ttbar in charged Higgs boson events

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on behalf of the ATLAS Collaboration

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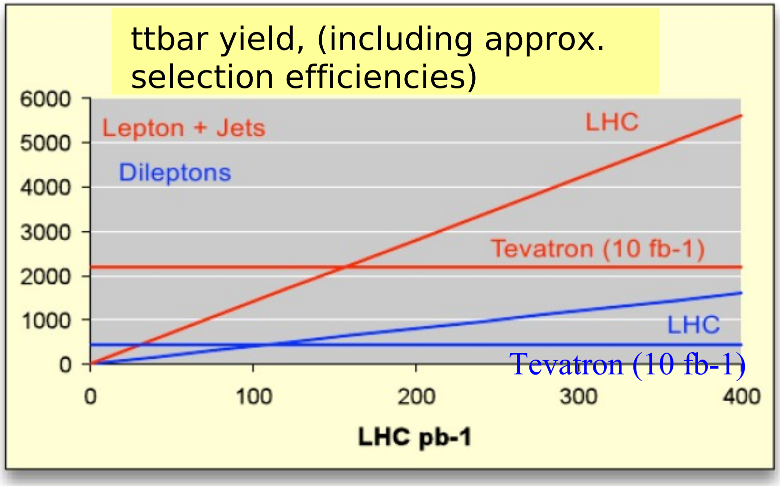
Outline

- Characteristics of ttbar events
- Early LHC data: ATLAS ttbar search
- ttbar as a background in H+ studies
- Data-driven ttbar background estimation

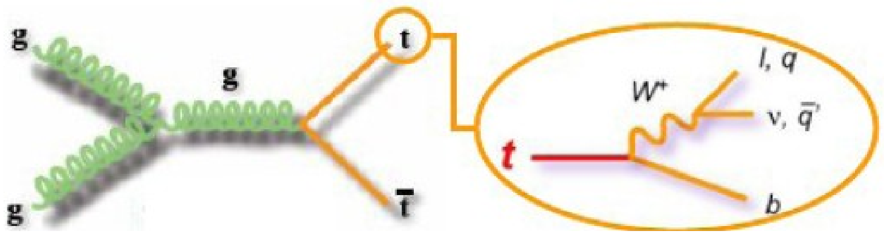
LHC: A top quark factory

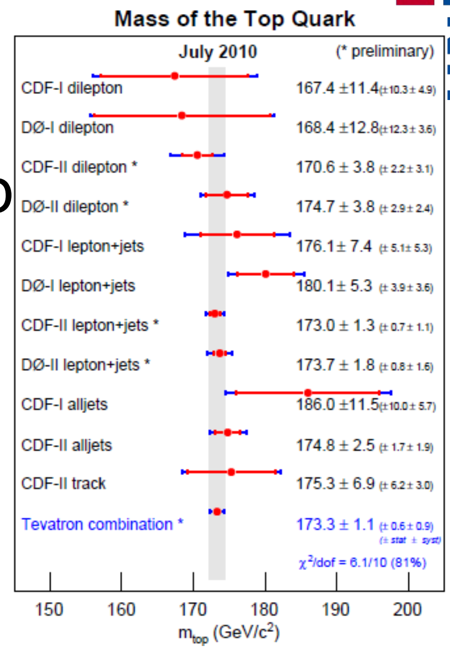
- ttbar discovery (1995), after selection:
  - CDF: **56 ttbar events** (exp. bkg: ~23±3), mt=176±8±10 GeV
  - D0: **17 ttbar events** (exp. bkg: 3.8±0.6), mt=199±21±22 GeV
- Tevatron, total number of ttbar events so far:
  - **≈140k ttbar events**
- LHC, total number of ttbar events so far:
  - **≈1000 ttbar events**
    - Already competitive to top discovery [and much better S/B, next slides]
- LHC, expected, one good year at low luminosity (14 TeV, 10 fb^{-1}):
  - **≈20M ttbar events**



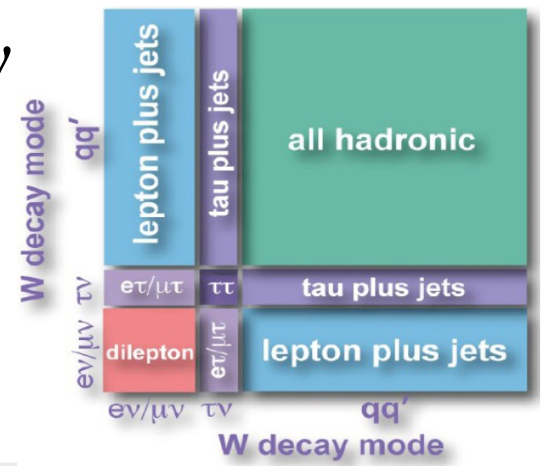
Top and ttbar characteristics

- m_t: 173.3±1.1 GeV
- $\sigma_{t\bar{t}}$ (LHC prediction 7 TeV): 165+8-11 pb





- Production, dominant at LHC:
  gg → ttbar
- Decay: ≈100%(?) t → Wb; W → qq/lν
- Classification of ttbar events:
  - 7% dilepton (e/mu) 6.7
  - 35% semi-leptonic (e/mu+qq) 34.6
  - 44% fully hadronic, 14% tau(had)+X

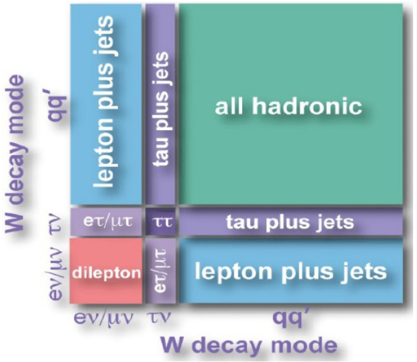


ttbar decay modes

ATLAS ttbar searches

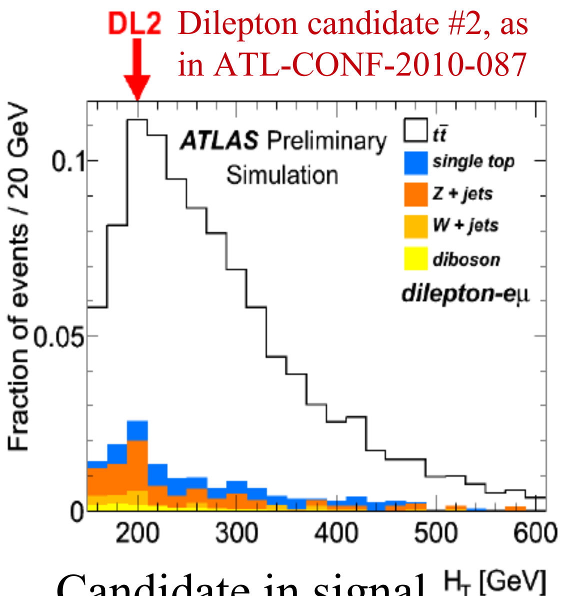
- Searches proceed in 3 steps:
  - Test of understanding of backgrounds and collection of first candidate events => L≈300 nb^{-1}, see next slides
  - ttbar observation (5σ) => L≈3-10 pb^{-1}
  - ttbar cross section and mass measurement => right after observation

