Universidad Autónoma de Madrid
HEP Seminar

January 8, 2007

Evidence for production of single top quarks at DØ and a first direct measurement of $|V_{tb}|$

- Electroweak production of top quarks at DØ
- Event selection and background estimation
- Multivariate methods
  - Decision Trees, Matrix Elements, Bayesian NN
- Cross checks. Expected sensitivity
- Cross sections and significance
- First direct measurement of $|V_{tb}|$
- Summary

University of Washington

Arán García-Bellido

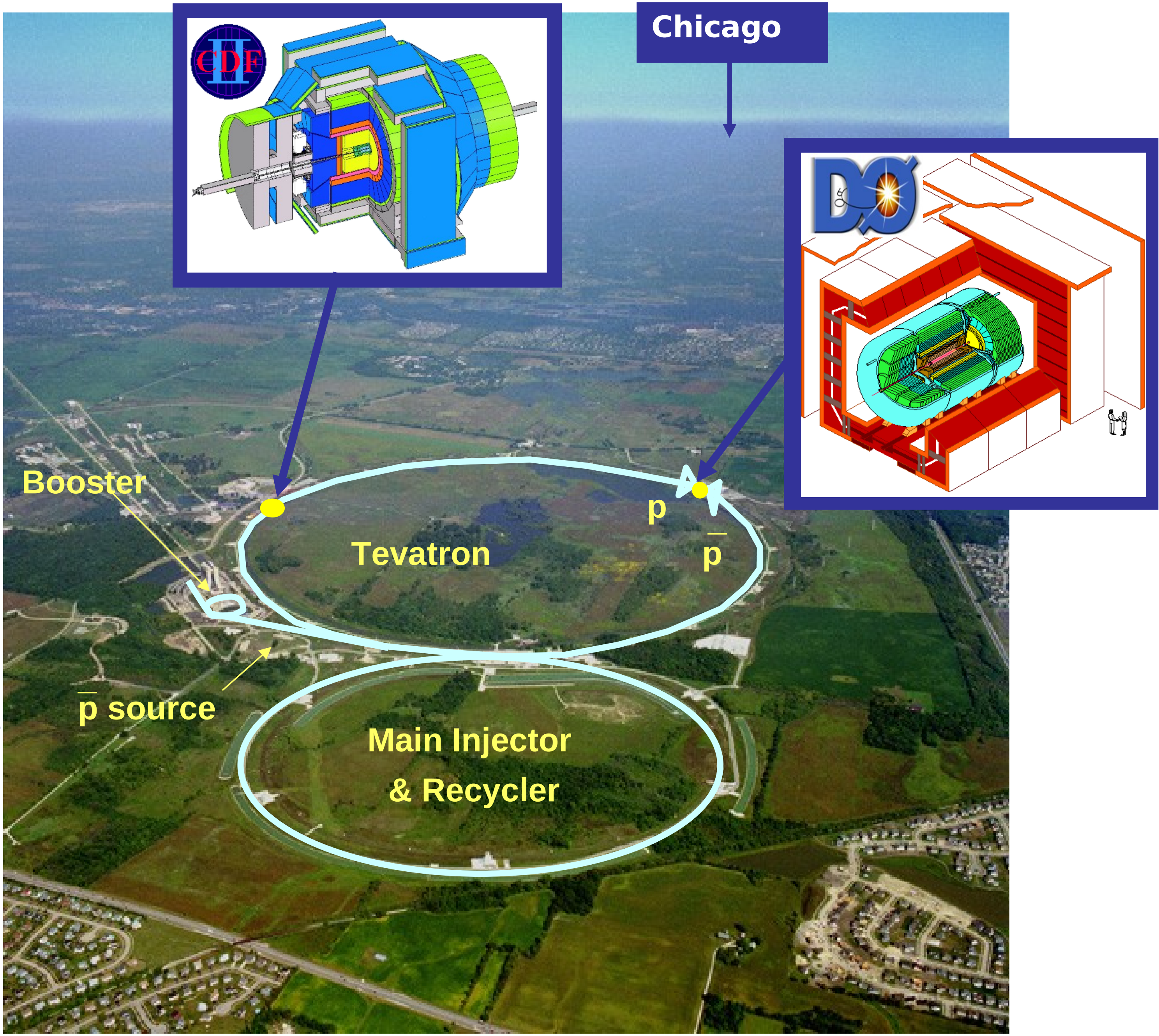
The Tevatron

The highest energy particle accelerator in the world!

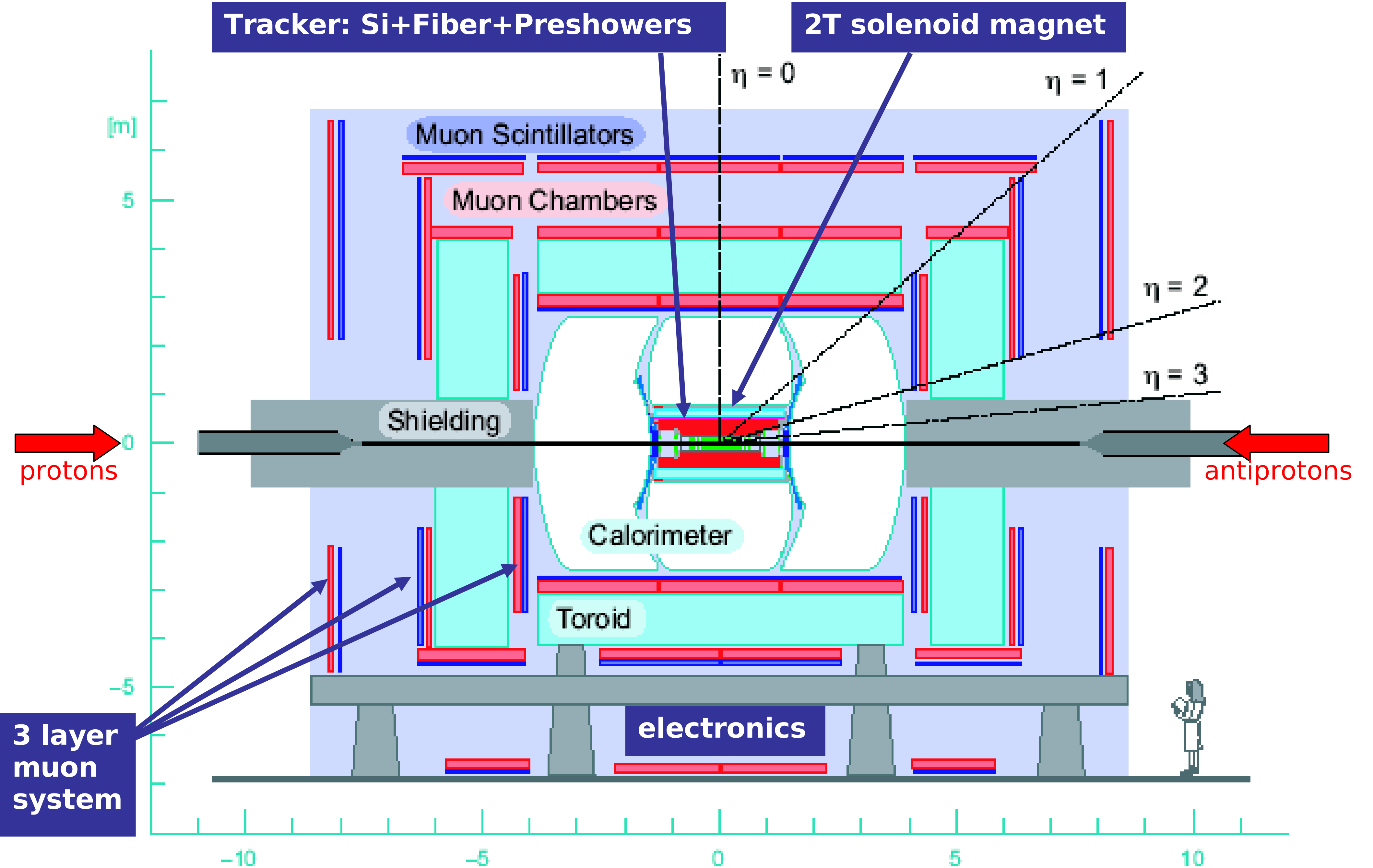
Proton-antiproton collider

Run I 1992-1995
Top quark discovered!

Run II 2001-09(?)
$\sqrt{s}$ = 1.96 TeV
Δt = 396ns
$>2fb^{-1}$ delivered
Peak Lum: $2\cdot10^{32}cm^{-2}s^{-1}$

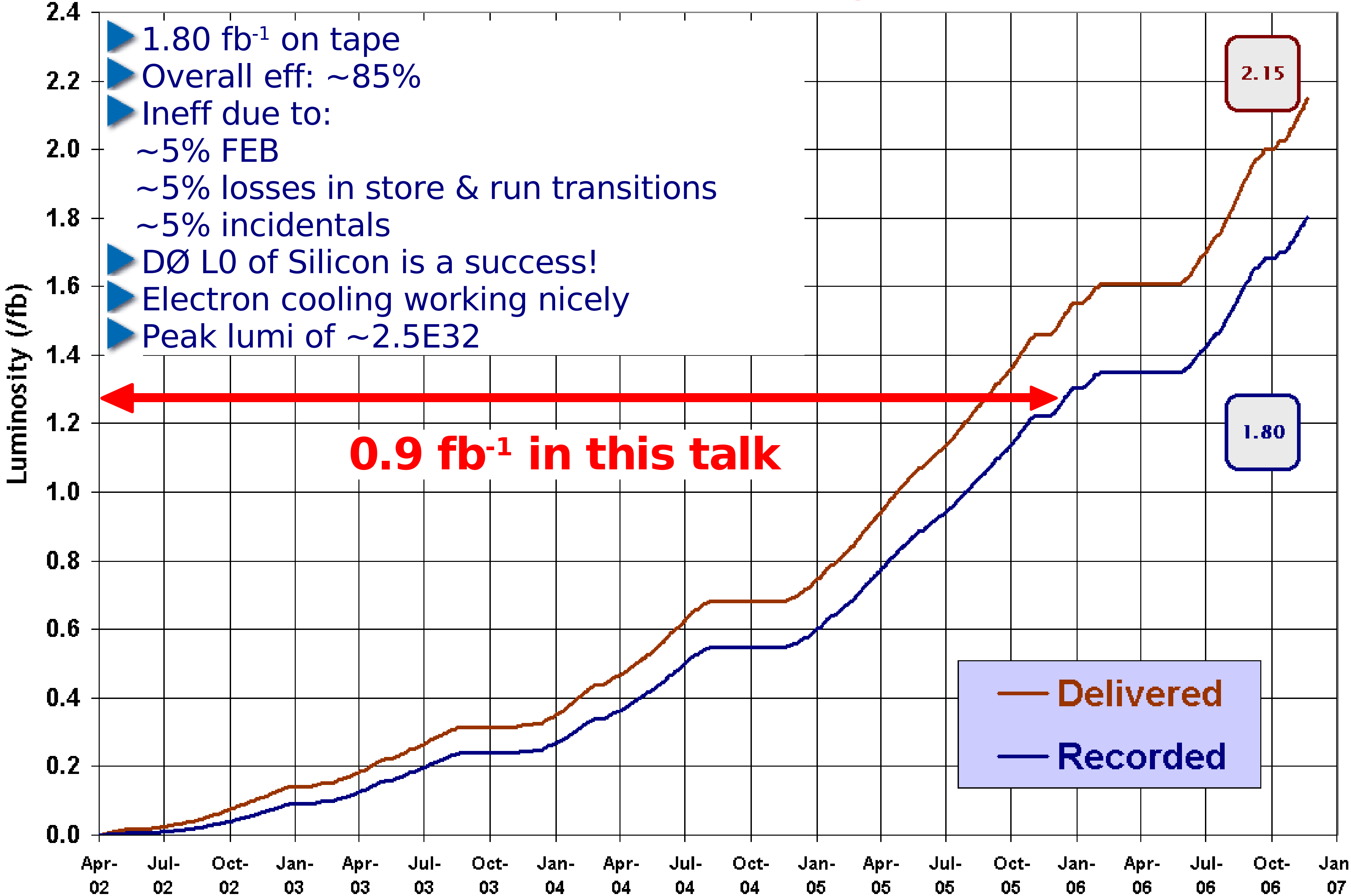


DØ for Run II



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
3 layer muon system
electronics
−10
−5
0
5
10

Data taking



1.80 fb-1 on tape
Overall eff: ~85%
Ineff due to:
~5% FEB
~5% losses in store & run transitions
~5% incidentals
DØ L0 of Silicon is a success!
Electron cooling working nicely
Peak lumi of ~2.5E32
0.9 fb-1 in this talk
2.15
1.80
Delivered
Recorded
Luminosity (/fb)
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Apr-02
Jul-02
Oct-02
Jan-03
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Jul-03
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Jan-04
Apr-04
Jul-04
Oct-04
Jan-05
Apr-05
Jul-05
Oct-05
Jan-06
Apr-06
Jul-06
Oct-06
Jan-07

Top quark physics

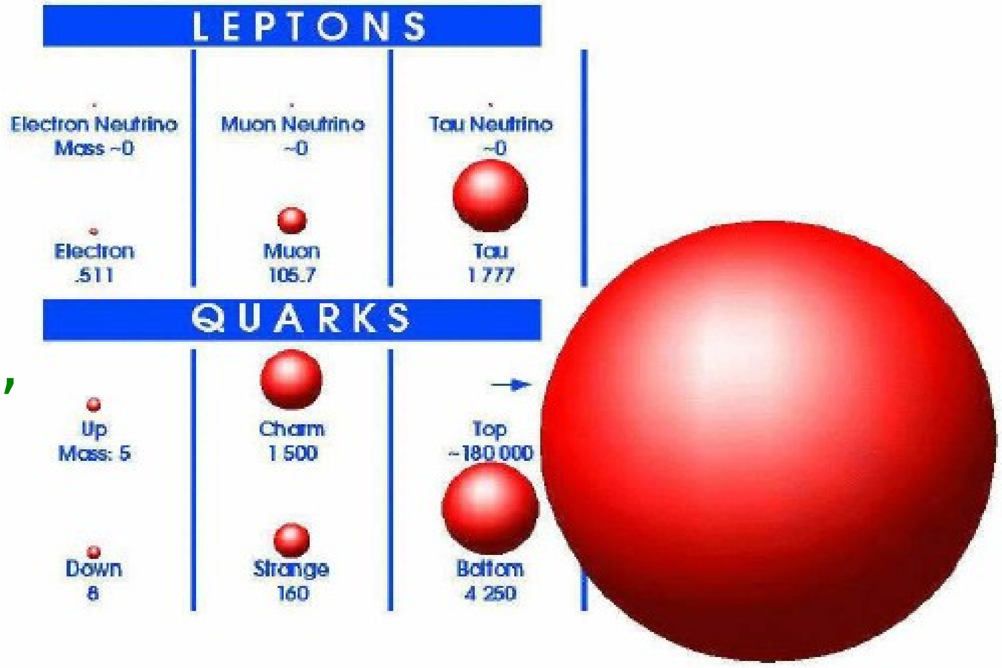
The top quark is a very special fermion:

- Heaviest known particle: 171.4±2.1 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 $\ll \Lambda_{QCD}^{-1}$
  - Spin information is passed to its decay products
  - Test V-A structure of the SM

We still don't know: spin, width, lifetime

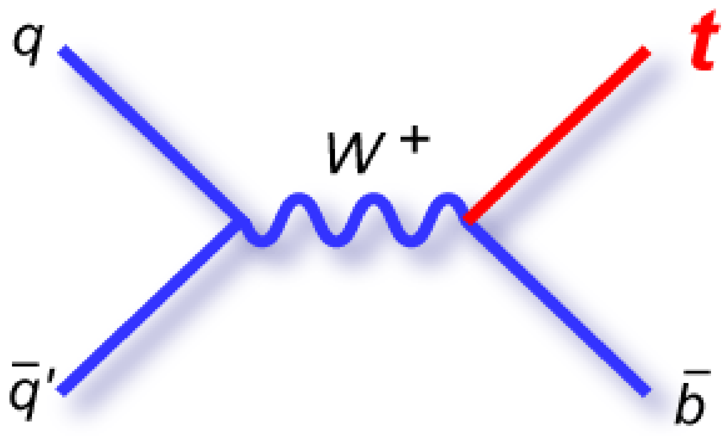
We know the mass, cross section, charge and its BR($t\rightarrow Wb$)~1

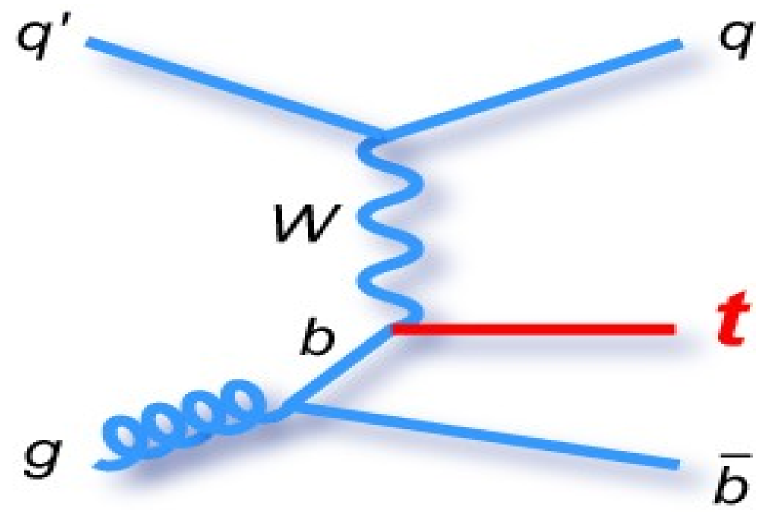
Plenty of room for new physics



Top quark electroweak production

PRD 66 (02) 054024
hep-ph/0408049





s-channel (tb)

σ_{NLO}**=0.88±0.11 pb**

Current limits @ 95% C.L.:

DØ (370pb^{-1}) σ_{tb}<5.0pb

CDF (700pb^{-1}) σ_{tb}<3.1pb

t-channel (tqb)

σ_{NLO}**=1.98±0.25 pb**

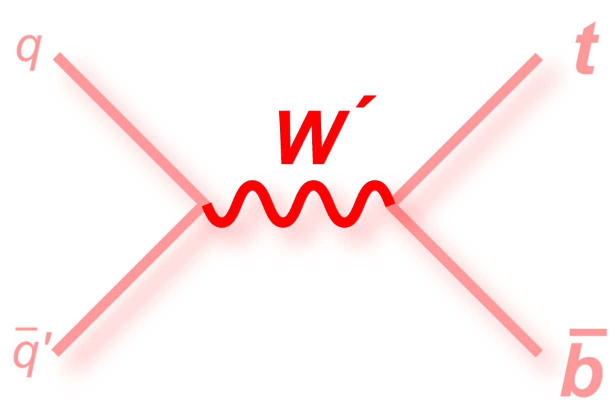
Current limits @ 95% C.L.:

DØ (370pb^{-1}) σ_{tqb}<4.4pb

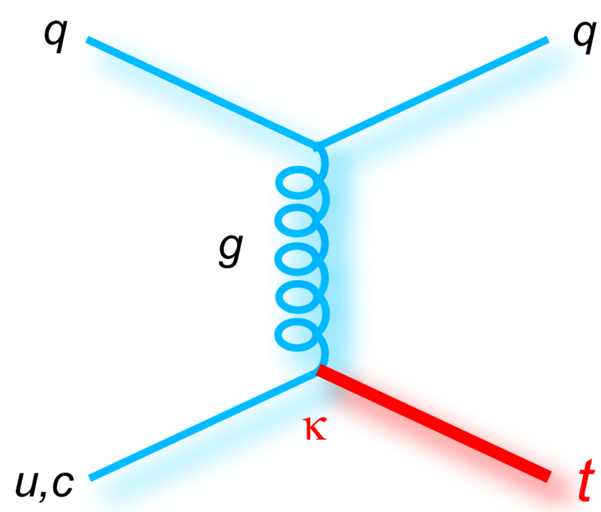
CDF (700pb^{-1}) σ_{tqb}<3.2pb

Why search for single top?

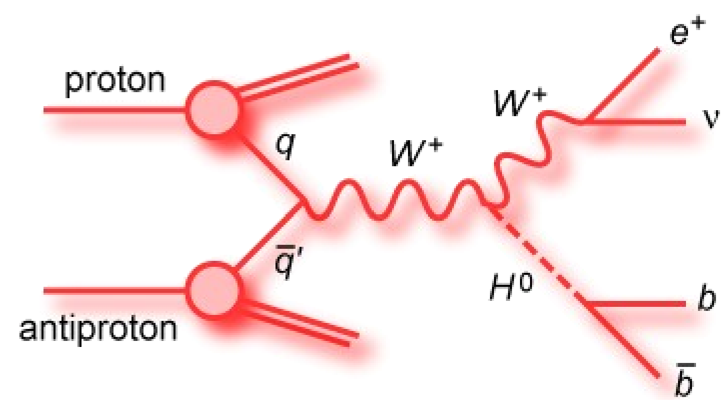
- Access W-t-b coupling
  - measure V_{tb} directly → more on this later
  - test unitarity of CKM
- New physics:
  - s-channel sensitive to resonances: W’, top pions, SUSY, etc…
  - t-channel sensitive to FCNCs, anomalous couplings
- Source of polarized top quarks
- Extract small signal out of a large background



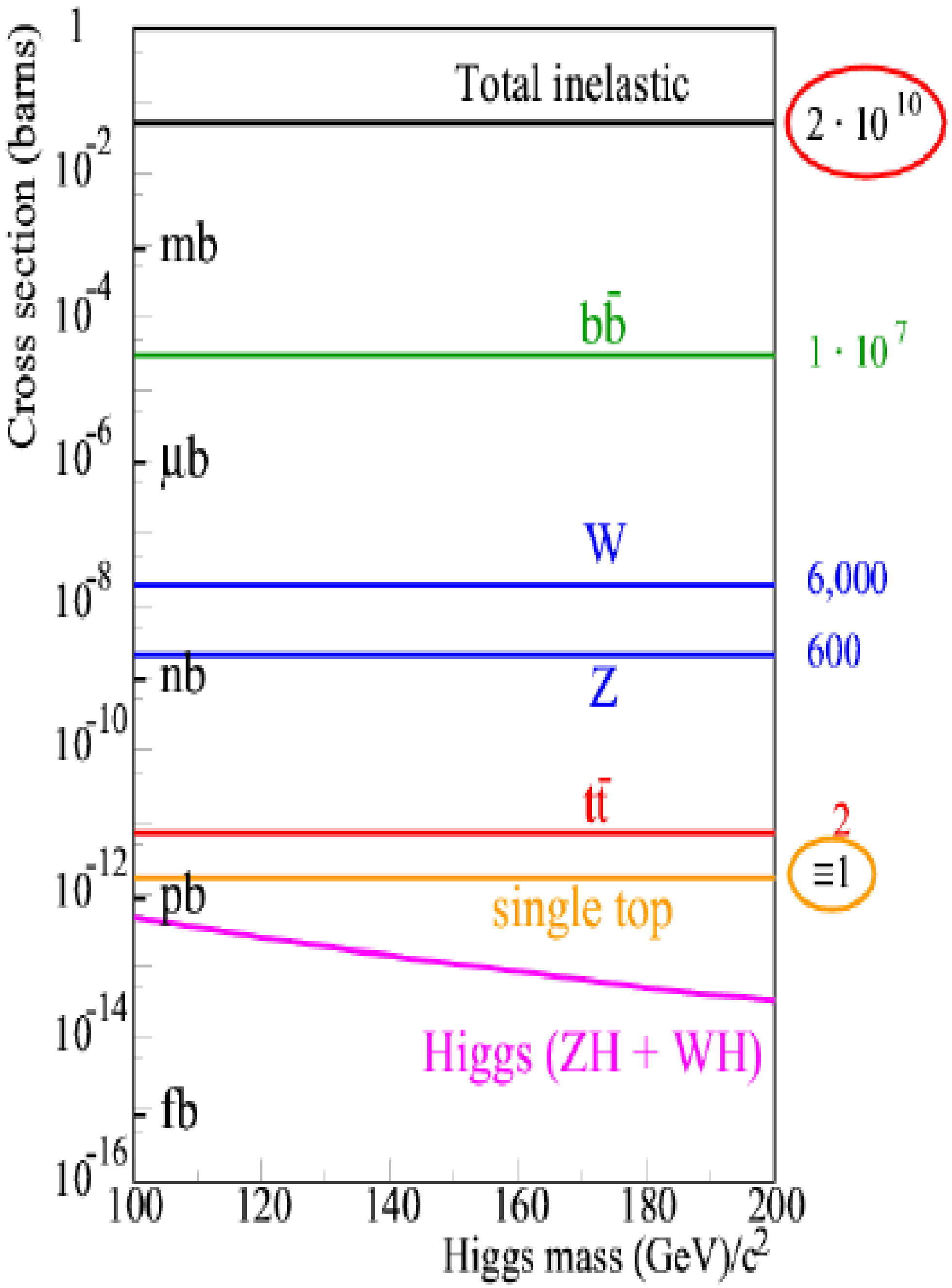
DØ search: hep-ex/0607102



DØ search: t.b.s. PRL



A big challenge!

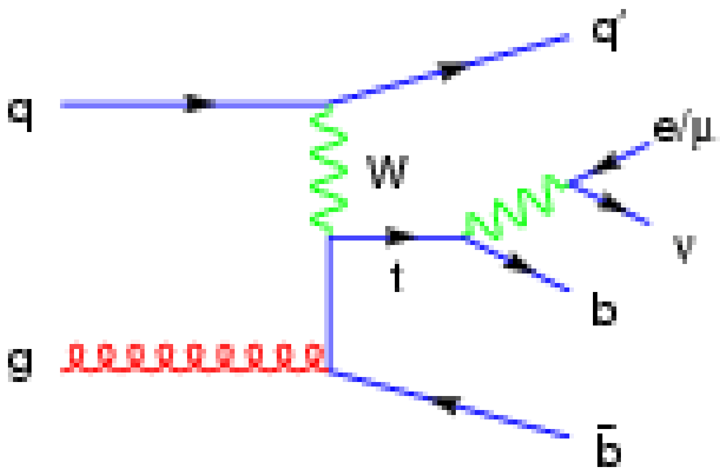


~20 single top events produced per day

But huge backgrounds!

