DØ Results on Electroweak, Top and Higgs Physics

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For the DØ collaboration

Fermilab Users Meeting

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Outline

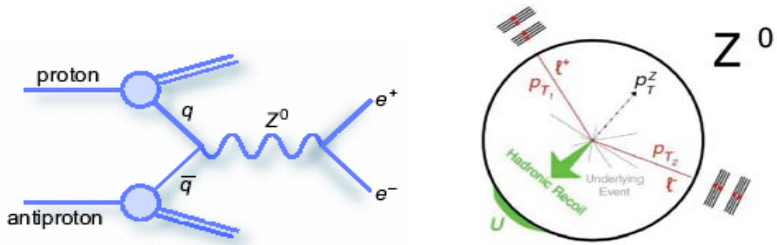
- Electroweak physics
  - W/Z inclusive production
  - Direct measurement of the W width
  - Diboson production and anomalous couplings
- Top quark physics
  - Top pair production cross section
  - Top quark mass measurement
  - W helicity measurement
  - Single top production
- Higgs searches
  - SM Higgs
  - MSSM Higgs

More results and detailed information at

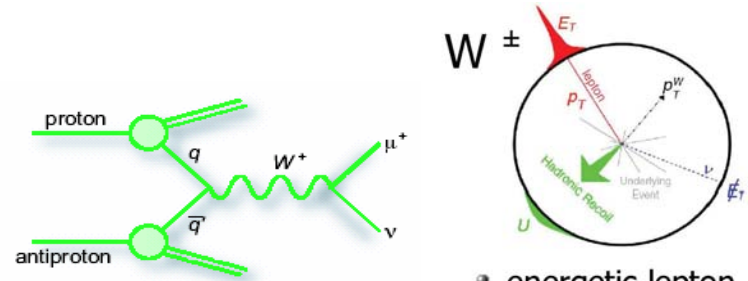
http://www-d0.fnal.gov/Run2Physics/WWW/results.htm

W and Z production cross sections: e / μ channels

- Clean, abundant and well-know signal
- Test of the Standard Model (indirect W width, lepton universality)
- Tool to calibrate the detector and study its performance



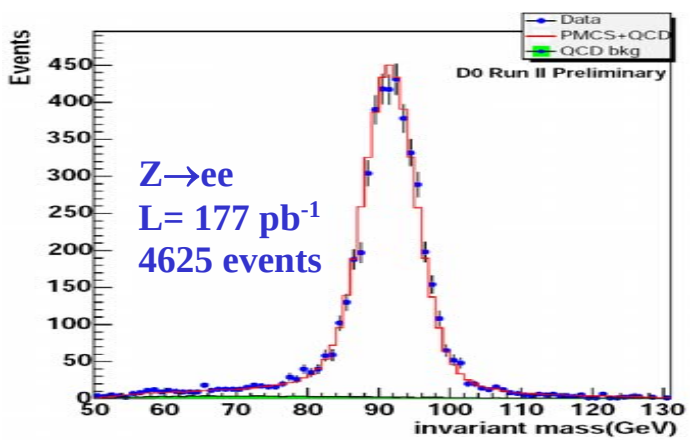
- 2 energetic leptons
- (leptons w/ opposite signs)

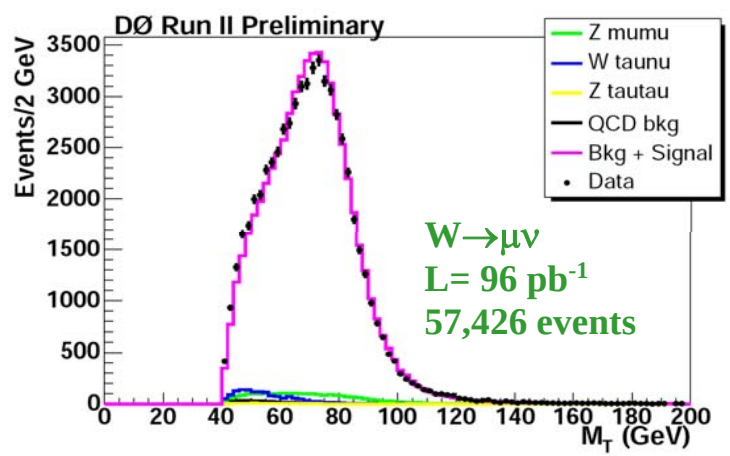


- energetic lepton
- missing E_T ("$\not{E}_T$")

Bkgd: QCD multijets, z → ττ

Bkgd: QCD multijet, W→τν, Z→ττ, Z→ee/μμ



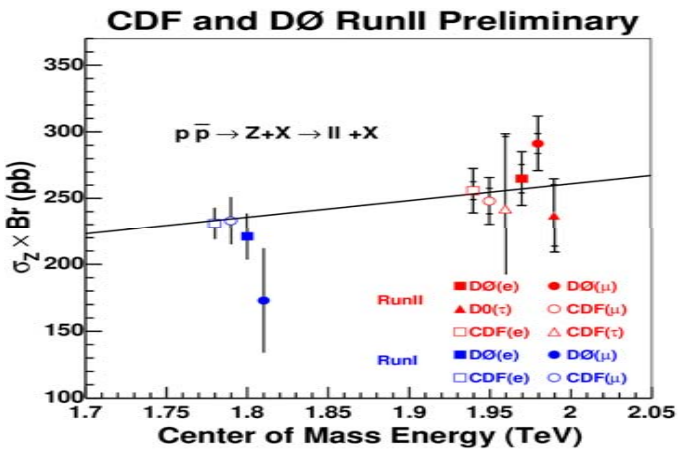


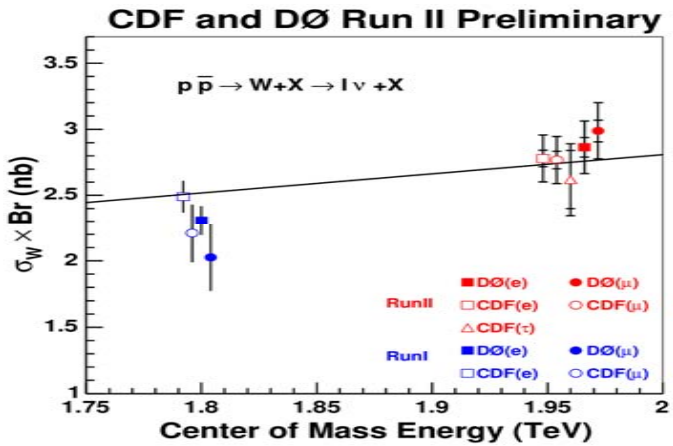
W and Z cross section summary

- **Main systematic uncertainties on cross sections:**
  - Luminosity error 6.5%
  - PDF 1- 2%
  - Lepton identification 1- 2%
  - Detector modelling ~1.5%

$\sigma \times Br(Z \to ee) = 264.9 \pm 3.9_{stat} \pm 9.9_{syst} \pm 17.2_{lumi}$ pb
$\sigma \times Br(Z \to \mu\mu) = 291.3 \pm 3.0_{stat} \pm 6.9_{syst} \pm 18.9_{lumi}$ pb

$\sigma \times Br(W \to e\nu) = 2865 \pm 8.3_{stat} \pm 76_{syst} \pm 186_{lumi}$ pb
$\sigma \times Br(W \to \mu\nu) = 2989 \pm 15_{stat} \pm 81_{syst} \pm 194_{lumi}$ pb





NNLO calculations:
C.R. Hamberg,
W.L. van Neerven
and T. Matsuura

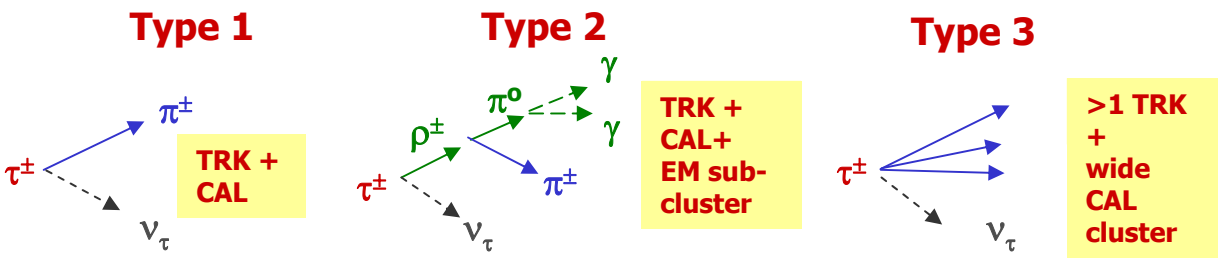
- **Cross section ratio**
  - Indirect measurement of W width

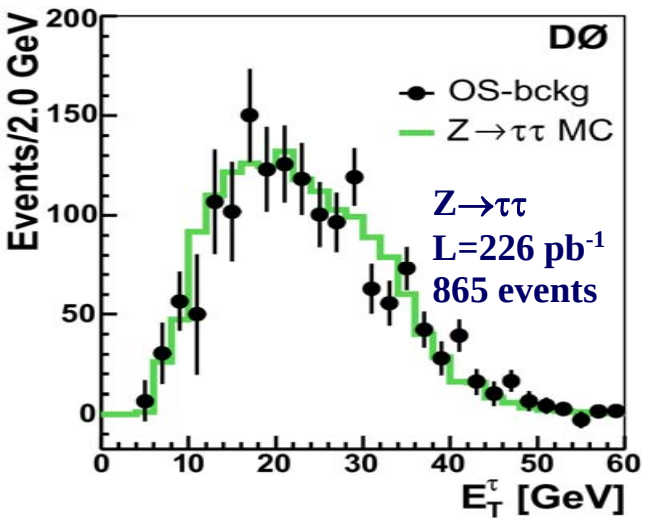
$$R(e) = \frac{\sigma(pp \to W) \times (W \to e\nu)}{\sigma(pp \to Z) \times (Z \to ee)} = 10.8 \pm 0.16_{stat} \pm 0.28_{sys}$$

$Z \to \tau\tau$ production cross section

- **Test of the Standard Model.**
- **Establishes tau identification.** Many new physics processes involving taus: Higgs, SUSY trileptons, extra gauge bosons.
- **Event selection for $Z/\gamma^* \to \tau\tau \to \mu\nu\nu$ + hadrons:**

  Isolated μ back-to-back with hadronic tau.





