Measurement of $\sigma(t\bar{t} \rightarrow \tau + jets)$

And future plans

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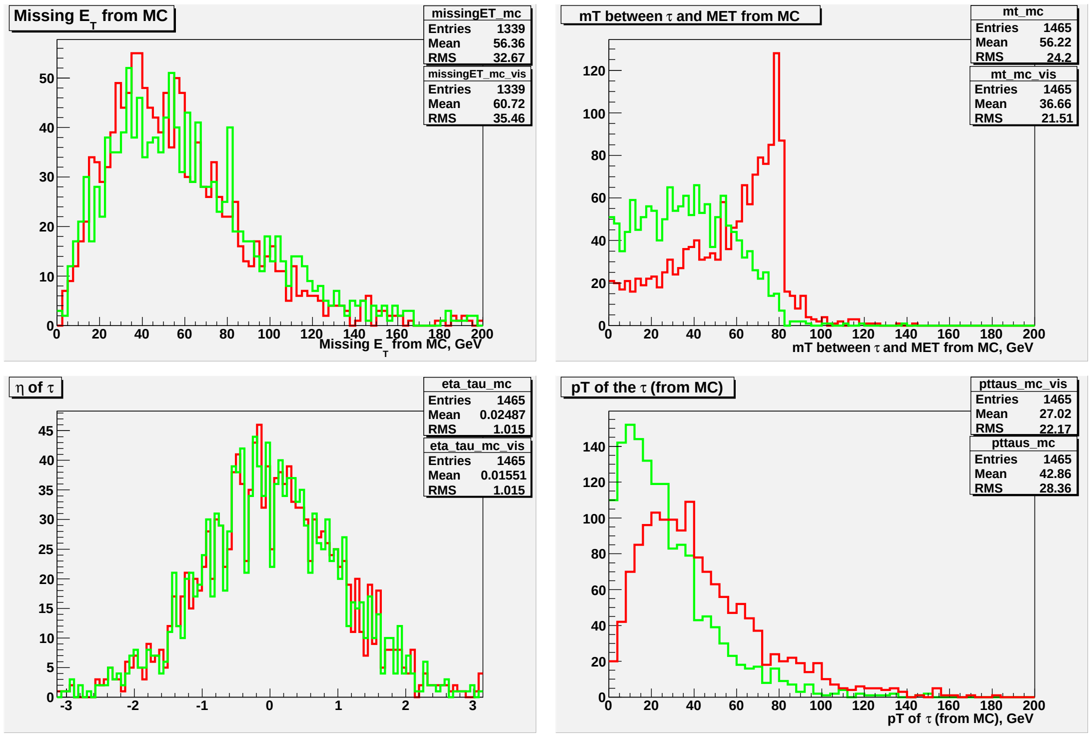
The objective

- Measurement of $\sigma(t\bar{t} \rightarrow \tau + jets)$using the full Run II dataset is the goal
- Charged Higgs search in $\sigma(t\bar{t} \rightarrow \tau + jets)$ channel. In RunI only 62.2 pb^{-1} (572272 events) ⇒3 observed events with 4.1±1.3 background events predicted
- $\sigma(t\bar{t} \rightarrow 6jets)$ measurement was performed in Run II. Our strategy is based in part on this work

Signal characteristics / challenges

- $Br(t\bar{t} \rightarrow \tau + jets) \cdot Br(\tau \rightarrow hadrons) \cdot \sigma(t\bar{t}) = 0.15 \cdot 0.65 \cdot 6.8 = 0.66\, pb$ - lower then $e + jets$ and $\mu + jets$!
- τ decays before reaching the detector volume. Only part of its energy is visible



Red is the generated τ lepton. Green is the visible part of it.

Triggers

Combination of two triggers provides the highest efficiency:

- The Higgs Missing HT trigger (MHT30_3CJT5 and its later incarnations)
- The ALLJET trigger (4JT10 and its later incarnations)

Only the ALLJET data is available at the moment $\Rightarrow$ 75 $\pm$ 5% efficiency rather than 85 $\pm$5%

Dataset

The full PASS2 ALLJET data has been processed. The total of are available, which includes per trigger version:

Trigger version	Trigger name	Luminosity, pb^{-1}
8.0	4JT10	19.44±4.4
9.0	4JT10	21.23±4.61
10.0	4JT10	15.11±3.89
11.0	4JT10	57.28±7.55
12.0	4JT12	196±14
13.0	JT2_4JT12L_HT	13.48±3.67
13.1	JT2_4JT12L_HT	27.77±5.26
13.3	JT2_4JT12L_HT	0
Total		349±19

Preselection

17M events are in the ALLJET skim. Needs to be reduced at the preselection stage.
Preselection cuts were:

- $|Z_{PV}| < 60$, Number of tracks at PV > 3
- No isolated electron or muon
- $\not\!\!E_T$ significance > 3
- $N_{jets} \geq 4$

MET Significance (D0Note 4254)

$\not\!\!E_T$ Significance combines the probability densities of various physical objects to give the total likelihood of physical $\not\!\!E_T$

- Probability densities of jets, electrons and unclustered energy are taken as Gaussian defined by energy and resolution σ_E of corresponding object:

$$p(E_T) \equiv N(E_T, \sigma_{E_T}) \Rightarrow p(\Delta E_T) \equiv N(0, \sigma_{E_T})$$

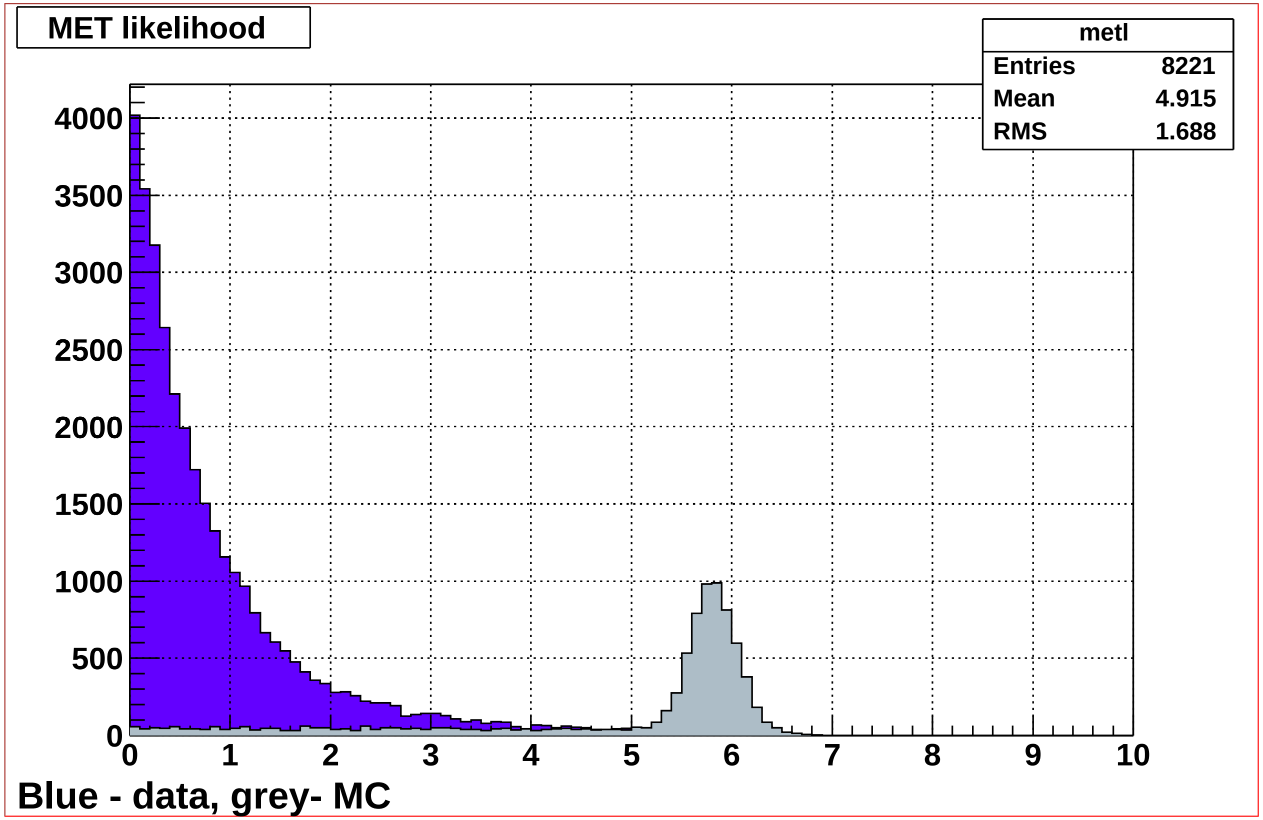
- The $\not\!\!E_T$ probability distribution is obtained as linear combination of these and also parameterized by a Gaussian:

$$p(\Delta \not\!\!E_T) \equiv p(\not\!\!E_T) - \not\!\!E_T = -\sum p(\Delta E_T)$$
$$\Rightarrow p(\not\!\!E_T) = \not\!\!E_T - \sum p(\Delta E_T) = \not\!\!E_T - N(0, \sqrt{\sum \sigma_i})$$

