Discovery Through Precision Measurements

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for the CDF & D0 Collaborations

Thanks to my CDF & D0 colleagues for help in preparation

Outline

- **Discuss potential for 5 physics topics**
  - **Top quark mass, M_t**
  - **W boson mass, M_W**
  - **Single top production**
  - **B_S Mixing**
  - **$\Delta\Gamma_s/\Gamma_s$**

Precision measurements in the electroweak and flavor sectors

- **Chosen for importance and TeV contribution**
- **<u>Not an exhaustive list</u>**
  - **If we do these, there are others which basically come along, or which are required to do these…**
  - **Many independent analyses**

Measuring M_t & M_W

- **Constrain Higgs Mass**
  - **Need to measure both**

$$m_W^2 = \frac{\pi \alpha_{EM}}{\sqrt{2} G_F (1 - m_W^2/m_Z^2)(1 - \Delta r)}$$

$$\Delta r = \Delta r(M_t, M_H)$$

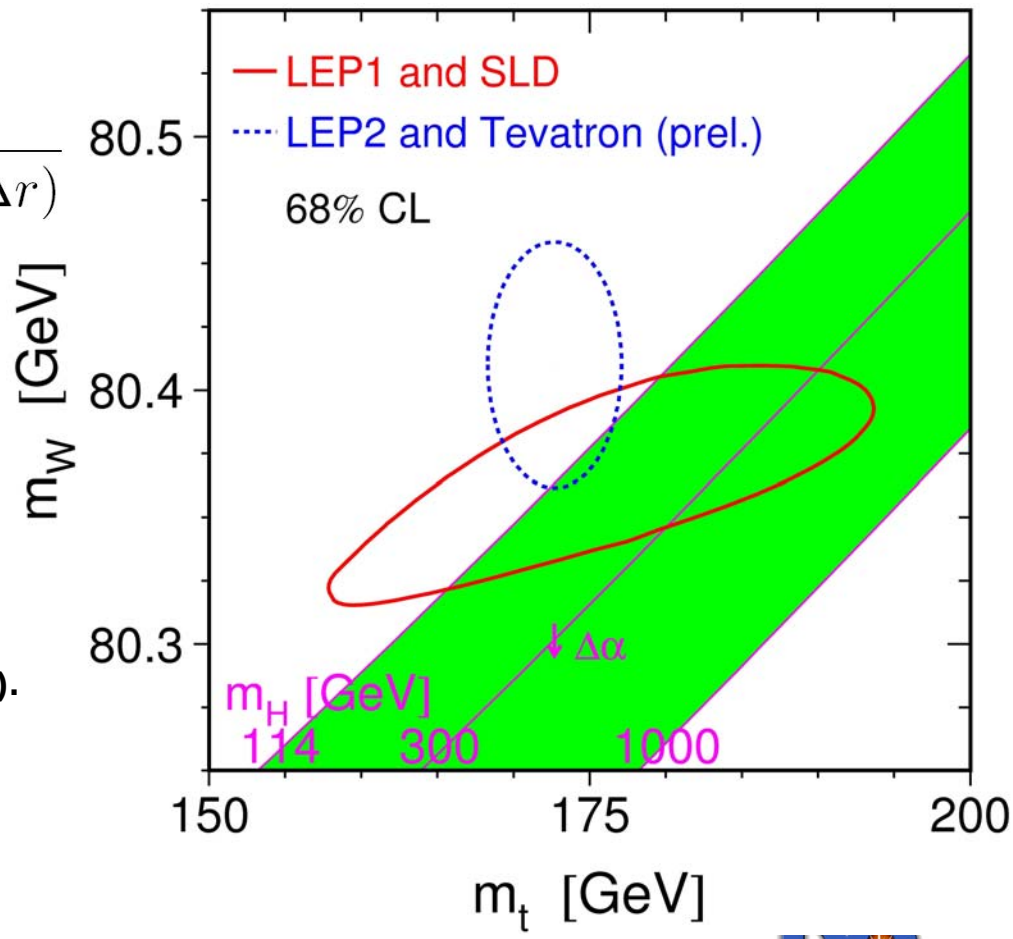
For equal weights in SM χ^2 fits,

$$\delta M_W = 0.007\ \delta M_t$$

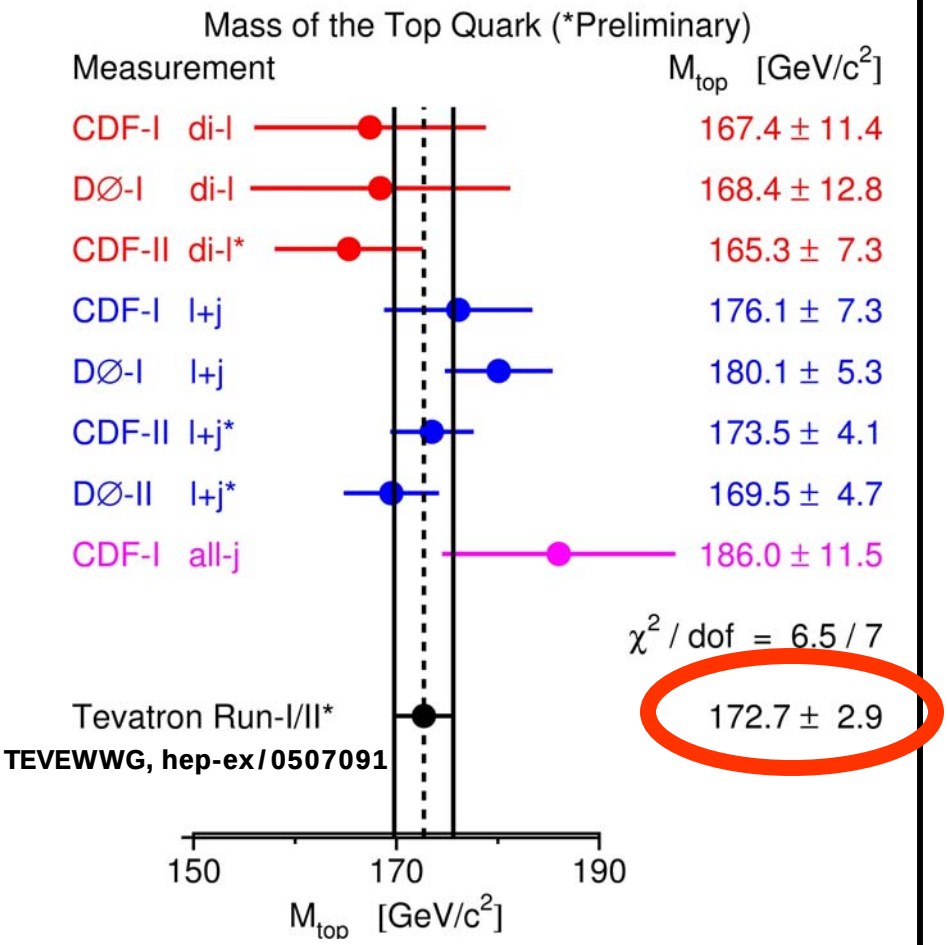
Don't neglect M_W!

Azuelos, *et. al.*, hep/ph-0003275 (2000).