We have benefited greatly from the following improvements for this analysis:

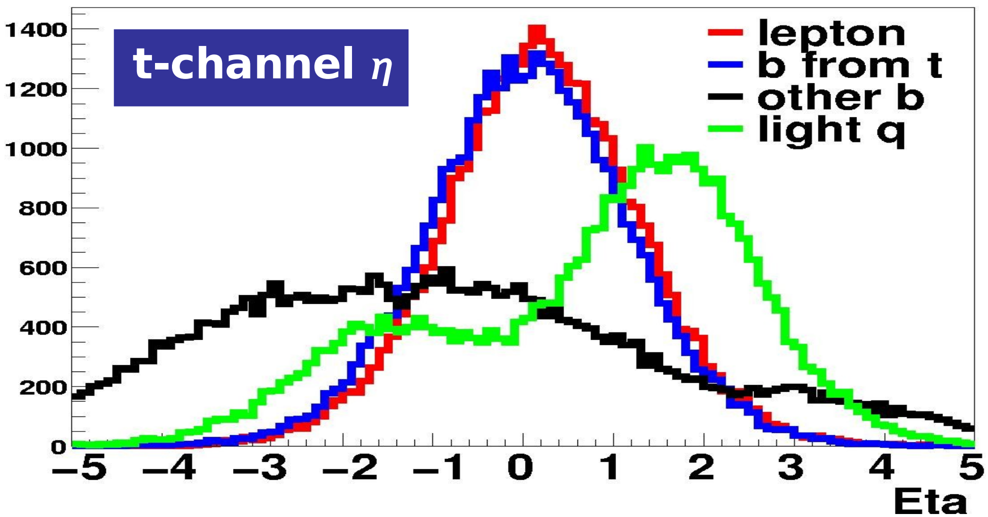
- Background model improvements (PS↔ME matching: MLM)
- Fully reprocessed dataset: new calibrations, jet thresholds, JES,...
- New more efficient NN b-tagger
- Split channels by jet multiplicity
- Combined s+t search added (SM s:t ratio is assumed)



Signal selection

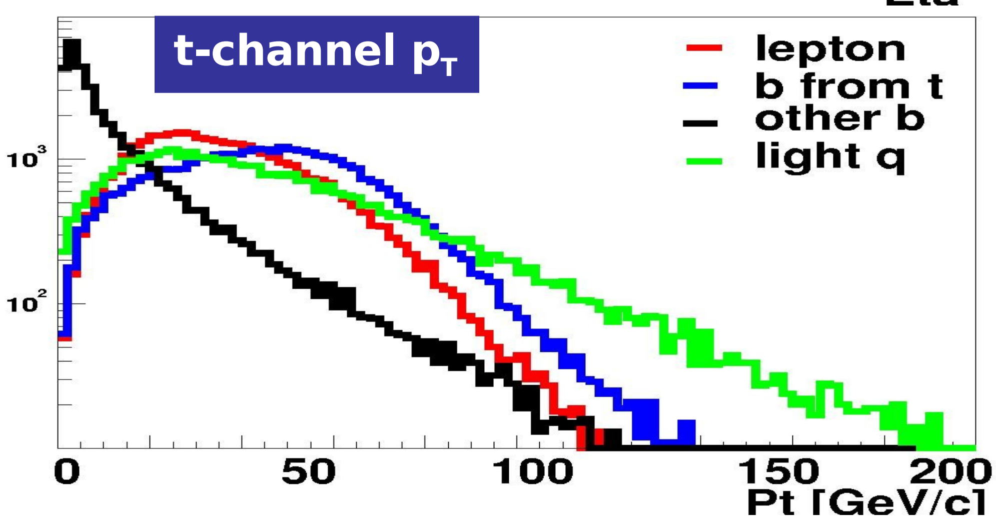
Signature:

- 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



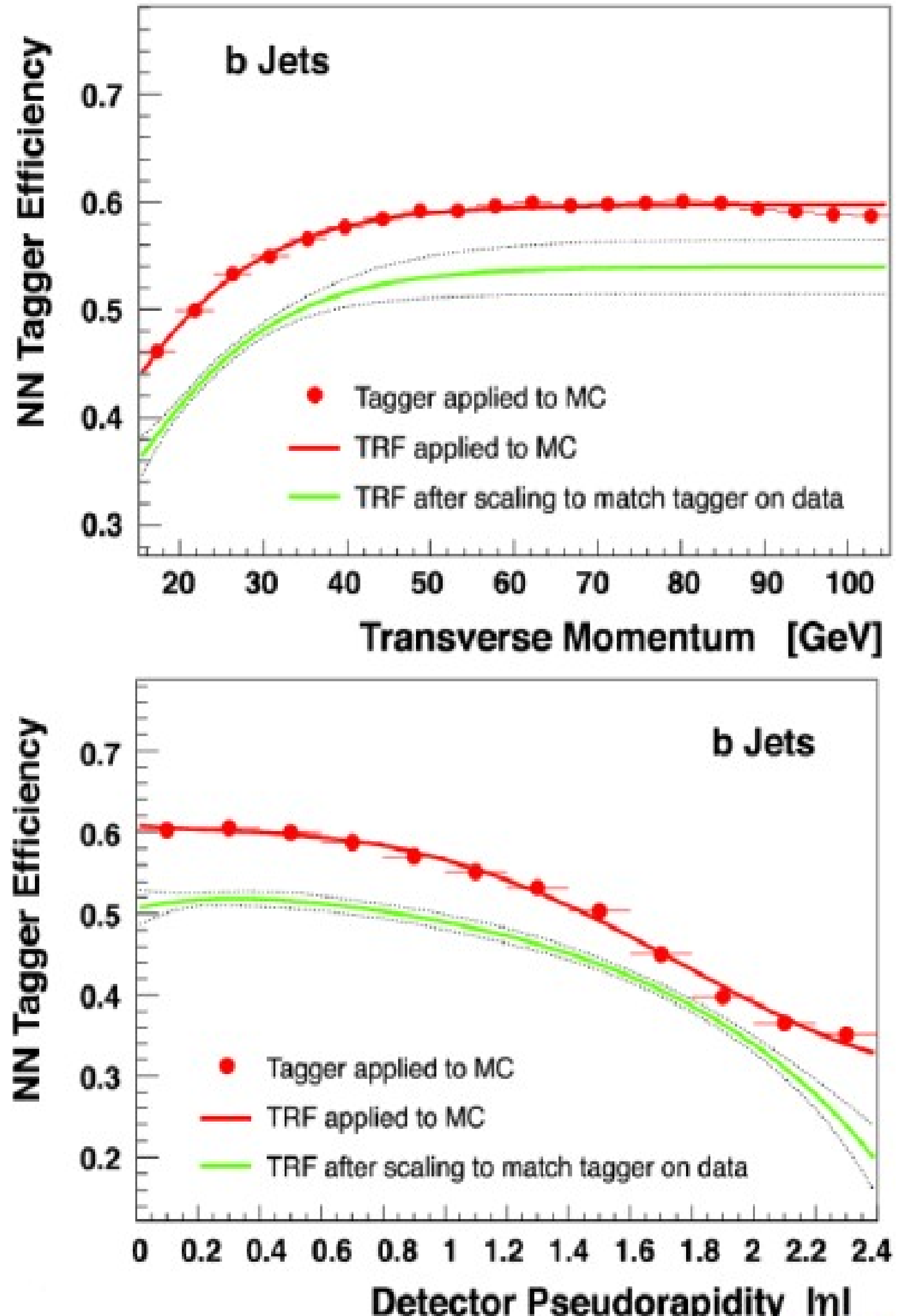
Event selection:

- Only one tight (no loose) lepton:
  - e: p_T >15 GeV and $|\eta^{det}|$<1.1
  - μ: p_T >18 GeV and $|\eta^{det}|$<2.0
- MET > 15 GeV
- 2-4 jets: p_T >15 GeV and $|\eta^{det}|$<3.4
  - Leading jet: p_T>25 GeV ; $|\eta^{det}|$<2.5
  - Second leading jet: p_T >20 GeV
- One or two b-tagged jets



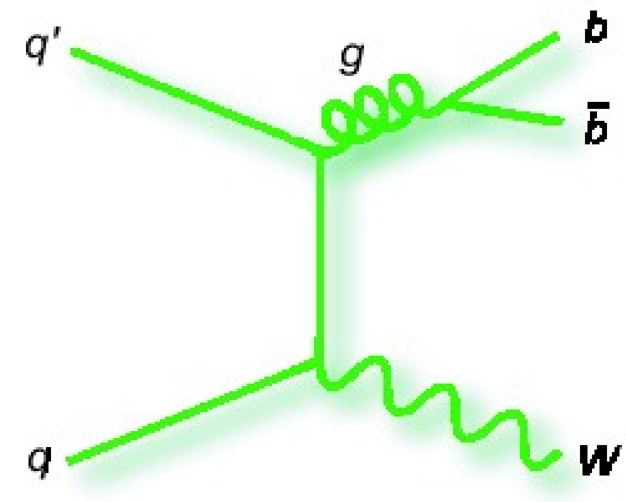
NN b-jet tagger

- NN trained on 7 input variables from SVT, JLIP and CSIP taggers
- Much improved performance!
  - Fake rate reduced by 1/3 for same b-efficiency relative to previous tagger
  - Smaller systematic uncertainty
- Tag Rate Functions (TRFs) in η, p_T and z-PV derived in data are applied to MC
- Our operating point:
  - b-jet efficiency: ~50%
  - c-jet efficiency: ~10%
  - Light-jet efficiency: ~0.5%

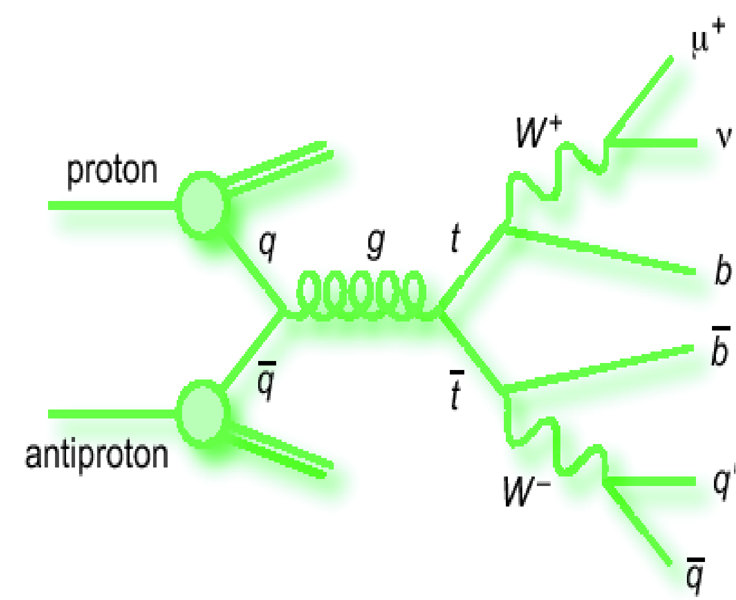


Background modeling

- W+jets: ~o(1000) pb
  - Distributions from Alpgen 2.0
  - Normalization from data
  - Heavy flavor fractions from data



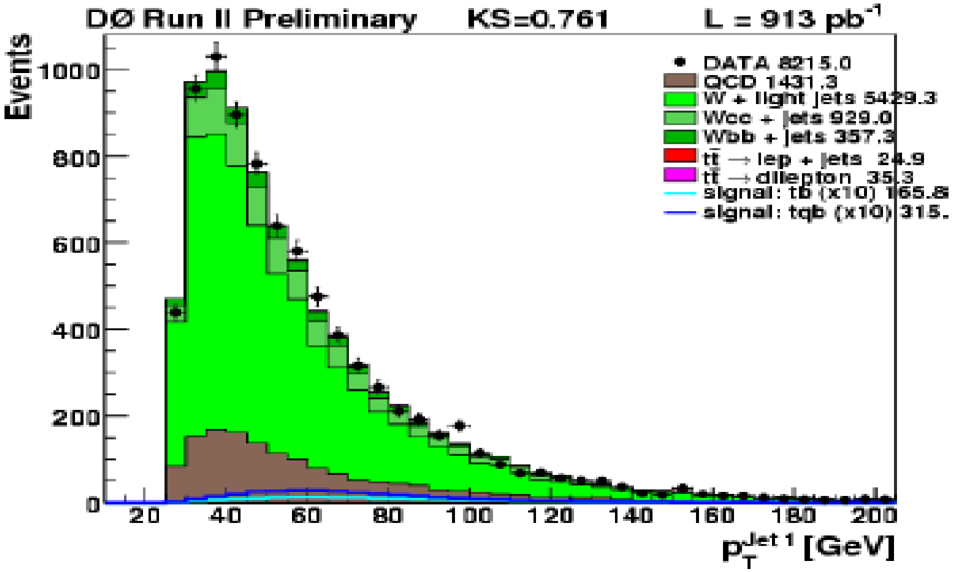
- Top pairs: ~7 pb
  - Topologies: dilepton and ℓ+jets
  - Use Alpgen 2.0 with MLM matching
  - Normalize to NNLO σ

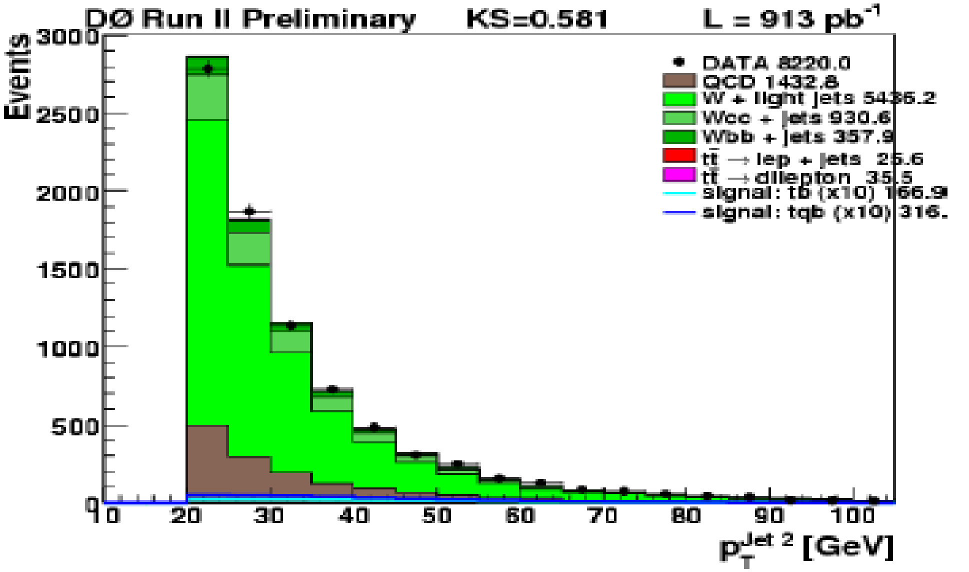


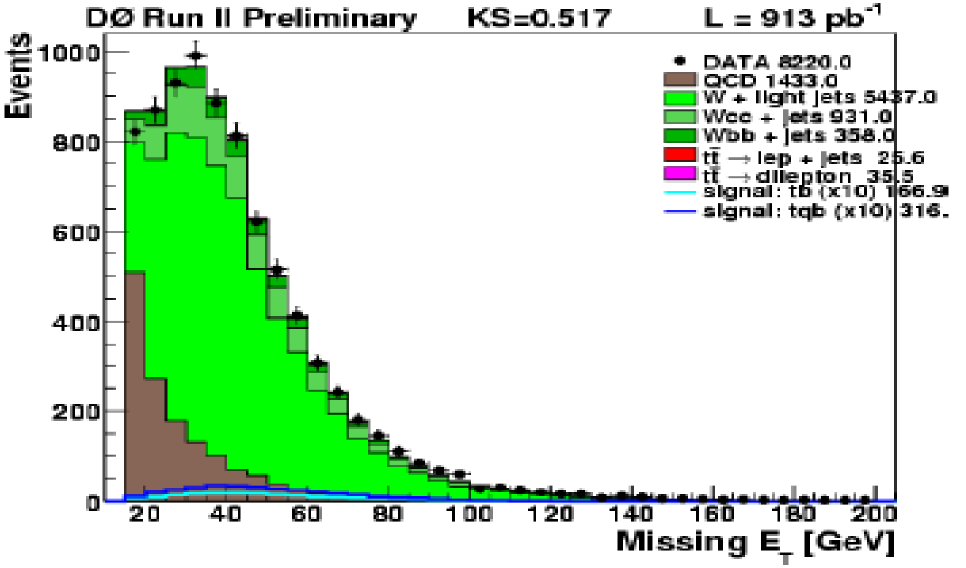
- Multijet events (misidentified lepton)
  - From data

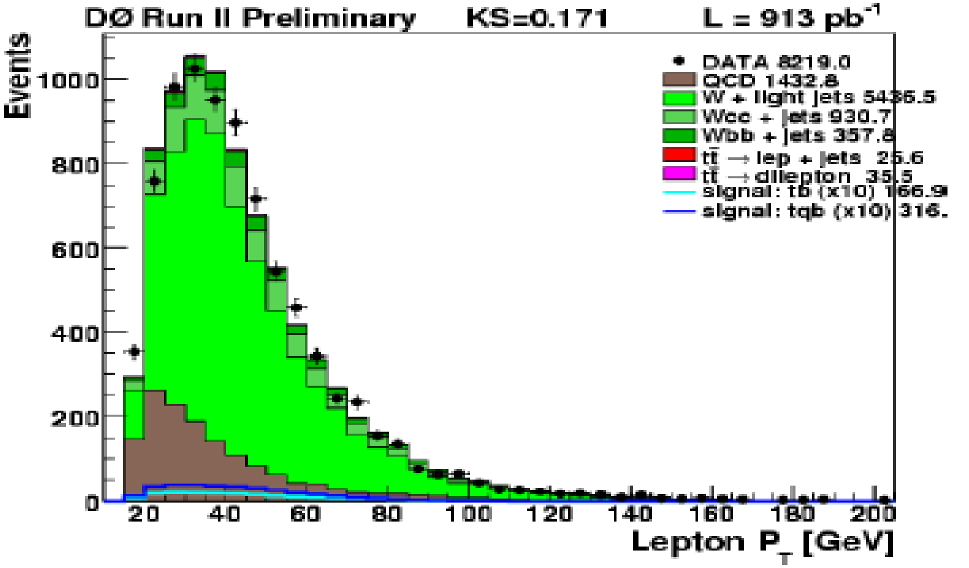
Agreement before tagging

- Normalize W+jets and QCD yields to data before tagging
- Check 90 variables (in e,mu x 2,3,4 jets)
- Good description of data









Yields after event selection

Source	Event Yields in 0.9 fb^{-1} Data Electron+muon, 1tag+2tags combined 2 jets	3 jets	4 jets
tb	16 ± 3	8 ± 2	2 ± 1
tqb	20 ± 4	12 ± 3	4 ± 1
$t\bar{t} \rightarrow ll$	39 ± 9	32 ± 7	11 ± 3
$t\bar{t} \rightarrow l$+jets	20 ± 5	103 ± 25	143 ± 33
$W+b\bar{b}$	261 ± 55	120 ± 24	35 ± 7
$W+c\bar{c}$	151 ± 31	85 ± 17	23 ± 5
$W+jj$	119 ± 25	43 ± 9	12 ± 2
Multijets	95 ± 19	77 ± 15	29 ± 6
Total background	686 ± 131	460 ± 75	253 ± 42
Data	697	455	246

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

Event selection and S:B

Percentage of single top *tb+tqb* selected events and S:B ratio (white squares = no plans to analyze)

Electron + Muon	1 jet	2 jets	3 jets	4 jets	≥ 5 jets
0 tags	10% 1 : 3,200	25% 1 : 390	12% 1 : 300	3% 1 : 270	1% 1 : 230
1 tag	6% 1 : 100	21% 1 : 20	11% 1 : 25	3% 1 : 40	1% 1 : 53
2 tags		3% 1 : 11	2% 1 : 15	1% 1 : 38	0% 1 : 43

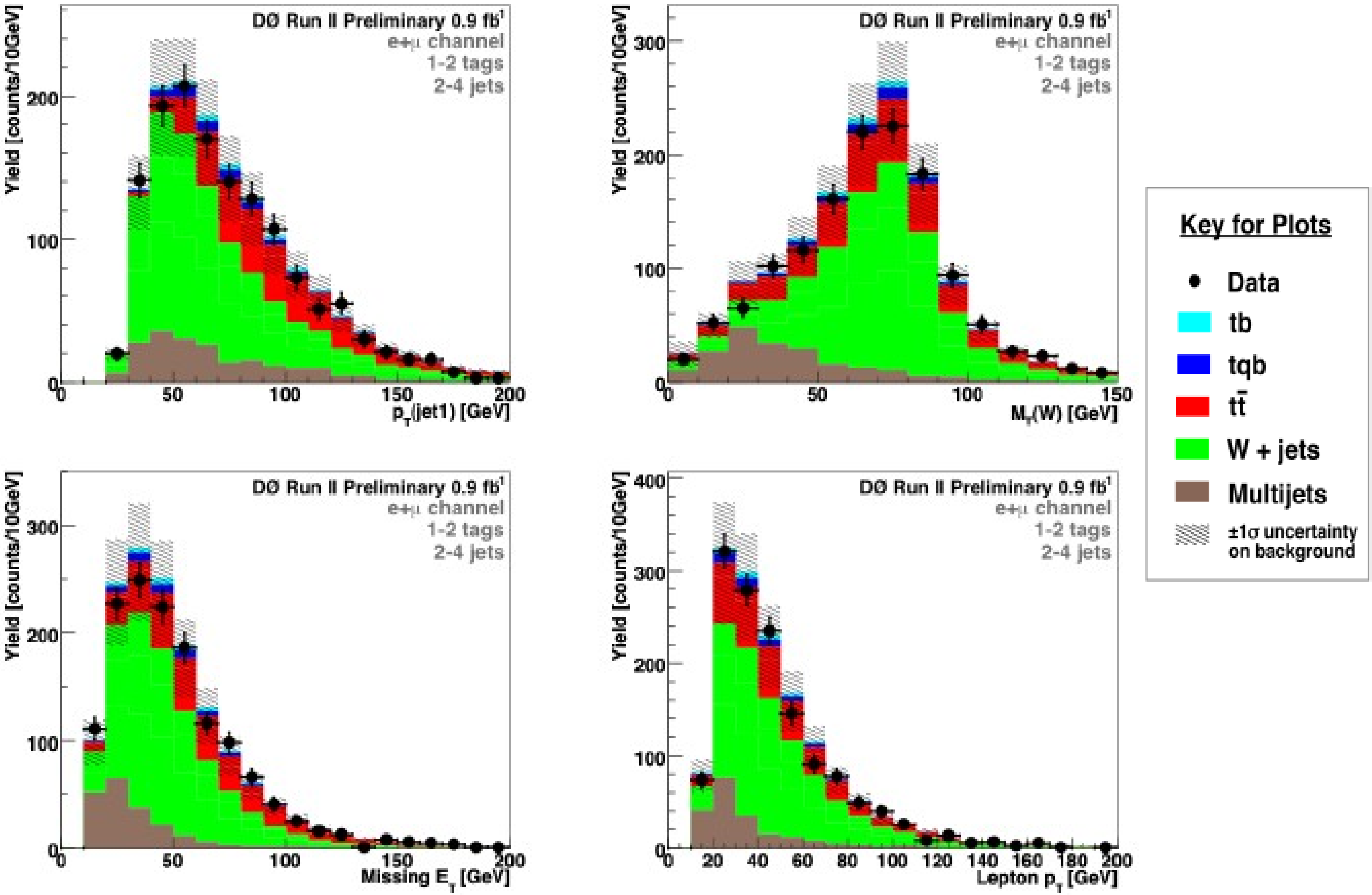
Systematic uncertainties

- Uncertainties are assigned per background, jet multiplicity, lepton channel, and number of tags
- Uncertainties that affect both the **normalization** and the **shapes**: JES and tag rate functions
- Correlations between channels and sources are taken into account

Examples of Relative Systematic Uncertainties

$t\bar{t}$ cross section	18%
Luminosity	6%
Electron trigger	3%
Muon trigger	6%
Jet energy scale	wide range
Jet fragmentation	5–7%
Heavy flavor ratio	30%
Tag-rate functions	2–16%

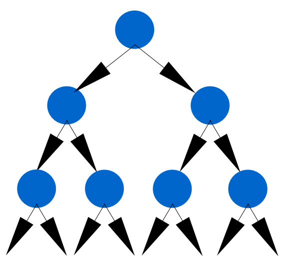
And check 1000s of plots again...