- With this, the significance is defined as

$$L = log \frac{p(\not\!\!E_T)_{max}}{p(\not\!\!E_T = 0)}$$

MET likelihood distribution



Preselection results

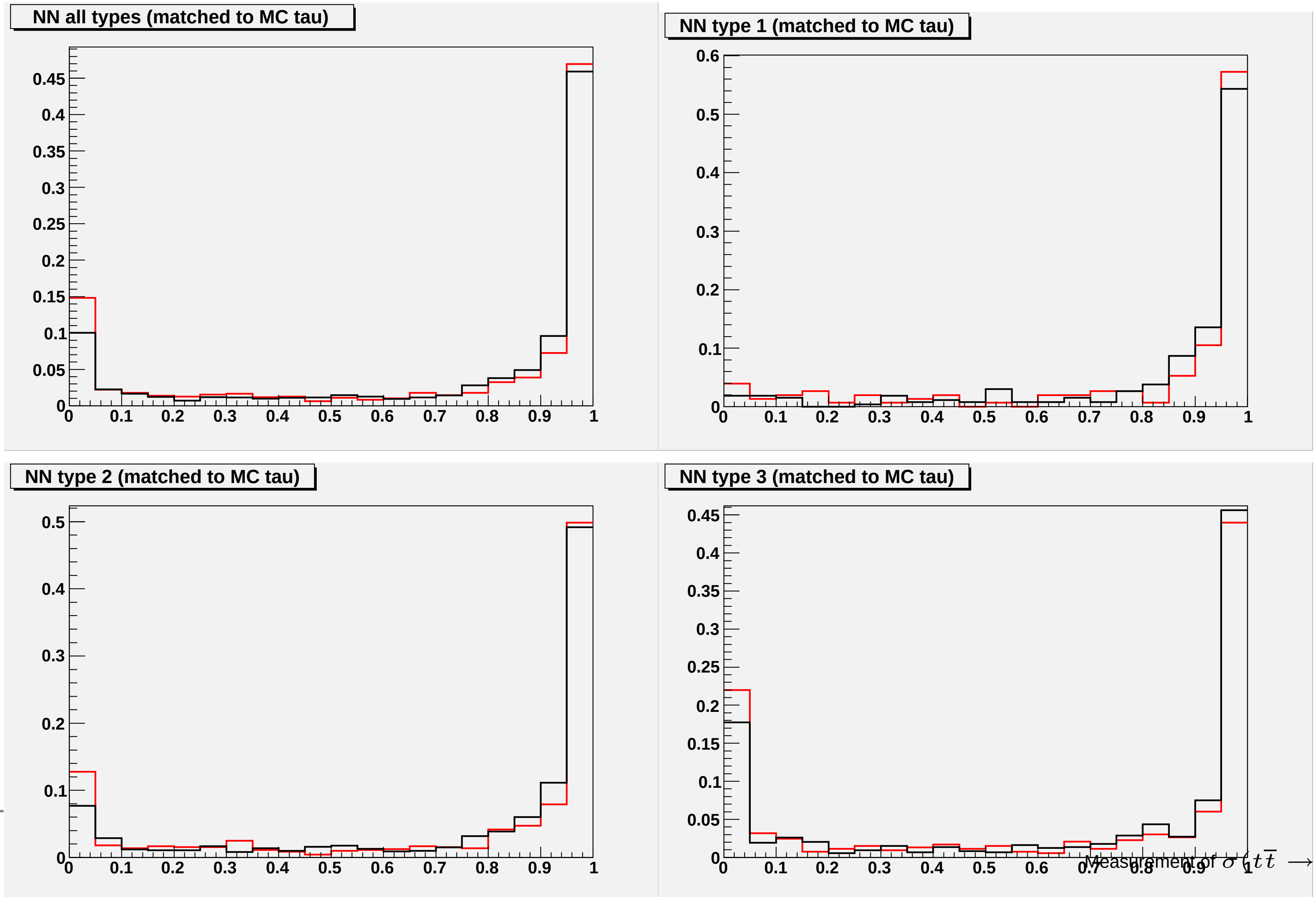
	# passed	ALPGEN σ, pb	# passed scaled
data	653727/17M		653727
$t\bar{t} \rightarrow \tau + jets$	6141/10878	0.821 $\pm$ 0.004	109.93 $\pm$7.26
$Wbbjj \rightarrow \tau\nu + bbjj$	2321/11576	0.222 $\pm$ 0.044	9.98 $\pm$ 2.08
$Wccjj \rightarrow \tau\nu + ccjj$	2289/10995	0.527 $\pm$ 0.059	24.77 $\pm$ 3.22
$Wcjjj \rightarrow \tau\nu + cjjj$	2169/10435	0.920 $\pm$0.087	42.23 $\pm$ 4.87
$Wjjjj \rightarrow \tau\nu + jjjj$	2683/11920	14.14 $\pm$ 1.3	720.33 $\pm$ 81.48

W samples had been normalized to the CDF measured W+4j cross section of 4.5 $\pm$ 2.2 pb. The ALPGEN value of 5.54 pb has been used for the $t\bar{t}$

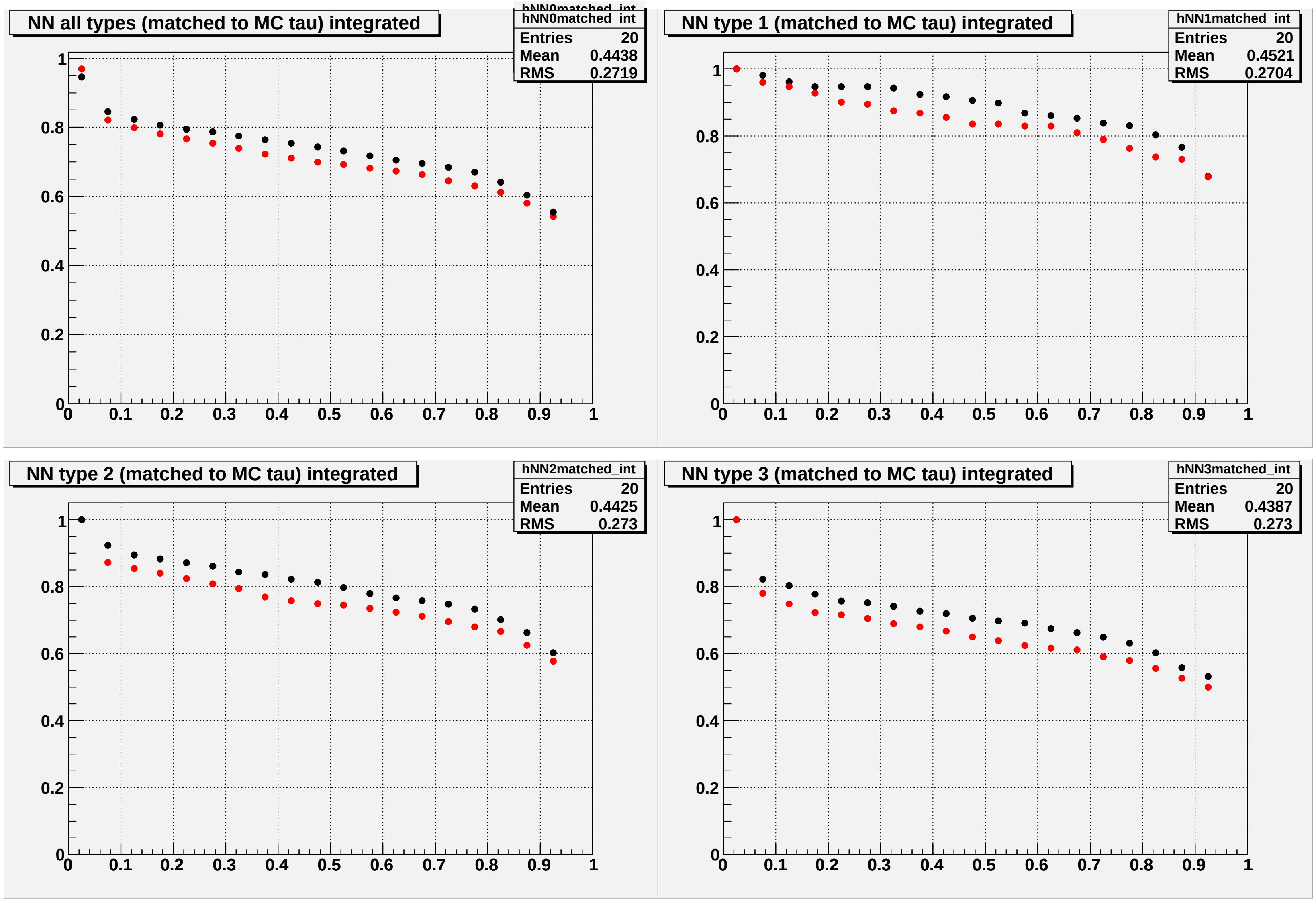
We plan to apply now τ ID and b-tagging to further reduce data and increase the signal content