- The best S/B ratio is expected in the dilepton and lepton+jets modes
  - Event selection, data and MC distributions and event displays on the following slides



ttbar dilepton event selection

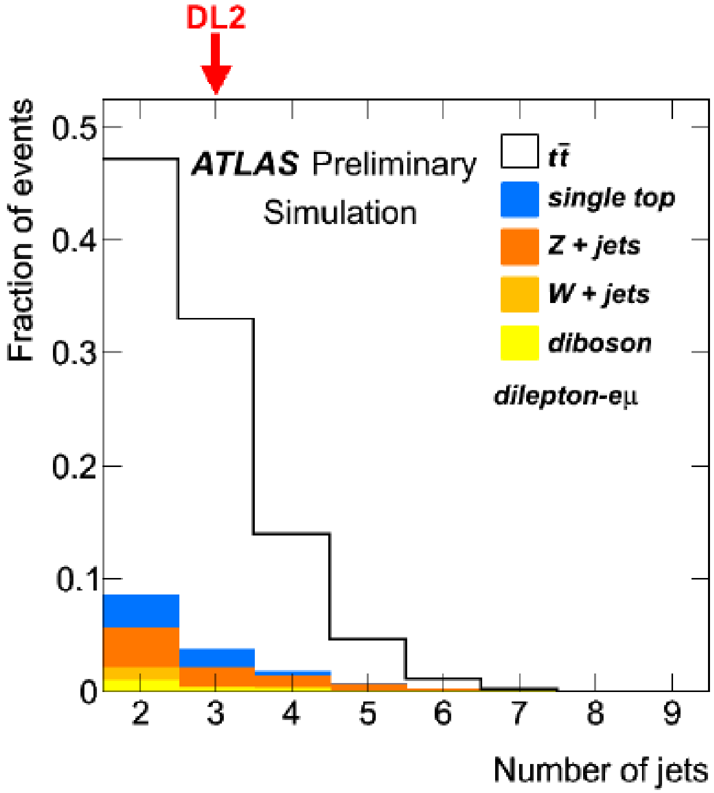
- Dilepton selection:
  - Lepton trigger — *suppresses:*
  - ==2 leptons, pT>20 GeV — *QCD*
  - Leptons: opposite charge — *QCD*
  - 2 jets, pT>20 GeV
  - ee/μμ: ET(miss)>40/30 GeV; |m(ll)-m(Z)|>5/10 GeV — *QCD, Z Z+jets*
  - eμ: HT>150 GeV (Et sum over leptons, jets) — *QCD*

