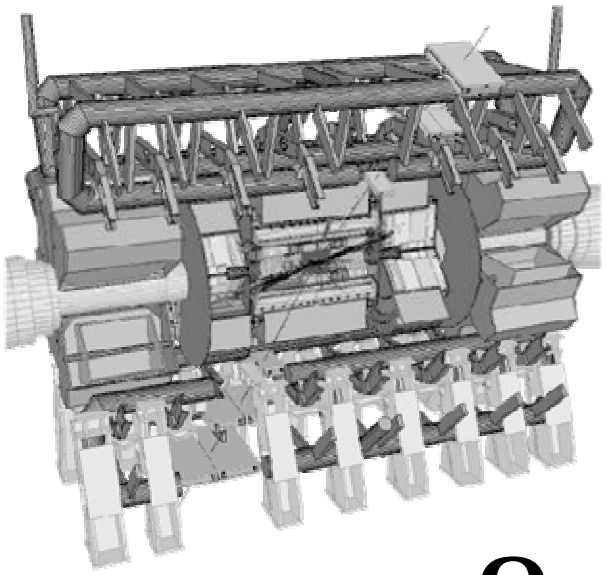


ATLAS

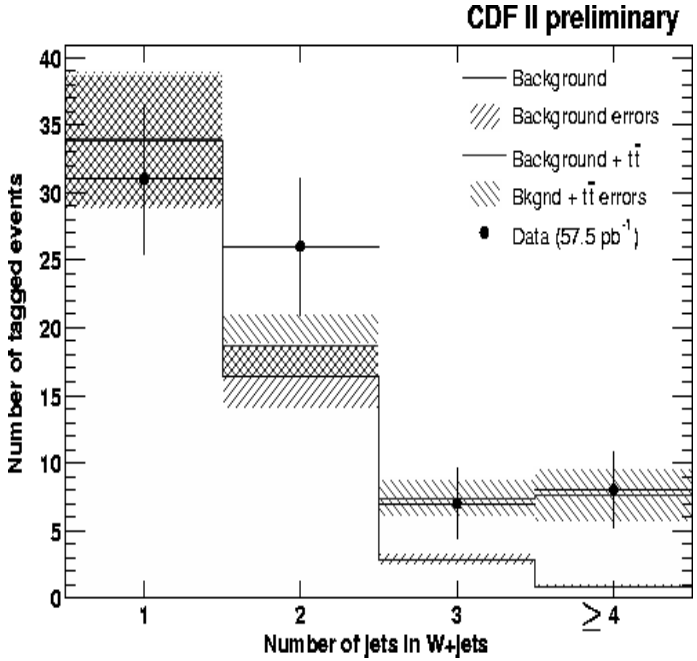
Overview of Top Quark and (Other) Standard Model Physics

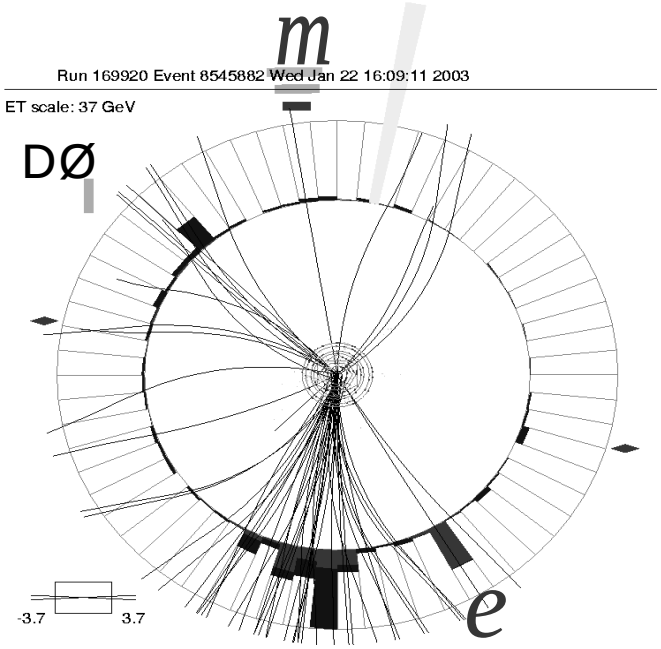
John Parsons
Nevis Labs, Columbia University

US ATLAS Software Mtg, BNL, August 28/2003

Why study the top quark?

- **The top quark (still) exists!**





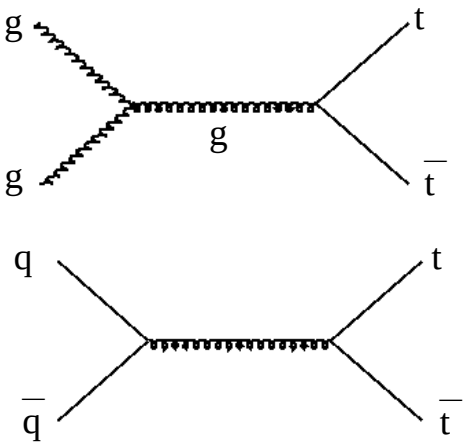
- **m(top) is a fundamental parameter of the SM (and plays role in rad. corr's)**
  - **want precision measurement**
- **large value of m(top) makes top quark unique**
  - **top is a sensitive window through which to look for new physics**

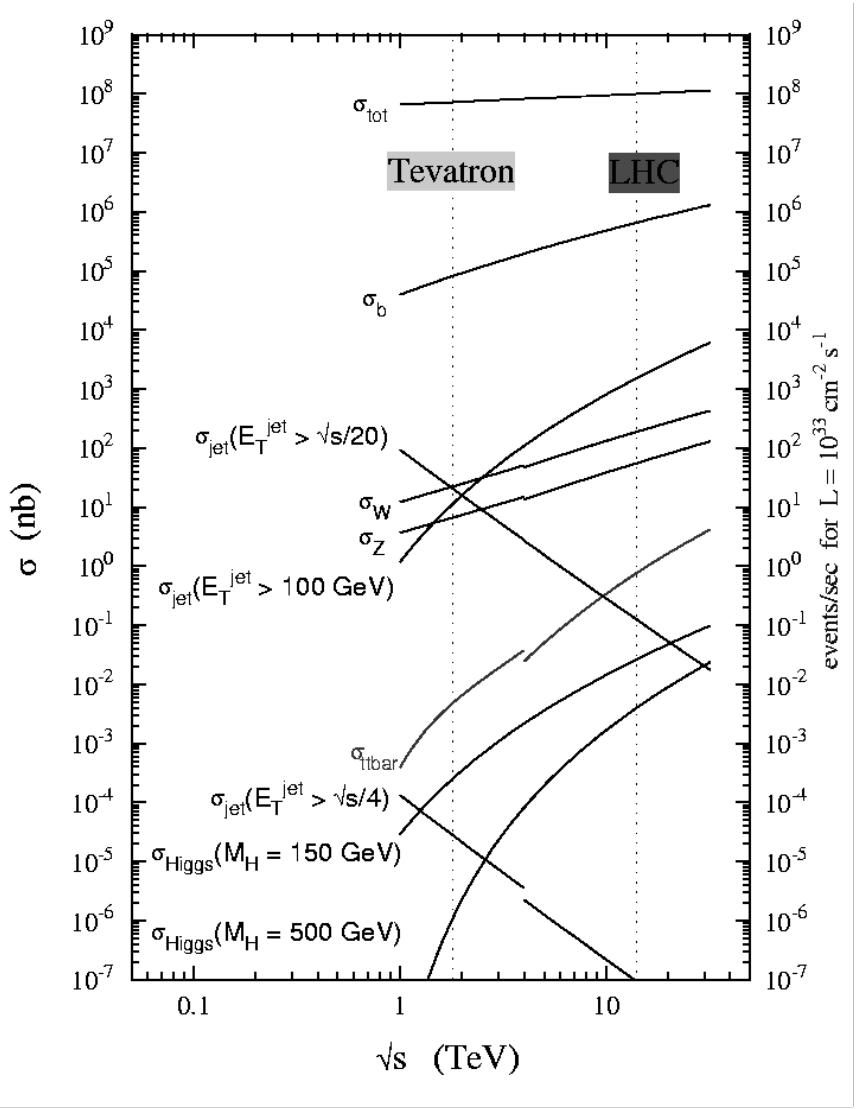
Top Quark Pair Production

- **NLO prediction of s(t-tbar) at LHC is 833 pb, which is » 100X larger than at FNAL**
  - **Producing 8 million t-tbar pairs per low lumi year, LHC will be a top factory**
- **Production processes at LHC:**

  90% gg + 10% q-qbar

  (opposite at FNAL)





