FNAL in D0 Physics

Herbert Greenlee

DOE Annual Review

Sept. 26, 2007

Outline

- D0 organization and FNAL D0 group.
- Physics topics.
  - QCD.
  - B Physics / B_s Mixing.
  - Electroweak / diboson.
  - Top.
  - Higgs.

The D0 Collaboration

- The current D0 masthead.
  - 600 names
  - 81 institutions (one of which is FNAL).
- The FNAL D0 group.
  - 54 names (9% of D0 collaboration).
    - 42 Particle Physics Division.
    - 9 Computing Division.
    - 3 other.
  - FNAL group is the largest institutional group in D0 (by far).

D0 Physics Organization

Convener change Aug. 2007

Spokespeople
Dmitri Denisov
Darien Wood

1/2 outgoing
1/2 incoming

Physics Coordinators
Aurelio Juste
Stefan Soldner-Rembold

0/2 outgoing
1/2 incoming

Physics Groups
Higgs
Top Quark
Electroweak
New Phenomena
QCD
Heavy Flavor

2/13 outgoing
0/14 incoming

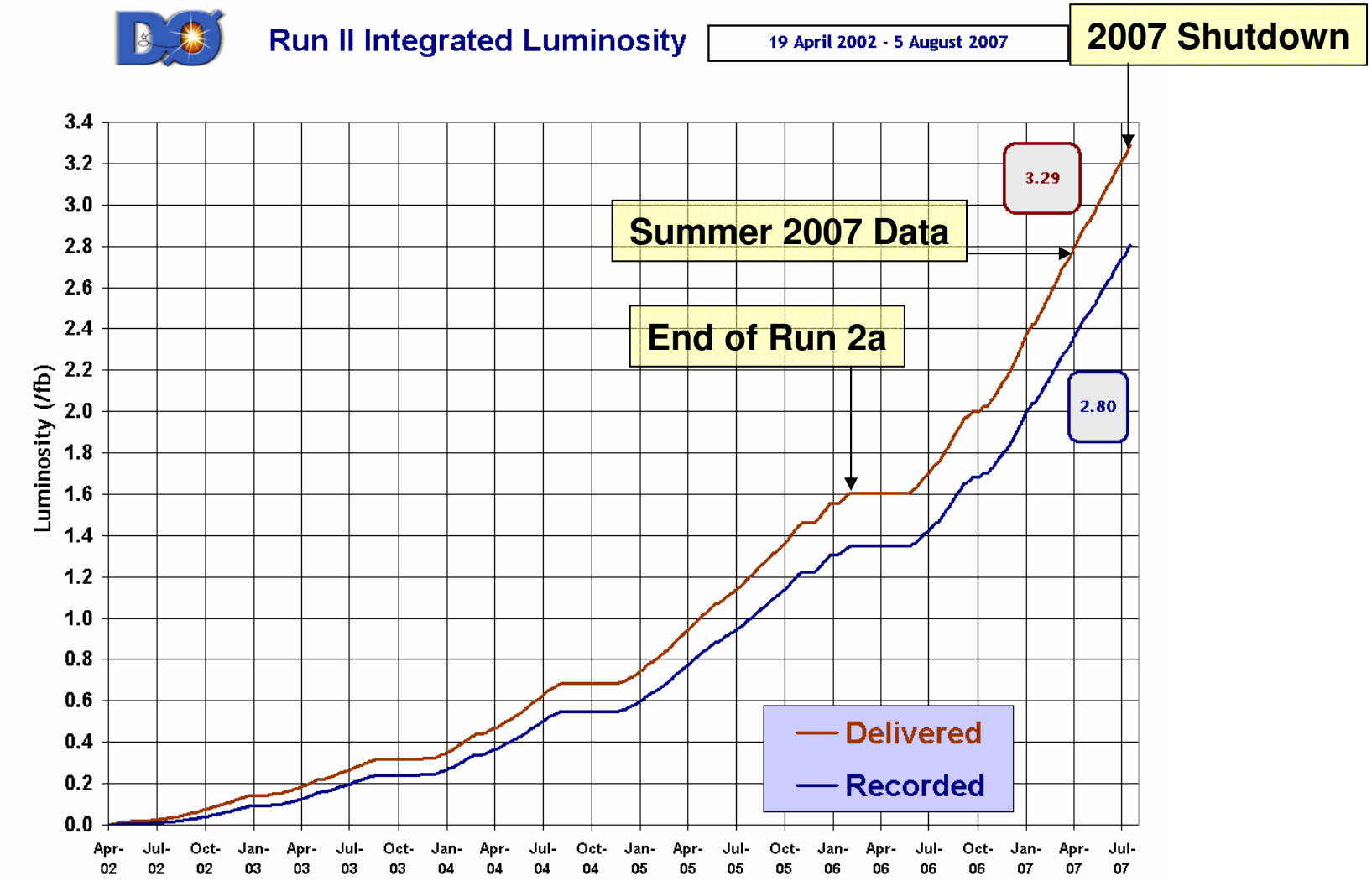
Working Groups
Jet Energy Scale
Common Samples
Luminosity
V+jets
Trigger Board
Trigger Studies

3/10 outgoing
2/12 incoming

Editorial Boards
EB1-EB37

4/36

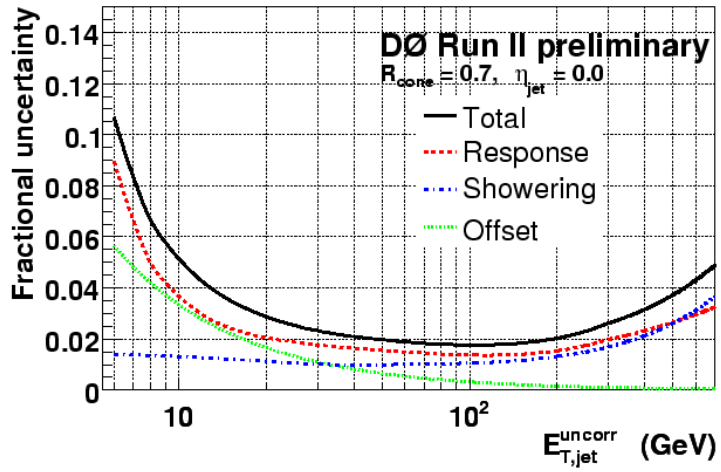
D0 Luminosity History

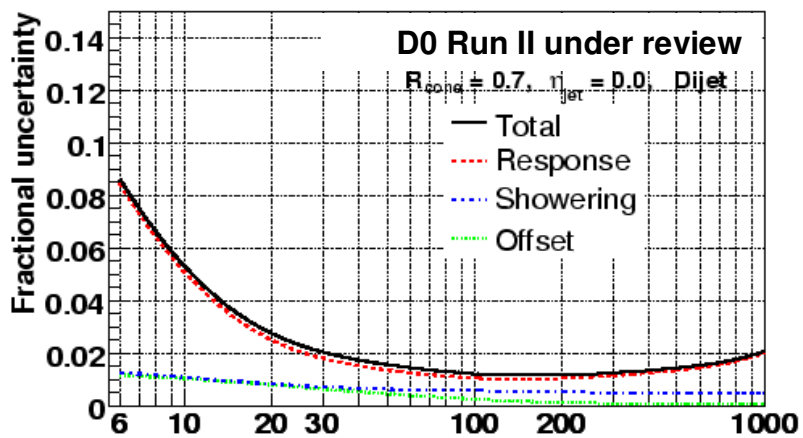


Jet Energy Scale

- Match energy scale of reconstructed data and mc jets to idealized particle jets.
- JES and JES systematic error are an important component of most D0 physics analyses.
  - Major improvement coming.
- JES working group convened by Fermilab physicist A. Juste (until recently).