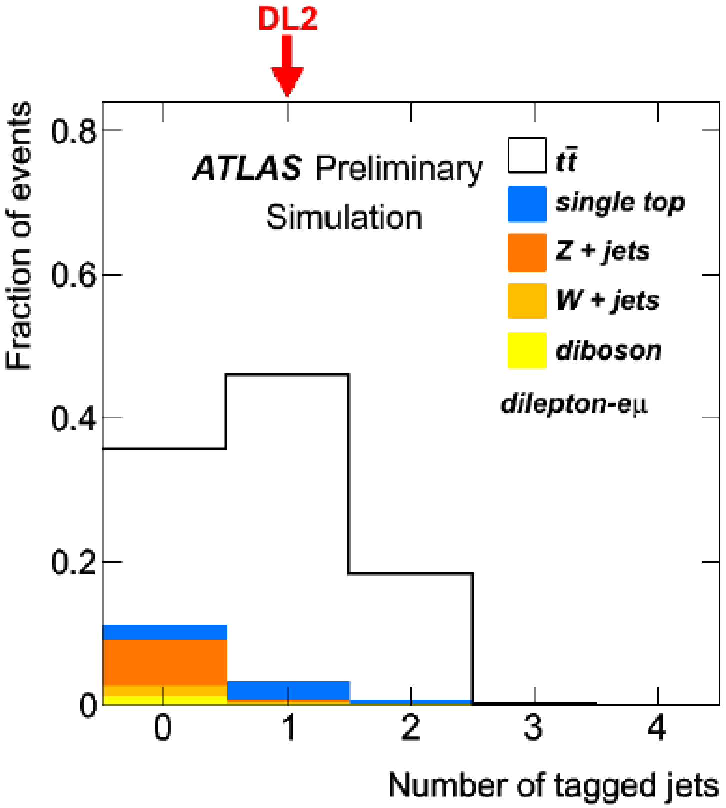


Candidate in signal MC peak; good S/B

ttbar dilepton events

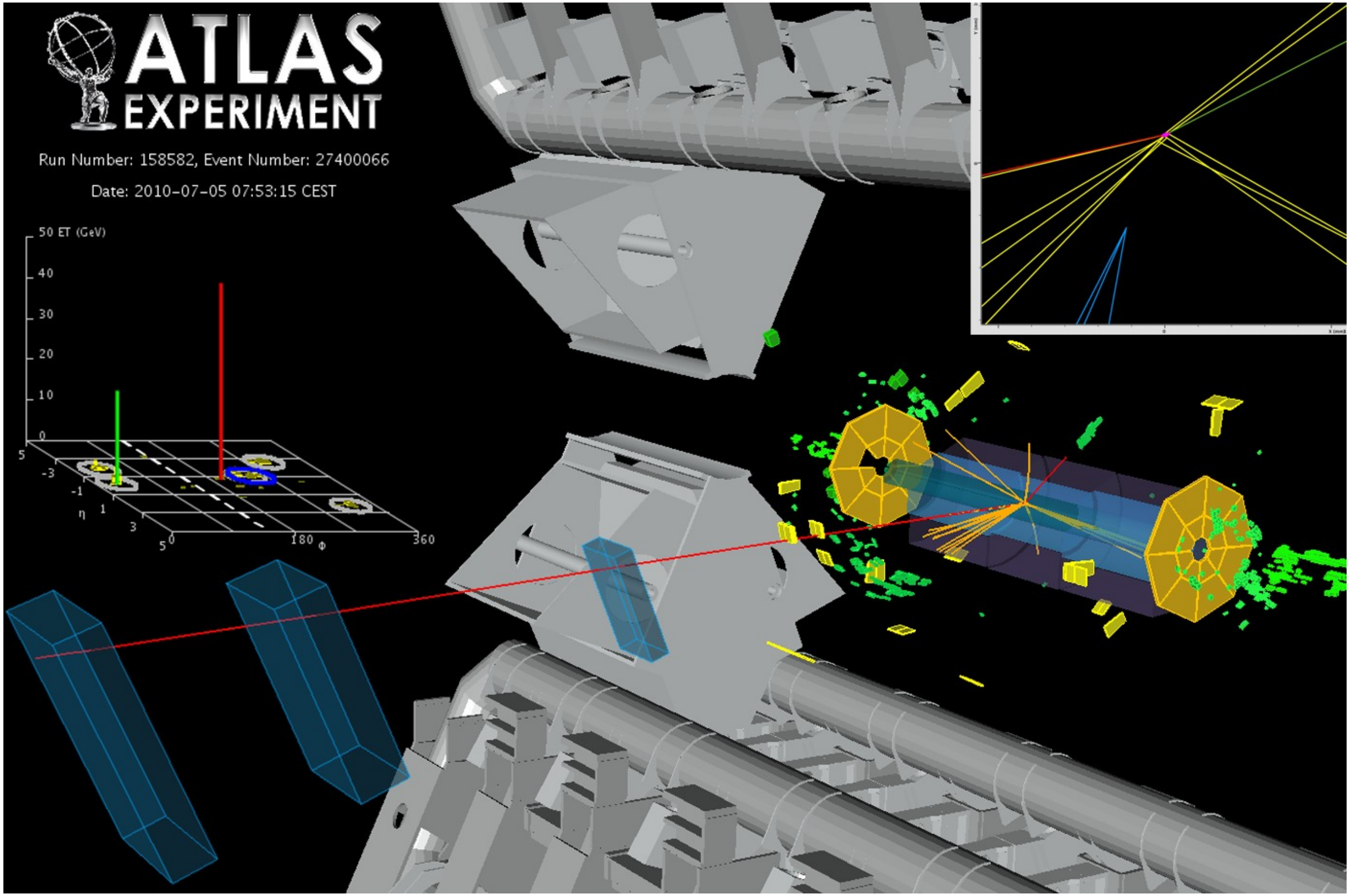
- Plots for events passing the dilepton (e+mu) selection



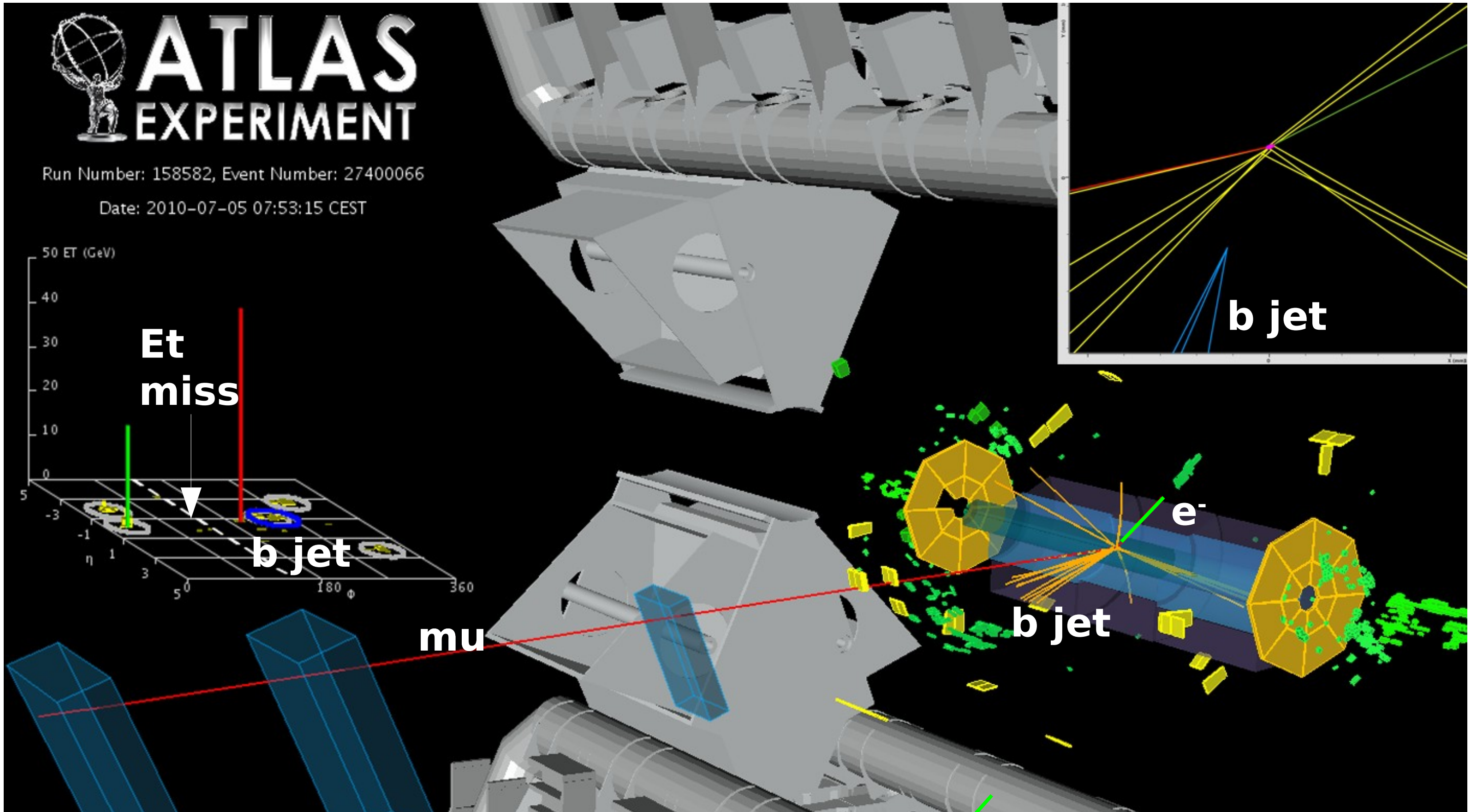


S/B increases a bit with number of jets, and strongly with number of required b tags

