

Discovery of Single Top Quark Production at D0

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Outline

Introduction
Motivation
Tools of our Trade

Analysis Steps
Understanding the data
Event Selection
Background Modeling
Multivariate Analysis
Expected Sensitivity

Cross Sections and Significance

Direct Measurement of $|V_{tb}|$

What is the nature and origin of this universe?

How it all started and how it will end?

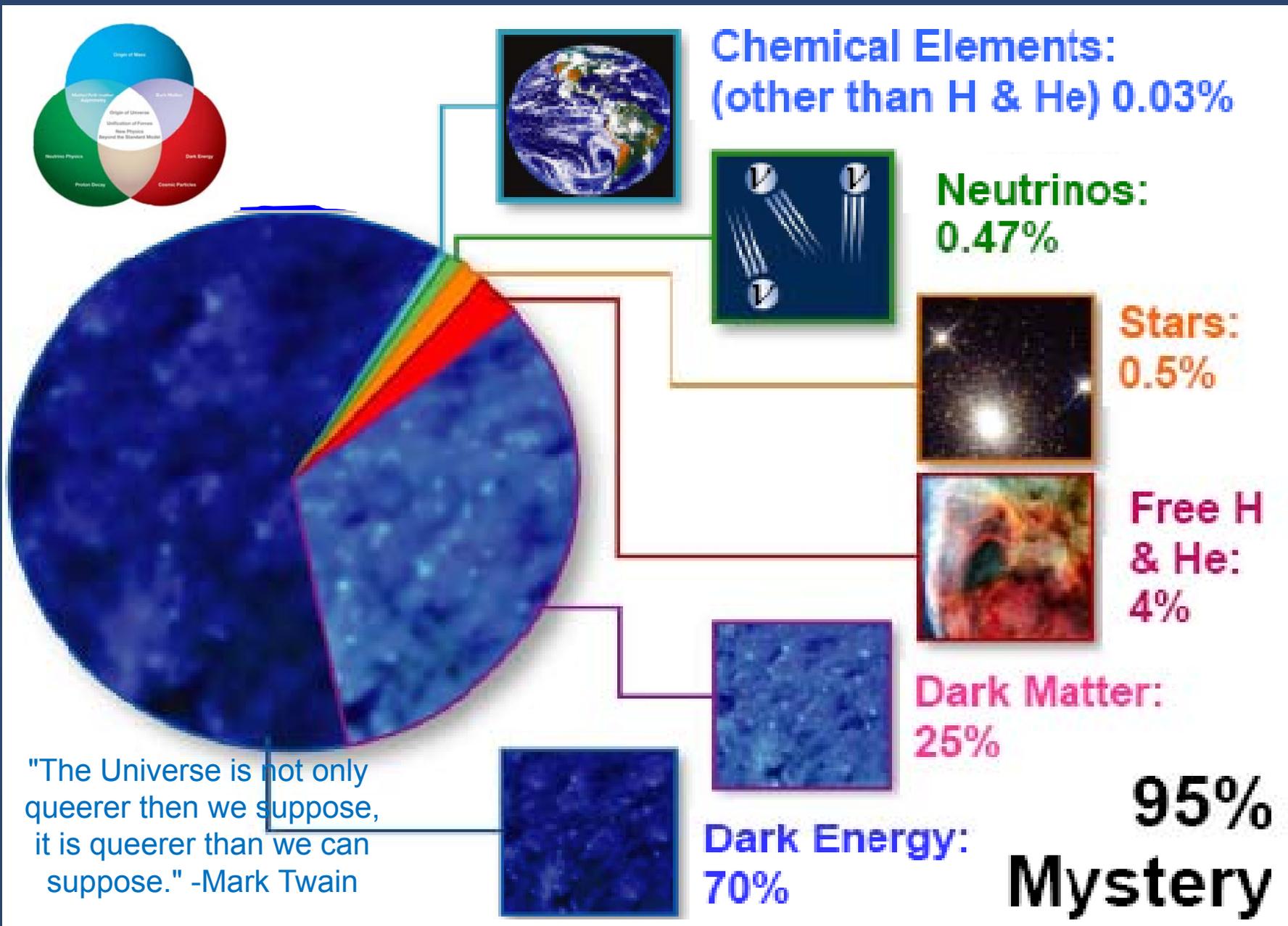
What is everything around us made of?

Where are my socks?

Does s/he like me?

.....?





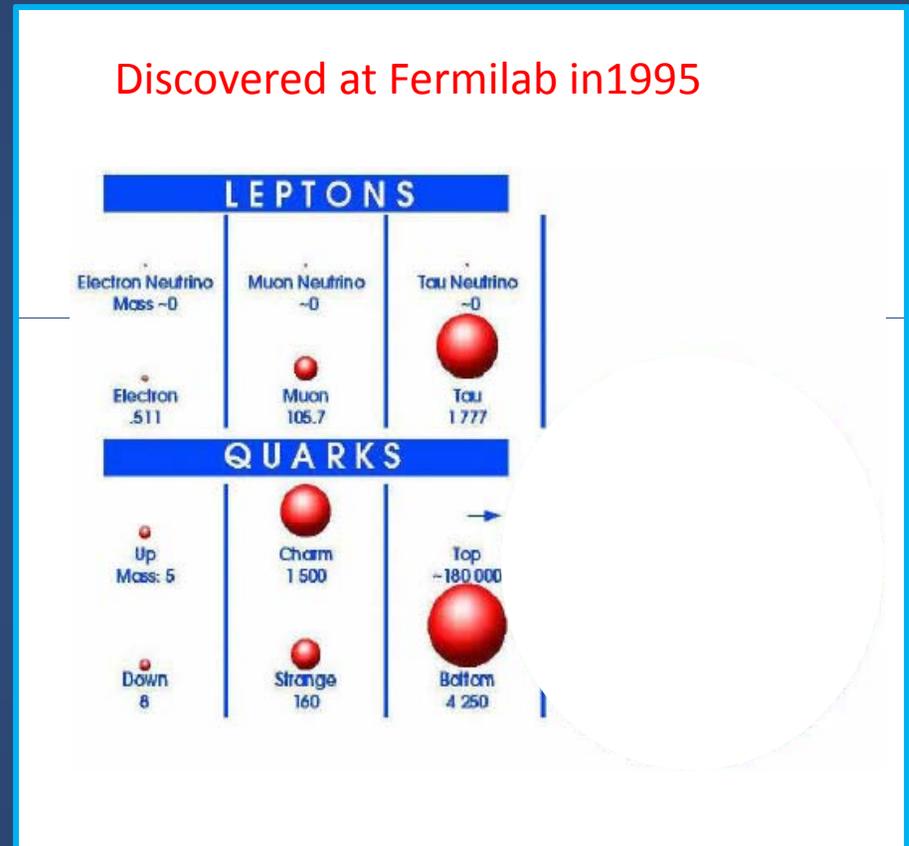


The Outstanding Questions

- What is origin of mass?
- Why the values of quark and Lepton masses so different?
- Why are there 3 generations of particles ?
(everyday matter comprises particles only from first generation)
- What about gravity?
- What is dark matter?
- What is dark energy?
- Matter antimatter asymmetry?

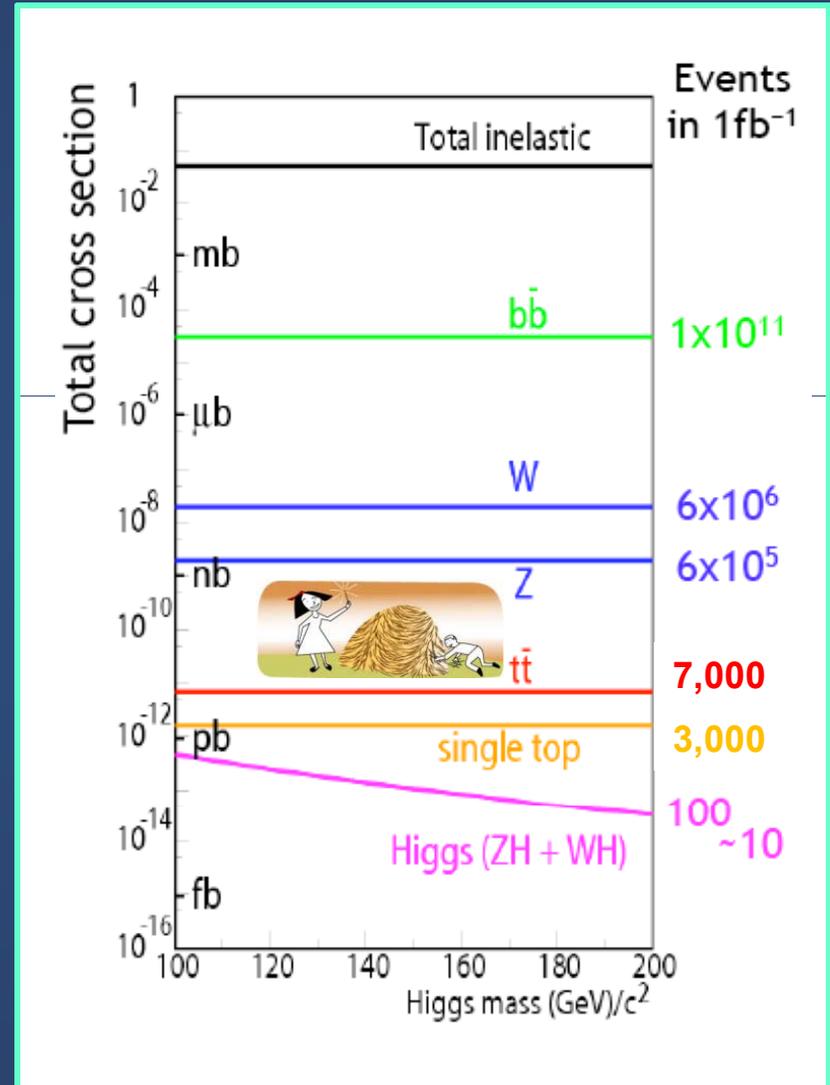
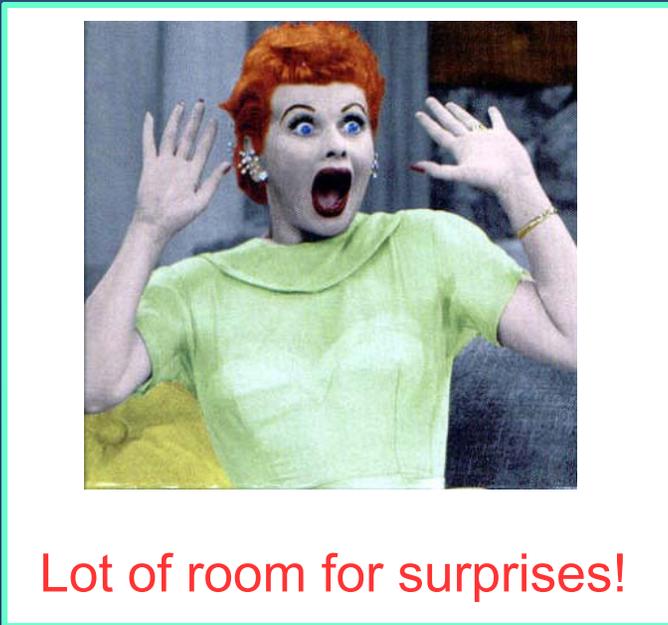
Why Look at the Top Quark

- Was discovered at Fermilab in 1995
- The heaviest known fundamental particle
 - $m_t = 172.4 \pm 1.4 \text{ GeV}$ ($\sim 1\%$ precision)
 - Close to a gold atom
 - $\tau = 5 \times 10^{-25} \text{ s} \ll \Lambda_{\text{QCD}}^{-1}$
 - Decays before hadronization
- Mass close to scale of electroweak symmetry breaking
 - Only quark for which coupling to Higgs is significant
 - May shed light on EWSB mechanism
- Top quark plays special role in many of the new physics models



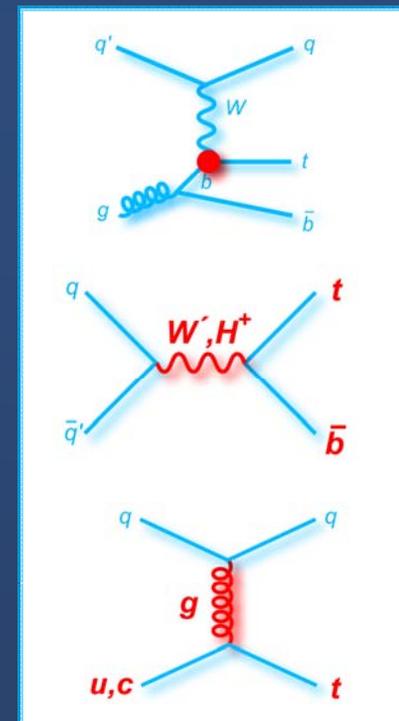
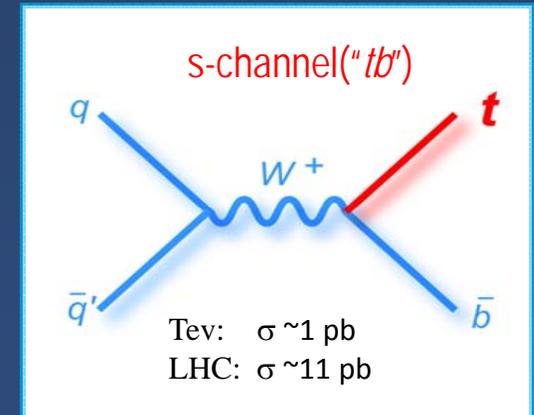
Why Keep Looking at the Top?

- Tevatron is the only place (so far) where top quarks can be produced
- Even more than a decade after its discovery, our sample consists of ~ 1000 top quark events



Why Being Single is Good?

- Study Wtb coupling in top production
 - Measure $|V_{tb}|$ directly: $\sigma \propto |V_{tb}|^2$
- Cross sections sensitive to new physics
 - s-channel: resonances (heavy W' boson, charged Higgs boson, Kaluza-Klein excited W_{KK} , technipion, etc.),
 - t-channel: flavor-changing neutral currents ($t - Z / \gamma / g - c / u$ couplings), Fourth generation of quarks
- Top properties
- Similar search for WH associated Higgs production





- **DØ**
- Search: PRD 63, 031101 (2000)
- Search: PLB 517, 282 (2001)
- Search: PLB 622, 265 (2005)
- W': PLB 641, 423 (2006)
- Search: PRD 75, 092007 (2007)
- Evidence: PRL 98, 181802 (2007)
- FCNC: PRL 99, 191802 (2007)
- W': PRL 100, 211802 (2007)
- Evidence: PRD 78, 012005 (2008)
- Wtb: PRL 101, 221801 (2008)
- Wtb: PRL 102, 092002 (2009)
- H⁺: (PRL) arXiv:0807.0859
- Observation: (PRL) arXiv:0903.0850
- CDF
- Search: PRD 65, 091102 (2002)
- W' PRL 90, 081802 (2003)
- Search: PRD 69, 052003 (2004)
- Search: PRD 71, 012005 (2005)
- Evidence: PRL 101, 252001 (2008)
- FCNC: (PRL) arXiv:0812.3400
- W': (PRL) arXiv:0902.3276
- Observation: (PRL) arXiv:0903.0885

PHYSICAL REVIEW LETTERS

EVIDENCE FOR PRODUCTION OF SINGLE TOP QUARKS AND FIRST DIRECT MEASUREMENT OF $|V_{tb}|$

V. M. Abazov,¹ B. Abbott,¹ M. Abolins,¹ B. S. Acharya,² M. Adams,³ T. Adams,³ E. Aguilo,³ S. H. Ahn,³ M. Ahsan,³ G. D. Alexeev,³ G. Alkhazov,³ A. Alton,³ G. Alvarado,³ G. A. Alves,³ M. Anastasiosse,³ L. S. Anicic,³ T. Andeen,³ S. Anderson,³ A. C. S. Assis Jesus,³ O. Azizi,³ B. Baldin,³ D. V. Bandurin,³ J. Barreto,³ J. F. Bart³ C. Belanger-Champagne,³ L. Bernzoni,³ L. Bertram,³ M. C. Bisscheri,³ I. Blackler,³ G. J. T. A. Bolton,³ E. E. Boos,³ D. Brown,³ N. J. Buchanan,³ T. H. Burnett,³ E. Busato,³ W. Carvalho,³ B. C. K. Casey,³ A. Chandra,³ F. Charles,³ E. G. B. Clement,³ C. Clément,³ B. Cox,³ S. Crépé-Blanchard,³ K. De³ P. de Jong,³ S. J. de M. D. Donato,³ R. Dentana,³ A. Dominguez,³ H. Dong,³ A. Dyshkant,³ M. Eads,³ D. DeLorenzo,³ J. Ellison,³ V. D. Elvira,³ P. Estabrook,³ S. Eraso,³ F. Ertel,³ E. Evans,³ A. Evdokimov,³ V. N. Evdokimov,³ L. Feligioni,³ A. V. Ferrer,³ T. Ferrel,³ F. Fiedler,³ F. Filthaut,³ W. Fisher,³ H. E. Fisk,³ M. Fox,³ M. Fortner,³ H. Fox,³ S. Fu,³ S. Fu,³ S. Fuster,³ T. Gafford,³ C. E. Gales,³ E. Gallas,³ E. Galyas,³ C. Garcia,³ A. Garcia-Bellido,³ V. Gavrilov,³ A. Gav³, P. Gav³, W. Geist,³ D. Gelé,³ R. Gelhaus,³ C. E. Gerber,³ Y. Gerstein,³ D. Gillberg,³ G. Gint³ D. D. Greenwood,³ E. M. Gregore,³ M. W. Griggs,³ F. Guo,³ J. C. S. Haggerty,³ J. Haley,³ I. Hall,³ R. Harrington,³ J. M. Hauptma³ J. M. Heinmiller,³ A. P. Heinson,³ U. J. D. Hobbs,³ B. Hoeneisen,³ H. Hoer³ V. Hydrus,³ I. Isayeva,³ R. Illgner,³ A. Jenkins,³ R. Jesik,³ K. Johns,³ C. S. Kahn,³ E. Kafaric,³ A. M. Kalinin,³ I. Katsanos,³ D. Kau³, R. Kaur,³ Y. M. Kharzeev,³ D. Khafizadeh,³ H. M. Kopylov,³ V. M. Korolov,³ J. Kotcheva,³ T. Kuhl,³ A. Kumar,³ S. Kuroki,³ J. Lazoforo,³ A. C. Le Bihan,³ P. Le J. Li,³ L. Li,³ Q. Z. Li,³ S. M. Lietti,³ L. Lobo,³ A. Lobodenko,³ M. Lo³ A. K. A. Maciel,³ R. J. Madarac,³ H. B. Malhotra,³ S. Malik,³ V. A. Mendes,³ L. L. Mendonça,³ P. G. Mei³ A. H. Miettinen,³ T. Millet,³ J. Mireno³ T. Moutafis,³ A. S. Muir,³ M. Mul³ M. Naranjo,³ N. A. Naurama,³ H. A. T. Nunnemann,³ V. O'Dell,³ D. C. N. Oshinwa,³ J. Osta,³ R. Orec,³ G. PRL 101, 252001 (2008) PHYSICAL REVIEW LETTERS week ending 19 DECEMBER 2008