Analysis methods

- Once we understand our data, need to measure the signal
- We cannot use simple cuts to extract the signal: use **multivariate techniques**
- DØ has implemented three analysis methods to extract the signal from the same dataset:

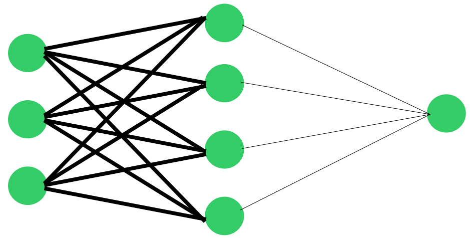
Decision Trees



Matrix Elements

$$\int M$$

Bayesian NNs



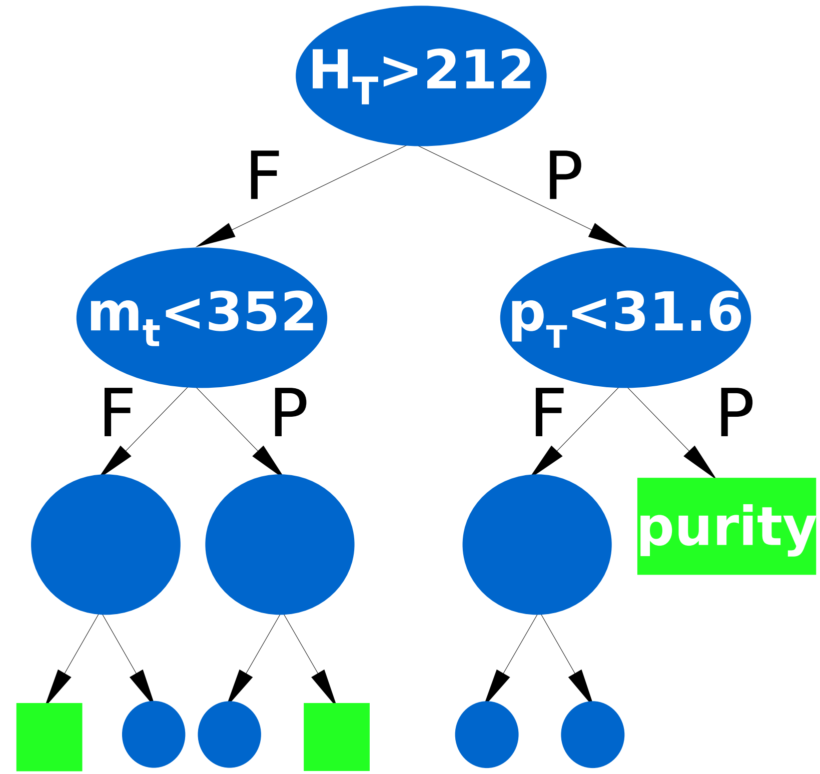
- DT and BNN use same pool of discriminating variables
- ME method uses 4-vectors of reconstructed objects
- Optimized separately for s-channel, t-channel and s+t
- Test response and robustness with ensemble testing

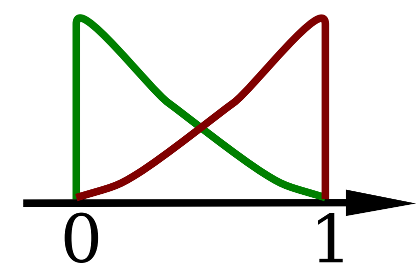
Decision Trees

Machine learning technique widely used in social sciences

Idea: recover events that fail criteria in cut-based analysis

- Start with all events (first node)
- For each variable, find the splitting value with best separation between children
- Select best variable and cut: produce **P**ass and **F**ailed branches
- Repeat recursively on each node
- Stop when improvement stops or when too few events left
- Terminal node: leaf with purity $= N_S/(N_S+N_B)$
- Output: purity for each event





Decision Trees + Boosting

Boosting is a recent technique to improve the performance of any weak classifier: recently used in DTs by GLAST and MiniBooNE

AdaBoost algorithm: adaptive boosting

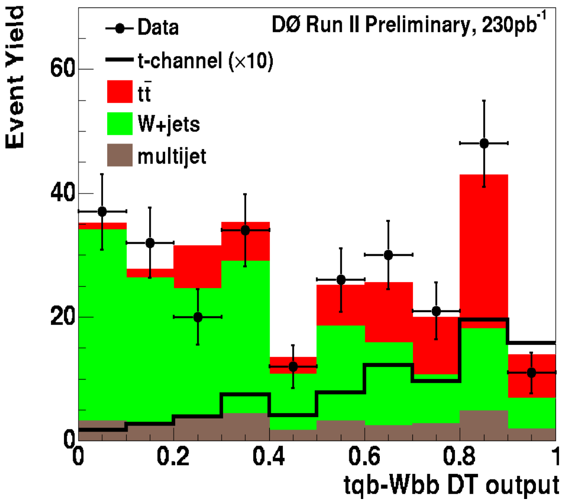
1) Train a tree T_k

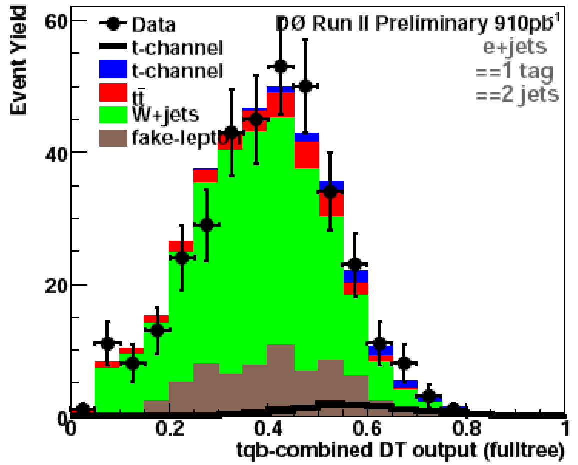
2) Check which events are **misclassified** by T_k

3) Derive tree weight α_k

4) Increase weight of misclassified events

5) Train again to build T_{k+1}





- We have trained 36 separate trees: (s, t, s+t)x(e,mu)x(2,3,4 jets)x(1,2 tags)
- Use 1/3 of MC events for training
- For each signal, train against sum of backgrounds
- Signal leaf if purity>0.5; Minimum leaf size=100 events; Goodness of split: Gini factor; Adaboost β=0.2; boosting cycles=20

Decision Trees: 49 variables

Object Kinematics

p_T(jet1)
p_T(jet2)
p_T(jet3)
p_T(jet4)
p_T(best1)
p_T(notbest1)
p_T(notbest2)
p_T(tag1)
p_T(untag1)
p_T(untag2)

Angular Correlations

ΔR(jet1,jet2)
cos(best1,lepton)$_{\mathrm{besttop}}$
cos(best1,notbest1)$_{\mathrm{besttop}}$
cos(tag1,alljets)$_{\mathrm{alljets}}$
cos(tag1,lepton)$_{\mathrm{btaggedtop}}$
cos(jet1,alljets)$_{\mathrm{alljets}}$
cos(jet1,lepton)$_{\mathrm{btaggedtop}}$
cos(jet2,alljets)$_{\mathrm{alljets}}$
cos(jet2,lepton)$_{\mathrm{btaggedtop}}$
cos(lepton,Q(lepton)$\times z$)$_{\mathrm{besttop}}$
cos(lepton,besttopframe)$_{\mathrm{besttopCMframe}}$
cos(lepton,btaggedtopframe)$_{\mathrm{btaggedtopCMframe}}$
cos(notbest,alljets)$_{\mathrm{alljets}}$
cos(notbest,lepton)$_{\mathrm{besttop}}$
cos(untag1,alljets)$_{\mathrm{alljets}}$
cos(untag1,lepton)$_{\mathrm{btaggedto}}$

Event Kinematics

Aplanarity(alljets,W)
M(W,best1) ("best" top mass)
M(W,tag1) ("b-tagged" top mass)
H_T(alljets)
H_T(alljets$-$best1)
H_T(alljets$-$tag1)
H_T(alljets,W)
H_T(jet1,jet2)
H_T(jet1,jet2,W)
M(alljets)
M(alljets$-$best1)
M(alljets$-$tag1)
M(jet1,jet2)
M(jet1,jet2,W)
M_T(jet1,jet2)
M_T(W)
Missing E_T
p_T(alljets$-$best1)
p_T(alljets$-$tag1)
p_T(jet1,jet2)
Q(lepton)$\times\eta$(untag1)
$\sqrt{\hat{s}}$
Sphericity(alljets,W)

- Adding variables does not degrade performance
- Tested shorter lists, lose some sensitivity
- Same list used for all channels

Matrix Elements method

- The idea is to use all available kinematic information from a **fully differential cross-section calculation**
- Calculate an event probability for signal and background hypothesis

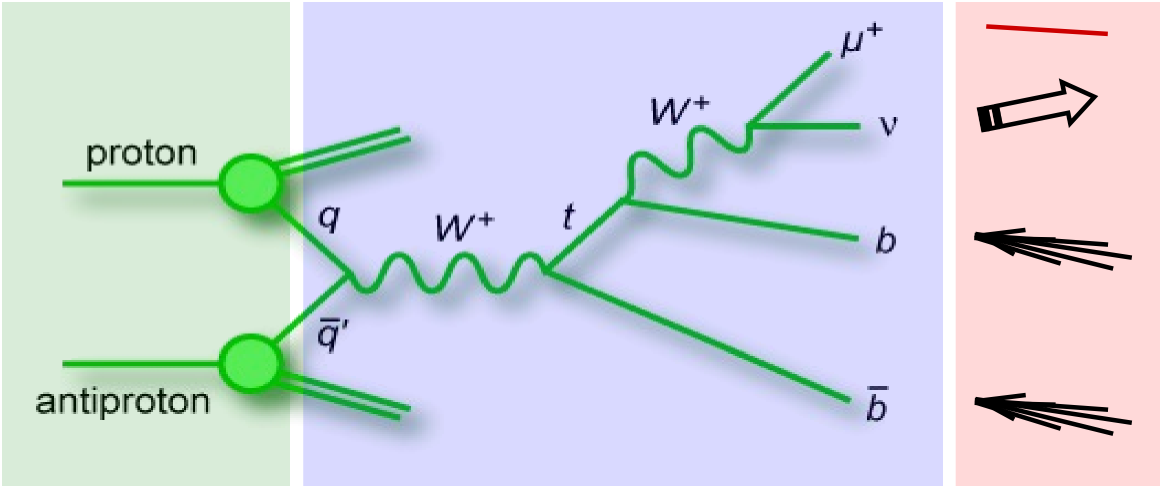
$$P(\vec{x}) = \frac{1}{\sigma} \int f(q_1;Q)\,dq_1\, f(q_2;Q)\,dq_2 \times |M(\vec{y})|^2 \phi(\vec{y})\,dy \times W(\vec{x},\vec{y})$$

Parton distribution functions CTEQ6

Differential cross section (LO ME from Madgraph)

Transfer Function: maps parton level (y) to reconstructed variables (x)

- Uses the 4-vectors of all reconstructed ℓs and jets
- This analysis: 2&3 jet events only, match partons to jets
- Apply b-tagging information



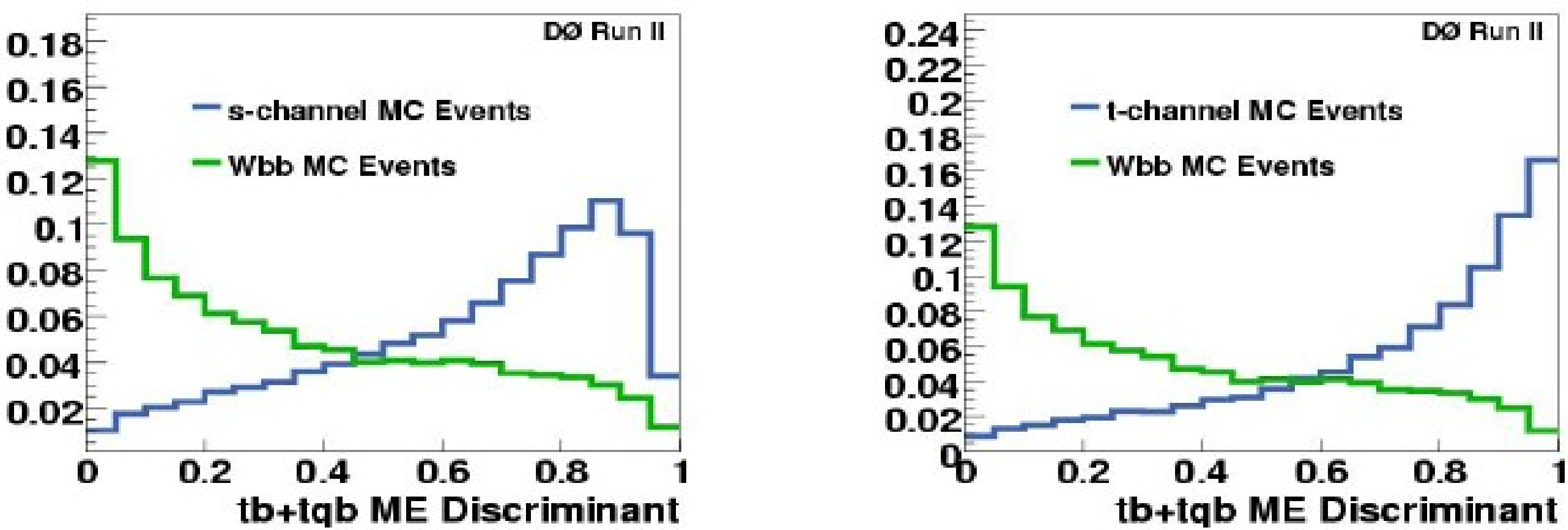
- Need to integrate over 4 independent variables: assume angles well measured, known masses, momentum and energy conservation

ME discriminant

- Define discriminant based on event probabilities for signal and background

$$D_s(\vec{x}) = P(S|\vec{x}) = \frac{P_{Signal}(\vec{x})}{P_{Signal}(\vec{x}) + P_{Background}(\vec{x})}$$

- In 2 jet events: use ME for Wbg, Wcg and Wgg backgrounds
- In 3 jet events: use ME for Wbbg background
- No ttbar ME used thus far: no separation in the 3rd jet bin!



Bayesian Neural Networks

A different sort of NN (http://www.cs.toronto.edu/radford/fbm.software.html):

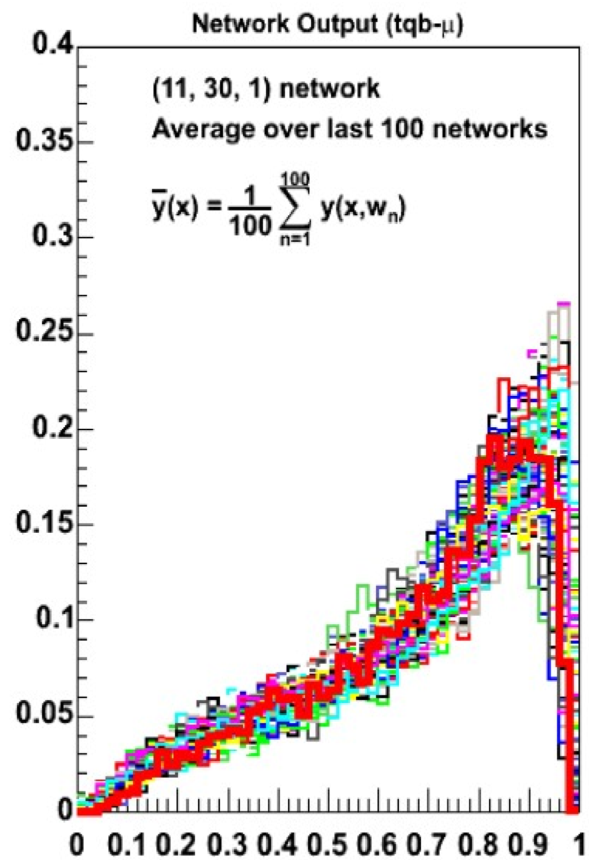
- Instead of choosing one set of weights, find posterior probability density over all possible weights
- Averages over many networks weighted by the probability of each network given the training data
- Use 24 variables (subset of the DT variables) and train against sum of backgrounds

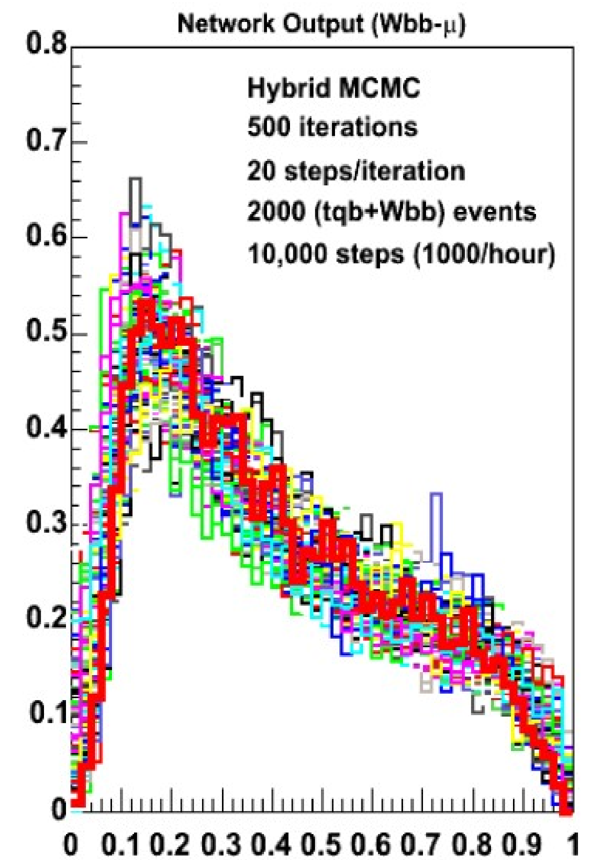
Advantages:

- Less prone to overfitting, because of Bayesian averaging
- Network structure less important: can use large networks!
- Optimized performance

Disadvantages:

- Computationally demanding!



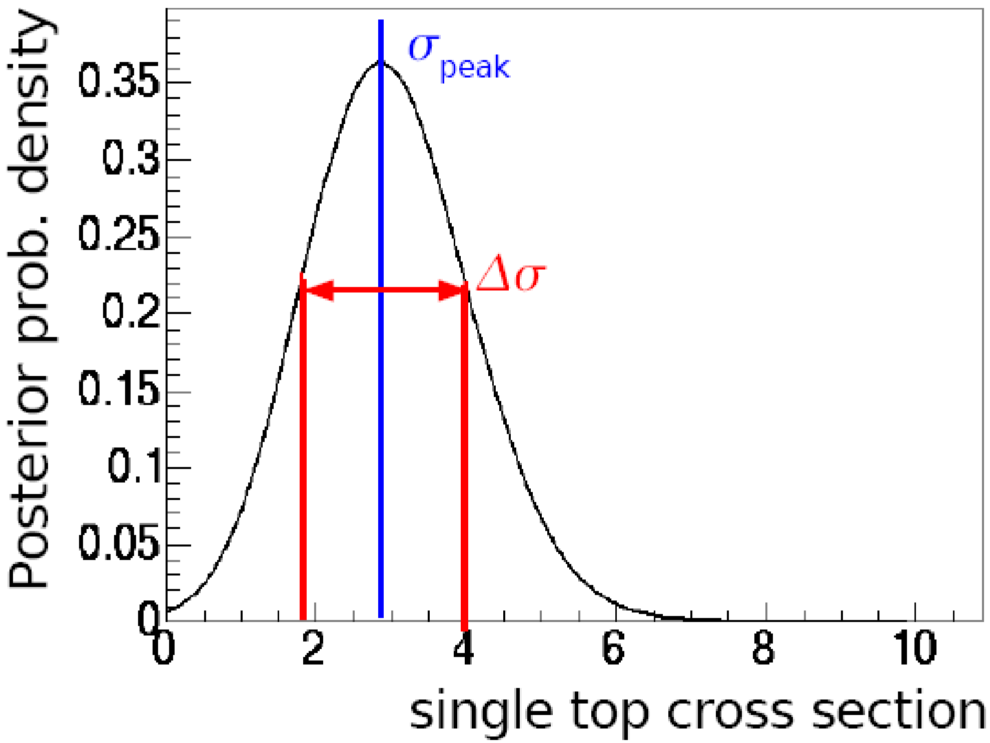


Measuring the cross section

- We form a binned likelihood from the discriminant outputs
- Probability to observe data distribution D, expecting y:

$$y = \alpha l \sigma + \sum_{s=1}^{N} b_s \equiv a\sigma + \sum_{s=1}^{N} b_s$$

$$P(D|y) \equiv P(D|\sigma, a, b) = \prod_{i=1}^{nbins} P(D_i|y_i)$$



- And obtain a Bayesian posterior probability density as a function of the cross section:

$$Post(\sigma|D) \equiv P(\sigma|D) \propto \int_a \int_b P(D|\sigma, a, b) Prior(\sigma) Prior(a, b)$$

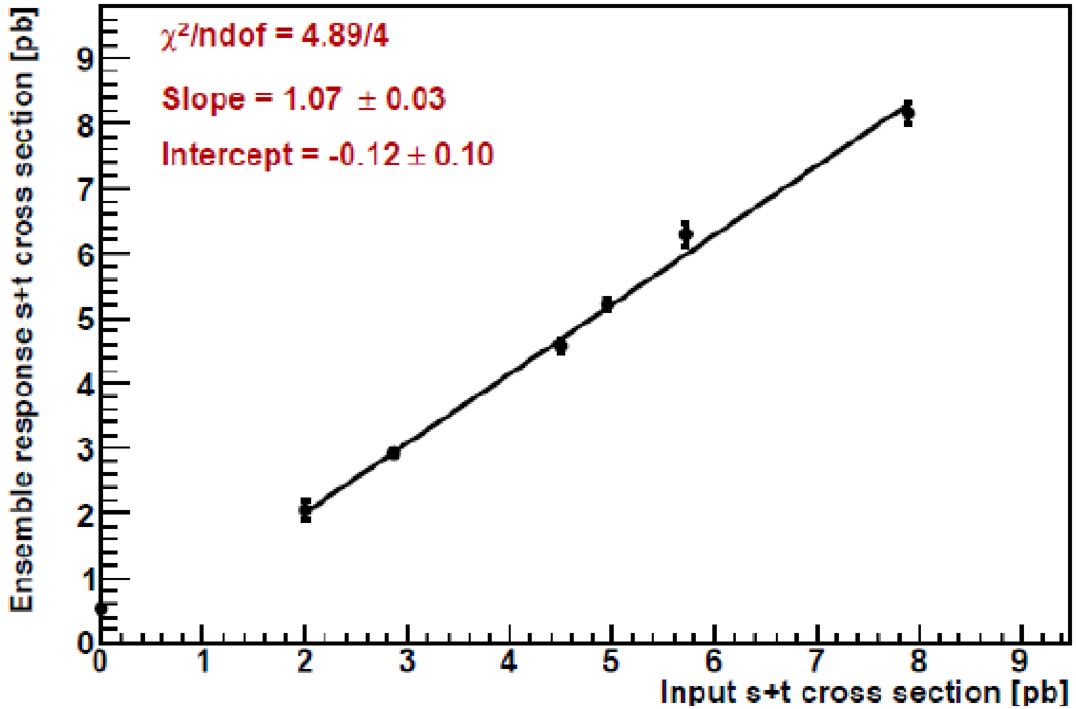
- Shape and normalization systematics treated as nuisance parameters
- Correlations between uncertainties properly accounted for
- Flat prior in signal cross section

Ensemble testing

- To verify that all this machinery is working properly, we test with many sets of **pseudo-data**
- Wonderful tool to test analysis methods! Run DØ experiment 100s of times
- Use pool of MC events to draw events with bkgd. yields fluctuated according to **uncertainties**, reproducing the **correlations** between components introduced in the normalization to data
- Randomly sample a Poisson distribution to simulate **statistical** fluctuations
- Generated ensembles include:
  1) 0-signal ensemble (σ_{s+t} = 0 pb)
  2) SM ensemble (σ_{s+t} = 2.9 pb)
  3) “Mystery” ensembles to test analyzers (σ_{s+t} = ?? pb)
  4) Ensemble at measured cross-section ($\sigma_{s+t} = \sigma_{measured}$)
  5) A high luminosity ensemble
- Each analysis tests linearity of “response” to single top

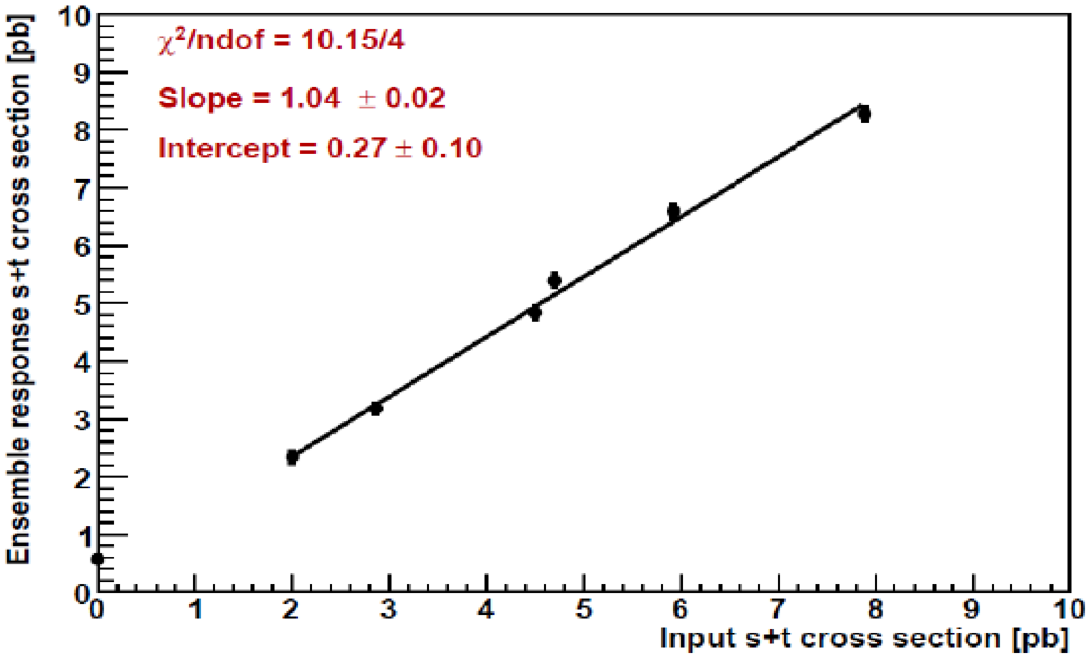
Responses

DT analysis

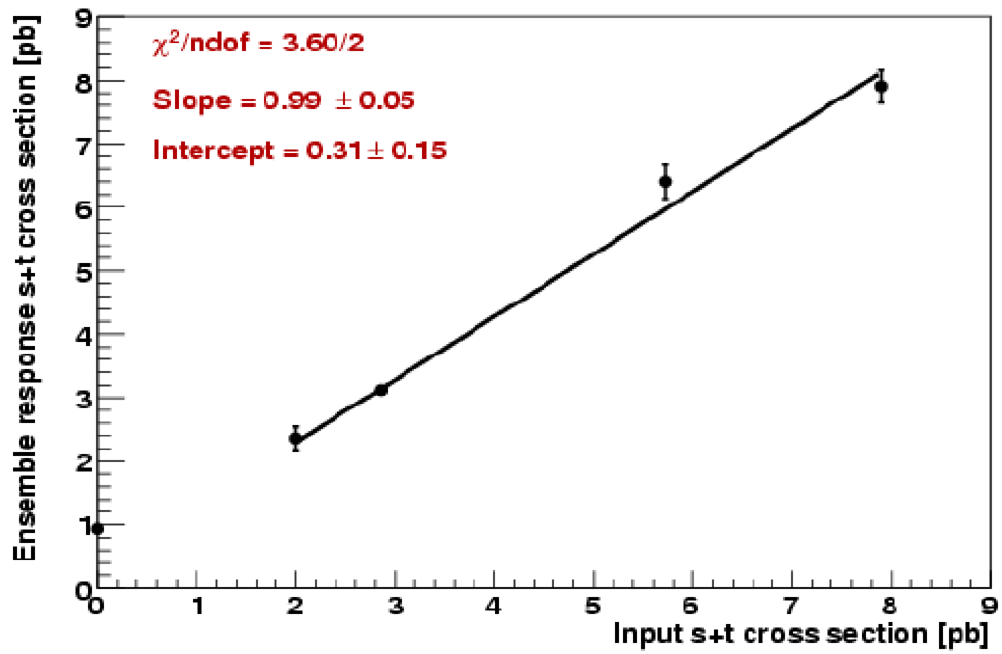


Using the ensemble tests:
- SM ensemble is returned at the right value
- “Mystery” ensembles are unraveled
- Linear response is achieved

ME analysis



BNN analysis



Sensitivity and Significance

We have used our 0-signal ensembles to determine a significance for each measurement

Expected p-value: the fraction of 0-signal pseudo-datasets in which we measure at least 2.9 pb

Observed p-value: the fraction of 0-signal pseudo-datasets in which we measure at least the measured cross section