- **NN used for hadronic tau identification**
- **Main backgrounds:** QCD, $Z \to \mu\mu$,W/Z+jet

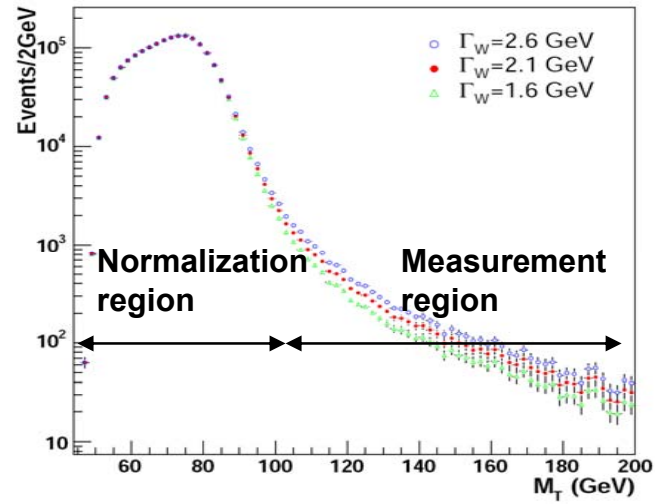
$$\sigma(pp \to Z) \cdot Br(Z \to \tau\tau) = 256 \pm 16_{stat} \pm 17_{syst} \pm 16_{lumi} \text{ pb}$$

- **First measurement at hadron colliders**
- **Hadronic tau identification efficient down to E_T<10 GeV – important for SUSY searches!**
- **Published in PRD 71, 072004 (2005)**

Direct measurement of W width

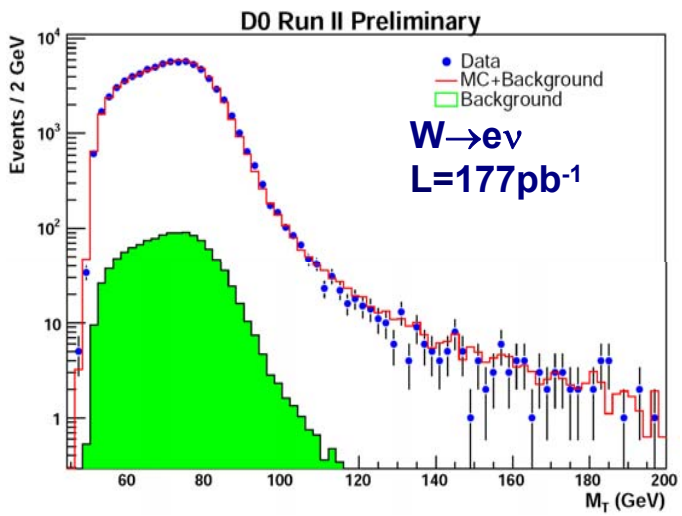
- **Test of the Standard Model.**
  $\Gamma(W)=2.090 \pm 0.008$ GeV is predicted by SM in terms of gauge boson masses and couplings

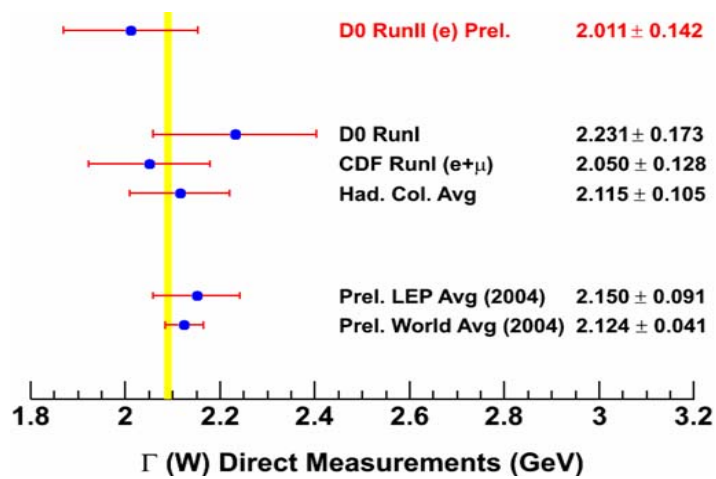
- **Method of the measurement.**
  - Normalize predicted signal+background transverse mass distributions to the data in 50-100 GeV region
  - Fit the predicted shape to the data distribution in the tail region $100 < M_T < 200$ GeV



- **Main Systematic Uncertainties:**
  - Hadronic response & resolution ~64 MeV
  - Underlying event ~47 MeV
  - EM resolution ~30 MeV

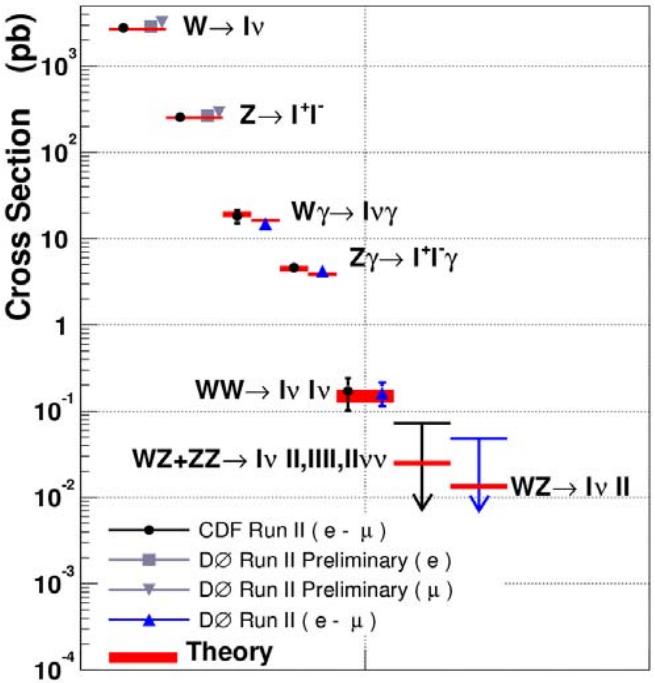
DØ Run II preliminary:
$\Gamma(W)= 2.011 \pm 0.93_{stat} \pm 0.107_{sys}$ GeV





Dibson production: Wγ, WW, WZ, Zγ

- Small production cross sections
  - 10^{-2} – 10^{-4} of single boson production σ
- Any excess above SM expectations could indicate new physics
- Measure production cross sections and test Anomalous Couplings (AC)
- Background for other processes
  - Top quark, Higgs, NP searches
- Look for final states with W,Z decaying to e or μ
  - Smaller branching ratio, but also small background



Excursions from the SM can be described via effective Lagrangian:

$$L_{WWV}/g_{WWV} = \boxed{g_V^1}(W^\dagger_{\mu\nu}W^\mu V^\nu - W^\dagger_\mu V_\nu W^{\mu\nu}) + \boxed{\kappa_V} W^\dagger_\mu W_\nu V^{\mu\nu} + \frac{\boxed{\lambda_V}}{M_W^2} W^\dagger_{\lambda\mu} W^\mu_\nu V^{\nu\lambda}$$

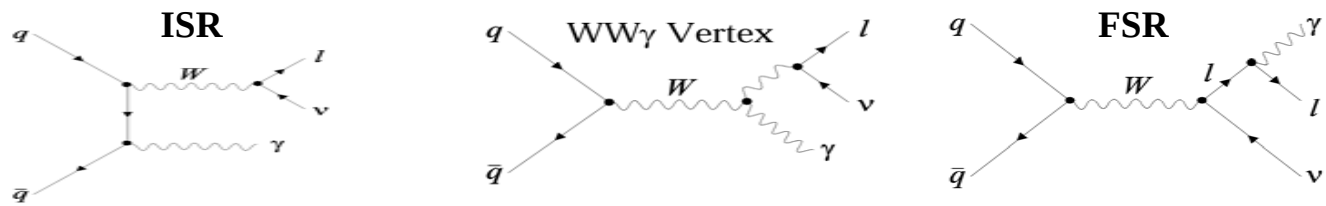
where V = Z,γ

In SM:
$g^1_V = \kappa_V = 1$, $\lambda_V = 0$

Determine deviation from SM values:
$\Delta g^1_V = g^1_V - 1$; λ_V; $\Delta\kappa_V = \kappa_V - 1$

