Search for Single Top Quark Production

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for the Single Top Working Group:

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Top Group Meeting, 3/11/2004

Outline

- Introduction
- Single Top Quark Production
- Analysis Outline
- Analysis Details
  - Preselection
  - Data Backgrounds
  - MC Backgrounds
- Results
- Conclusions/Outlook

Introduction

- Single Top Production has not yet been observed
  - limits exist from DØ and CDF Run I
    - DØ: 95% CL: s-channel 17pb, t-channel 22pb
  - we should be able to observe it in RunII
    - more data, better b-quark tagging
- initial p13-based analyses presented in the summer
  - trigger studies had also been done
- Single Top Working group was formed in September
  - first official meeting: October 6, 2003
  - analysis is a group effort
    - rather than a collection of individual analyses

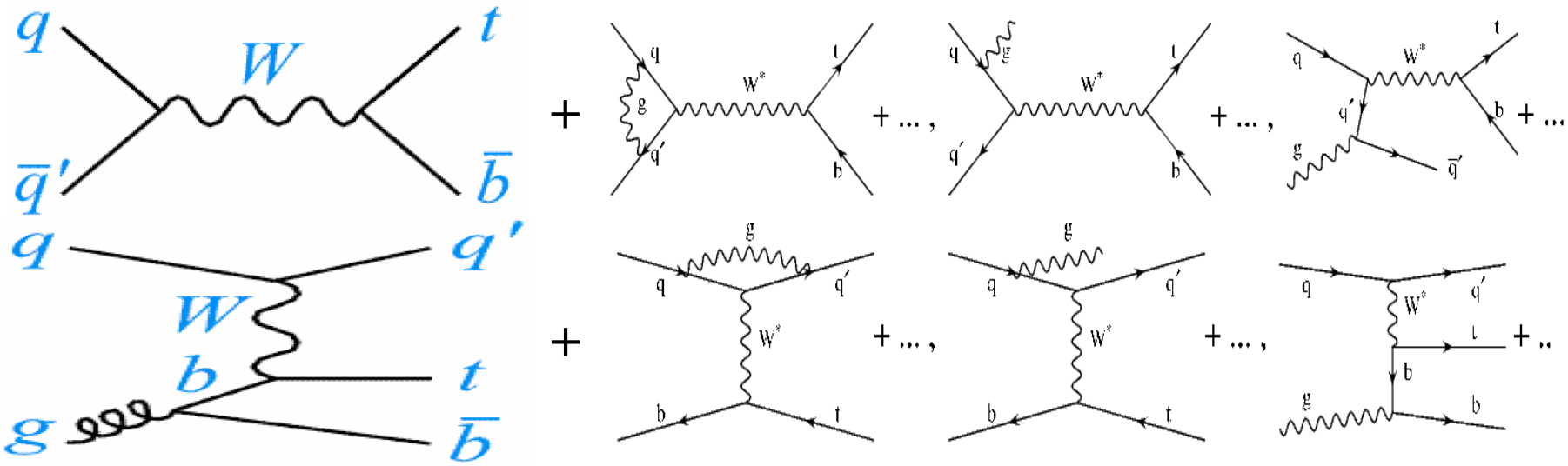
Goals we set for ourselves in October

Goals

- Produce competitive results for winter conferences
  - Highest priority
  - Short–term goal
    - Need to work on tight schedule
  - Requires cooperation
    - Within our group
    - With others in the Top group
    - With other Physics groups, ID groups, etc.
- Prepare for cross section measurement
  - Lower priority
  - Long–term goal
  - Allows for more flexibility, creativity

Single Top Quark Production

t-channel



s-channel

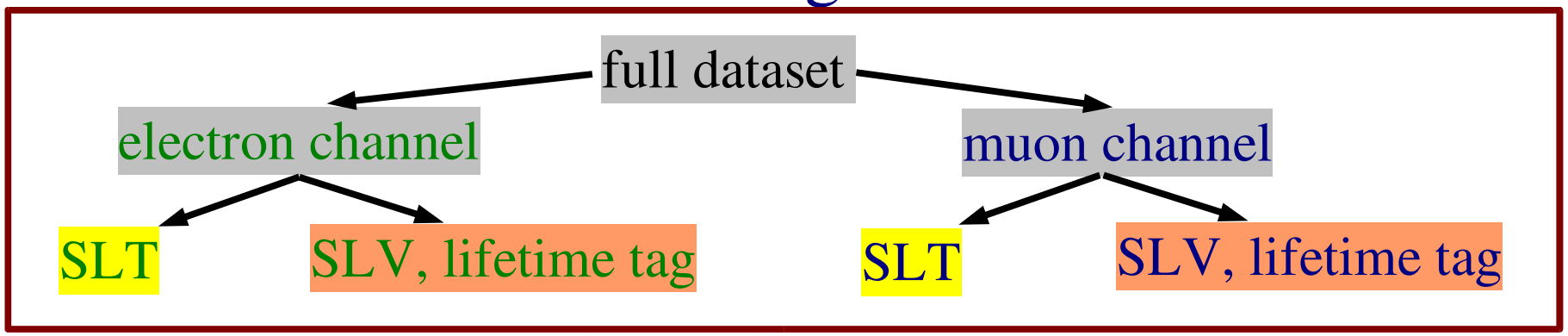
- electroweak production of top
  - s-channel production (tb) cross section = 0.88pb
  - t-channel production (tqb) cross section = 1.98pb
- single top quark production can be used to
  - measure CKM matrix element V_{tb} (test CKM unitarity)
  - observe top spin correlations, measure top mass

Analysis Overview

- single top event signature
  - one high-pt lepton (from W decay)
  - MET (neutrino from W decay)
  - one b-quark jet (from top decay)
  - more jets (light quark-jet, other b-jet)
- backgrounds
  - W+jet production (Wll, Wcc, Wbb, etc)
  - ttbar to lepton+jets
  - ttbar to di-lepton (one lepton mis-identified)
  - mis reconstructed multi-jet events
  - others (WZ, WW, Zμμ)

Analysis Channels

- split data into orthogonal channels
  - electron channel ⇔ muon channel
    - veto on events containing the other lepton
  - soft-muon-tagging (SLT) ⇔ lifetime tagging
    - lifetime tagging analyses apply SLT Veto
    - use both SVT (electron and muon channel) and JLIP (electron ch)
      - not orthogonal, cannot combine
- derive single top limit in each channel
- combine limits from orthogonal channels

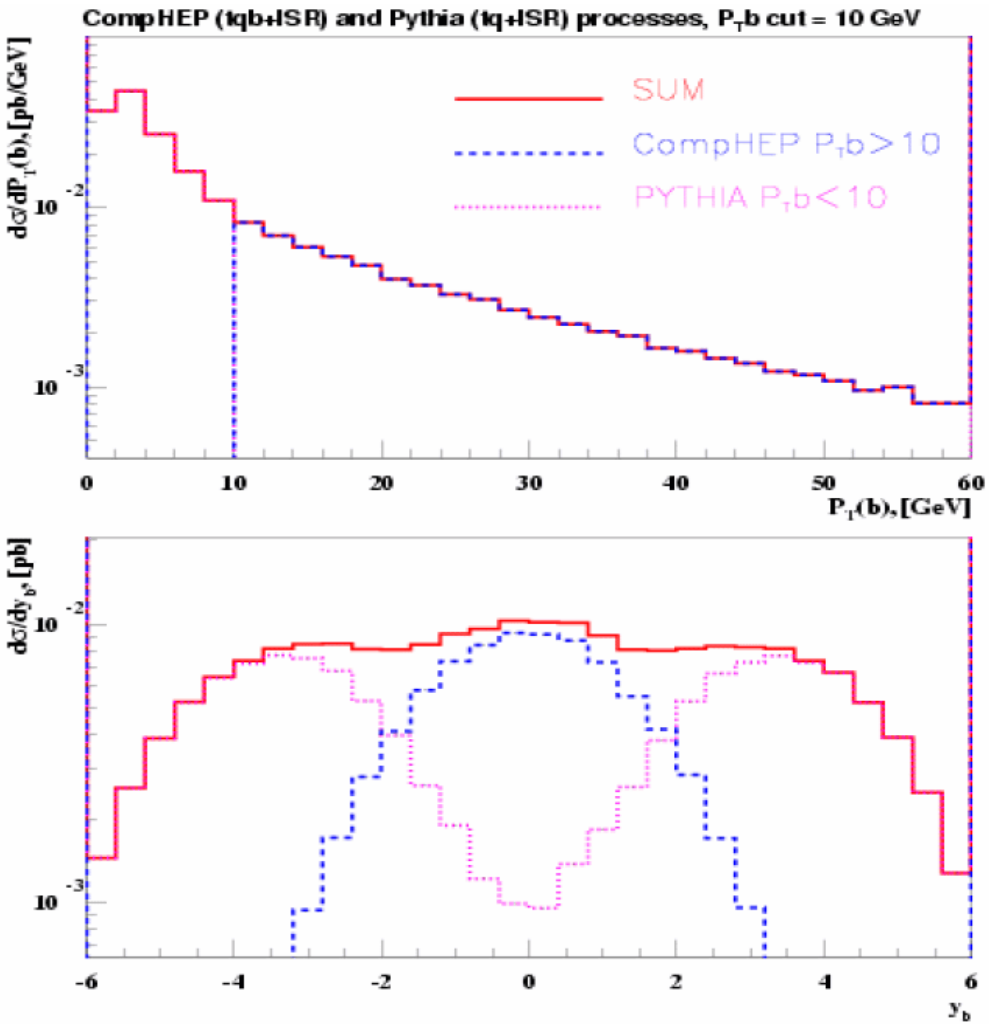


Data Samples

- top_analyzed EMQCD and MUQCD skims
- luminosity
  - electron channel with SLT: 156.24pb^{-1}
  - electron channel with SVT,JLIP: 168.68pb^{-1}
  - muon channel: 158.39pb^{-1}
- triggers
  - electron channel: EM15_2JT15 (v8-11), ELE_SHT15_2JT20 (v12)
    - one electron, pt>15GeV
    - two jets (one of which is the electron)
    - signal efficiency ~85%
  - muon channel: MU_JT20_L2M0 (v8-v11), MU_JT25_L2M0 (v12)
    - one muon
    - one jet
    - signal efficiency ~88%

MC Samples

- CompHep for single top
  - gives NLO-corrected distributions, not just LO diagrams
  - including full spin correlations
- Alpgen for ttbar
  - lepton+jets and di-lepton
- Pythia – Zμμ
  - only for muon channel SLT
- all interfaced to Pythia, followed by full simulation chain



Analysis Software

- standard Top-Group and DØ packages and code
  - top_trigger
  - top_dq
  - b-tagging
- user analysis code
  - several analysis frameworks
    - typically shared within institution
  - two variations:
    - based on top_tree and d0root
      - code shared by many Top Group and other DØ analyses
    - run MakeClass over top_analyze root tuple

Analysis Outline

- follow DØ Run I Single Top analysis outline
  - and Run II ttbar to lepton+jets analysis
- start from top_analyzed data skims
- Preselection:
  - select events containing W and jets
  - require b-quark tag
  - study background estimation in detail
- determine background and signal yield in tagged preselcted sample
- derive limit for tagged preselected samples
- *final selection*

