Single Top Searches at DØ

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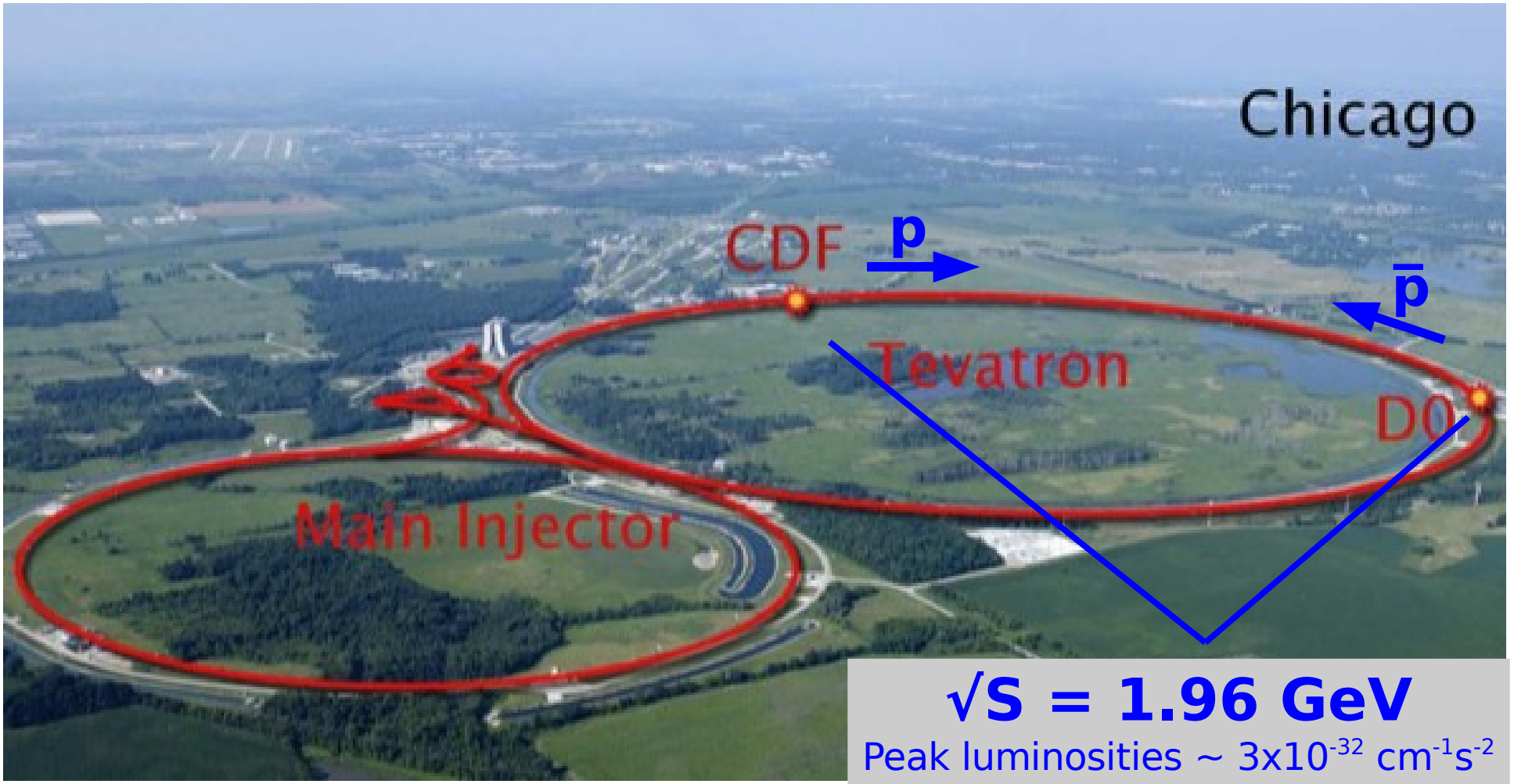
Outline

- The DØ Experiment
- Introduction to single top
- Event selection
- B-tagging
- Background modeling
- Systematic uncertainties
- Multi-variate techniques
- Cross-section measurement
- Summary

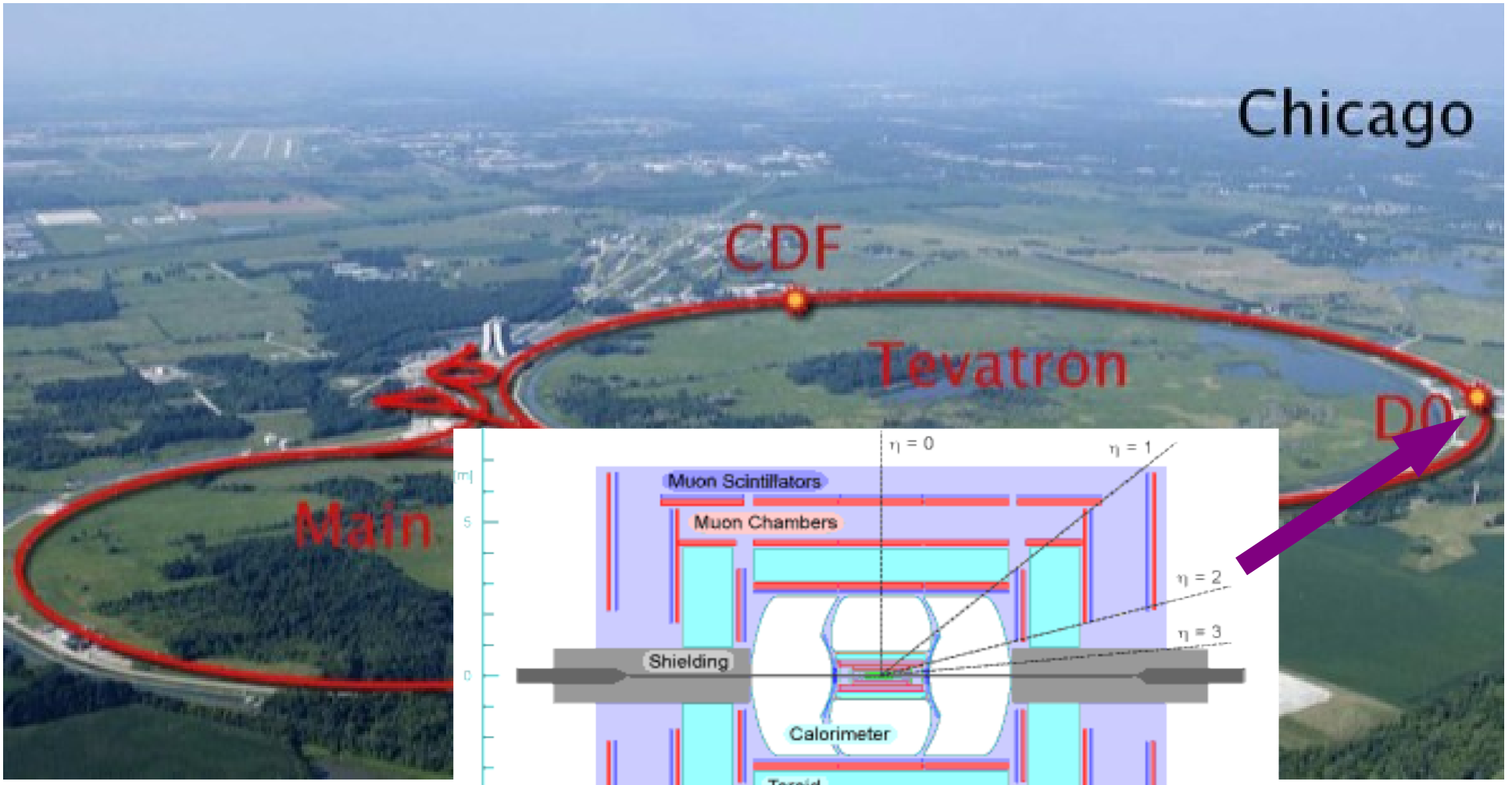
The DØ Experiment



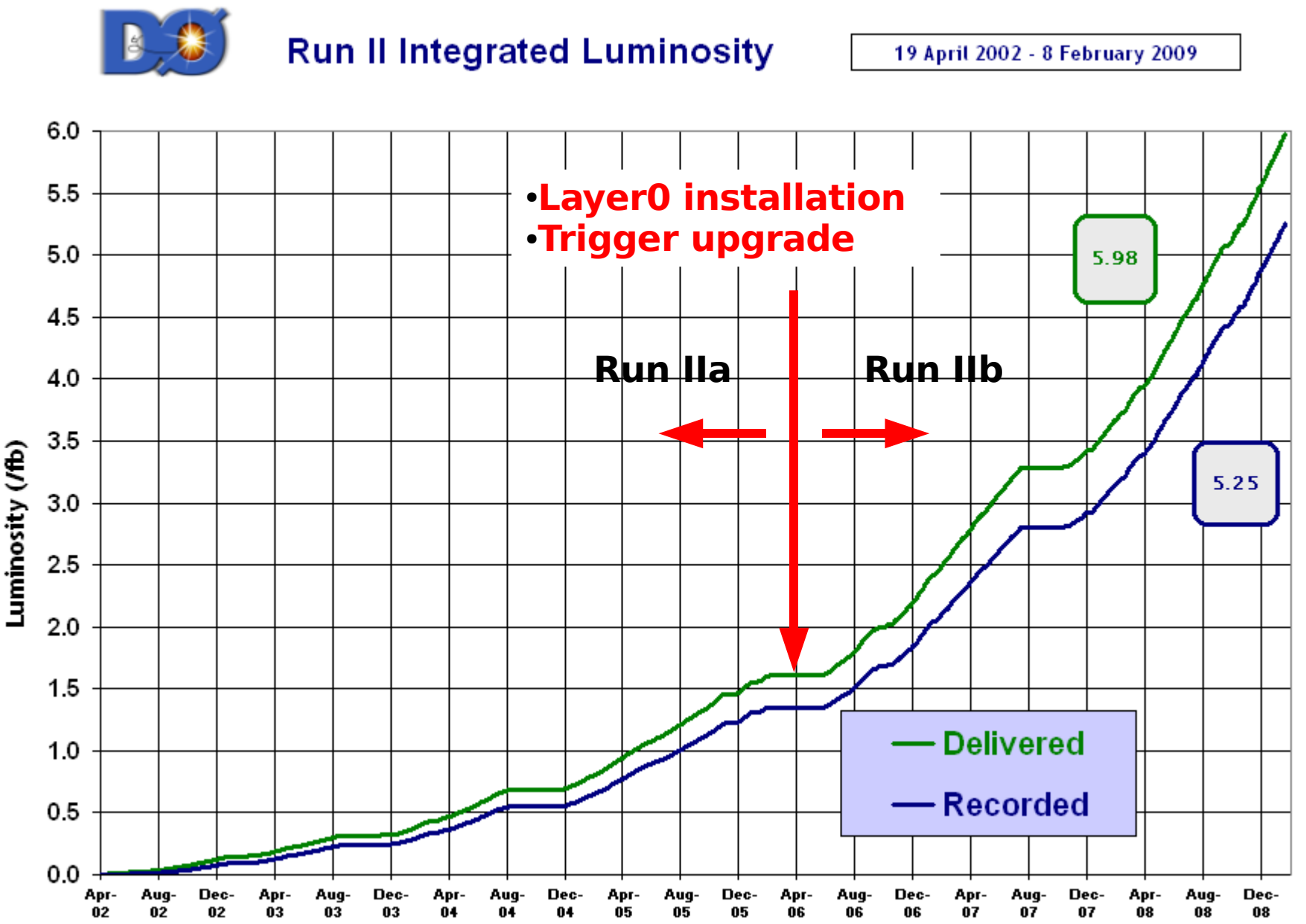
√S = 1.96 GeV

Peak luminosities ~ 3×10^{-32} $cm^{-1}s^{-2}$

The DØ Experiment

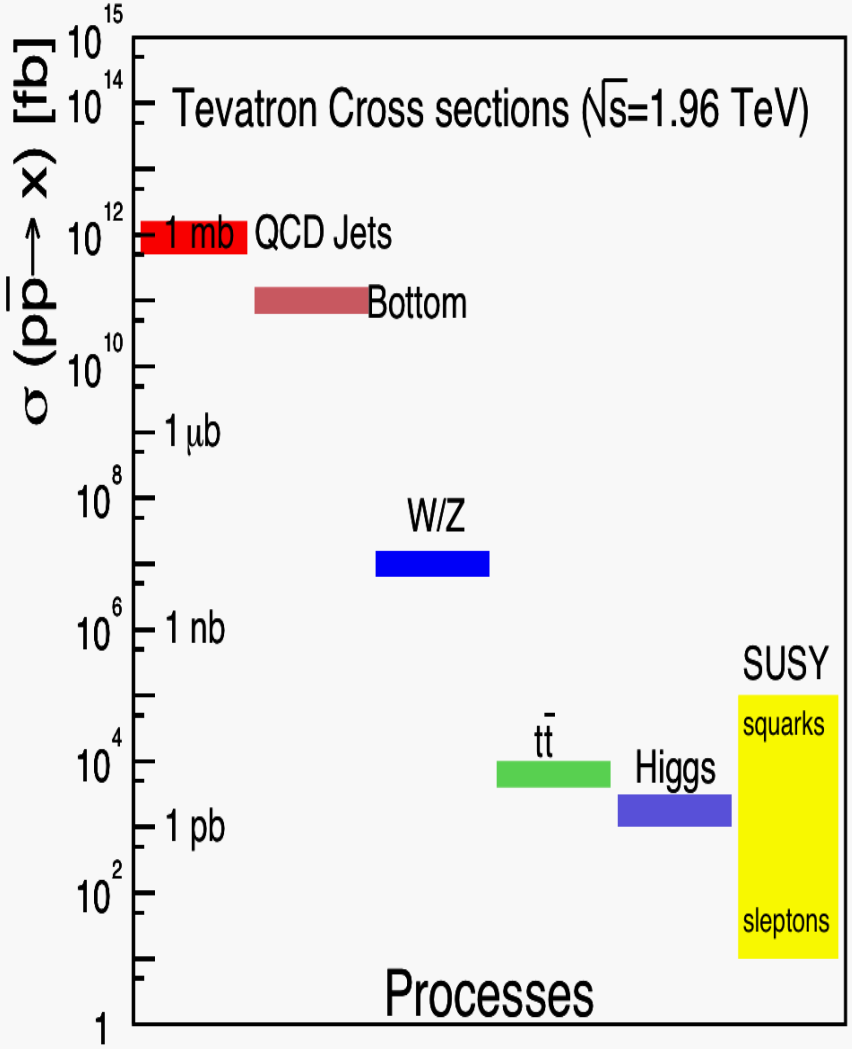


The DØ Experiment



Physics at DØ

- QCD
- B Physics
- Electroweak Physics
- Top Physics
- Higgs Searches
- New Phenomena



