Top Quark Mass Measurement using Lepton Transverse Momenta at ATLAS

BND School 2009

Jan A. Stillings

Physikalisches Institut
Rheinische Friedrich-Wilhelms-Universität Bonn

2009-09-21

universitätbonn

Outline

Top Mass Measurement

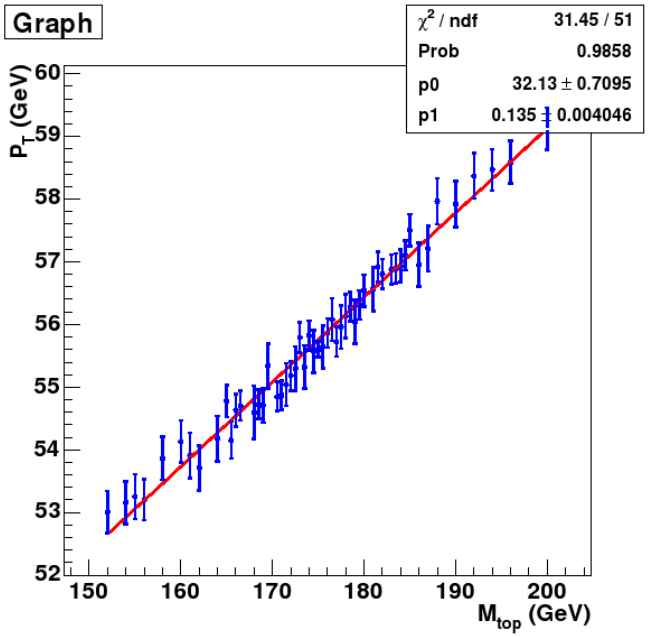


FIG. 1: Mean P_T vs Top Mass from signal only P_T distributions

Plot: Tevatron

$$M_t = 173.5^{+8.9}_{-9.1}(stat) \pm 4.2(syst)\ \text{GeV}$$

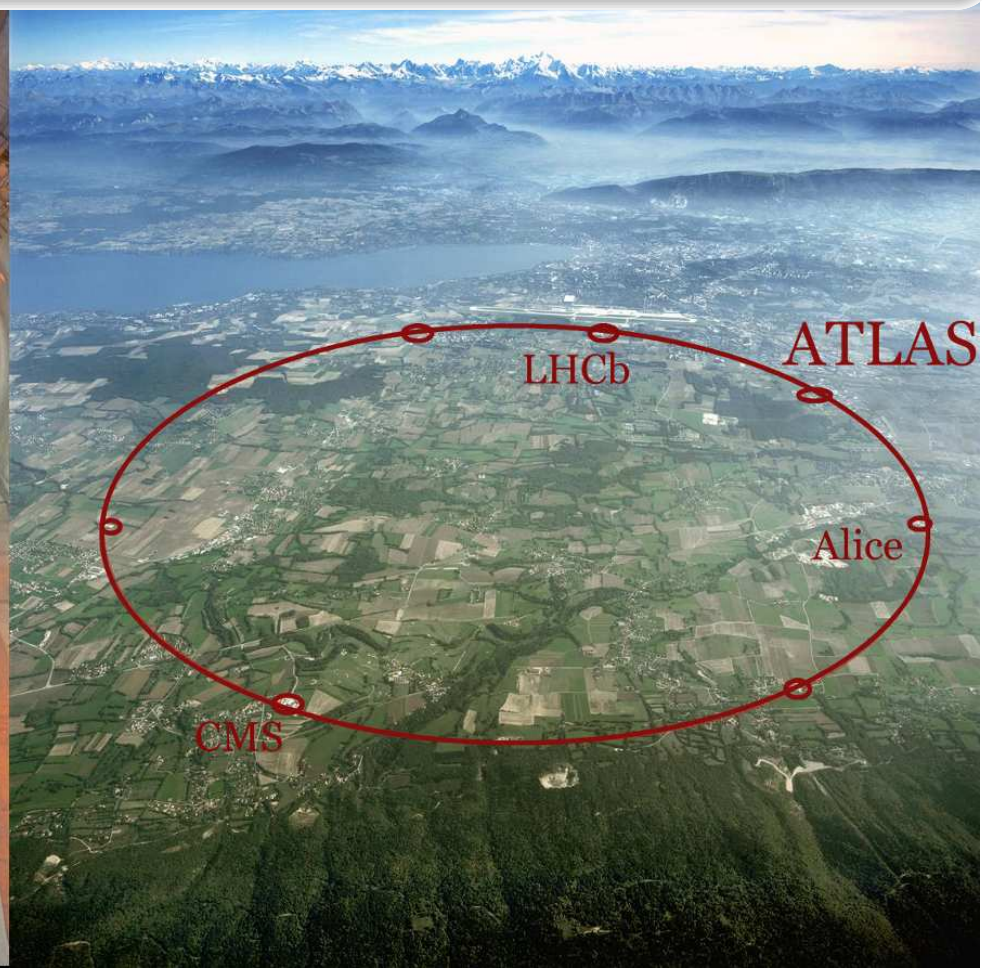
Motivation

- Prove suitability of Tevatron method for ATLAS
- Lepton mean transverse momentum ($\langle p_T \rangle$) linearly dependent on M_t
- Low impact of jet energy scale uncertainty
  $\Rightarrow$ Good method for first years of running