ttbar dilepton candidate



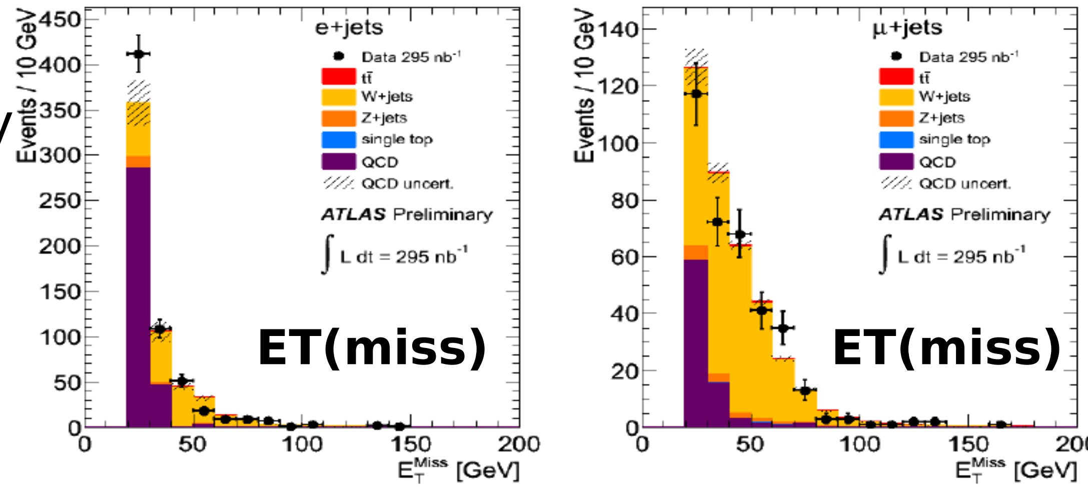
ttbar dilepton candidate



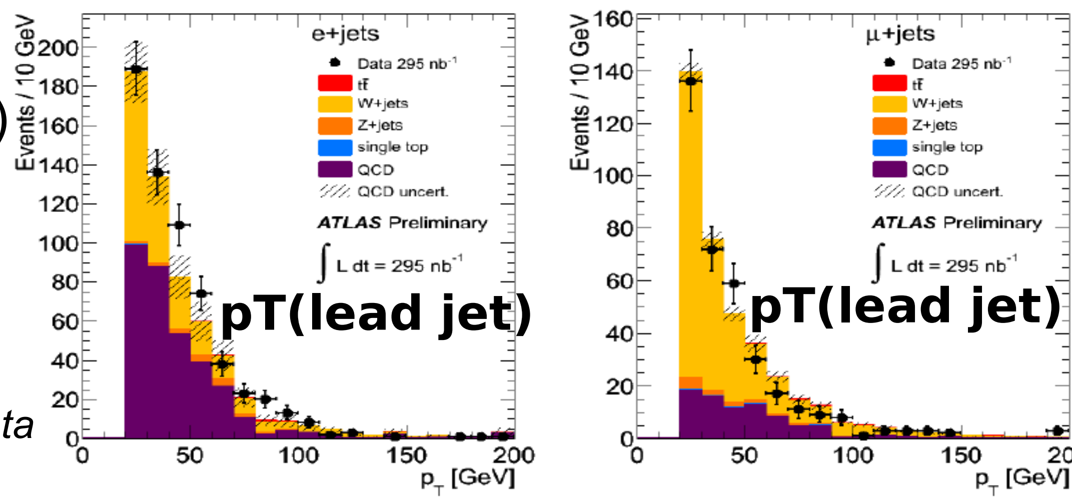
ID	Run number	Event number	Channel	p_T^{lep} (GeV)	E_T^{miss} (GeV)	H_T (GeV)	#jets $p_T > 20$ GeV	#b-tagged jets
DL2	158582	27400066	$e\mu$	22.7/47.8	76.9	196	3	1

ttbar lepton+jets event selection

- Lepton (e/mu)+jets
  - Lepton trigger
  - ==1 lepton, pT>20 GeV
  - >=4 jets, pT>20 GeV