Measurement of the Single-Top-Quark Production Cross Section at CDF

T. Aaltonen,²⁴ J. Adelman,²⁴ T. Akinos,²⁶ M. G. Albrow,²⁶ B. Alvarez Gonzalez,²⁶ S. Amerio,^{44b} D. Amidei,²⁵ A. Anastasov,²⁶ A. Anon,²⁵ J. Antos,²⁵ G. Apollinari,²⁴ A. Apresyan,²⁶ T. Ariwa,²⁶ S. Asakura,²⁶ A. Artoos,²⁶ V. Ascherman,²⁴ A. Attal,²⁴ A. Aurisano,²⁶ E. Azfar,²⁶ P. Azzurri,^{26a} W. Badger,^{1,14} A. Barbour-Galderi,²⁹ V. E. Barnes,²⁶ B. A. Barstow,^{25b} V. Barshch,²⁶ G. Bauer,²⁶ D. H. Beauchemin,²⁶ B. Bedeschi,²⁴ P. Bednarz,²⁴ D. Beecher,²⁴ S. Behari,²⁴ G. Bellefleur,²⁴ J. Bellinger,²⁶ D. Benjamin,²⁴ A. Benvenuti,²⁴ J. Bengtsson,²⁴ A. Bhatti,²⁴ M. Binkley,²⁴ D. Birkel,²⁴ M. Bishara,²⁴ J. Black²⁴ R. E. Blair,²⁴ C. Blocker,²⁴ B. Blumenfeld,²⁴ A. Bocci,²⁴ A. Bodek,²⁴ V. Boisvert,²⁴ G. Bokil,²⁴ D. Borah,²⁴ J. Boudreau,²⁴ A. Bovea,²⁴ B. Buan,²⁴ A. Bridgeman,²⁴ L. Brigakori,²⁴ C. Bromberg,²⁴ E. Brubaker,²⁴ J. Budgoy,²⁴ H. S. Budd,²⁴ S. Budd,²⁴ K. Burkert,²⁴ G. Busato,²⁴ P. Bussey,²⁴ A. Buzati,²⁴ K. L. Byrum,²⁴ S. Cabrera,²⁴ C. Calancha,²⁴ M. Campanelli,²⁴ M. Campbell,²⁴ P. Canelli,²⁴ A. Caporini,²⁴ D. Caronni,²⁴ R. Casas,²⁴ S. Carrillo,²⁴ S. Carson,²⁴ R. Casal,²⁴ M. Casarsa,²⁴ A. Castro,²⁴ P. Catastini,²⁴ A. Castro,²⁴ V. Cavaliere,²⁴ M. Cavaliere,²⁴ M. Cavaliere,²⁴ A. Cerri,²⁴ T. Cerrito,²⁴ S. H. Chang,²⁴ Y. C. Chen,²⁴ M. Chertok,²⁴ G. Chiarelli,²⁴ G. Chlachidze,²⁴ F. Chlebana,²⁴ K. Cho,²⁴ D. Chokheli,²⁴ J. P. Chou,²⁴ G. Choudhury,²⁴ S. H. Chung,²⁴ K. Chung,²⁴ W. H. Chung,²⁴ Y. S. Chung,²⁴ C. I. Ochoa,²⁴ M. A. Chiofalo,²⁴ A. Chiofalo,²⁴ D. Clark,²⁴ G. Compostelli,²⁴ M. E. Conroy,²⁴ J. Conway,²⁴ K. Copp,²⁴ M. Cordelli,²⁴ G. Cortina,²⁴ J. Cou²⁴, F. Crescoli,²⁴ C. Cuenca Almenar,²⁴ J. Cuevas,²⁴ G. De Lorenzo,²⁴ M. Dell'Orto,²⁴ C. Deluca,²⁴ L. Demortier,²⁴ J. Deng,²⁴ M. D'Onofrio,²⁴ P. F. Drell,²⁴ G. P. Di Girolamo,²⁴ C. Dionisi,²⁴ B. Di Ruzza,²⁴ J. R. Dittmann,²⁴ M. D'Onofrio,²⁴ S. Dori,²⁴ P. Dong,²⁴ J. Doroshenko,²⁴ T. Dorigo,²⁴ S. Dube,²⁴ J. Efron,²⁴ A. Ehsan,²⁴ R. Ehrlich,²⁴ D. Erdre,²⁴ S. Errede,²⁴ R. Eusebi,²⁴ H. C. Fung,²⁴ S. Farrington,²⁴ W. T. Fedorko,²⁴ R. G. Feitel,²⁴ M. Feindt,²⁴ J. P. Fernandez,²⁴ C. Ferraz,²⁴ F. Ferrel,²⁴ G. Flanagan,²⁴ M. Flores,²⁴ M. Franklin,²⁴ J. C. Freeman,²⁴ J. Feng,²⁴ M. Gallinaro,²⁴ J. Galyati,²⁴ F. Garberoa,²⁴ J. E. Garcia,²⁴ A. F. Garfinkel,²⁴ K. Gemert,²⁴ H. Gerberich,²⁴ S. Gerdes,²⁴ S. Ghosh,²⁴ V. Giakomopoulos,²⁴ P. Giaretta,²⁴ K. Gibson,²⁴ J. L. Gimpl,²⁴ C. M. Gibson,²⁴ N. Gokhale,²⁴ M. Goussard,²⁴ P. Goussard,²⁴ M. Goussard,²⁴ G. Grigori,²⁴ V. Grigoriev,²⁴ D. Greljo,²⁴ N. Grolms,²⁴ A. Grodzinski,²⁴ A. Grodzinski,²⁴ G. Grunert,²⁴ G. Grunert-Cobalza,²⁴ M. Groncharov,²⁴ O. Gronka,²⁴ A. T. Goshaw,²⁴ K. Goulianos,²⁴ A. Gressler,²⁴ S. Grinstein,²⁴ C. Grosso-Filcher,²⁴ R. C. Group,²⁴ U. Grunthal,²⁴ J. Guimaraes da Costa,²⁴ Z. Gunay-Unalan,²⁴ C. Haber,²⁴ K. Hahn,²⁴ S. R. Hahn,²⁴ E. Haffner,²⁴ B. Y. Han,²⁴ J. Y. Han,²⁴ R. Handberg,²⁴ P. Hapanis,²⁴ K. Han,²⁴ D. Han,²⁴ M. Han,²⁴ S. Harnik,²⁴ R. Harland-ang,²⁴ M. Hart,²⁴ K. Hatakeyama,²⁴ J. Hauser,²⁴ C. Hays,²⁴ M. Heck,²⁴ A. Heijboer,²⁴ B. Heinemann,²⁴ J. Heinrich,²⁴ C. Henderson,²⁴ M. Hendon,²⁴ J. Heuser,²⁴ S. Hewamanage,²⁴ D. Hidas,²⁴ C. S. Hill,²⁴ D. Hirschbuhl,²⁴ A. Hocker,²⁴ S. Hou,²⁴ M. Houlikin,²⁴ S. C. Hsu,²⁴ B. T. Huffman,²⁴ R. E. Hughes,²⁴ U. Huisman,²⁴ J. Huston,²⁴ J. Incandella,²⁴ G. Inzani,²⁴ M. Iori,²⁴ B. Jayatilaka,²⁴ E. Jans,²⁴ B. Jayatilaka,²⁴ E. J. Jeon,²⁴ M. K. Jha,²⁴ S. Jindariani,²⁴ W. Johnson,²⁴ M. Jones,²⁴ K. K. Joo,²⁴ S. Y. Jun,²⁴ J. E. Jung,²⁴ T. R. Junk,²⁴ T. Kamon,²⁴ D. Kar,²⁴ P. E. Karch,²⁴ Y. Kato,²⁴ K. Keightley,²⁴ J. Keung,²⁴ V. Khachatryan,²⁴ B. Kilminster,²⁴ H. Kim,²⁴ H. S. Kim,²⁴ J. E. Kim,²⁴ M. J. Kim,²⁴ S. B. Kim,²⁴ S. H. Kim,²⁴ K. Kim,²⁴ N. Kimura,²⁴ L. Kiran,²⁴ S. Kimura,²⁴ R. Kinnison,²⁴ B. R. Ko,²⁴ S. A. Koop,²⁴ K. Korol,²⁴ D. J. Korylov,²⁴ J. Korytov,²⁴ A. Korytov,²⁴ A. Krasna,²⁴ M. Kratochvil,²⁴ D. Kravitz,²⁴ R. Krauss,²⁴ M. Kruse,²⁴ V. Krut'kov,²⁴ T. Kuba,²⁴ T. Kuri,²⁴ N. P. Kulkarni,²⁴ M. Kurata,²⁴ Y. Kuwahara,²⁴ S. Kwang,²⁴ A. T. Laasanen,²⁴ S. Lami,²⁴ S. Lamm,²⁴ M. Lancaster,²⁴ R. L. Lande,²⁴ K. Lannon,²⁴ A. Latt,²⁴ G. Latta,²⁴ I. Lazzarini,²⁴ T. LeCompte,²⁴ E. LeCompte,²⁴ H. Lee,²⁴ S. Lee,²⁴ D. Lewis,²⁴ S. Lewis,²⁴ C. S. Lin,²⁴ P. J. Linde,²⁴ M. Lindgren,²⁴ E. Lipeles,²⁴ T. M. Liss,²⁴ A. Lister,²⁴ D. O. Litvinov,²⁴ C. Liu,²⁴ T. Liu,²⁴ N. S. Lockyer,²⁴ A. Logothetis,²⁴ M. Loreti,²⁴ L. Lovas,²⁴ R. S. Lu,²⁴ D. Lucchesi,²⁴ J. Lueck,²⁴ C. Luci,²⁴ P. Lujan,²⁴ P. Lukens,²⁴ G. Lungu,²⁴ I. Lyons,²⁴ J. Lyons,²⁴ R. Lykken,²⁴ E. Lyken,²⁴ P. Mack,²⁴ D. MacQueen,²⁴ R. Madrak,²⁴ K. M. Madsen,²⁴ K. Mahdoul,²⁴ T. Malik,²⁴ P. Malinin,²⁴ S. Malhotra,²⁴ S. Malik,²⁴ G. Manca,²⁴ A. Manousiouthakis,²⁴ F. Margaritis,²⁴ C. Marino,²⁴ C. P. Marino,²⁴ A. Martin,²⁴ V. Martin,²⁴ M. Martinez,²⁴ R. Martinez-Ballarín,²⁴ T. Maruyama,²⁴ P. Mavrounas,²⁴ T. Maue,²⁴ M. E. Mattson,²⁴ P. Mazzanti,²⁴ K. S. McFarland,²⁴ P. McIntyre,²⁴ R. McNulty,²⁴ A. Mehta,²⁴ P. Mehta,²⁴ A. Meunier,²⁴ P. Merkt,²⁴ C. Merino,²⁴ T. Miao,²⁴ N. Mikhaylov,²⁴ R. Miller,²⁴ C. Mills,²⁴ M. Mirza,²⁴ A. Mitra,²⁴ G. Mittlefelder,²⁴ H. Miyake,²⁴ M. Moggi,²⁴ C. S. Moon,²⁴ R. Moore,²⁴ M. J. Morello,²⁴ P. Morlok,²⁴ P. Movic,²⁴ P. Movic,²⁴ J. Milentovic,²⁴ A. Mukherjee,²⁴ T. Muller,²⁴ R. Munford,²⁴ P. Murri,²⁴ M. Musini,²⁴ Y. Nagai,²⁴ A. Nagano,²⁴ J. Nagano,²⁴ K. Nakamura,²⁴ I. Nakano,²⁴ 00319007/08/10/25/252001(8) 252001:1 © 2008 The American Physical Society



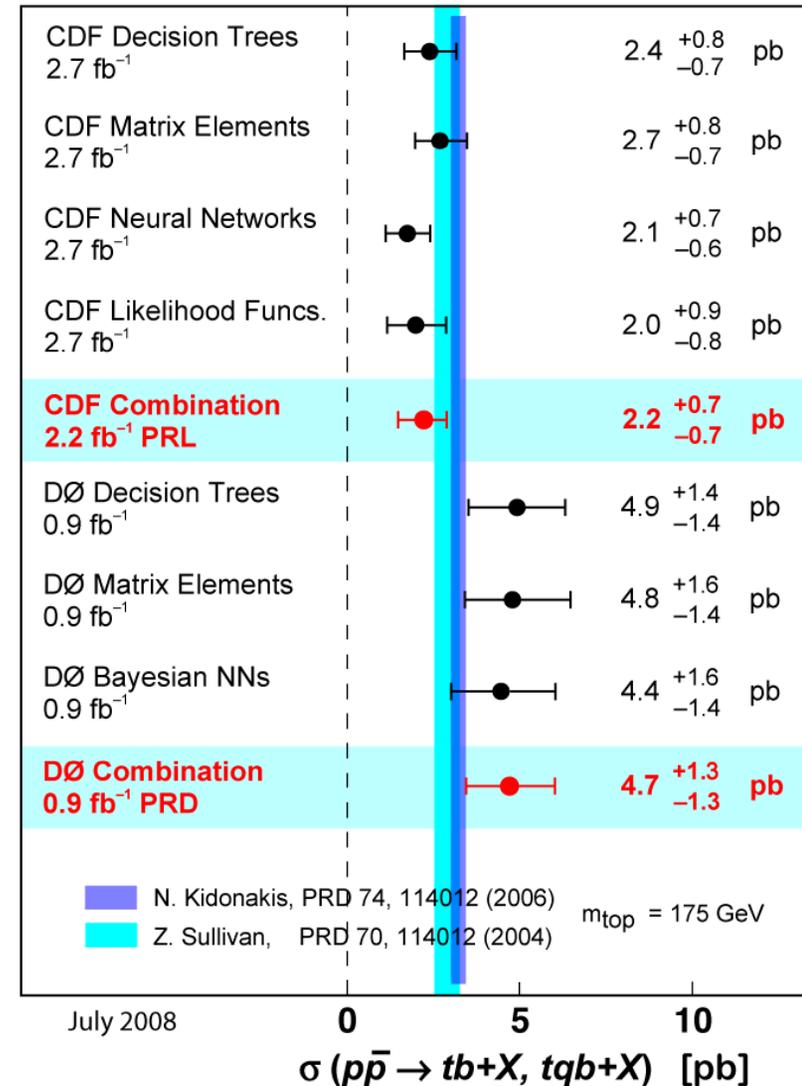
Evidence for Single Top Production

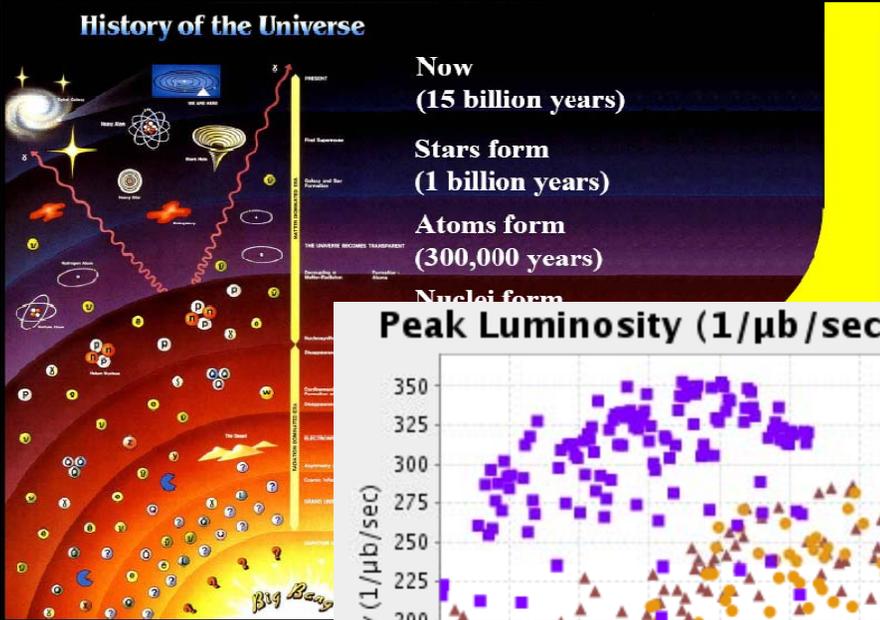
Status as of March 3, 2009

Signal Significance		Cross Section
Expected	Observed	Measured
DØ (0.9 fb⁻¹) PRL 98, 181802 (2007)		
2.3σ	3.6σ	4.7±1.3 pb
$ V_{tb} = 1.31 + 0.25 - 0.21$		
CDF (2.2 fb⁻¹) PRL 101, 252001 (2008)		
4.9σ	3.7σ	2.2 ± 0.7 pb
$ V_{tb} = 0.88 ± 0.12 ± 0.07$		

