Argonne National Laboratory
HEP Seminar

January 18, 2006

Search for Single Top at DØ

- The Tevatron and DØ
- Electroweak production of top quarks
- Search strategy:
  - Event selection, background estimation
  - Cuts, Decision Trees, NNs, likelihoods
  - Statistical analysis, limit extraction
- New physics reach, sensitivity for discovery
- Lessons learned & Conclusions

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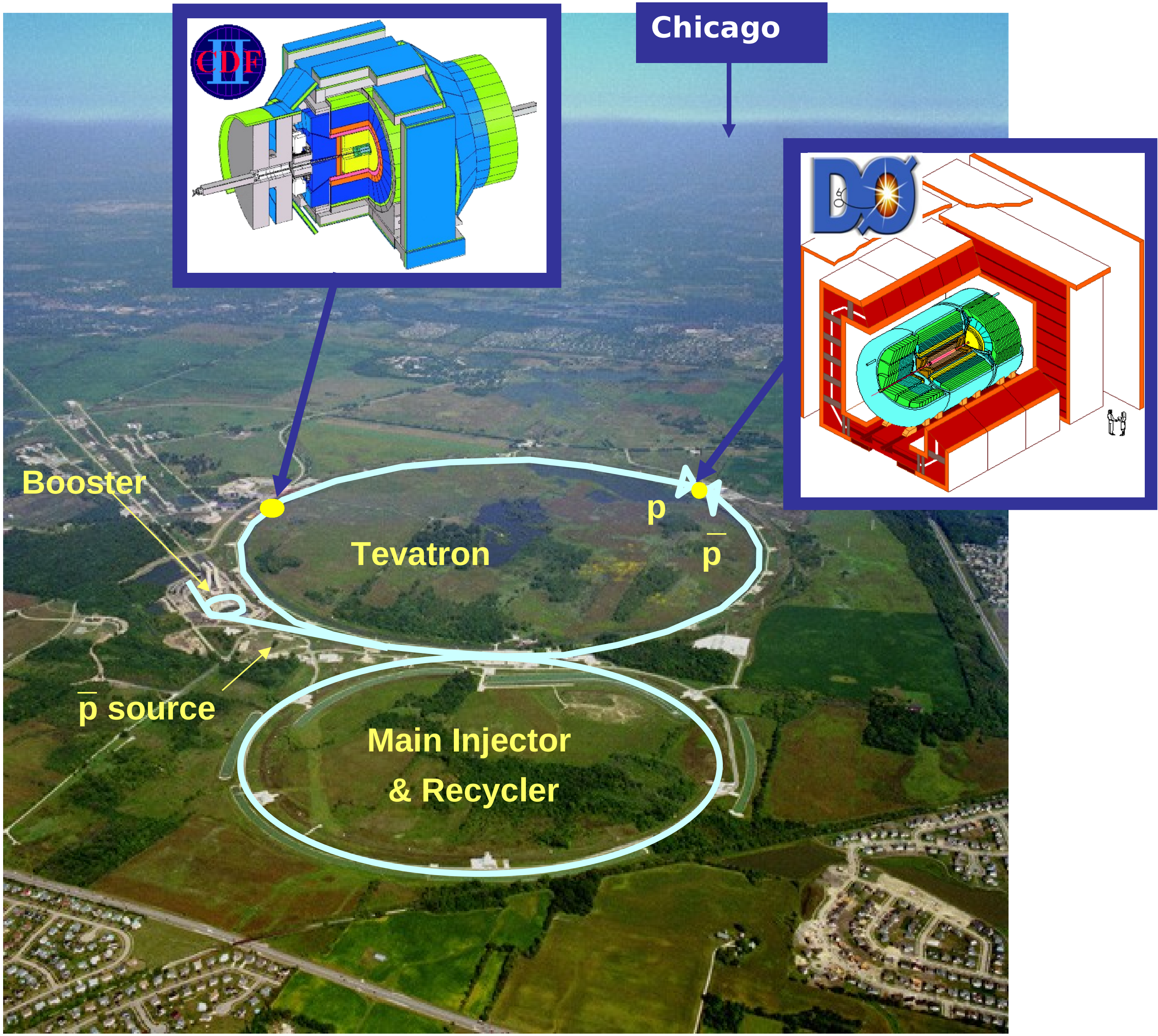
The Tevatron

The highest energy particle accelerator in the world!

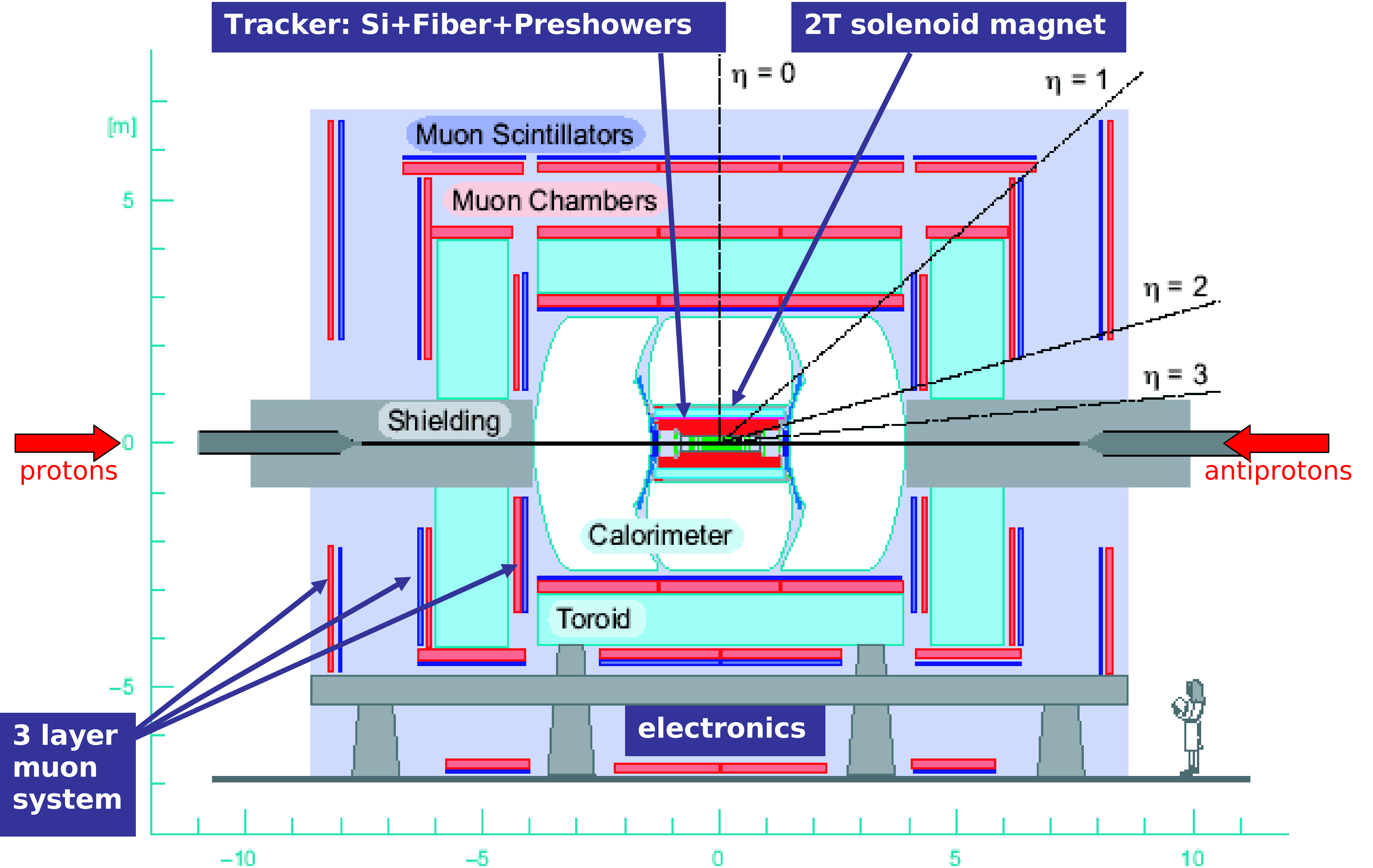
Proton-antiproton collider

Run I 1992-1995
Top quark discovered!

Run II 2001-09(?)
$\sqrt{s}$ = 1.96 TeV
Δt = 396ns
>1fb^{-1} delivered
Peak Lumi: 10^{32}cm^{-2}s^{-1}

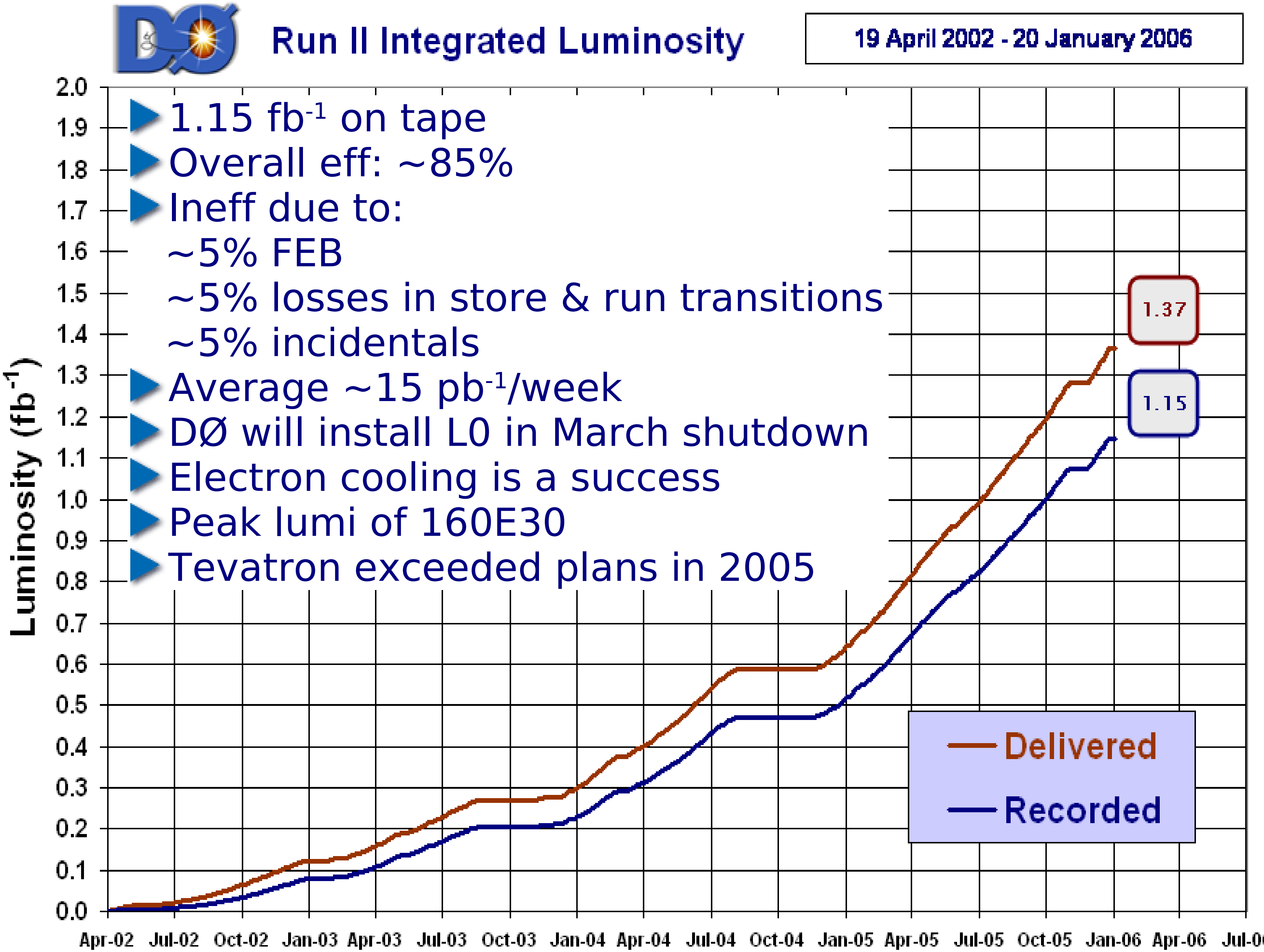


DØ for Run II



Tracker: Si+Fiber+Preshowers
2T solenoid magnet
η = 0
η = 1
η = 2
η = 3
[m]
5
0
–5
Muon Scintillators
Muon Chambers
Shielding
Calorimeter
Toroid
protons
antiprotons
electronics
3 layer muon system
–10
–5
0
5
10

Data taking



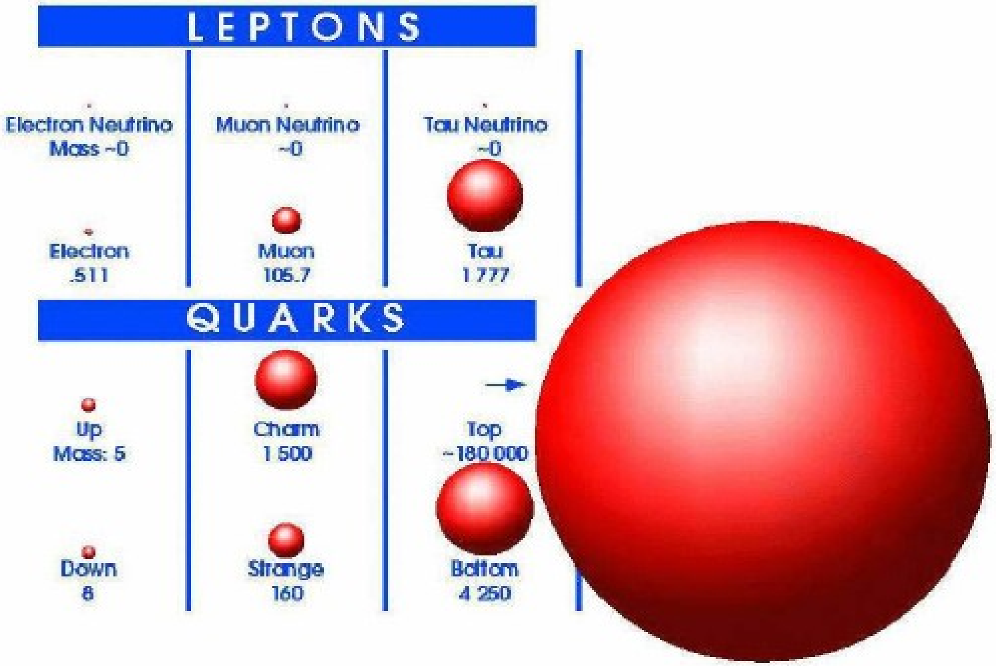
- 1.15 fb^{-1} on tape
- Overall eff: ~85%
- Ineff due to:
  - ~5% FEB
  - ~5% losses in store & run transitions
  - ~5% incidentals
- Average ~15 pb^{-1}/week
- DØ will install L0 in March shutdown
- Electron cooling is a success
- Peak lumi of 160E30
- Tevatron exceeded plans in 2005

Top quark physics

The top quark is a very special fermion:

- Heaviest known particle: 172.7±2.9 GeV
  - $m_t \sim v/\sqrt{2}$, $\lambda_t \sim 1$ $\rightarrow$ Related to EWSB!
  - Sensitive probe for new physics, FCNCs, ...
- Decays as a free quark: $\tau_t = 5\times10^{-25}$ s $\ll$ Λ_{QCD}^{-1}
  - Spin information is passed to its decay products
  - Test V-A structure of the SM

We still don't know: charge, spin, width, lifetime
We know its mass, its cross section and its BR($t\rightarrow Wb$)~1
Plenty of room for new physics

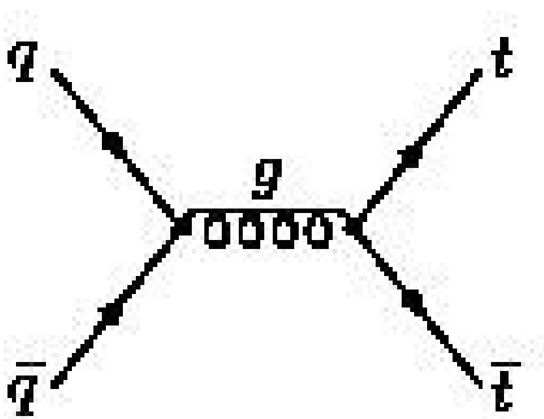


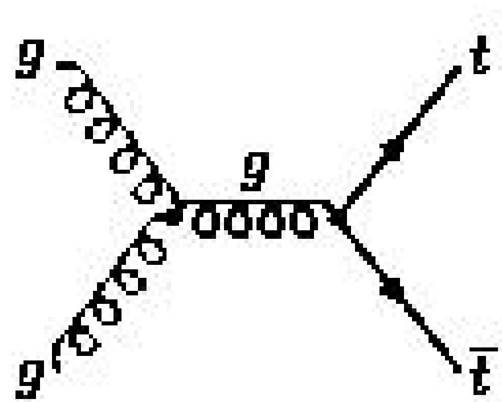
Top quark strong production

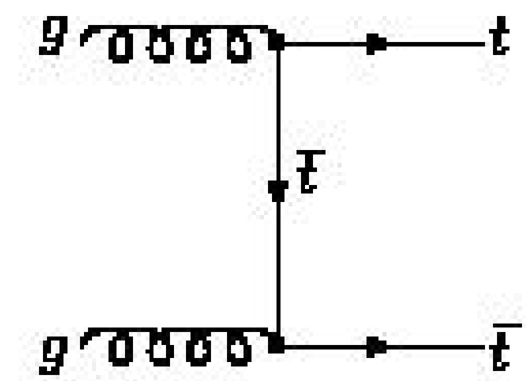
Pair production through strong interaction

σ(tt) ~ 7.0 pb at √s=1.96TeV (NNLO CTEQ6M, Kidonakis et al.)

- Main production mode at Tevatron
- 30% higher σ(tt) than in Run I
- 0.8 events/hour at recent Luminosities







TeV: qq~85% of σ(tt) **gg~15% of σ(tt)**

LHC: qq~10% of σ(tt) **gg~90% of σ(tt)**

σ(tt) ~ 833±100 pb at √s=14TeV (Cacciari et al.)

0.8 events/second at initial (low) luminosities

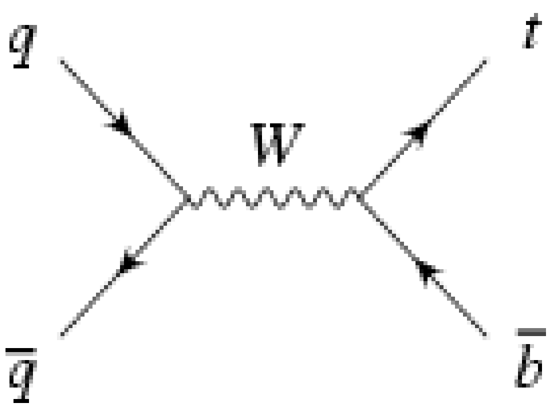
Top quark Electroweak production

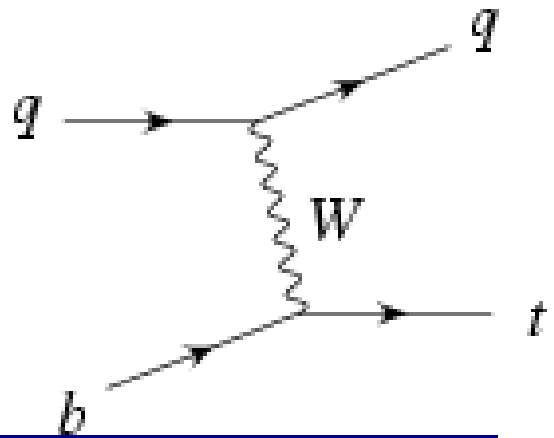
Single top production via EW interaction

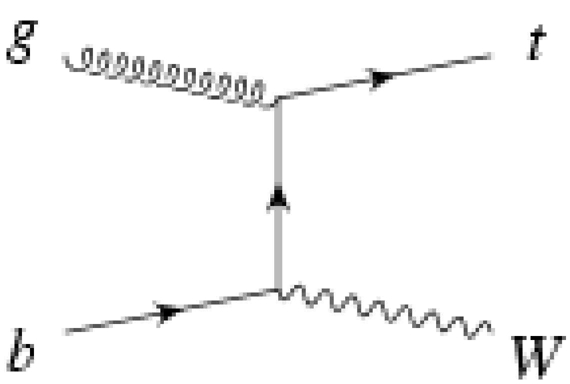
$\sigma(t) \sim 2.86$ pb at $\sqrt{s}$=1.96TeV (NLO Sullivan et al.)

