Single Top Quark. First Evidence

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Outline

- Part 1
  - Introduction
  - Basic single top processes and rates
  - Decays and spin correlations
  - "New Physics" via single top quark
  - NLO event generator SINGLETOP
- Part 2
  - First Evidence by D0
  - Conclusions

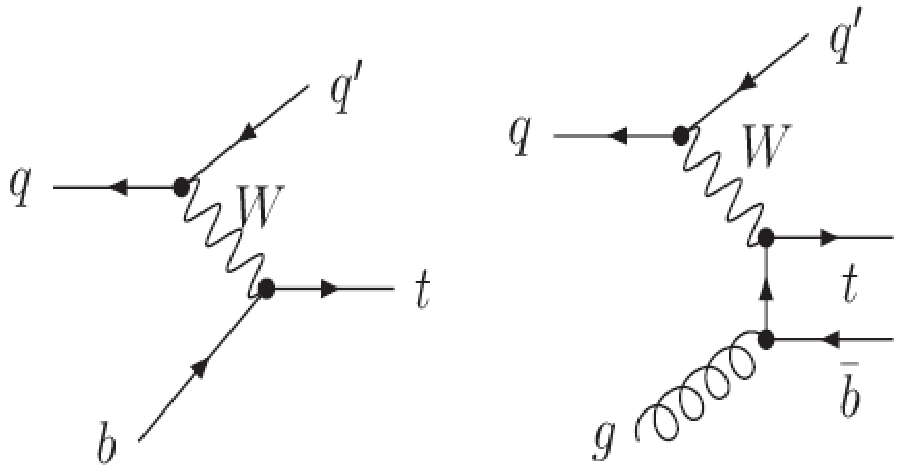
Three mechanisms of the single top production:

t-channel ($Q_W^2 < 0$)

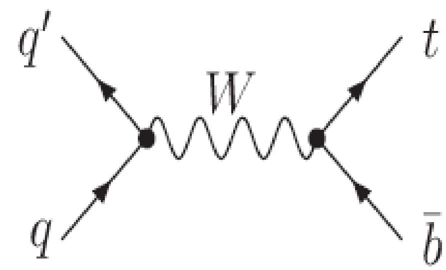
s-channel ($Q_W^2 > 0$)

associated tW ($Q_W^2 = M_W^2$)

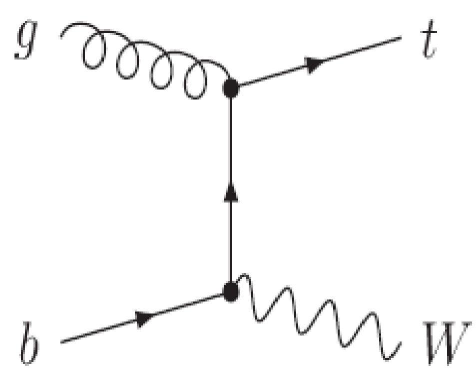
Q_W^2 - W-boson virtuality



t-channel



s-channel



Wt associated production

The main goals to search for single top:

- Independent electroweak channel of the top quark production
- Direct $|V_{tb}|$ CKM matrix element measurement
- Significant background to Higgs and many "new physics" (MSSM) processes
- Unique spin correlations properties
- Process of interest for "New physics"
  - W_{tb} anomalous couplings
  - FCNC
  - Searches for W' (Kaluza-Klein excitation of W-boson)
  - Searches for new strong dynamics (π_T, ρ_T)
- New delicate analysis techniques to extract small signals

Часть II: Экспериментальное наблюдение одиночного рождения топ кварка на детекторе D0

Коллаборация DZero: 600 человек, 90 институтов, 19 стран

Группа DZero Single Top:

E. Aguilo, P. Baringer, A. Bean, C. Belanger-Champagne, J.A. Benitez, E.E. Boos, R. Brock, V. Bunichev, K. Chan, L. Christofek, Y. Coadou, L.V. Dudko, M. Erdmann, T. Gadfort, A. Garcia-Bellido, C. Gerber, D. Gillberg, G. Gutierrez, P. Gutierrez, A.P. Heinson, U. Heintz, S. Herrin, S. Jabeen, S. Jain, A. Juste, S. Kappler, D. Kau, G. Kertzscher, M. Kirsch, L. Li, J. Mitrevski, R. Moore, M. Narain, D. O'Neil, M. Pangilinan, J. Parsons, M. Perflov, C. Potter, H.B. Prosper, R. Schwienhorst, E. Shabalina, J. Steggemann, T. Tim, C. Tully, M. Vetterli, B. Vachon, G. Watts, M. Weber

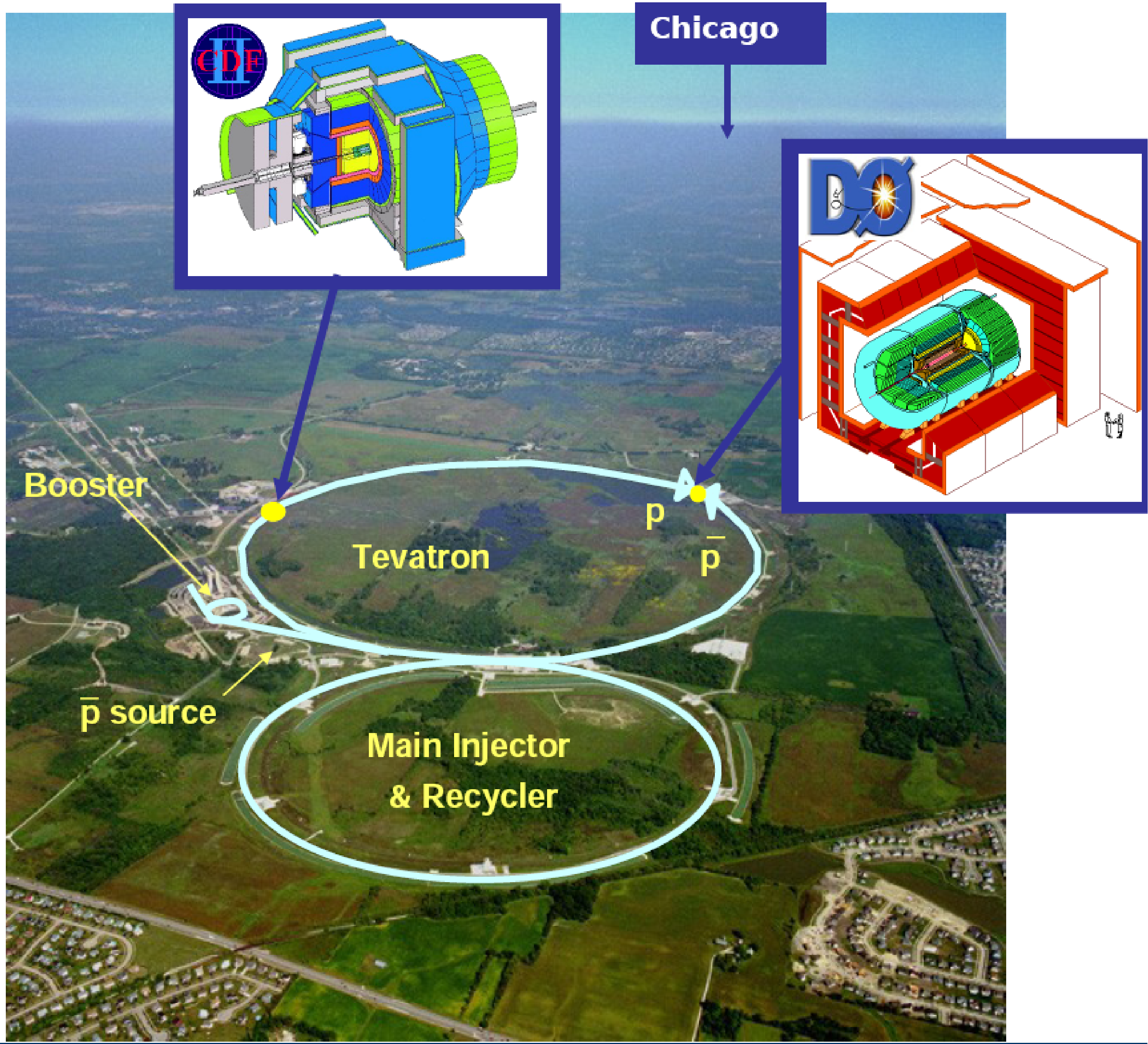
The Tevatron

The highest energy particle accelerator in the world!

Proton-antiproton collider

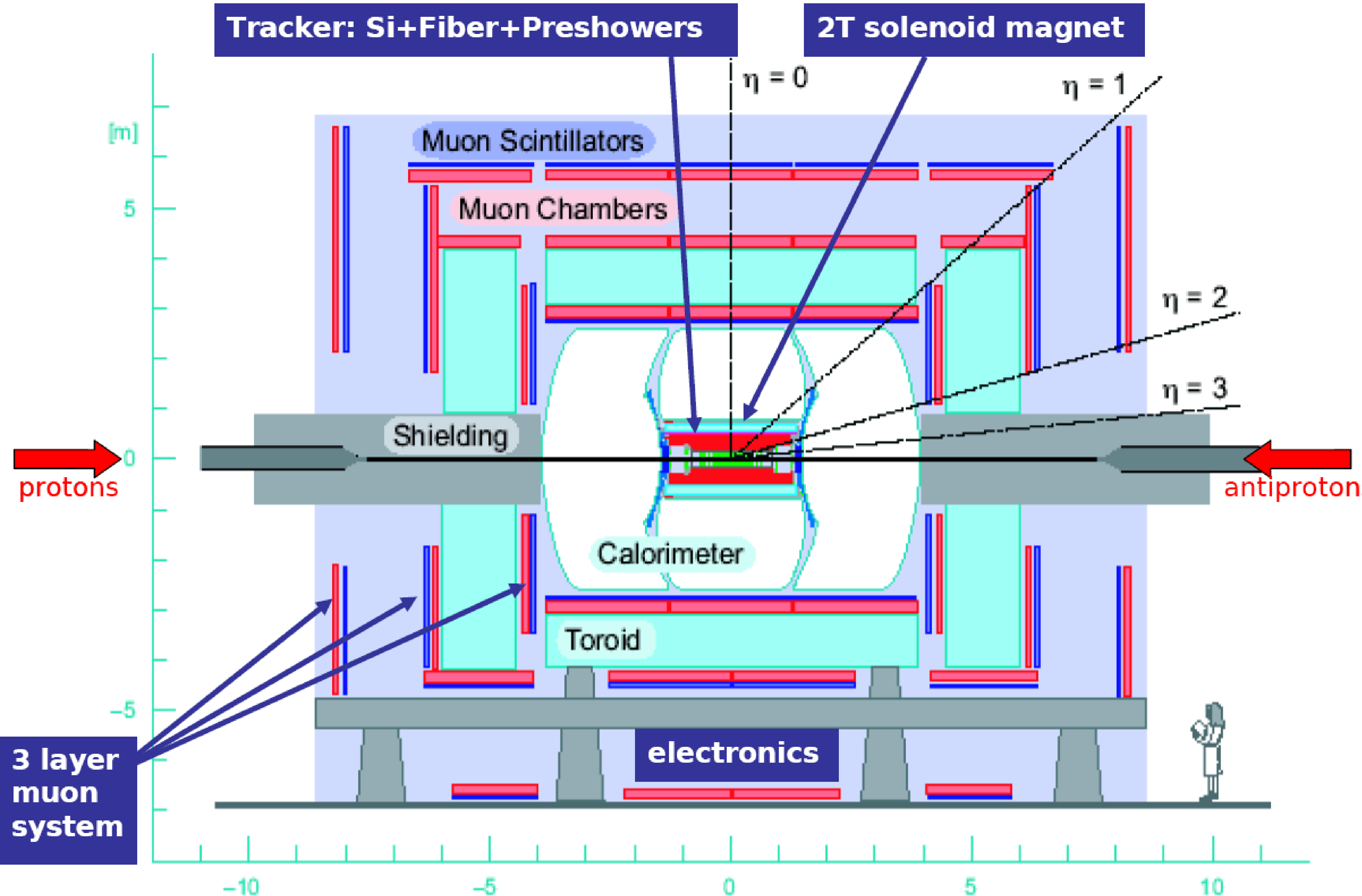
Run I 1992-1995
Top quark discovered!

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



D0 детектор

DØ for Run II


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

Историческое введение

	s-channel	t-channel
Theory NLO cross section:	0.88 pb	1.98 pb

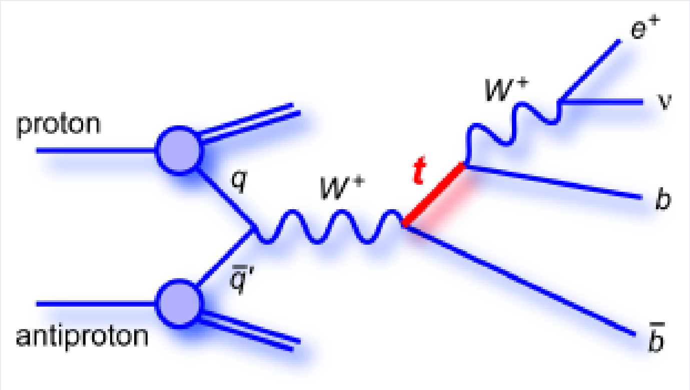
95% CL upper cross section limits [pb]:

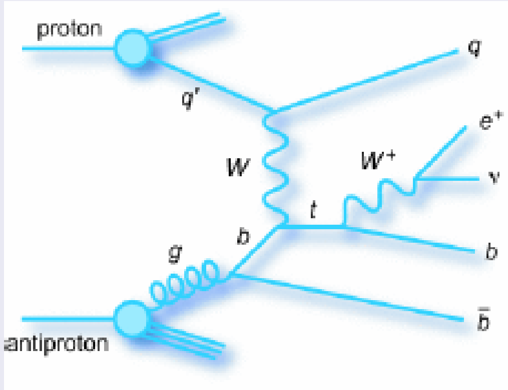
	s-channel	t-channel
Run I (100 pb^{-1})		
D0 (Phys.Rev.D63:031101,2001; Phys.Lett.B517:282-294,2001)	17	22
CDF (Phys.Rev.D65:091102,2002)	18	13
Run II		
CDF (160 pb^{-1}; Phys.Rev.D71:012005,2005)	13.6	10
D0 (230 pb-1; Phys.Lett.B622:265-276,2005)	6.4	5
D0 230 pb^{-1}, Comparison of the analysis methods:		
Cut based analysis	10.6	11.3
Decision Tree	8.3	8.1
Neural Net	6.4	5

Аннотация

- Моделирование и отбор данных
- Критерии предварительного выбора событий
- Оптимальные наблюдаемые
- Систематические ошибки
- Методы оптимального выделения сигнальных событий
  - Метод Байесовских нейронных сетей
  - Метод матричных элементов
  - Метод деревьев решений
- Статистическая значимость и проверка гипотез
- Результаты

Предварительный отбор событий





Signature

- isolated lepton
- $\not{E}_T$
- 2-4 jets
- at least 1 b-jet

- Only one tight and no other loose lepton
  - electron: $p_T > 15$ GeV and $|\eta_{det}| < 1.1$
  - muon: $p_T > 18$ GeV and $|\eta_{det}| < 2$
- $15 < \not{E}_T < 200$ GeV
- 2-4 jets with $p_T > 15$ GeV and $|\eta_{det}| < 3.4$
  - Leading jet with $p_T > 25$ GeV and $|\eta_{det}| < 2.5$
  - Second leading jet $p_T > 20$ GeV

Моделирование и Данные

- Сигнал: NLO генератор SingleTop
- Фон:
  - ttbar (l+jets, ll+jets), ALPGEN, MLM matching, NLO нормировка
  - W+jets (Wjj, Wbb, Wcc, ...), ALPGEN, MLM matching, нормировка на данные
  - Multijets Fake (jbb, jjbb, ...) одна из струй (j) идентифицируется как лептон, фон оценивается из данных
- Данные (предварительный отбор, без b-tagging)
  - e-channel 913 pb^{-1}, 39762 события
  - mu-channel 871 pb^{-1}, 27738 событий

Определение фракции W+jets и QCD Multijets Fake событий в Данных

- Matrix Method определяет фракции событий с реальным и ложным лептоном до b-tagginga, вероятности ложной идентификации определяются из анализа событий Z->ll

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

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

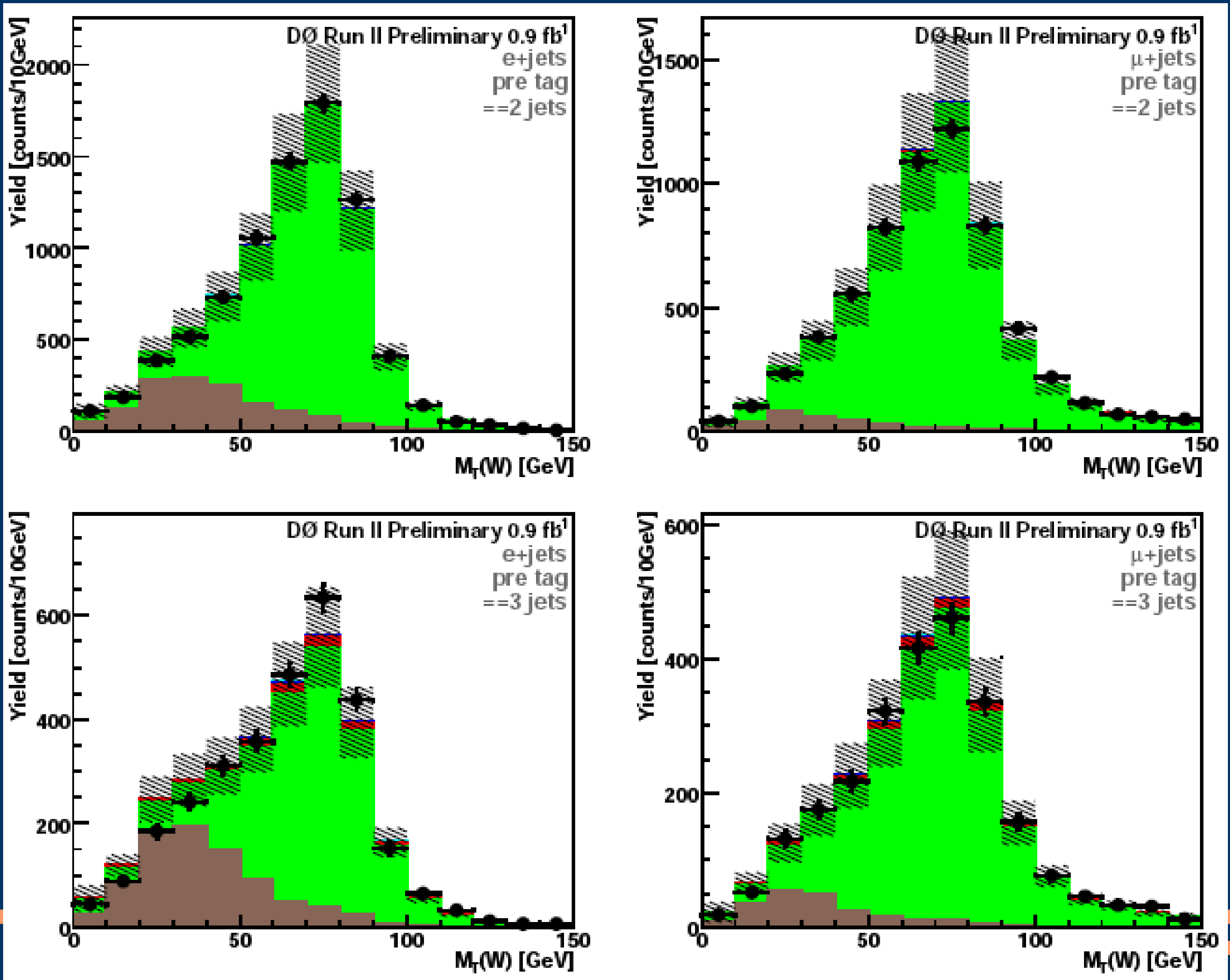
$$N^{final}_{WQCD} = N^{final}_{W+jets} + N^{final}_{fake-l}$$

