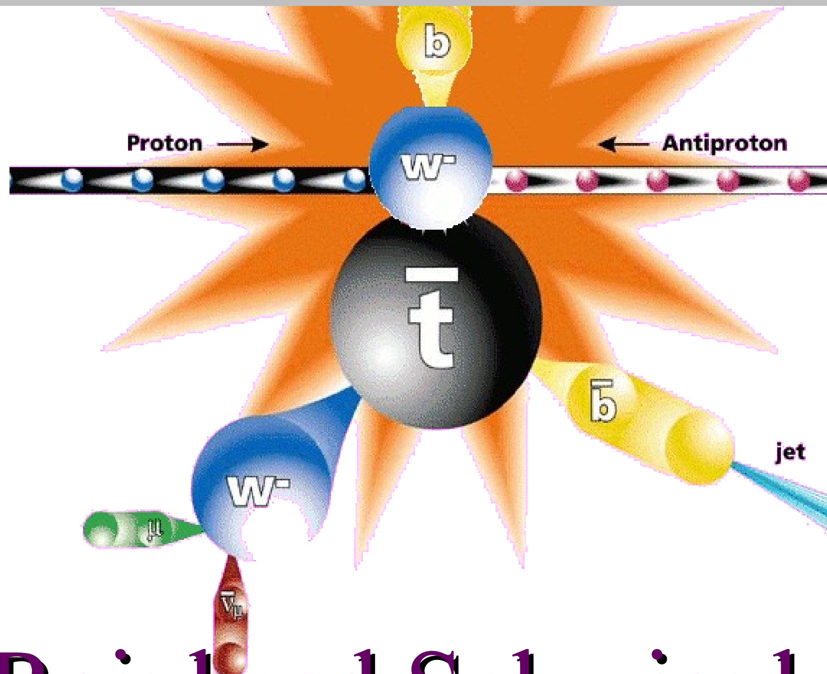
Single top quark physics at the Tevatron



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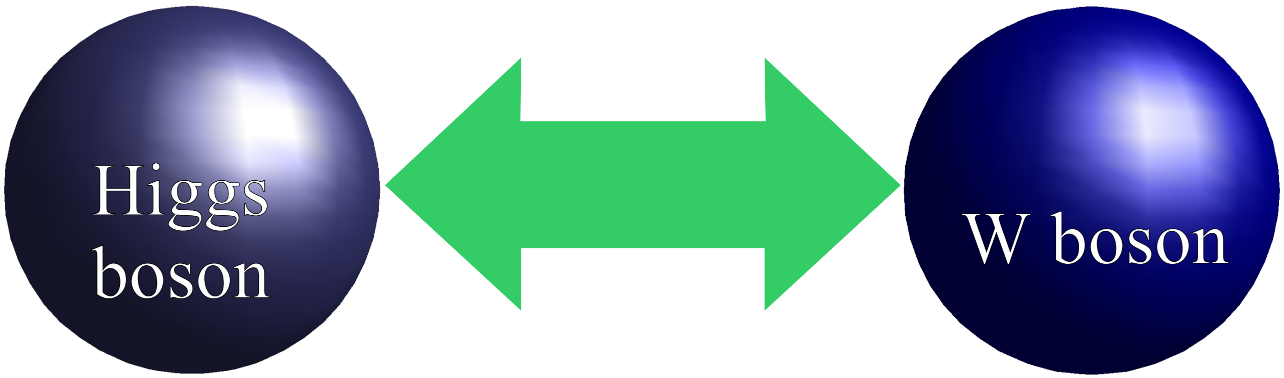
Séminaire LAL, 1er juillet 2008

Outline

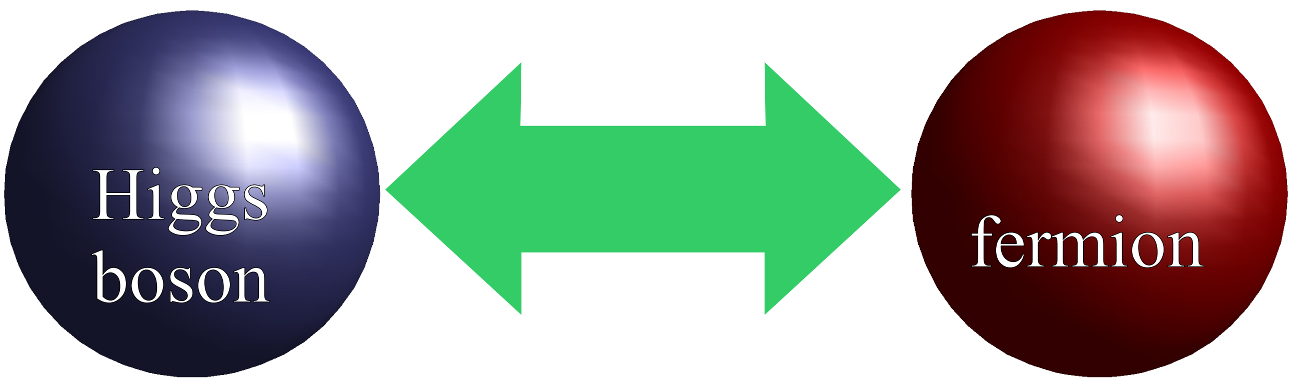
- Introduction
- Single top quark production
- DØ results
- CDF results
- LHC outlook
- Conclusions

Electroweak symmetry breaking

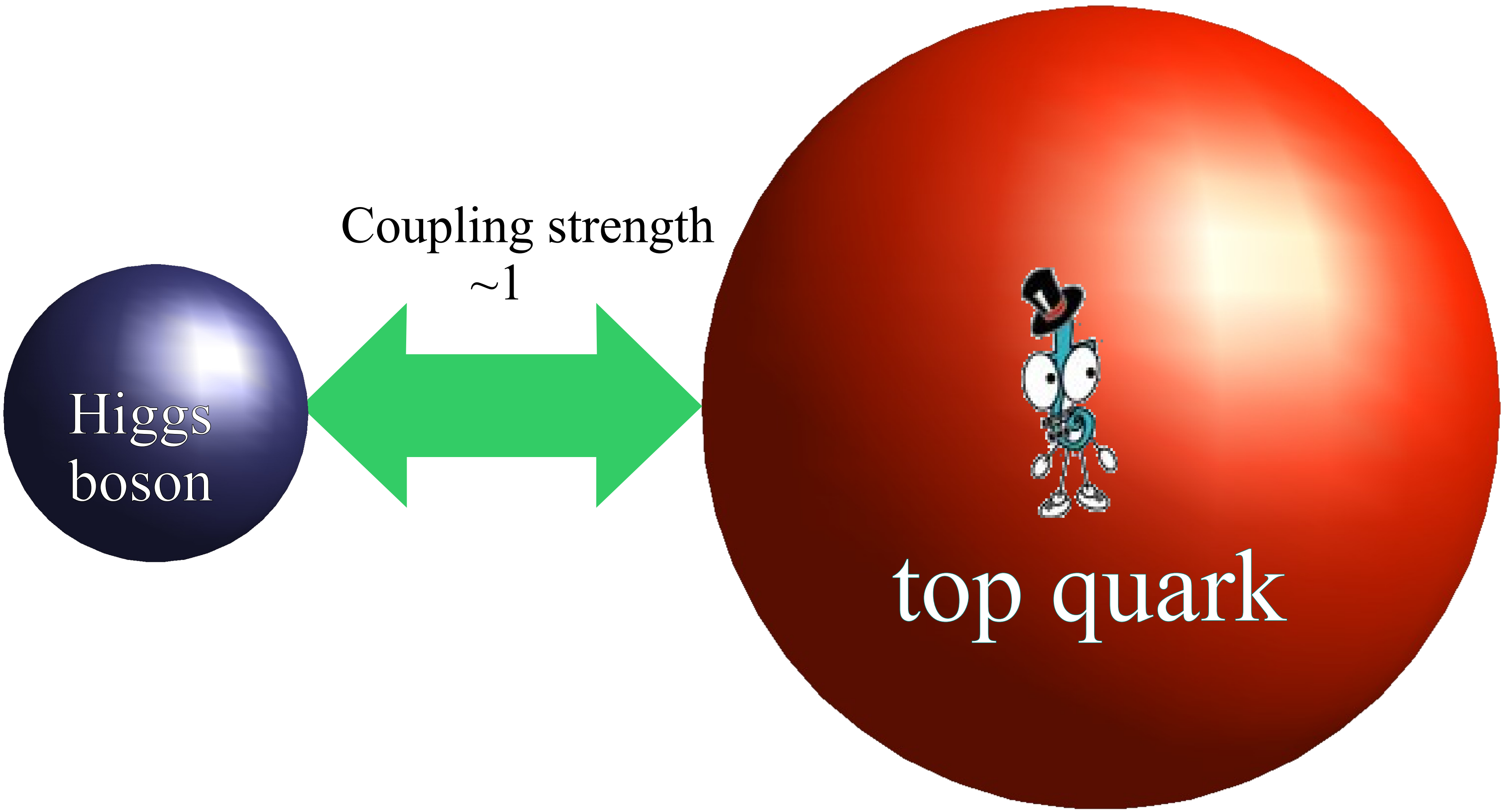
Gauge boson coupling to Higgs field



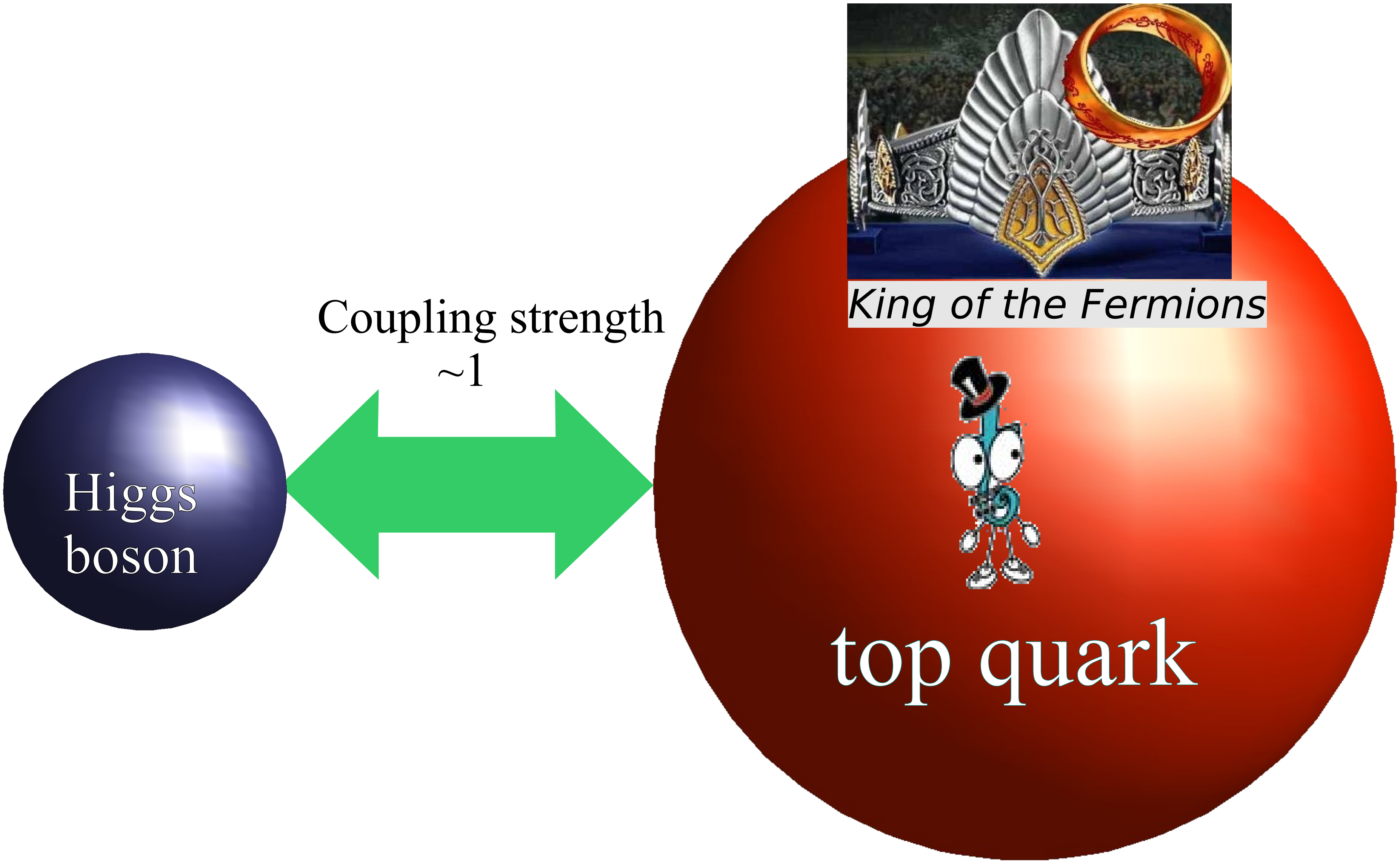
Fermions acquire mass through Higgs coupling