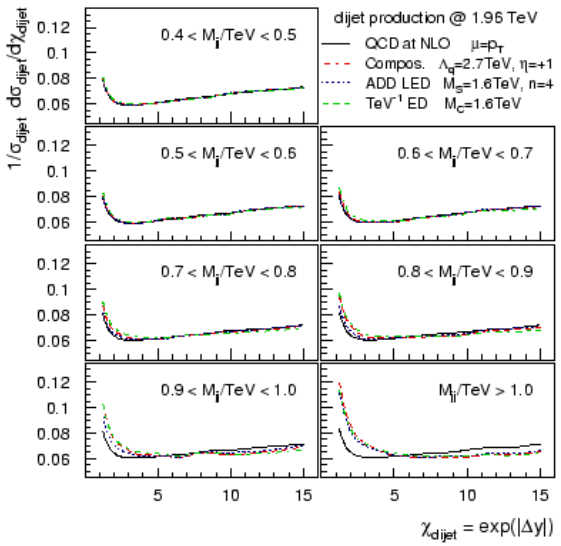
JES Uncertainty





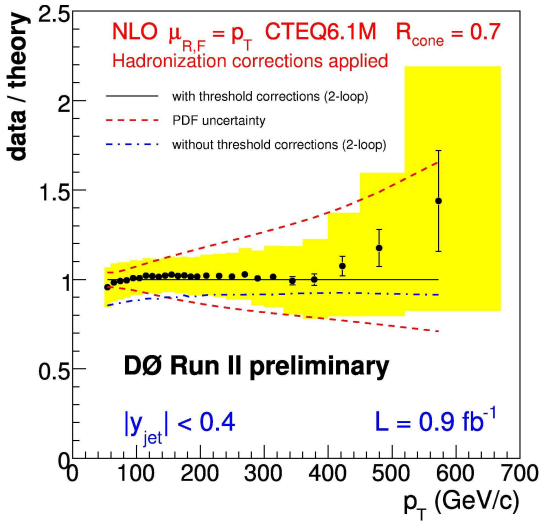
QCD

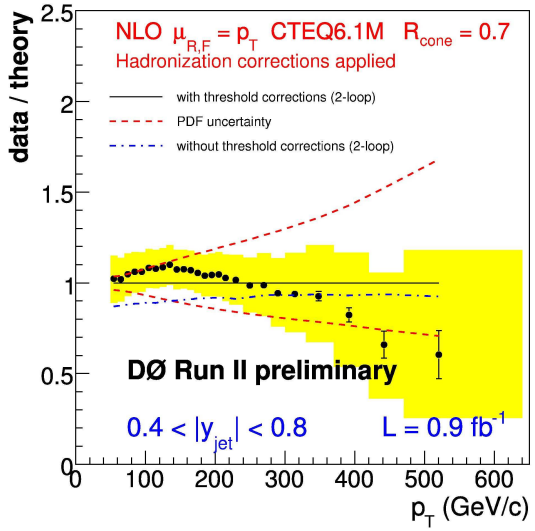
- Jets.
  - Inclusive jets.
  - Dijet mass. (D. Lincoln)
  - Dijet angular (χ) distributions. (M. Wobisch, V. O'Dell)
  - 3-jets.
- Vector bosons.
  - Photons.
  - W,Z + jets.
- Heavy flavors.
  - bb dijets. (D. Lincoln)
- Diffracitve, rapidity gaps.

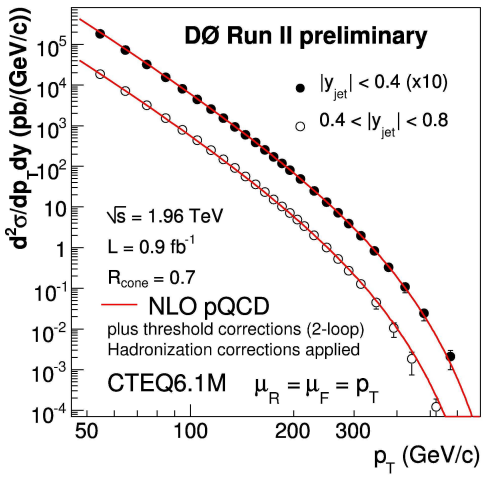


Inclusive Jets

- Probes highest available p_T.
- Highly sensitive to JES.







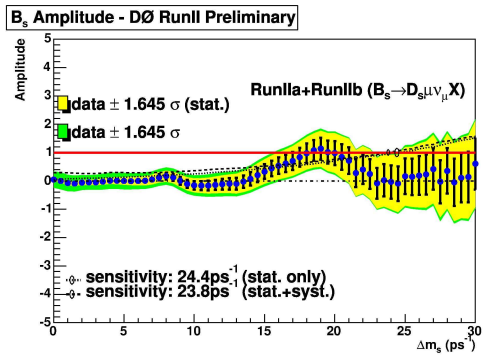
D0 B Physics

- Flavor oscillation & CPV.
  - B_s mixing (S. Burdin, A. Nomerotski, M. Naimudden).
- Lifetimes.
- Branching ratios.
- Spectroscopy.
- Rare decays
  - $B_s \rightarrow \mu\mu$. (B. Casey).

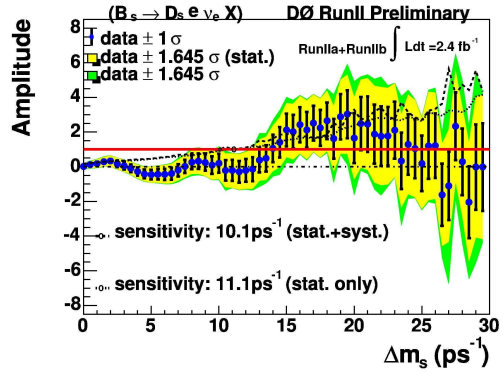
B_s Mixing

- Four B_s decay modes with OS and SS flavor tagging.

