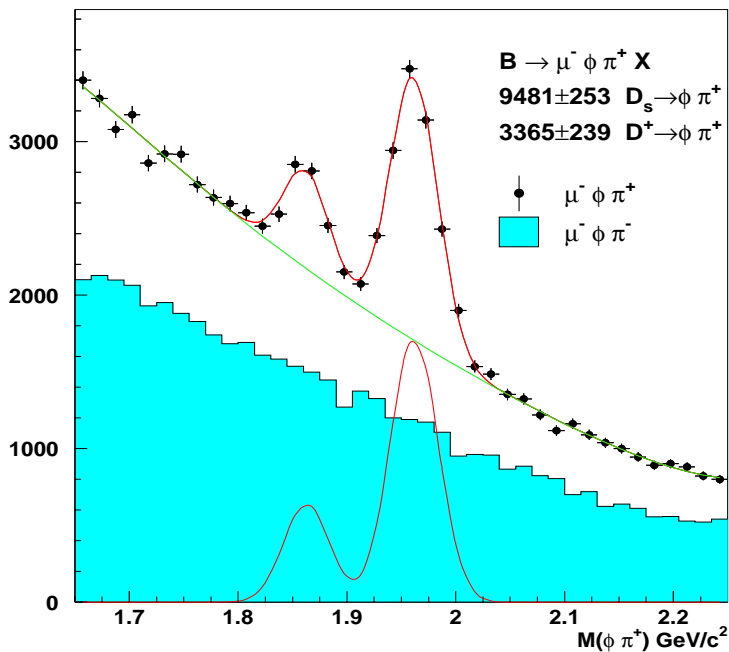
$$B_s \rightarrow \mu \nu D_s (\rightarrow \phi \pi)$$

Pro: easy to trigger on

Con: neutrino in final state

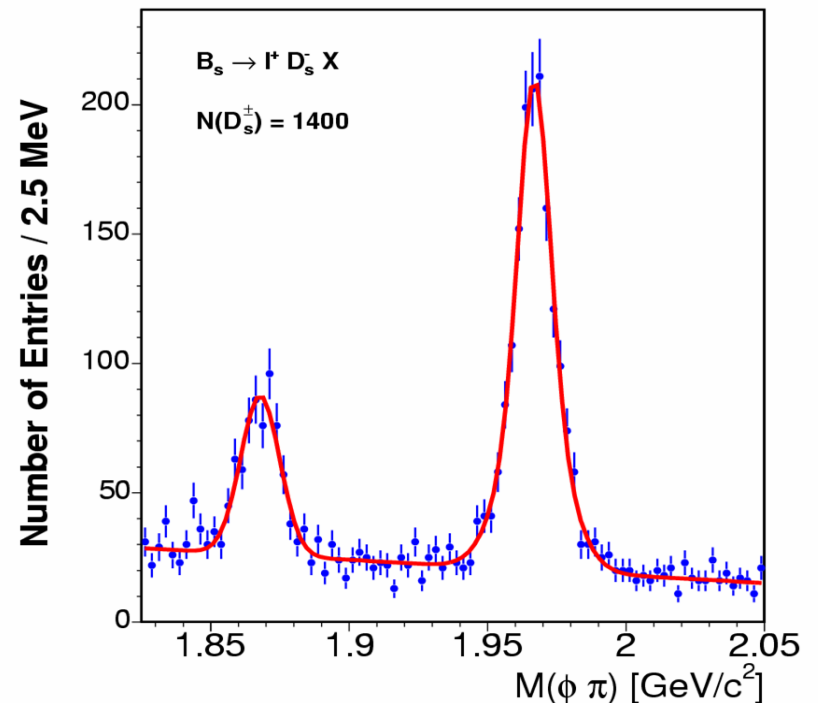
Nice illustration of different detector strengths

DØ RunII Preliminary, Luminosity = 250 pb<sup>-1</sup>



CDF RunII Preliminary

L ≈ 185 pb<sup>-1</sup>





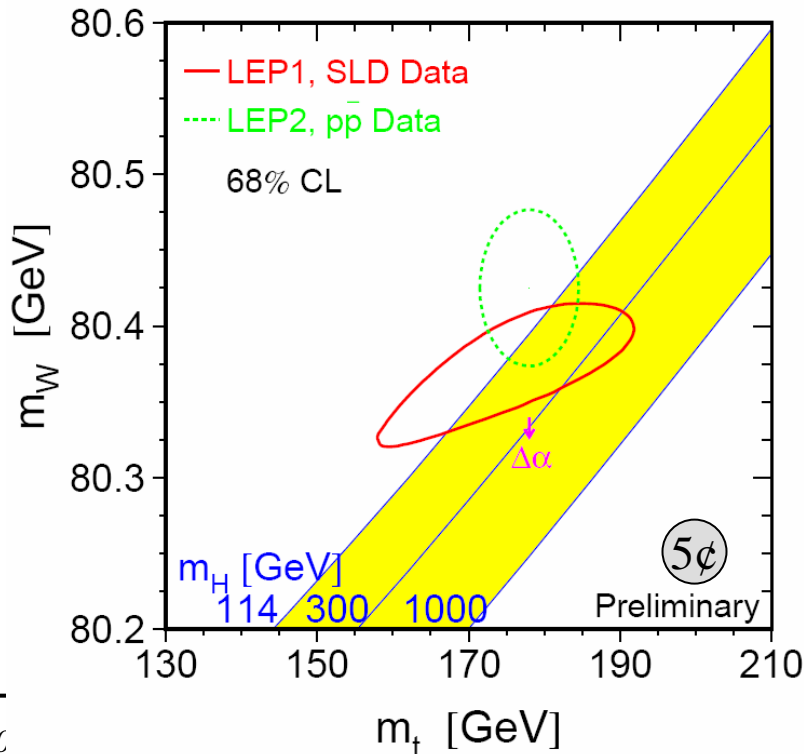
# Electroweak



# Measuring the W Mass

- ❖  $M_W$  is a fundamental parameter of the standard model
- ❖ Depends on the top quark and Higgs masses through loop effects

$$M_W = M_{\text{tree}} + \underbrace{M_Z, \alpha_{EM}, G_F}_{\text{Tree Level}} + \underbrace{\text{Top Loop}}_{\propto \frac{m_t^2}{M_W^2}} + \underbrace{\text{Higgs Loop}}_{\propto \ln \frac{M_H}{M_W}}$$

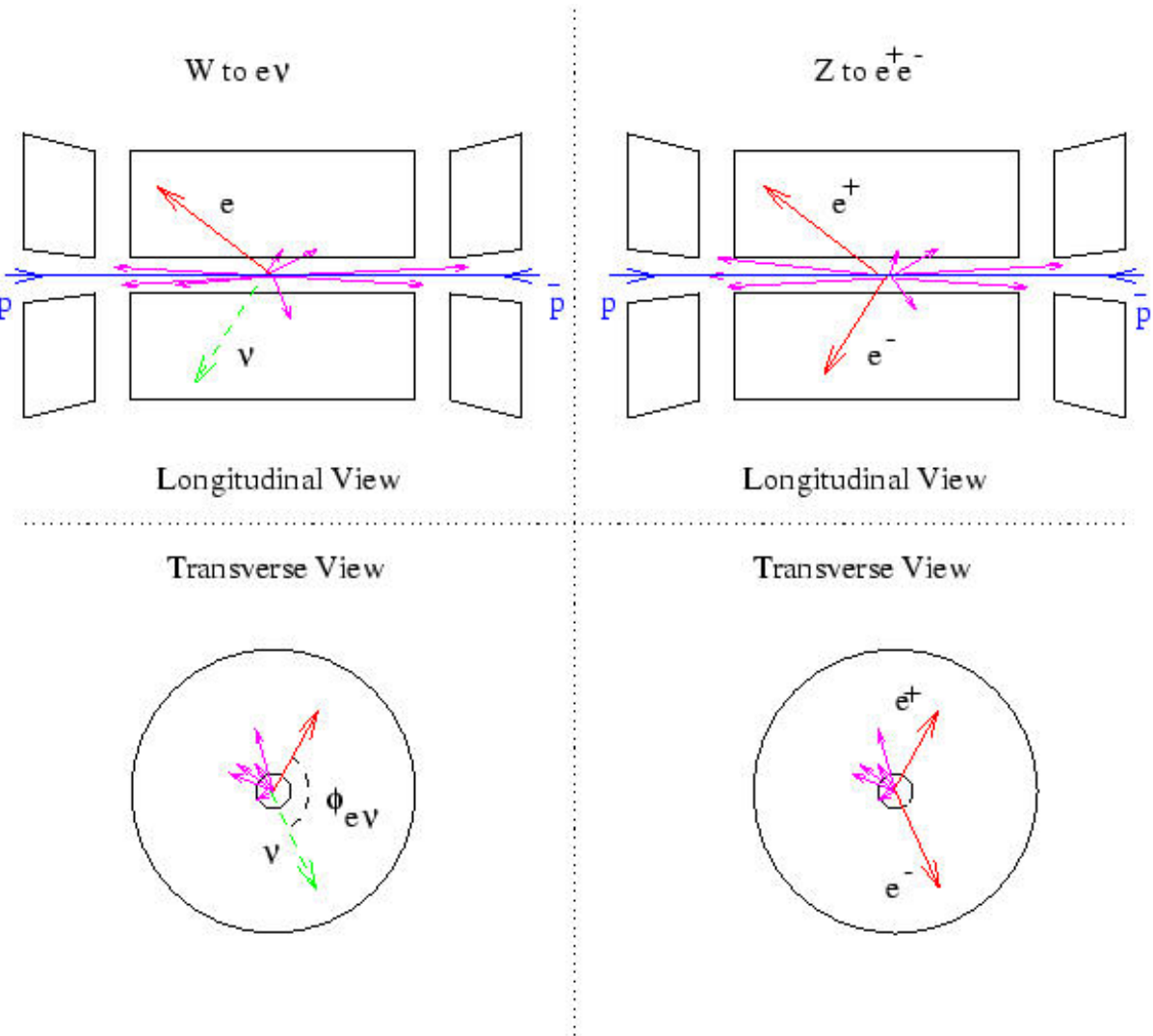


Run I data favor a low Higgs mass

Run II can indirectly determine  $\delta M_H / M_H$  to 35% if  $\delta m_t = 3$  GeV and  $\delta M_W = 40$  MeV



# W Mass at a Hadron Collider



- ❖ Need to use leptonic decays
- ❖ Complicated by neutrino  
→ can't compute invariant mass
- ❖ Z sample is used extensively for controlling measurement