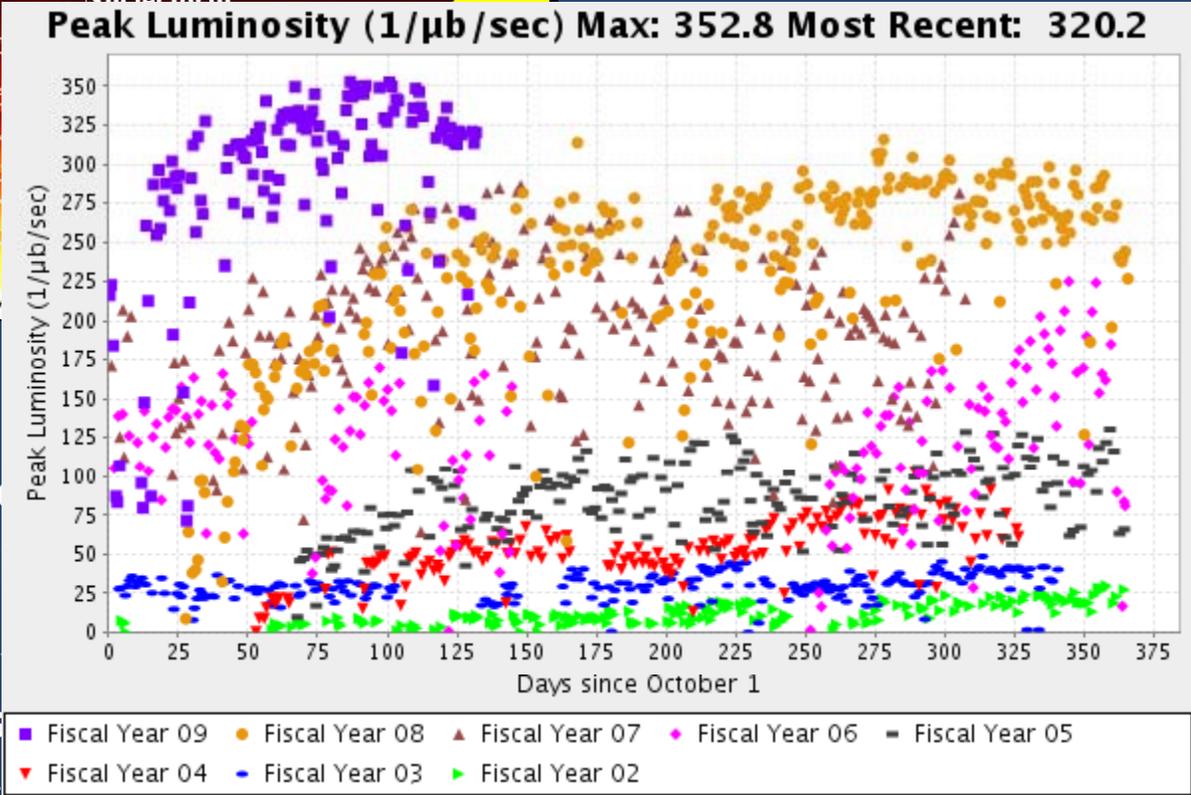
Observed significance is a measure of how likely it is to measure the cross section in the absence of signal

CDF and DØ tb+tb Cross Section

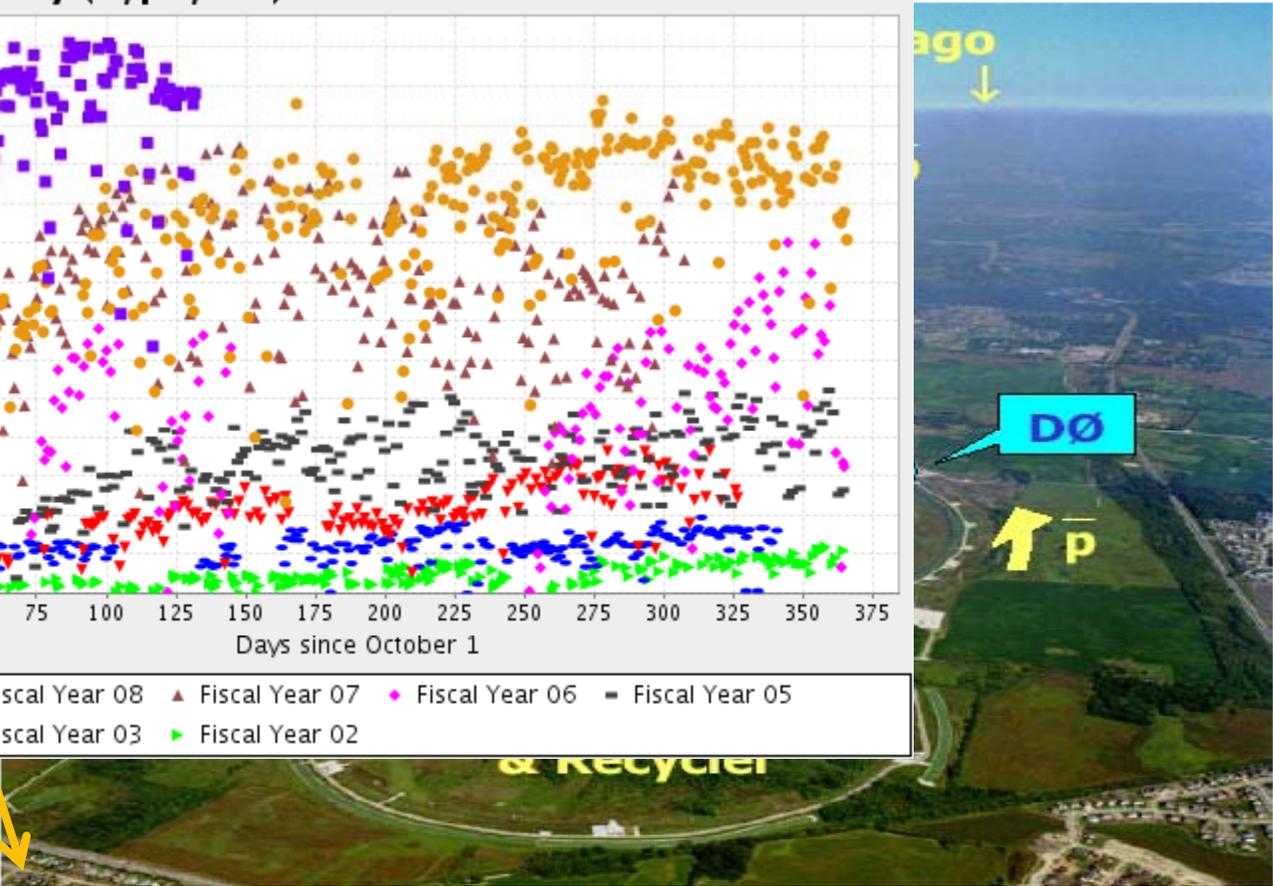




The Tevatron Accelerator

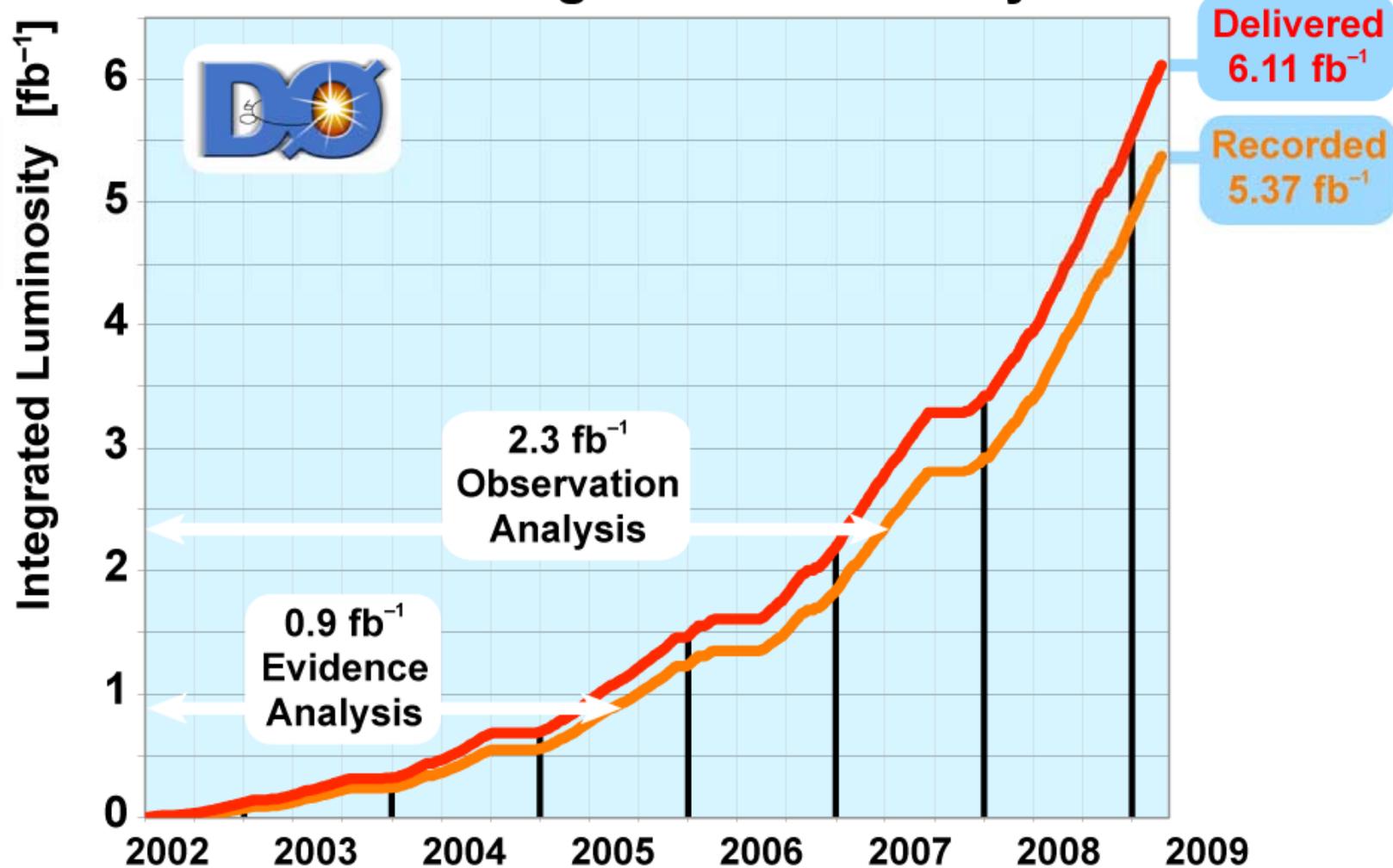


~ 20 countries
 ~ 80 institutions
 ~ 700 enthusiastic physicists per experiment



The only place where top quarks are produced and measured (on average, we are collecting more than 400 top pairs per week now)
 Shabnam Jabeen (Boston University)

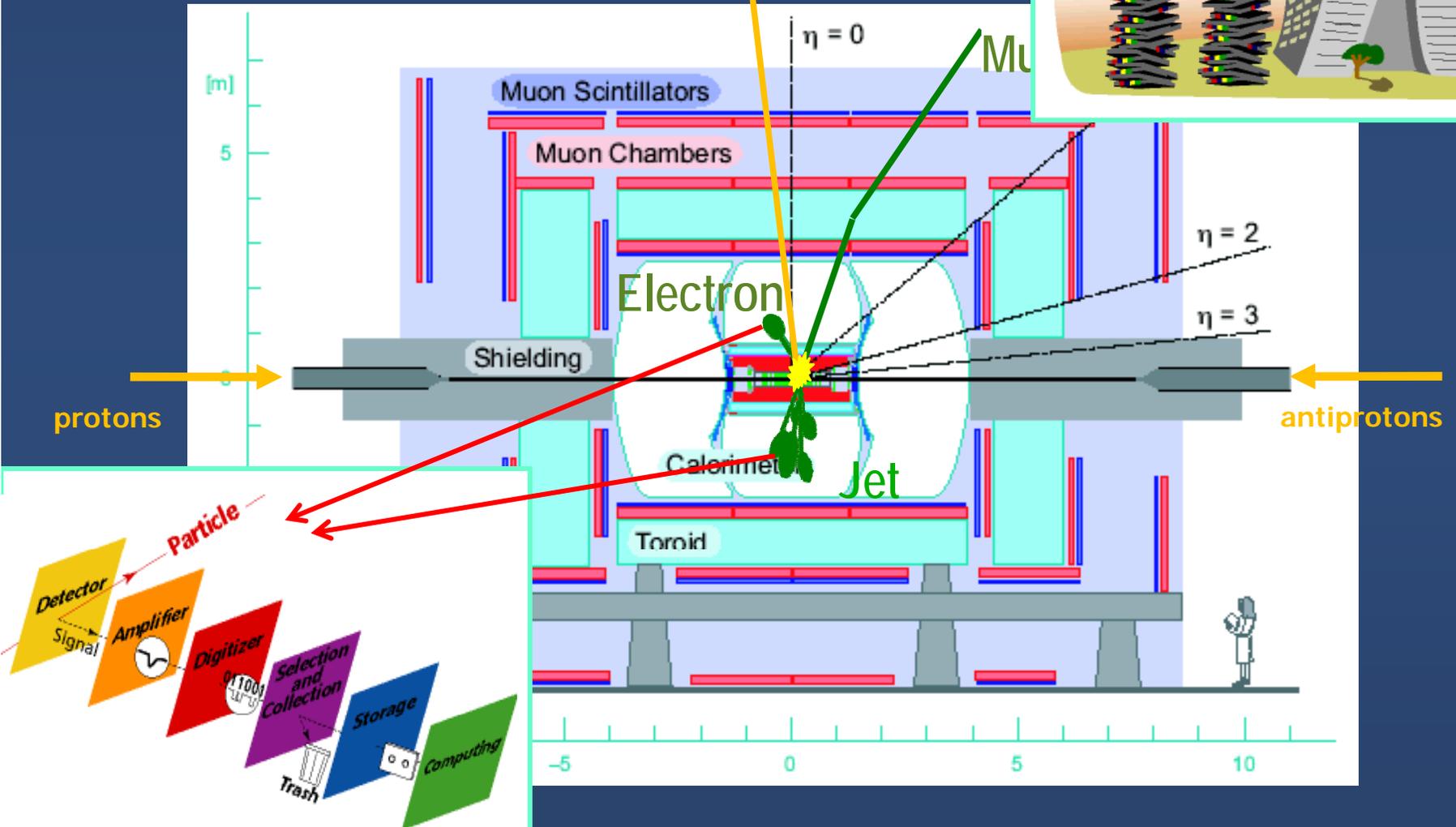
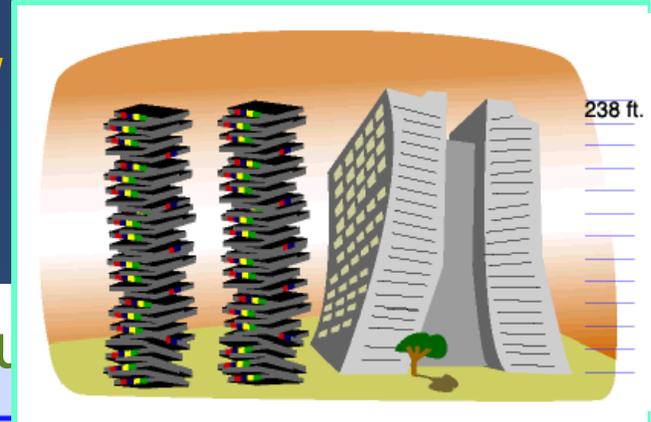
Fermilab Tevatron Run II Integrated Luminosity





Every 396 ns....