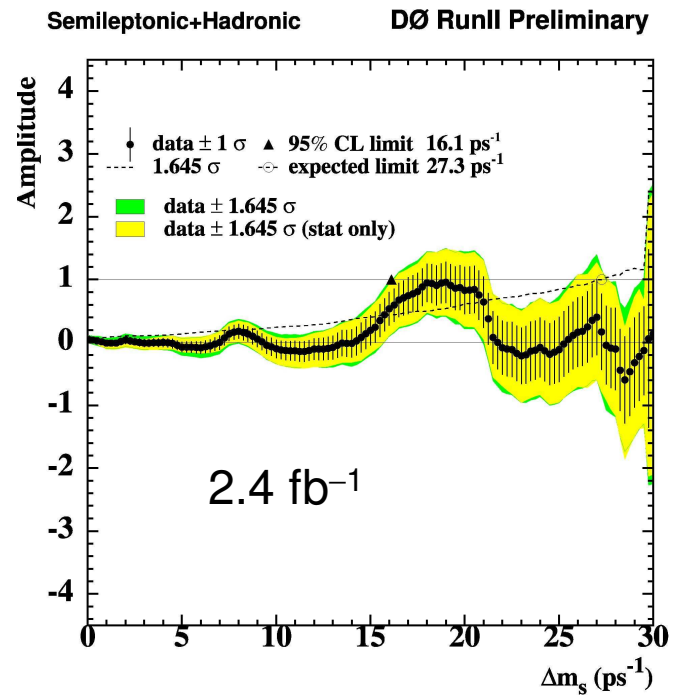
$B_s \rightarrow \mu\phi\pi$



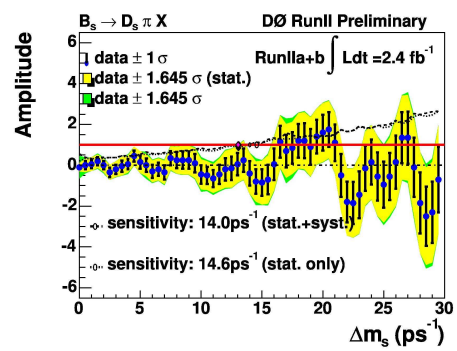
$B_s \rightarrow e\phi\pi$



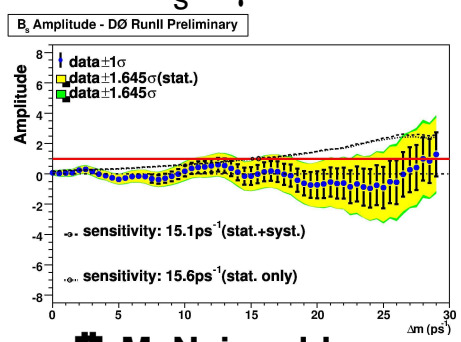
Combined



$B_s \rightarrow \pi\phi\pi$



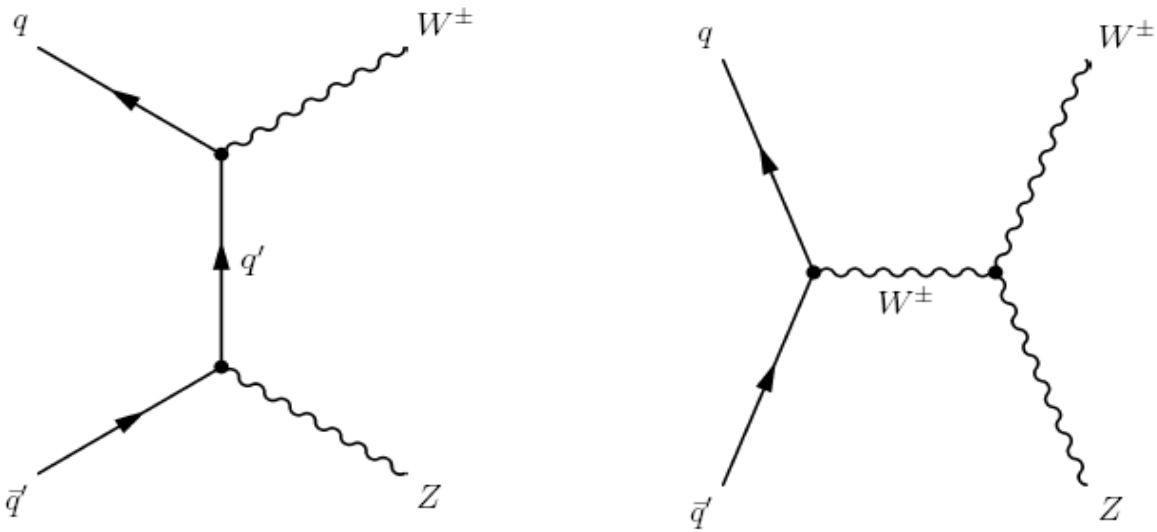
$B_s \rightarrow \mu K^{*0} K$



$\Delta m_s = 18.56 \pm 0.87\ ps^{-1}$

M. Naimudden

Electroweak Diboson Production



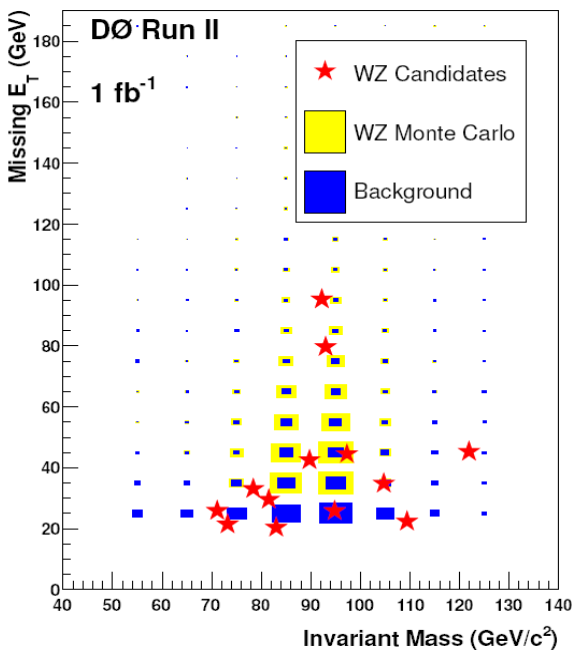
- The Standard Model makes nontrivial and unambiguous predictions for trilinear gauge couplings.
- TGC couplings probed by diboson production.
  - Wγ, Zγ, WW, WZ, ZZ.

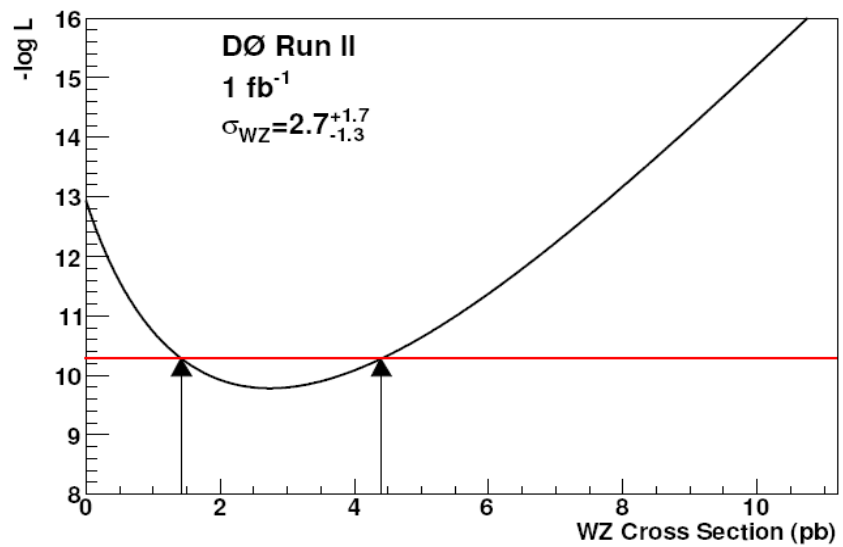
D0 Diboson Results

- Tevatron and D0 have an illustrious history of diboson results over the years.
- D0 Diboson Group has been led by FNAL physicists for many years (T. Diehl, A. Lyon).
- Recent results:
  - WZ (σ, Anomolous Couplings), 1 fb^{-1}, submitted.
  - ZZ (σ), 1 fb^{-1}, preliminary.
  - $Z\gamma$, (σ, AC), 1 fb^{-1}, published 2007.
  - $W\gamma$ (σ), 900 pb^{-1}, preliminary.
  - WW (σ, AC), 200 pb^{-1}, published 2005, 2006 (update soon).

WZ Cross Section

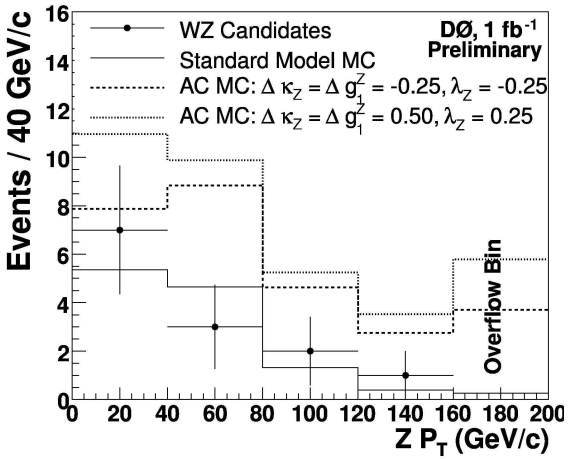
- WZ → eee, eeμ, μμe, μμμ.
- Counting experiment results (1 fb^{-1}).
  - 13 events observed, 4.5 ± 0.6 background.
  - $\sigma_{WZ} = 2.7\ ^{+1.7}_{-1.3}$ pb (3.0 σ significance), σ_{WZ} (SM) = 3.7 pb.