Experiment

LHC - First Run

$E_{\mathrm{CM}} = 7 - 10$ TeV (p-p) Target Luminosity: $\int \mathcal{L}\, \mathrm{d}t = 200\ \mathrm{pb}^{-1}$



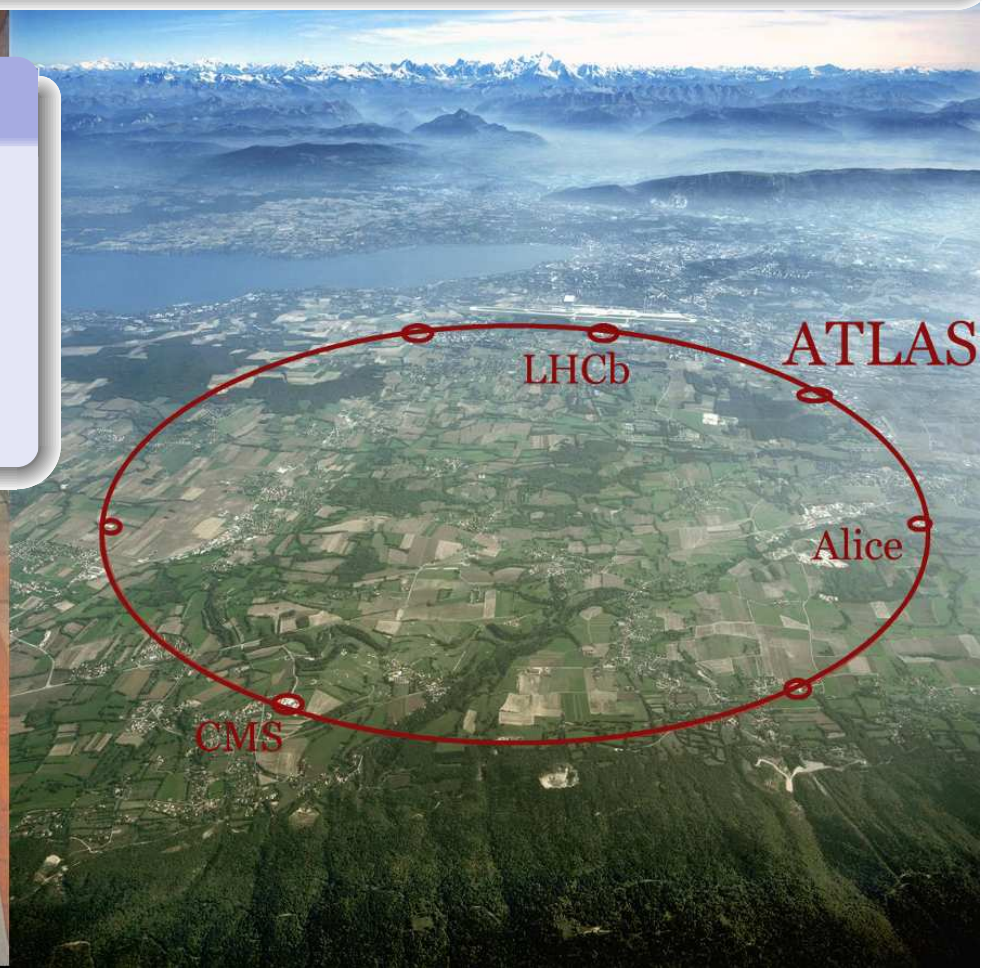
Experiment

LHC - First Run

$E_{CM} = 7 - 10$ TeV (p-p) Target Luminosity: $\int \mathcal{L}\, dt = 200\ \text{pb}^{-1}$