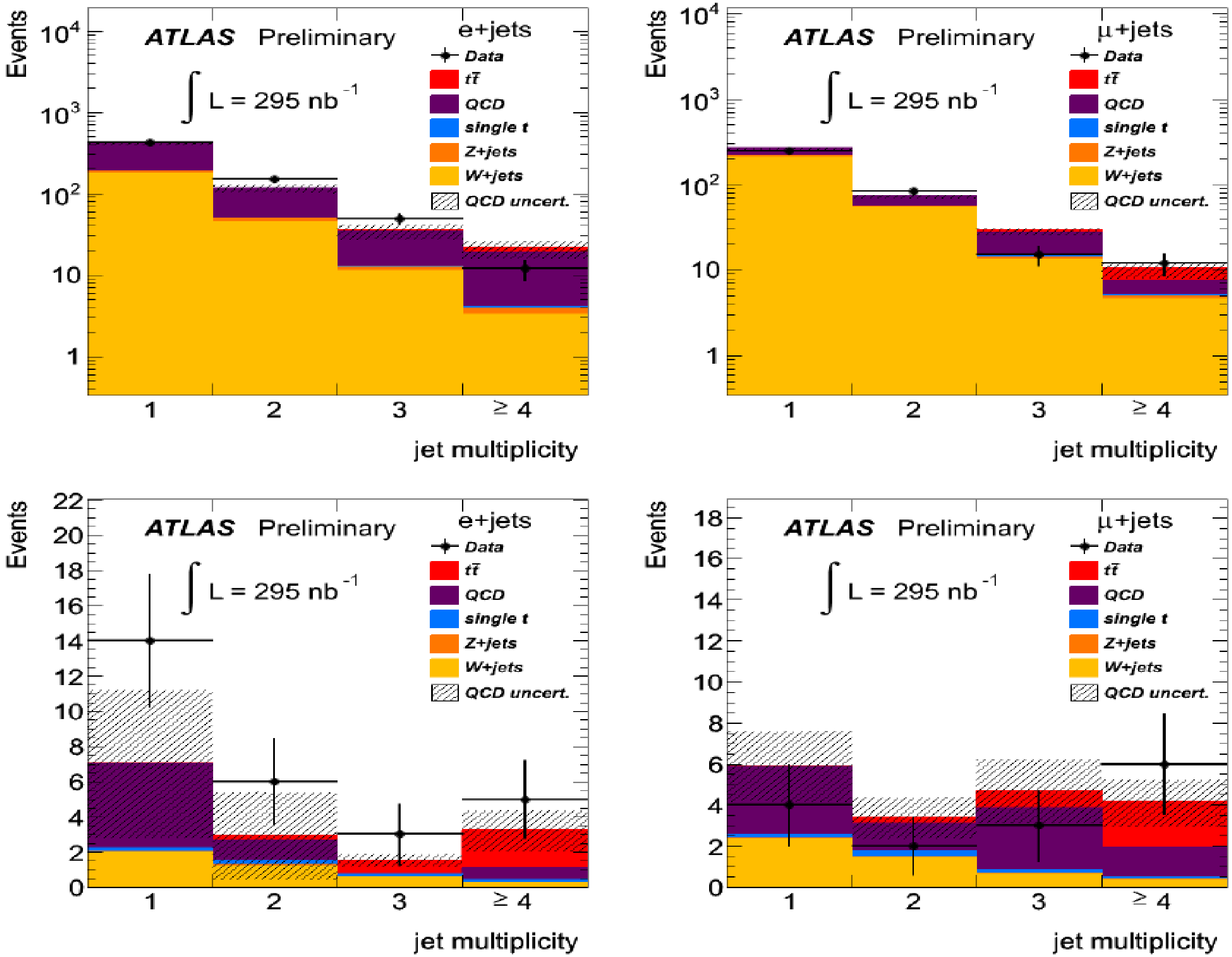


  - >=1 b-tag (secondary vertex, 50% efficiency)
  - ET(miss)>20 GeV



QCD background estimated from data

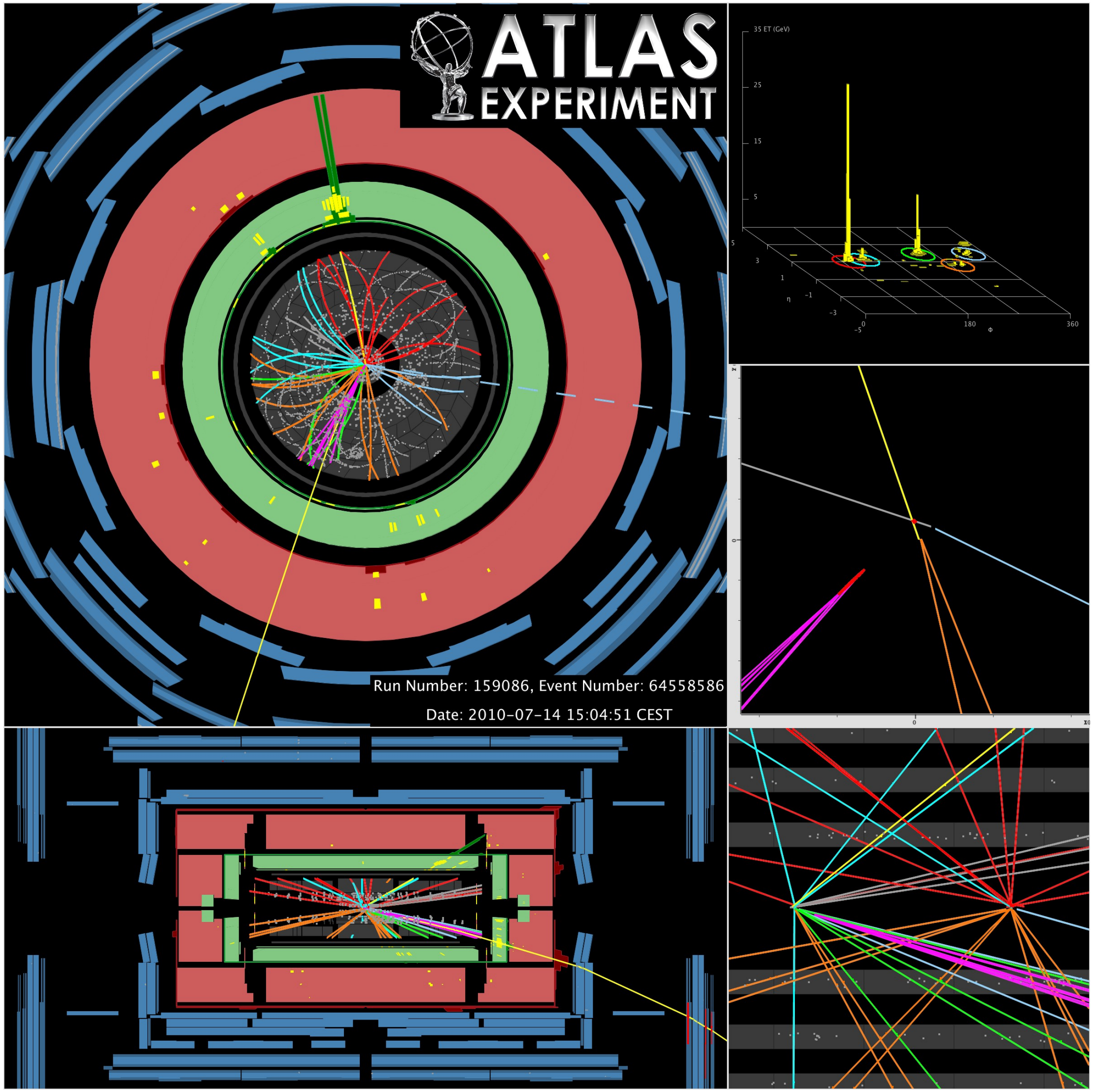
ttbar leptons+jets events



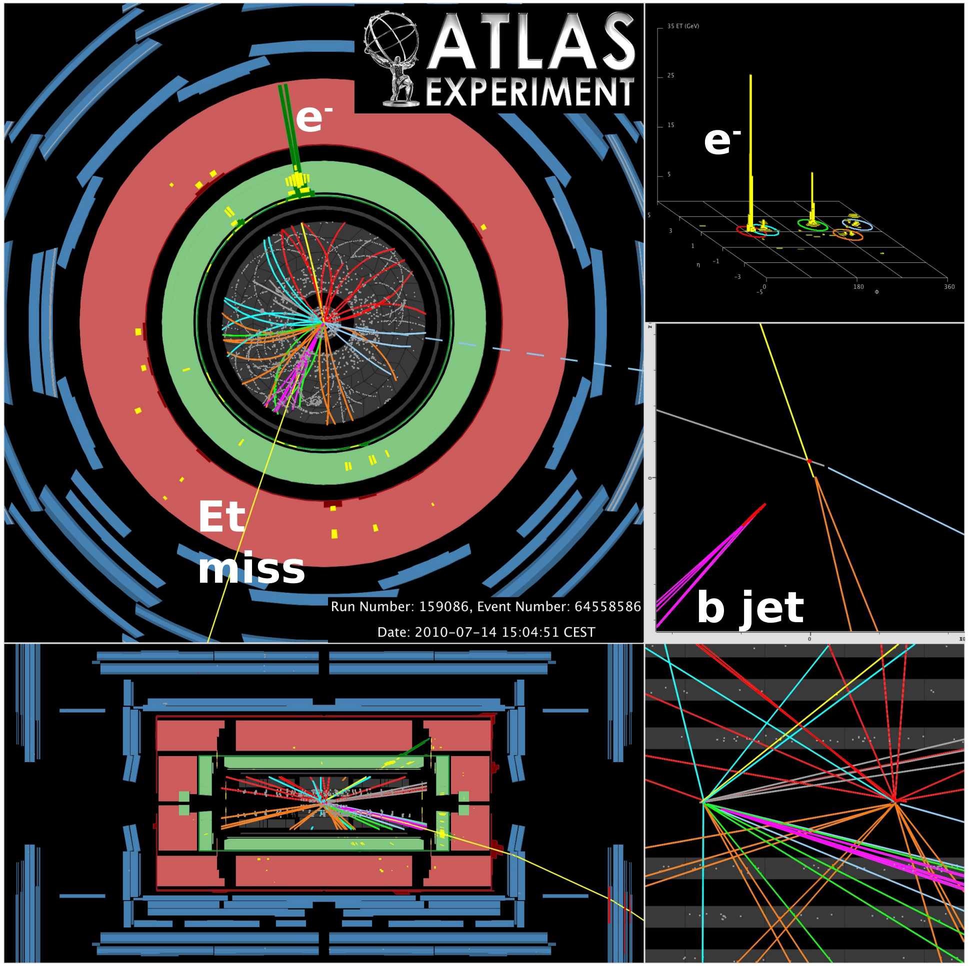
no b-tag

>=1 b-tag

ttbar lepton+jets candidate



ttbar lepton+jets candidate



Left: primary vertex
Right: pile-up vertex

ID	Run number	Event number	Channel	p_T^{lep} (GeV)	E_T^{miss} (GeV)	m_T (GeV)	m_{jjj} (GeV)	#jets $p_T > 20$ GeV	#b-tagged jets
LJ5	159086	64558586	e+jets	79.3	43.4	86.7	122	4	1

ttbar as background to H+ searches

- Conclusions from simulation studies [3,5]
  - Backgrounds, H+ in ttbar decay searches [σ / fb at 14 TeV]
  - =>ttbar->lep+X dominates

selection:

tau(had)+jets	presel	final
H+ (130)	79	31
tt (>=1 lep)	**307**	**26**
tt (hadr.)	21	
W+jets	30	
Single top	17	
QCD jets	<1	

tau(lep)+jets	presel	final
H+ (130)	75	21
tt (>=1 lep)	**1963**	**144**
tt (hadr.)		
W+jets	173	
Single top		
QCD jets	<50	