- Flagship measurement at Run II
- Dominant bkgds: Wjj, tt, QCD
- Measure s- and t-channel cross sections separately
- First direct probe of $|V_{tb}|$

TeV:	**0.88±0.11 pb**	**1.98±0.25 pb**	**<0.1 pb**
LHC:	**10.6±1.1 pb**	**246.6±0.25 pb**	**$62.0^{+16.6}_{-3.6}$ pb**



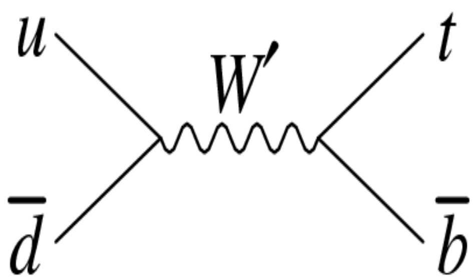


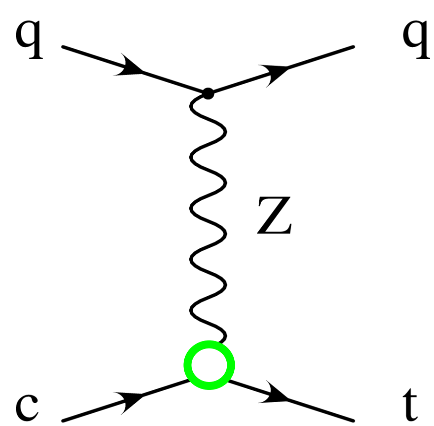


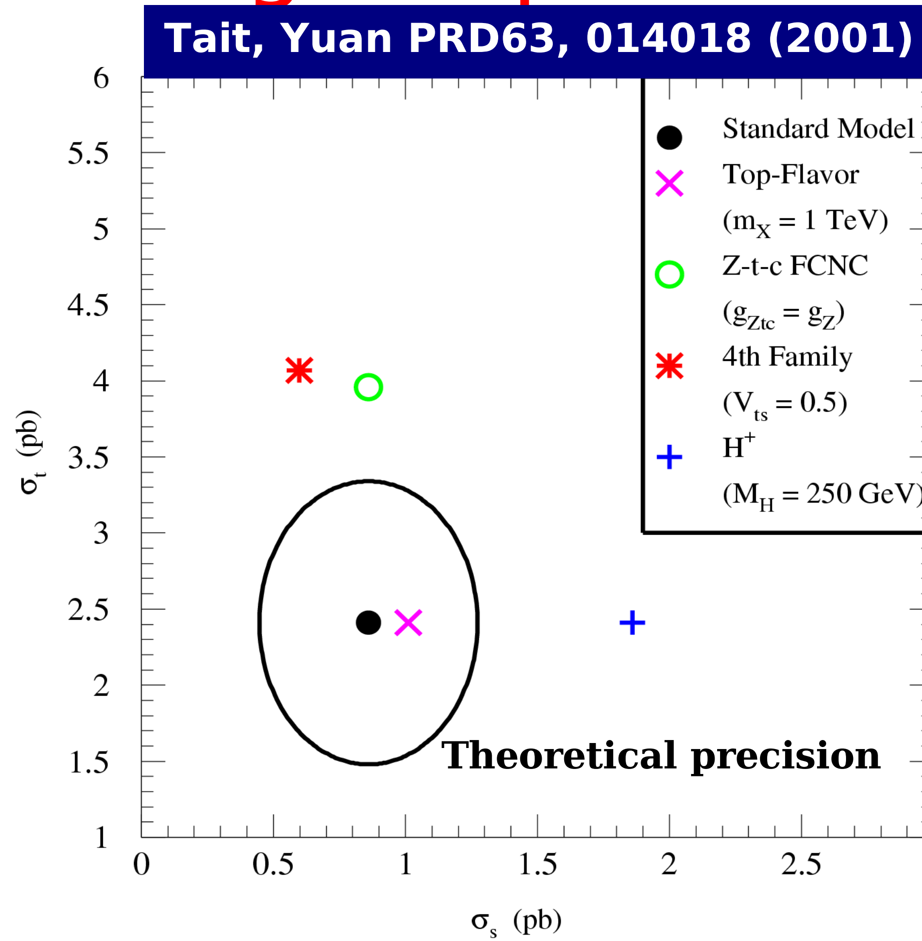
Harris, Laenen, Phaf, Sullivan, Weinzierl, PRD 66 (02) 054024
Sullivan hep-ph/0408049

Tait, PRD 61 (00) 034001
Belyaev, Boos, PRD 63 (01) 034012

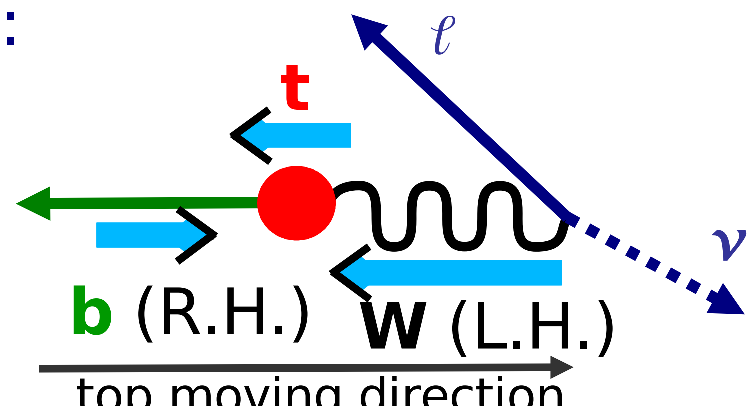
Why search for single top?



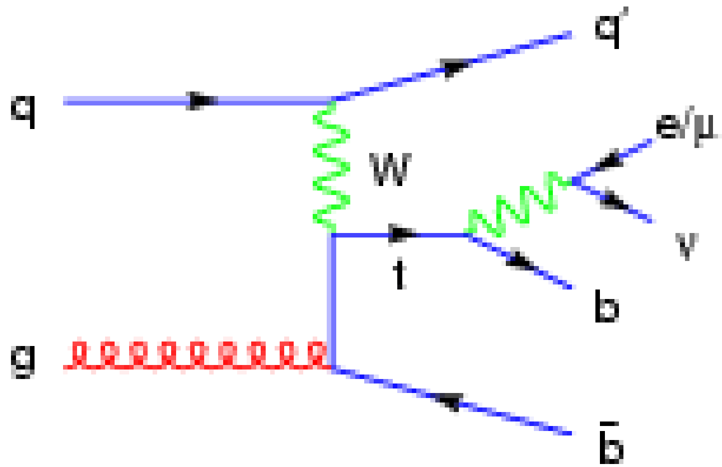




- Access W-t-b
  - measure V_{tb} directly
  - test unitarity of CKM
- Test V-A structure of SM
- New physics:
  - s-channel sensitive to resonances: W’, top pions, SUSY, etc…
  - t-channel sensitive to FCNCs
- Study top polarization, mass

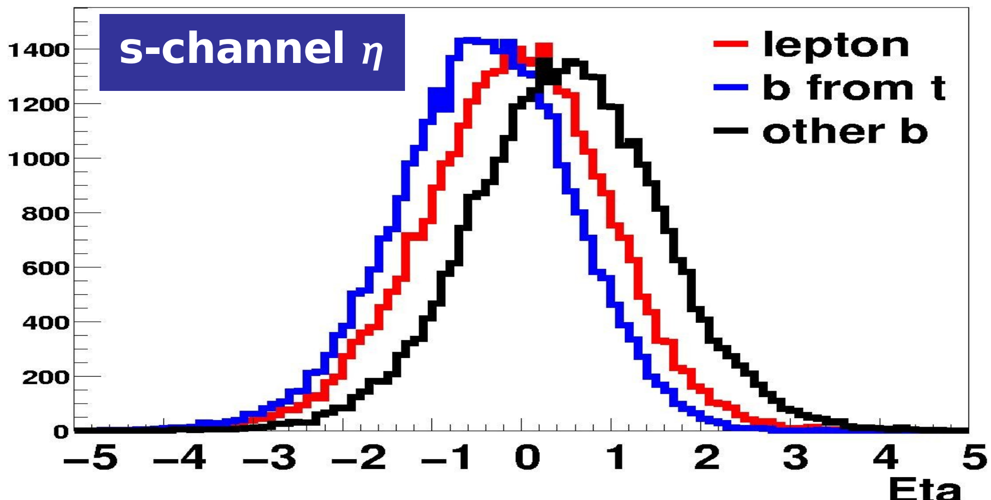


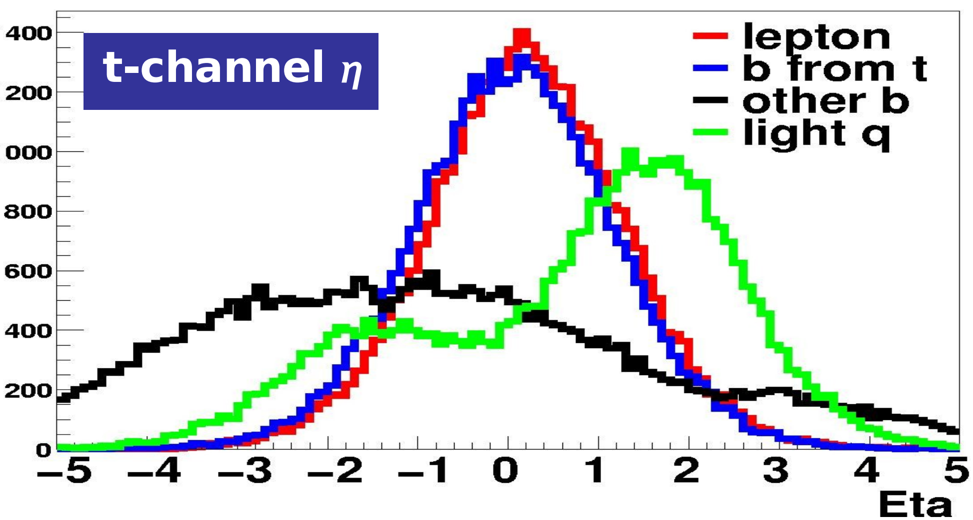
Signal topology

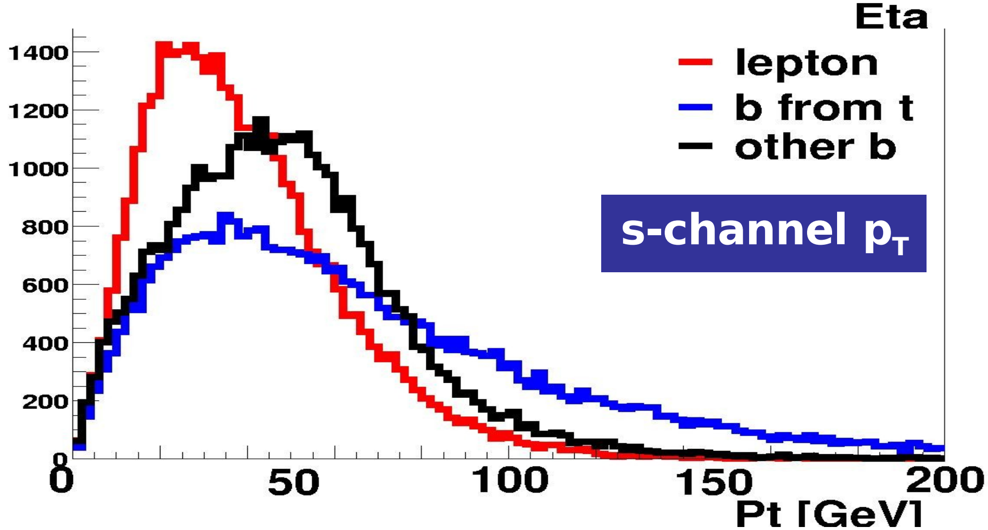


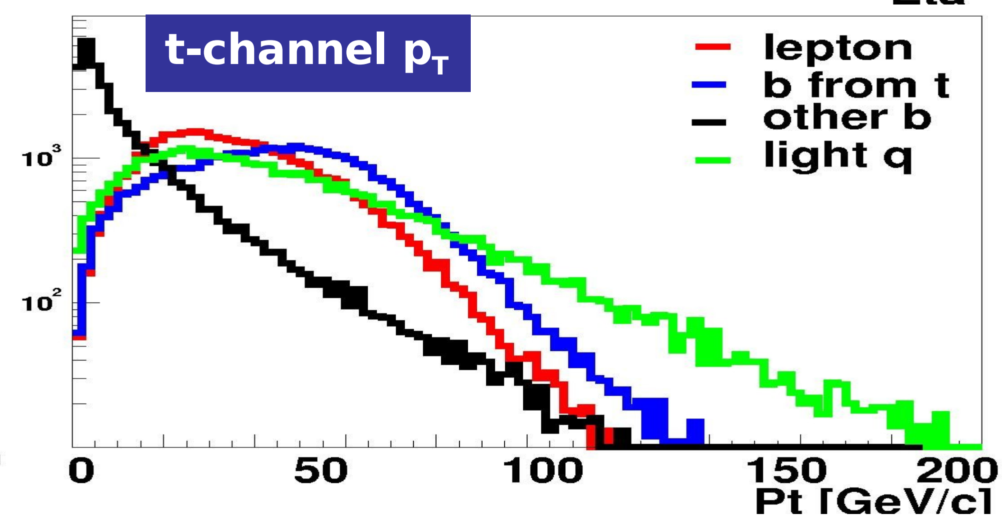
We are looking for:

- One high p_T isolated lepton (from W)
- MET (ν from W)
- One b-quark jet (from top)
- A light flavor jet and/or another b-jet









Signal modeling

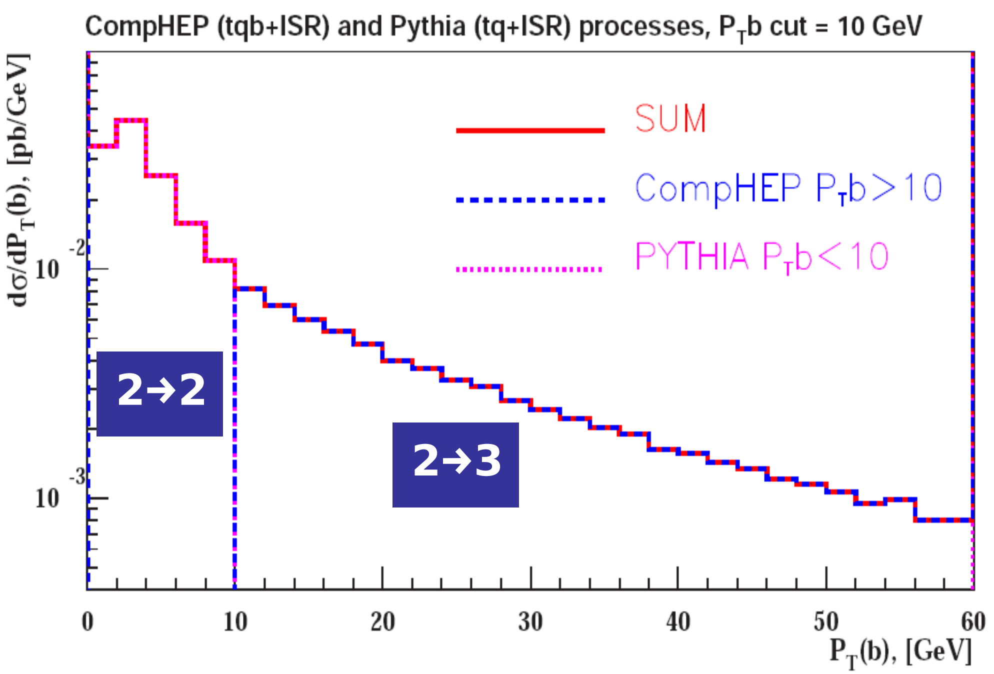
Have to get the t-channel right:
Avoid double counting when different diagrams produce same final states in different kinematic regions
Use ZTOP as NLO benchmark http://home.fnal.gov/~zack/ZTOP

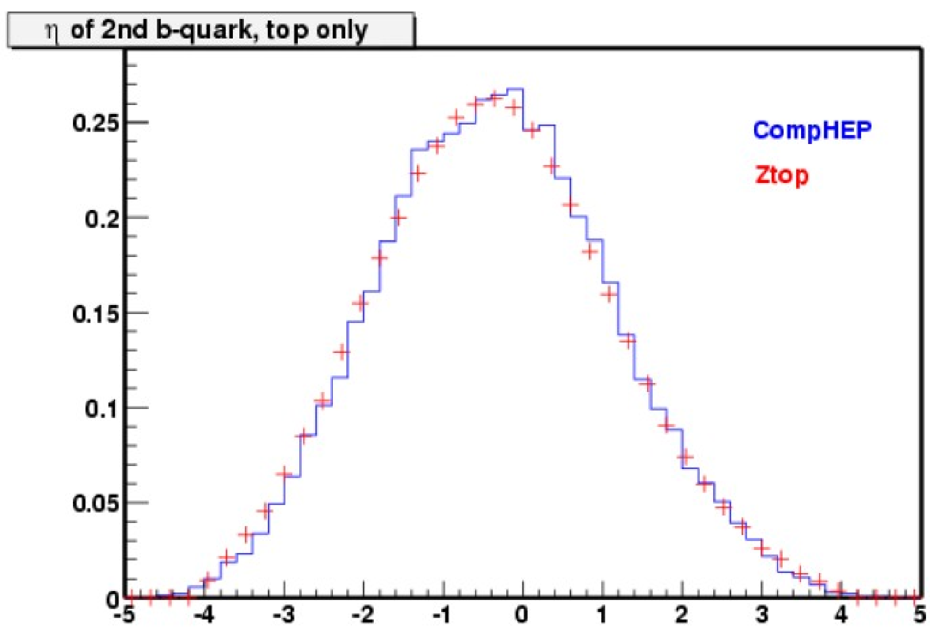
- DØ: "Effective" NLO CompHEP (also used in CMS)

Match 2→2 and 2→3 processes using b p_T for cross over, normalize to NLO

Resulting distributions agree well with ZTOP & MCFM

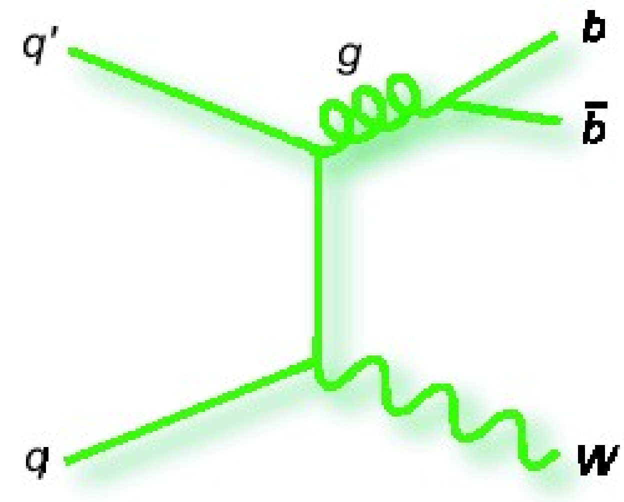
- Recently available: MC@NLO, Alpgen 2, C.-P. Yuan et al.