Signal Channel

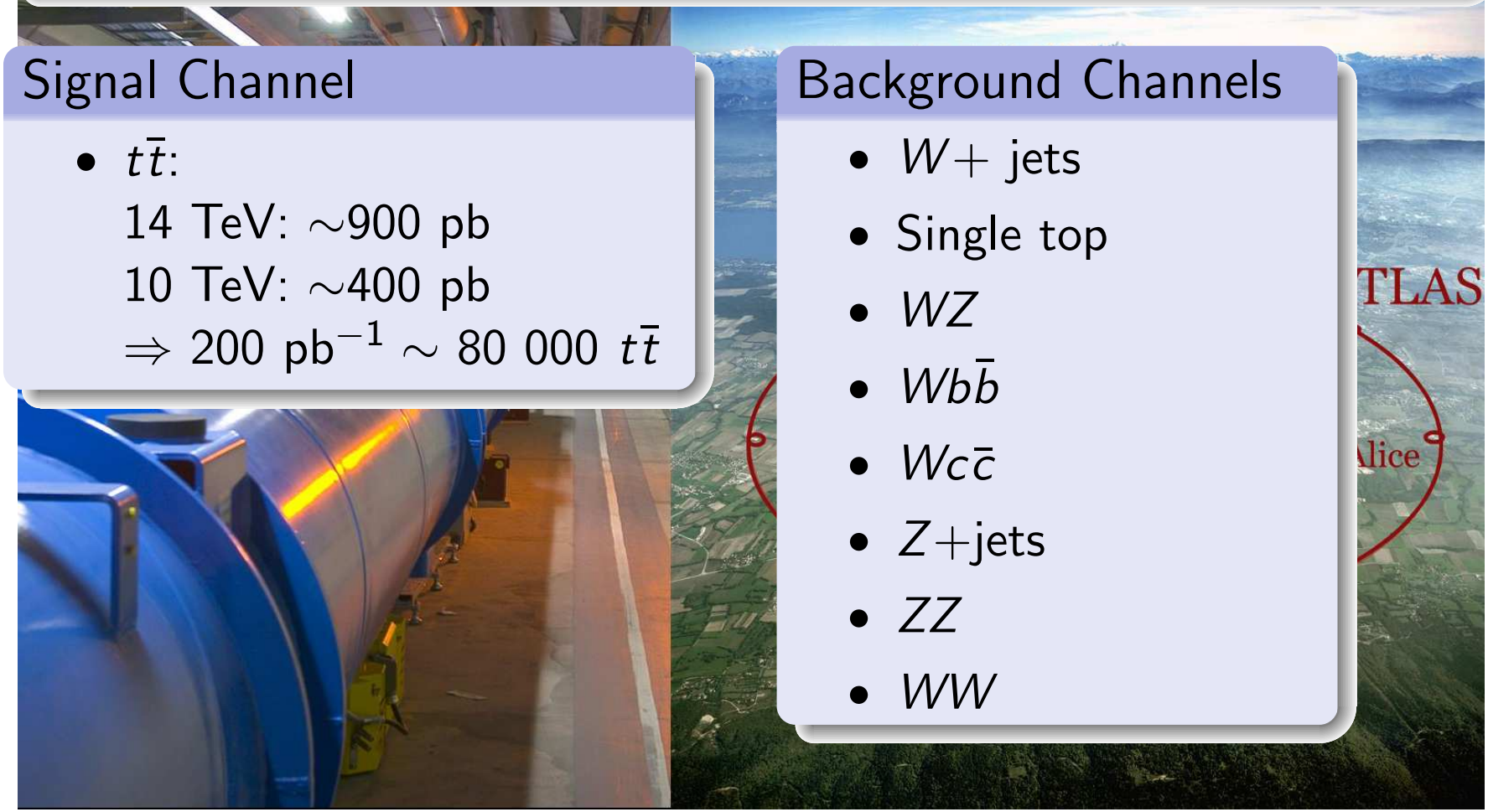
- $t\bar{t}$:
  14 TeV: ∼900 pb
  10 TeV: ∼400 pb
  $\Rightarrow$ 200 $\text{pb}^{-1} \sim$ 80 000 $t\bar{t}$



Experiment

LHC - First Run

$E_{CM} = 7 - 10$ TeV (p-p) Target Luminosity: $\int \mathcal{L}\, dt = 200\ \text{pb}^{-1}$



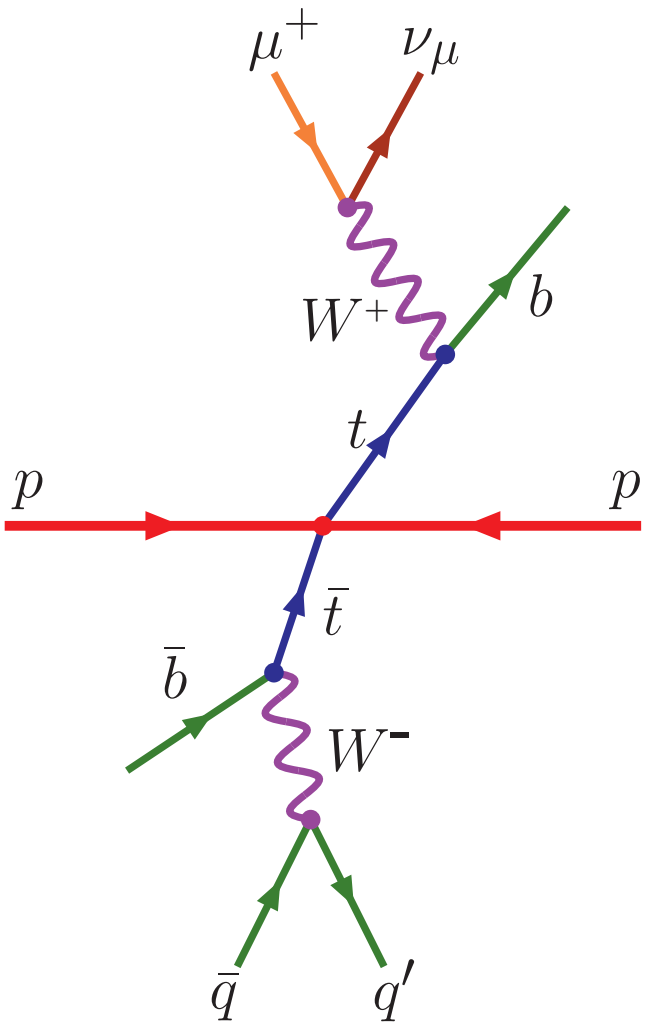
Signal Channel

- $t\bar{t}$:
  14 TeV: ∼900 pb
  10 TeV: ∼400 pb
  $\Rightarrow 200\ \text{pb}^{-1} \sim 80\,000\ t\bar{t}$