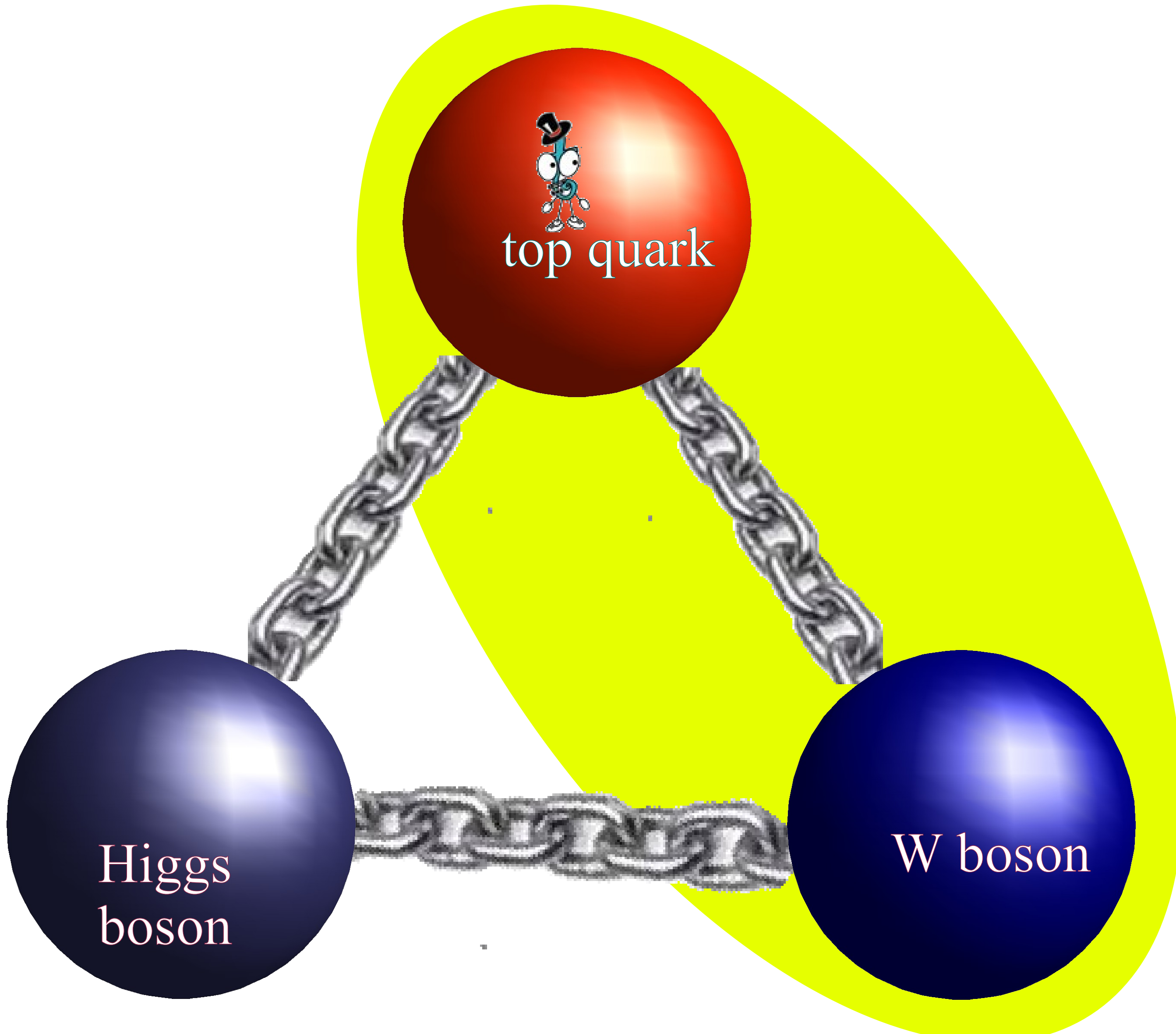
Top quark



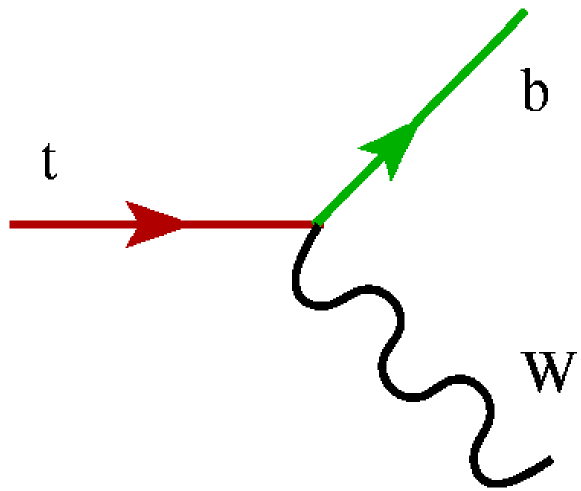
Top quark


King of the Fermions
Coupling strength
~1
Higgs
boson
top quark

Key to electroweak symmetry breaking

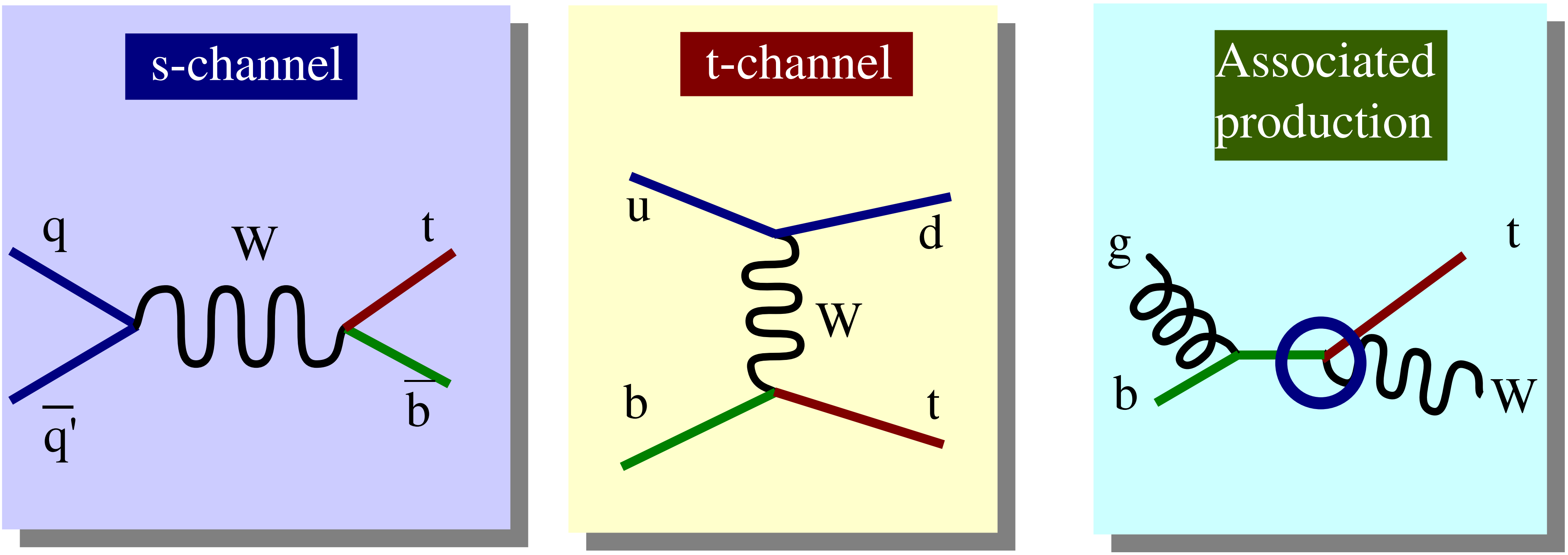


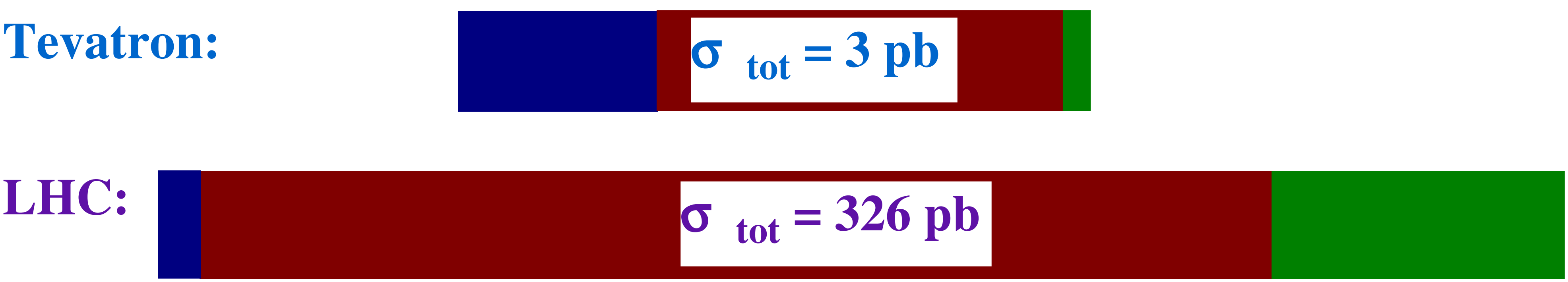
Top quark electroweak charged current interaction



top quark decay

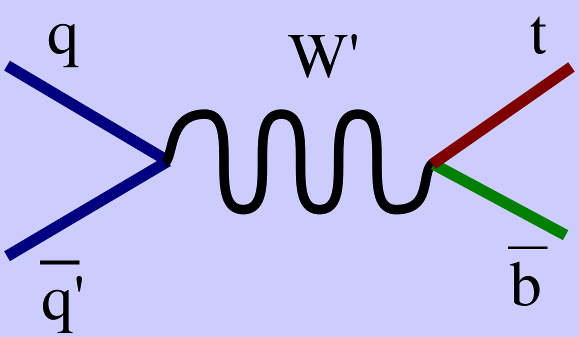
SM single top quark production





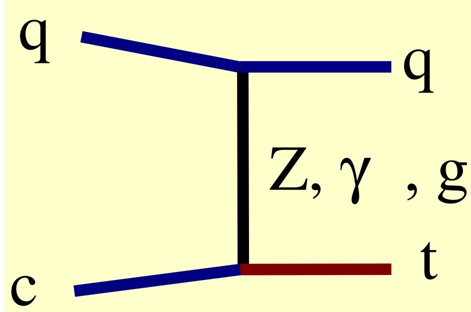
New physics

s-channel



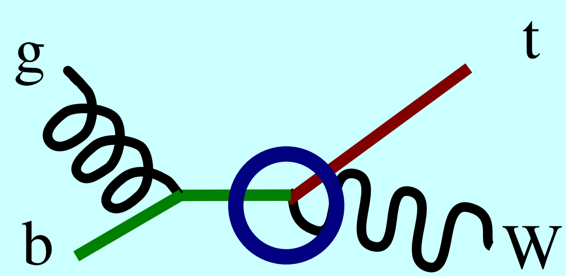
New heavy boson

t-channel



Flavor
Changing
Neutral
Current

Associated production



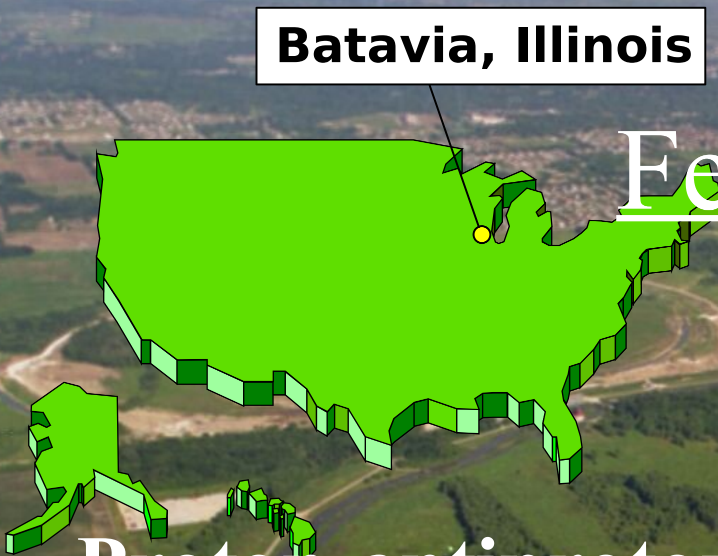
Modified
Wtb coupling

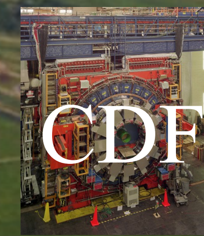
Tevatron single top goals

Production cross sections:	*s-channel*	*t-channel*
NLO calculation:	**0.88 pb (±8%)**	**1.98 pb (±11%)**

- Discover single top quark production!
- Measure production cross sections
  $\rightarrow$ CKM quark mixing matrix element V_{tb}
- Look for physics beyond the standard model
  - Coupled to the heavy top quark
- Study top quark spin correlations
- Understand as background to many other searches
- Explore analysis techniques that will also be used elsewhere

Experimental setup: Fermilab Tevatron in Run II





Proton-antiproton collider

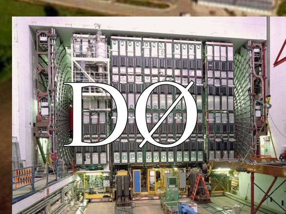
CM energy 1.96TeV

→ ***Energy frontier***

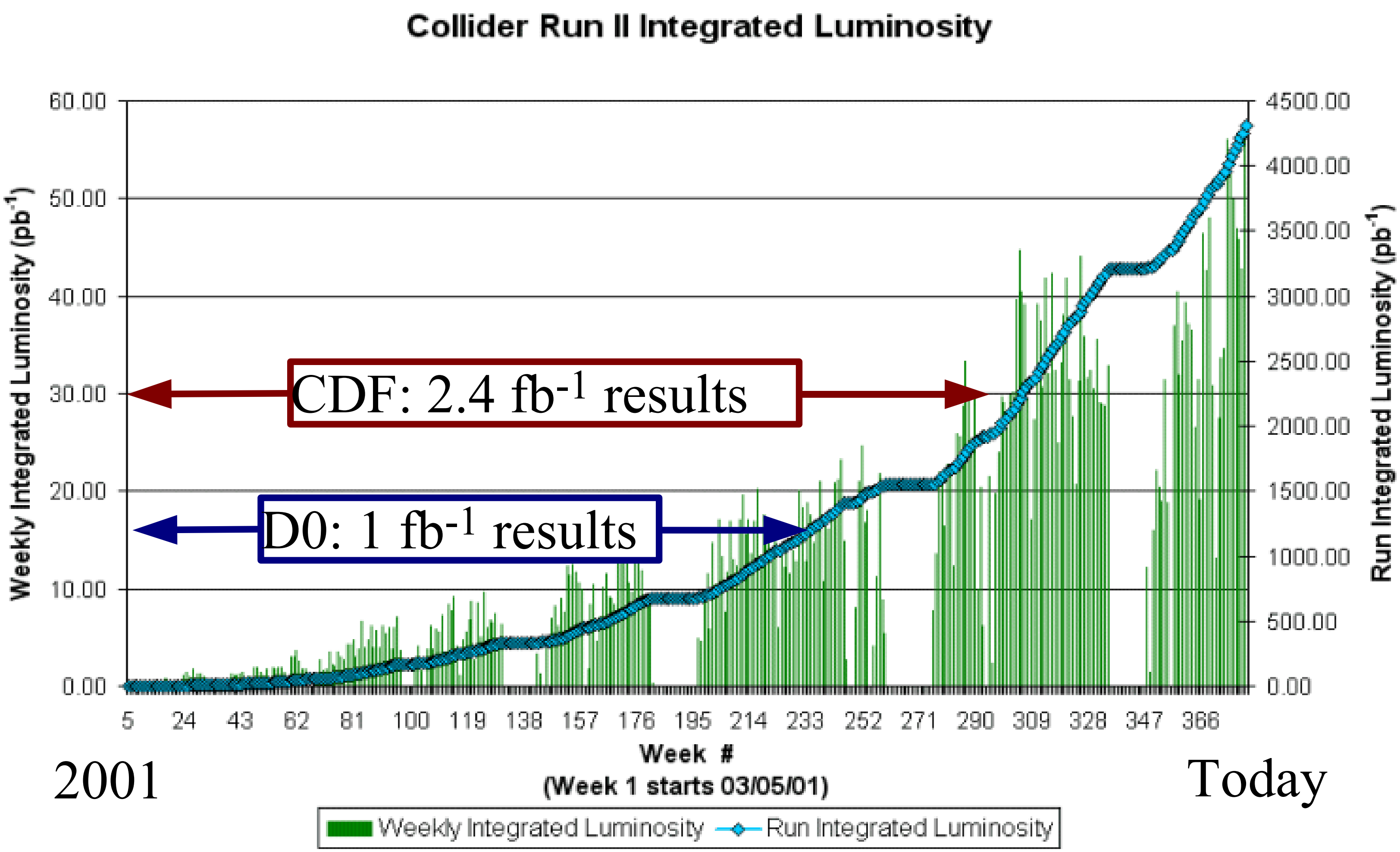
Instantaneous luminosity >250E30cm^{-2}s^{-1}

