Strategies for top pair cross section measurements in ATLAS

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on behalf of the ATLAS top groups

Why precise cross section measurements?

General Strategies and Analyses

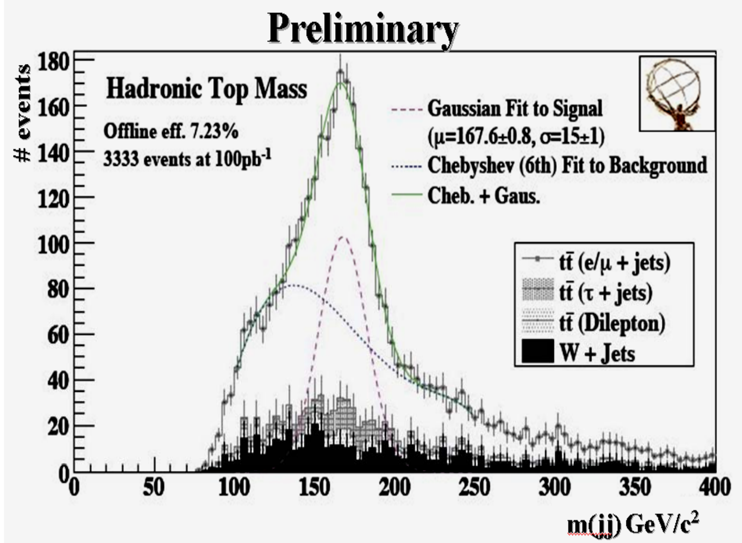
General Issues

Remarks

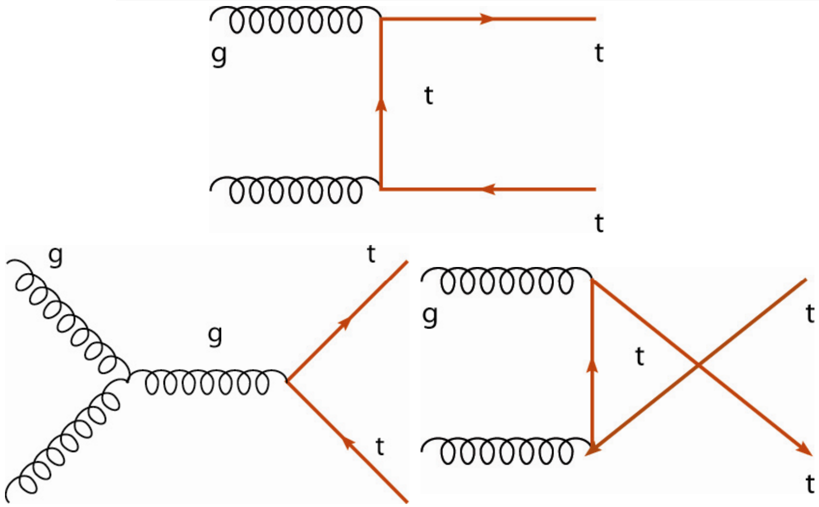
- All plots and results shown in this talk are preliminary
- The consolidation and finalizing of the results is ongoing right now
- Will see the definitive plots and results in the forthcoming CSC notes

Why precise cross section measurement?

- 1 $t\bar{t}$ pair per second, top peak visible after a few weeks
  - Theoretical prediction: NLO+NLL 833+52-39pb [Boniciani, Catani, Mangano, Nucl Phys B 529 (1998) 424-250]



- ~90% top pair production at LHC via gluons
  - Measurement would test QCD calculation, gluon pdfs



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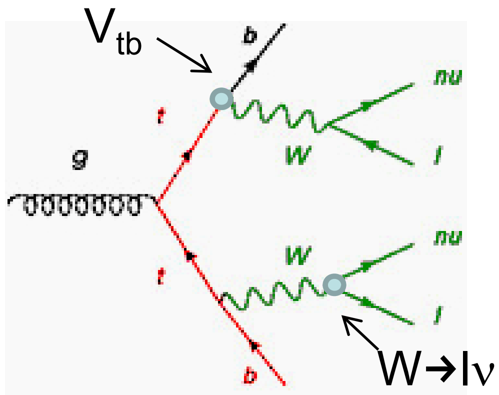
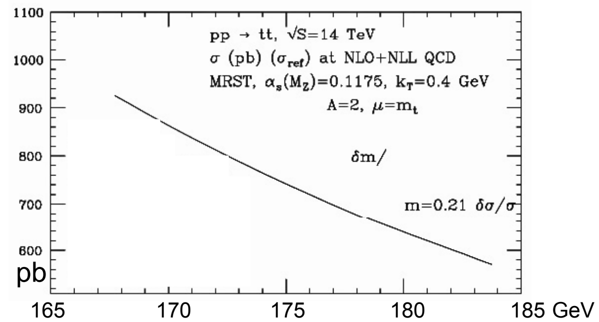
- Test of EW
  - Top quark decay (V_{tb}) of EW nature
  - W properties (BR $W \rightarrow l\nu$)
  - sensitivity on top mass