Normalization of W+Jets and Multijets to Data

	Electron Channel					Muon Channel				
	1 jet	2 jets	3 jets	4 jets	5+ jets	1 jet	2 jets	3 jets	4 jets	5 jets
$N_{\rm loose}$	38,935	15,213	7,118	2,191	654	18,714	7,092	3,054	878	221
$N_{\rm tight}$	27,370	8,220	3,075	874	223	17,816	6,432	2,590	727	173
$N^{\rm fake-e}_{\rm tight}$	1,691	1,433	860	256	86	498	329	223	56	10
$N^{\rm real-e}_{\rm tight}$	25,679	6,787	2,215	618	137	17,319	6,105	2,369	669	162
$\varepsilon_{\rm real-e}$	0.873	0.874	0.874	0.875	0.875	0.991	0.989	0.987	0.961	0.878
$\varepsilon_{\rm fake-e}$	0.177	0.193	0.188	0.173	0.173	0.408	0.358	0.342	0.309	0.253

Loose, tight - критерии идентификации лептона

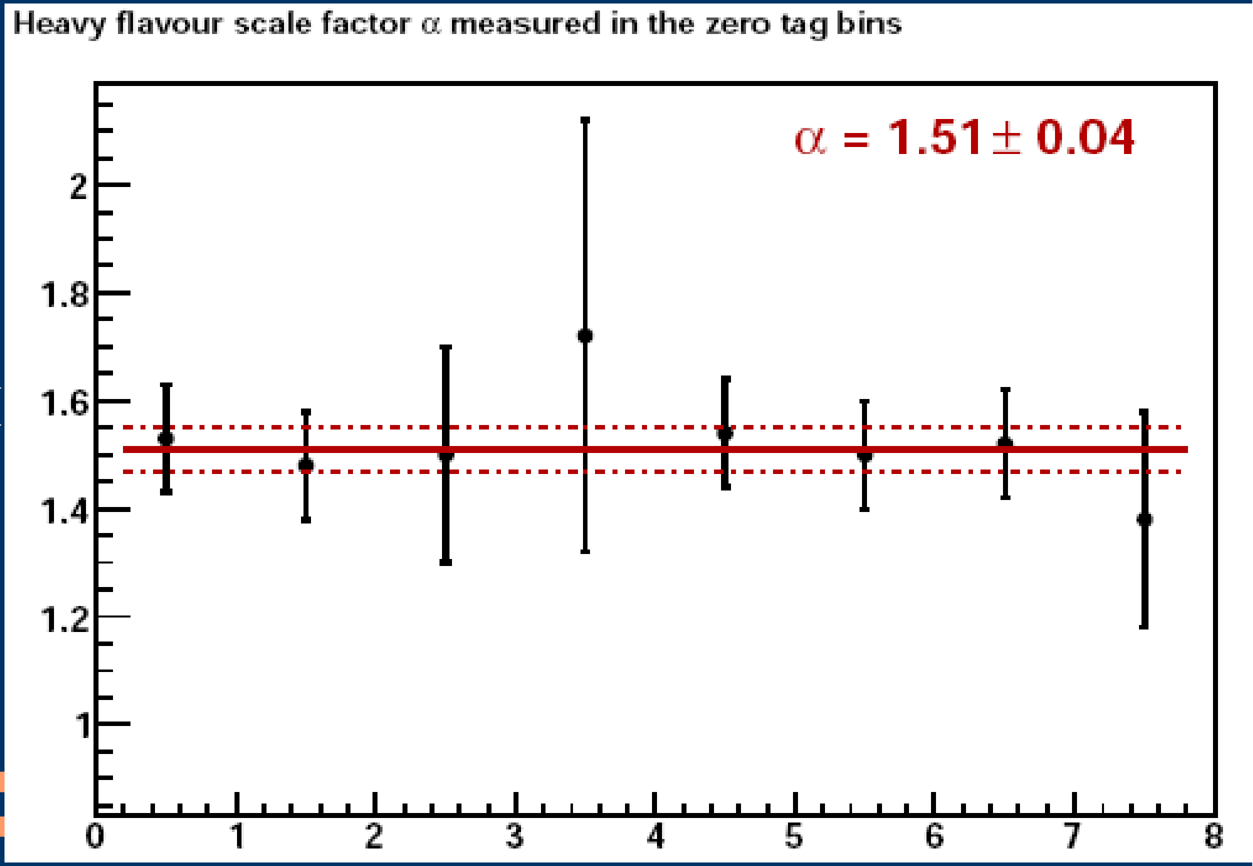
W+jets (зеленый), Multijet fake (коричневый), ttbar (красный), Данные



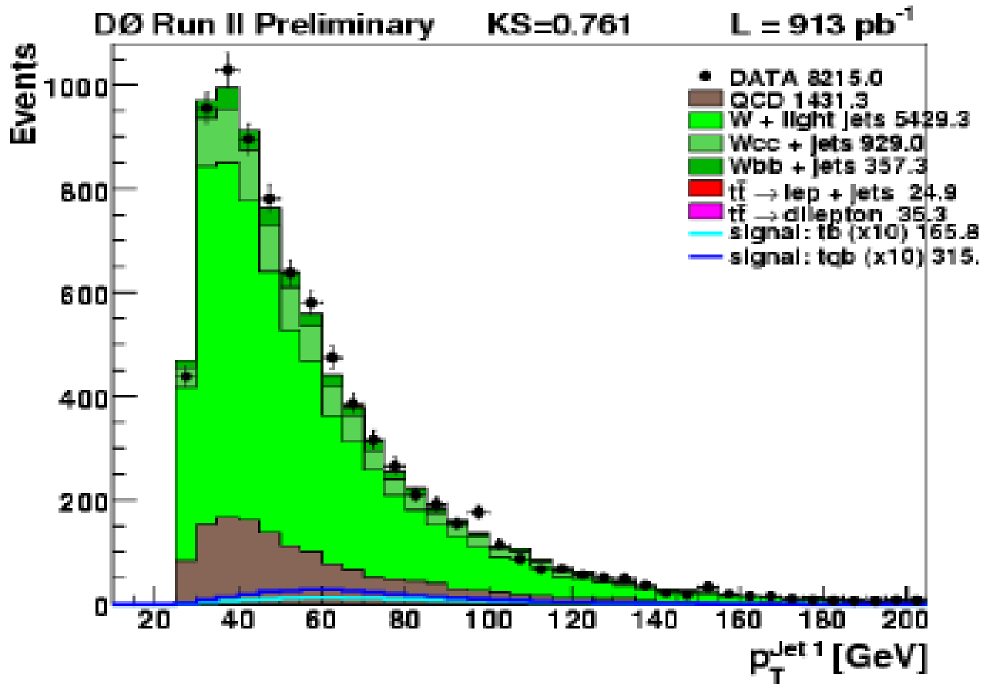
Нормализация W+heavy flavour (b,c) jets

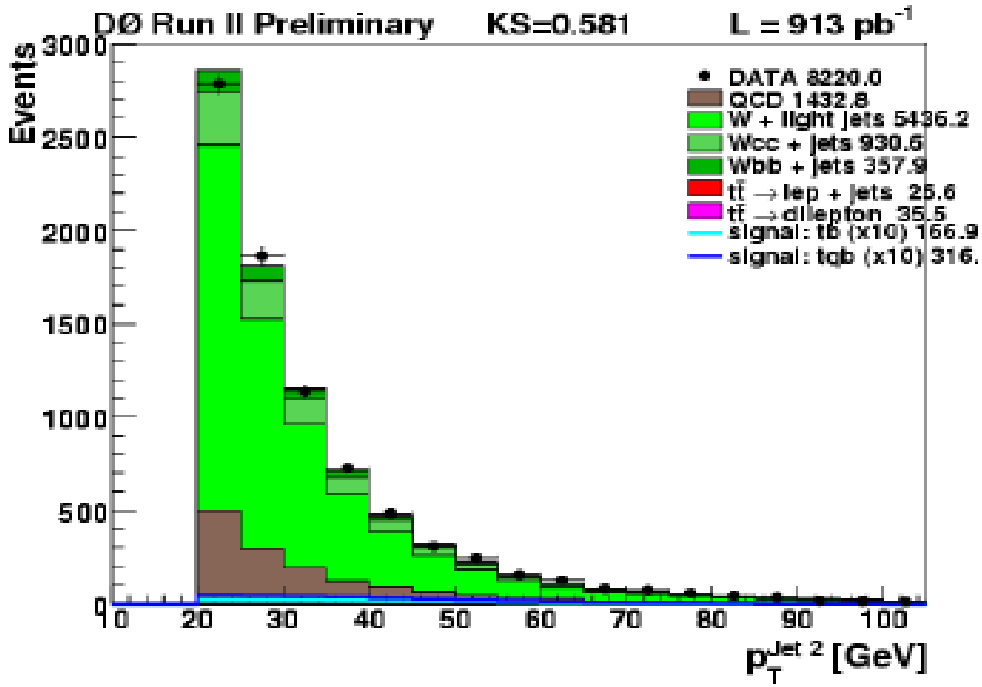
$$\alpha(Wb\bar{b} + Wc\bar{c}) + Wjj + t\bar{t} + \mathrm{QCD} = \mathrm{Data}$$

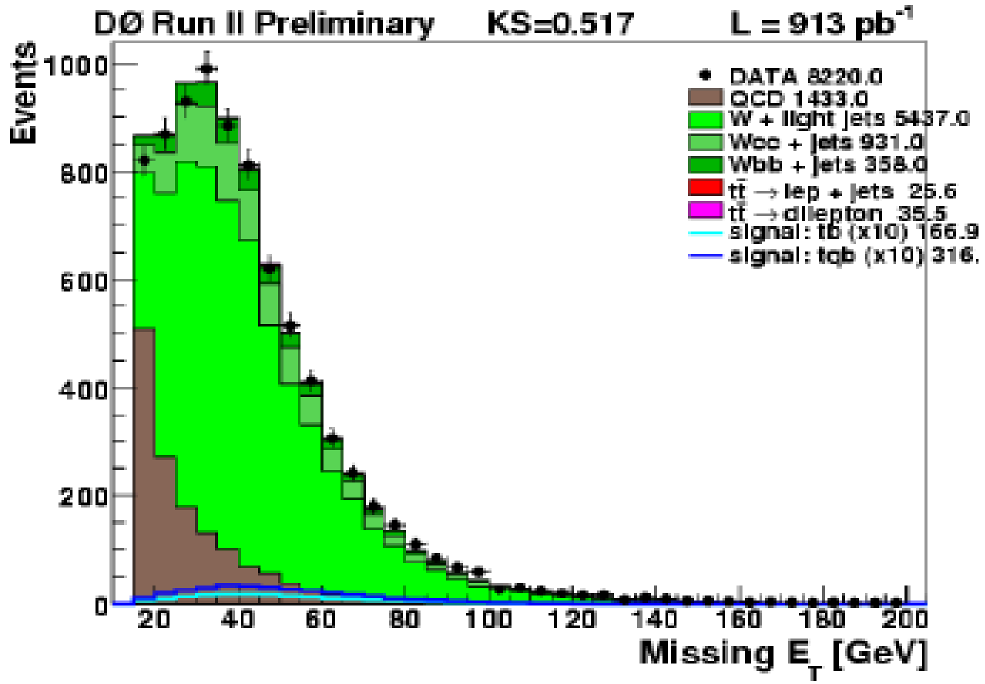
- Не корректно использовать NLO сечение из MCFM для нормализации смоделированных в ALPGEN событий
- α определяется на отдельной выборке событий без b-tag струй, такие события не используются в дальнейшем анализе.

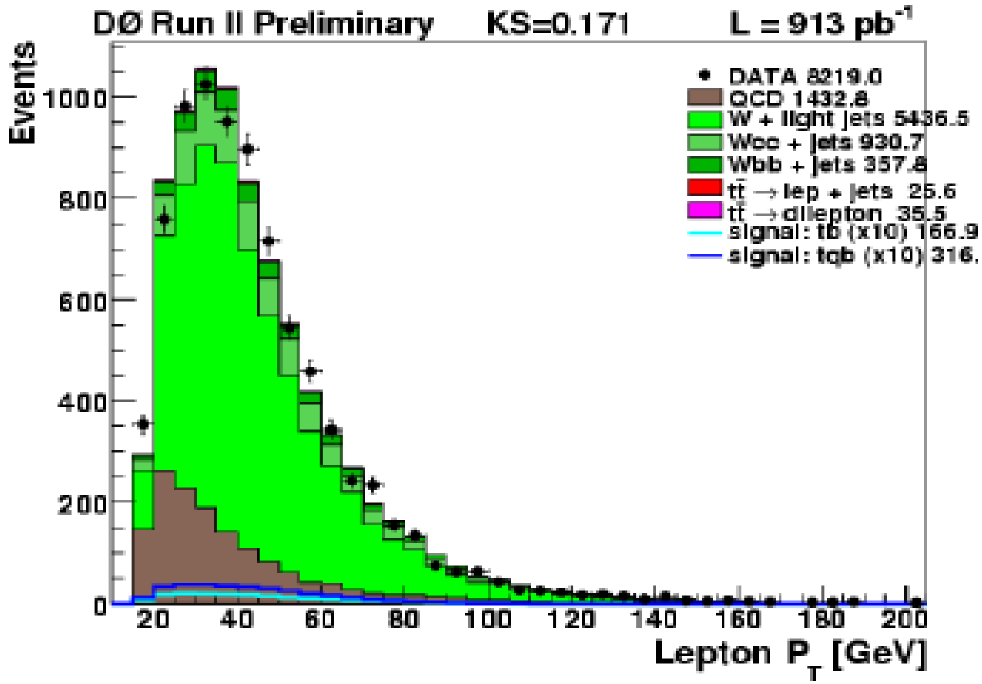


Согласование Данных и Модели фона до b-tagginga



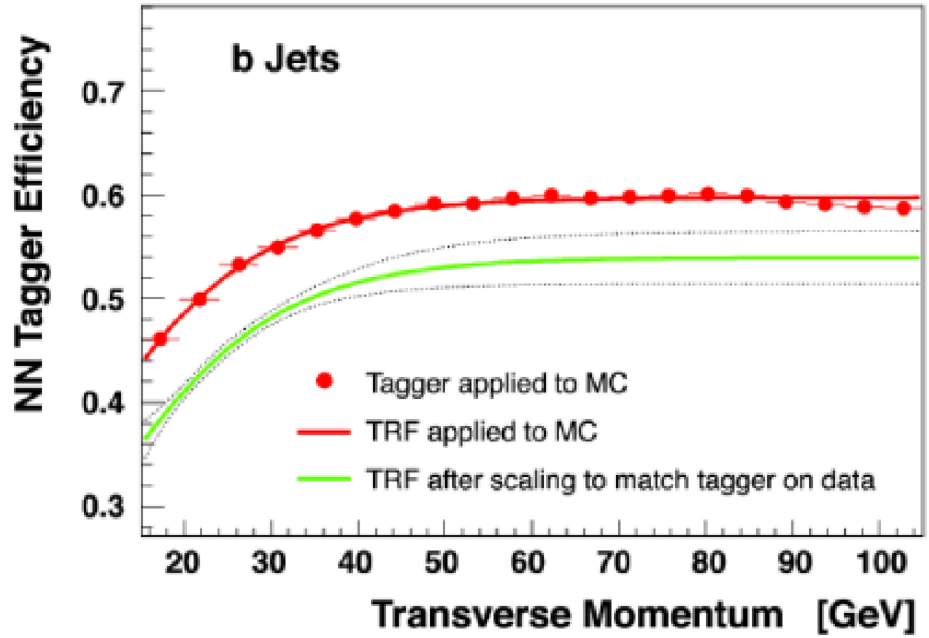


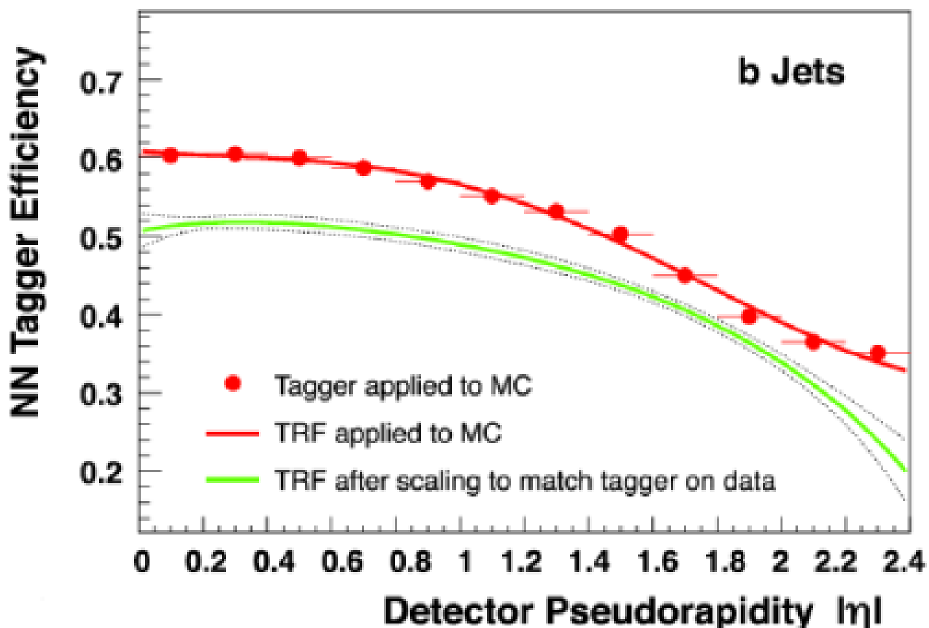




Neural Network b-jet Tagger

- 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 uncertainties
- Tag Rate Functions (TRFs) in η, P_T, z-PV applied to MC
- Our operating point:
    - b-jet efficiency $\sim 50\%$
    - c-jet efficiency $\sim 10\%$
    - Light jet efficiency $\sim 0.5\%$





Распределение сигнала и соотношение S/B в каждом канале анализа, после предварительного отбора

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

Результаты первичного отбора

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
$t\bar{t} \to ll$	39 ± 9	32 ± 7	11 ± 3
$t\bar{t} \to l$+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

Систематические ошибки

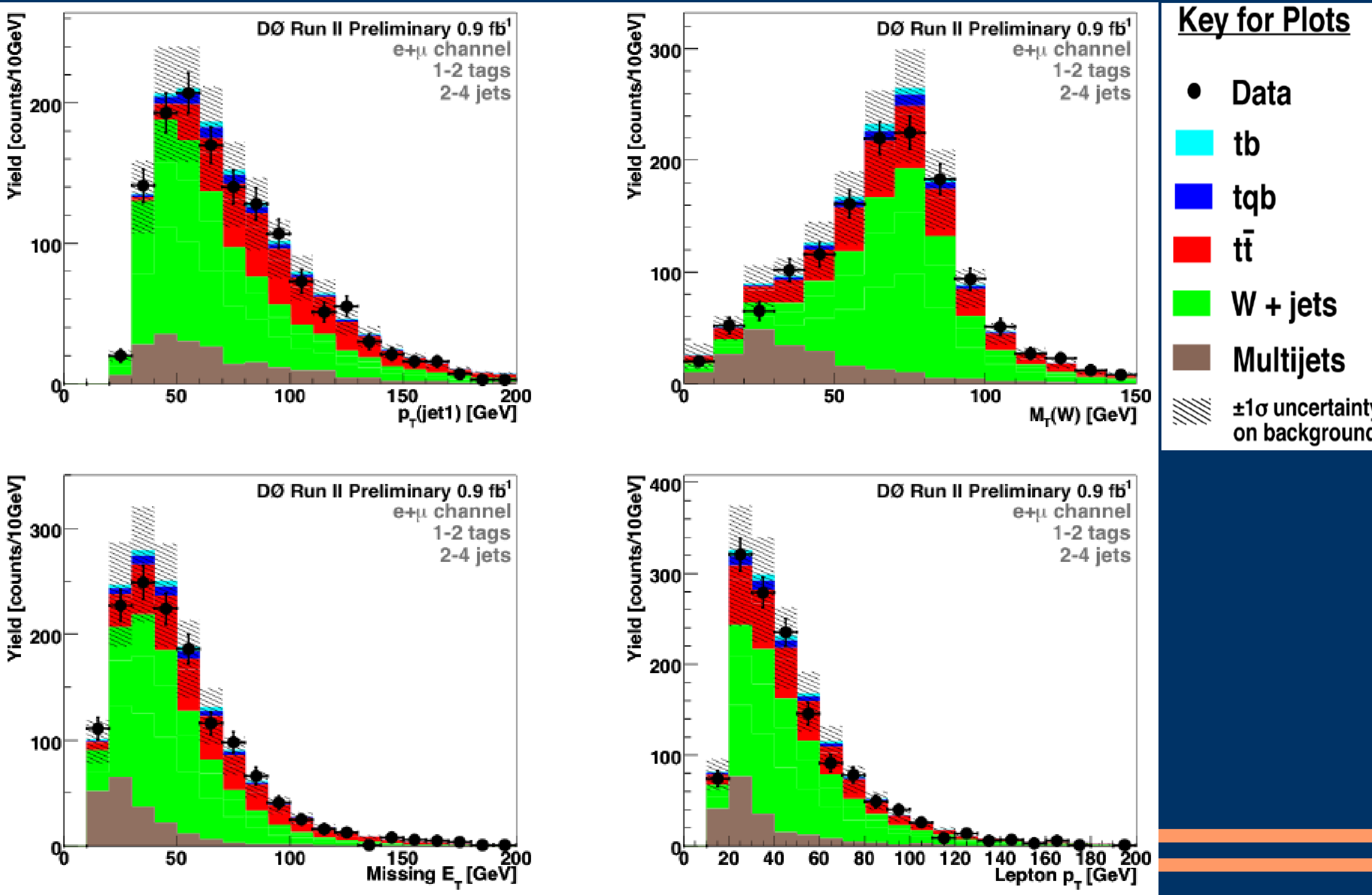
- Систематические ошибки связанные только с нормализацией
  - Luminosity, cross section, ...
- Систематические ошибки меняющие распределения
  - Jet Energy Scale, Tag Rate Function, ...