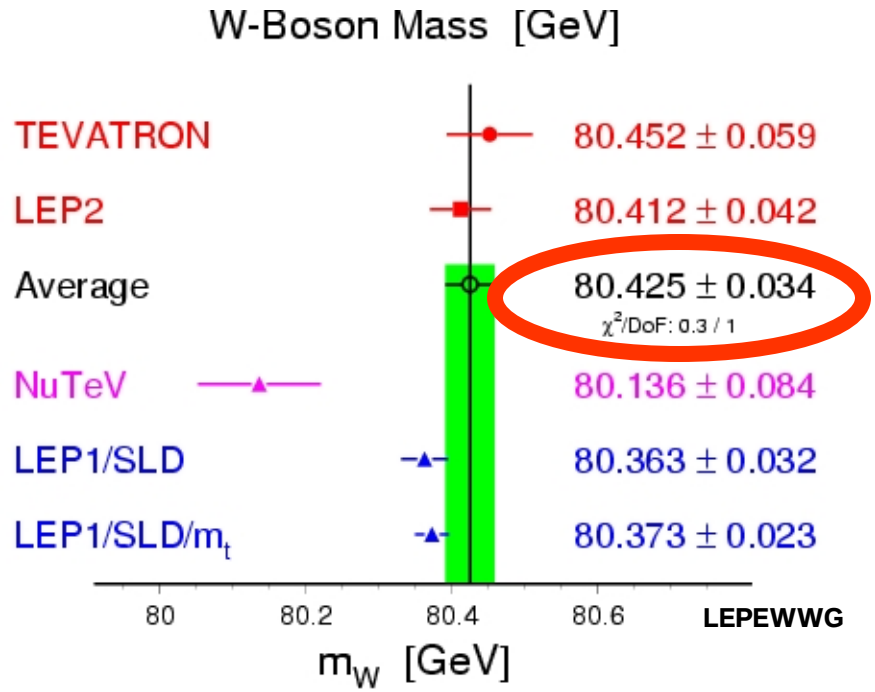
LEPEWWG, EPS05



Measuring M_t & M_W: Results



TEVEWWG, hep-ex/0507091



Like to measure as precisely as possible, but must have

δM_t < 2.9 GeV

δM_W < 40 MeV

Measuring M_t: Analysis

- Recall three categories for tt pair events (l=e,μ)
  - Both W's leptonic: dilepton
  - One W leptonic: l+jets
  - No W leptonic: all jets
- Analyses in all channels, but l+jets is most useful
  - Large branching ratio
  - Only one neutrino from W
  - Better S/B than all jets
- Initially estimated M_t using constrained fit + b tag(s)
- New techniques
  - Kinematic template methods (D0, late run I)
    - Use consistancy with ttbar matrix element
    - Now by D0+CDF
  - In Situ energy calibration scale (CDF, Run II)
    - Scale M(JJ) in l+jets events to match M_W on average
    - Now by CDF+D0

Measuring M_t: Assumptions

- **Projections consider only l+jets**
  - Most sensitive final state
  - Determine JES using W constraint
- **Current results**
  - Run II, l+jets, 320pb^{-1}

CDF: $M_t = 173.4 \,^{+3.7}_{-3.6}$ (stat+JES) $\pm$ 1.7 (sys) GeV

D0: $M_t = 169.5 \pm 4.4$ (stat+JES) $\,^{+1.7}_{-1.6}$ (sys) GeV

Consistent with each other
and of similar sensitivity

Measuring M_t: Assumptions

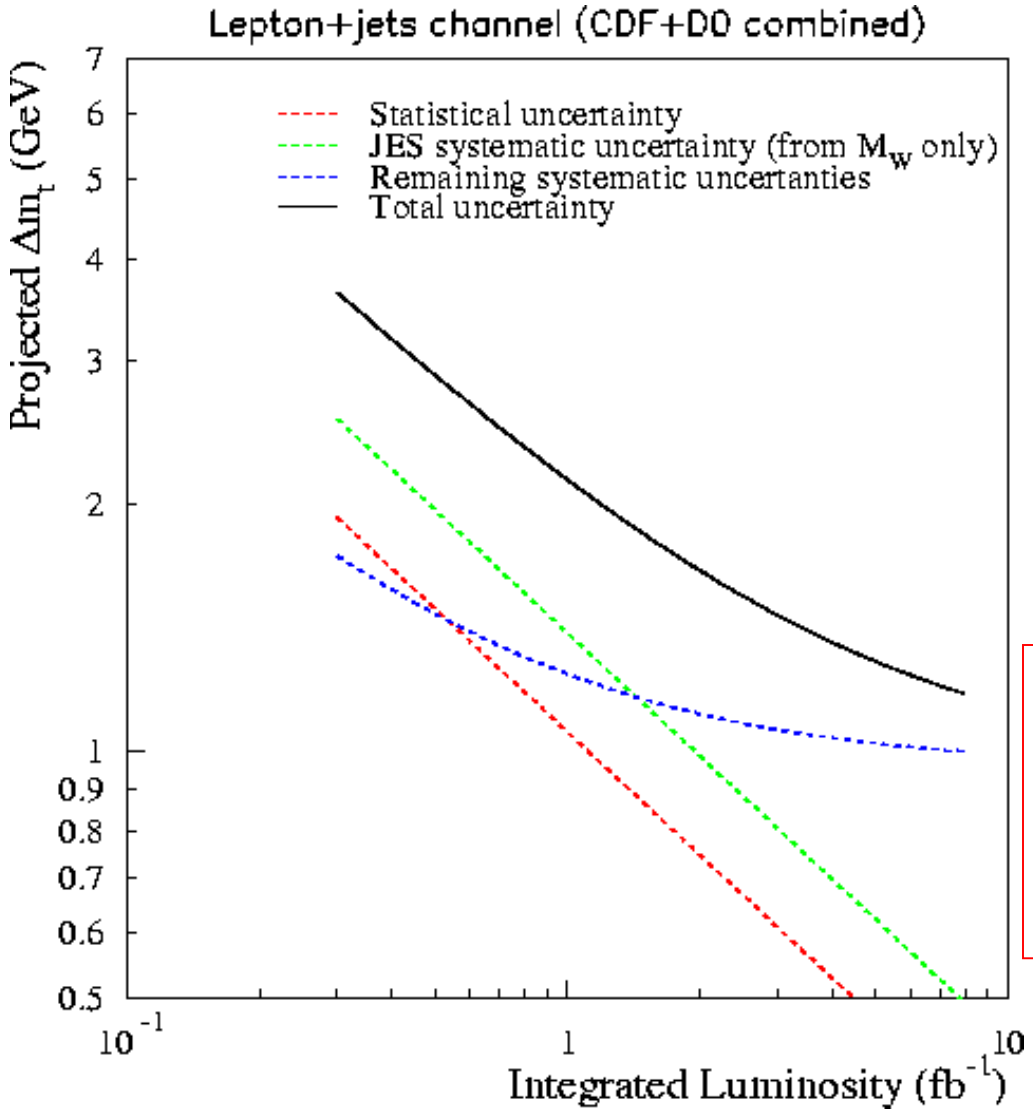
- Some uncertainties scale with lumi, some don't
- Non-scaling for
  - PDF's, b-jet JES, b-tagging, extra jets
  - Approach:
    - Start as is
      - 1.5 GeV, CDF → 1.2*
      - 1.7 GeV, DZero
    - but assume asymptotic 1 GeV using large TeV data set (e.g. bkg shape)

Run II CDF l+jets:

Source	Uncertainty	
JES	3.1 GeV	scale
MC stats	0.4	
Bkg. Shape	1.0 → 0.5*	?
b-jet Energy	0.6	
ISR	0.4	Irreducible?
FSR	0.4	
PDF	0.4	
Generators	0.3	
b-tagging	0.2	

*Just approved

Measuring M_t: Projections



δm_t = 1.4 GeV @ 4 fb^{-1}
= 1.2 GeV @ 8 fb^{-1}

(assuming reduction in systematic from 1.7 GeV to 1.0 GeV over time)

M_t: Comments

LHC?

Predict 1.5 GeV (hep-ph/0412214), perhaps as good as 1.0 GeV (hep-ex/0403021) or better?

Same scale as at TeV!