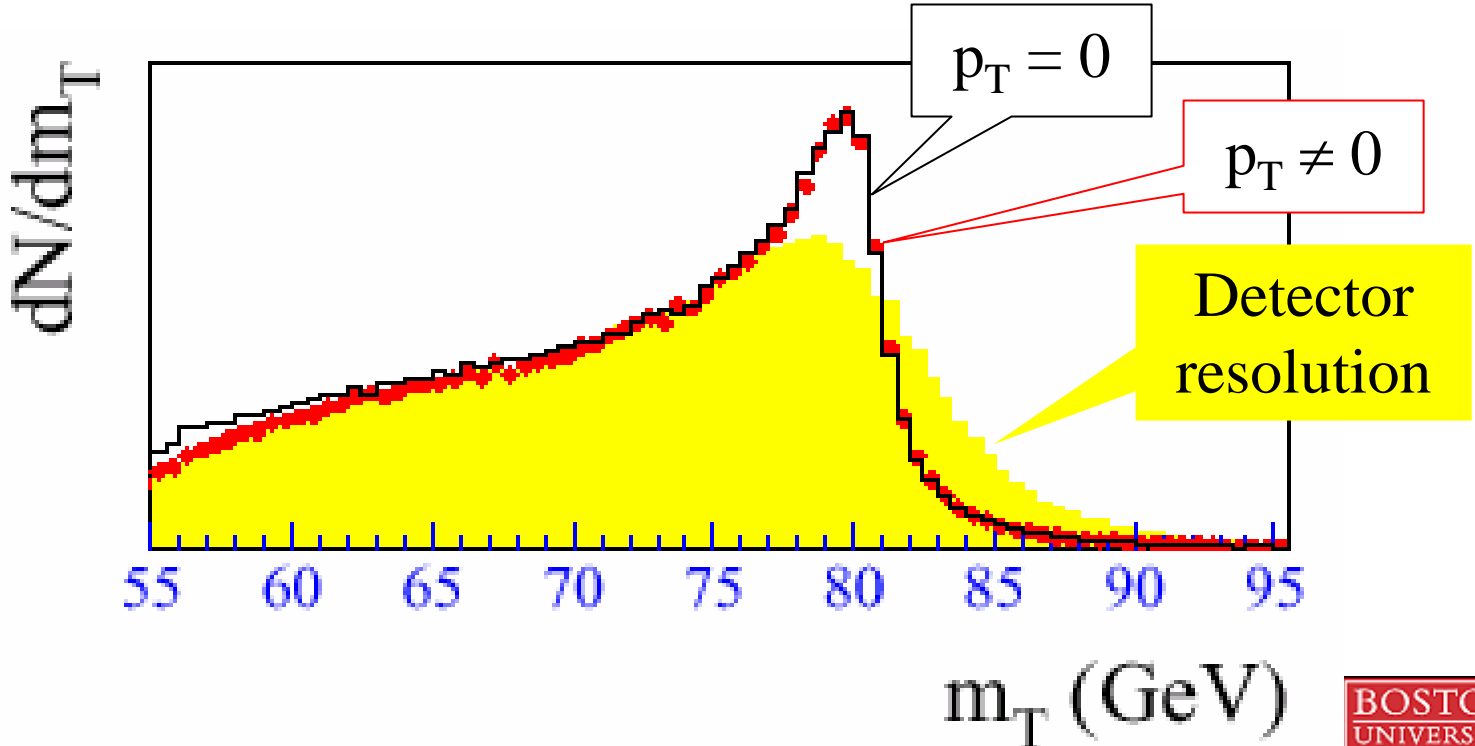
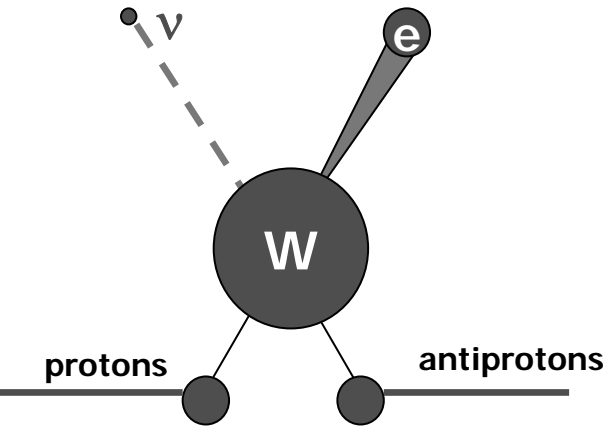


# Measuring the W Mass

$p_z(\nu)$  is unknown  $\Rightarrow$  can't calculate  $m_W$   
Fit to distributions of transverse quantities

$$p_{Te}, p_{T\nu} = \cancel{E}_T, m_T$$

$$m_T = \sqrt{(E_{T\ell} + E_{T\nu})^2 + (\vec{p}_{T\ell} + \vec{p}_{T\nu})^2}$$
$$= \sqrt{2E_{T\ell} \cancel{E}_T (1 - \cos \phi_{\ell\nu})}$$

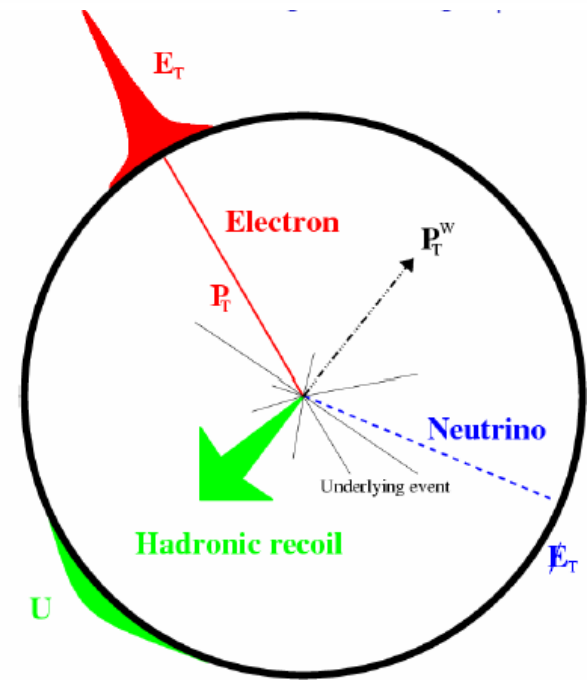
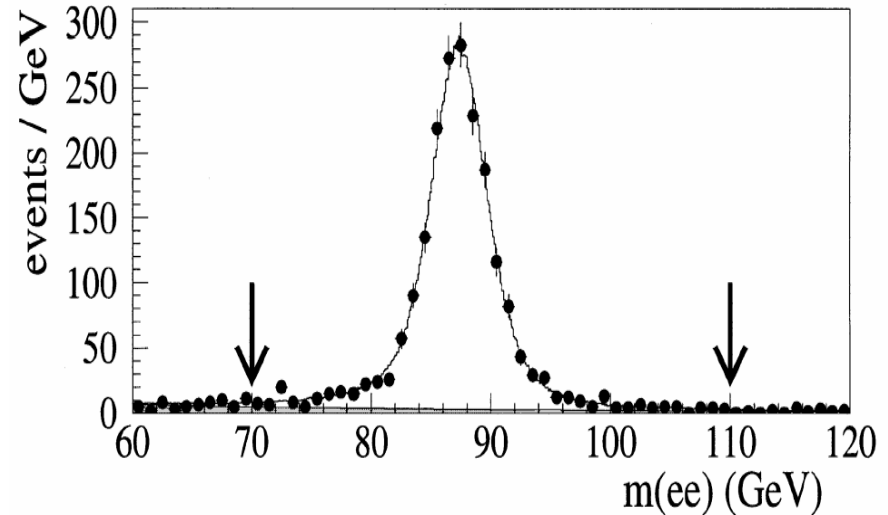




# Calibration with the Z Boson



- ❖ Must use the data to determine calibration, corrections, and systematics
  - Monte Carlo and theory not good enough
- ❖ Use the decay modes
  - $Z \rightarrow ee$  and  $\mu\mu$
- ❖ Clear, low-background signal
- ❖ Used as the basis for energy calibrations
- ❖  $p_T$  balance in Z events is used to understand the detector response to the hadronic recoil and underlying event

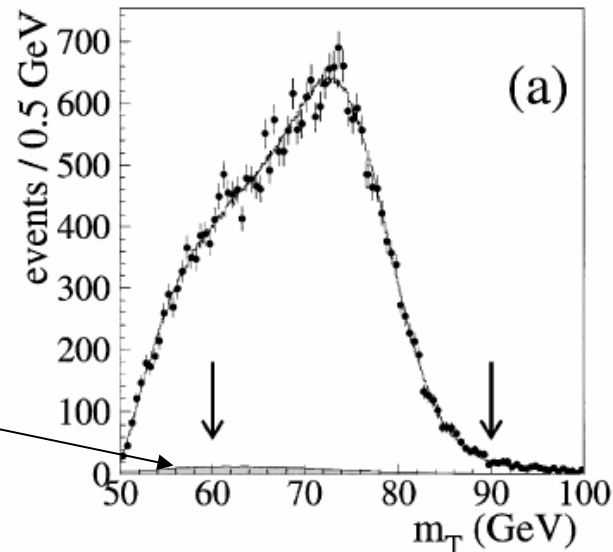




# Measuring the W Mass

$$W \rightarrow e\nu$$

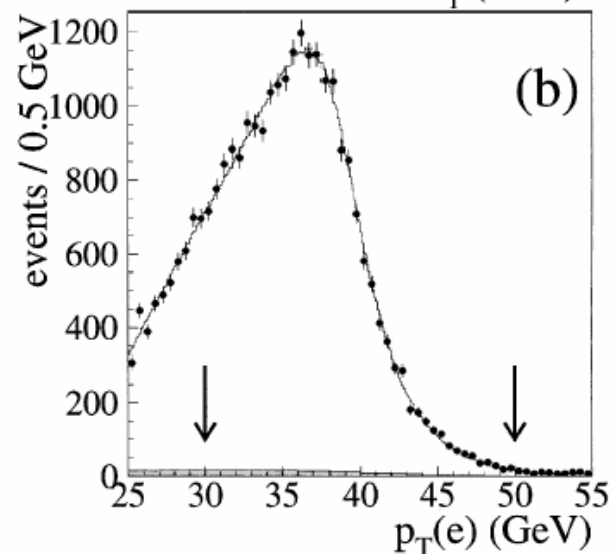
Background estimate



Likelihood fits to templates of transverse mass distributions

Points: data

Curves: best fit

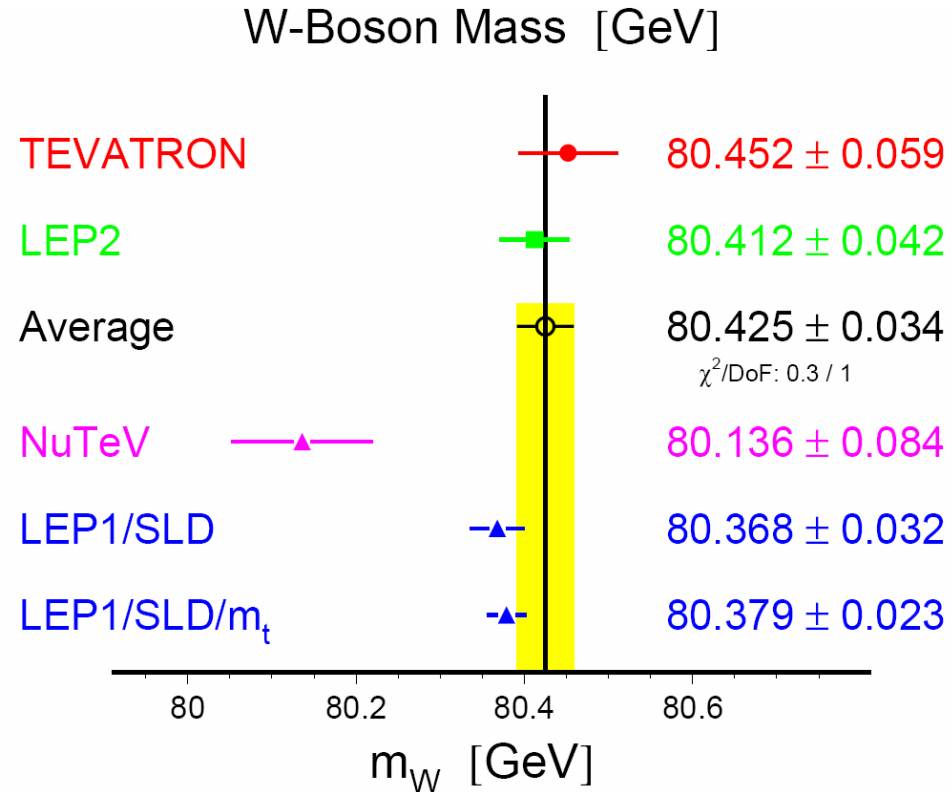






# Uncertainties on W mass

- ❖ Precision measurement
  - Effects of a few MeV are important on measuring an 80,000 MeV quantity in 2,000,000 MeV collisions
- ❖ Most systematic effects are studied using the W and Z samples
  - ➔ scale with luminosity
- ❖ Goal for Run II:  $\delta M_W \sim 25$  MeV per channel per experiment