(Сдвиг переменных на $\pm 1\sigma$ и пересчет результатов)

Relative Systematic Uncertainties

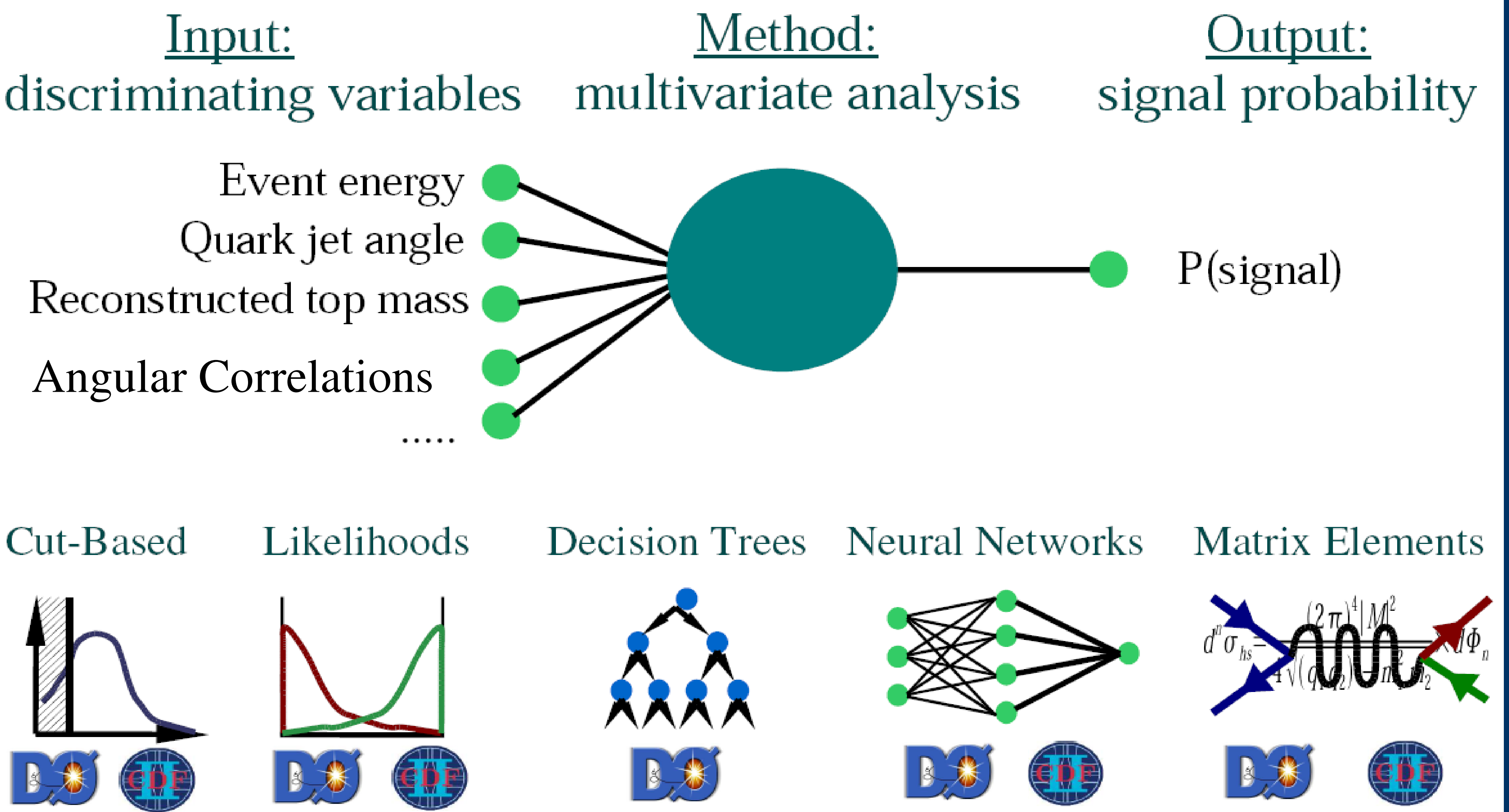
$t\bar{t}$ cross section	18%	Primary vertex	3%
Luminosity	6%	Electron reco * ID	2%
Electron trigger	3%	Electron trackmatch & likelihood	5%
Muon trigger	6%	Muon reco * ID	7%
Jet energy scale	wide range	Muon trackmatch & isolation	2%
Jet efficiency	2%	$\varepsilon_{\mathrm{real}-e}$	2%
Jet fragmentation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

Систематические ошибки



Оптимизация регистрации сигнала

Optimized Event Analysis



Method of Optimal Observables

- Provides general receipt how to choose most effective variables to separate Signal/Background
- Based on the analysis of Feynman diagrams which contribute to signal and Background
- Described in different examples:
  - Higgs search hep-ph/0406152 p.69-71 (E.Boos and L.Dudko)
  - Single Top search AIHENP'99 (E.B. and L.D.), hep-ph/9903215 and D0 publications on Single Top Search
  - Proceedings of TEV4LHC workshop

Three Classes of Variables

- “Singular” Sensitive Variables

 (denominator of Feynman diagrams)

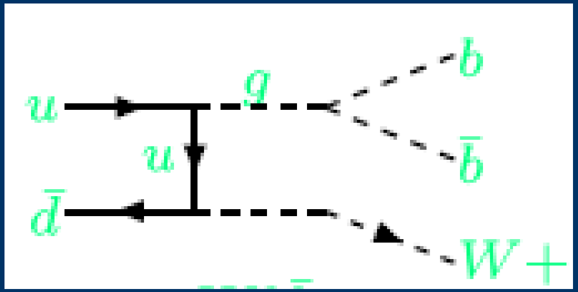
Most of the rates of signal and background processes come from the integration over the phase space region close to the singularities. If some of the singular variables are different or the positions of the singularities are different the corresponding distributions will differ most strongly

s-channel singularities

$$M_{f1,f2}^2 = (p_{f1} + p_{f2})^2$$

t-channel singularities

$$\hat{t}_{i,f} = (p_f - p_i)^2 = -\sqrt{\hat{s}}\, e^{Y} p_T^f e^{-|y_f|}$$



Three Classes of Variables

- "Angular" variables, Spin effects
  (numerator of Feynman diagrams)

$$\frac{1}{\sigma}\frac{d\sigma}{d\cos\theta^*_{ql}} = \frac{1+P\cos\theta^*_{ql}}{2}$$

- "Threshold" variables
  s_hat and Ht variables relate to the fact that various signal and background processes may have very different energy thresholds

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

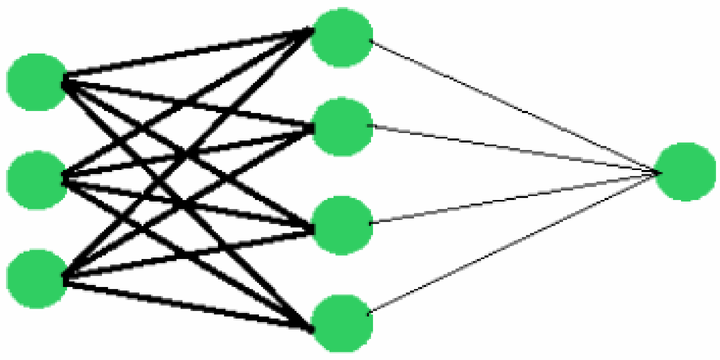
Event Kinematics

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)

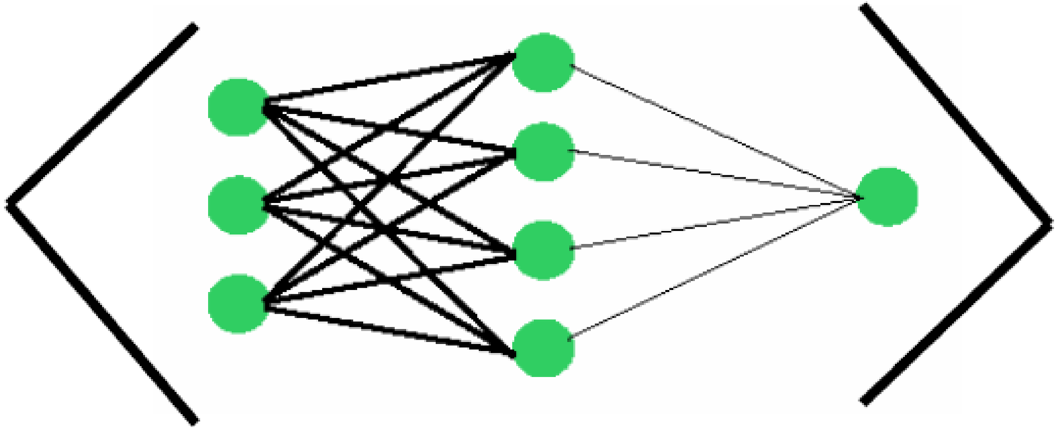
- Adding variables does not degrade performance
- Tested shorter lists, lose some sensitivity
- Same list used for all channels

D0 Multivariate Techniques

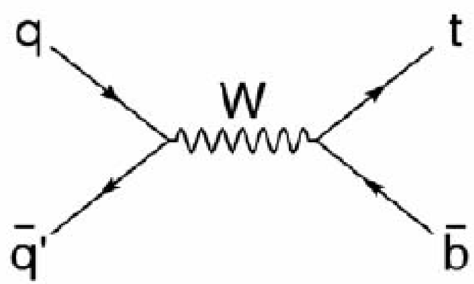
Neural Networks



Bayesian Neural Networks

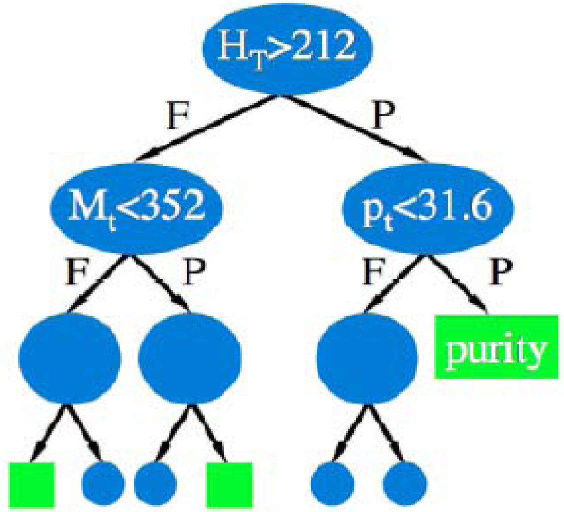


Matrix Element



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

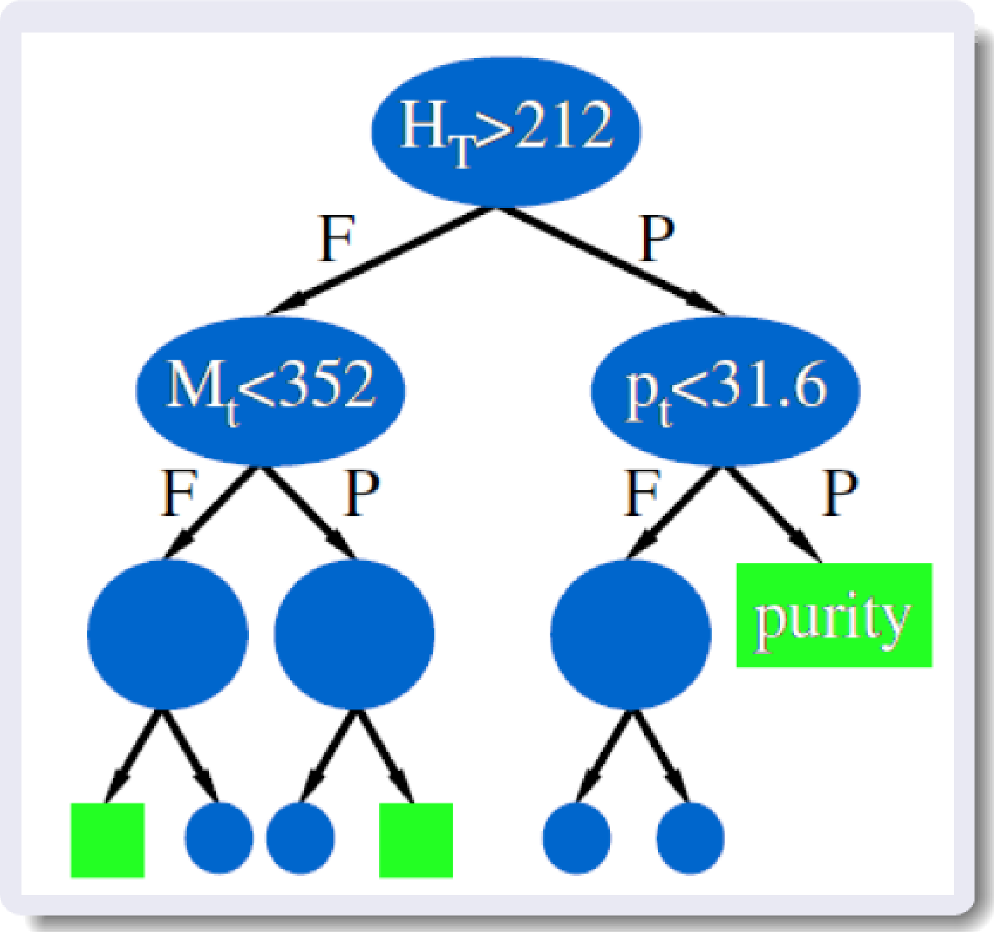
Decision Trees



Decision Trees

Train

- Start with all events (first node)
- For each variable, find the splitting value with best separation between children (best cut).
- select best variable and cut and produce Failed and Passed branches
- Repeat recursively on each node
- Stop when improvement stops or when too few events left. Terminal node = leaf.



purity $N_S/(N_S+N_B)$

Decision Trees - Boosting

Boosting

- Recent technique to improve performance of a weak classifier
- Recently used on DTs by GLAST and MiniBooNE
- Basic principal on DT:
  - train a tree T_k
  - $T_{k+1} = \text{modify}(T_k)$

AdaBoost algorithm

- Adaptive boosting
- Check which events are misclassified by T_k
- Derive tree weight α_k
- Increase weight of misclassified events
- Train again to build T_{k+1}
- Boosted result of event i: $T(i) = \sum_{n=1}^{N_{\text{tree}}} \alpha_k T_k(i)$

- Averaging dilutes piecewise nature of DT
- Usually improves performance

Ref: Freund and Schapire, "Experiments with a new boosting algorithm", in *Machine Learning: Proceedings of the Thirteenth International Conference*, pp 148-156 (1996)

Decision Trees - Application to this Analysis

DT Choices

- 1/3 of MC for training
- Adaboost $\beta = 0.2$
- Boosting cycles $= 20$
- Signal leaf if purity > 0.5
- Minimum leaf size $= 100$ events
- Same total weight to signal and background to start
- Goodness of split - Gini factor

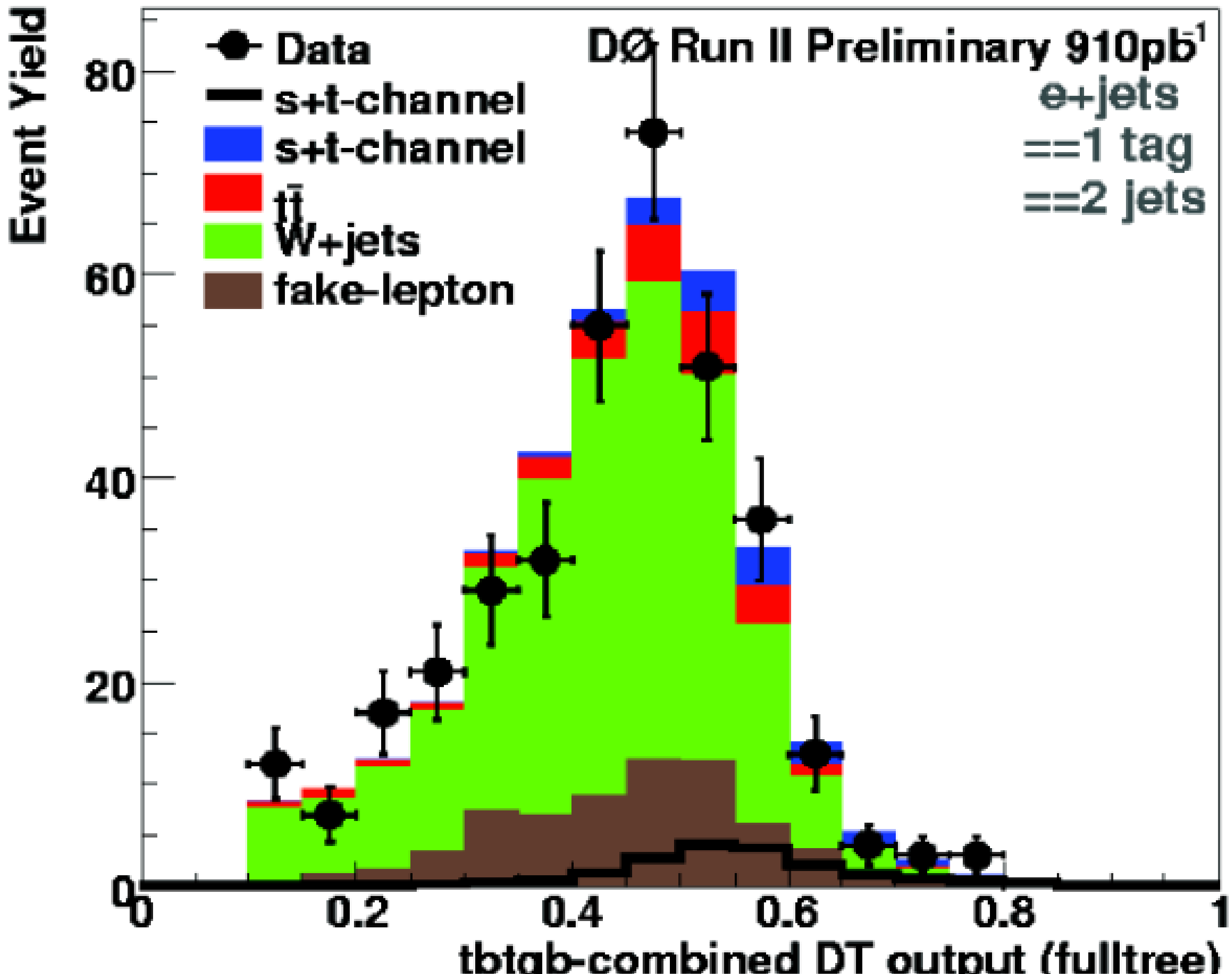
Analysis Strategy

- Train 36 separate trees: $(s,t,s+t)$ x (e,μ) x (2,3,4 jets) x (1,2 tags)
- For each signal train against the sum of backgrounds

$$\text{Gini} = 1 - \sum_{i=s,b} p_i^2 = \frac{2sb}{(s+b)^2};$$

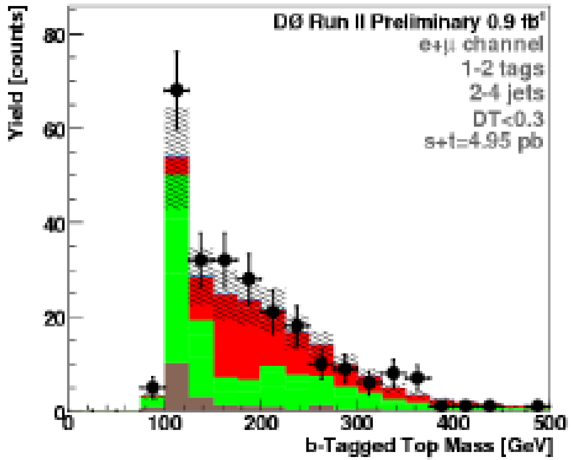
Decision Trees on Data

Of course, we have 36 different Decision Trees, let's look at electron, 2 jet, 1 tag:

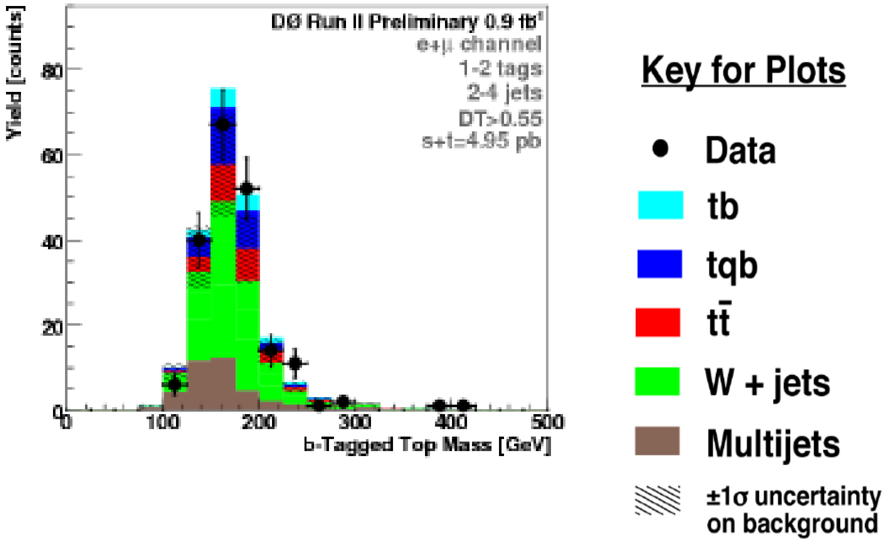


Decision Trees - Event Characteristics $M(W, b)$

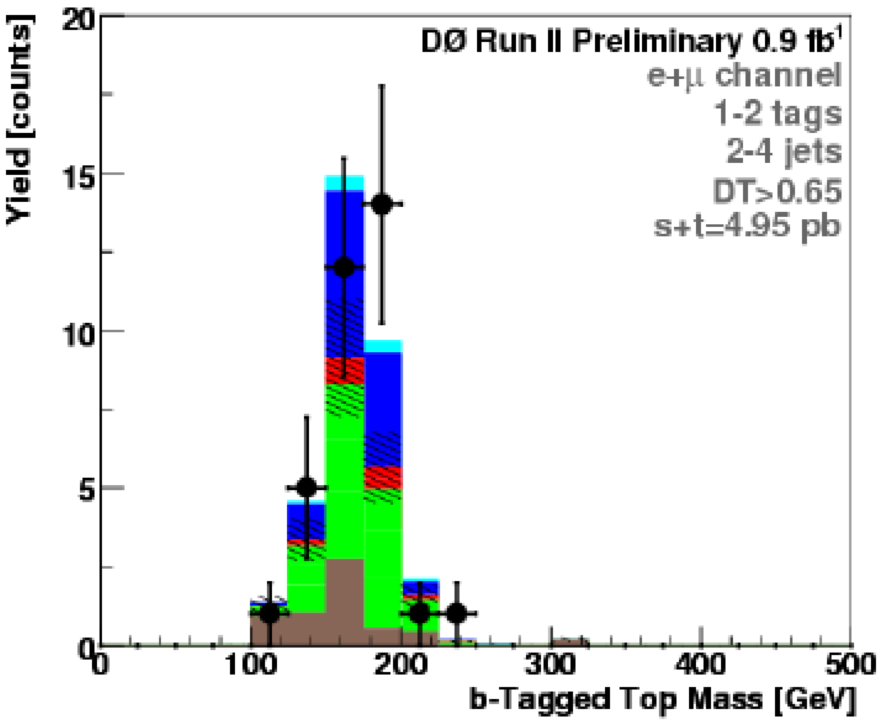
$DT < 0.3$



$DT > 0.55$



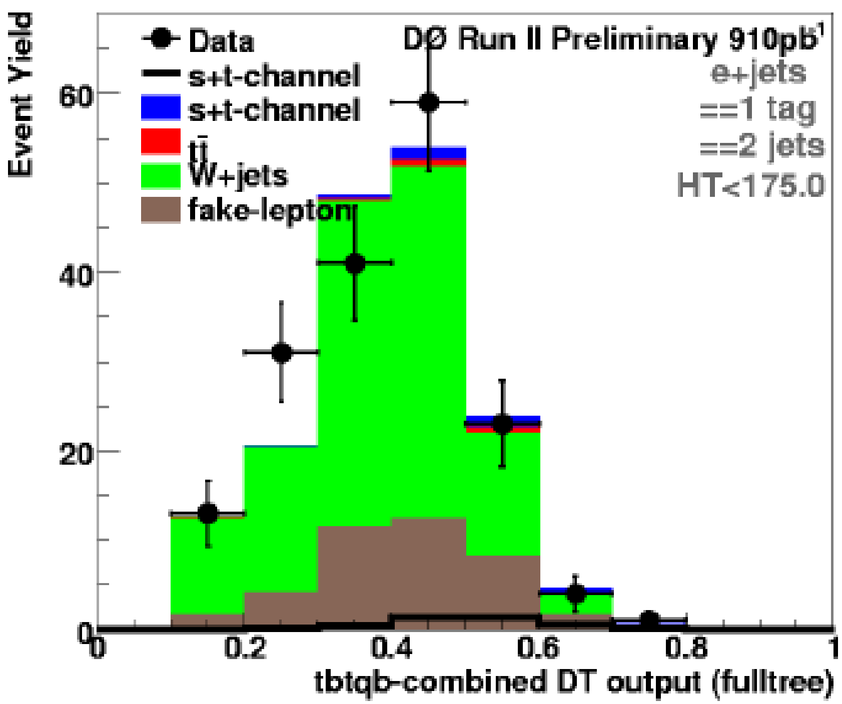
$DT > 0.65$

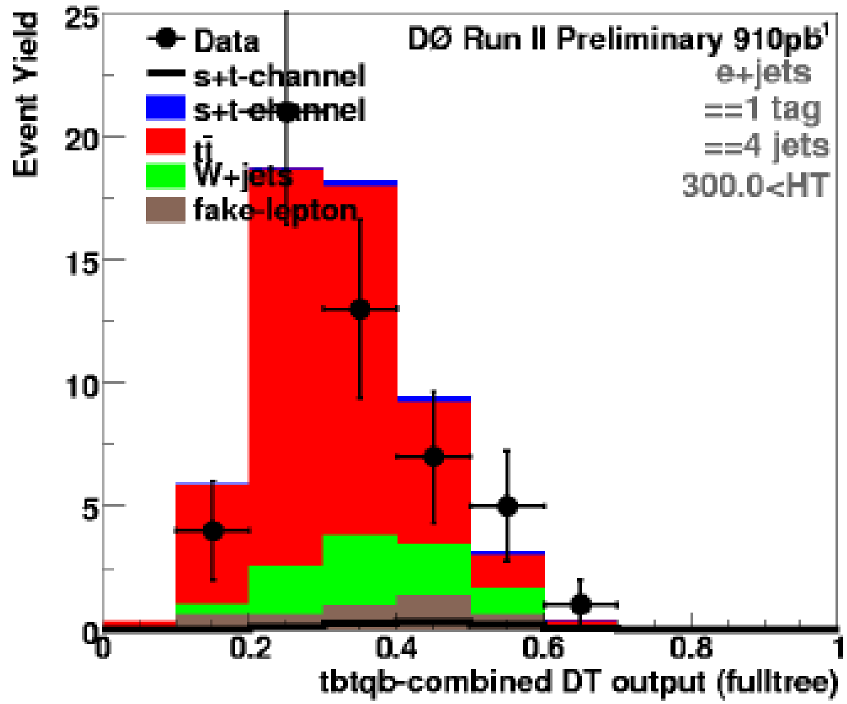


- Excess in high DT output region.

Cross-check samples

- "W+jets": =2jets, H_T(lepton,$\not\!\!E_T$,alljets) < 175 GeV
- "ttbar": =4jets, H_T(lepton,$\not\!\!E_T$,alljets) > 300 GeV
- Shown: $tb+tqb$ DT output for e+jets



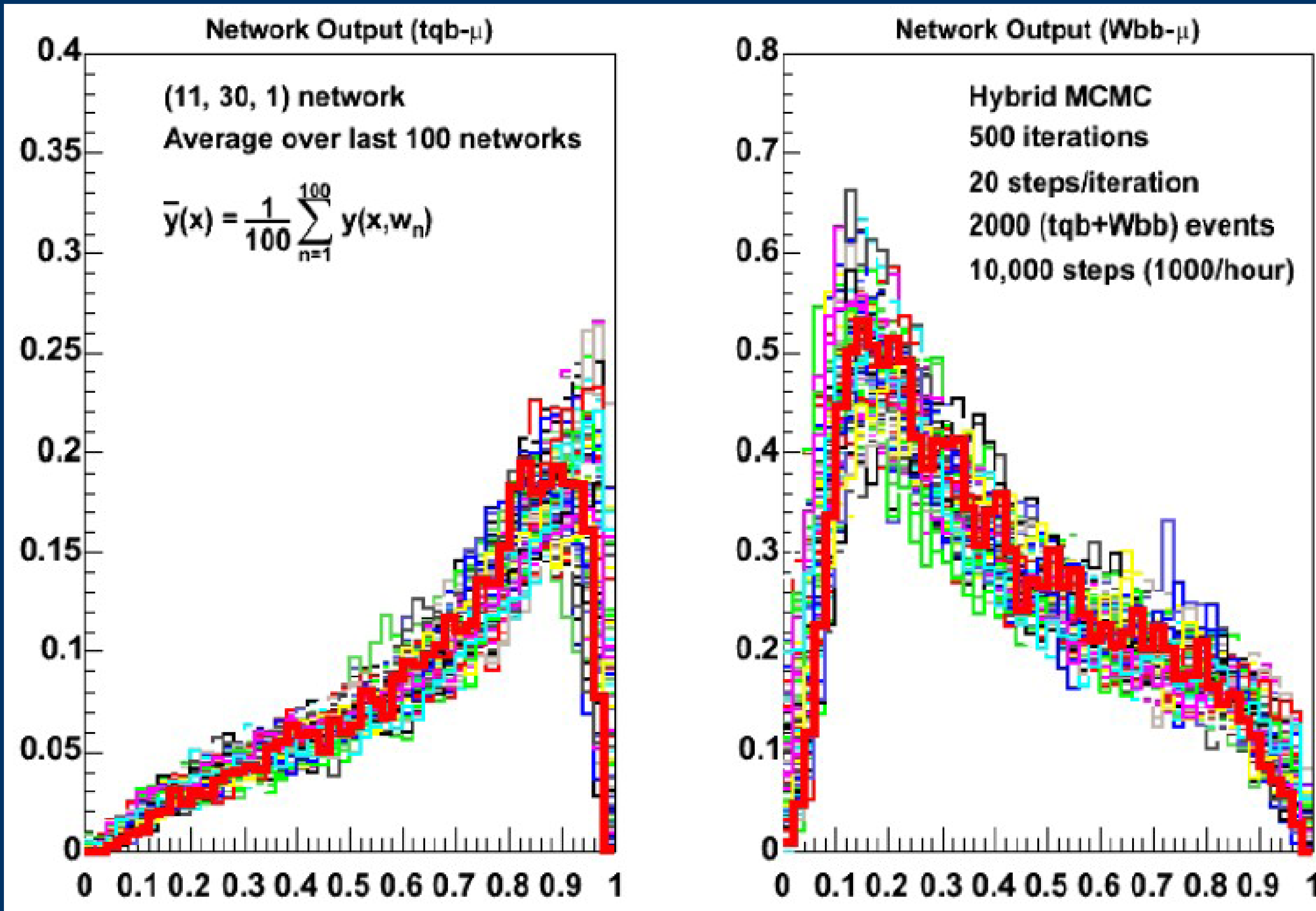


- Good agreement of model with data

Bayesian Neural Network - Introduction

- A different sort of neural network:
  - Instead of choosing one set of weights, find posterior probability density over all possible weights
  - Averaging over many networks weighted by the probability of each network given the training data
  - Less prone to overtraining
  - For details see: http://www.cs.toronto.edu/radford/fbm.software.html
- Use 24 variables (subset of DT variables)

BNN output for tqb (left) and Wbb (right) events



Matrix Elements Method - Introduction

A matrix elements analysis takes a very different approach:

- Use the 4-vectors of all reconstructed leptons and jets
- Use matrix elements of main signal and background diagrams to compute an event probability density for signal and background hypotheses.
- Goal: calculate a discriminant:

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

- Define P_{Signal} as properly normalized differential cross section

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

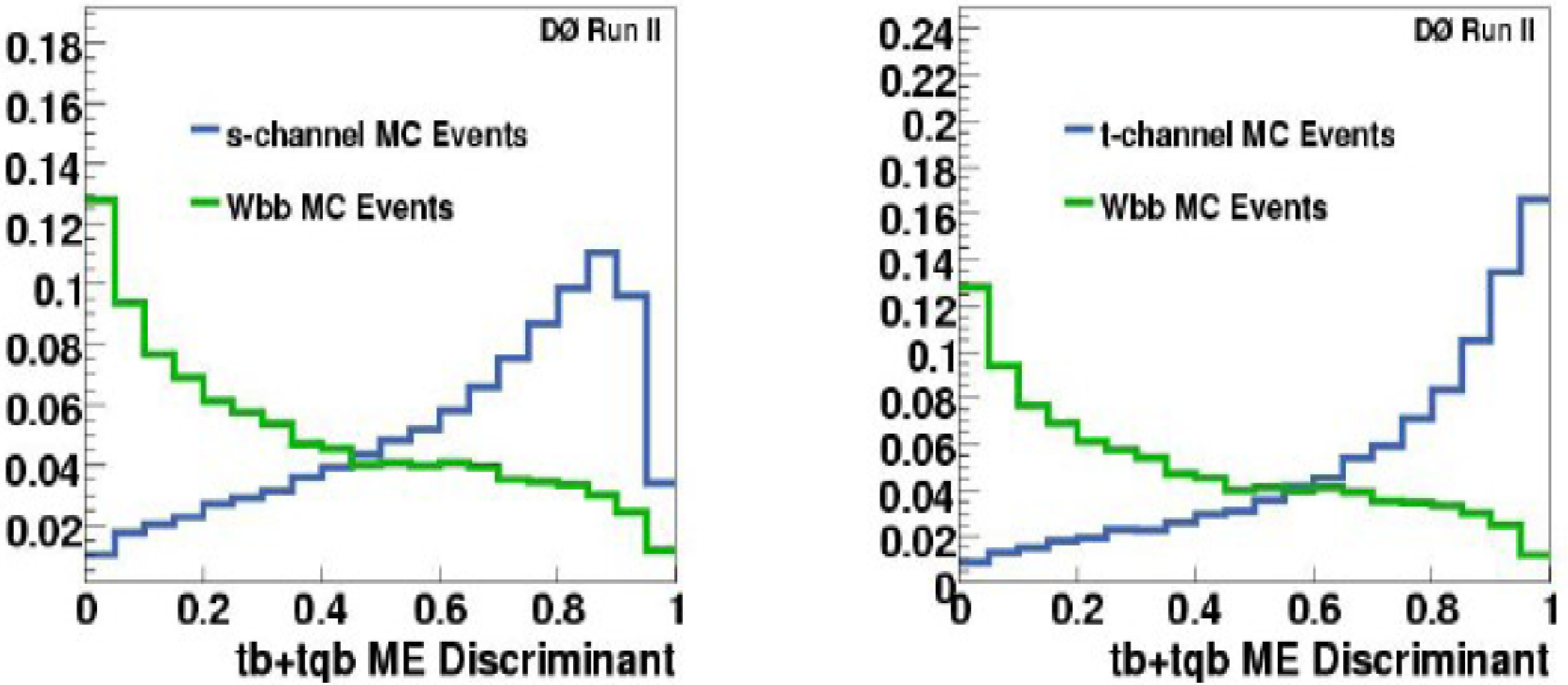
Parton distribution functions CTEQ6

Differential cross section (LO ME from Madgraph)

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

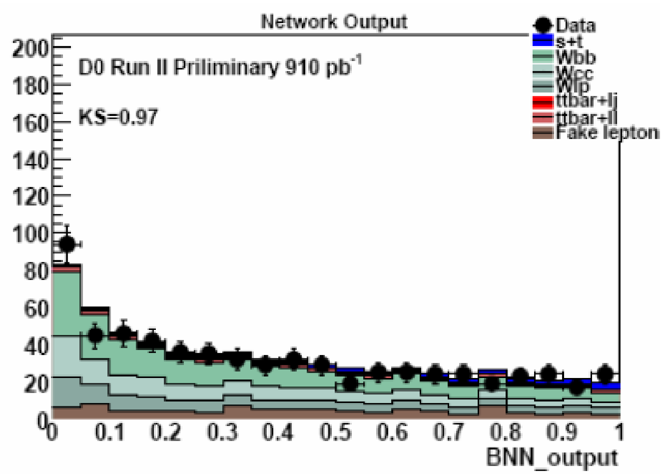
- Shared technology with mass measurement in $t\bar{t}$(eg. transfer functions)