When?

techniques known in advance ala Run II

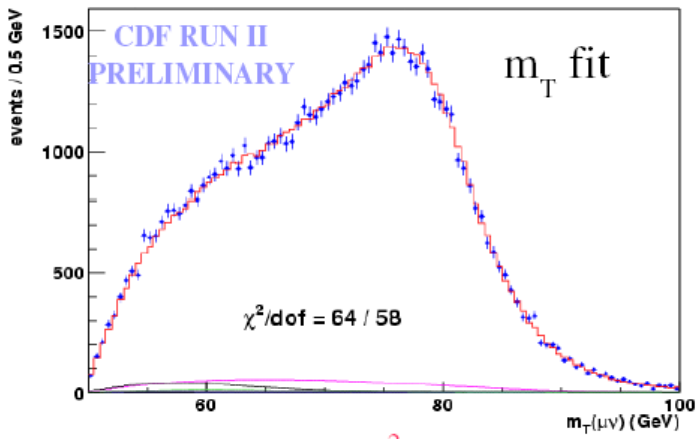
How well are the detector and pp physics understood? These will be the crucial issues…

My guess, based on TeV Run II is at least two years after significant data sample → 2010? 2011? Maybe more…

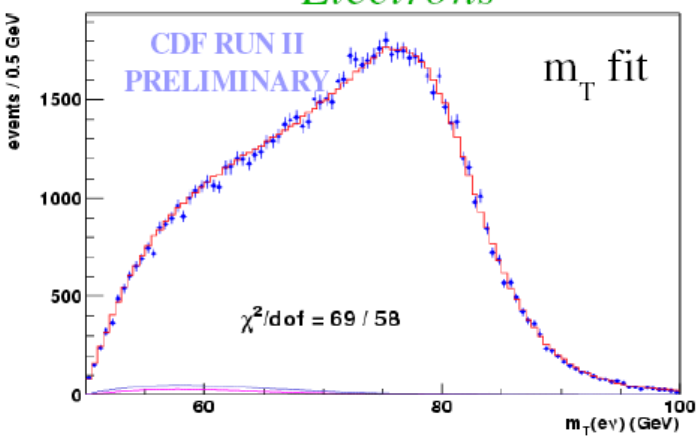
M_W: Analysis Method

CDF Run 2 W Mass Fits

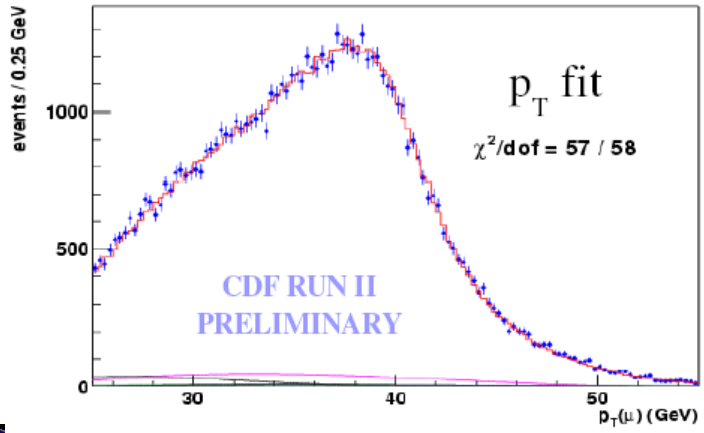
Muons



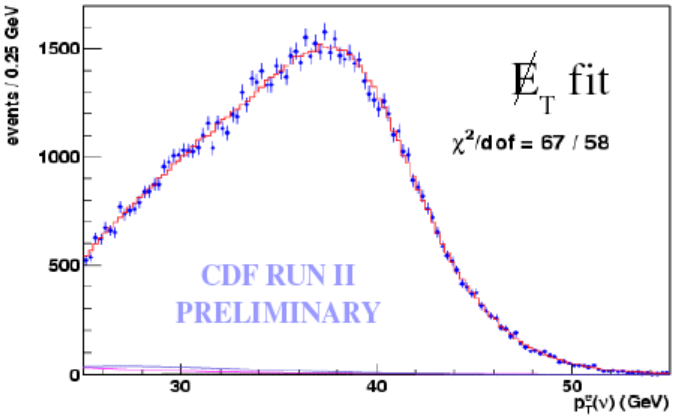
Electrons



Good χ^2 for fits



Fits blinded with [-100,100] MeV offset



M_W: Assumptions/Scaling

Uncertanties are be split into two categories

Scale w/data set size

statistical uncertainty;
calibration uncertainty;
energy and momentum scale,

Requires good understanding of lepton ET and hadron recoil calibration, including B field, material, … Lots of work!

Don't (automatically) scale

W production and decay;
PDF's,
$d\sigma(W)/dp_T$;
higher order QED/QCD

In making projections, assume either no improvement or modest improvement (e.g. acceptance changes) in non-scaling uncertertainties

(NB: Run I/II improvements from TeV data beyond initial)

M_W: Assumptions/Systematics

- **Look at current Run II uncertainty (CDF)**

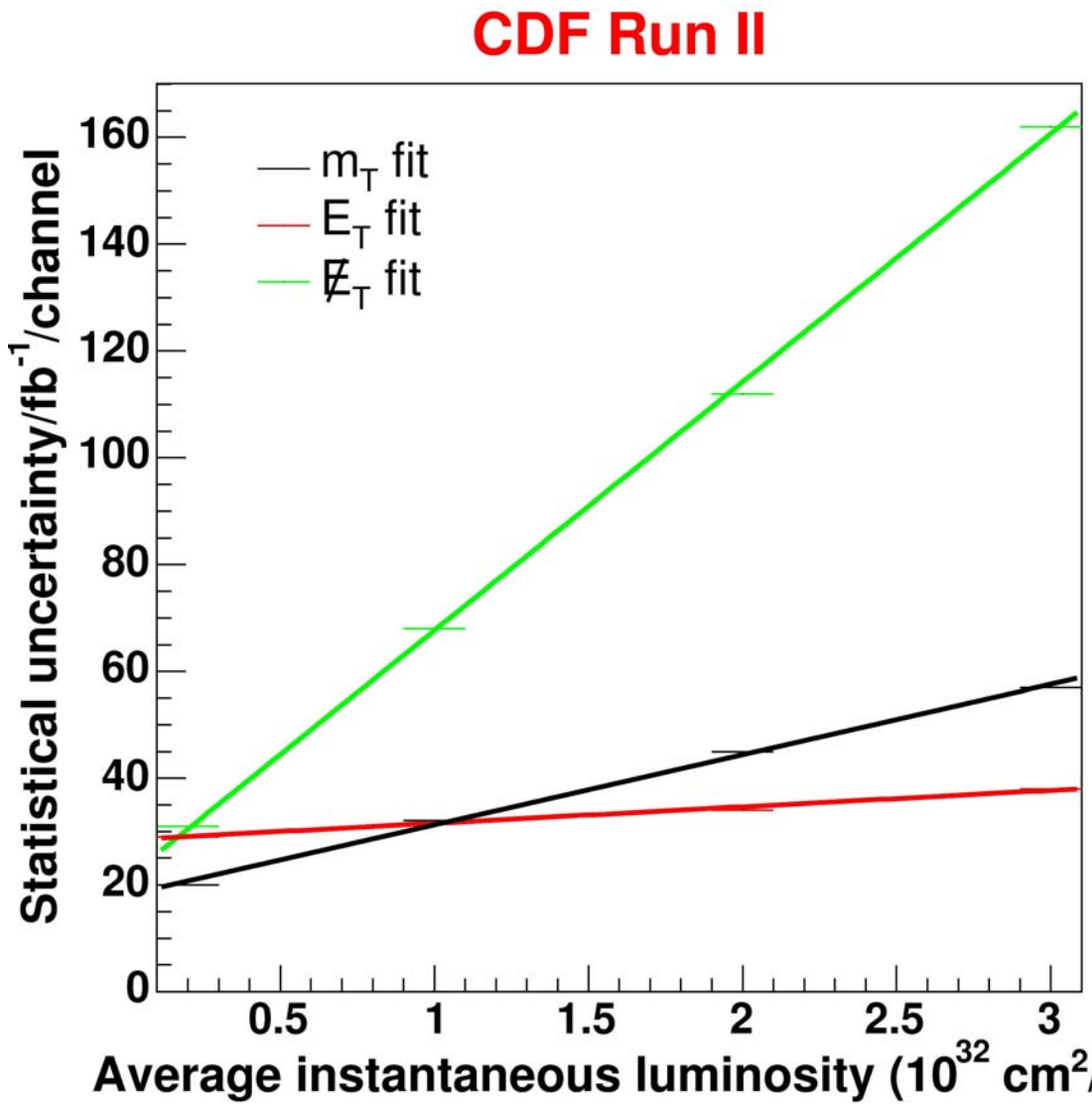
Determined from collider data control samples