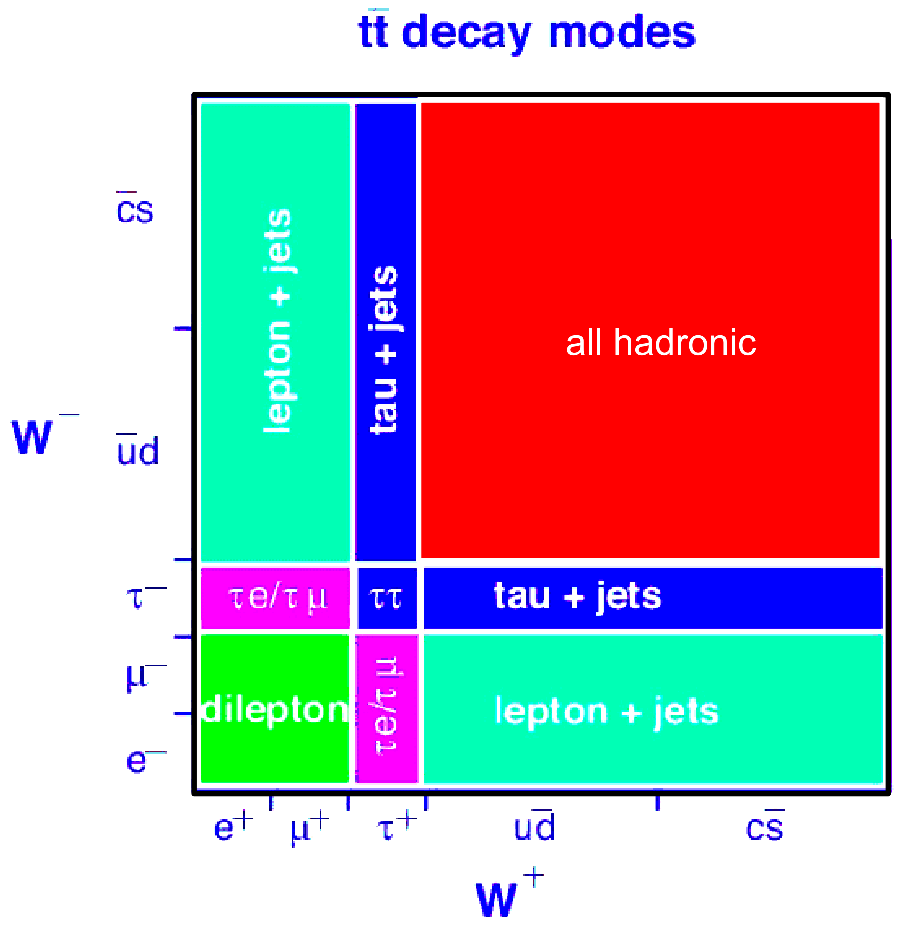
- New physics searches
  - $t \rightarrow H^{+}+b$, rare top decays
  - resonances $Z' \rightarrow t\bar{t}$
- Background to other analyses
  - Single Top, Higgs, SUSY



- Measurement of cross section can provide consistency test of SM and physics beyond SM

General strategies

- Measurement in different W decay modes:
  - all hadronic
    - 6-jet environment, most difficult
  - lepton+jets
    - golden channel
  - di-leptonic
    - cleanest selection possible
    - include leptonically decaying τ
    - exploit τ-tagging
  - different backgrounds, different systematic issues, use as consistency check
- with or without b-tagging
  - w/o b-tagging suitable for first measurements
  - with b-tagging purer selection at later stage



- different data amount aims
  - commissioning analysis, early data
    - also used for detector commissioning and calibration
  - first data analysis
    - without b-tagging, not perfect alignment
  - later stage analysis
    - make use of b-tagging
    - more statistics for rare decay channels (e.g. τ to leptons)
    - systematic error will dominate soon