Background Channels

- $W+$ jets
- Single top
- WZ
- $Wb\bar{b}$
- $Wc\bar{c}$
- $Z+$jets
- ZZ
- WW

Dileptonic and Lepton + Jets Top Quark Decay



Branching Ratios

$t\bar{t} \to \ell\nu\ell\nu$	11 %
$t\bar{t} \to \ell\nu q\bar{q}$	45 %
$t\bar{t} \to q\bar{q}q\bar{q}$	45 %

This analysis

- $\ell = e, \mu$ (no τ)
- Dileptonic channel
  $t\bar{t} \to \ell\nu\ell\nu$ | 5%
- Lepton + jets channel
  $t\bar{t} \to \ell\nu q\bar{q}$ |30%

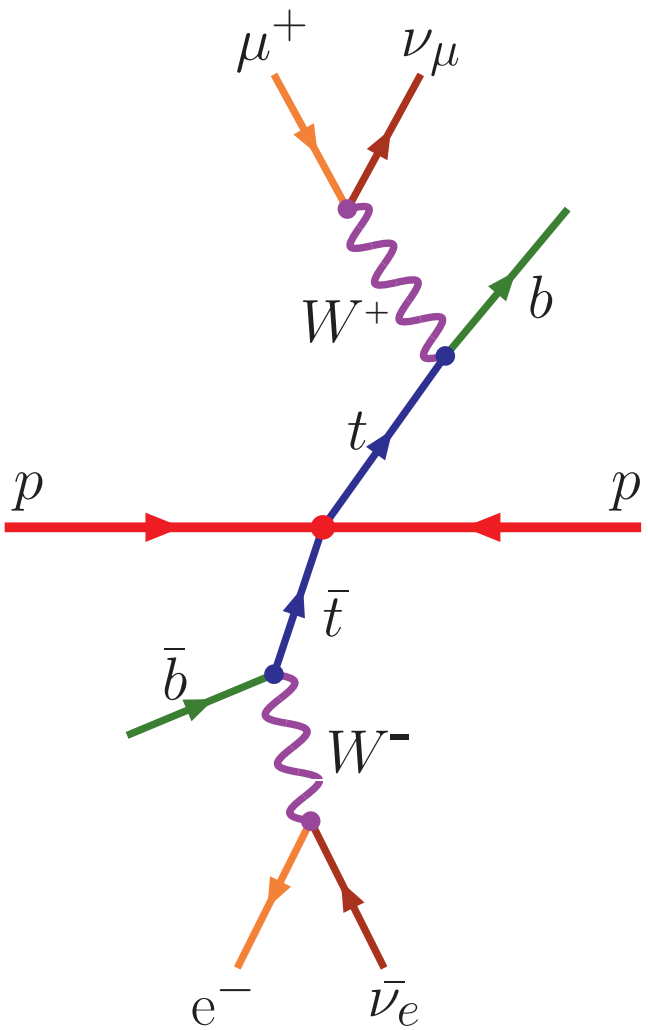
Monte Carlo Samples

- Monte Carlo Samples from official ATLAS production
- $t\bar{t}$ events generated for $E_{CM} = 10$ TeV, not all-hadronic
- Four sets of 60 000 events for $M_t = 160, 170, 180, 190$ GeV
- One set of 500 000 events for $M_t = 172.5$ GeV