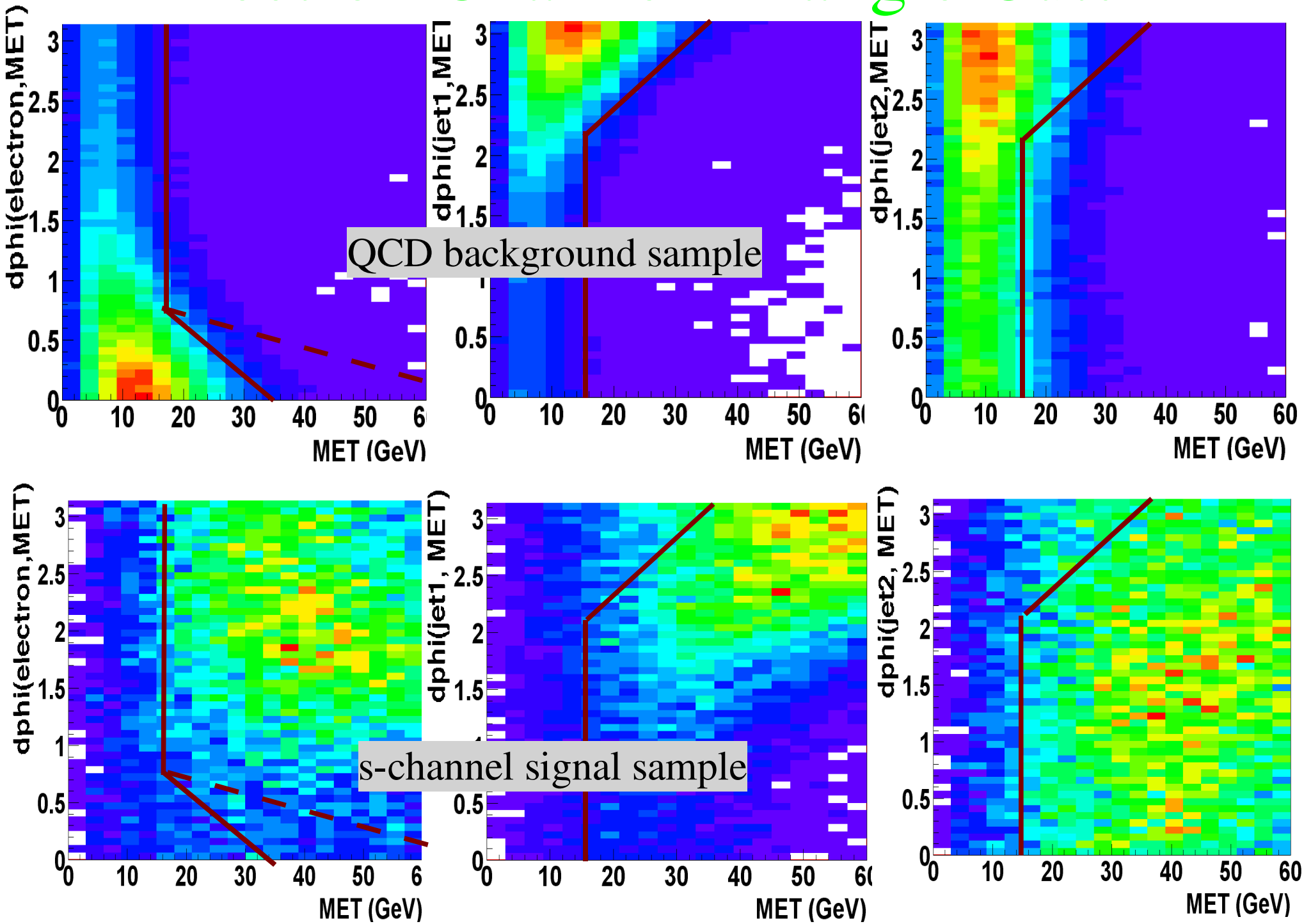
Preselection Cuts

- goals:
  - loose event selection, retaining high single-top efficiency
  - understand data sample, model all backgrounds well
  - reject patterns not described well by background models
- select Trigger, Data quality
- require exactly one high-pt isolated lepton (pt>15GeV)
  - electron: track-match, $|\eta_{det}|<1.1$ (CC only), likelihood>0.75
  - muon: $|n_{seg}|=3$, $|DCA_{sig}|<3s$, central-track-match,
    - loose isolation: dR(muon,jet)>0.5
    - tight isolation(calo- and track-based): rat11<0.08, rattrk<0.06

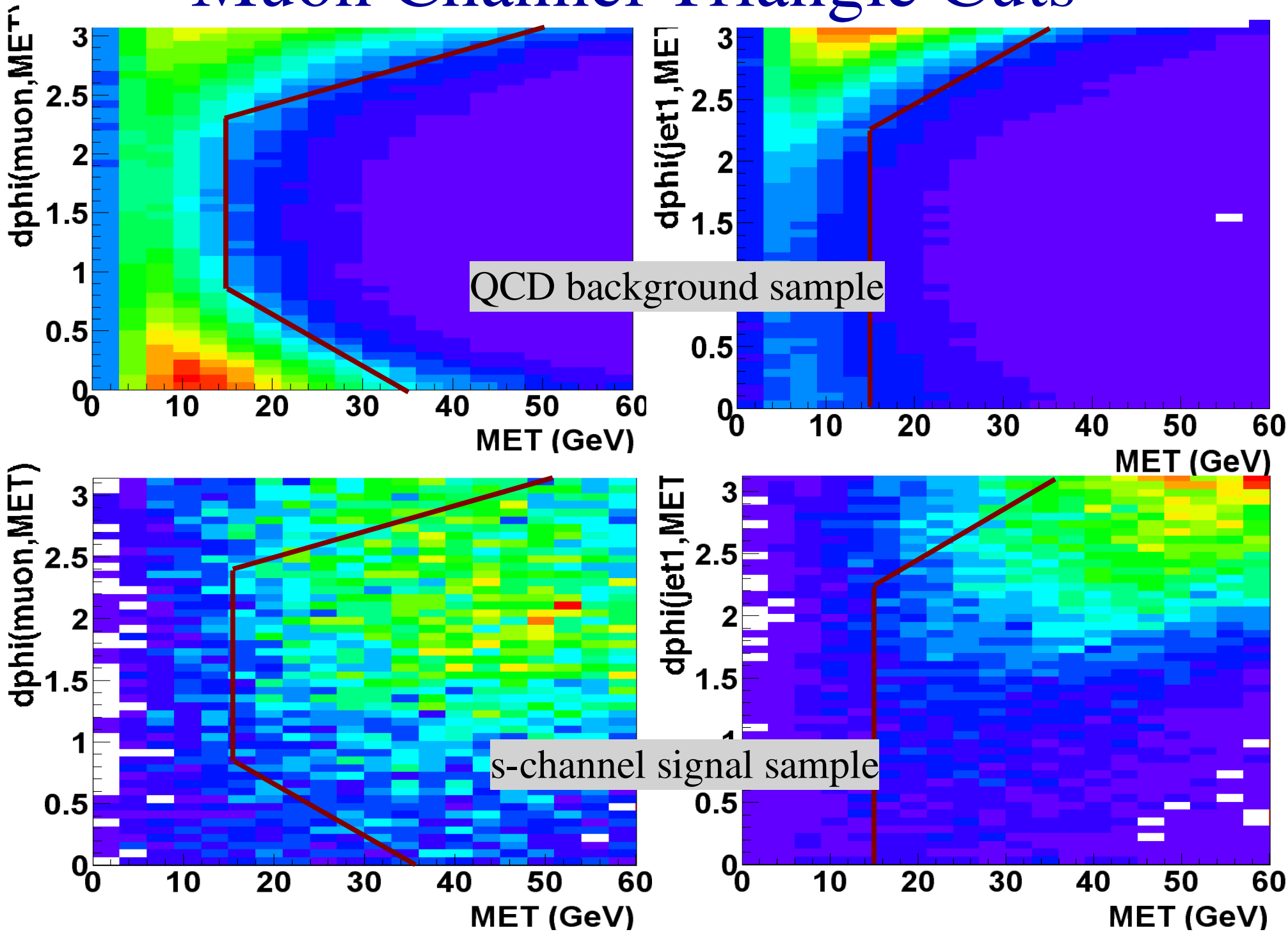
Preselection Cuts

- require $2 \leq n_{jets} \leq 4$
  - good jets: pt>15GeV, $|\eta_{det}|<3.4$
  - leading jet: pt>25GeV, $|\eta_{det}|<2.5$
- require well-reconstructed events
  - vertex: $n_{tracks} \geq 3$, $|z|<60$cm
  - $|\Delta z$(lepton track, vertex)<1cm
  - $n_{badjets} \leq 2$
  - MET<200GeV
  - mis-reconstructed leptons and jets: triangle cuts

Electron Channel Triangle Cuts



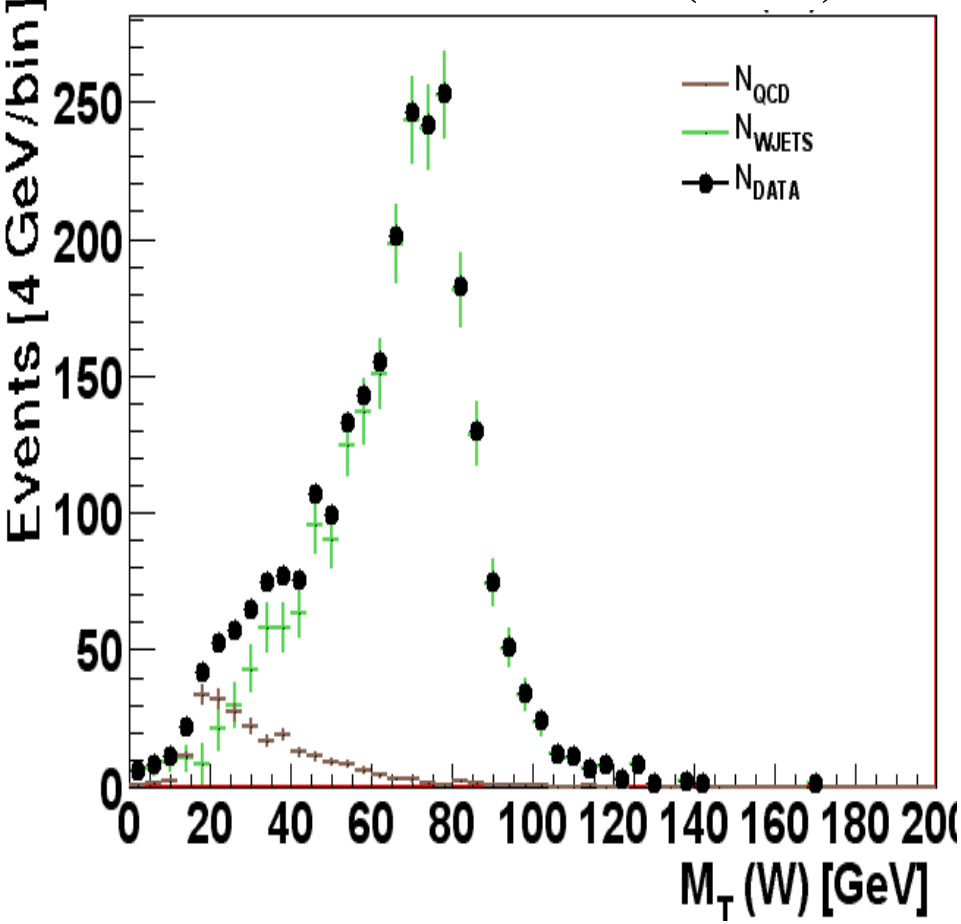
Muon Channel Triangle Cuts



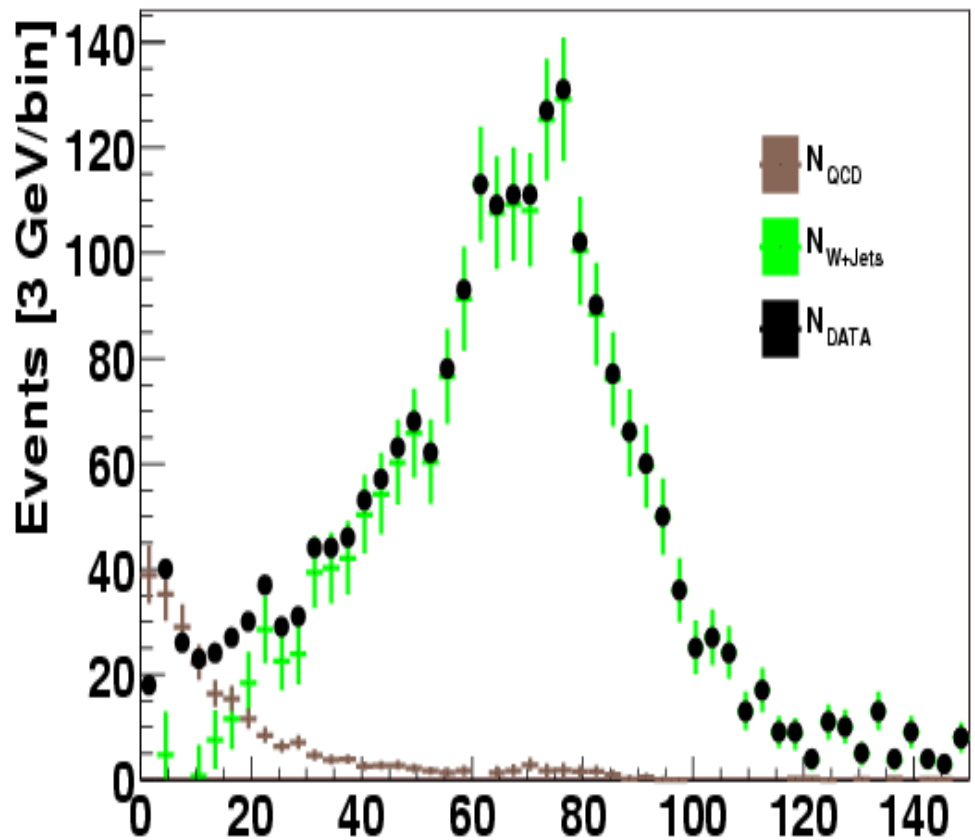
Background Yield Estimation

- in preselected (pre-tagged) sample: W+jets and QCD
  - Matrix Method, loose/tight sample:
    - before/after electron likelihood cut
    - before/after tight muon isolation cut

electron channel (SLV)



