Search for Single Top Quark Production at DØ in Run II

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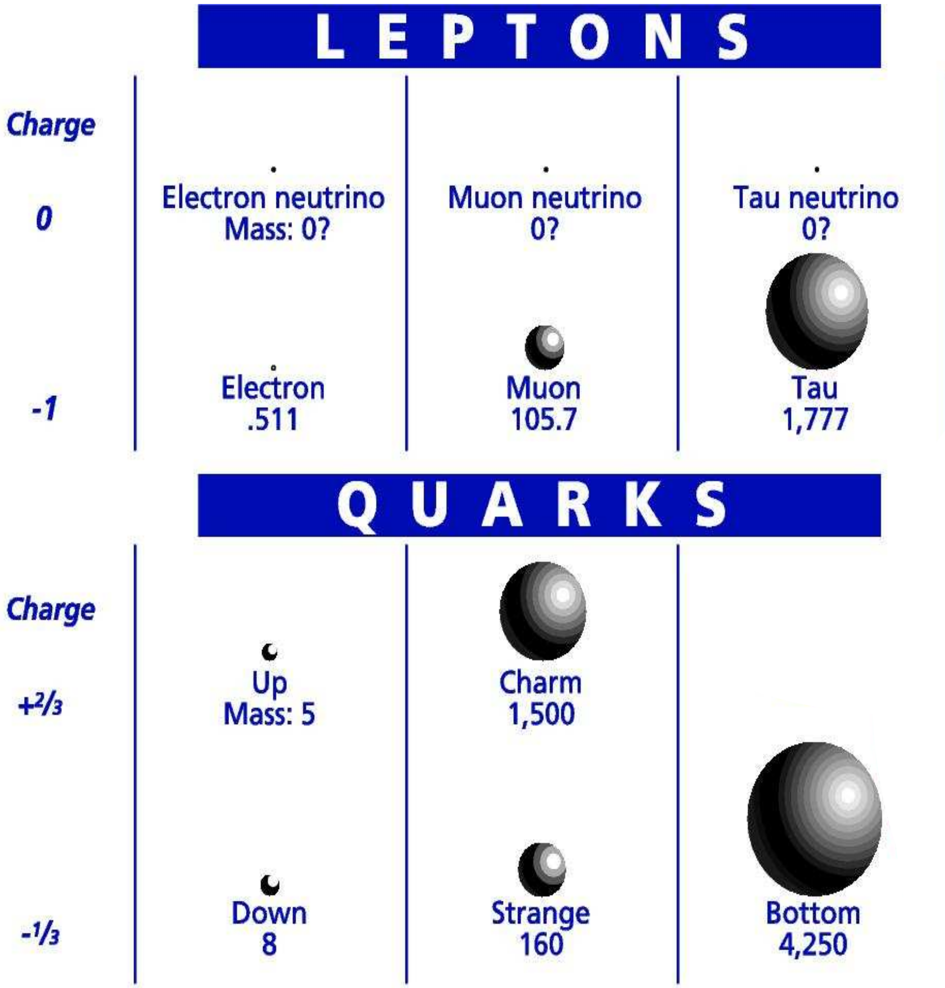
Thank You!

- This is the result of the work of many people
  - One of the most advanced analyses done so far at DØ
  - Relying on detailed understanding and modeling of data
- Thanks to everyone!
  - The single top working group at DØ
    - This result was a group effort
    - Consider this as your award, too
  - The top quark physics group at DØ
  - The DØ detector, operations, and trigger groups
  - Mentors and others whose support made this possible

Fundamental Fermions



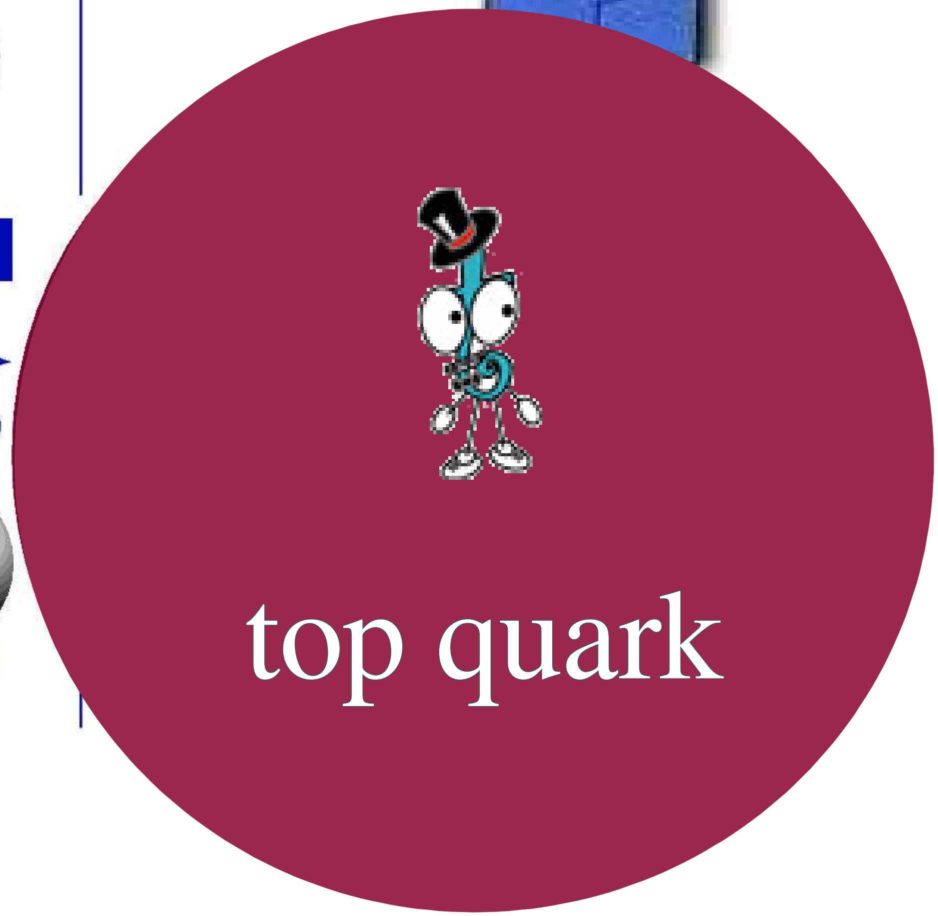
Fundamental Fermions

LEPTONS

Charge			
0	Electron neutrino Mass: 0?	Muon neutrino 0?	Tau neutrino 0?
-1	Electron .511	Muon 105.7	Tau 1,777

QUARKS

Charge			
+2/3	Up Mass: 5	Charm 1,500	Top ~180,000
-1/3	Down 8	Strange 160	Bottom 4,250

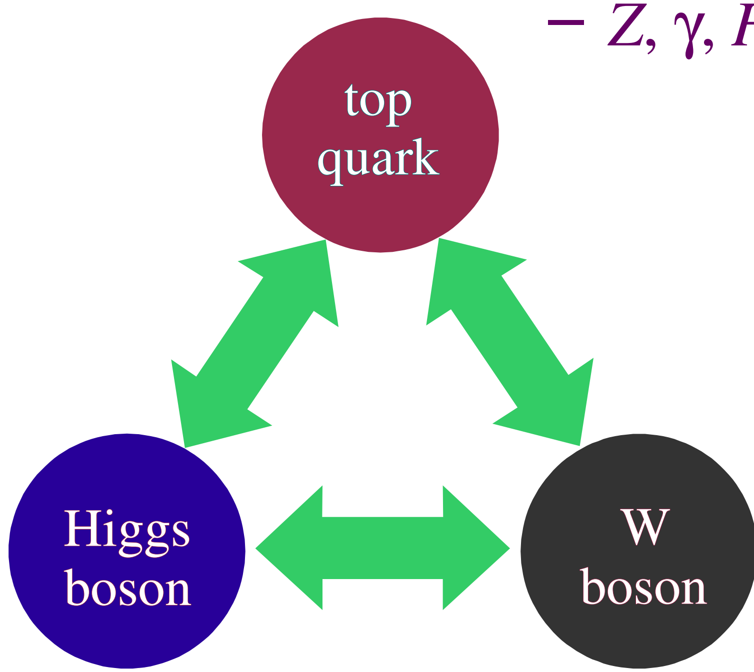


Experimentally known:

- Top quark mass 178.0 ± 4.3 GeV
- SM strong interaction
- Top quark usually decays to W boson and b quark

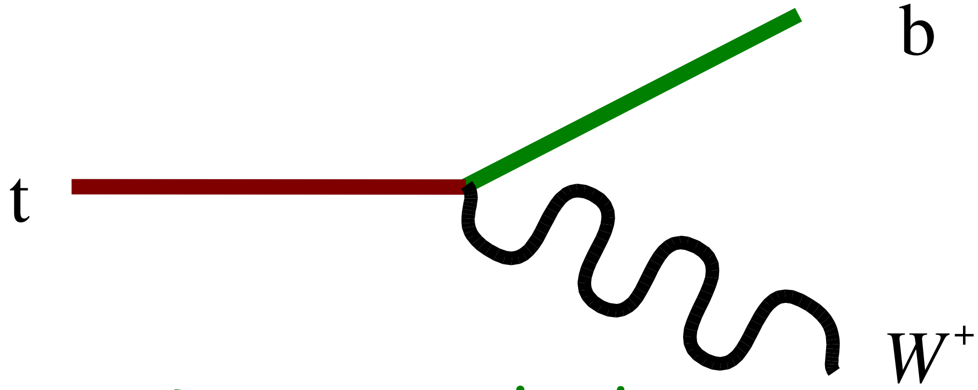
Top quark unknowns:

- Electroweak interaction?
  - Strength? – CKM mixing angle?
  - Structure?
    - Modified in new physics models of EWSB
- Other couplings?
  - *Z*, γ, *H*? – New physics?