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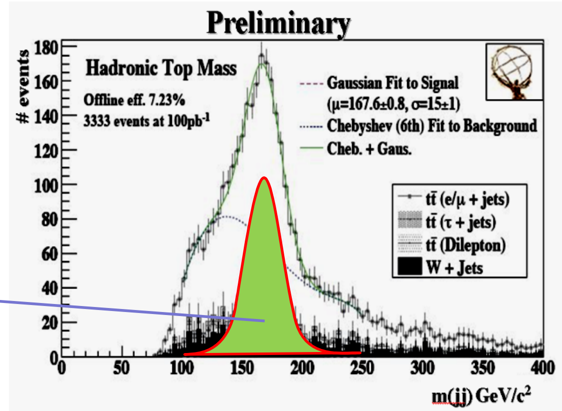
General strategies (II)

- direct measurement
  - cut and count
    - simple and powerful for first measurements



$$\sigma = \frac{N_{measured} - N_{background}}{A \cdot \varepsilon \cdot L}$$

    - selection from top mass measurement or use selection for fruther top property measurement
  - Likelihood methods
    - more sensitive to actual top events shapes (from MC)
  - Phase space resolved measurements
    - expect high statistics available for fine phase space binning, sensitive to new physics mimicking top decay events

Cut and count (I)

- lepton+jets channel: *B. Acharya et al.* INFN Udine, CERN
  - commissioning study, W+jets background only
  - MC divided into 1/3 "MC" and 2/3 "data"
  - efficiencies and acceptance determined by "MC"

Cuts
p_T(lepton) > 20 GeV
3 jets with p_T > 40 GeV
4^{th} jet with p_T > 20 GeV
η(lepton) < 2.5, η(jet) < 2.5
Missing E_T > 20 GeV
Top is reconstructed as the 3-jet comb.
Require m(2 of 3 jets) within 10 GeV of M_W

ε from MC	**N_{bkg} from MC**	**S+B from data**
2.7 %	1243.1	1418.0

Total BR	**Result for $100 pb^{-1}$**
5/9	820.4pb± 3.2%(stat) ± 11% (JES)

- lepton+jets channel: *A. Bangert et al.* MPI Munich
  - looking into the effect of different jet algorithms

Cut and count (II)

- di-lepton channel: *D.B Ta and J. Sjölin et al.* University of Bonn, University of Stockholm
  - $t\bar{t}$ lepton+jets, Z→ll and di-boson backgrounds
  - both group obtain comparable numbers

Cuts for best S/sqrt(S+B) ratio	
2 opposite charged, isolated leptons	
at least 2 jets	
p_T (leptons, jets) > 20 GeV, η(lepton, jets) < 2.5	
remove overlap of muons with jets	
ee / μμ veto on M(ll) 85GeV - 95GeV	
eμ:$E_{T,Miss}$>20 GeV	ee / μμ: $E_{T,Miss}$>35 GeV

<table>
<tr><th></th><th>efficiency</th><th>S/B</th><th>S/sqrt(S+B)</th></tr>
<tr><td>sig eμ</td><td>(5.76±0.8)%</td><td rowspan="2">13.01 ±0.60</td><td rowspan="2">22.13±0.03</td></tr>
<tr><td>bkg</td><td>(0.01±0.001)%</td></tr>
<tr><td>ee</td><td colspan="2">6.71 ±0.61</td><td>12.43±0.05</td></tr>
<tr><td>μμ</td><td colspan="2">5.16 ±0.57</td><td>14.60±0.04</td></tr>
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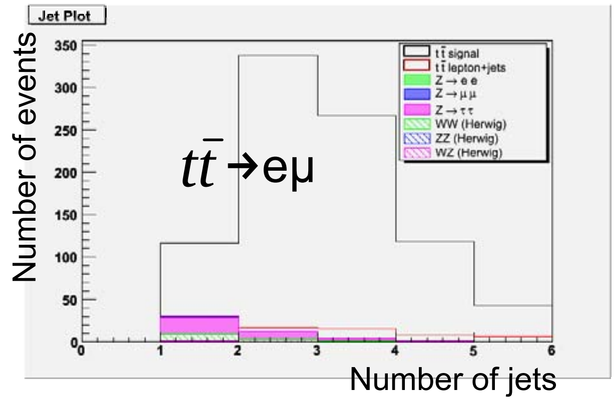
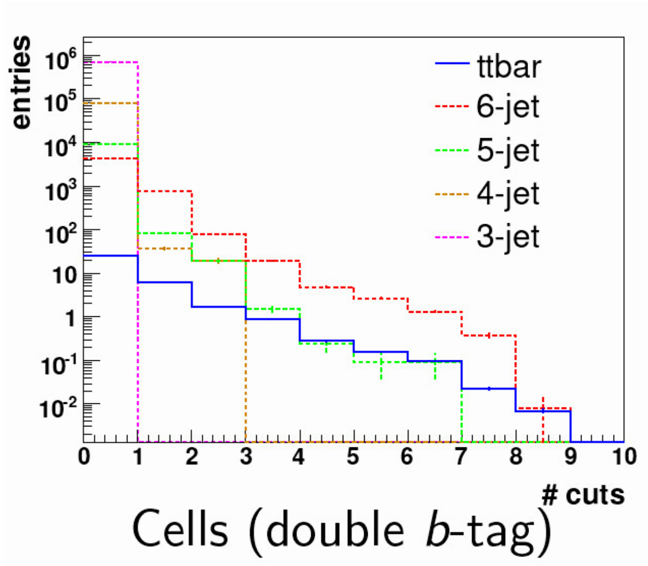
- expected relative error: $(\Delta\sigma/\sigma)^2$(eμ,100pb^{-1}) ~(4.4%)² (stat)