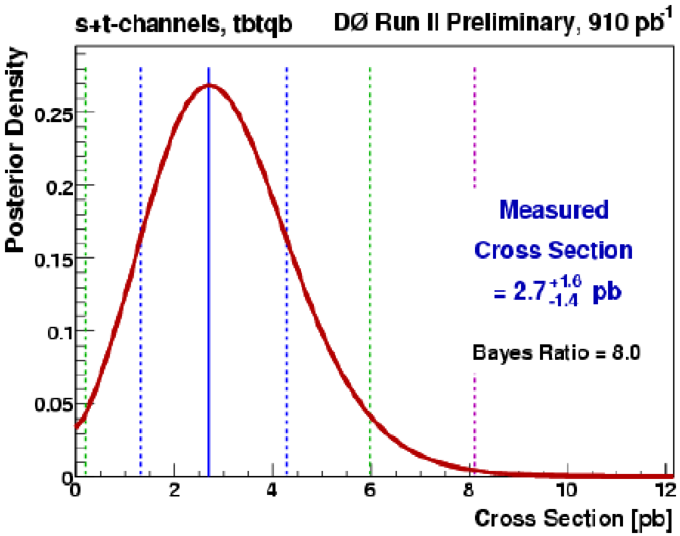
- We also use the SM ensembles to see how compatible our measured value is with the SM

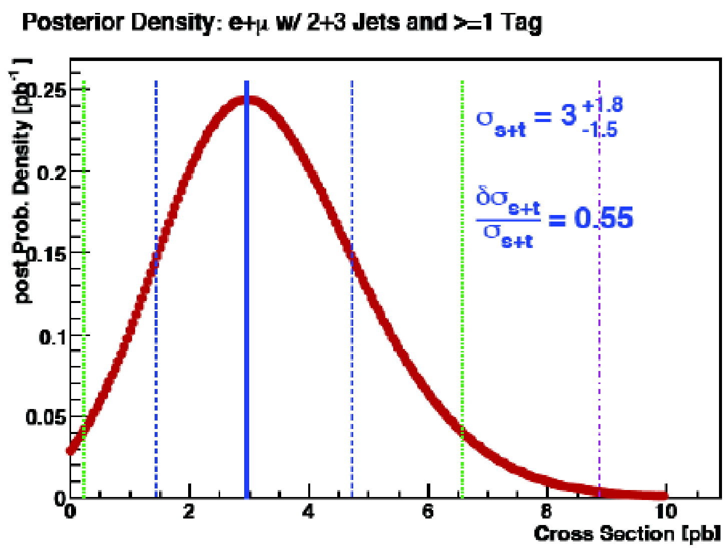
Expected p-values

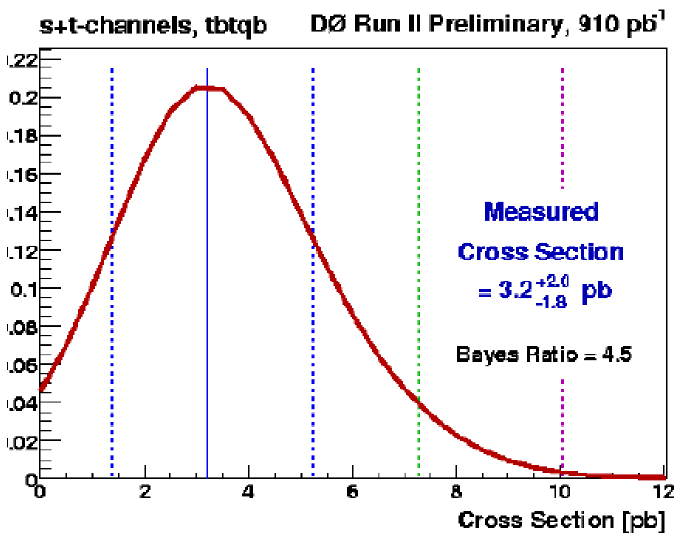
Decision Trees
p-value 1.9%

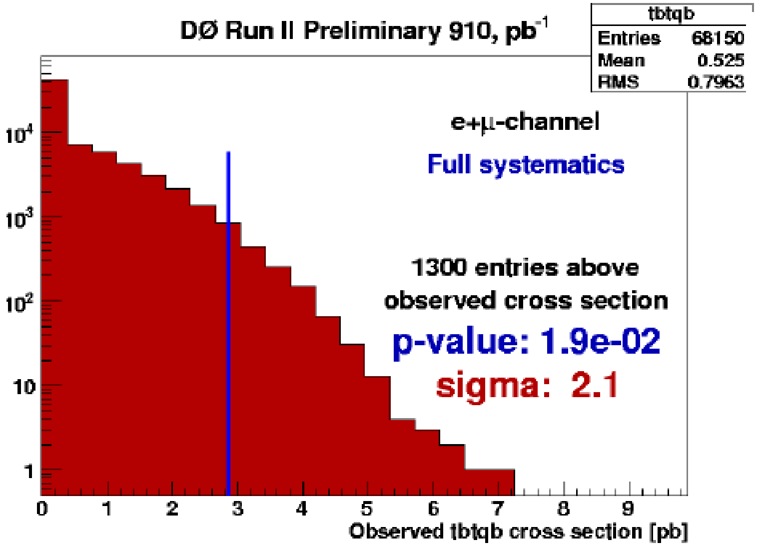
Matrix Elements
p-value 3.7%

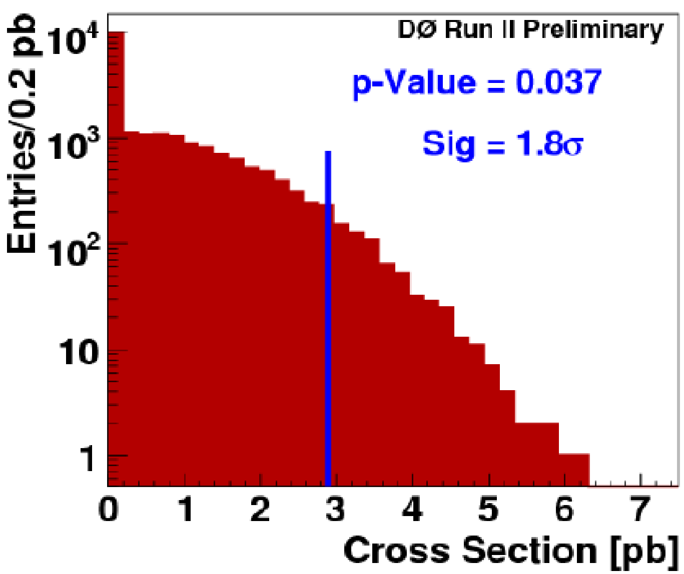
Bayesian NN
p-value 9.7%

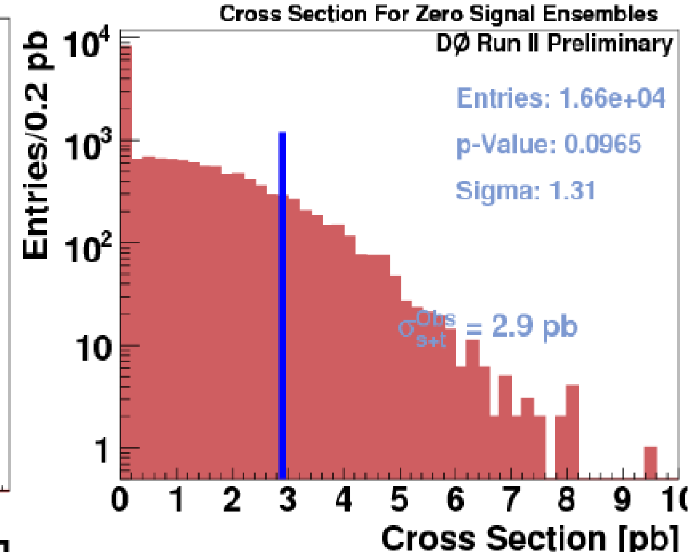








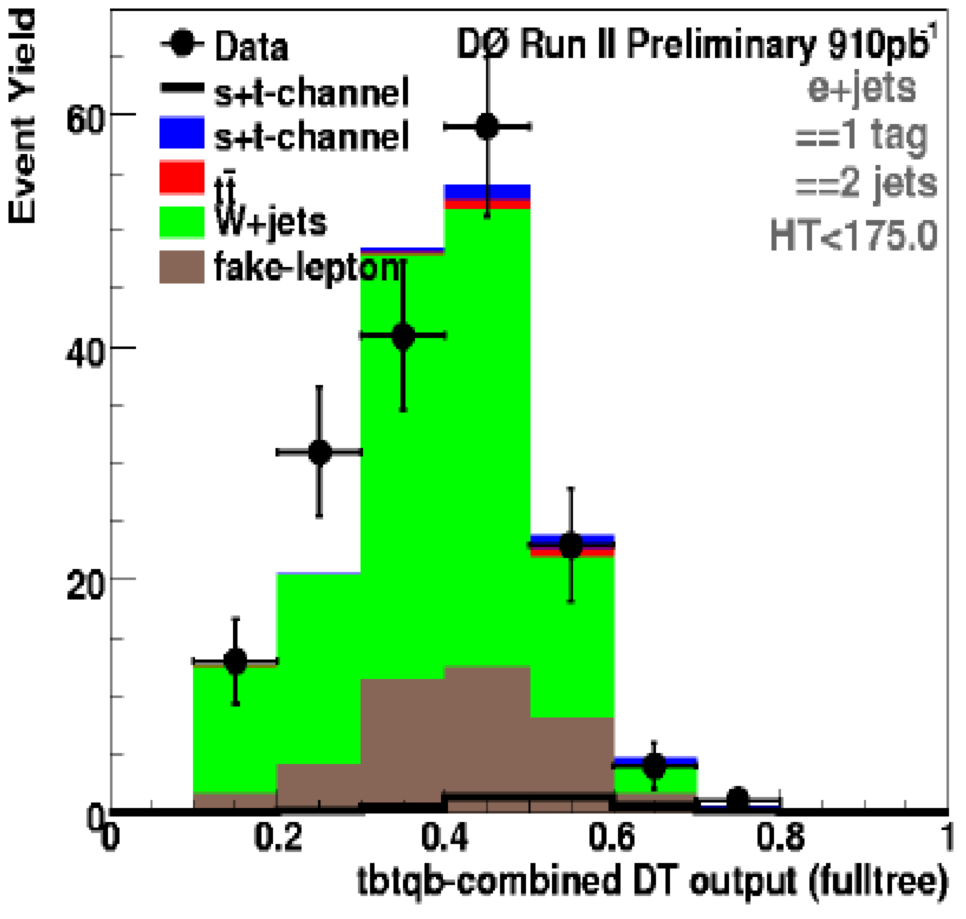


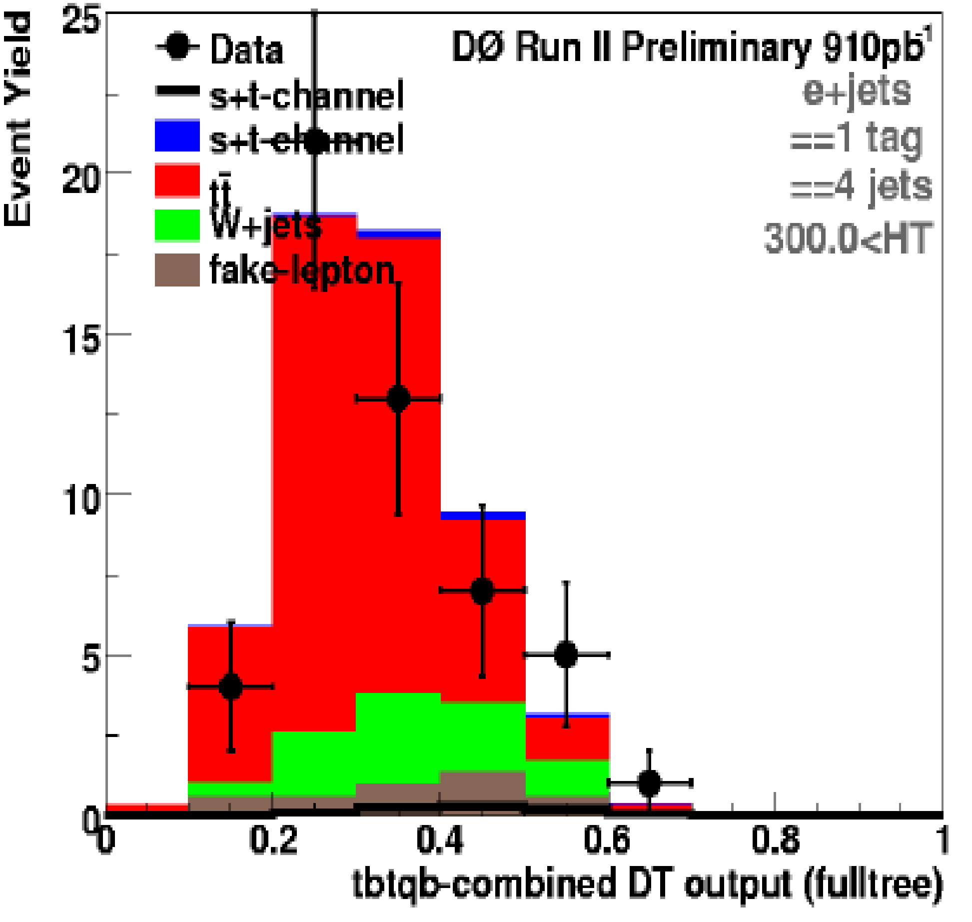


DT cross check samples

Check the description of the data in the DT output

- W+jets: 2 jets and H_T(lepton,MET,alljets) < 175 GeV
- tt: 4 jets and and H_T(lepton,MET,alljets) > 300 GeV

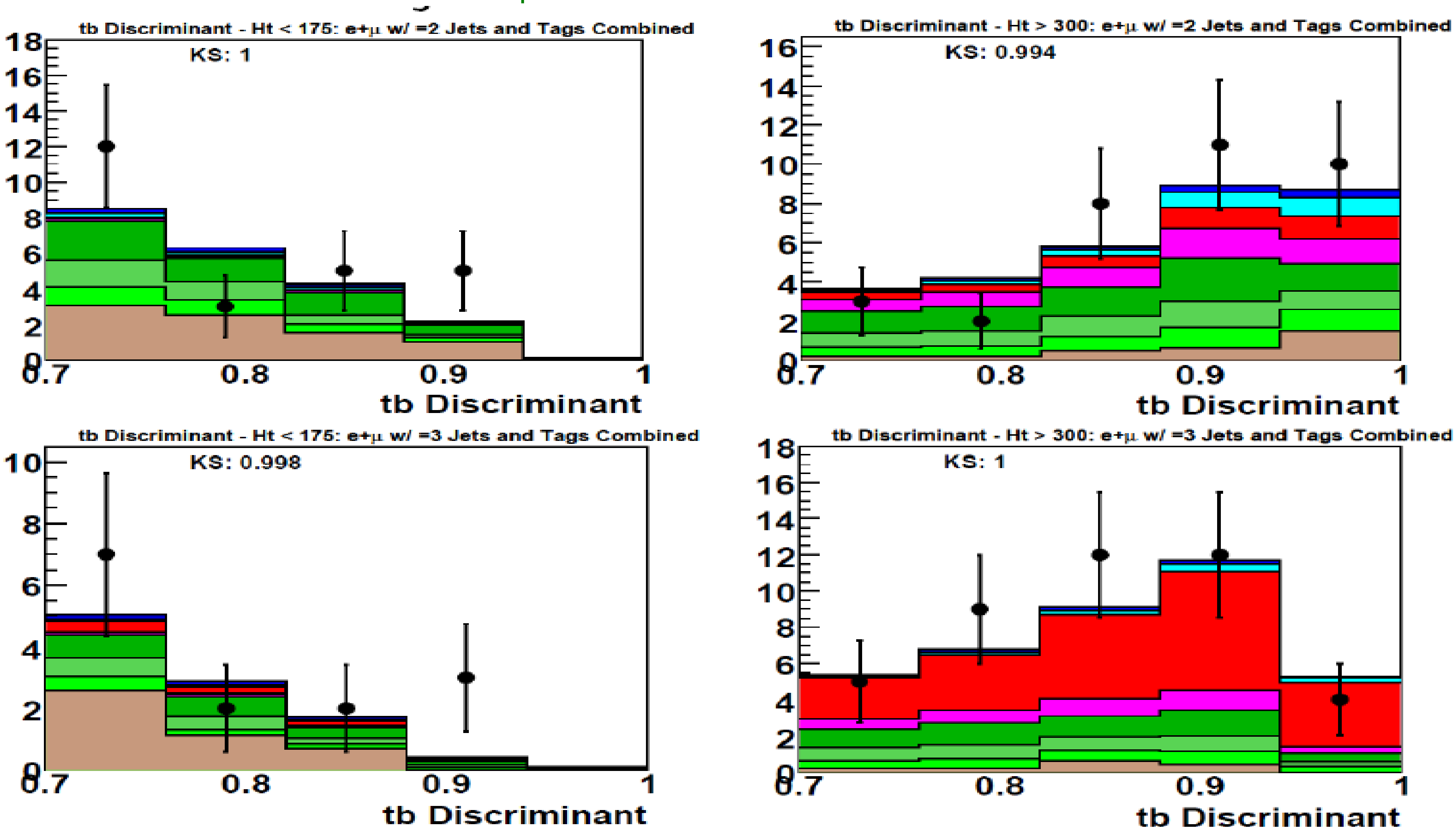




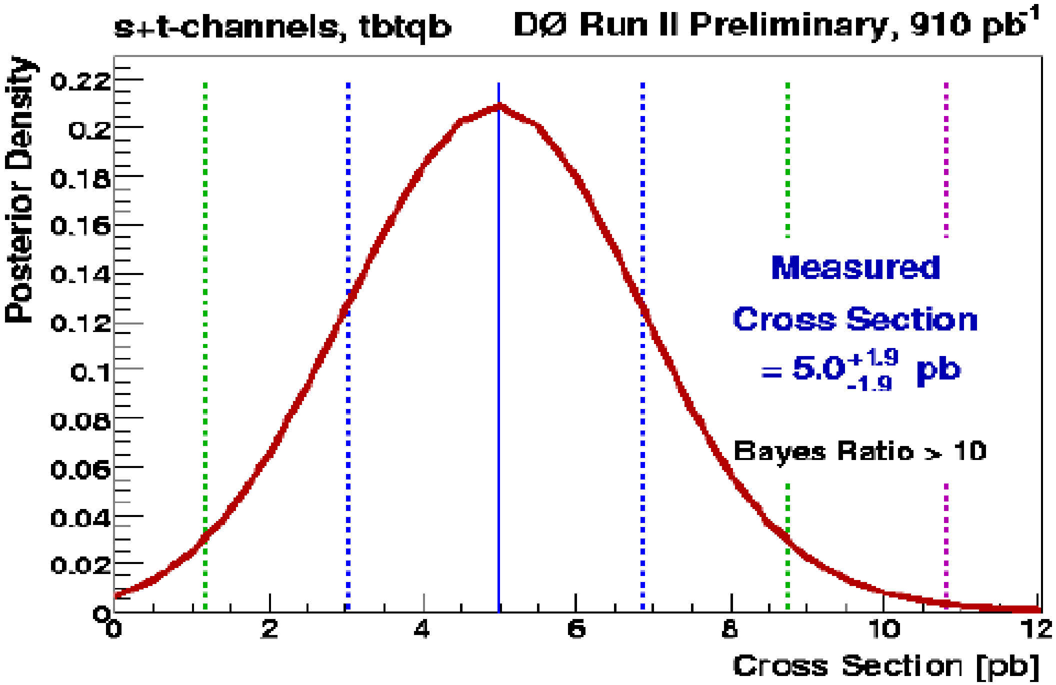
ME cross check samples

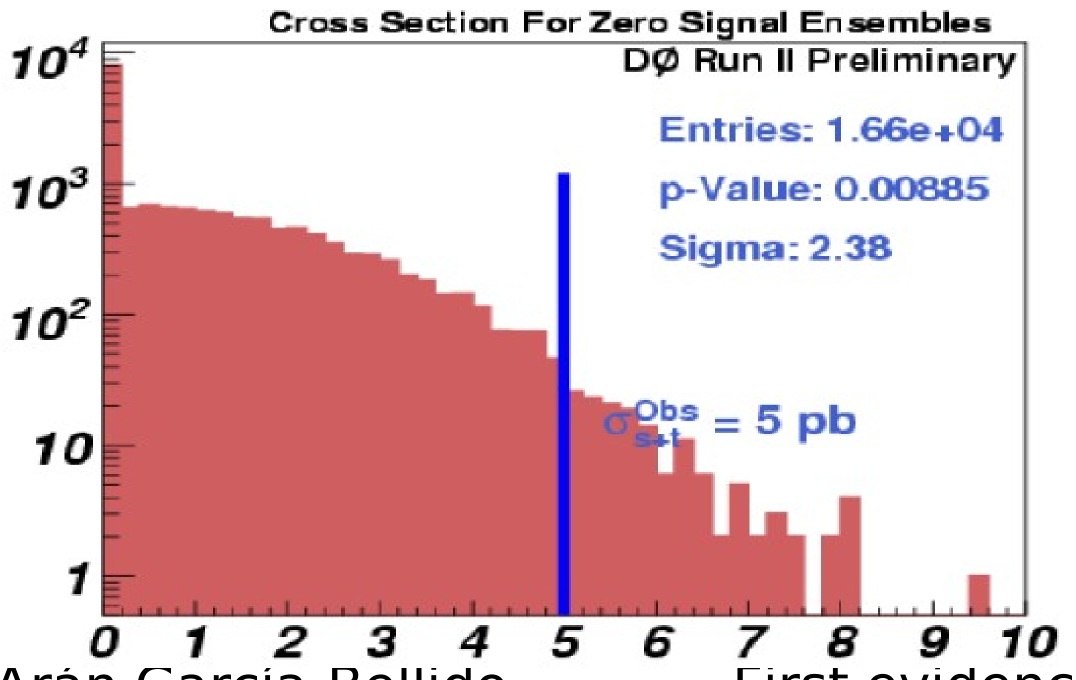
Check the description of the data in the ME output

- Soft W+jets: H_T(lepton,MET,alljets) < 175 GeV
- Hard W+jets: H_T(lepton,MET,alljets) > 300 GeV



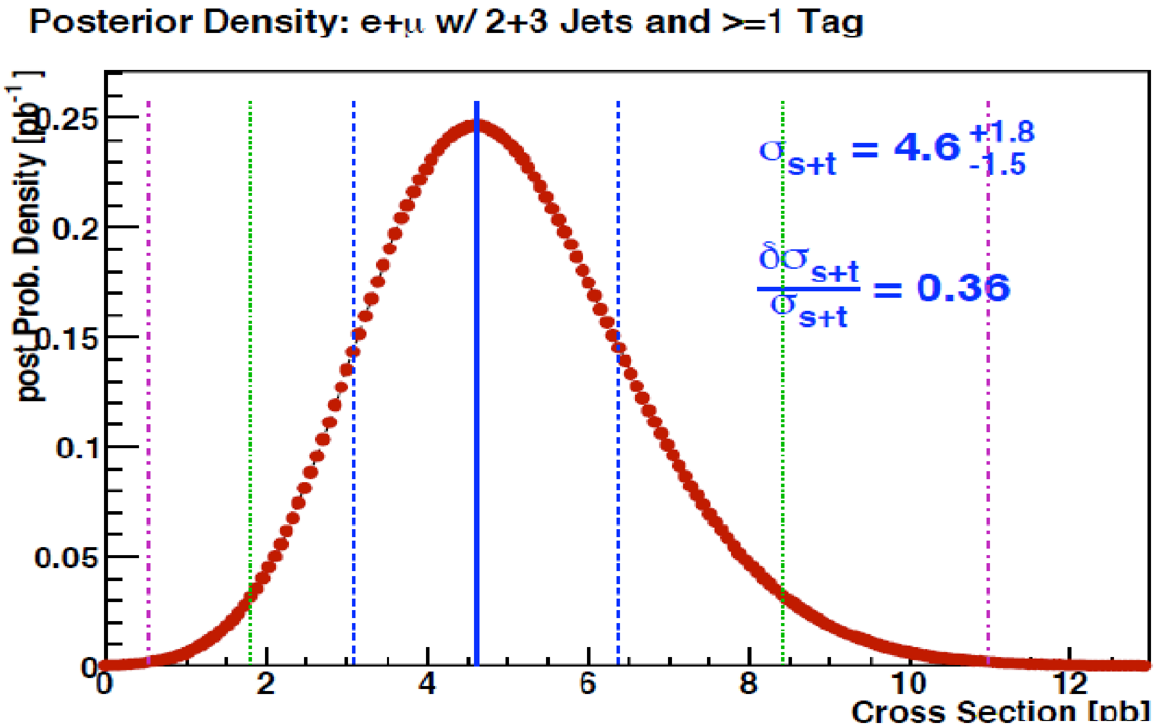
Bayesian NN observed results





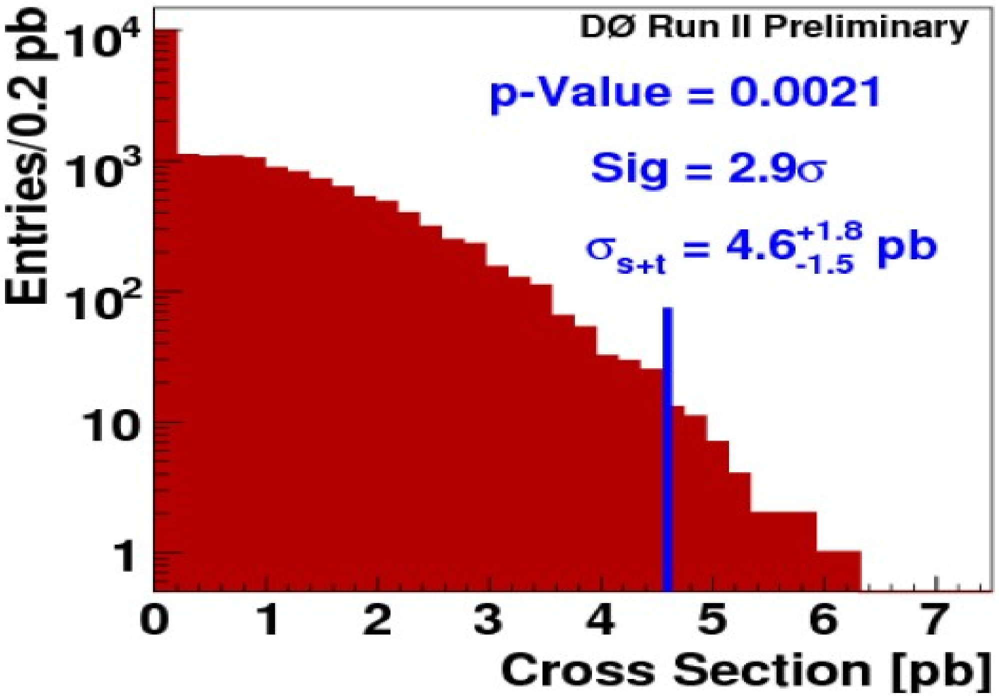
Least sensitive (a-priori) analysis sees a 2.4σ effect!