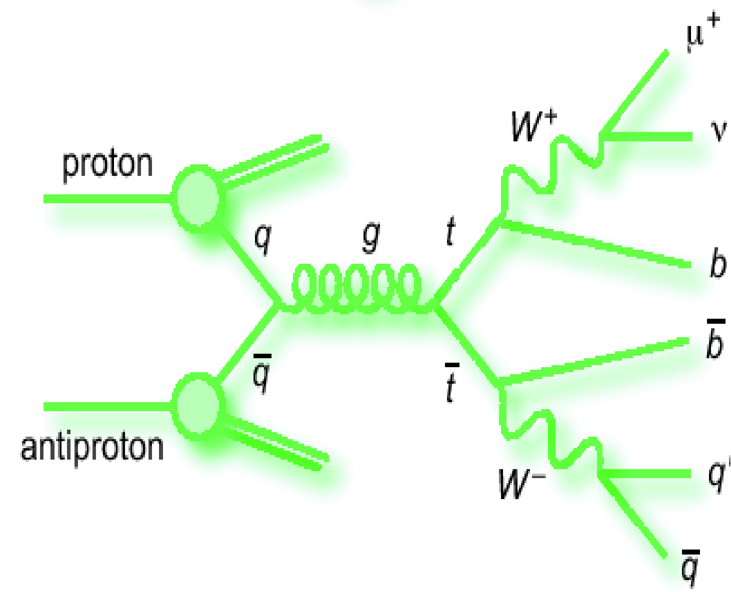


Background modeling

- W+jets (~300 pb)
  - Distributions from Alpgen
  - Normalization from data
  - Flavor fractions from NLO
  - NB: Few % of W+jets have heavy flavor in final state

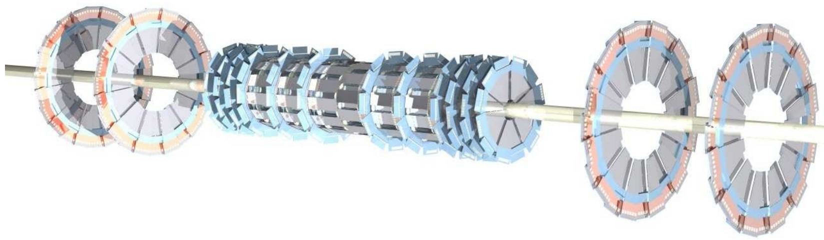


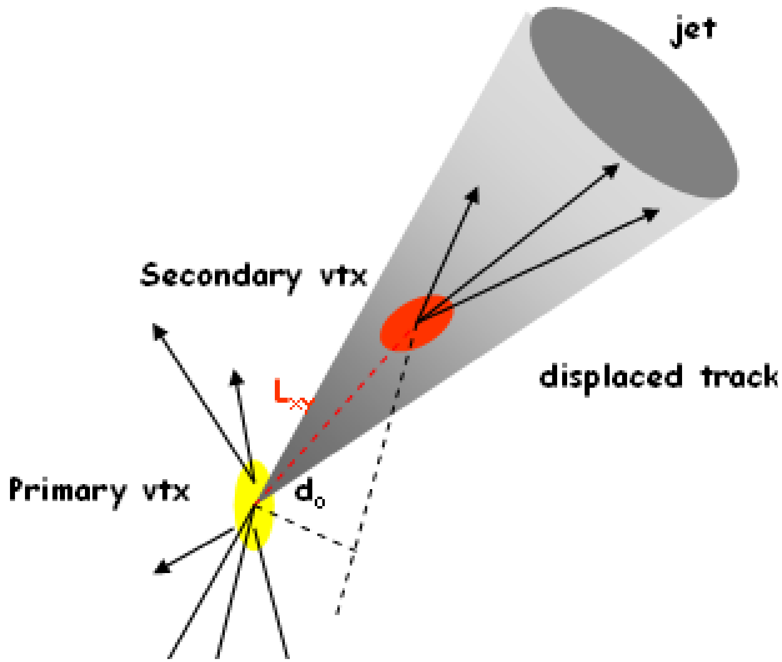
- Top pairs (~7 pb)
  - Topologies: dilepton and ℓ+jets
  - Use Alpgen

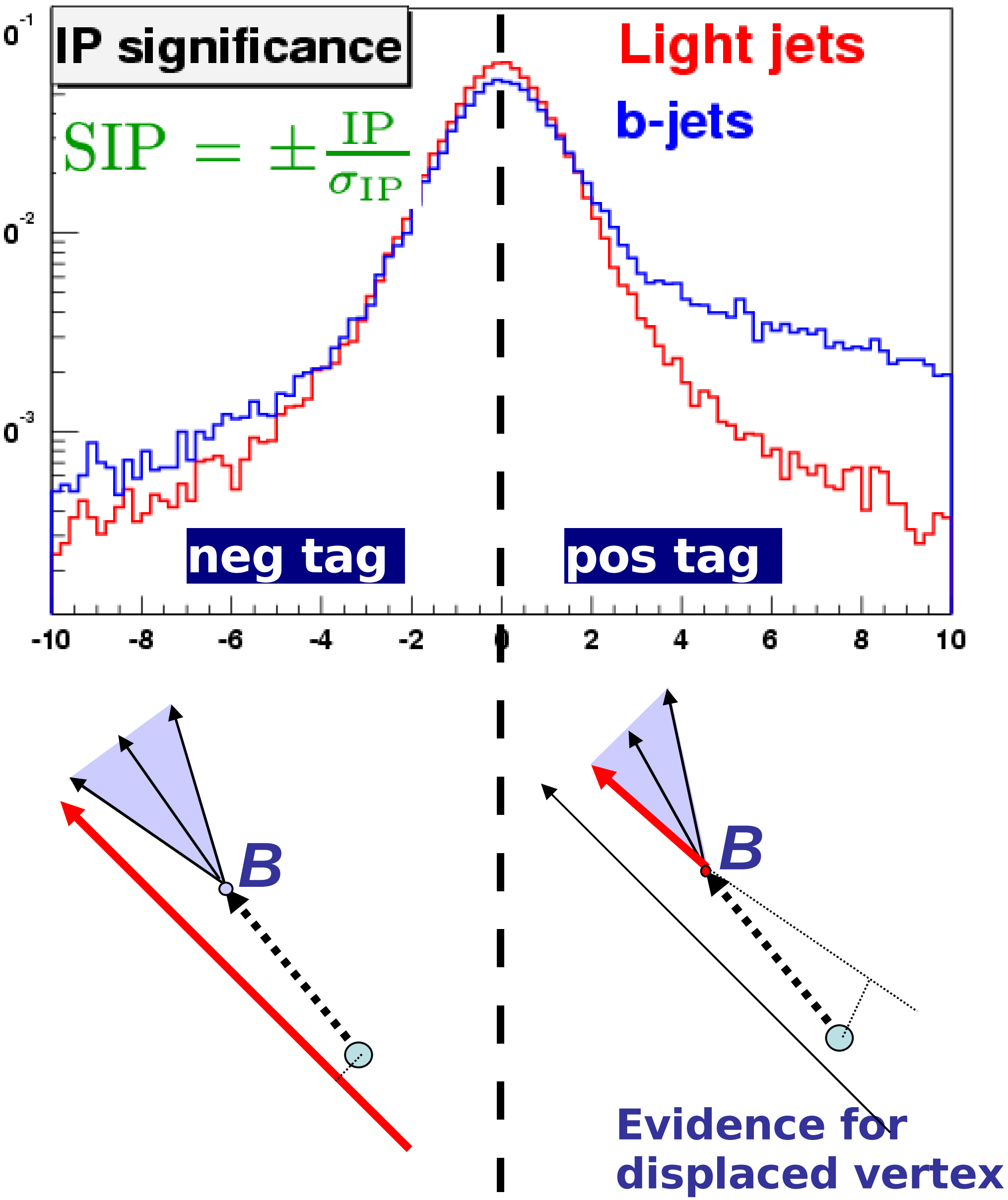


- Multijet events (misidentified lepton)
  - From data
- Diboson WZ, WW (~3 pb)
  - Estimated with Alpgen

Tagging b-jets





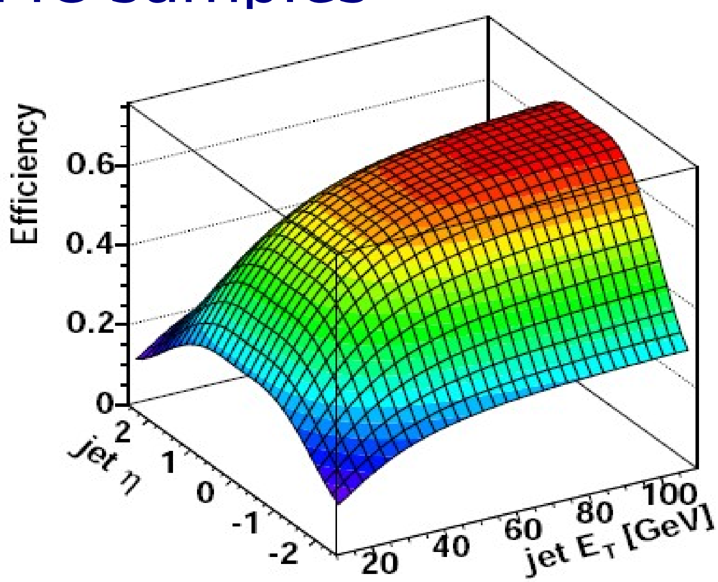


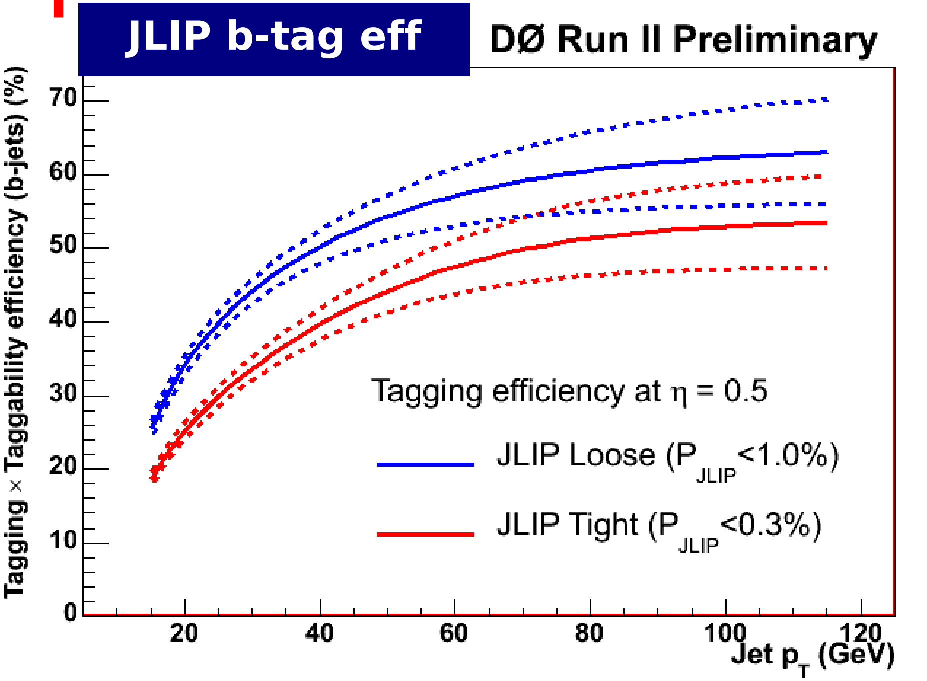
Three different algorithms for b-jet identification at DØ:

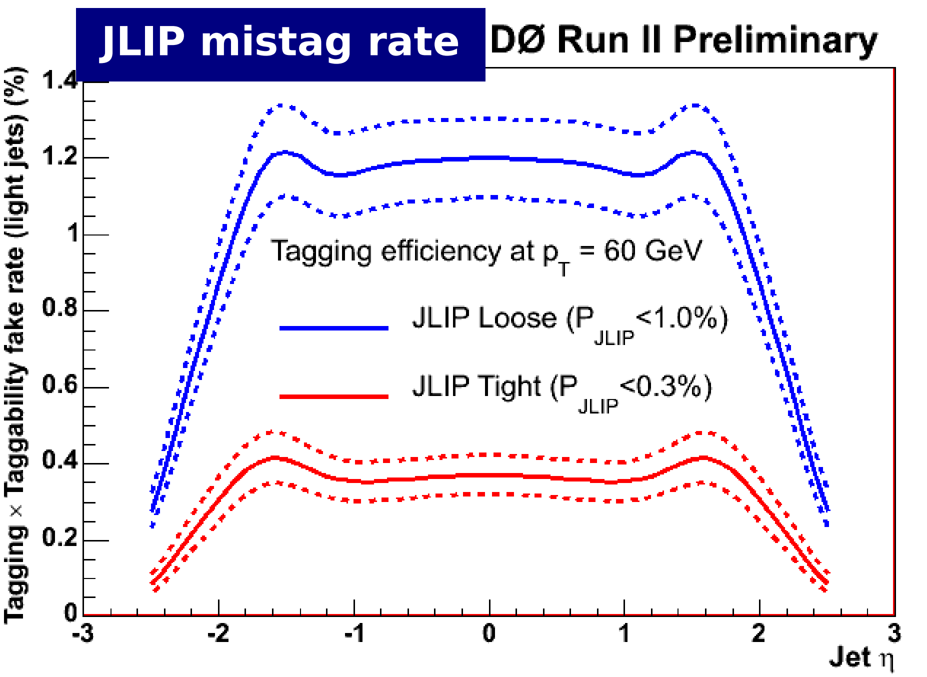
- Two based on tracks with large IPs
- One based on secondary vertex reconstruction

Lifetime taggers performance

- Efficiency to identify a b-quark jet ~50%
- Mistag-rate ~0.5%
- Soon to have NN tagger with much improved performance
- Use parametrisations derived in data to apply to MC samples







Analysis strategy

1) Event selection

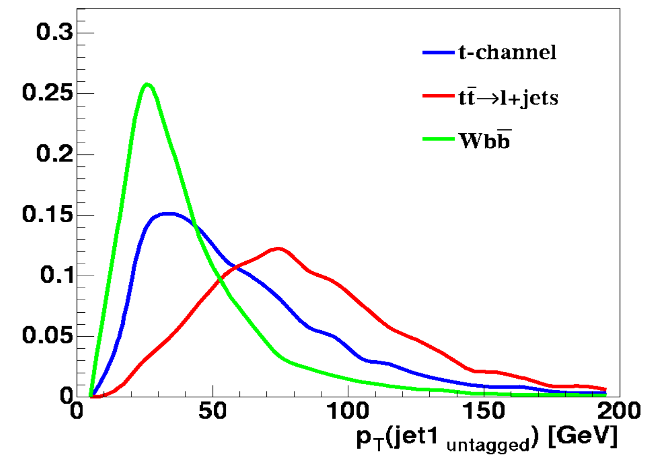
- Select W like events
- Maximize acceptance
- Model backgrounds well

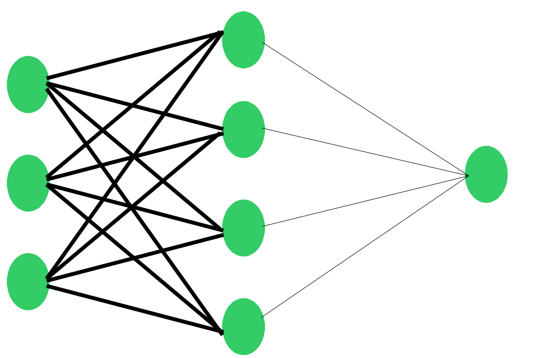
2) Separate signals from backgrounds

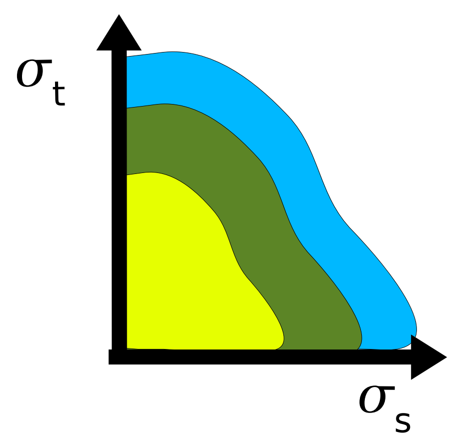
- Find discriminating variables
- Multivariate analysis

3) Determine cross section

- Use shape information
- Bayesian statistical analysis







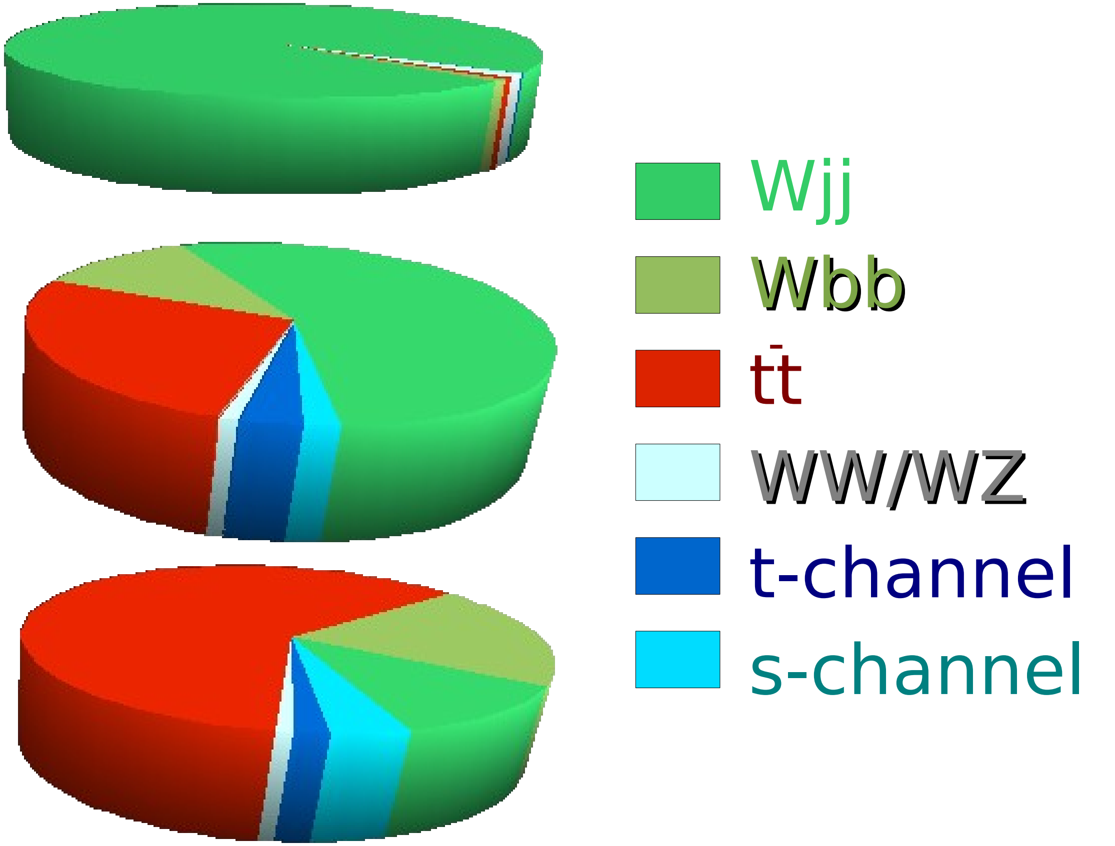
1) Event Selection

Lepton(e,μ): p_T>15 GeV, $|\eta_{e(\mu)}|$<1.1 (2.0)
Jets: $2 \le N_{jets} \le 4$, E_T>15 GeV, $|\eta|$<3.4
Jet1: E_T>25 GeV
MET: MET>15 GeV
Other clean-up cuts

Pretagged
7100 events

=1 b-tagged jet
252 events

≥2 b-tagged jets
31 events



Yields after event selection

- Optimize the selection to maximize acceptance
- Allow a lot of background at this stage!
- Then use multiple distributions to separate signal-background

Source	s-channel search	t-channel search
tb	5.5 ± 1.3	4.7 ± 1.0
tqb	8.6 ± 1.9	8.5 ± 1.9
$t\bar{t}$	78.3 ± 18.3	75.9 ± 17.6
W+jets	169.1 ± 20.1	163.9 ± 18.7
Multijet	31.4 ± 3.3	31.3 ± 3.2
Total background	287.4 ± 43.6	275.8 ± 40.6
Observed events	283	271

- Acceptance: 2.7±0.2% (s-channel) and 1.9±0.2% (t-channel)
- Main contributions:
  - Wjj 47%, Wbb 12%
  - tt ℓ+jets 21%, tt dilepton 6%
  - Multijet 10%, s or t-channel as bkgd to the other 3%

W+jets normalization

- Find fractions of real and fake isolated ℓ in the data before b-tagging. Split samples in loose and tight isolation:

$$N^{loose} = N^{loose}_{fake} + N^{loose}_{real}$$

$$N^{tight} = \varepsilon_{fake} N^{loose}_{fake} + \varepsilon_{real} N^{loose}_{real}$$

Obtain: N^{loose}_{real} and N^{loose}_{fake}

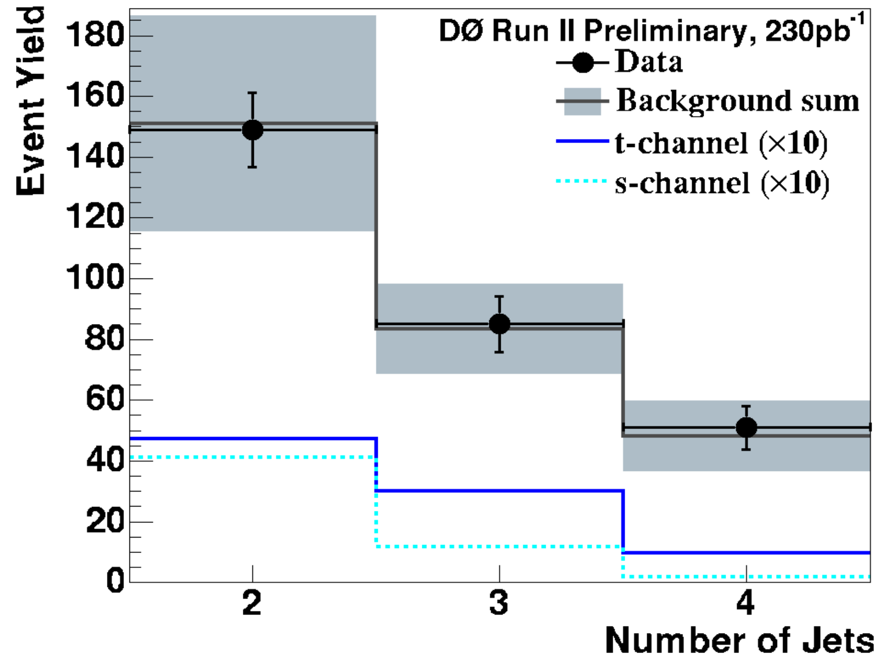
- Normalize the MC Wjj and Wbb samples to the real ℓ yield found in data, after correcting for the presence of tt and diboson events:

$$\varepsilon_{real} N^{loose}_{real} = SF[Y(Wjj) + Y(Wb\bar{b})] + Y(t\bar{t}) + Y(WW) + Y(WZ)$$ SF=1.05

- The sum Y(Wjj)+Y(Wbb) is done according to the NLO ratio of cross sections (MCFM) before b-tagging $\rightarrow$ 25% uncertainty
- Then apply b-tagging
  - Greatly reduce W+jets background (Wbb ~1% of Wjj)
  - Shift distributions, changes flavor composition