– ~ 4 interactions per crossing, 1.7M crossing per second

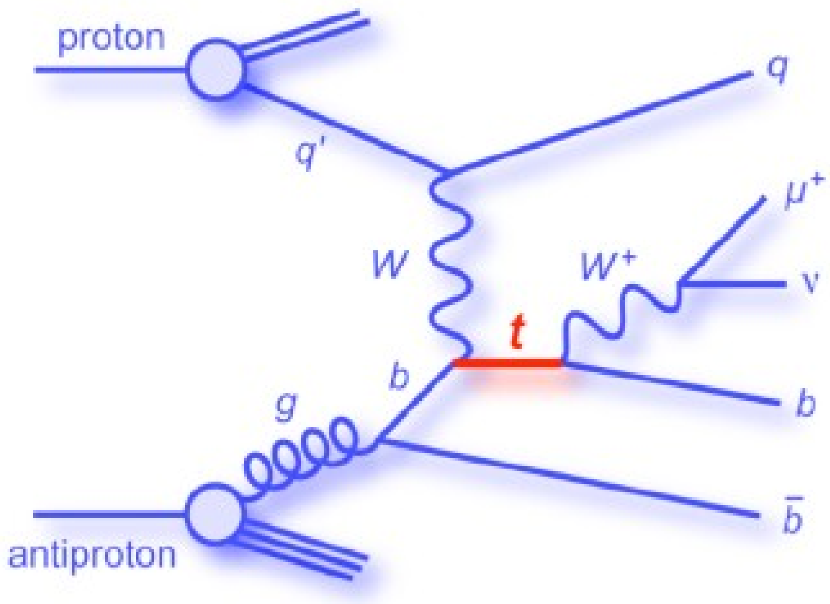
→ ***Luminosity frontier***



Tevatron luminosity

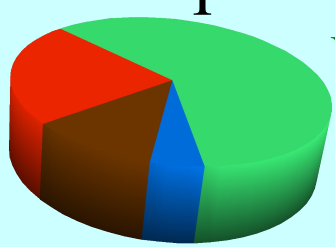


Single top event selection



- Basic event signature (e or μ)
  - Single lepton trigger
    or lepton+jets trigger
  - One high-E_T leptons
    - E_T > 20 GeV or 15 GeV
  - Missing transverse energy
    - Missing E_T > 25 GeV
      or 15 GeV
  - 2-3 high-E_T jets (2-4 jets)
    - E_T > 15 GeV
  - At least one b-tag

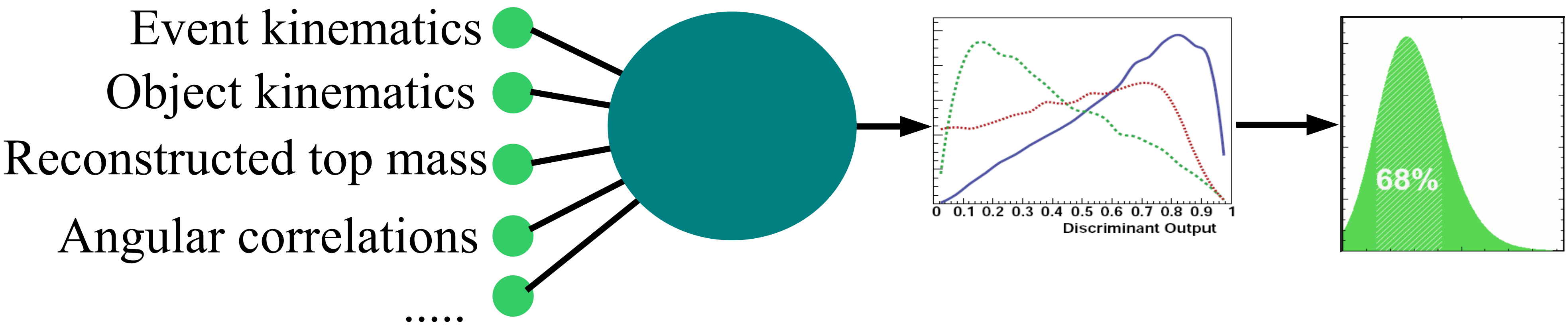
Event sample composition



Expect ~ 50 signal events per fb^{-1}
- After b-tagging
- S:B ~ 1:20

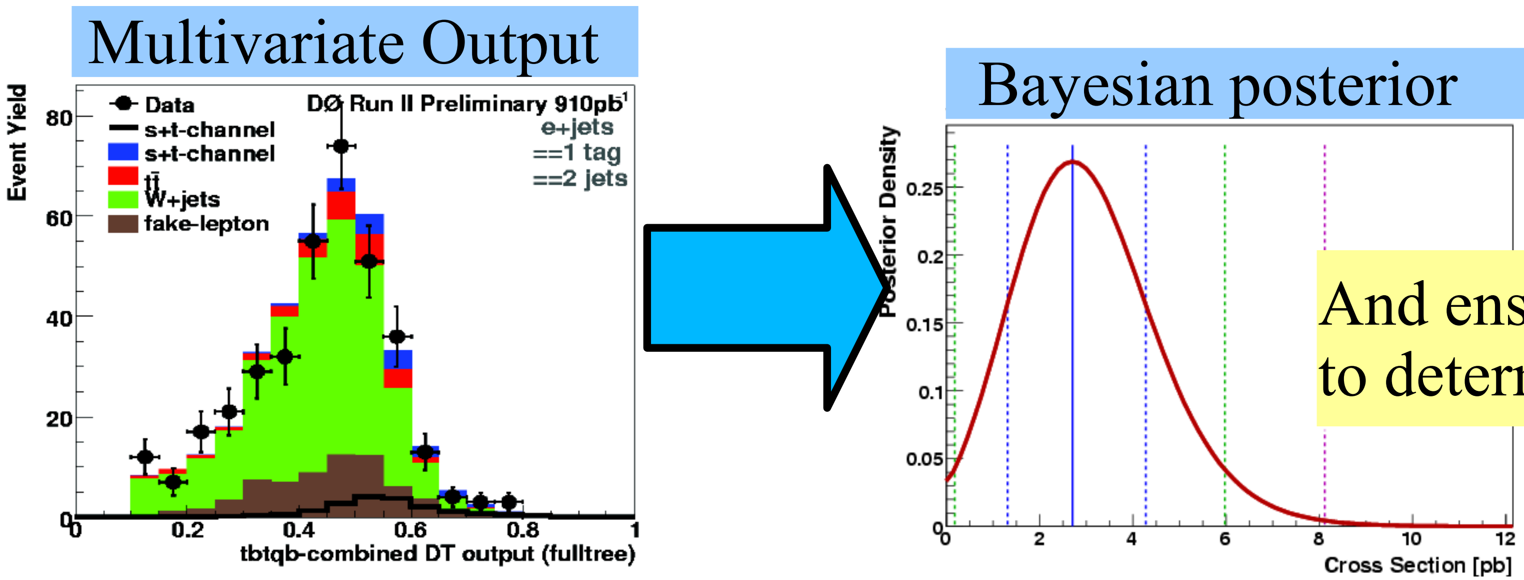
Single top analysis

discriminating variables | multivariate classifier | signal likelihood | statistical analysis



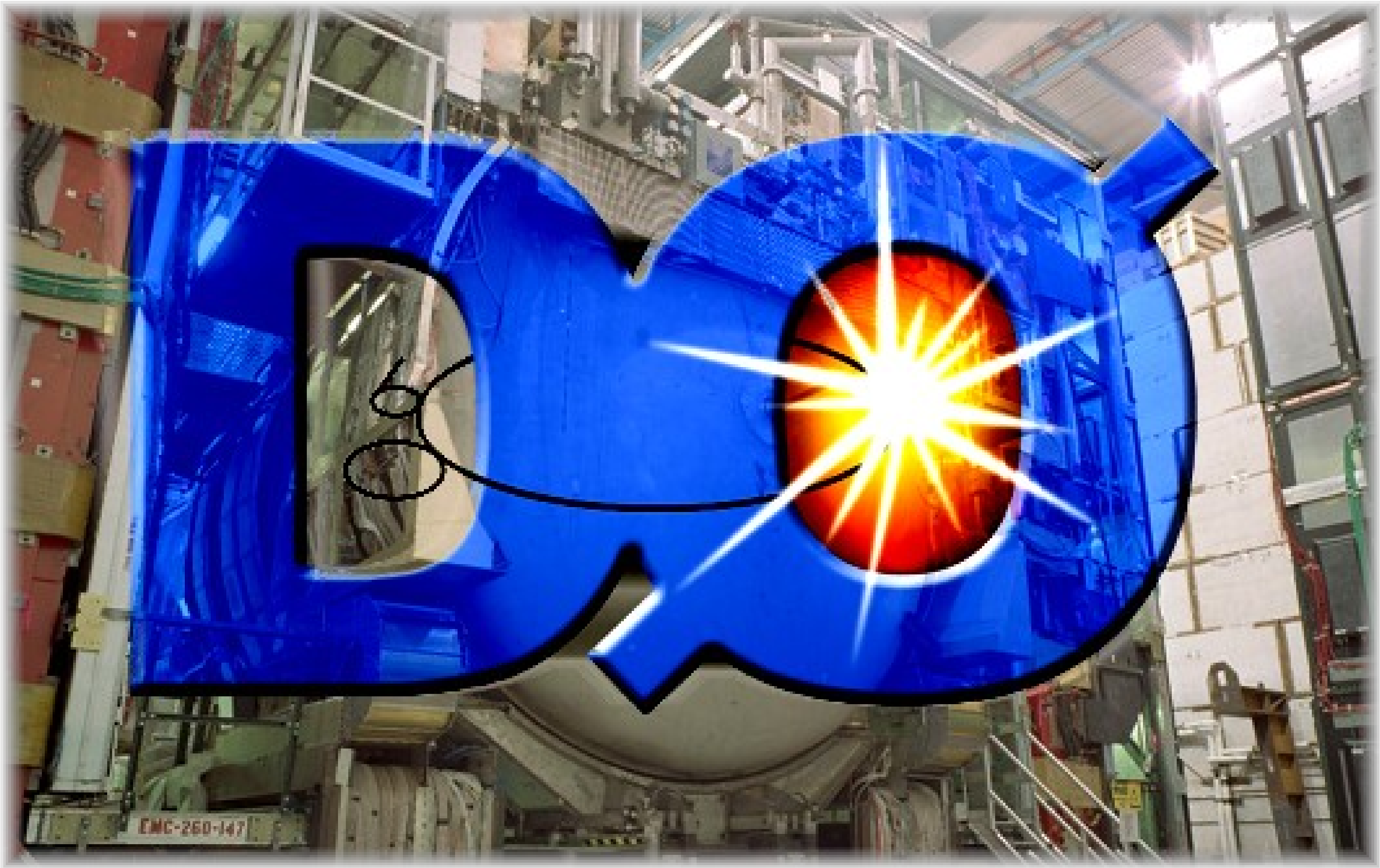
- Classifiers:
  - Likelihood function
  - Neural network
  - Bayesian neural networks
  - Matrix Element
  - Boosted decision trees

Measurement Procedure



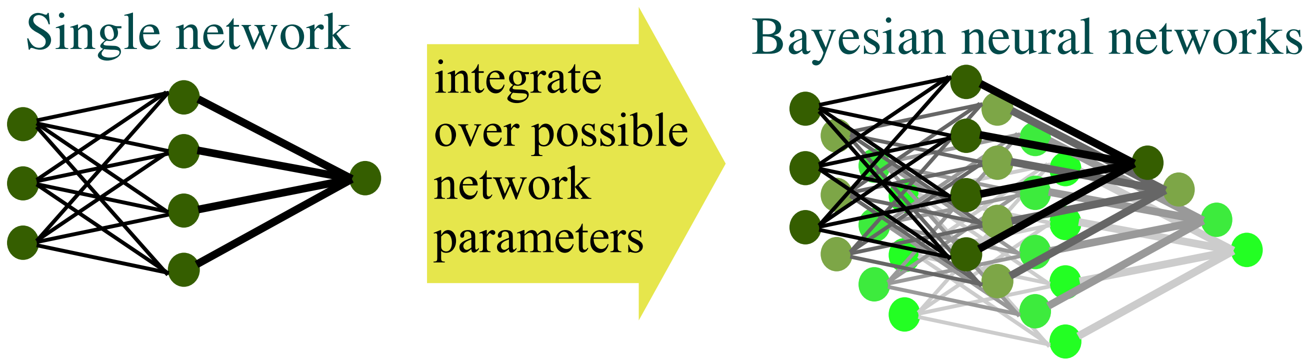
And ensemble testing
to determine significance

- Separate optimization for each process
  - s-channel, t-channel
    - Different processes, sensitivity to new physics
  - s+t combined
    - Assuming ratio of SM XS
      - Maximize sensitivity to SM single top
    - Measure V_{tb}