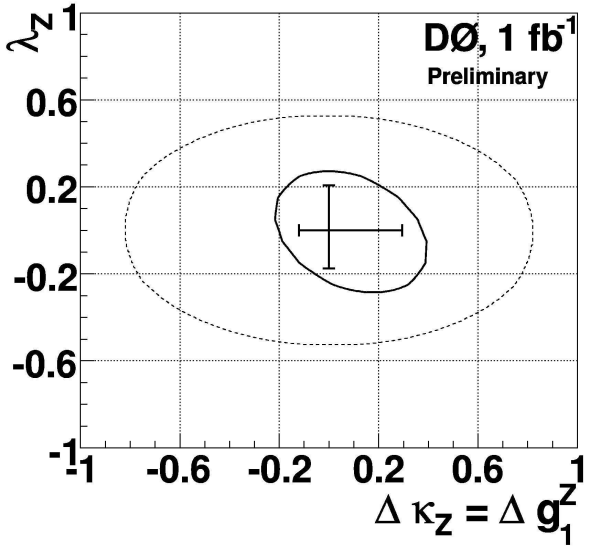


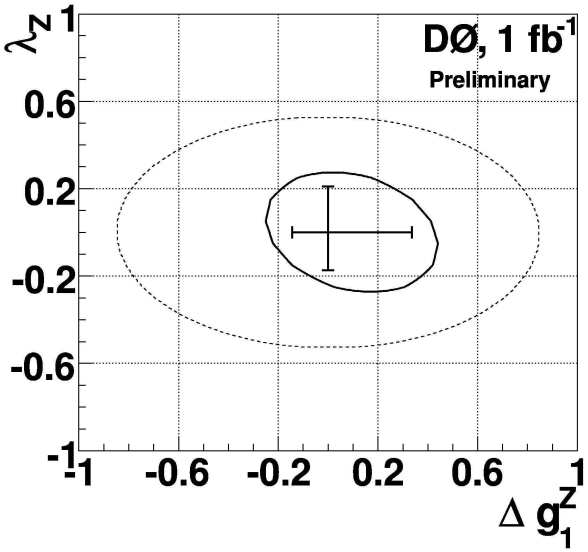


WZ Anomalous Couplings

- Three anomalous coupling parameters for WWZ trilinear coupling.
  - Δg_1^Z, $\Delta\kappa_Z$, λ_Z





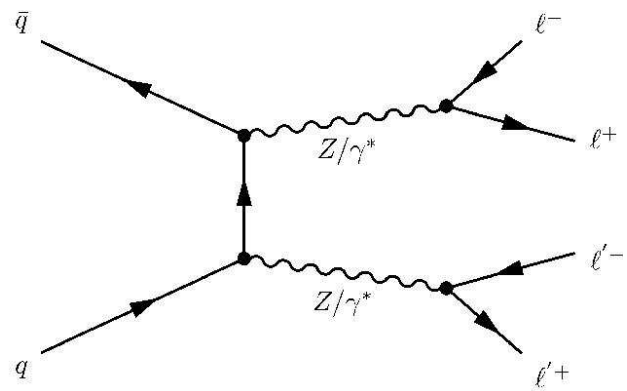


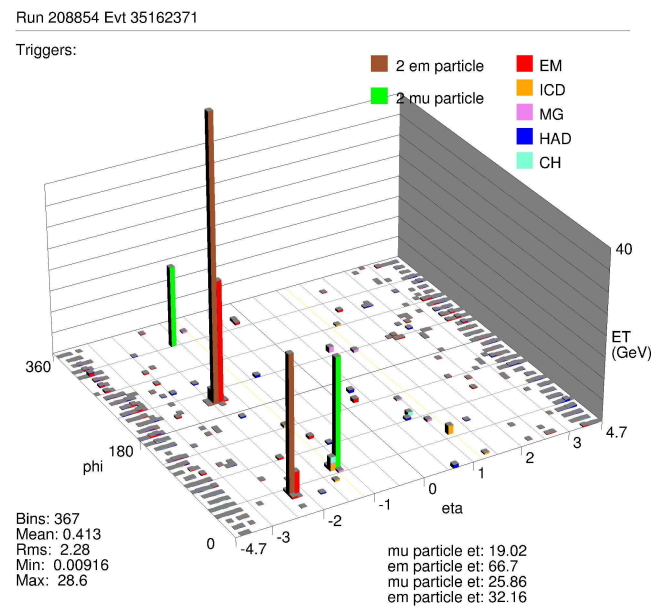
Experimental limit

Unitarity limit

ZZ Cross Section

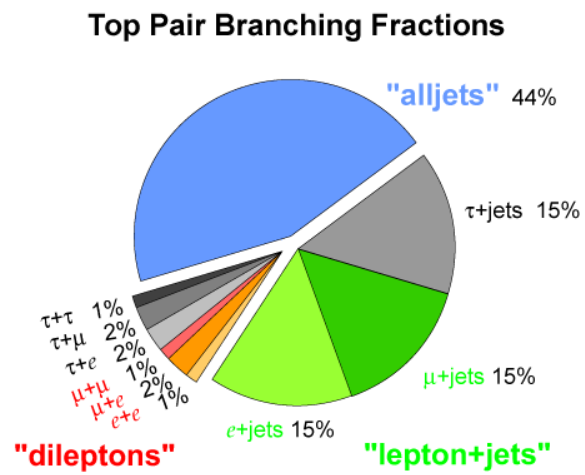
- ZZ→eeee, eeμμ, μμμμ.
- Counting experiment results (1 fb^{-1}).
  - 1 eeμμ event observed, (0.17 ± 0.04 background).
  - σ < 4.3 pb @ 95% CL
  - SM predicts σ = 1.6 pb (1.7 events expected).
- Consistent with SM.
- AC limits available shortly.

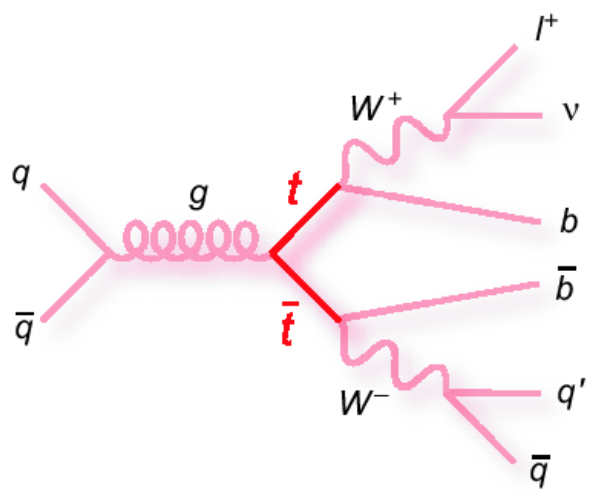




Top Quark Mass in Lepton + Jets

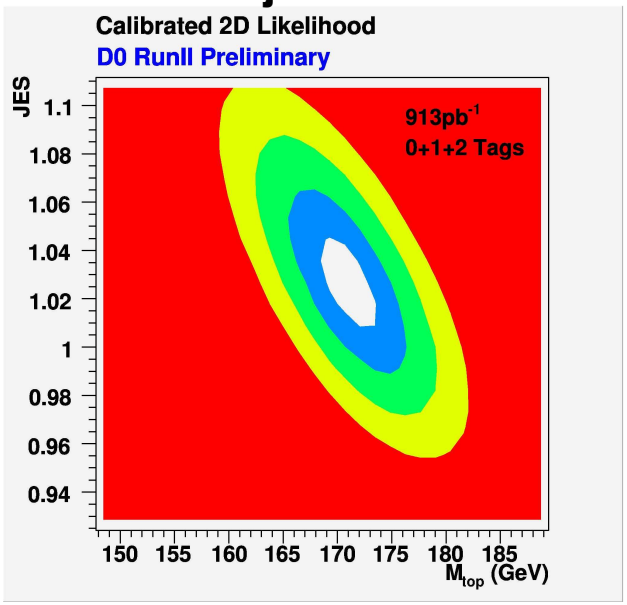
- The top quark mass is overconstrained in l+jets channel.
  - With and without b-tagging.
- Matrix element method.
  - Calculate probability $P(m_{top}, \text{JES})$ for each candidate event.
    - JES=jet energy scale factor.
      - Includes internal (W mass) and external JES constraint.
  - Combine probabilities from all events.