Wγ production

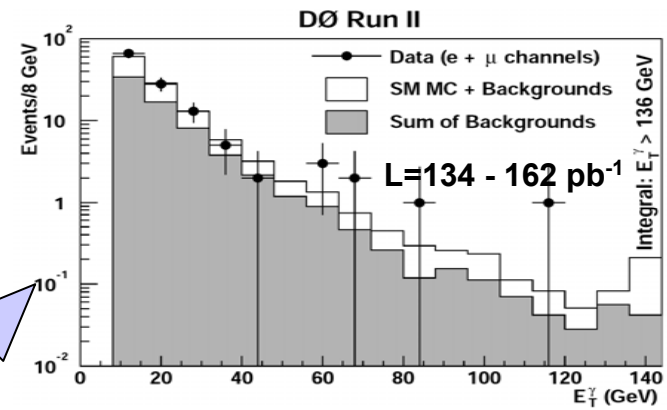
- Three diagrams contribute at LO



- Look for W decays to e or μ
- Require central photon with E_T^γ > 8 GeV and $\Delta R(l\gamma)$ > 0.7

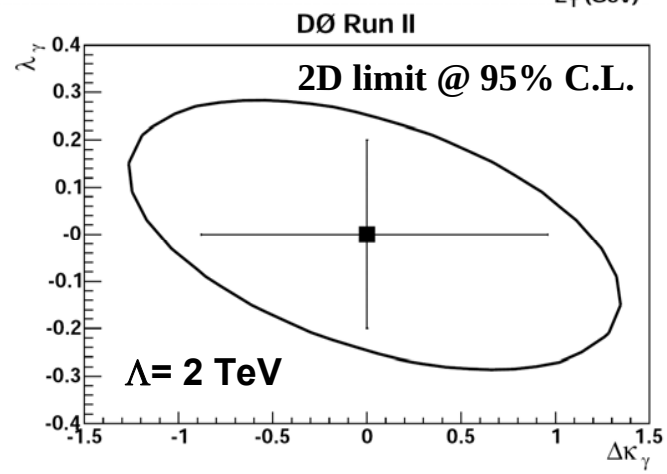
$\sigma(pp \rightarrow l\nu\gamma + X)$ = 14.8 ± 2.1 pb
SM prediction* = 16.0 ± 0.4 pb

**U. Baur and E.L. Berger*



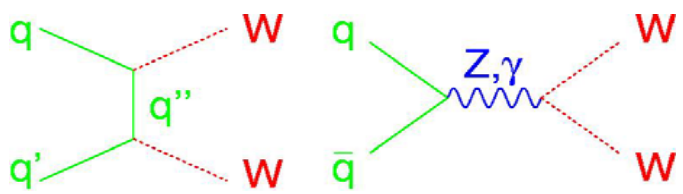
- Photon E_T^γ spectrum sensitive to the presence of anomalous coupling

1D limits at 95%C.L. for Λ= 2 TeV
$-0.88 < \Delta\kappa_\gamma < 0.96$
$-0.20 < \lambda_\gamma < 0.20$



- Improved limits compared to Run I
- Published in PRD 71, 091108 (2005)

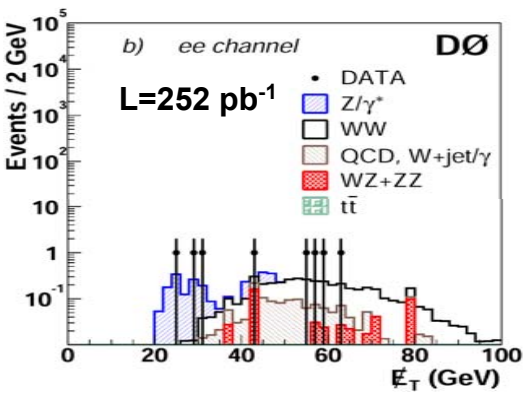
WW production

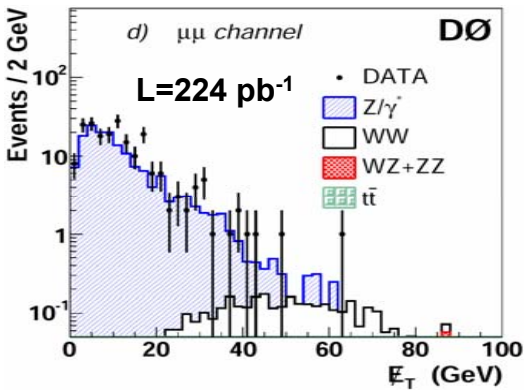


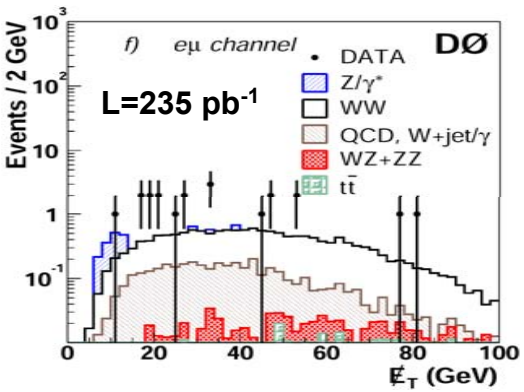
- Sensitive to WWZ /WWγ couplings
- Background to Higgs, NP searches, top pairs
- Dilepton analysis: ee, μμ, eμ –– clean, but low branching fraction
- Main Backgrounds: W+j/γ, dijet, Drell-Yan, top pairs, WZ, ZZ

$$\sigma(pp\rightarrow W^+W^-) = 13.8^{+4.3}_{-3.8}(stat)^{+1.2}_{-0.9}(sys)\pm 0.9(lum)\ pb$$

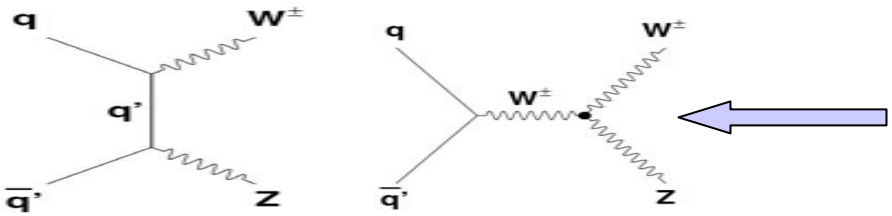
- Consistent with the theory prediction of 12.0-13.5 pb *(J. Ohnemus, J. M. Campbell, R. K. Ellis)*
- Published in PRL 94, 151801 (2005)







WZ production



- Only sensitive to WWZ coupling (WW is sensitive to WWZ and WWγ)
- WZ is unavailable at e+e- colliders

- Search for WZ to 3 leptons (eee, eeμ, eμμ, μμμ) + missing E_T
- Distinct, but rare signature: σ(pp→WZ)~4.0 pb, branching fraction ~1.5%
- Expected total bkgd of 0.71±0.08 events; 2μμμ +1eee candidates data

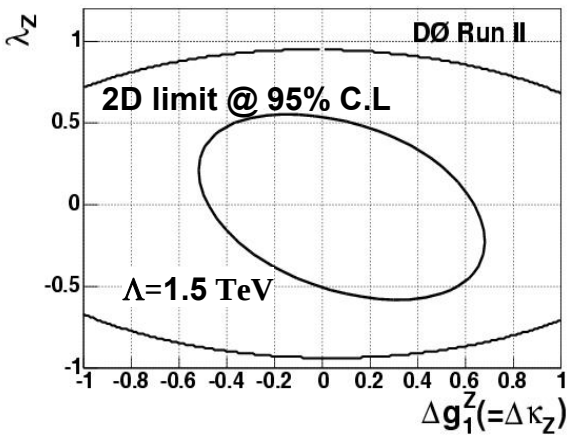
Cross section limit: σ(WZ+X) < 13.3 pb (95% C.L.)

P(0.71 bkgd)→ 3 signal events is 3.5%

Cross section $\sigma(WZ) = 4.5^{+3.8}_{-2.6}$ pb
SM prediction* = 3.7 ± 0.1 pb

**J. M. Cambell and R. K. Ellis*

L = 280-320 pb^{-1}



- Best AC limits from WZ final states
- Factor of ~2-3 improvement over DØ Run I limits
- Best limits on Δg^Z, $\Delta\kappa_Z$ and λ_Z from direct, model-independent measurements
- Submitted to PRL, hep-ex/0504019

1D limits at 95% C.L. for =1 TeV
$-0.53 < \lambda_Z < 0.56$
$-0.57 < \Delta g^Z < 0.76$
$-2.0 < \Delta\kappa_Z < 2.4$