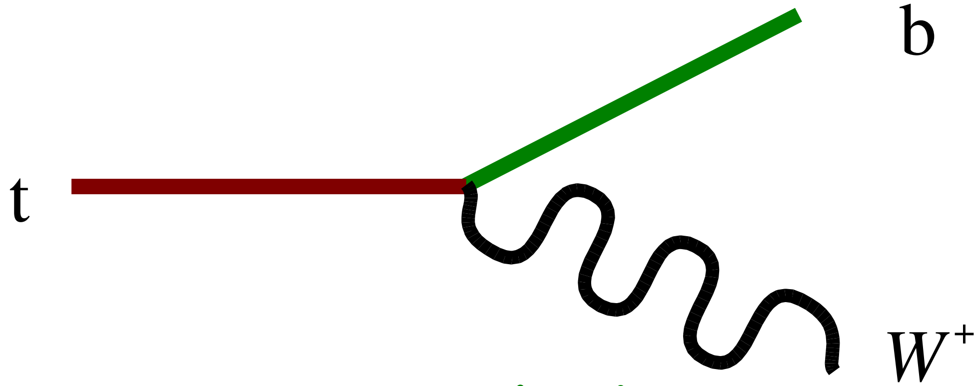
Key to electroweak symmetry breaking

Top Quark Electroweak Charged Current Interaction

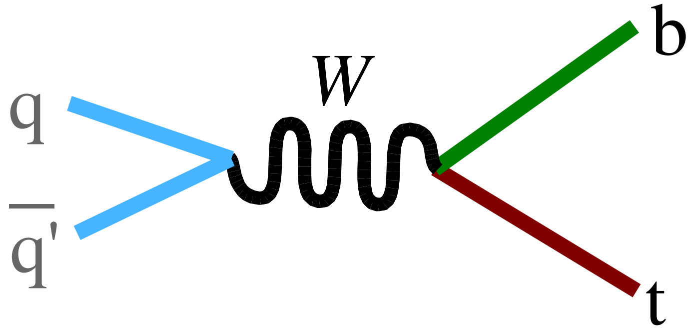


Top quark decay

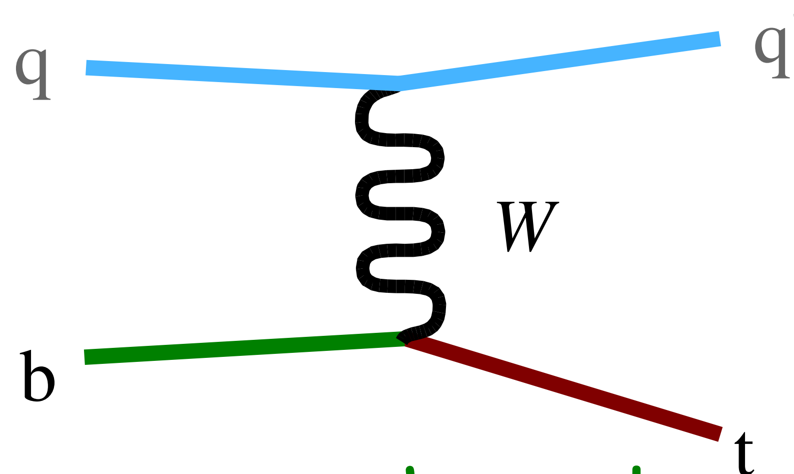
Top Quark Electroweak Charged Current Interaction



Top quark decay



s-channel single top production



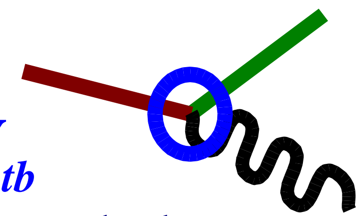
t-channel single top production

Tevatron Single Top Goals

- Observe single top quark production
- Measure production cross sections

	s-channel	*t-channel*	*s+t*
NLO calculation:	**0.88pb (±8%)**	**1.98pb (±11%)**	
Run I 95% CL limits, DØ:	< 17pb	< 22pb	
CDF:	< 18pb	< 13pb	< 14pb
Run II CDF 95% CL limits:	< 14pb	< 10pb	< 18pb

  - Direct measurement of CKM matrix element V_{tb}



- Look for physics beyond the Standard Model
- Study top quark spin correlations – probe V-A
- Study as background to associated Higgs production

Experimental Setup

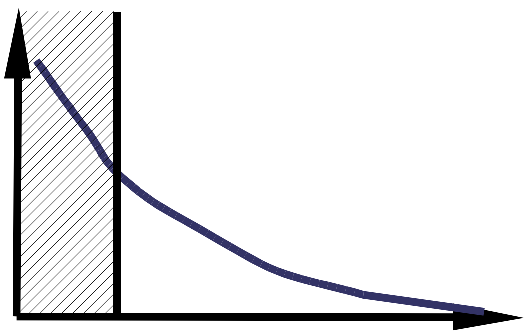
- **Fermilab Tevatron**
  - **Proton-Antiproton Collider**
  - **CM Energy 1.96TeV**
- **DØ experiment**
  - **Dataset of $230pb^{-1}$ used in this analysis**

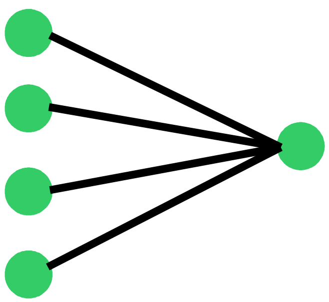
CDF

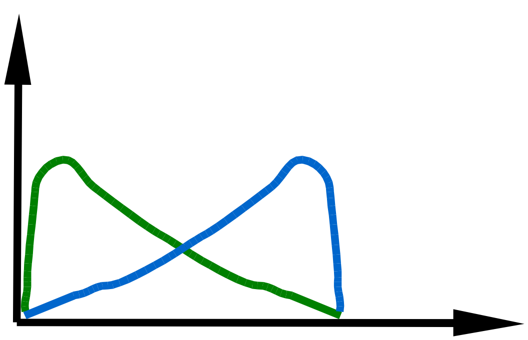
Analysis Outline

Goal:

Maximize Sensitivity







1. Event Selection
   - Select *W*-like events
   - Maximize acceptance
   - Model backgrounds
2. Separate signal from backgrounds
   - Find discriminating variables
   - Combine in multivariate analysis
3. Determine cross section
   - Binned likelihood
   - Bayesian statistical analysis

Event Selection

- Lepton: $p_T > 15\text{GeV}$
  - Electrons and muons
- Neutrino: $\not{E}_T > 15\text{GeV}$

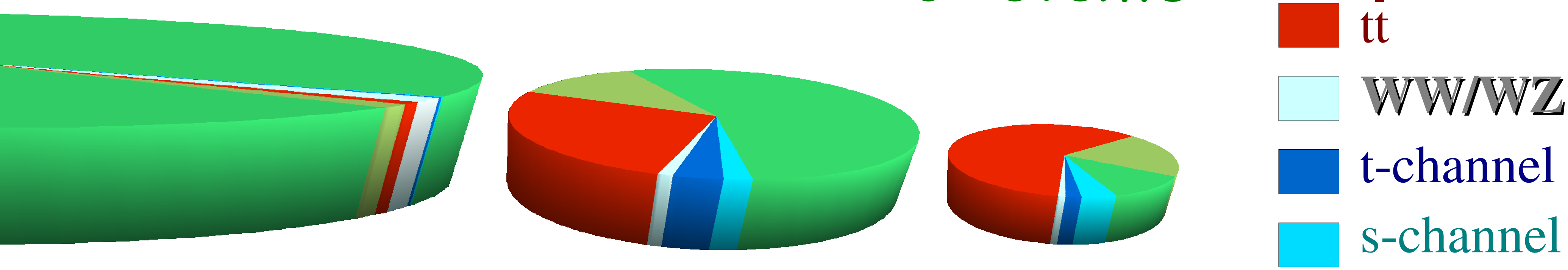
	s-channel	t-channel
Signal yield	5.5	8.5
Signal/bkgnd	1:52	1:32