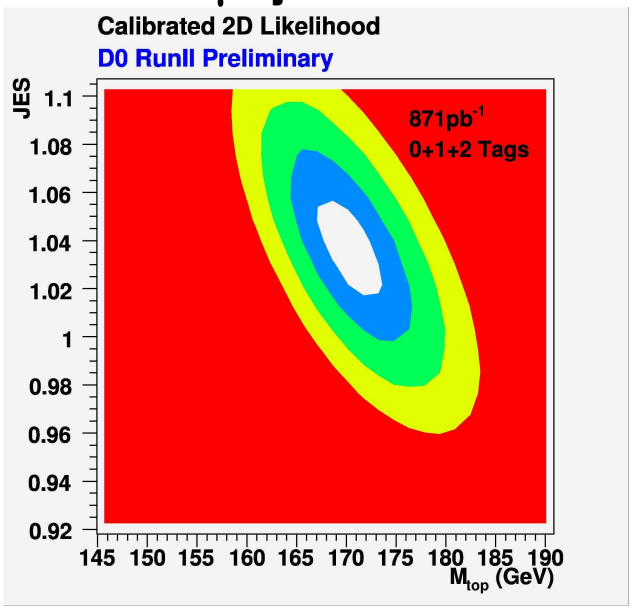


Matrix Element Top Mass Results

e+jets



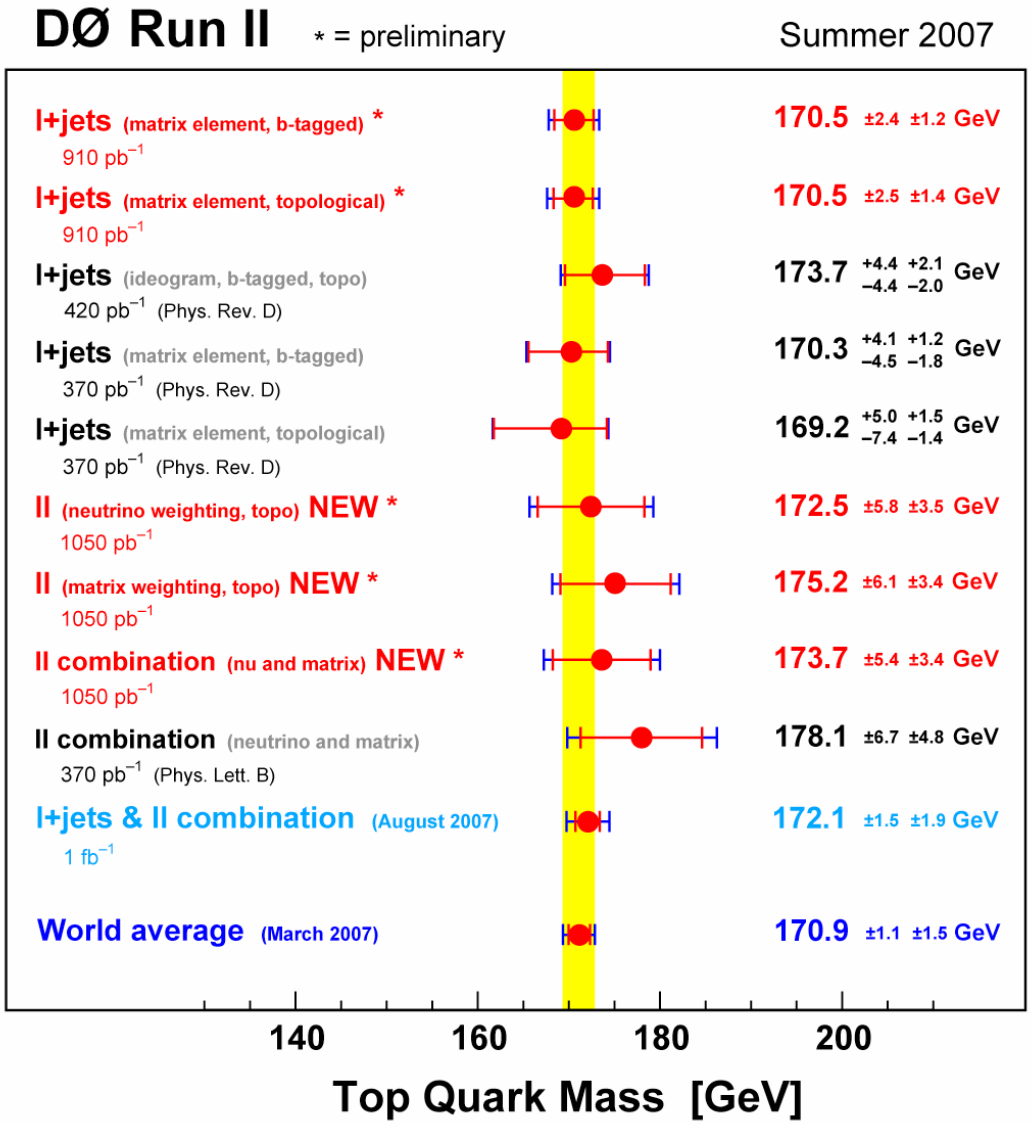
μ+jets



m_{top}=170.5±2.4(stat+JES)±1.4(syst) GeV.

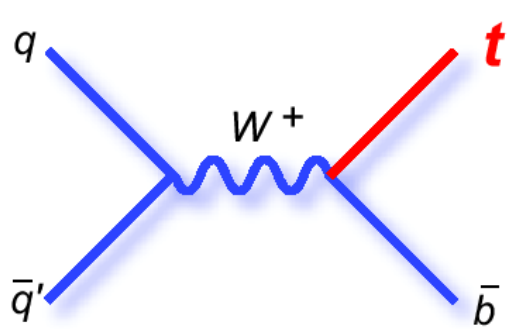
- FNAL physicists
  - Gaston Gutierrez (coinventor of ME method).
  - Mike Wang (pioneered use of the grid for analysis).

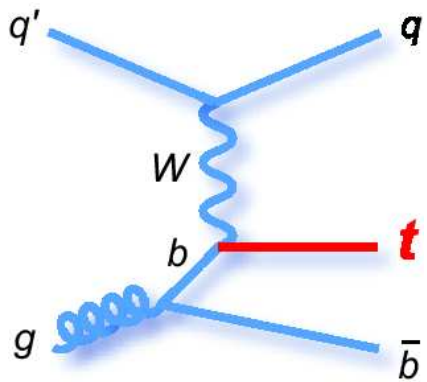
Top Quark Mass Summary



- (Gutierrez, Wang)
- (Gutierrez, Wang)
- (M. Weber)
- (Gutierrez, Wang)
- (Gutierrez, Wang)

Single Top Quark Production





- Directly probe weak couplings of top quark.
- One of D0's physics highlights from the past year is first evidence (3.4σ) for single top production.
  - Much worse background than top quark pairs.
- D0 has a large and active single top physics subgroup including FNAL physicists.

Single Top Analyses

- D0 has used three different methods to search for single top production.
  - Decision Trees.
  - Matrix Element. (A. Juste)
  - Bayesian Neural Network.
- Each method is a different way of constructing a multivariate discriminant.

Single Top Matrix Element

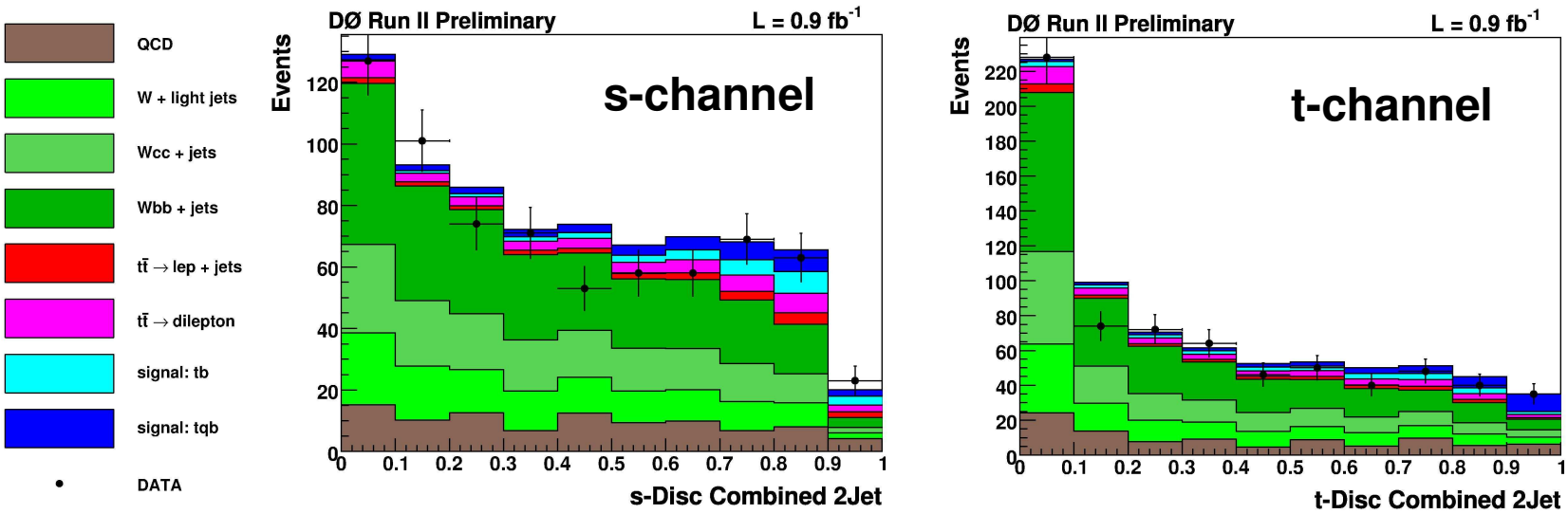
- Matrix element uses analytic multivariate discriminant of the form:

$$D(x) = \frac{P_{\text{signal}}(x)}{P_{\text{signal}}(x) + P_{\text{background}}(x)} \quad \text{where} \quad P_i(x) = \frac{1}{\sigma_i}\frac{d\sigma_i}{dx}$$