Theory + acceptance

Systematic [MeV]	Electrons (Run 1b)	Muons (Run 1b)	Common (Run 1b)
Lepton Energy Scale and Resolution	70 (80)	30 (87)	25
Recoil Scale and Resolution	50 (37)	50 (35)	50
Backgrounds	20 (5)	20 (25)	
Production and Decay Model	30 (30)	30 (30)	25 (16)
Statistics	45 (65)	50 (100)	
Total	105 (110)	85 (140)	60 (16)

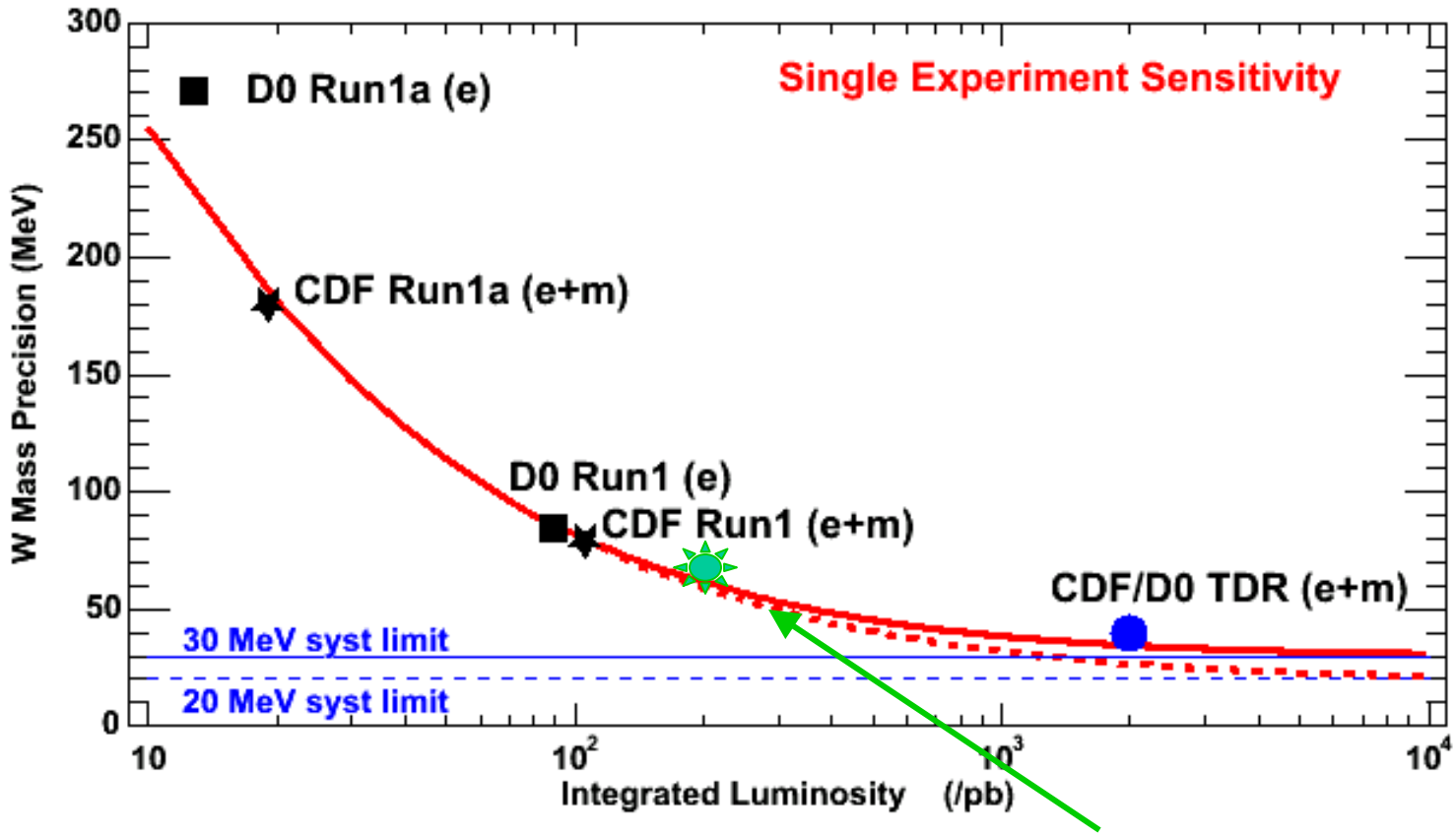
M_W: Luminosity Effects

Effects of higher instantaneous lumi on uncertainty



Hobbs, Stony Brook/FNAL

M_W: Projections



CDF, Run II e+μ,
76 MeV uncertainty

M_W: Comments

- **Current expected irreducible uncertainty**
  - **Approx. 20 MeV – 30 MeV**
  - **Improvements possible from large data set?**
- **Other methods?**
  - **Ratio method? Primary systematic from differences (e.g. p_T and acceptance) arising from difference between M_W and M_Z.**
- **LHC?**
  - **10 – 20 MeV hoped for, but must be taken at low luminosity. How many years will it take to understand the detector and production well enough and how fast will luminosity grow? For example, U.E. does not transfer.**

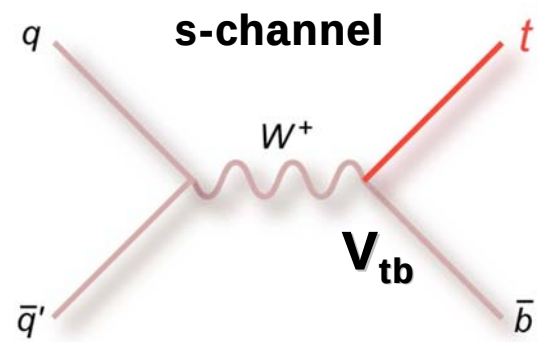
Single Top

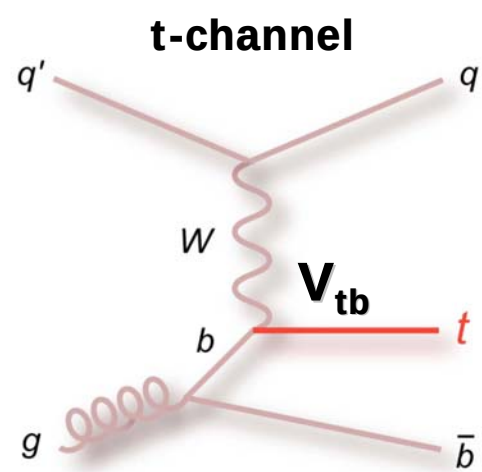
- **Important to tt and Higgs**
- **S.M. EW top production**
  - **Both s- and t-channel predictions**

    $\sigma(tb) = 0.88 \pm 0.14$ pb

    $\sigma(tbq) = 1.98 \pm 0.30$ pb
  - **Depends on V_{tb}**
- **Beyond the S.M. (σ_s, σ_t)**

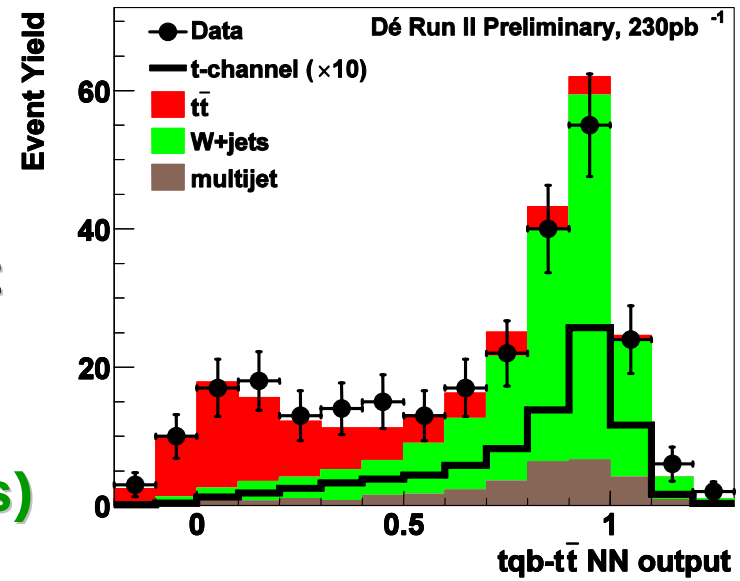
  H^+, (2 pb, 2 pb); $t \to Zc$, (1 pb, 4 pb)
- **Currently published, bounds**
  - **s-channel $\sigma < 6.4$ pb (D0, 230 pb^{-1})**
  - **t-channel $\sigma < 5.0$ pb**