tau id

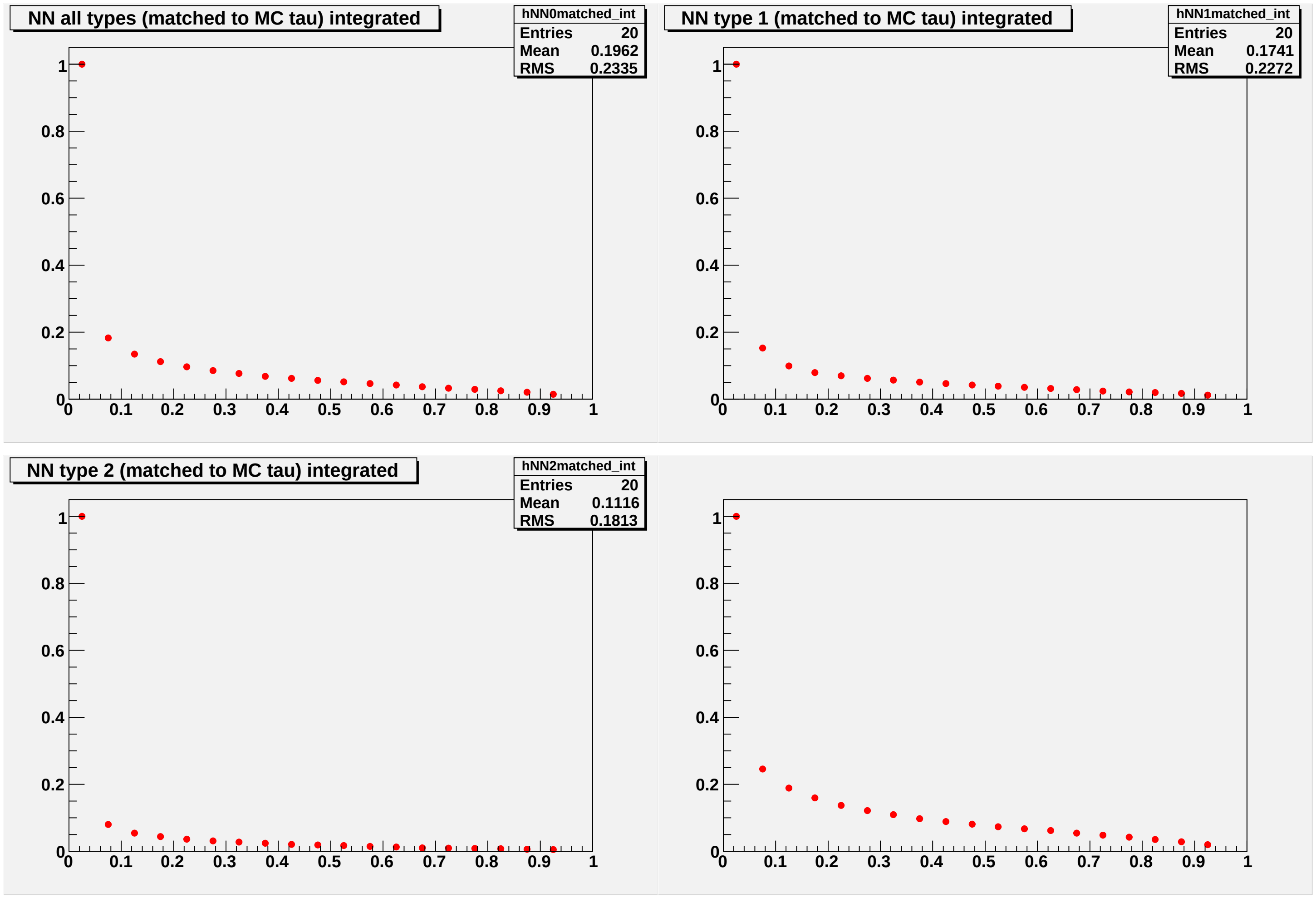
In Run II D0 uses a dedicated tau ID Neural Net. On the plot below red is $t\bar{t} \rightarrow \tau + jets$ and black is $Z \rightarrow \tau + \overline{\tau}$



tau ID efficiency vs NN cut

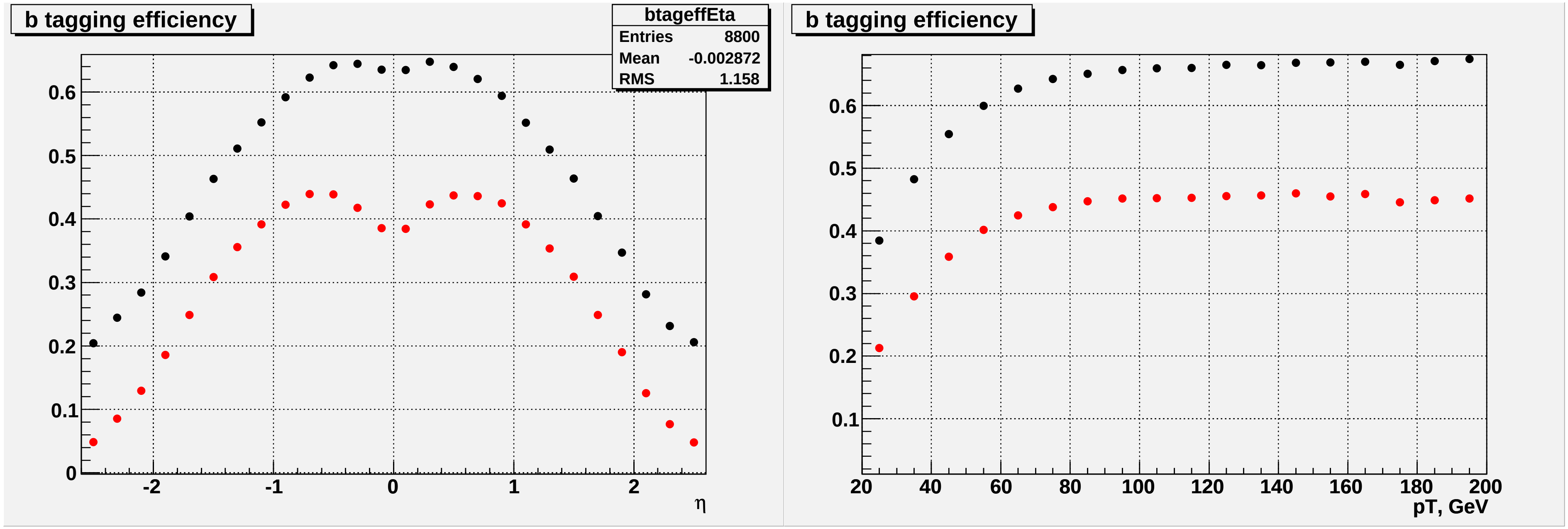


tau ID fake rate vs NN cut



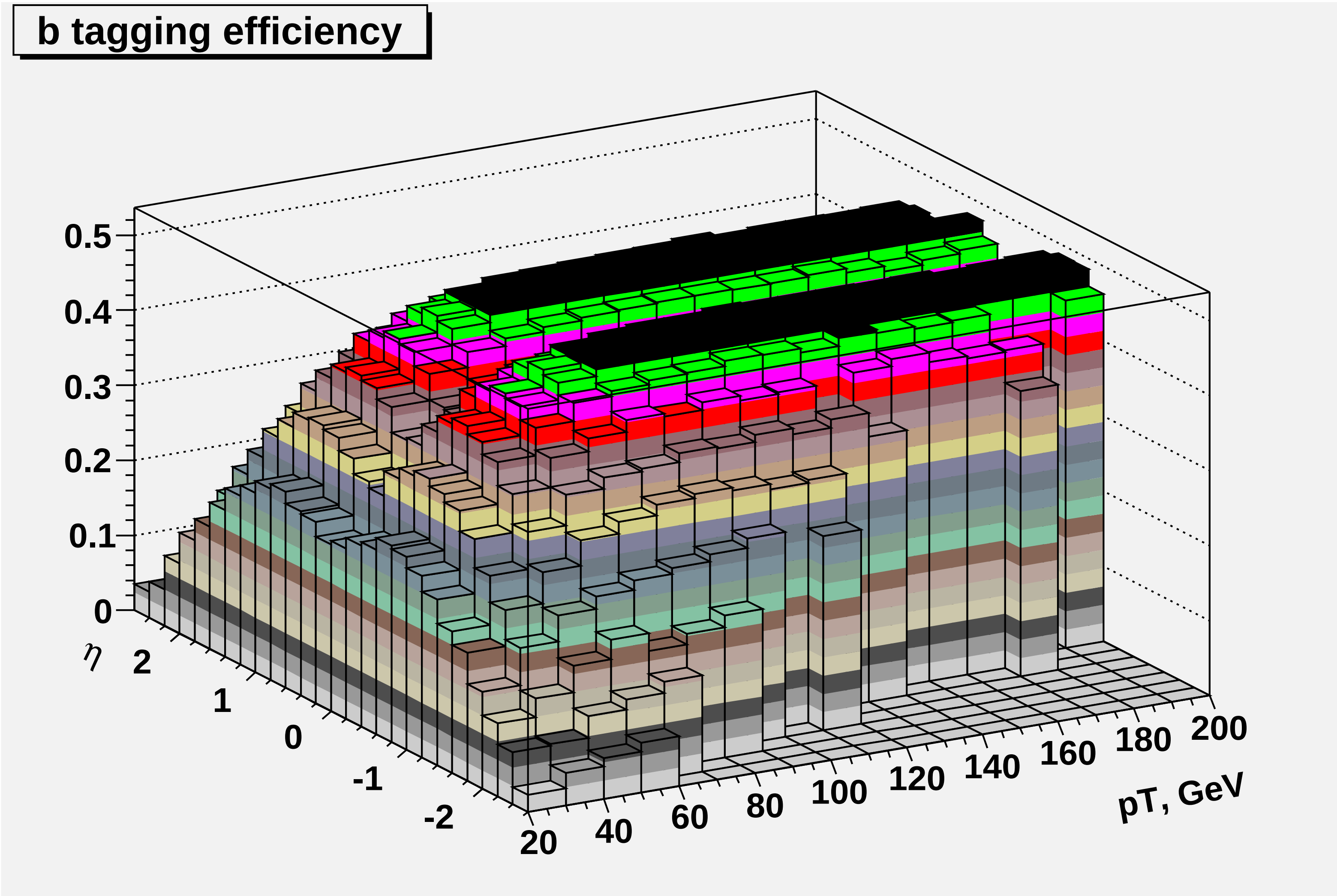
From the above we had selected NN>0.95 as criteria for a "good" τ candidate.