Cut and count (III)

- all hadronic channel: *M. Lambacher et al.* LMU Munich:
  - $t\bar{t}$ events generated with PYTHIA
  - main background QCD from ALPGEN (3,4,5,6+ fs partons)/PYTHIA
  - ATLFAST simulation study
  - S/B ~1/16, with b-tagging S/B ~1/1
  - Going towards likelihood measurements or neural network?

	Cuts
0	$\lvert\eta_{jets}\rvert < 3$
1	$N_{jets} == 6$
2	$p_T >$ 115,90,70,55,40,30 GeV
3	Σp_T (jets) > 140 GeV
4	75 GeV < m(jj) < 150 GeV
5	165 GeV < m (jjj) < 400 GeV
6	Σp_T (jjj) > 250 GeV
7	Aplanarity > 0.1
8	(double b-tag)



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Likelihood methods

$$Likelihood = -\sum_{i=1}^{N_{tot}} \ln(G(x_i \mid N_s, N_b)) + N_{tot}$$

- Multidimensional likelihood PDF $G(x_i \mid N_{signal}$ and $N_{background})$ with constraint on a fixed total number of events N_{tot}

- PDFs mostly obtained from MC, need trusted MC and high statistics
  - sensitive to certain signal and background shapes unlike cut and count

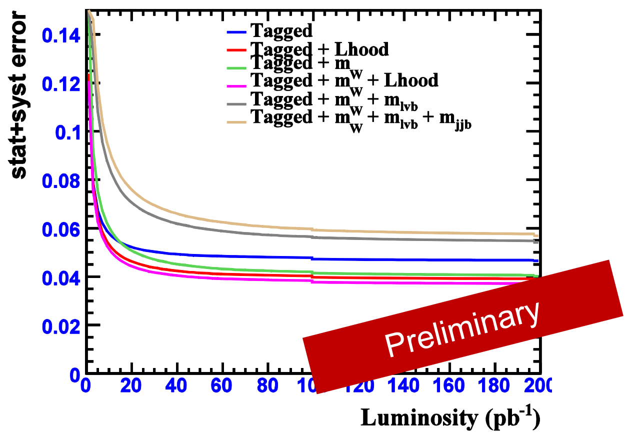
- Can fit more quantities (e.g. b-jet efficiencies) at the same time with sensible PDFs

Likelihood methods (II)

- lepton+jets channel: *F. Chevallier* LPSC Grenoble
  - Cross section extraction in 16 excusive channels
    - 1,2 b-tag, e or μ channel with 3,4,5,6+ jets

$$Likelihood = \prod_{16\,\text{channels}} P[N_{obs} \mid N_{pred}(\sigma_{t\bar{t}})]$$

  - select events with lepton+jets cuts
    - one isolated lepton p_T>20 GeV $|\eta|$<2.5, $E_{T,Miss}$ > 20 GeV
    - at least 2 jets p_T >30 GeV, $|\eta|$<2.5, at least1 b-tag p_T >40 GeV, $|\eta|$<2.5
    - Hadronic W: m(jj) = m_W ± 30 GeV, associate b-jet giving best m_{top}
    - Likelihood selection on topologcal variables
  - sensitivity of method:
    - m_{top} and luminosity uncertainties excluded