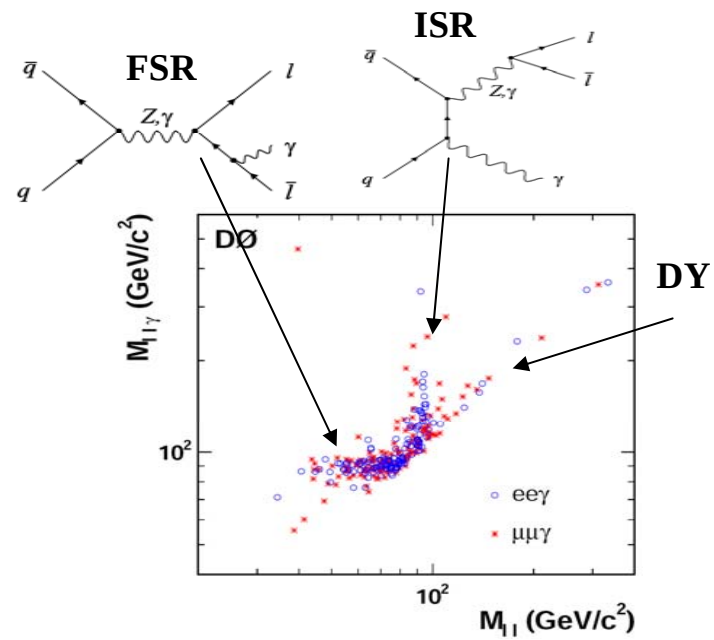
Zγ production

- ISR and FSR contributions, but no ZZγ or Zγγ vertices in SM
- Look for $Z/\gamma^* \rightarrow ee/\mu\mu$ with M(ll) > 30 GeV
- Photon: $E_T^\gamma > 8$ GeV and $\Delta R(l\gamma) > 0.7$
- Main background is Z+jet(s) production

$$\sigma(pp \rightarrow Z\gamma) = 4.2 \pm 0.4_{stat+sys} \pm 0.3_{lum}\ pb$$

$$\text{SM prediction*} = 3.9^{+0.1}_{-0.2}\ pb$$

**U. Baur, T. Han and J. Ohnemus*

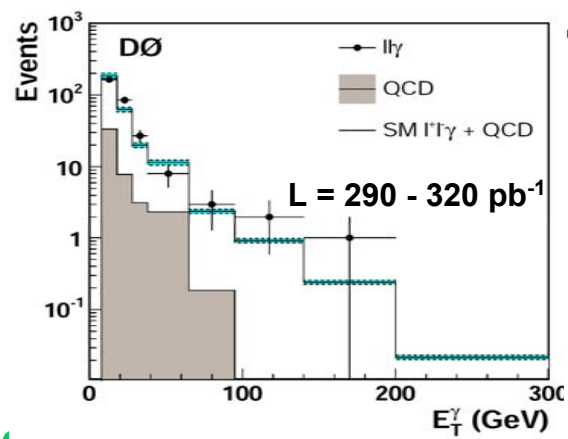


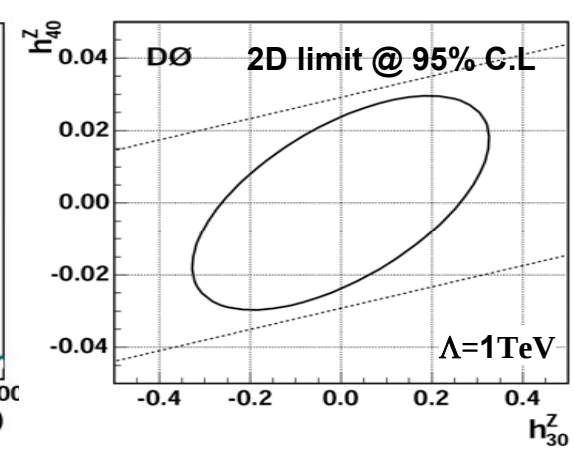
- L_{eff} has 8 coupling parameters
  - $h^V_{10}, h^V_{20}, h^V_{30}, h^V_{40}$ (V=Z,γ)
  - All = 0 in SM

1D limits at 95% C.L. for Λ=1 TeV

$|h^\gamma_{10,30}| < 0.23$, $|h^\gamma_{20,40}| < 0.019$

$|h^Z_{10,30}| < 0.23$, $|h^Z_{20,40}| < 0.020$

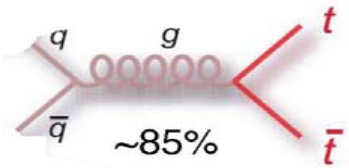




- Most stringent limits to date
- Submitted to PRL, hep-ex/0502036

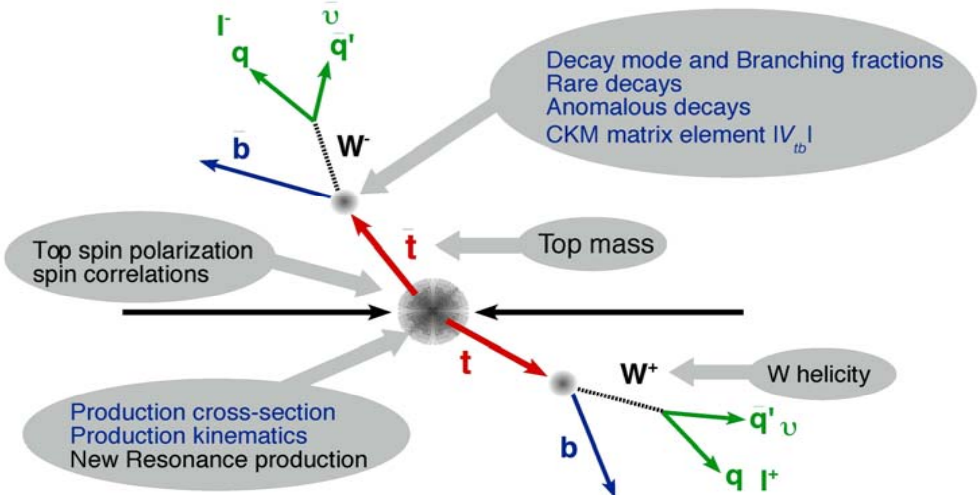
Top pair production

- Top quark has a special place in the SM and understanding it is important
  - m_{top} = 178 ± 4.3 GeV ⇒ Yukawa coupling ≈ 1
  - May play a key role in Electroweak Symmetry Breaking
- Top quarks life-time $\tau \approx 10^{-24}$ s ⇒ decays before hadronization giving opportunity to study decays of a bare quark
- In the SM m_{top} and M_W constrain M_H. Therefore precision measurement of the top quark and W boson masses provide crucial guidance for Higgs boson searches.
- Top quarks are mainly produced in pairs at Tevatron with the cross section of ~ 6.8 pb



Br(t→Wb) ≈100% ⇒
2 b quark-jets in each event

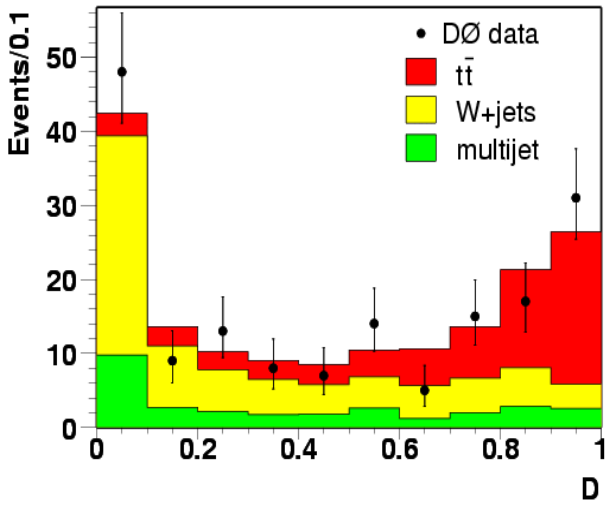
type of events:
5% in ee, eμ, μμ + 2 jets
30% in e/μ + 4 jets
44% all hadronic, 21% τ

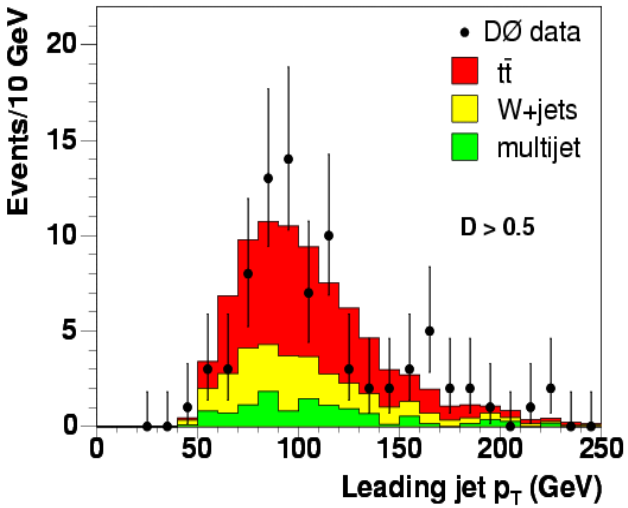


ttbar→lepton+jets cross section (topological)

- ttbar→ $W^+b+W^-\bar{b}$ → e(μ)υb+jjbbar decays give:
  a high-P_T lepton, E_T^{miss}, ≥ 4jets
- Dominant backgrounds: W+jets and QCD multijet
- Identify most sensitive topological variables for optimal cross section measurement: ttbar events are more central and spherical than background events.
- Combine selected variables in event discriminant, *D.*
- Cross section is obtained from fitting data *D* distribution to signal+background shape

L=230 pb^{-1}





Measured cross section assuming m_{top}=175 GeV

e+jets : $\sigma(\text{ttbar}) = 8.2^{+2.1}_{-1.9}(\text{stat})^{+1.9}_{-1.3}(\text{syst})\pm0.5(\text{lumi})$ pb

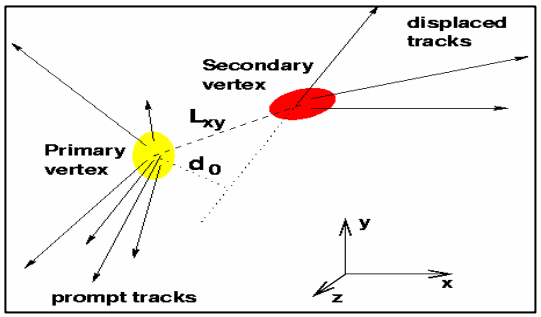
μ+jets : $\sigma(\text{ttbar}) = 5.4^{+1.8}_{-1.6}(\text{stat})^{+1.2}_{-1.0}(\text{syst})\pm0.4(\text{lumi})$ pb