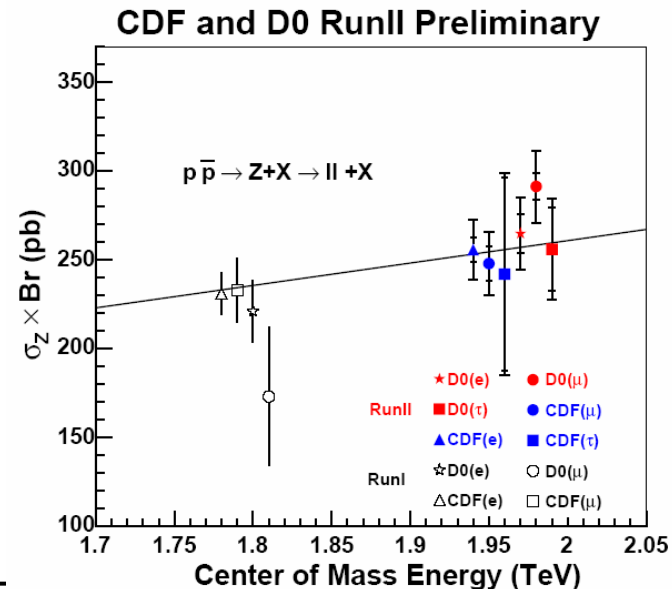
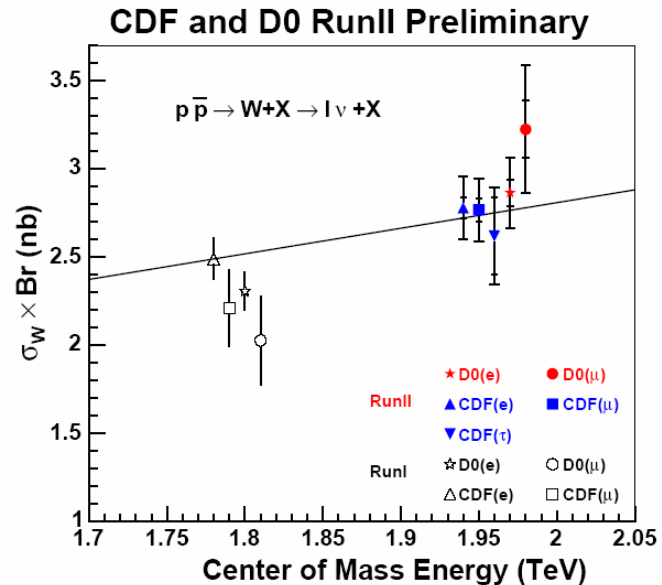
Source	$\delta M_W$ (MeV)	
	$M_T$ fit, EC	$M_T$ fit, CC+EC
CC-EC Z mass stat.	37	16
EC-EC Z mass stat.	107	21
EC W mass stat.	179	34
CC-EC Z width stat.	47	14
EC-EC Z width stat.	56	4
Hadronic Energy Resolution	45	21
$P_T^W$	22	9
PDF	35	15
Hadronic Energy Scale	16	10
Electron Angle Calibration	28	7
Backgrounds	21	4
W Width	10	6
Radiative Decays	4	1



# W and Z Cross Sections



- ❖ Test SM predictions for W and Z production
- ❖ Ratio of  $\sigma \cdot B$  can be used to determine the W width
- ❖ Leptonic decays of the W and Z are standard candles of hadron collider physics
  - Detector calibration
  - Understanding precision measurements
  - Measure luminosity!

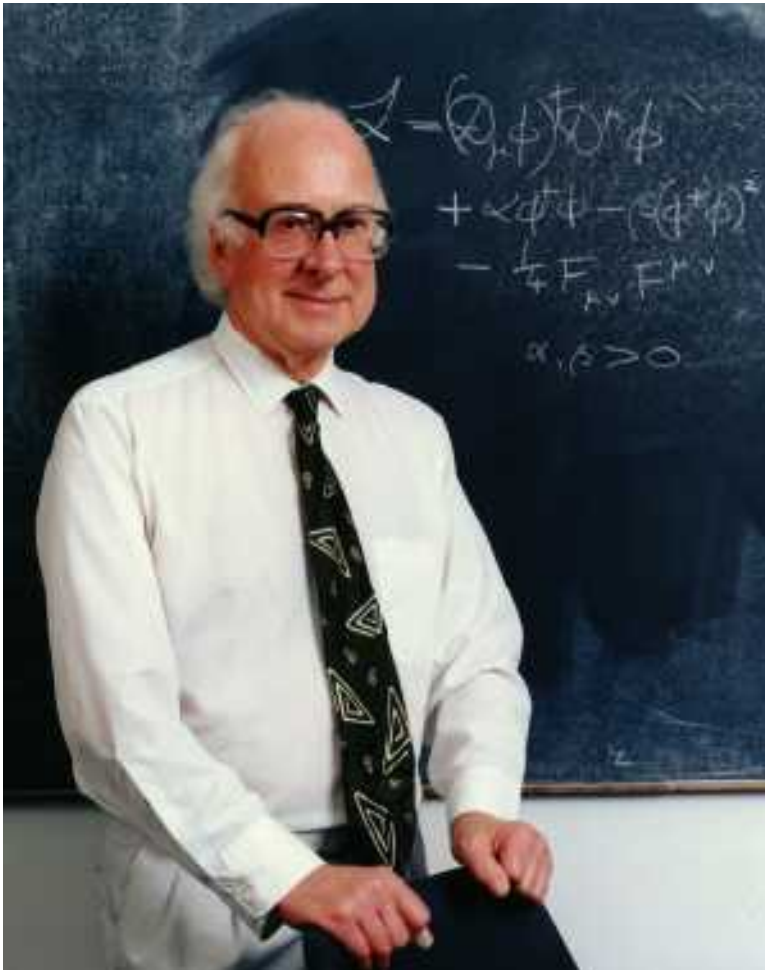




# Higgs Search



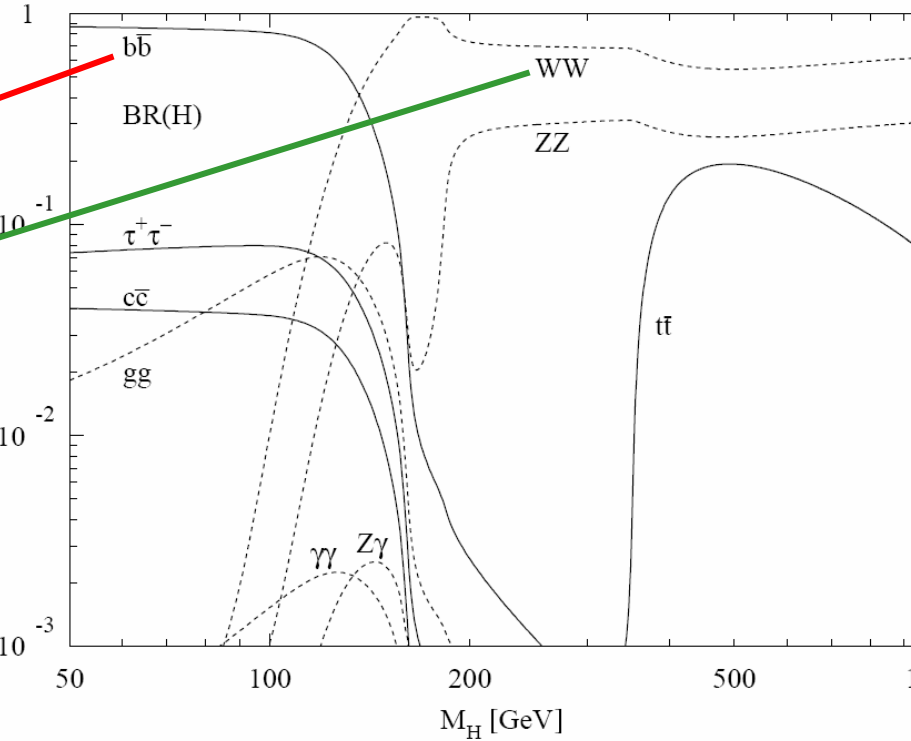
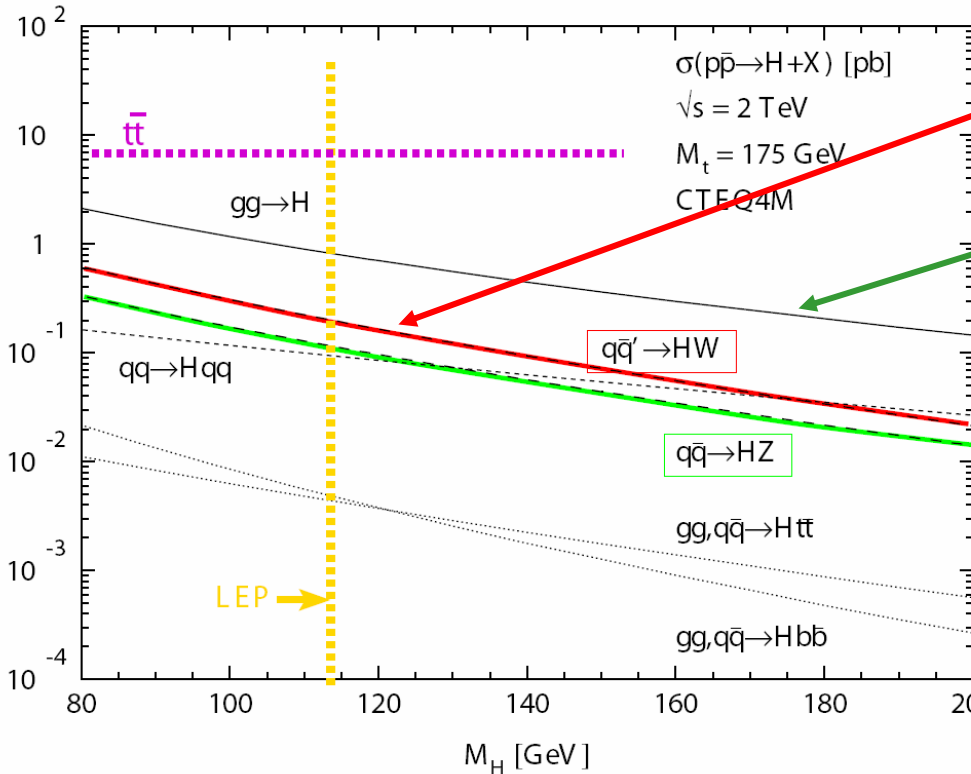
# The Standard Model Higgs