Missing Transverse Energy (Neutrino)



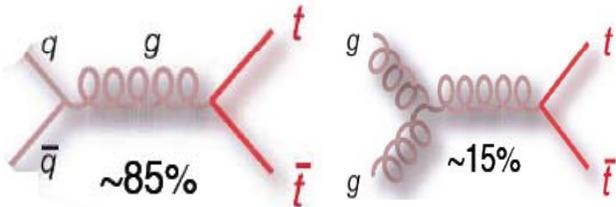
Shabnam Jabeen (Boston University)



Production

Top quark pair production

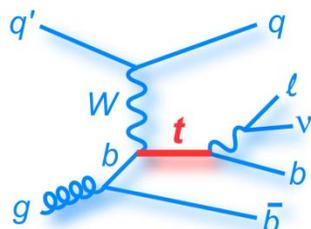
$$\sigma_{tt} \sim 7 \text{ pb}$$



Single Top quark production

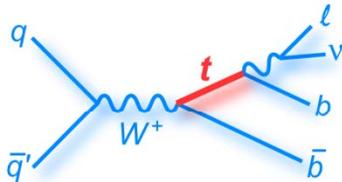
t-channel

$$\sigma \sim 2 \text{ pb}$$



s-channel

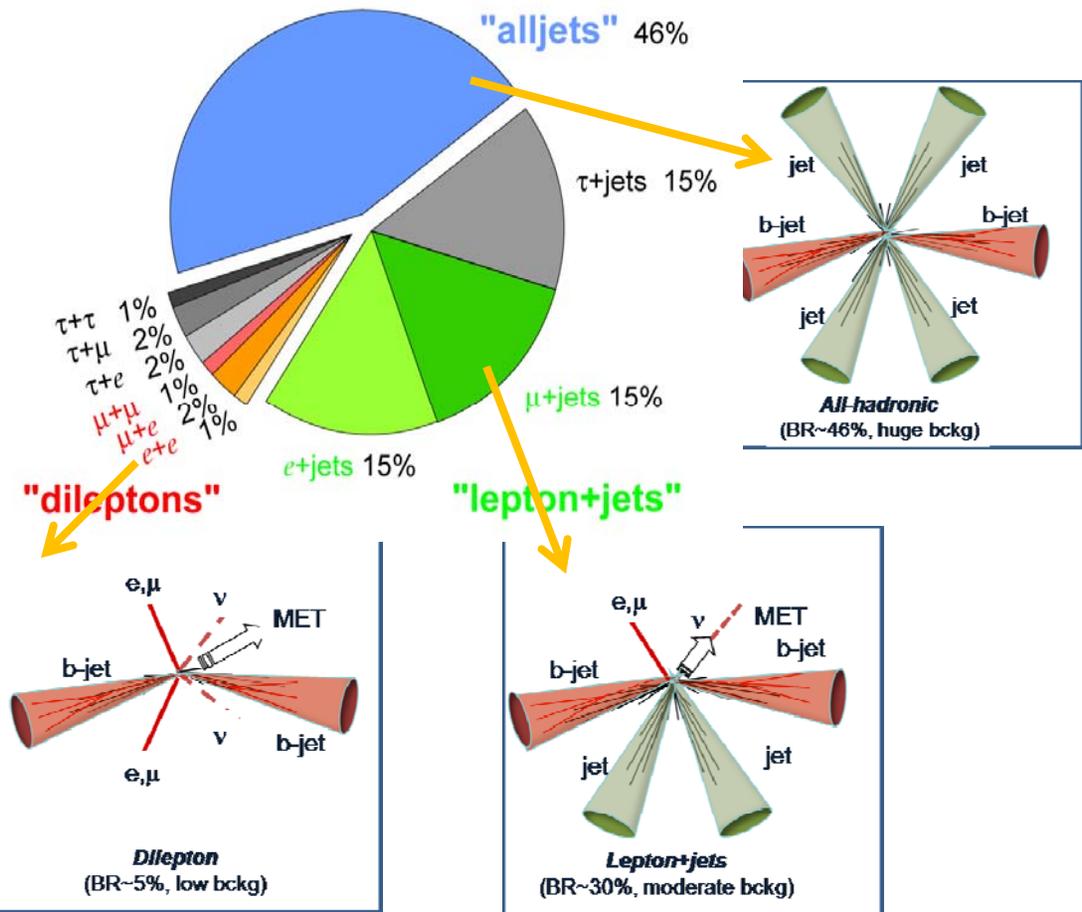
$$\sigma \sim 1 \text{ pb}$$



Decay

Within Standard Model $t \rightarrow Wb \sim 100\%$

Top Pair Branching Fractions





Event Signatures and Event Selection

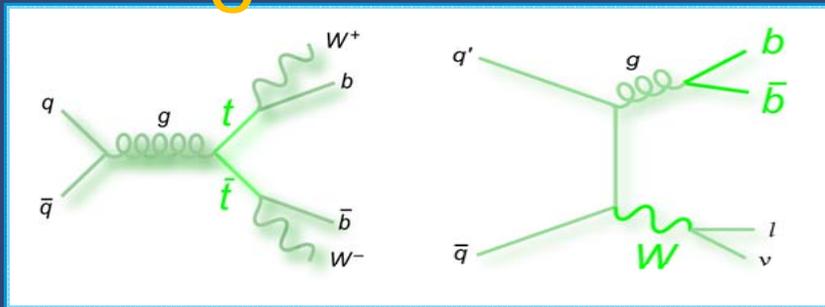
$e : p_T > 15 \text{ GeV}, |\eta| < 1.1$
 $\mu : p_T > 18 \text{ GeV}, |\eta| < 2.0$

Missing E_T $15 < MET < 200 \text{ GeV}$

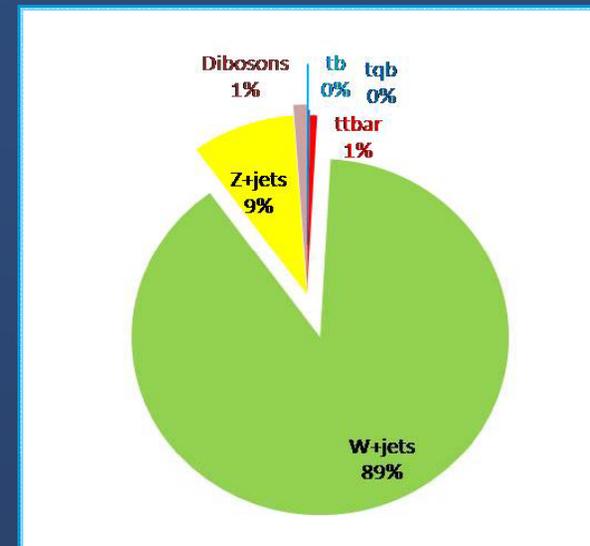
Jets $2-4, p_T > 15 \text{ GeV}, |\eta| < 3.0$
 $p_{T,1} > 25 \text{ GeV}, |\eta| < 2.5$
 $p_{T,2} > 20 \text{ GeV}$

B-jet 1 or 2

Backgrounds



- Top pairs W+jets, and Multijets are the main processes that can mimic these signatures
- Single top signal is negligible compared to these backgrounds



Background Modeling

- Single top signal

Modeled using SINGLETOP based on COMPHEP

- W+jets background

- Event kinematics and flavor composition modeled using Alpgen generator and PYTHIA for parton hadronization
- $\eta(\text{jets})$, $\Delta\phi(\text{jet1},\text{jet2})$, $\Delta\eta(\text{jet1},\text{jet2})$ corrected to match data
- Normalized to data before b tagging and after subtracting other backgrounds

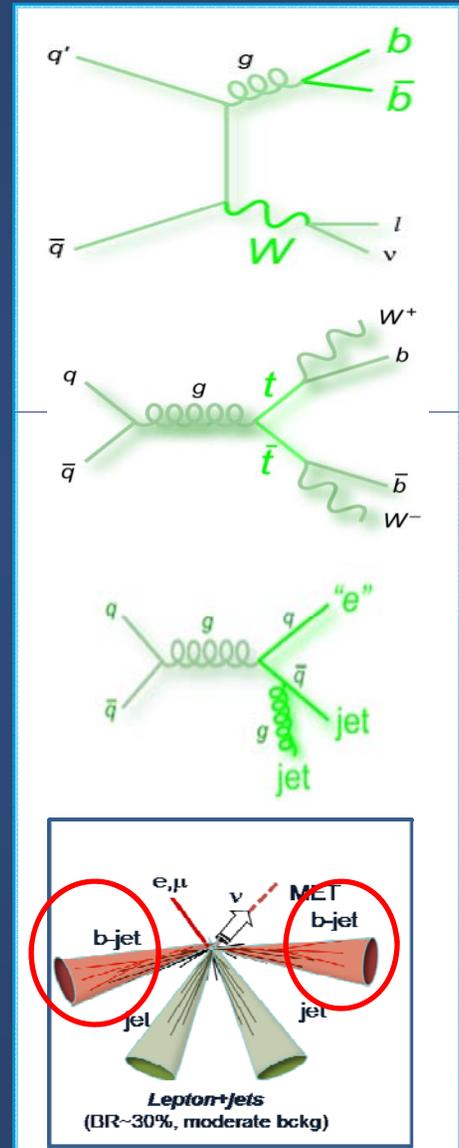
- Multijet background

- Modeled using data with a non-isolated lepton and jets
- Kept small ($\sim 5\%$) with topological selection cut

- Top pair backgrounds modeled using ALPGEN +PYTHIA

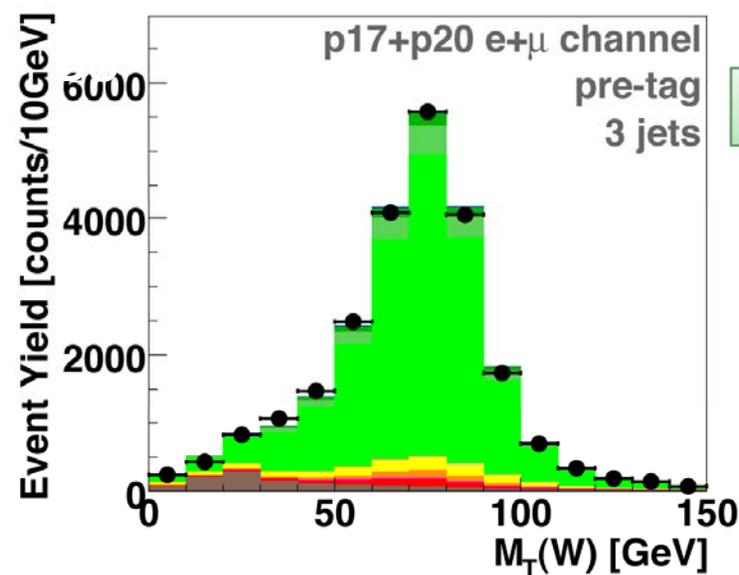
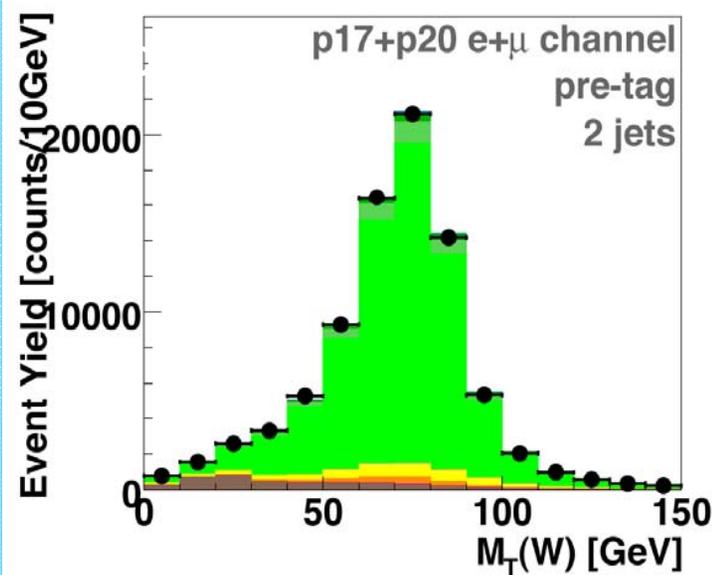
- Z+jets modeled using ALPGEN + PYTHIA

- Dibosons modeled using PYTHIA



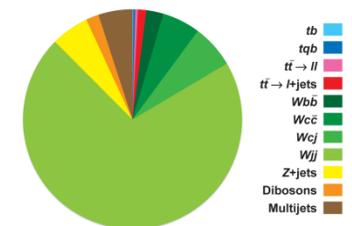
Background Normalization

- W+jets and multijet normalized using iterative template fits to data BEFORE TAGGING on three sensitive variables: $p_T(\ell)$, E_T , $M_T(W)$



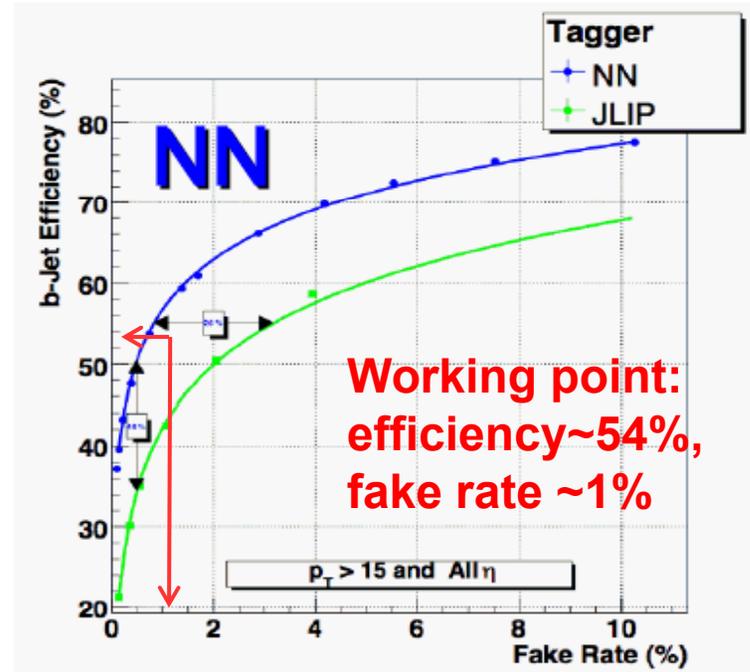
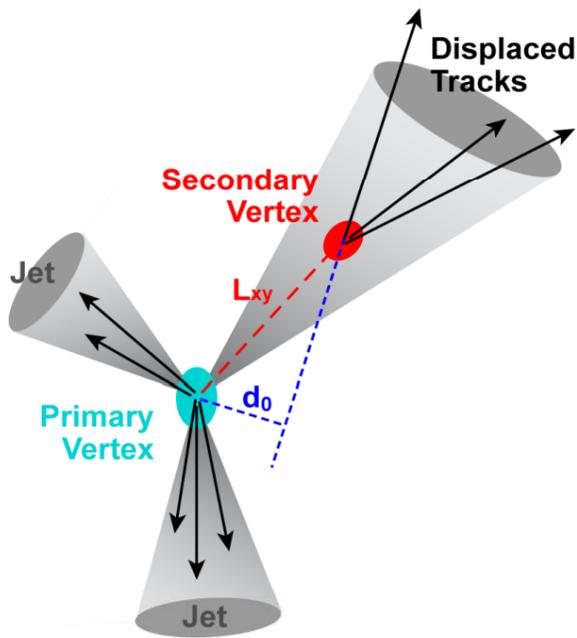
S:B = 1:259

DØ Single Top 2.3 fb⁻¹ Signals and Backgrounds
(All channels combined, before b-tagging)



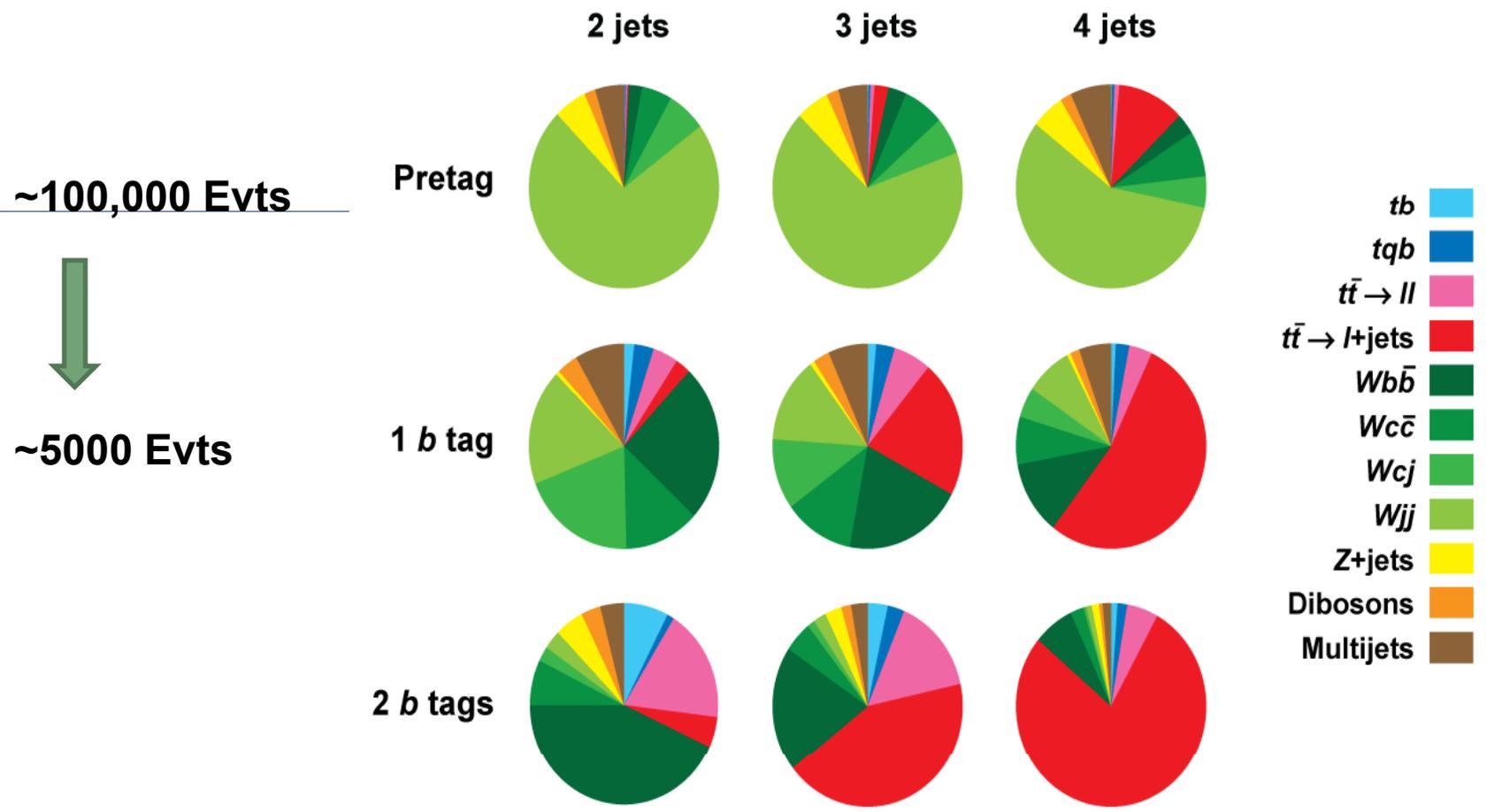
B-jet Identification (aka b-tagging)

- Separate *b*-jets from light-quark and gluon jets to reject most *W*+jets background
- DØ uses a neural network algorithm with seven input variables based on impact parameter and reconstructed vertex