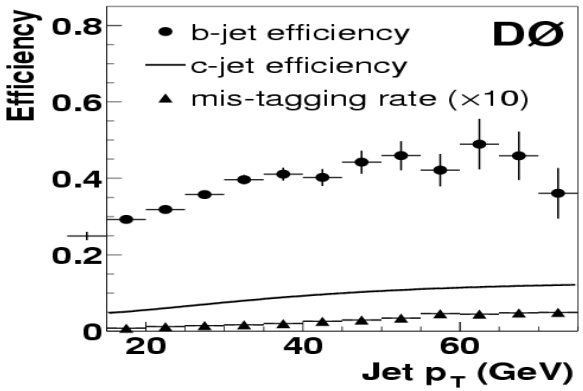
combined: $\sigma(\text{ttbar}) = 6.7^{+1.4}_{-1.3}(\text{stat})^{+1.6}_{-1.1}(\text{syst})\pm0.4$ (lumi) pb

- Measurements consistent with SM prediction
- Submitted to PLB, hep-ex/0504043

ttbar→lepton+jets cross section (lifetime tagging)

- Every ttbar event contains 2 b-quark jets
- B-hadrons travel 500 μm - several mm before decay – resolvable distance thanks to Silicon Microstrip Detector





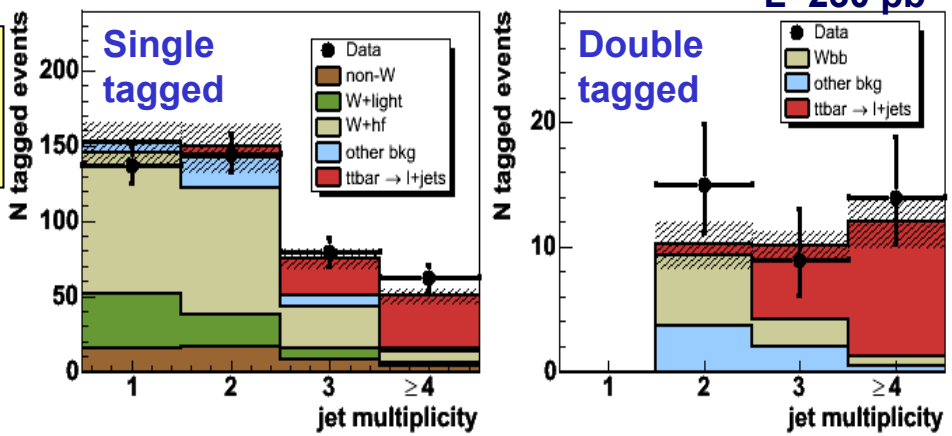
- Backgrounds: W+jets, QCD, single top, Z+jets, diboson productions
- About 60 % of signal events have at least 1 btag jet; Only ~ 5% of W+jets survives

Assuming m_{top}=175 GeV

σ(ttbar) = $8.2^{+1.6}_{-1.5}$(stat+syst) ± 0.6(lumi) pb

- Consistent with SM prediction
- Submitted to PLB, hep-ex/0504058

L=230 pb^{-1}

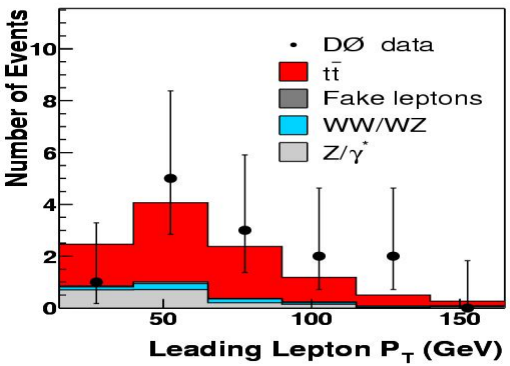


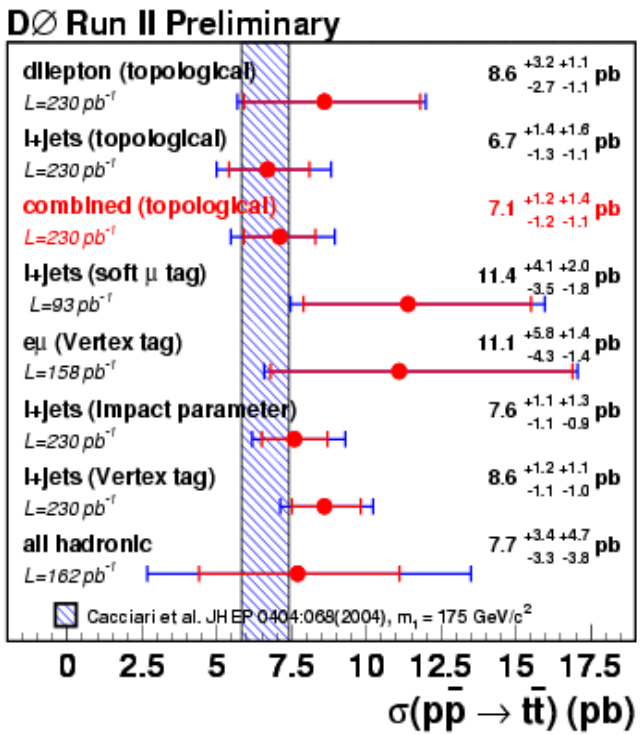
ttbar→dilepton cross section

- ttbar→ $W^+b+W^-\bar{b}$ → e(μ)υb+e(μ)υbbar decays give: 2 high-P_T leptons, E_T^{miss}, ≥ 2jets
- Backgrounds: Z→ττ, Z→ee/μμ, diboson, W/Z+jets and QCD.
- Selection cuts are optimized separately for ee, eμ and μμ final states.

L=230 pb^{-1}

	ee	eμ	μμ
bkgd	0.9	0.9	1.4
signal	1.9	5.1	1.6
data	5	8	0





Assuming m_{top}=175 GeV

$\sigma(ttbar) = 8.6^{+3.2}_{-2.7}(stat) \pm 1.1(syst) \pm 0.6(lumi)$ pb

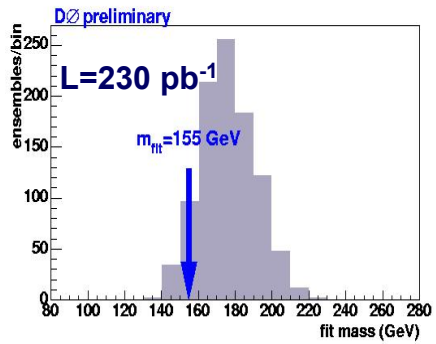
- Measurement consistent with SM prediction
- Submitted to PLB, hep-ex/0504082

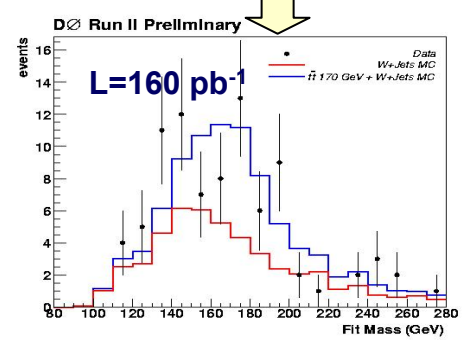
Top mass measurement

- Run I (DØ update 2004+CDF): m_{top}=178.0±4.3 GeV ⇒ Run II goal: ±2 GeV
- Currently using only 160-230 pb-1 data
- Jet energy calibration is dominant source of systematics
- Expect improvements for both, statistical and systematic errors

di-lepton final state: 13 evts, expect 3 bkgd. Weight each event vs. mass hypothesis.
$m_{top} = 155\ ^{+14}_{-13}$ (stat) ± 7(syst) GeV

lepton+jets final state; ideogram method: use all jet permutations and event likelihood discriminant for fit.
m_{top} = 177.5 ± 5.8(stat) ± 7.1(syst) GeV

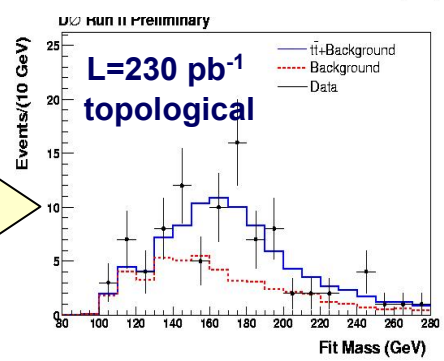


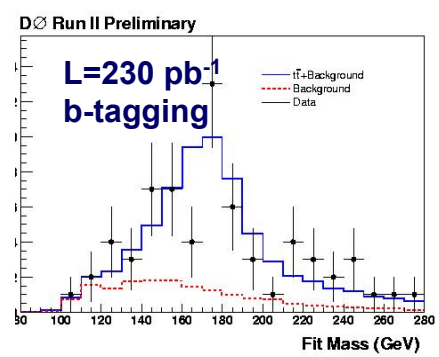


lepton+jets final state; template method: kinematic fit. Keep permutation with best χ^2; Use mass templates.

topological selection
m_{top}=169.9 ± 5.8(stat) $^{+7.8}_{-7.1}$ (syst) GeV

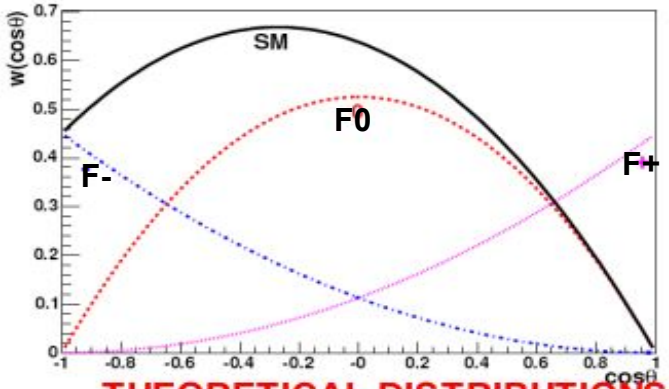
b-tagging selection
m_{top}=170.6 ± 4.2(stat) ± 6.0(syst) GeV