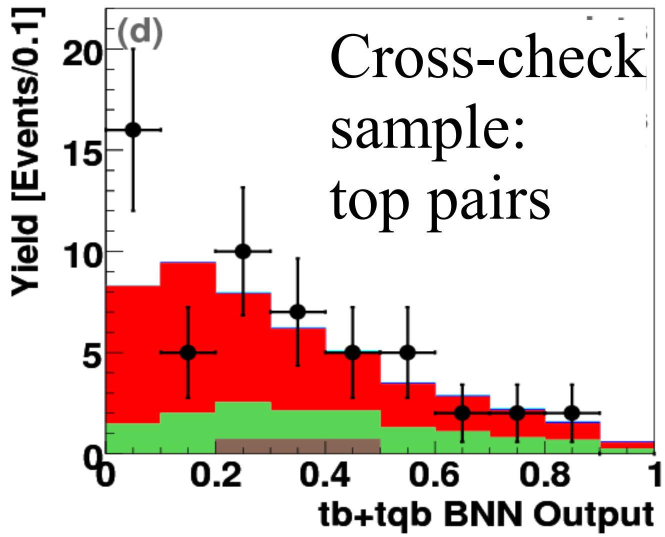
- Update to 0.9 fb^{-1} analysis (3.4 σ, PRL 98, 181802 (2007))
  - Improved Bayesian Neural Network analysis
  - Improved Matrix Element analysis

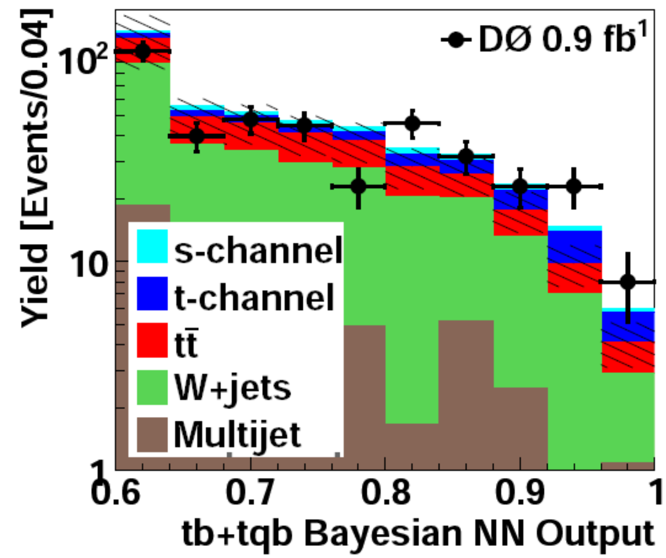
Bayesian neural networks

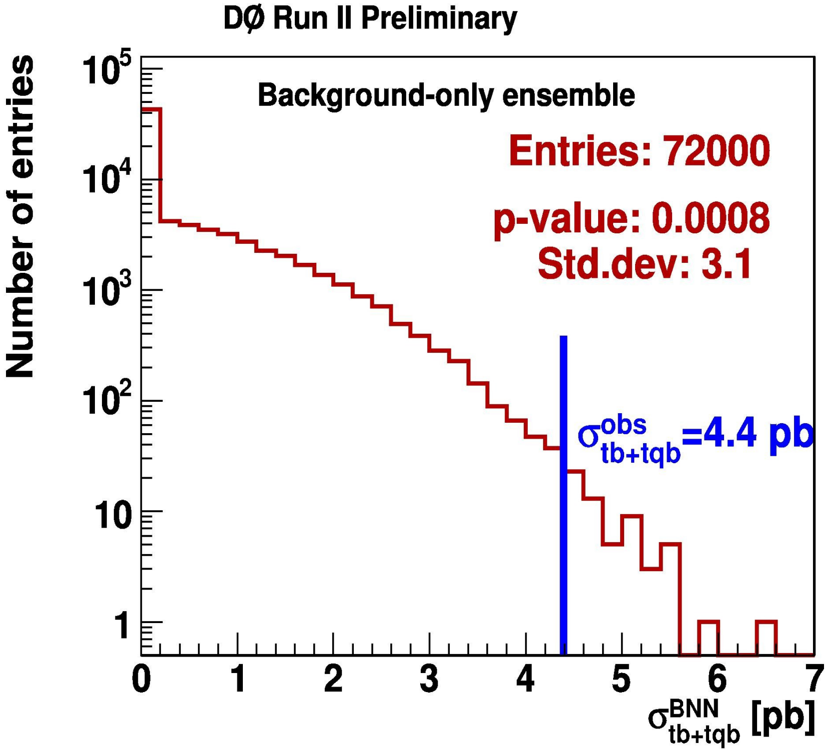


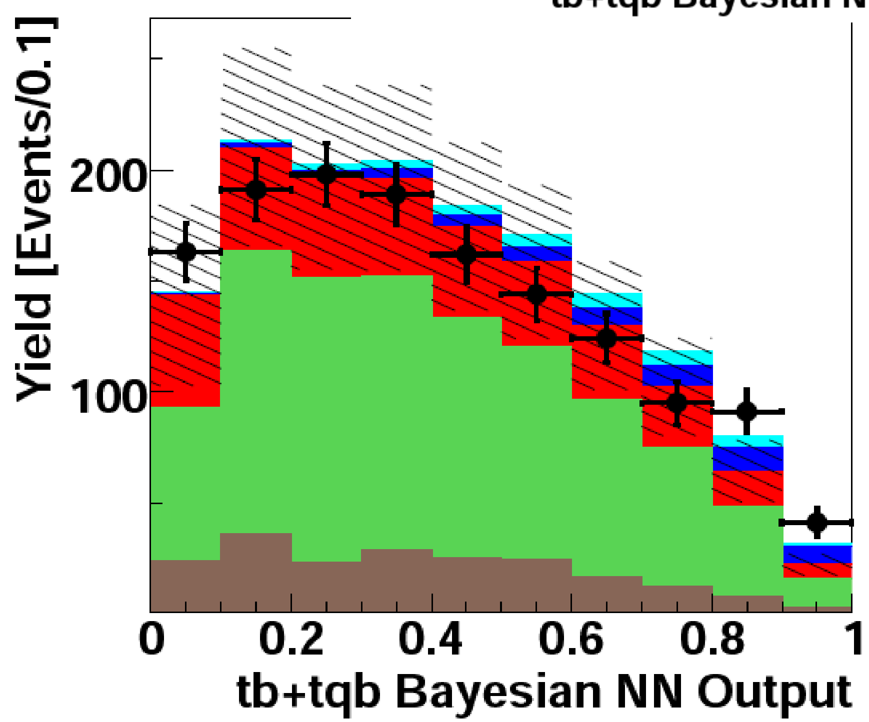
- NN with three layers
  - 24 in put nodes (variables), 40 hidden nodes
  - Each node and each connection has a weight
- Bayesian Idea:
  - Rather than finding one value for each weight, use many values
  - Determine the posterior probability for each weight
  - Sample from this posterior
  - Here: Average over 100 networks

Bayesian neural networks



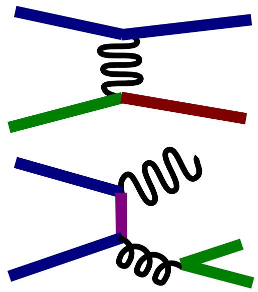






Matrix element analysis

Parton level
matrix elements



integrate over measurement uncertainties

Signal discriminant

$$L = \frac{P(sig)}{P(sig) + P(bkg)}$$

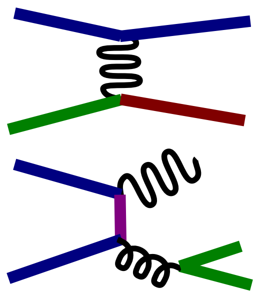
- Signal and background probability for each event is calculated from differential cross section

$$P_{Signal}(\vec{x}) = \frac{1}{\sigma_S} d\sigma_S(\vec{x}) \quad \sigma_S = \int d\sigma_S(\vec{x})$$

  – Integration over final state momenta
    - And over reconstructed momenta, transfer function
- Include ME for s-channel, t-channel, Wbb, Wcg, Wgg
- In 3-jet bin also tt→l+jets

Matrix element

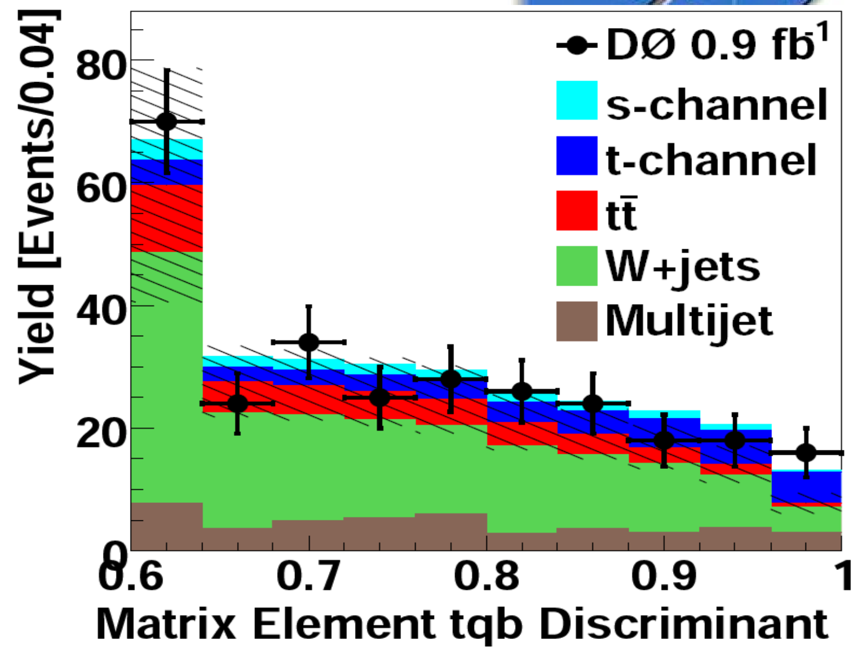
Parton level matrix elements

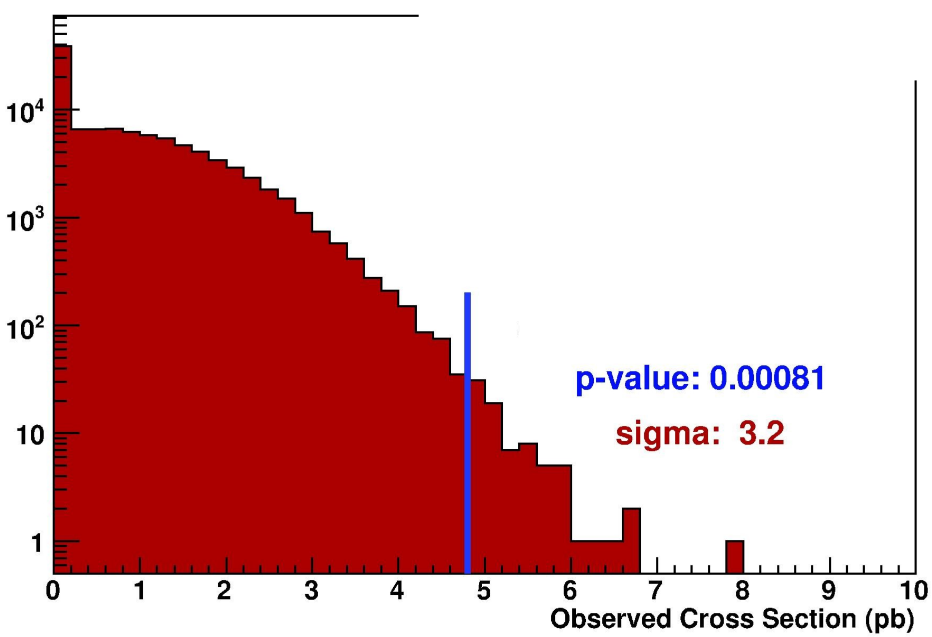


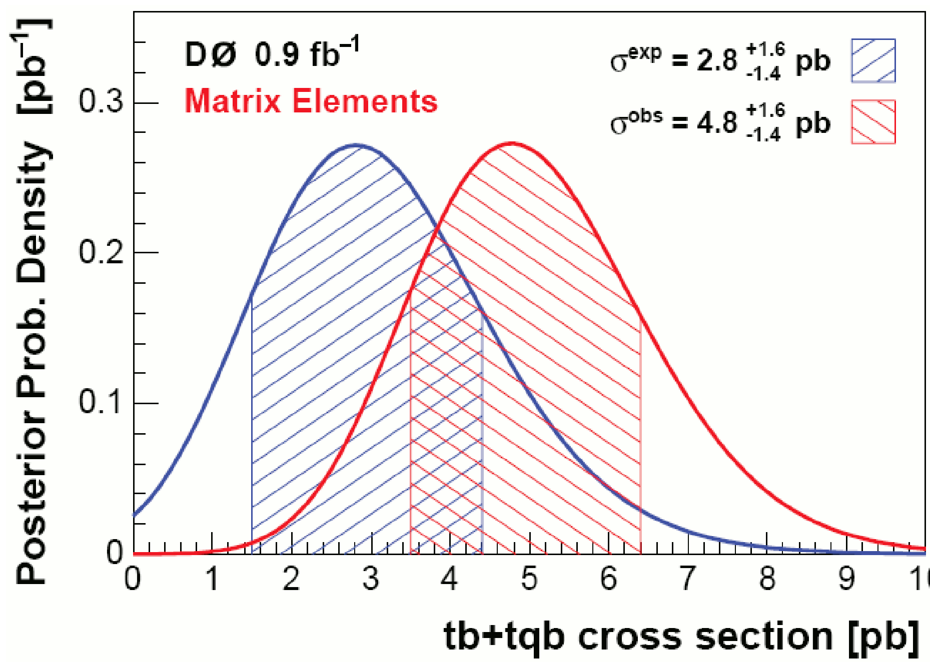
integrate over measurement uncertainties