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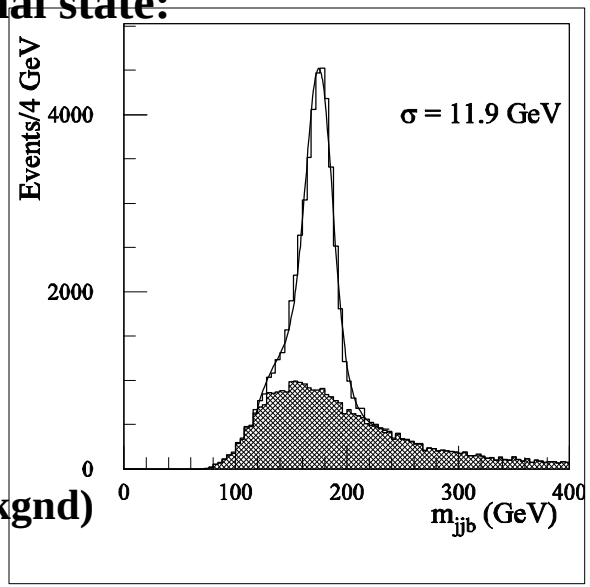
Top Quark Event Yields

- **NLO Xsect for t-tbar production = 833 pb**
  - ⇒ **8 million t-tbar pairs produced per 10 fb^{-1}**
- **Example cuts to select single lepton (e/m) plus jets final state:**
  - **pT(lep) > 20 GeV, pTmiss > 20 GeV**
  - **= 4 jets with pT(j) > 40 GeV, incl. = 2 jets with b-tag**
  - **selection effic. = 5% Þ 126k events, with S/B = 65**

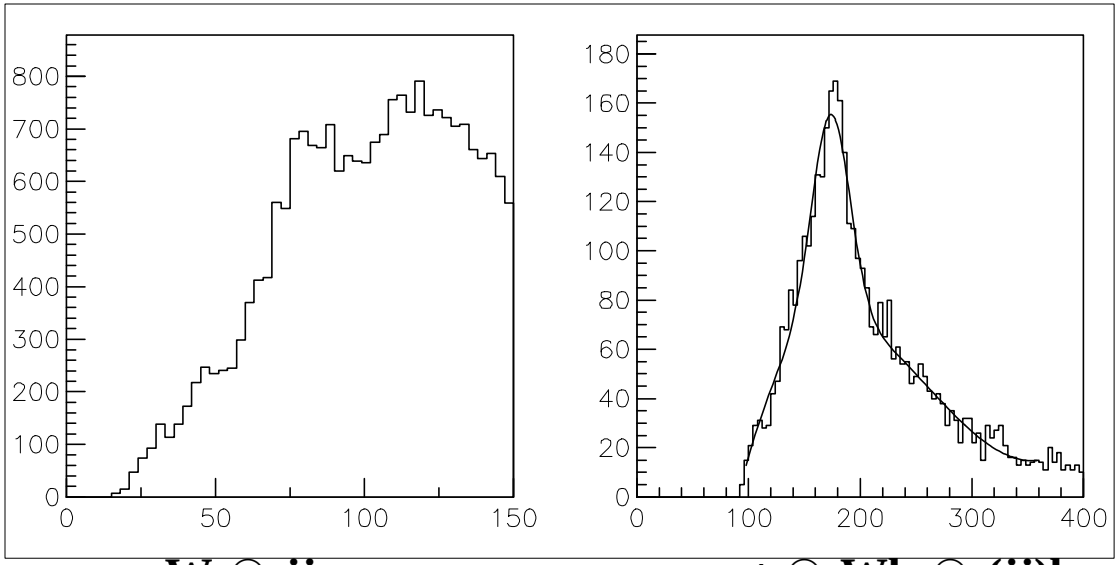


- **Reconstruct t ® Wb ® (jj)b**
  - **In ± 35 GeV window around mtop, have:**
    - **30k signal events**
    - **14k bkgnd events (dominated by t-tbar combo. bkgnd)**
- **Example cuts to select dilepton final state:**
  - **pT(lep1, lep2) > 35, 25 GeV, pTmiss > 40 GeV**
  - **= 2 jets with pT(j) > 25 GeV**
  - **80k events, with S/B = 10**

Initial s(t-tbar) Measurement

- **Analysis of 100k DC1 events with no b-tagging info.**

  (< 2 days of running at 1E33 !!)

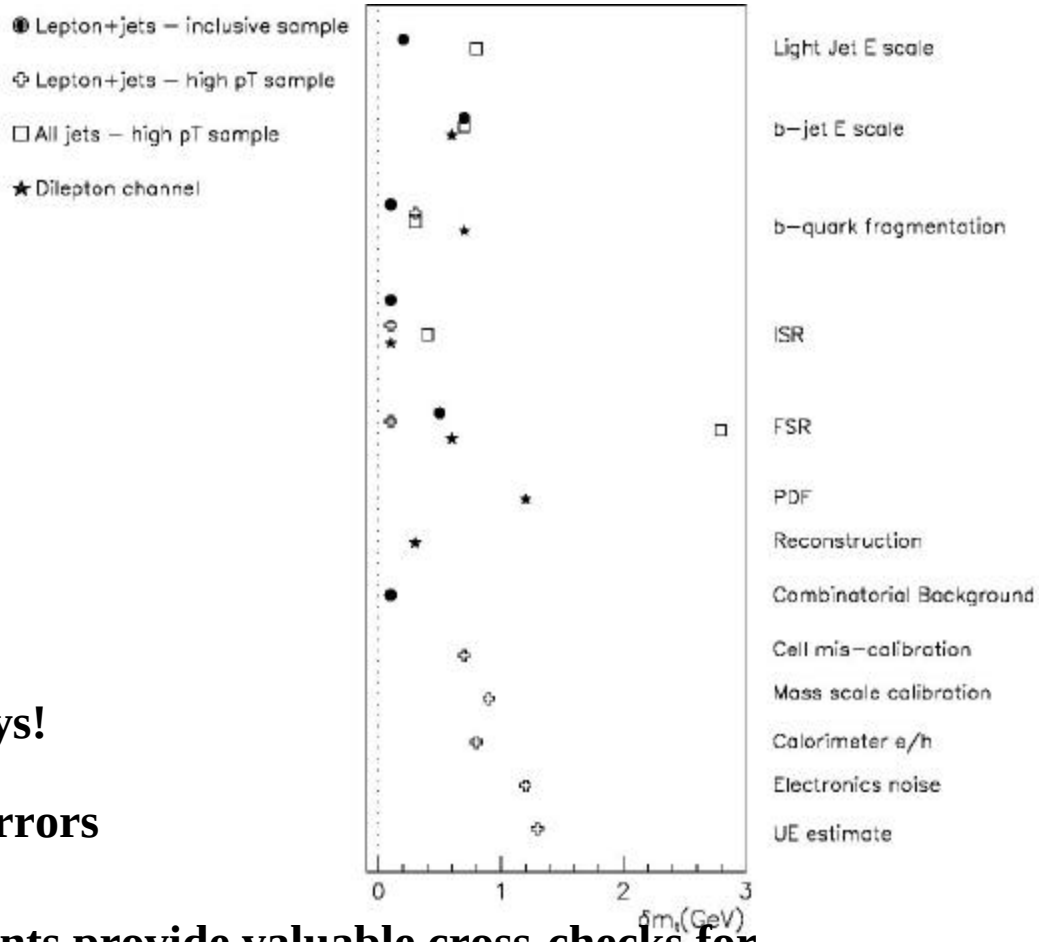


W ® jj **t ® Wb ® (jj)b**

- **Fit of m(jjb) spectrum provides Xsect measurement with stat. error » 7%**
- **Even with no b-tagging, can measure s(t-tbar) to < 10% with few days of integrated luminosity at 1E33**
  - **Could be first sign of new physics at LHC??**
- **Sample will be important for jet scale calibration and b-tagging commissioning**