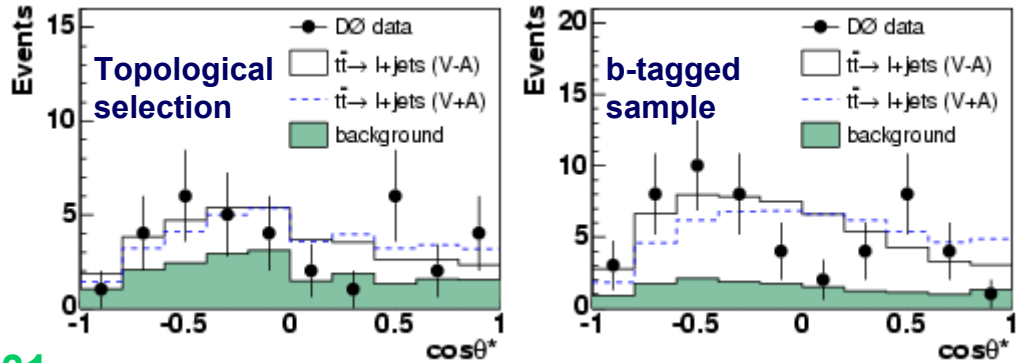
W helicity measurement in ttbar events

- SM Prediction: ~70% longitudinal, ~30% left-handed and ~3.6×10^{-2} % right handed Ws from ttbar decays
- Non-SM value would indicate
  - New physics at tWb vertex
  - Source other than ttbar contributing to signal
- W helicity determines the distribution of $\cos\theta^*$ — angle between lepton and top direction in the W rest frame
- Two independent analyses of orthogonal data sets: topological and b-tagging



THEORETICAL DISTRIBUTIONS

L=230 pb^{-1}



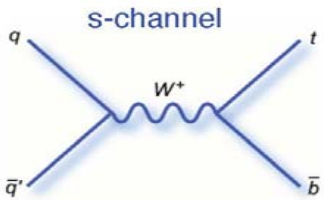
$f+ = 0.00 \pm 0.13(\text{stat}) \pm 0.07\ (\text{sys})$

$f+ < 0.25$ at 95% C.L.

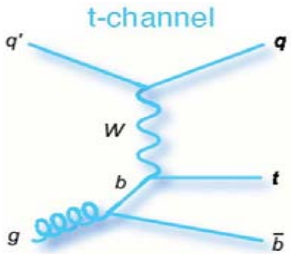
- Consistent with the SM prediction
- Submitted to PRD-RC, hep-ex/0505031

Single top production

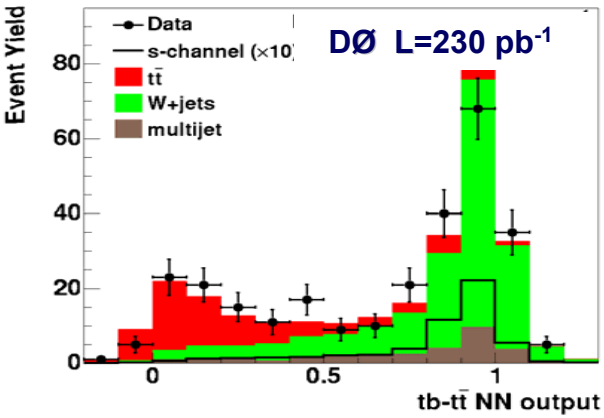
- Electroweak production of top quark ⇒ direct measurement of $|V_{tb}|$
- More difficult to detect than ttbar: smaller cross section and much larger backgrounds
- Signal topology: high-P_T isolated e/μ, E_T^{miss}, one b-jet, a ligh jet and/or another b-jet
- Four independent samples for each channel: (e,μ)x(single b-tag, double b-tag)
- Use NN for optimal signal-to-background separation

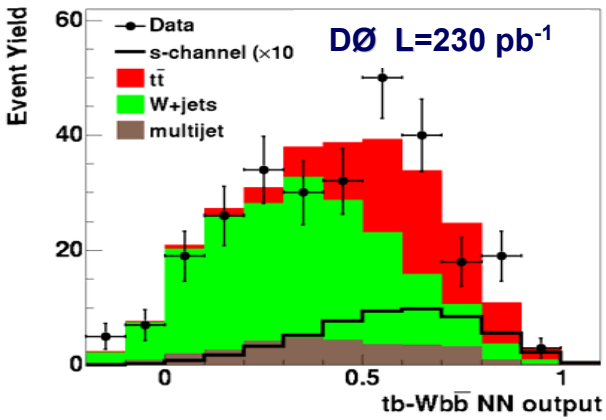


0.88 ± 0.07 pb



$0.88^{+0.23}_{-0.18}$ pb





95% C.L. upper limits on cross sections:	expected	observed
s-channel	4.5 pb	6.4 pb
t-channel	5.8 pb	5.0 pb

- Most stringent limits to date
- Submitted to PLB, hep-ex/0505063
- More data is needed for single top observation

Standard Model Higgs

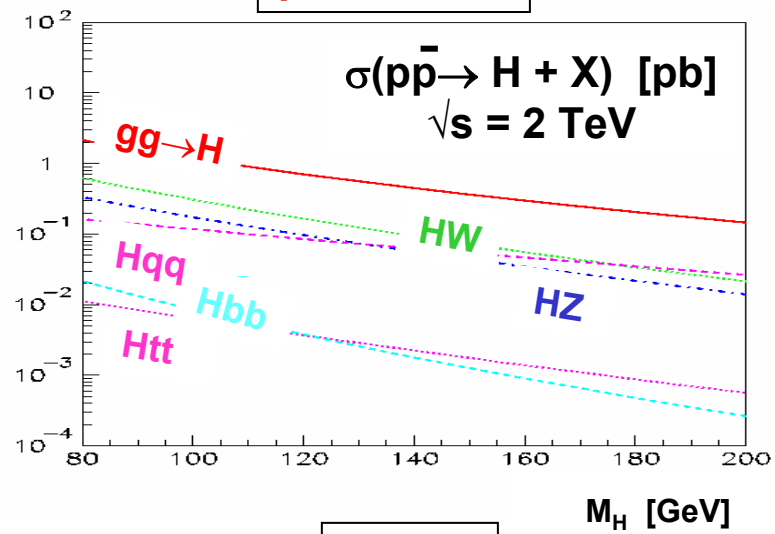
- Higgs mechanism remains most popular for Electroweak Symmetry Breaking
- Direct limit from LEP

  m_H > 114.4 GeV at 95% C.L.
- Hint (~2σ) for a Higgs around 115 GeV at LEP
- Indirect bounds from precision EW measurements combined with Fermilab's top quark mass:

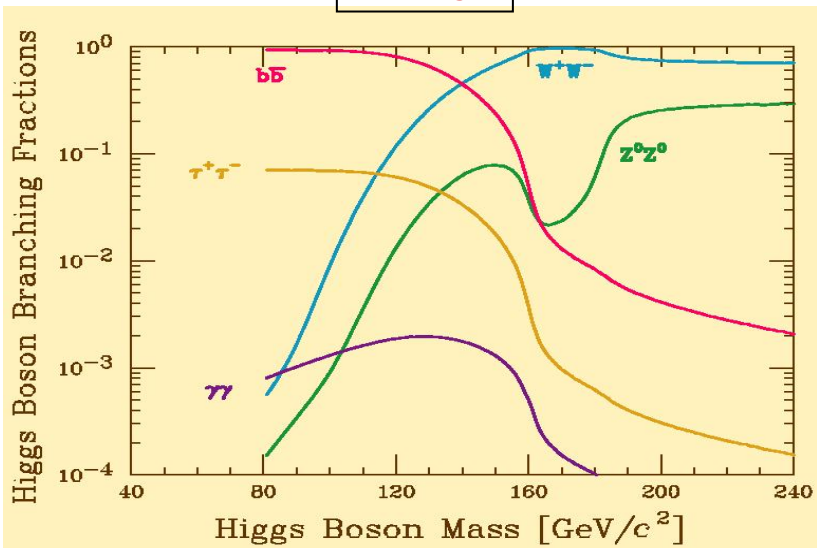
  m_H < 280 GeV at 95% C.L.