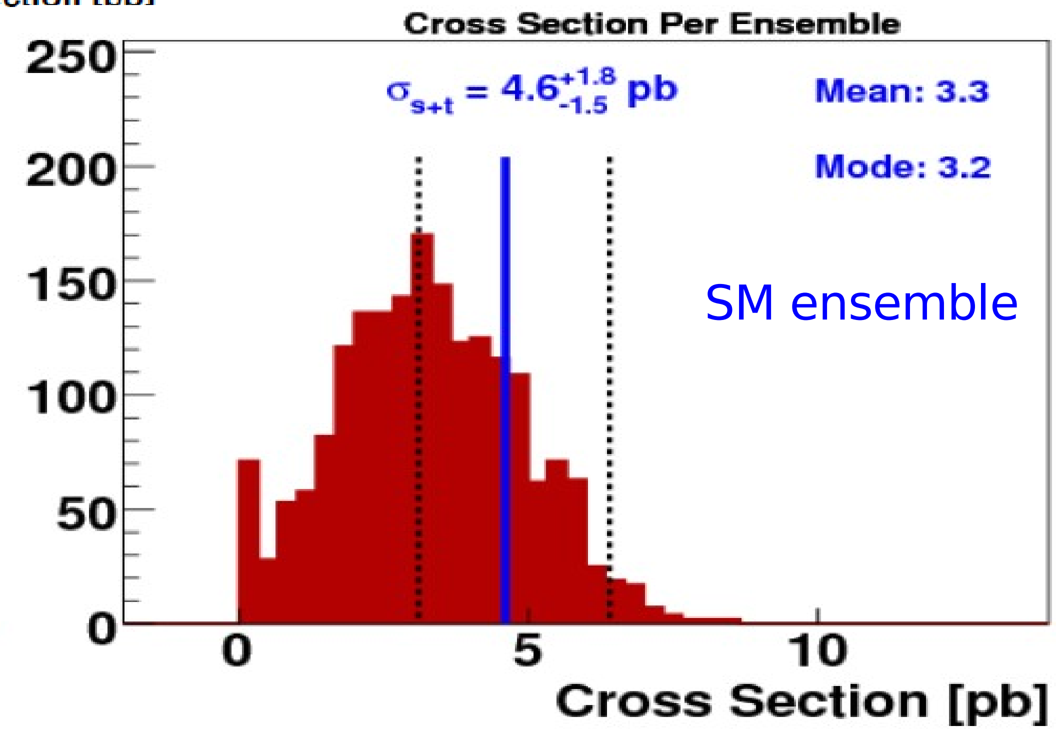
Matrix Elements observed results



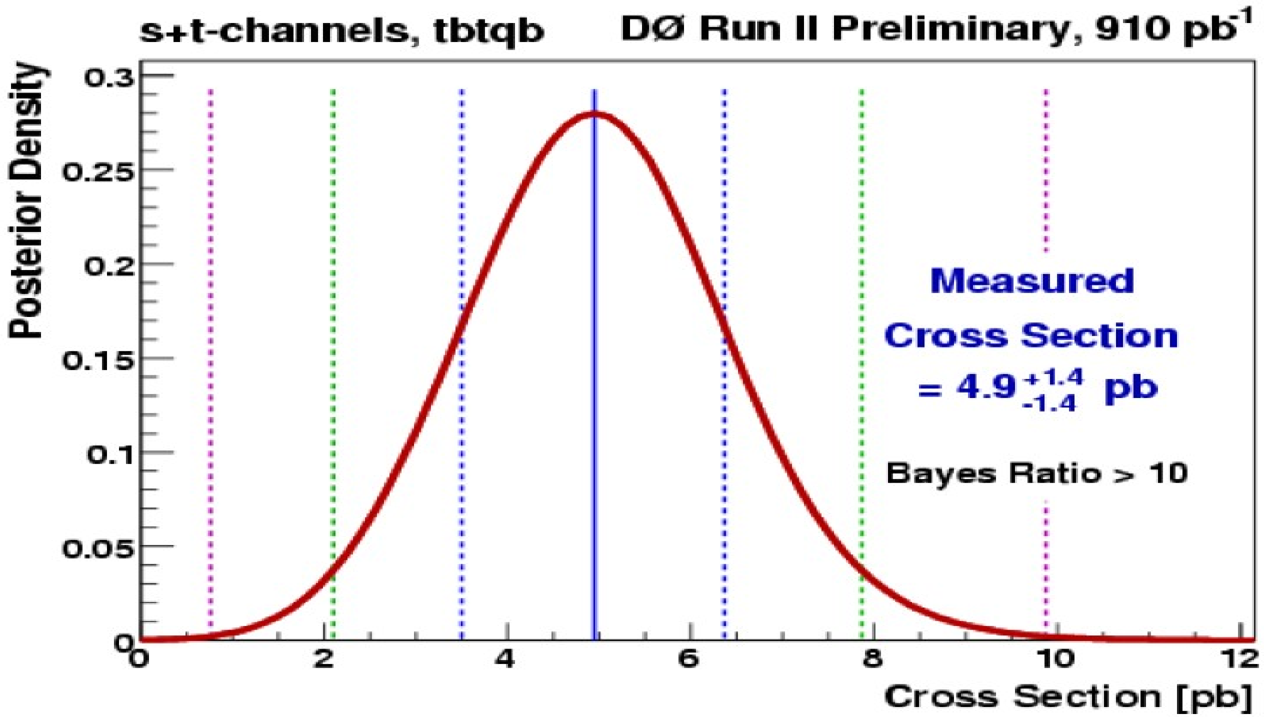
2.9σ excess!

SM compatibility = 21%





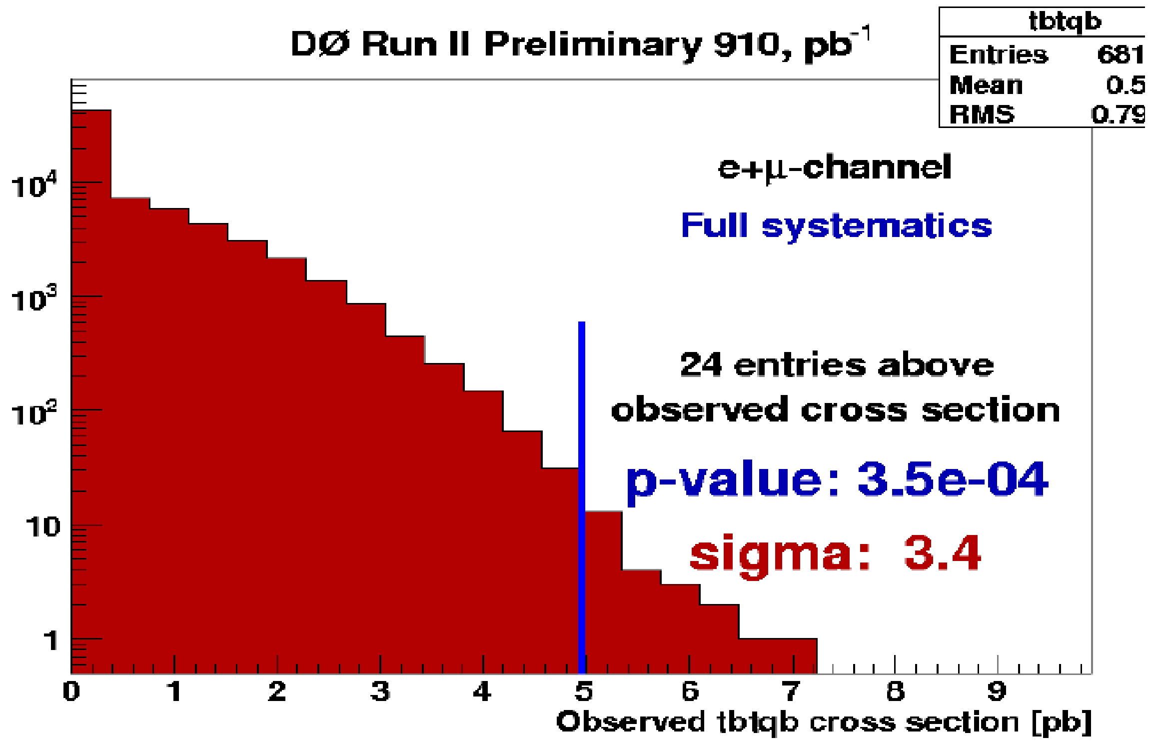
Decision Trees observed results

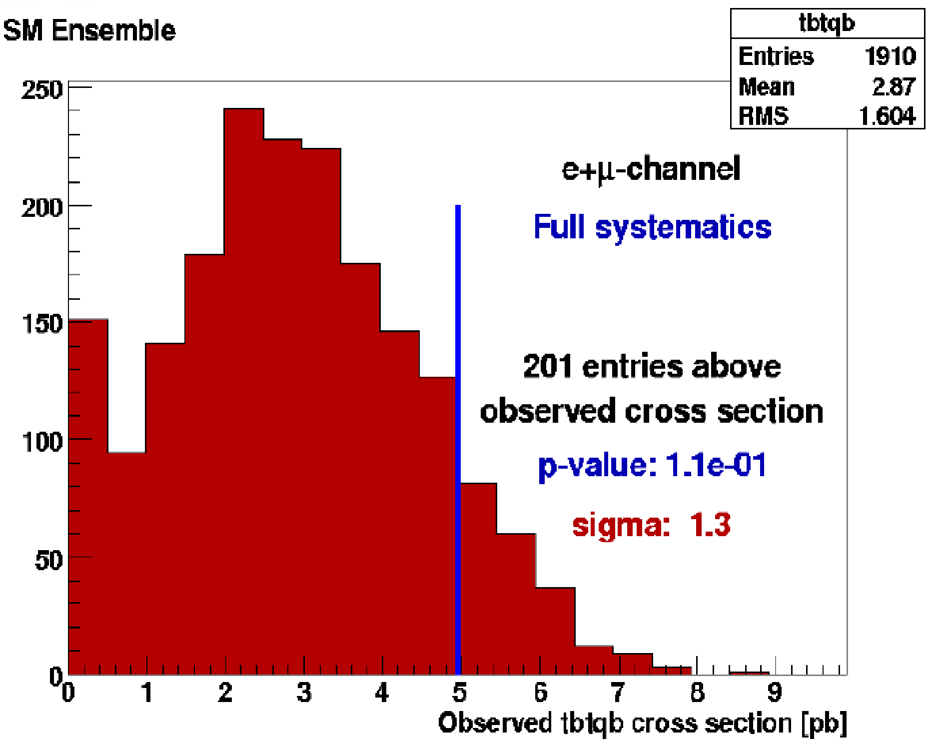


σ = 4.9 ± 1.4 pb

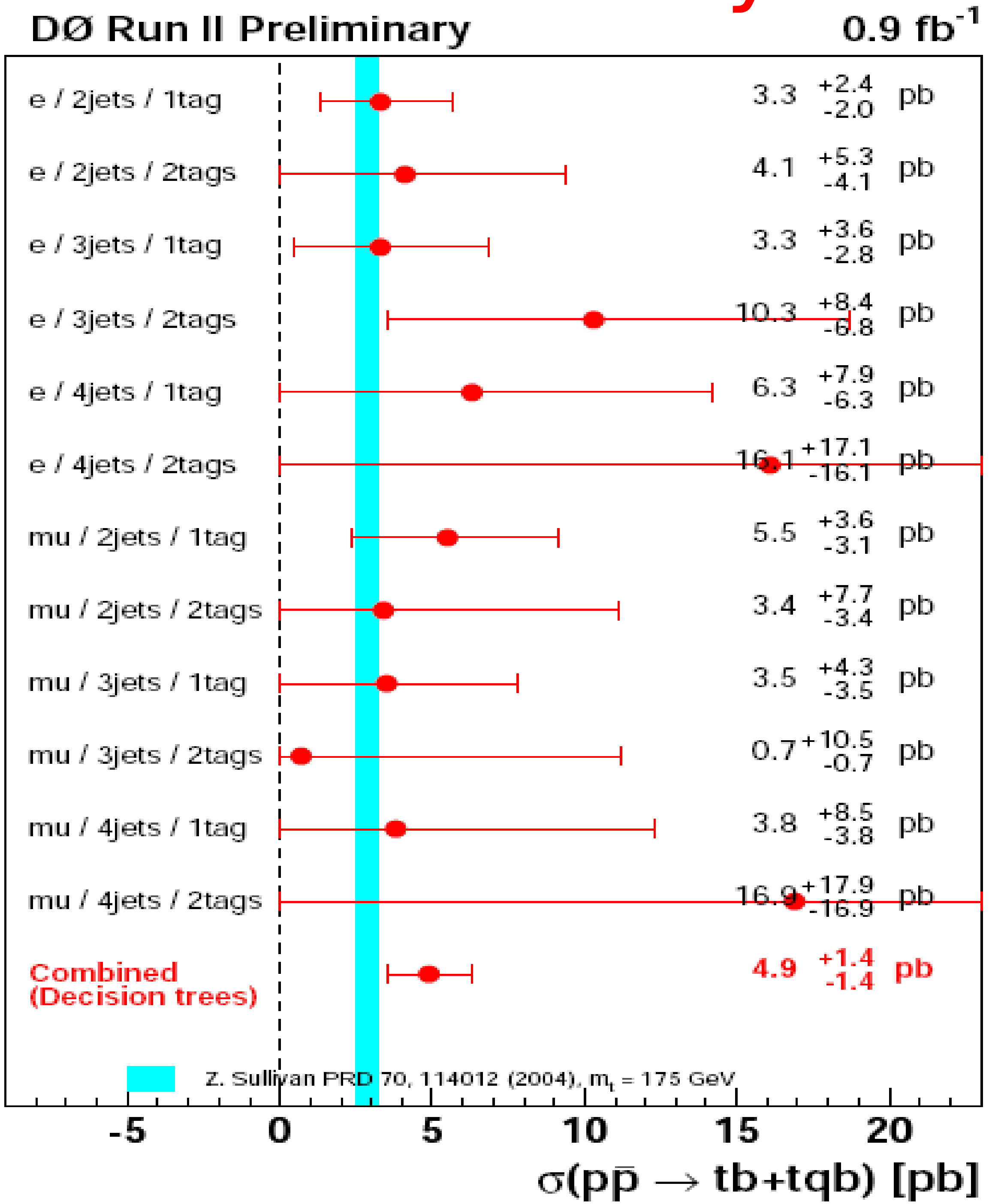
3.4σ excess!

SM compatibility = 11%

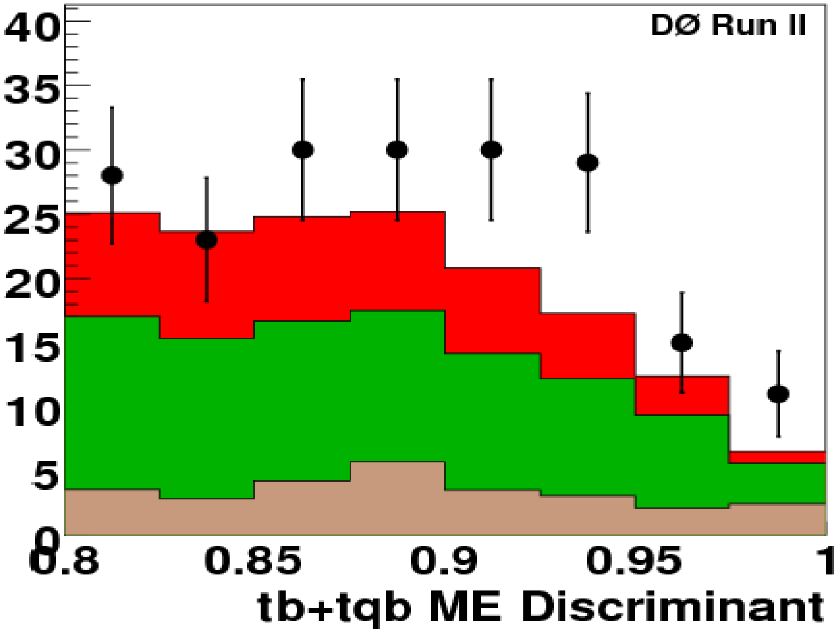


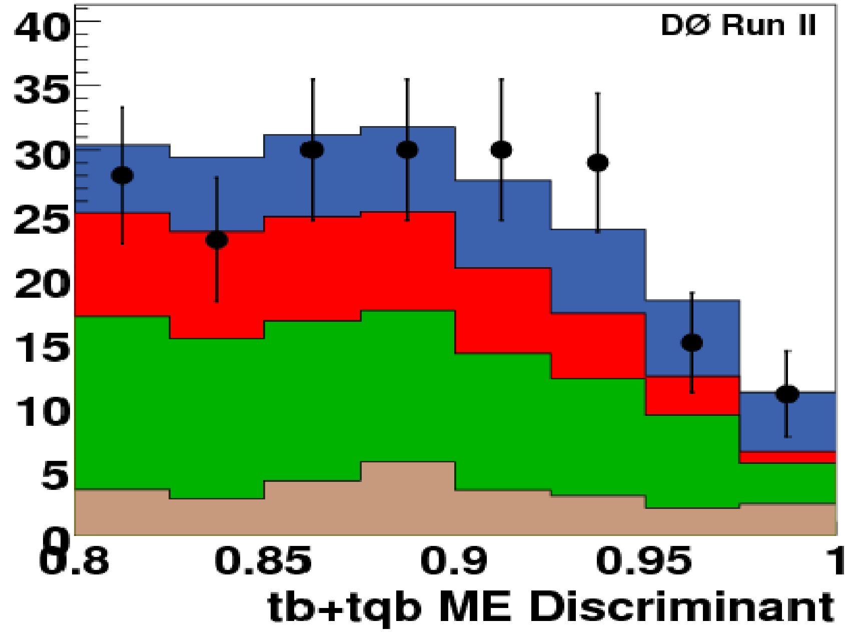


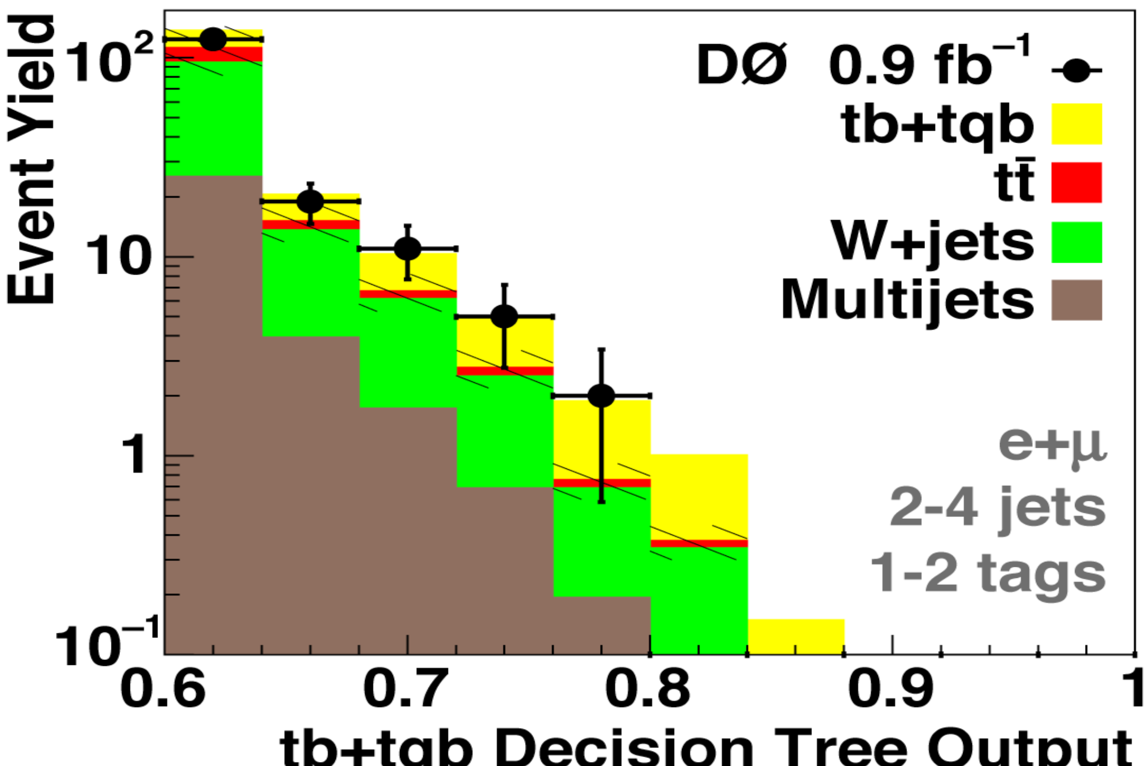
DT summary


DØ Run II Preliminary
0.9 fb-1
e / 2jets / 1tag
3.3 +2.4 -2.0 pb
e / 2jets / 2tags
4.1 +5.3 -4.1 pb
e / 3jets / 1tag
3.3 +3.6 -2.8 pb
e / 3jets / 2tags
10.3 +8.4 -6.8 pb
e / 4jets / 1tag
6.3 +7.9 -6.3 pb
e / 4jets / 2tags
16.1 +17.1 -16.1 pb
mu / 2jets / 1tag
5.5 +3.6 -3.1 pb
mu / 2jets / 2tags
3.4 +7.7 -3.4 pb
mu / 3jets / 1tag
3.5 +4.3 -3.5 pb
mu / 3jets / 2tags
0.7 +10.5 -0.7 pb
mu / 4jets / 1tag
3.8 +8.5 -3.8 pb
mu / 4jets / 2tags
16.9 +17.9 -16.9 pb
Combined
(Decision trees)
4.9 +1.4 -1.4 pb
Z. Sullivan PRD 70, 114012 (2004), mt = 175 GeV
-5
0
5
10
15
20
σ(pp̄ → tb+tqb) [pb]