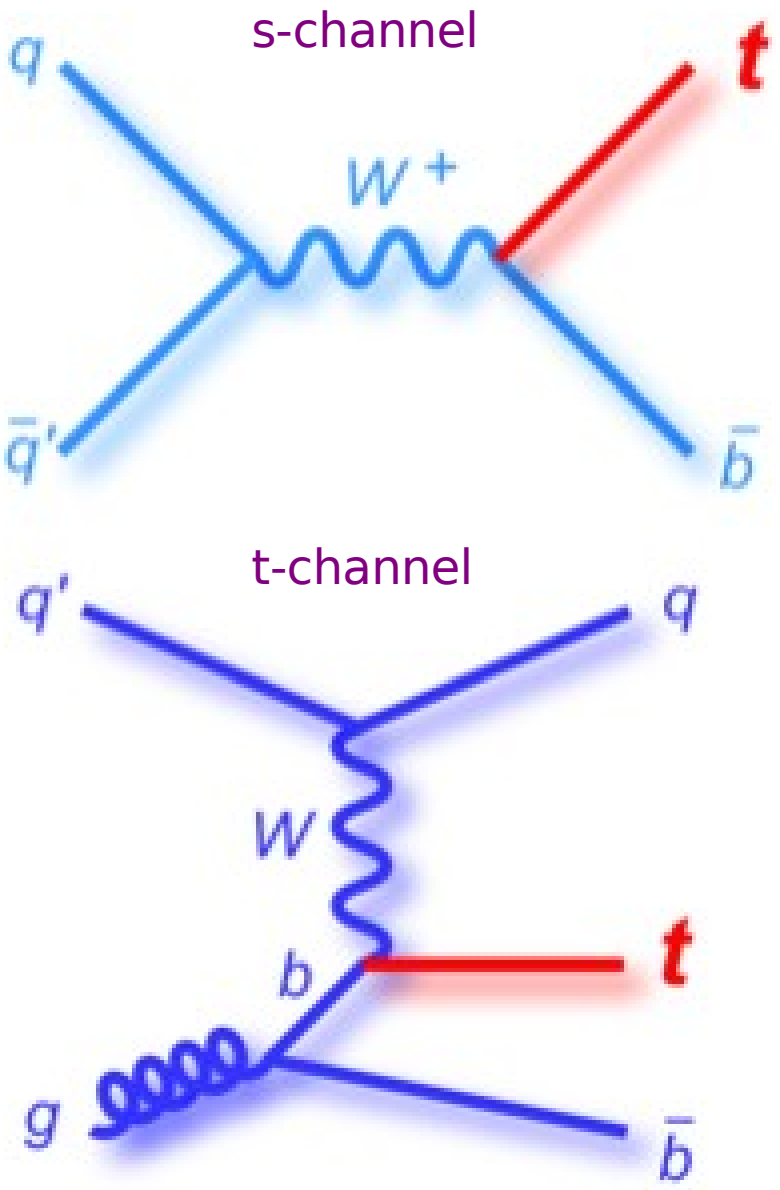
Introduction to single top

- S.M. Cross-section:

  $\sigma = 3.46 \pm 0.18$ pb
  @ $m_{top} = 170$ GeV

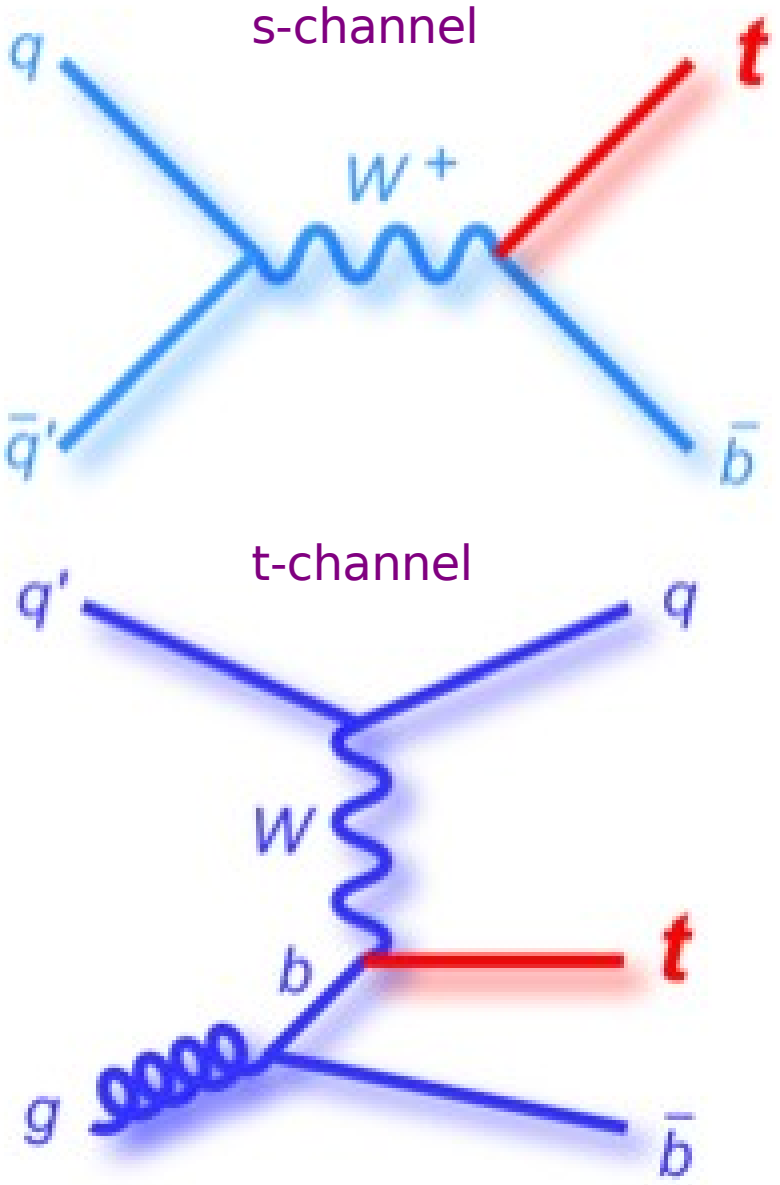
  [PRD 74,114012 (2006)]

- Motivation:
  - Serves as a probe to the Wtb coupling
  - Provides a direct measurement of $|V_{tb}|$
  - Sensible to heavy bosons (W')
  - Background to Higgs and Physics beyond the S.M. searches

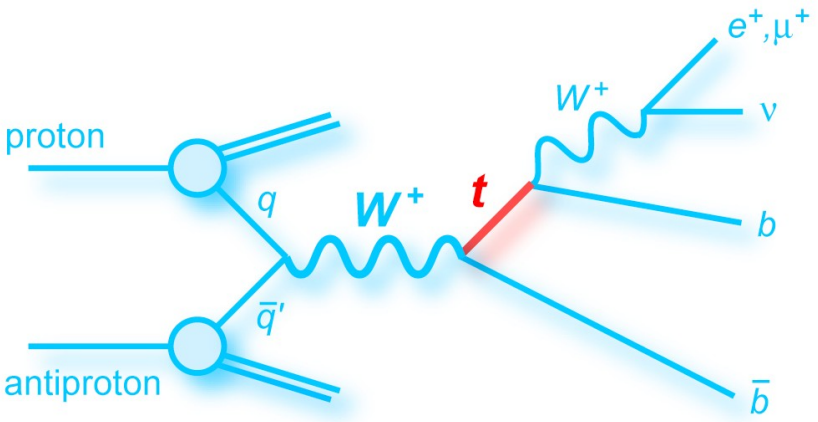


Introduction to single top

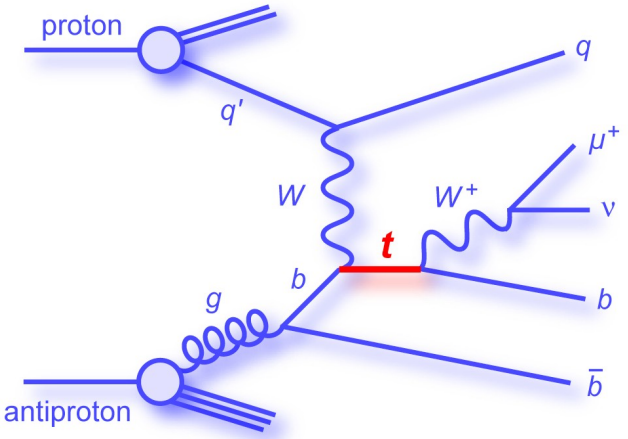
- Challenging:
  - Difficult background environment
  - Low jet multiplicities
  - Sophisticated multivariate techniques needed
- History:
  - Evidence by DØ with 0.9 fb^{-1} [PRL 98, 181802 (2007)]
  - Evidence by CDF with 2.2 fb^{-1} [PRL 101, 252001 (2008)]



Event Selection



s-channel (tb)



t-channel (tqb)

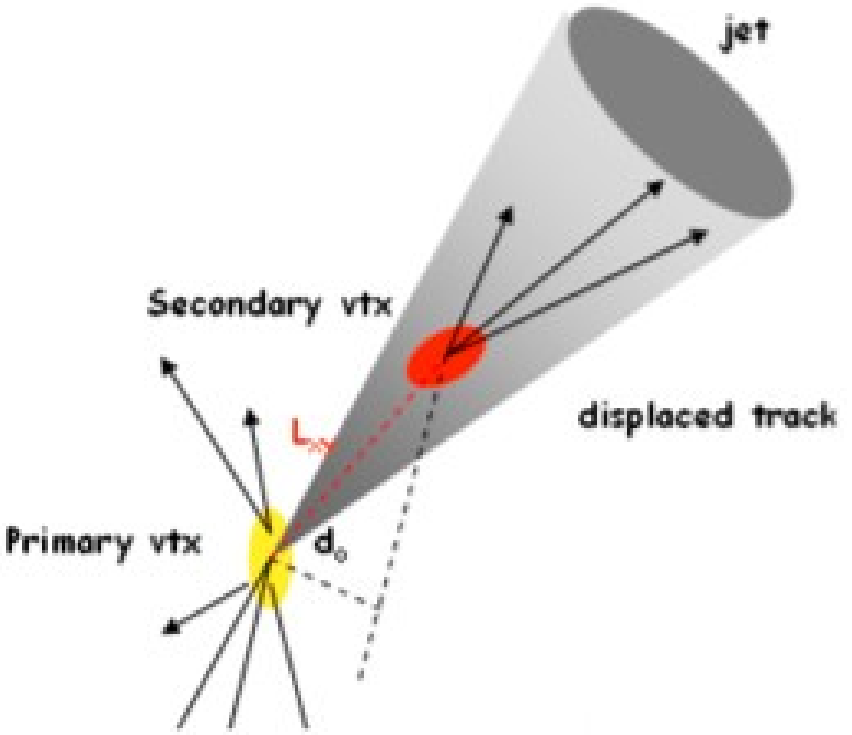
- Current analysis (e+jets & μ+jets):
  - Integrated luminosity: 2.3 fb^{-1}
  - 1.1 fb^{-1} from *RunIIa* (p17) & 1.2 fb^{-1} from *RunIIb* (p20)
- 18% increase in signal acceptance since 2007
  - Trigger efficiency increased with a logical OR of many conditions
  - Loosening of selection cuts

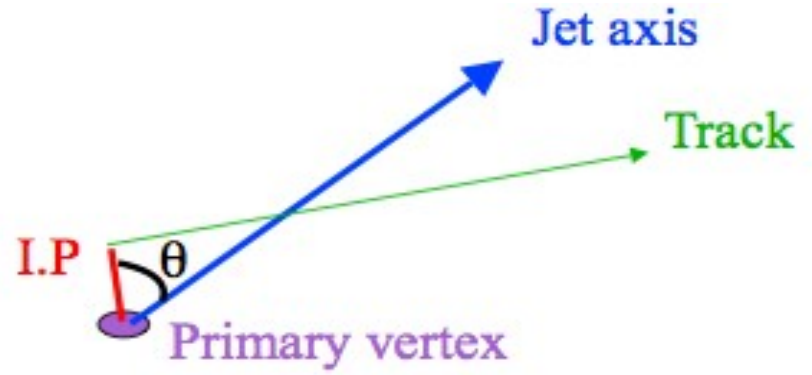
Event Selection

- Lepton + jets + MET:
  - 2-4 jets ($|\eta|$<3.4, p_T>15 GeV); leading: p_T>25 GeV
  - Lepton: electron (CC) $|\eta|$<1.1 & p_T>15 GeV
    muon (MU) $|\eta|$<2.0 & p_T>15 GeV
  - MET>15 GeV
  - $|z_{PV}|$< 6 cm
  - 1 or 2 b-jets; leading b-jet p_T>20 GeV
- Cuts to supress multijet background:
  - Triangular cuts in the MET-$\Delta\phi$(MET,e/μ/jet) plane
  - lepton p_T & MET cuts increased for 3,4 jet bins
  - HT cuts & higher p_T cut for jets in ICD
  - MU track curve significance cut