- ❖ Bathroom scale should be sufficient to determine the mass
- ❖ Last particle of the SM to be observed
- ❖ “Why is everybody looking for the SM Higgs? Everybody knows the SM is not the right theory!” – lunchtime conversation at BU
- ❖ Many extensions of the SM have particles that look ~identical to the SM Higgs
  - Lightest MSSM higgs  $h$
  - Technipion  $\pi_T$



# Higgs Production and Decay



## ❖ Higgs search strategy at the Tevatron

- Low mass Higgs, use Higgs-strahlung  $q\bar{q} \rightarrow HW$  or  $HZ$  followed by  $H \rightarrow b\bar{b}$
- High mass Higgs, use  $gg \rightarrow H \rightarrow WW$  or  $ZZ$

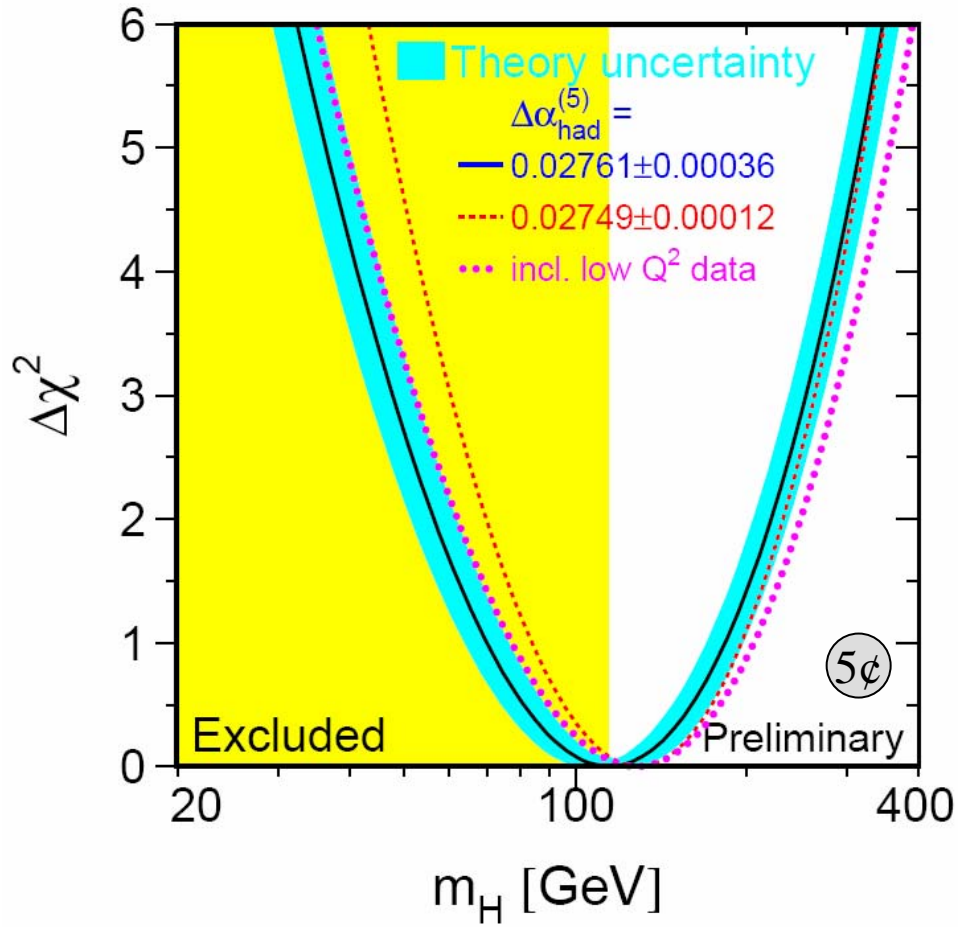


# Where do we expect the Higgs?



- ❖ As seen from  $M_W$ , SM parameters depend on  $M_H$   
→ use precision EW measurements to limit allowed Higgs mass
- ❖ Result is the “blue band” plot
  - $M_H > 114$  GeV ruled out by LEP
  - $M_H < 260$  GeV from fit
- ❖ MSSM lightest Higgs  $< 135$  GeV

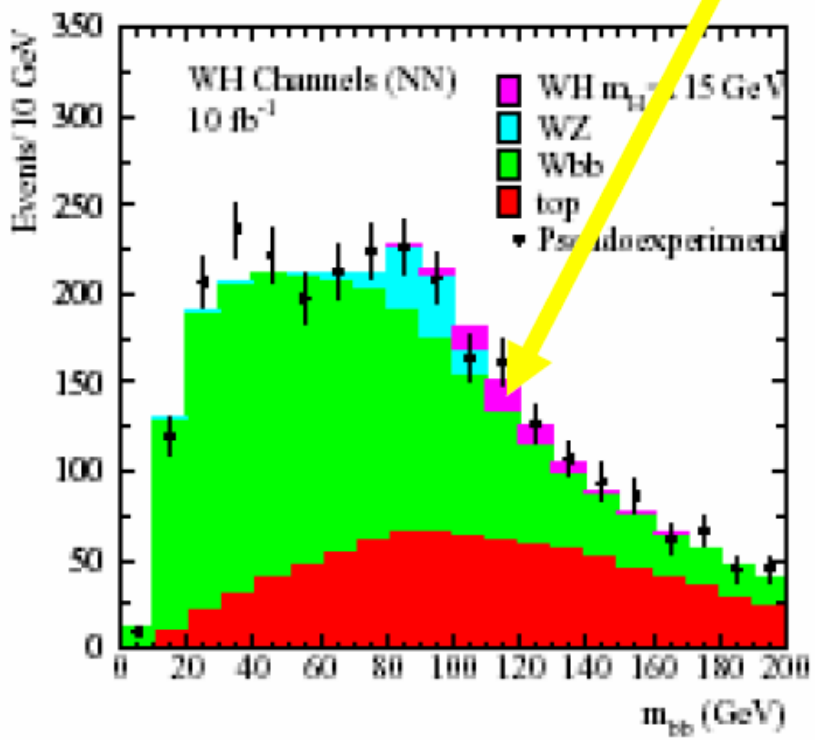
LEP Electroweak Working Group:  
[lepewwg.web.cern.ch/LEPEWWG/](http://lepewwg.web.cern.ch/LEPEWWG/)