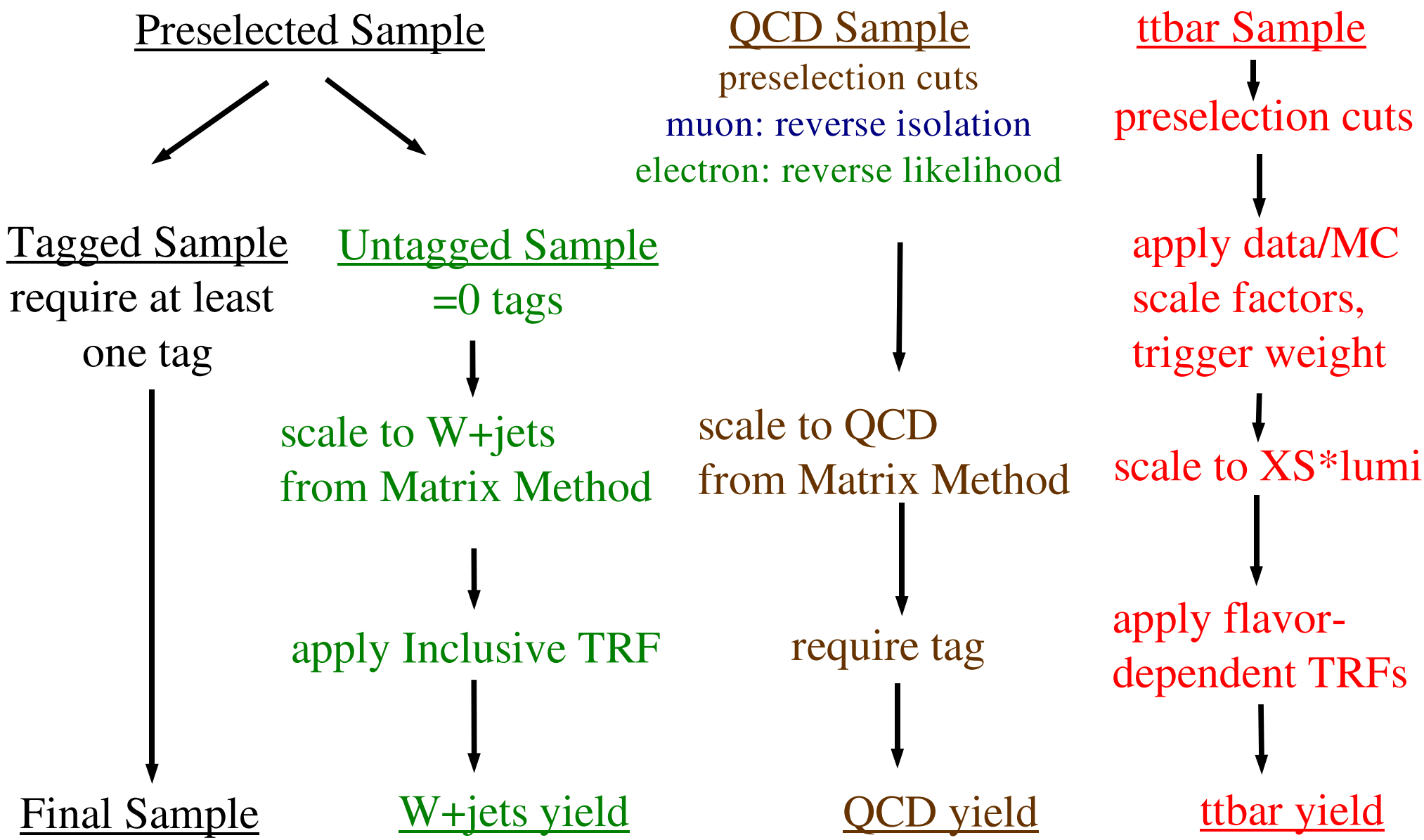
muon channel (SLV)



Tagged Preselection

- divide preselected sample into orthogonal sets
- SLT analysis:
  - full preselection data set
- lifetime tagging analyses:
  - JLIP and SVT
  - apply soft-lepton-tag veto (SLV)
  - electron channel: additional electron-MET triangle cut
    - excess of low MT(W) events not present in background sample
    - only seen in electron channel lifetime
- Check prediction in W, QCD-dominated sample
  - suppress ttbar, single top: require n_{jets}=2, HT<200GeV

Tagged Background Estimation



Tagged Data Background Estimation

- W+jets
  - using un-tagged sample
    - sample in which events are required not to be tagged
    - normalized to W+jets in pre-tagged sample
  - using flavor-inclusive tag-rate-function (TRF)
    - derived on a QCD multi-jet sample
    - same (within uncertainty) jet flavor composition as W+jets
- QCD
  - using orthogonal QCD-like sample
    - electron: fail likelihood cut, muon: fail tight isolation cut
    - normalized to QCD in pre-tagged sample
  - apply tagging directly to this sample

Tagged MC Yield Estimate

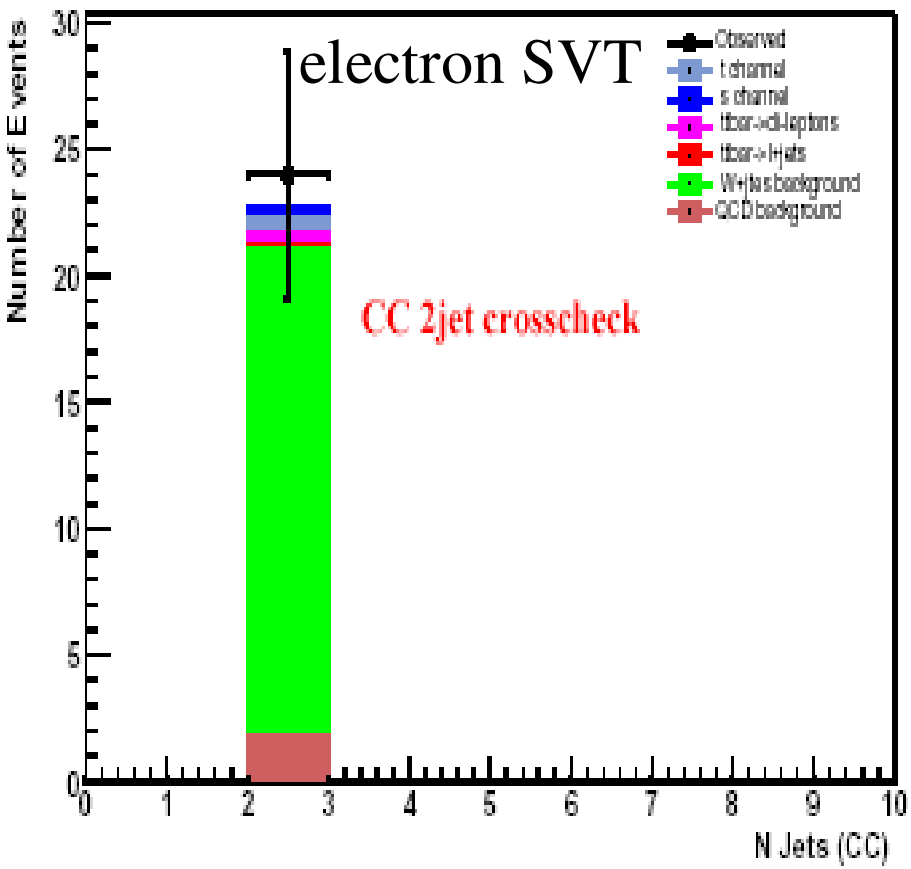
- for ttbar background
  - apply all preselection cuts to the sample
  - scale factors to correct for data/MC efficiency differences
    - electron: cal clustering, cal ID, tracking+matching, likelihood
      - overall data-MC scale factor: 0.869 ±0.021
    - muon: reco+ID, tracking+matching, isolation
      - overall data-MC scale factor: 0.86 ±0.054
  - apply flavor-dependent TRFs
    - event weight: 1 – (probability not to tag event)
  - apply trigger weight
- same for single top signal acceptance calculation

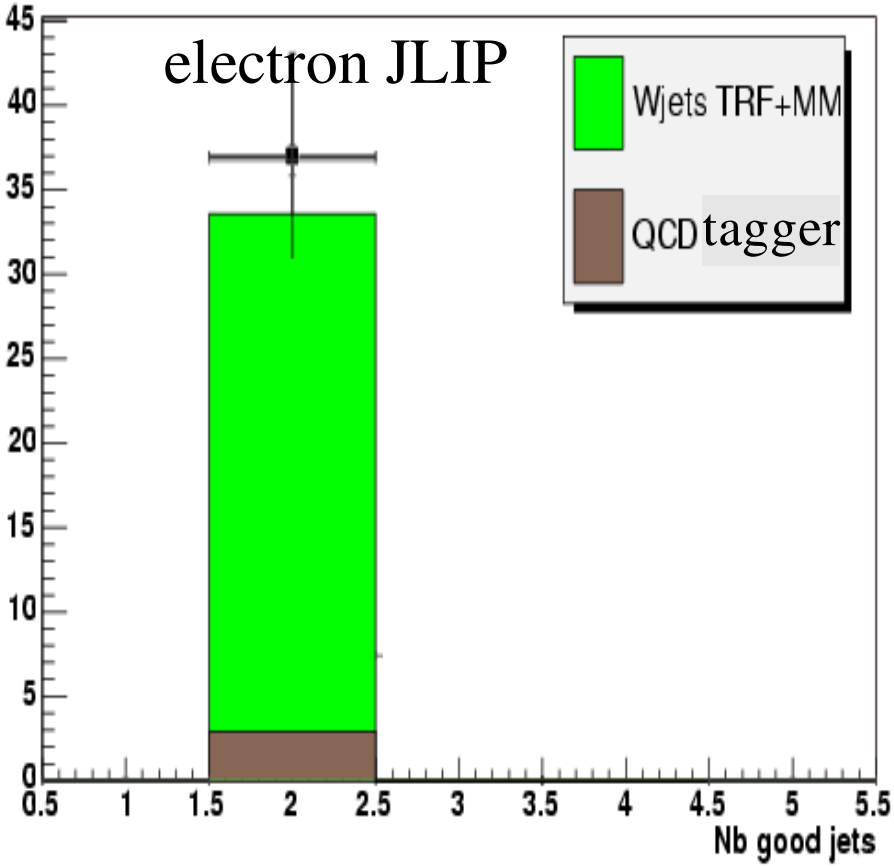
Inclusive TRF

- flavor composition of jets in W+jet events is approximately the same as in multi-jet QCD events
  - within 20% measurement uncertainty
- derive average per-jet tag-rate in multi-jet sample
  - 3jetloose (2-4 jets, low HT): SVT, JLIP
    - parameterized as $f(\eta_{det},E_T)$
    - introduce scale factor (1.18) to make multi-jet samples consistent
  - alljet (SLT, 4 jets, HT>100GeV): SLT
    - parameterized as $f(\eta_{det},\phi_{det},E_T)$
- test flavor-composition assumption
  - Z+jets sample
  - W+jets cross-check sample (HT<200GeV)

Inclusive TRF cross-checks

- Z+≥2jet sample:
  - SVT: TRF prediction: 15.7 events, tags found: 17
- W cross-check sample
  - muon channel SVT: prediction: 22.8, tags found: 20