B-tagging

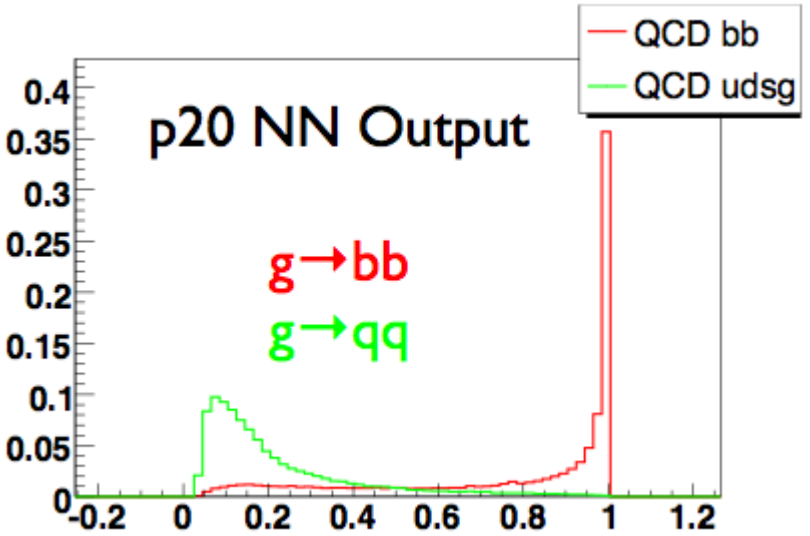
- How to reconize a b-jet:
  - B-hadrons longer lifetime: displaced vertex from the primary vertex.
  - More charged particles (more tracks)
  - Larger mass than c,s,d,u.
  - ~20% of b-jets are involved in a muonic decay
- B-tagging algorithms at DØ:
  - Three lifetime b-taggers:
    - CSIP: sum tracks IP significance
    - SVT: build secondary vertex & use its variables
    - JLIP: probability that a jet with tracks originates rom PV
  - Soft Lepton Tagger (SLTNN)

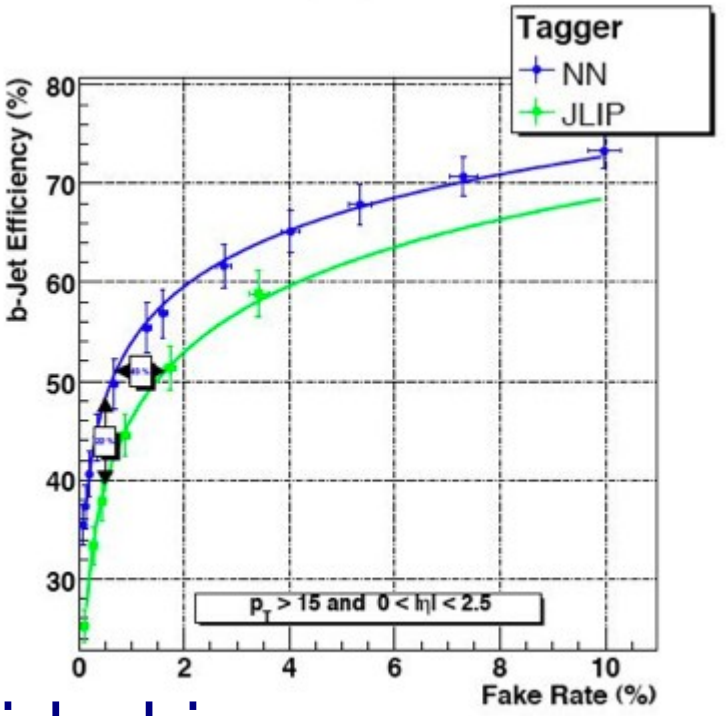




B-tagging

- NN b-tagger:
  - Combination of the 3 lifetime b-taggers using a NN.
  - Trained on QCD b-jets as signal and QCD light jets as background.





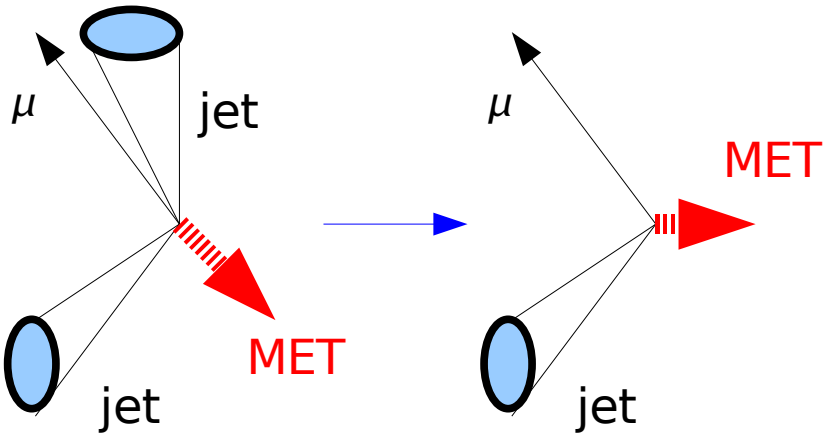
- Currently samples are divided in:
  - *One tag*: 1 jet with NN>0.775 (others with NN<0.5)
  - *Two tags*: 2 jets with NN>0.5

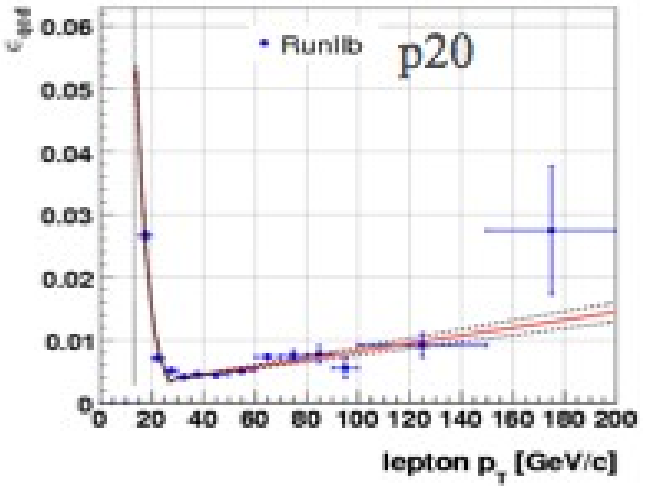
Background modeling

- Main backgrounds to single top:
  - ttbar: lepton+jets or dilepton (one lepton lost)
  - W+jets: same signature as single top
  - Multijet (QCD): one fake lepton
  - Z+jets & diboson (not in 2007)
- Signal & background methods:
  - Signal: SINGLETOP (NLO, COMPHEP based) + PYTHIA
  - ttbar, W+jets & Z+jets: ALPGEN (LO) + PYTHIA
  - diboson: PYTHIA
  - Multijet: from data

Background modeling

- In 2007 very few statistics in QCD after b-tagging. Now larger samples used.
- For MU channel:
  - Drop isolation requirements on μ (ΔR(μ,jet)<0.5)
  - Remove close jet and re-compute MET
- For CC channel:
  - Use orthgonal sample with looser EM ID (drop likelihood & track matching)
  - Need to re-shape using the lepton p_T distribution of a fake electron enhanced sample.



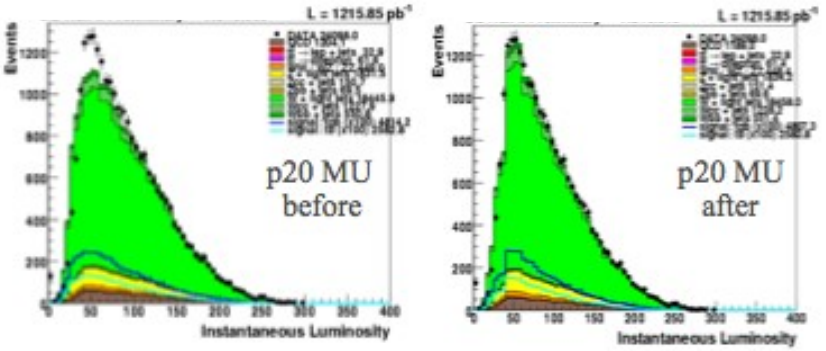


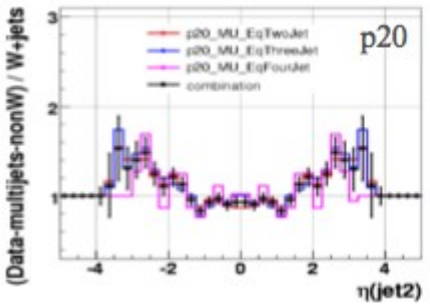
Background modeling

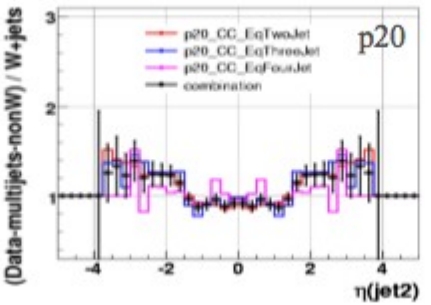
- ALPGEN is a LO simulation:
  - Two k-factors are applied to W+jets & Z+jets according to NLO calculations:
    - global k-factor for all W+jets & all Z+jets
    - k-factor for Wbb, Wcc, Zbb, Zcc + light jets
- ALPGEN doesn't reproduce correctly the yields in data nor the shapes.
- Need to normalize W+jets & QCD to data:
  - This is done at pre-b-tagging level
  - Determine W+jets and QCD scale factors that give best KS-test value for three sensible variables (lepton p_T, MET, W M_T)
  - KS-test weighted averaged scale factors used.

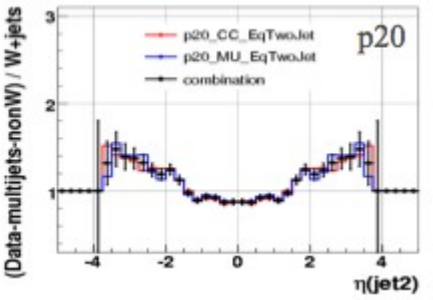
Background modeling

- Need to reweight MC to get good agreement:
  - Instantaneous luminosity reweighting for every MC source
  - Just for W+jets: jet η distributions are off due to an ALPGEN model weakness. Re-weighting functions are common for CC/MU & jet bins.









Background modeling

- Iterative KS method:
  - Apply a first normalization (slide 15)
  - Then apply the re-weighting on several variables consecutively.
  - Use re-weighted distributions as input to next re-weighting
  - Normalize after every re-weighting
  - Order of re-weightings: Instant luminosity, η(jet1), η(jet2), ΔΦ(jet1,jet2), Δη(jet1,jet2), η(jet3), η(jet4)
  - Method converges: scale factors stable

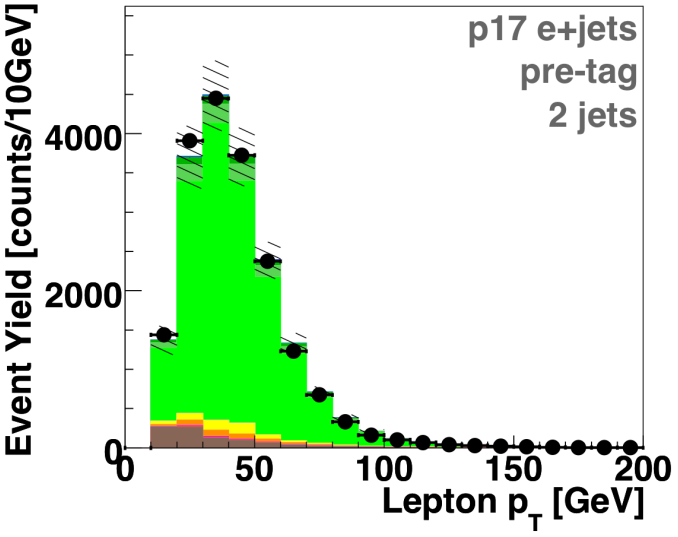
W+jets and Multijets Normalization Scale Factors

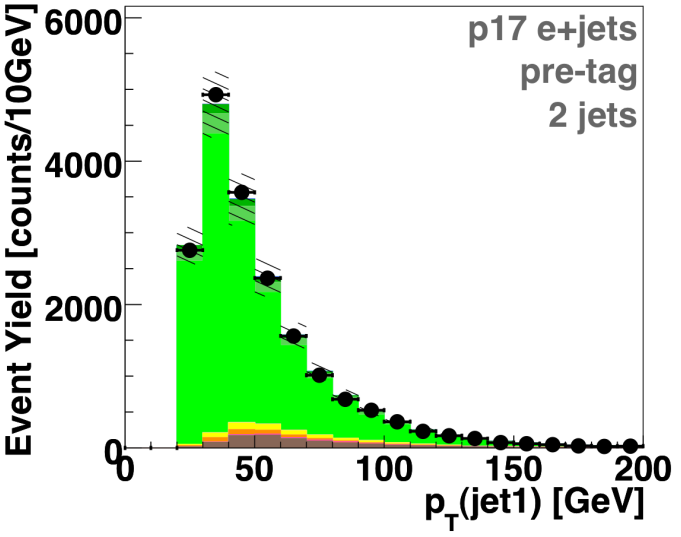
	S_{W+jets}				$S_{multijets}$			
	RunIIa		RunIIb		RunIIa		RunIIb	
	e	μ	e	μ	e	μ	e	μ
2 jets	1.51	1.30	1.41	1.23	0.348	0.0490	0.388	0.0639
3 jets	1.92	1.79	1.75	1.57	0.291	0.0291	0.308	0.0410
4 jets	2.29	2.06	1.81	1.92	0.189	0.0244	0.424	0.0333