Signal discriminant

$$L = \frac{P(sig)}{P(sig) + P(bkg)}$$

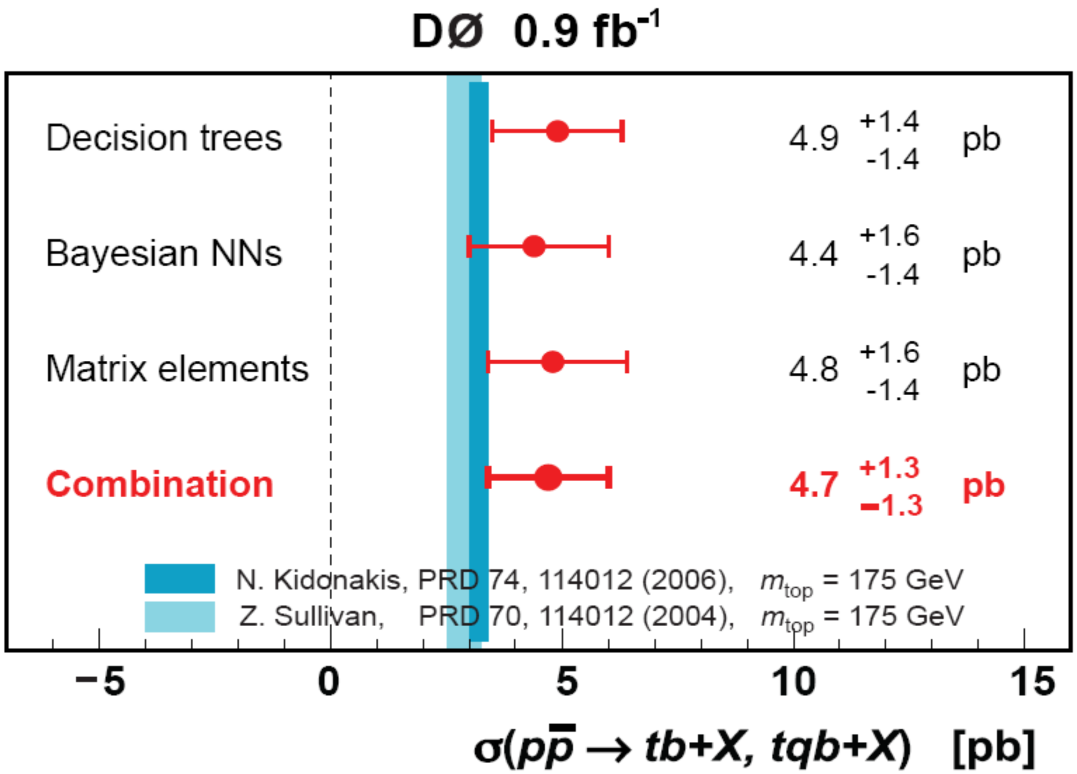




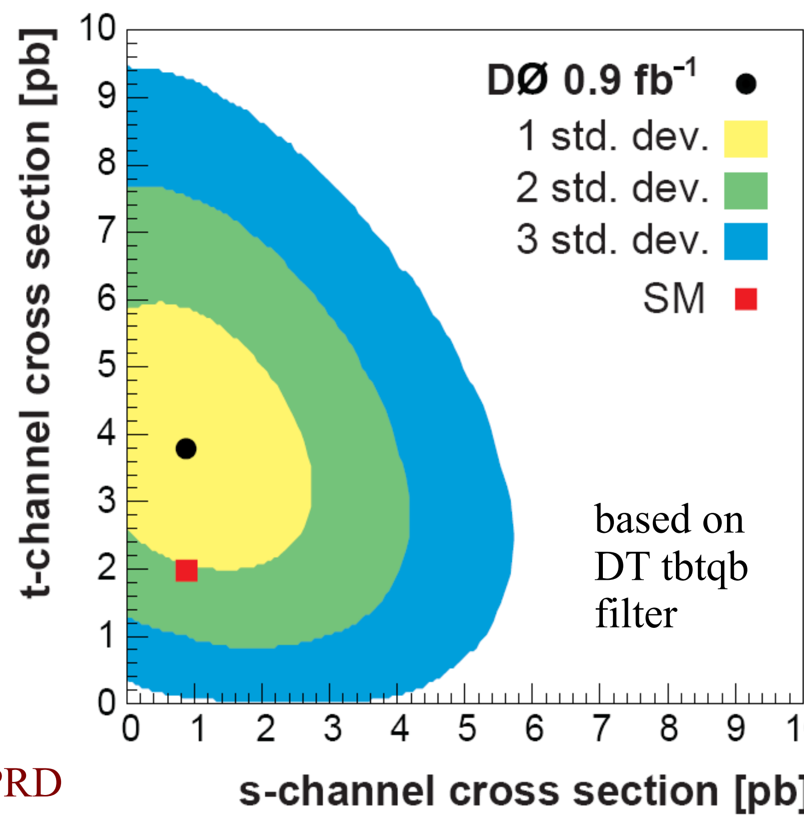


Summary

- Combination using BLUE method
  - Using large sets of ensembles for weights and correlations



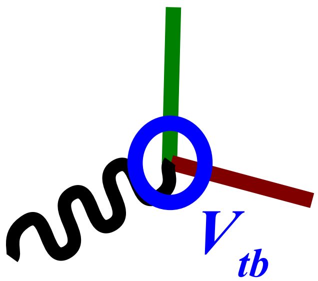
3.6 σ evidence for single top
(2.3 σ expected)



$\sigma(s+t) = 4.7 \pm \mathbf{1.3}$ pb
$\sigma(s) = 1.0 \pm \mathbf{0.9}$ pb
$\sigma(t) = 4.2\ ^{+1.8}_{-1.4}$ pb

Accepted by PRD

CKM matrix element $|V_{tb}|$

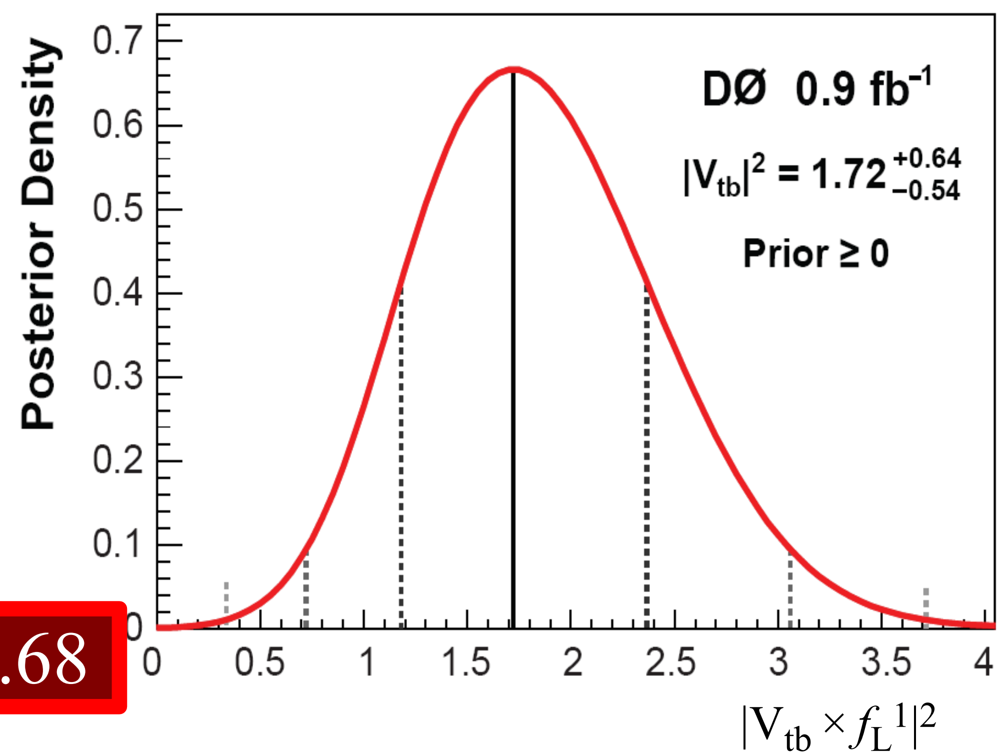


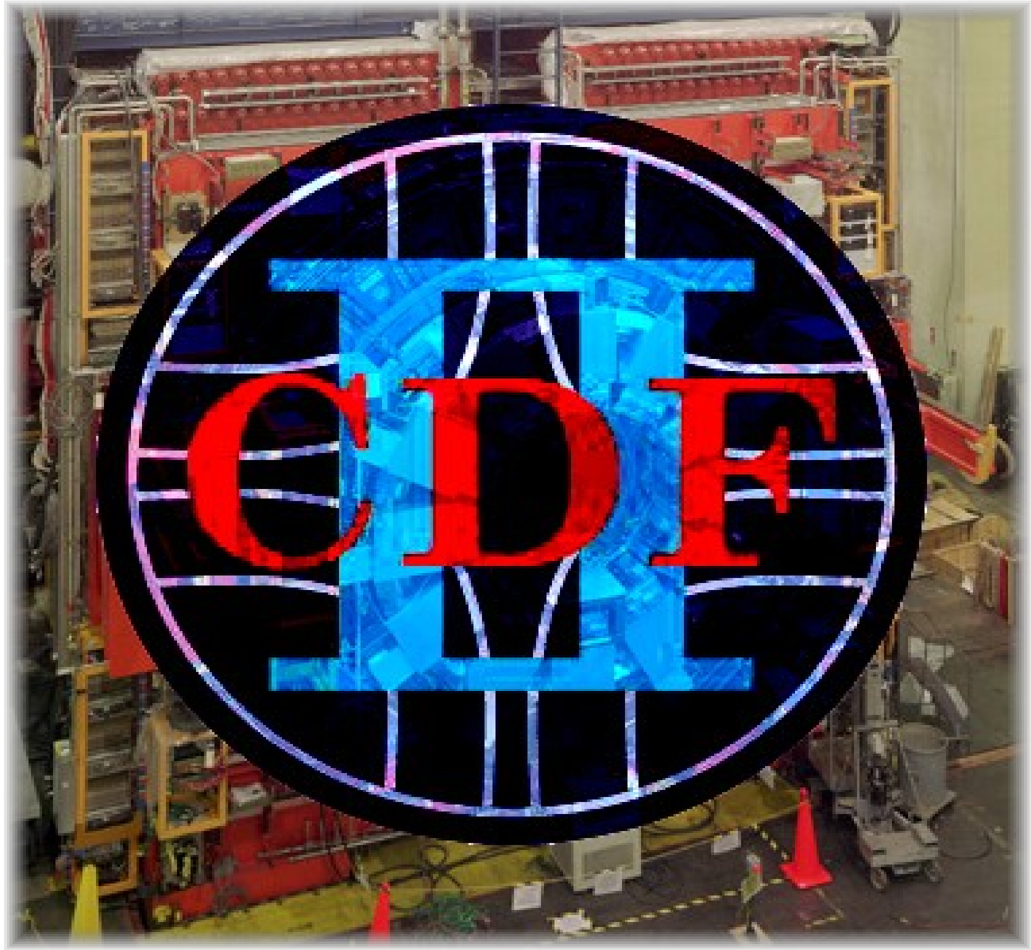
CKM Matrix

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

- Measurement: $|V_{tb} \times f_L^{\,1}|$
  - Based on DT result
  - Assume top decays to b ($V_{tb} \gg V_{ts}, V_{td}$)
- No constraint on # of generations
- Assume $f_L^{\,1} = 1$

  $\rightarrow$ lower limit on V_{tb}
  - At the 95% C.L.: $|Vtb| > 0.68$

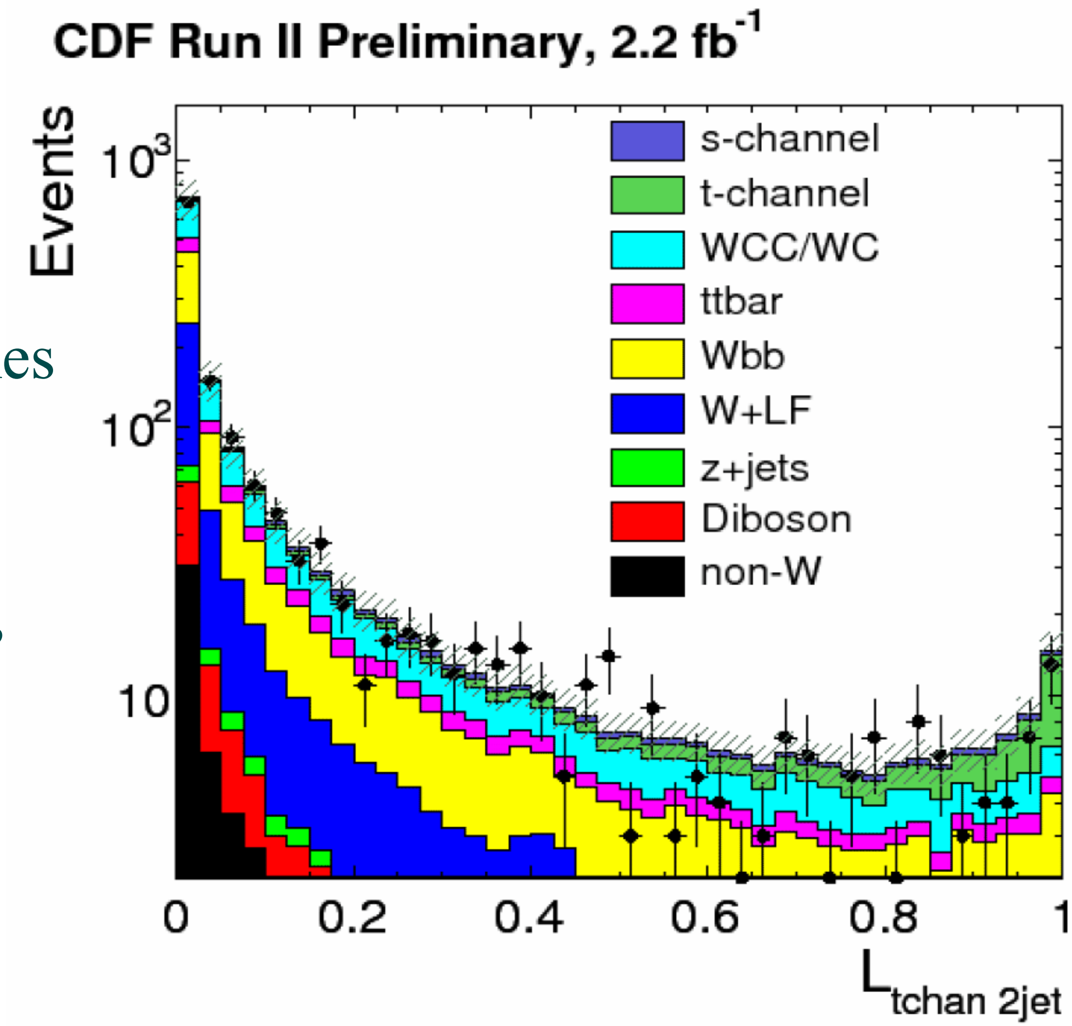




- Analyses based on 2.2 fb^{-1}
- Increased acceptance
  - MET trigger
  - more muons
- Now including 3-jet channel
- Improved background model

Multivariate likelihood function

- Likelihood functions built from 7 variables (10 for 2-tags)
  - Kinematic variables
  - b-tag NN output
  - kinematic solver
    - Assign which jet comes from top decay
  - t-channel ME
    - No transfer functions, no integration