Top Mass Measurement

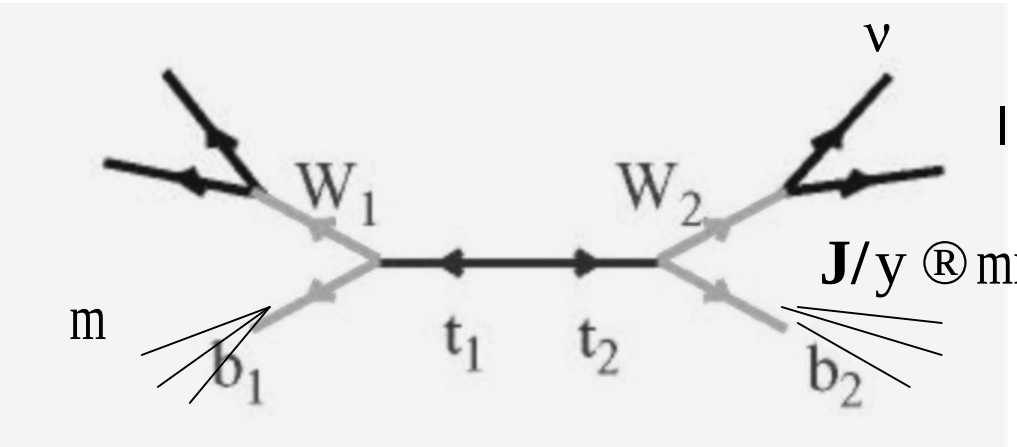
- **Fundamental parameter of SM**
  - **Precision measurement helps constrain m(H) or over-constrain SM once m(H) known**
- **Many different samples and techniques have been investigated**
  - **Inclusive single lepton plus jets**
  - **High pT single lepton plus jets**
  - **Dileptons**
  - **All jets mode**
  - **Sample with J/ψ**
- **Stat. error negligible after few days!**
- **Individual contributions to syst. errors < 1 GeV**



- **Variety of signals and measurements provide valuable cross-checks for controlling overall error**
- **Results so far collected into Scientific Note**

Leptonic final state with a J/ψ

- Correlation between m(t) and m(lJ/ψ)
- Require a non-iso μ inside b-jet



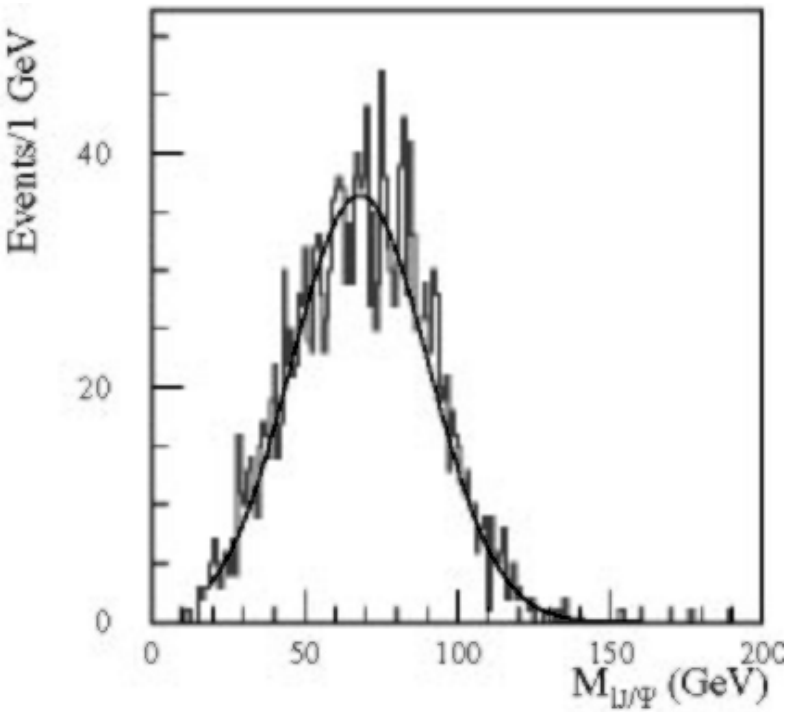
- BR=BR(pp→tt→Xb+lνb)xBR(b→J/ψ→μμ)xBR(b→μ)=3.2x10^{-5}
- Channel can be used only with high *L* (2700 evts/year)

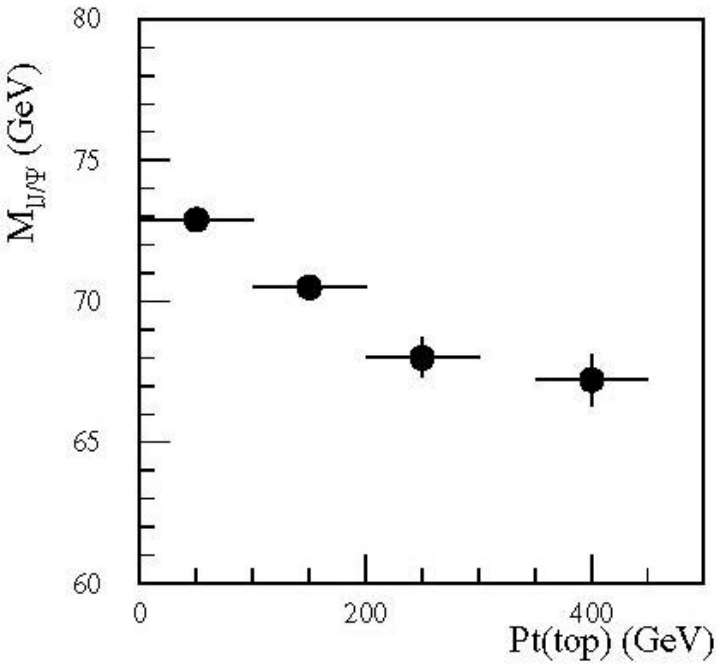
- **Selection:** 1 iso lepton, pT > 30 GeV, |η| < 2.4
  3 non-iso muons, pT > 3 GeV, |η| < 2.4, m(μμ) = m(lJ/ψ)
  ε ~16% ⇒ 430 evts/ year at high *L*

- **Background:** W/Z +jets, WW,WZ. Wbb, ε ~12% ⇒ S/B=55

Leptonic final state with a J/ψ

- m(lJ/ψ) distributions for several m(t) from MC compared with data
- δm(lJ/ψ) ~0.58 δm(t)
- δm^{stat}(lJ/ψ) ~0.5 GeV ⇒ (5y/high *L*)
  δm^{stat}(t) ~ 0.8-0.9 Gev





Uncertainties: not sensitive to jet E scale, ISR,PDF,b-quark fragmentation
δm^{sys}(lJ/ψ) ~0.5 GeV -> $\delta m(t)^{sys}$ < 0.9 GeV

Strong pT(t) dependence of m(lJ/y)

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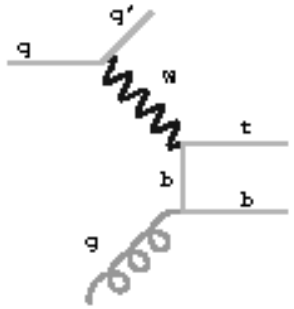
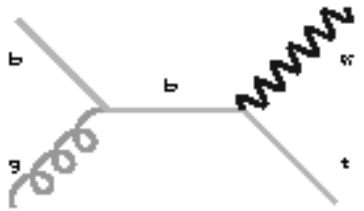
Electroweak Single Top Quark Production

- **3 separate production processes:**



W-gluon fusion (250 pb)

W*/s-channel (10 pb)



Wt (60 pb)

- **ATLAS studies have shown:**
  - **Can measure cross-sections for all 3 processes separately**
    - **important since each is sensitive to different kinds of possible new physics**
  - **For 30 fb^{-1}, can measure Vtb with stat. error of 0.4% – 2.7% (dep. on process)**
  - **For W-gluon fusion, can measure predicted W and top helicity**
    - **sensitive to possible V+A contribution at level of few per cent**
  - **More studies of sensitivity to possible new physics need to be done**

Example Analysis for W* Process

- **trigger on isolated lepton with p_T > 20 GeV**

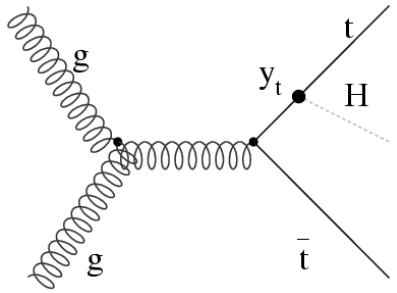
- **selection cuts**
  - **Njet = 2, with p_T > 30 GeV**
  - **Nbjet = 2 with p_T > 75 GeV**
  - **N(forward jet) = 1, p_T > 50 GeV, |h | > 2.5**
  - **Sum pt > 175 GeV (lepton plus jets)**
  - **Mtotal > 200 GeV (lepton plus jets)**

- **after all cuts, have (for 30 fb^{-1})**
  - **1.1k signal events (effic. = 1.7%)**
  - **2.4k bkgnd events (mostly ttbar, plus Wg fusion single top, Wjj)**
  - **ie. S/B » 0.46, S/ÖB » 23**