Production Details

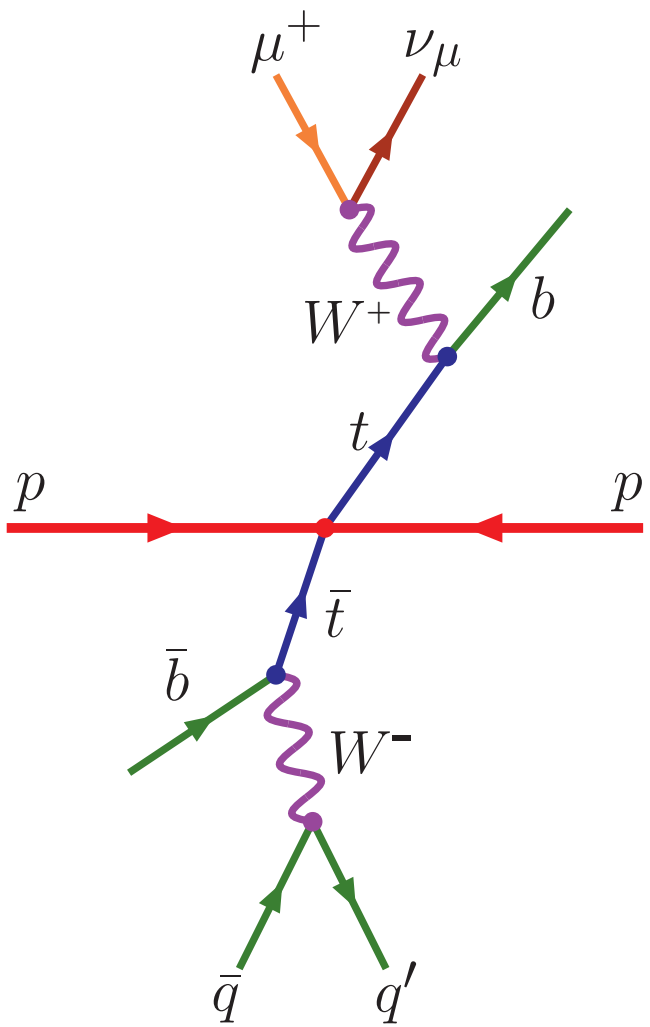
- Event generation:
  - MC@NLO: Hard process events from p-p-collisions
  - JIMMY: Multiple parton scattering
  - HERWIG: ISR, FSR, hadronisation, decays
  - TAUOLA: τ decays including spin polarization
  - PHOTOS: QED bremsstrahlung corrections
- Fast detector simulation (Atlfast II)

Dileptonic Selection



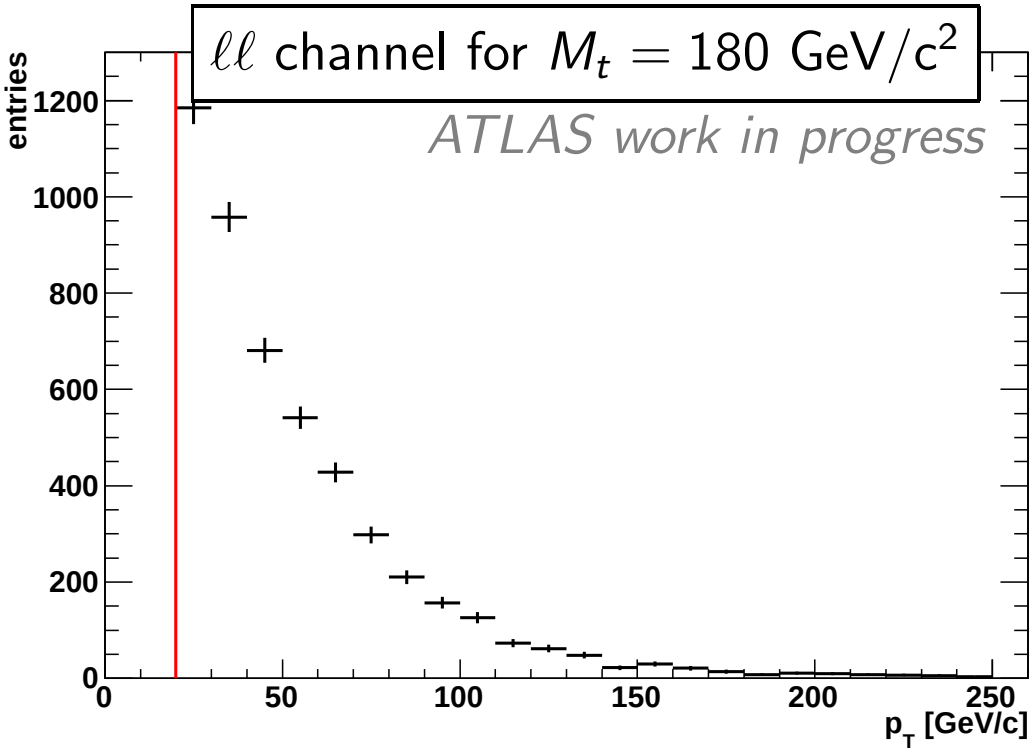
- $E_T^{miss} > 30$ GeV
- At least 2 leptons
  - ATLAS standard e, μ definition
  - $p_T^\ell > 20$ GeV
  - $|\eta^\ell| < 2.5$
- Opposite charged lepton pair with highest p_T

Lepton + Jets Selection



- $E_T^{miss} > 20$ GeV
- Only 1 lepton
  - ATLAS standard e, μ definition
  - $p_T^\ell > 20$ GeV
  - $|\eta^\ell| < 2.5$
- At least 4 jets $p_T^j > 20$ GeV
  - 3 jets with $p_T^j > 40$ GeV