Multivariate likelihood function

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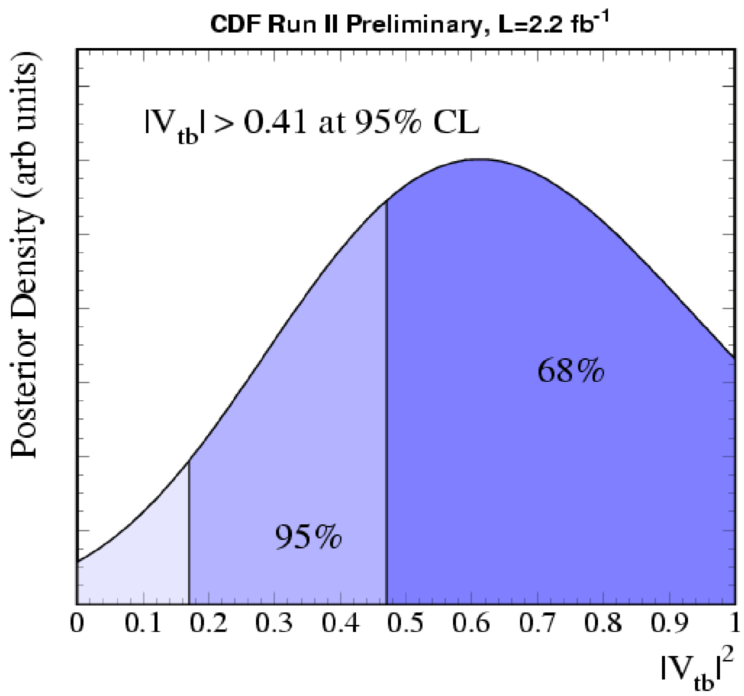


Expected/observed significance:

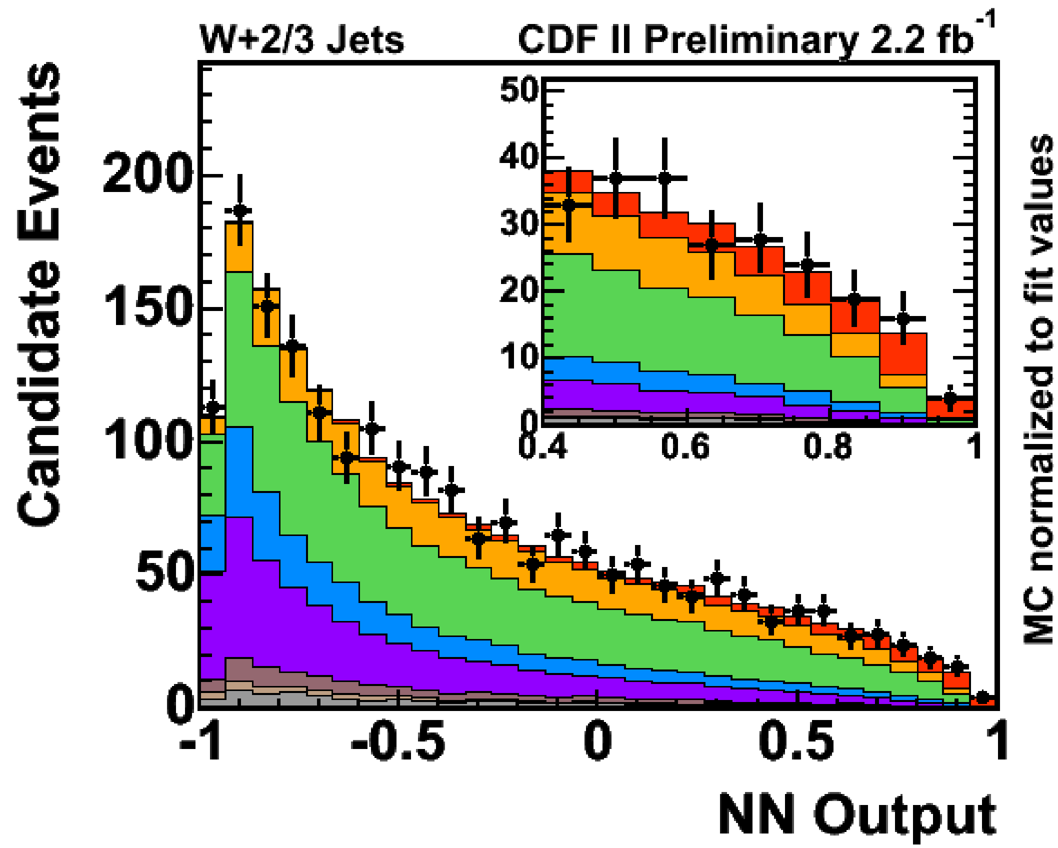
3.4σ / 2.0σ

Measured cross section:

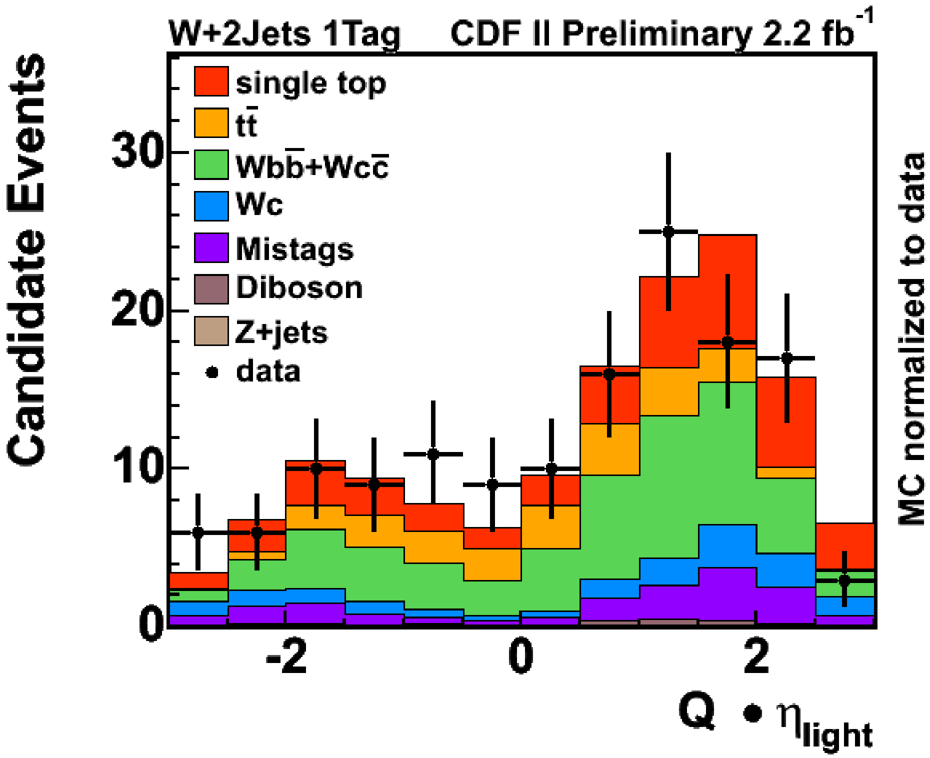
$\sigma(s+t) = 1.8^{+0.9}_{-0.8}$ pb

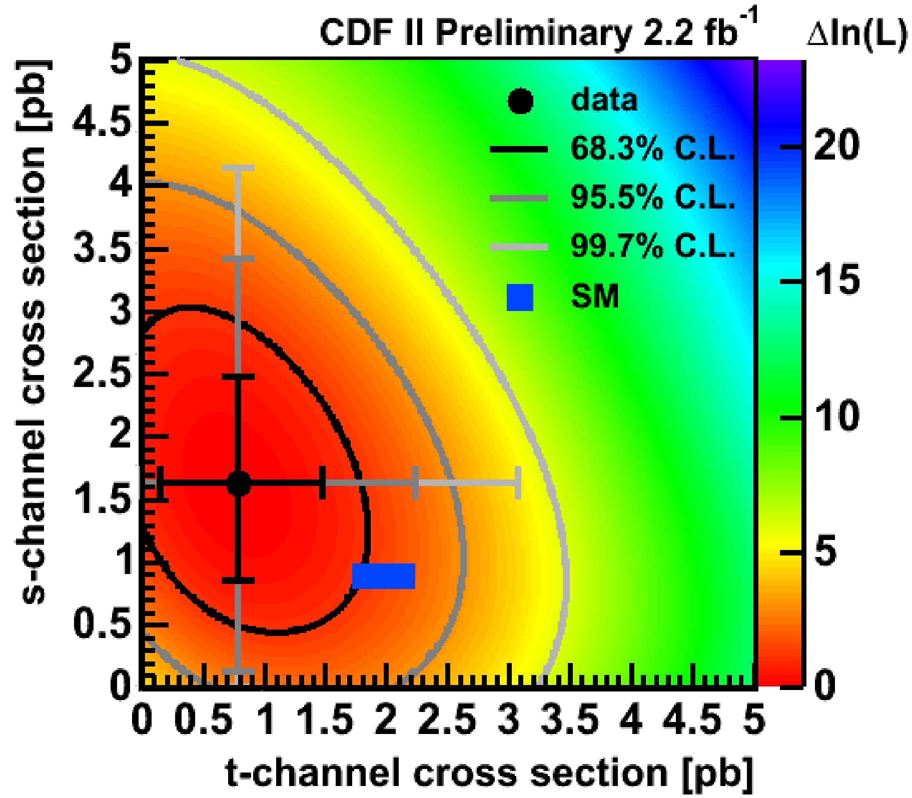
Neural Networks

- 4 separate s+t networks
  - By jet and b-tag multiplicity
- Built from 10-14 variables each
  - Kinematic variables
  - angular correlations
  - B-tag NN output



Neural Network Result





Expected/observed significance:

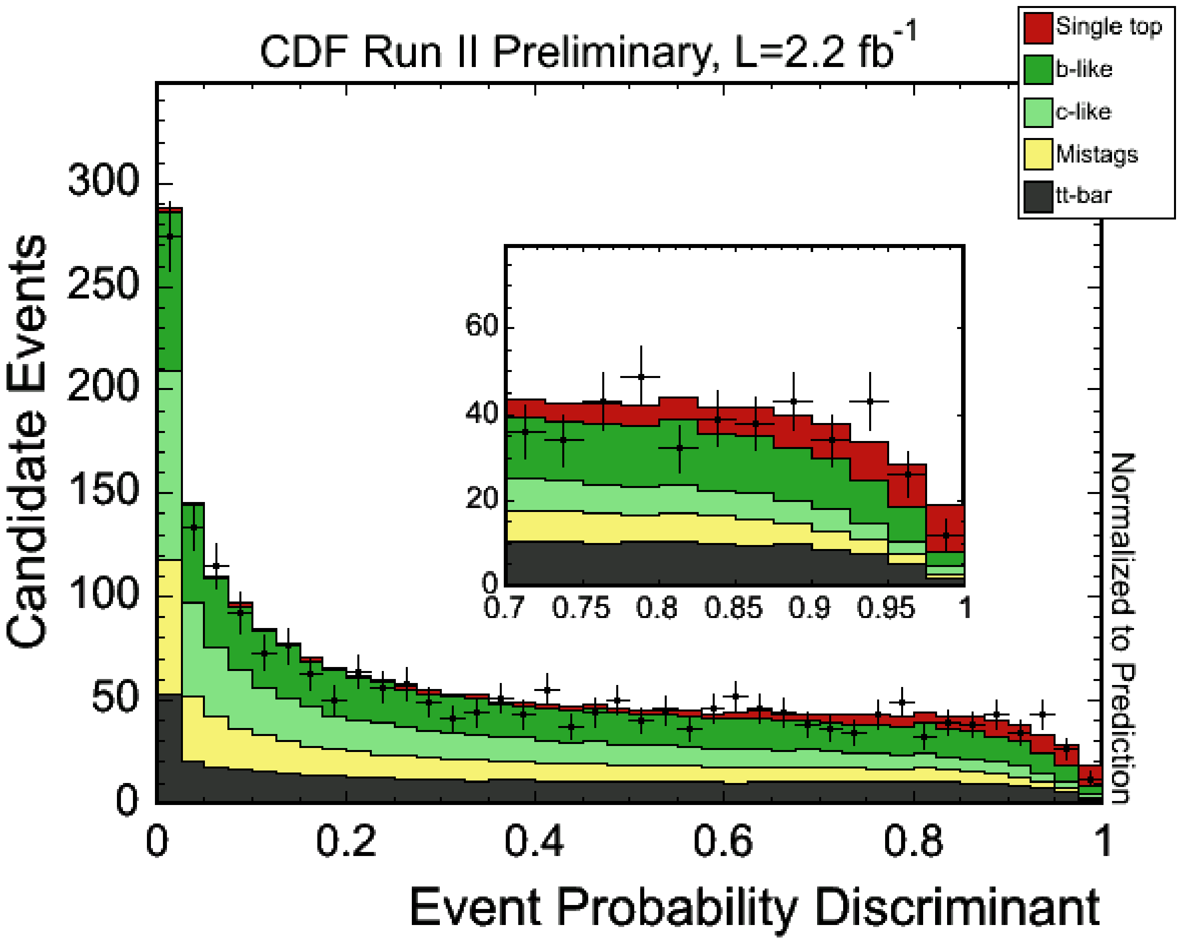
4.4σ / 3.2σ

Measured cross section:

$\sigma(s+t) = 2.0^{+0.9}_{-0.8}$ pb

Matrix element

– Analyze 2-jet and 3-jet events
  - Include ttbar matrix element for both 2-jet and 3-jet events
  - Include b-tag NN as weight in likelihood ratio



Expected/observed significance:

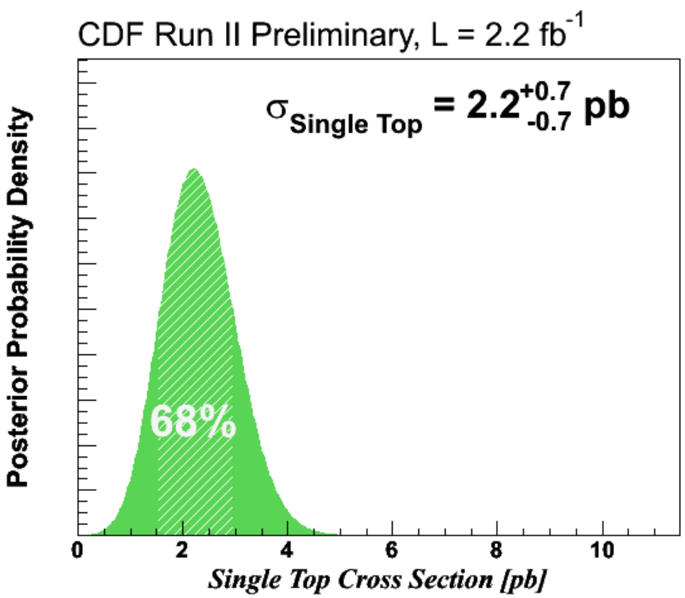
4.5σ / 3.4σ

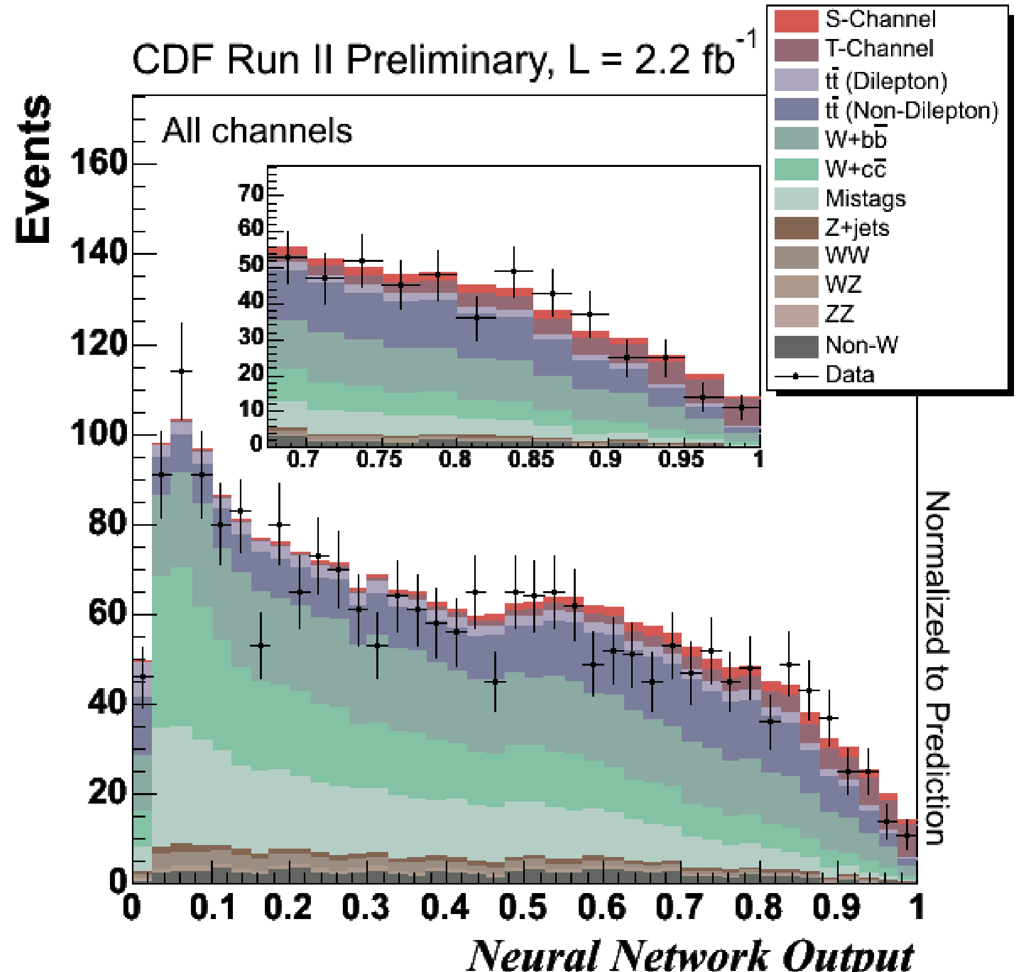
Measured cross section:

$\sigma(s+t) = 2.2^{+0.8}_{-0.7}$ pb

CDF combination

- NEAT: NeuroEvolution of Augmenting Topologies
  - Optimization procedure chooses network structure and weights
    - And final binning
    - Train a few to also find optimum when including systematics





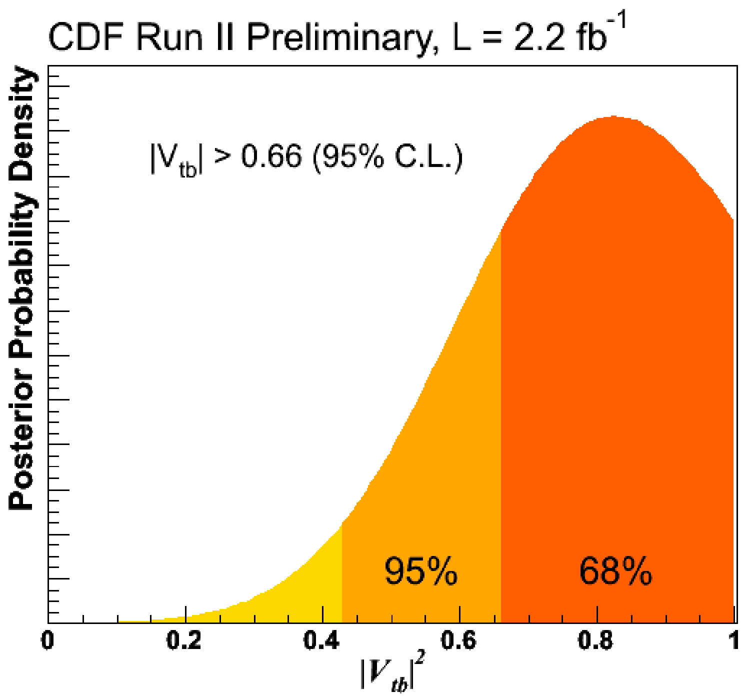
Expected/observed significance: 5.1σ / 3.7σ

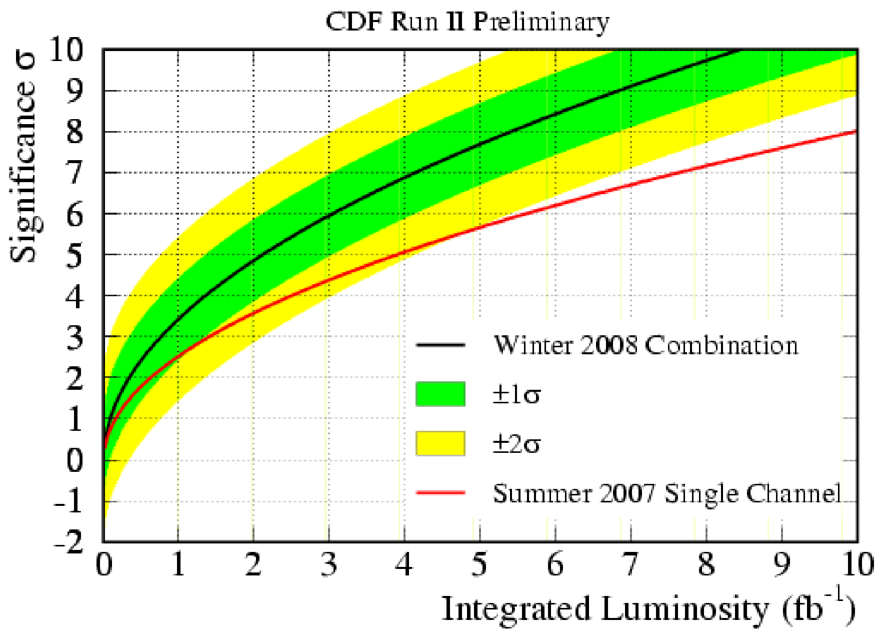
Other CDF analyses

- Boosted decision trees
  - Not in combination
- Separate s-channel search
  - $\sigma < 2.77$ pb (95% CL)
- |Vtb| measurement using NEAT output

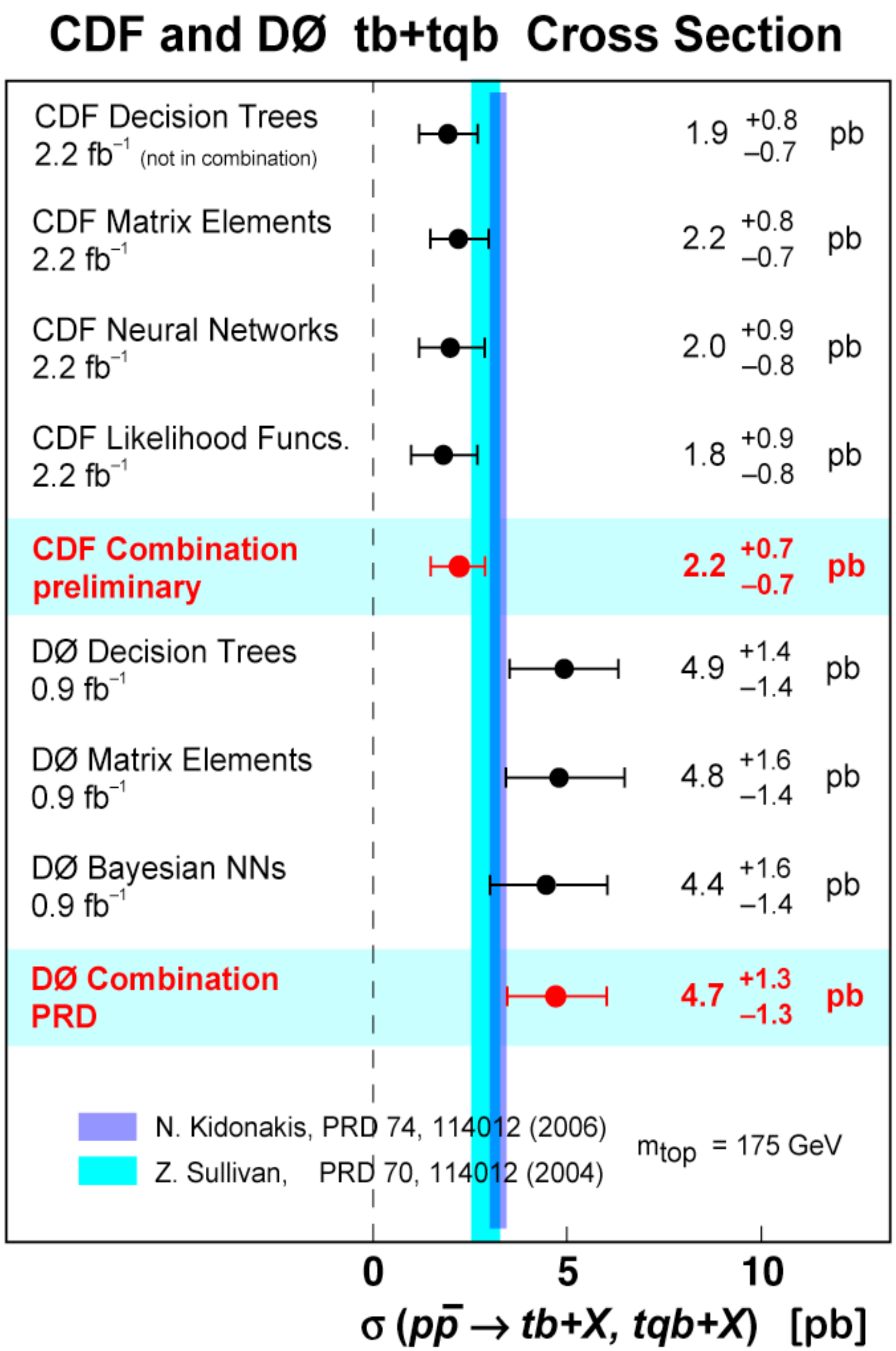
Measured cross section:

$\sigma(s+t) = 1.9^{+0.8}_{-0.7}$ pb



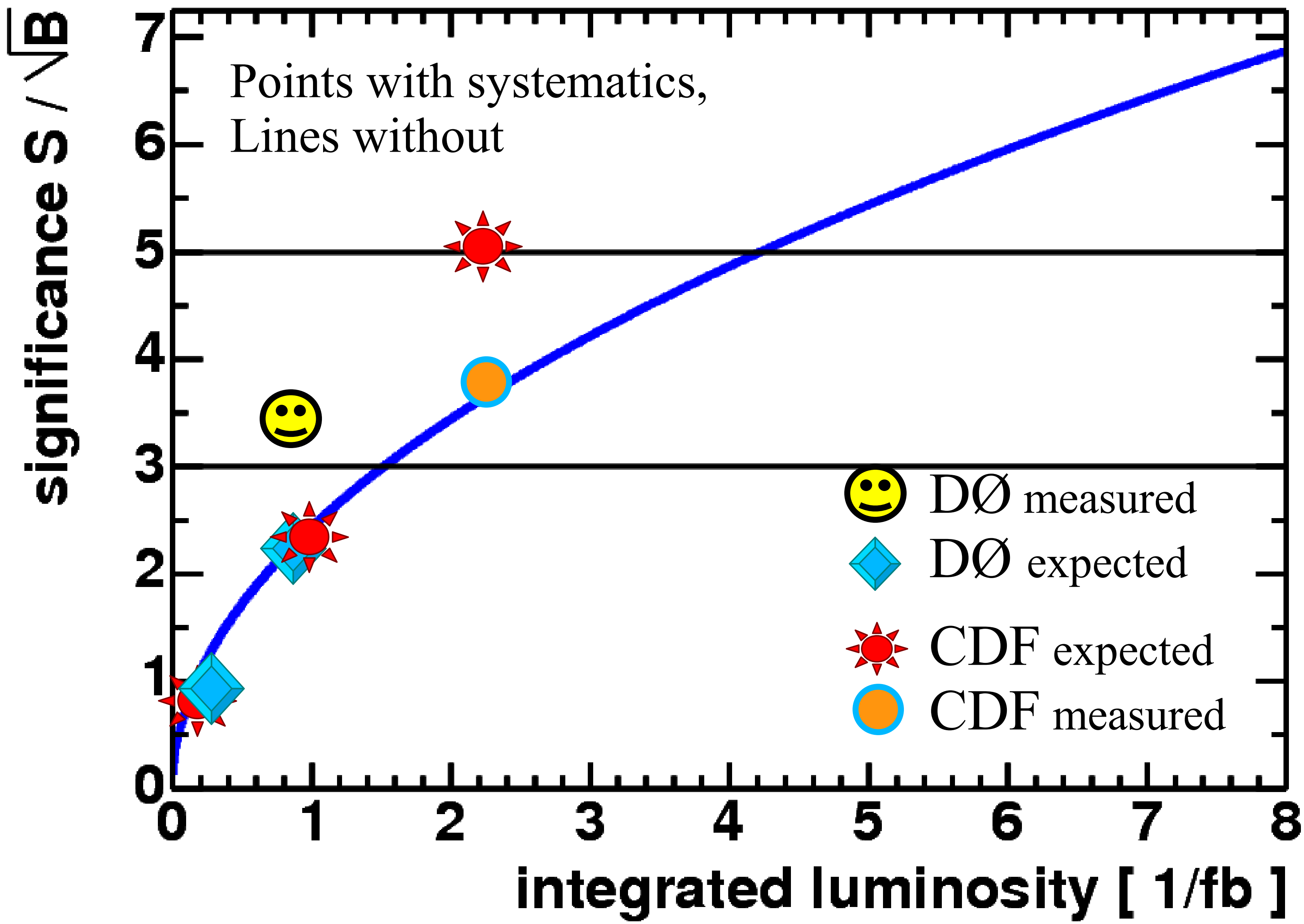


Tevatron summary



Tevatron prospects for s+t

Projection by CDF for P5 in 2005



D0 outlook

- Currently analyzing 2.4fb^{-1} of data
- Goal: Show the updated result at ~~Moriond 2008 (March)~~