- Jets: $2 \le n_{jets} \le 4$

  $p_T > 15\text{GeV}$

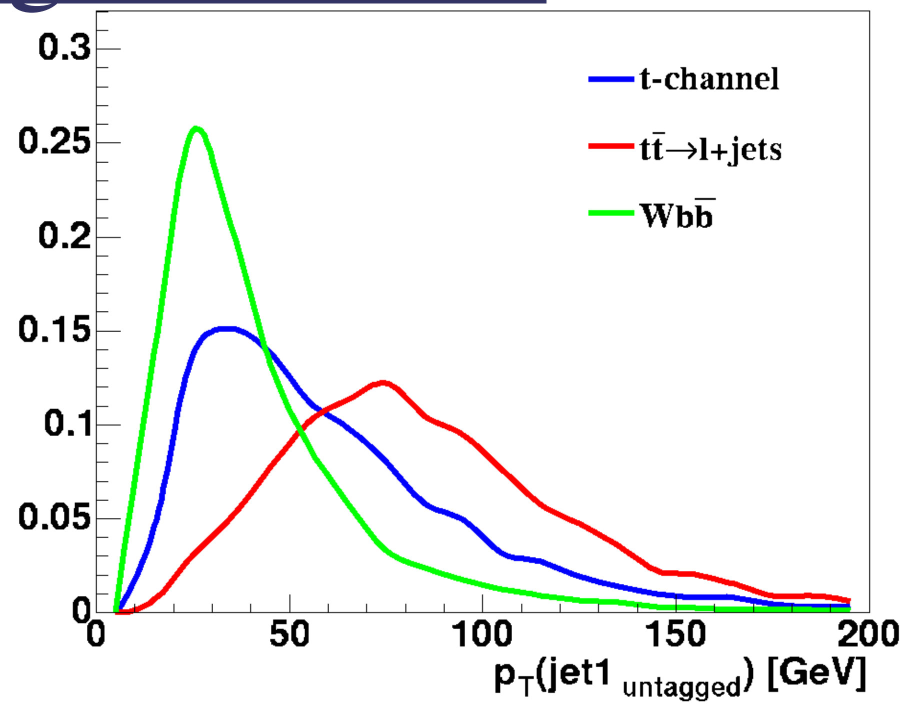
  Leading jet: $p_T > 25\text{GeV}$
- Secondary vertex b-quark jet tagging

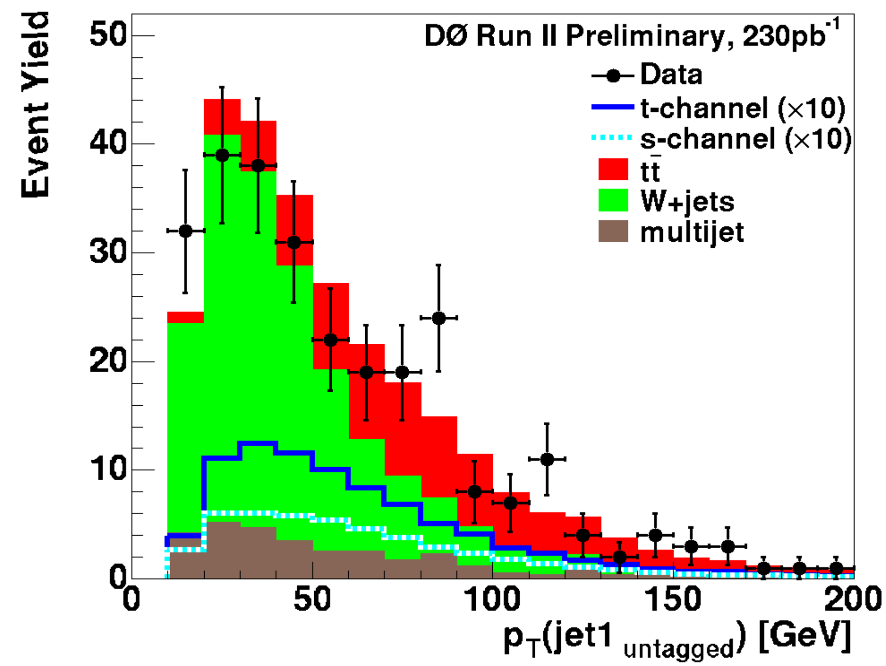
Pre-tagged	=1 b-tag	≥2 b-tags
7100 events	252 events	31 events



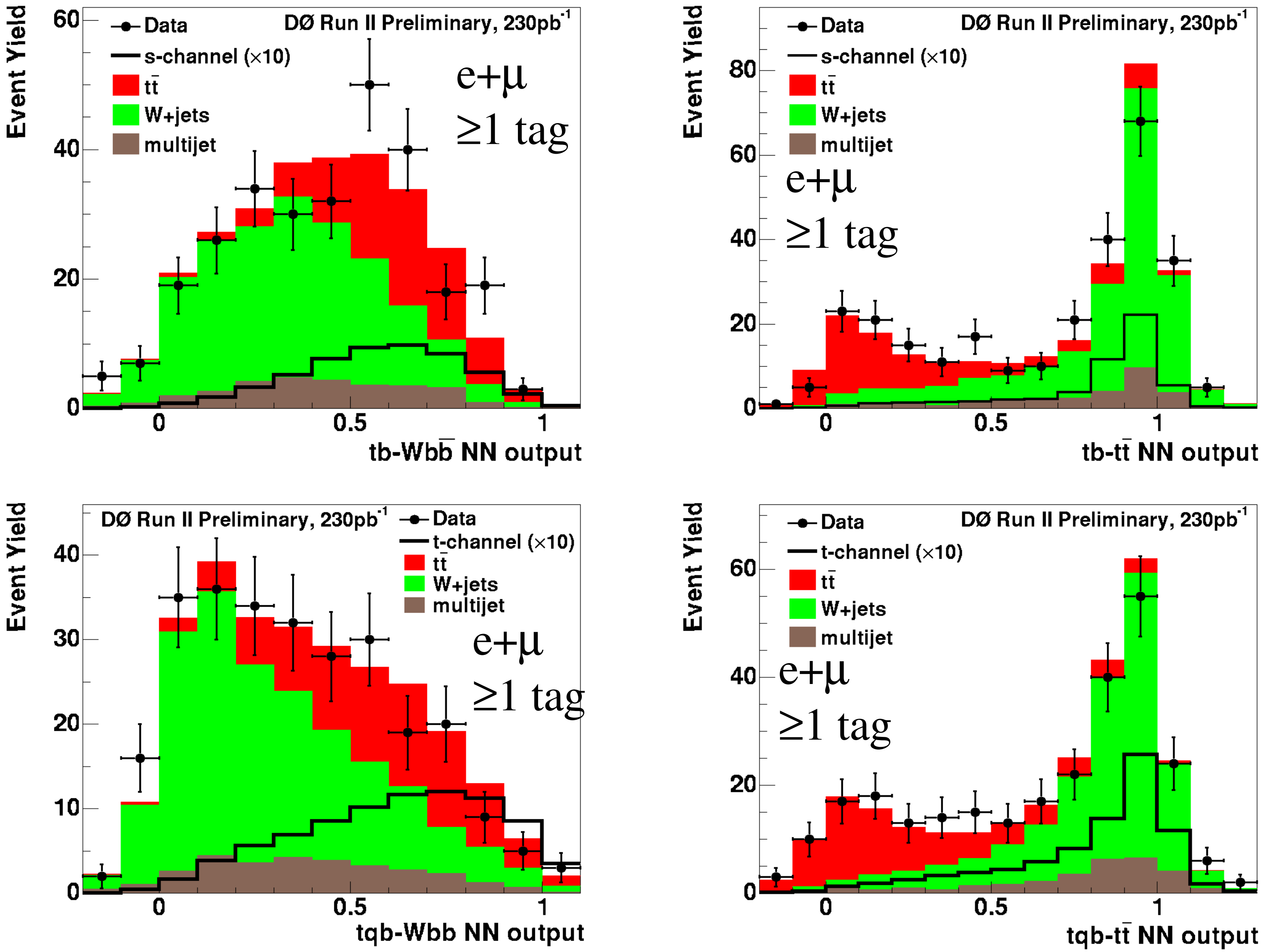
Discriminating Variables

- Object kinematics
  - Jet p_T for different jets
    - Tagged, untagged,...
- Event kinematics
  - H (total energy)
  - H_T (transverse energy)
  - M (invariant mass)
  - M_T (transverse mass)
  - Summing over various objects in the event
- Angular variables
  - Jet-jet separation
  - Jet pseudorapidity (t-channel)
  - Top quark spin