Excess in the high discriminant regions

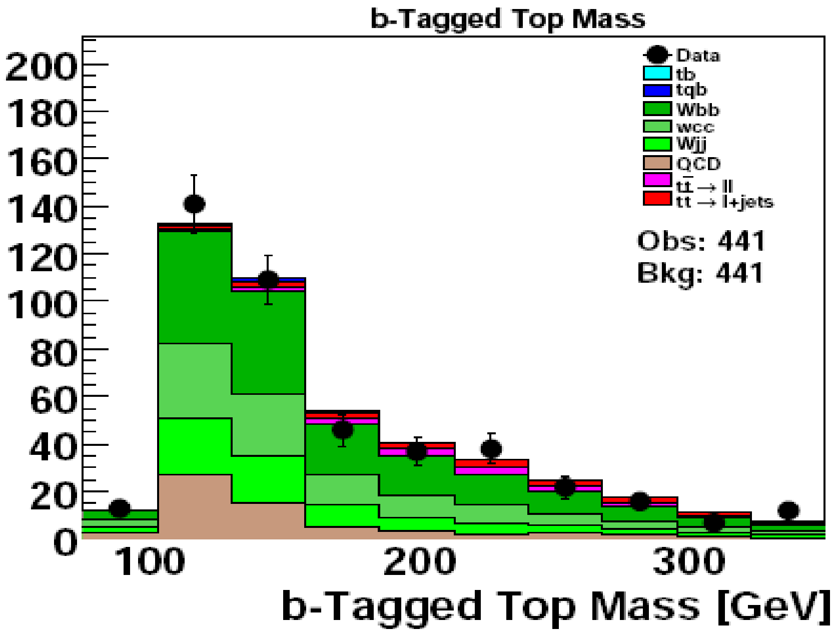


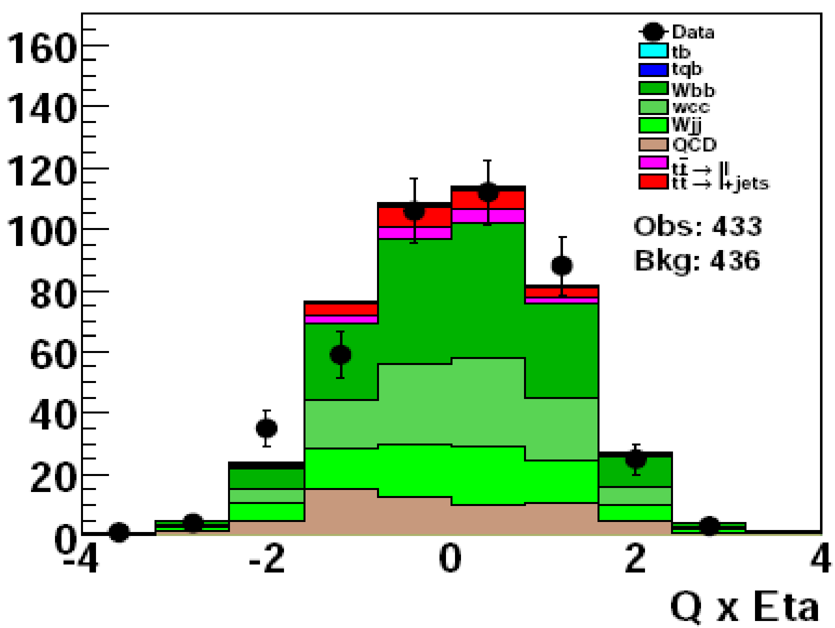




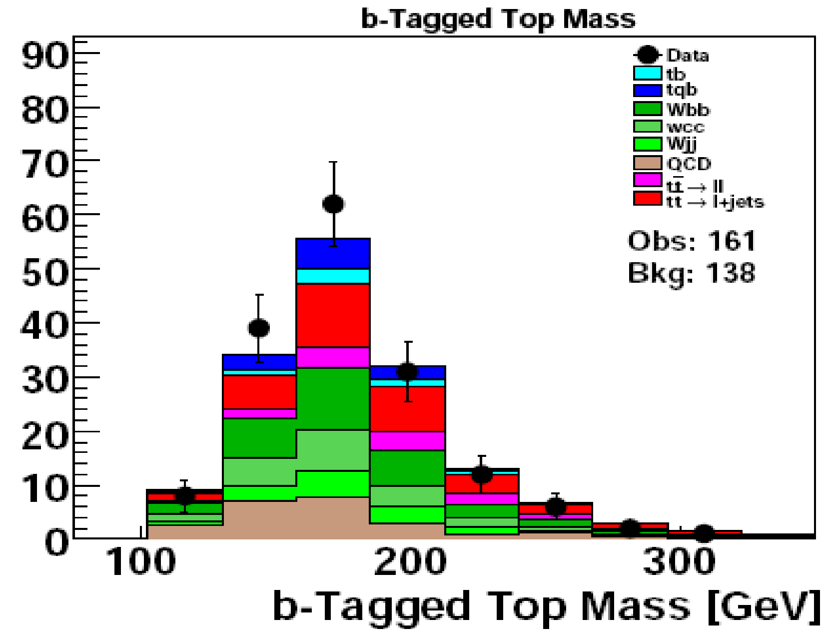
ME event characteristics

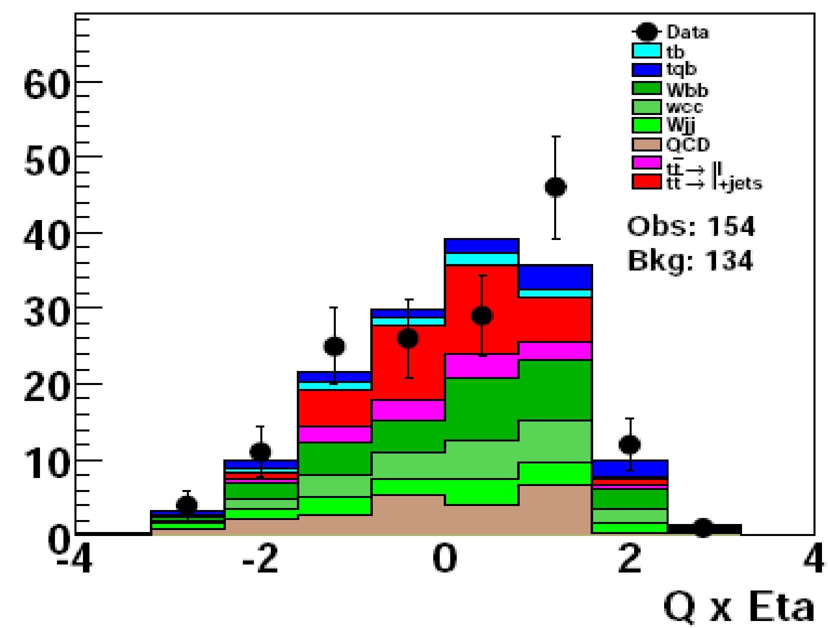
ME Discriminant < 0.4





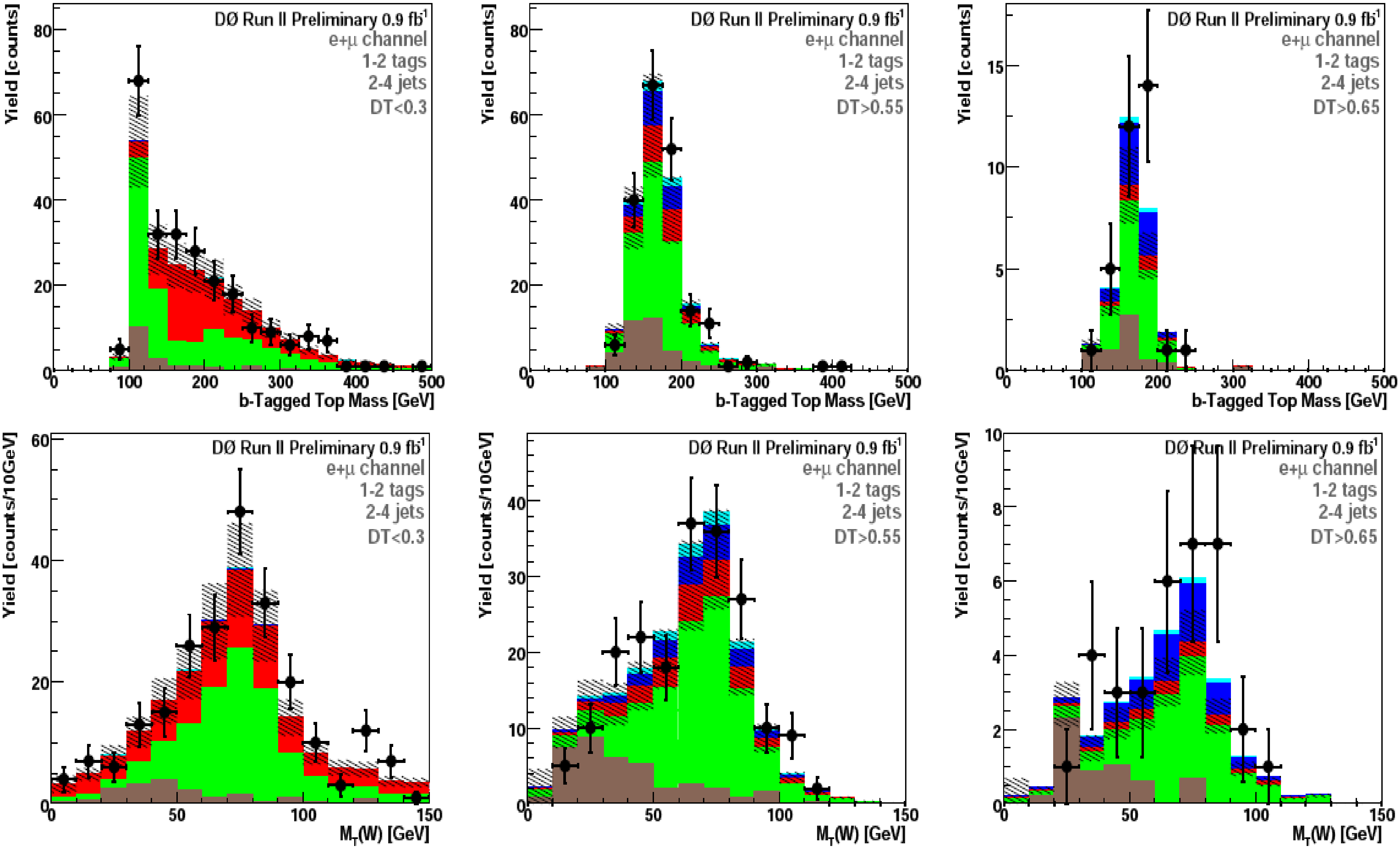
ME Discriminant > 0.7



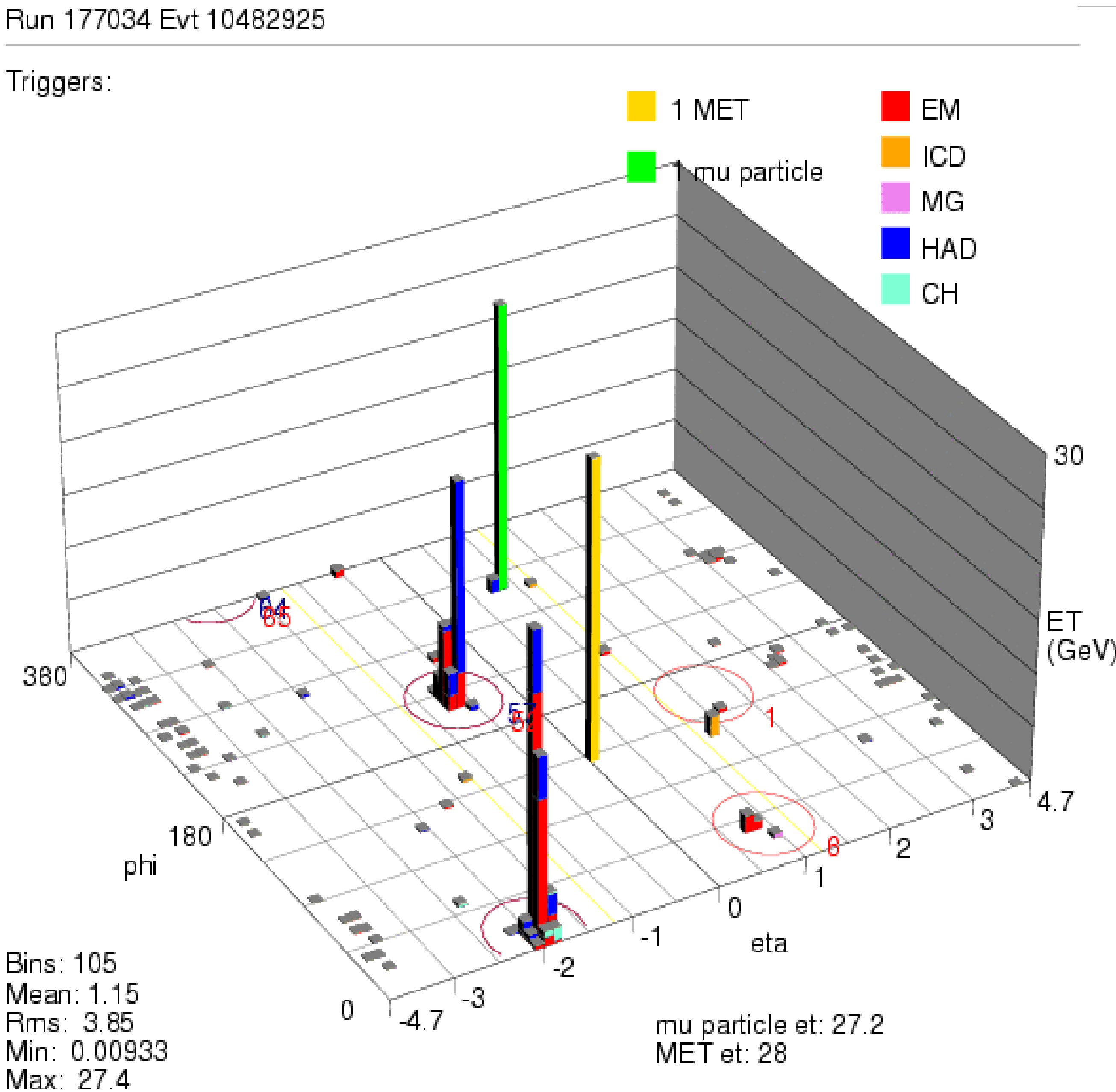


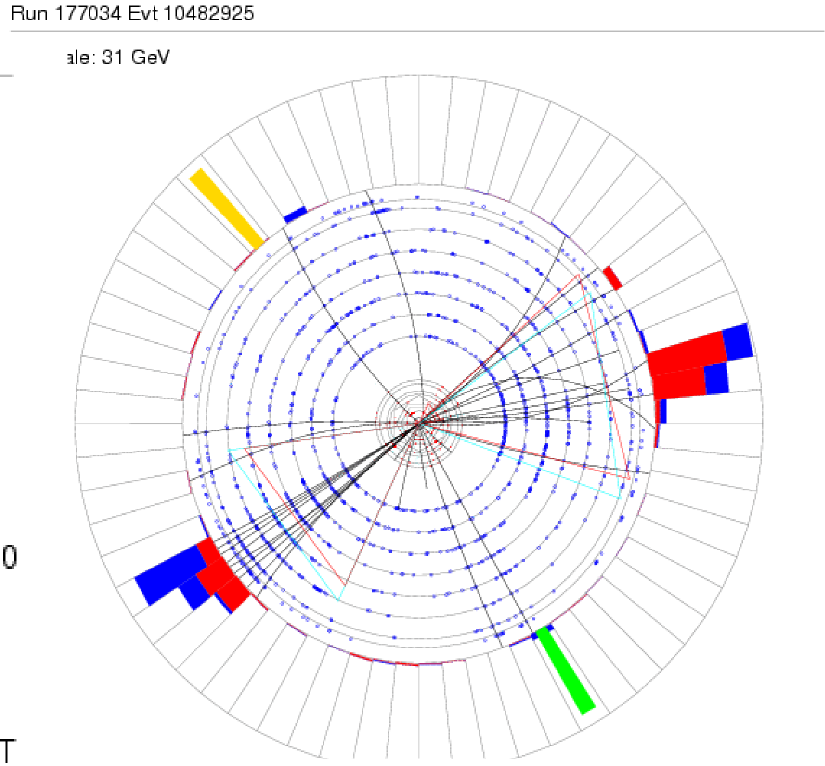
DT event characteristics

DT Discriminant < 0.3	DT Discriminant > 0.55	DT Discriminant > 0.65

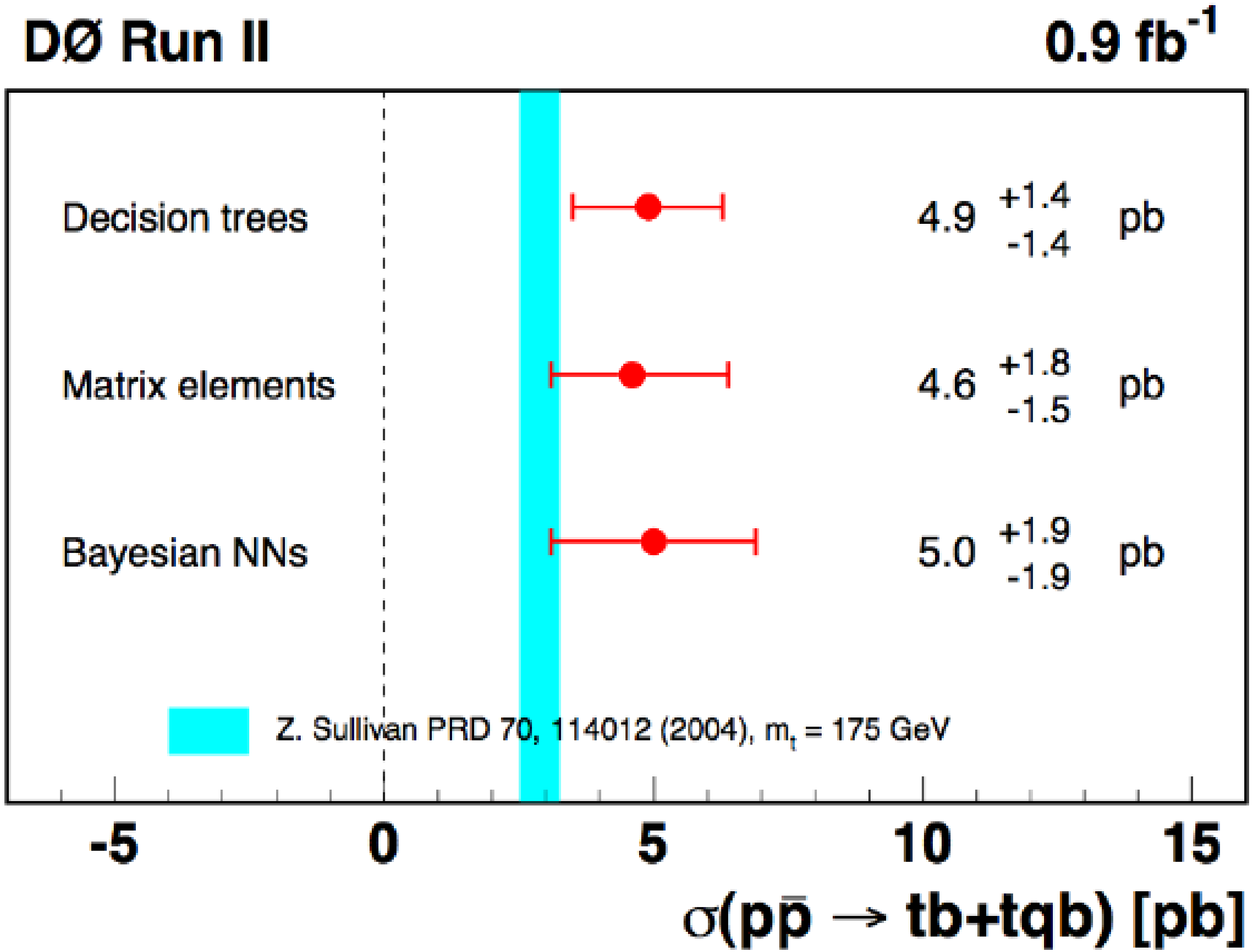


A candidate event





s+t summary: all methods



Correlations

- Take the 50 highest ranked data events in each method and look for overlap:

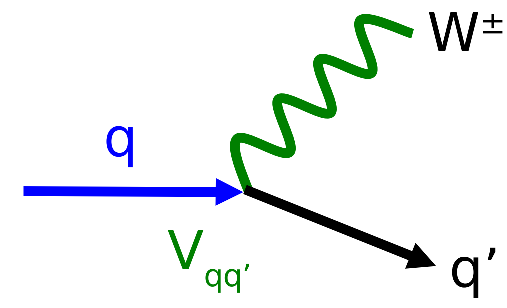
Technique	Electron	Muon
DT vs ME	52%	58%
DT vs BNN	56%	48%
ME vs BNN	46%	52%

- Calculate the linear correlation between the measured cross sections in the same 400 members of the SM ensemble

	DT	ME	BNN
DT	100%	39%	57%
ME		100%	29%
BNN			100%

CKM matrix element V_{tb}

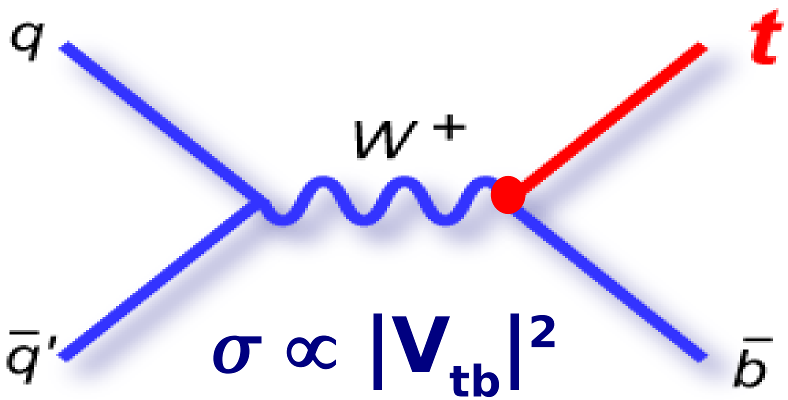
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$



- Weak interaction eigenstates and mass eigenstates are not the same: there is **mixing** between quarks → CKM matrix
- In SM: top must decay to W and d, s or b quark
  - $V_{td}^2+V_{ts}^2+V_{tb}^2 = 1$
  - Strong constraints on V_{td} and V_{ts}: $\mathbf{V_{tb} > 0.998}$
  - Assuming unitarity and 3 generations: B(t→Wb)~100%
- If there is new physics:
  - $V_{td}^2+V_{ts}^2+V_{tb}^2 < 1$
  - No constraint on V_{tb}
  - Interactions between the top quark and weak gauge bosons are extremely interesting!

Measuring $|V_{tb}|$

- Once we have a cross section measurement, we can make the first direct measurement of $|V_{tb}|$
- Use the same infrastructure as for the cross section measurement, but make a posterior in $|V_{tb}|^2$



Additional theoretical errors are needed

	s	t
top mass	13%	8.5%
scale	5.4%	4.0%
PDF	4.3%	10.0%
α_s	1.4%	0.01%

hep-ph/0408049

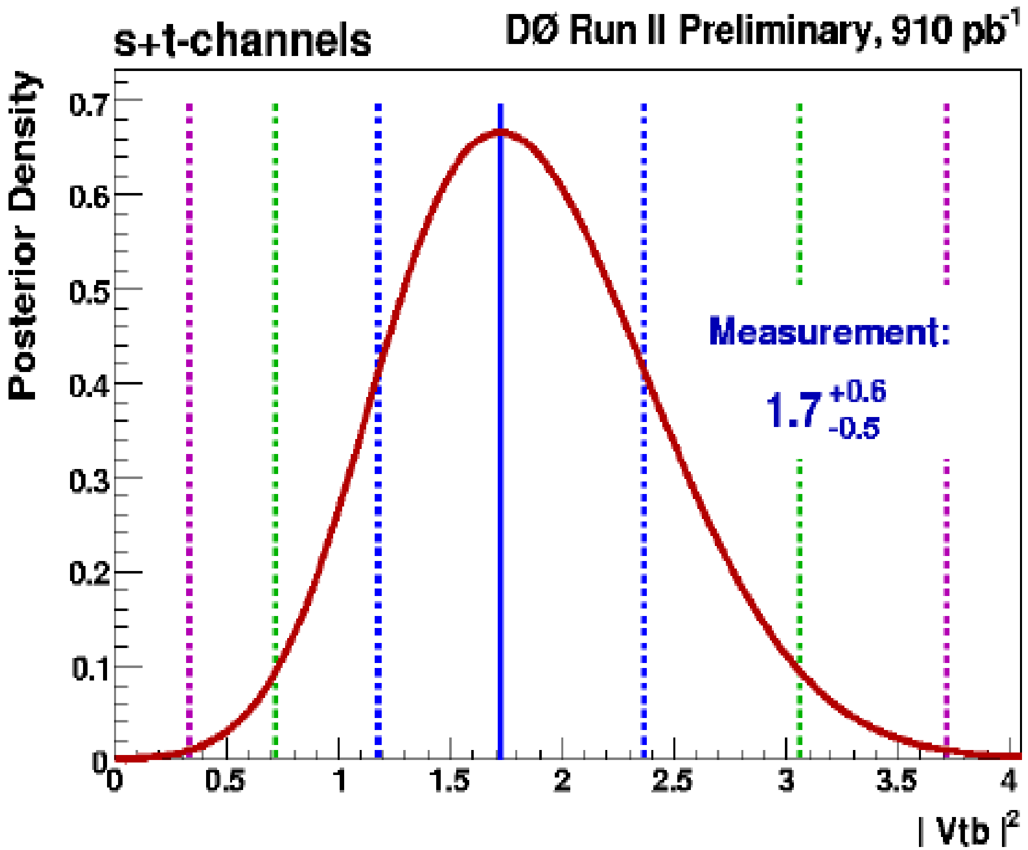
- Caveat: **assume SM decays**
- Most general Wtb vertex:

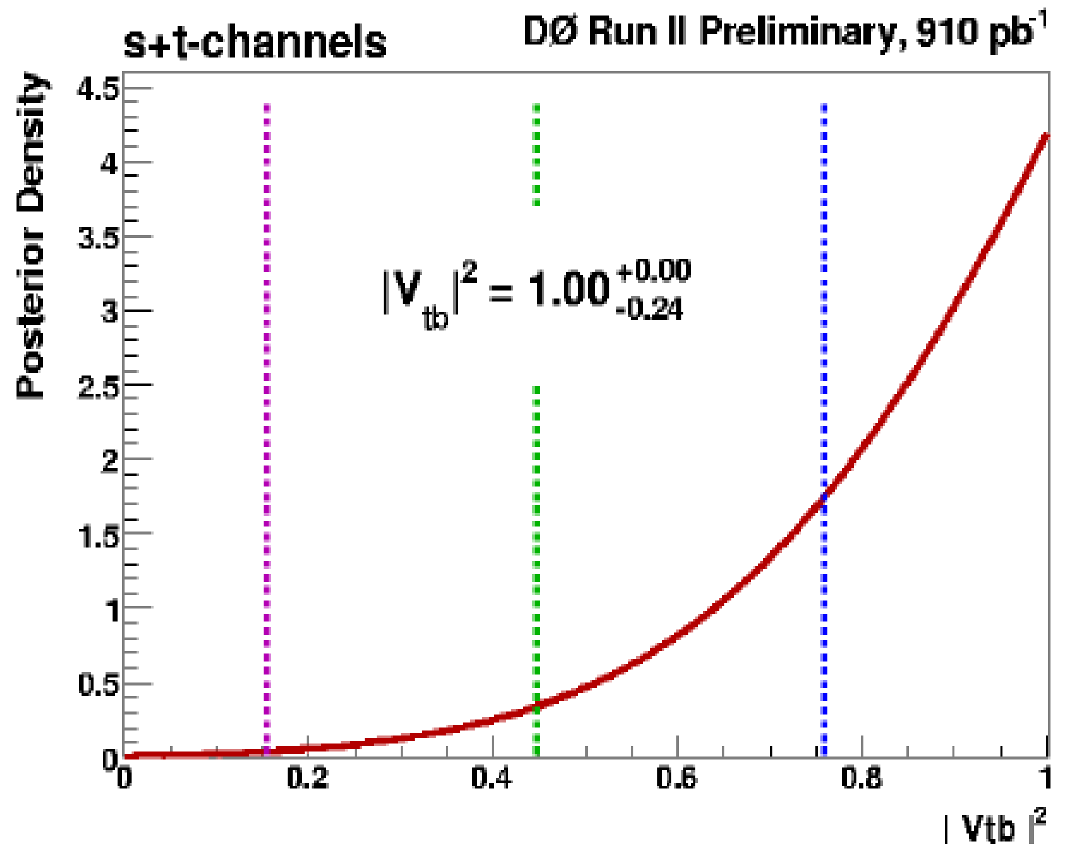
$$\Gamma^{\mu}_{tbW} = -\frac{g}{\sqrt{2}} V_{tb} \left\{ \gamma^{\mu} \left[f_1^L P_L + f_1^R P_R \right] - \frac{i\,\sigma^{\mu\nu}}{M_W} (p_t - p_b)_{\nu} \left[f_2^L P_L + f_2^R P_R \right] \right\}$$

SM: $f_1^L = 1$ and $f_1^R = f_2^L = f_2^R = 0$ ➔ CP is conserved

We are effectively measuring the **strength of the V-A coupling**: $|\mathbf{V_{tb} f_1^L}|$, which can be >1

First direct measurement of $|V_{tb}|$





$\boxed{|V_{tb} f_1^L| = 1.3 \pm 0.2}$

$|V_{tb}| > 0.68$ @ 95 C.L.