tau(had)+lep	presel	final
H+ (130)	265	20
tt (>=1 lep)	**1730**	**78**
tt (hadr.)		
W+jets	58	
Single top	38	
QCD jets		

- ttbar composition
  - m_{H+} =300 GeV, tau(had)+jets
  - Events/30 fb-1, 14 TeV

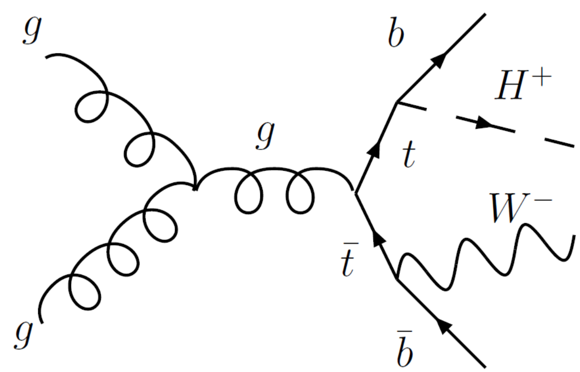
W_1	W_2	Events	W/t_{rec} (b)	τ-Cuts (c)	p_T^{miss} (d)	$\Delta\phi$ (e)
lepton	lepton	822000	3	1	0	0.0
lepton	tau	858000	436	18	2	1.1
lepton	jet	8090000	330	11	2	1.6
jet	tau	2690000	22000	869	208	0.9
jet	jet	5160000	303	2	0	0.0
tau	tau	224000	661	38	3	1.8
SUM		17700000	23800	939	216	5.4

Data-driven ttbar estimation

- ttbar background expectation:
  large systematic uncertainties (theoretical, experimental)
  - ttbar cross section O(10%)
  - MC generator (e.g. shower and fragmentation models)
  - Detector model (e.g. dead material)
  - Jet, tau energy scale 10-35%
  - b-tagging efficiency O(10%)
  - Luminosity 3-10%
    - **Total: 15-40%**, depending on H+ selection
- Need to estimate it from data to keep H+ sensitivity
  - Embedding
  - Matrix method