Single Top: Analysis Method(s)

- Basic W+2 jet selection
- Then, optimized analysis for single top
  - Evolved considerably over past year
    - Optimized square cuts
    - Add multivariate selection(s)
    - Add 2D likelihood fit to spectrum



	s-channel	t-channel
Square cuts	9.8 pb	12.4 pb
MV + fit	4.5 pb	5.8 pb

D0, predicted limits for 230 pb^{-1} analysis

½ gain, MV
½ gain, fitting

Single Top: Assumptions

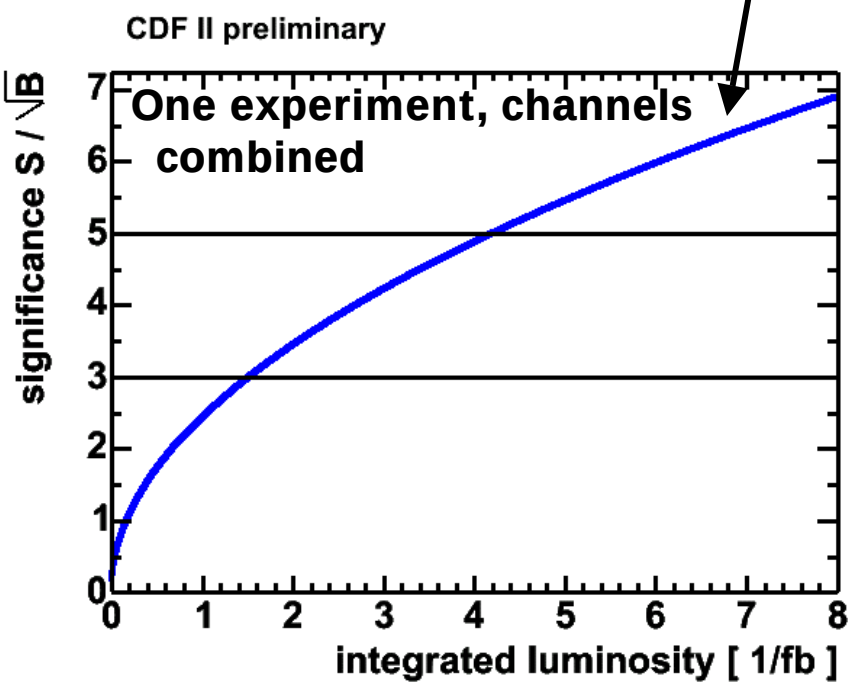
- analyses methods are improving rapidly
  - A snapshot, but w/recent improvements
- Assumptions
  - No changes to
    - Techniques
    - Efficiencies
    - Resolutions
  - Systematics ignored, but assume no better analysis
    - Improved tagging?
    - Lepton coverage?

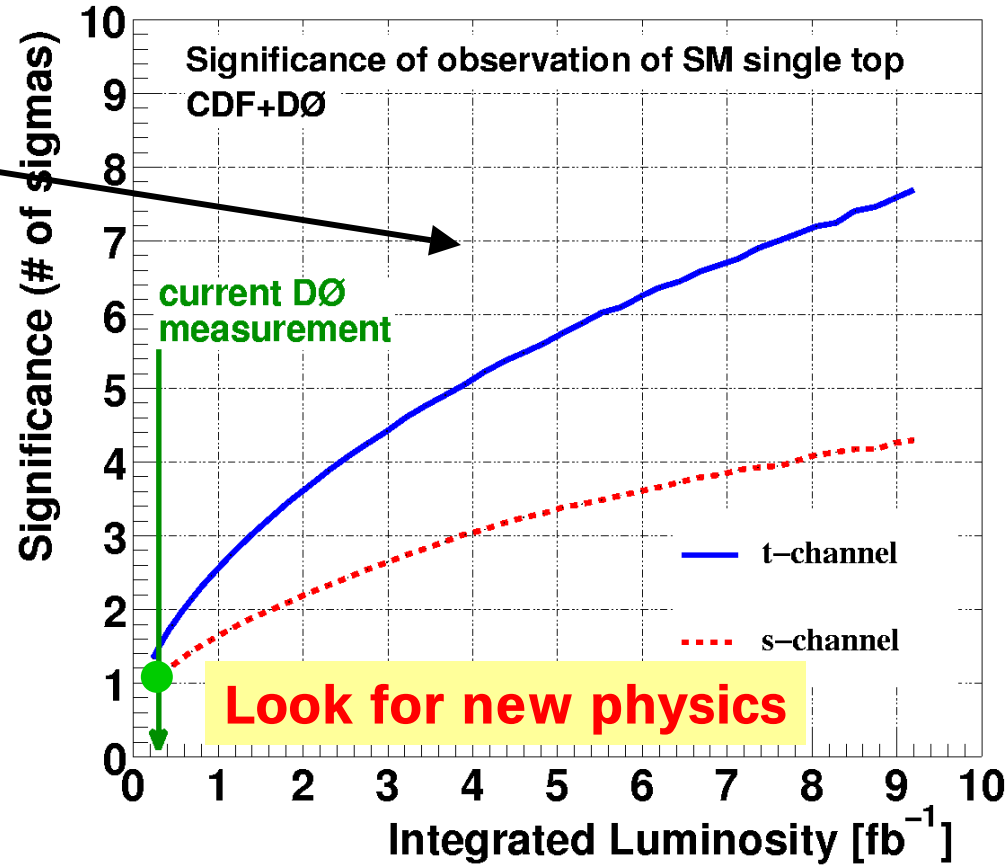
Summary:
use recent result, assume expected improvements offset lack of systematics in estimate

Single Top: Projections

Two approaches:
separate s- and t-channel

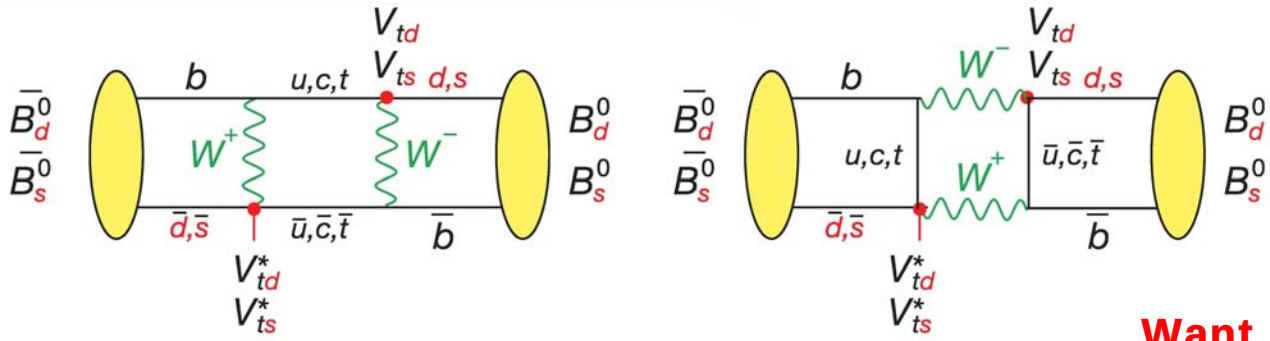
combined likelihood for "SM"





$\delta|V_{tb}| = 11\%$ with 4 fb^{-1}; 9%, 8 fb^{-1}

B_S Mixing



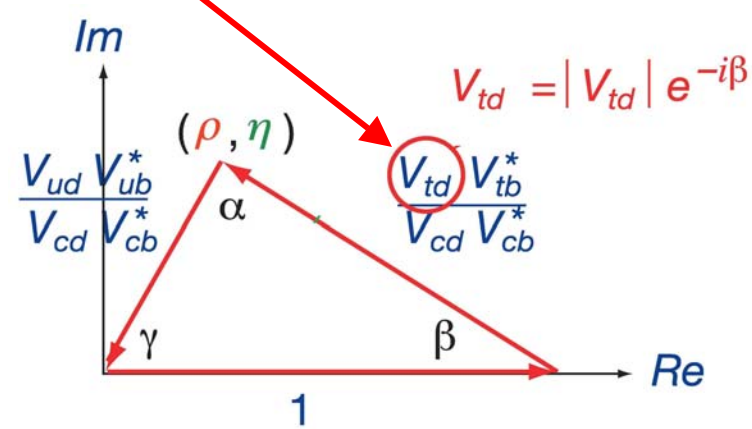
States oscillate between B_x^0 and $\overline{B_x^0}$ with a freq. related to ΔM_x