    Þ d**Vtb (stat.) » 2.7%**

Top Quark Couplings and Decays

- need to determine whether top quark behaves as described in the SM
  - Electric charge
    - Can use bjet charge tagging, or look at t tbar g events
  - Yukawa coupling can be measured to < 20% from t-tbar H production



- according to SM, top decays are rather "uninteresting"
  - Br(t ® Wb) » 99.9%
  - Br(t ® Ws) » 0.1%, Br(t ® Wd) » 0.01% (tough to measure!)
  - Many Beyond SM models involve anomalous top couplings
  - Several possible rare decay modes (eg. FCNC) have clear experiment signatures and, if observed at the LHC, would be evidence for new physics

Top Quark Rare Decays

- **In SM, FCNC top decays are highly suppressed (Br < 10^{-13} - 10^{-10})**
- **Several models of Physics Beyond SM can give HUGE enhancements**
- **Sensitivities according to ATLAS studies:**

t ® Zq (CDF Br < 33% @ 95%CL)

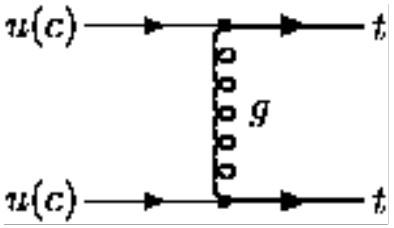
- **Reconstruct t ® Zq ® (l^+l^-)j**
- **Sensitive to Br(t ® Zq) = 1 X 10^{-4} (100 fb^{-1})**

t ® gq (CDF Br < 3.2% @ 95%CL)

- **Sensitive to Br(t ® gq) = 1 X 10^{-4} (100 fb^{-1})**

t ® gq

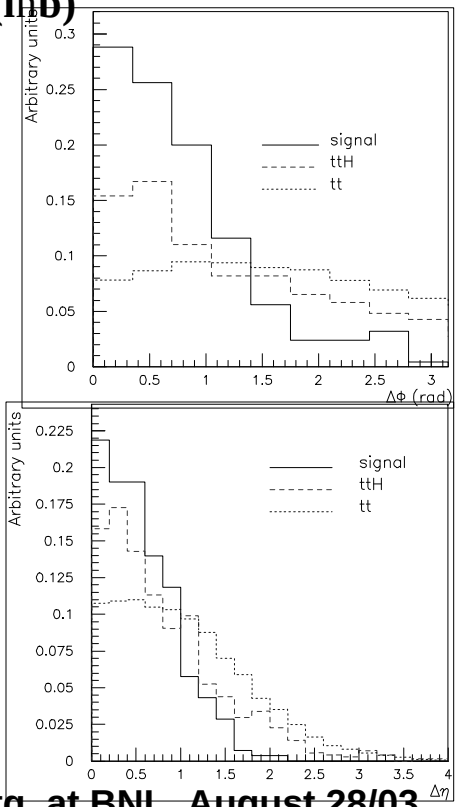
- **Decay process overwhelmed by QCD bkgnd**
- **Search instead for "like-sign" top production (ie. tt)**
- **Sensitive to Br(t ® gq) = 7 X 10^{-3} (100 fb^{-1})**



Top Quark Rare Decays (cont'd)

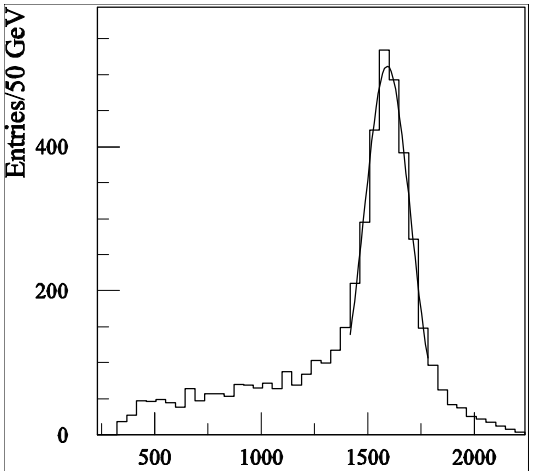
t ® Hq

- Tblisi group has been studying various approaches to t ® Hq
- Earlier results for t tbar ® Hq Wb ® (b-bbar)j (lnb) for mH = 115 GeV
  - Sensitive to Br(t ® Hq) = 4.5 X 10^{-3} (100 fb^{-1})
- New results for t tbar ® Hq Wb ® WW*q Wb ® (ln lnj) (lnb)
  - = 3 isolated leptons with pT(lep) > 30 GeV
  - pTmiss > 45 GeV
  - = 2 jets with pT(j) > 30 GeV, incl. = 1 jet with b-tag
  - kinematic cuts to take advantage of angular and other correlations
  - Sensitive to Br(t ® Hq) = 2.4 X 10^{-3} for mH = 160 GeV (100 fb^{-1})

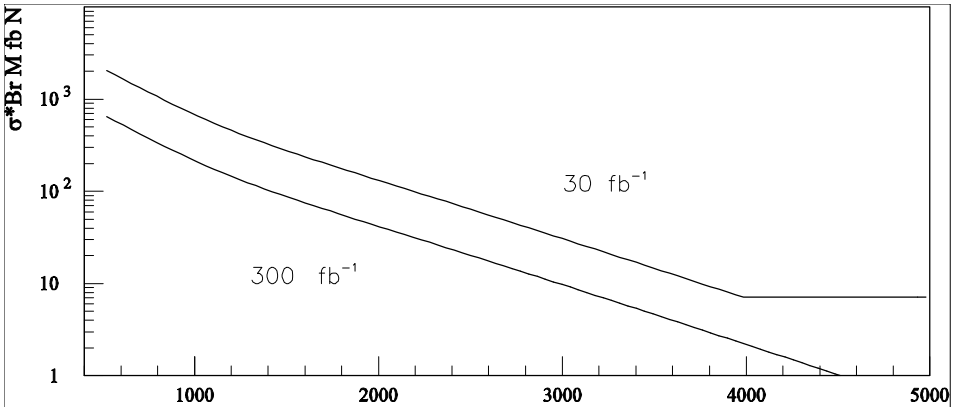


Top Quark and Exotica

- **Due to its large mass, top is likely candidate to couple strongly to new massive particles**
- **Clear experimental signature and ability to reconstruct top also make it a useful "tool" for studying exotica**
- **Some examples include:**
  - **Resonances decaying to t tbar (sensitive to few TeV)**
    - **Mass resolution » 6%**



Reconstructed M(tt) [GeV]

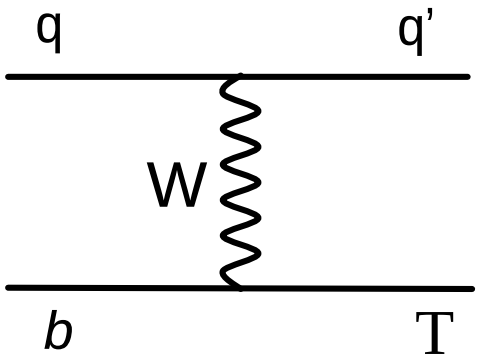


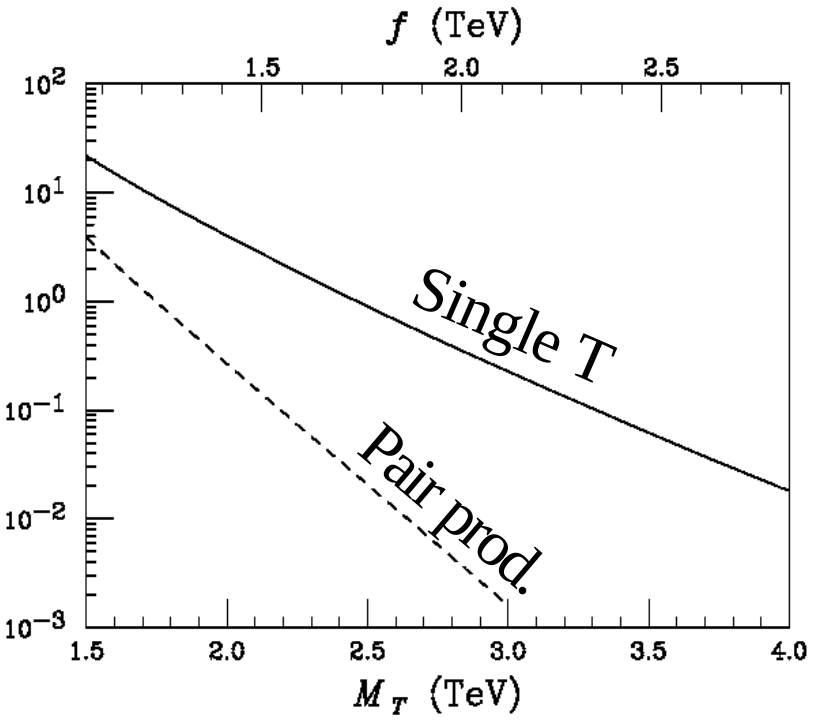
Reconstructed M(tt) [GeV]