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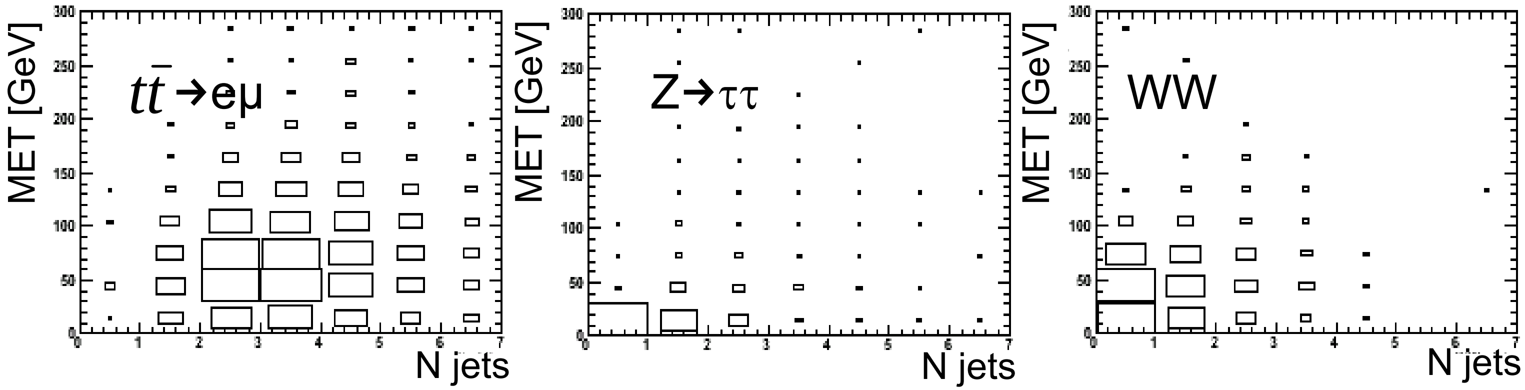
Likelihood methods (III)

- di-lepton channel: *J. Sjölin*, University of Stockholm
    - adopted from CDF method
    - backgrounds WW, $Z \rightarrow \tau\tau$
    - select di-lepton events:
        - $E_T(e) > 20$ GeV, $E_T(\mu) > 20$ GeV, Jets $E_T > 20$GeV (γ and τ are jets)
        - ee and $\mu\mu$ with MET/sqrt(ΣE_T)>2.5
    - binned fit in MET and number of jets space



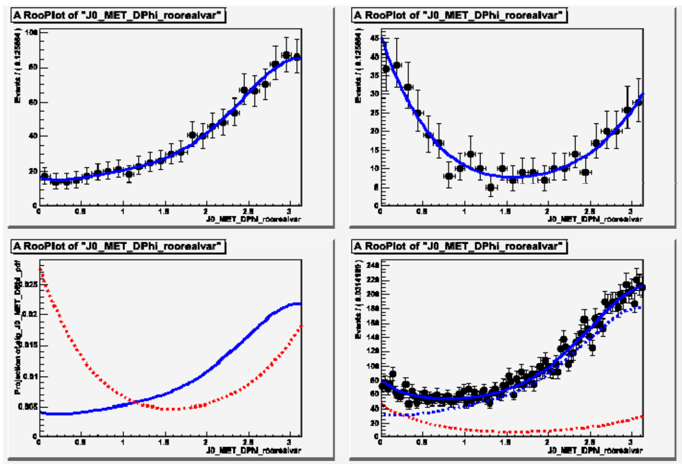
- uncertainties from pseudo experiments

Likelihood methods (IV)

- dilepton channel: *D.B. Ta et al.* University of Bonn
  - Selection of events with cut from the cut and count method
    - but have to include all channels due to limited MC statistics, MET>30 GeV
  - pdfs fitted to 5 good variables:
    - $|\Delta\phi|$ Lepton0 MET, $|\Delta\phi|$ Lepton1 MET, $|\Delta\phi|$ Jet0 MET, $|\Sigma\eta|$ Leptons, $|\Delta\phi|$ Leptons
  - Sensitivity with pseudo experiments and different S/B fractions:

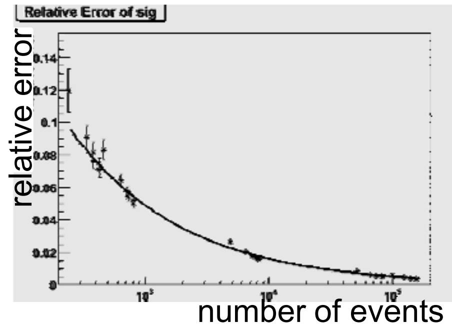
Example:
$|\Delta\phi|$ Jet0 MET

Normalized pdf-fit
→ fit and sum gives G



S/B 5:1 mix
and random data
from pdfs

Sensitivity (statistical error only):