Event Analysis using Neural Networks



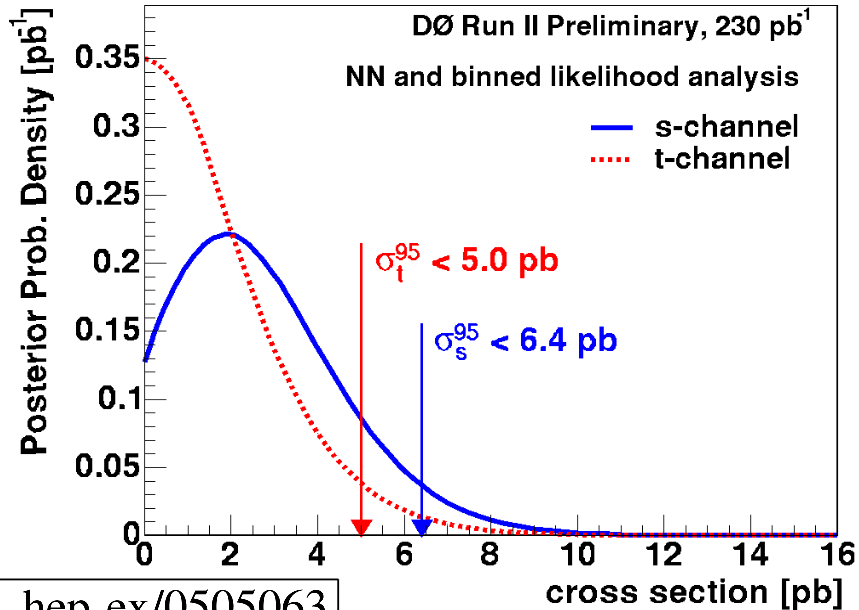
Result

- No evidence for single top signal
  - ➔ Set 95% CL upper cross section limit
  - – Using Bayesian approach and binned likelihood
    - Built from 2-d histogram of Wbb NN vs tt NN
    - Including bin-by-bin systematics and correlations

Expected/Observed limit:

σ_s < 4.5 / 6.4 pb

σ_t < 5.8 / 5.0 pb

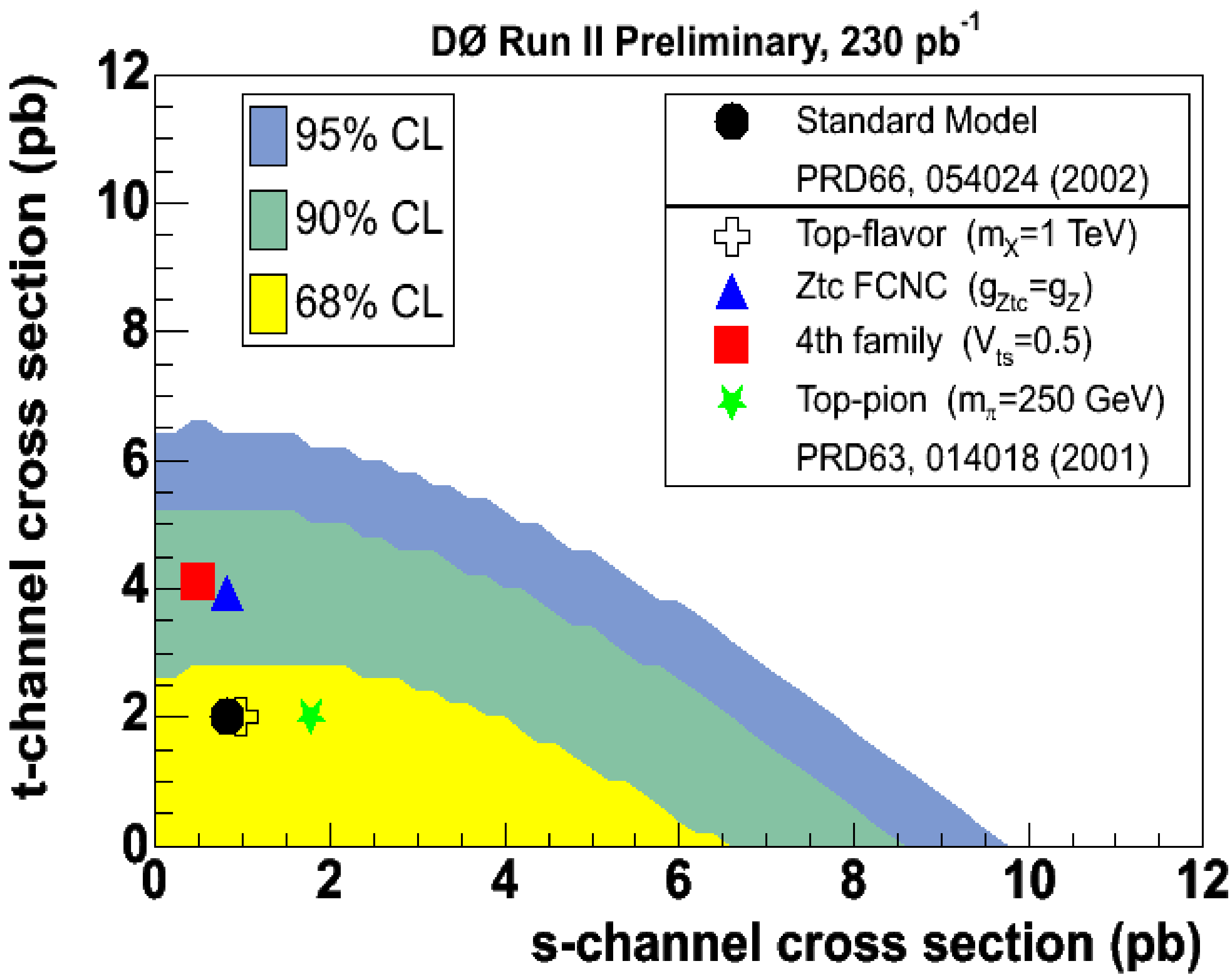


Submitted to PLB, hep-ex/0505063

Factor 2 improvement in sensitivity

Sensitivity to New Physics

using only muon channel data



using only electron channel data

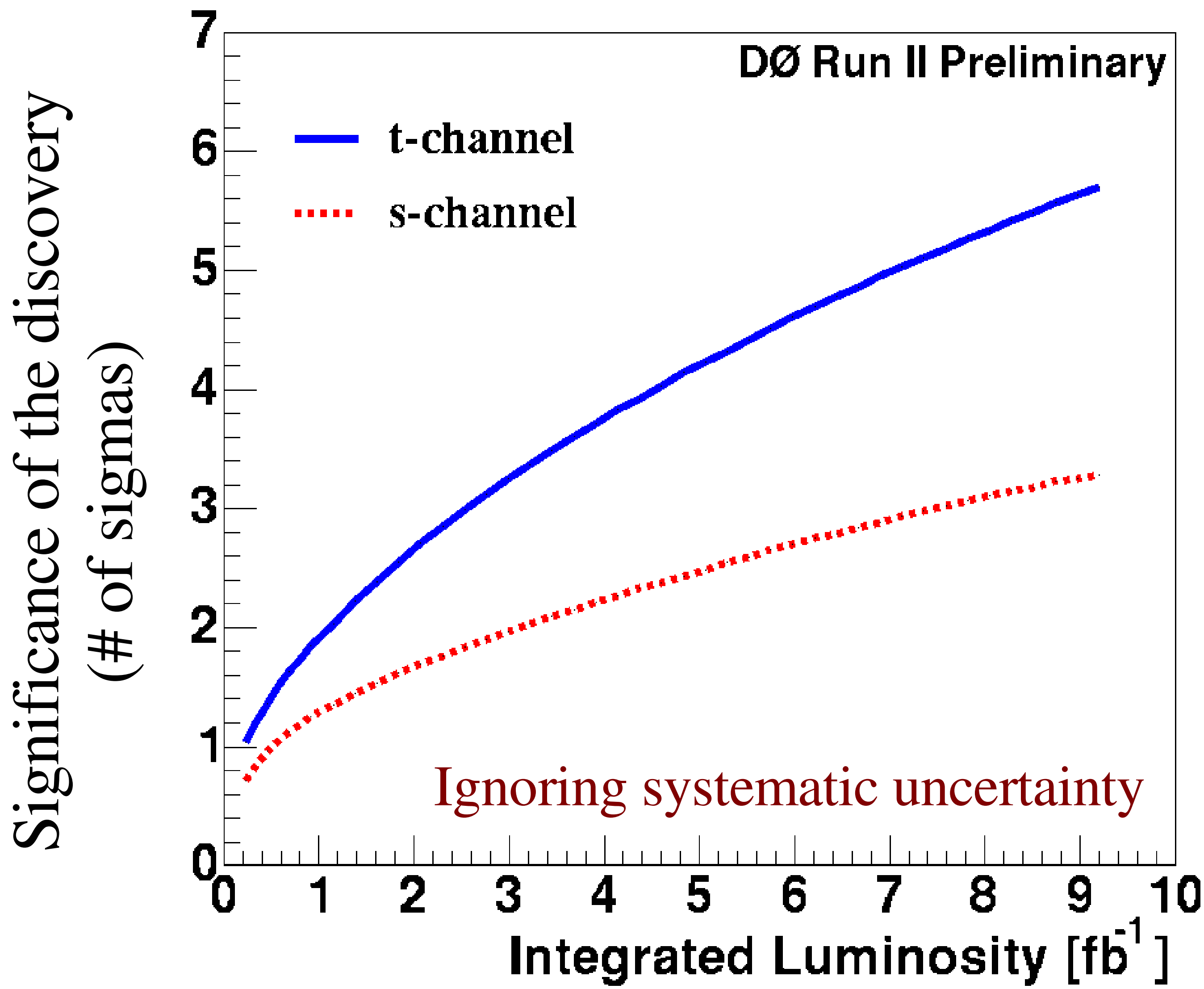
Conclusions

- DØ Run II single top analysis with 230pb^{-1} completed
  - 95% CL cross section limits of $\sigma_s < 6.4$ pb, $\sigma_t < 5.0$ pb
  - Factor 2 improvement over previous limits
  - Reaching sensitivity to new physics
  - Sufficient sensitivity to discover SM single top with few fb^{-1}
- Single Top is important for Run II
  - New and old (SM) physics
- This is just the beginning
  - Expect ×3 dataset by end of year
  - Improve all aspects of the analysis

Dawn of Run II discoveries

Backup Slides

Luminosity needed for observation

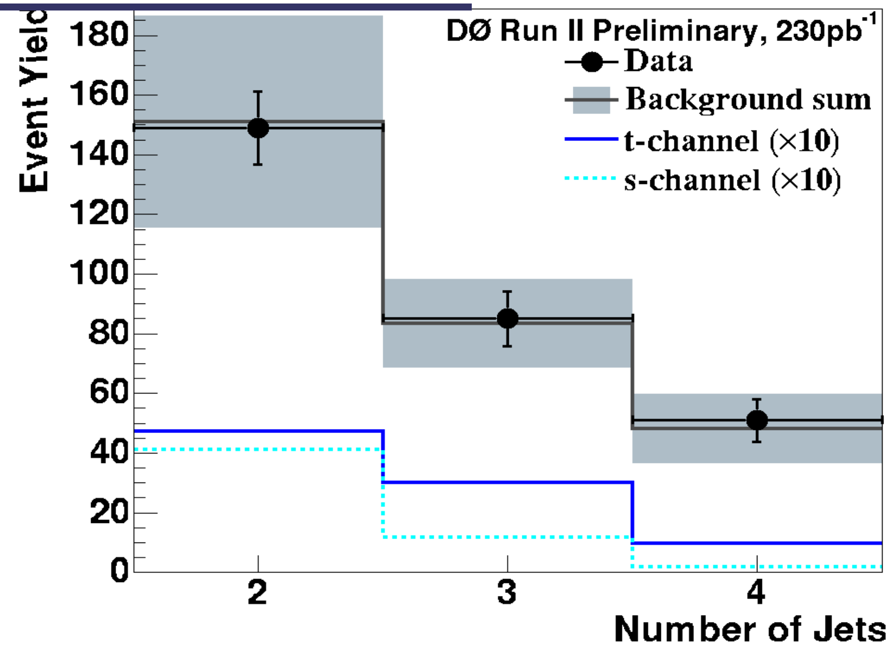


Variables:

	Signal-Background Pairs			
	tb		tqb	
	Wbb	$t\bar{t}$	Wbb	$t\bar{t}$
Individual object kinematics				
$p_T(\text{jet1}_{\text{tagged}})$	✓	✓	✓	—
$p_T(\text{jet1}_{\text{untagged}})$	—	—	✓	✓
$p_T(\text{jet2}_{\text{untagged}})$	—	—	—	✓
$p_T(\text{jet1}_{\text{nonbest}})$	✓	✓	—	—
$p_T(\text{jet2}_{\text{nonbest}})$	✓	✓	—	—
Global event kinematics				
$M_T(\text{jet1,jet2})$	✓	—	—	—
$p_T(\text{jet1,jet2})$	✓	—	✓	—
$M(\text{alljets})$	✓	✓	✓	✓
$H_T(\text{alljets})$	—	—	✓	—
$M(\text{alljets} - \text{jet1}_{\text{tagged}})$	—	—	—	✓
$H(\text{alljets} - \text{jet1}_{\text{tagged}})$	—	✓	—	✓
$H_T(\text{alljets} - \text{jet1}_{\text{tagged}})$	—	—	—	✓
$p_T(\text{alljets} - \text{jet1}_{\text{tagged}})$	—	✓	—	✓
$M(\text{alljets} - \text{jet}_{\text{best}})$	—	✓	—	—
$H(\text{alljets} - \text{jet}_{\text{best}})$	—	✓	—	—
$H_T(\text{alljets} - \text{jet}_{\text{best}})$	—	✓	—	—
$M(\text{top}_{\text{tagged}}) = M(W,\text{jet1}_{\text{tagged}})$	✓	✓	✓	✓
$M(\text{top}_{\text{best}}) = M(W,\text{jet}_{\text{best}})$	✓	—	—	—
$\sqrt{\hat{s}}$	✓	—	✓	✓
Angular variables				
$\Delta R(\text{jet1,jet2})$	✓	—	✓	—
$Q(\text{lepton}) \times \eta(\text{jet1}_{\text{untagged}})$	—	—	✓	✓
$\cos(\text{lepton}, Q(\text{lepton}) \times z)_{\text{top}_{\text{best}}}$	✓	—	—	—
$\cos(\text{lepton}, \text{jet1}_{\text{untagged}})_{\text{top}_{\text{tagged}}}$	—	—	✓	—
$\cos(\text{alljets}, \text{jet1}_{\text{tagged}})_{\text{alljets}}$	—	—	✓	✓
$\cos(\text{alljets}, \text{jet}_{\text{nonbest}})_{\text{all jets}}$	—	✓	—	—

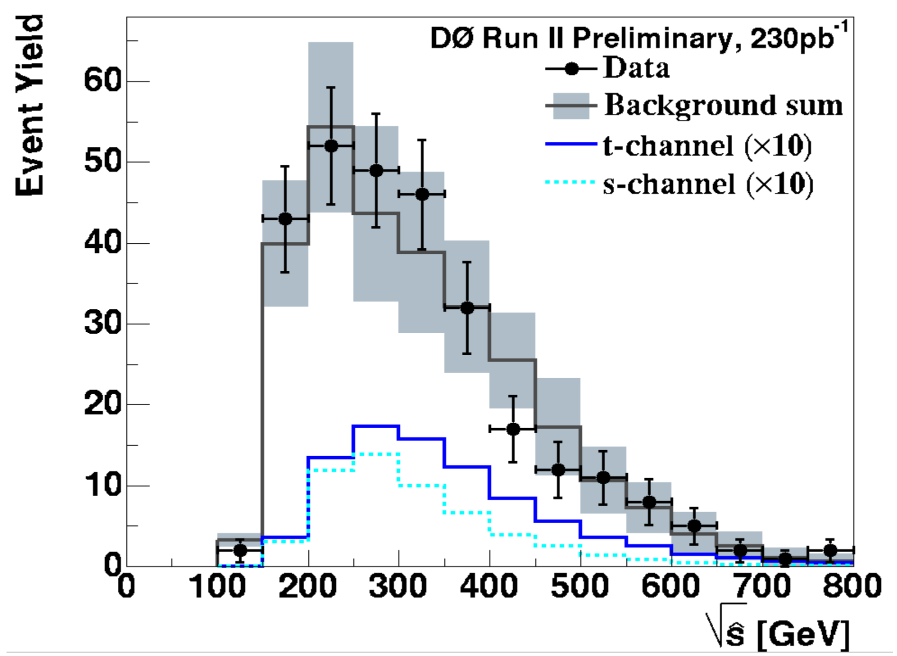
Systematic Uncertainties

Monte Carlo Systematic Uncertainties	
Theory cross sections	15 %
SVT modeling, single (double) tag	10 %(20 %)
Jet Energy Scale	10 %
Trigger Modeling	6 %
Jet Fragmentation	6 %
Jet ID	5 %
ℓ ID	5 %