(assuming: $f_1^L = 1$)

This measurement does not assume 3 generations or unitarity

Conclusions

First direct evidence for single top quark production and measurement of $|V_{tb}|$

(hep-ex/0612052 submitted to PRL)

$$\sigma(s+t) = 4.9 \pm 1.4 \text{ pb}$$

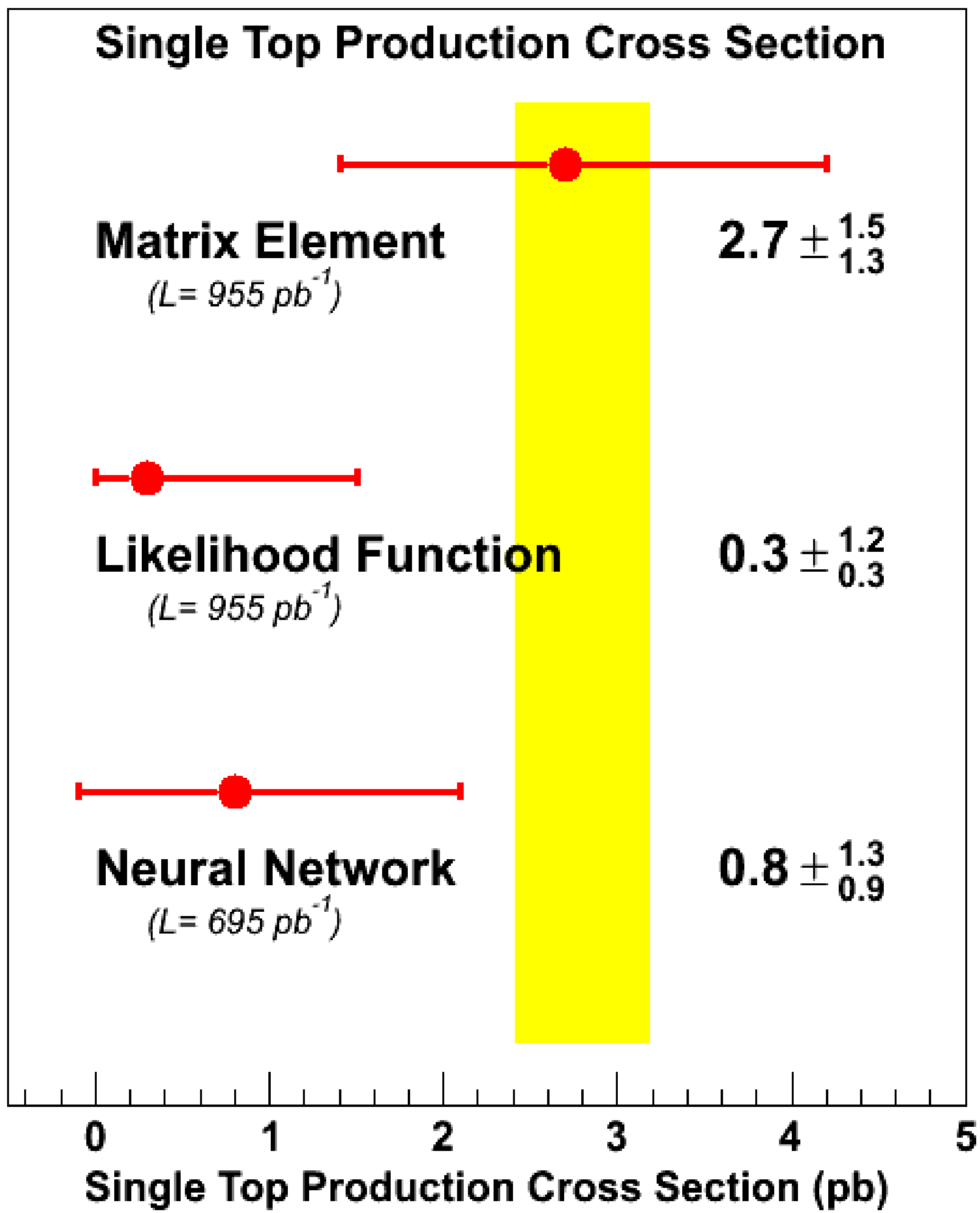
3.4σ significance!

$|V_{tb}|>0.68$ @ 95%C.L.

- Working on the combination and more!
- Expand to searches of new phenomena
- We now have double the data to analyze!

Extra slides

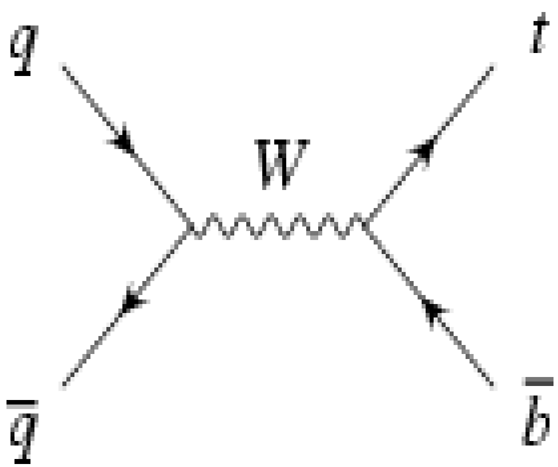
CDF's latest results

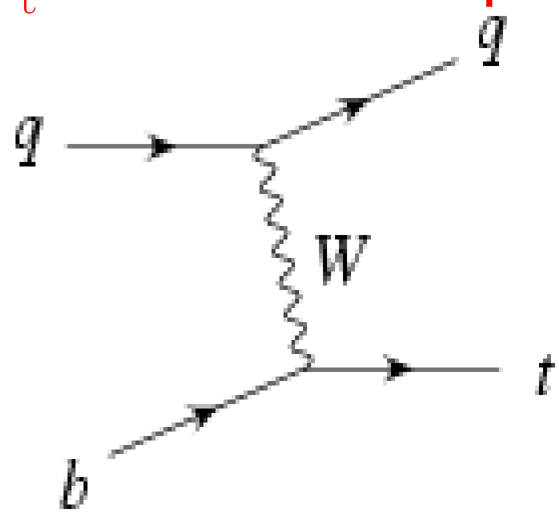


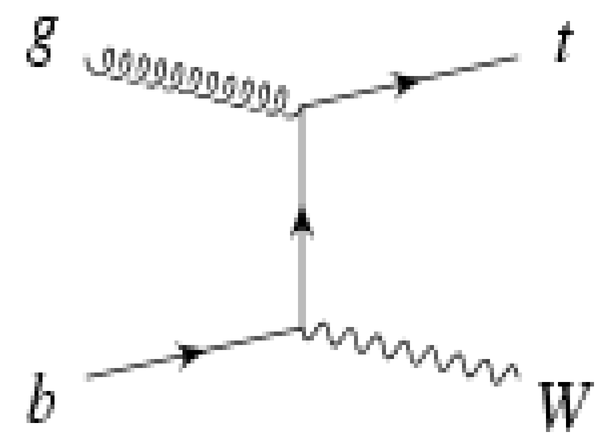
Single top in a couple of years

- 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 σ_{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

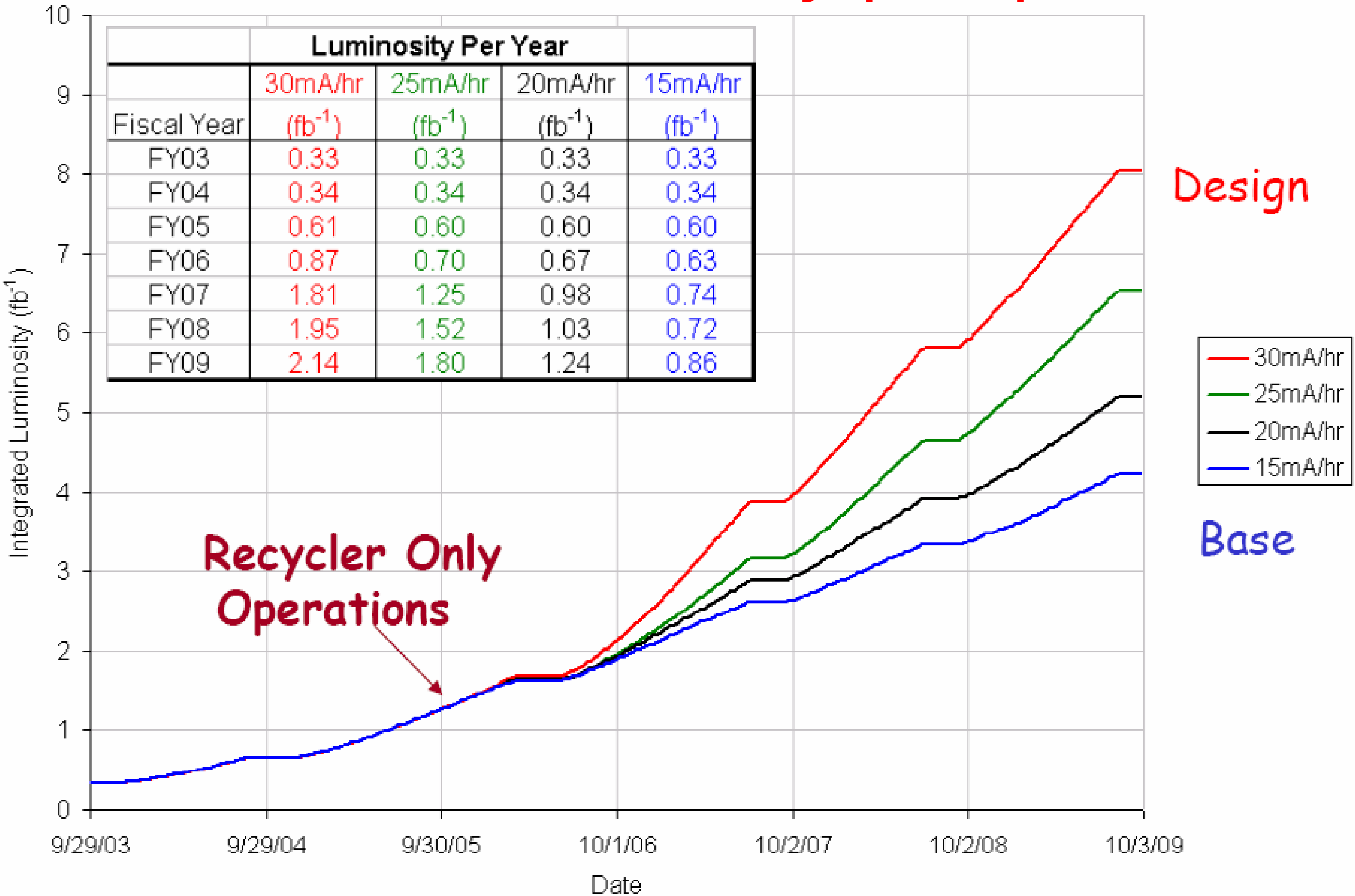
Studies at the Tevatron will help the LHC:

- 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

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

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

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

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

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

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

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

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

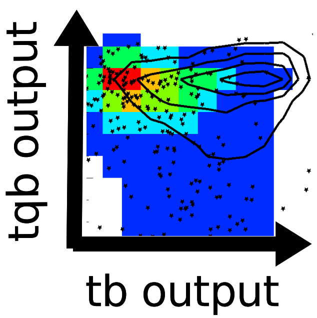
Full 2D limits

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

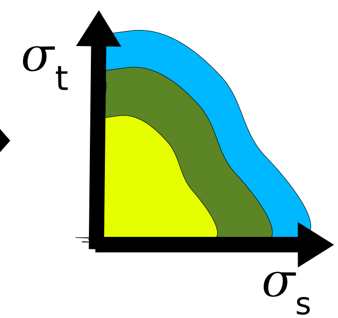
As before, use likelihood from 2D discriminant output

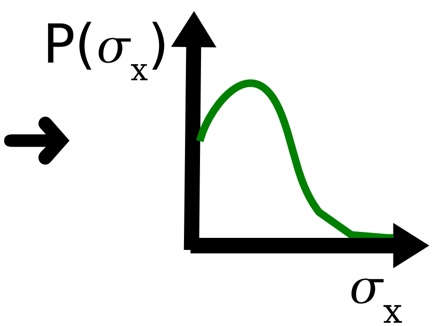
Float σ_s and σ_t and consider flat priors



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

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





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

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

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

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

- 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

Non-SM couplings

Top is a good place to look for deviations from SM:

σ 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:

There are strong bounds on tensor couplings:
from unitarity $|f_2|<0.6$, and from $b\rightarrow s\gamma$: $|f_2^L|<0.004$
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

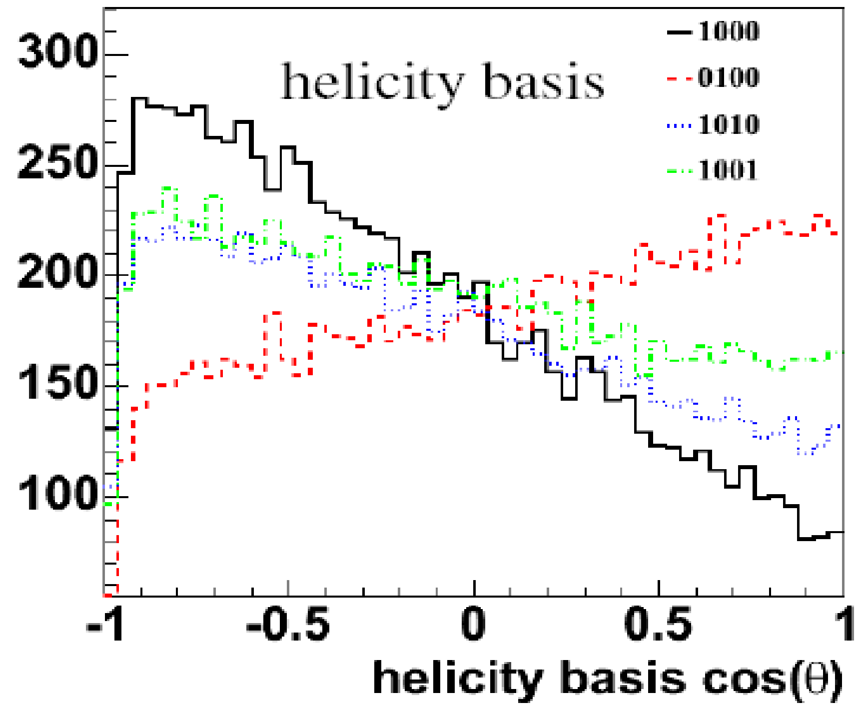
- Separate data into s-channel (2 tags) and t-channel (1tag+⩾1untag) samples based on NN output
- Top quark spin correlations separate between L and R couplings

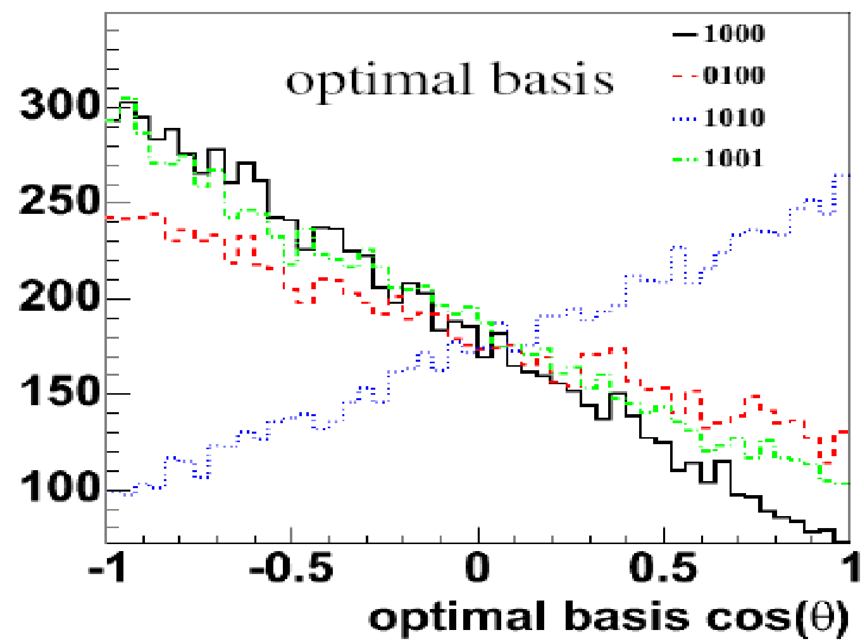
  tb: Helicity basis θ (lepton, top direction)

  tqb: Optimal basis θ (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





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

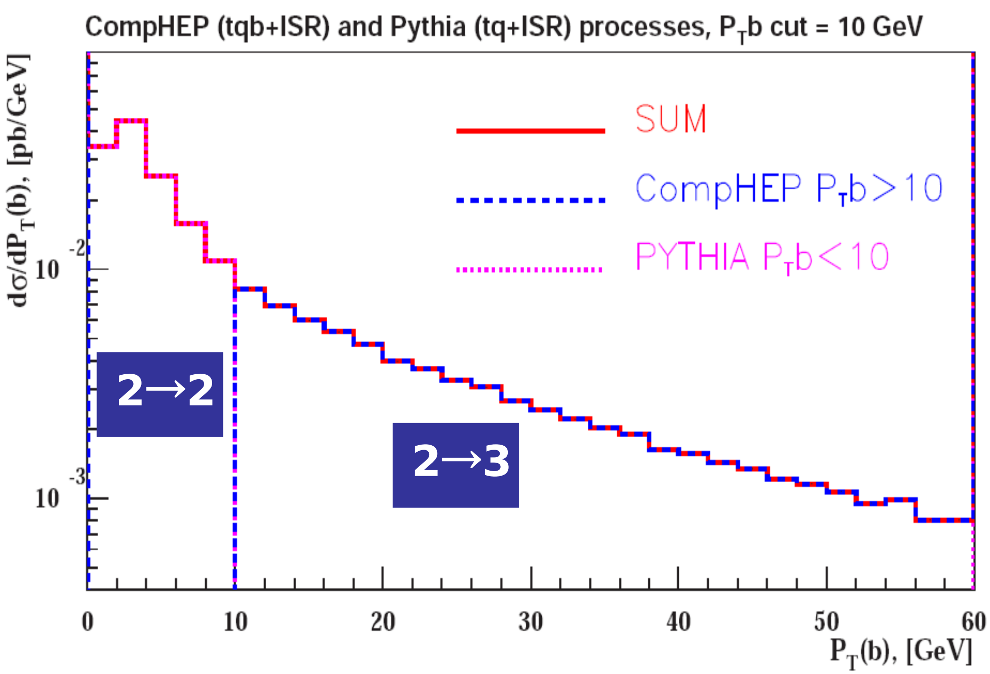
- DØ: "Effective" NLO CompHEP (also used in CMS)

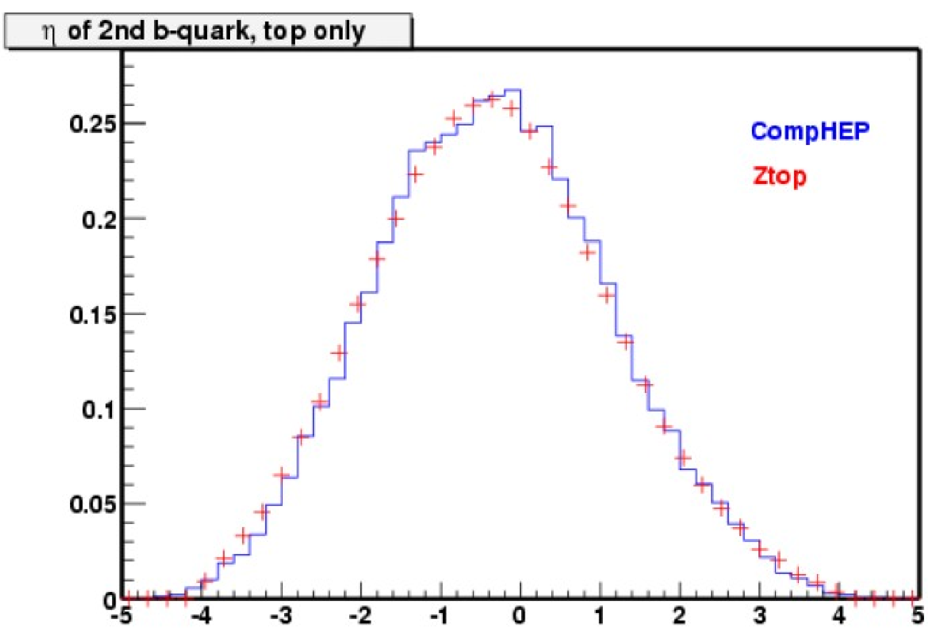
Match 2→2 and 2→3 processes using b p_T for cross over, normalize to NLO

σ

Resulting distributions agree well with ZTOP & MCFM

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





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 events:

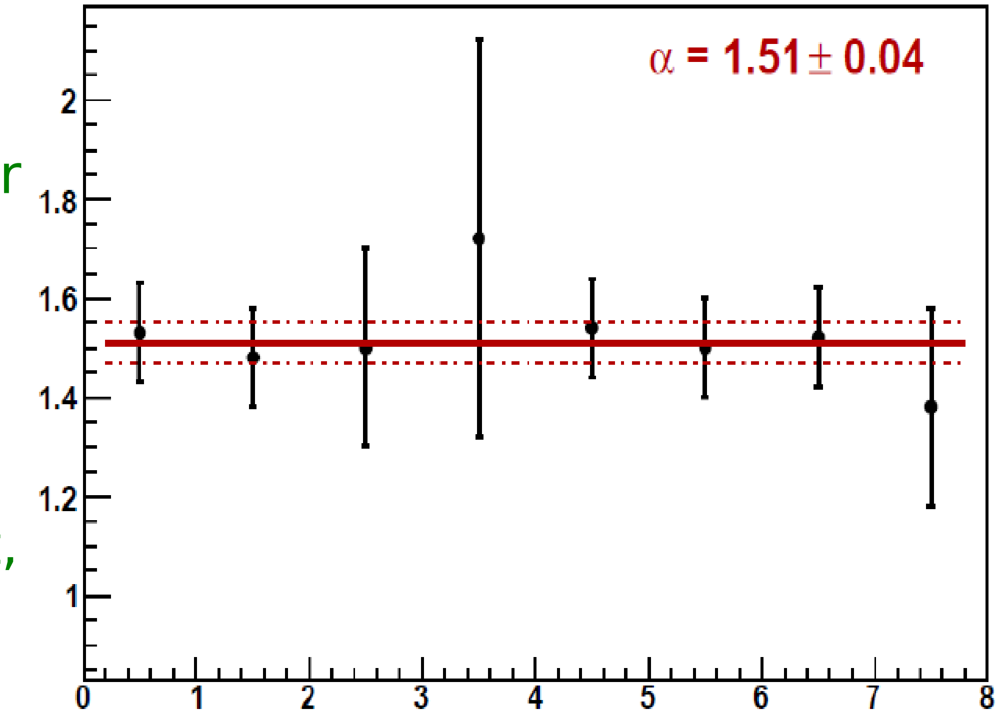
$$\varepsilon_{real} N^{loose}_{real} = SF[Y(Wjj) + Y(Wb\bar{b}) + Y(Wc\bar{c})] + Y(t\bar{t})$$

SF=1.4

- The sum Y(Wjj)+Y(Wbb)+Y(Wcc) is done according to the ratio of (Wbb+Wcc)/Wjj found in 0-tag data $\rightarrow$ 1.5±0.5
- Then apply b-tagging
  - Greatly reduce W+jets background (Wbb ~1% of Wjj)
  - Shift distributions, changes flavor composition

Wbb and Wcc fraction

- We use our own data to derive the Wbb+Wcc fraction: something very close to 1.5 is needed to describe our data
- This is not a measurement of Wbb, but a fraction determination. The full W+jets yield is scaled to data
- Until we have our own measurement, this is the best we can do

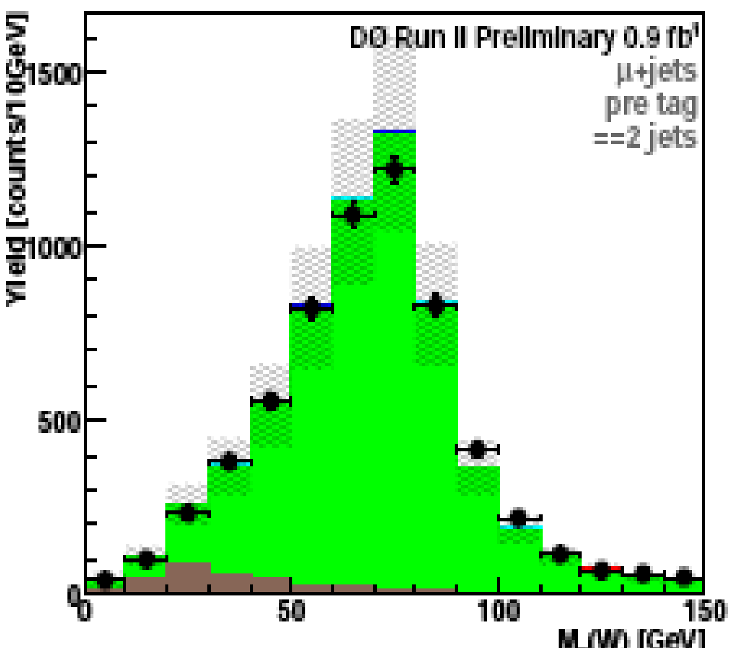


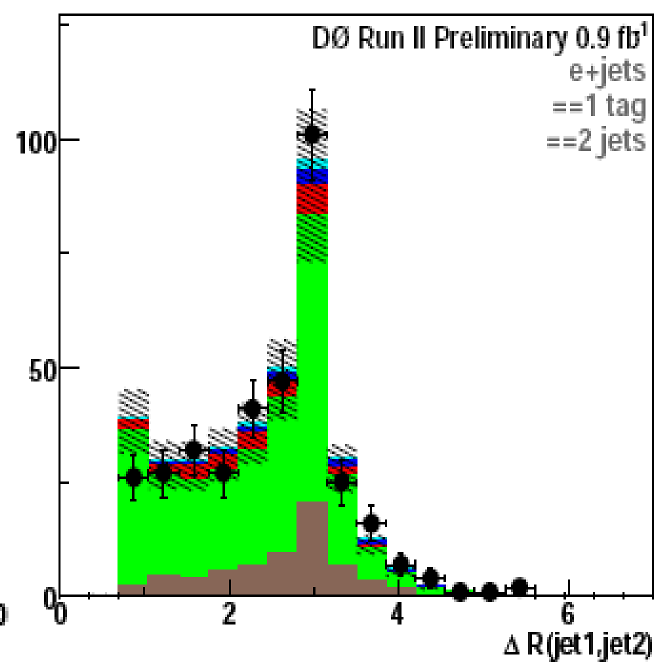
Scale Factor α to Match Heavy Flavor Fraction to Data

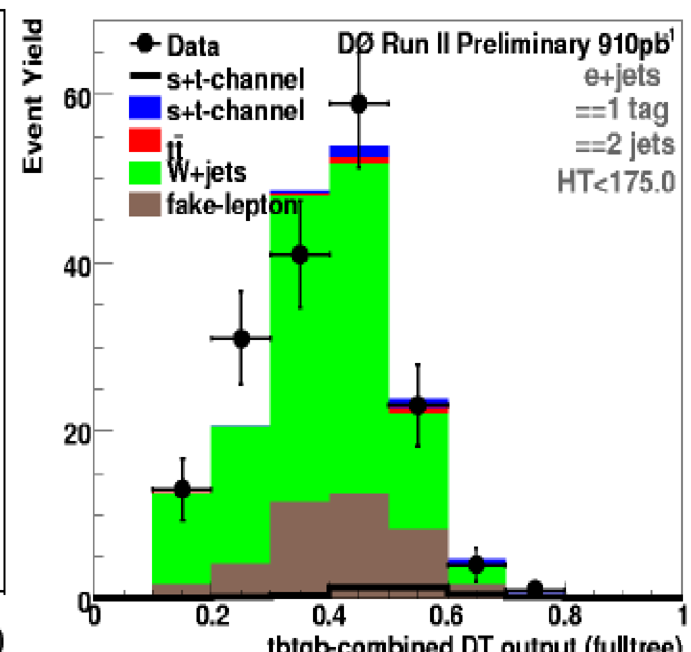
	1 jet	2 jets	3 jets	4 jets
Electron Channel				
0 tags	1.53 ± 0.10	1.48 ± 0.10	1.50 ± 0.20	1.72 ± 0.40
1 tag	1.29 ± 0.10	1.58 ± 0.10	1.40 ± 0.20	0.69 ± 0.60
2 tags	—	1.71 ± 0.40	2.92 ± 1.20	-2.91 ± 3.50
Muon Channel				
0 tags	1.54 ± 0.10	1.50 ± 0.10	1.52 ± 0.10	1.38 ± 0.20
1 tag	1.11 ± 0.10	1.52 ± 0.10	1.32 ± 0.20	1.86 ± 0.50
2 tags	—	1.40 ± 0.40	2.46 ± 0.90	3.78 ± 2.80

Wbb shapes

- The kinematic distributions of the Wbb samples used are in gross disagreement with LO samples using conventional scale choices and with NLO calculations
  - Alpgen v2.05 with MLM matching disagrees with NLO shapes
  - The data should be the judge. We have found overall good agreement in all kinds of distributions inside our acceptance before and after tagging: angular correlations, pTs, background cross check samples, discriminant outputs...