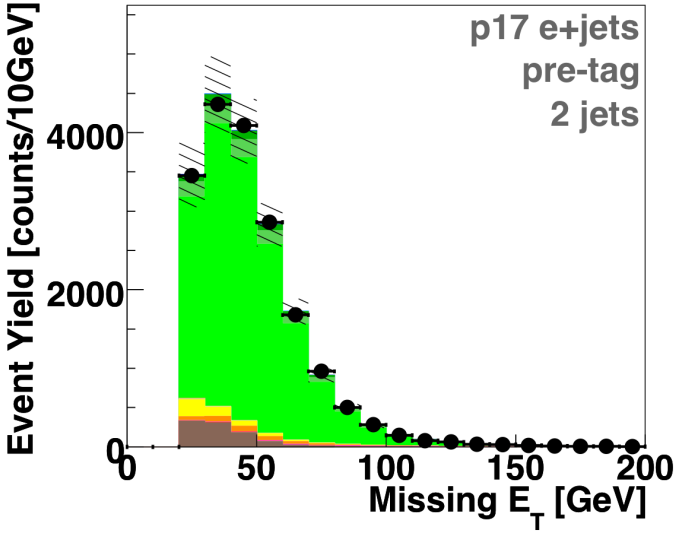
Background modeling

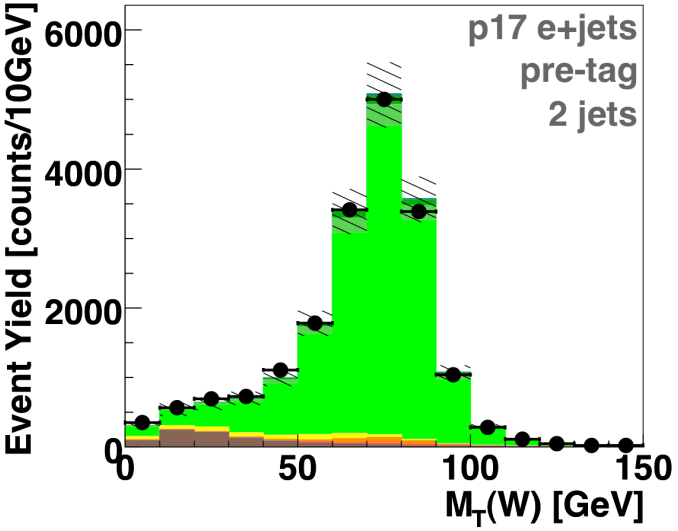
Run IIa, e+jets, 2 jet bin

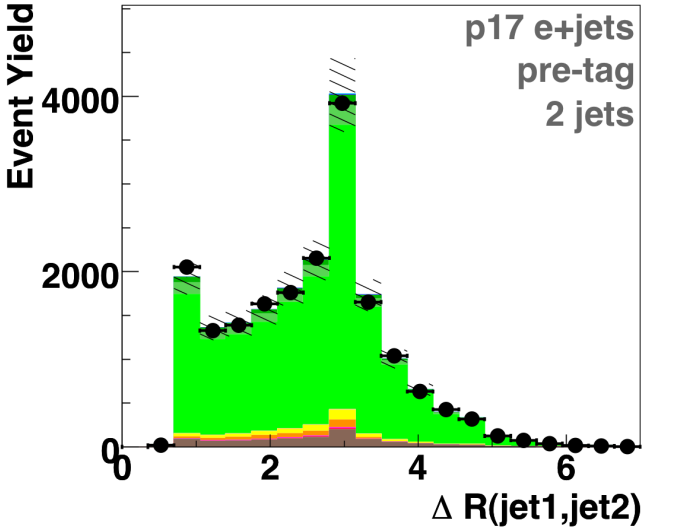
- Data
- Multijet
- W+light jets
- W+cc+light jets
- W+bb+light jets
- Z+light jets
- Z+cc+light jets
- Z+bb+light jets
- diboson
- ttbar→lepton+jets
- ttbar→dilepton
- signal t-channel (tqb)
- signal s-channel (tb)







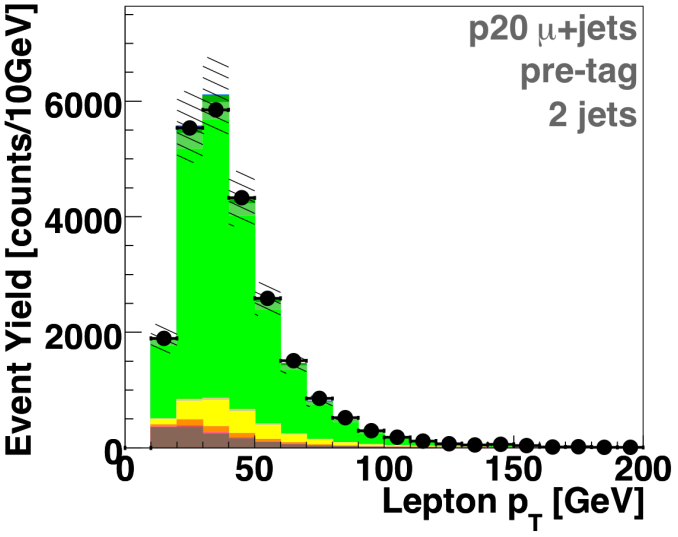


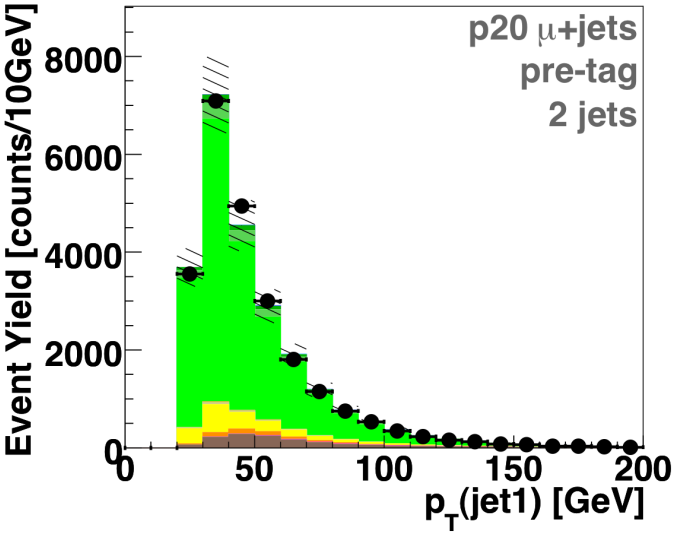


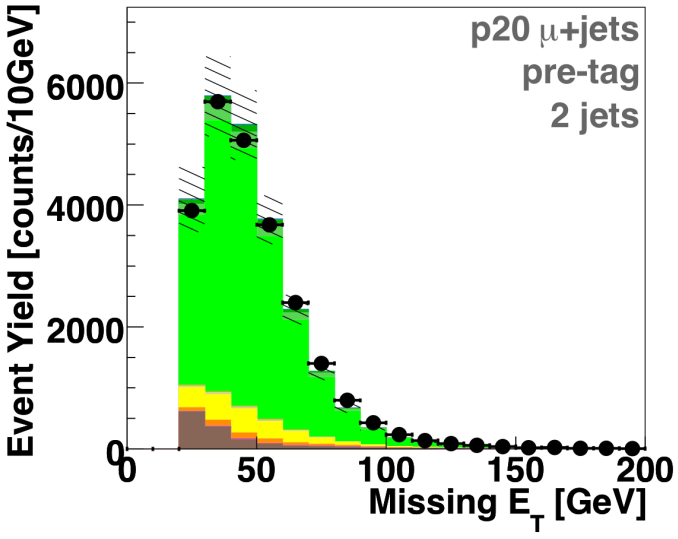
Background modeling

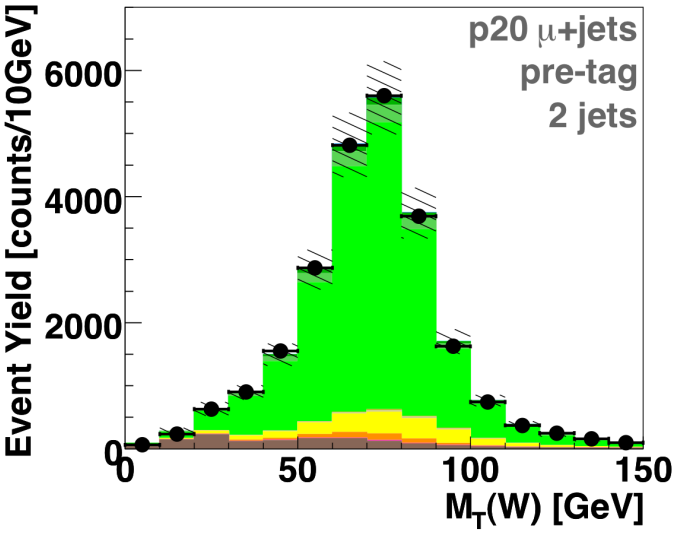
Run IIb, μ+jets, 2 jet bin

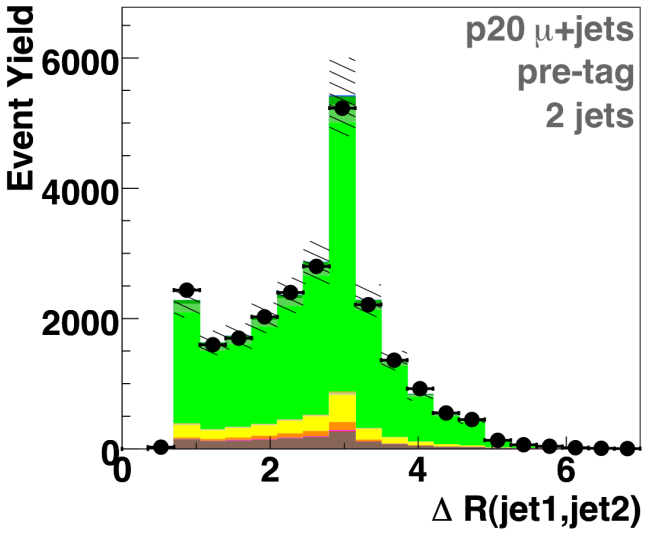
- Data
- Multijet
- W+light jets
- W+cc+light jets
- W+bb+light jets
- Z+light jets
- Z+cc+light jets
- Z+bb+light jets
- diboson
- ttbar→lepton+jets
- ttbar→dilepton
- signal t-channel (tqb)
- signal s-channel (tb)











Background modeling

- B-tagging for QCD: just run b-tagging algorithm
- B-tagging for MC: apply tag rate functions (TRF)
  - B-tagging algorithm overestimates NN output in MC
  - TRF: probability from data of a MC jet to be b-tagged parametrized in p_T, η & flavor (b, c or light)
  - Method: permute every event with all the possible combinations of jets being tagged or not tagged and give it a weight = probability of the combination.
  - Sum of all weights must be 1

$$P(\text{only jet i tagged}) = TRF(\text{jet}_i) \cdot \prod_{j \neq i} \{1\text{-}TRF(\text{jet}_j)\}$$

$$P(\text{only jets i \& j tagged}) = TRF(\text{jet}_i) \cdot TRF(\text{jet}_j) \cdot \prod_{k \neq i,j} \{1\text{-}TRF(\text{jet}_k)\}$$

Background modeling

- Currently in the 1-tag bin more than one jets with NN>0.5 are vetoed:

$$P(\text{only jet i tagged}) = TRF_{0.775}(jet_i) \cdot \prod_{j \neq i}\{1\text{-}TRF_{0.5}(jet_j)\}$$

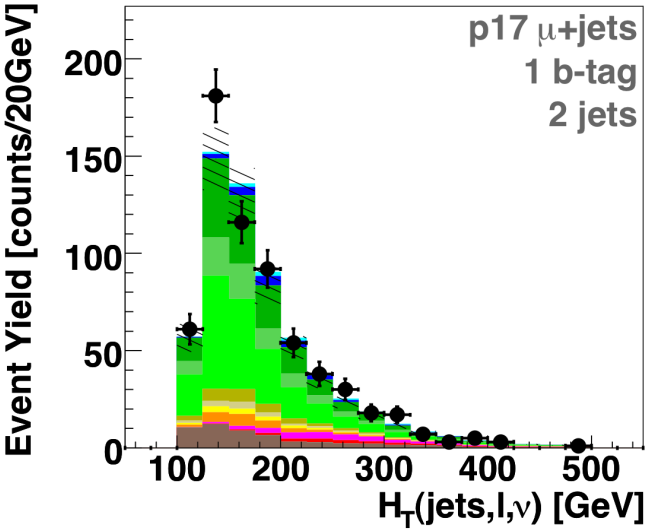
- Another correction factor still needed:
  - Ratio between W+hf & W+light jets is not well known
  - It is determined by normalizing to data the b-tagged yields
  - Only the 2-jet bin used to avoid any bias from ttbar
  - Value obtained by combining runs IIa & IIb, CC & MU, 1-tag & 2-tag: 0.95 ± 0.13
  - Error takes into account statistic, single top cross section, Wbb/Wcc cross section ratio and W+1c contents in W+light jets uncertainties