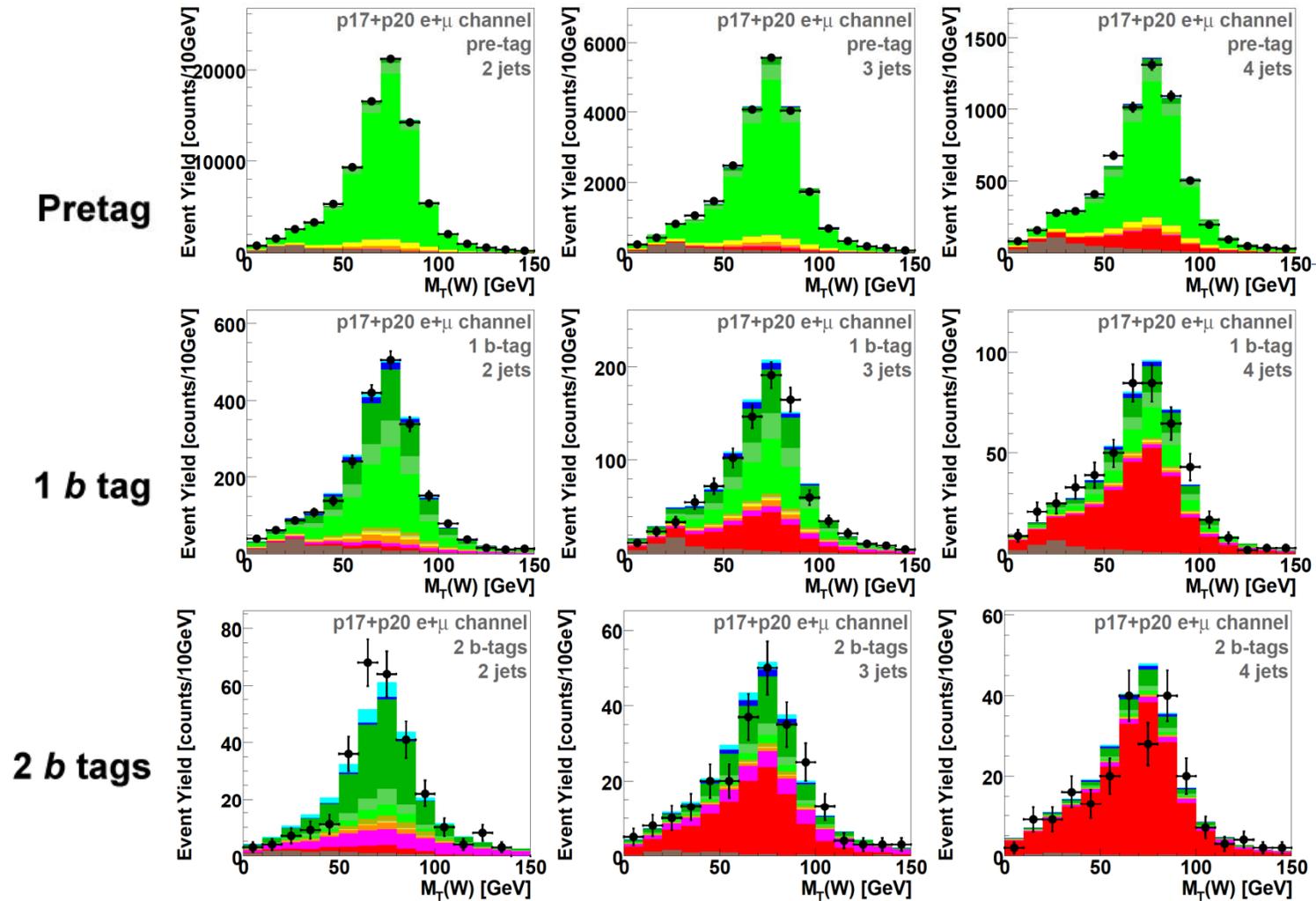
Before and After

DØ Single Top 2.3 fb⁻¹ Signals and Backgrounds



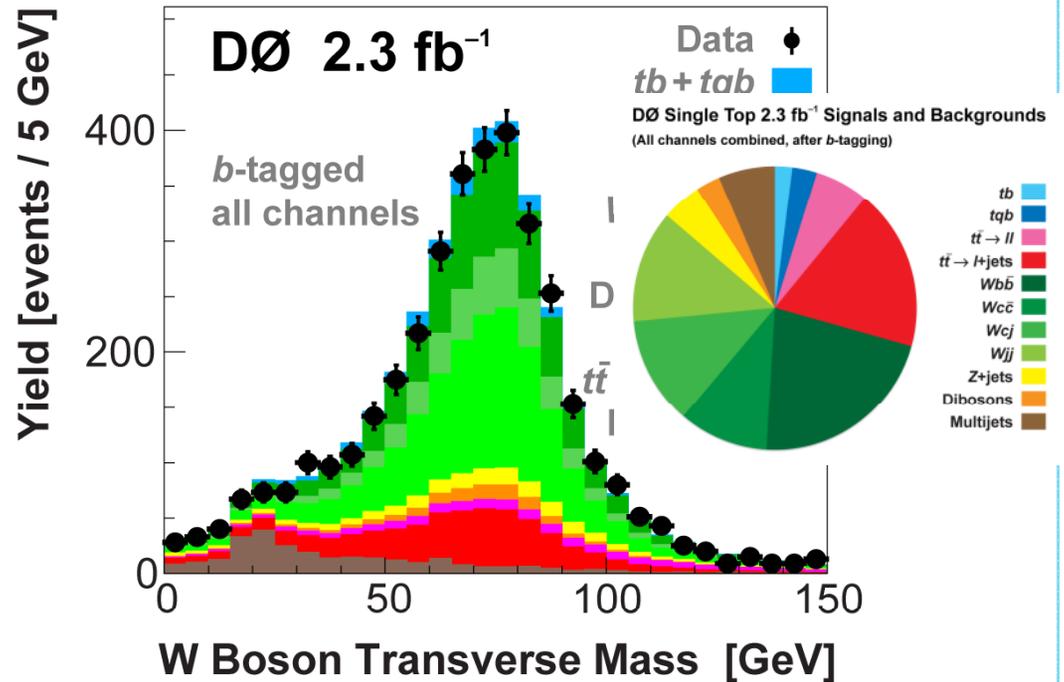
Before and After

DØ Single Top 2.3 fb⁻¹ Signals and Backgrounds



Event Yields After B-Tagging

Event Yields in 2.3 fb ⁻¹ of DØ Data	
e,μ, 2,3,4-jets, 1,2-tags combined	
<i>tb + tqb</i>	223 ± 30
W+jets	2,647 ± 241
Z+jets, dibosons	340 ± 61
<i>t\bar{t}</i> pairs	1,142 ± 168
Multijets	300 ± 52
Total prediction	4,652 ± 352
Data	4,519



S:B = 1:21 in 1Tag
S:B = 1:15 in 2Tag

- Single top signal is smaller than total background uncertainty
- Counting events is not a sensitive enough method

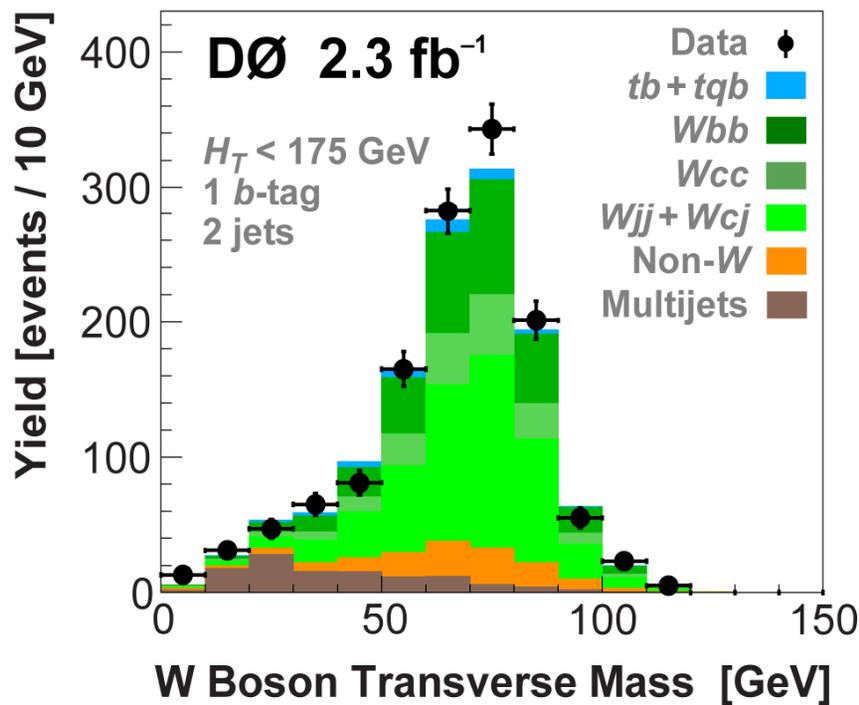


Cross Check Samples

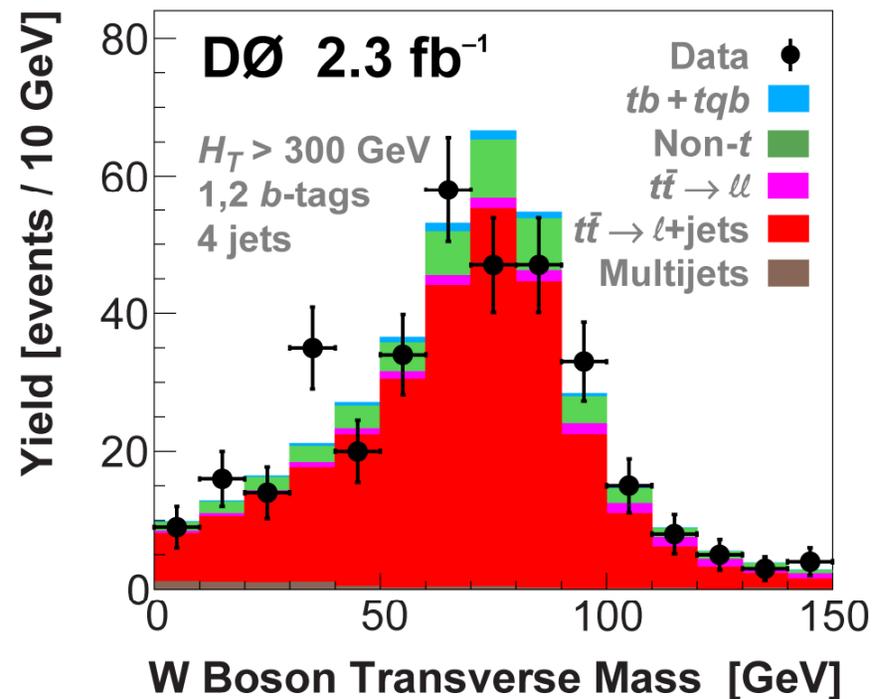
Validate a background model in side-band regions

- a) An enriched W +jets background
- b) An enriched top pair background

W +Jets Cross-Check Sample



$t\bar{t}$ -Pairs Cross-Check Sample



Search Strategy

- **Maximize the signal acceptance**

- Particle ID definitions set as loose as possible
- Transverse momentum thresholds set low, pseudo-rapidities wide
- As many decay channels used as possible
- All channels analyzed separately since S:B and background compositions differ

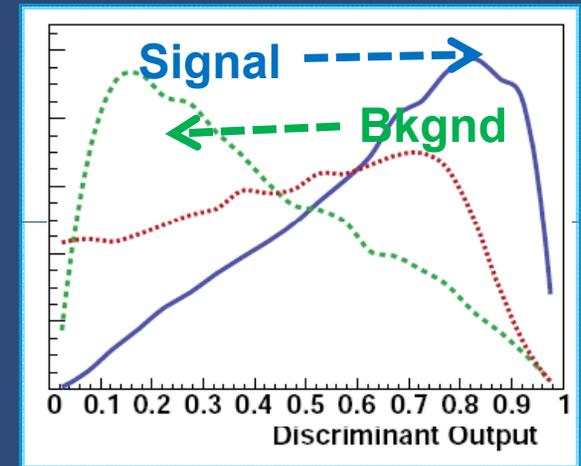
- **Use multivariate techniques**

- **Three techniques used for this analysis**

- Boosted Decision Trees
- Matrix Elements
- Bayesian Neural Networks
- Check discriminant Performance using data control samples

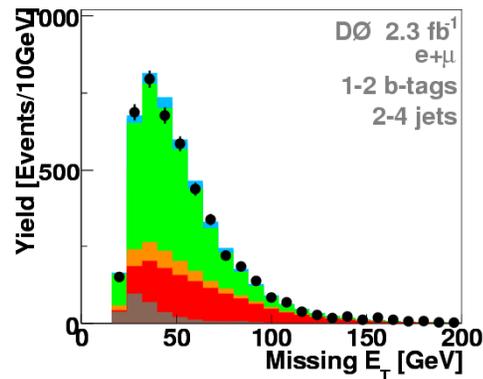
- **Use ensembles of pseudo-data to test validity of methods**

- **Cross sections measured using binned likelihood calculation of signal + background to data**

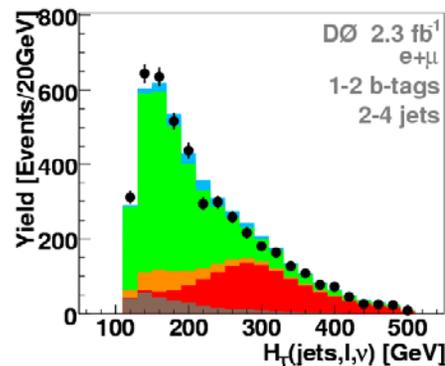


Discriminating Variables–BDT/BNN

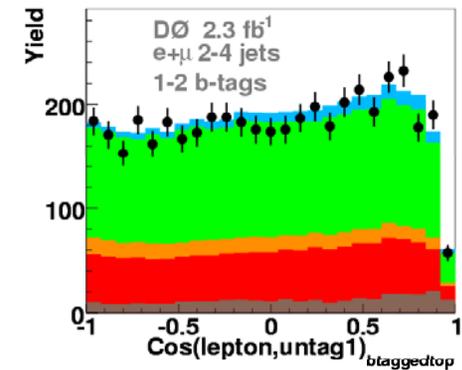
OBJECT KINEMATICS



EVENT KINEMATICS



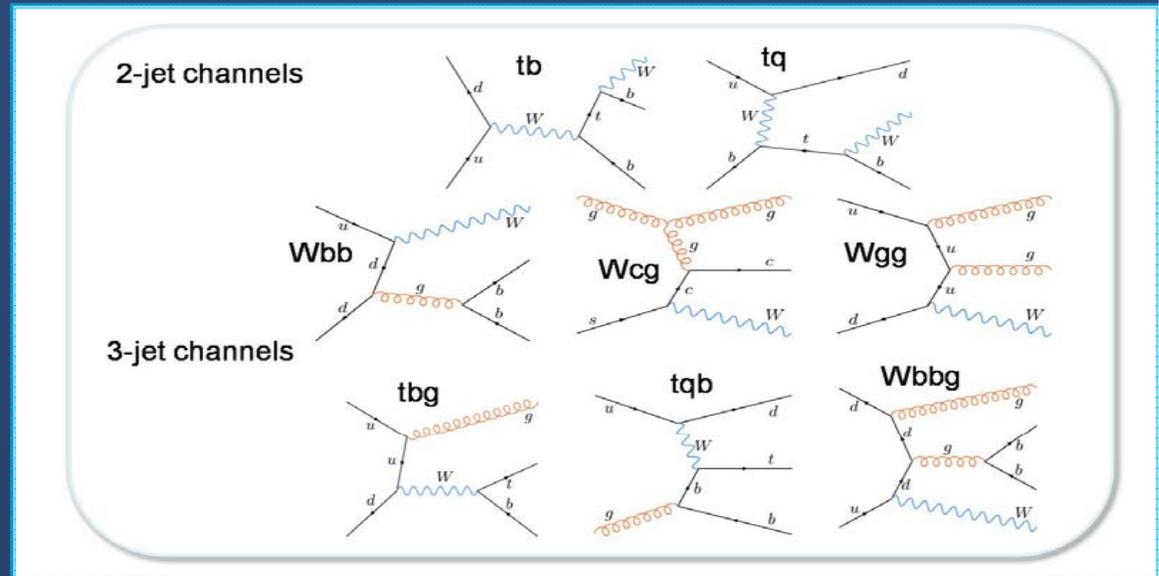
ANGULAR CORRELATIONS



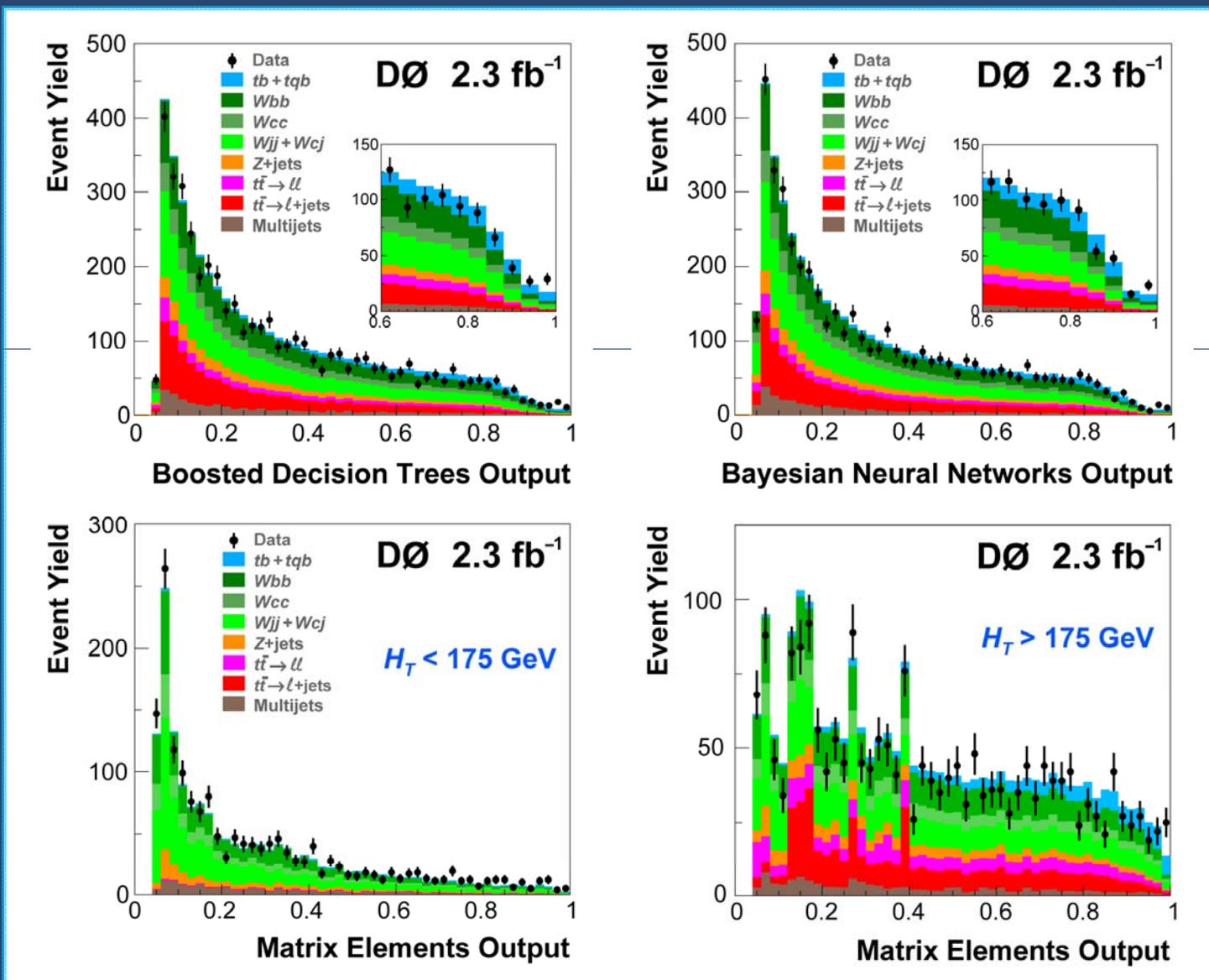
Feynman Diagrams Matrix Elements

Added additional Matrix Elements since 2006

2jets: top pair, WW, WZ, ggg;
3jets: top pair, Wugg



Multivariate Discriminant Output



Systematic Uncertainties

Systematic Uncertainties

Components for normalization	
Integrated luminosity	6.1%
$t\bar{t}$ cross section	12.7%
Z+jets and dibosons cross section	5.8%
Branching fractions	1.5%
Parton distribution functions (signal only)	3.0%
Triggers	5.0%
Instantaneous luminosity reweighting	1.0%
Primary vertex selection	1.4%
Lepton identification	2.5%
Jet fragmentation	(0.7–4.0)%
Initial-state and final-state radiation	(0.6–12.6)%
b -jet fragmentation	2.0%
Jet reconstruction and identification	1.0%
Jet energy resolution	4.0%
W +jets and Z +jets heavy flavor correction	13.7%
Multijets normalization to data	(30–54)%
Monte Carlo and multijets statistics	(0.5–16)%

