The Hunt For Single Top Production at

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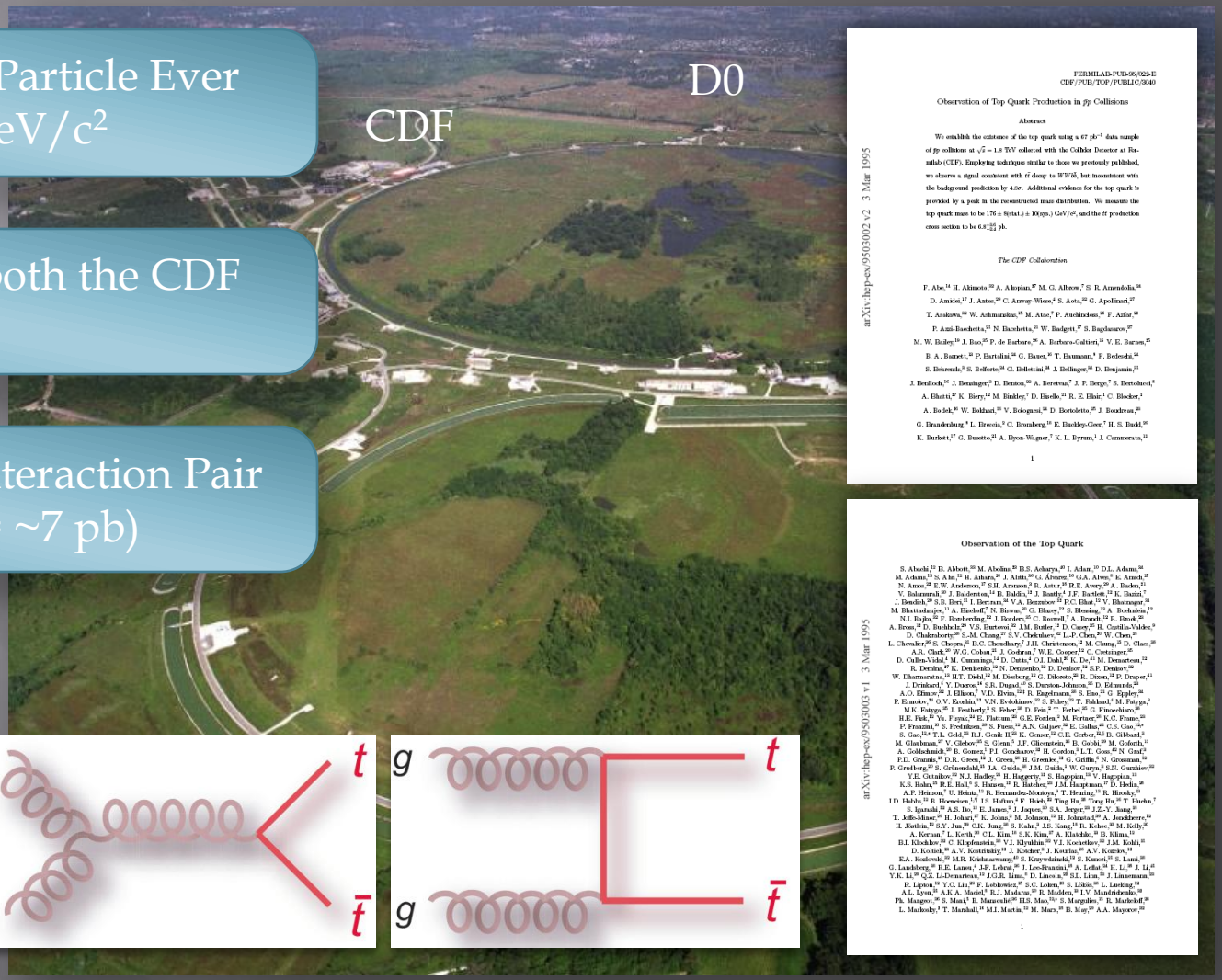
For the DØ Collaboration

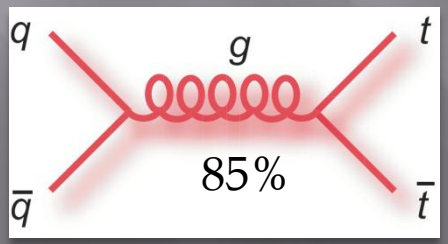
The Top Quark

Heaviest Fundamental Particle Ever Observed: 172.5 ± 2.3 GeV/c^2

Discovered in 1995 by both the CDF and DØ Experiments

Discovered in Strong Interaction Pair Production Process (σ = ~7 pb)



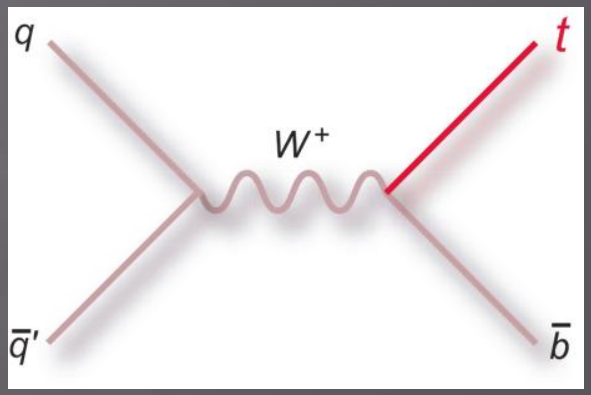


Single Top Production

Top Quark Also Produced by the EW Process

Smaller Cross Section

0.88 ± 0.11 pb
s-channel



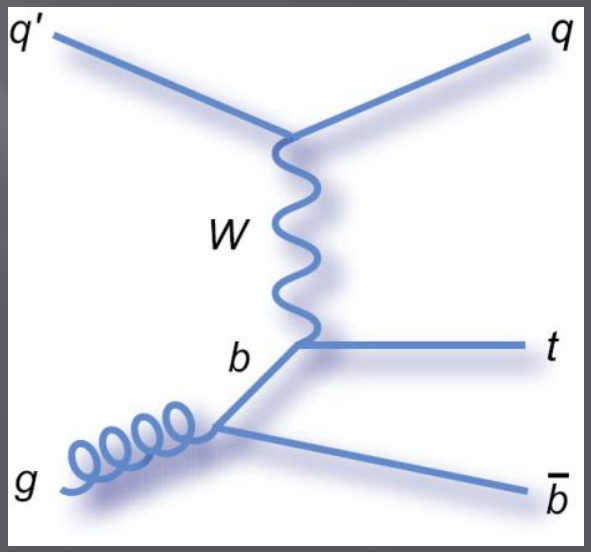
Top Decays to Wb ~ 100%

Require Isolated High p_T e, μ

- W→jj - Dijet decay backgrounds too large
- W→ττ included only when it decays to a isolated lepton