  ~~Have a result by APS 2008 (April)~~

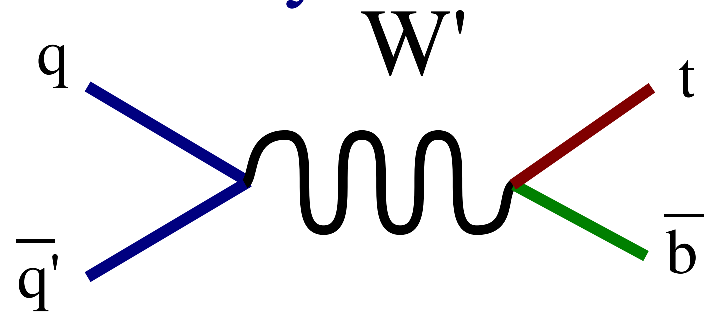
  ~~Have a result by June (this talk)~~

  ~~Have a result by ICHEP (July)~~

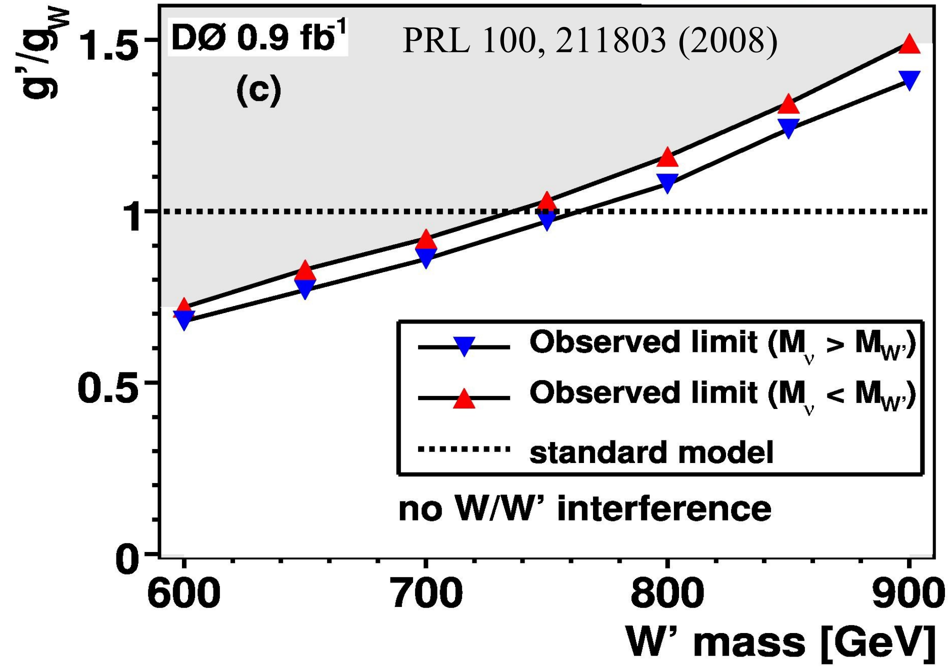
  Have a result soon!
- Main problems:
  - Completely updated W+jets background model
    - New Algen version
  - Updated trigger, detector
  - Ambitious analysis: reach "observation of" sensitivity

Searches for new physics in single top

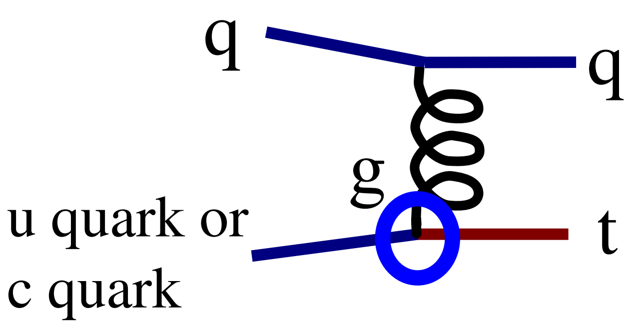
- Searches for new heavy boson W':

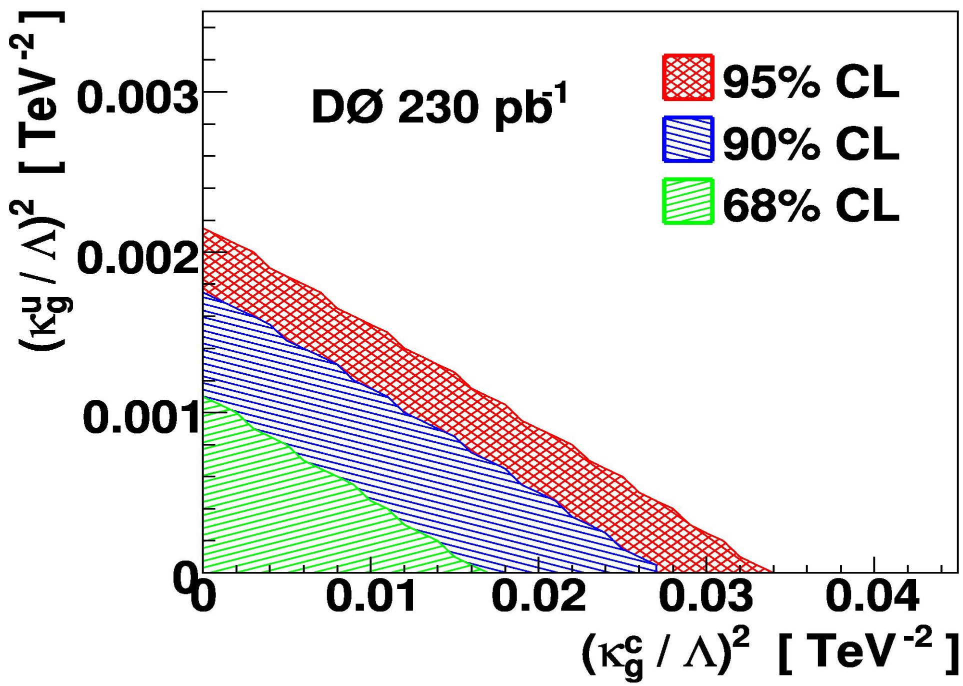


  - CDF prelim result, 1.9fb^{-1}: M > 800 GeV and M > 825 GeV



- Similar: DØ Susy H^+ search
- Flavor-changing neutral currents:



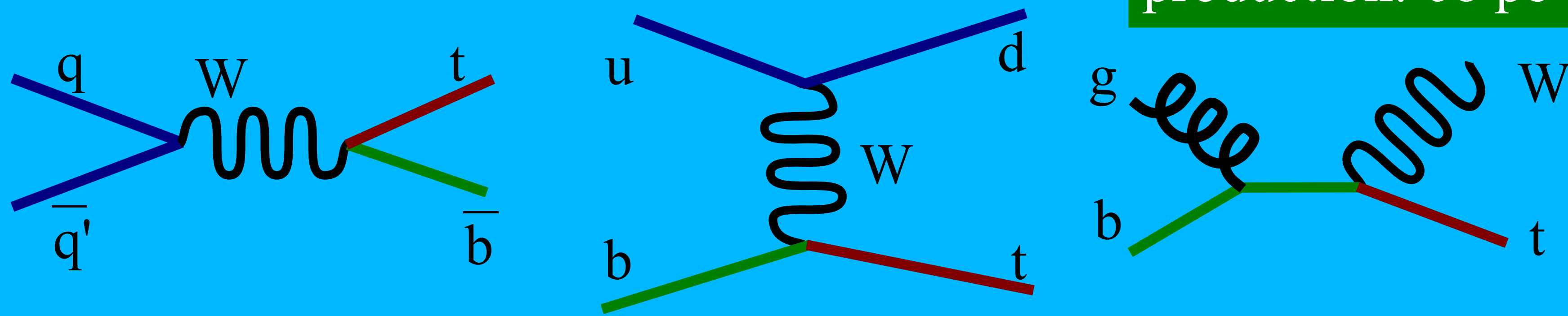


Single Top future: LHC

s-channel: 10.7 pb

t-channel: 247 pb

associated production: 68 pb

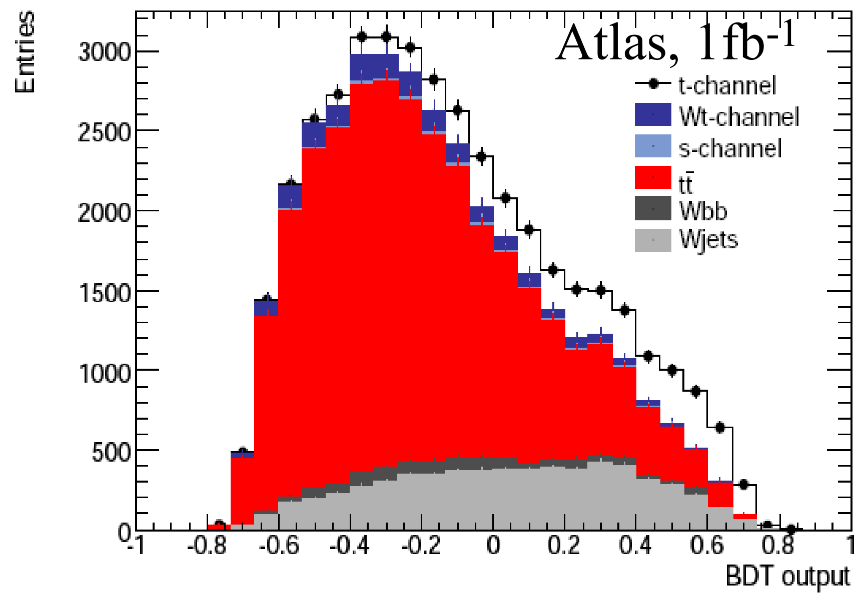


- Observe three single top production modes separately
  - t-channel: easy 🙂 s-channel and assoc. prod: harder
- Observe new physics *(if it can be seen)*
- Measure V_{tb} to few %
- Study spin correlations

SM Single Top at the LHC

- Backgrounds are similar to Tevatron, yet different
  - W+jets less important
  - $t\bar{t}$ is dominant background
- t-channel observation early
  - Large cross section
- s-channel and Wt with 30 fb^{-1}
  - Separate by b-tag and jet multiplicity

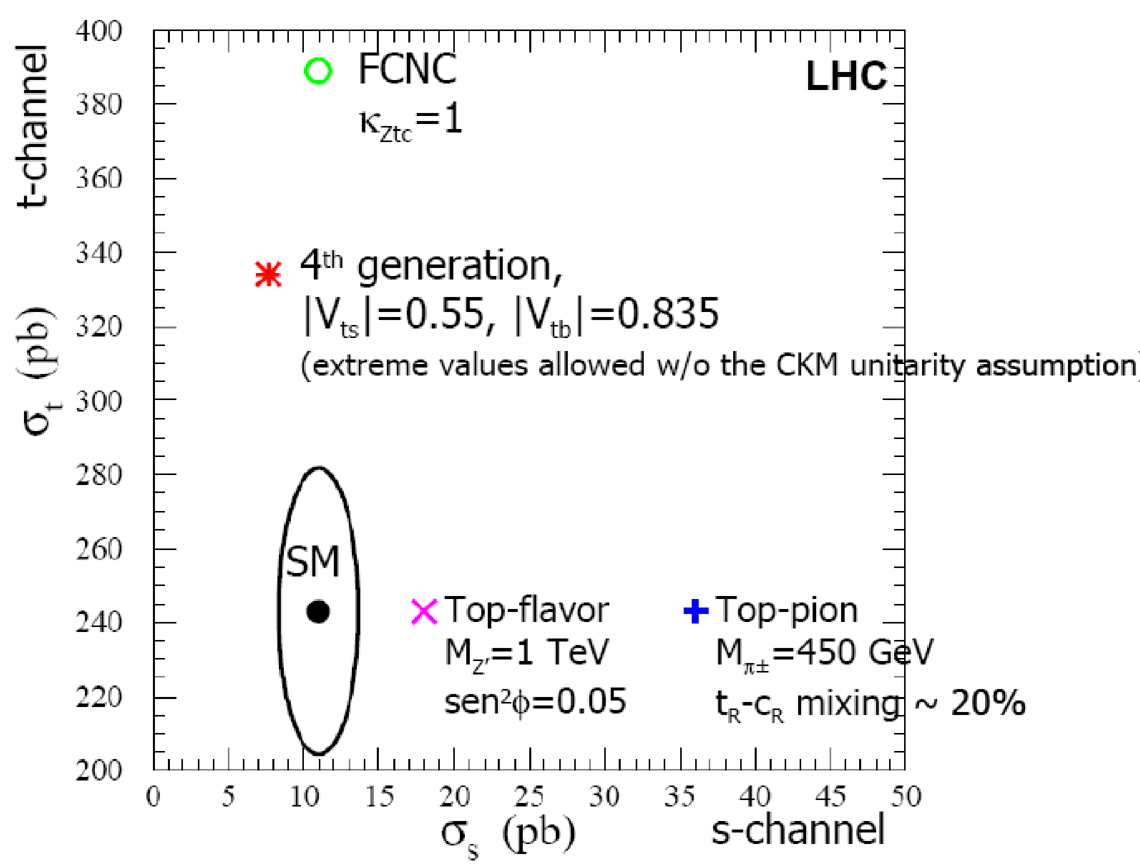
t-channel



LHC: new physics in single top

- Dedicated searches for specific signatures
  - New heavy boson W'
  - FCNC interactions via gluon, photon, Z
  - Anomalous couplings
- Measure SM cross sections in detail
  - And compare their ratios

T.Tait, C.-P.Yuan, Phys.Rev. D63 (2001) 0140018



Conclusions/Outlook

- The Tevatron experiments are getting to know the top quark very well
- Both experiments have evidence for single top quark production
- Tevatron dataset will increase to over 5 fb^{-1}
  - 5 sigma observation of single top
  - Separate s-channel from t-channel
  - Measure top quark spin correlation
- LHC:
  - Precision measurements in single top
  - Look for new physics in single top