Systematic Uncertainites

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 %



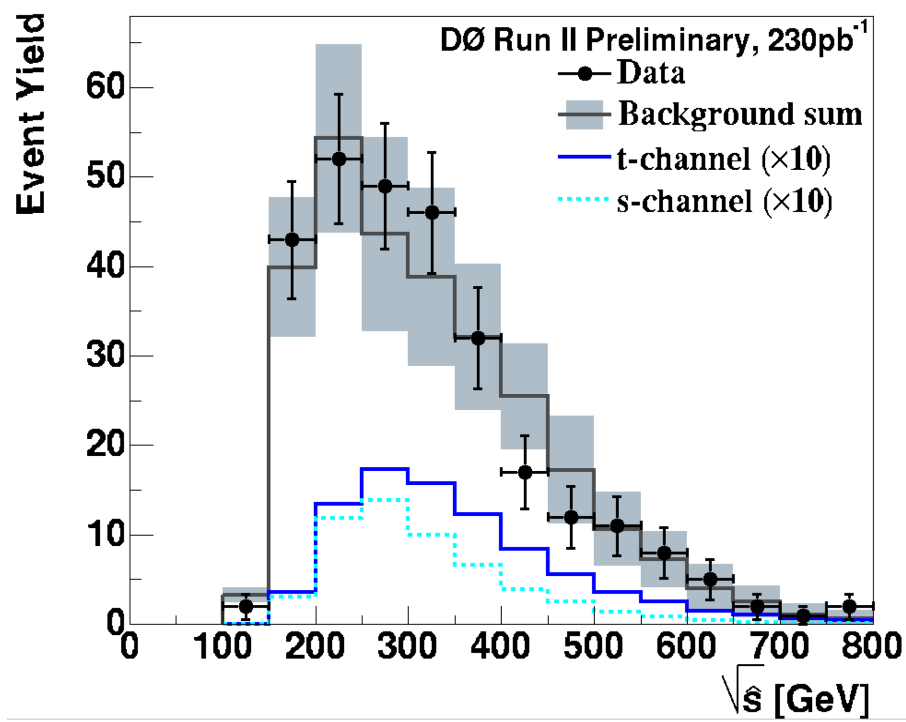
- Some systematic uncertainties also affect shape:

  JES, b-tag and trigger modeling

- Total uncertainty:

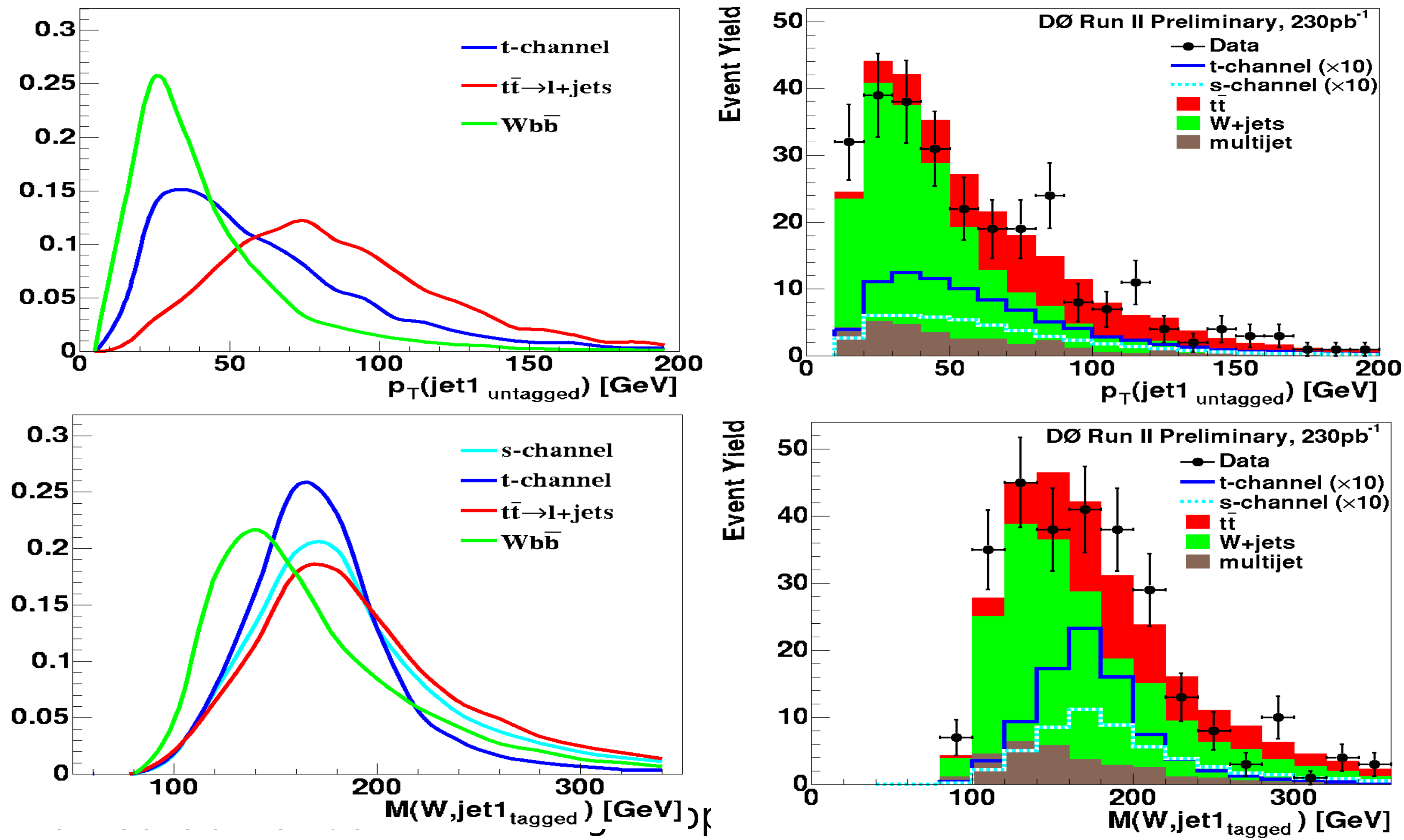
	1 tag	2 tags
Signal acceptance	15%	25%
Background sum	10%	26%

- Result is statistics limited

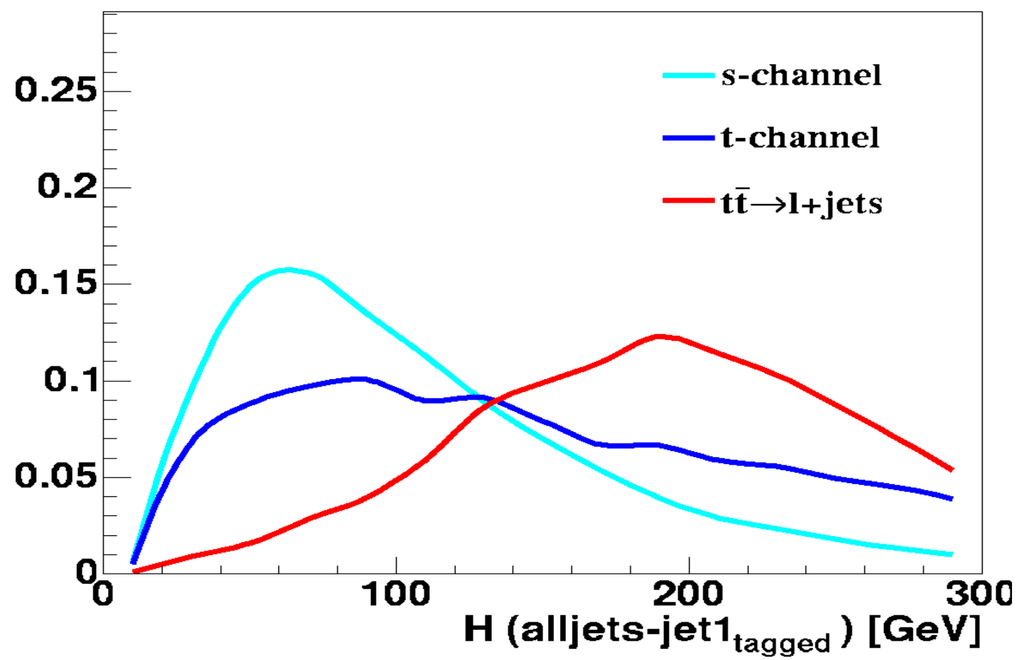


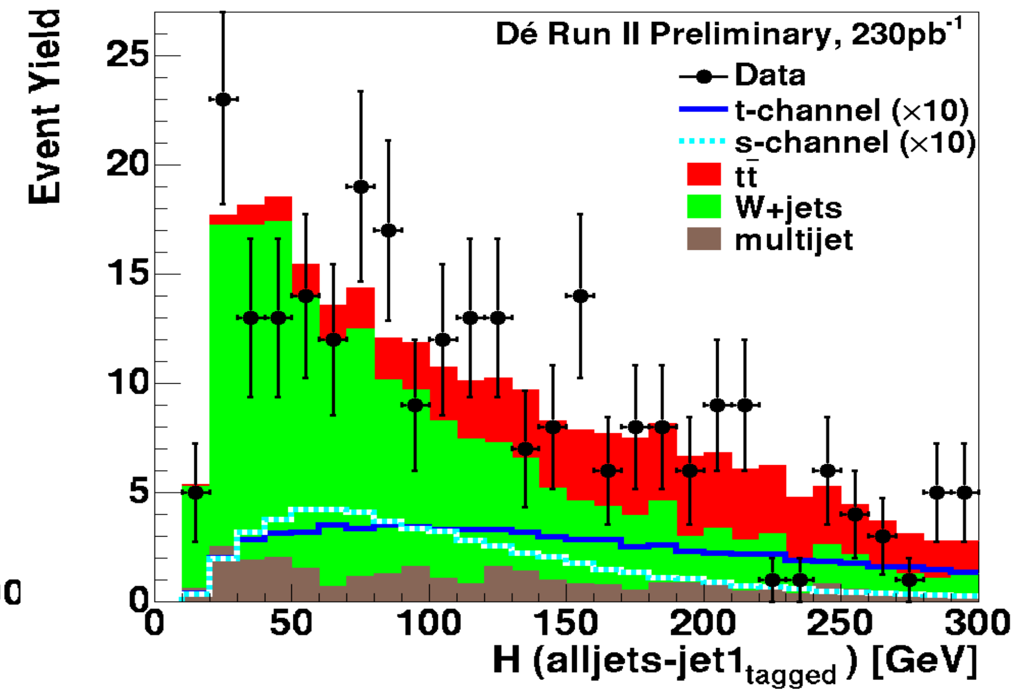
2) Separate signals from backgrounds

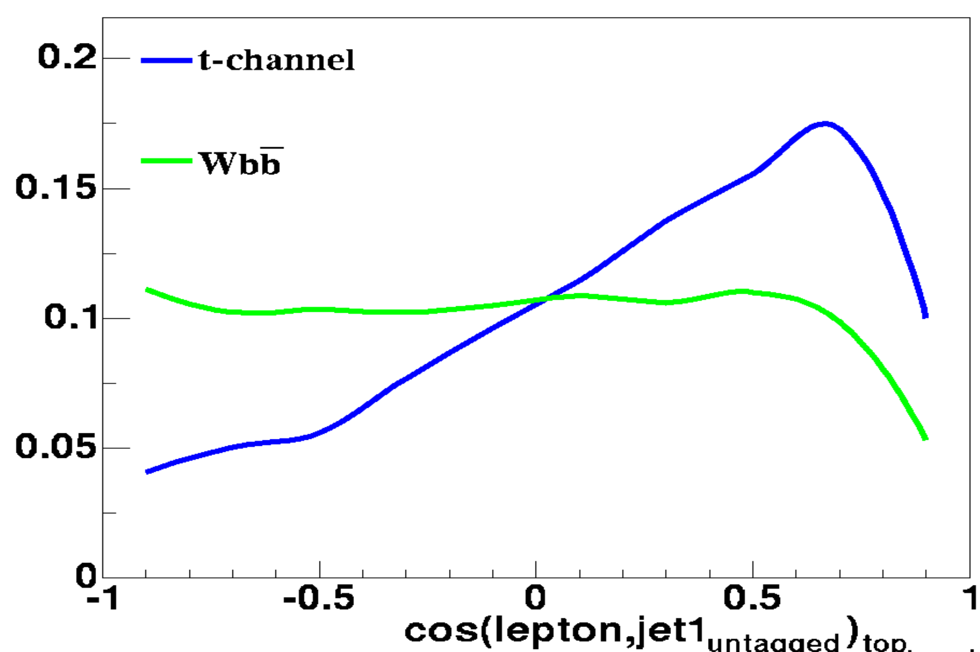
- Make sure your data agrees well with your prediction
- Choose variables (final pool of 25) that show good discrimination
- Object kinematics, event kinematics, angular correlations

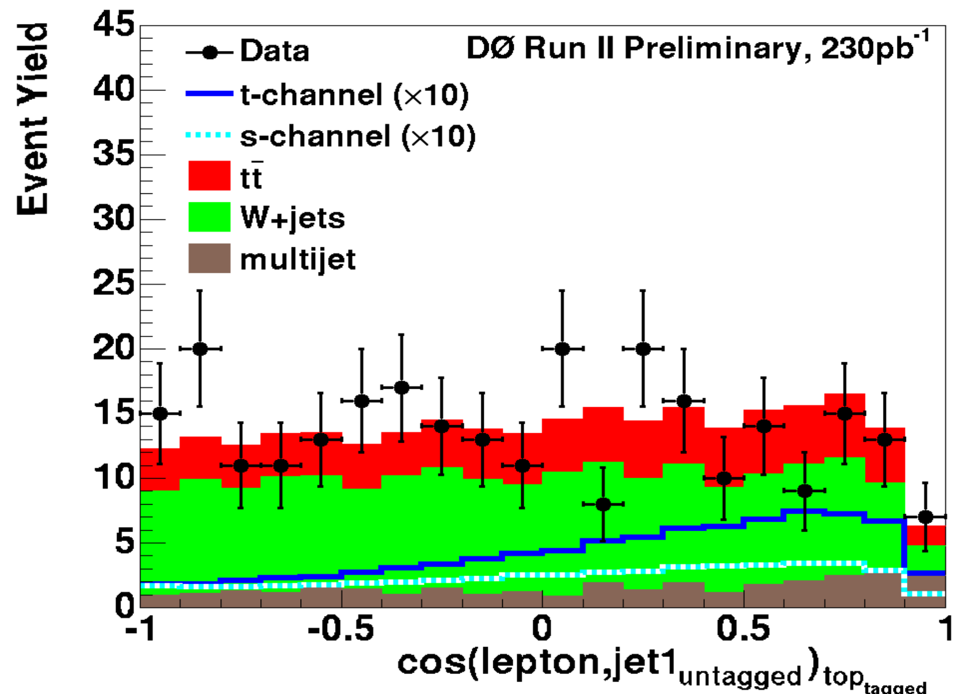


Event kinematics & angular variable





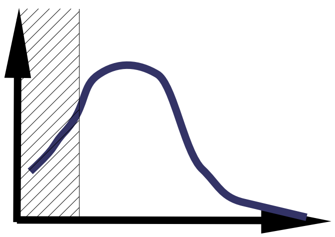




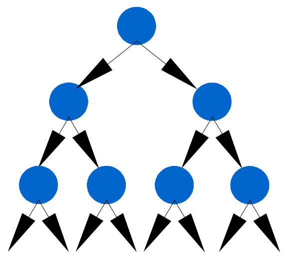
Analysis methods

DØ has implemented four analysis methods:

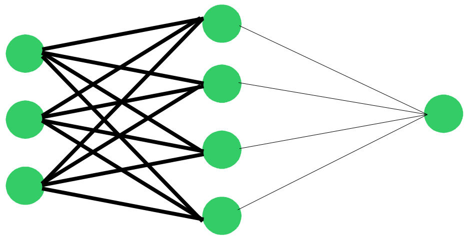
Cut-based



Decision Trees



Neural Networks



Likelihoods

$$L = \frac{P(S)}{P(S)+P(B)}$$

- Use same pool of discriminating variables for all 4 analyses
- Optimize separately for s-channel and t-channel
- Focus on two dominant backgrounds: Wbb and tt
- A total of 8 sets of cuts/trees/networks/likelihoods:

  tb-Wbb, tb-tt→ℓ+jets, tqb-Wbb & tqb-tt→ℓ+jets (for e and μ)

Cut-based analysis

1) Rate each discriminant variable according to its optimal cut

Optimal cut values are obtained minimizing the expected limit with respect to cut values derived from the signal sample

2) Try several sets of ANDed variables and re-optimize

3) Select the set that yields the lowest expected limit

before cuts S/B = 1/52 1/32

	s-channel	t-channel
tb	4.5 ± 1.0	3.2 ± 0.8
tqb	5.5 ± 1.2	7.0 ± 1.6
$t\bar{t}$	27.6 ± 7.6	55.9 ± 12.3
W+jets	102.9 ± 13.7	72.6 ± 9.7
Mis-ID'd lepton	17.2 ± 2.0	17.0 ± 2.0
Background sum	153.1 ± 24.5	148.7 ± 24.8
Observed events	152	148

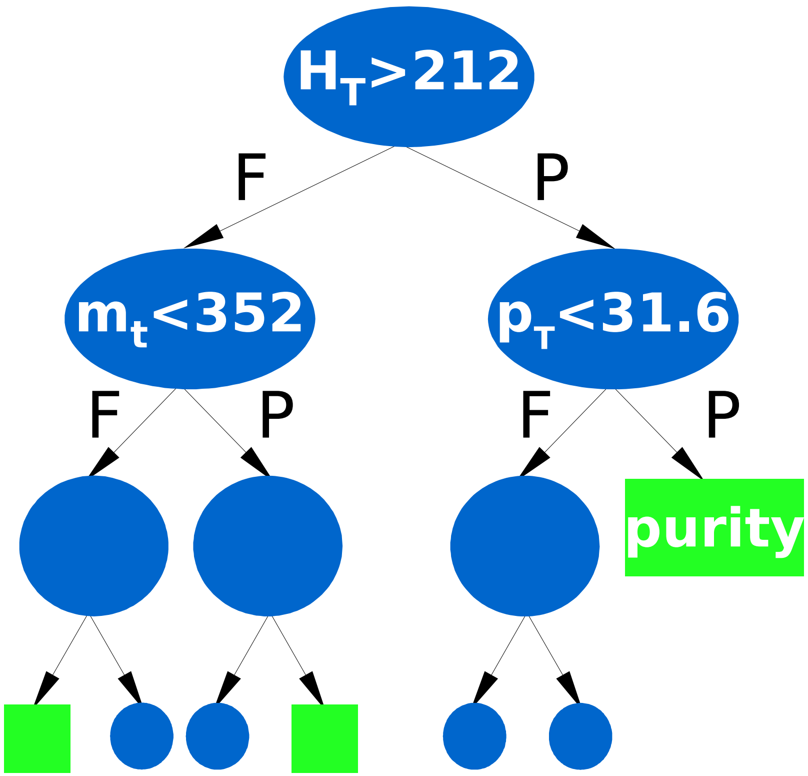
after cuts S/B = 1/34 1/21

Cut-based analysis: cuts

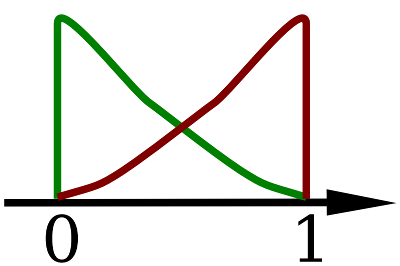
	s-channel		t-channel	
Channel	Variables	Cuts	Variables	Cuts
Electron				
=1 Tag	$p_T(\text{jet1}_{\text{tagged}})$	> 27 GeV	$H_T(\text{alljets})$	> 71 GeV
	$M(\text{alljets} - \text{jet1}_{\text{tagged}})$	< 70 GeV	$M(\text{alljets})$	> 57 GeV
	$\sqrt{\hat{s}}$	> 196 GeV	$\sqrt{\hat{s}}$	> 203 GeV
			$\lvert 175 - M(\text{top}_{\text{tagged}})\rvert$	< 57 GeV
			$p_T(\text{jet1}_{\text{tagged}})$	> 21 GeV
≥2 Tags	$p_T(\text{jet1}_{\text{tagged}})$	> 42 GeV	$p_T(\text{jet1}_{\text{tagged}})$	> 34 GeV
	$M(\text{alljets} - \text{jet1}_{\text{tagged}})$	< 98 GeV	$M(\text{alljets} - \text{jet1}_{\text{tagged}})$	< 75 GeV
	$H(\text{alljets} - \text{jet1}_{\text{tagged}})$	< 304 GeV	$H(\text{alljets} - \text{jet1}_{\text{tagged}})$	< 504 GeV
	$H(\text{alljets} - \text{jet}_{\text{best}})$	< 304 GeV	$H(\text{alljets} - \text{jet}_{\text{best}})$	< 504 GeV
Muon				
=1 Tag	$p_T(\text{jet1}_{\text{tagged}})$	> 33 GeV	$\lvert 175 - M(\text{top}_{\text{tagged}})\rvert$	< 60 GeV
	$M(\text{alljets} - \text{jet1}_{\text{tagged}})$	< 74 GeV	$\sqrt{\hat{s}}$	> 210 GeV
	$H(\text{alljets} - \text{jet1}_{\text{tagged}})$	< 504 GeV	$M(\text{alljets})$	> 70 GeV
	$H(\text{alljets} - \text{jet}_{\text{best}})$	< 504 GeV	$H_T(\text{alljets})$	> 58 GeV
≥2 Tags	$p_T(\text{jet1}_{\text{tagged}})$	> 33 GeV	$\lvert 175 - M(\text{top}_{\text{tagged}})\rvert$	< 213 GeV
	$M(\text{alljets} - \text{jet1}_{\text{tagged}})$	< 74 GeV		
	$H(\text{alljets} - \text{jet1}_{\text{tagged}})$	< 504 GeV		
	$H(\text{alljets} - \text{jet}_{\text{best}})$	< 504 GeV		