  $m_H = 126\ ^{+73}_{-48}$ GeV
- Mass range favorable for searches at Tevatron

production



decay

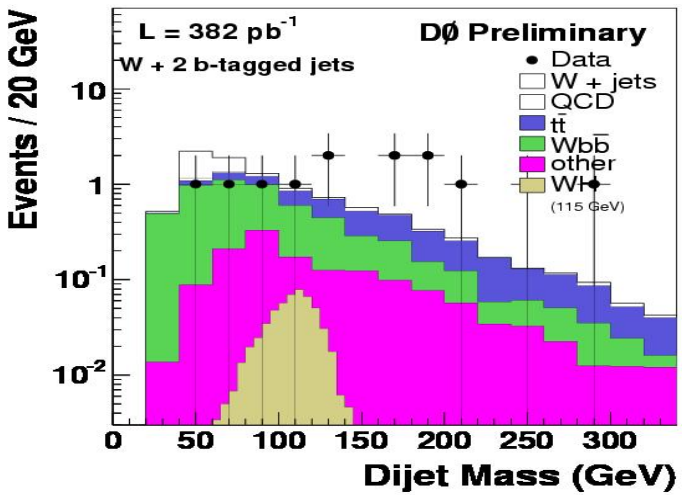


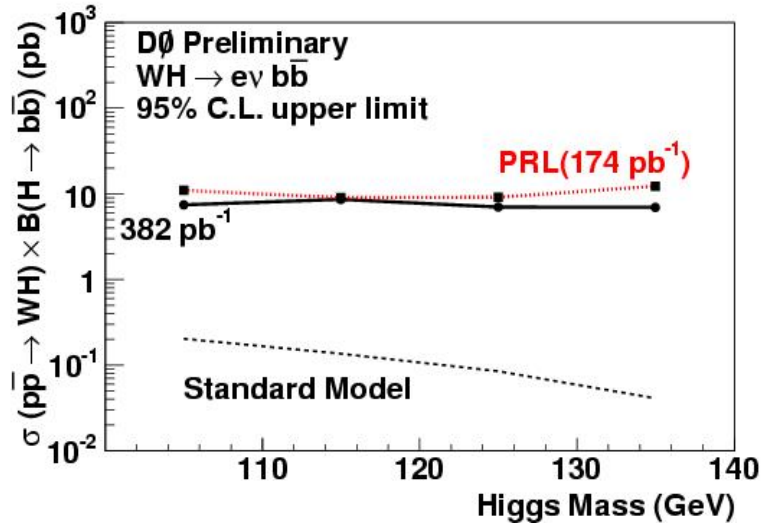
Search strategy at the Tevatron

- Low mass region, M_H <135 GeV:
  - Associated production WH and ZH with H→bb decay
  - Backgrounds: top, Wbb, Zbb…
- High mass region, M_H >135 GeV:
  - gg →H production with H→WW* decay
  - Backgrounds: electroweak WW production, W+γ/jets …

WH →eυbb searches

- WH→eυ+bbbar signal:
  - Events with high-p_T electron, E_T^{miss}, and 2 b-jets
- Start with untagged sample
  - 3844 events in data; 3817 ± 916 expected from background
  - ≥1 b-tag: 153 events observed; 154 ± 37 expected
  - ≥2 b-tag: 13 events observed; 5.7±1.5 expected





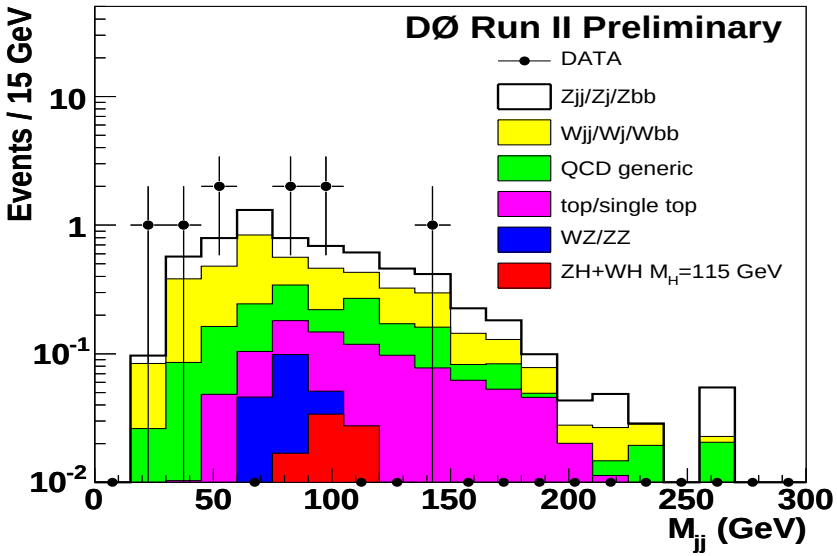
- For M_H=115 GeV Higgs, in a 85-135 GeV mass window:
  - 4 candidates, 0.12 expected Higgs signal, 2.4 bkgd.

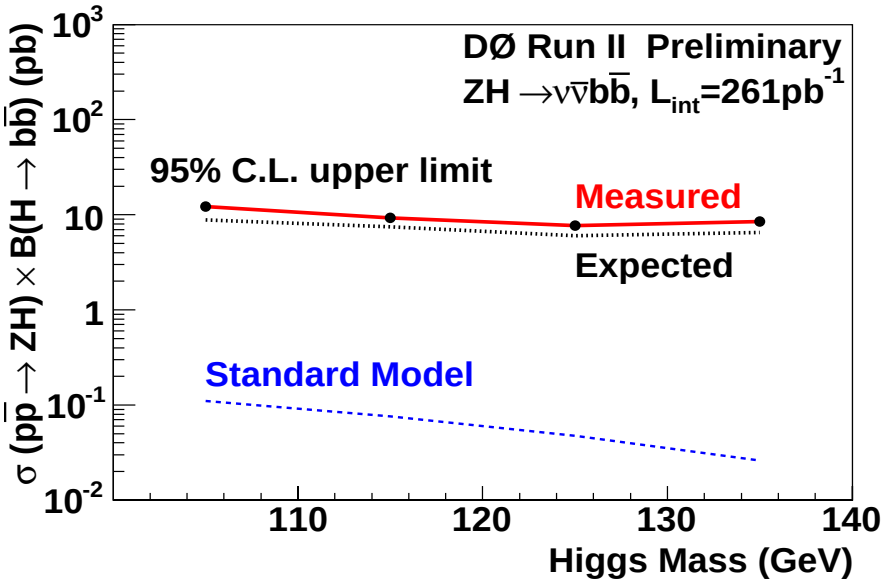
- Also derived 95% C.L. upper limit on Wbb production X-section for p_T^b > 20 GeV, $|\eta^b|$<2.5 and ΔR(bb) >0.7

  σ(Wbb)<4.6 pb
- Tighter limits compared to published Run II results

ZH→υυbb searches

- Event signature: Missing E_T and 2 acoplanar b-jets
- Background: W/Z+jets, top, WZ/ZZ, QCD multijet
- Challenging to trigger and separate from huge background
  - ➢Trigger on events with large missing H_T = vector sum of jets' E_T
  - ➢Cut on various missing energy/momentum and asymmetry variables to reject QCD



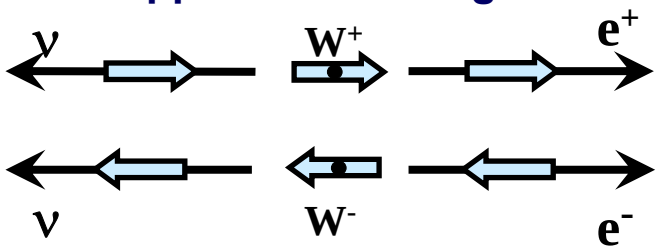


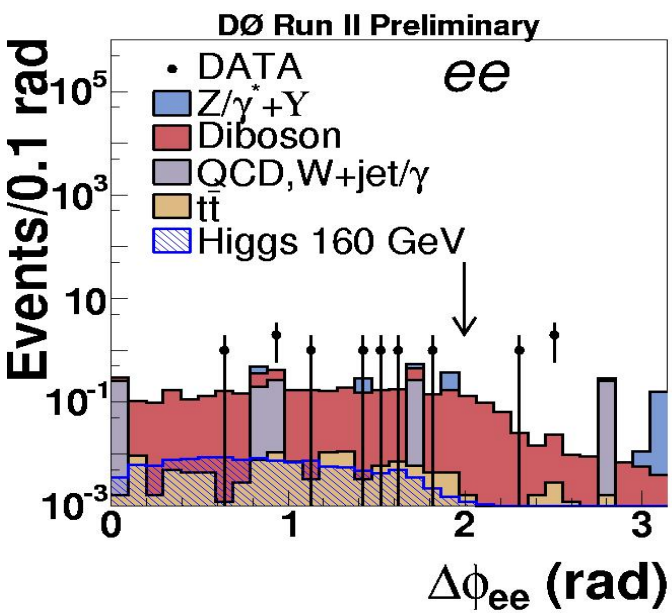
- Before tagging: 2140 events observed; 2125 expected from background
- ≥1 b-tag : 131 events observed; 145 expected
- ≥2 b-tag: 9 events observed; 6.4 expected

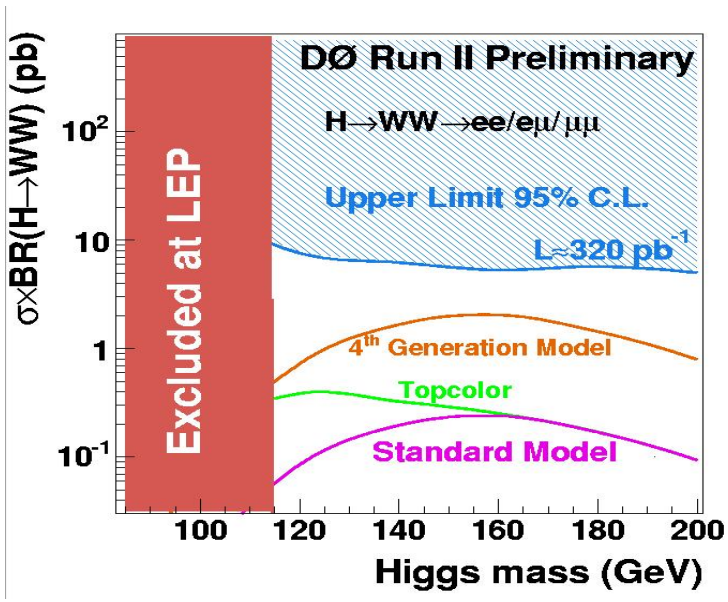
In dijet mass window around 115 GeV: 3 candidate with 2.2 bkgd.