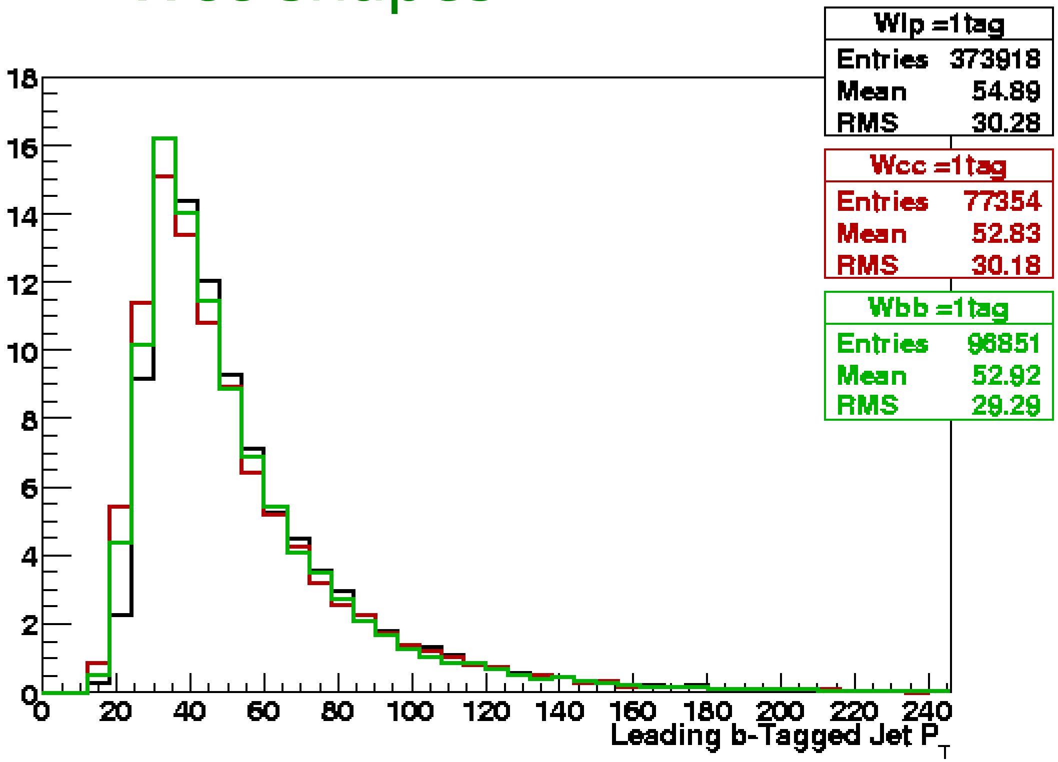


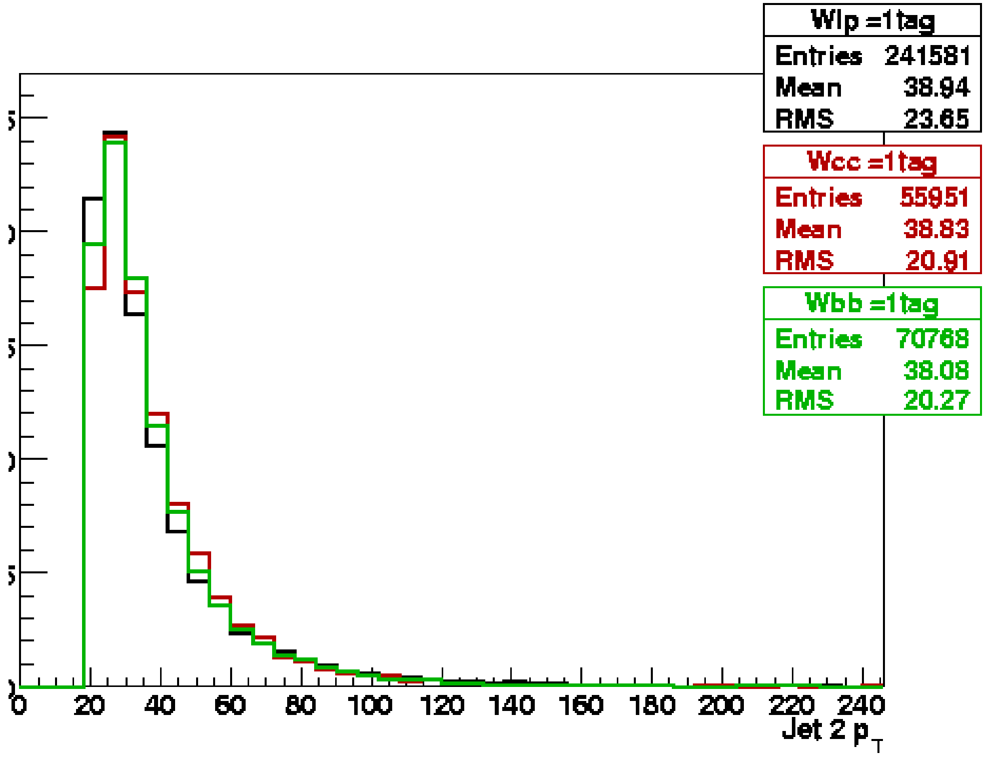




Wbb/Wcc shape difference

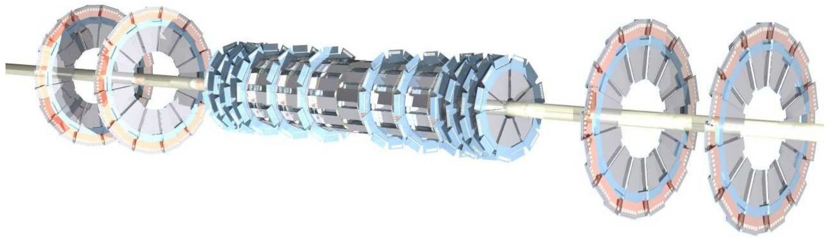
- Can you assume that Wbb and Wcc fractions separately can be described by the Wbb+Wcc fraction?
  - We changed the Wbb/Wcc ratio by ±10% and re-calculated the single top cross section:
  - More Wbb, less Wcc: σ(tb+tqb)=4.85±1.4pb
  - Less Wbb, more Wcc: σ(tb+tqb)=4.98±1.5pb
  - Weak dependence based on similarity between Wbb and Wcc shapes



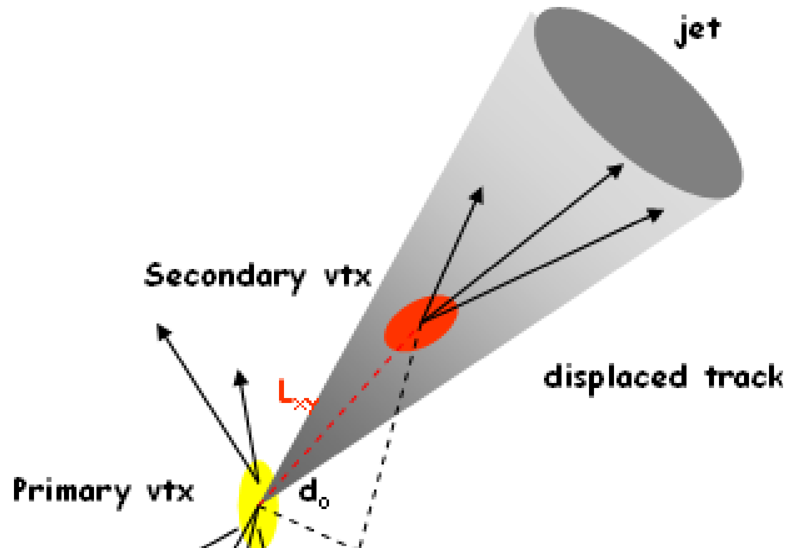


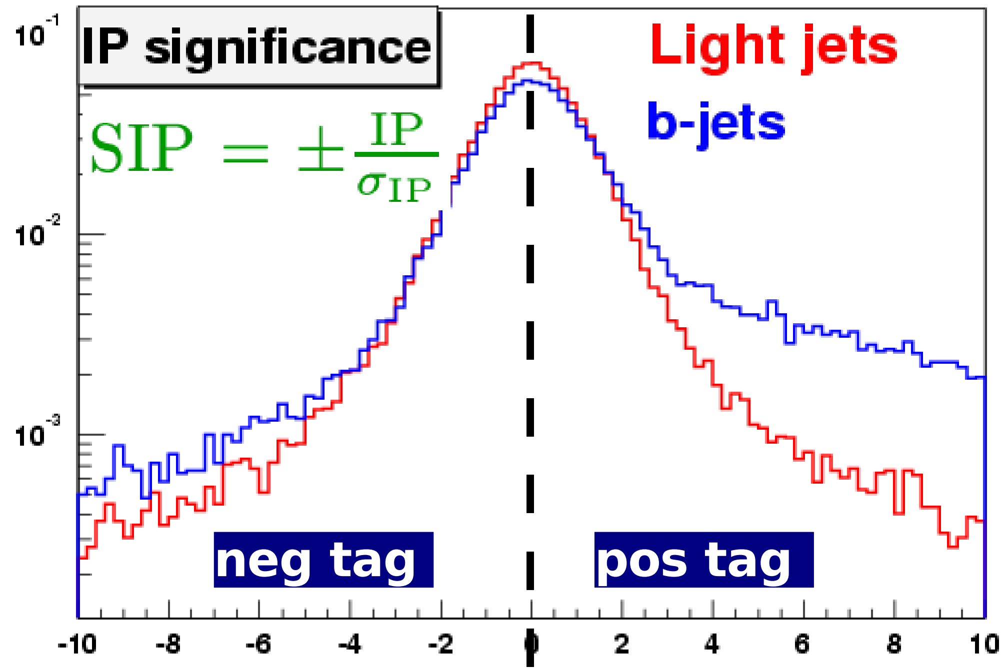
Error on the HF fraction

- How come a 30% error on HF fraction doesn't destroy all sensitivity?
  - This (still) is a statistics limited analysis: 1.2pb out of 1.4pb error comes from stats alone
  - After tagging, the uncertainty on the total W+jets yield is reduced from 30% because:
  - a) Not the entire sample is Wbb+Wcc, the uncertainty on the sum is smaller than 30%
  - b) The anti-correlation between Wjj and Wbb+Wcc due to the normalization before tagging further reduces the uncertainty
  - This uncertainty is still one of the largest in the end



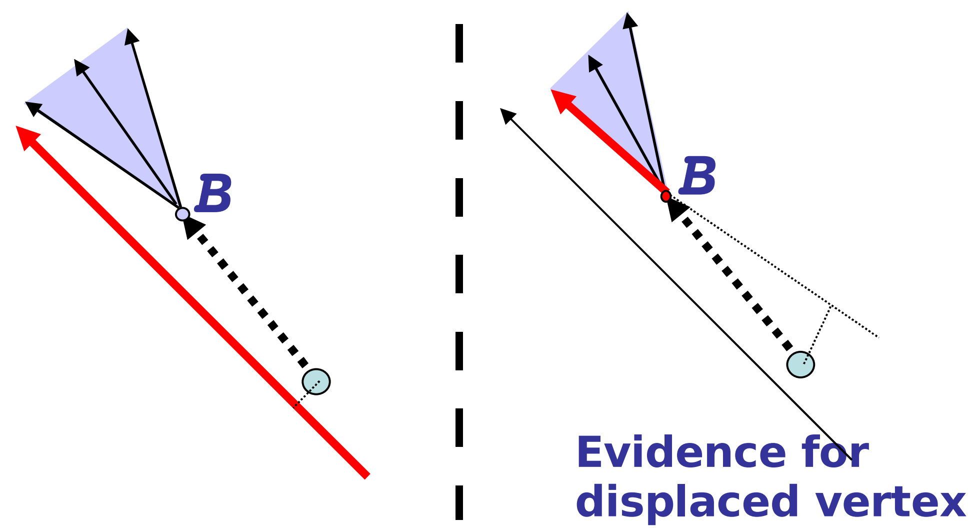
Tagging b-jets





Three different algorithms for b-jet identification at DØ:

- Two based on tracks with large IP (JLIP, CSIP)
- One based on secondary vertex reconstruction (SVT)
- Combine in NN



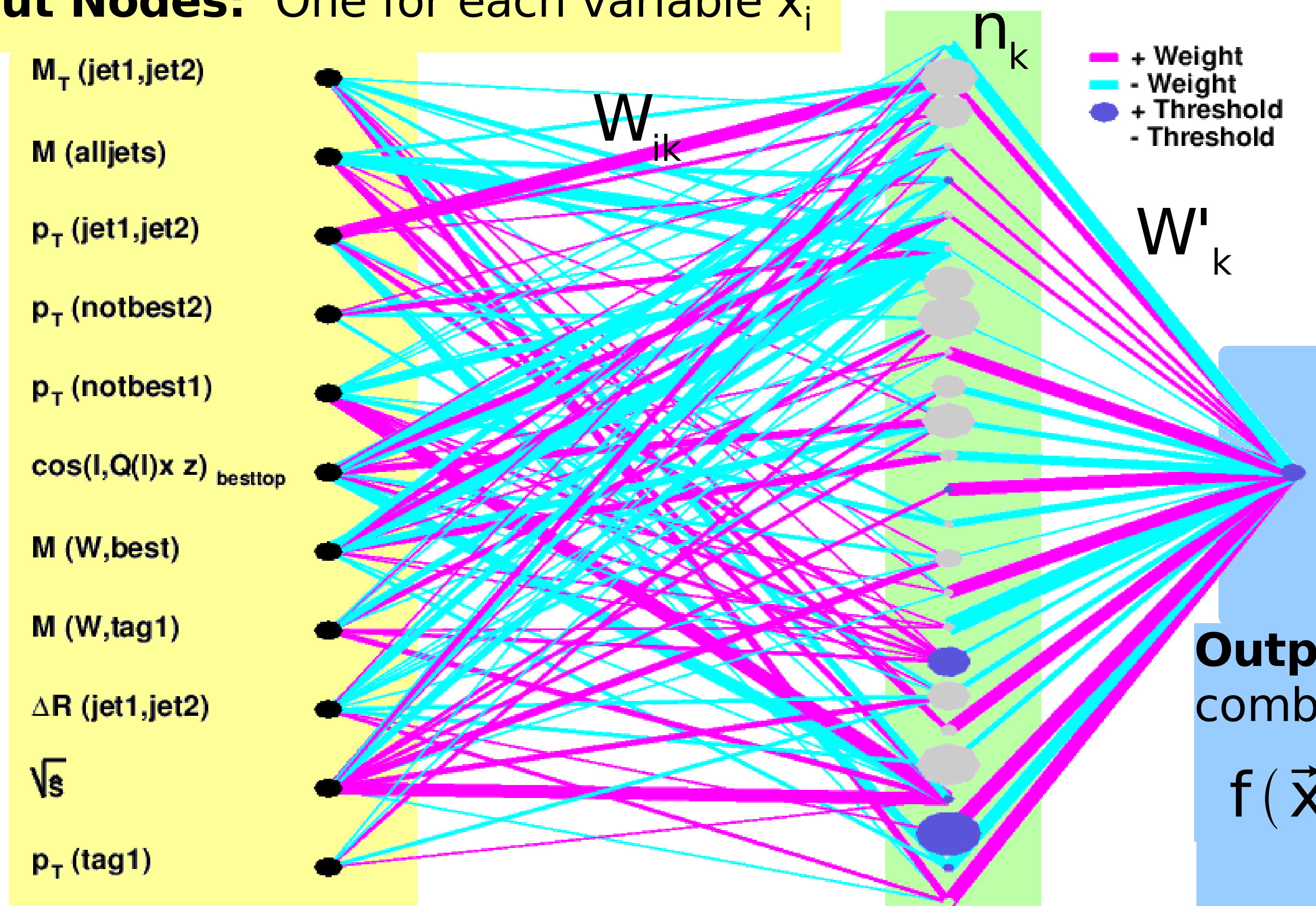
NEW

Ensemble testing details

- Use a pool of weighted signal+background events (about 850k in each of electron and muon)
- Fluctuate relative and total yields in proportion to **systematic errors**
  - reproducing the **correlations** between backgrounds imposed by our normalization to data
- Randomly sample from a Poisson distribution about the total yield to simulate **statistical fluctuations**
- Generate a set of pseudo-data (a member of the ensemble)
- Pass the pseudo-data through the full analysis chain (including systematic uncertainties)

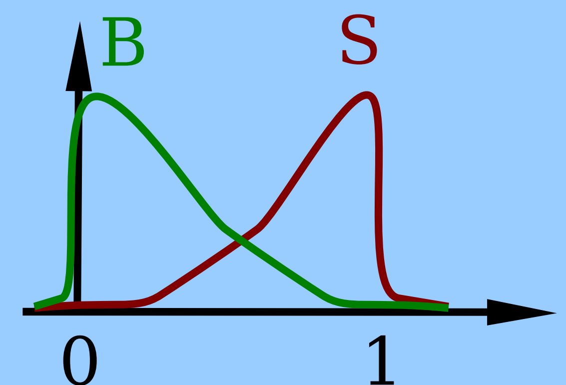
Neural Networks

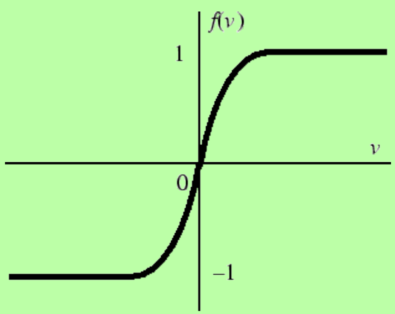
Input Nodes: One for each variable x_i



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

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

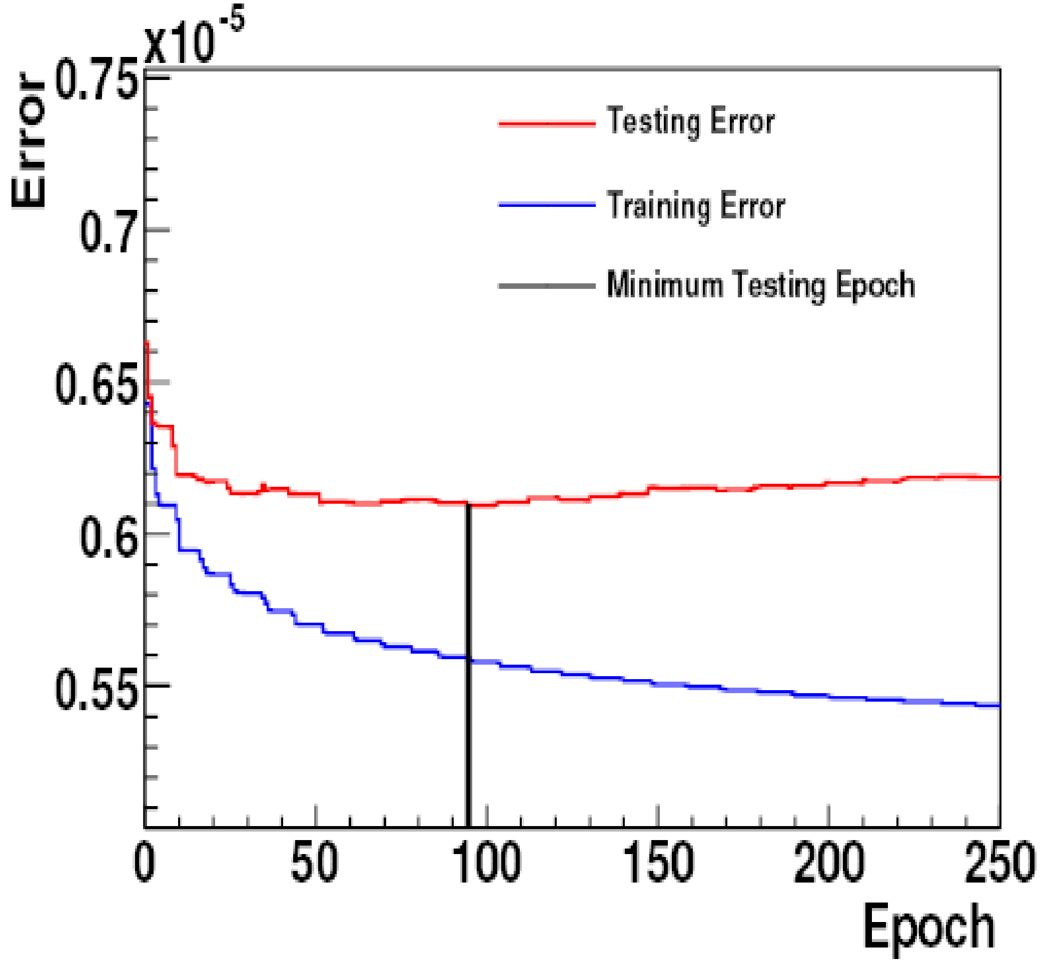
Training method and optimization

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



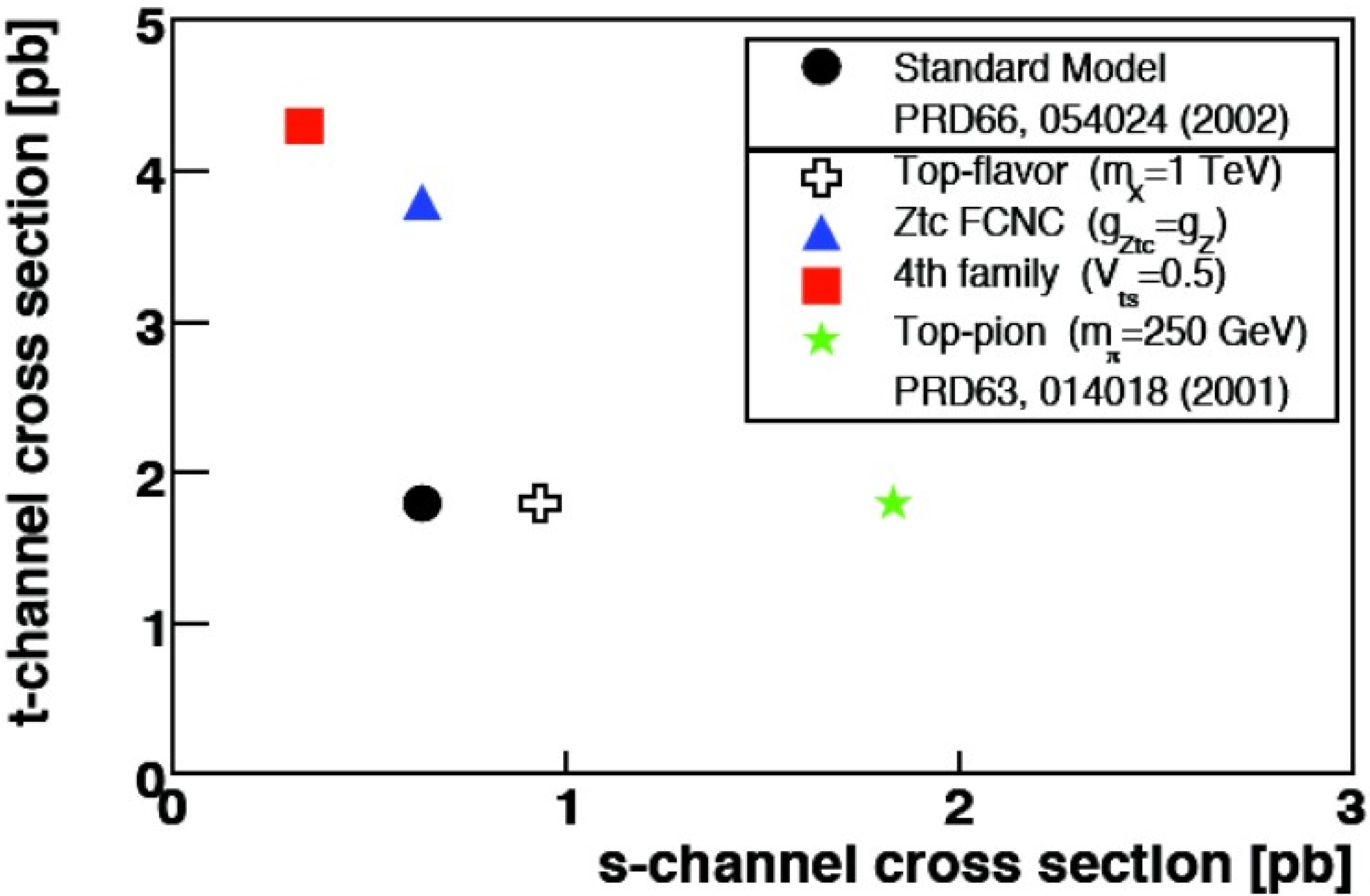
- Used 60% of events for training, 40% for testing
- Optimize number of training epochs and number of hidden nodes
- MLPFit implementation, many others in the market

Systematics

Relative Systematic Uncertainties

$t\bar{t}$ cross section	18%	Primary vertex	3%
Luminosity	6%	Electron reco * ID	2%
Electron trigger	3%	Electron trackmatch & likelihood	5%
Muon trigger	6%	Muon reco * ID	7%
Jet energy scale	wide range	Muon trackmatch & isolation	2%
Jet efficiency	2%	$\varepsilon_{\mathrm{real}-e}$	2%
Jet fragmentation	5–7%	$\varepsilon_{\mathrm{real}-\mu}$	2%
Heavy flavor fraction	30%	$\varepsilon_{\mathrm{fake}-e}$	3–40%
Tag-rate functions	2–16%	$\varepsilon_{\mathrm{fake}-\mu}$	2–15%

New physics


Standard Model
PRD66, 054024 (2002)
Top-flavor (m_x=1 TeV)
Ztc FCNC ($g_{Ztc}=g_Z$)
4th family (V_{ts}=0.5)
Top-pion (m_π=250 GeV)
PRD63, 014018 (2001)
t-channel cross section [pb]
s-channel cross section [pb]
0
1
2
3
4
5
0
1
2
3