- Eight channels: e,μ + 2,3 jets + 1,2 b-tags.
- Separate discriminants for s-channel and t-channel.
- Cross section obtained by fitting distribution of discriminants in the different channels to a combination of signal and background.
  - Assume σ_s/σ_t=0.44 (SM prediction).

Single Top Results

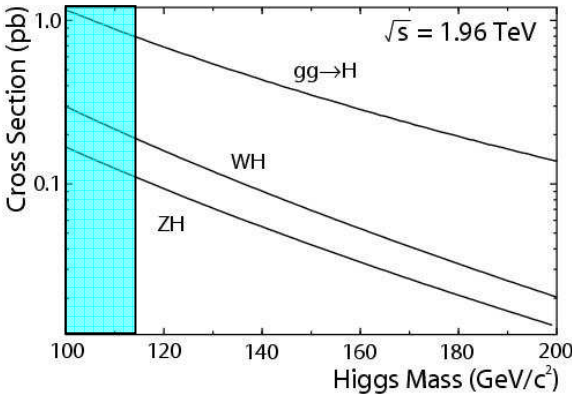
Matrix Element Results

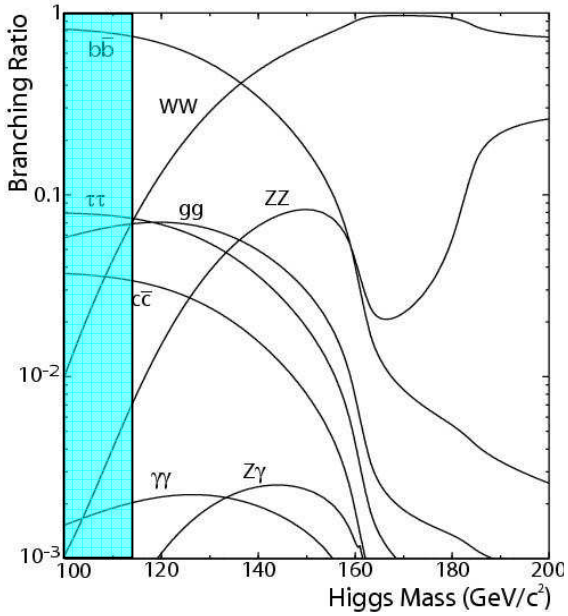


- ME method: $\sigma_t = 4.8^{+1.6}_{-1.4}$ pb (3.2 σ).
- Combined (3 methods): $\sigma_t = 4.7 \pm 1.3$ pb (3.6 σ).
- SM prediction (s+t): $\sigma_t = 2.9$ pb.

Higgs Physics

- Higgs Channels.
  - SM Higgs.
    - WH, ZH. (W. Fisher, A. Juste, S. Fu, T. Yasuda)
    - H→WW.
    - Combination. (W. Fisher)
  - Non-SM Higgs.
    - SUSY/high tan β.
    - H^+ / H^{++}
    - Bosonic Higgs.



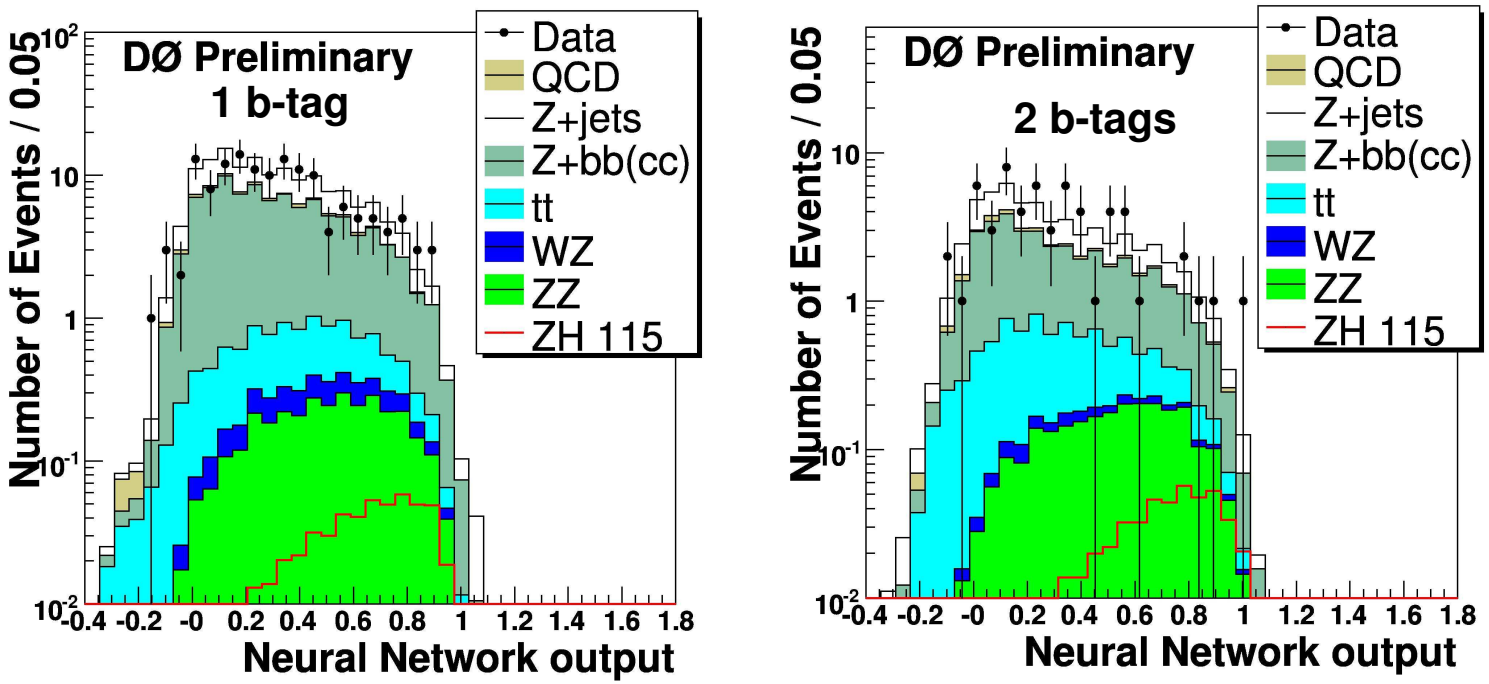


D0 SM Higgs Results

- $WH \rightarrow ebb, \mu bb$ (1.7 fb^{-1}). (W. Fisher, A. Juste)
- $ZH \rightarrow eebb, \mu\mu bb, \nu\nu bb$ (1.1 fb^{-1}). (S. Fu, T. Yasuda)
- $WH \rightarrow WWW \rightarrow \ell^+\ell^+ + X$ (1.0 fb^{-1}).
- $H \rightarrow WW \rightarrow ee, e\mu, \mu\mu$ (1.7 fb^{-1}).
- $H \rightarrow WW \rightarrow \mu\tau$ (1.0 fb^{-1}).
- D0 Combined limit. (W. Fisher)
- Tevatron Combined limit. (W. Fisher)