Signature: Lepton, Missing E_T, jets

1.98 ± 0.25 pb
t-channel

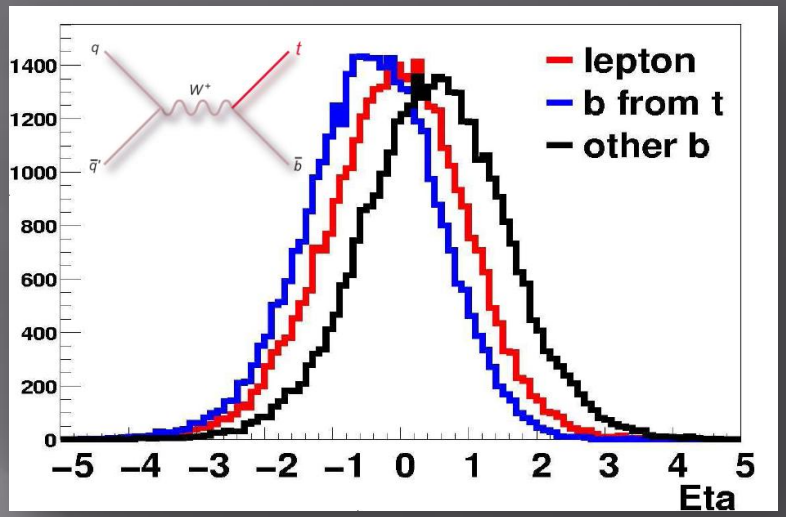


Single Top Final State

s-channel

The top decay products and the b tend to all be central

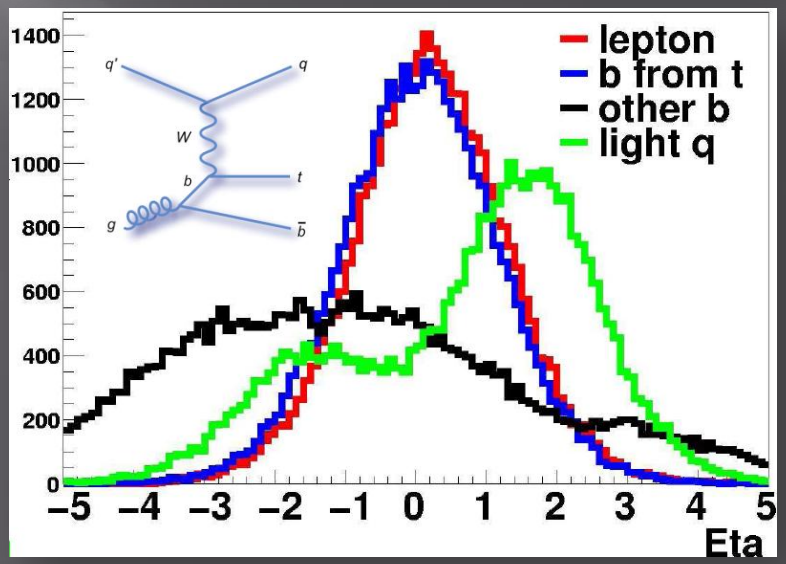
- Lepton, neutrino, and two b-quark jets



t-channel

The b-bar tends to be very close to the beam pipe

- Lepton, neutrino, and one b-quark jets (second only if you are lucky!)



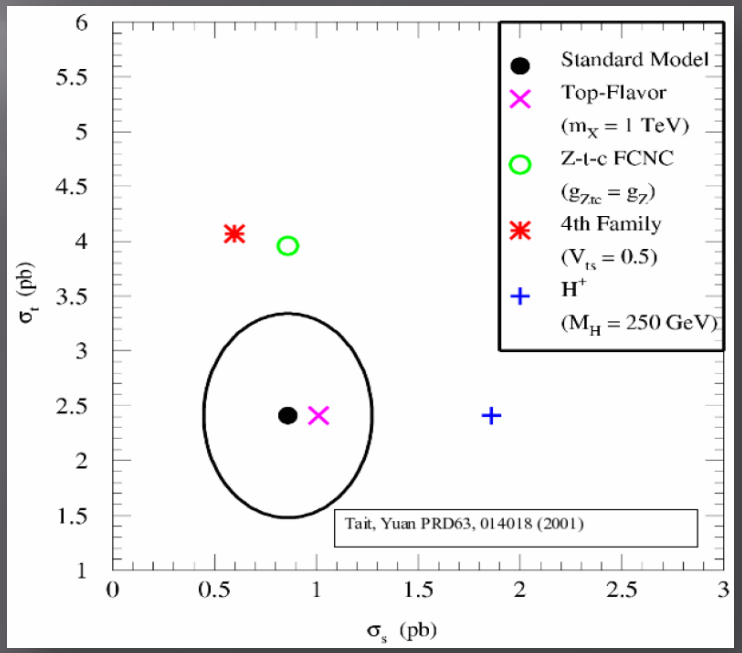
Single Top Physics

What Do We Know About the Top Quark?

- Cross Section for Pair Production
- Mass
- BR(t→Wb) ~ 1 assuming the SM
- Charge

Plenty is Unknown

- Decay Width
- Lifetime
- Spin
- BR not assuming the SM
- Direct measurement of V_{tb}



Measuring σ_s and σ_t

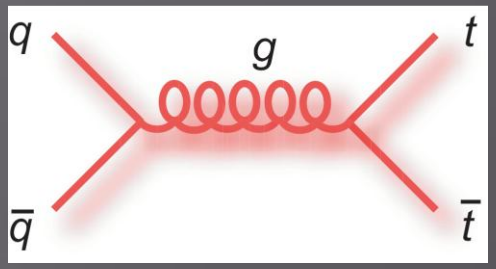
- Cross Sections for s and t are sensitive to different types of new physics
  - t-channel is sensitive to FCNC
  - s-channel is sensitive to new resonances

It is important to measure the rates independently

Where Is It?

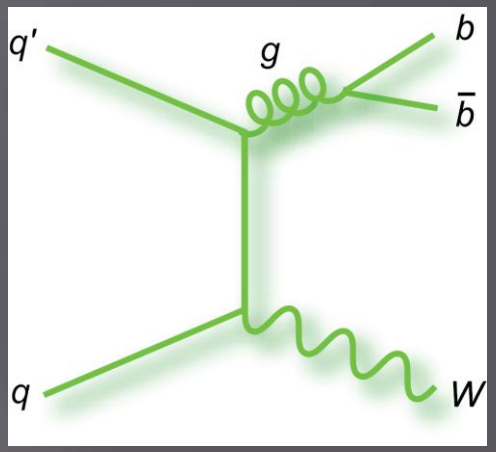
Single Top Final State

Lepton, missing E_T, and jets



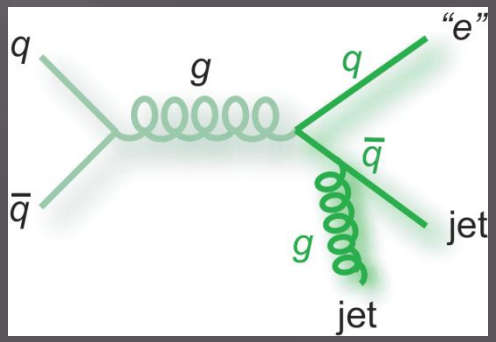
Backgrounds

W+Jets – σ = 1000 pb
tt – σ = 7 pb
QCD multi-jet background/jet mistaken ID



Finding It

Basic Selection Cuts
b-jet tagging
Multi-variate techniques and sensitive variables