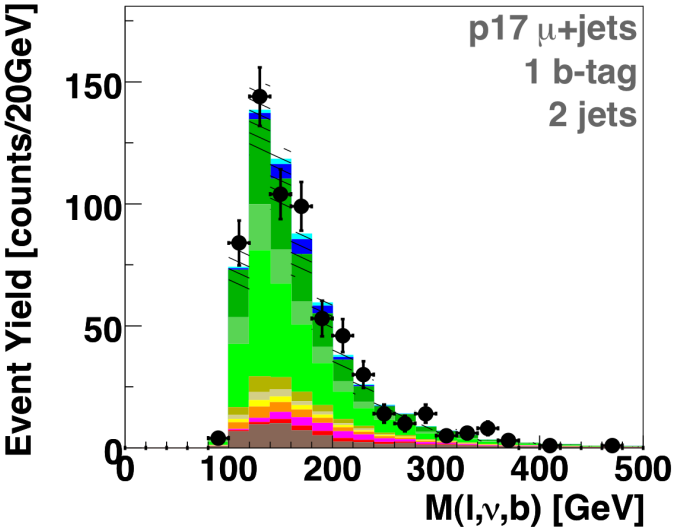
Background modeling

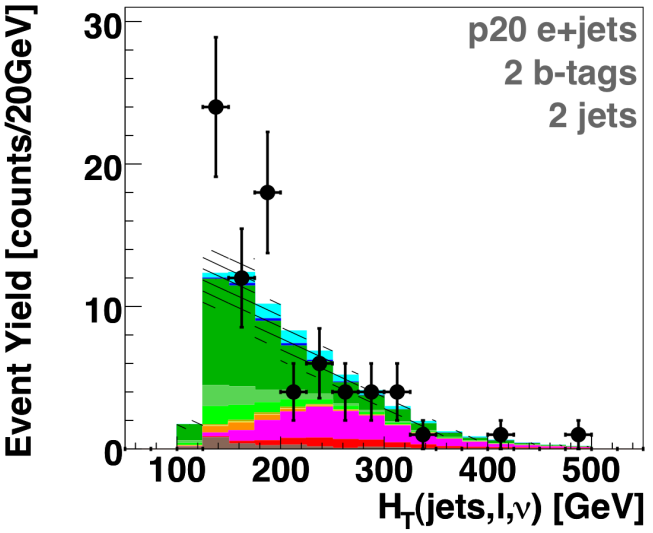
RunIIa, μ+jets, 2jets, 1tag

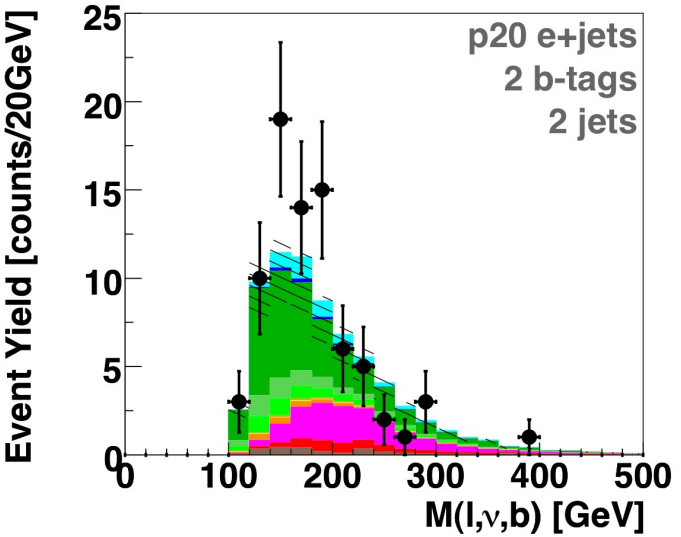
- Data
- Multijet
- W+light jets
- W+cc+light jets
- W+bb+light jets
- Z+light jets
- Z+cc+light jets
- Z+bb+light jets
- diboson
- ttbar→lepton+jets
- ttbar→dilepton
- signal t-channel (tqb)
- signal s-channel (tb)

RunIIb, e+jets, 2jets, 2tags









Background modeling

All channels combined
- Data
- Multijet
- W+light jets
- W+cc+light jets
- W+bb+light jets
- Z+light jets
- Z+cc+light jets
- Z+bb+light jets
- diboson
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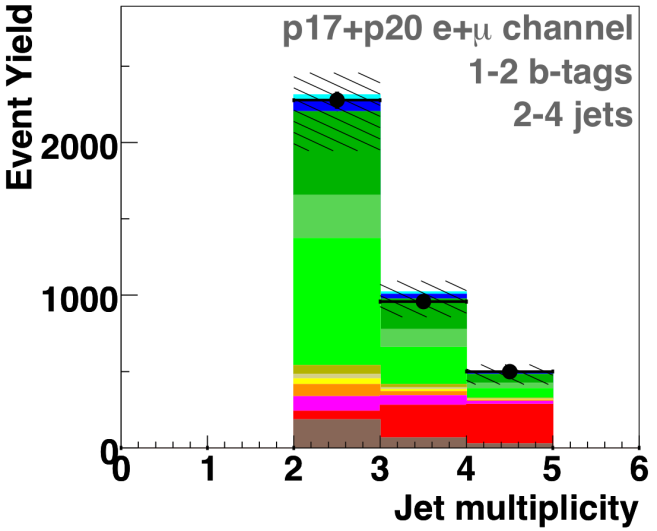
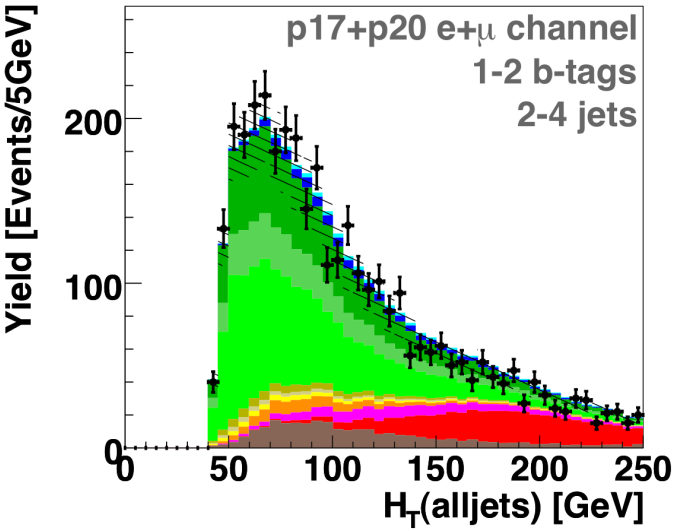
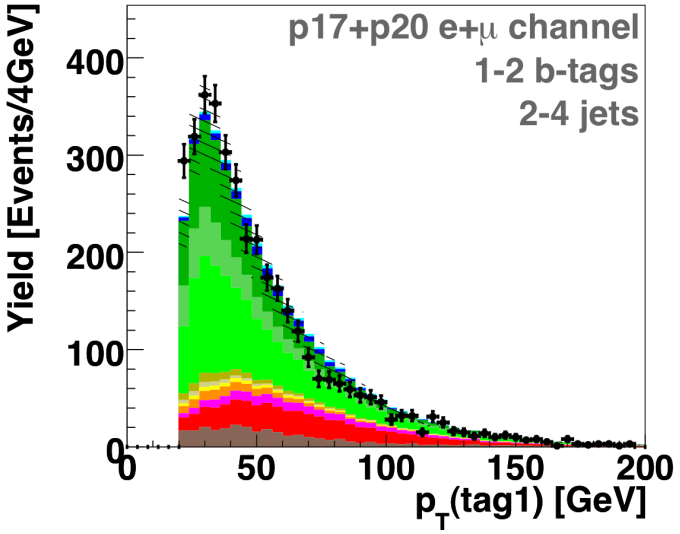
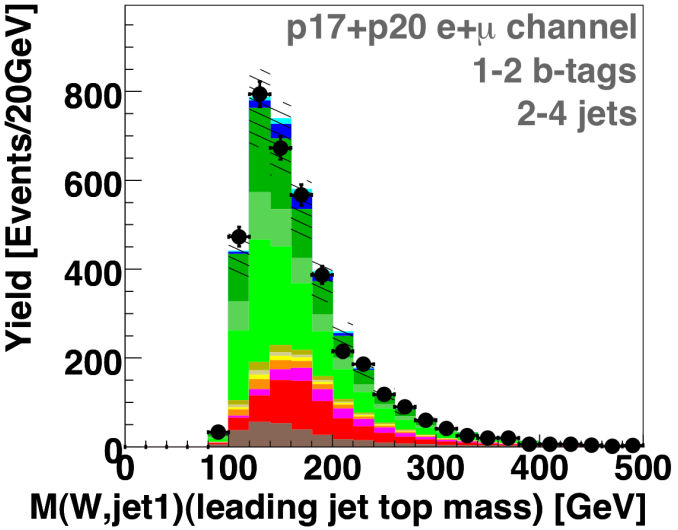
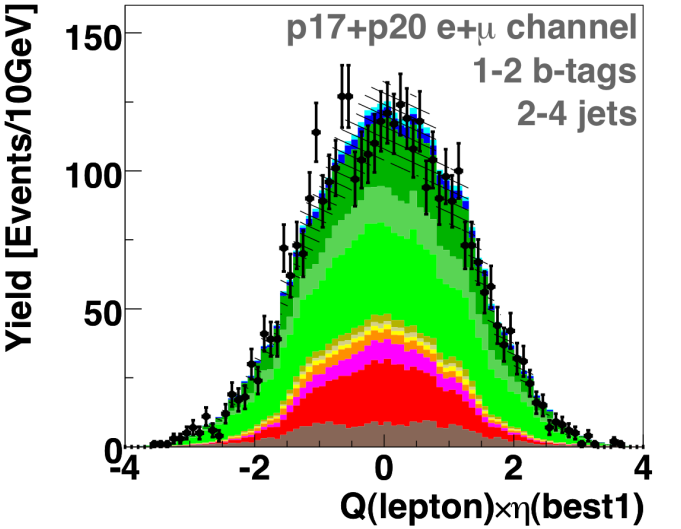










Systematic Uncertainties

- Flat:

  For all backgrounds but W+jets and multijets:

  - Cross sections: Z+jets (4.7%), signal (6%) dibosons (6%) ttbar (9%)
  - W branching fractions (1%), PDF's (3%)
  - Jet fragmentation (5% from PYTHIA-HERWIG difference and ISR/FSR model uncertainty), b-jet fragmentation (2%)
  - Integrated luminosity (6.1%)
  - Trigger efficiency (5%), Beam reweighting (1.4%), InstLumi reweighting (1%)
  - Lepton ID (2.5%), Jet ID (1%), JER (4%)

  For W+jets and multijets:

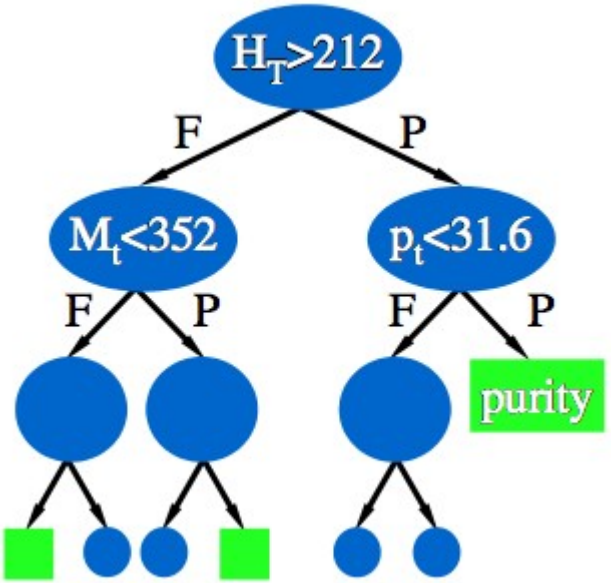
  - Normalization: multijets (7-29%) and W+jets (0.6-6.7%) anticorrelated
  - Heavy-flavor scale factor (14% for Wcc and Wbb, 20% for Zcc and Zbb)

- Shape-changing: (they affect the shape of the background and expected signal distributions)

  - Jet Energy Scale
  - W+jets re-weighting
  - TRFs (affects also heavy flavor scale factor)

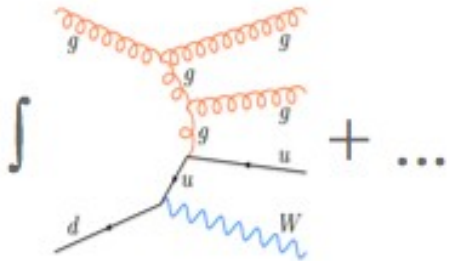
Multi-variate techniques

- Boosted Decision Trees (BDT)
  - Decision trees: split events according to which cut on which variable gives better separation consecutively.
  - Adaptative boosting: improve performance by training different trees giving more weight to mis-classified events.
  - Discriminant: weighted average of DT's