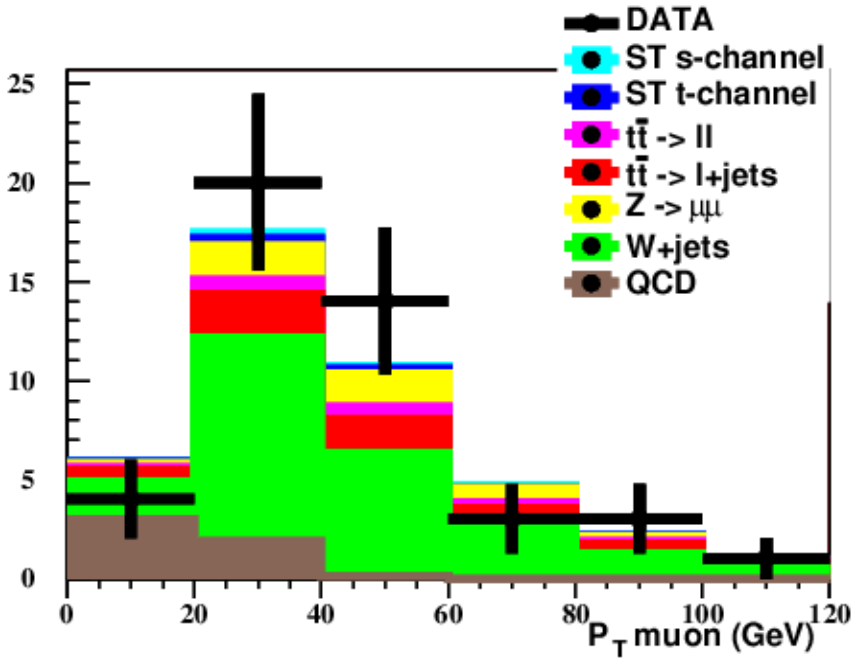
Systematic Uncertainties

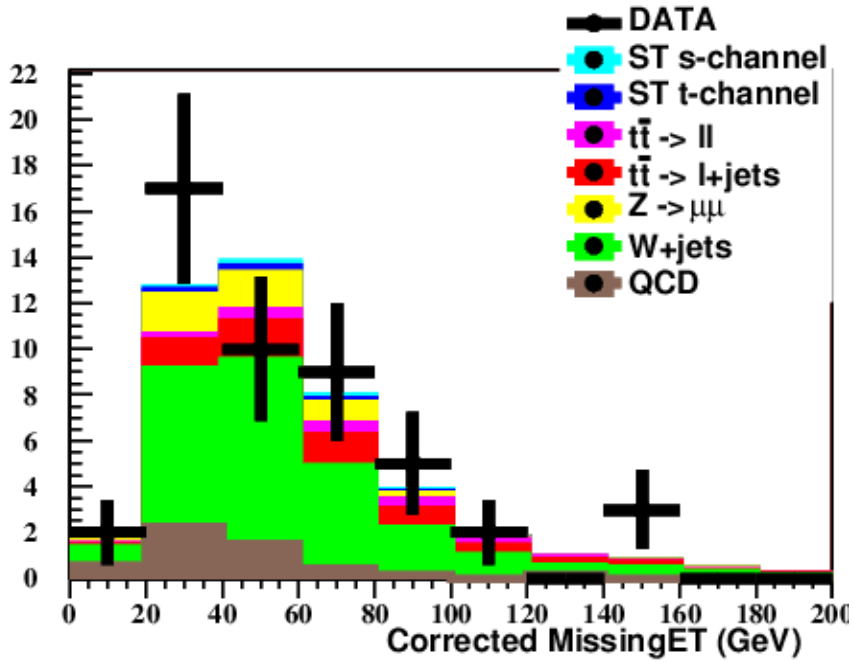
- MC (acceptance and ttbar bg):
  - luminosity: 6.5%
  - branching fraction: 2%
  - electron ID: 2.4%
  - muon ID: 6.3%
  - tagging muon modeling: 2.6%
  - tagging muon ID: 2.1%
  - tagging muon veto: 3.3%
  - primary vertex: 0.6%
  - trigger parameterization: ~10%
  - L1 trigger eta change: 4%
  - jet fragmentation: 5%
  - Jet Energy Resolution: 0.5%
  - Jet Energy Scale: ~3%
  - flavor-dependent TRF: ~12%
- Data (QCD and W+jets):
  - QCD scale factor: ~13%
  - W+jets scale factor: ~3%
  - inclusive TRF: 20%

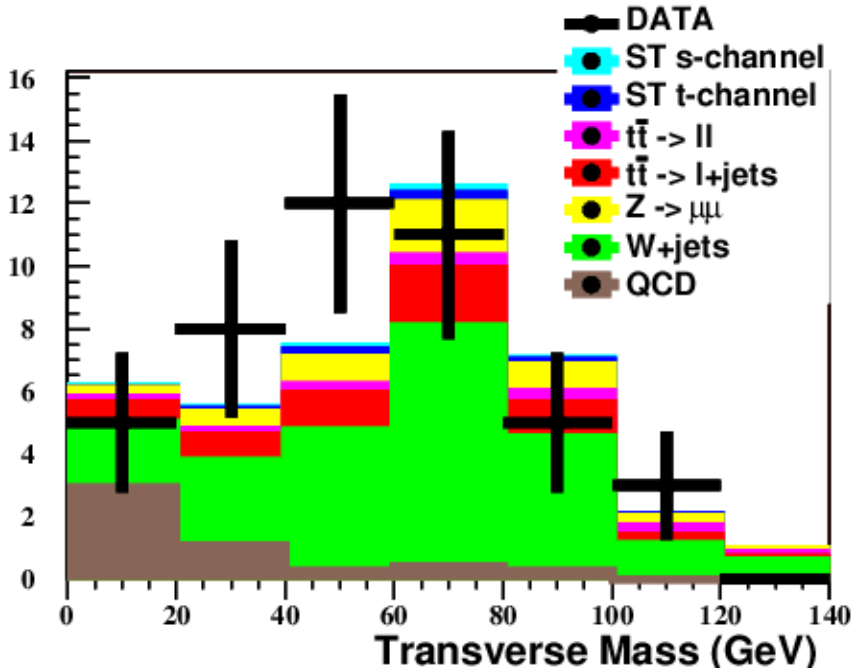
Event Yields

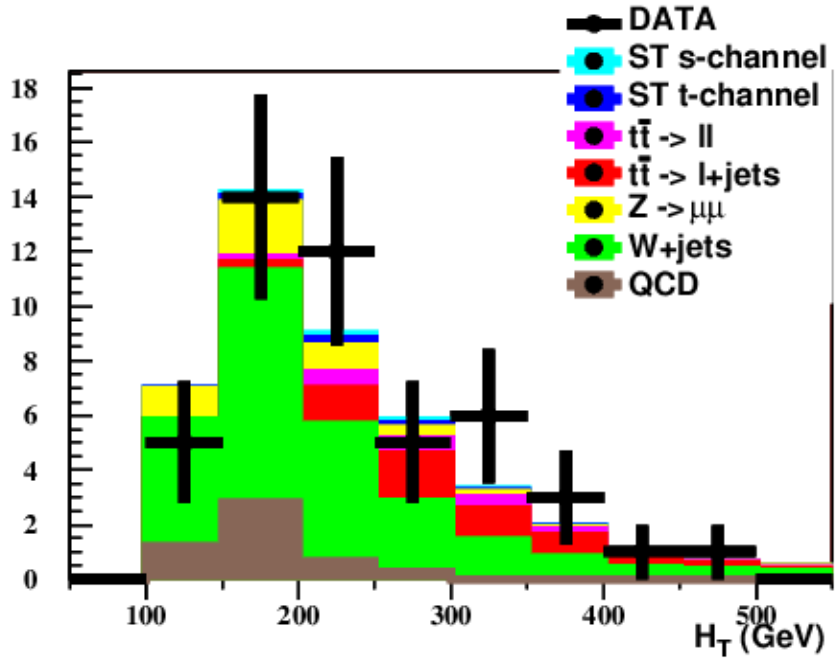
	Electron Channel (CC)			Muon Channel	
	SLT	SVT	JLIP	SLT	SVT
Signals					
MC tb	0.67 ± 0.14	1.68 ± 0.42	1.88 ± 0.46	0.63 ± 0.13	1.22 ± 0.31
MC tqb	0.95 ± 0.20	3.03 ± 0.74	3.20 ± 0.82	0.88 ± 0.18	2.10 ± 0.54
MC tb+tqb	1.62 ± 0.24	4.71 ± 0.85	5.08 ± 0.94	1.51 ± 0.22	3.32 ± 0.63
Backgrounds					
MC $t\bar{t} \to l$+jets	7.00 ± 1.59	16.08 ± 4.17	19.29 ± 5.32	6.25 ± 1.33	12.40 ± 3.13
MC $t\bar{t} \to ll$	2.60 ± 0.55	4.49 ± 1.11	5.29 ± 1.34	2.18 ± 0.46	3.80 ± 0.98
MC $Z\mu\mu$	–	–	–	4.79 ± 0.86	–
W+jets data	25.01 ± 5.04	51.66 ± 10.41	65.00 ± 13.09	24.07 ± 4.92	48.60 ± 9.94
QCD data	6.13 ± 0.75	4.85 ± 0.61	6.68 ± 0.84	4.94 ± 0.75	10.90 ± 1.58
Sum of Bkgs	40.6 ± 5.36	77.08 ± 11.28	96.26 ± 14.22	42.23 ± 5.13	75.70 ± 10.59
Sum of Bkgs for tb	41.55 ± 5.37	80.11 ± 11.31	99.46 ± 14.25	43.11 ± 5.32	77.80 ± 10.60
Sum of Bkgs for tqb	41.27 ± 5.37	78.76 ± 11.29	98.14 ± 14.22	42.86 ± 5.32	76.92 ± 10.59
Signal data	49 ± 7	83 ± 9	99 ± 10	48 ± 7	83 ± 9