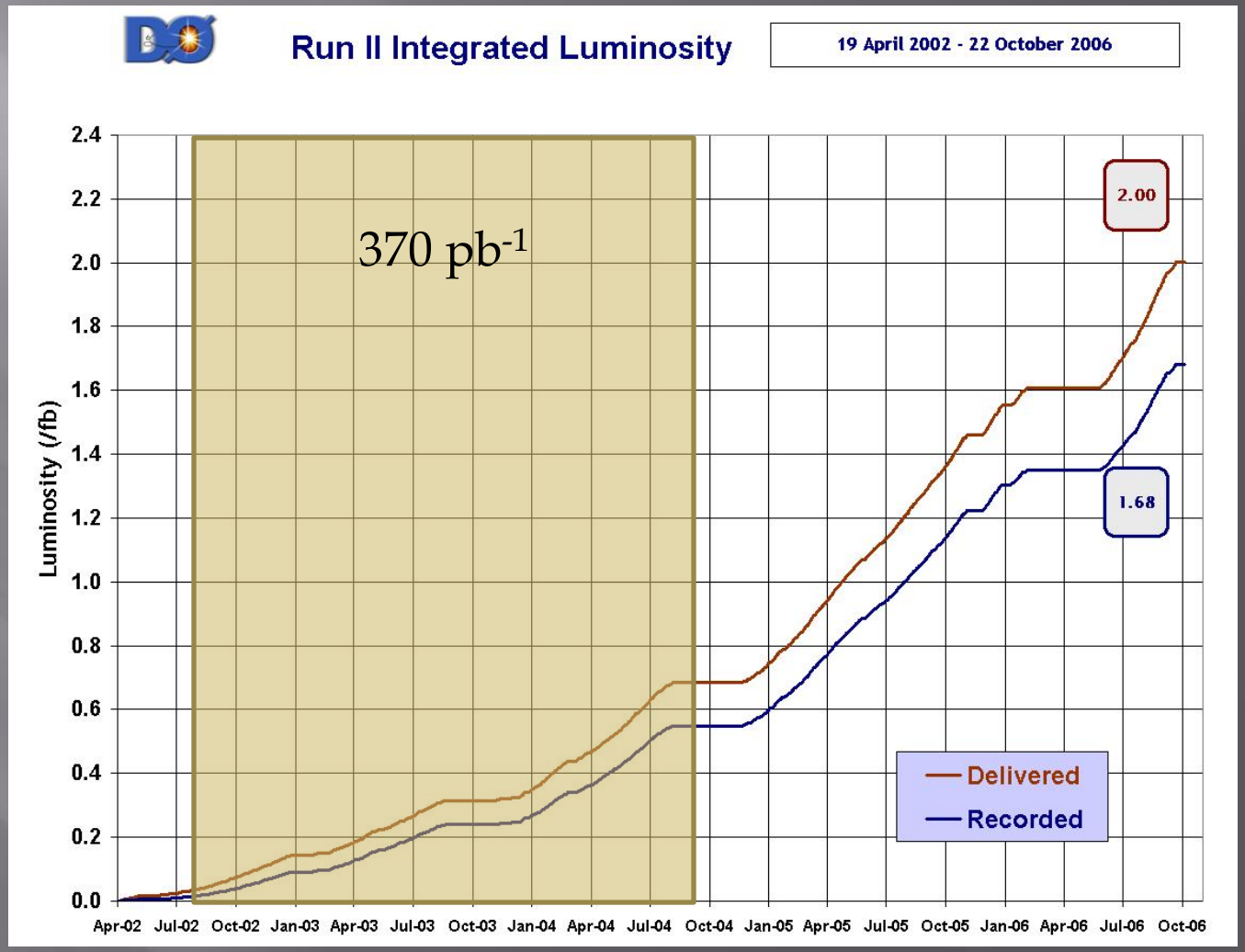


The Data

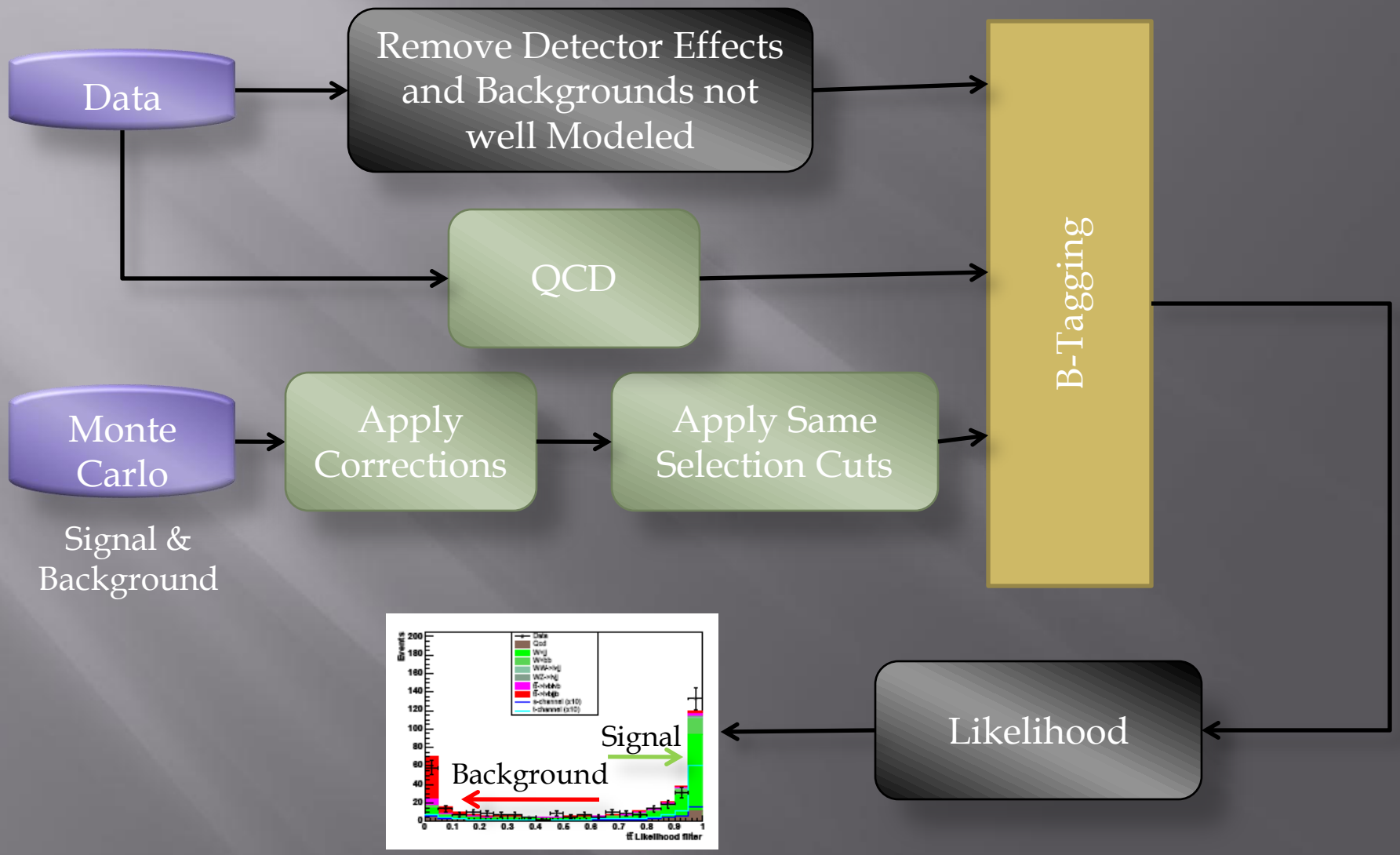
Collected between August 2002 and August 2004

Standard Data Quality Requirements Applied.

The total is 370 pb^{-1} of data



The Analysis



Basic Selection Cuts

Triggers

High p_T Lepton + jet trigger

Lepton

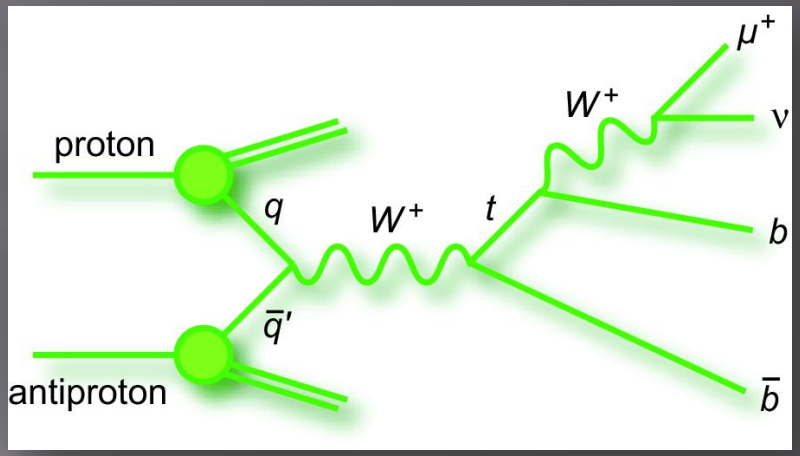
p_T > 15 GeV, Central
Isolated
No Other High p_T Leptons allowed

Missing Energy

Missing E_T > 15 GeV

Jets

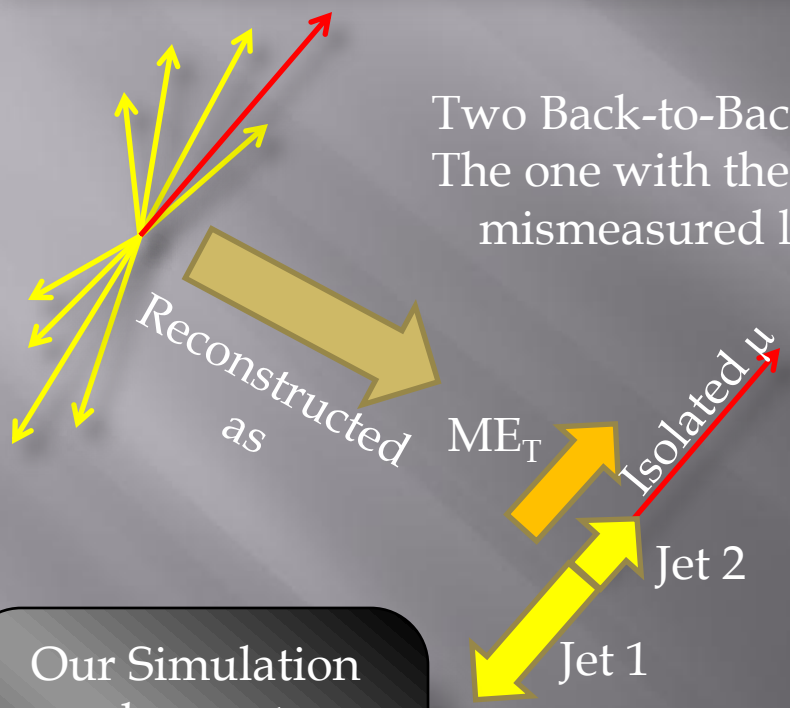
Between 2 and 4 Jets ← Upper bound eliminates tt
E_{T1} > 25 GeV, $|\eta|$ < 2.5
E_T > 15 GeV, $|\eta|$ <3.4