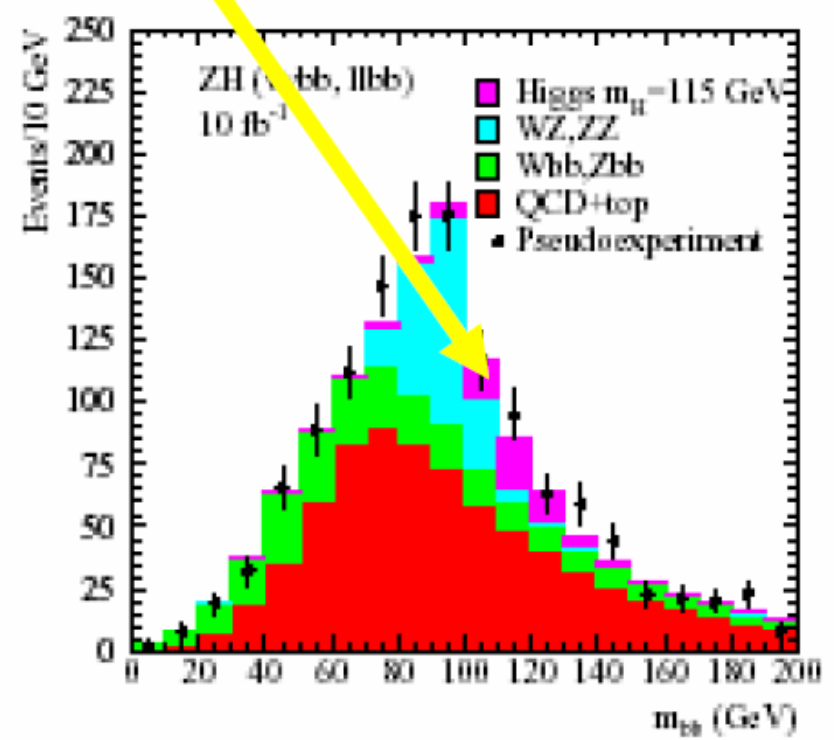


# A 115 GeV Higgs signal

$pp\bar{p} \rightarrow W h$  with  $W \rightarrow \ell\nu$



$pp\bar{p} \rightarrow Z h$  with  $Z \rightarrow \ell^+\ell^-, \nu\bar{\nu}$

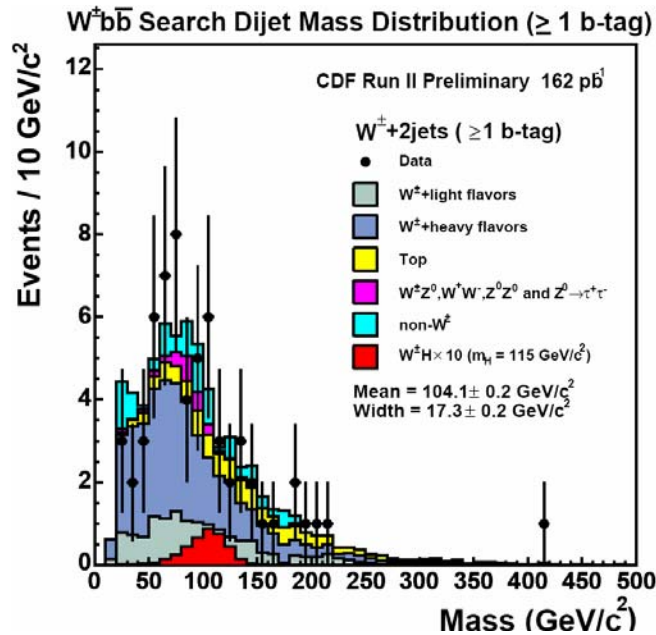


*This is a statistically 'unlucky' case...*

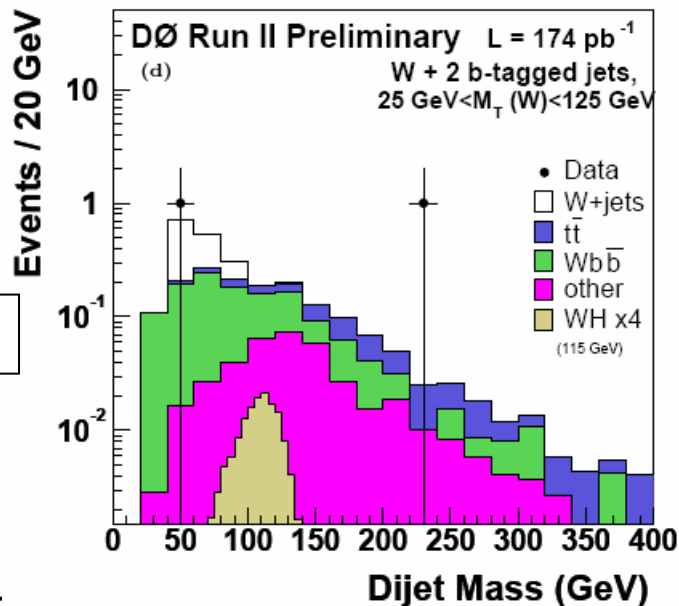
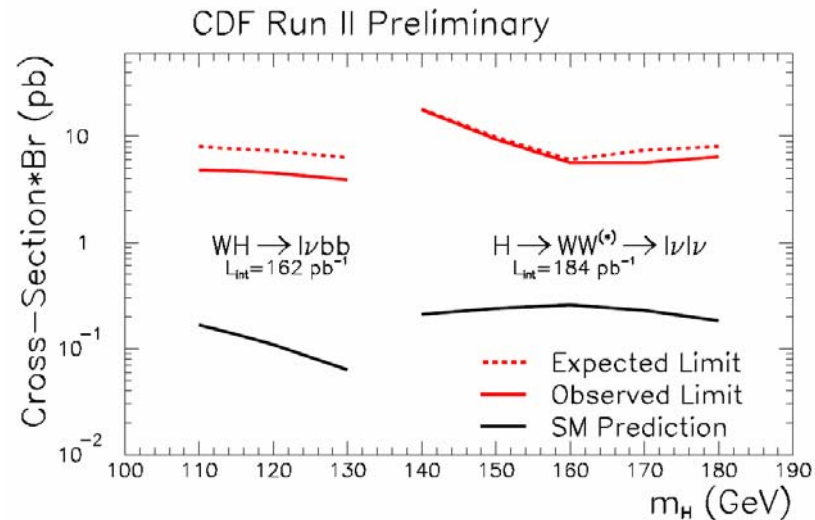
*This is a statistically 'typical' case...*

SM backgrounds are formidable →  
 must tag the b jets  
 need good dijet mass resolution





Single Tag

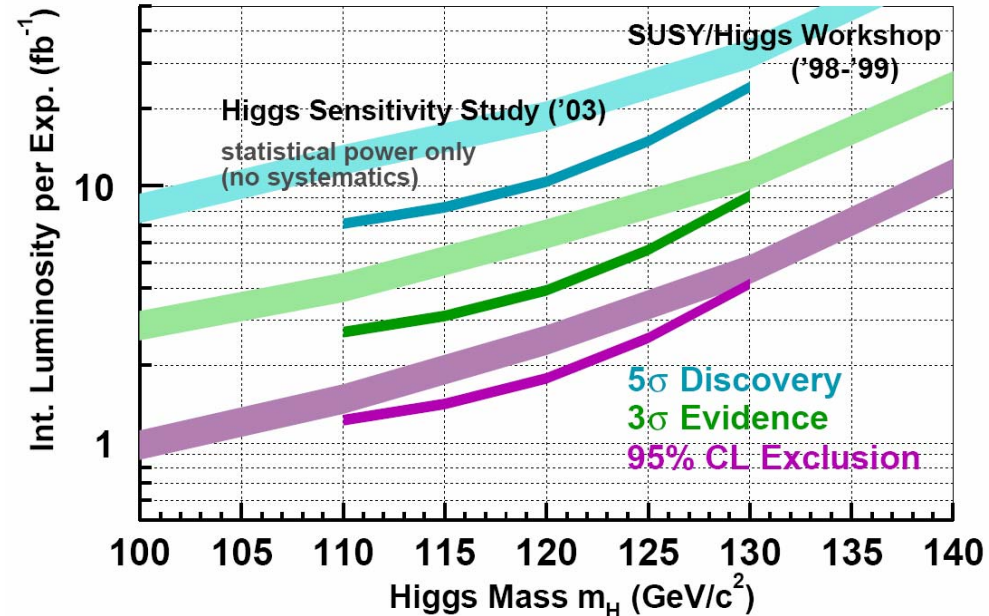
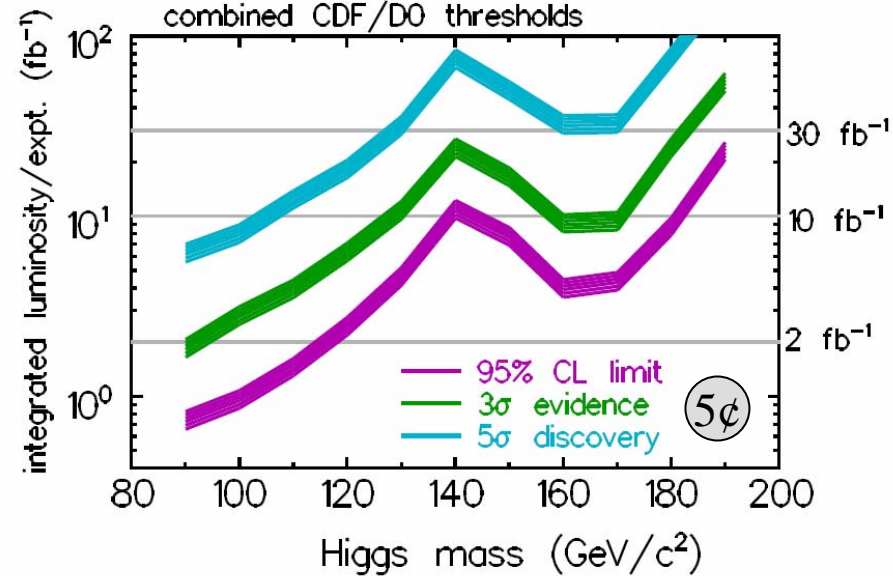


Double Tag





# Tevatron Higgs Prospects



- ❖ It's going to be tough! May have to wait for the LHC
- ❖ Will definitively rule out the hints for a 116 GeV Higgs seen at LEP (unless, of course, the hints were right!)



# Searches for Physics Beyond the SM



# Searches for Supersymmetry



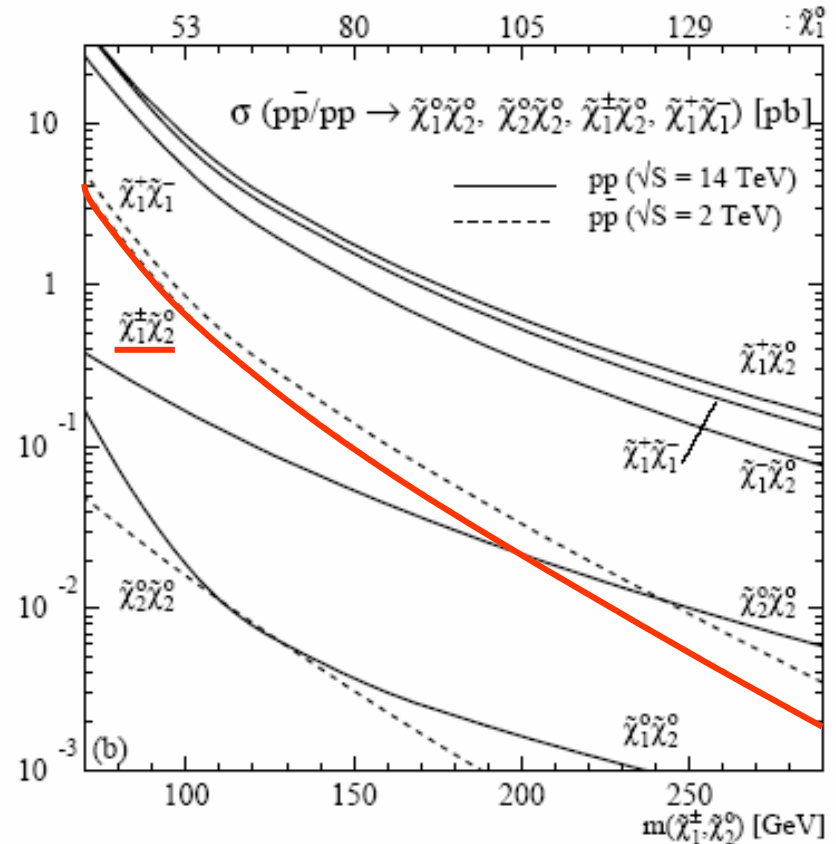
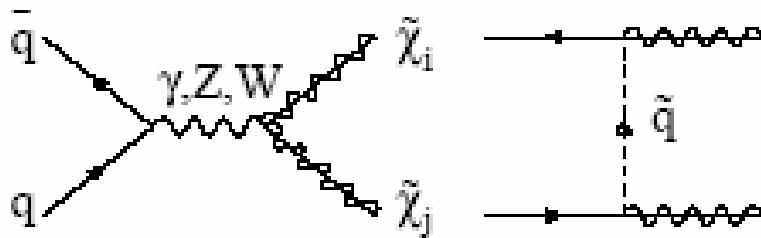
- ❖ SUSY is the current favorite idea for extending the SM
- ❖ SUSY is a postulated symmetry between bosons and fermions
  - All observed particles would have superpartners
  - Clearly, SUSY is broken
- ❖ Why people like SUSY
  - Additional particles cancel divergences in the Higgs mass
  - Allows unification of forces at higher energies
  - Lightest neutralino is a good explanation for cosmic dark matter
  - Plays well with string theory
- ❖ Predicts multiple Higgs bosons, strongly interacting squarks and gluinos, and electroweakly interacting sleptons, charginos and neutralinos
  - Masses are unknown but expected to be in range 100 GeV - 1 TeV
    - ➔ accessible at the Tevatron
- ❖ R parity =  $(-1)^{3(B-L)+2S}$ 
  - R = +1 for SM particles  
R = -1 for superpartners
  - Conservation implies
    - Pair production
    - LSP is stable
- ❖ Gold plated channels
  - Jets + missing ET
  - Trileptons



# Hadroproduction of Charginos & Neutralinos



- In R parity conserving SUSY,  $\tilde{\chi}_i^\pm$  and  $\tilde{\chi}_j^0$  are produced and decay into fermions and 2 LSP's
- $W^*$  exchange in s-channel
- Squark exchange in t-channel
- $\sigma(p\bar{p} \rightarrow \tilde{\chi}_1^\pm \tilde{\chi}_2^0)$  accessible to the Tevatron experiments



W. Beenakker et al., PRL 83, 3780 (1999)



# Trilepton Final State



$$p\bar{p} \rightarrow \tilde{\chi}_1^\pm \tilde{\chi}_2^0 \rightarrow 3l\nu \tilde{\chi}_1^0 \tilde{\chi}_1^0$$

Signature =  $3l + \cancel{ET}$

- “Gold plated” channel  
Low standard model and instrumental backgrounds

- In the mSUGRA model

$$m_{\tilde{\chi}_1^\pm} \approx m_{\tilde{\chi}_2^0} \approx 2m_{\tilde{\chi}_1^0}$$