Event Yield: Muon Channel SLT

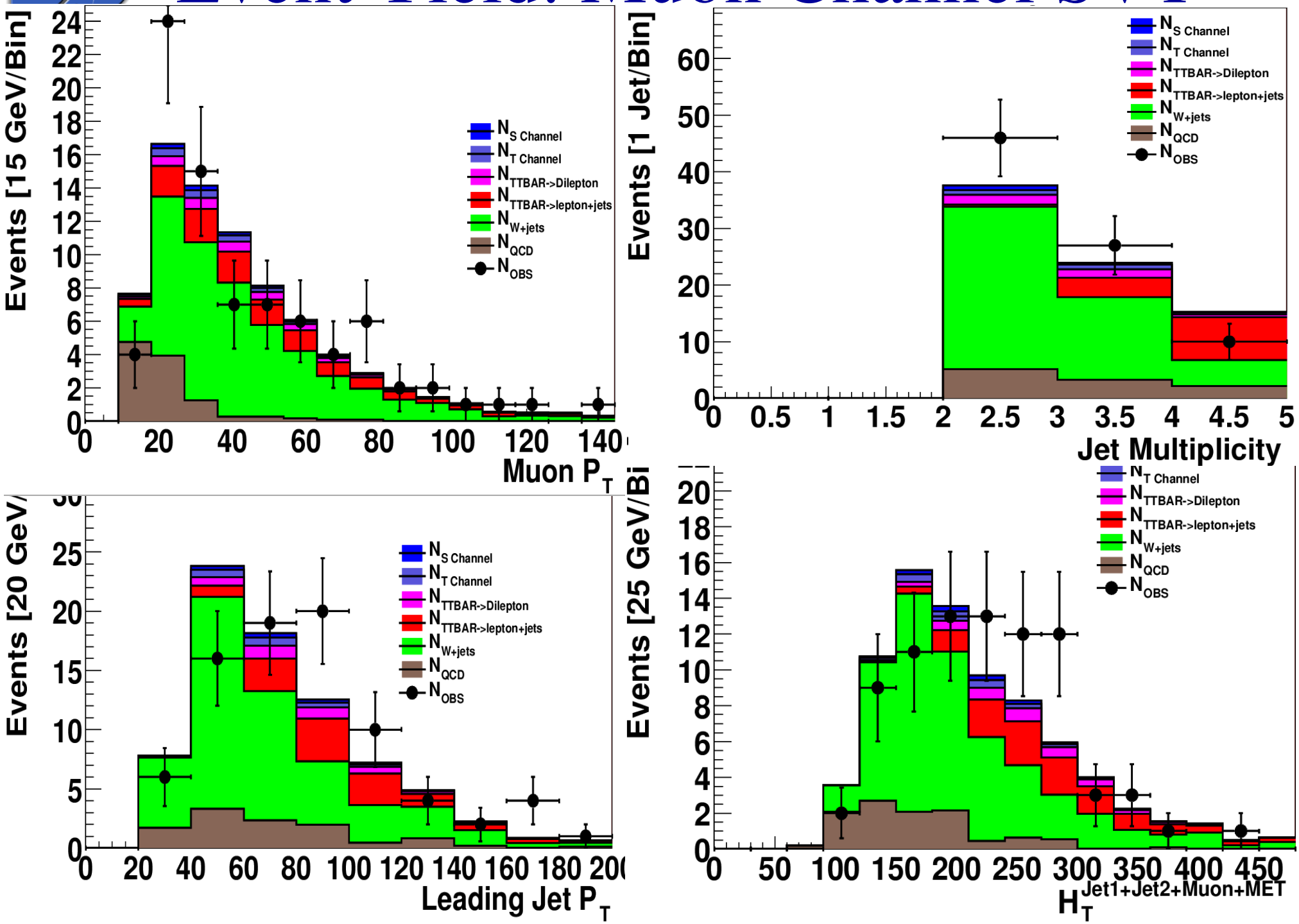




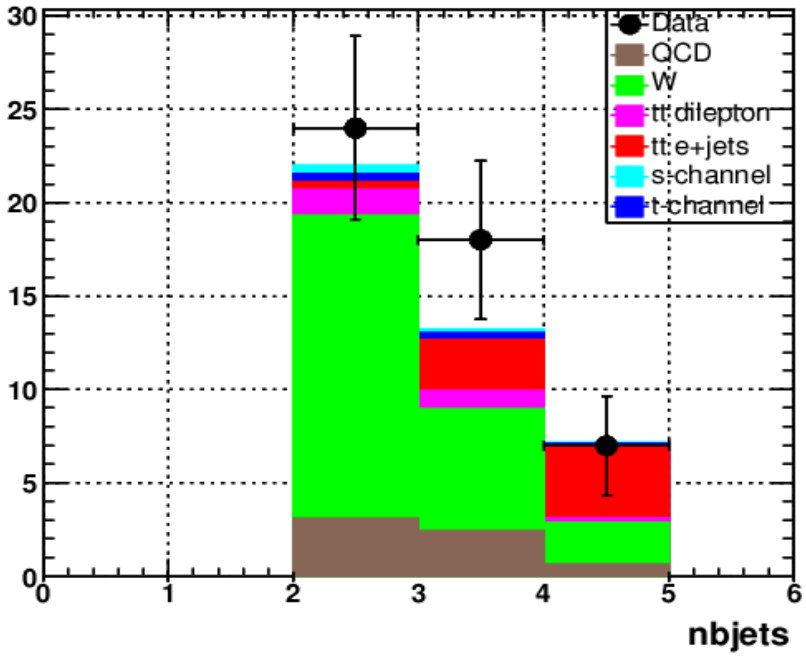


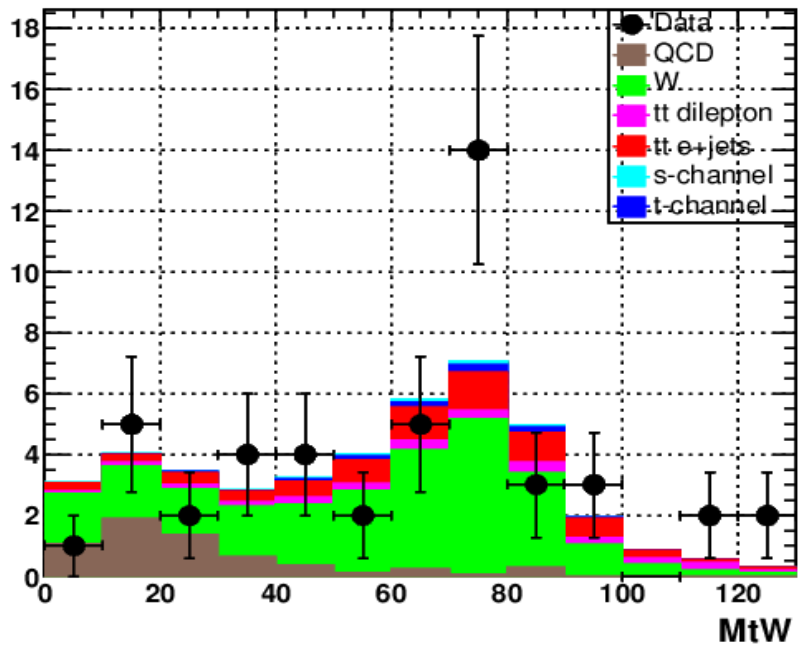


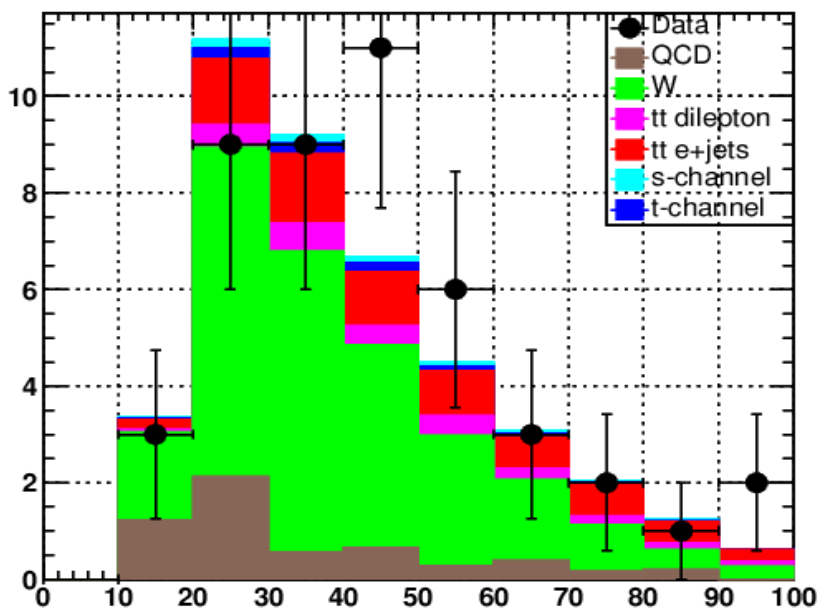
Event Yield: Muon Channel SVT



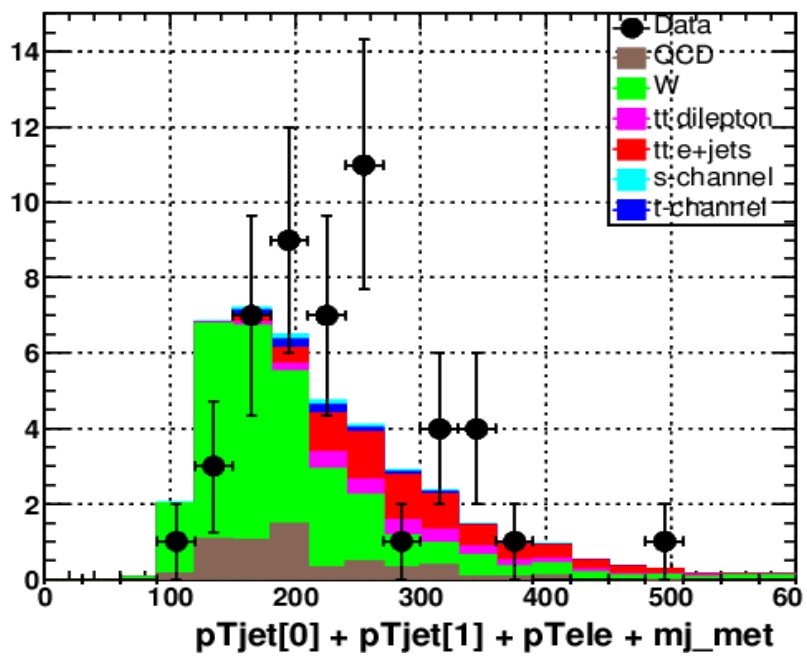
Event Yield: Electron Channel SLT



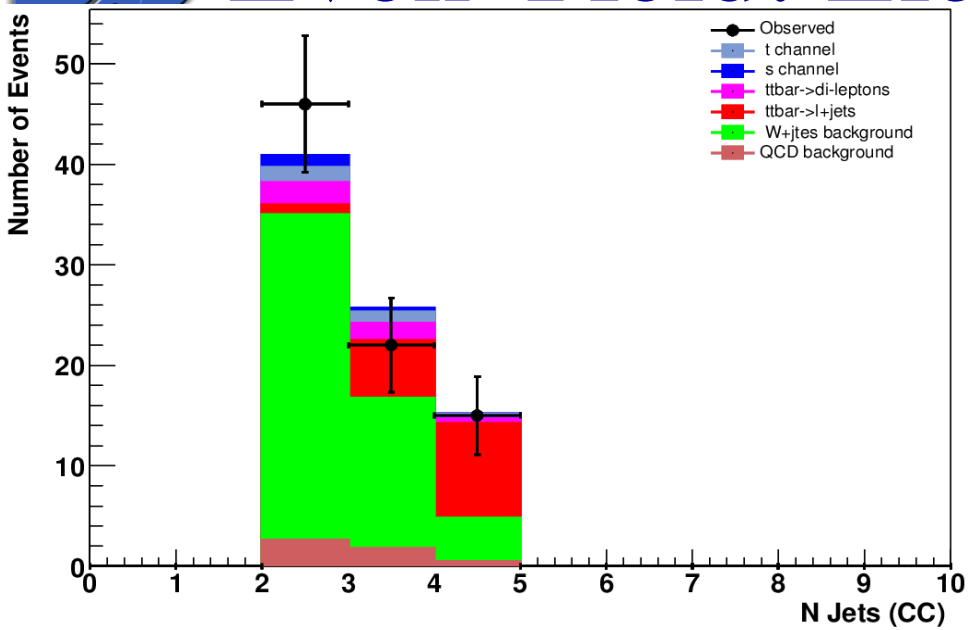


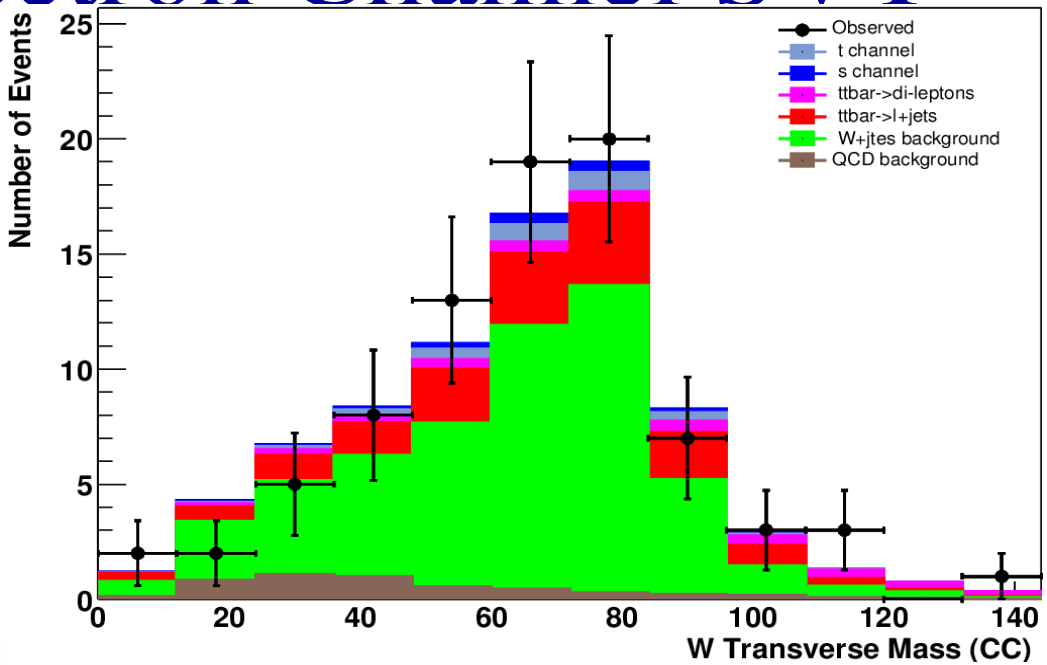


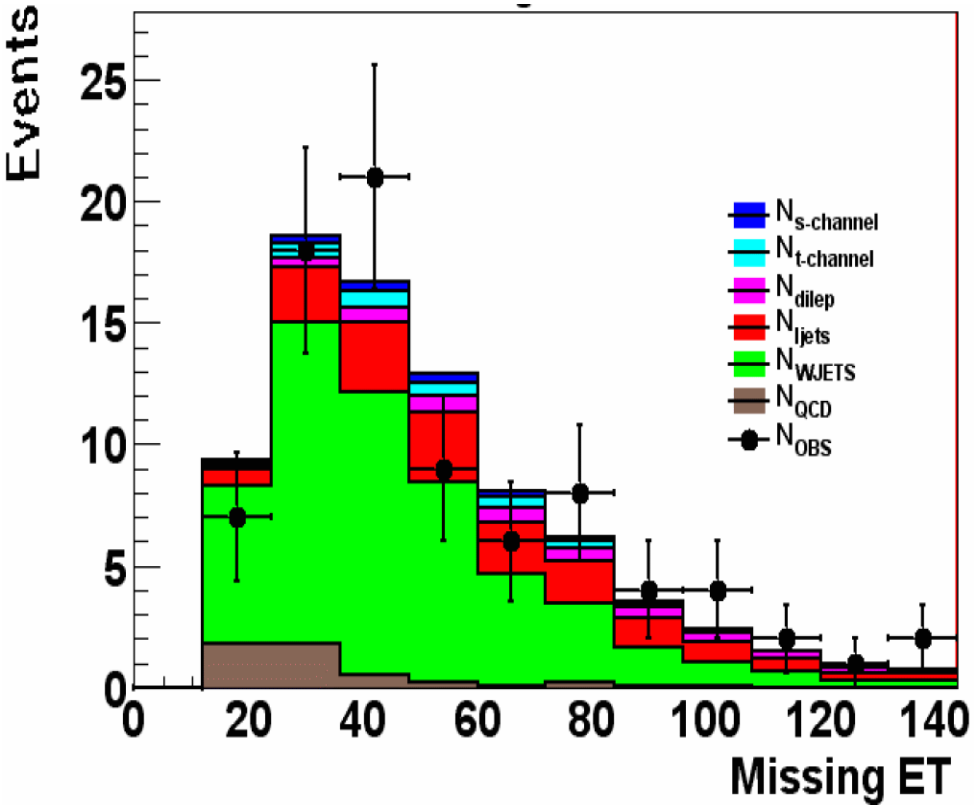
jet1 ET (GeV)