Decision Trees

Multivariate technique widely used in social sciences
Recently applied to HEP: MiniBooNE (object ID), GLAST
Gives probability for an event to be signal

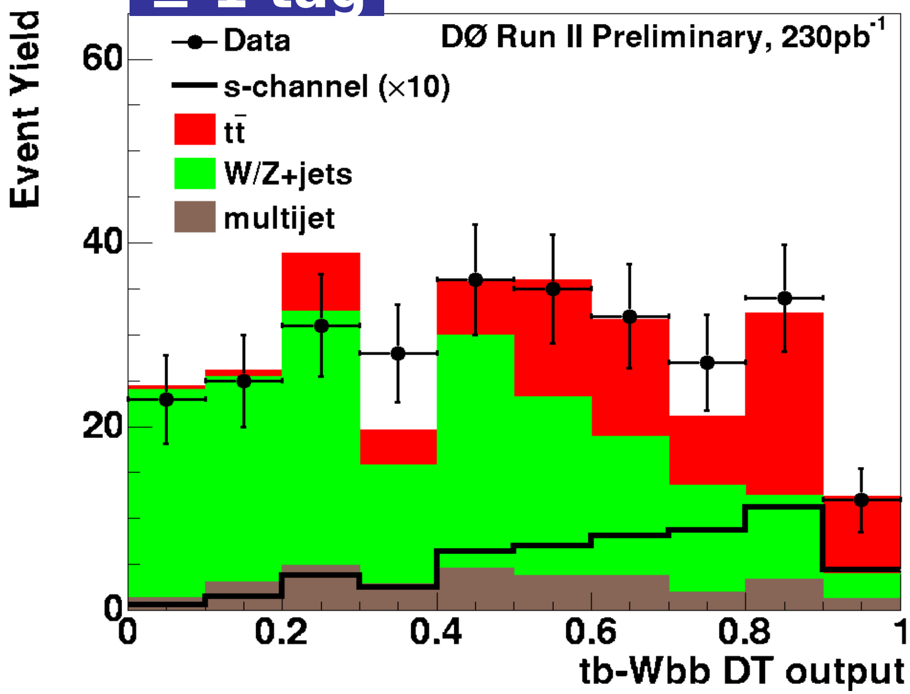


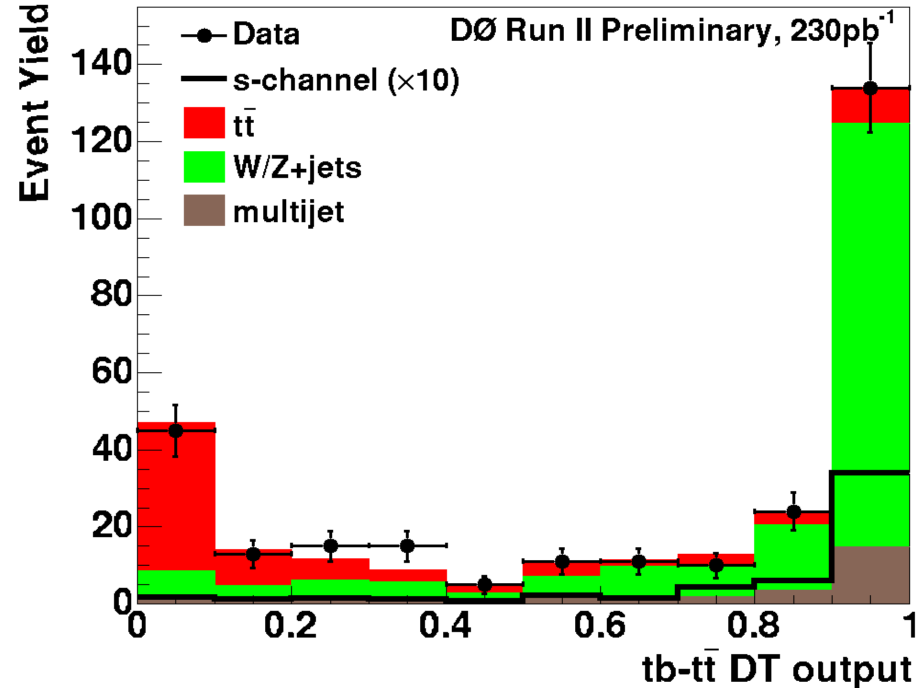
- Send each event down the tree
- Each node corresponds to a cut
  - Pass cut (P): right branch
  - Fail cut (F): left branch
- A leaf corresponds to a node without branches
- Define purity= $N_S/(N_S+N_B)$
- Training: optimize Gini improvement
  - Gini=2 $N_S\,N_B\,/(N_S + N_B)$
- Output: purity for each event

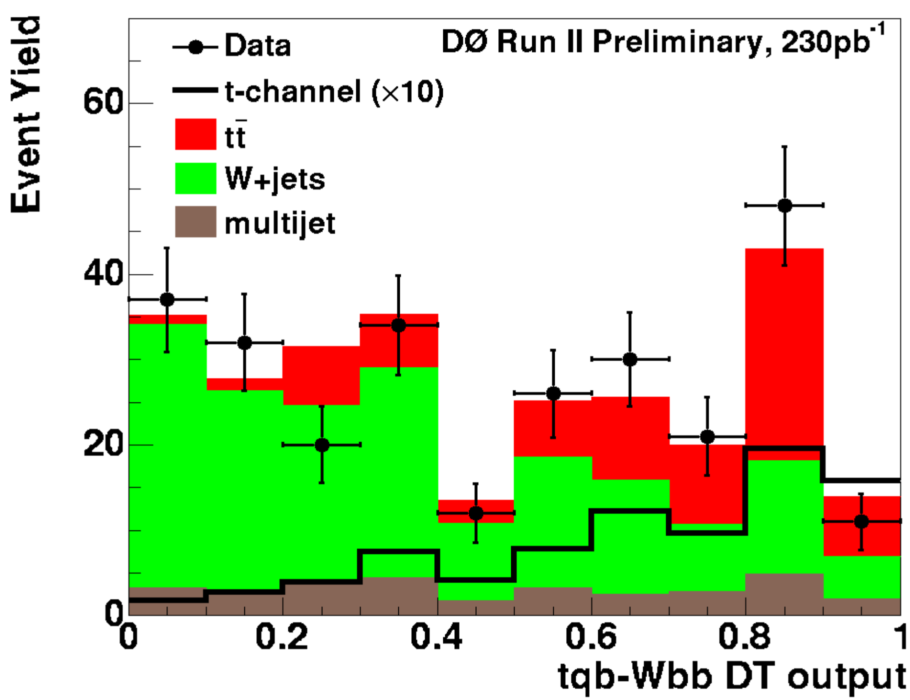


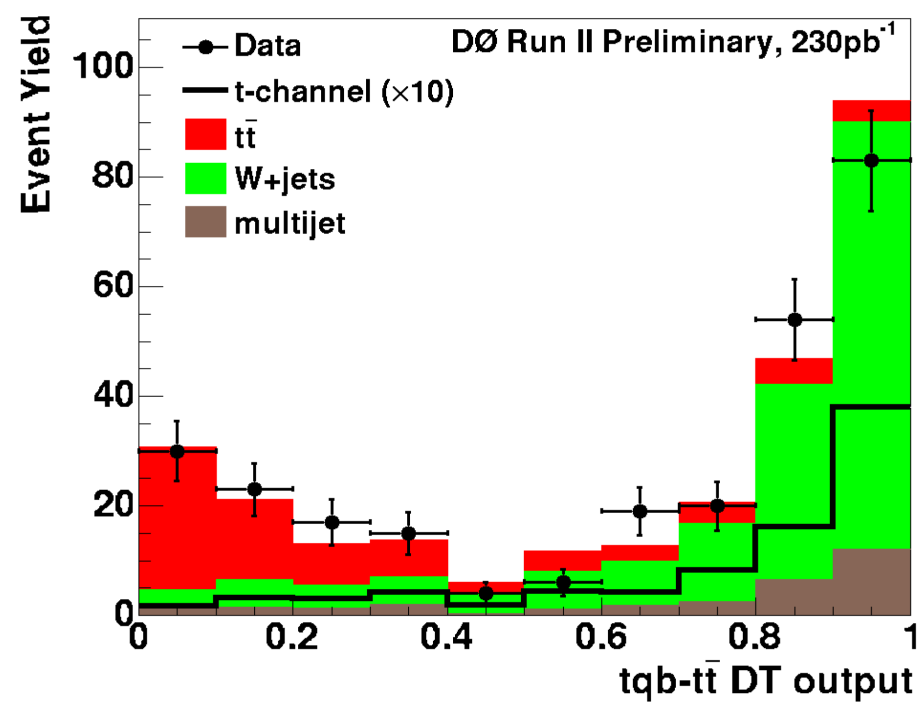
Decision Tree outputs

e+μ
≥ 1 tag



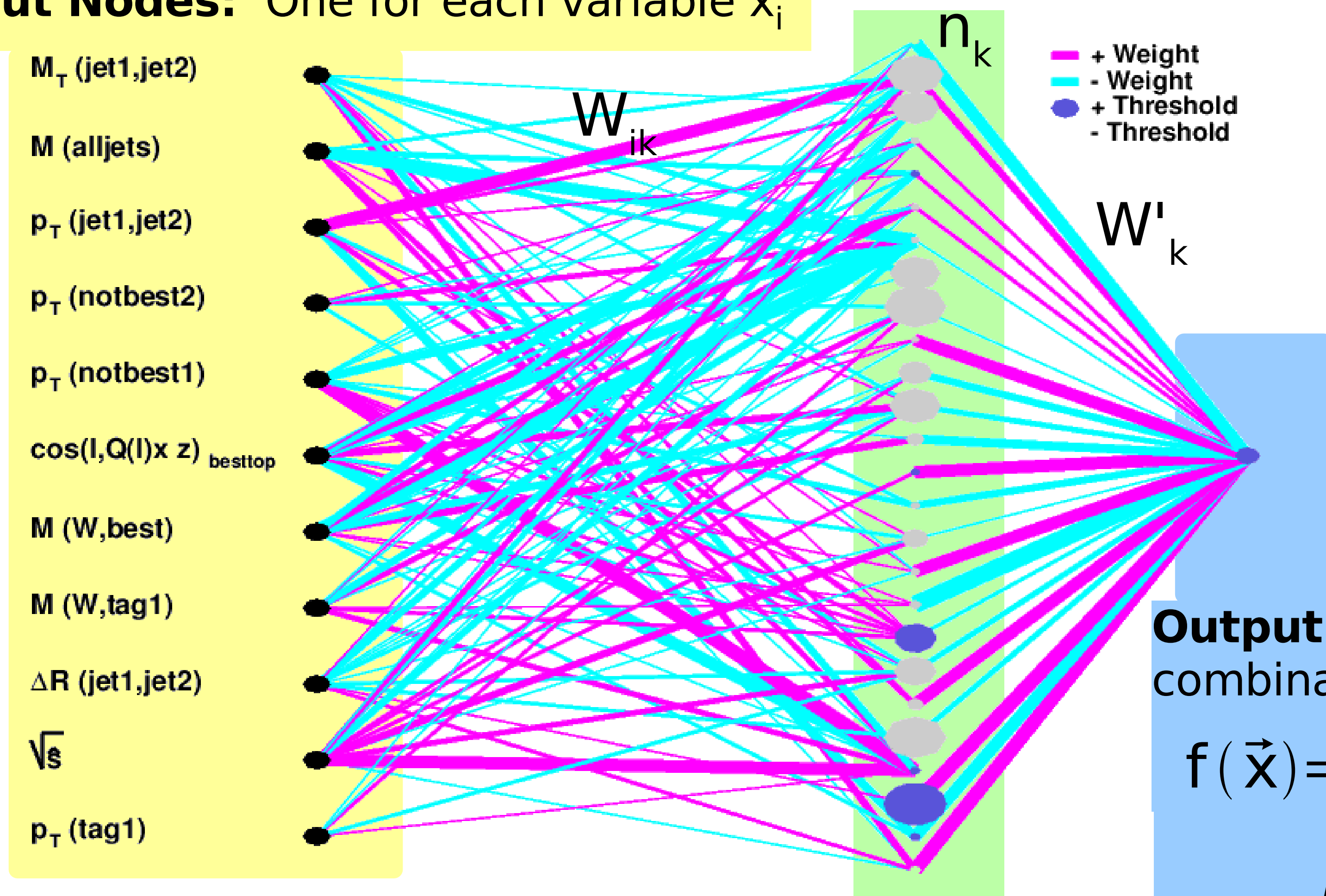






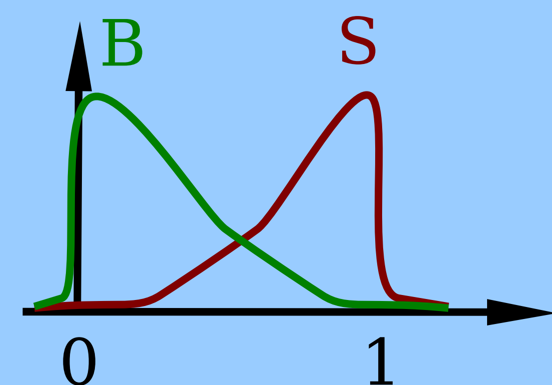
Neural Networks

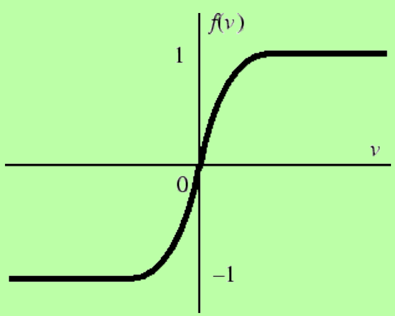
Input Nodes: One for each variable x_i



Output Node: linear combination of hidden nodes

$$f(\vec{x}) = \sum w'_k \, n_k(\vec{x}, \vec{w}_k)$$





Hidden Nodes: Each is a sigmoid dependent on the input variables

$$n_k(\vec{x}, \vec{w}_k) = \frac{1}{1 + e^{-w_{ik} x_i}}$$

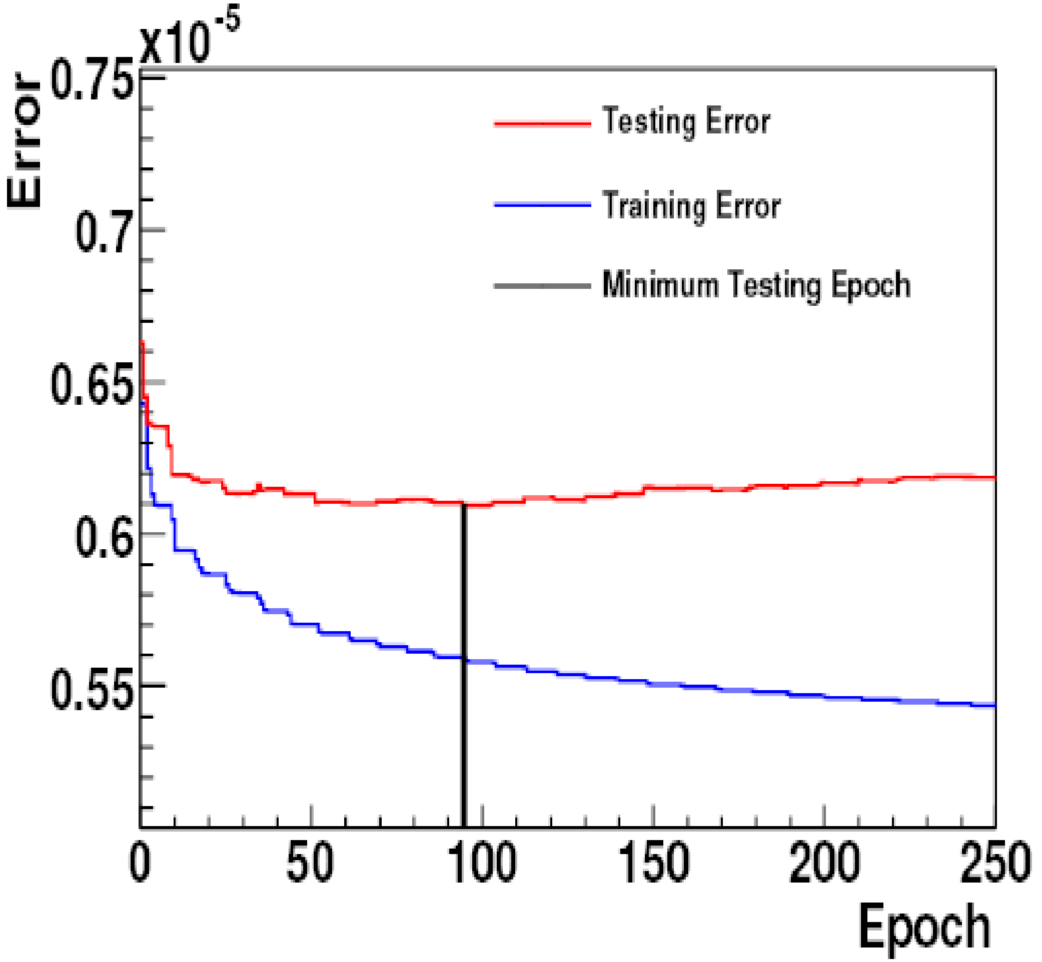
Training method and optimization

1) Initialize weights

2) Minimize error function on training sample

3) Update weights. This is the first epoch.

4) Repeat procedure.
After each epoch, apply NN filter on independent testing sample. Stop training when testing error increases

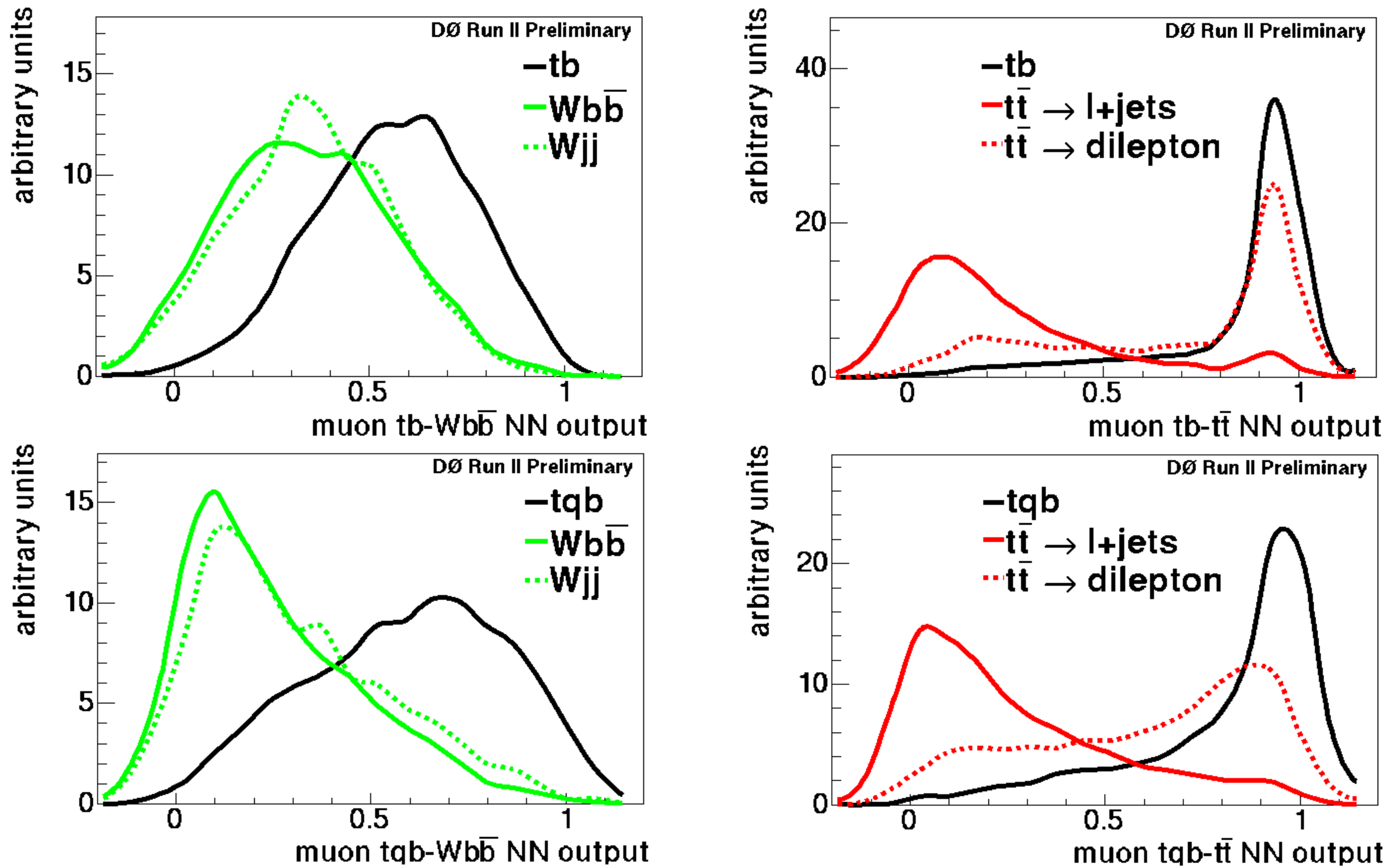


- Used 60% of events for training, 40% for testing
- Optimize number of training epochs and number of hidden nodes
- MLPFit implementation, many others in the market