Cleaning Up The Data

Triangle Cuts

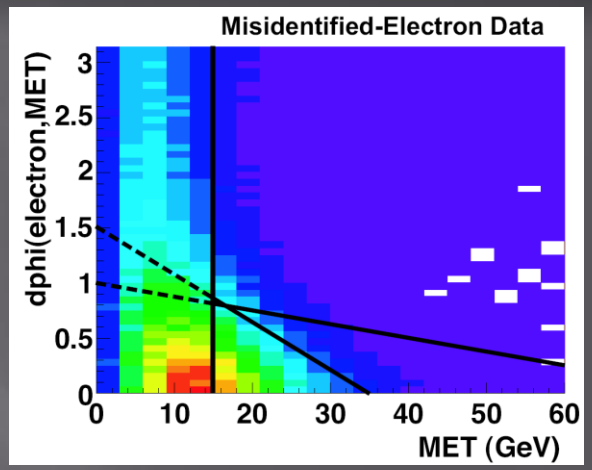
We have cuts to clean up particularly pathological backgrounds like badly mismeasured muons or noise in the calorimeter.

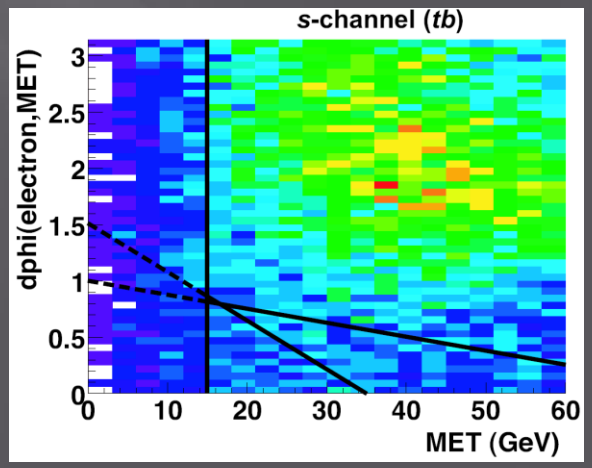


Two Back-to-Back Jets
The one with the muon is mismeasured low

Our Simulation does not reproduce this effect so we remove it

All objects (jets, e, μ) can be at the source of this effect

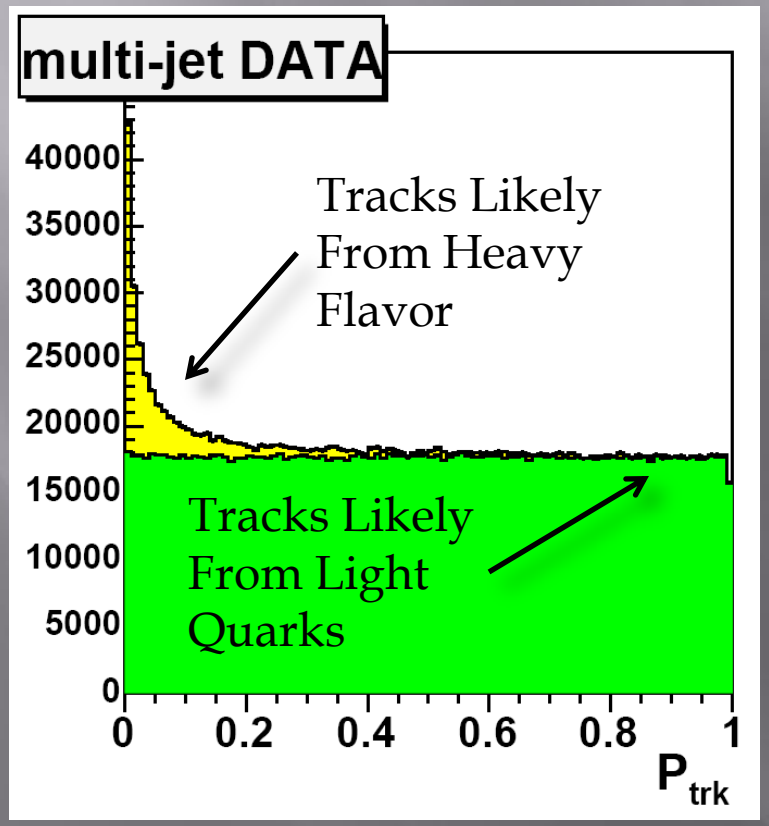




b-Jet Identification

The JLIP algorithm determines how likely a jet is to be from a light quark.

Based on $S=IP/\sigma_{IP}$ of the tracks in a jet



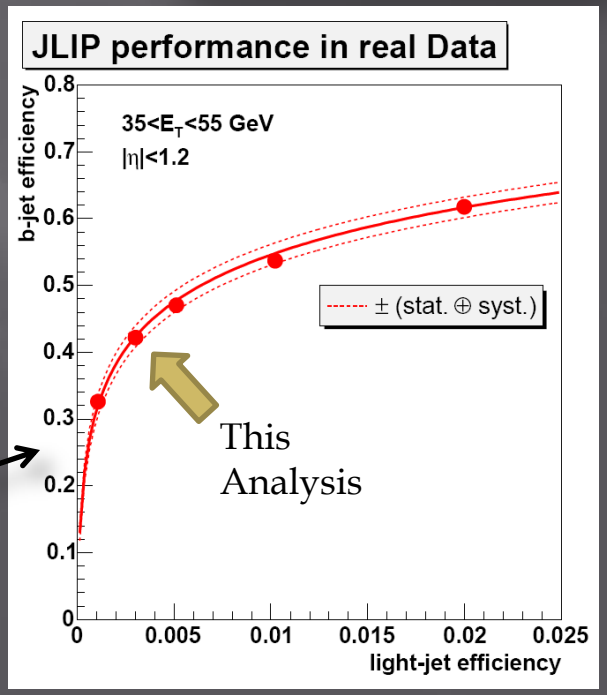
P_{trk} becomes a probability density function which is combined to determine an actual jet probability

Response can be changed depending on cut on P

DØ has a number of tagging algorithms:

- SVT
- ***JLIP***
- CSIP
- NN

New



b-Jet Event Selection

Single Top Has 2 b-quarks

Split the analysis depending on # and type of tags

Keep different S:B channels apart

Splitting Schemes

- 1 TIGHT Tag Sample
  2 TIGHT Tag Sample
- 1 TIGHT Tag Sample
  1 TIGHT Tag and additional LOOSE Tag Sample

Gives a 5% Gain in Expected Limit

In both cases we make sure the samples are orthogonal!

Boos, et al. Nucl.Instrum.Meth. A534 (2004) 250-259
Boos, Dudko, et al., CMSNote 2000/065.

Monte Carlo Samples

Signal

CompHEP-SingleTop + Pythia

Background

tt, Wjj, Wbb - ALPGEN + Pythia

No Jet Matching (for this analysis!)!