$\Delta sig_{rel}(N)=\exp(a)\, N^{-b}$
$a=0.32\pm0.02$
$b=0.483\pm0.002$

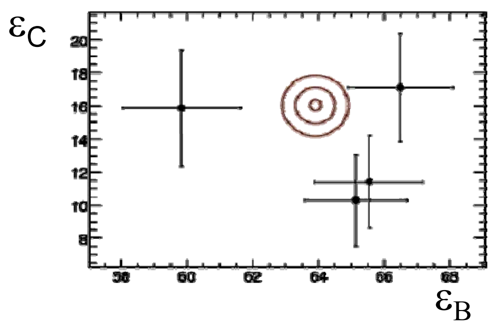
Likelihood methods (V)

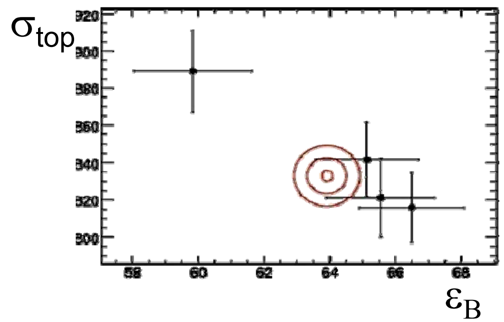
- lepton+jets and di-lepton channel: *H. Bachacou et al.* Saclay
  - simultaneous fit of ε(b-jet), ε(c-jet), N_{sig}
  - count number of events with 0,1,2,3 tagged jets
  - assume BR(t→Wb)=1 and ε(light jets)=0.01

$$< N_n >=$$
$$(L\cdot\sigma_{t\bar{t}}\cdot A_{pre-tag})\cdot\Sigma_{i,j,k}F_{i,j,k}\Sigma_{combi.}A_i^{i'}\cdot\epsilon_b^{i'}\cdot(1-\epsilon_b)^{i-i'}\cdot A_j^{j'}\cdot\epsilon_c^{j'}\cdot(1-\epsilon_c)^{j-j'}\cdot A_k^{k'}\cdot\epsilon_l^{k'}\cdot(1-\epsilon_l)^{k-k'}$$

  - select events:
    - one isol. lepton |η|<2.5, p_T>20 GeV, $E_{T,Miss}$>20 GeV
    - at least 4 jets E_T >40 GeV, |η|<2.5, b-tag weight > 6.5

mean uncertainty
for 4 subsamples
of 100pb^{-1}
ε_b 2%
ε_c 3%
σ_{top} 21pb





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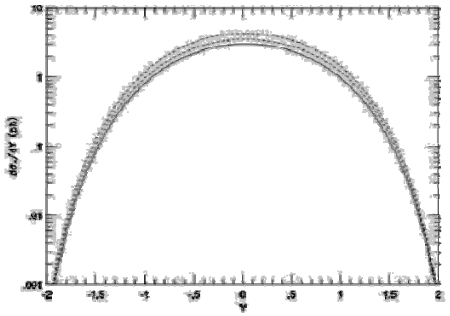
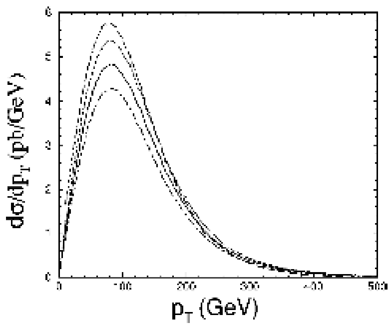
Phase space resolved cross section

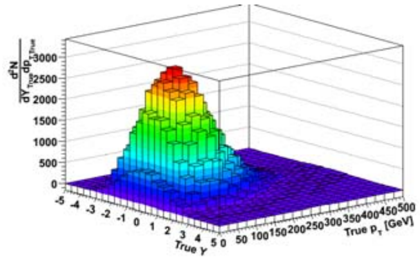
- lepton+jets channel: *M. Bunse et al.* University of Dortmund
  - assumed bin-size of 0.2x20GeV in $|\eta|<3$ and $p_T < 250$ GeV
    one has 375 phase space cells
  - for Tevatron only ~130 events/cell, LHC: ~21.000 events/cell