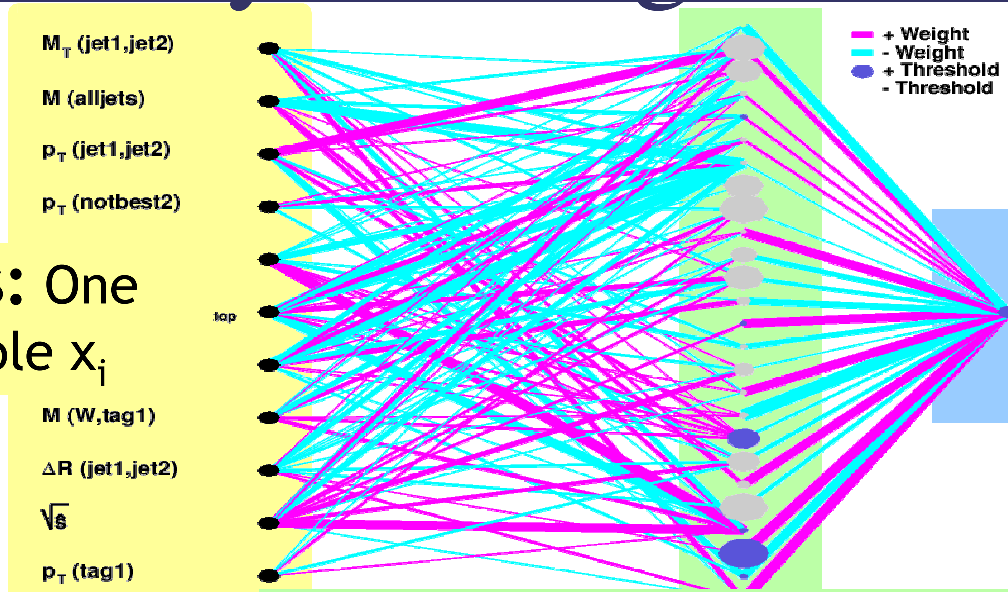
- Some uncertainties also affect shape
  - JES, b-tag and trigger modeling
- Total Uncertainty

	=1 tag	≥2 tags
Signal acceptance	15%	25%
Background sum	10%	26%



Result is statistics limited

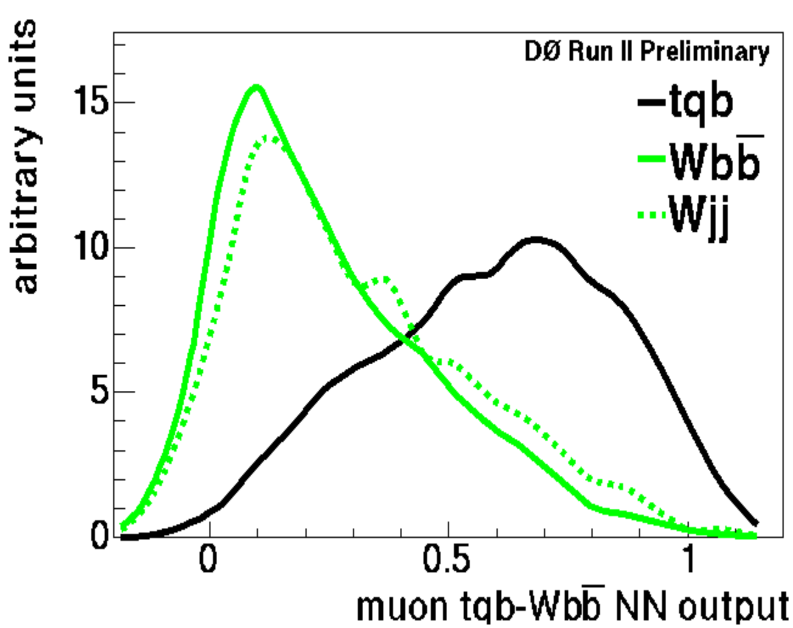
Event Analysis using Neural Networks

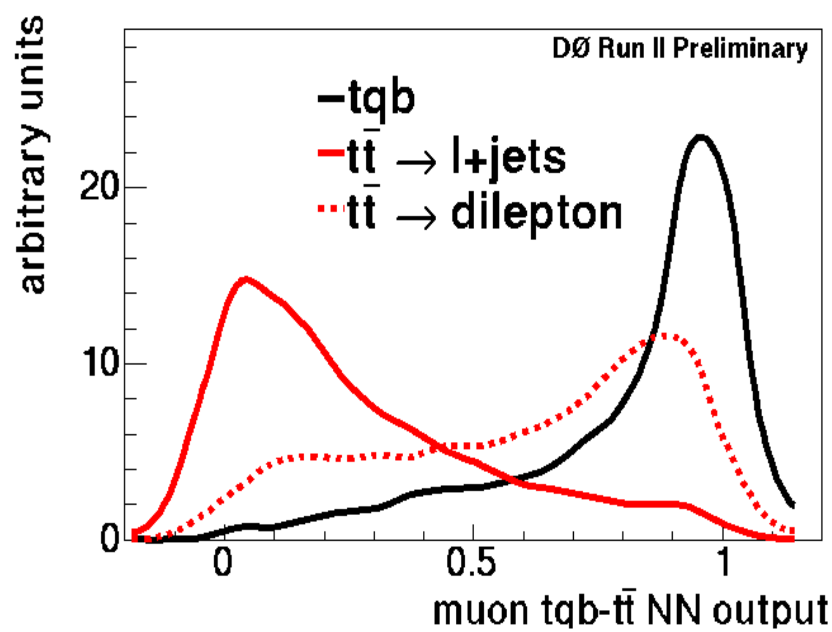


Input Nodes: One for each variable x_i

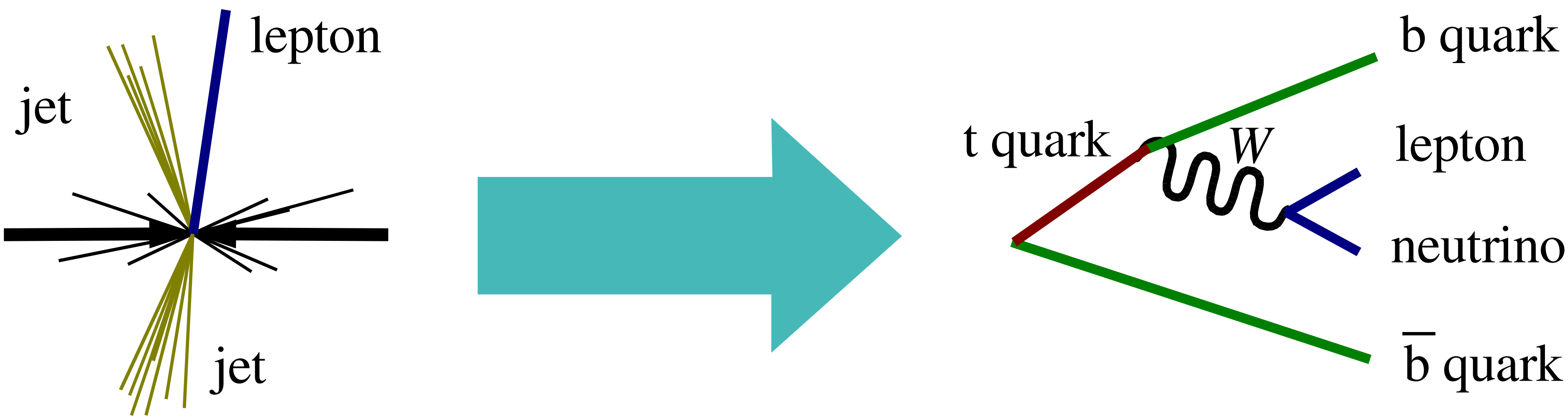
Output Node: Linear combination of hidden nodes