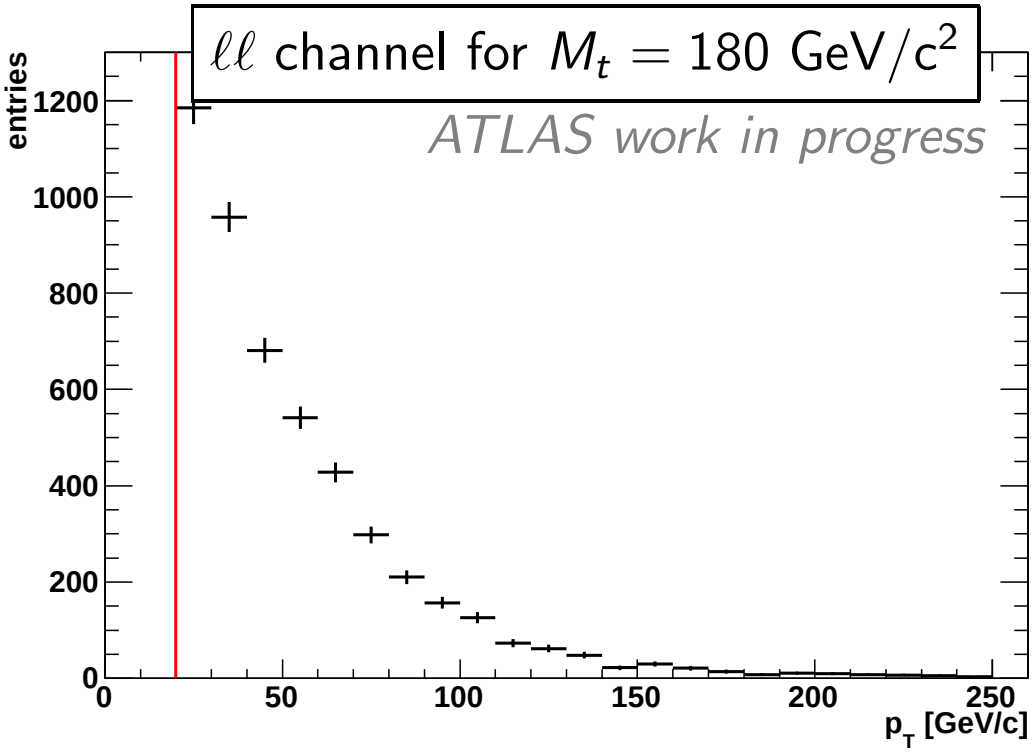
Top Mass Measurement



Analysis Variants

1. Linear fit of mean p_T^ℓ ($\langle p_T^\ell \rangle$)
2. Linear fit of median p_T^ℓ ($\tilde{p}_T^\ell$)
3. Shape fits of p_T^ℓ spectra

Top Mass Measurement



Analysis Variants

1. Linear fit of mean p_T^ℓ ($\langle p_T^\ell \rangle$)
2. Linear fit of median p_T^ℓ ($\tilde{p}_T^\ell$)
3. Shape fits of p_T^ℓ spectra

Linear Fit of Mean p_T^ℓ

Method description

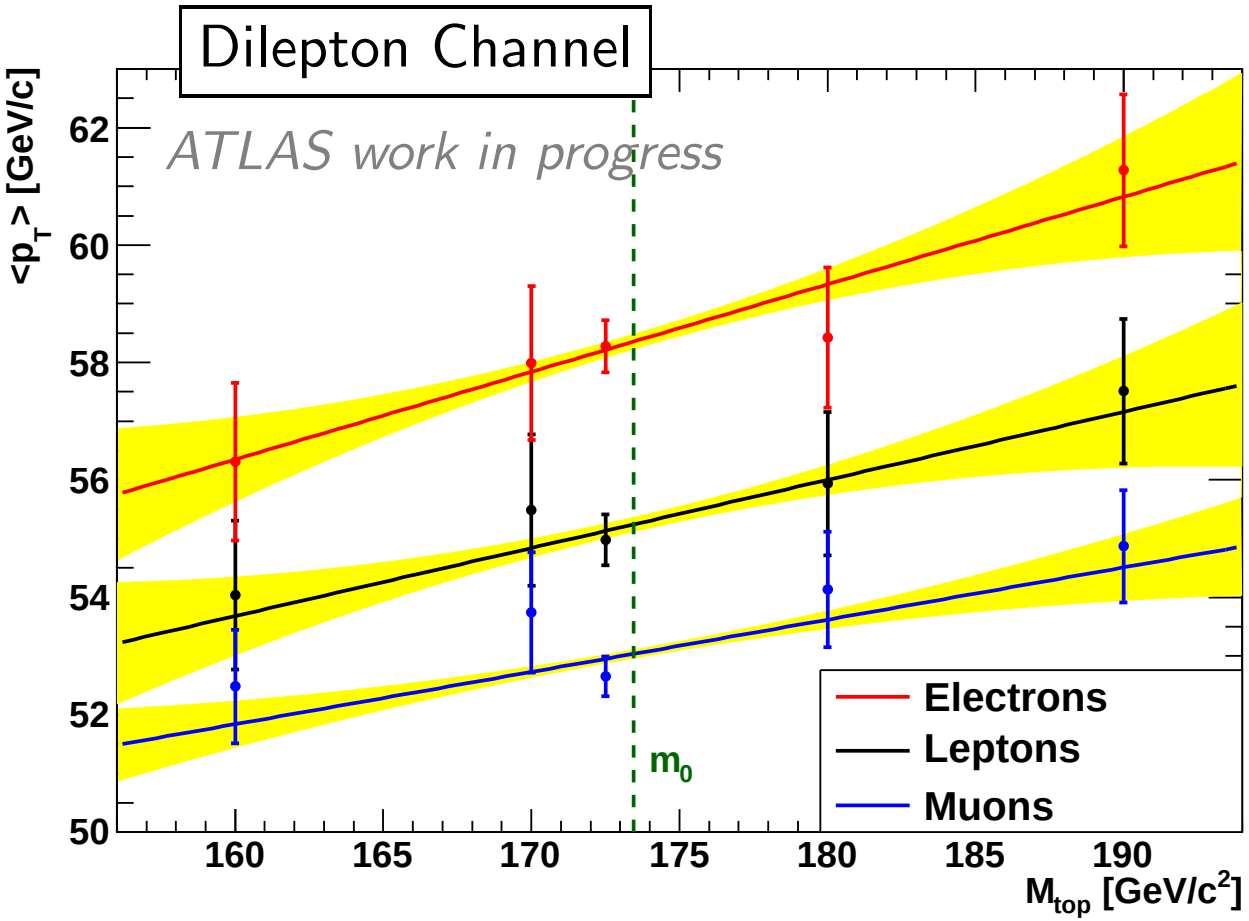
- Calculate $\langle p_T^\ell \rangle$ for each top quark mass
  - Independent calculation for electrons and muons
  - Error calculation including MC weights
- Plot $\langle p_T^\ell \rangle$ over M_t
- Linear fit of resulting graph with shift to centre-of-gravity (m_0)
  $\Rightarrow$ fit parameters κ, λ