Components for normalization and shape

Jet energy scale for signal	(1.1–13.1)%
Jet energy scale for total background	(0.1–2.1)%
b tagging for single-tagged	(2.1–7.0)%
b tagging for double-tagged	(9.0–11.4)%

Component for shape only

ALPGEN reweighting	–
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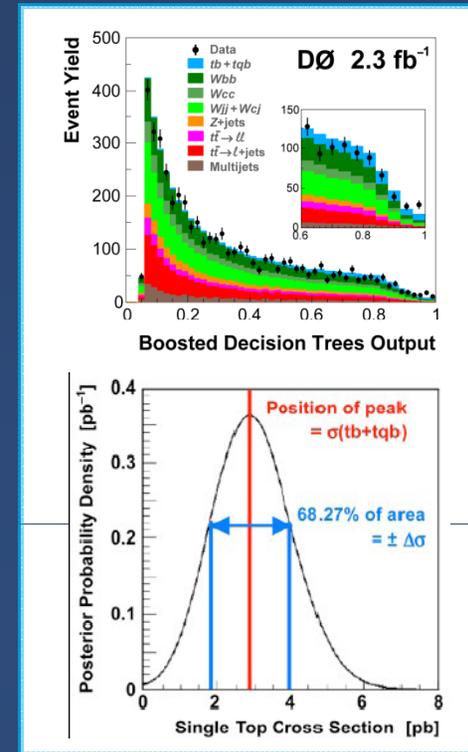
Components that most affect the cross section measurement are shown in yellow

Other important contributions are shown in *pink*

Statistical Analysis

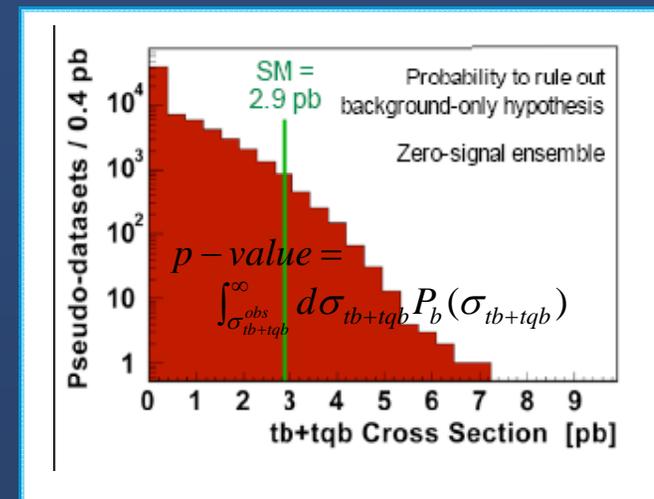
Cross Section Measurement

- Calculate cross sections using binned likelihood fits of (floating) signal + (fixed) background to data
- Compute posterior probability density of $tb+tbq$ using Bayes' theorem:
 - Flat positive-defined prior for the cross section
 - Systematic uncertainties are treated as Gaussian nuisance parameters



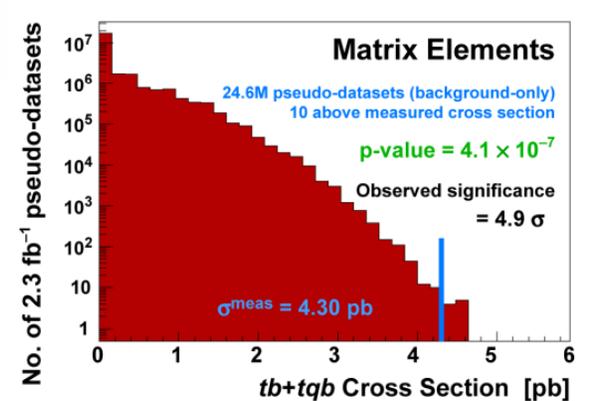
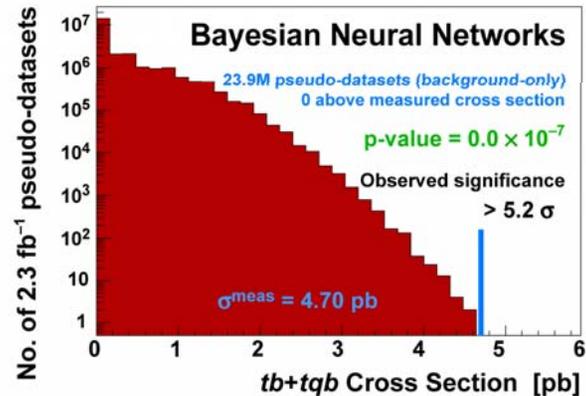
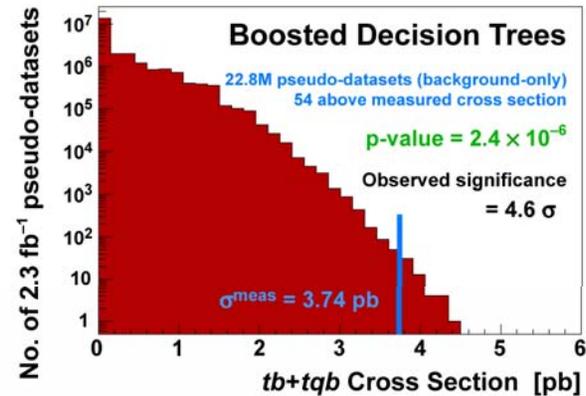
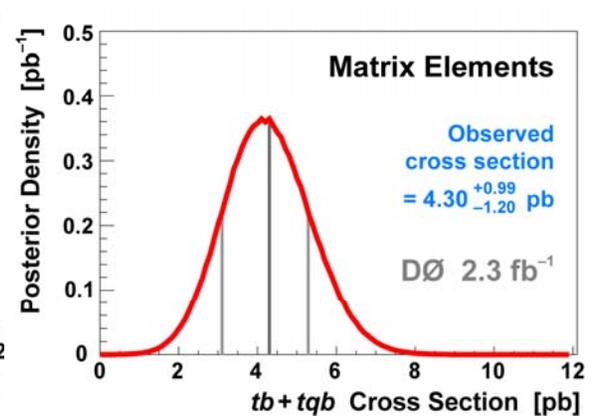
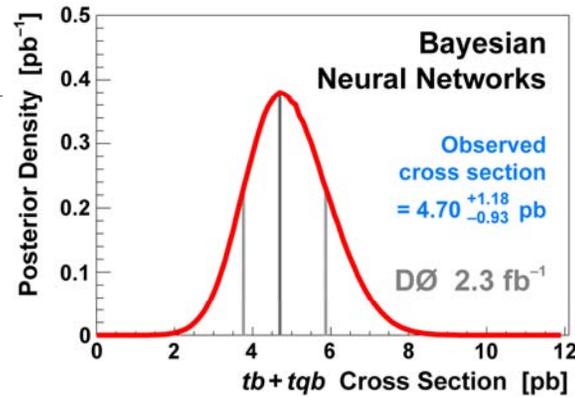
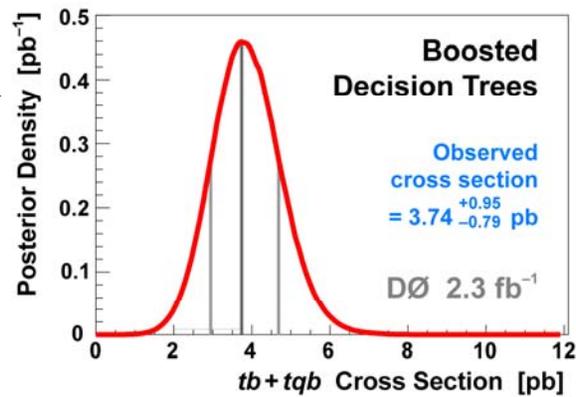
Significance

- Use the ensemble of zero-signal pseudo-datasets to find what fraction give a cross section at least as large as the measured value: the “measured p-value”
- Convert p-value to “measured significance



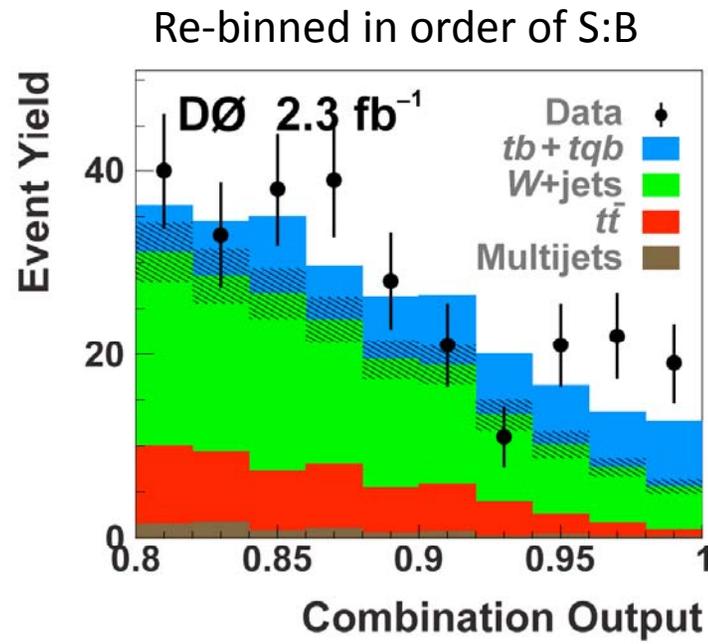
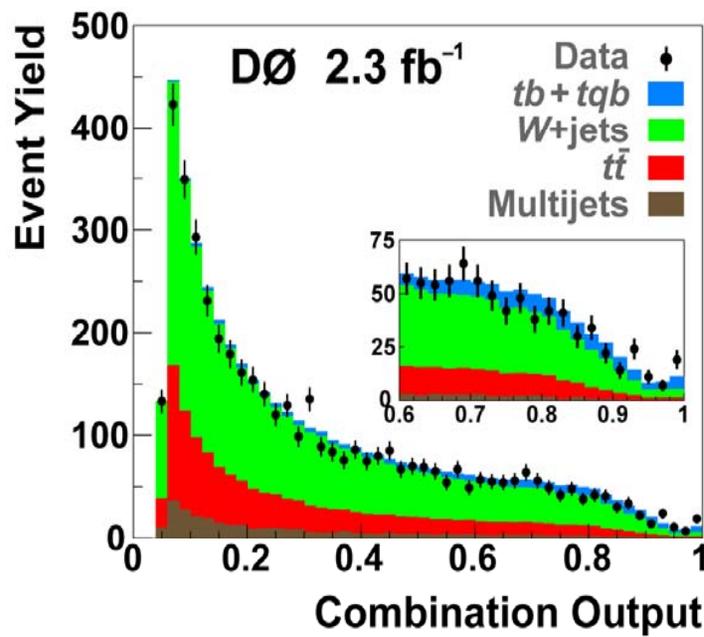
Results

DØ 2.3 fb ⁻¹ Single Top Results			
Analysis Method	Single Top Cross Section	Significance	
		Expected	Measured
Boosted Decision Trees	3.74 ^{+0.95} _{-0.79} pb	4.3 σ	4.6 σ
Bayesian Neural Networks	4.70 ^{+1.18} _{-0.93} pb	4.1 σ	5.2 σ
Matrix Elements	4.30 ^{+0.99} _{-1.20} pb	4.1 σ	4.9 σ



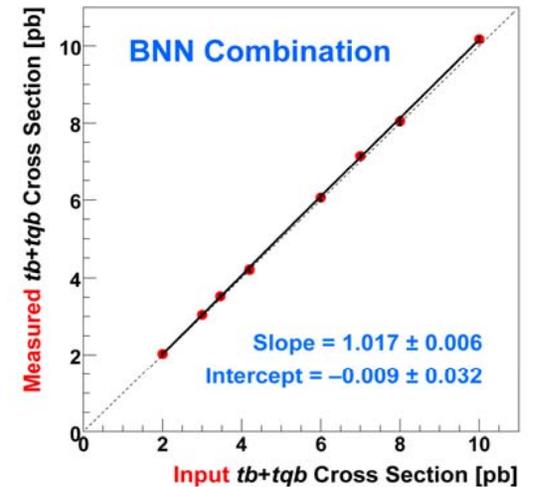
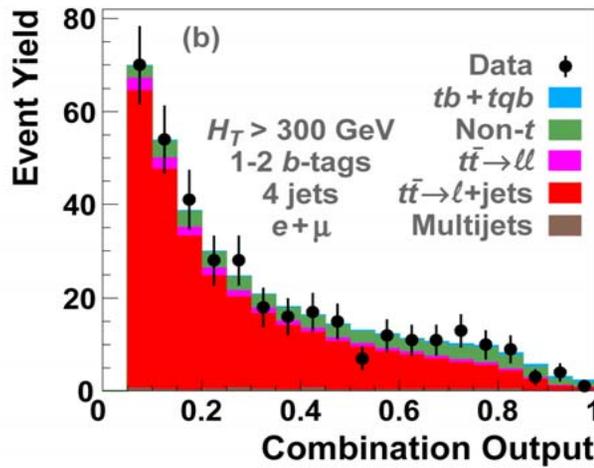
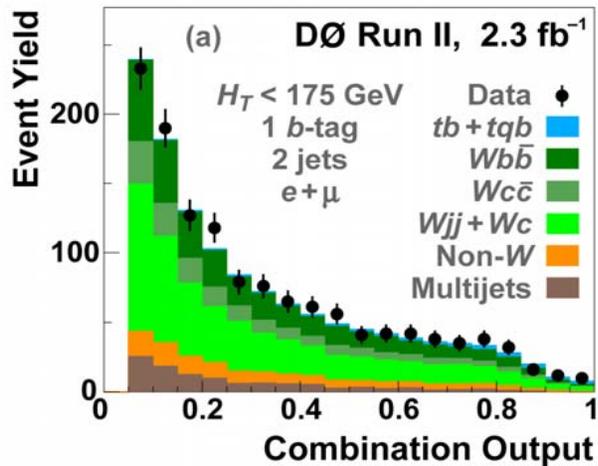
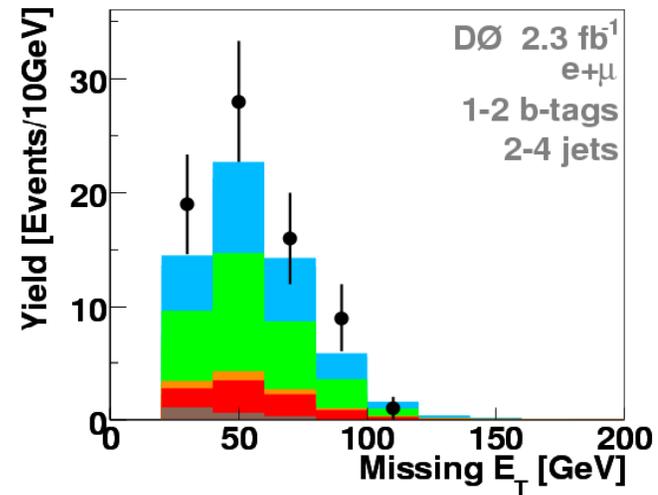
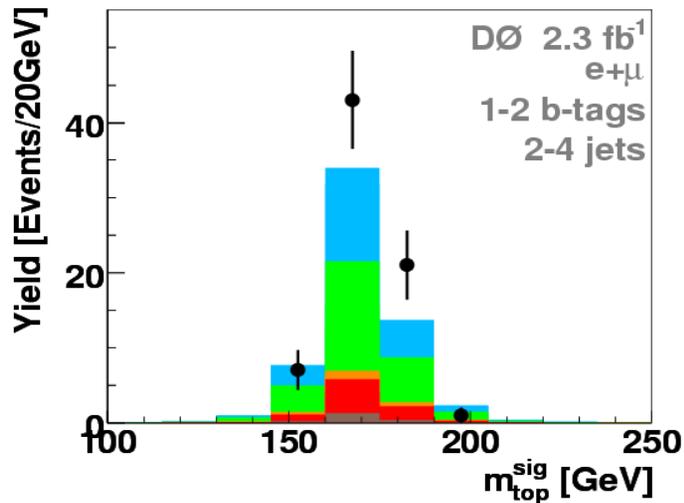
Combination of Results