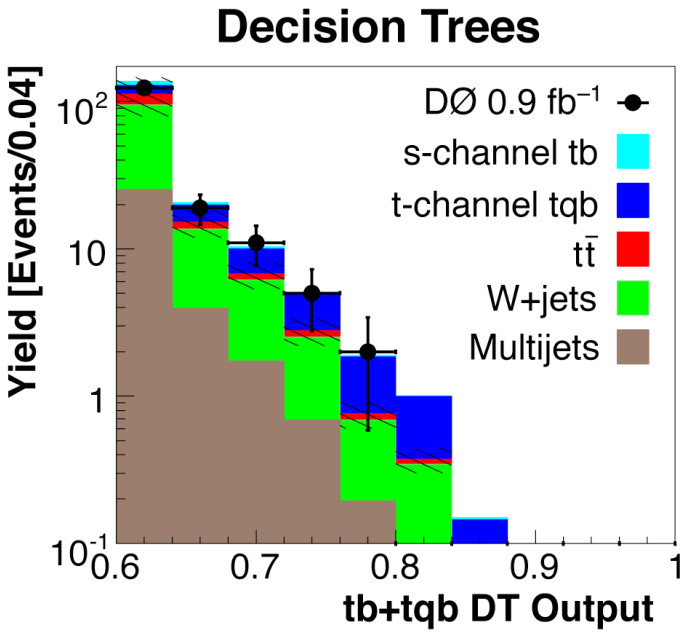


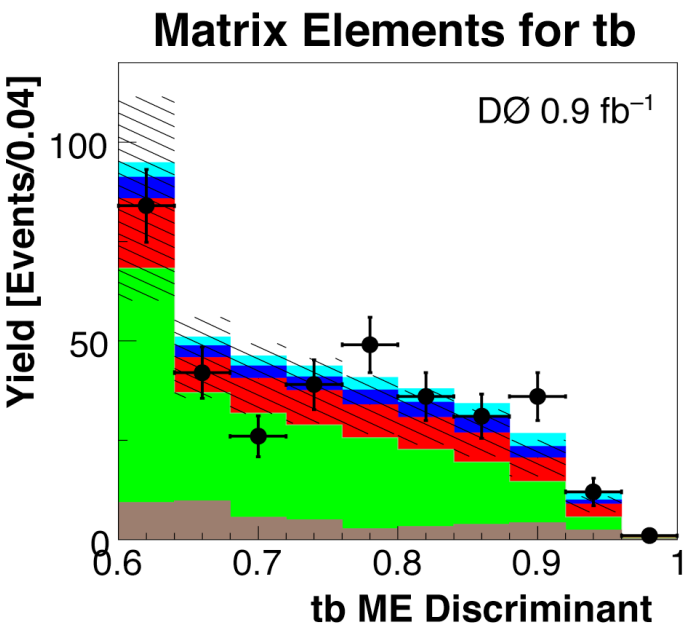
- Matrix Element (ME)
  - Integrate matrix elements of signal and background diagrams together with transfer functions to get their probability for each event.
  - Discriminant: $P_{signal}/(P_{signal}+P_{background})$

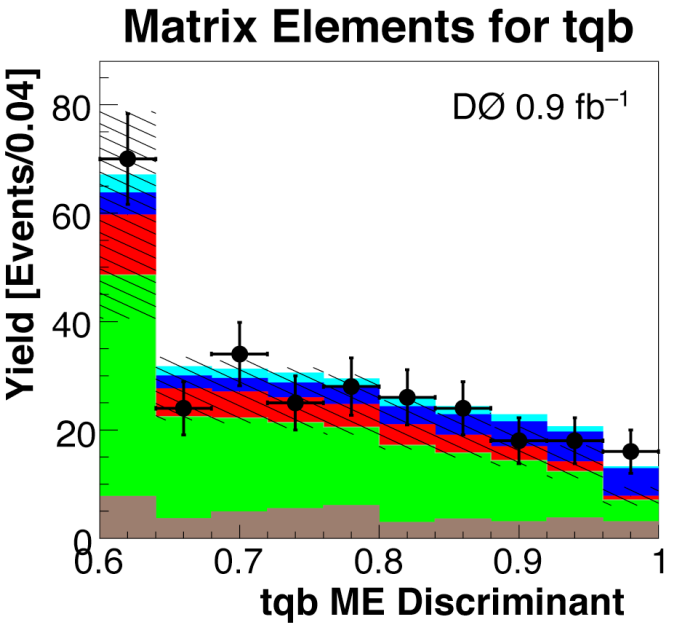
- Bayesian Neural Networks (BNN)
  - Find posterior probability density for NN weights.
  - Create many NN's & weight them by their probability given the training input.
  - Discriminant: average of NN's



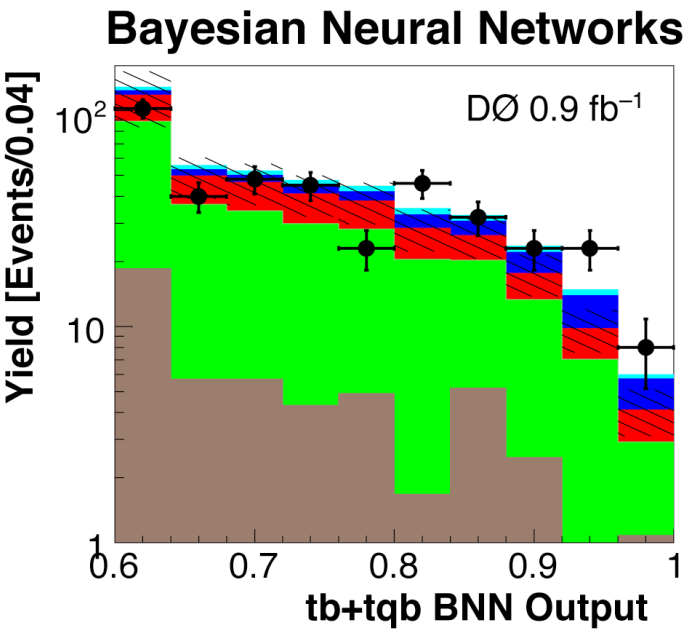
Multi-variate techniques







- Combination using three discriminants as inputs to BNN
- Background samples split in 3:
  - Training sample
  - Testing sample
  - Yield sample: to measure expected & observed cross-sections



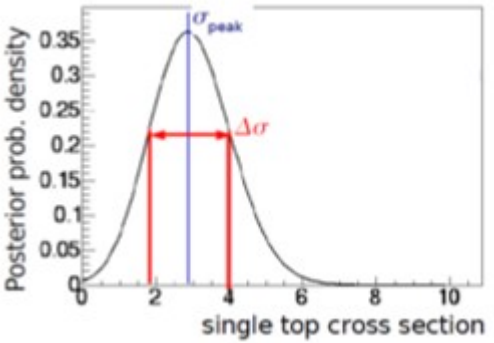
Cross-section Measurement

- Bayesian approach:
  - No cut on the discriminant output. Divided in bins.
  - Each bin has a data distribution value (D_i). Given a certain cross section σ one expects the distribution y:

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

  - The probability of D given y is:

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



  - The posterior distribution for is:

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

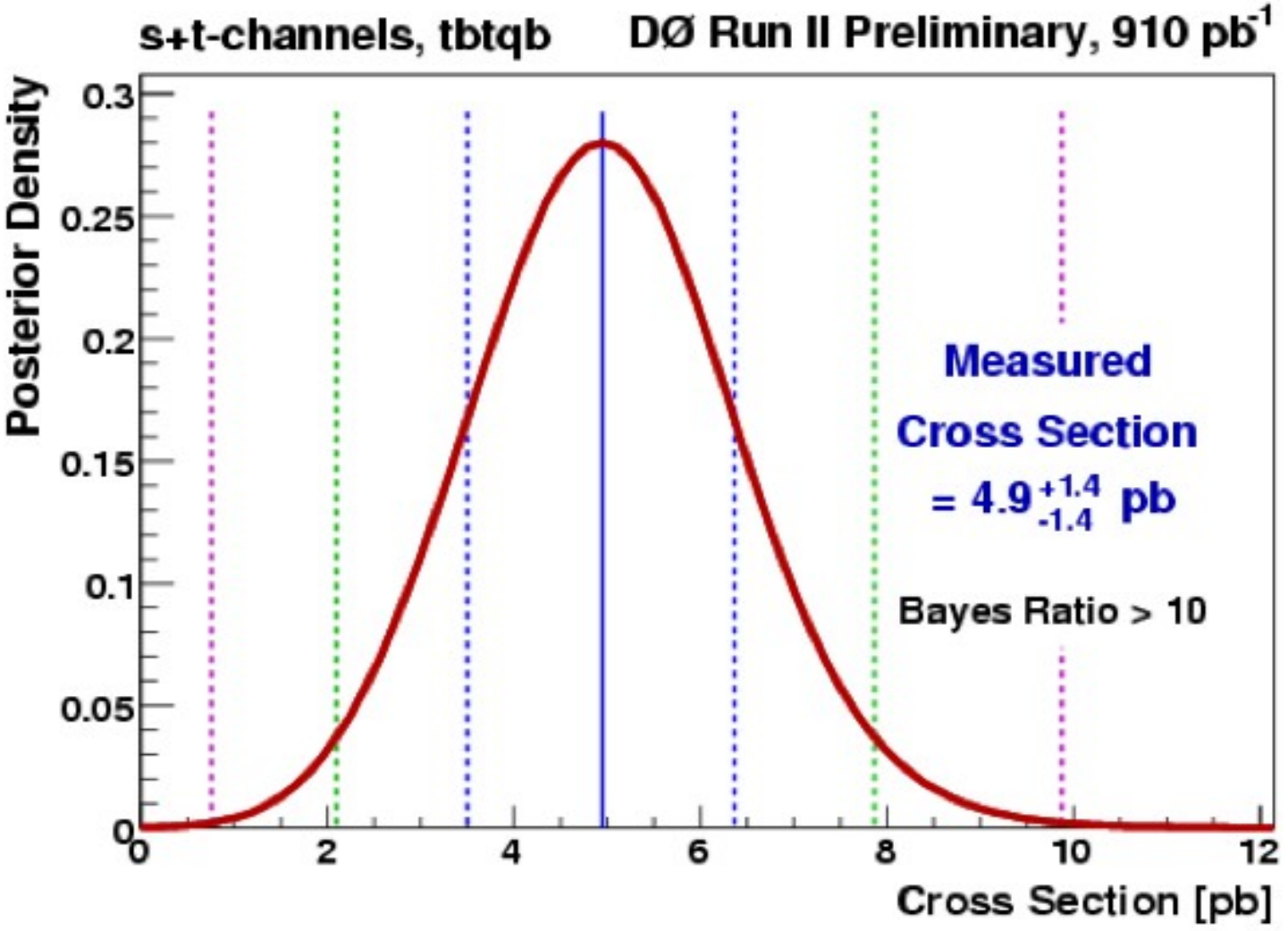
  - The measured cross section is at the peak

Cross-section Measurement

- Bayesian approach:
  - Shape and flat systematic uncertainties treated as nuisance parameters
  - Correlations between uncertainties properly accounted for
  - Flat prior distribution for the signal cross section
  - Observed: D is data; Expected: D is background+signal models
- Significance:
  - Pseudo-experiments produced with zero-signal hypothesis
  - Their number above the expected/observed cross-section is translated into the expected/observed significance
- Cross-checks:
  - Linearity with pseudo-experiments at different cross-sections
  - Pseudo-experiments at SM and measured cross-sections

Cross-section Measurement

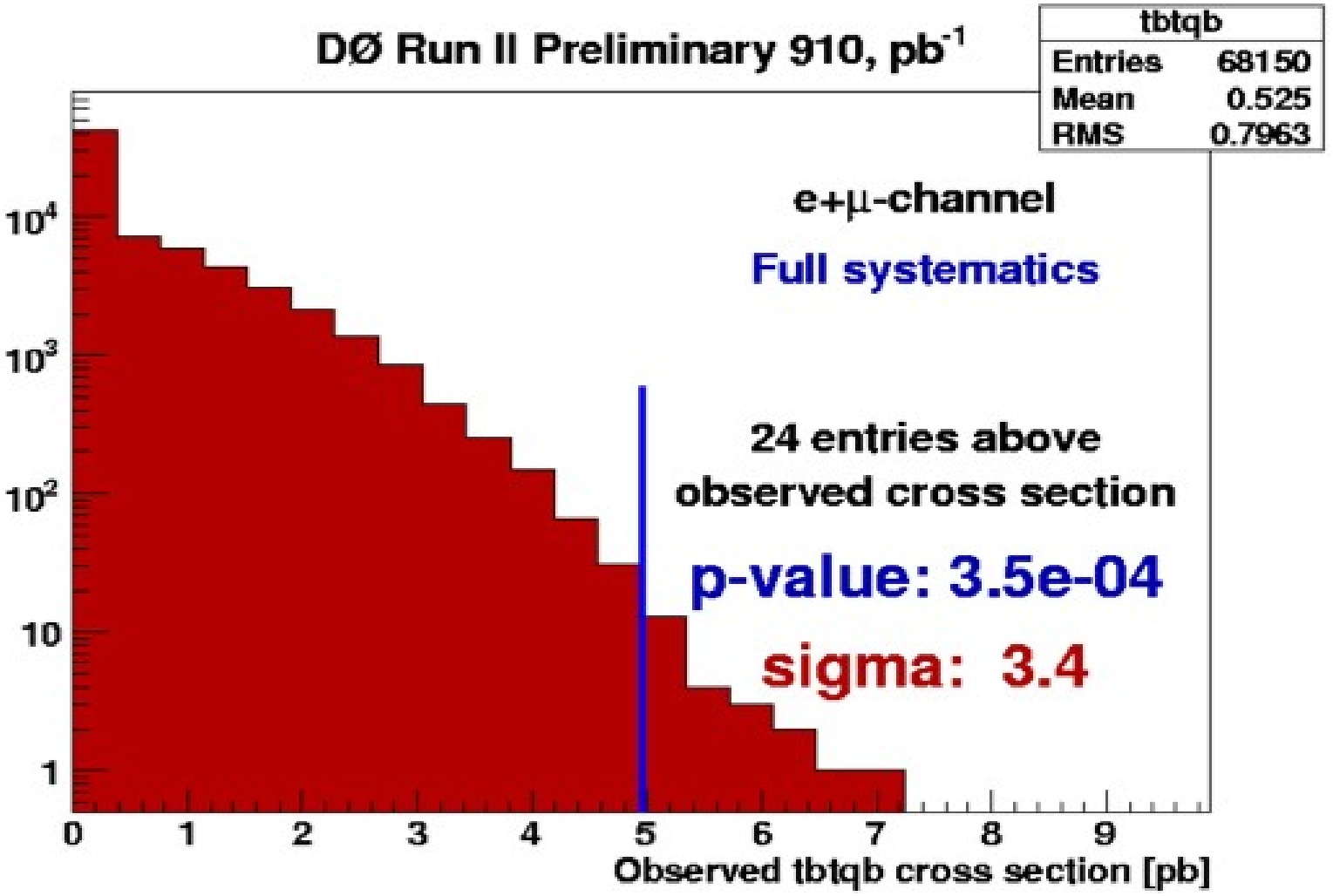
- Example from 2007:



Measured cross section at the peak of the posterior distribution

Cross-section Measurement

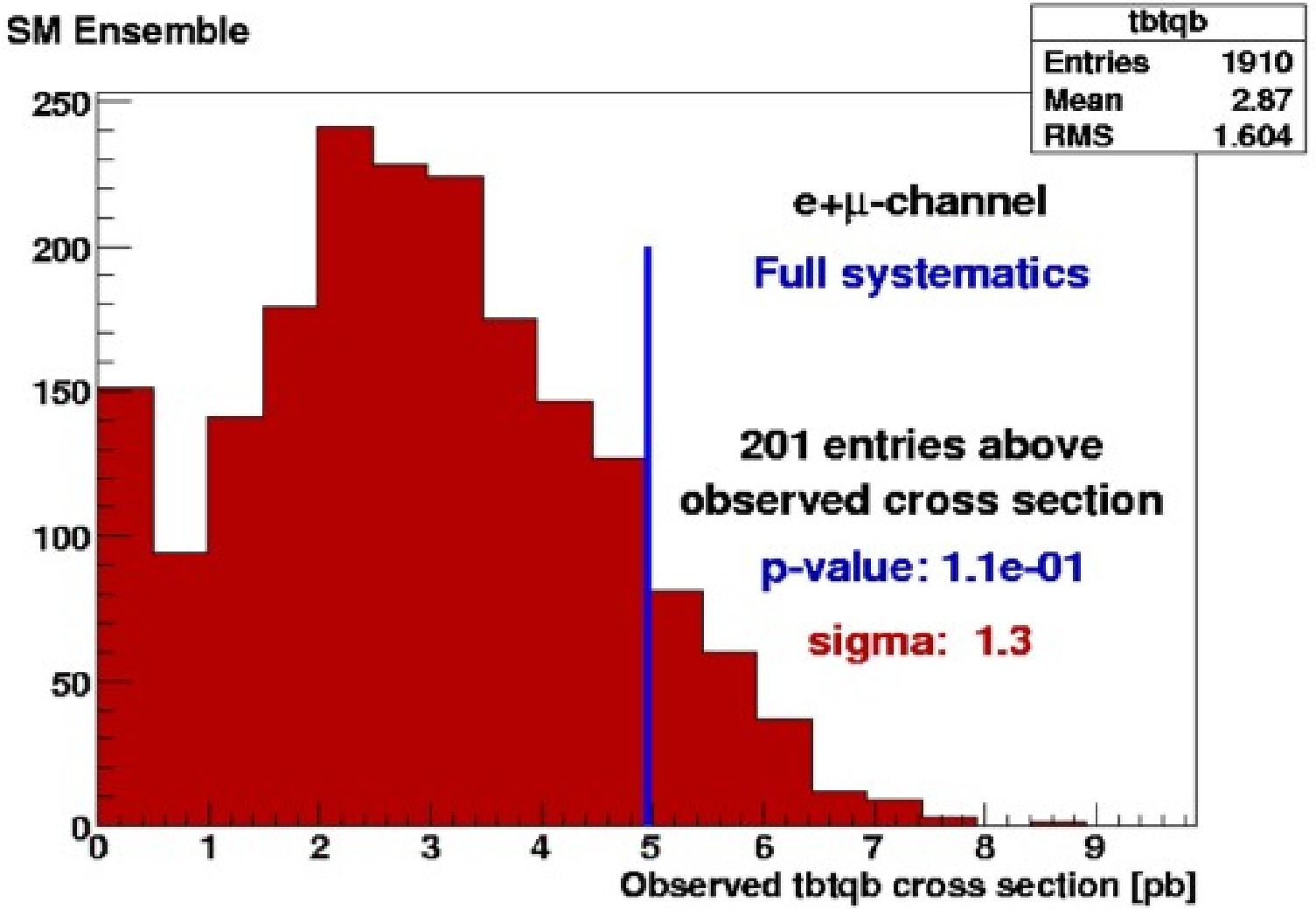
- Example from 2007:



Pseudo-experiments cross-section distribution for significance

Cross-section Measurement

- Example from 2007:



Pseudo-experiments to measure consistency wth SM

Summary

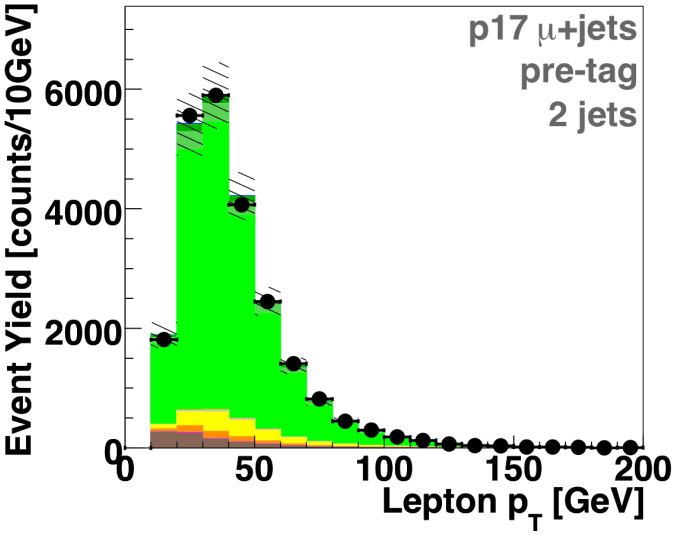
- Single top has still not been observed
- DØ is not just adding data to observe single top but great improvements are being acheived in background modeling, b-tagging, discriminant techniques and statistical measurement methods.
- Hopefully new results soon.

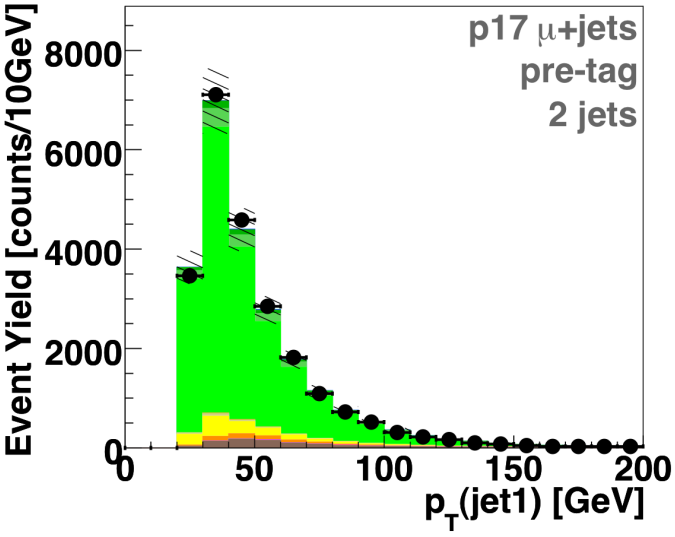
Backup slides

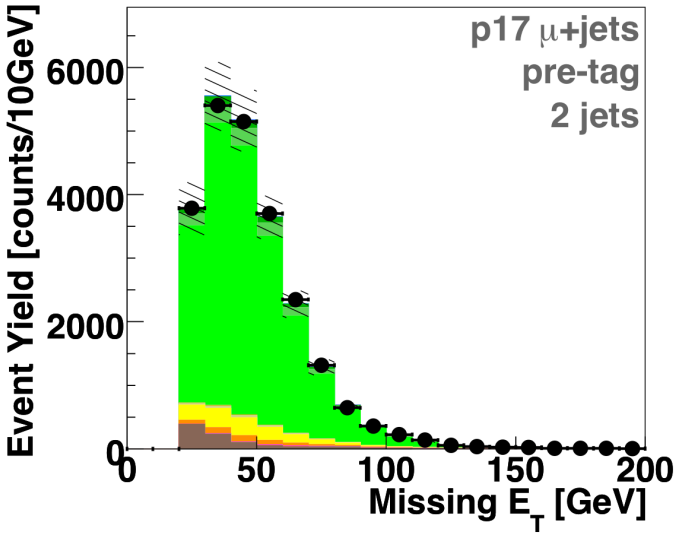
Background modeling

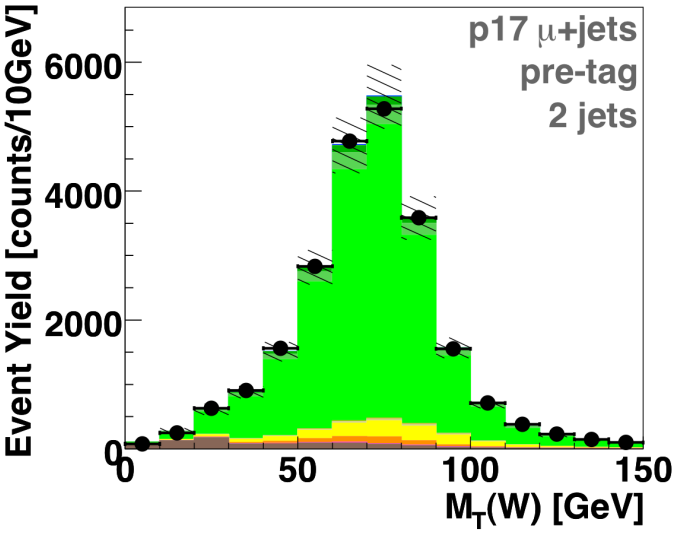
Run IIa, μ+jets, 2 jet bin

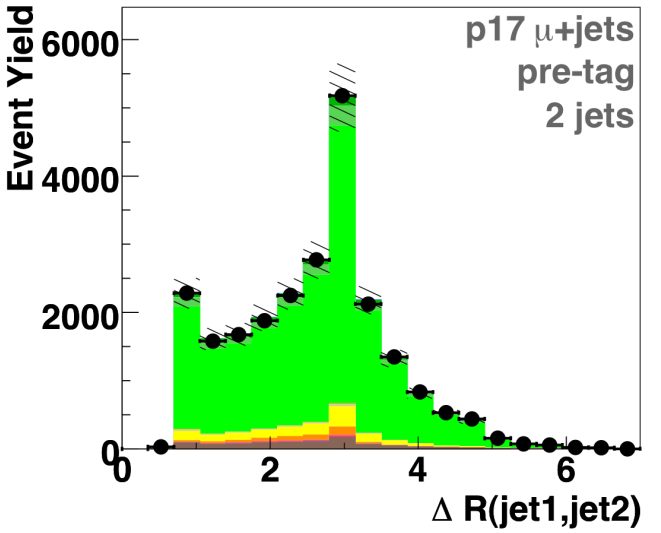
- Data
- Multijet
- W+light jets
- W+cc+light jets
- W+bb+light jets
- Z+light jets
- Z+cc+light jets
- Z+bb+light jets
- diboson
- ttbar→lepton+jets
- ttbar→dilepton
- signal t-channel (tqb)
- signal s-channel (tb)