  - **"Heavy top" (T) in Little Higgs models**
  - **Top signatures in extra dimension models**

Heavy T in Little Higgs Models

- **Main production mechanism is similar to “single top” production**

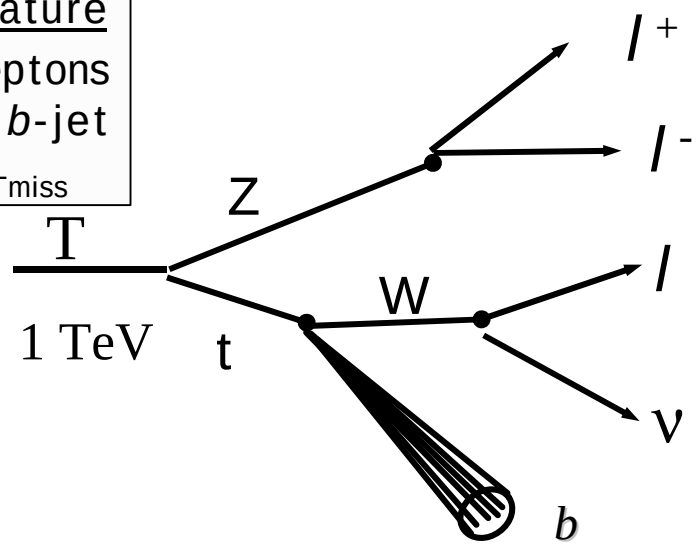




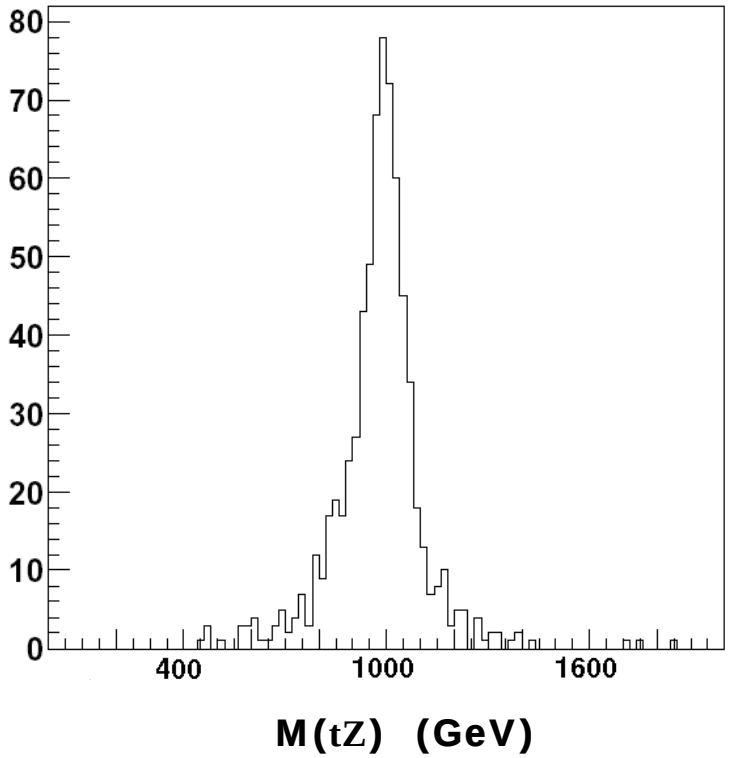
BR	T →	bW	50 %
	T →	tZ	25 %
	T →	th	25 %

T ® tZ Analysis

Signature
3 leptons
+ 1 *b*-jet
+ E_{Tmiss}



M(T) = 1 TeV



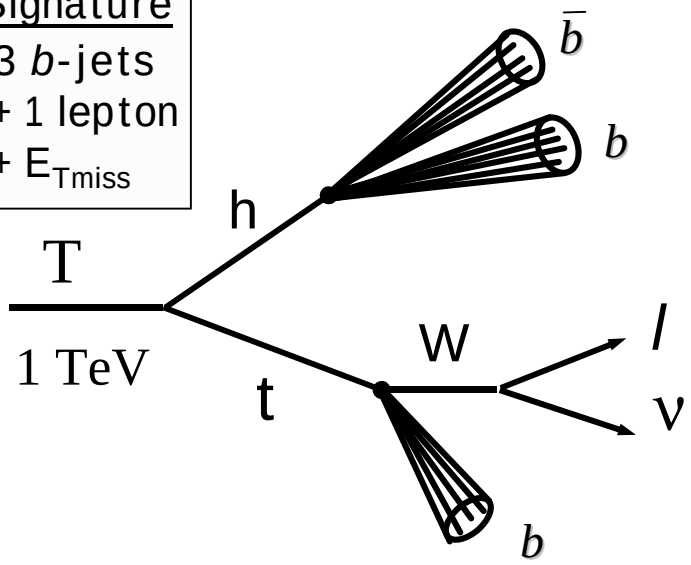
Cuts:

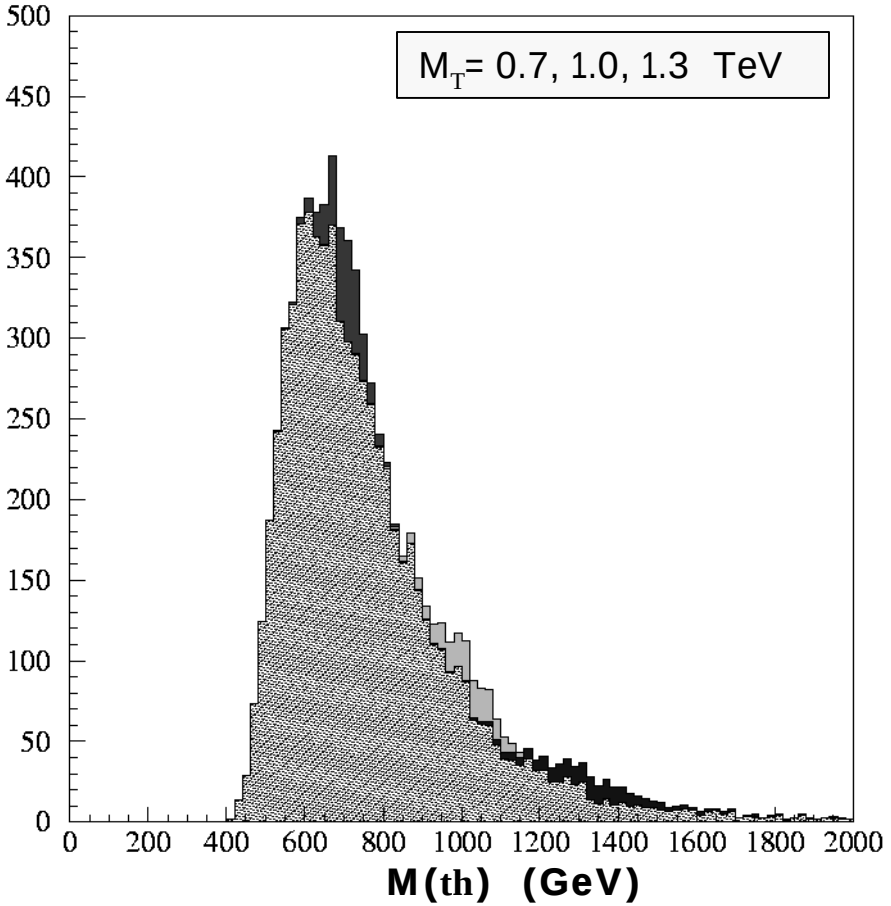
- *3 isolated leptons*
  (2 of them with $M_{ll} = M_Z$*)*
- 1 b –jet
- $E_{Tmiss} > 100$ GeV