Matrix Element Discriminant

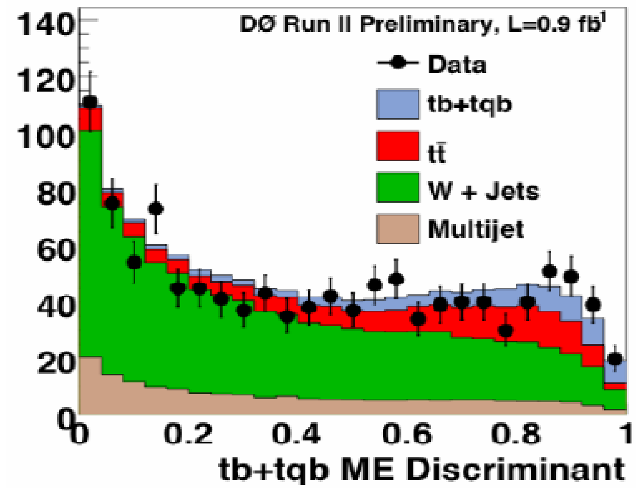


Распределение событий в суммарных дискриминантах в e и mu каналах анализа

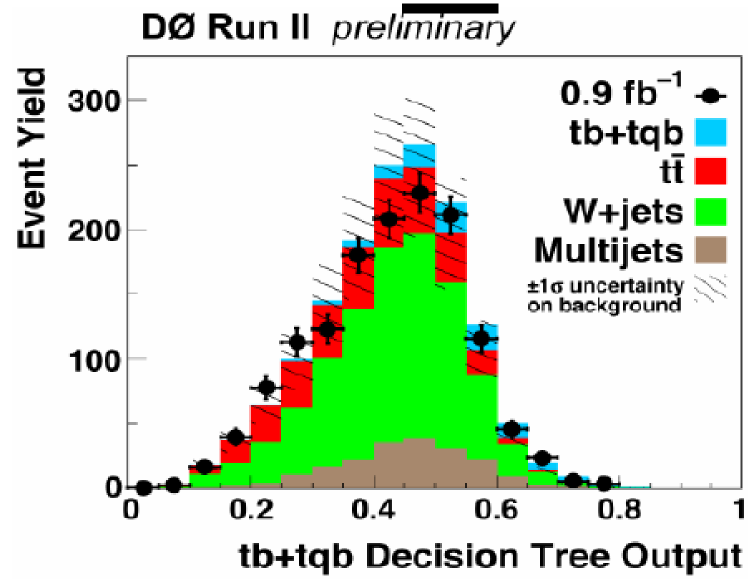
BNN

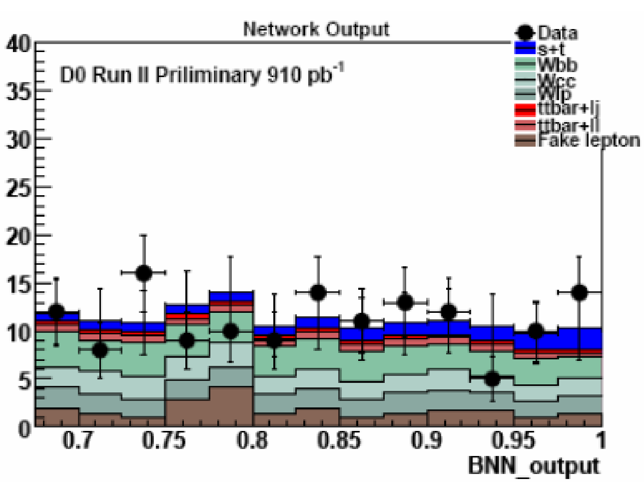


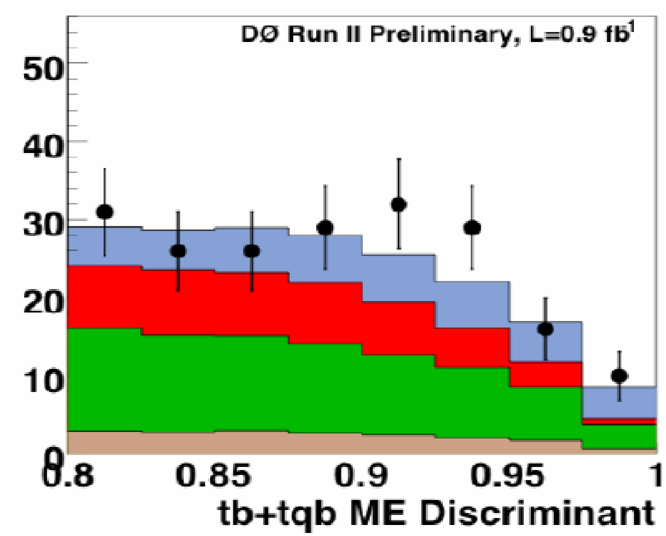
ME

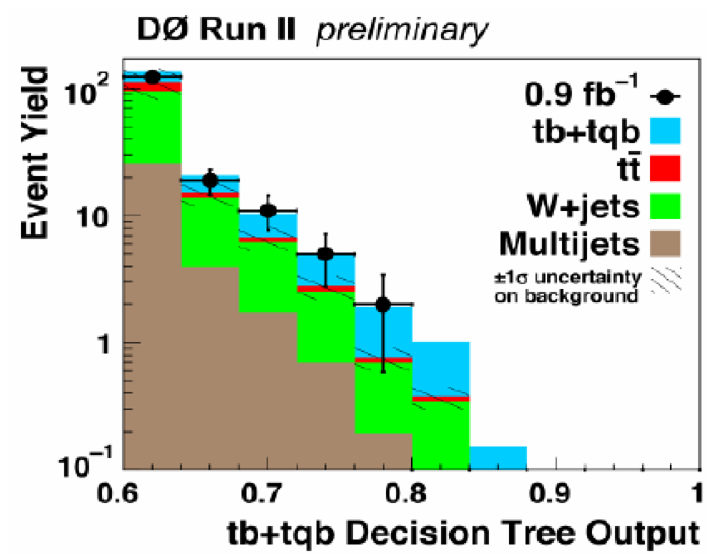


DT







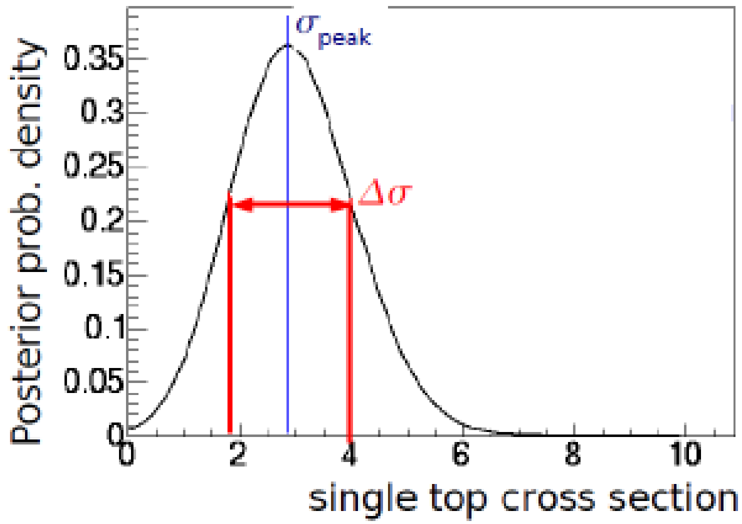


Measuring the Cross Section

Probability to observe data distribution D, expecting y:

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

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



The cross section is obtained

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

- Bayesian posterior probability density
- 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 of this machinery is working properly we test with many sets of **pseudo-data**.
- Wonderful tool to test analysis methods! Run DØ experiment 1000s of times!
- Generated ensembles include:
  1. 0-signal ensemble ($s + t\ \sigma = 0pb$)
  2. SM ensemble ($s + t\ \sigma = 2.9pb$)
  3. "Mystery" ensembles to test analyzers ($s + t\ \sigma = ??pb$)
  4. Ensembles at measured cross section ($s + t\ \sigma =$measured)
  5. A high luminosity ensemble
- Each analysis tests linearity of "response" to single top.

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
- Randomly sample from a Poisson distribution about the total yield
- Generate a set of pseudo-data (a member of the ensemble)
- Pass the pseudo-data through the full analysis chain (including systematic uncertainties)

Significance/Sensitivity Determination

We use our 0-signal ensemble to determine a significance for each measurement.

Expected p-value

The fraction of 0-signal pseudo-datasets in which we measure at least 2.9pb.

Observed p-value

The fraction of 0-signal pseudo-datasets in which we measure at least the measured cross section.

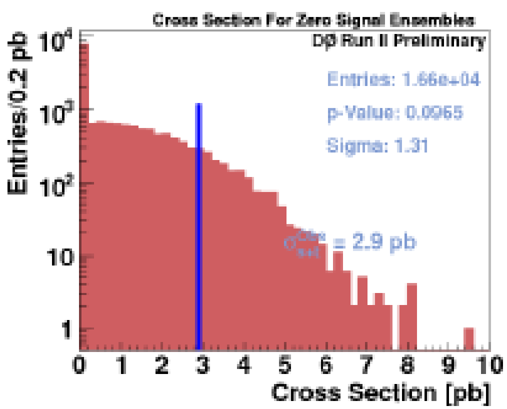
We also can use the SM ensemble to see how compatible our measured value is with the SM.