Embedding

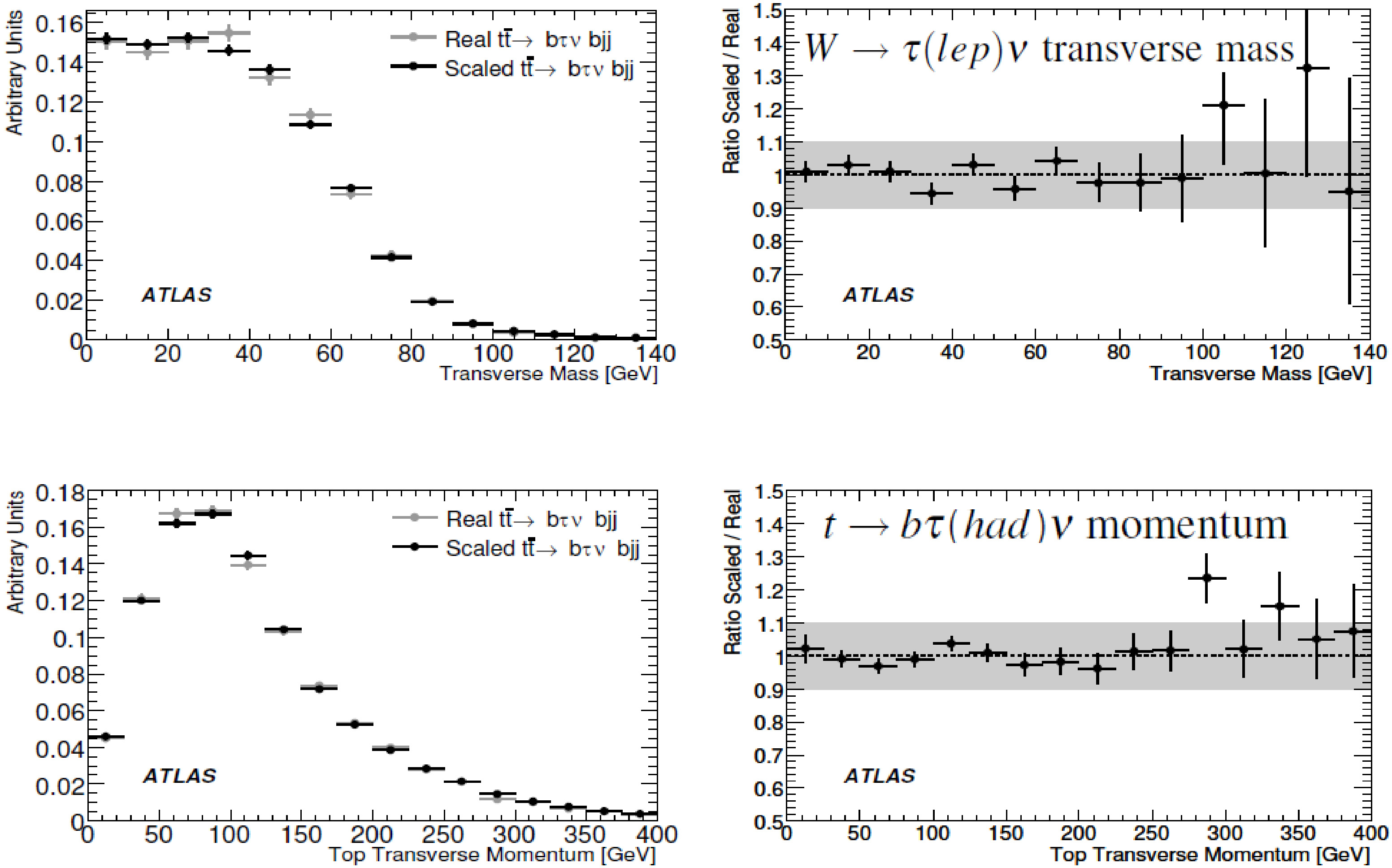
- Example: ttbar background in tau+jets mode
  1. Select a pure sample of $t\bar{t}$->$b\mu\nu\ \bar{b}qq'$ from data
  2. Remove muon from event (tracks, calorimeter deposition)
  3. Replace with *simulated* τ with (rescaled) muon-4-momentum
  4. Run this ($b\tau\nu\ \bar{b}qq'$) through event selection
- Use shape of distributions of embedded events, e.g. m_T(H+)
  - Perhaps later normalization as well



- Everything except τ taken from data:
  - Jets, b, ET(miss), UE, MI, pile-up, …
- Weakness:
  - Technically complex
  - can only model one ttbar decay mode at a time

Embedding: Shapes

- Agreement within ≈10% (MC syst. unc. >15-40%)



Matrix method

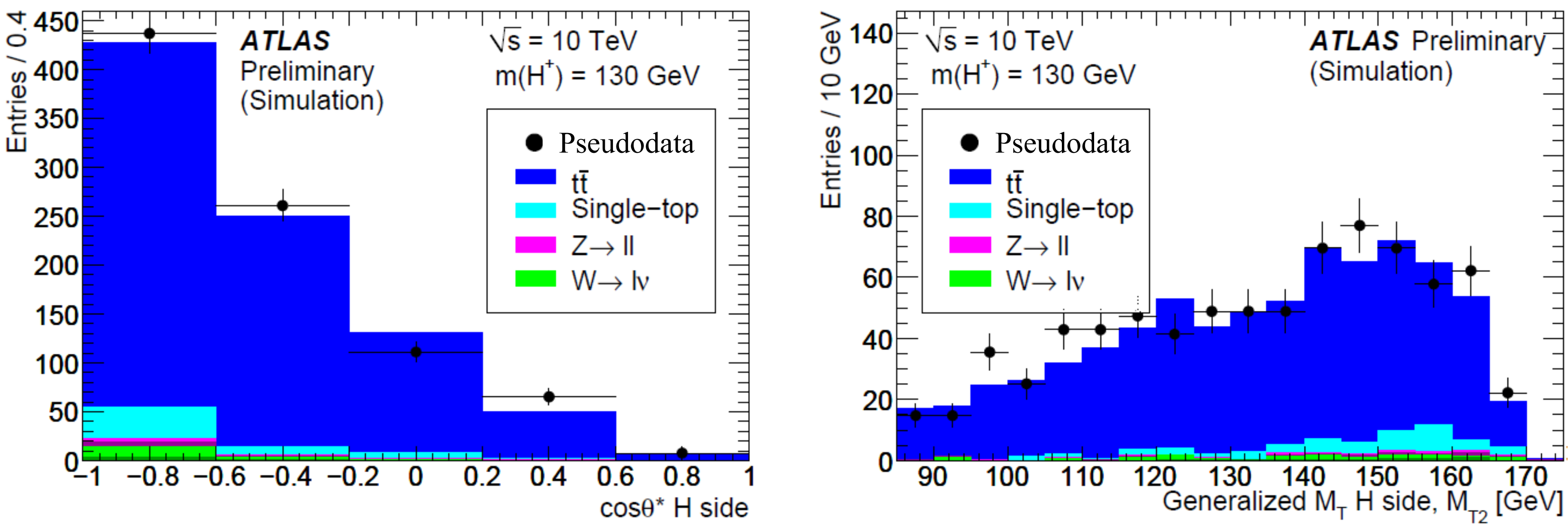
- For each background: modified selection such that this background dominates (referred to as sideband)
- Obtain data/MC ratio from sideband and apply it to the MC background expectation in the signal region
- Example: H+ dilepton search