-Bkgnd (tZ, WZ) under study, but should be small

T ® th Analysis

Signature
:3 *b*-jets
+ 1 lepton
+ E_{Tmiss}





Cuts:
- p_T(3-jets) > 90 GeV
- p_T(lepton) > 70 GeV
- 100 < M_h < 140 GeV

At least 1 b-tag

Bkgnd due to t-tbar, W bb

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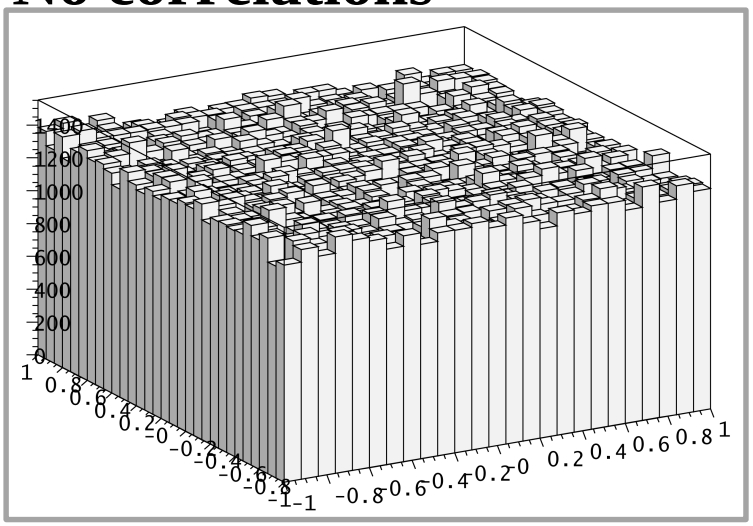
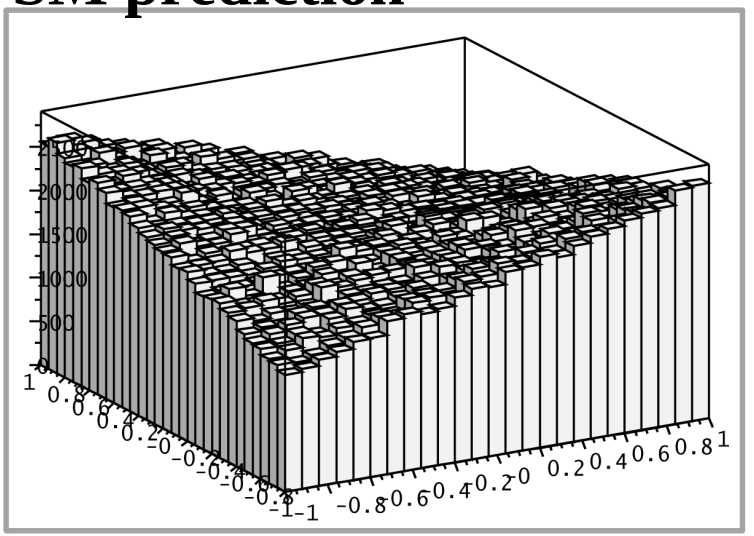
t-tbar Spin Correlations

- SM predicts substantial t-tbar spin correlations
- Dilepton case has been studied, using the t-tbar rest frame angles of the charged leptons as probe of correlations

No correlations



SM prediction



- Studies underway to determine sensitivity to various sources of anomalous couplings:
  - CP violation
  - New Higgs
  - Graviton effects in models with extra dimensions

Some Top Physics Topics for Further Studies

- **Putting "more meat on the bones"**
  - **DC samples of fully simulated events**
  - **Impact of initial (staged) detector layout**
  - **Improving level of understanding of detector performance and commissioning both for and using top samples**
    - **Study of high pT isolated electrons and muons**
    - **Calibration of jet energy scale from W ® jj**
    - **Measurement of missing E_T**
    - **Optimization and efficiency measurement for b-tagging**
    - **Triggering schemes and efficiency determinations**
  - **We must be ready for Day 1 (t-tbar production ~ 1 Hz @ 1E33!)**

- **Single top sensitivity to new physics**
  - **Existence of W', V+A, other anomalous couplings, …**

- **Impact of new physics on spin correlations**
  - **CP violation, models with extra dimensions, …**

Scope of ATLAS SM Group (M. Dobbs, LBNL)

- **Strong Coupling Constant**
- **QCD Dynamics**
- **Parton Density Functions**
- **Min. bias & Underlying Event**
- **W mass**
- **$\sin^2 \theta_W$**
- **tau physics**
- **triple gauge-boson couplings**
- **heavy ion collisions**

Standard Model Working Group

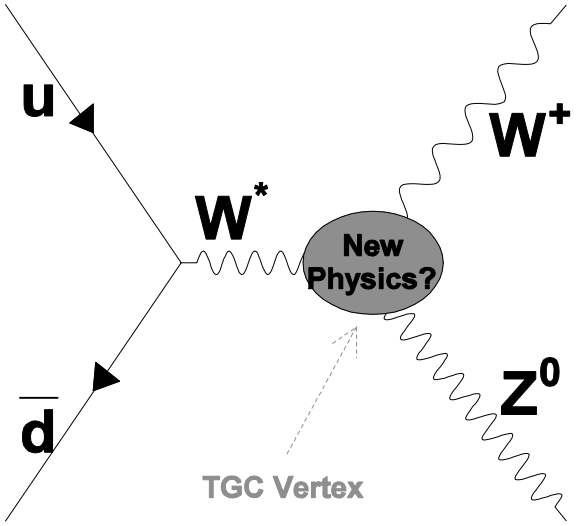
- born December 2001

- **encompasses all SM physics except:**
  - bottom
  - top
  - Higgs

  for which there are separate WG's.
- **nominally includes heavy ions**

Triple Gauge-Boson Couplings

- **TGC tests gauge structure of SM and provides sensitive probe for new physics at higher scale**
- **can measure charged TGC couplings through WZ, W? production**
- **Statistics will dominate LHC measurements (except for ? g_1)**
  - **sensitivity derived from a few events in the high $P_T(V)$ tail**



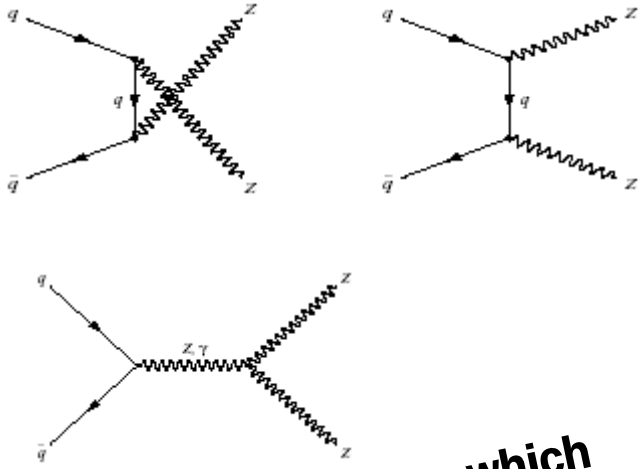
$-0.0035 < ?_? < +0.0035$
$-0.0073 < ?_Z < +0.0073$
$-0.075 < ? ?_? < +0.076$
$-0.11 < ? ?_Z < +0.12$
$-0.0086 < ? g^1_Z < 0.011$

95% Confidence Intervals
For 30 fb^{-1}, systematics included.

• typically factor 10 improvement over LEP/TeVatron

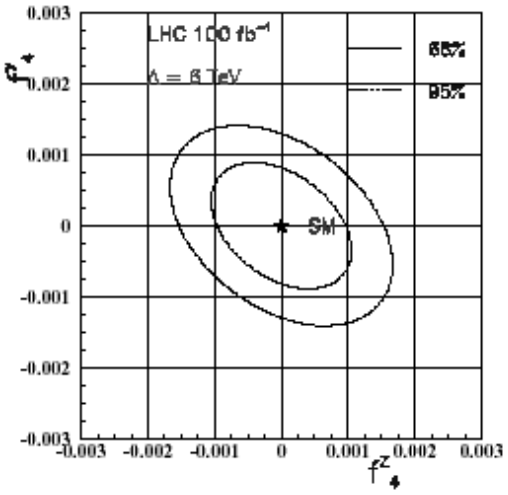
Triple Gauge-Boson Couplings (cont'd)

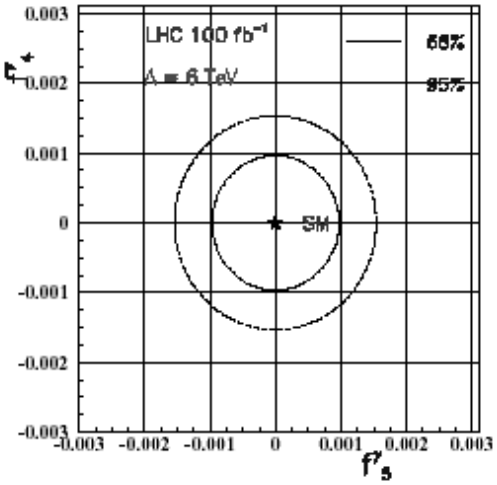
- **probe neutral couplings with ZZ, Z? production**