- **Ratios best constrain CKM**

$$\frac{\Delta m_s}{\Delta m_d} = \frac{m_{Bs}}{m_{Bd}} \frac{f_{Bs}^2}{f_{Bd}^2} \frac{B_{Bs}}{B_{Bd}} \left| \frac{V_{ts}}{V_{td}} \right|^2$$

CKM fit *predicts* : $\Delta m_s = 18.3 \,^{+6.5}_{-2.3}$ ps^{-1}

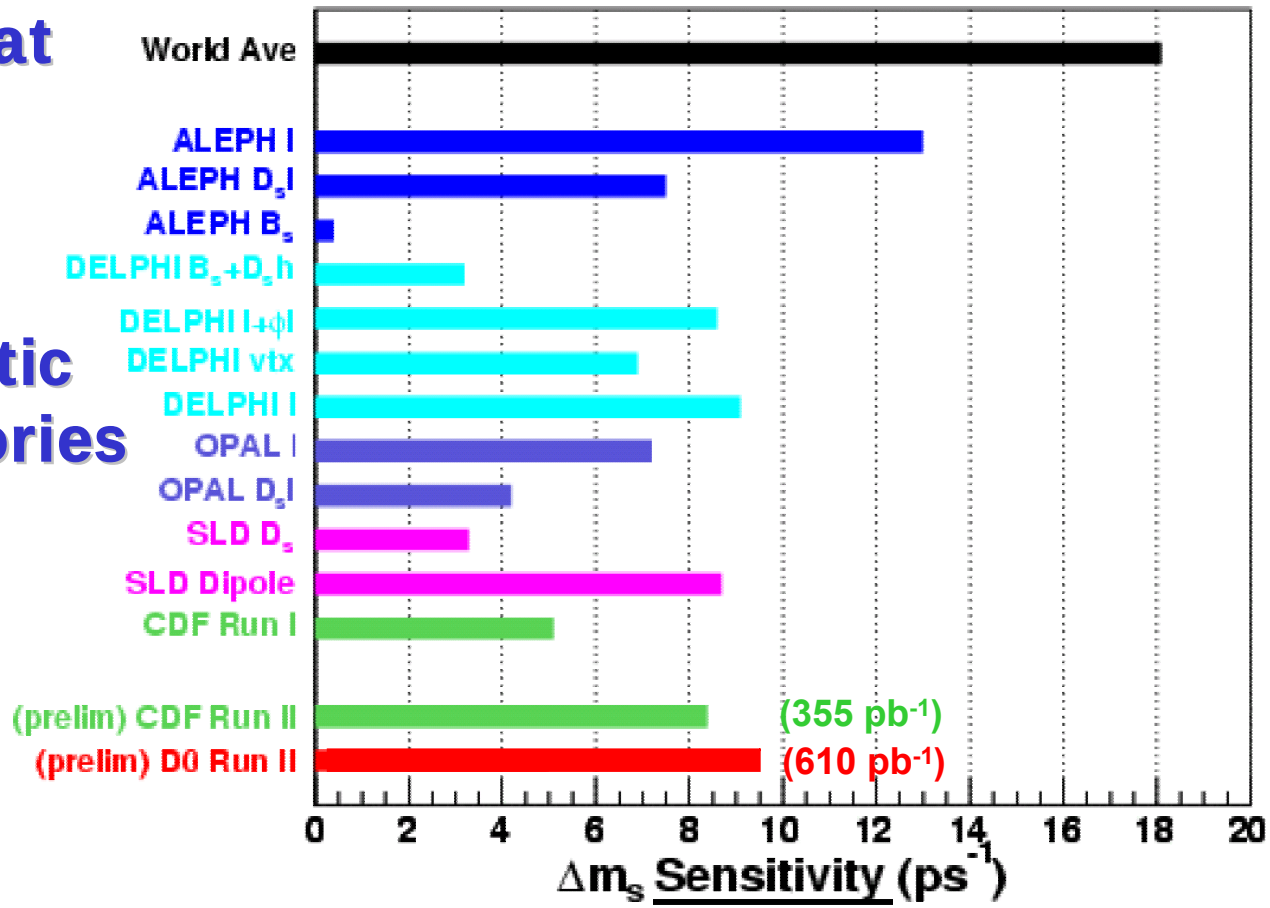
Want $|V_{td}|$ with precision



- **New physics can either increase or decrease oscillation frequency**

B_S Mixing: Current Situation

- **Measurements at**
  - **LEP**
  - **SLD**
  - **Tevatron**
- **Beyond kinematic range of B factories**

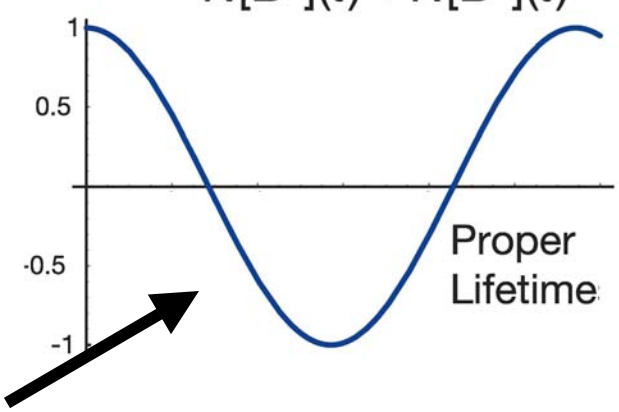


B_S Mixing: Analysis Approach

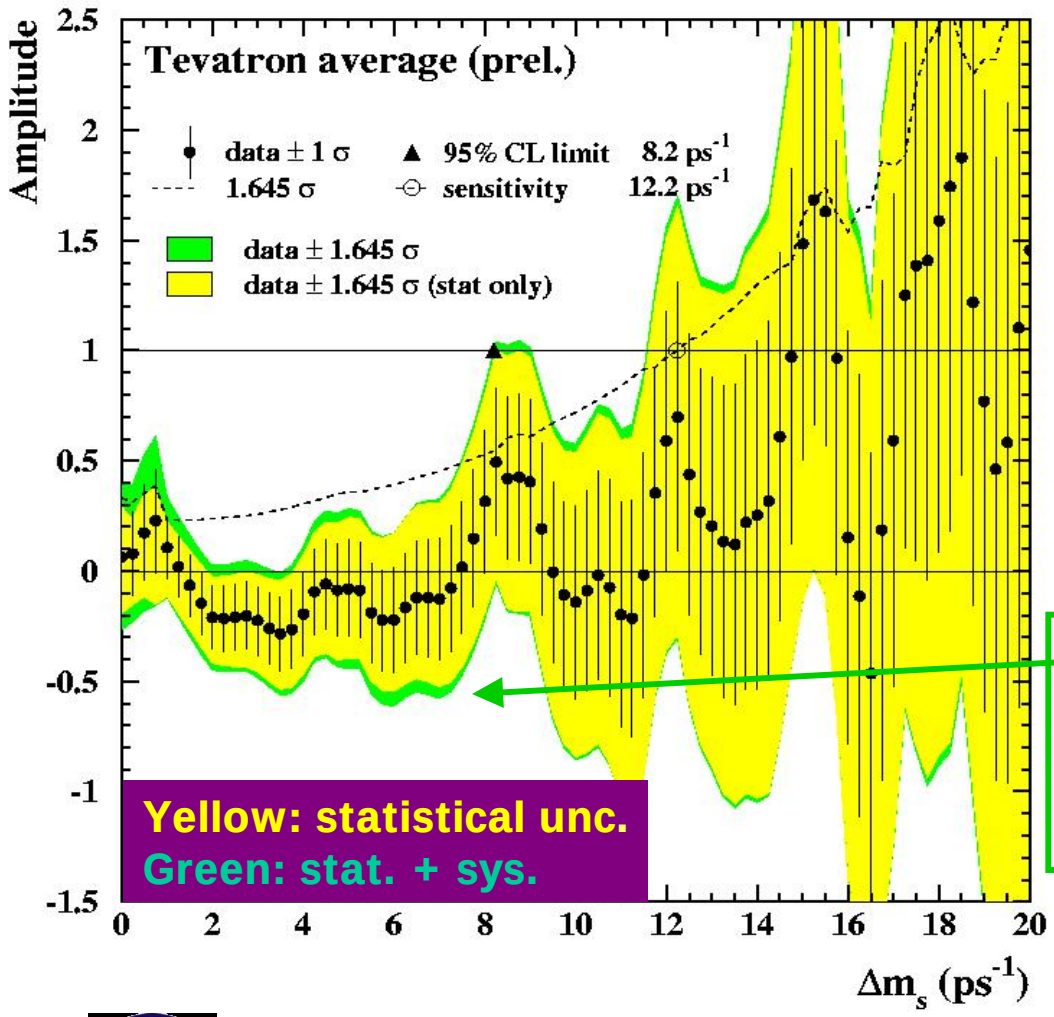
- **Basic selection: vertexing and mass**
- **Optimize selection using MV (likelihood) to reduce bkg.**
- **Flavor tag**
  - **OST (now)**
  - **SST (coming)**
  - **Dilution (+efficiency, εD^2) caused by opposite side oscillation/mis-ID**
- **Determine flavor asymmetry as a function of time (VPDL)**