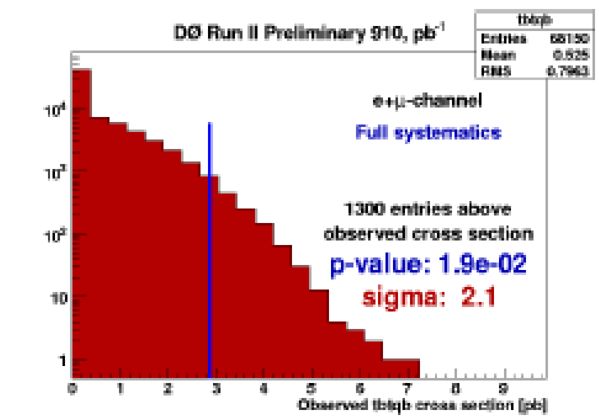
Expected p-value $s + t$

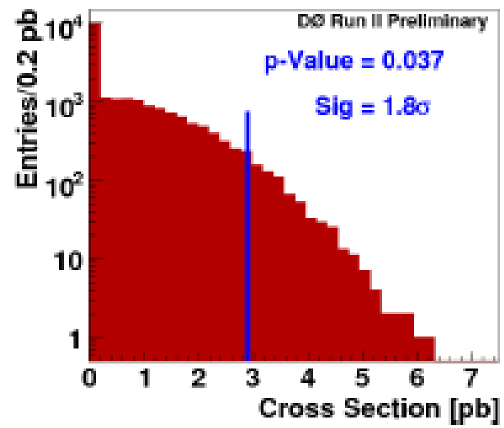
Decision Trees
p-value **1.9%**

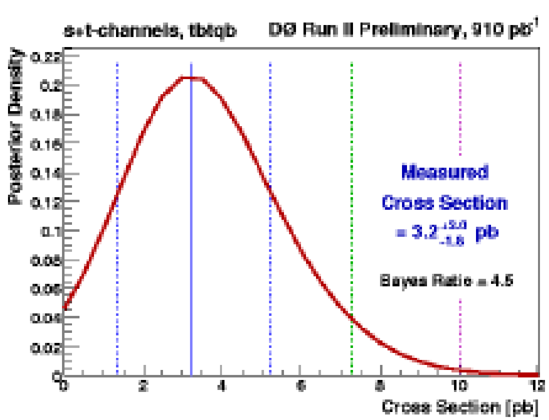
Matrix Elements
p-value **3.7%**

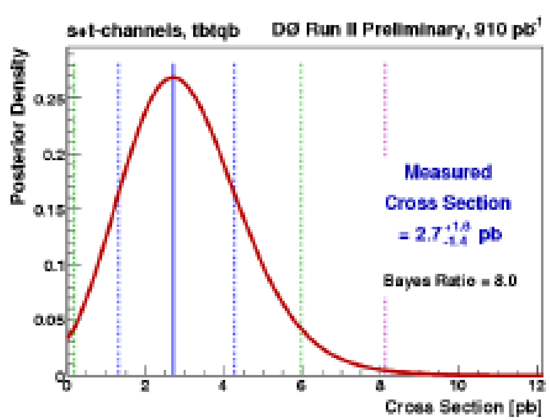
Bayesian NN
p-value **9.7%**

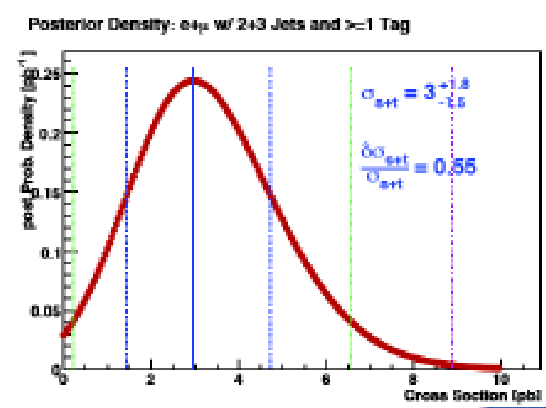




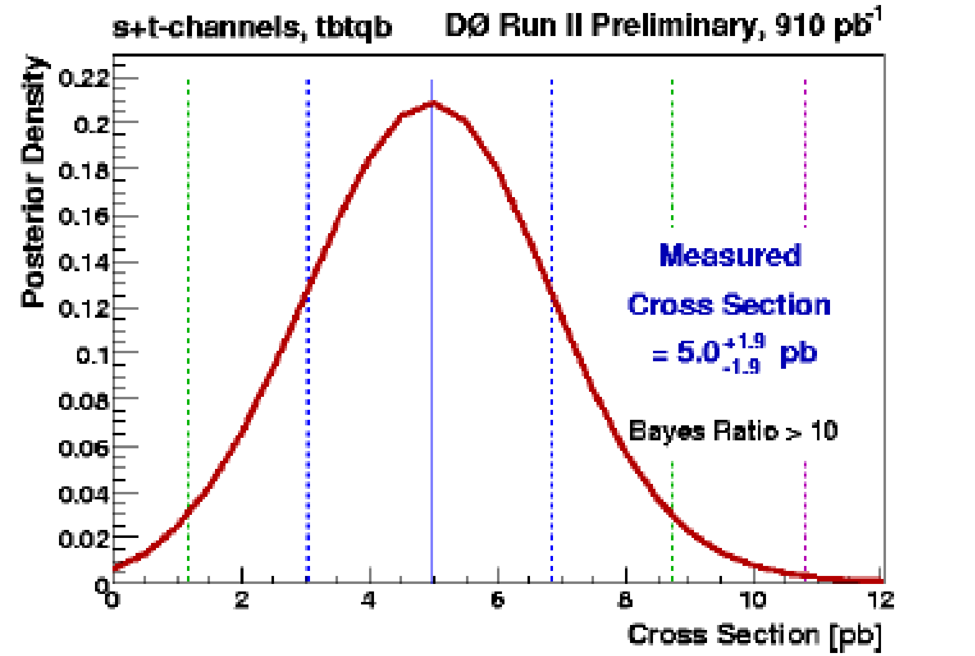


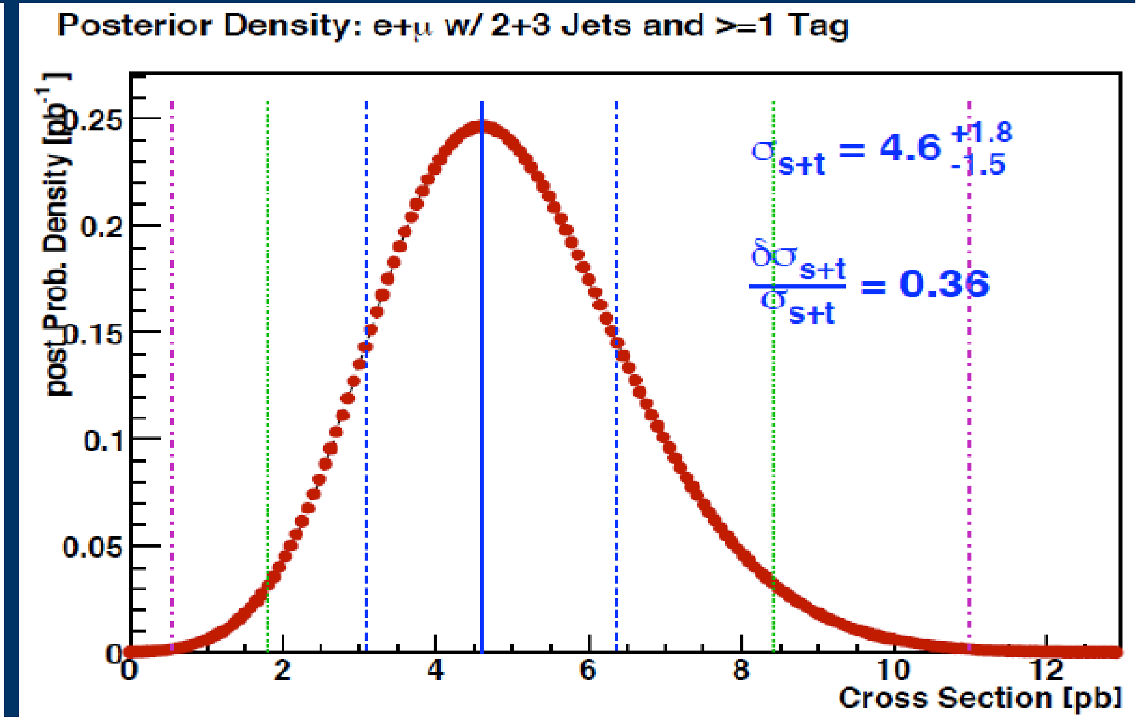


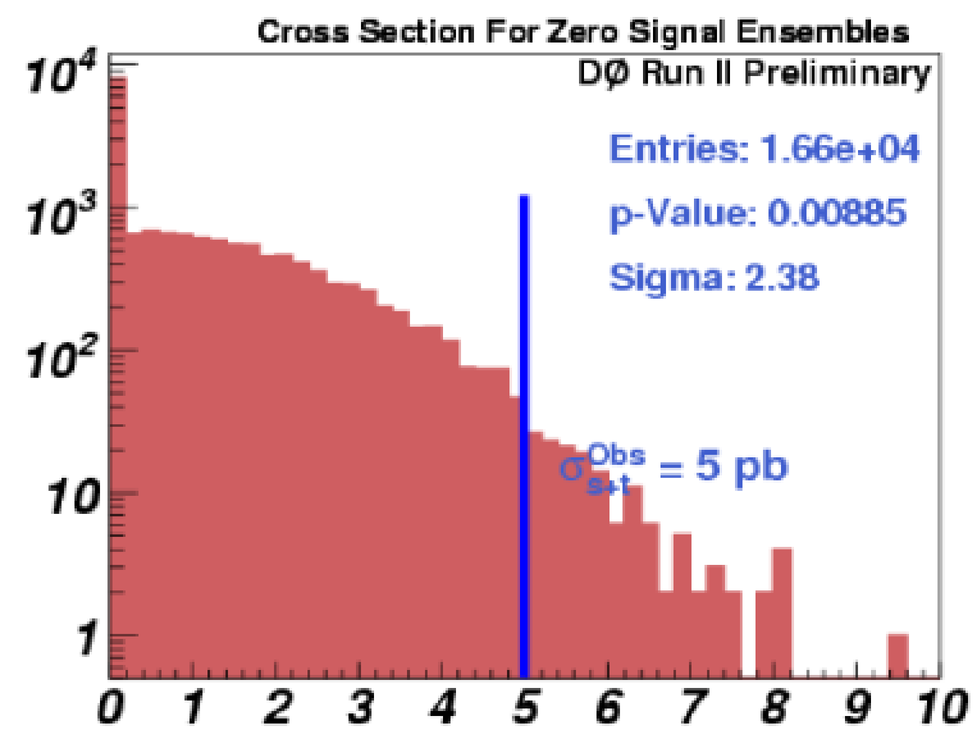


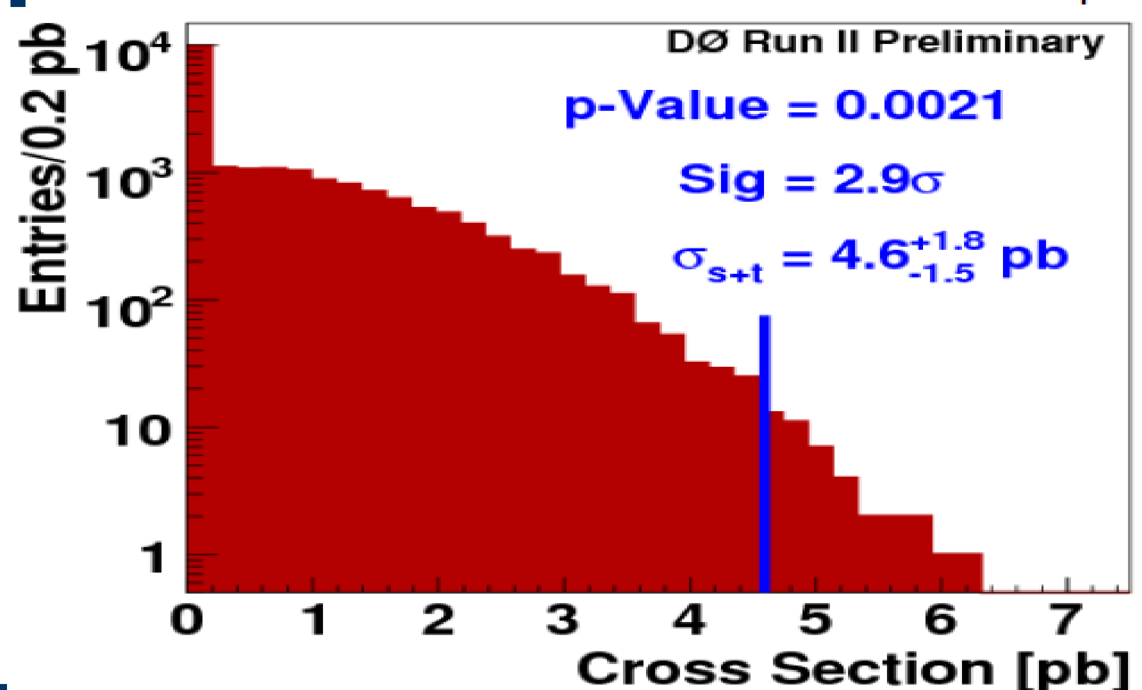


OBSERVED: Bayes NN Matrix Elements

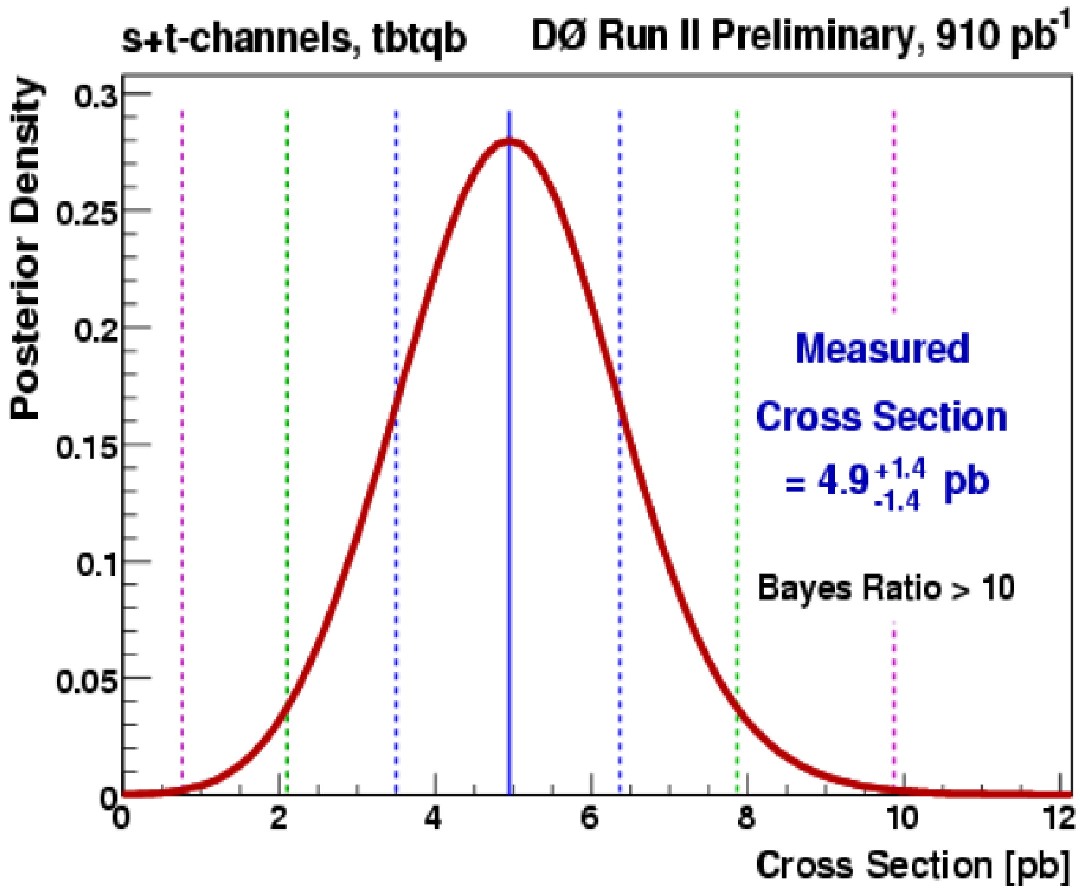


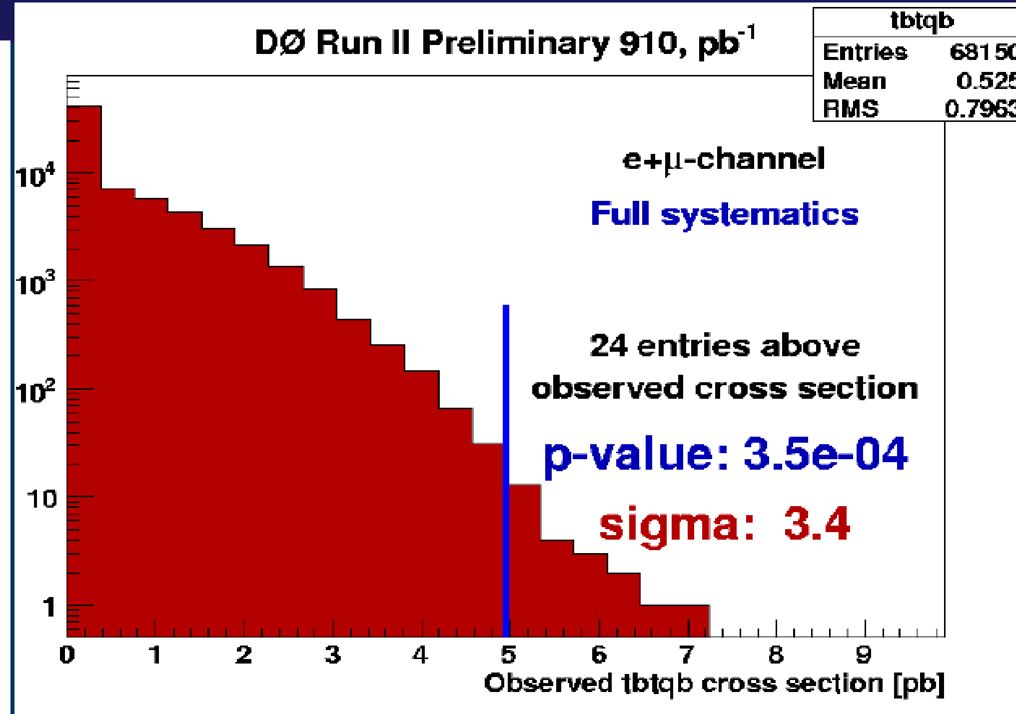


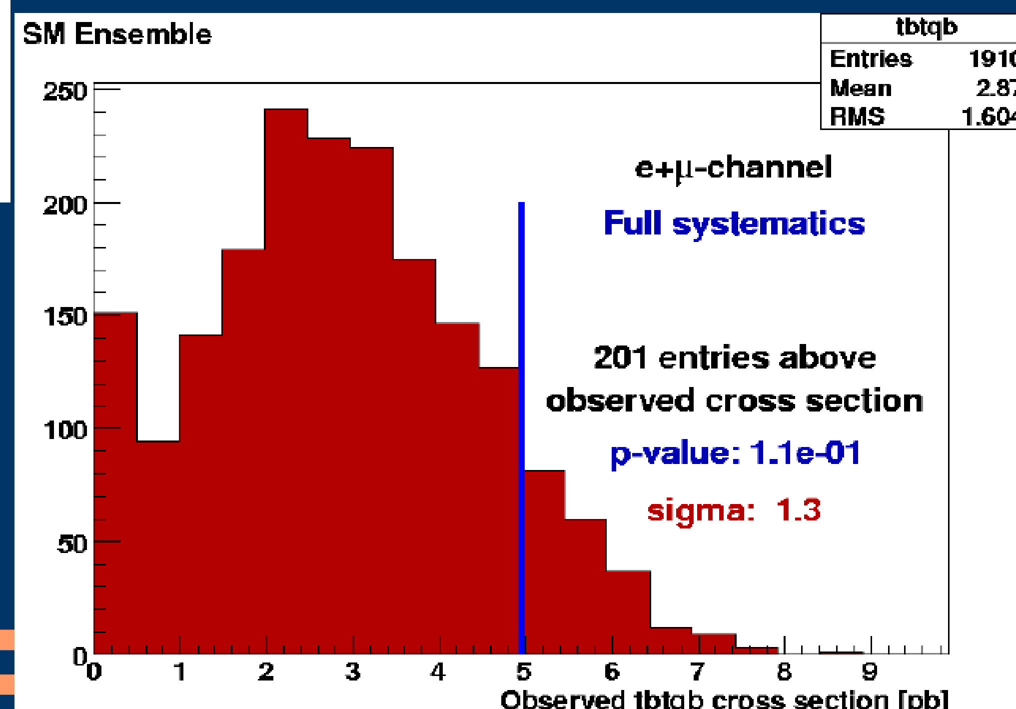




Decision Trees - Observed





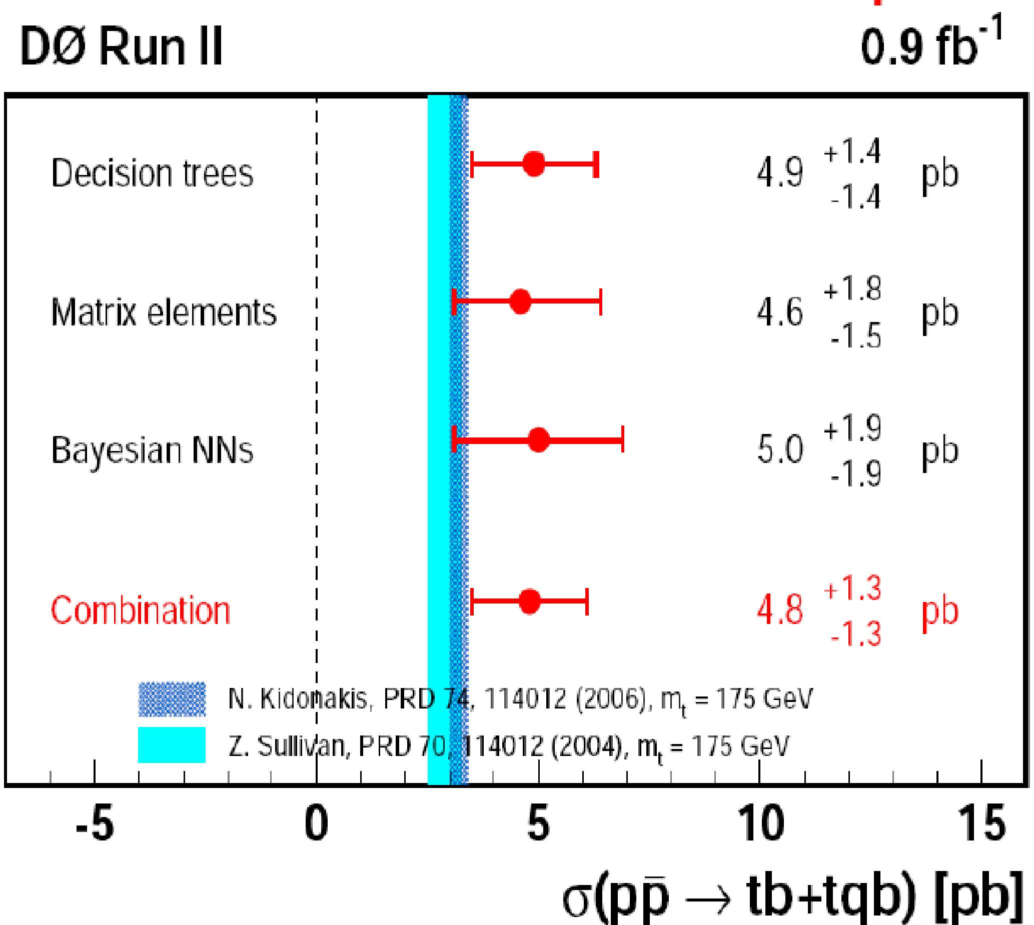


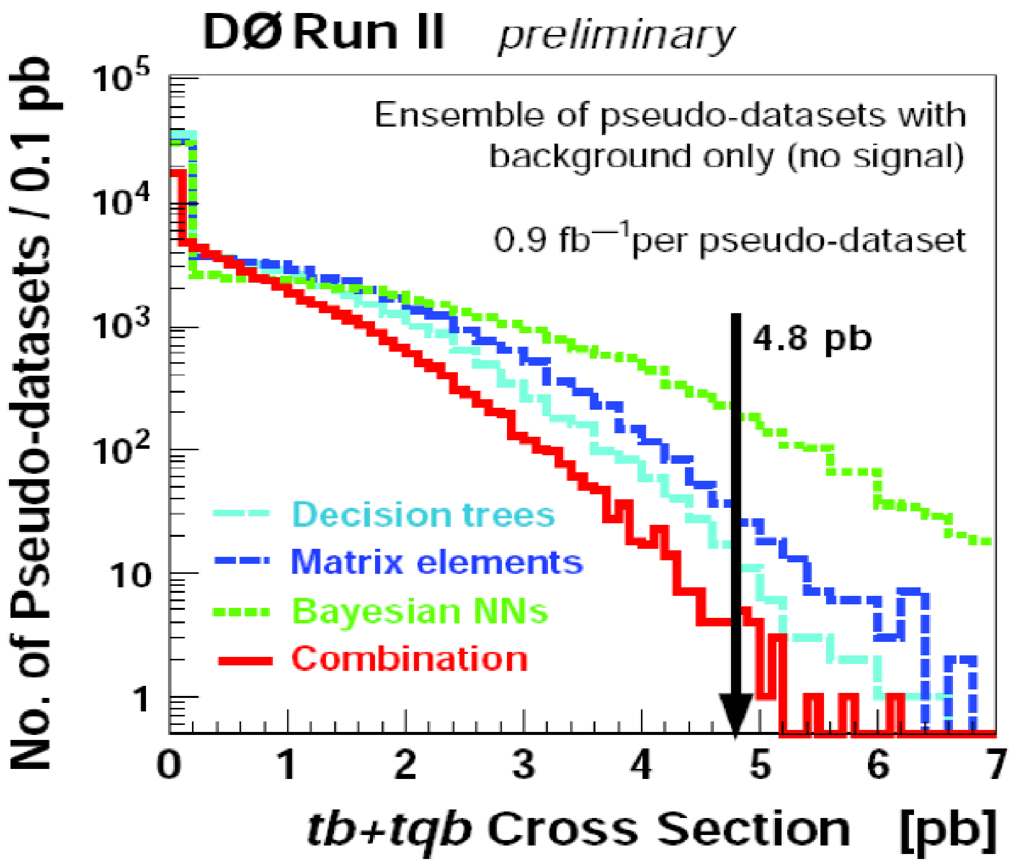
Combination of DT, ME, BNN analysis

- Combine the three measurements with BLUE method
- Method requires to measure the correlations
- Used SM pseudo-datasets with systematics

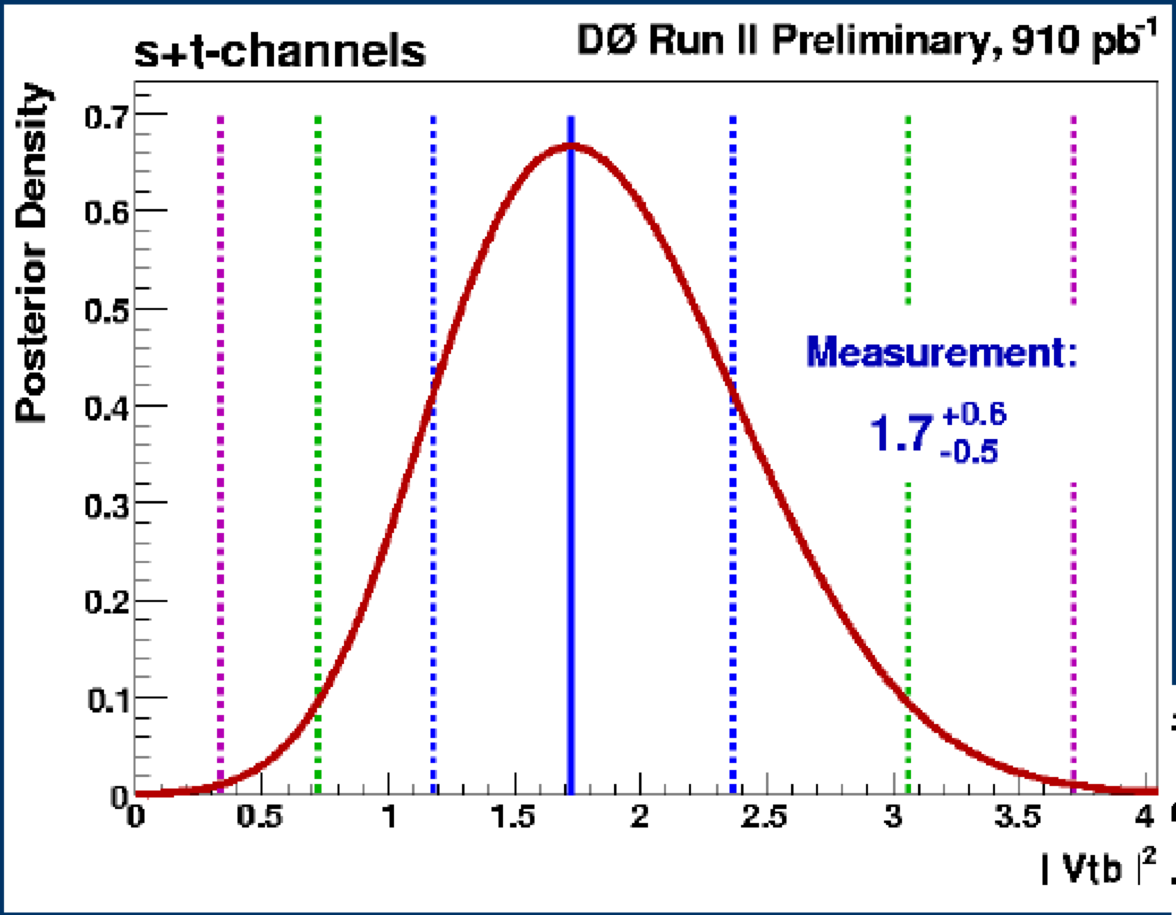
$$\rho = \begin{array}{c} \begin{array}{cccc} DT & ME & BNN & \end{array} \\ \begin{pmatrix} 1 & 0.57 & 0.51 & DT \\ 0.57 & 1 & 0.45 & ME \\ 0.51 & 0.45 & 1 & BNN \end{pmatrix} \end{array}$$

Combined result: 4.8 ± 1.3 pb ➔ Significance of 3.5 std. dev.