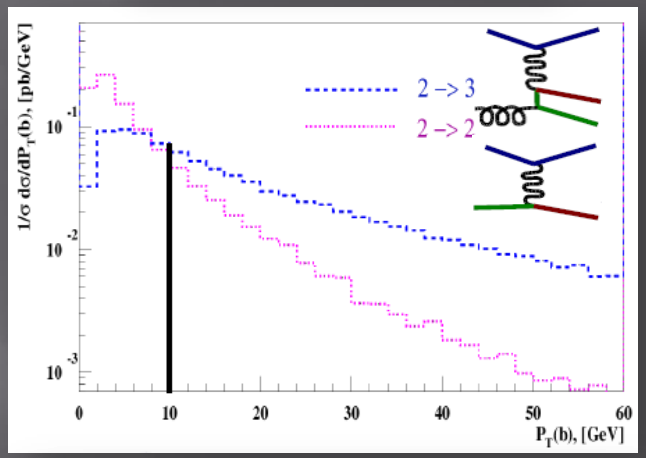
Relative Wbb and Wjj cross section is set with the MCFM NLO generator.

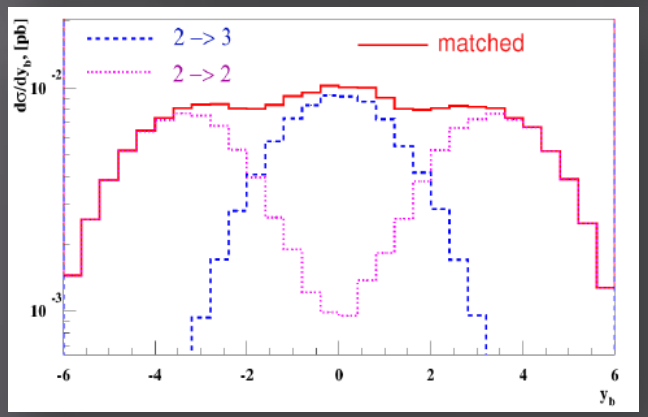
MC/Data Differences

Other than b-tagging similar selection cuts are all applied

Event weights applied to account for differences in vertex finding, jet reconstruction efficiency, etc.

Getting the NLO t-channel shape





Apply Tagging To MC

Tag Rate in MC and Data

b-tagging in MC is 15-20% more efficient

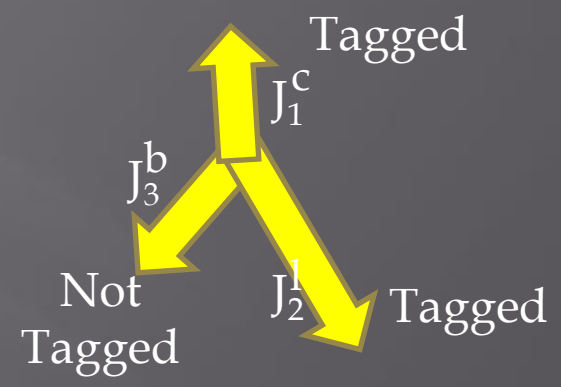
Final Variables Require Tagged Jets

Can't just weight the event. Either:

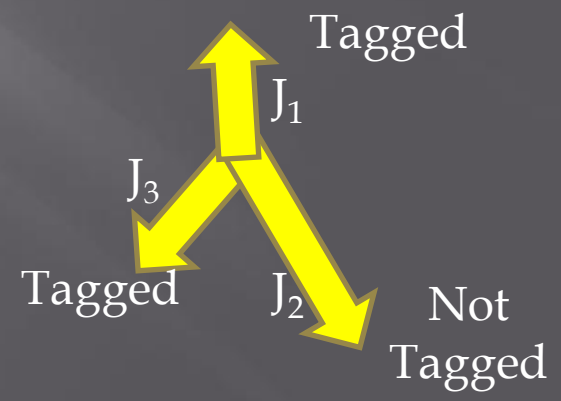
A. Run tagger on MC and apply Data/MC Scale factor on a jet-by-jet basis.
   - Requires large statistics to model light quark tags

★ B. Permute the event through every possible tag configuration
   - Assign weight based on probability of that configuration.

Same Event appears multiple times in sample with different tagging configuration and event weight.

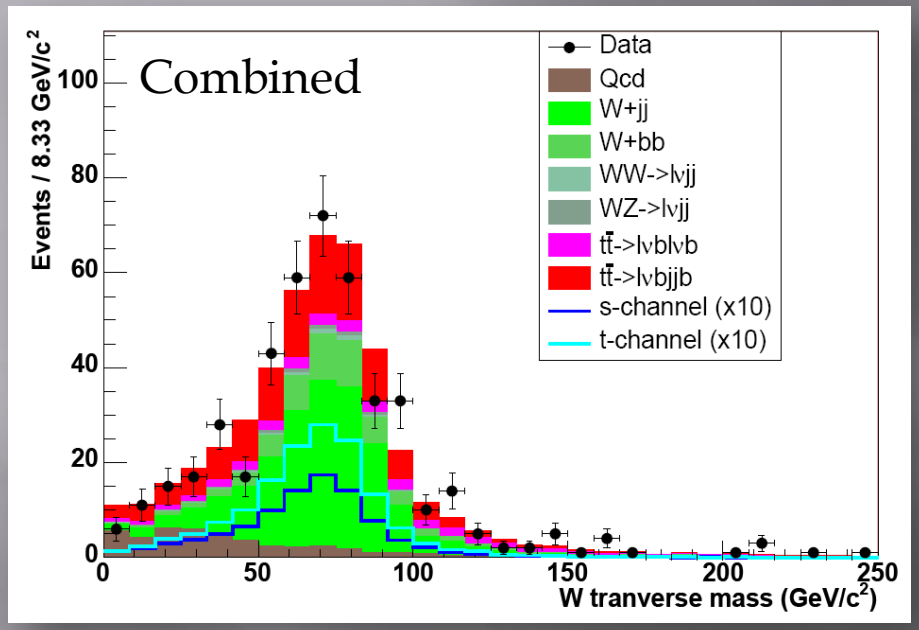


$W=P_T(J_1)P_T(J_2)P_{NT}(J_3)$



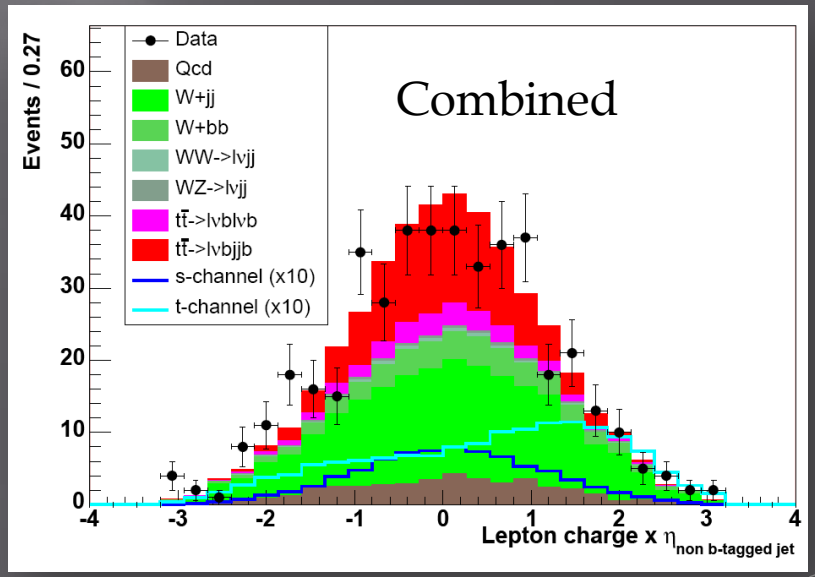
$W=P_T(J_1)P_{NT}(J_2)P_T(J_3)$

Post-Tagging Agreement



Sample (single tag, e)	# of Events
s&t Signal	11.10
Wjj	114.04
tt→l+jets	47.11
Wbb	27.00
Mis-ID's leptons	22.60
Diboson,tt→ dileptons	17.56

Sample (single tag, e)	# of Events
Data	248
Total Background	228.31



This is the data sample used as input to the likelihood analysis.