$\tilde{\chi}_1^0$  is the LSP

- SUSY parameters

$$\tan \beta = 3, \mu > 0, A_0 = 0$$

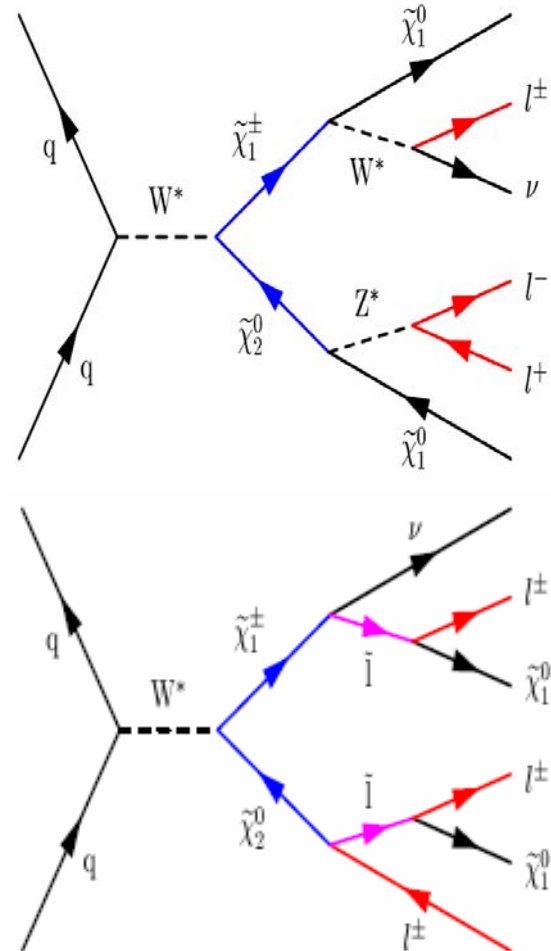
$$m_0 = [72, 88] \text{ GeV}$$

$$m_{1/2} = [165, 185] \text{ GeV}$$

$$m_{\tilde{\chi}_1^\pm} = [97, 114] \text{ GeV}$$

$$m_{\tilde{\ell}} \approx m_{\tilde{\chi}_1^\pm} \Rightarrow \text{enhanced leptonic BR}$$

$$\sigma \times BR \approx 0.2 - 0.4 \text{ pb}$$





# Search Strategies



- ❖ Observe all 3 leptons plus missing  $E_T$ 
  - Tevatron Run I approach  
DØ: PRL 80 (1998) 8; CDF: PRL 80 (1998) 5275
- ❖ Clean but limited – lepton acceptance and ID efficiency, 3<sup>rd</sup> lepton can be soft, miss hadronic  $\tau$ 's
- ❖ Can increase search sensitivity by alternate strategies
  - Observe 2 leptons plus an isolated track
    - Gain  $\varepsilon$  by relaxing the particle ID requirement
  - Observe only 2 out of 3 leptons
    - Leptons from different generations
    - Leptons are like-sign\*
- ❖ Present 3 analyses that exploit these alternate approaches
  1.  $e + e + \ell$ , where  $\ell =$  isolated charged track
  2.  $e + \mu$  and  $e + \mu + \ell$
  3.  $\mu^\pm + \mu^\pm$
- ❖ Combine the results to maximize the sensitivity

\*Nachtman, Saltzberg, Worcester,  
Int. J. Mod. Phys., A16S1B, 797 (2001)

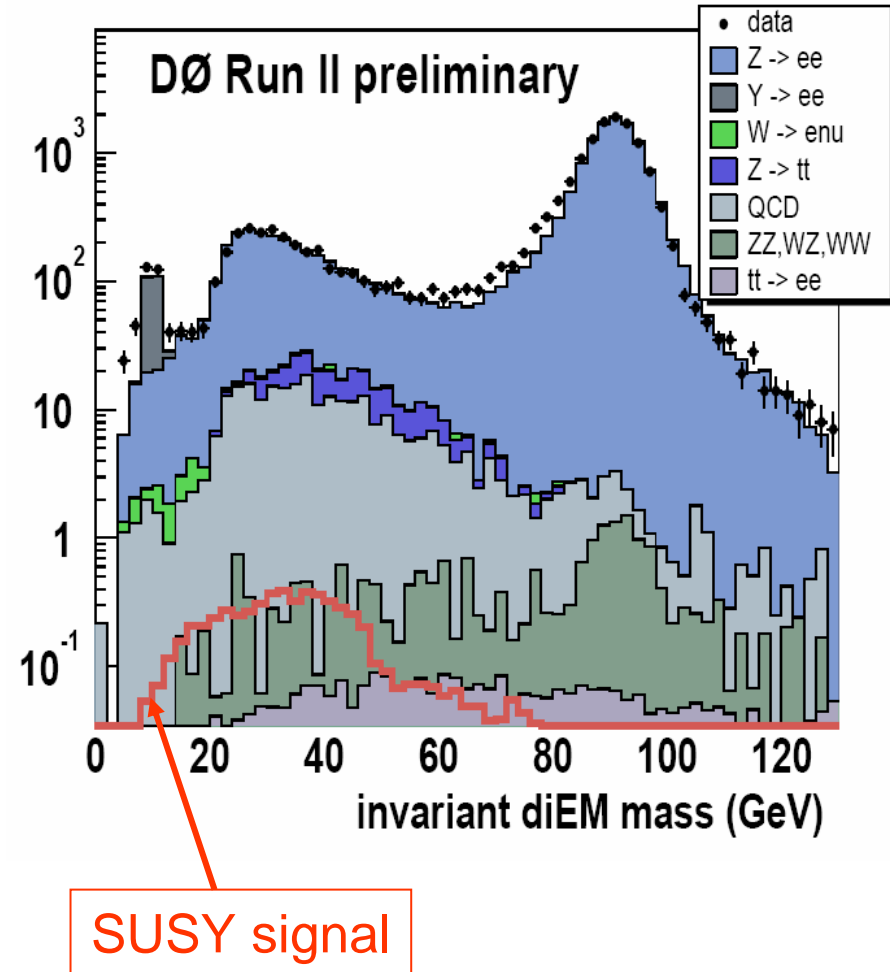


# $e + e + \ell$ Search



[DØ Note 4405]

- $\int \mathcal{L} dt = 175 \pm 11 \text{ pb}^{-1}$
- Event selection
  - 2 good  $e$ ,  $p_T > 12, 8 \text{ GeV}$
  - $\geq 1e$  with  $|\eta| < 1.1$
  - 16,200 events
- Reject backgrounds
  - $Z \rightarrow ee$ ,  $W \rightarrow e\nu\gamma$ ,  $t\bar{t}$ , DY
  - Cut  $15 < m_{ee} < 60 \text{ GeV}$
  - $\Delta\phi(e, e) < 2.8$
  - $\geq 1$  SMT or tight  $e$  likelihood
  - Jet  $E_T < 80 \text{ GeV}$
  - Scaled  $\cancel{E}_T > 10 \text{ GeV}^{1/2}$
  - $M_T(e + \cancel{E}_T) > 15 \text{ GeV}$
  - $\cancel{E}_T > 20 \text{ GeV}$
  - $\Delta\phi(e, \cancel{E}_T) > 0.4$

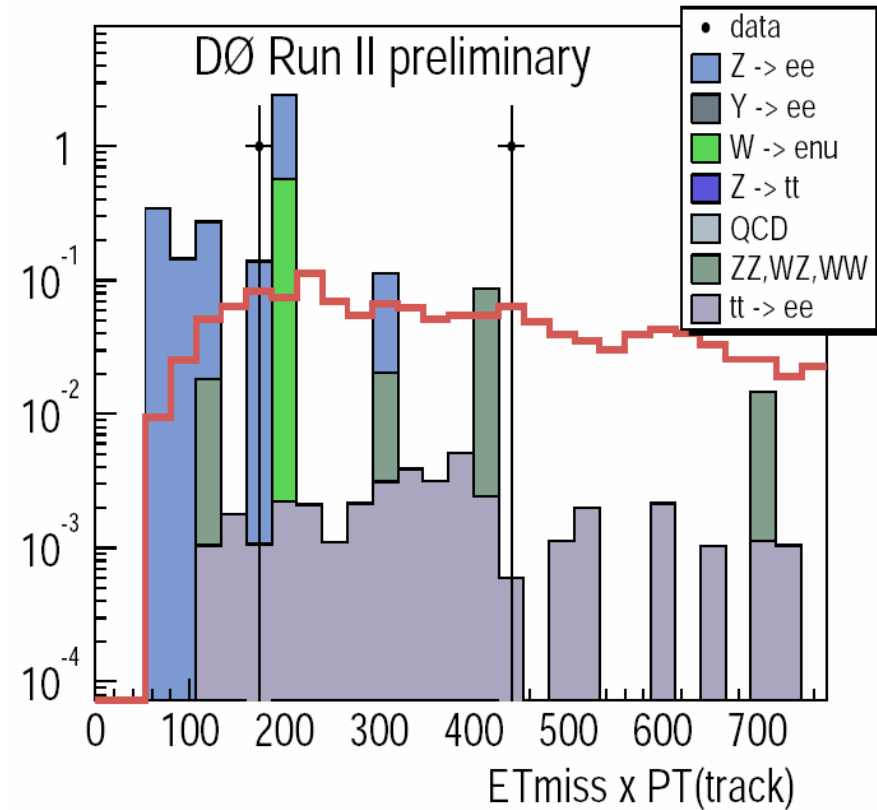




# $e + e + \ell$ Search



- Isolated track,  $p_T > 3$  GeV
- Residual SM backgrounds killed by requiring  $p_T(\text{track}) \times \cancel{E}_T > 250$  GeV<sup>2</sup>  
1 event remains
- Expect  
0.27 background events  
0.8-1.6 events from SUSY





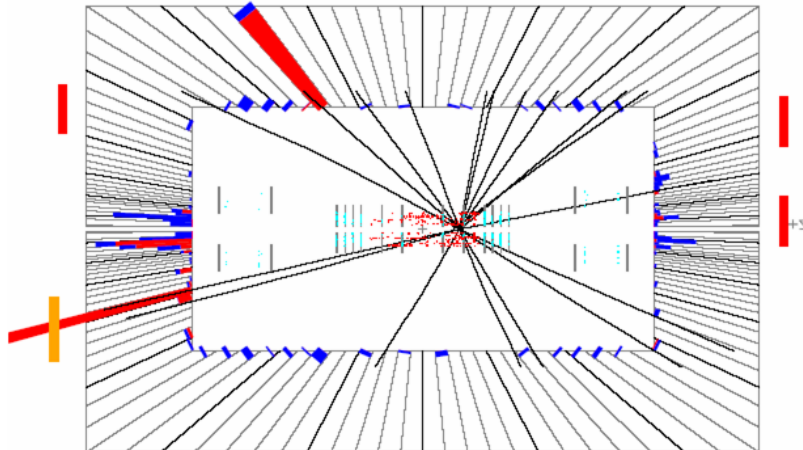
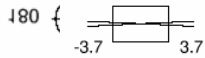
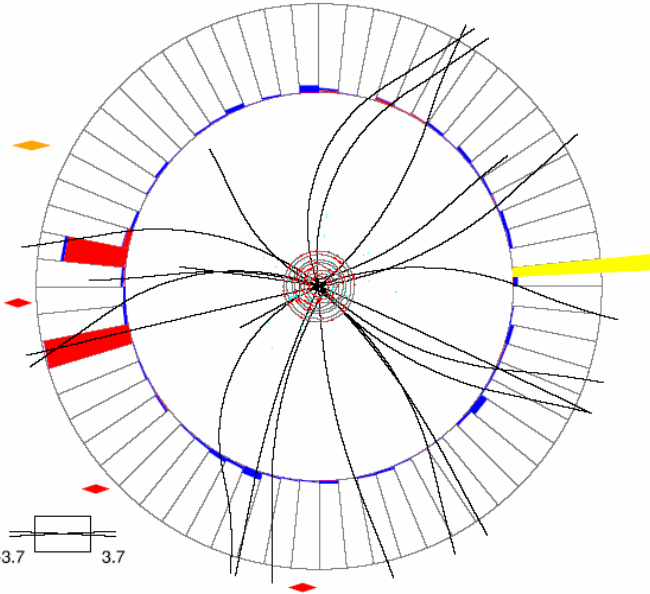