Hidden Nodes: Sigmoid dependent on the input variables



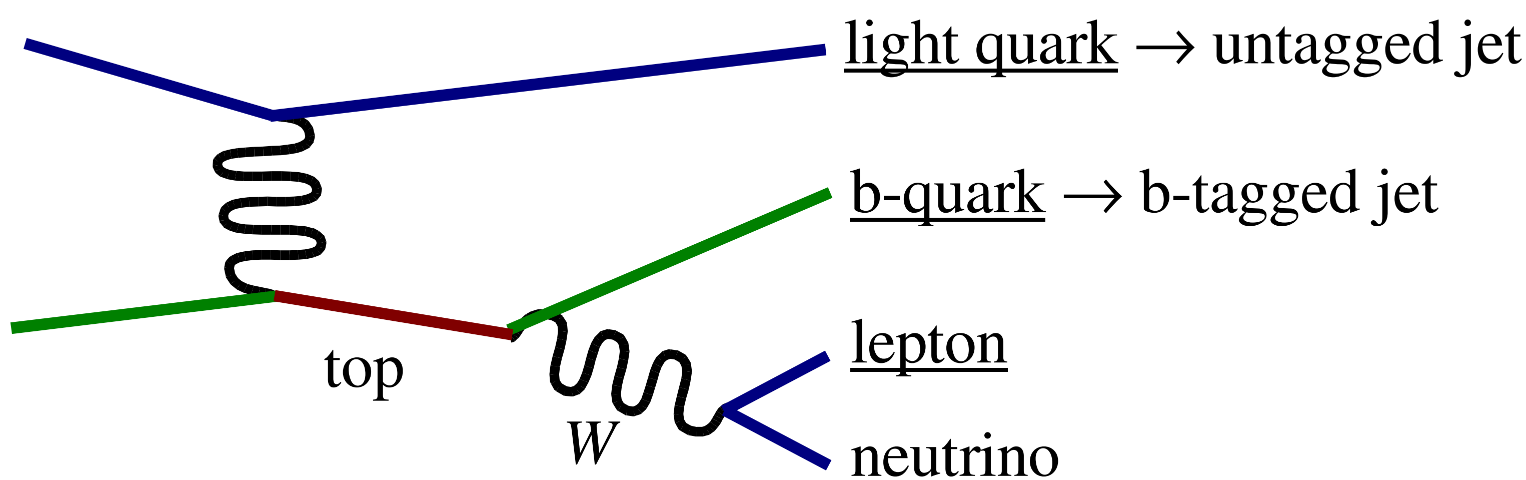


Maximize Sensitivity:
Final State Reconstruction



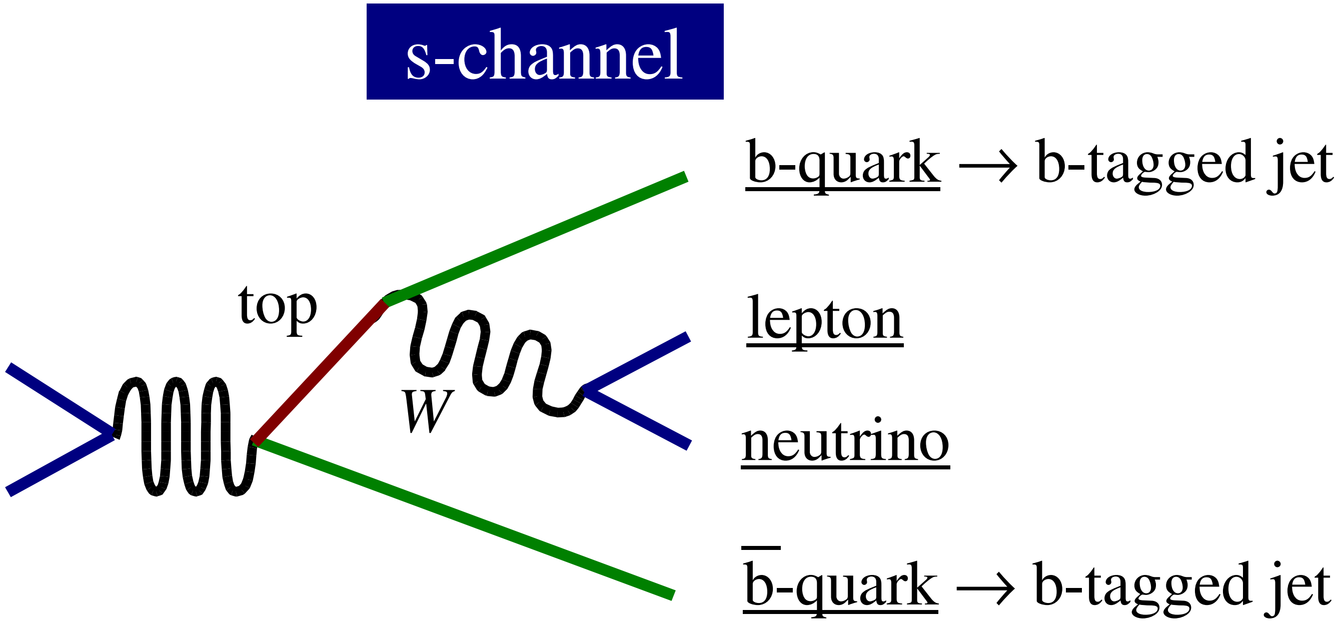
Final State Reconstruction

t-channel



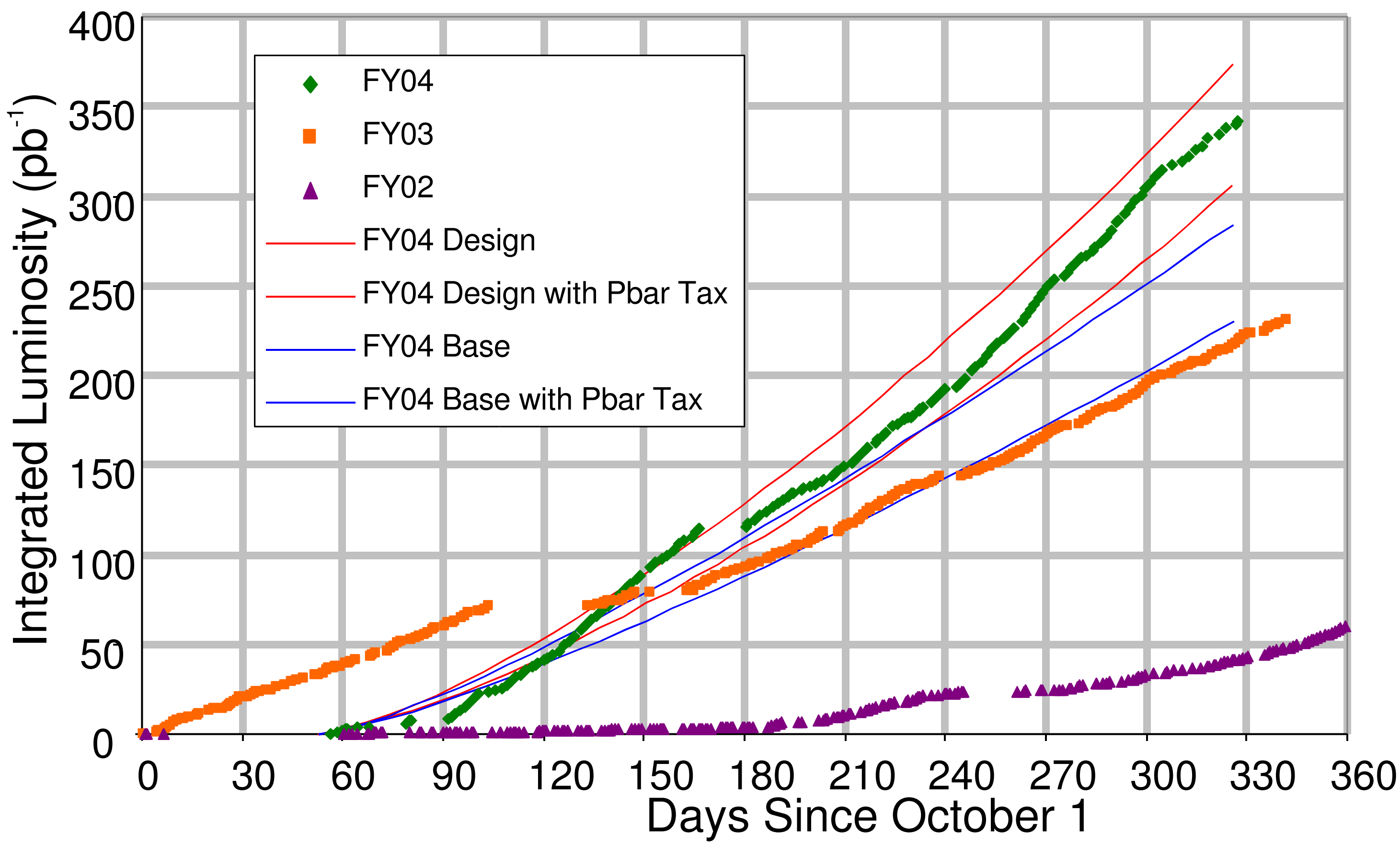
- Reconstruct *W* from lepton and $\not{E}_T$
- Reconstruct top quark from *W* and leading b-tagged jet
- Reconstruct light quark as leading untagged jet