Application

- Measure $\langle p_T^\ell \rangle$ from data and calculate the mass:

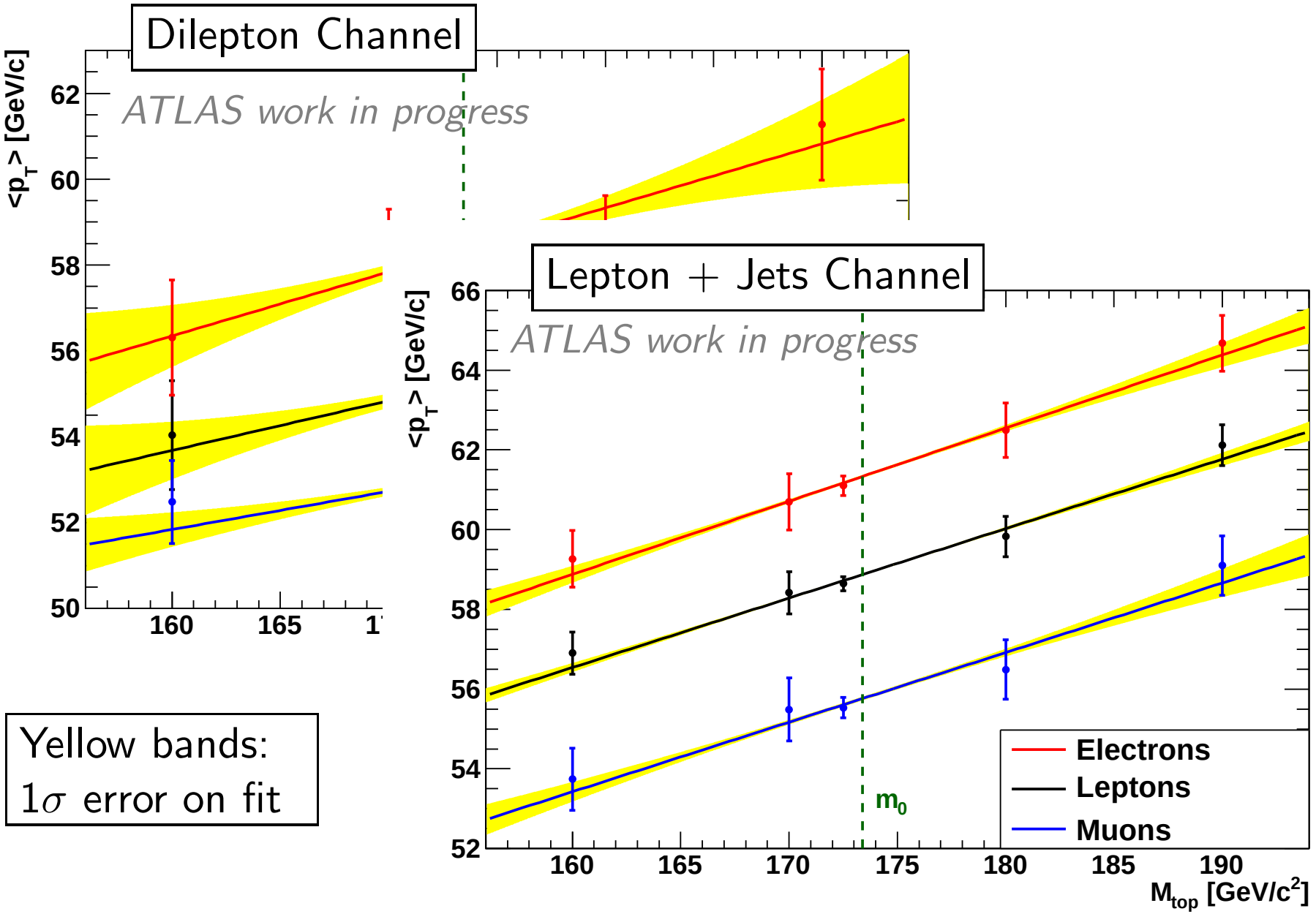
$$M_t = \frac{\langle p_T^\ell \rangle_{data} - \kappa}{\lambda} + m_0$$