# $e + e + \ell$ Candidate Event



Run 179596 Event 31573241 Fri Feb 13 19:42:18 2004

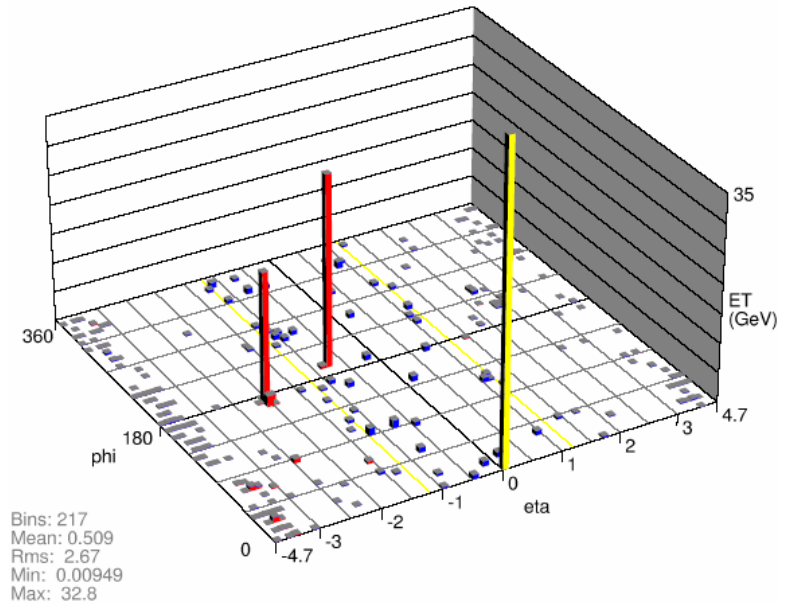
ET scale: 34 GeV



	$E_T$ (GeV/c)	$\eta$	$\phi$
$e_1$	33.2	-0.97	3.37
$e_2$	25.7	-2.19	2.97
$\ell$	8.6	0.67	5.87
$\cancel{E}_T$	52.1	-	0.12

$m(e_1 e_2) = 39.5 \text{ GeV}$

Run 179596 Event 31573241 Fri Feb 13 19:42:23 2004



Bins: 217  
 Mean: 0.509  
 Rms: 2.67  
 Min: 0.00949  
 Max: 32.8

$mE_t$ : 54.2  
 $\phi_t$ : 4.19 deg

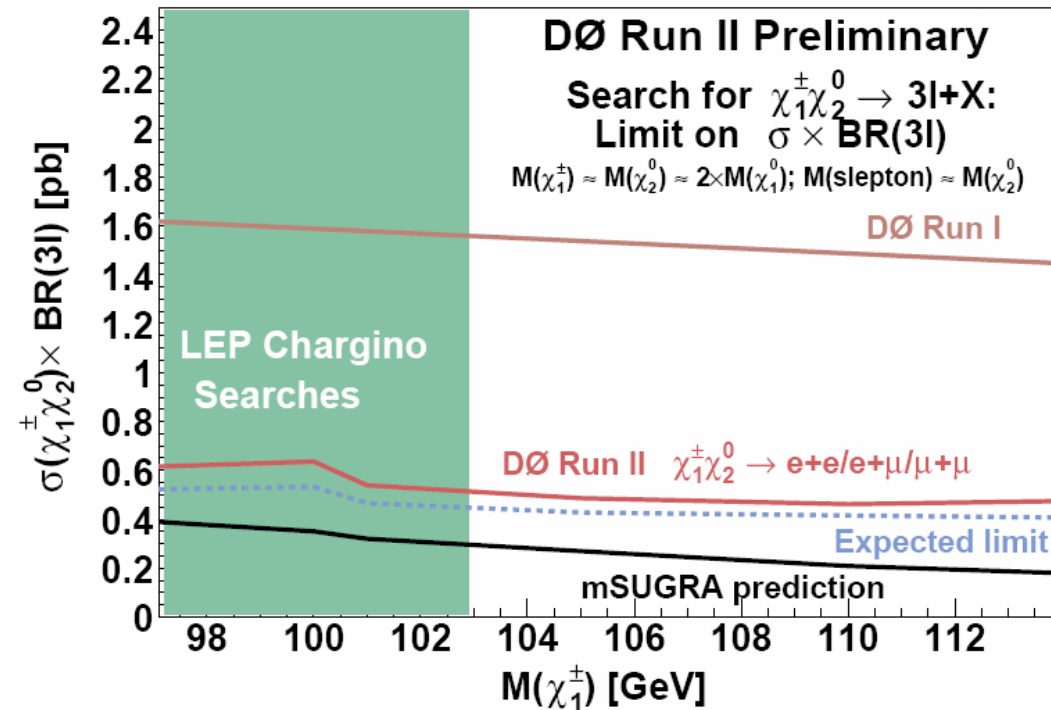


# Combined Limit



- See 3 events from data, expect 3.4 from SM sources
- Set a 95% CL limit on  $\sigma(\tilde{\chi}_1^\pm \tilde{\chi}_2^0) \times BR(3l)$  using the  $CL_S$  method\*
- Significant improvement over Run I results
- Can not rule out the mSUGRA prediction (yet!)
- Can use these results to constrain other SUSY models with a similar mass hierarchy

Channel	Data	Background
$e + e + l$	1	$0.27 \pm 0.42 \pm 0.02$
$e + \mu$	1	$2.49 \pm 0.37 \pm 0.18$
$e + \mu + l$	0	$0.54 \pm 0.24 \pm 0.04$
$\mu^\pm + \mu^\pm$	1	$0.13 \pm 0.06 \pm 0.02$



\*T. Junk, NIM A434, 435 (1999).



# Recycling is good!



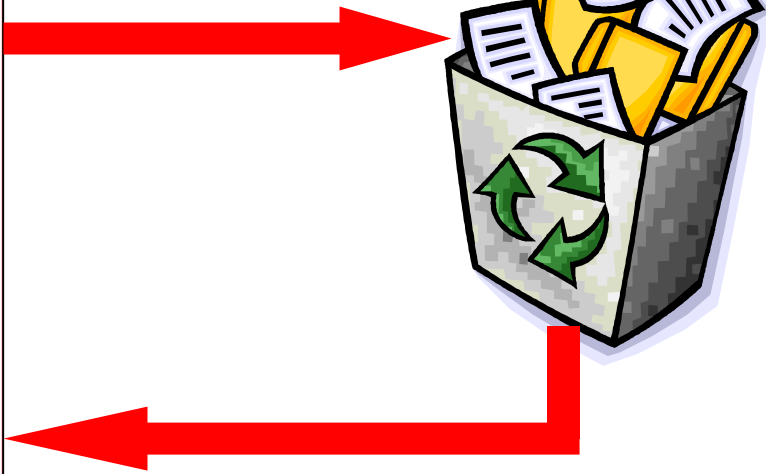
- ❖ Signature for new physics often contain common objects
  - High pT leptons
  - Large missing ET
- ❖ Certain final states can be used to place limits on a wide variety of extensions to the SM

VOLUME 86, NUMBER 7      PHYSICAL REVIEW LETTERS      12 FEBRUARY 2001

Search for Large Extra Dimensions in Di-lepton and Di-photon Production

B. Abbott<sup>1</sup>, M. Abolins<sup>2</sup>, G. Abouzeid<sup>3</sup>, B. Adelman<sup>4</sup>, M. Adkins<sup>5</sup>, G. Agostini<sup>6</sup>, M. Agre<sup>7</sup>,  
 E. W. Anderson<sup>8</sup>, M. M. Baerwald<sup>9</sup>, V. V. Bahin<sup>10</sup>, L. Bahin<sup>11</sup>, A. Balci<sup>12</sup>, B. Balci<sup>13</sup>, P. W. Balci<sup>14</sup>,  
 S. Banerjee<sup>15</sup>, J. Banerjee<sup>16</sup>, S. Banerjee<sup>17</sup>, P. Banerjee<sup>18</sup>, J. J. Barak<sup>19</sup>, U. Barak<sup>20</sup>, A. Barak<sup>21</sup>, M. Barak<sup>22</sup>,  
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 D. Chakrabarti<sup>55</sup>, M. Chao<sup>56</sup>, S. Chakrabarti<sup>57</sup>, R. K. Chakrabarti<sup>58</sup>, S. Chakrabarti<sup>59</sup>, J. H. Chakrabarti<sup>60</sup>,  
 M. Chang<sup>61</sup>, D. Chao<sup>62</sup>, A. R. Clark<sup>63</sup>, J. Cochran<sup>64</sup>, L. Cozzani<sup>65</sup>, B. Conroy<sup>66</sup>, W. E. Cooper<sup>67</sup>, D. Coppin<sup>68</sup>,  
 M. A. C. Courau<sup>69</sup>, D. Coum<sup>70</sup>, G. I. Daloz<sup>71</sup>, G. A. Davis<sup>72</sup>, K. DeLuca<sup>73</sup>, E. DeLuca<sup>74</sup>, M. Demina<sup>75</sup>,  
 E. Demina<sup>76</sup>, P. Demina<sup>77</sup>, D. Demina<sup>78</sup>, S. P. Demina<sup>79</sup>, S. Desai<sup>80</sup>, H. T. Diehl<sup>81</sup>, M. Diehl<sup>82</sup>, G. Di Lorenzo<sup>83</sup>,  
 S. Di Lorenzo<sup>84</sup>, P. Di Lorenzo<sup>85</sup>, Y. Duca<sup>86</sup>, L. V. Duca<sup>87</sup>, S. Durring<sup>88</sup>, S. H. Durring<sup>89</sup>, A. Dykstra<sup>90</sup>, D. Eitel<sup>91</sup>,  
 J. Eitel<sup>92</sup>, V. D. Elvira<sup>93</sup>, R. Engelhardt<sup>94</sup>, S. Eng<sup>95</sup>, G. Engler<sup>96</sup>, P. Engler<sup>97</sup>, O. V. Erkin<sup>98</sup>, J. Erkin<sup>99</sup>,  
 H. Esarey<sup>100</sup>, N. Esarey<sup>101</sup>, T. Falck<sup>102</sup>, S. Falck<sup>103</sup>, D. Falck<sup>104</sup>, T. Falck<sup>105</sup>, H. E. Falck<sup>106</sup>, Y. Falck<sup>107</sup>, E. Falck<sup>108</sup>,  
 T. Falck<sup>109</sup>, M. Falck<sup>110</sup>, R. C. Falck<sup>111</sup>, S. Falck<sup>112</sup>, G. Falck<sup>113</sup>, A. V. Gaidis<sup>114</sup>, P. Gaidis<sup>115</sup>, V. Gaidis<sup>116</sup>,  
 R. J. Gair<sup>117</sup>, R. Gair<sup>118</sup>, C. E. Gair<sup>119</sup>, Y. Gair<sup>120</sup>, B. Gair<sup>121</sup>, R. Gair<sup>122</sup>, G. Gair<sup>123</sup>, H. Gair<sup>124</sup>, R. Gair<sup>125</sup>,  
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1556      0003-9071/01/86(7):1556\$15.00      © 2001 The American Physical Society