Theory

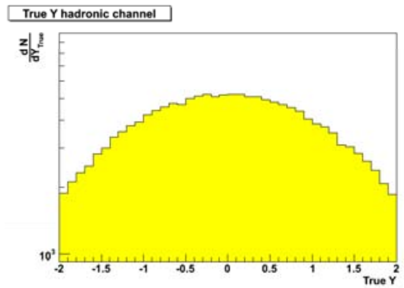


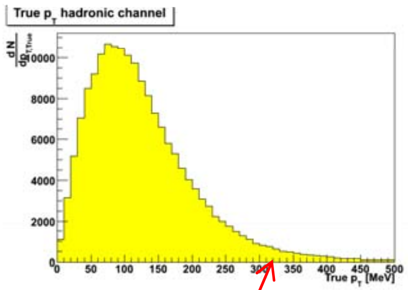


Top from truth

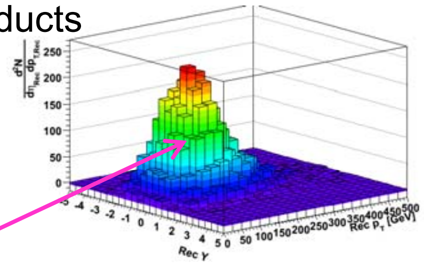


True events





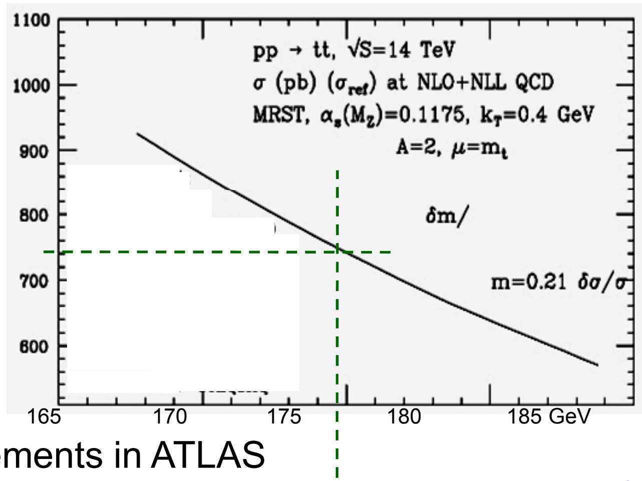
Top from reconstructed decay products



- regions with small statistics
- understand top from reconstructed events

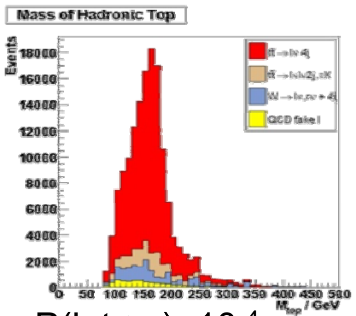
General strategies (III)

- cross section ratios
  - common uncertainties on *L*, higher order effects, PDFs etc. cancel out
- in streaming test data
  - testing different data stream modes (incl./exclu.)
  - 18pb^{-1} (~30 min @10^{33} ,3.6 Mevents) in 10 runs with different L
  - streaming test data as if real data (SM mix, no truth)
  - ideal for cross section exercise, test of “from data methods”: cross section ratio Z->ll/ttbar, lepton efficiencies from Z->ll
- Top mass vs. cross section
  - no one looked into that $\Delta m/m \sim 0.21 \Delta\sigma/\sigma$

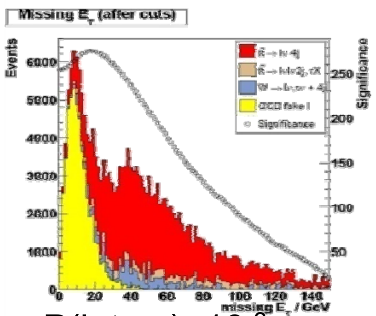


Cross section ratios

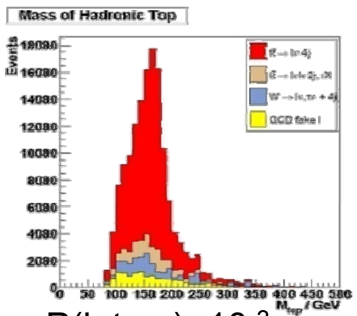
- cross section ratio lepton+jets and di-lepton channel: *R.Mameghani et al.* LMU Munich
    - focus on effect of fake rate
    - lepton+jets with QCD background and assumed fake rate jet→e