Event Yields

	Electron		Muon	
	Single Tag	Double Tag	Single Tag	Double Tag
s&t Channel	10.22	2.61	9.22	2.45
tt	51.67	25.83★	47.75	25.84★
Wbb	24.15	8.06	14.67	5.38
Wjj	111.55 ★	4.87	74.70★	3.42
WW	2.28	0.03	2.40	0.03
WZ	1.99	0.74	1.82	0.72
Multijet	21.79	1.41	17.92	2.67
Background	213.43	40.94	158.47	37.98
S/Sqrt(B)	**0.70**	**0.41**	**0.73**	**0.40**

Systematic Errors

Flat Systematics

Source	Error
Luminosity Measurement	6.5%
Theoretical Cross section	2%-18%
Jet and Lepton MC/Data Reconstruction Efficiencies	2%-5%
Jet Fragmentation (PYTHIA/HERWIG & FSR/ISR)	5%-7%

Shape Systematics

These sources of error could change the shapes of our distributions. We re-run the analysis with each error source at ±1σ.

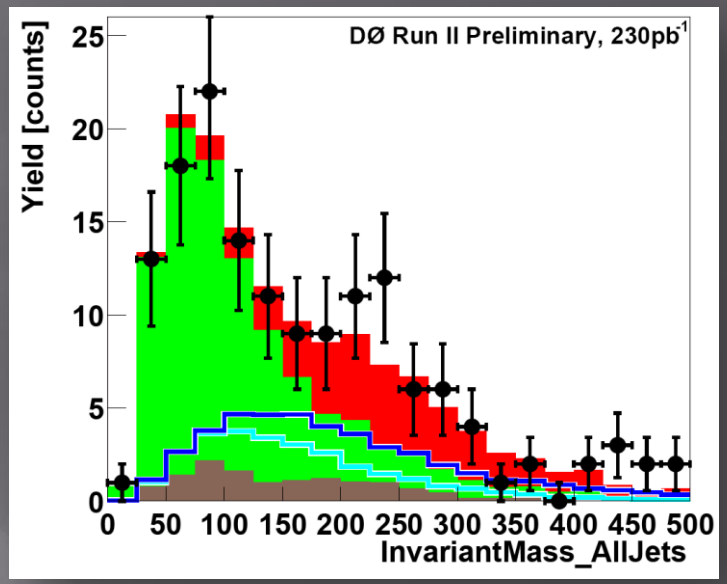
Source	Error
b-jet Identification	6%-8%
Jet Identification/Reconstruction	4%-5%
Jet Energy Scale	4%-5%
Jet Energy Resolution	2%-3%

Sensitive Variables

Inputs To a Multivariate Likelihood

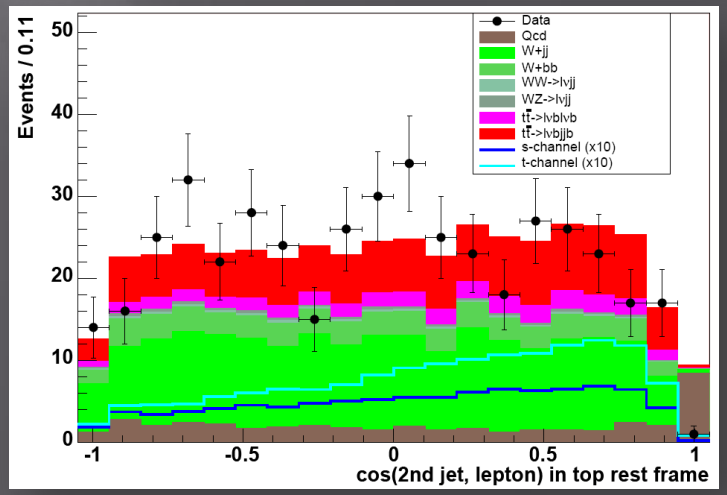
Look for variables that show differences between various signals and backgrounds

- Top Mass
- Spin Correlation Variables
- Anything else that is well modeled and has some separating power



Used in this Analysis

- p_T of the 1st, 2nd, and 3rd leading jets
- Scalar sum of the ME_T and E_T of lepton
- Invariant mass of all jets, W M_T, $M_{W,tagged}$
- Minimum angular separation between jets
- Cos of 2nd leading jet and lepton in top frame
- Sphericity of event
- Centrality of event
- Qxη – Charge of lepton, η of untagged jet



Likelihood

- Uses shapes of distributions rather than a straight cut
- Components determined from Background and Signal model
- No training (as with a neural network or decision tree)

Determine $\mathcal{L}(\vec{x})$ for each event

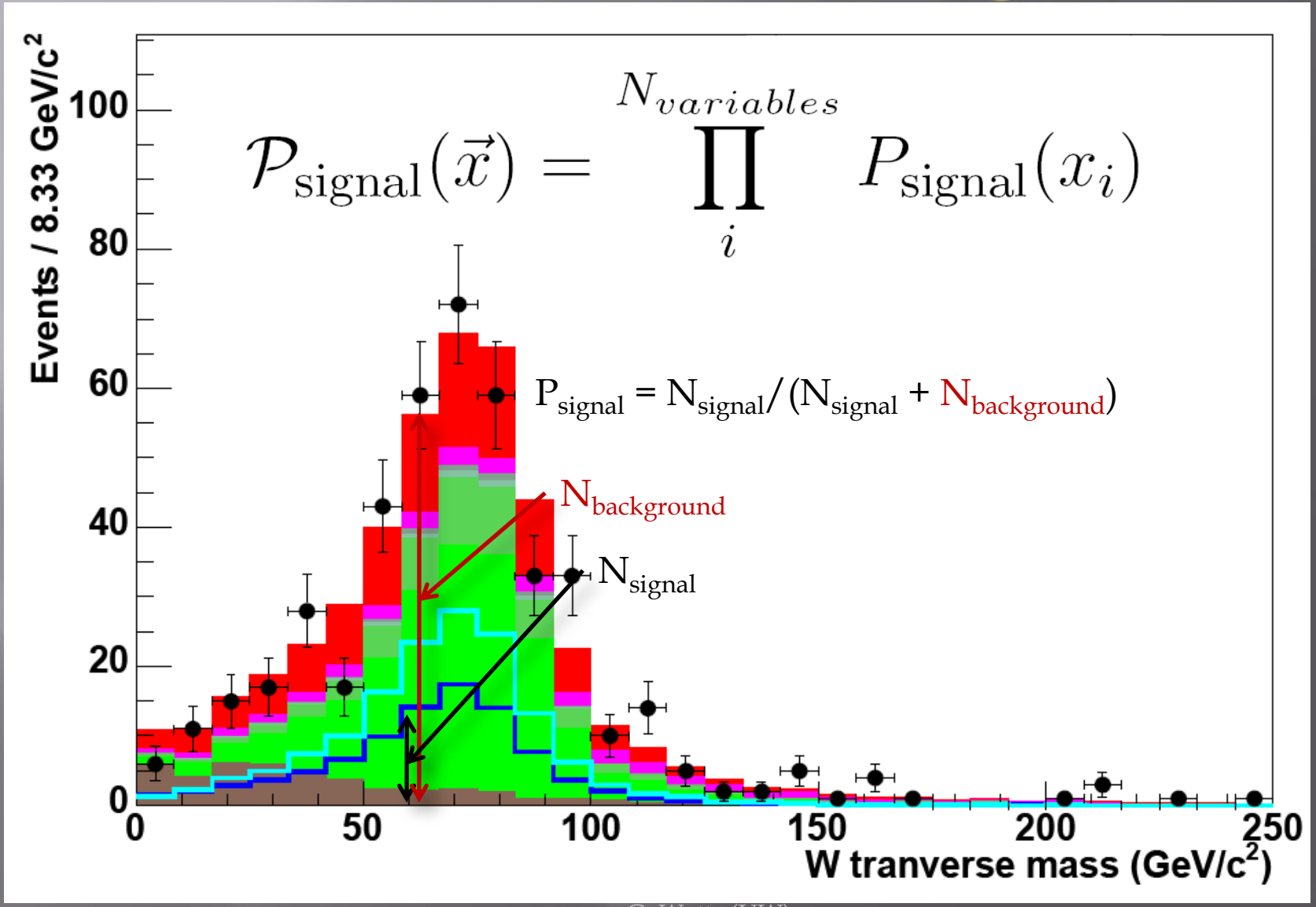
$$\mathcal{L}(\vec{x}) = \frac{\mathcal{P}_{\text{signal}}(\vec{x})}{\mathcal{P}_{\text{signal}}(\vec{x}) + \mathcal{P}_{\text{background}}(\vec{x})}$$