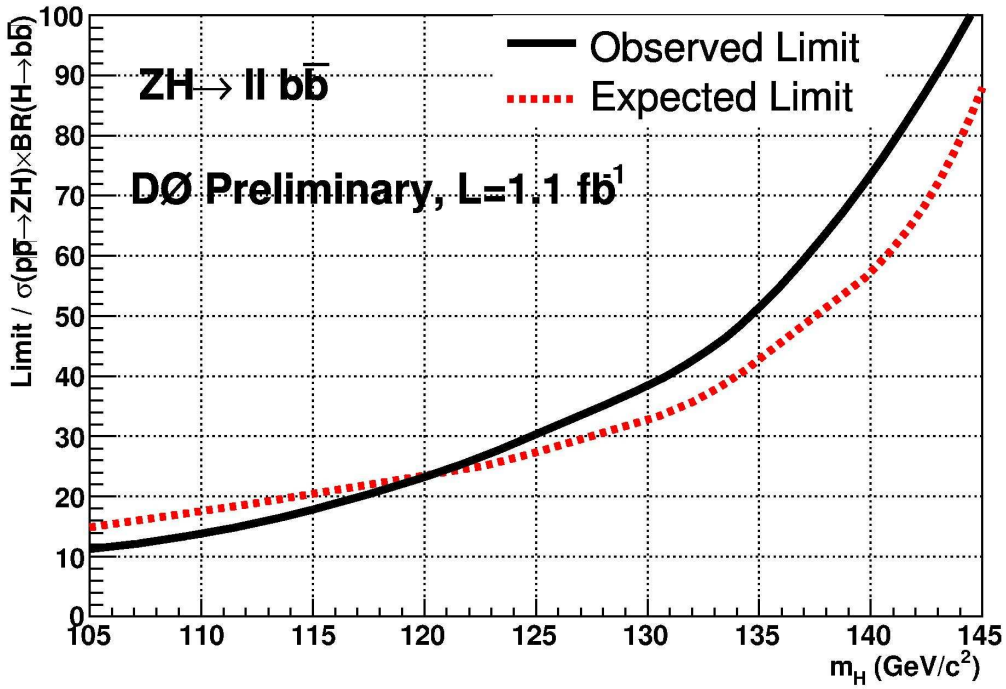
$ZH \rightarrow \ell\ell bb$

- Select events with two e,μ, two jets, and 1 or 2 b-tags.
- Next step is 10-variable neural network.
  - Most important variable is m_{bb}.



$ZH \rightarrow \ell\ell bb$ Result

- Limit on Higgs cross section obtained from fit of entire NN histogram.



Higgs Combination

- Best limit or discovery potential for Higgs will require combining all available information from all possible Higgs channels.
- Current D0 combination includes information from 23 channels and subchannels.
  - Integrated luminosity 0.9 – 1.7 fb^{-1}.

Combination Method

- Input from each channel consists of a "final histogram" (often a NN histogram).
  - In effect, each bin of the final histogram is a separate counting experiment.
- For each bin, calculate "log-likelihood-ratio" (LLR) of Poisson probability of signal+background compared to background.

$$LLR_i = -2\log\left[P_{s+b}(n_i)/P_b(n_i)\right]$$

- Find global LLR as sum over all channels and bins.

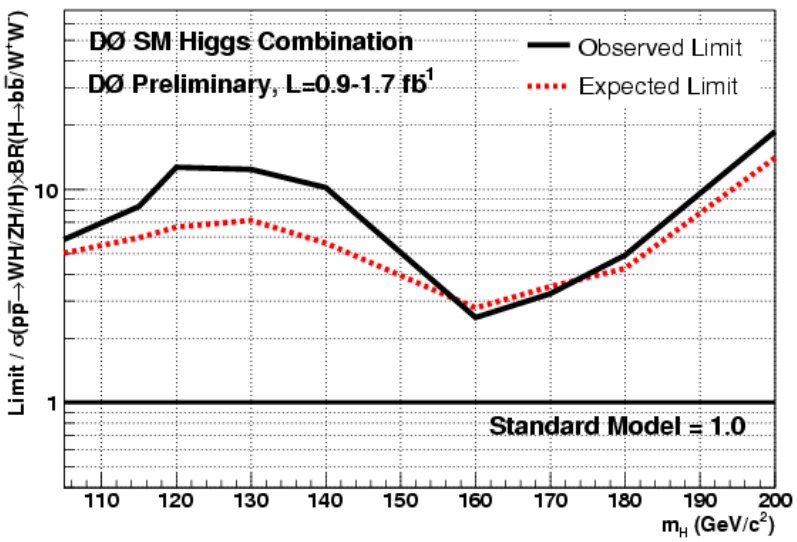
$$LLR = \sum_i LLR_i$$

CLs Method

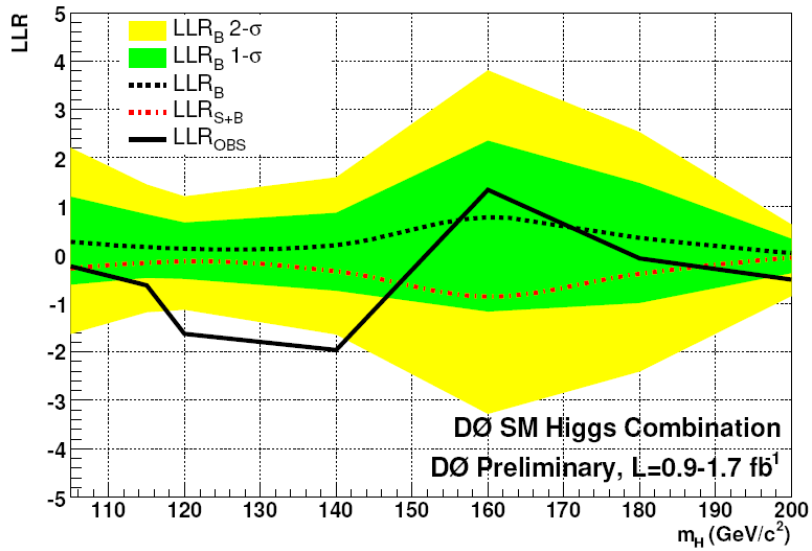
- For any given experimental outcome, calculate CL from expected LLR distribution.
  - $CL_b = P_b(LLR < LLR_{obs})$.
  - $CL_{s+b}(\sigma_H, m_H) = P_{s+b}(LLR < LLR_{obs}|\sigma_H, m_H)$.
  - P(LLR) takes into account statistical and (correlated) systematic error fluctuations.
- CLs (modified frequentist) method.
  - Define $CL_s(\sigma_H, m_H) = CL_{s+b}(\sigma_H, m_H) / CL_b$.
  - 95% CL limit obtained by requiring $CL_s > 0.05$.
- For comparison, pure frequentist result would maximize or limit CL_{s+b} only.

Higgs Combined Limit

Higgs Limit (SM ratio)



LLR Plot



Editorial Boards

- Each physics analysis is assigned to an editorial board.
- EBs review physics analyses and papers.
  - An unglamorous task that improves the quality of the final product.
- EBs chaired by FNAL scientists.
  - EB 010 (D. Lincoln)
    - Top quark pairs to all jets.
  - EB 023 / EB 028 (G. Fisk)
    - B spectroscopy.
  - EB 027 (R. Lipton)
    - B lifetimes.
  - EB 034 (D. Elvira)
    - Jet energy scale.