Already well established in current analyses of 350 pb^{-1} to 600 pb^{-1}

$$A = \frac{N[B^0](t) - N[\bar{B}^0](t)}{N[B^0](t) + N[\bar{B}^0](t)}$$



B_s Mixing: Analysis Approach



Fit for presence of oscillation, A, as a function of Δm_s

A = 0 for wrong Δm_s (= no oscillation)

=1 for actual Δm_s

Will not be systematics limited! More data is better

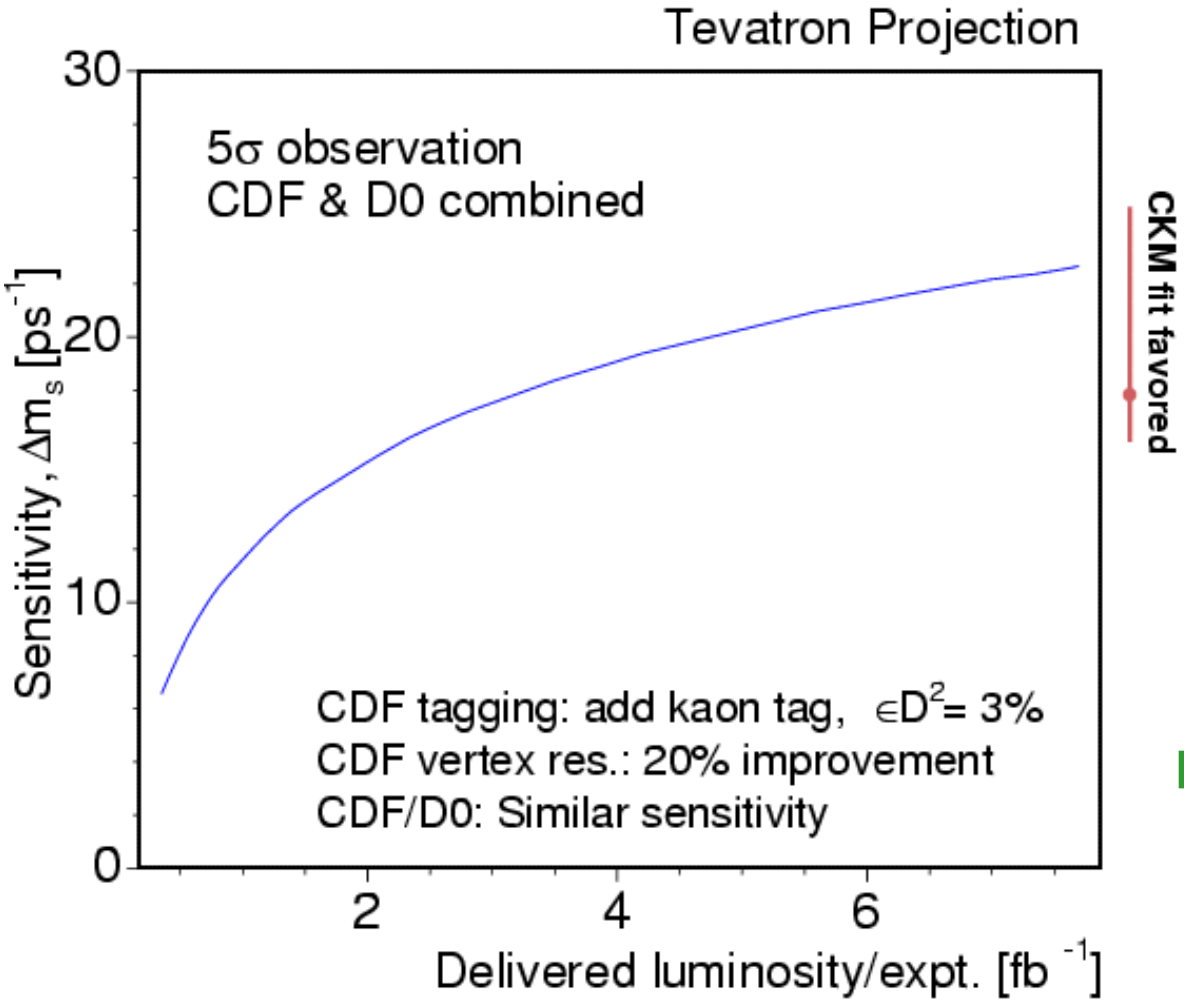
B_S Mixing: Assumptions

- **General Analysis improvements**
  - Event-by-event fits, not binned likelihood
  - Improved tagging ("same side")
    - CDF: εD^2 1-3% increase for same side (kaon) tag

- **CDF specific issues**
  - Vertex resolution +20%
    - Improve by better hit assoc
  - Lumi >2007, 1/2x (prescale)

- **DZero specific issues**
  - Layer 0 silicon, improves L_{XY}
  - L3 bandwidth 50 Hz 100 Hz
    - now, offline CPU limited
    - add new, dedicated CPU
    - Proposal submitted

B_S Mixing: Projections



LHCb:

$\delta(\Delta m_s)$ = 0.01 ps^{-1}
or 5σ @ 68 ps^{-1}
(1 yr, stats only, TDR)

$\Delta\Gamma_s/\langle\Gamma_s\rangle$ in B_s^0

- As necessary for mixing, heavy/light eigenstates with different masses.
- Theory value (with experimental input)
  $\Delta\Gamma_s/\Gamma_s = 0.12 \pm 0.05$
  A. Lenz hep-ph/0412007
- Current results

PDG 2004: < 0.54 (95% CL)
< 0.29 using $\tau(B_d)$

CDF: $0.65^{+0.25}_{-0.33}$ (stat) ± 0.01 (sys)

D0: $0.25^{+0.28}_{-0.38}$ (stat) $^{+0.03}_{-0.04}$ (sys)

Can be improved using $\tau(B_s)$ semi-leptonic e.g.