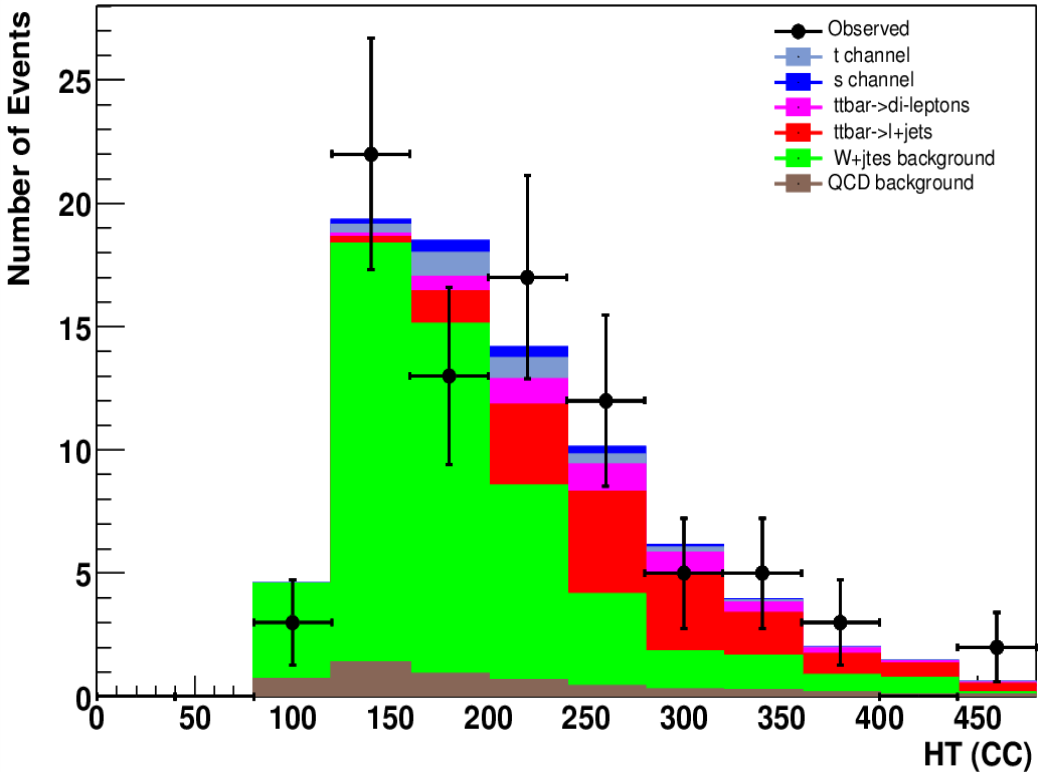


Even Yield: Electron Channel SVT

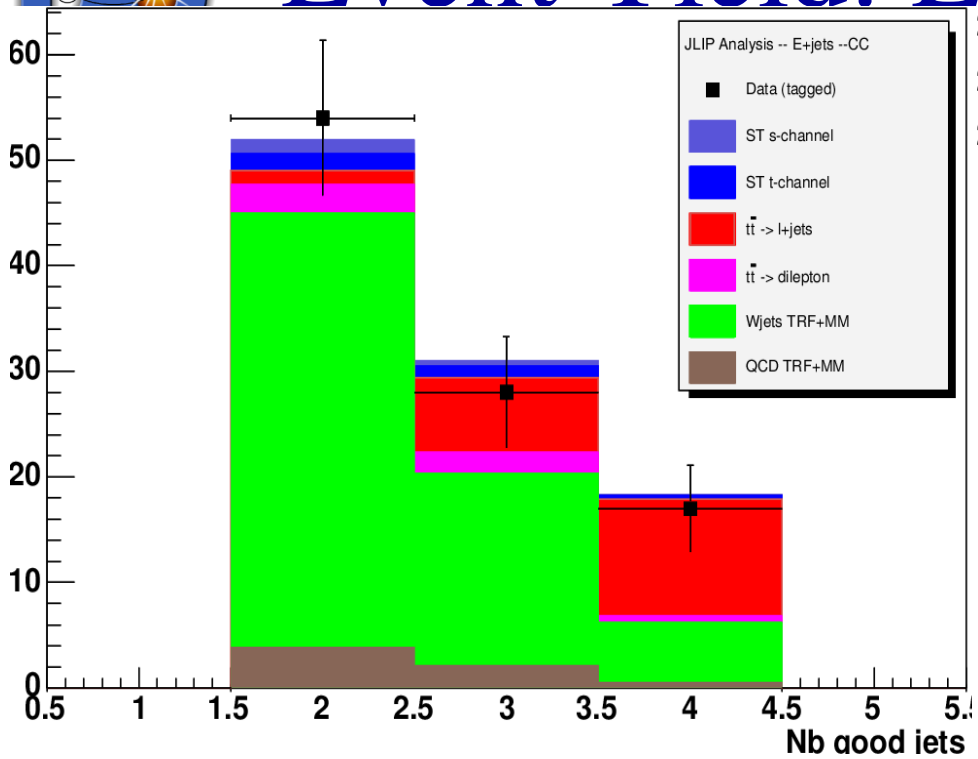


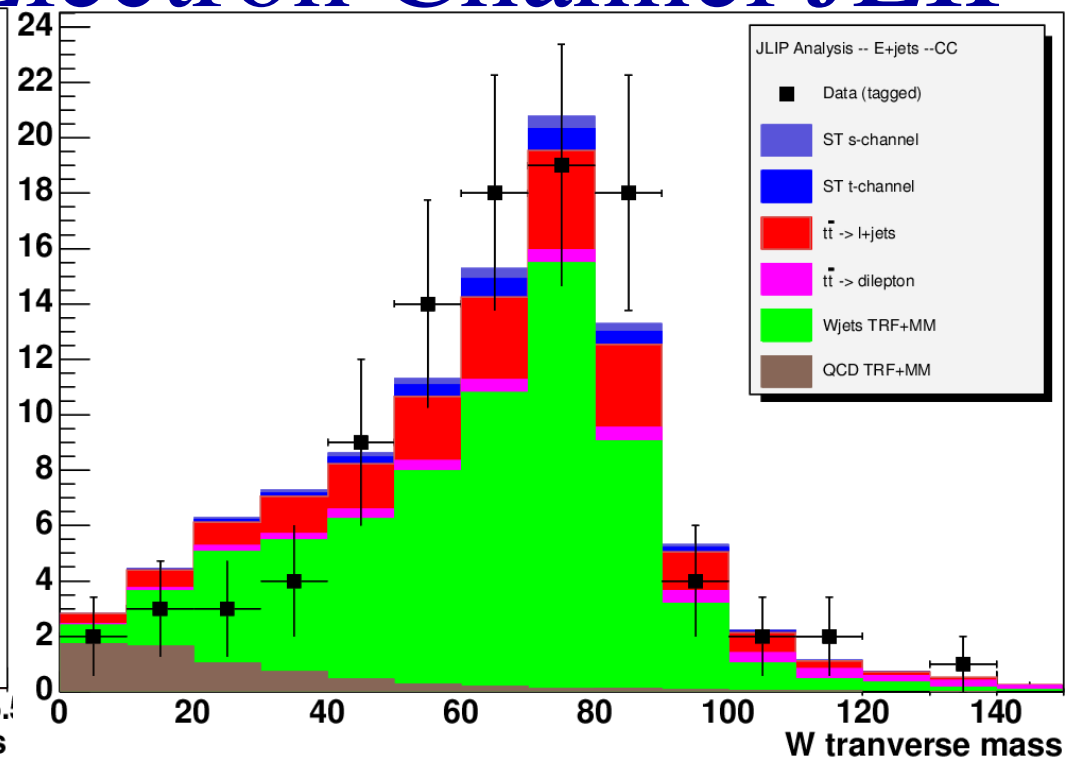


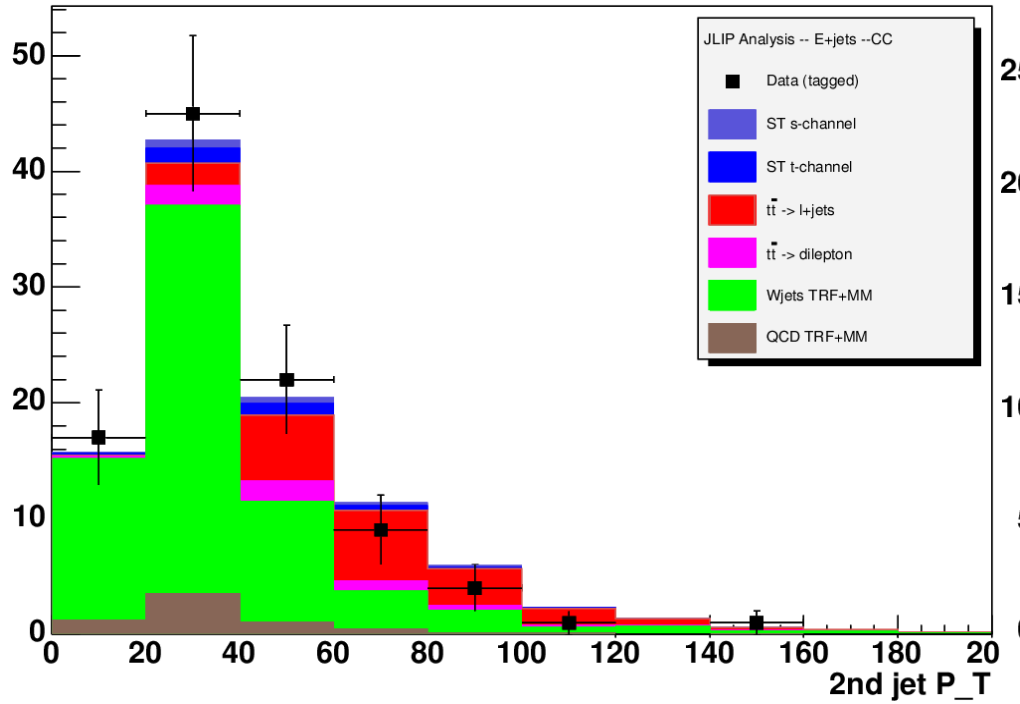


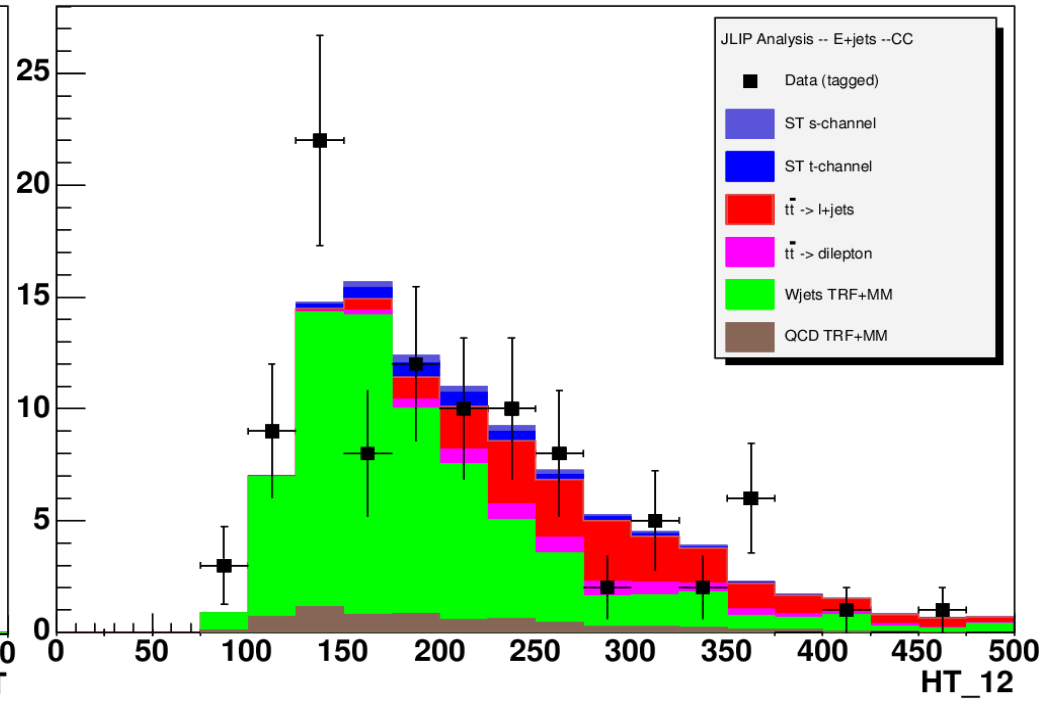


Event Yield: Electron Channel JLIP









Single Top Cross Section Limit

- individual channels and combinations
  - electron, muon; SLT, SVT
  - electron: SLT, JLIP
- observed # of events:
    - observed (SLT+SVT): 264
    - predicted background (SLT+SVT): 235.6 ± 17.2
    - expected from single top (s+t channel): 11.16 ± 1.1
  - slight excess of events, consistent with background fluctuation
- proceed to set cross section limits
  - modified frequentist approach (CLs method)
  - include all systematic uncertainties
  - separately for s-channel, t-channel, s+t combined