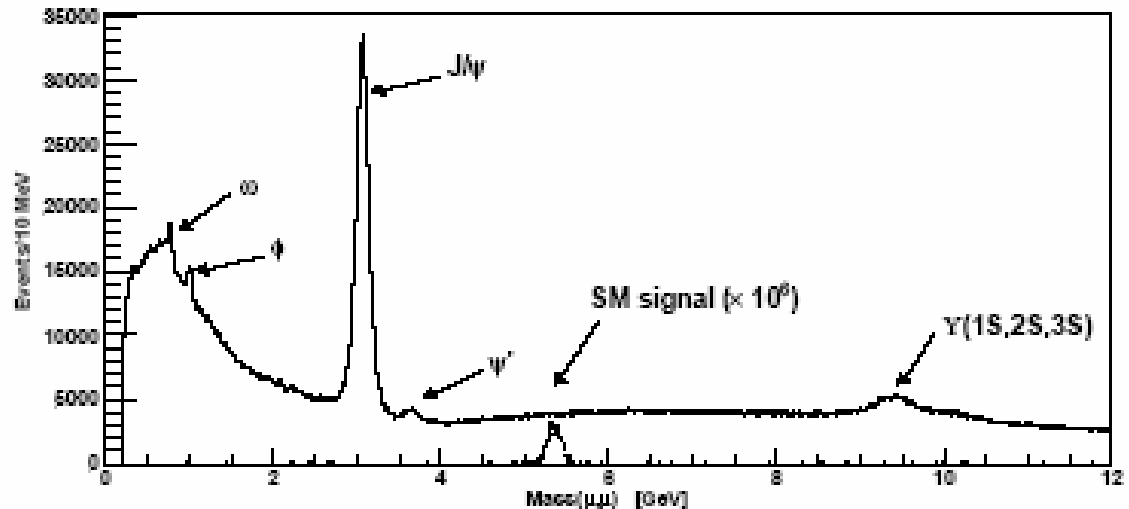
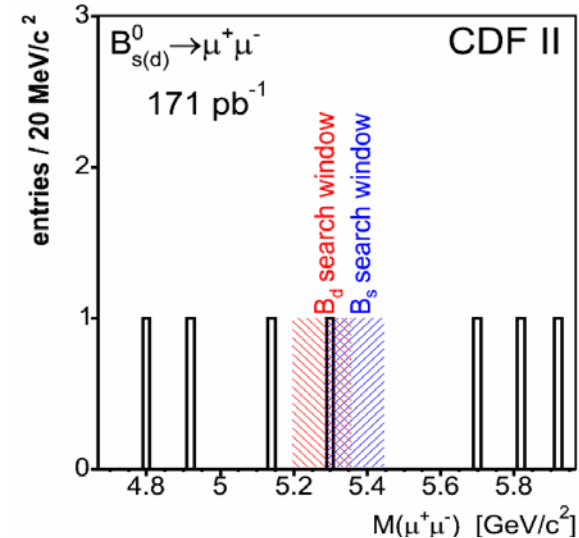




# Recycling example – dileptons



- ❖ Historically, a discovery channel
- ❖ Can use  $e^+e^-$  and  $\mu^+\mu^-$  events to study many SM processes
  - b/c physics:
  - EW: e.g. Z cross section
  - top  $\rightarrow$  dileptons
- ❖ Look for rare decays
  - SM  $B(B_s \rightarrow \mu^+\mu^-) \sim 3 \times 10^{-9}$
  - In SUSY, can get enhancements ( $\sim \tan^4\beta - \tan^6\beta$ ) up to factor of 1000
  - $B(B_s \rightarrow \mu^+\mu^-) < 5 \times 10^{-7}$
  - Example of analysis where SM is out of reach, any excess is new physics

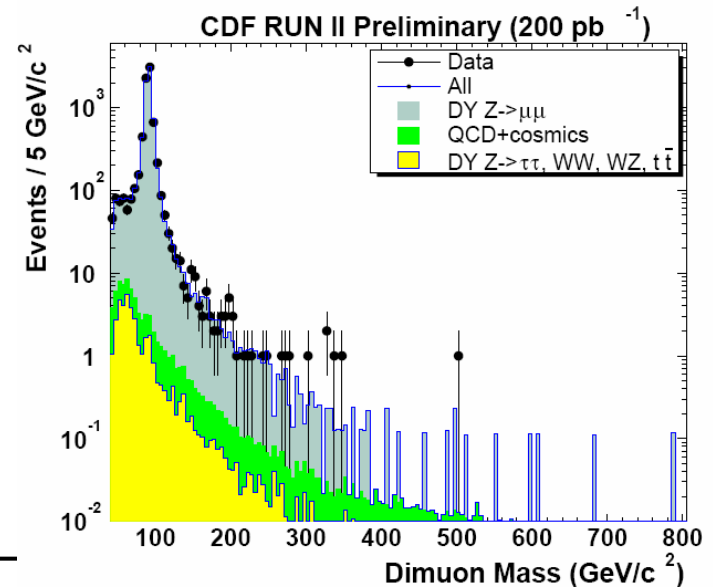
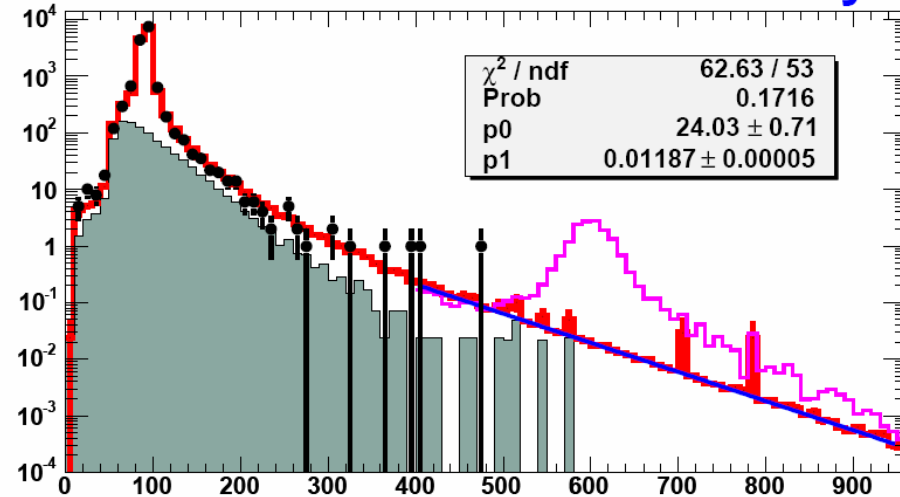




# Recycling example – dileptons

- ❖ In a wide variety of theories/models, new physics can show up as a resonance or excess of events at high dilepton mass
- ❖ Dilepton mass distributions have been used to place limits on
  - Extra dimensions (Greg Landsberg on Friday)
  - New gauge bosons:  $Z'$
  - Technicolor:  $\rho_T$  and  $\omega_T$
  - RS Gravitons
  - RPV sneutrino
  - Little Higgs

diEM Mass Spectrum **DØ Run II Preliminary**

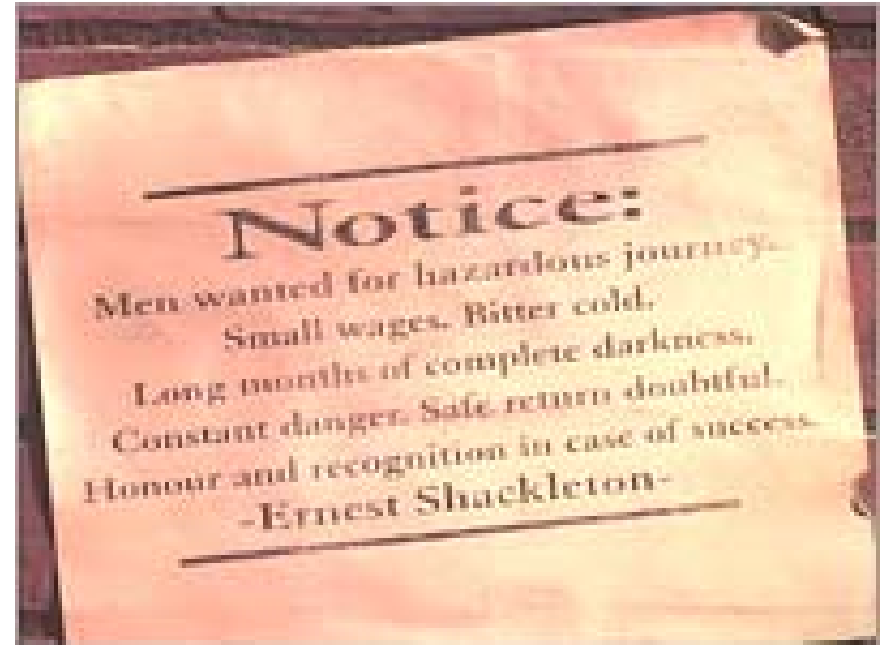




# Summary



- ❖ I hope I've convinced you there is a "rich" (in the good way!) ongoing program of physics at the Tevatron
- ❖ Only in Illinois (for now)
  - Top quark
  - W mass
  - $B_s$ ,  $\Lambda_b$ , ...
  - Search for the SM Higgs and new phenomena
  - Plus lots of other stuff I didn't have time to talk about
- ❖ Will LHC do better?
  - You bet!
  - But not yet!



Graduate student life hasn't changed much over the years!



# Roll the credits



- ❖ “Borrowed” lots of slides from the excellent talks by my DØ and CDF colleagues, many thanks to them
- ❖ The talks from NEPPSR I and II are very good!
- ❖ Web sites
  - Fermilab: <http://www.fnal.gov/>
  - DØ: <http://www-d0.fnal.gov/>
  - CDF: <http://www-cdf.fnal.gov/>
  - LEP EWWG: <http://lepewwg.web.cern.ch/LEPEWWG/>
  - Tevatron EWWG: <http://tevewwg.fnal.gov/>
  - LEP SUSY: <http://lepsusy.web.cern.ch/lepsusy/>