P(jet→e)=10^{-4}
MET>0 GeV



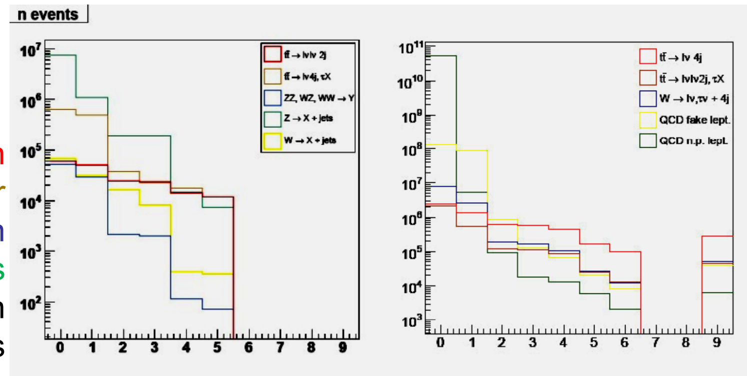
P(jet→e)=10^{-3}



P(jet→e)=10^{-3}
MET>30 GeV

- cut flow for both analysis with same fake electron rates 10^{-4}

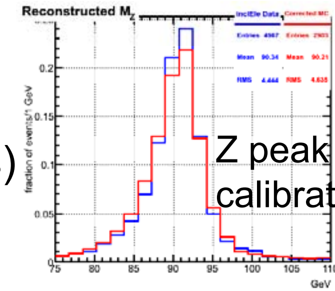
ttbar dilepton
other ttbar
diboson
Z+jets
yellow: W+jets with fake electrons



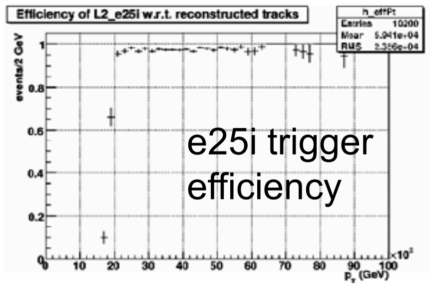
ttbar l+jets
other ttbar
QCD non prompt
yellow: QCD, fake

Streaming test analysis

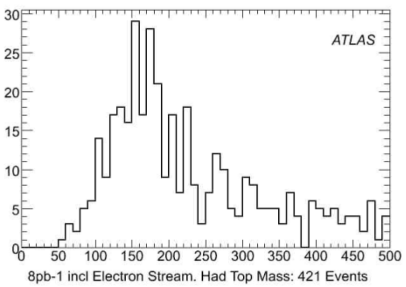
- streaming test data analysis: *A. Holloway, M. Shapiro et al.* LBL, *B. Acharya et al.* INFN Udine
  - Original CDF top discovery analysis in electron+jets
    - use tag and probe Z→ee (efficiencies/energy corrections)
    - measure W+0,1jet→e and predict W+4jet numbers, compare with data, interpret excess as top
    - $\sigma = (N(W+\geq 4)_{stream} - N_{W+4jets\ predicted})/(L_{stream}\ \varepsilon_{Trig}\ (A^{*}\varepsilon)_{reco})$
    - $\sigma = 941 \pm 96$ (stat) pb
    - in principle works on “data” !
  - similar method with Z+4,5jets events
    - also using three jet mass



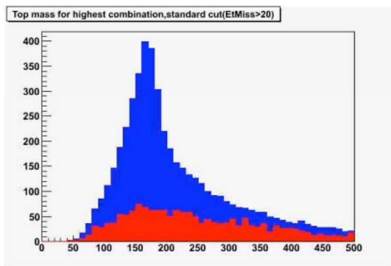
Z peak after calibration



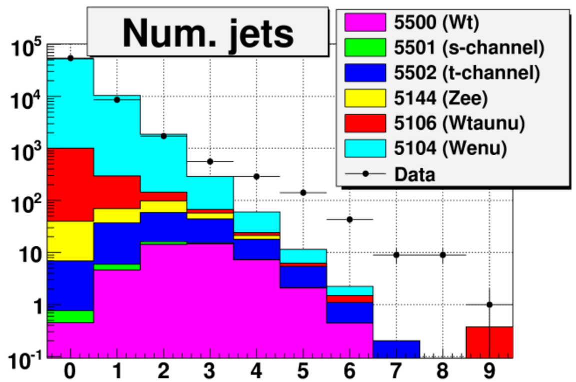
e25i trigger efficiency



in streaming test data



in MC data



General issues

- Obvious systematics
  - trigger evaluation
  - PDF uncertainties
  - ISR/FSR variation

- Main issue: additional leptons
  - hard to estimate from MC
    - from QCD background, from W+jets background
    - detector effects leading to fake leptons
    - non-prompt leptons from b-decay
  - a lot of work is put into developing determination methods
  - also need real data

Summary

- ATLAS analyses make use of many methods
  - cut and count
  - likelihood
  - phase space resolved cross section
  - cross section ratios
  - relative cross section measurement to standard candles / (efficiencies from) in streaming test data
- Measurement of the cross section gives a good understanding on selecting top events
  - need knowledge to reject the main background for new physics
- Analyses will give final results soon in CSC note: **“T6:Top Cross Section”**