Final State Reconstruction

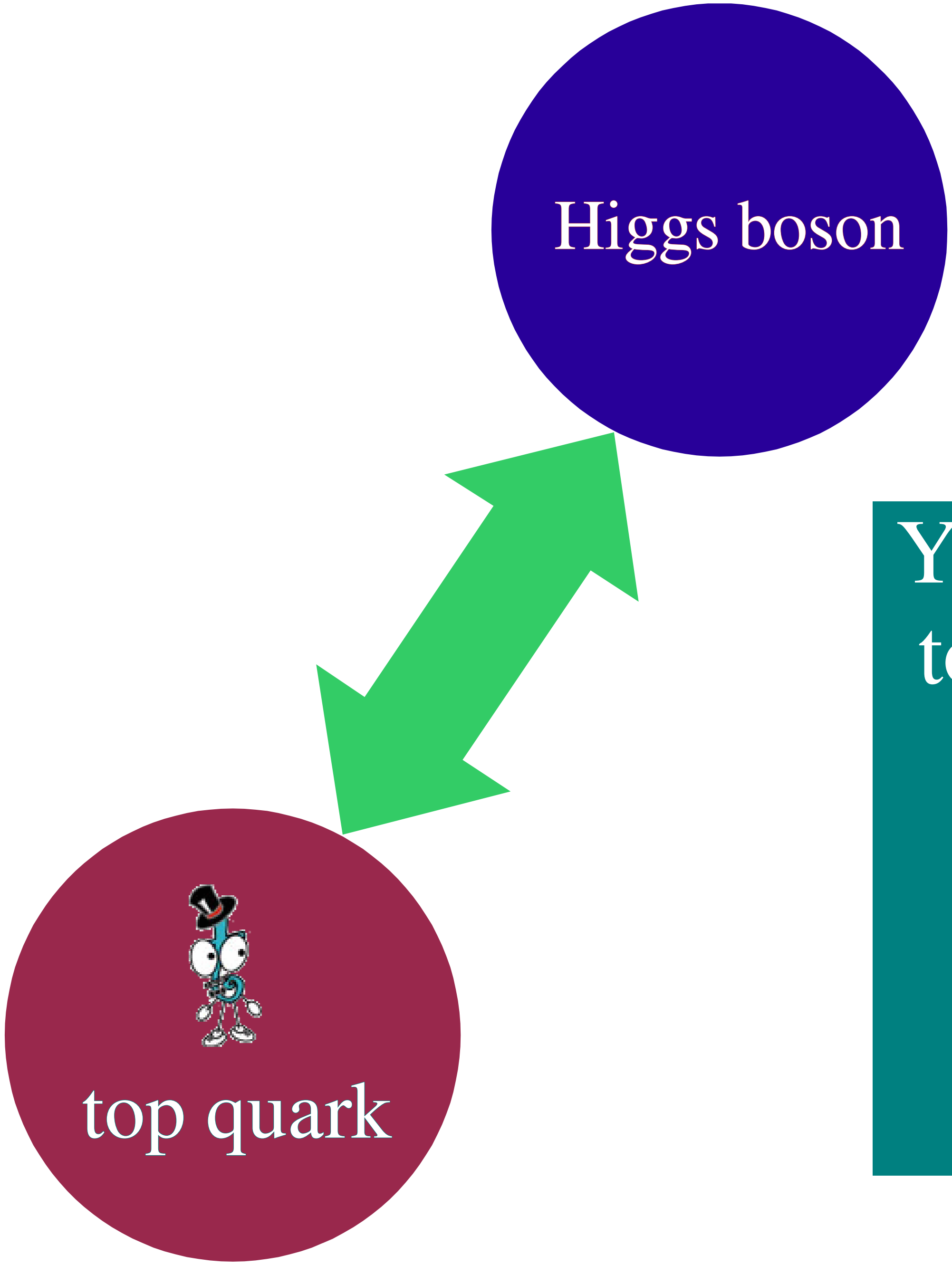


- Reconstruct *W* from lepton and $\not{E}_T$
- Reconstruct top quark from *W* and one of the jets using Best Jet Algorithm:
  - Pick jet for which *M*(*W*,jet) is closest to true top mass (175GeV)
- Reconstruct $\bar{b}$-quark as leading non-best jet

Tevatron Integrated Luminosity per year



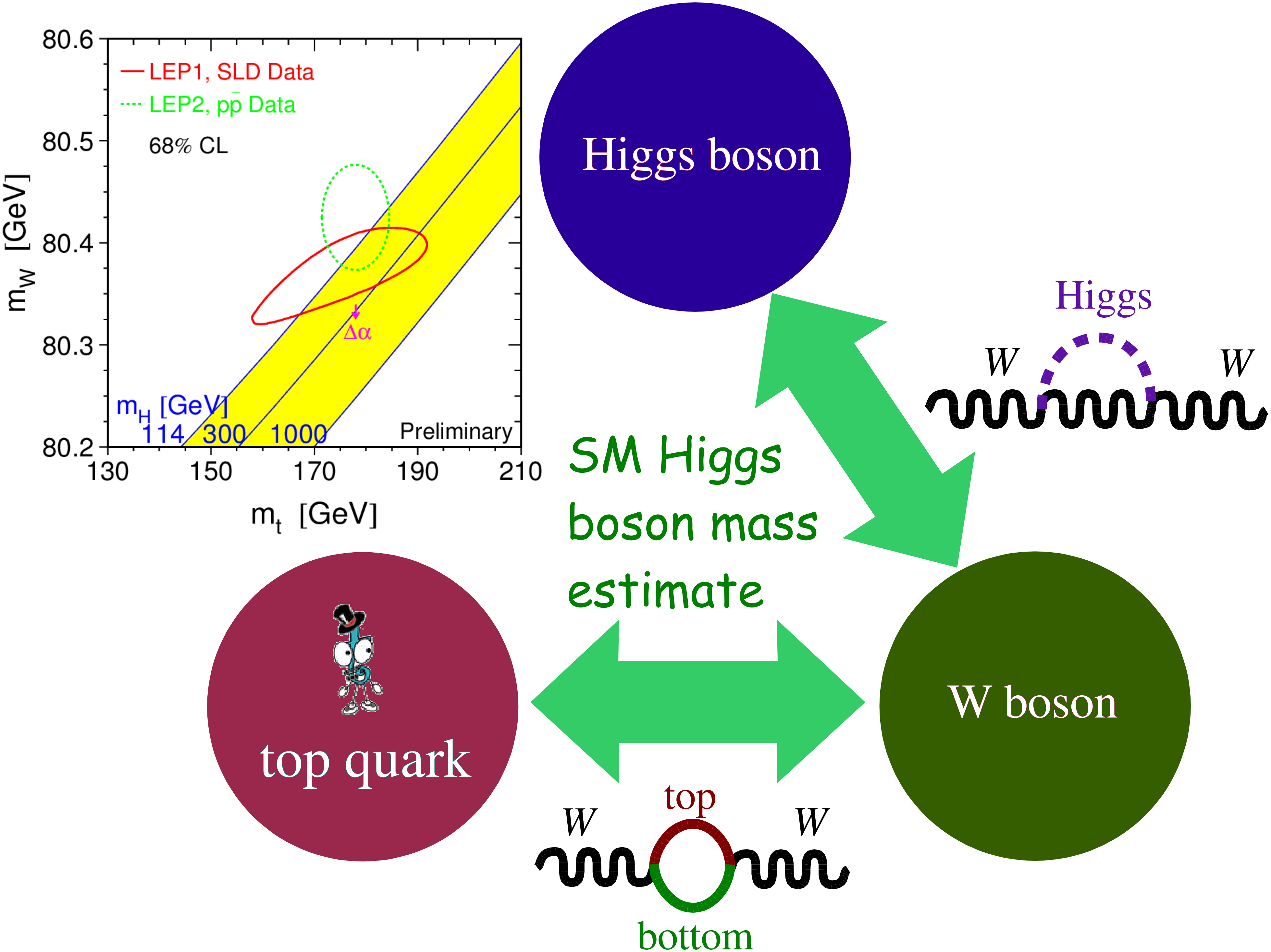
- Tevatron delivered luminosity is exceeding "baseline" and "design" projections



Yukawa coupling to Higgs field v

$$m_t = y_t \, v$$

$$y_t \sim 1$$



80.6
80.5
80.4
80.3
80.2
LEP1, SLD Data
LEP2, pp̄ Data
68% CL
Δα
m_H [GeV]
114 300 1000
Preliminary
m_W [GeV]
130 150 170 190 210
m_t [GeV]
Higgs boson
Higgs
W
W
SM Higgs boson mass estimate
top quark
W boson
top
W
W
bottom