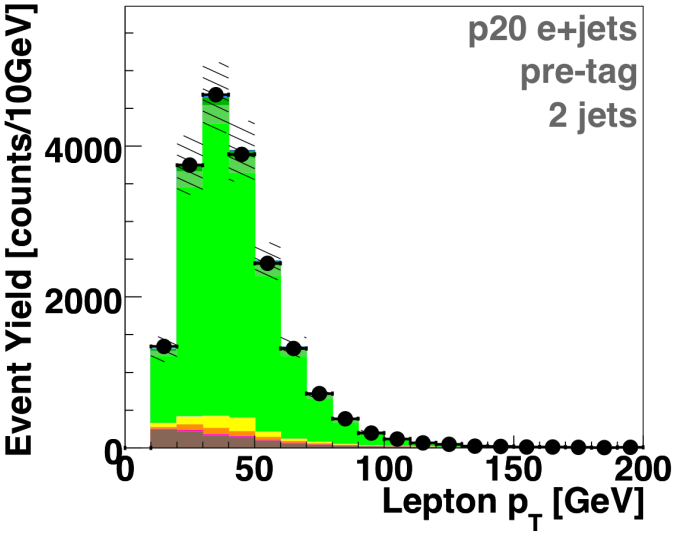


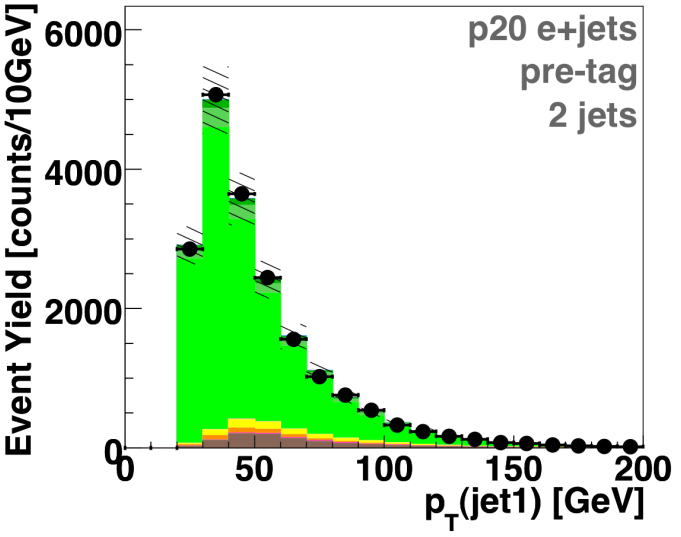


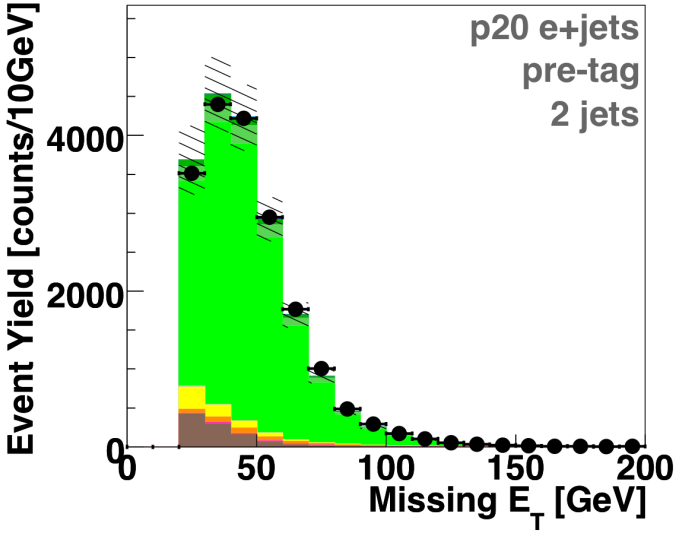
Background modeling

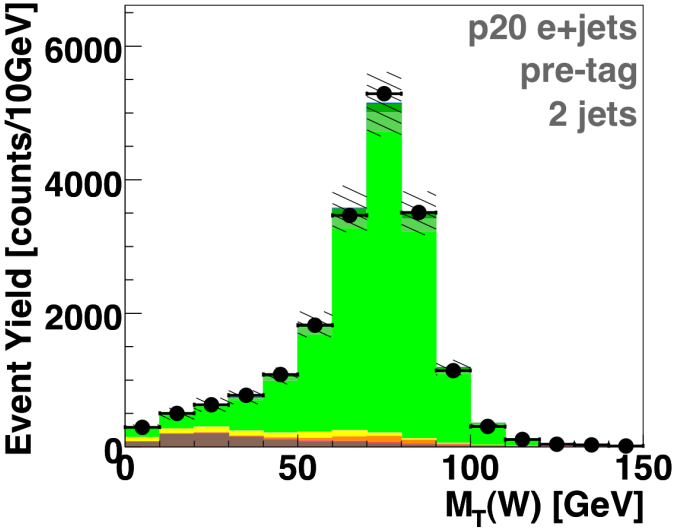
Run IIb, e+jets, 2 jet bin

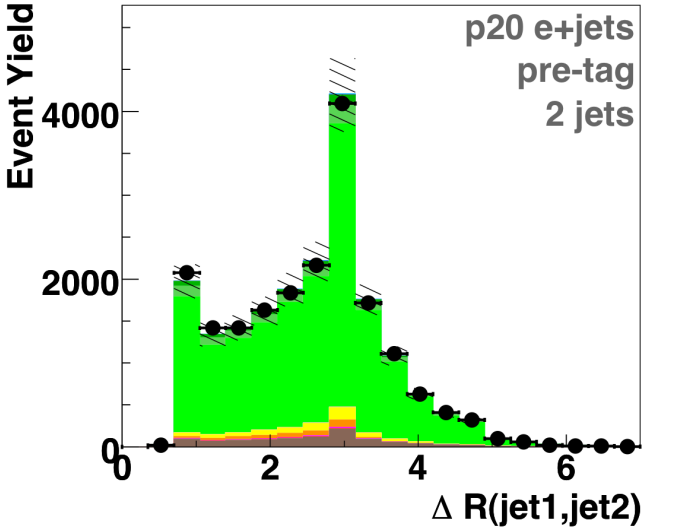
- Data
- Multijet
- W+light jets
- W+cc+light jets
- W+bb+light jets
- Z+light jets
- Z+cc+light jets
- Z+bb+light jets
- diboson
- ttbar→lepton+jets
- ttbar→dilepton
- signal t-channel (tqb)
- signal s-channel (tb)









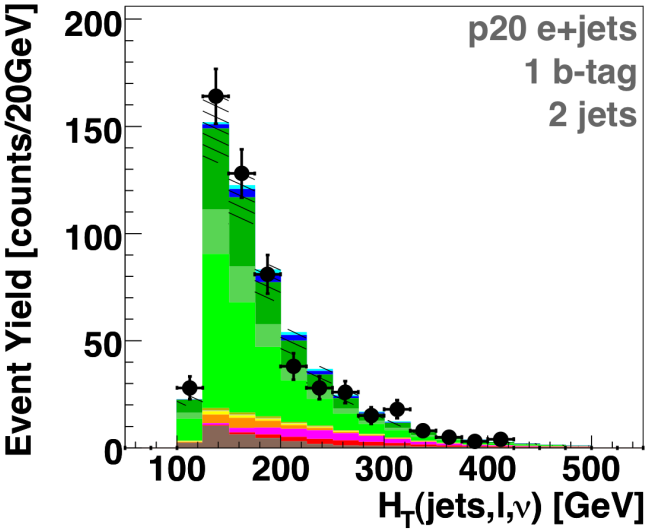


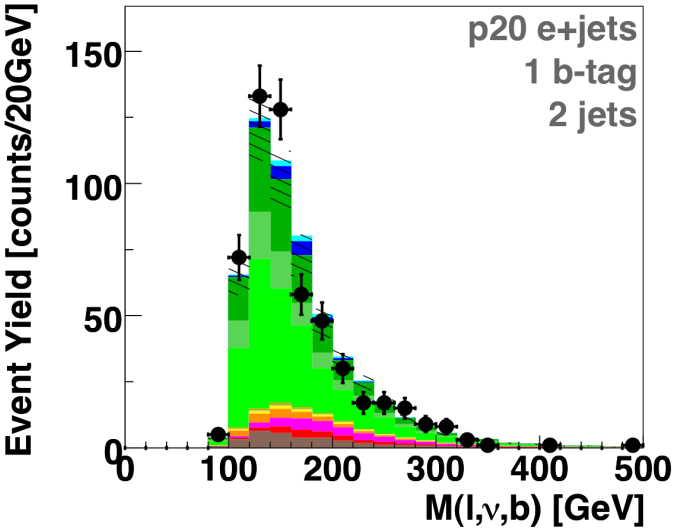
Background modeling

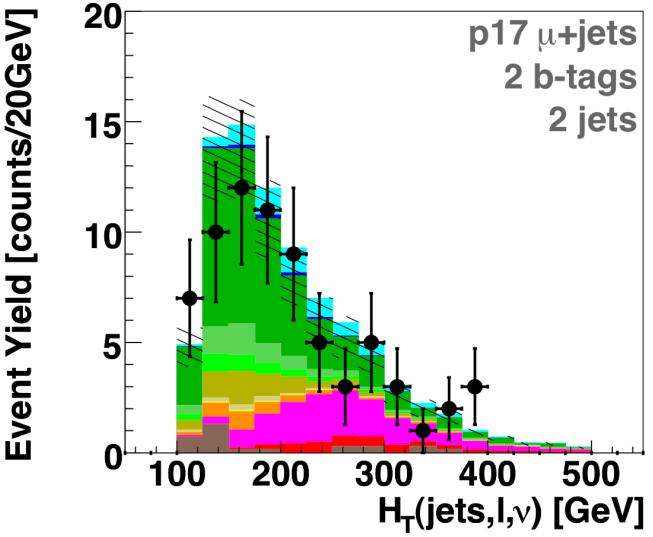
RunIIb, e+jets, 2jets, 1tag

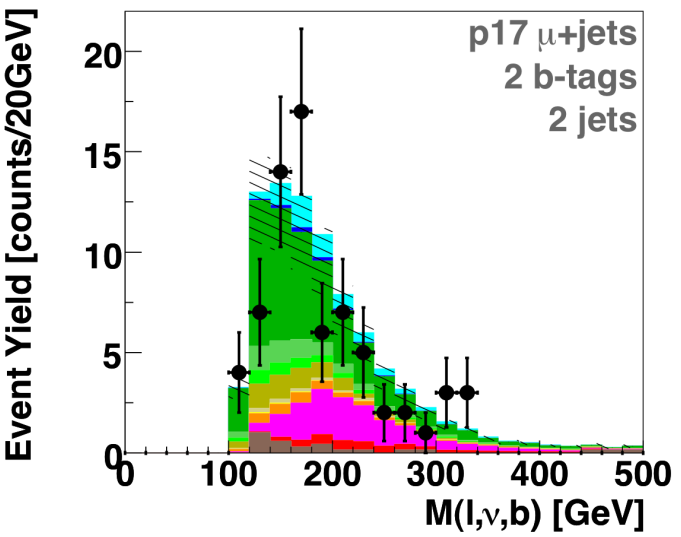
- Data
- Multijet
- W+light jets
- W+cc+light jets
- W+bb+light jets
- Z+light jets
- Z+cc+light jets
- Z+bb+light jets
- diboson
- ttbar→lepton+jets
- ttbar→dilepton
- signal t-channel (tqb)
- signal s-channel (tb)

RunIIa, μ+jets, 2jets, 2tags









Background modeling

RunIIb, μ+jets, 2jets, 1tag

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- Z+cc+light jets
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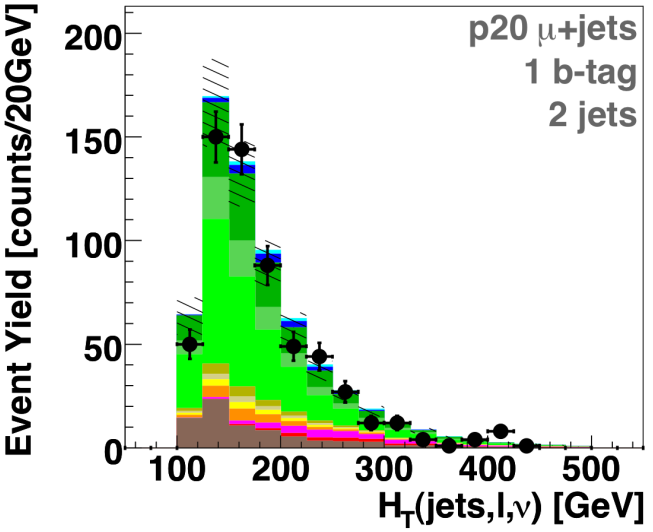
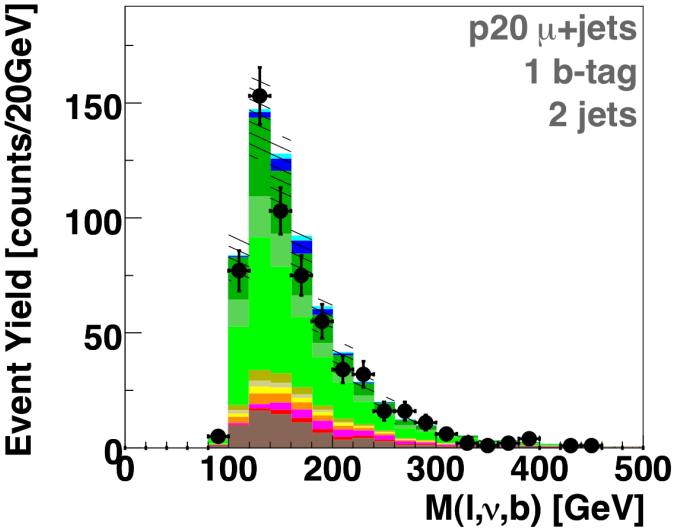
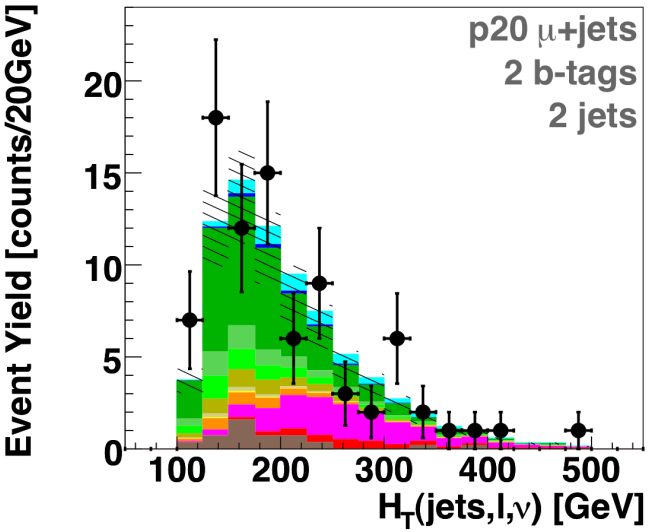
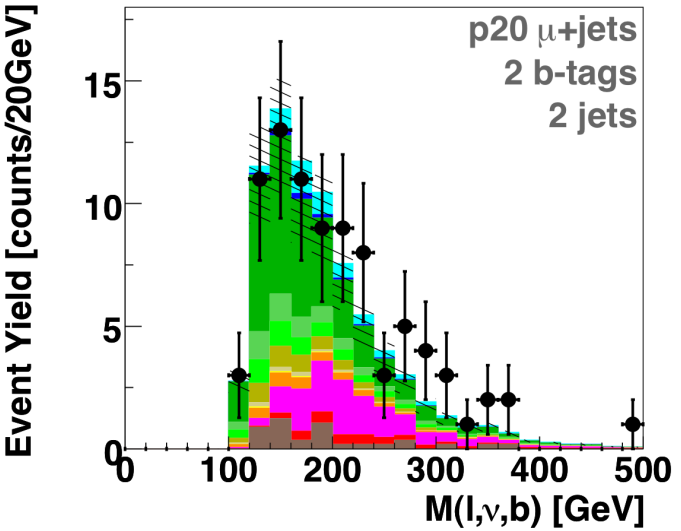
RunIIb, μ+jets, 2jets, 2tags









Background modeling

RunIIa, e+jets, 2jets, 1tag

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RunIIa, e+jets, 2jets, 2tags