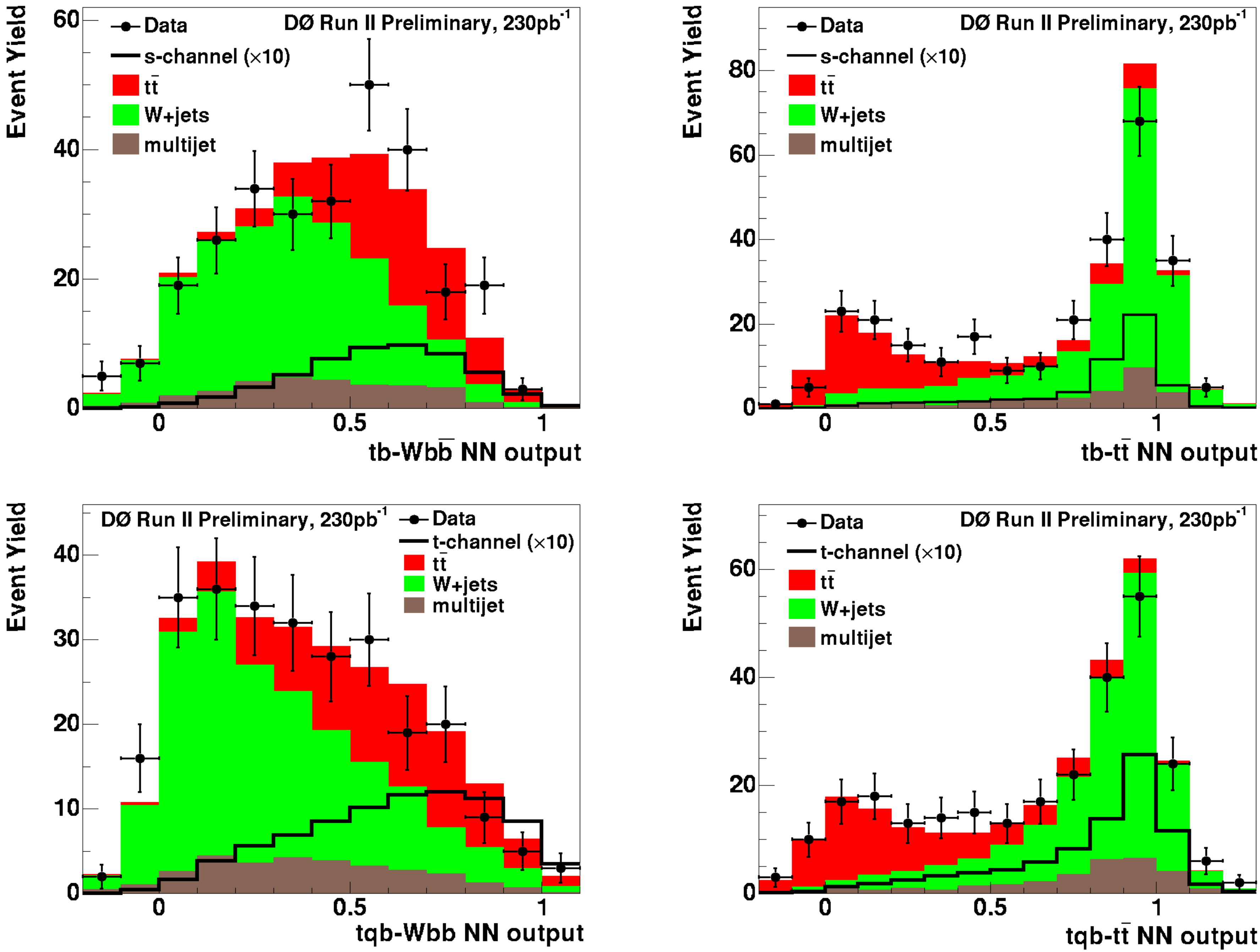
Neural Networks separation

Why we only focused on two main backgrounds:

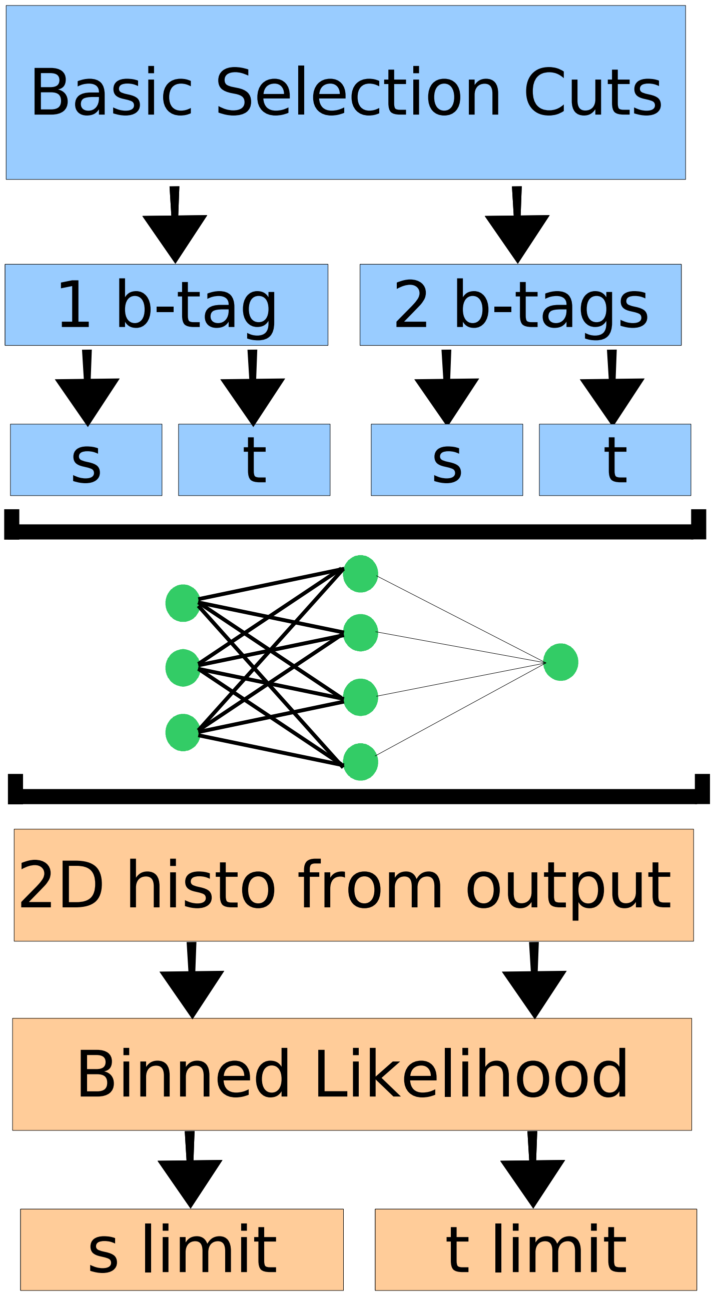
- Wbb takes care well of Wjj (j=g,u,d,s,c)
- tt dilepton is small compared to tt ℓ+jets



Neural Networks output



Analysis flow revisited



1) Separate s- and t-channel in electron or muon and 1 or 2 b-tags

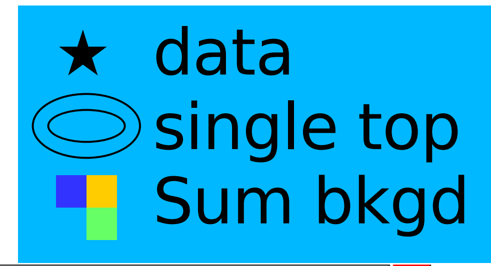
2) Apply discrimination method

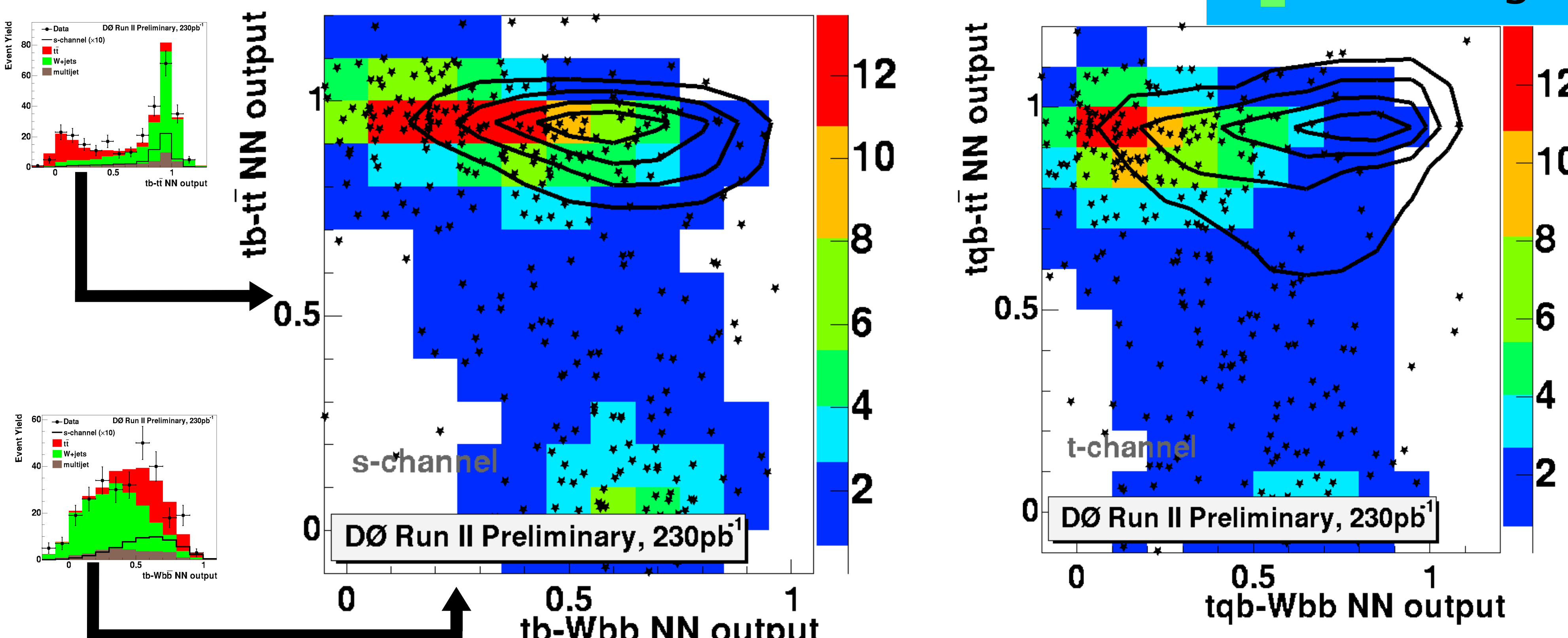
3) Take the Wbb and tt NN outputs and make a 2D histogram Construct a binned likelihood and evaluate signal hypothesis based on shape information

3) Limits from binned likelihood

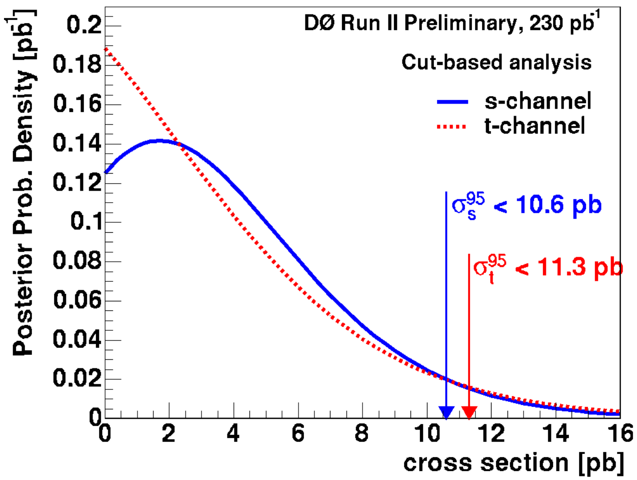
- No evidence for single top signal
- Set 95% CL upper cross section limit with Bayesian approach
- Use 2D histograms as input for binned likelihood
- Including bin-by-bin systematics and correlations

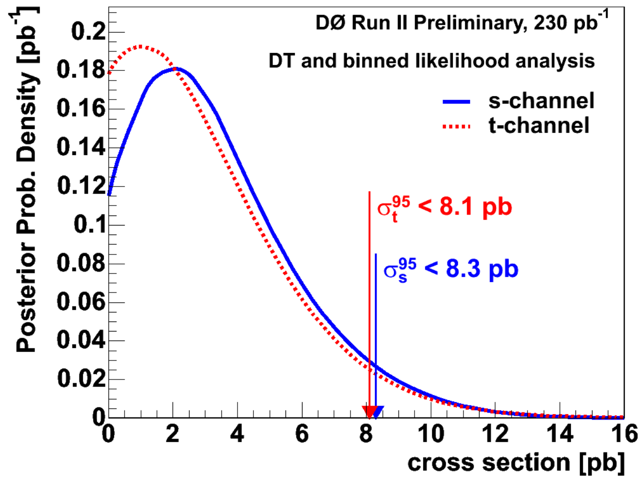
Used for DT and NN analyses
Cut-based analysis uses likelihood from event count

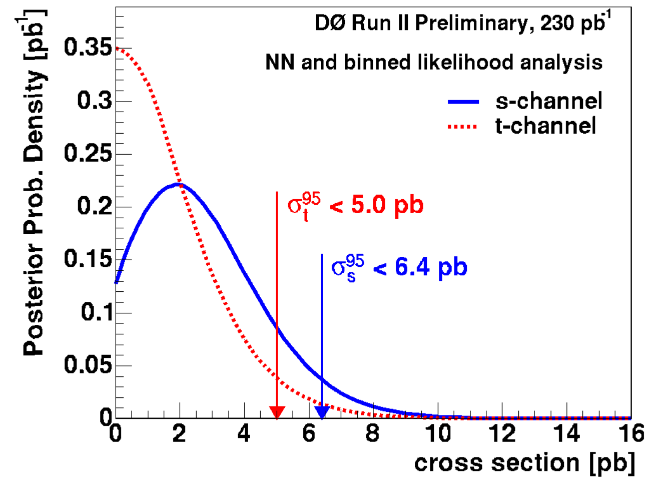




Results







$\mathscr{L}$=230pb^{-1}	Cut-based		Decision Trees		Neural Networks	
	Observed	Expected	Observed	Expected	Observed	Expected
s-channel	**10.6**	9.8	**8.3**	4.5	**6.4**	4.5
t-channel	**11.3**	12.4	**8.1**	6.4	**5.0**	5.8

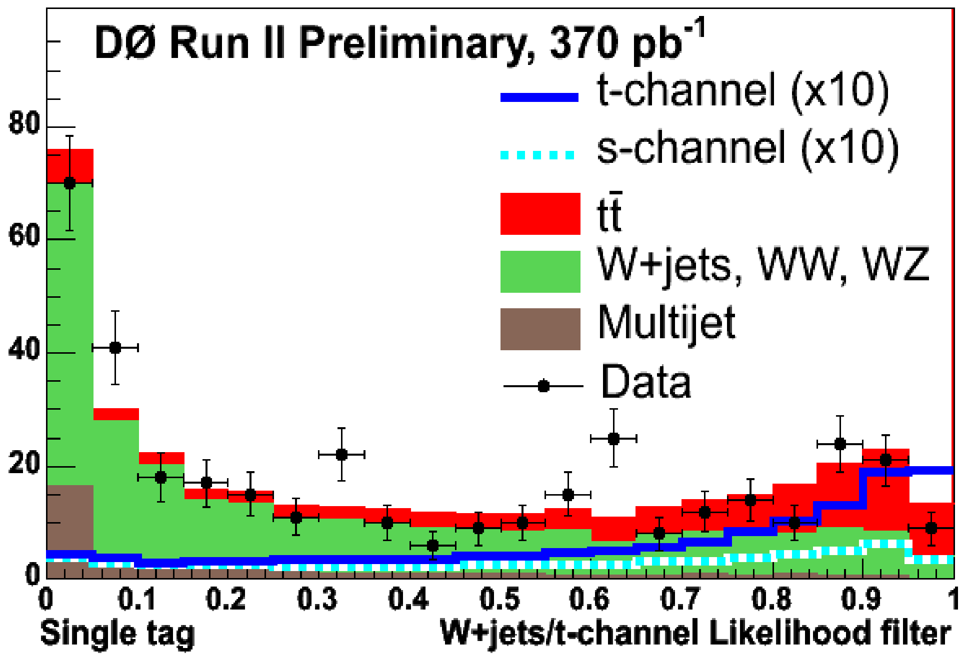
- Use Bayesian approach to combine channels (e, μ and 1 tag, 2 tags)
- Take systematics and correlations into account
- Decision Trees and Neural Networks have similar sensitivity
- Multivariate analysis + shape information from output:

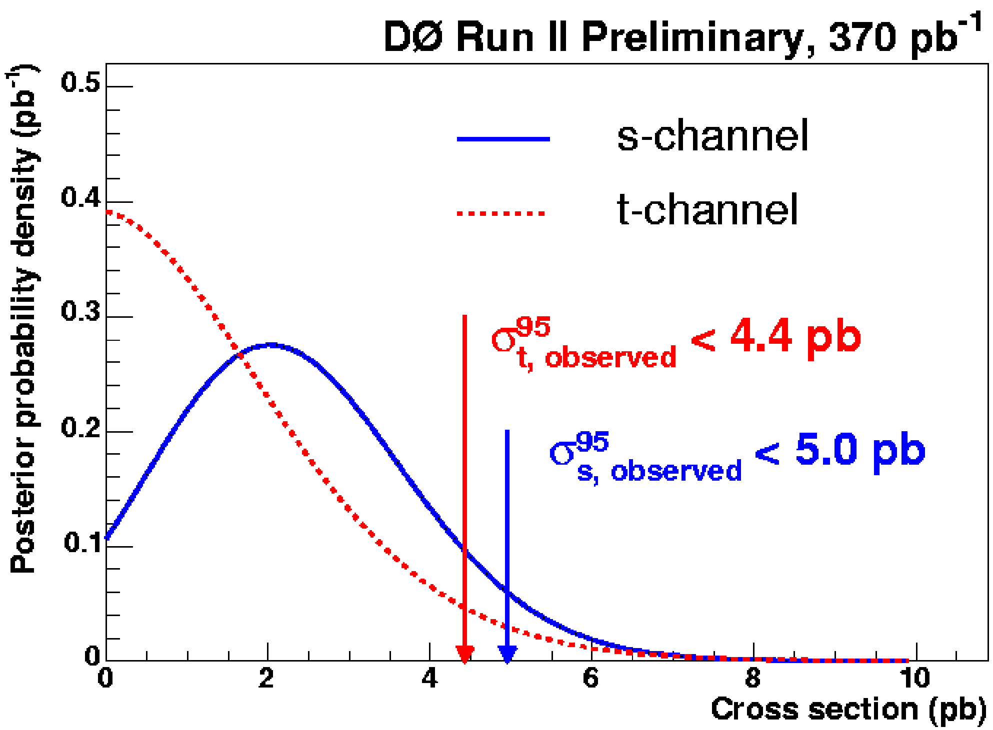
  → factor 2 better than simple cuts

Likelihood discriminant results on 370 pb^{-1}

$$L = \frac{P_{signal}(\vec{x})}{P_{signal}(\vec{x}) + P_{background}(\vec{x})} \quad ; \quad P(\vec{x}) = \prod_{vars} P(x_i)$$

- Use same analysis strategy: Wbb and tt discriminants
- Between 7-10 variables in the likelihoods
- Use one tight and one loose tagged jets in double tag sample
- Uncertainties: b-tag 6-17%, JES 5%, trigger 5%, theory σ 18%
- Achieved similar sensitivity to NNs