Expected Limits

Channel	Electron	Muon	$e+\mu$	$e+\mu$ combined with SLT
s-channel				
SLT	19.8	21.9	14.2	
SVT	10.7	14.5	8.7	6.5
JLIP	11.2	—	11.2	8.3
t-channel				
SLT	32.5	36.3	23.2	
SVT	14.2	20.5	11.3	10.3
JLIP	15.3	—	15.3	12.0
s- and t-channel				
SLT	27.9	29.9	19.4	
SVT	13.0	19.0	10.2	9.0
JLIP	13.5	—	13.5	10.7

Single Top Cross Section Limit

Channel	Electron	Muon	$e+\mu$	$e+\mu$ combined with SLT
s-channel				
SLT	34.6	31.7	27.6	
SVT	15.2	21.4	14.3	15.4
JLIP	13.5	—	13.5	13.8
t-channel				
SLT	49.0	48.6	36.9	
SVT	16.7	27.5	15.1	15.8
JLIP	15.7	—	15.7	16.3
s- and t-channel				
SLT	43.7	41.4	33.7	
SVT	16.7	25.6	15.1	16.2
JLIP	15.1	—	15.1	15.9

Summary/Conclusions

- preliminary single-top production cross section limit
  - based on ~156 to 167 pb^{-1} of RunII data
  - s-channel: 15pb
  - t-channel: 16pb
  - s+t channel: 16pb
- improvement over Run I limit
- sensitivity (expected limit) around 10pb
- limit based on loose preselection and tagging only
  - will improve further with final selection cuts
- result of huge amount of work in a short amount of time by everyone in the Single Top Working Group

Outlook (*to-do list*)

- apply final selection cuts
  - simple cuts, random-grid-search, likelihood, neural network
- derive limit from event-counting after final cuts
- derive limit based on histograms
  - bin-by-bin event counting
  - fit background templates to observed data
- improve analysis details
  - study systematics, preselection cuts, background estimates
  - add more triggers
- work towards observation

Thank You

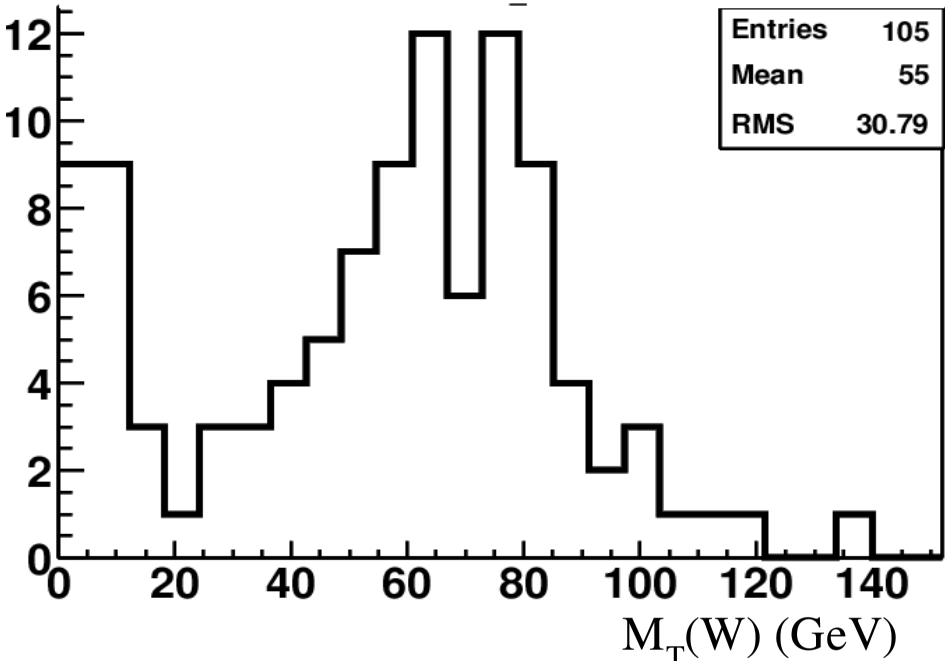
- This analysis was made possible through a lot of cooperation
  - The single top working group worked as a group
  - We greatly benefited from and contributed to the work done within the Top Group
- We all learned a lot about the analysis, the detector, and Single Top Physics over the last 5 months
- We have laid a solid analysis foundation
  - infrastructure, information, communication
- We can build on this experience as we work towards observing Single Top Quark Production

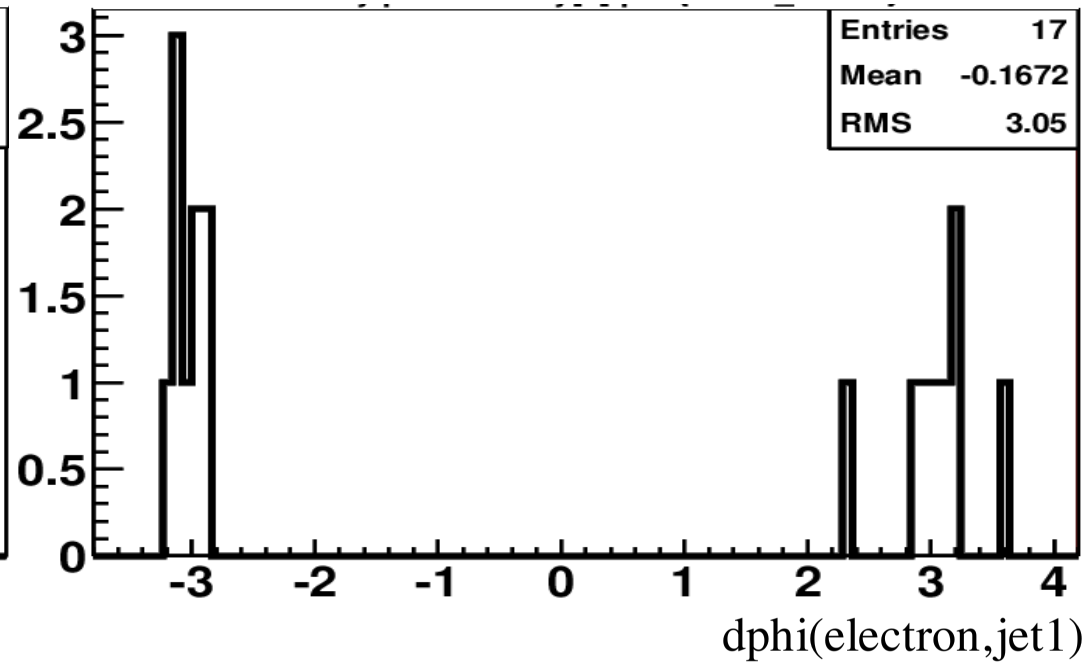
Supporting Slides

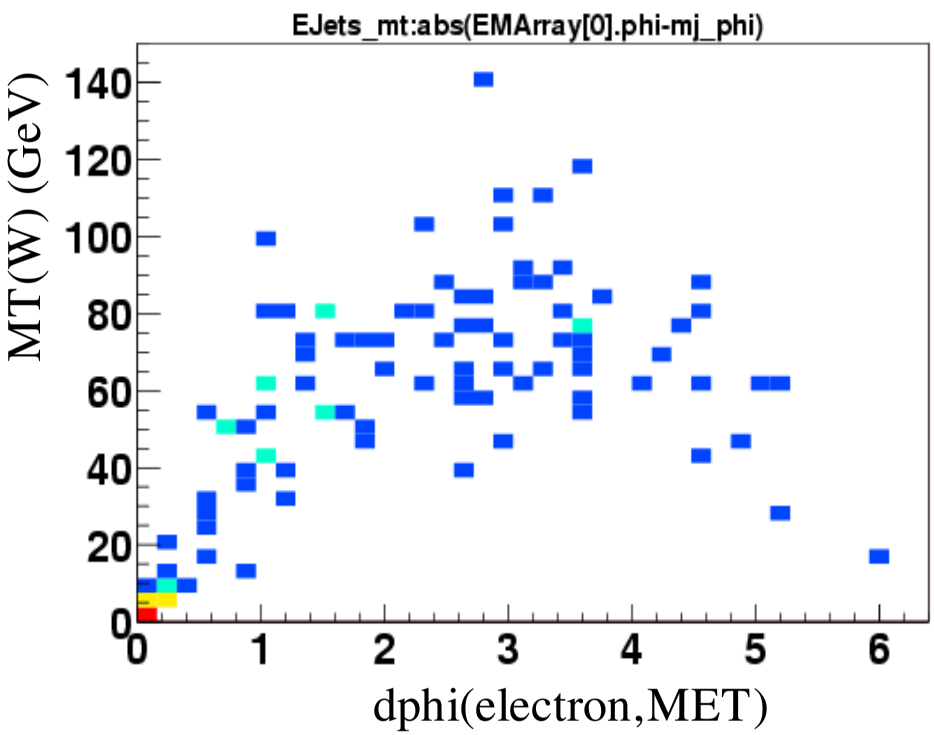
tagged low-dphi electron events

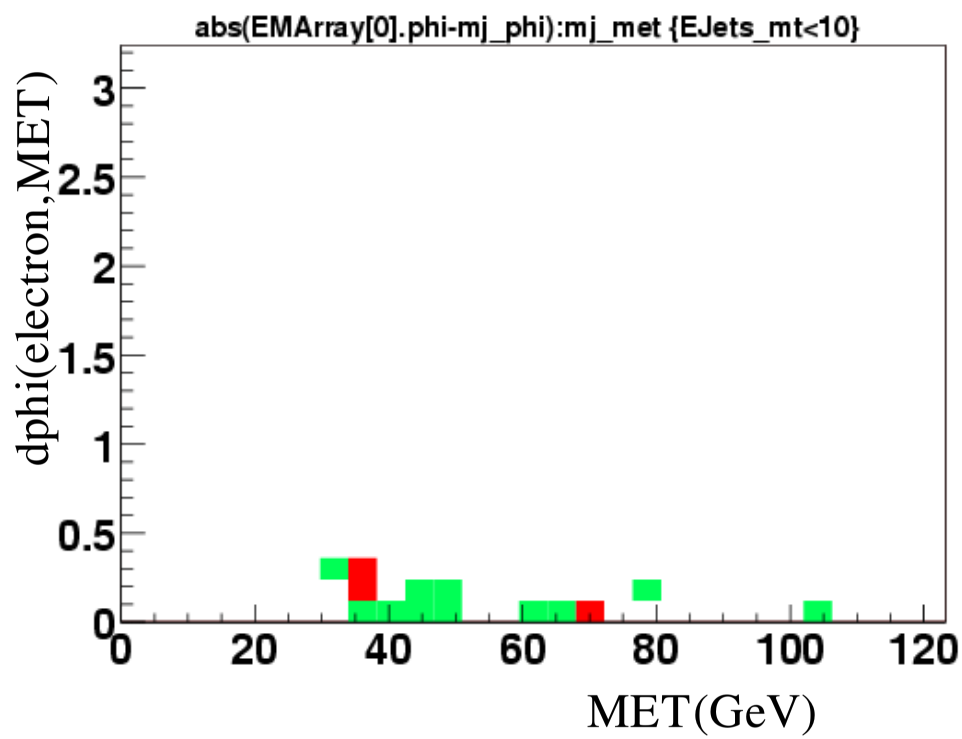
- found in JLIP analysis, also seen in SVT analysis
  - not reproduced by background model
  - not seen by SLT
- many event with similar properties
  - appear to be real electrons, low E_T ,high MET
  - more 3-jet events than 2-jet
    - leading jet back-to-back with electron
      - » but has jet-like EM fraction
  - no taus, not really high luminosity
- Zee or bb together with min bias?
- misreconstructed primary vertex?
- increase triangle cut to remove these
  - study more details post-Moriond