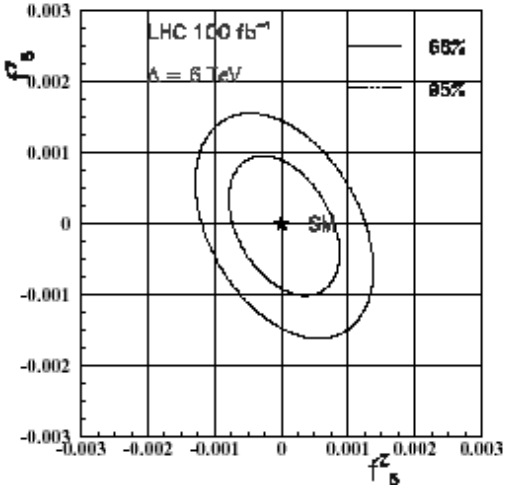


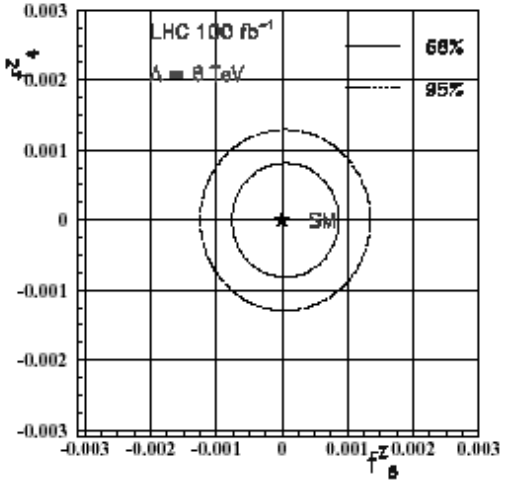
Test for this coupling which is Forbidden in the SM

- **factor 10^3 improvement over LEP limits**









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Precision EW: Measuring $\sin^2\theta_W$ with A_{FB}

- **$pp \rightarrow l^+l^-$ di-lepton signature is (almost) background free**
- **asymmetry arises from interference between neutral currents**
- **Statistical precision using 100 fb^{-1}, near Z-pole (±6GeV)**

Cuts	A_{FB} (%)	? A_{FB} (%)	? $\sin^2\theta_{eff}(M_Z)$
Both $e^{\pm}$, $\lvert\eta\rvert<2.5$	0.774	0.020	0.00066
One $e^{\pm}$, $\lvert\eta\rvert<2.5$ other $e^{\pm}$, $\lvert\eta\rvert<4.9$	1.98	0.018	0.00014

for comparison, ? $\sin^2\theta_{eff}$=0.00053 combining 4 **LEP** expts and e,μ,t channels [CERN-EP/2001-098]

- **Performance issue:**
  - **increasing forward lepton tagging acceptance greatly improves measurement**

  ➔ ***ideal study for persons involved with FCAL, or e/? performance group***

Precision EW: W Mass Measurement

- **60 million well measured W? *l*? events per low L year**

Source	CDF Run Ib	ATLAS	W? *l* ? , one lepton species
	30K evts, 84 pb^{-1}	60M evts, 10fb^{-1}	
Statistics	65 MeV	< 2 MeV	
Lepton scale	75 MeV	15 MeV	most serious challenge
Energy resolution	25 MeV	5 MeV	known to 1.5% from Z peak
Recoil model	33 MeV	5 MeV	scales with Z statistics
W width	10 MeV	7 MeV	?? $_{W}$~ 30 MeV (Run II)
PDF	15 MeV	10 MeV	LHC data further constrains
Radiative decays	20 MeV	<10 MeV	(improved Theory calc)
P_T(W)	45 MeV	5 MeV	P_T(Z) from data, P_T(W)/ P_T(Z) from theory
Background	5 MeV	5 MeV	
TOTAL	113 MeV	= 25 MeV	Per expt, per lepton species

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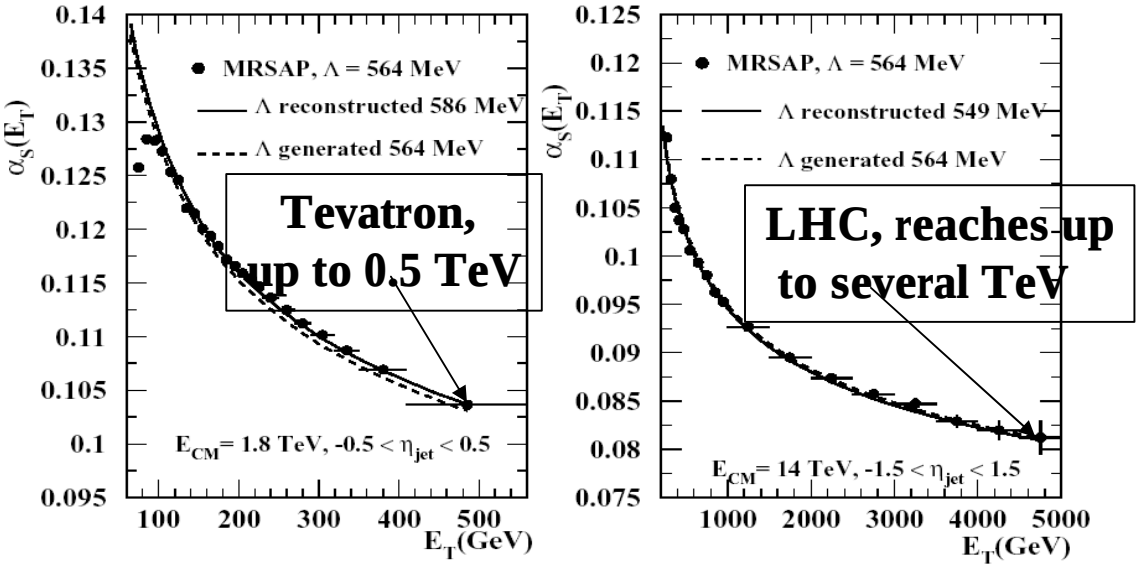
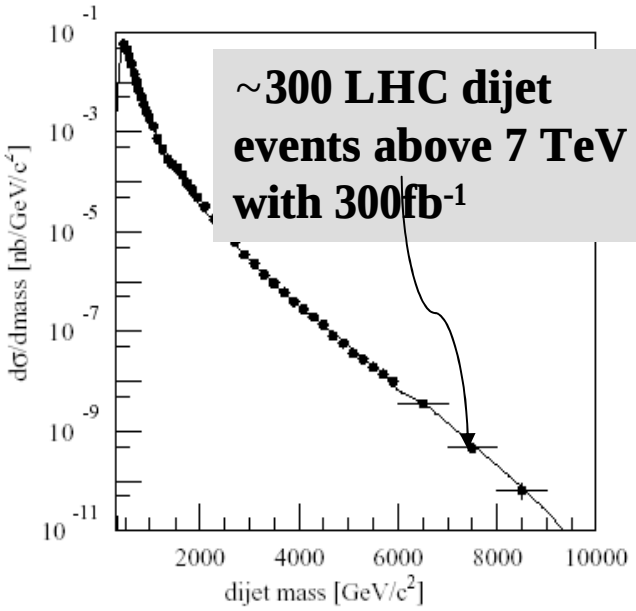
Some Examples of QCD Measurements

- LHC allows measurement to very large energy scales
- Can use, for example, to measure the running of the strong coupling constant over a wide range of scales
  - with the single inclusive jet cross section





- Other observables for measuring a_S have not yet been studied:
  - ratio of ?+jet to 2 jet production (Frixione)
  - ratio of 2 to 3 jet cross sections
  - ratio of W+1 jet to W+0 jet cross sections
  - jet shape observables

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Some Hot SM Topics for New Studies

- **ideal topics will have impact on performance issues and utilize Data Challenges.**
- **Some examples include:**
  - **Measuring Parton Density Functions**
    - **in particular the gluon**
  - **Measurement of the strong coupling constant**
    - **many channels not yet covered**
  - **W,Z production via vector boson fusion**
    - **performance issue: forward jet tagging (already much experience from Higgs group)**
    - **requires fancy Monte Carlos (Madison series)**
  - **Tau physics**
    - **Br(W→t ?)**
    - **limits on flavour violating t→μμμ, & t→μ ?**
  - **revisit $Z \rightarrow e^+e^-$, forward backward asymmetry**
    - **Performance issue: tagging of electrons in forward region**
    - **DC samples already requested.**