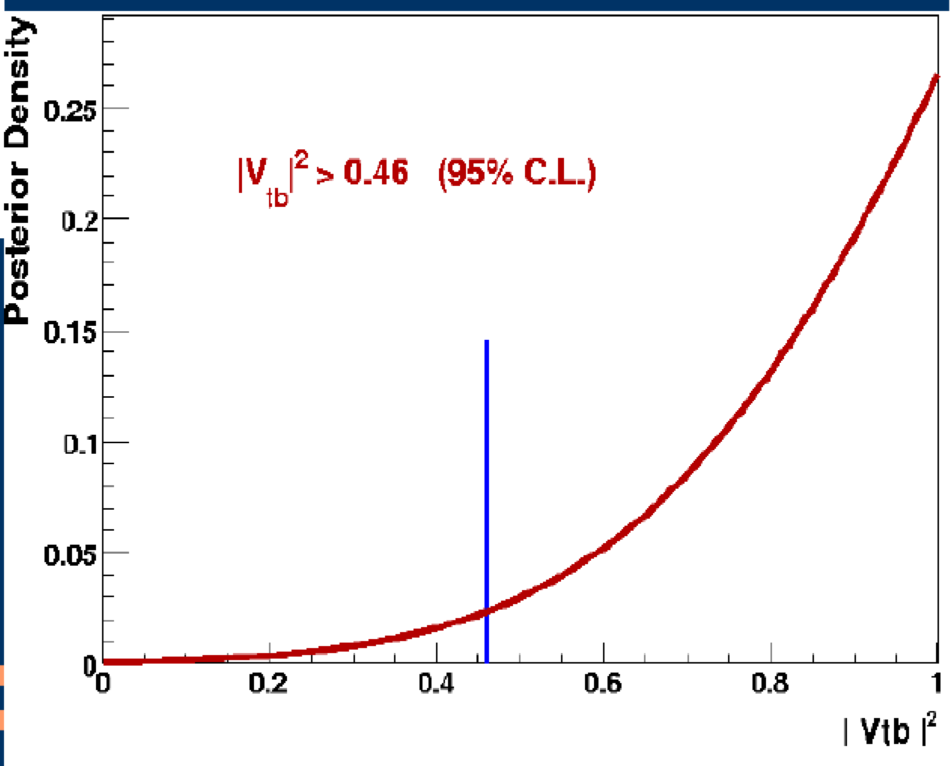
Measuring $|V_{tb}|^2$



First direct measurement:

|Vtb| = 1.3 +/- 0.2

Constrain |Vtb| to physical region and integrate:



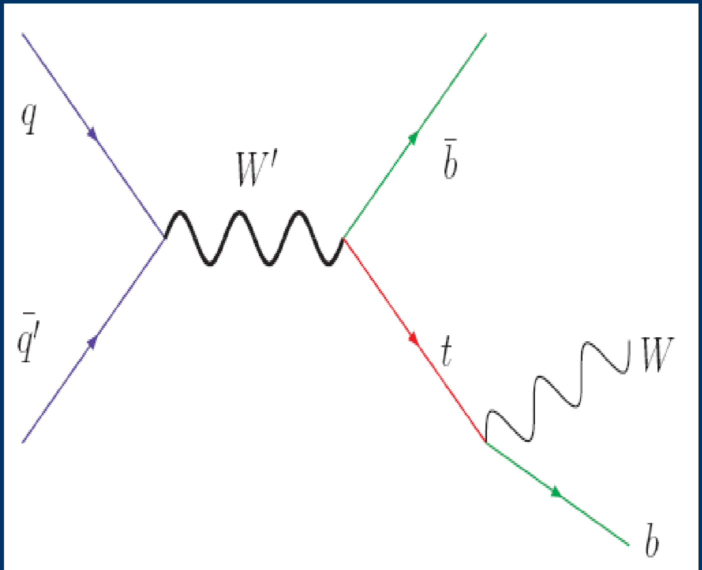
$$|V_{tb}| > 0.68$$

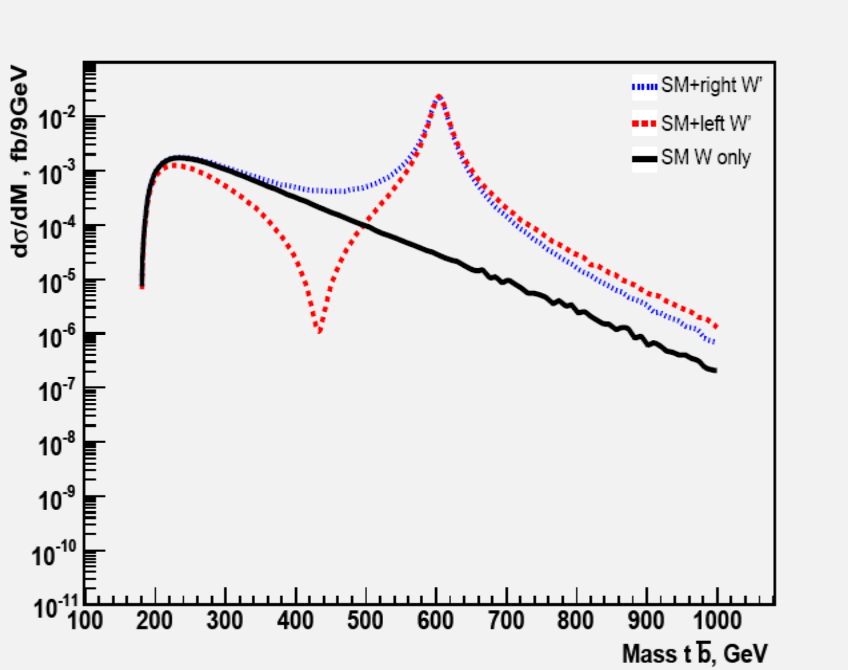
$$|V_{tb}| = 1.00^{-0.12}_{+0}$$

Поиск W' бозона

$$\mathcal{L} = \frac{V_{q_i q_j}}{2\sqrt{2}} g_w \overline{q}_i \gamma_\mu \left(a^R_{q_i q_j}(1+\gamma^5) + a^L_{q_i q_j}(1-\gamma^5)\right) W' q_j + \text{H.c.}\,,$$

The notations are taken such that for so-called SM-like W' $a^L_{q_i q_j} = 1$ and $a^R_{q_i q_j} = 0$.





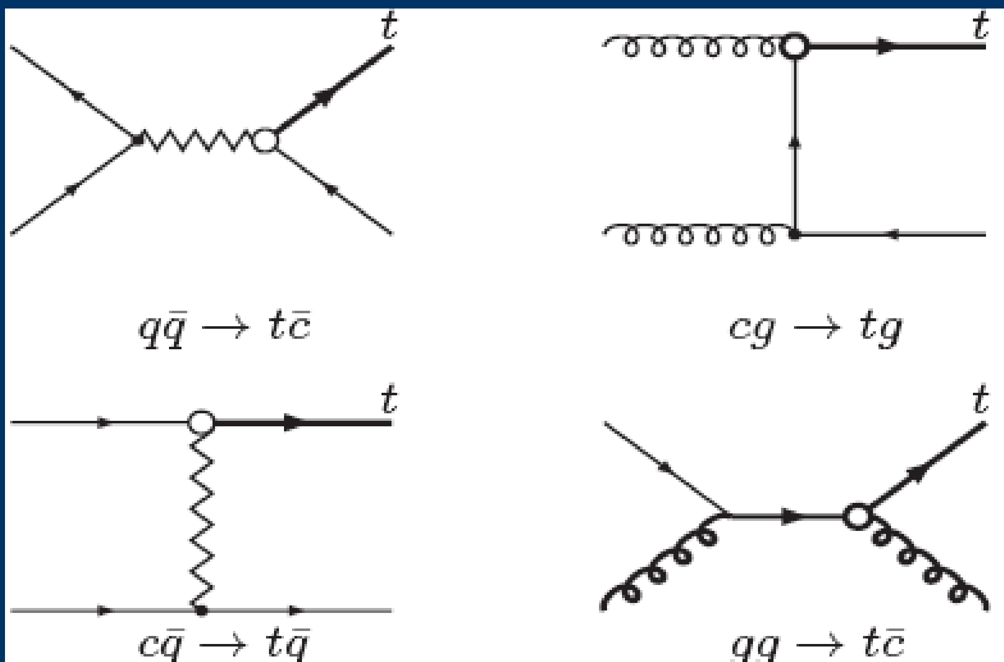
Ограничения на массу W' полученные D0 коллаборацией на статистике 230 пб$^{-1}$: M(W')> 610 (670) ГэВ R(L)

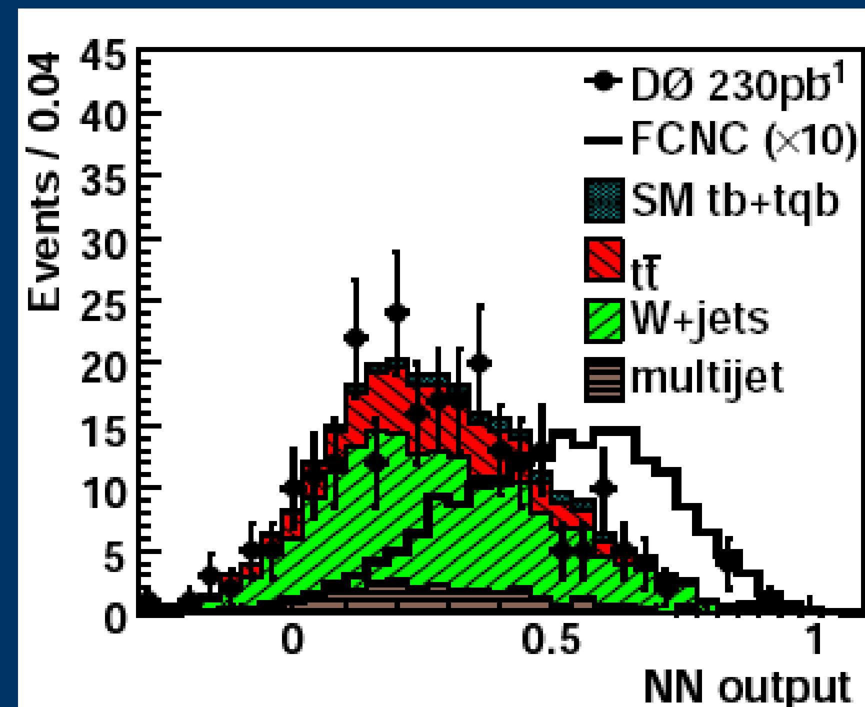
Phys.Lett.B641:423-431,2006; hep-ph/0610080

Поиск нейтральных токов (FCNC)

- Couplings: tqg, $tq\gamma$, tqZ, where $q = u, c$

$$\Delta\mathcal{L}^{eff} = \frac{1}{\Lambda}\left[\kappa_{tq}^{\gamma,Z} e\bar{t}\sigma_{\mu\nu}qF^{\mu\nu}_{\gamma,Z} + \kappa_{tq}^{g} g_s\bar{t}\sigma_{\mu\nu}\frac{\lambda^i}{2}qG^{i\mu\nu}\right] + h.c.$$





Ограничения на FCNC связи полученные коллаборацией D0 на статистике 230 пб$^{-1}$ (hep-ex/0702005):

$\kappa_g^c/\Lambda < 0.15\ \mathrm{TeV}^{-1}$ $\kappa_g^u/\Lambda < 0.037\ \mathrm{TeV}^{-1}$

Conclusion

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

(hep-ex/0612052 submitted to PRL)

$$\sigma(s+t) = 4.8 \pm 1.3 \text{ pb}$$

3.5σ significance!

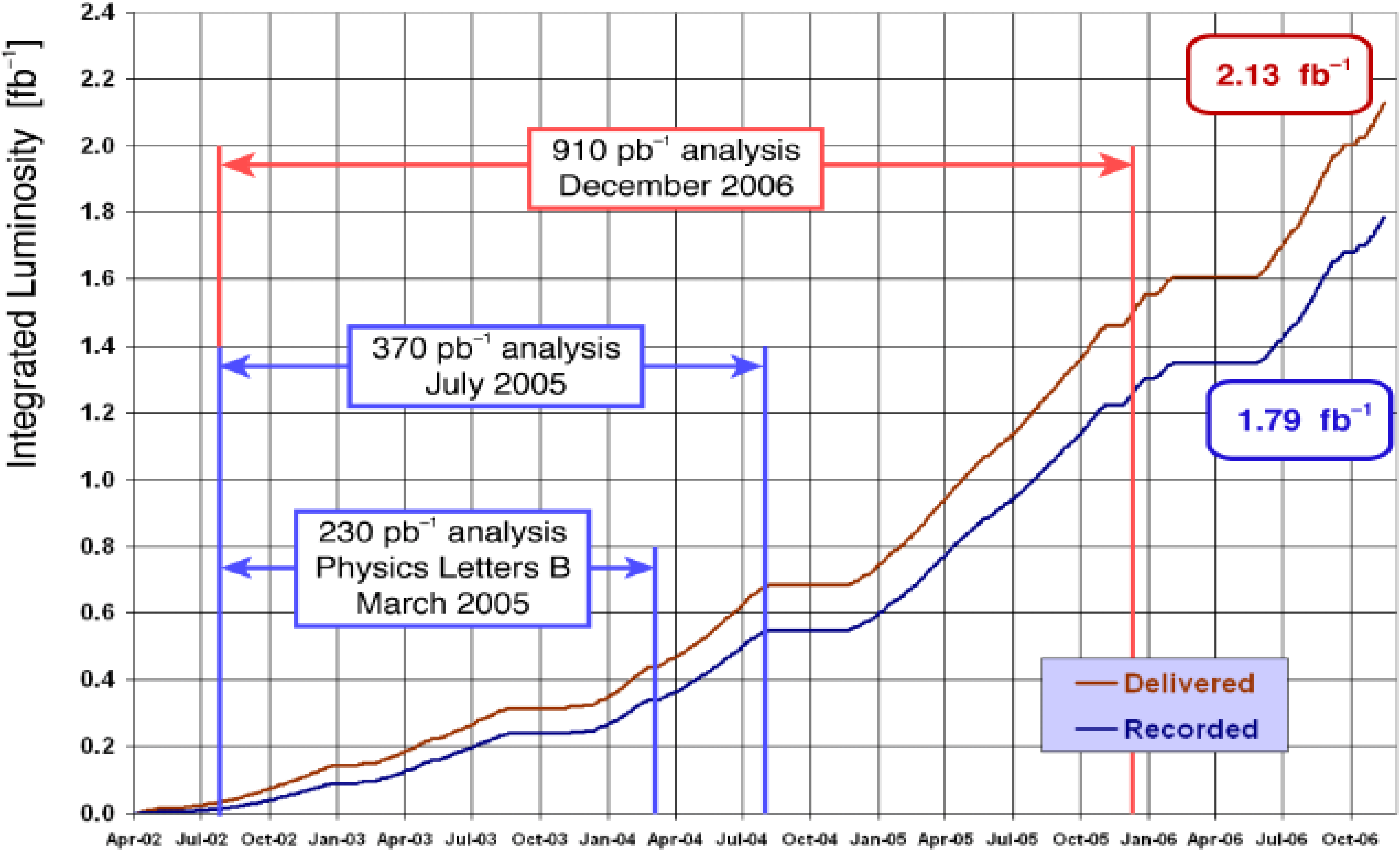
$$|V_{tb}| > 0.68 \text{ @ } 95\%\text{C.L.}$$

- Challenging analysis: small signal hidden in huge complex background
- Expand to searches of new phenomena
- We now have double the data to analyze!

BackUp Slides

Run II Integrated Luminosity

Apr 2002 – Dec 2006



Many thanks to the Accelerator Division

Event Selection

- Good data quality
- Pass trigger
- Good primary vertex
- $15 < \not{E}_T < 200$ GeV
- 2-4 jets with $p_T > 15$ GeV and $|\eta_{det}| < 3.4$
- Leading jet with $p_T > 25$ GeV and $|\eta_{det}| < 2.5$
- Second leading jet $p_T > 20$ GeV
- Triangle cuts in $\Delta\phi(jet1, \not{E}_T)$ vs $\not{E}_T$ and $\Delta\phi(\ell, \not{E}_T)$ vs $\not{E}_T$ planes
- Only one tight and no other loose lepton
  - electron: $p_T > 15$ GeV and $|\eta_{det}| < 1.1$
  - muon: $p_T > 18$ GeV and $|\eta_{det}| < 2$

Signature

- isolated lepton
- 2-4 jets
- $\not{E}_T$
- at least 1 b-jet

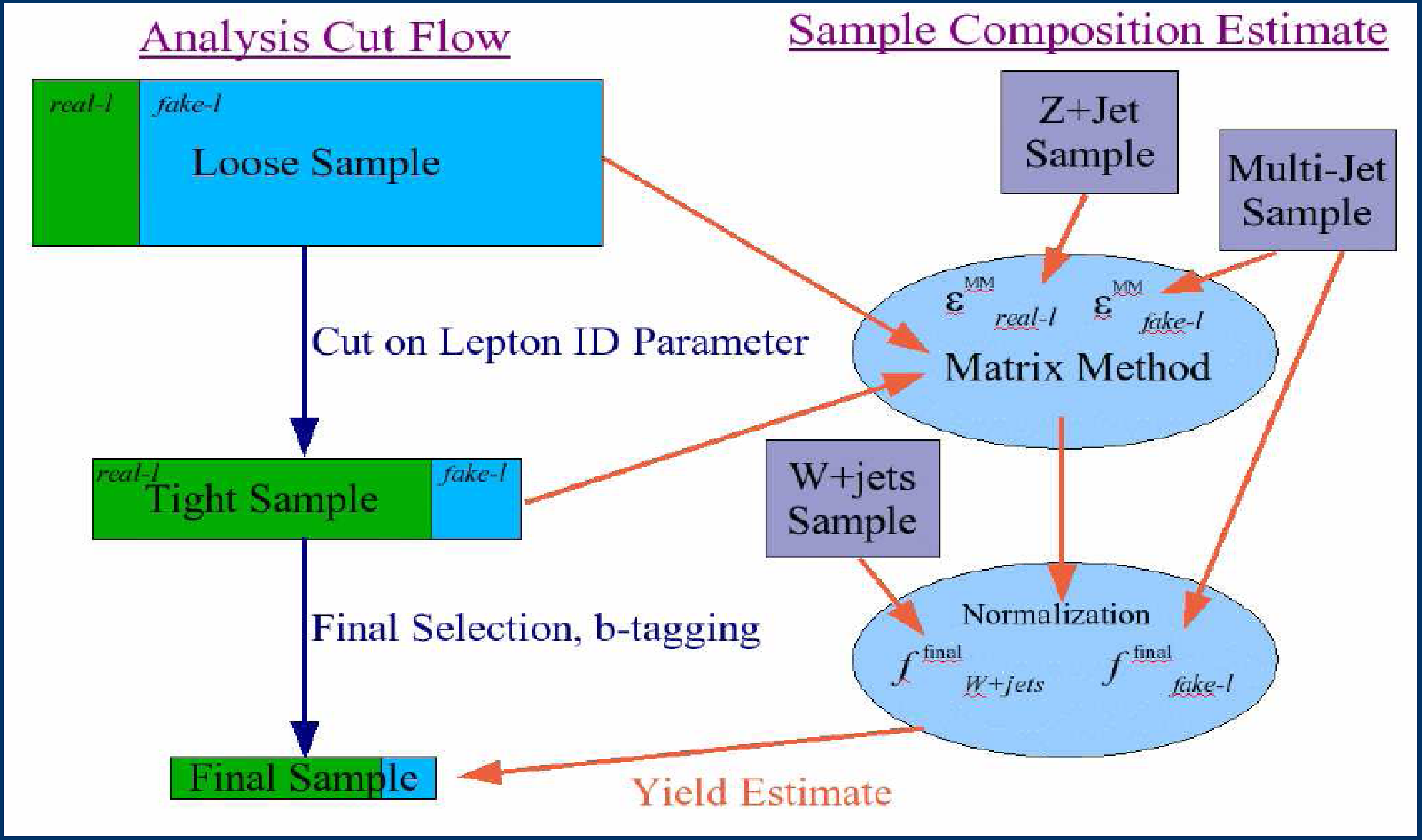
Монте-Карло события

The Monte Carlo Event Sets

Event Type	Cross Section [pb]	Branching Fraction	Number of Events	Int. Lum. [fb^{-1}]
Signals				
$tb \to e$+jets	0.88 ± 0.14	0.1111 ± 0.0022	92,620	804
$tb \to \mu$+jets	0.88 ± 0.14	0.1111 ± 0.0022	122,346	666
$tb \to \tau$+jets	0.88 ± 0.14	0.1111 ± 0.0022	76,433	1,066
$tqb \to e$+jets	1.98 ± 0.30	0.1111 ± 0.0022	130,068	502
$tqb \to \mu$+jets	1.98 ± 0.30	0.1111 ± 0.0022	137,824	534
$tqb \to \tau$+jets	1.98 ± 0.30	0.1111 ± 0.0022	117,079	453
Backgrounds				
$t\bar{t} \to \ell$+jets	6.8 ± 1.2	0.4444 ± 0.0089	474,405	205
$t\bar{t} \to \ell\ell$	6.8 ± 1.2	0.1111 ± 0.0089	468,126	804
$Wb\bar{b} \to \ell\nu bb$	142	0.3333 ± 0.0066	1,335,146	42,385
$Wc\bar{c} \to \ell\nu cc$	583	0.3333 ± 0.0066	1,522,767	11,746
$Wjj \to \ell\nu jj$	18,734	0.3333 ± 0.0066	8,201,446	1,313

TABLE 3: The cross sections, branching fractions, initial numbers of events, and integrated luminosities of the Monte Carlo event samples.