Process	Z+jets	W+jets	Single top	SM $t\bar{t}$	$H^+W \to 2$ leptons
b-weight cut	< 0		> 4.3		> 4.3
E_T^{miss} cut	< 30 GeV	> 30 GeV	< 50 GeV	> 50 GeV	> 50 GeV
Leptons	ee or $\mu\mu$	$e\mu$		no cut	no cut
m_{ll} cut	$86 \to 96$ GeV	no cut			no cut
$\cos\theta_l^*$ (H^+ side)	no cut			> -0.4	< -0.6

- Advantage: technically simple
- Weakness: - assumption data/MC ratio in sideband & signal region identical
  - need precise MC estimate (difficult: high-σ processes)
  - does not correct for a wrong differential cross section

Matrix method: Pseudodata test

- Using a mix of simulated ttbar, single top, W, Z and diboson events with scaled cross sections:
  - Can we estimate the scale factors?
- Figure: ttbar sideband (MC scaled via sidebands)



  - Estimated scale factor: 0.87 ± 0.07 (stat, ≈150 pb^{-1})

Conclusions

- ATLAS is collecting a large number of top candidates. Next steps:
  - Observation
  - Cross section measurement
- ttbar is the dominant background for all mainstream H+ searches.
  - Need reliable way to estimate it from data
  - Main methods studied:
    - Embedding
    - Matrix method
- Observing top quarks: first step towards observing data / SM disagreement in ttbar events!

Backup slides

References

- ATLAS Collaboration:

  - [1] Search for top pair candidate events in ATLAS at sqrt(s)=7 TeV, ATLAS-CONF-2010-063
  - [2] Background studies for top pair production in lepton plus jets final states in sqrt(s)=7 TeV ATLAS data,
    ATLAS-CONF-2010-087
  - [3] Expected performance of the ATLAS experiment : detector, trigger and physics, CERN-OPEN-2008-020
  - [4] Expected Sensitivity in Light Charged Higgs Boson Searches for H+ to tau+nu and H+ to c+sbar with Early LHC Data at the ATLAS Experiment, ATL-PHYS-PUB-2010-006

- Mohn, Flechl, Alwall:

  - [5] ATLAS Discovery Potential for the Charged Higgs Boson in
    $H^\pm \rightarrow \tau\nu$ Decays, ATL-PHYS-PUB-2007-006

Selections

- ATL-PHYS-PUB-2007-006 selection
  - Jets+LV:
    exactly one τ-jet with $p_T^{\tau} > 40$ GeV, $p_T^{miss} > 40$ GeV, at least three parton jets, among those exactly one b-jet, no isolated lepton with $p_T^{lep} > 7$ GeV.
  - W/t_{rec}:
    two jets with $|m_{jj} - m_W| < 25$ GeV, the same two jets plus the b-jet with $|m_{jjb} - m_t| < 25$ GeV.
  - τ-Cuts:
    $|\eta^{\tau}| < \{0.9, 1.0, 1.2\}$, $p_T^{\tau}/p_T^{\neg t} > \{6.0, 5.5, 5.0\}$, and $p_T^{\tau} > \{65, 80, 100\}$.
  - $p_T^{miss} > \{120, 135, 165\}$.
  - $\Delta\phi > \{1.1, 1.2, 1.3\}$.
- ATL-PHYS-PUB-2010-006 selection
  - two oppositely charged leptons (electron or muon) with $p_T > 20$ GeV (leading) and $p_T > 10$ GeV (sub-leading), and at least two jets with $p_T > 15$ GeV,
  - b-weight greater than 4.3 (as in the $H^+ \to c\bar{s}$ study, we use the IP3D+SV1 b-tagger),
  - $E_T^{miss} > 50$ GeV,
  - $\cos\theta_l^* < -0.6$ (H^+ side).

cos(θ)

4.1 Helicity Angle $\cos\theta_l^*$

In the SM top quark decays (i.e. those mediated by a W boson with purely V-A couplings), a fraction $m_t^2/(m_t^2+2m_W^2) \simeq 0.69$ of the W bosons is expected to be found with a longitudinal polarization. The remainder, i.e. a fraction $2m_W^2/(m_t^2+2m_W^2) \simeq 0.31$ of the W bosons, is expected to have a left-handed helicity in the top quark rest frame. With θ_ℓ^* defined as the angle of the lepton momentum with respect to the helicity axis, in the W rest frame, this leads to the following normalized angular distribution for the charged lepton $\ell = e, \mu, \tau$ arising from $W \to \ell\nu_\ell$:

$$\frac{1}{N}\frac{dN(W \to \ell\nu_\ell)}{d\cos\theta_\ell^*} = \frac{3}{4} \times \frac{m_t^2(1-\cos^2\theta_\ell^*) + m_W^2(1-\cos\theta_\ell^*)^2}{m_t^2+2m_W^2}. \quad (4)$$

In the rest frame of the decaying top quark, the recoiling b quark has its momentum anti-parallel to the momentum of the W boson. For the sake of simplicity, we now neglect the mass of the b quark and we assume that the decay is mediated by an on-shell W boson. Let p_b and p_ℓ be the 4-momenta of the b quark and the charged lepton ℓ, respectively. With our assumptions, $\cos\theta_\ell^*$ can be expressed as [16]:

$$\cos\theta_\ell^* \simeq \frac{4\,p_b \cdot p_\ell}{m_t^2 - m_W^2} - 1, \quad (5)$$

Note that p_b and p_ℓ can be advantageously chosen in the laboratory frame, since $\cos\theta_\ell^*$ contains an invariant product. Also, no knowledge about the momentum of the neutrino accompanying the charged lepton is required to compute $\cos\theta_\ell^*$. In the case of $H^+ \to \tau^+\nu$, the decay products are distributed isotropically because the charged Higgs boson has a spin 0. Unfortunately, an experimental angular analysis of dilepton $t\bar{t}$ events exclusively aimed at establishing the spin 0 of a presumptive charged Higgs boson in the top quark decays is very challenging, for two reasons. First, the kinematic assumptions that lead to Equation (5) are not valid as soon as m_{H^+} differs from m_W. More importantly, the presence of two neutrinos in the leptonic τ decays does not allow full reconstruction of its momentum.