- All MVA analyses use the same data, but they are not 100% correlated
- We use a BNN to combine the three methods. The BNN takes as input variables the output discriminants of the individual methods
- Expected sensitivity for the BNN Combination: 4.5σ



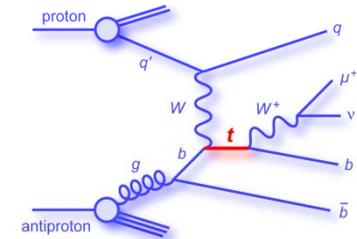
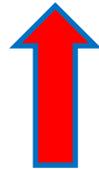
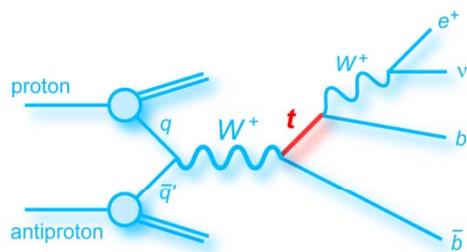
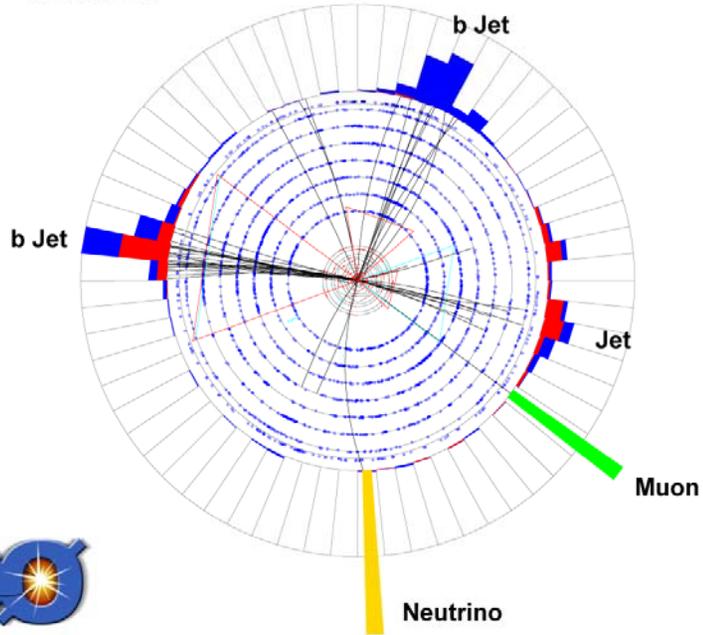
Combination of Results

Distributions for BNN Comb > 0.9



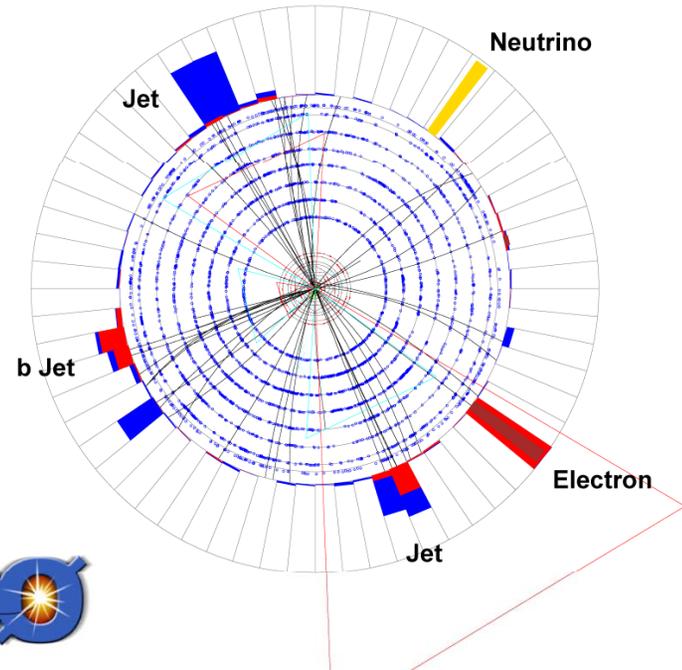
DØ Experiment Event Display Single Top Quark Candidate Event, 2.3 fb⁻¹ Analysis

Run 223473 Evt 27278544 Sun Jul 23 19:21:41 2006
ET scale: 28 GeV

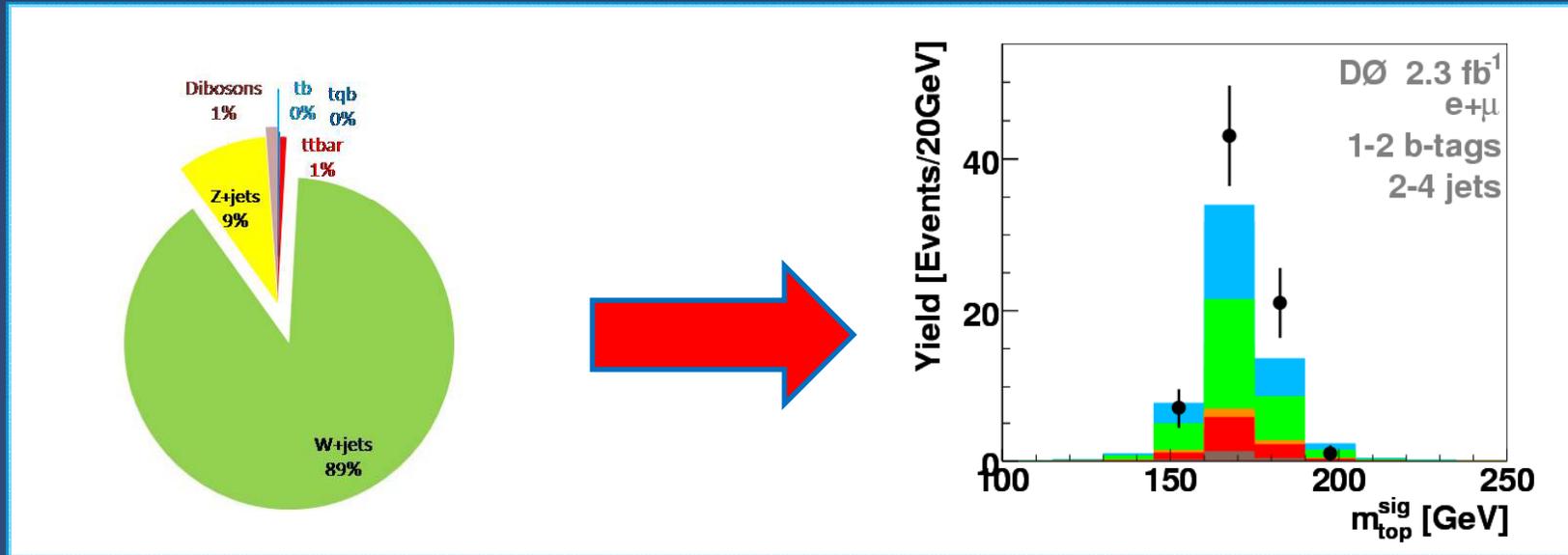


DØ Experiment Event Display Single Top Quark Candidate Event, 2.3 fb⁻¹ Analysis

Run 229388 Evt 13339887 Wed Jan 3 21:05:14 2007
ET scale: 39 GeV



Combined Results



$$\sigma(p\bar{p} \rightarrow tb + X, tqb + X) = 3.94 \pm 0.88 \text{ pb}$$

Measured Significance = **5.03σ**

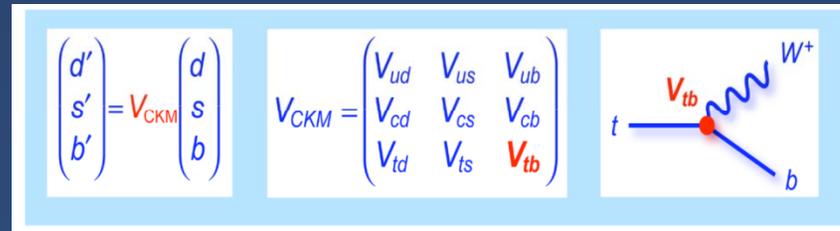
Discovery of single top production!!



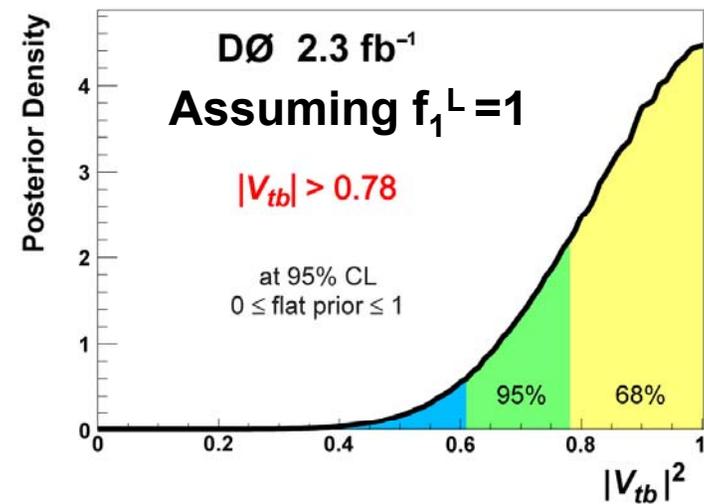
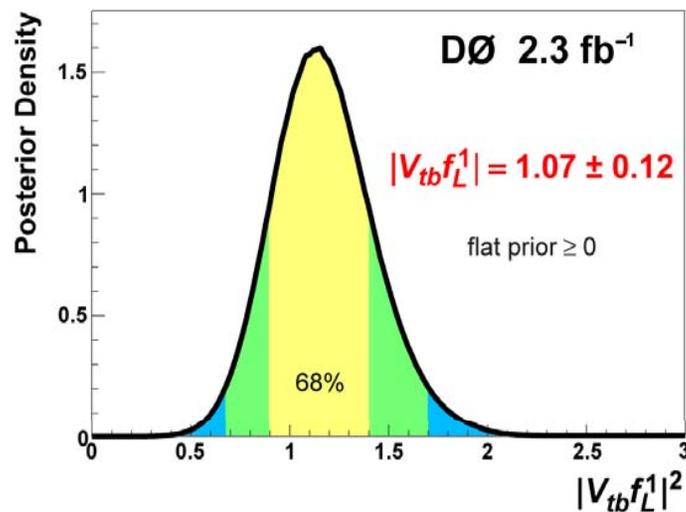
Measurement of $|V_{tb}|$

- Use the measurement of the single top cross section to make a direct measurement of $|V_{tb}|$:

- Calculate a posterior in $|V_{tb}|^2$
- Measure the strength of the V–A



$$\Gamma_{Wtb}^\mu = -\frac{g}{\sqrt{2}} V_{tb} \left\{ \gamma^\mu [f_1^L P_L + f_1^R P_R] - \frac{i\sigma^{\mu\nu}}{M_W} (p_t - p_b)_\nu [f_2^L P_L + f_2^R P_R] \right\}$$



Conclusions

- Both DØ and CDF collaborations at Tevatron have observed single top quark production in Run II data (I have presented only DØ analysis)

$$\sigma(p\bar{p} \rightarrow tb + X, tqb + X) = 3.94 \pm 0.88 \text{ pb}$$

Measured Significance 5.03σ

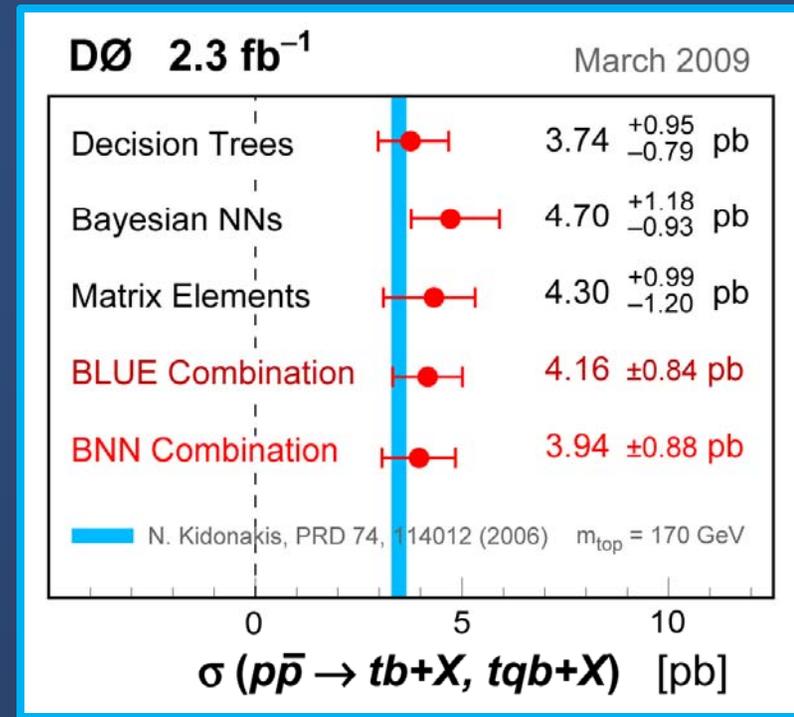
- Direct measurement of $|V_{tb}|$

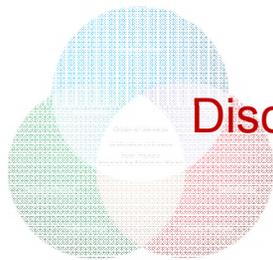
$$|V_{tb}| = 1.07 \pm 0.12$$

flat prior ≥ 0

$$0.78 < |V_{tb}| < 1 \text{ @ 95\% CL}$$

$0 \leq \text{flat prior} \leq 1$

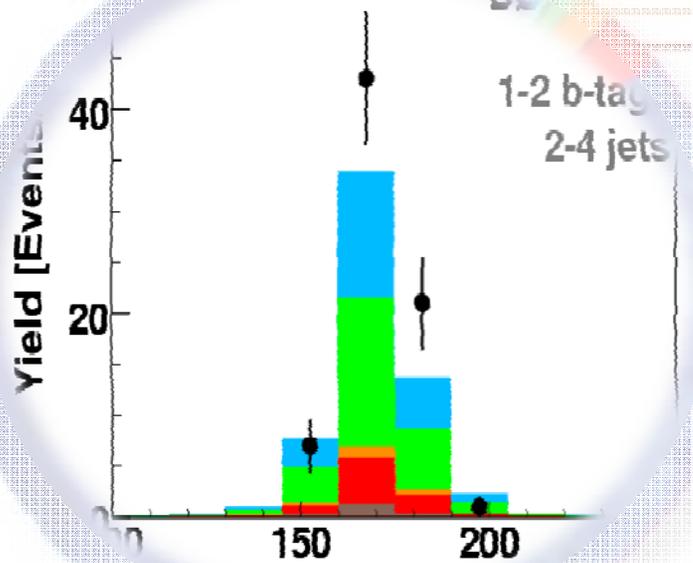




Discovery of single top:

One step further in our understanding

and another window of opportunity opened in our search for new physics and answers to big questions



"The Universe is not only queerer than we suppose, it is queerer than we can suppose." -Mark Twain