H→WW* →lυ+lυ searches

- Event signature: two high-p_T isolated leptons (e, μ) and missing E_T
- Higgs mass reconstruction not possible due to two neutrinos
- Backgrounds: Diboson, Z/γ+Y, ttbar, QCD, W+jets/γ
- Employ spin correlations to suppress the background



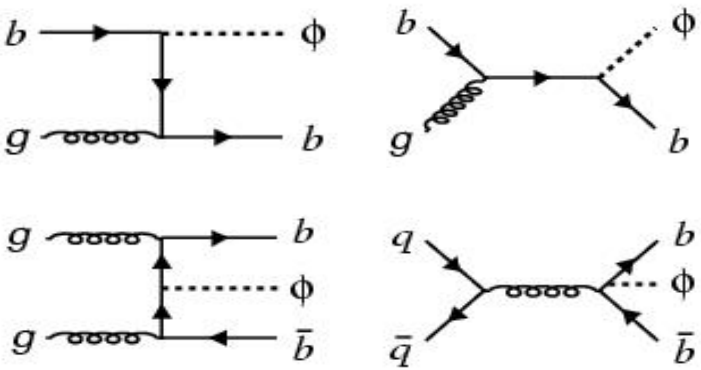




- Expected and observed number of evts. for m_H=160 GeV: 20 candidate events, 17.6 expected from background

SUSY higgs searches

- In MSSM there are two Higgs doublet fields
  - **H_u (H_d) couple to up- (down-) type fermions**
  - **The ratio of their VEV's, $\tan\beta = \langle H_u\rangle/\langle H_d\rangle$**
  - **5 Higgs particles after EWSB: h, H, A, H^+, H^-**
  - **h is expected to be light, m_h <~ 130-140 GeV**
- At large tanβ, A (h,H) coupling to b-quarks is enhanced wrt the SM
  - **At tree level production cross section increases as $\tan\beta^2$**



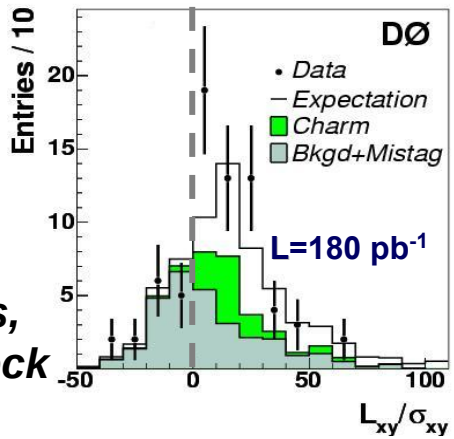
- **Multi-b-jet final states**

First study benchmark SM process
Z+b→ee/μμ+b (*PRL 94, 161801 (2005)*)

$\sigma(Z+b)/\sigma(Z+j) =$
$0.021 \pm 0.004(\text{stat})^{+0.002}_{-0.003}$

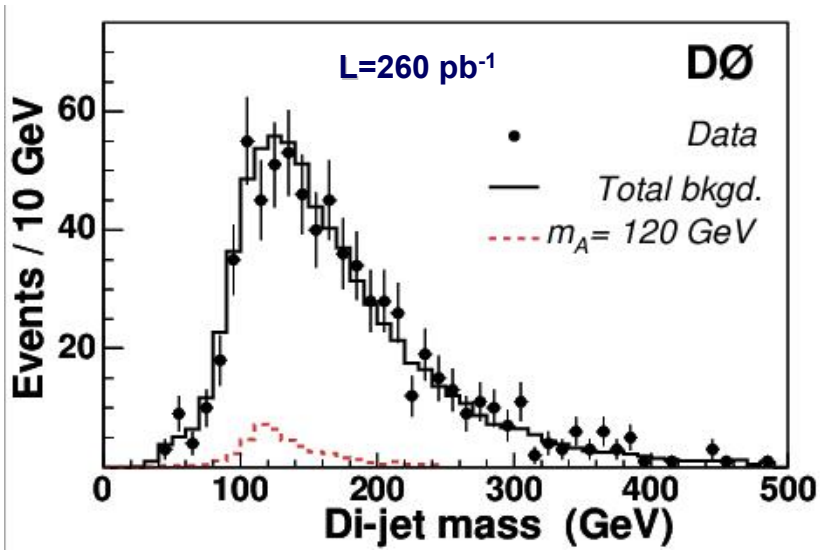
NLO prediction*
= 0.018 ± 0.004

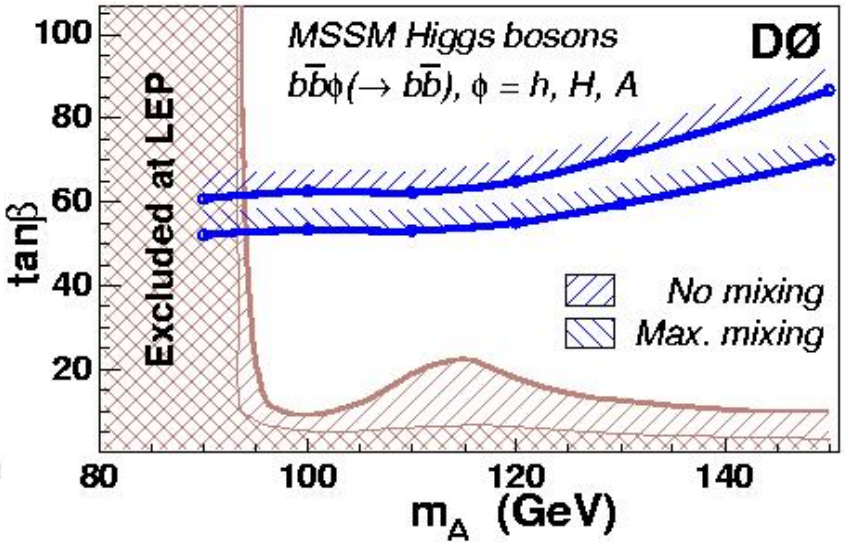
***J. Campbell, R. K. Ellis, F. Maltoni, S. Willenbrock**



SUSY higgs searches

- Use multi-jet trigger
- Offline:
  - at least 3 b-tagged jets
  - look for excess in di-jet mass
- Background, mostly QCD multi-jet, is determined from doubly b-tagged data by applying tag rate function to non-b-tagged jets



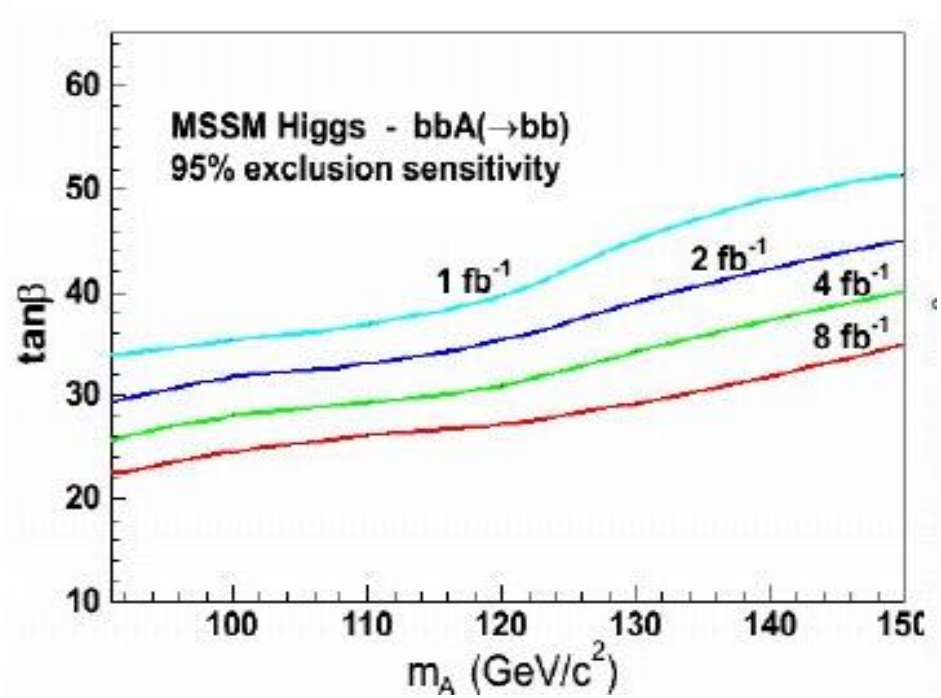


- Submitted to PRL, hep-ex/0504018

Theory input: *J. Campbell, M. Carena, S. Dawson, R. K. Ellis, C. Jackson, F. Maltoni, S. Mrenna, L. Reina, D. Wackeroth, C. E. M. Wagner, S. Willenbrock*

Tevatron prospects for SUSY higgs searches

- Expected reach at the Tevatron (CDF+DØ) based on DØ analysis and assuming similar performance at CDF.



- With 5 fb^{-1} of data can probe tanβ values down to 25-30 depending on the mass and model parameters

Summary

- Wealth of analyses with integrated luminosity of 170-320 pb^{-1}
  - 32 public results on Electroweak, Top quark and Higgs physics
- Many improved results compared to Run I
- Several "World's best" measurements/limits
- New processes not seen in Run I: $Z \rightarrow \tau\tau$, WW, WZ
- Many improvements to come
  - Better calibration and understanding of the detector
  - Better b-tagging
- $L \approx 750$ pb^{-1} physics quality data on tape; more to come
- Looking forward to a long and productive physics program