b tagging



Black represents the MC-derived parameterization. Red is the data-corrected one.

b tagging efficiency 2D



Datasets

For the purposes of this analysis we define 3 subsamples out of the original preselected data sample:

- The “signal” sample - require at least 1 τ with $NN > 0.95$ and at least one SVT tag (as in table **??**). This is the main sample used for the measurement.
- The “τ veto sample” - Same selection, but instead of $NN_\tau > 0.95$ $0 < NN_\tau < 0.5$ was required for τ candidates and no events with “good” (NN>0.8) taus were allowed. This sample is used for the topological NN training
- The “b veto” sample - at least 1 τ with $NN > 0.95$, but NO SVT

tagging efficiencies in data and MC

The following selection had been applied to the analysis sample and MC:

data	taggingMC
≥ 1 τ with $\|\eta\| < 2.4$ and $P_T > 20\,GeV$	≥ 1 τ with $\|\eta\| < 2.4$ and $P_T > 20\,GeV$
≥ 1 SVT	$TrigWeight \cdot bTagProb$
≥ 2 jets with $\|\eta\| < 2.4$ and $P_T > 20\,GeV$	≥ 2 jets with $\|\eta\| < 2.4$ and $P_T > 20\,GeV$

	# passed	Acceptance	# passed scaled
data	268/653727		268
$t\bar{t} \to \tau + jets$	524/6141	0.0480$\pm$0.0020	9.320$\pm$0.620
$Wbbjj \to \tau\nu + bbjj$	54.5/2321	0.0150$\pm$0.0024	0.012$\pm$0.002
$Wccjj \to \tau\nu + ccjj$	13.3/2289	0.0039$\pm$0.0012	0.034$\pm$0.005
$Wcjjj \to \tau\nu + cjjj$	8/2169	0.0025$\pm$0.0010	0.160$\pm$0.020
$Wjjjj \to \tau\nu + jjjj$	3.3/2683	0.0009$\pm$0.0006	0.860$\pm$0.100

efficiencies in data and MC (continued)

	Type 2	Type 3
data	91	71
$t\bar{t} \to \tau + jets$	5.61±0.37	2.81±0.18
$W \to \tau\nu + jets$	0.93±0.04	0.32±0.01

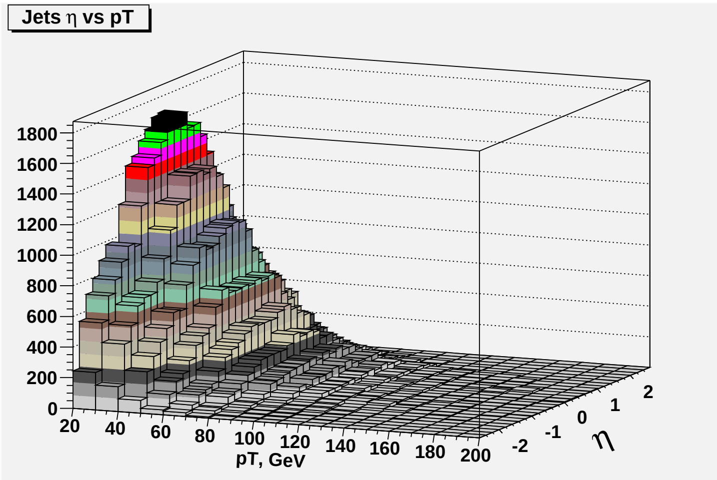
Conclusions:

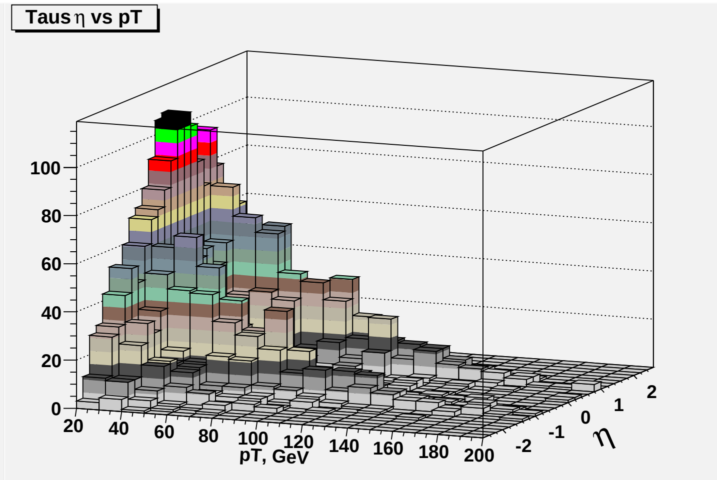
- Instrumental background (mostly QCD multijet) is responsible for most of the background. Need a reasonably reliable way to estimate it.
- 9.320 $\ll$268 $\Rightarrow$ S:B is very low at this stage and additional selection is needed. Topological NN (using MLPfit) was used for that

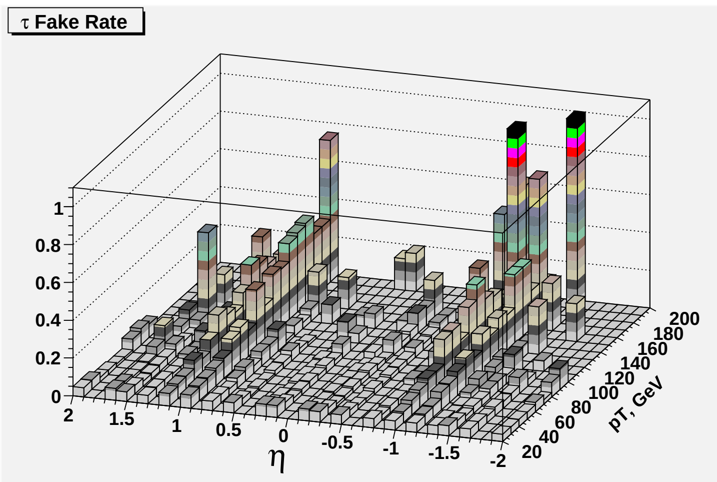
The following slides will describe the QCD prediction and NN

τ fake rate parameterization

Derived on the “b tag veto sample” in order to be statistical independent from the main analysis sample!







Fit

The fitting function was the following:

$$F(\eta, P_T) \equiv A(\eta) \cdot B(P_T)$$

$$A(\eta) \equiv a_1 + a_2 \cdot \eta^2 + a_3 \cdot \eta^3 + a_4 \cdot \eta^4 + ... + a_7 \cdot \eta^7$$

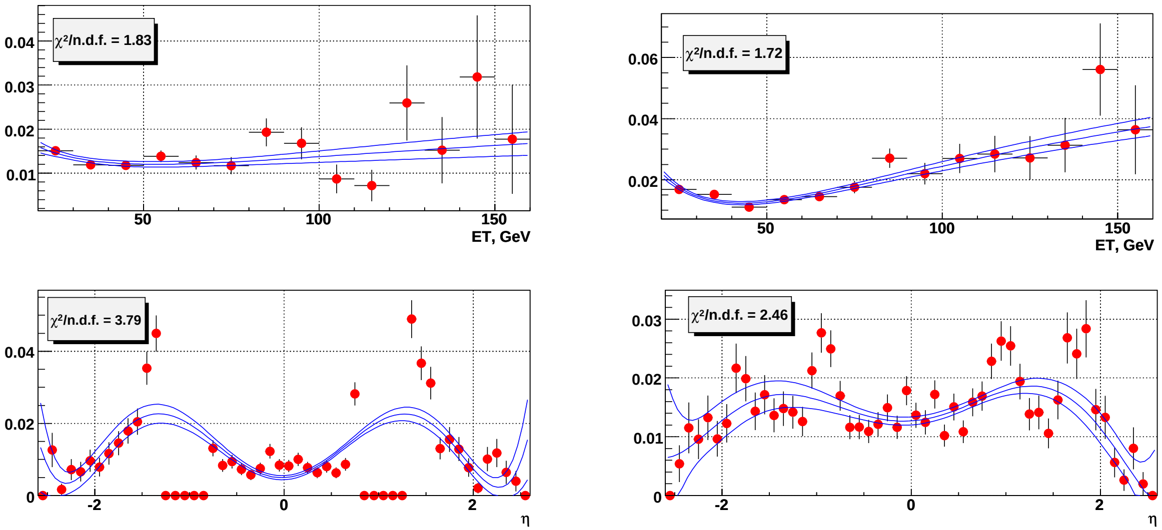
if $\eta = 0$ $a_1 = 0$ was set to avoid singularity.
The fitting function for P_T has been picked so that it would describe the data well and had not been monotonous (that is we want $\lim_{P_T \to \infty} B\left(P_T\right) \to const$) :

$$B(P_T) \equiv b_1 \cdot \exp\left(\frac{P_T}{\left(P_T + b_3\right)^2}\right) + b_2 \cdot \left(\frac{P_T}{P_T + b_3}\right)$$