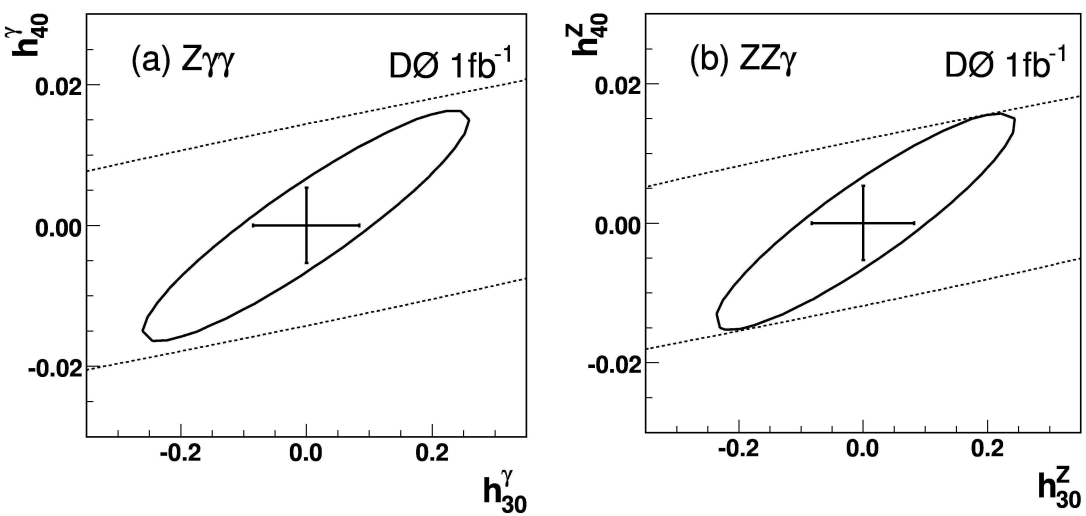
Summary

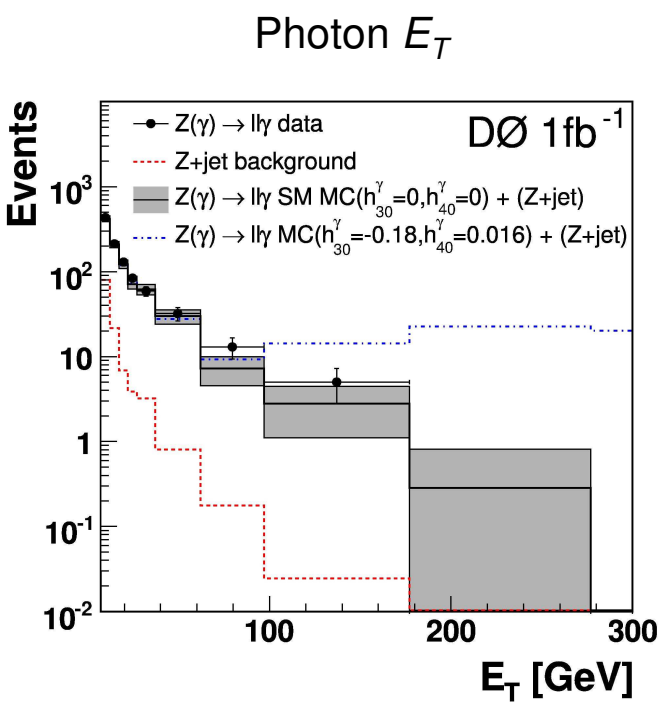
- D0 is running well and collecting data with ever higher integrated luminosity.
- Fermilab scientists play significant and leading roles in D0 physics management and individual physics topics.

Backup Slides

$Z\gamma$ Cross Section and AC

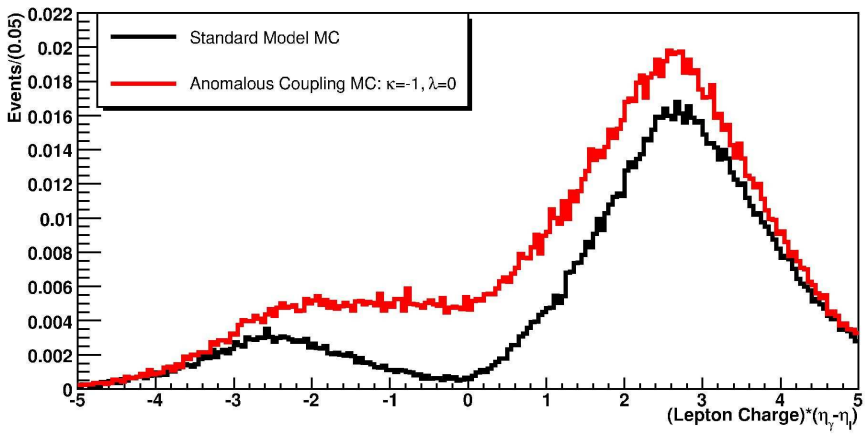
- $Z\gamma \rightarrow ee\gamma$, $\mu\mu\gamma$ ($E_{T\gamma} > 7$ GeV).
- Counting experiment (fb^{-1}).
  - $\sigma_{Z\gamma} = 4.96 \pm 0.30 \pm 0.30$ pb (SM predicts $\sigma_{Z\gamma} = 4.7$ pb).



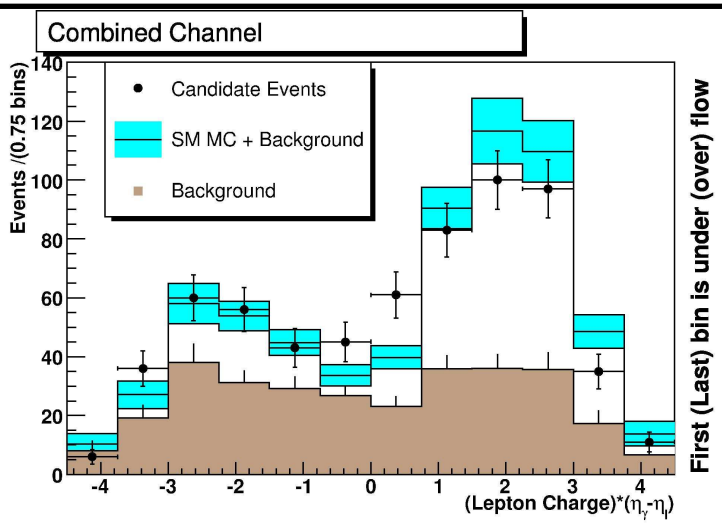


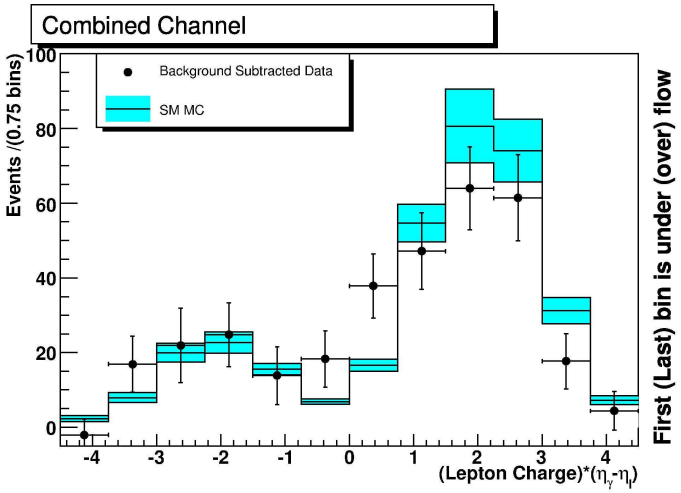
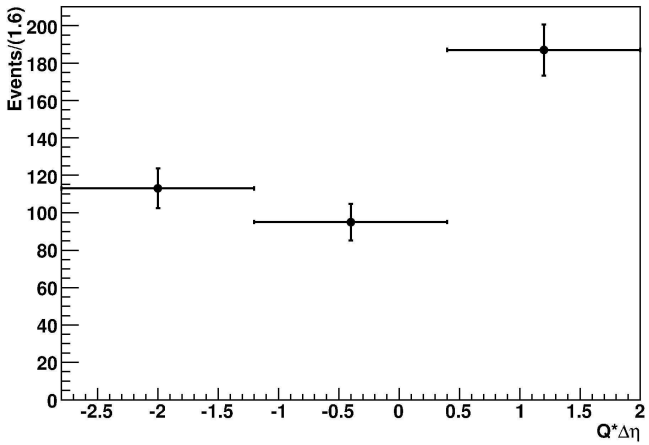
Wγ Radiation Zero

- $W\gamma \rightarrow e\nu\gamma$, $\mu\nu\gamma$.
- The Wγ differential cross section exhibits a "radiation zero" – a dip in the $\Delta\eta$ distribution between the photon and the lepton – due to interference effects.
- The radiation zero can be obscured by resolution smearing and background, as well as by anomalous couplings.



Wγ Results





- **Consistent with SM**
- **Bimodal hypothesis favored over unimodal hypothesis at 2σ level.**