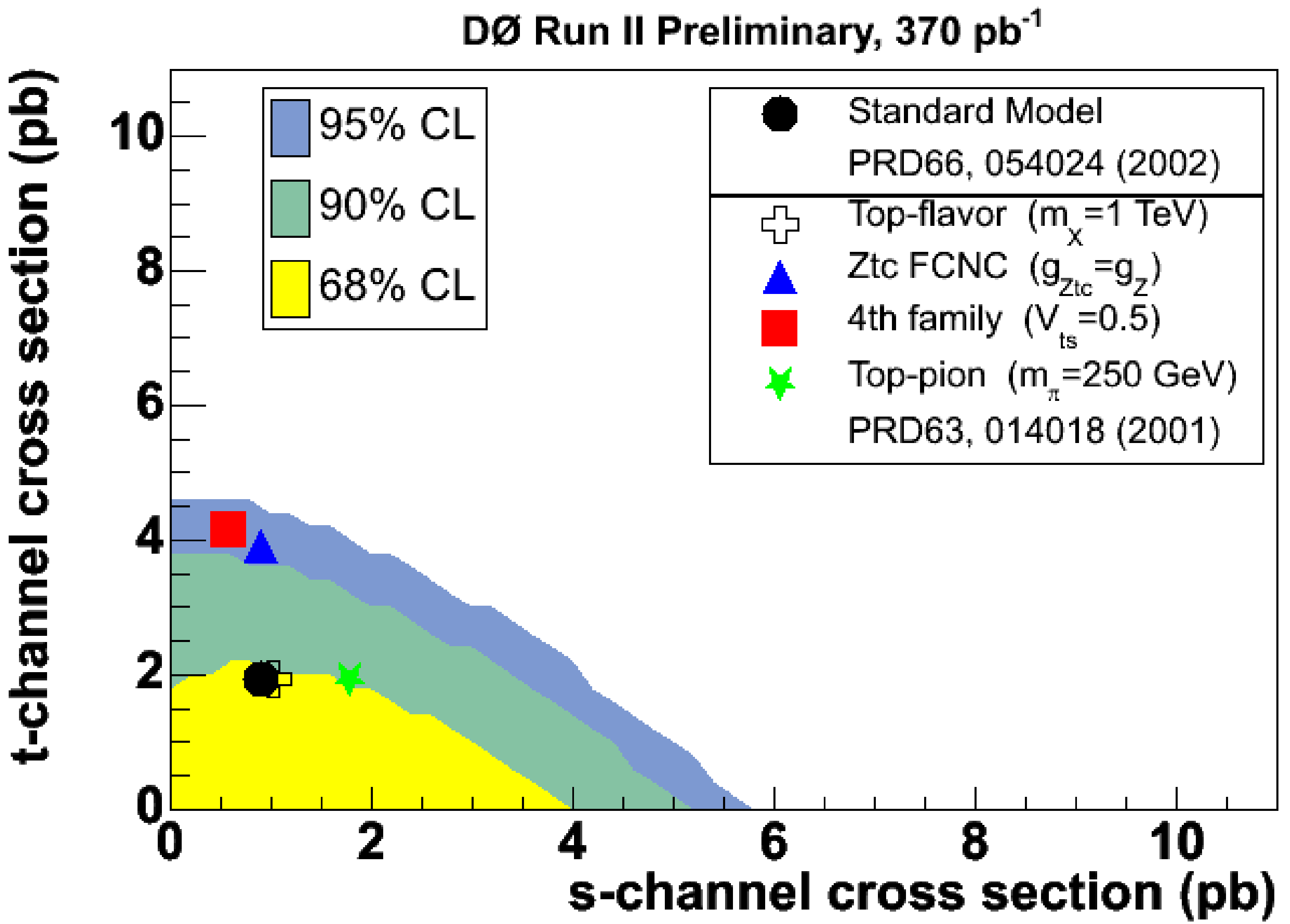


Summary of present limits

95 % CL Observed Upper Limits in pb			
	s-channel, tb	t-channel, tqb	
DØ Run I, 90 pb^{-1}	17	22	
CDF Run II, 162 pb^{-1}	13.6	10.1	PRD 71, 012005
DØ Run II, 230 pb^{-1}			
Cuts	10.6	11.3	
DTs & binned likelihood	8.3	8.1	
NNs & binned likelihood	6.4	5.0	PLB 622, 265 (2005) PRD in preparation
DØ Run II, 370 pb^{-1}			
LHs & binned likelihood	**5.0**	**4.4**	
NLO theory	$= 0.88$	$= 1.98$	

Model independent limits

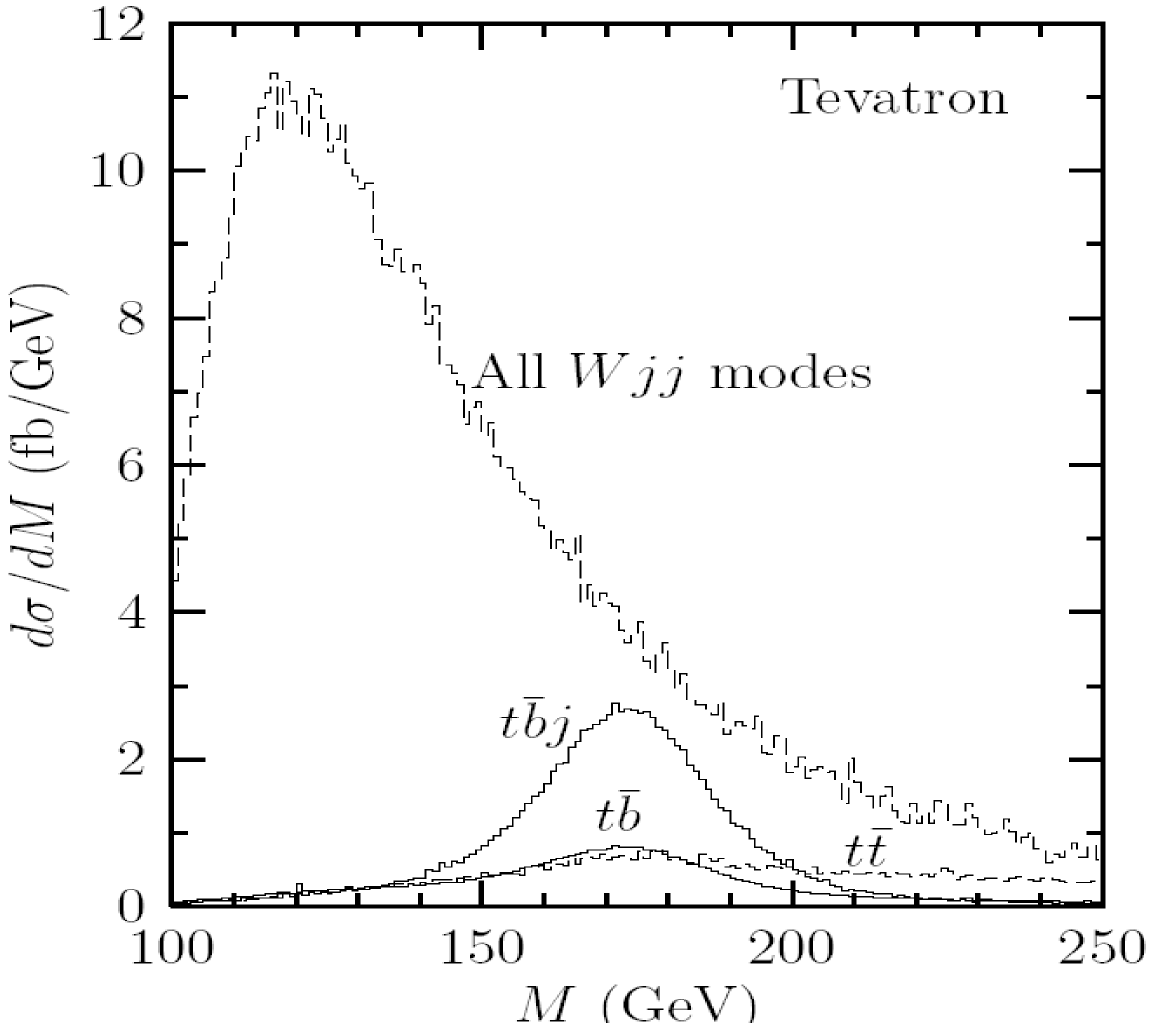
- Relax assumption of SM cross sections for s- and t-channel
- Study sensitivity to models beyond SM in the (σ_s,σ_t) plane



Single Top – Expectation

Predictions for Run II were to be sensitive to single top production with ~500pb^{-1} – *Where is it?*

We have recorded
>1fb^{-1} at DØ already
Observation soon?

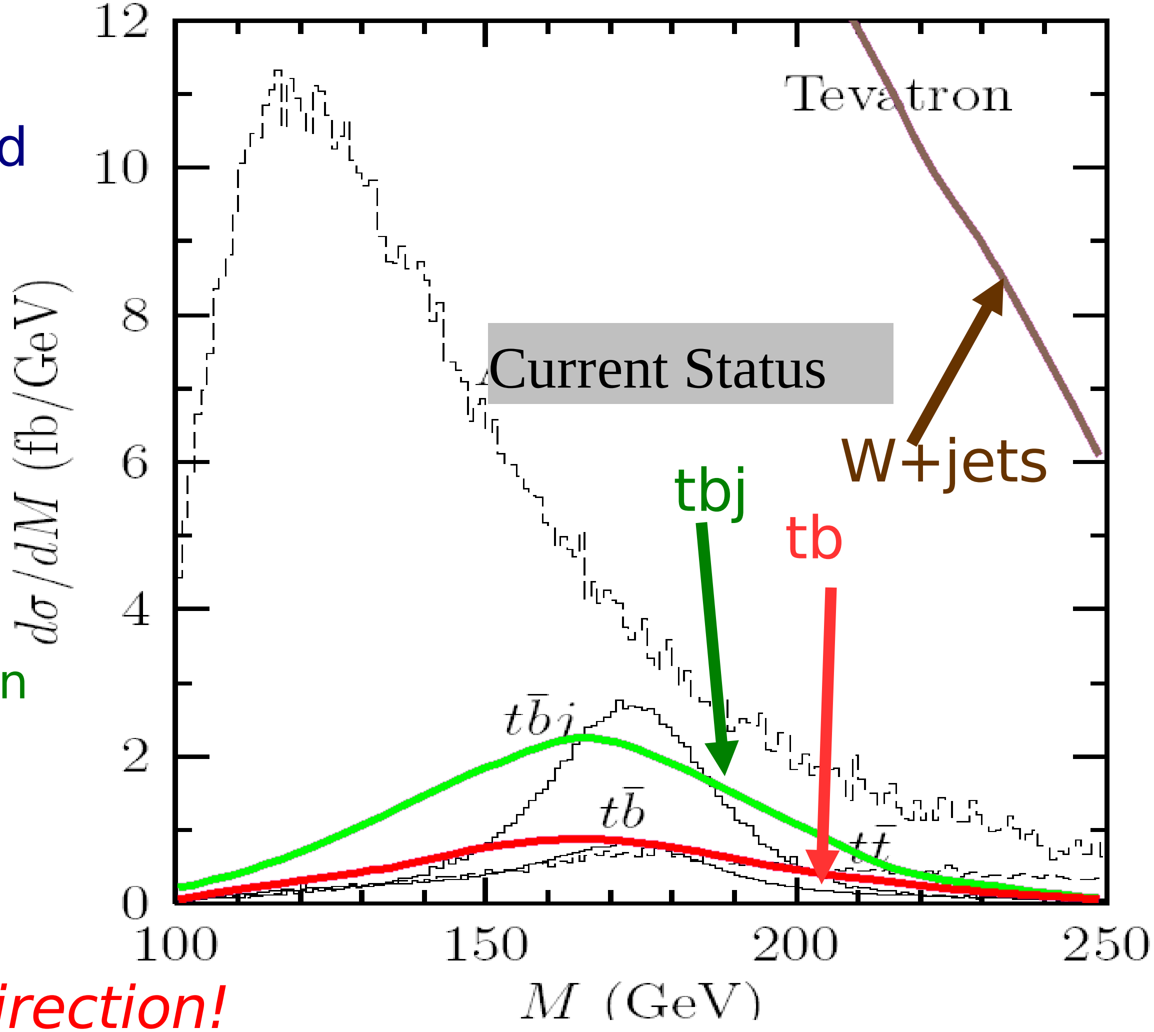


Stelzer, Sullivan, Willenbrock, PRD58 (98)

Single Top – Expectation vs Reality

Predictions for Run II were to be sensitive to single top production with ~500pb^{-1} – *Where is it?*

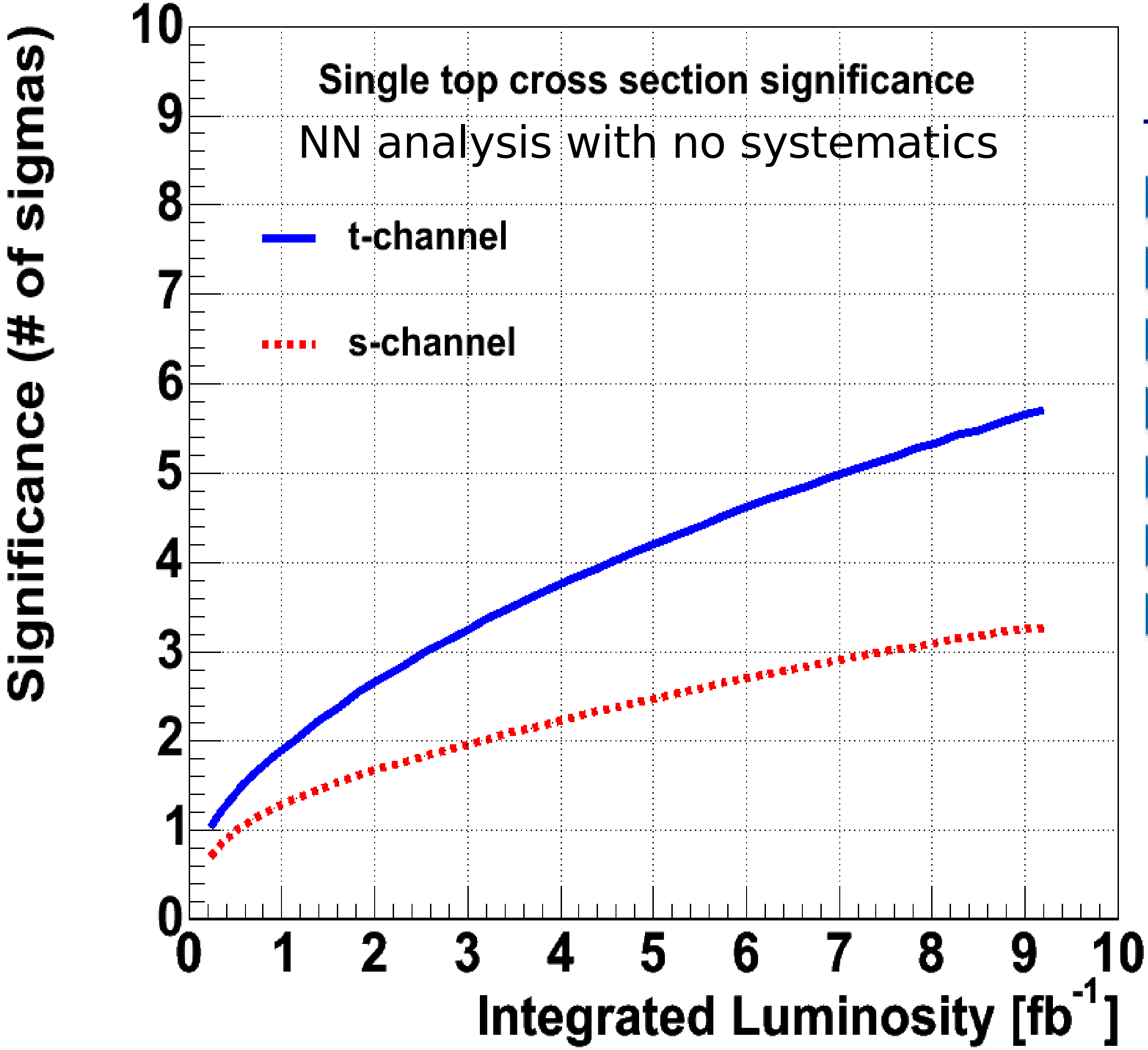
- Detector performance not (yet) as good as expected
  - b-tagging ~50% per jet
  - Trigger, ID <100%
  - Jet resolution not (yet) as good as expected
- W+jets background larger than expected
  - NLO calculations: LO×1.5
  - Gluon splitting, c-contamination
- Top mass
- b content of gluon PDF



Many effects, all in the wrong direction!

Sensitivity

With current analysis, we would need several fb^{-1} for an observation of SM single top



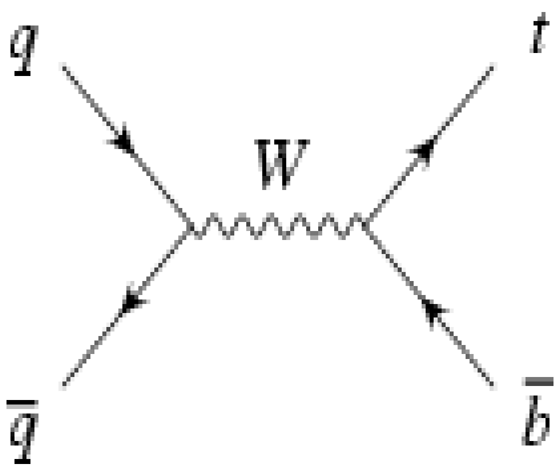
Need to work on many fronts to improve:

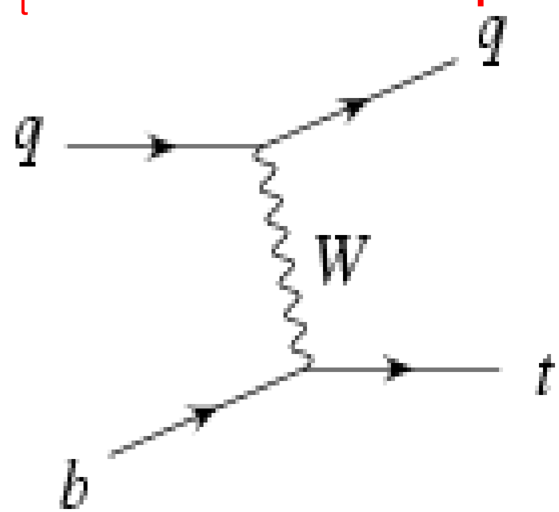
- Trigger efficiency
- Object ID: e, μ, jet, b
- Jets resolution
- Add more channels
- Background estimation
- Reduction of systematics
- Bkgnd-signal separation

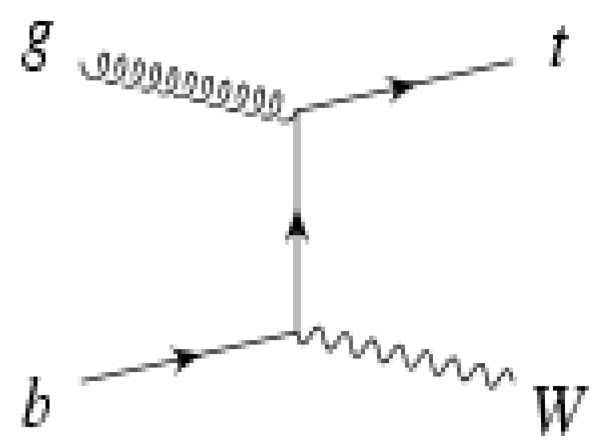
Single top in a couple of years

- By 2007 we will have observed single top and measured its cross section to ~10% at the Tevatron
- Then the LHC will start with huge production rates:

σ_s=10.6±1.1 pb σ_t=246.6±0.25 pb $\sigma_{tW}=62.0^{+16.6}_{-3.6}$ pb







- Observe all three channels (s-channel will be tough)
- tW mode offers new window into top physics
- Measure V_{tb} to a few %
- Large samples: study properties

Preparing the way for the LHC

Studies at the Tevatron will help the LHC:

- Wbb measurement (will also help WH search) (DØ: hep-ex/0410062)
  - Current limit at 4.6 pb for $p_T(b)>20$GeV
- In general, W+jets background determination techniques
  - tt will be main background, but large uncertainties come from W+jets
  - Effect of jet vetoes ($N_{jet}=2$), check other methods planned in LHC analyses
- Study charge asymmetries (Bowen, Ellis, Strassler: hep-ph/0412223)
  - Signal shows asymmetry in $(Q_\ell \times \eta_j\, ,\; Q_\ell \times \eta_\ell)$ plane at TeV
- Study kinematics of forward jets in t-channel (WW→H at LHC)
- Even measure asymmetry in production rate (Yuan: hep-ph/9412214) (probe CP-violation in the top sector):

$$A_t = \frac{\sigma(p\bar{p} \to tX) - \sigma(p\bar{p} \to \bar{t}X)}{\sigma(p\bar{p} \to tX) + \sigma(p\bar{p} \to \bar{t}X)}$$