x is a vector of the sensitive variables

Evaluated event-by-event on data

Determined using Background model

Determining P_{signal}



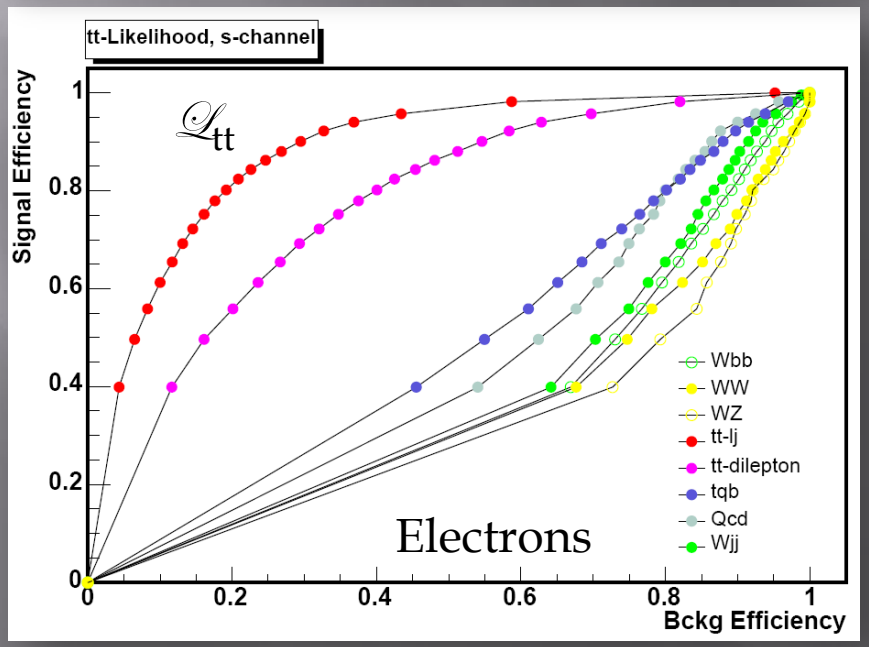
Multiple Likelihoods

Two Distinct Sources of Backgrounds

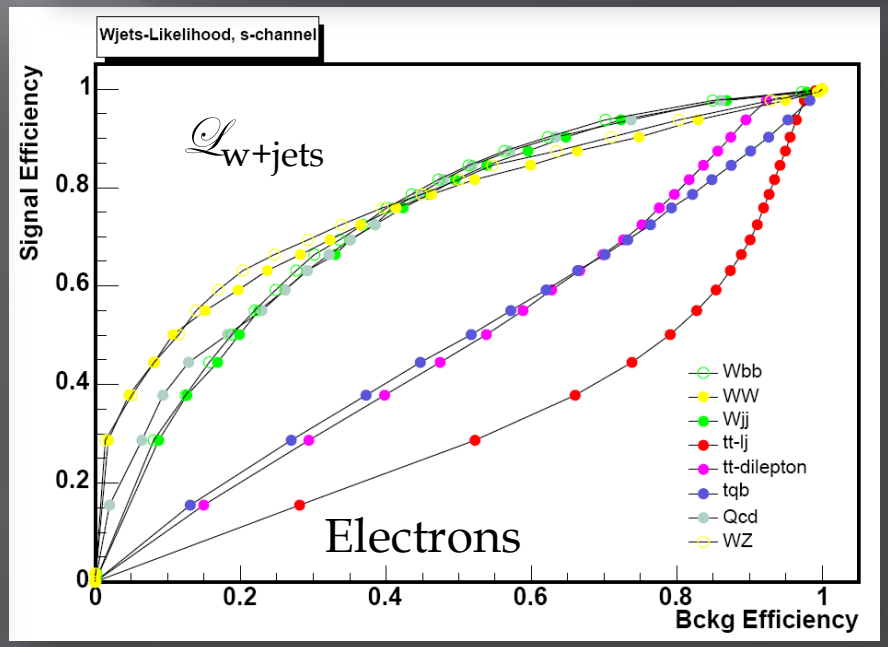
Wjj – 65% of total background
tt – 32% of total background

We construct one likelihood for each of these sets of backgrounds

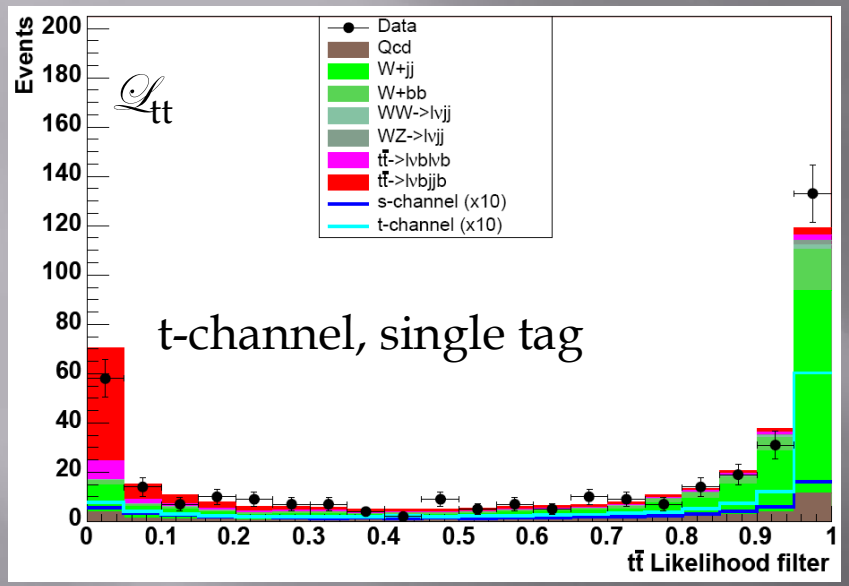
Final Likelihood Performance

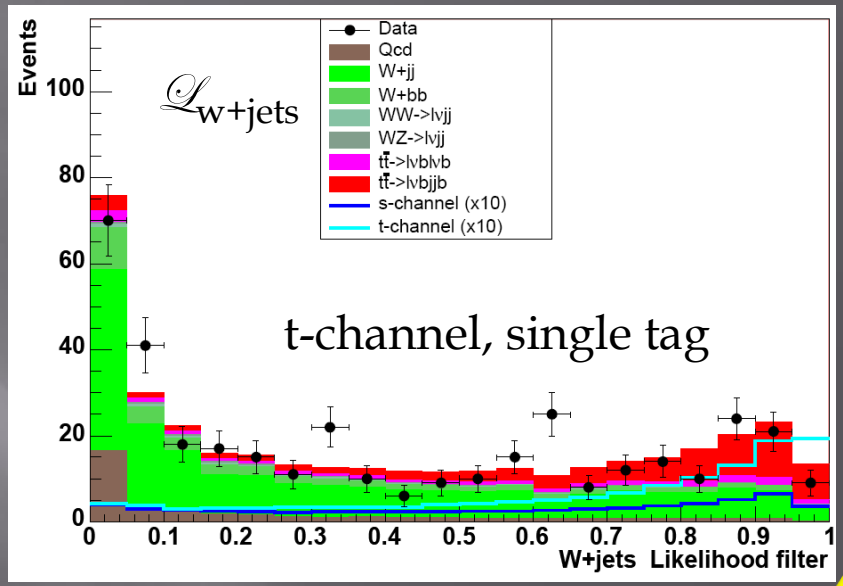


We Don't Actually Cut On the Likelihood!



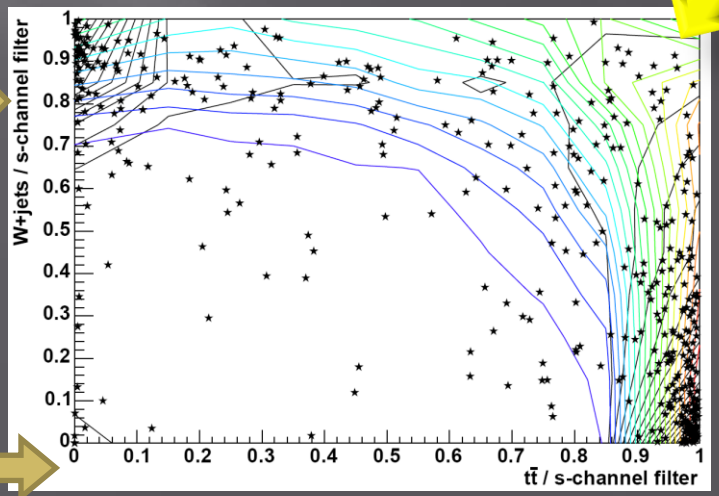
Likelihood Result





The output of each likelihood is plotted on a 2D plot.