Fit results

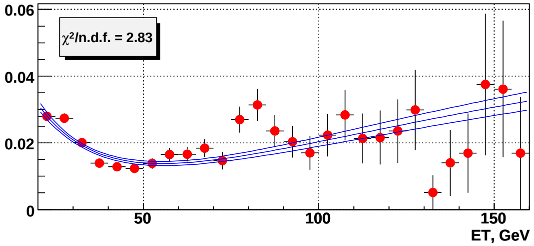
- For type 1: $0.8 < |\eta| < 1.3$ region cut off
- For type 3: $0.85 < |\eta| < 1.1$ region cut off

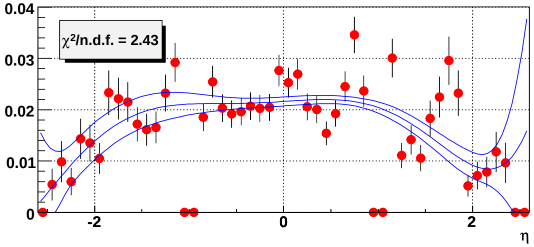
Types 1 and 2:



Fit results (continue)

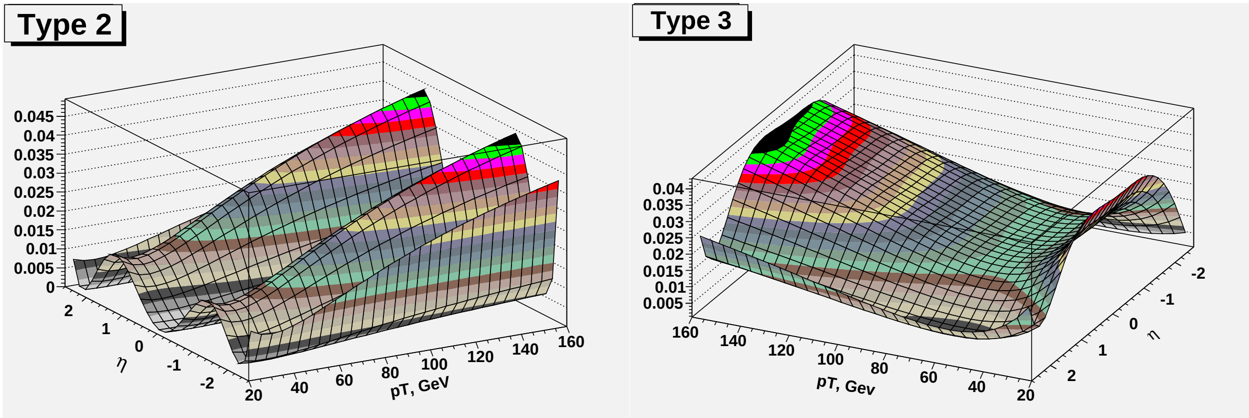
Type 3:





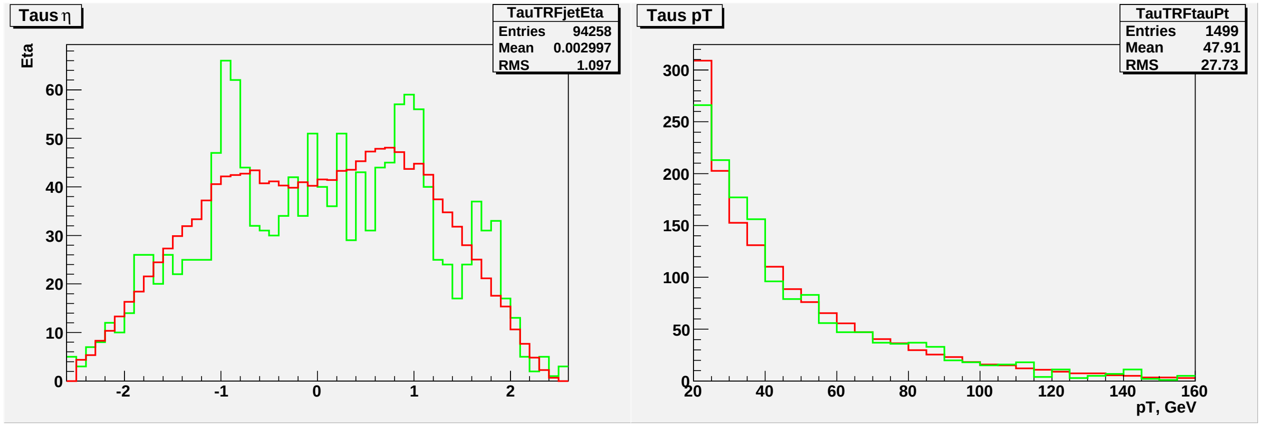
τ Fake rate parametrization (fitted).

$\geq 1\ \tau$ is required. NO SVT tags, in order to be statistically independent from the main analysis sample!

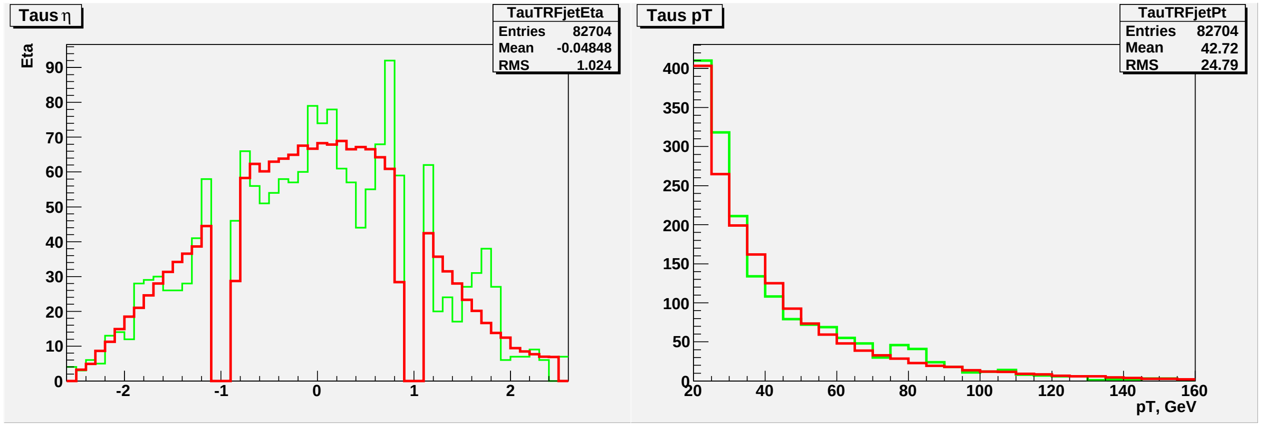


Closure tests

Type2:

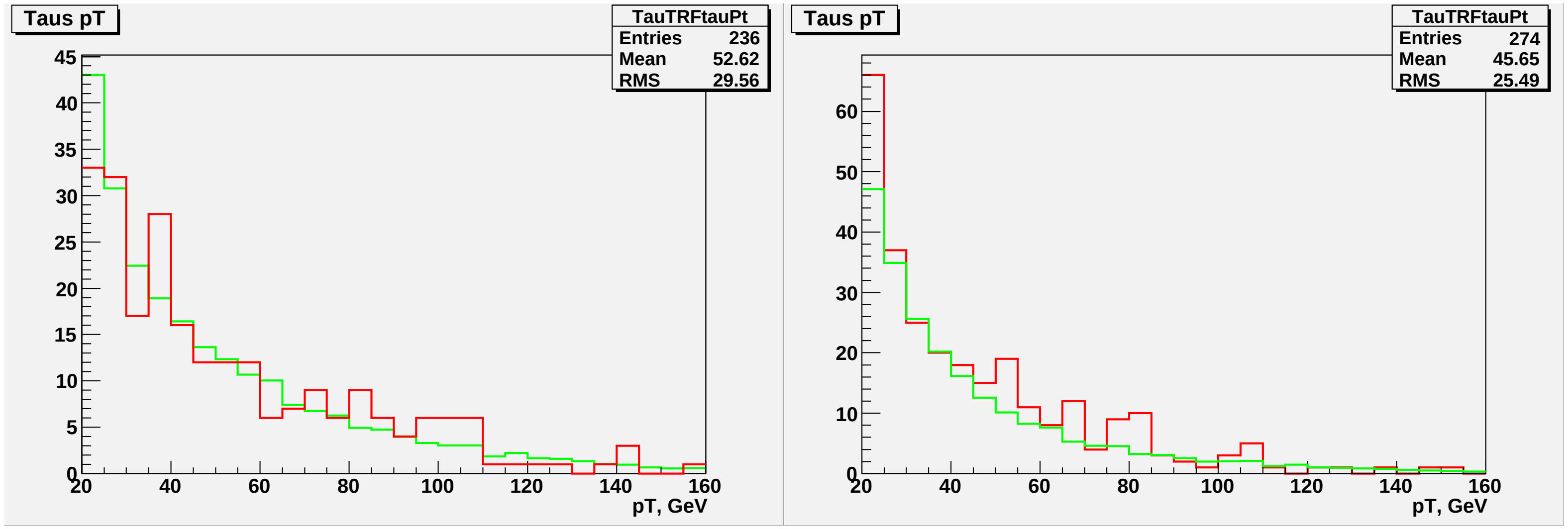


Type3:



Closure tests (continue)

In the $0.5 < \eta < 1$ region :



QCD prediction

The “QCD background” in this case is composed of the events with no real τ lepton in them, but with one or more 0.95 NN τ candidate (fake)
We assume that probability for jet to fake a tau is simply $F(\eta, P_T)$. Then, the probability that at least one of the jets in the event will fake τ can be computed as following:

$$P_{event} = 1 - \prod_j (1 - F(P_T^j, \eta^j))$$

Summing up such probabilities over the tagged data we obtain the QCD background estimation

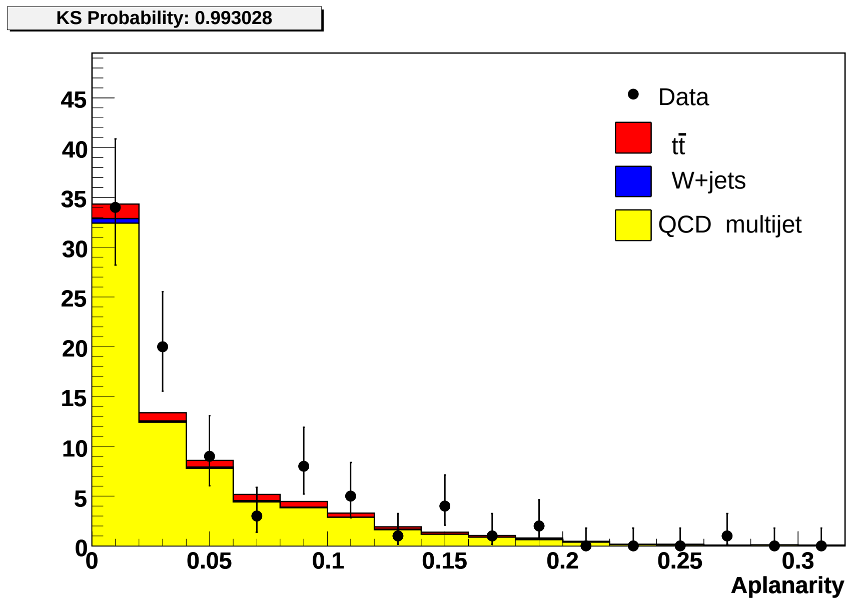
NN variables

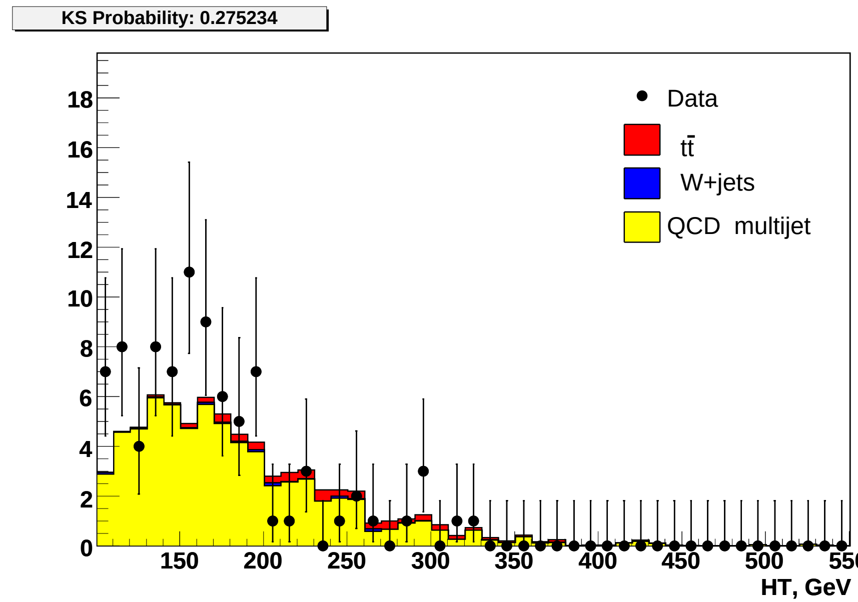
These are the kinematic and topological variables used:

- H_T- the scalar sum of all jet P_Ts (and τ)
- Sphericity and Aplanarity - these variables are formed from the eigenvalues of the normalized Momentum Tensor. These are expected to be higher in the top pair events than in a typical QCD event
- Centrality, defined as $\frac{H_T}{H_E}$, where $H_E$is sum of energies of the jets (and τ)
- Top and W mass likelihood - χ^2-like variable. $L \equiv \left(\frac{M_{3j} - M_t}{\sigma_t}\right)^2 + \left(\frac{M_{2j} - M_w}{\sigma_w}\right)^2$, where $M_t, M_W, \sigma_t, \sigma_W$ are top and W masses (175 GeV and 80 GeV respectively) and resolution values (45 GeV and 10 GeV respectively). M_{3j} and M_{2j} are composed of the jet combinations, so to minimize L
- P_T and SVT lifetime significance of the leading tagged jet

Control plots

Here are some of the control plots with the fitted QCD parameterization used.





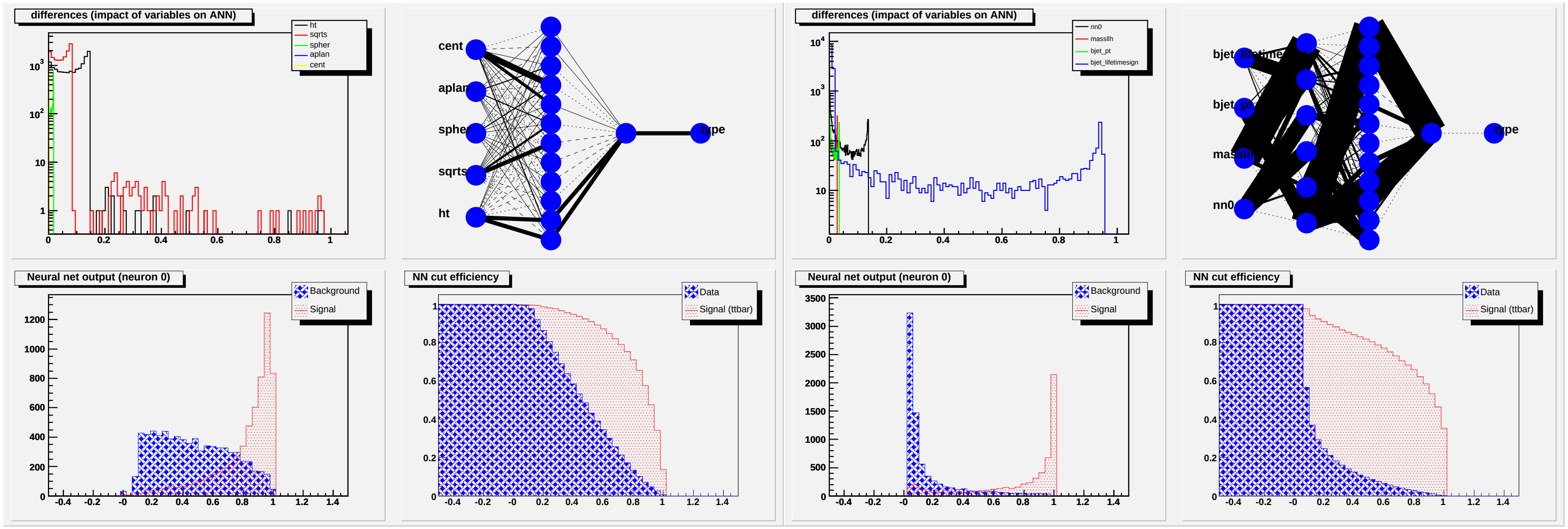
topological NN training

For signal training sample 7481 preselected $t\bar{t}$ MC events were used (NOT the same as the 6141 selection sample events). For the background, the τ veto sample was used. Similarly to the alljet analysis we define 2 networks:

1. Contains 3 topological (aplanarity, sphericity and centrality and 2 energy-based (H_T and $\sqrt{S}$)
2. Contains the output of the first, W and top mass likelihood, b-jet's P_T and b-jet's decay lengths

τ NN, also not being used as a variable has been applied as training weight.