Linear Fit of $\langle p_T^{\ell} \rangle$



Yellow bands:
1σ error on fit

Linear Fit of $\langle p_T^{\ell} \rangle$



Yellow bands:
1σ error on fit

Linear Fitting Results

$\langle p_T^\ell \rangle$ results

	Dilepton Channel		Lepton+Jets Channel	
	Slope (λ) [c]	Intercept (κ) [GeV/c^2]	Slope (λ) [c]	Intercept (κ) [GeV/c^2]
$\ell^\pm$	0.116 ± 0.055	55.24 ± 0.36	0.174 ± 0.023	58.87 ± 0.14
$e^\pm$	0.149 ± 0.057	58.35 ± 0.36	0.183 ± 0.031	61.33 ± 0.20
$\mu^\pm$	0.089 ± 0.042	53.04 ± 0.28	0.174 ± 0.033	55.76 ± 0.22

Linear Fit of $\tilde{p_T}$

- Calculate $\tilde{p_T}$ for each top quark mass similar to $\langle p_T^\ell \rangle$
- Apply proper error calculation for median value:

$$\Delta \tilde{p}_T^\ell = (a - b)/\sqrt{12}.$$

The values of a and b are equivalent to the value of the sorted list element at the positions

$$\left(\frac{n}{2} + \frac{\sqrt{3n}}{2}\right) \text{ for } a \qquad \text{and} \qquad \left(\frac{n}{2} - \frac{\sqrt{3n}}{2}\right) \text{ for } b,$$

where n is the total sum of the weights of all leptons in the sample.

Linear Fitting Results

$\langle p_T^\ell \rangle$ results

	Dilepton Channel		Lepton+Jets Channel	
	Slope (λ) [c]	Intercept (κ) [GeV/c^2]	Slope (λ) [c]	Intercept (κ) [GeV/c^2]
$\ell^\pm$	0.116 ± 0.055	55.24 ± 0.36	0.174 ± 0.023	58.87 ± 0.14
$e^\pm$	0.149 ± 0.057	58.35 ± 0.36	0.183 ± 0.031	61.33 ± 0.20
$\mu^\pm$	0.089 ± 0.042	53.04 ± 0.28	0.174 ± 0.033	55.76 ± 0.22

$\tilde{p}_T^\ell$ results

	Dilepton Channel		lepton+jets Channel	
	Slope (λ) [c]	Intercept (κ) [GeV/c^2]	Slope (λ) [c]	Intercept (κ) [GeV/c^2]
$\ell^\pm$	0.09 ± 0.02	44.69 ± 0.14	0.109 ± 0.016	48.70 ± 0.10
$e^\pm$	0.15 ± 0.03	47.88 ± 0.25	0.132 ± 0.017	51.54 ± 0.12
$\mu^\pm$	0.07 ± 0.03	42.64 ± 0.17	0.085 ± 0.018	45.06 ± 0.13

Linear Fit: Precision and Variant

Estimation of precision

- First measuring period: 200 pb^{-1} of data
- High statistics MC sample: 1658 pb^{-1} at $M_t = 172.5\ \text{GeV}/c^2$
- Propagation of MC error to data (l+j channel):

$$\Delta \langle p_T^\ell \rangle_{data} = 0.51\,\text{GeV}/c \qquad \Delta(\tilde{p}_T^\ell)_{data} = 0.33\,\text{GeV}/c$$

- Propagate error to mass uncertainty:
  Using mean values:

$$\begin{aligned} \Delta M_t &\approx 11.4\,\text{GeV}/c^2 && \text{dileptonic decays} \\ \Delta M_t &\approx 3.1\,\text{GeV}/c^2 && \text{lepton + jets decays} \end{aligned}$$

  Using median values:

$$\begin{aligned} \Delta M_t &\approx 5.6\,\text{GeV}/c^2 && \text{dileptonic decays} \\ \Delta M_t &\approx 3.2\,\text{GeV}/c^2 && \text{lepton + jets decays} \end{aligned}$$

Summary and Results

Summary

- Tevatron methods studied and extended for ATLAS
- Mean and median p_T^ℓ values fitted
- Errors and MC weights taken into account

Results

- $\langle p_T^\ell \rangle$ of leptonic decay products linearly dependent on M_t
- Possible statistical precision 200 pb^{-1} in the order of 3 GeV
- Monte Carlo statistics is still too low for both methods
- Background impact and systematics should be studied