Chemical Elements:
(other than H & He) 0.03%

Neutrinos:
0.47%

Stars:
0.5%

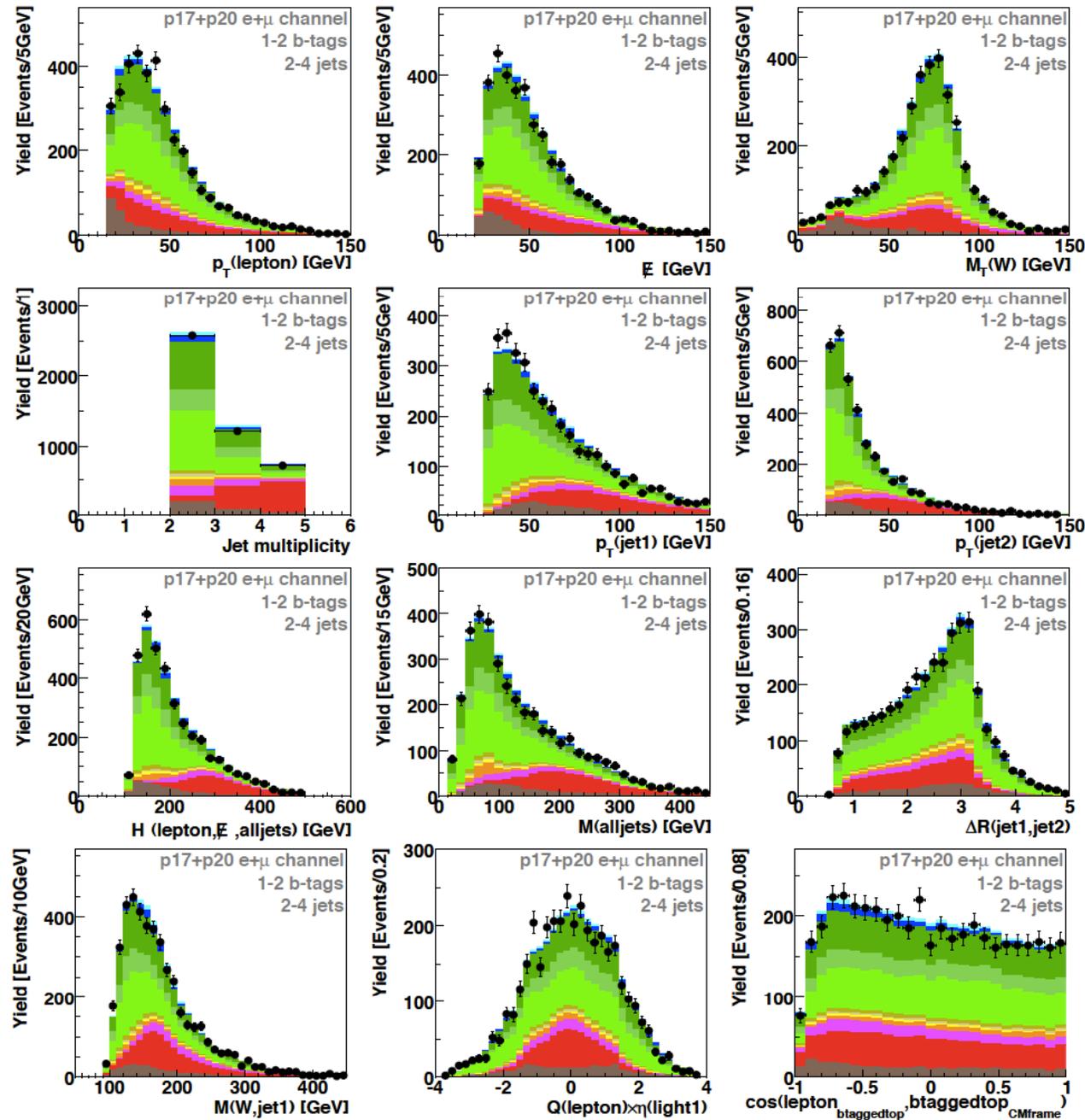
Free H
& He:
4%

Dark Matter:
25%

Dark Energy:
70%

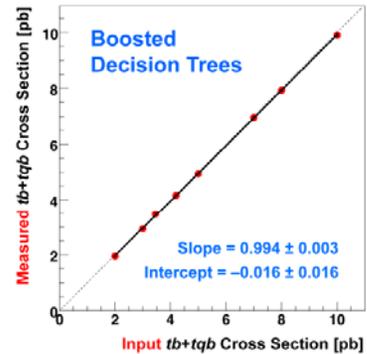
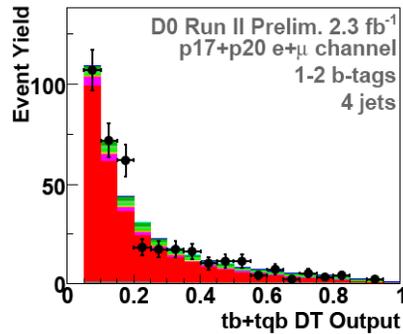
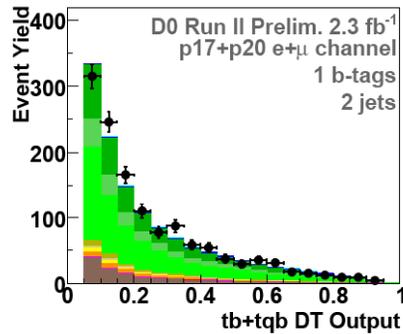
95%
Mystery

Data/MC agreement (for all channels combined)

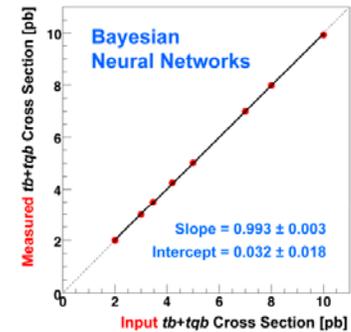
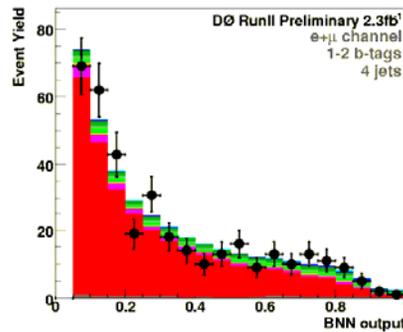
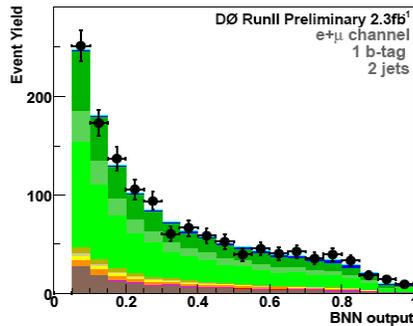


Separating Signal from Background

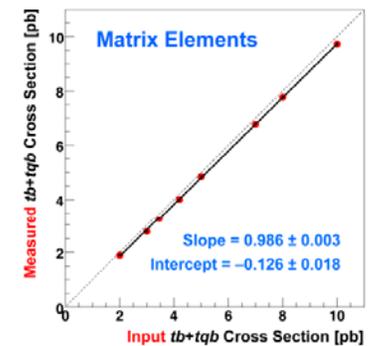
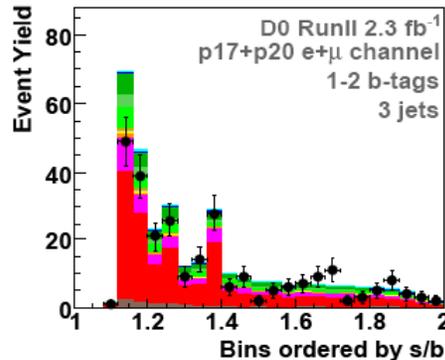
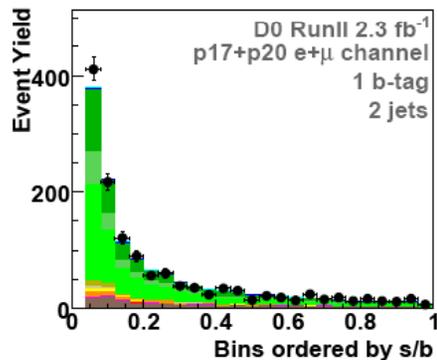
Cross Check Samples and Linearity



BDT



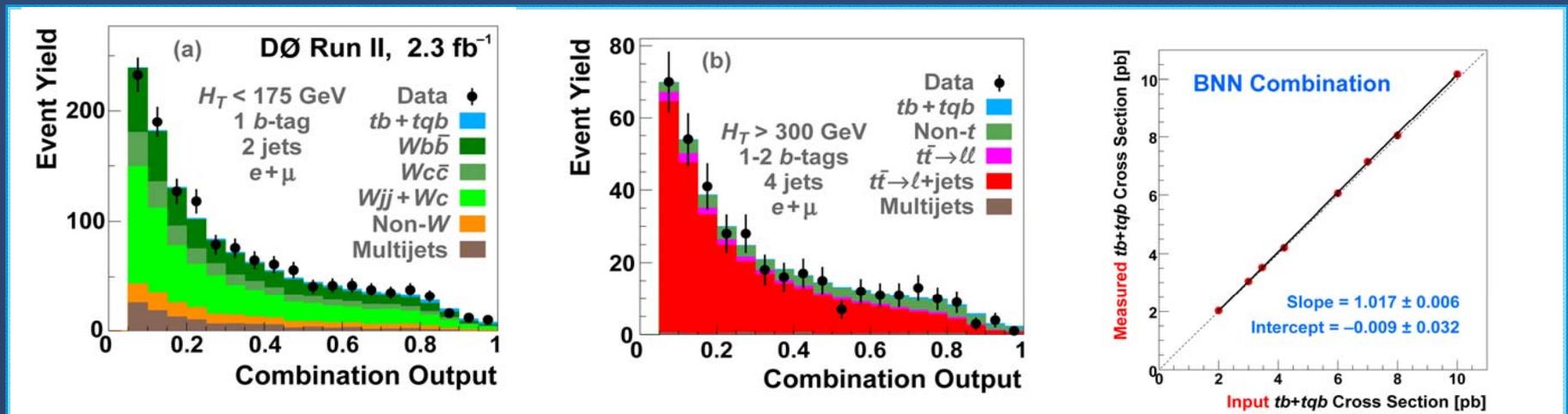
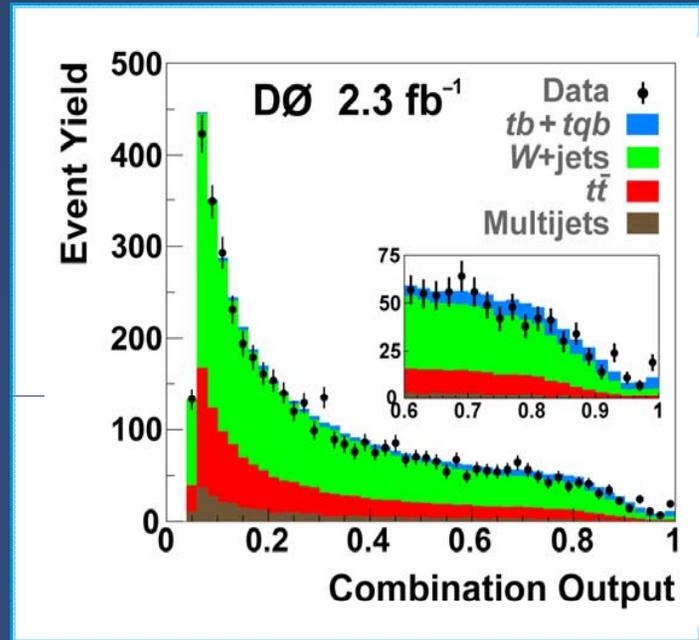
BNN



ME

Combination of Results

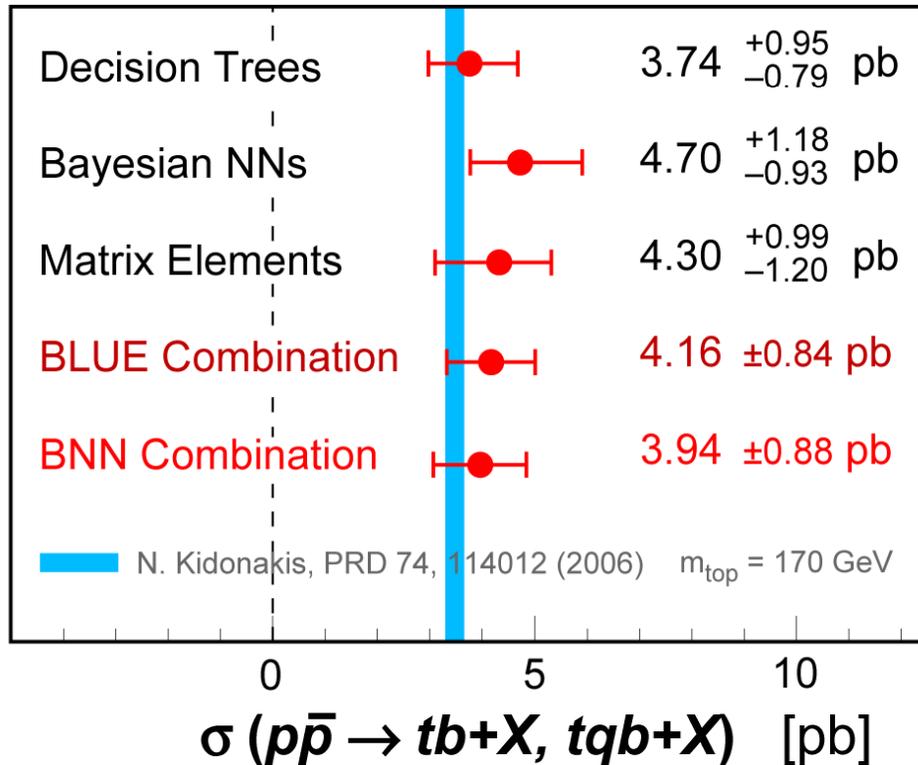
- All MVA analyses use the same data, but they are not 100% correlated
- We use a BNN to combine the three methods. The BNN takes as input variables the output discriminants of the individual methods
- Expected sensitivity for the BNN Combination: 4.5σ



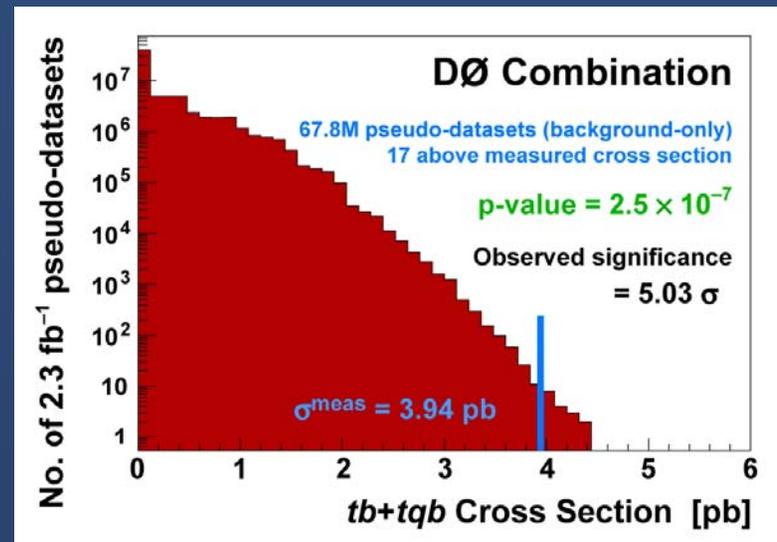
Cross Section Summary

DØ 2.3 fb⁻¹

March 2009



MVA	Expected Signif.	Observed Signif.
BDT	4.3σ	4.6 σ
BNN	4.1σ	5.2 σ
ME	4.1σ	4.9 σ
BNNComb	4.5σ	5.0 σ



CKM Matrix Element V_{tb}

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = V_{CKM} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$\sigma(tb, tqb) \propto |V_{tb}|^2$

Additional Systematic Uncertainties for the $ V_{tb} $ Measurement	
DØ 2.3 fb⁻¹	
For the $tb+q\bar{q}b$ theory cross section	
Top quark mass	4.2%
Parton distribution functions	3.0%
Factorization scale	2.4%
Strong coupling α_s	0.5%

- Weak interaction eigenstates and mass eigenstates are not the same: there is mixing between quarks, described by CKM matrix
- General form of the W_{tb} vertex

$$\Gamma_{W_{tb}}^\mu = -\frac{g}{\sqrt{2}} V_{tb} \left\{ \gamma^\mu [f_1^L P_L + f_1^R P_R] - \frac{i\sigma^{\mu\nu}}{M_W} (p_t - p_b)_\nu [f_2^L P_L + f_2^R P_R] \right\}$$

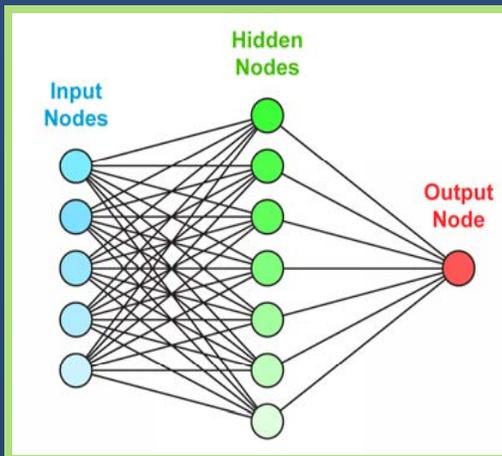
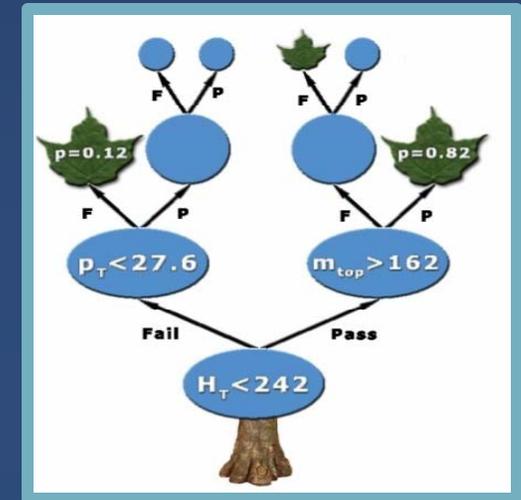
- Measurement assumes SM production mechanisms
- Pure V–A and CP-conserving interaction ($f_1^R = f_2^L = f_2^R = 0$)
- f_1^L : strength of the left-handed W_{tb} coupling, is allowed to be anomalous
- $|V_{td}|^2 + |V_{ts}|^2 \ll |V_{tb}|^2$ (supported by CDF & DØ “ratio” measurements)
- Does not assume 3 generations or unitarity of the CKM matrix

Multivariate Analyses: BDT & BNN

Use common Object and Event Kinematics, Angular Correlations, Jet Reconstruction and Top Quark Reconstruction variables

Boosted Decision Trees (BDT)

- Recover events that fail criteria in cut-based analysis
- Boosting averages the results over many trees, improving the performance
- Uses highest ranked common 64 variables



Bayesian Neural Network (BNN)

- NN train on signal and background, producing one output discriminant
- Bayesian NN average over many networks, improving the performance
- Uses highest ranked 18-28 variables in each channel

Matrix Element (ME)

- Method pioneered by DØ for the top quark mass measurement in Run I
- Use the 4-vectors of all reconstructed leptons and jets
- Use Feynman diagrams to compute an event probability density for signal and background hypotheses

transfer function: mapping from parton-level variables (y) to reconstruction-level variables (x)

differential cross section
(LO matrix element)

parton distribution functions

$$P_i(\vec{x}) = \frac{1}{\sigma} \int \dots \int \sum_{comb} d^n \sigma_i(\vec{y}) dq_1 dq_2 f(q_1) f(q_2) W(\vec{x} | \vec{y})$$

Calculate a discriminant using above probability:

$$D_S(\vec{x}) = \frac{P_S(\vec{x})}{P_S(\vec{x}) + P_{bckg}(\vec{x})}; \quad S = tb \text{ or } tqb$$

- Uses events with 2 and 3 jets only
- Split the sample in high and low H_T