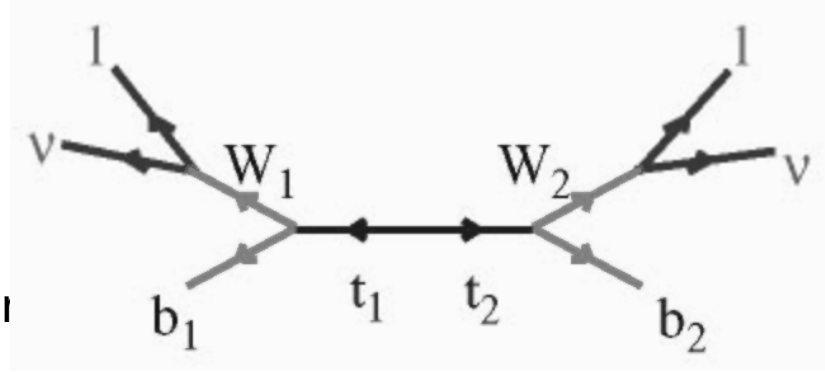
Summary and Conclusions

- **LHC will be a top quark factory**
  - **Studies of the top quark provide a sensitive window onto possible new physics beyond the SM**
- **SM measurements at the LHC will be extended in precision (eg. TGC) and into new kinematic regimes**
- **Some of the earliest ATLAS physics results, and earliest sensitivity to new physics, will come from top and SM physics**
  - **eg. can measure σ(t tbar) with stat. error < 10% with a few days of lumi**
- **Early top/SM signals will also be critical to commissioning the detector**
  - **Study of high pT isolated electrons and muons**
  - **Calibration of jet energy scale**
  - **Measurement of missing E_T**
  - **Optimization and efficiency measurement for b-tagging**
- **There is a lot of work to do, and volunteers are anxiously sought**
  - **Contact myself (top) or Matt Dobbs (SM) to get involved**

Backup Slides

Dilepton channel

- **Indirect measurement of m(t)**
- **For the TDR, correlations between some kinematical distributions (e.g.: m(lb) and m(t))**
- **Also, trying to reconstruct the** entir



- Selection:

  2 iso leptons, pT > 25, 35 GeV, |h| < 2.5

  EmissT > 40 GeV

  2 b-jets with pT > 25 GeV , |h| < 2.5

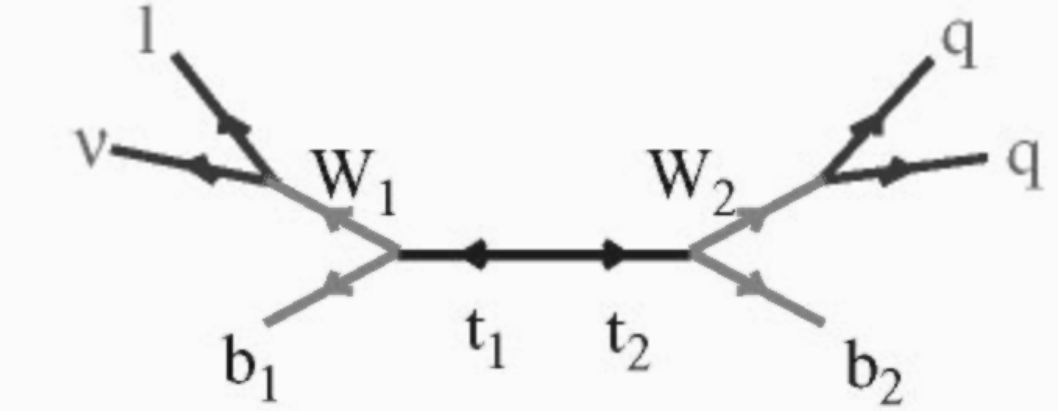
→ **80000 evts/year at low L, S/B =10**

- Background:

  Negligible

Single lepton channel

- **Clean sample, one top directly reconstructed**



- **Methods:**
  - **Hadronic part reconstruction**
  - **Kinematic fit of the entire event**
  - **Continuous jet definition**
  - **High pT top sample**

Single lepton channel

- Selection
  - 1 iso lepton, pT > 20 GeV, |η| < 2.5
  - pTmiss > 20 GeV
  - = 4 jets with pT > 40 GeV, |η| < 2.5
  - = 2 jets with b-tag

  - **Selection effic. = 5% Þ 126k events, with S/B ~65**

- **Reconstruct t ® Wb ® (jj)b**
  - **In ± 35 GeV window around m(top), have:**
    - **30k signal events**
    - **14k bkgnd events (dominated by "wrong combinations" from t-tbar events)**

❖ Reconstruction of the hadronic part

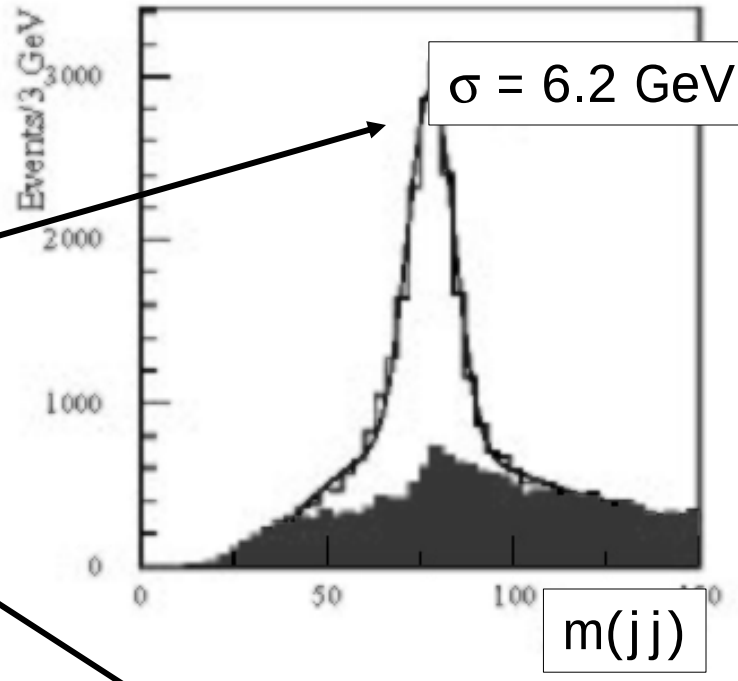
W from jet pair with the closest invariant mass to m(W)
Cut on $|m_{jj}-m_W| < 20$ GeV

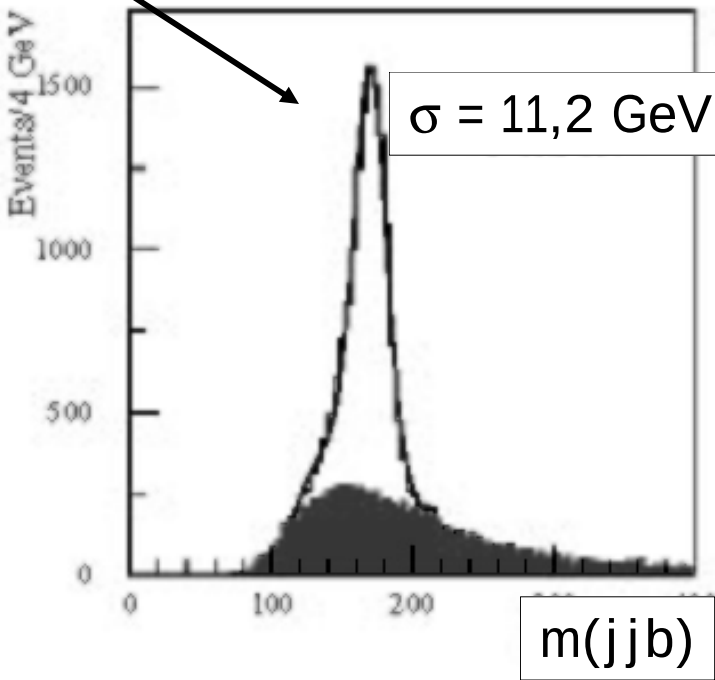
Association of W with a b-tagged jet
Cut on $|m_{jjb}-\langle m_{jjb}\rangle| < 20$ GeV

❖ Kinematic fit

Using remaining l+b-jet, the leptonic part is reconstructed
$|m_{l\nu b}-\langle m_{jjb}\rangle| < 35$ GeV

Kinematic fit to the ttbar hypothesis, with m(top) and m(W) constraints
Energy and direction of all objects (jets, l, ν) can vary within their resolution





Statistical Error

Period	tt events
1 year	**8×10^6**
1 month	**2×10^6**
1 week	**5×10^5**

In the **single lepton channel**, where we plan to measure m(top) with the best precision:

Period	evts	δM_{top}(stat)
1 year	**3×10^5**	**0.1 GeV**
1 month	**7.5×10^4**	**0.2 GeV**
1 week	**1.9×10^3**	**0.4 GeV**

$L = 1 \times 10^{33}\ cm^{-2}s^{-1}$

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