tagged low-dphi electron events



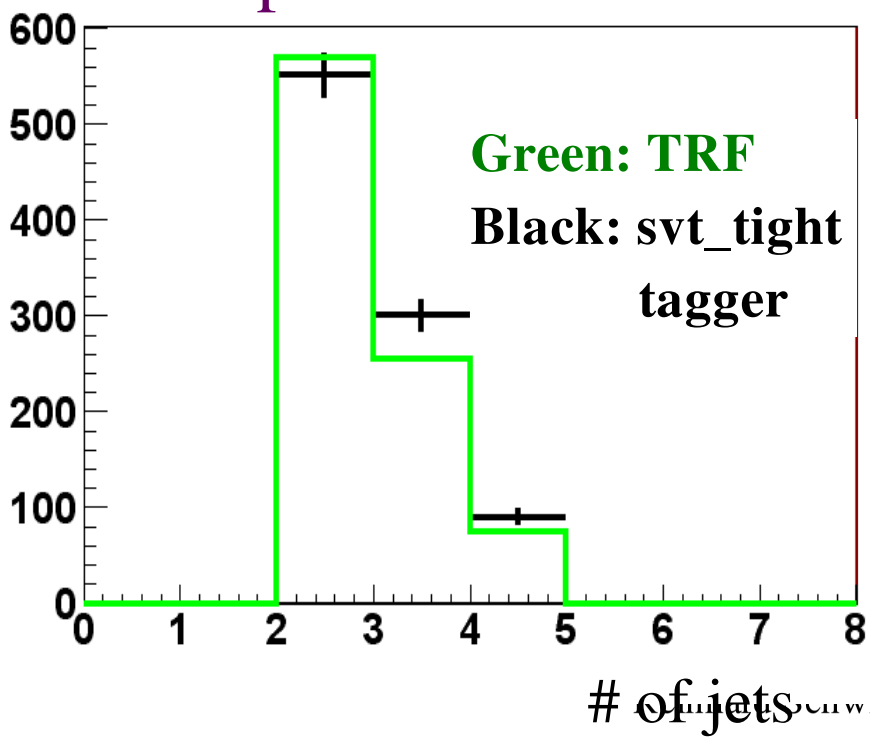


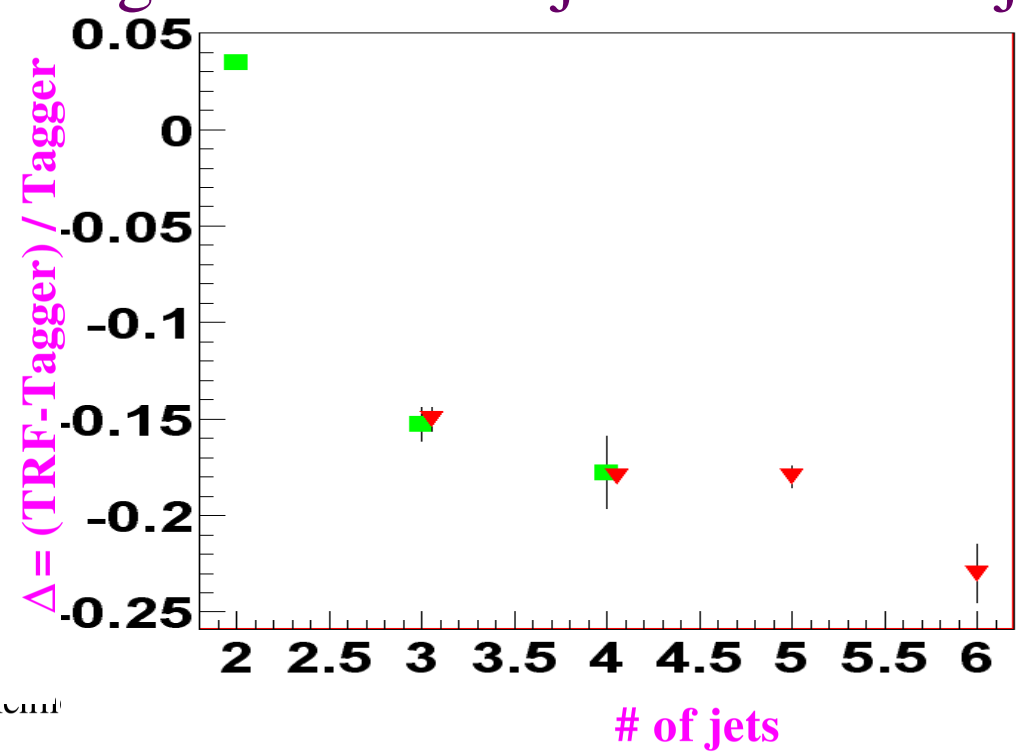




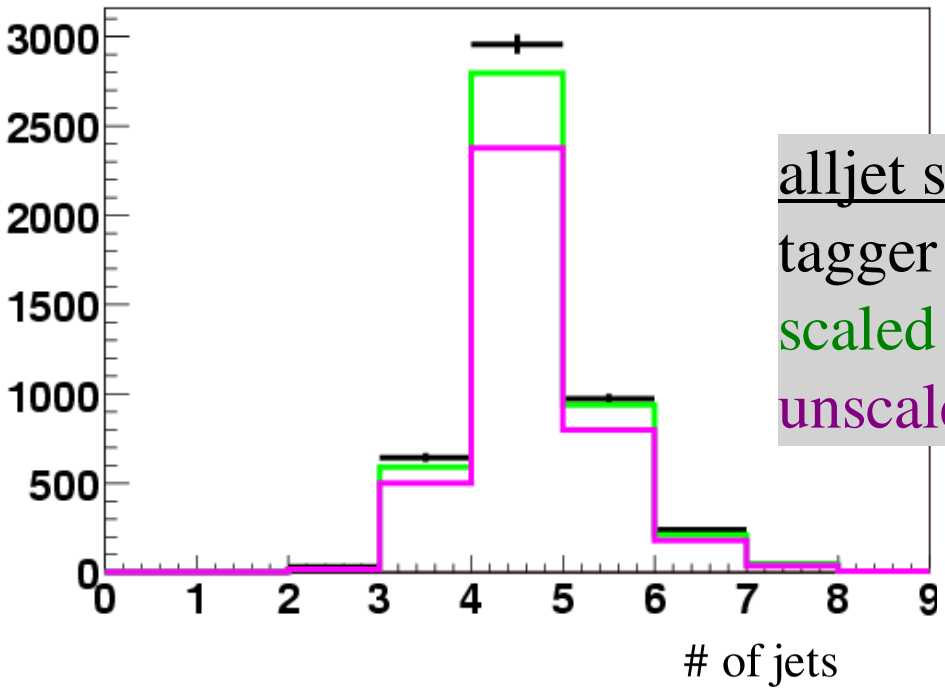
inclusive TRF scale factor

- found inconsistency in tagging rates from 3jetloose and alljet samples
  - tagging rate depends on jet multiplicity
- derive TRF on 3jetloose sample and apply scale factor to make observed tag rate agree with predicted rate
  - now predicted and observed agree both for 3jetloose and alljet

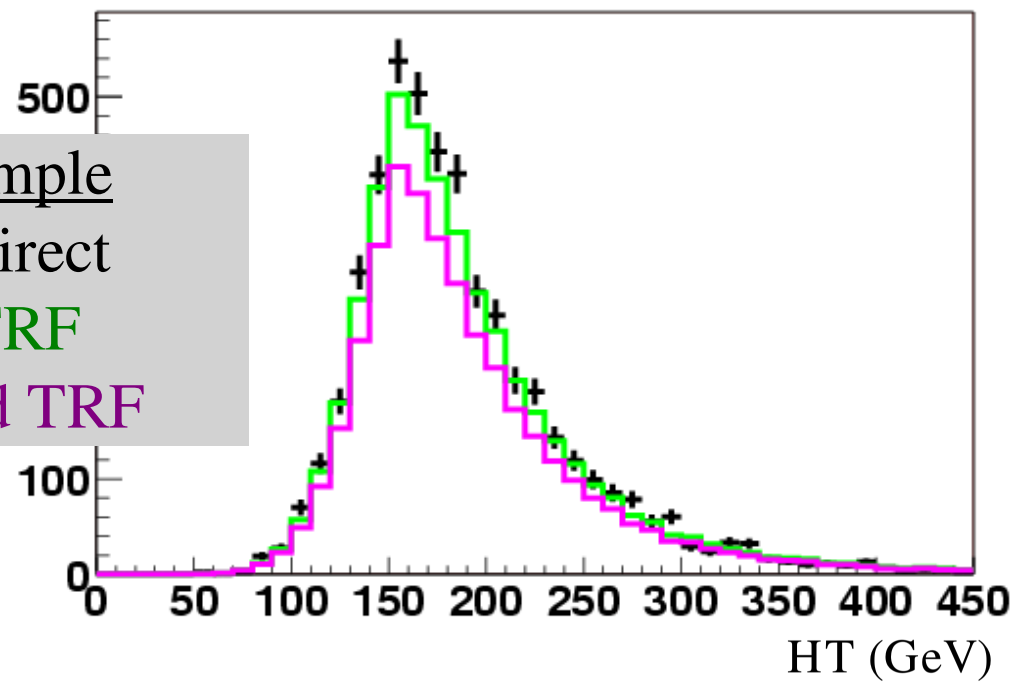


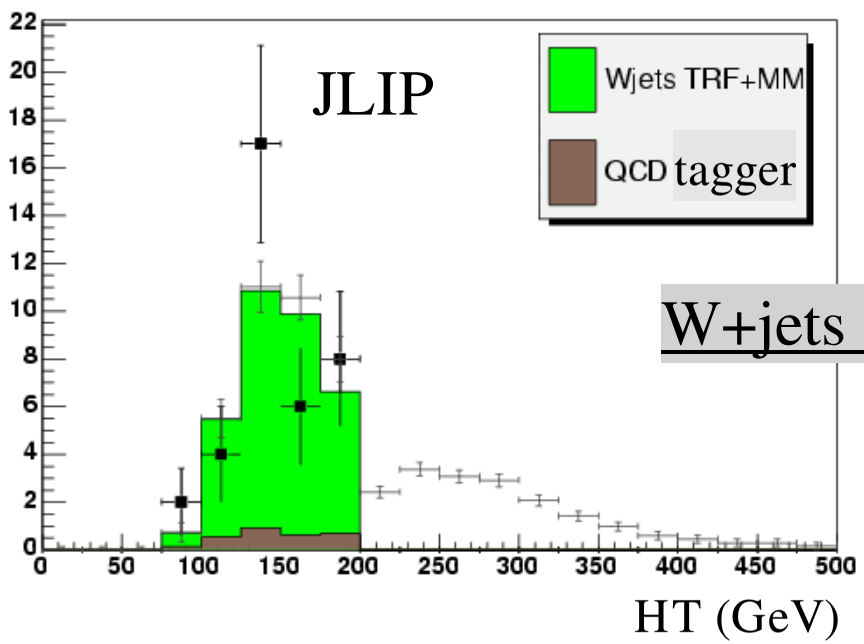
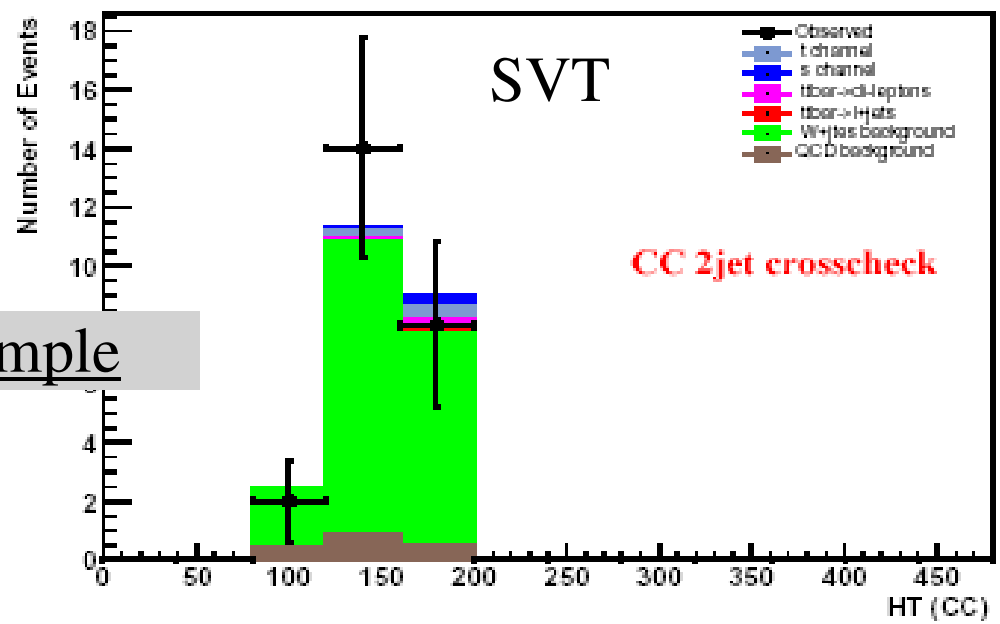


inclusive TRF cross-checks



alljet sample
tagger direct
scaled TRF
unscaled TRF





W+jets sample