- This plot, binned, is input to the Bayes Limit Calculation

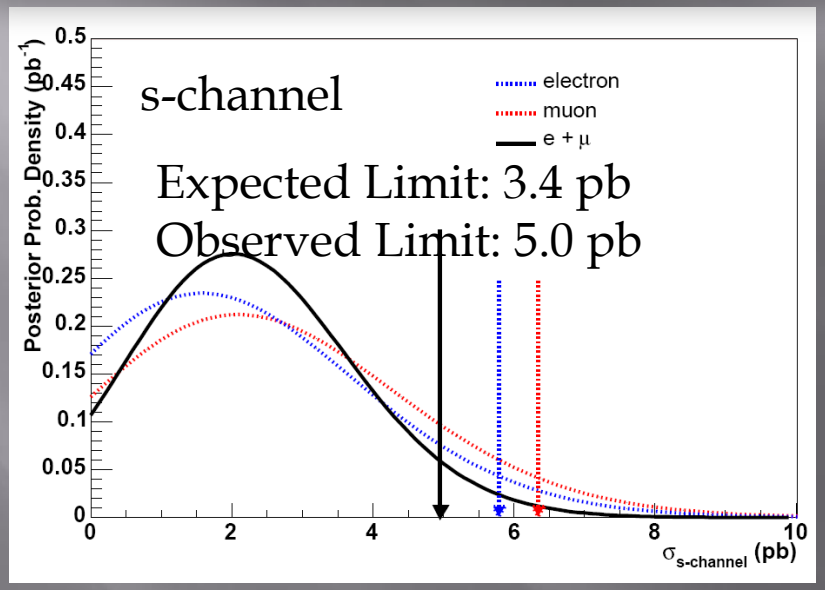


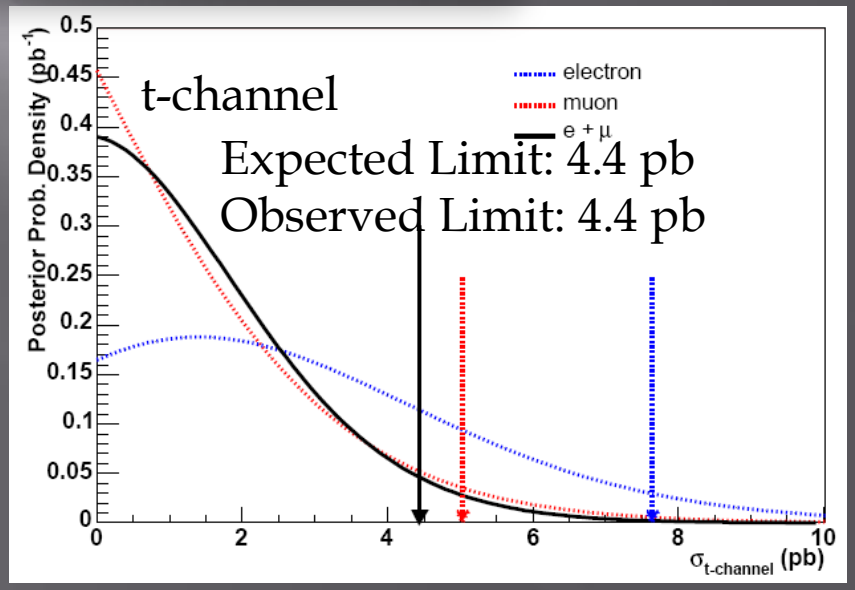
Limits

No Evidence for Single Top Production in 370 pb^{-1} of DØ Data

Using Bayesian approach in a binned likelihood fit
Include bin-by-bin systematics

Observed Limits





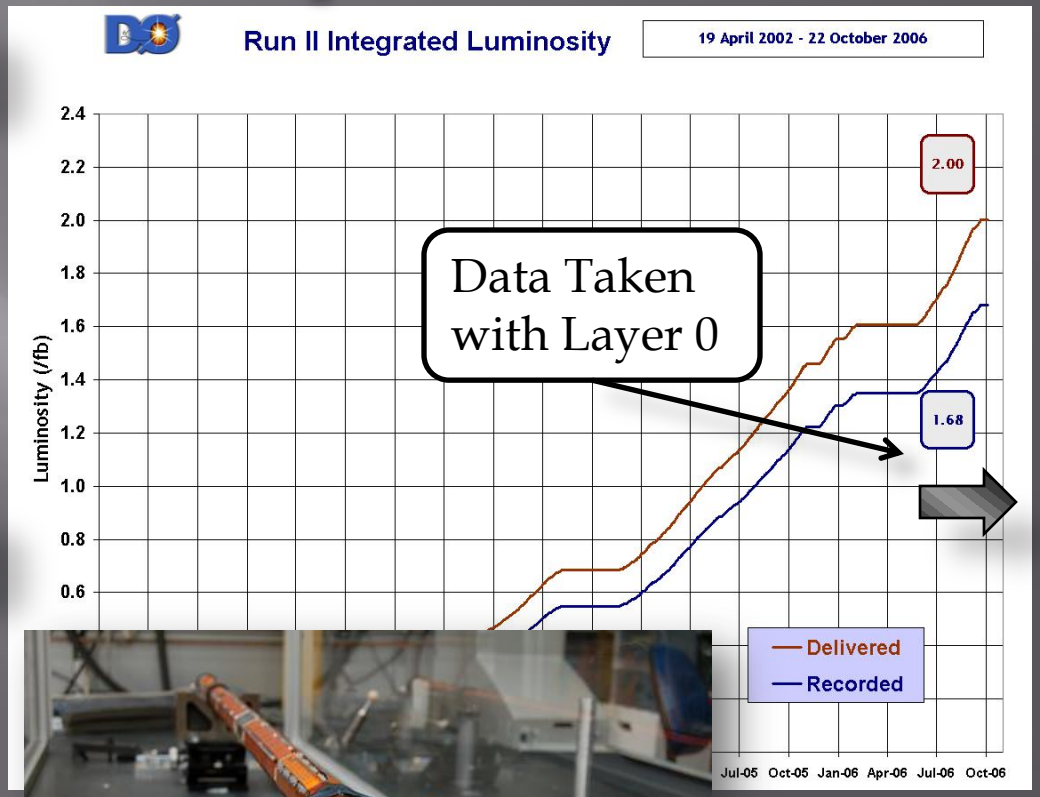
Future Prospects

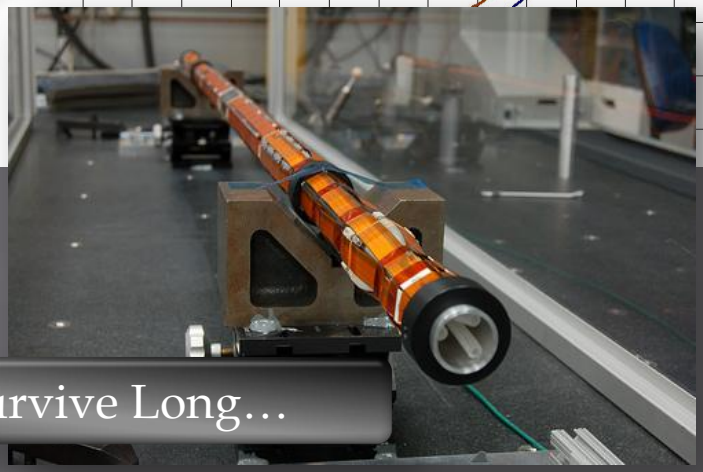
Near Term Prospects

- We have close to 1 fb^{-1} being analyzed as we speak.
- Includes major upgrade to the b-tagging performance
- Improved analysis techniques

Long Term Prospects

- Data since summer includes new Layer 0 of the Silicon detector
  - Another improvement to b-tagging





A SM Single Top Can't Survive Long…