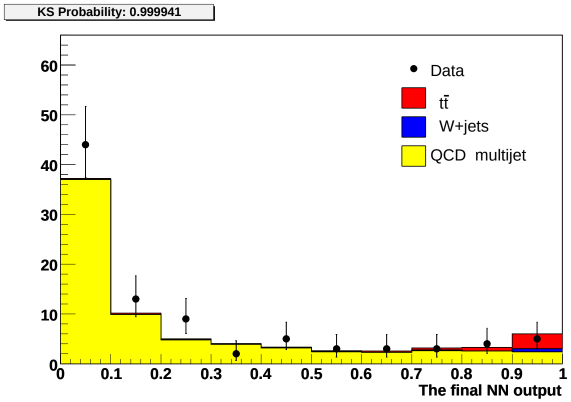
NN structure plots

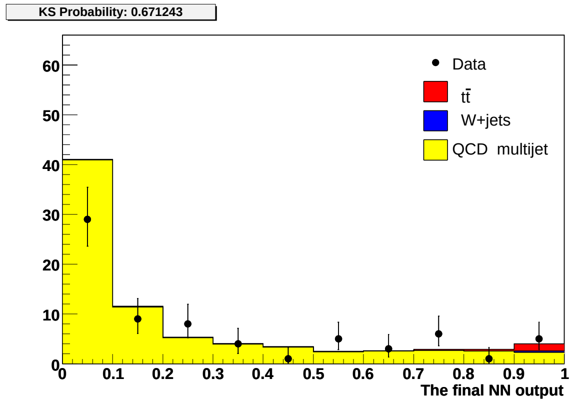


Upper left plots demonstrate the relative effect of change in each variable. The lower right plot shows the final effectiveness of the NN (red is signal)

NN cut results

The final NN discriminant looks like this:

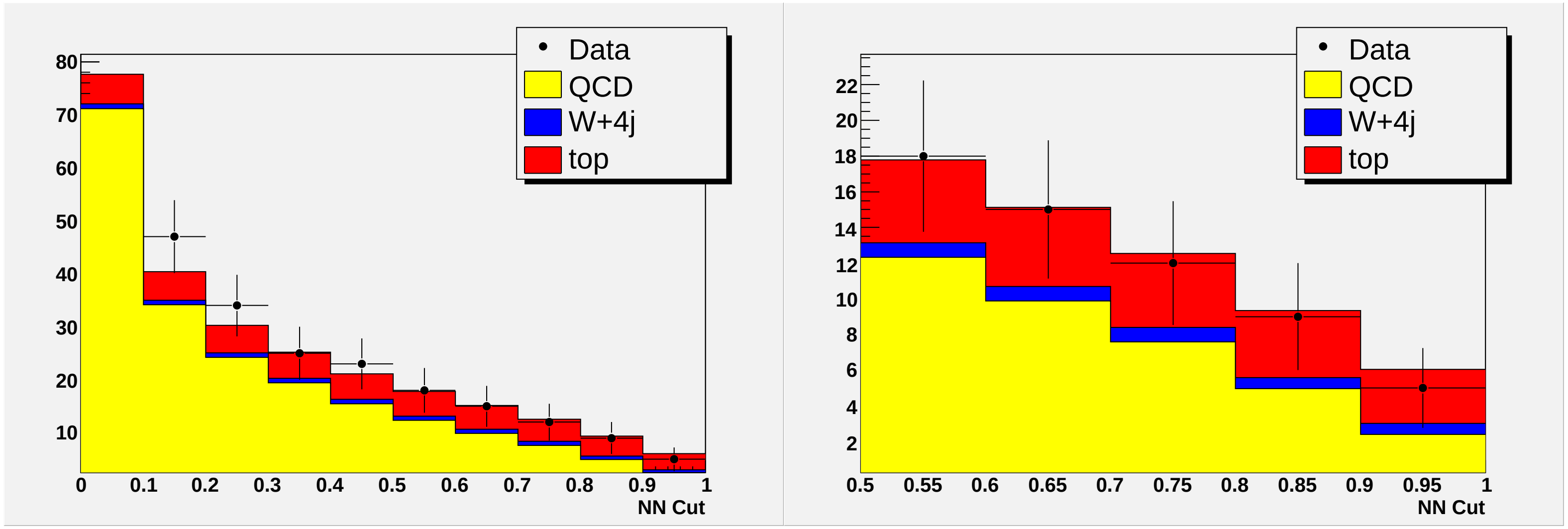




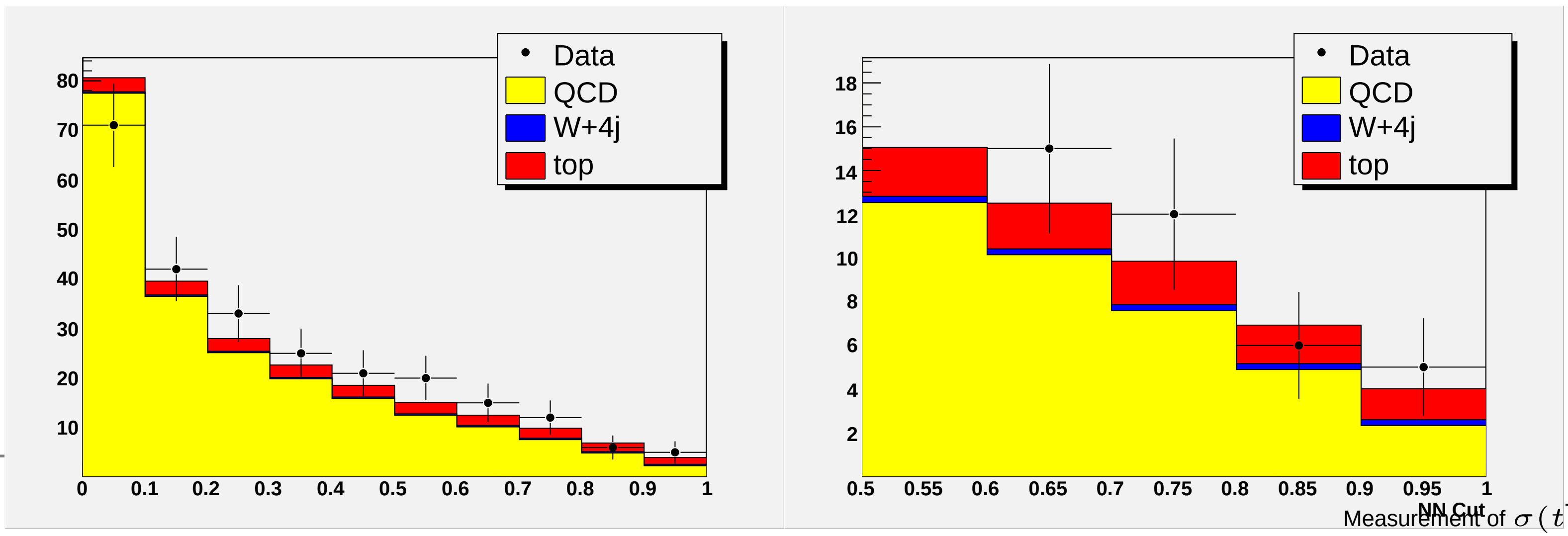
And by applying the cuts on it we can improve S:B

NN Results

Type 2:



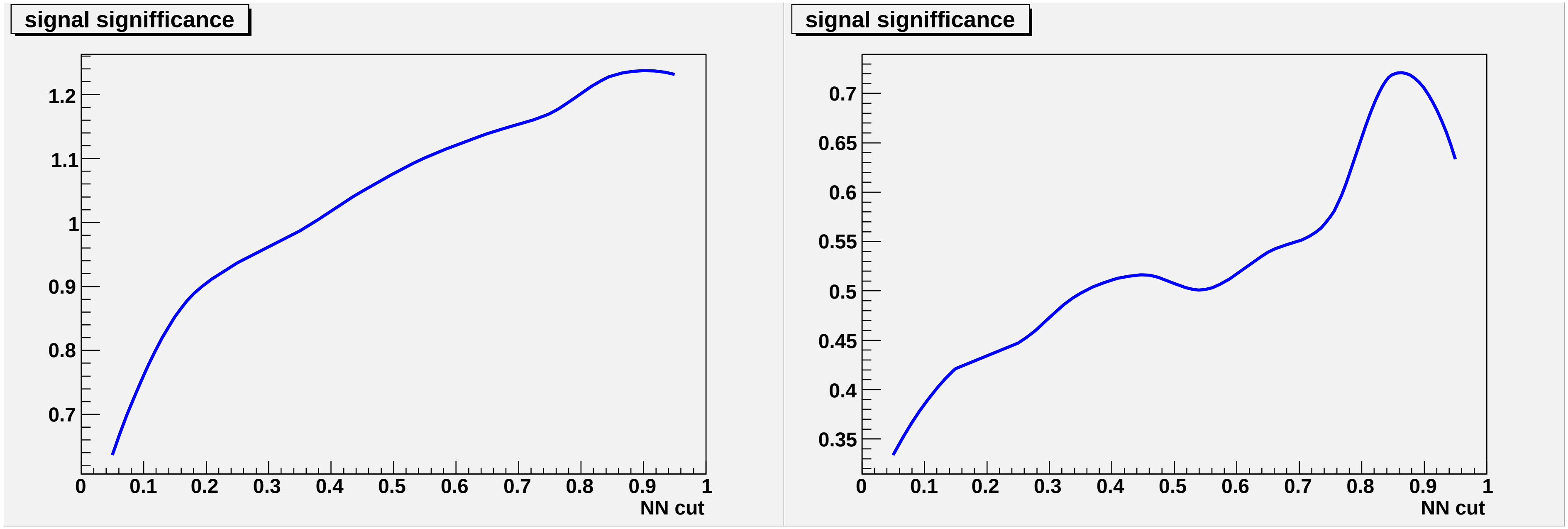
Type 3:



NN Cut Significance

The signal significance is defined as

$$\frac{Number\ of\ signal\ events}{\sqrt{Number\ of\ Signal+Background\ events}}$$



0.9 Appears to be optimal in both cases!

NN Cut Results

Channel	N^{obs}	$\mathcal{B}$	Bakgrounds		$\varepsilon(t\bar{t})$ (%)	s (7 pb)	s+b
type 2	5	0.1	$W \rightarrow \tau\nu$	0.60±0.03	1.57±0.01	$3.83^{+0.46}_{-0.51}$	$6.84^{+0.46}_{-0.51}$
			fakes	2.41±0.09			
type 3	5	0.1	$W \rightarrow \tau\nu$	0.27±0.01	0.73±0.01	$1.80^{+0.22}_{-0.23}$	$4.39^{+0.22}_{-0.23}$
			fakes	2.33±0.09			

Systematic uncertainties

Channel	τ+jets type 2	τ+jets type 3
Jet Energy Scale	$+0.30$ -0.27	$+0.53$ -0.69
Primary Vertex	-0.036 $+0.037$	-0.093 $+0.095$
MC stat	-0.22 $+0.25$	-0.58 $+0.65$
Trigger	$+0.0025$ -0.020	$+0.0056$ -0.069
Branching ratio	-0.071 $+0.074$	-0.18 $+0.19$
QCD fake rate parametrization	-0.17 $+0.17$	-0.34 $+0.34$
$W \to \tau\nu$	-0.19 $+0.19$	-0.19 $+0.19$

b-tagging relates systematics

Channel	τ+jets type 2	τ+jets type 3
b-tagging	$^{+0.076}_{-0.13}$	$^{+0.41}_{-0.26}$
c-tagging	$^{+0.16}_{-0.20}$	$^{+0.60}_{-0.48}$
l-tagging	$^{+0.0051}_{-0.0051}$	$^{+0.014}_{-0.014}$
SF_{hf}	$^{+0.00036}_{-0.00036}$	$^{+0.00094}_{-0.00094}$
SF_{ll}	$^{+0.00036}_{-0.00036}$	$^{+0.00094}_{-0.00094}$
μ b-tagging (data)	$^{+0.094}_{-0.091}$	$^{+0.25}_{-0.24}$
μ b-tagging (MC)	$^{-0.10}_{+0.11}$	$^{-0.25}_{+0.28}$
taggability	$^{+0.049}_{-0.048}$	$^{+0.13}_{-0.13}$

Cross section result

The top group's combination macro gives the following results:

τ+jets type 2 cross section:

$$3.63 \;{}^{+4.72}_{-3.50}\;(stat)\;{}^{+0.49}_{-0.48}\;(syst)\;\pm 0.24\;(lumi)\;pb$$

τ+jets type 3 cross section:

$$9.39 \;{}^{+10.10}_{-7.49}\;(stat)\;{}^{+1.25}_{-1.18}\;(syst)\;\pm 0.61\;(lumi)\;pb$$

The combined τ+jets cross section:

$$5.05 \;{}^{+4.31}_{-3.46}\;(stat)\;{}^{+0.68}_{-0.67}\;(syst)\;\pm 0.33\;(lumi)\;pb$$

Electron contribution

Serban Protopopescu had made an interesting point during the review: Large fraction of electrons won't be rejected by the EM veto, so my analysis has some sensitivity to $t\bar{t} \to e + jets$
In fact, I've run my selection on the e+jets (including $\tau \to e$) sample and had the following (all for type 2):

- Preselection efficiency: 0.2229±0.0004 (compared to 56% for $t\bar{t} \to \tau + jets$)
- 2. The subsequent cuts yield 0.037±0.0001 (comparable with $t\bar{t} \to \tau + jets$)
- 2. The total acceptance is (0.2229±0.0004)(0.037±0.0001) = 0.8% (compared to 1.57% $t\bar{t} \to \tau + jets$)
- 3. The normalaized # of events (with 5.5 pb $t\bar{t}$ cross section) is ~1 events (compared to 3 for $t\bar{t} \to \tau + jets$)

Cross section effect and (some) control plots

Here are the cross section without electorns:

τ+jets type 2 cross section:

$$3.63\ ^{+4.72}_{-3.50}\ (stat)\ ^{+0.49}_{-0.48}\ (syst)\ \pm 0.24\ (lumi)\ pb$$

τ+jets type 3 cross section:

$$9.39\ ^{+10.10}_{-7.49}\ (stat)\ ^{+1.25}_{-1.18}\ (syst)\ \pm 0.61\ (lumi)\ pb$$

Here are the cross section with electorns (systematics not computed yet):

τ+jets type 2 cross section:

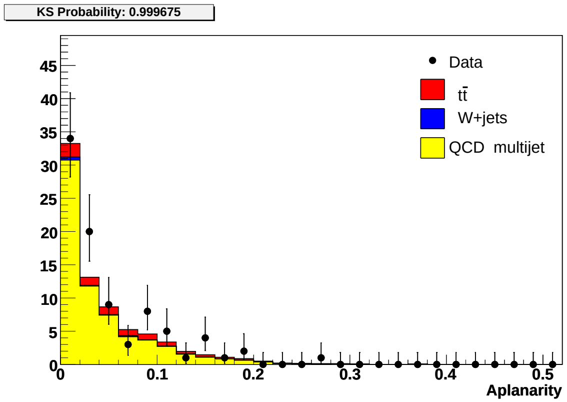
$$2.51\ ^{+2.67}_{-2.67}\ (stat) \pm 0.24\ (lumi)\ pb$$

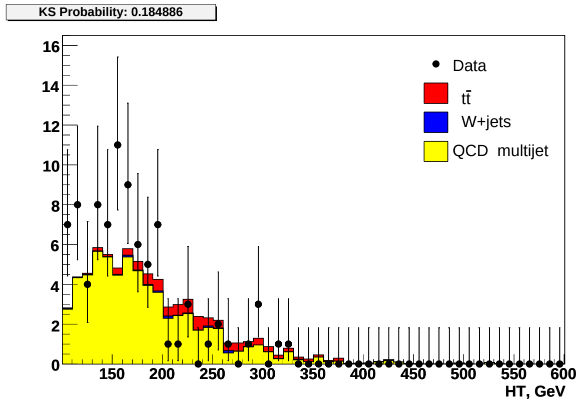
τ+jets type 3 cross section:

$$7.171\ ^{+6.84}_{-6.84}\ (stat) \pm 0.61\ (lumi)\ pb$$

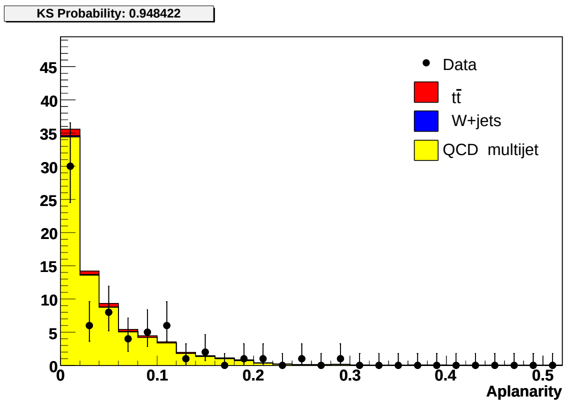
Some control plots including electrons

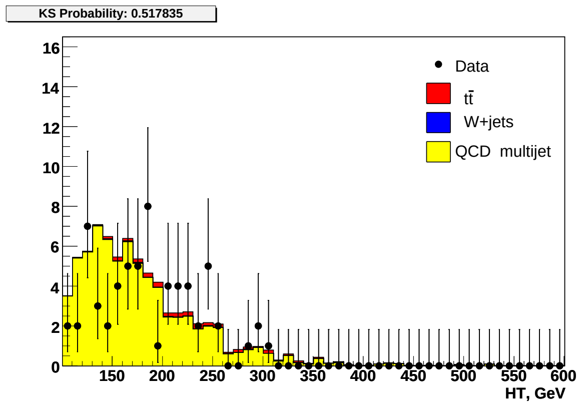
- Type 2:





- Type3:





Conclusions

- The p14 cross section measurement had been completed
- The results aren't impressive but will be much improved in p17, which is in the works right now
- The complete analysis can be read in D0Note 5158
- The method has been developed fully
- The agreement with theory is fairly good
- Results will be updated to base on the full p17 sample
- Including electrons is easy and almost done, need only recompute systematics and combine types 2 and 3