Analysis Flow (left) and sample composition estimation procedure (right) to determine contributions from W+jets and fake-lepton backgrounds in analyses looking for events with a W in the final state and at least one tagged jet.



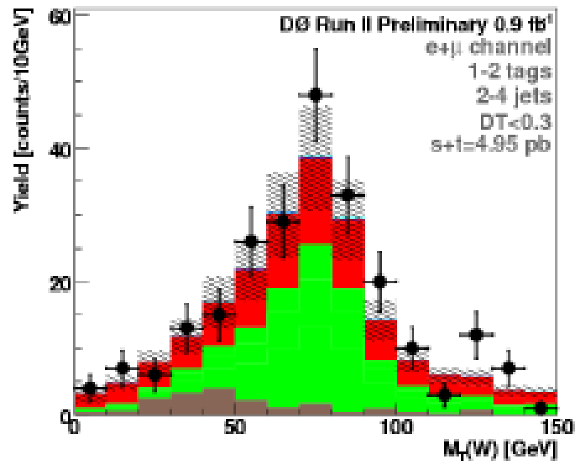
История поиска одиночного т-кварка в D0

1. 2001 Search for electroweak production of single top quarks in ppbar collisions" Phys. Rev. D 63, 031101 (2001)
2. 2001 "Search for Single Top Quark Production at DØ Using Neural Networks," Phys. Lett. **B 517**, 282 (2001).
3. 2004 "Search for Single Top Quark Production at DØ in Run II," DØ Note 4398 (2004).
4. 2005 "Improved Search for Single Top Quark Production," DØ Note 4670 (2005).
5. 2005 "Search for Single Top Quark Production in $p\overline{p}$ Collisions at $\sqrt{s} = 1.96$ TeV," Phys. Lett. **B 622**, 265 (2005).
6. 2006 "Multivariate Searches for Single Top Quark Production with the DØ Detector," submitted to Phys. Rev. D, hep-ex/0604020.

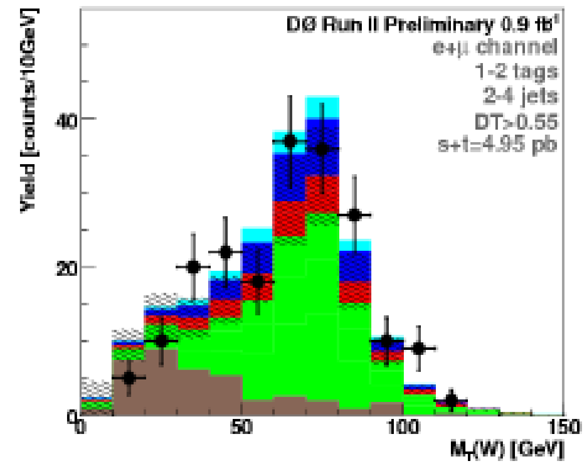
plus 7 PhDs. (CDF has a similar list)

Decision Trees - Event Characteristics M_{Tw}

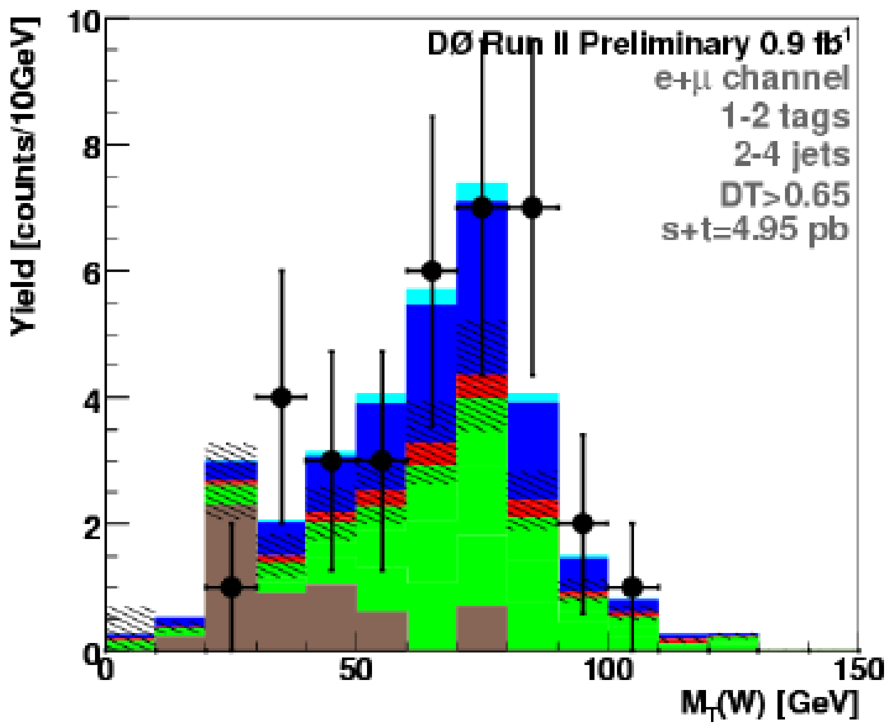
$DT < 0.3$



$DT > 0.55$



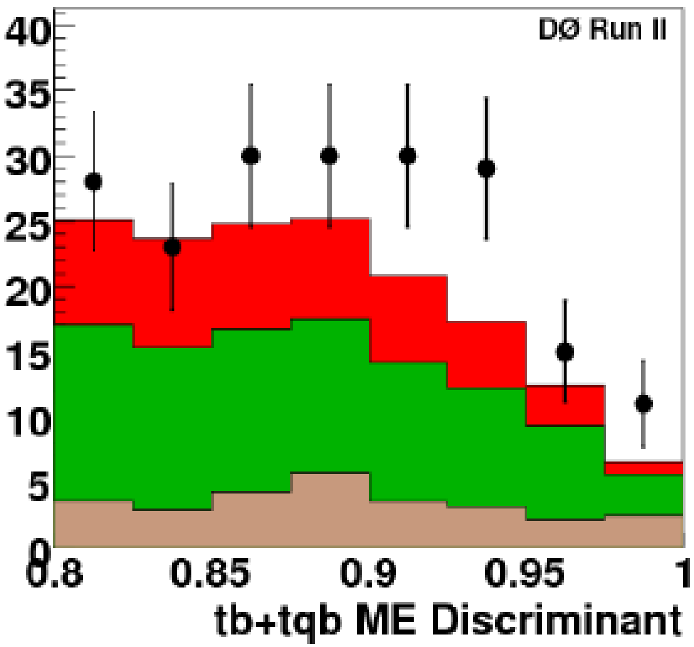
$DT > 0.65$

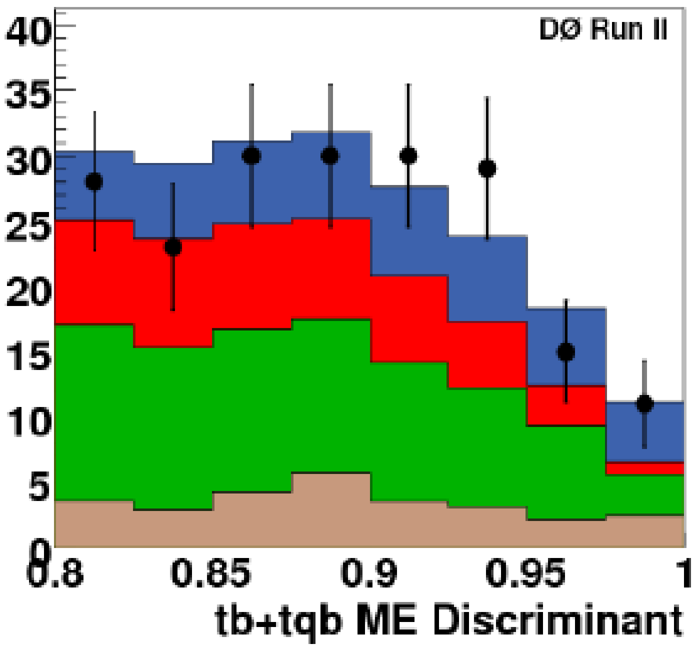


- Excess in high DT output region.

Matrix Elements Method - Observed

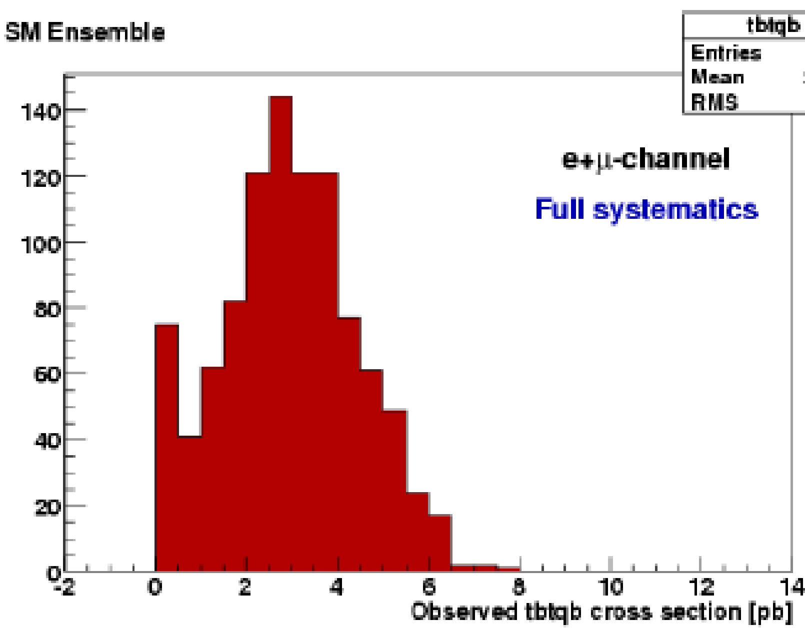
Discriminant output with and without signal component (all channels combined in 1D to "visualize" excess)

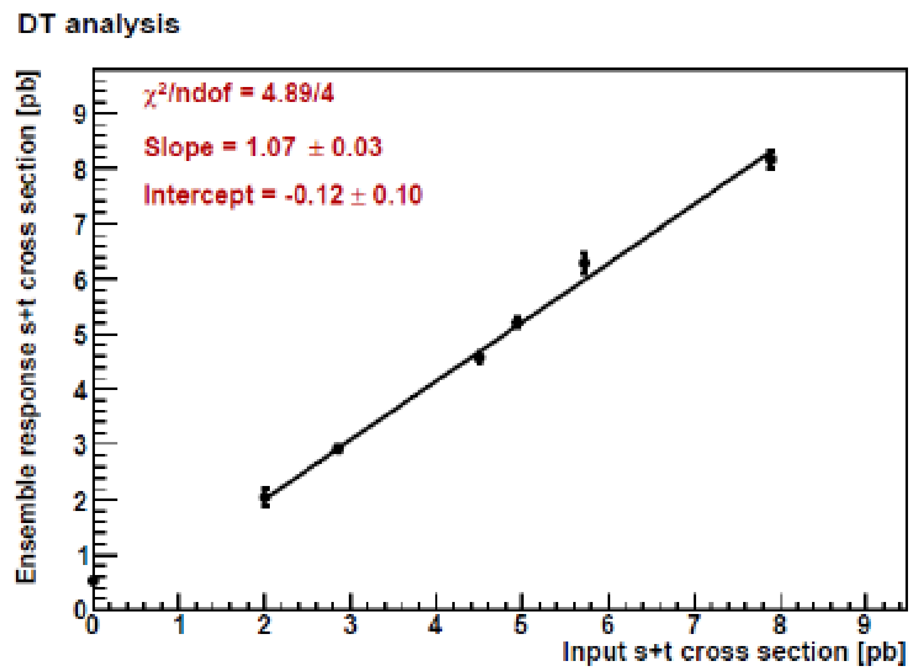




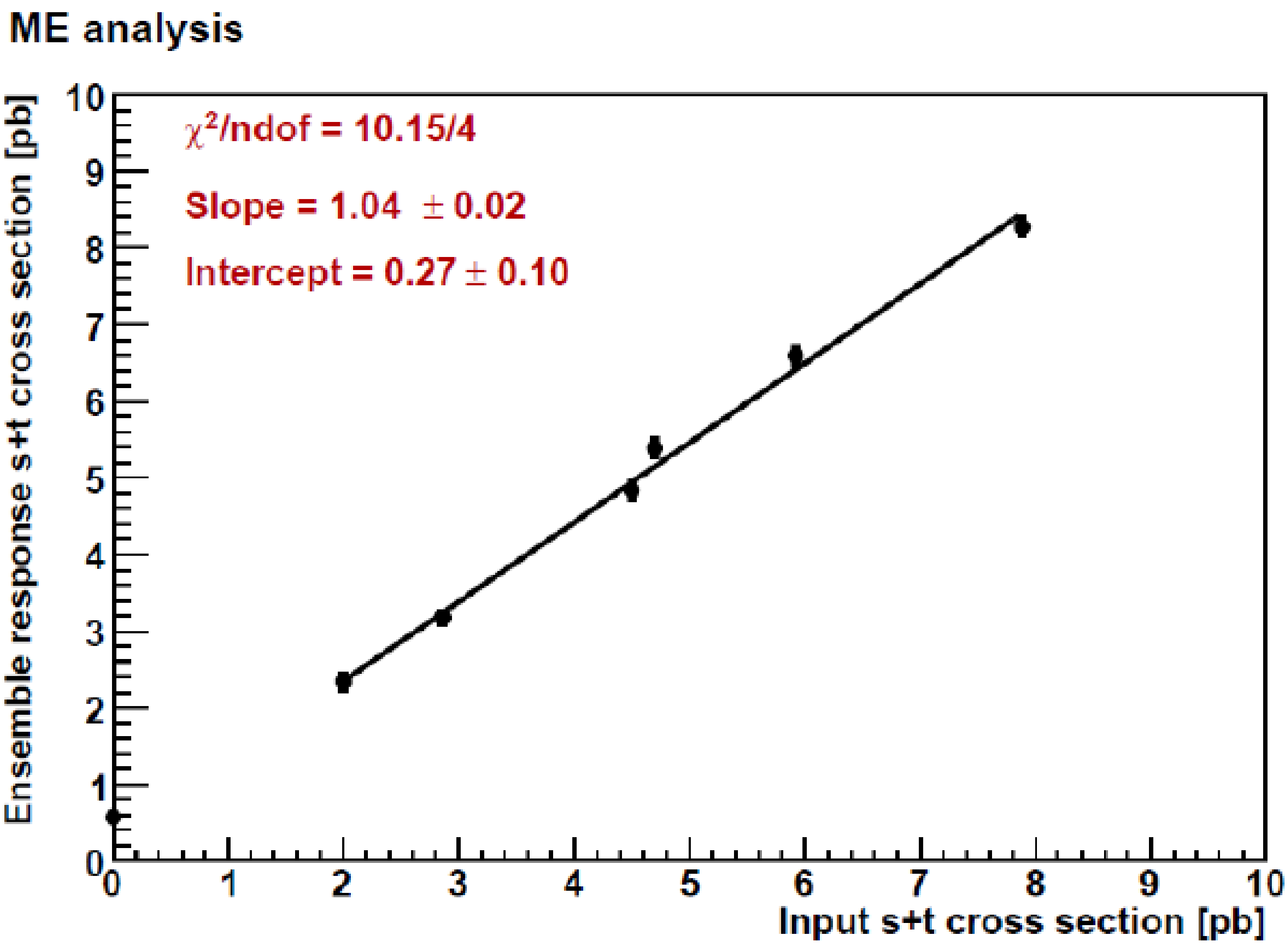
Decision Trees - Ensembles

- SM input is returned by DTs
- "Mystery" ensembles are unraveled by the DTs
- Linear response is achieved

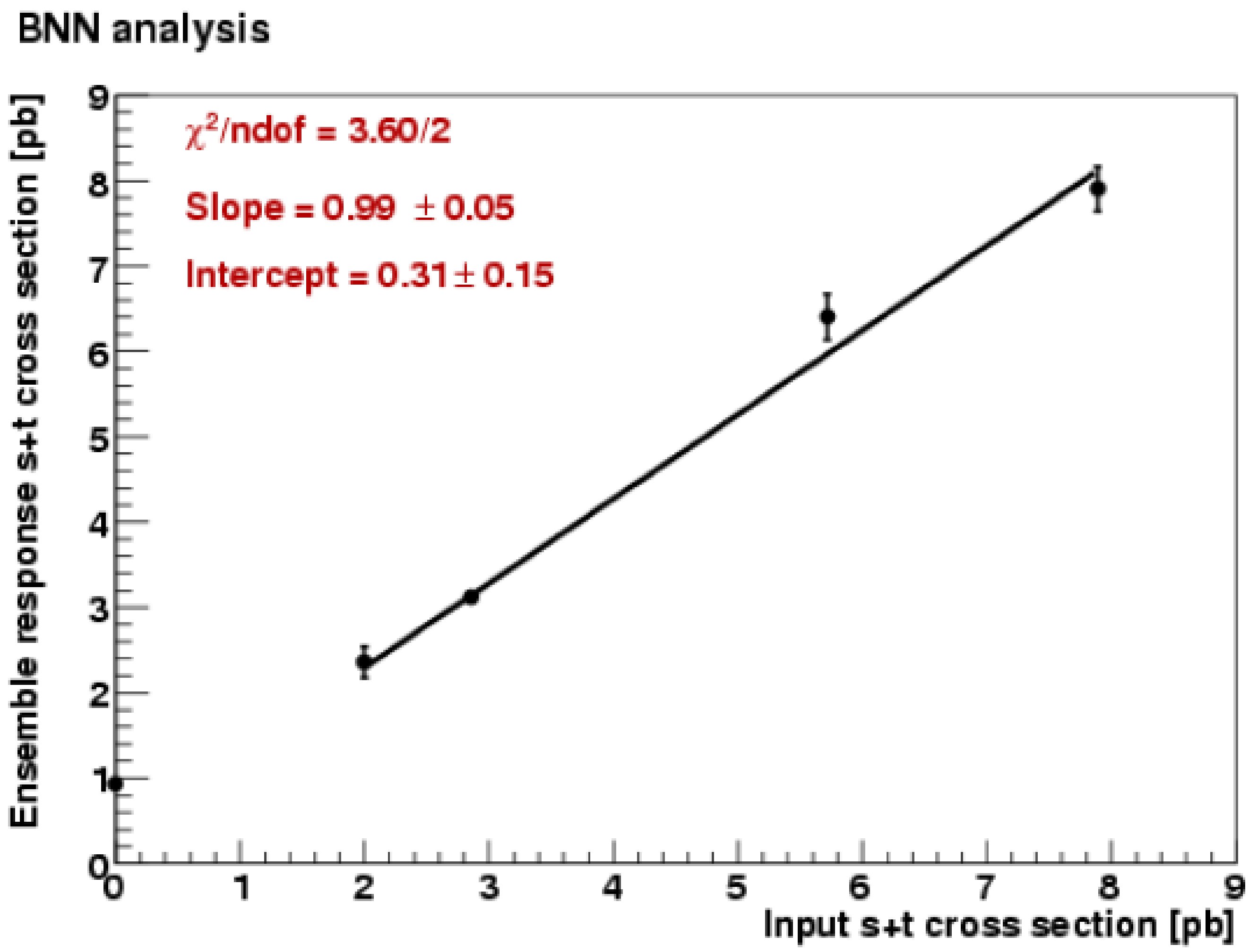




Matrix Elements Method - Ensembles



Bayesian Neural Network - Ensembles



Correlations - All methods

Choose the 50 highest events in each discriminant and look for overlap

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

Also measured the cross section in 400 members of the SM ensemble with all three techniques and calculated the linear correlation between each pair:

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