D0: $0.25^{+0.14}_{-0.15}$

$\Delta\Gamma_s/\langle\Gamma_s\rangle$: Analysis

- **Reconstruct**

$$B_s^0 \rightarrow (J/\psi)\phi$$

$\phi \rightarrow K^+K^-$

$J/\psi \rightarrow \mu^+\mu^-$

- **Simultaneous fit to**
  - **$(J/\psi)\phi$ mass distribution**
  - **Proper decay length**
  - **Transversity, $d^3\Gamma(t)/d\cos(\Theta)\, d\phi\, d\cos(\psi)$ ***

(Θ,ϕ) are μ^+ angles in J/ψ rest frame (w/ ϕ along x)

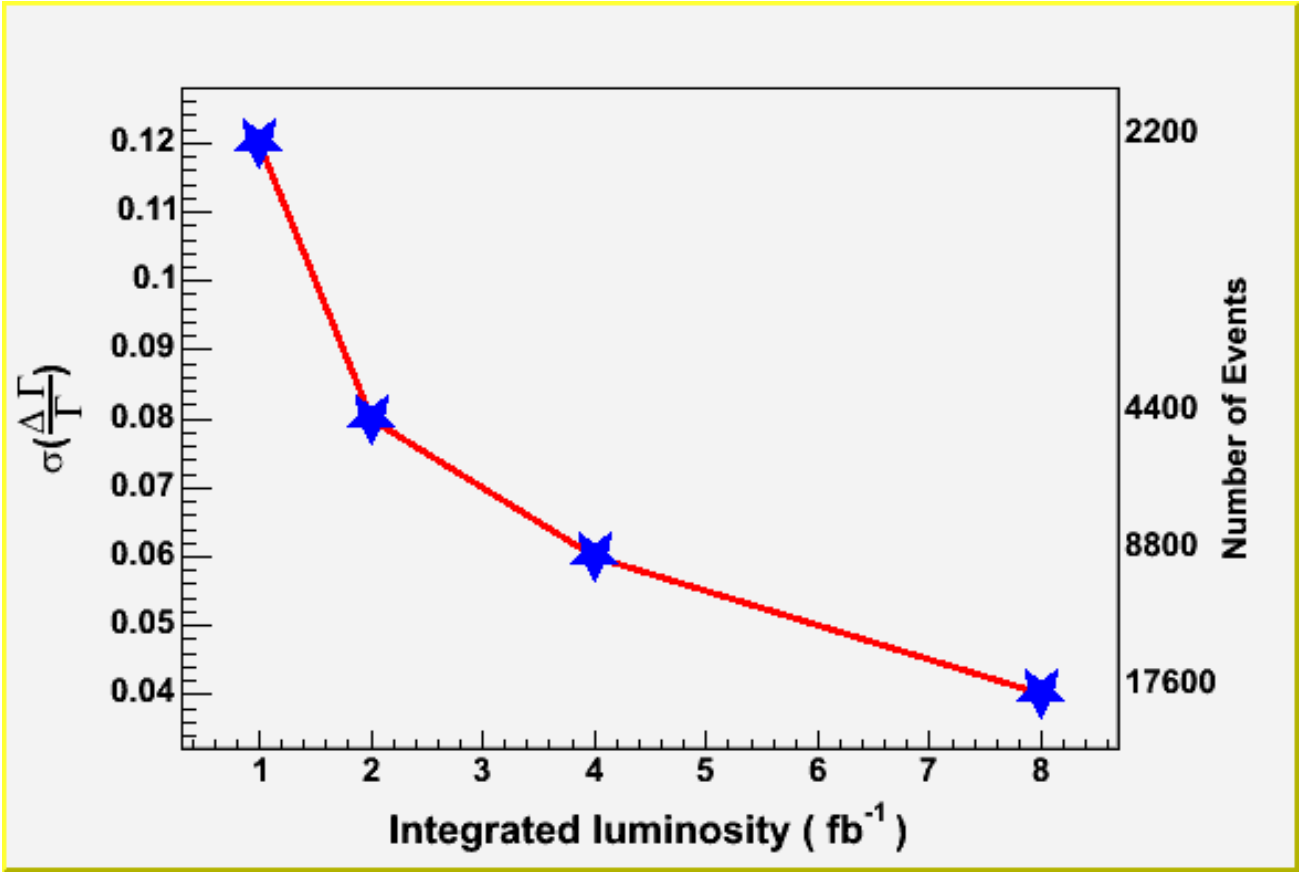
ψ is angle between K^+ momentum and negative of J/ψ momentum.

*Currently integrating out $d\phi\, d\cos(\psi)$

$\Delta\Gamma_s/\Gamma_s$: Assumptions

- **Similar sensitivity for CDF & D0**
  - CDF: better mass resolution
  - D0: better polar angle coverage
- **Modest analysis improvement**
  - Fit all 3 angles in transversity, not current 1 angle
  - D0: Layer 0 silicon
- **Projections**
  - Use D0 full simulation of run IIa
  - Scaled for inclusion of Layer 0

$\Delta\Gamma_s/\Gamma_s$: Projection

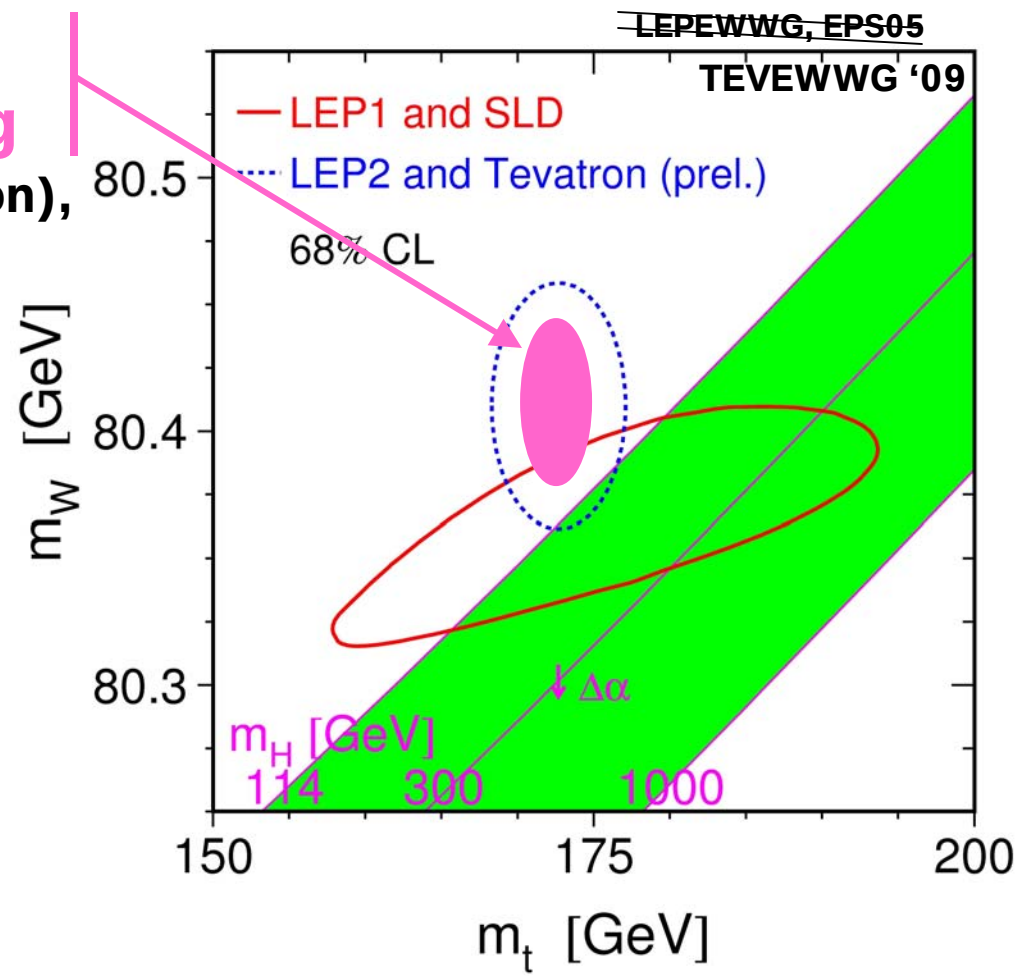


LHCb: $\delta(\Delta\Gamma/\Gamma)$ **= 0.05**
(1 yr, stats only, TDR)

Conclusions: I

- Can make important S.M. tests in
  - Top mass and W mass
  - Single top, $|V_{tb}|$
  - B_S mixing and lifetime difference
  - Many other publishable analyses, not discussed
- In the period before LHC.
  - takes time to get understanding for precision
- Some results may be roughly equivalent to LHC, some will (eventually) be bettered
- Luminosity goals well matched to program

Conclusions II: A Legacy?

δM_t = 1.2 GeV,
δM_W = 24 MeV, world avg

(LEP2 + δM_W = 30 MeV(Tevatron), no LEP/TeV correlations)