TeV4LHC workshop report to appear soon

Conclusions

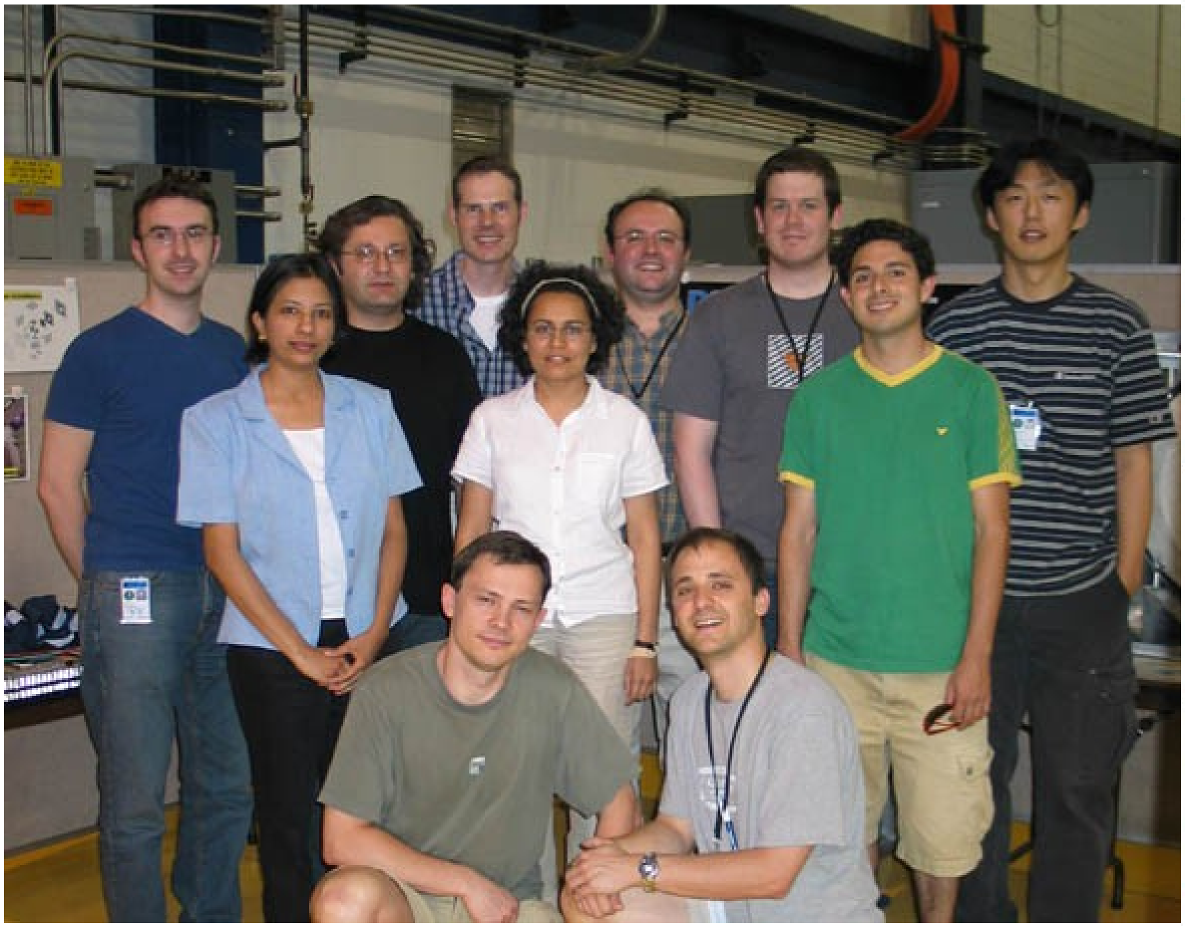
- Single Top is a very exciting opportunity for Run II
  - Challenging signature: sandwiched between W+jets and tt
  - A lot of activity, both theoretical and experimental
  - Understanding the top sector is crucial for EWSB
  - Open door to physics beyond the SM
- The DØ Run II Single Top Search producing best limits so far:

  σ_s<5.0 pb σ_t<4.4 pb   @ 95% CL

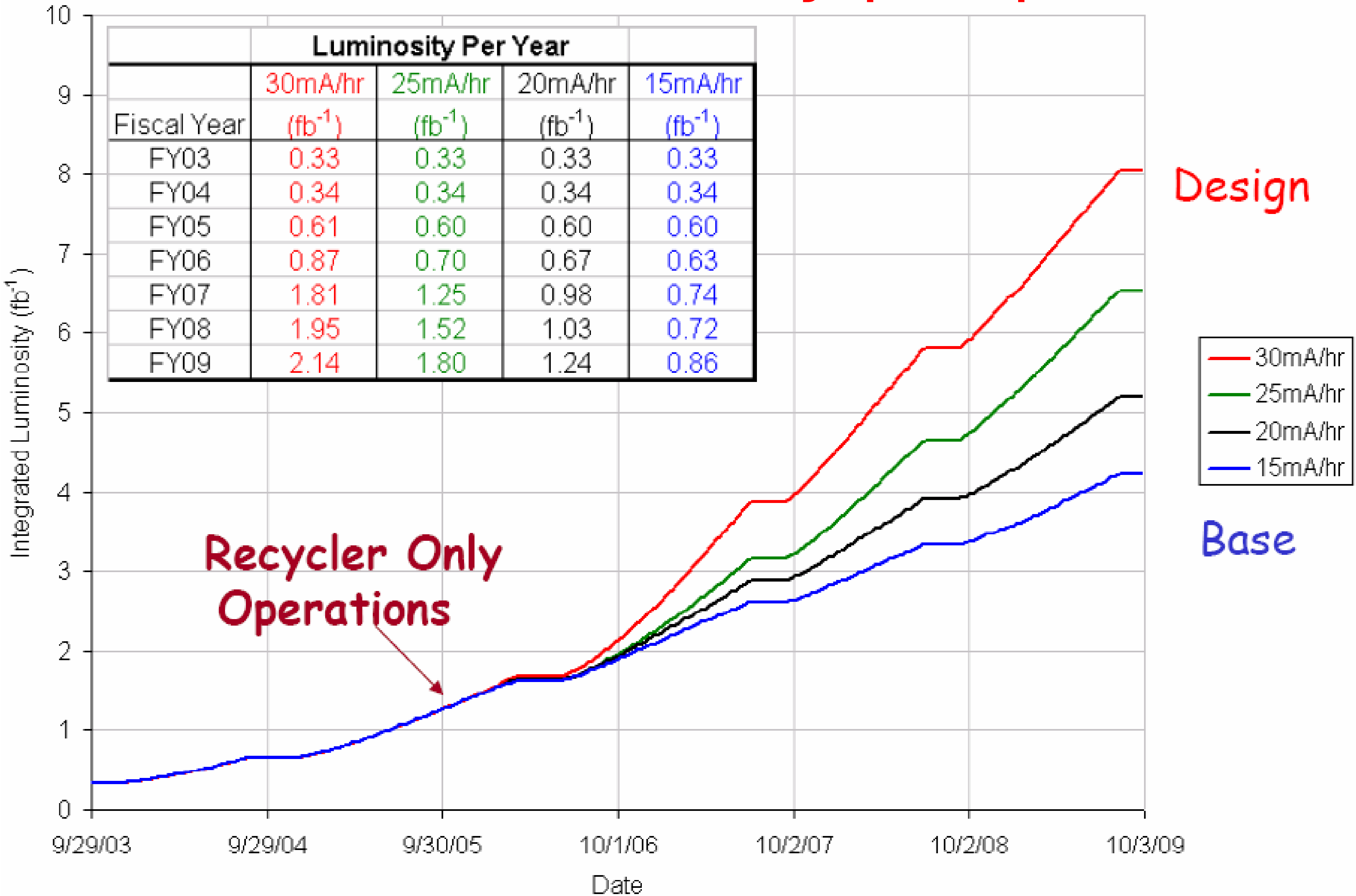
- Close to discovery: getting exciting!
- Already sensitive to new physics: expect the unexpected!
- The Tevatron experience will help the LHC
- Then enter the era of precision studies with large statistics

All possible by the work of many

DØ Single top group



Tevatron luminosity prospects



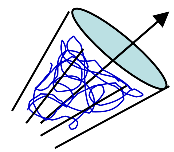
	Luminosity Per Year			
Fiscal Year	30mA/hr (fb^{-1})	25mA/hr (fb^{-1})	20mA/hr (fb^{-1})	15mA/hr (fb^{-1})
FY03	0.33	0.33	0.33	0.33
FY04	0.34	0.34	0.34	0.34
FY05	0.61	0.60	0.60	0.60
FY06	0.87	0.70	0.67	0.63
FY07	1.81	1.25	0.98	0.74
FY08	1.95	1.52	1.03	0.72
FY09	2.14	1.80	1.24	0.86

Extra slides

Discriminating variables

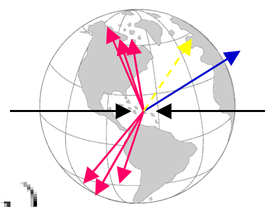
Individual object kinematics

- $p_T(\text{jet1}_{\text{tagged}})$
- $p_T(\text{jet1}_{\text{untagged}})$
- $p_T(\text{jet2}_{\text{untagged}})$
- $p_T(\text{jet1}_{\text{nonbest}})$
- $p_T(\text{jet2}_{\text{nonbest}})$



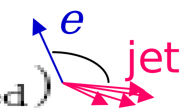
Global event kinematics

- $M_T(\text{jet1},\text{jet2})$
- $p_T(\text{jet1},\text{jet2})$
- $M(\text{alljets})$
- $H_T(\text{alljets})$
- $M(\text{alljets} - \text{jet1}_{\text{tagged}})$
- $H(\text{alljets} - \text{jet1}_{\text{tagged}})$
- $H_T(\text{alljets} - \text{jet1}_{\text{tagged}})$
- $p_T(\text{alljets} - \text{jet1}_{\text{tagged}})$
- $M(\text{alljets} - \text{jet}_{\text{best}})$
- $H(\text{alljets} - \text{jet}_{\text{best}})$
- $H_T(\text{alljets} - \text{jet}_{\text{best}})$
- $M(\text{top}_{\text{tagged}}) = M(W,\text{jet1}_{\text{tagged}})$
- $M(\text{top}_{\text{best}}) = M(W,\text{jet}_{\text{best}})$
- $\sqrt{\hat{s}}$



Angular variables

- $\Delta R(\text{jet1},\text{jet2})$
- $Q(\text{lepton}) \times \eta(\text{jet1}_{\text{untagged}})$
- $\cos(\text{lepton}, Q(\text{lepton}) \times z)_{\text{top}_{\text{best}}}$
- $\cos(\text{lepton},\text{jet1}_{\text{untagged}})_{\text{top}_{\text{tagged}}}$
- $\cos(\text{alljets},\text{jet1}_{\text{tagged}})_{\text{alljets}}$
- $\cos(\text{alljets},\text{jet}_{\text{nonbest}})_{\text{all jets}}$



This is where our phenomenology friends come so handy!

Three broad categories:

- Object kinematics
- Global event kinematics
- Angular correlations

Reconstruct W: from ℓ and

To reconstruct the top quark:

- s-channel: "best" jet algorithm

Chose the jet that gives m_t closest to 175GeV

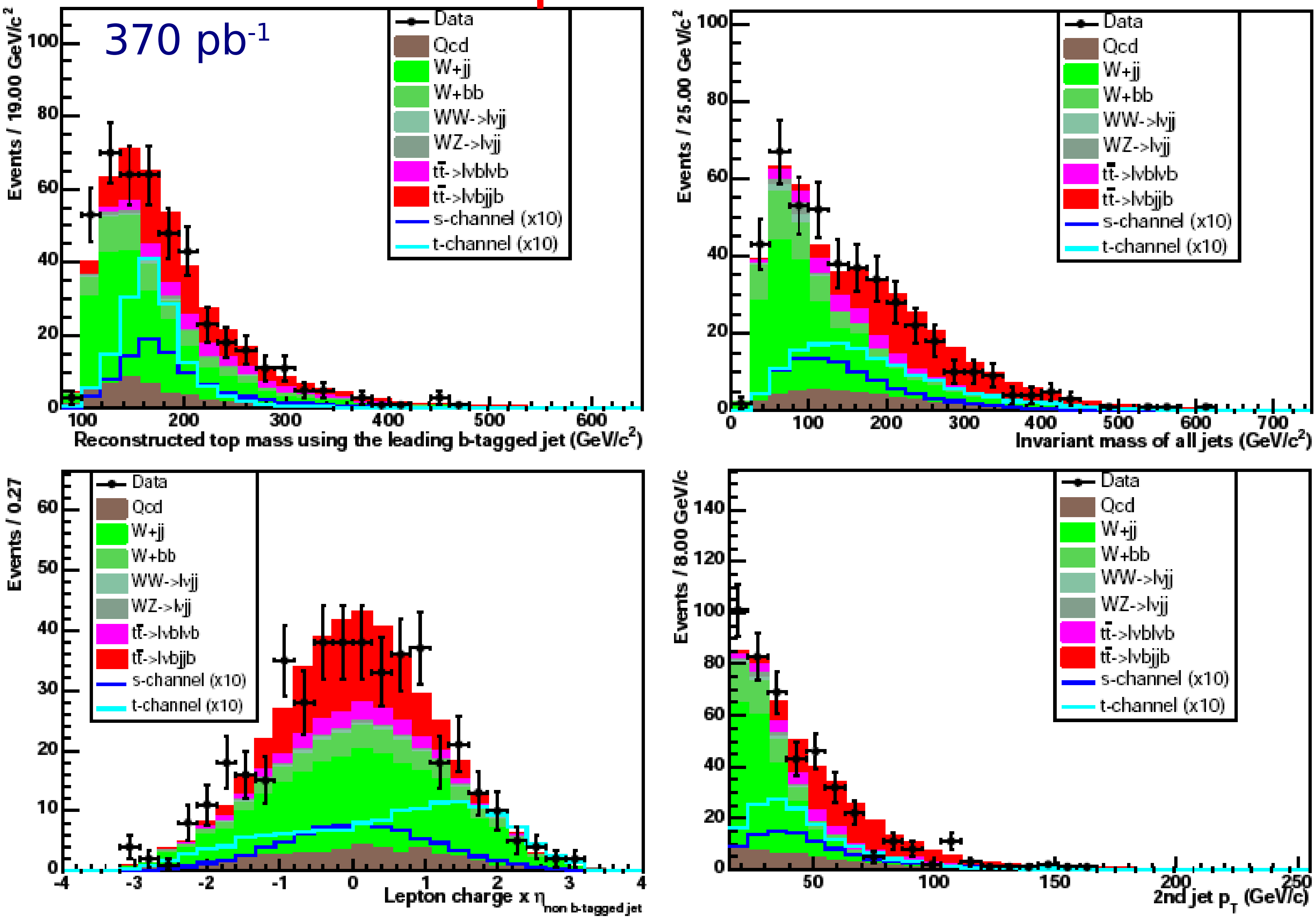
- t-channel: lead b-tagged jet + W

Reconstruct q': lead untagged jet

- **s-channel search only**
- **t-channel search only**
- **used in both**

Input variables

$e+\mu$ =1tag+2tag



Crash course in Bayesian probability

Bayes' theorem expresses the degree of belief in a hypothesis A, given another B. "Conditional" probability P(A|B):

$$P(A|B) = \frac{P(B|A)\,P(A)}{P(B)}$$

In HEP: $B \to N_{observed}$, $A \to n_{predicted} = n_{signal} + n_{bkgd}$, $n_s = Acc * L * \sigma$

P(B|A): "model" density, or likelihood: $L(N_{observed}|n_{predicted}) = n^N e^{-n}/N!$

P(A): "prior" probability density $\prod(n_{pred}) = \prod(Acc*L, n_b)\prod(\sigma)$

$\prod(n_s, n_b)$ multivariate gaussian ; $\prod(\sigma)$ assumed flat

P(B): normalization constant Z: $P(N_{observed})$

P(A|B): "posterior" probability density $P(n_{predicted}|N_{observed})$

$$P(n_{predicted}|N_{observed}) = 1/Z\ L(N_{observed}|n_{predicted}) \prod(n_{pred})$$

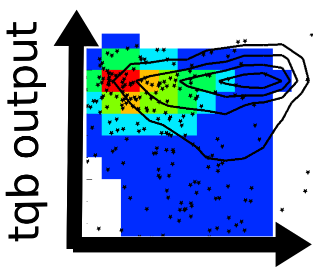
Full 2D limits

The goal is to obtain σ_s, σ_t, and σ_{s+t}, without any SM assumption

Previously we have used σ_s^{SM} to derive σ_t and vice versa

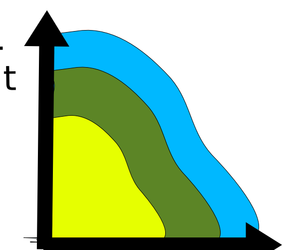
As before, use likelihood from 2D discriminant output

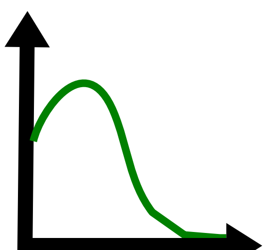
Float σ_s and σ_t and consider flat priors



$$\text{Build Likelihood} \equiv L(\sigma_s, \sigma_t)$$

$$\text{Obtain Posterior} \equiv P(\sigma_s, \sigma_t; n_{obs})$$





$$P(\sigma_s; n_{obs}) = \int P(\sigma_s, \sigma_t; n_{obs})\, d\sigma_t$$

$$P(\sigma_t; n_{obs}) = \int P(\sigma_s, \sigma_t; n_{obs})\, d\sigma_s$$

$$P(\sigma_{z=s+t}; n_{obs}) = \frac{1}{\sigma_z} \int P(\sigma_z, \sigma_t; n_{obs})\, d\sigma_t$$

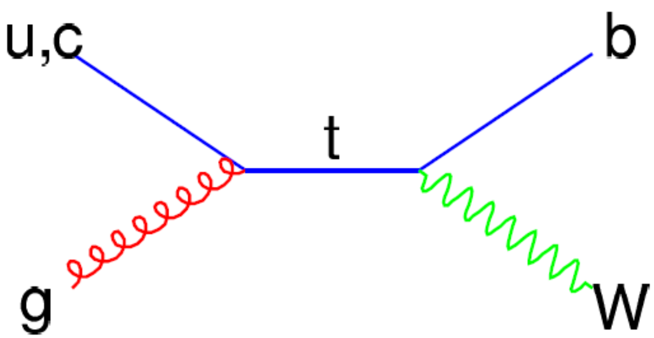
$$\sigma_x^{95} = \int_0^{\sigma^{95}} P(\sigma_x; n_{obs})\, d\sigma_x$$

- For the combined limit: replace: s →z-t where z=s+t at the Likelihood level
- Additional constraint on priors: t≤z →the prior for t depends on z

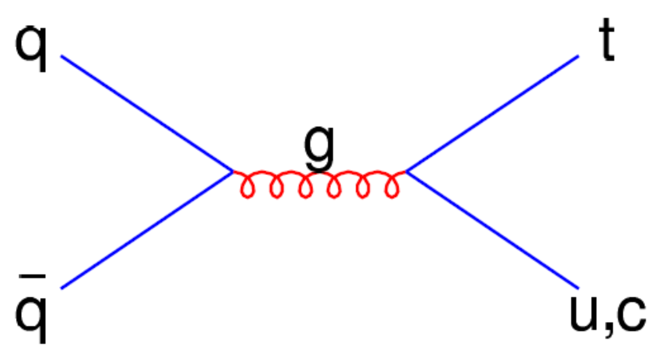
Single top beyond the SM

Plethora of possibilites:

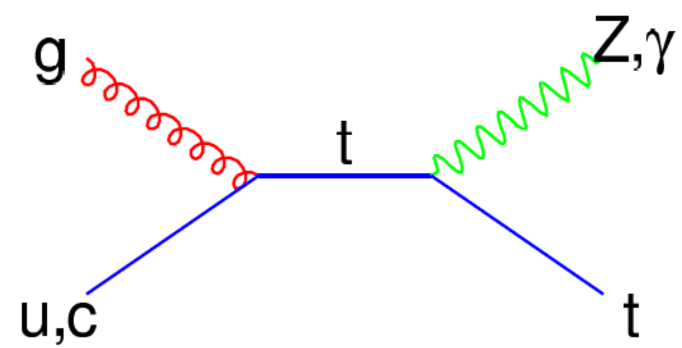
- Wtb interaction: anomalous couplings, “beautiful mirrors”, top see-saw (little Higgs)
- New particles: 4th generation *q*, W', H±, SUSY, technicolor
- FCNC: probe *tgu* coupling (extends LEP limits because involves a *g*)
- Extra SU(2), Universal Extra Dimensions



~25pb?



~3.5pb



~0.4pb

Non-SM couplings

Top is a good place to look for deviations from SM:
under control, one dominant decay t→Wb, no top hadrons,...

- Generalized Lagrangian for the Wtb interaction (hep-ph/0503040):

$$\mathcal{L}_{tbW} = \frac{g}{\sqrt{2}} W_\mu^- \bar{b}\,\gamma^\mu \left(f_1^L P_L + f_1^R P_R\right) t - \frac{g}{\sqrt{2} M_W} \partial_\nu W_\mu^- \bar{b}\,\sigma^{\mu\nu} \left(f_2^L P_L + f_2^R P_R\right) t \;+\; h.c.$$

f_1: "vector"-like
f_2: "tensor"-like
$P_{R(L)}=(1\pm\gamma_5)/2$
In SM: $f_1^L=V_{tb}\sim1$;
$f_1^R=f_2^L=f_2^R=0$

- Effective single top production cross section:

$$\sigma = A(f_1^L)^2 + B(f_1^R)^2 + C(f_1^L+f_2^R)^2 + D(f_2^L+f_1^R)^2$$

There are strong bounds on tensor couplings:
from unitarity $|f_2|<0.6$, and from b→sγ: $|f_2^L|<0.004$
But Tevatron can set direct limits. The goal is:

- Set limits simultaneously on all four couplings
- Set individual limits

Non-SM couplings strategy

f_1^L and f_1^R have same p_T distributions

Angular variables and spin are different

- Separate data into s-channel (2 tags) and t-channel (1tag+⩾1untag) samples based on NN output
- Top quark spin correlations separate between L and R couplings

  tb: Helicity basis (lepton, top direction)

  tqb: Optimal basis (lepton,pbar)
- Use flat prior for four square terms:

  $|f_1^L|^2$, $|f_1^R|^2$, $|c_1 f_1^L+f_2^R|^2$, $|c_1 f_1^R+f_2^L|^2$

  c_1 is a fixed constant
- Obtain limits on these four terms