Measurement of the b-jet cross section in events with a W boson in pp collisions at $\sqrt{s} = 7$ TeV with the ATLAS detector

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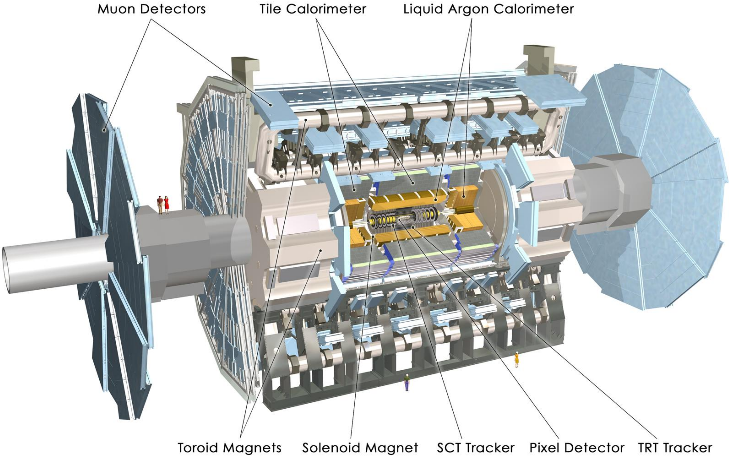
Outline

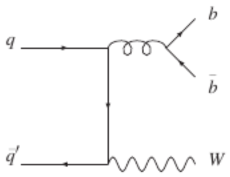
- The ATLAS detector
- Production of b partons in association with a W boson
- Selection of the analysis
- The analysis method: the secondary vertex mass fit
- Background normalization: QCD
- Background normalization: $t\bar{t}$
- Unfolding and cross section extraction
- Results



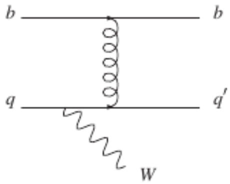
Subdetectors

- Inner Detector (ID)
  - Solenoidal field
  - Silicon tracker up to $|\eta| < 2.5$
  - TRT tracker
- Calorimeters
  - EM up to $|\eta| < 3.2$
    - Liquid Argon sampling calorimeter
  - Hadronic up to $|\eta| < 4.9$
    - Tile sampling calorimeter
    - Liquid Argon Calorimeter (forward)
- Muon Spectrometer (MS)
- Toroidal field
  - Tracking up to $|\eta| < 2.7$
  - Trigger up to $|\eta| < 2.4$

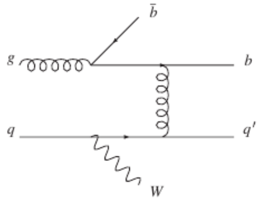
Production of b partons in association with a W boson



LO process



LO process



NLO process

Important channel for SM and beyond

- There is a large uncertainty on the theory prediction
- QCD test
- Main background for WH production with $H \to b\bar{b}$ decay
- Important background for Top physics
- Background of many new phsysics channel (see [1] for example)

CDF results

Big discrepancy between CDF results and NLO theoretical calculation
$\sigma^{th}_{NLO} = 1.22 \pm 0.14$
$\sigma_{CDF} \times BR = 2.74 \pm 0.27 \pm 0.42$
See [2]

Phase space definition and simulated samples

Requirement	Cut
Lepton transverse momentum p_T	$p_T^l > 20\ GeV$
Lepton pseudo-rapidity η	$\|\eta_l\| < 2.5$
Neutrino	$p_T^\nu > 25$ GeV
W mass	$m_T > 40$ GeV
Jet transverse momentum p_T	$p_T^j > 25$ GeV
Jet rapidity y	$\|y^j\| < 2.1$
Jet Multiplicity	$n^j \leq 2$
b-Jet Multiplicity	$nb^j \geq 1$
Jet Isolation	$\Delta R(l, jet) > 0.5$

Measurement performed

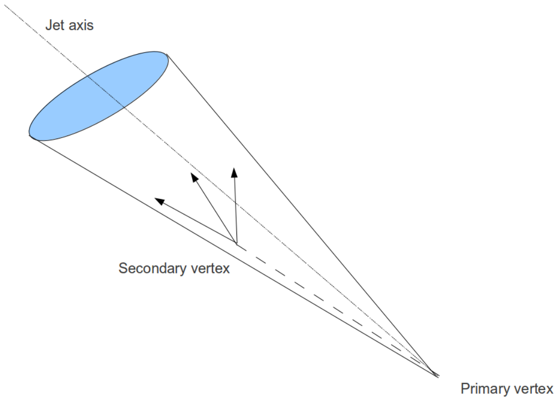
- Muon and Electron decays of W boson
- 1, 2 jets bin and combined
- 2010 data, $\int L = 35.5\ pb^{-1}$

Truth b-jet definition

Jet matched in $\sqrt{\Delta\eta^2 + \Delta\phi^2} < 0.3$ with b parton with $p_T > 5$ GeV

Physics process	Generator	$\sigma \cdot$ BR (nb)	
$W \to \ell\nu$ + jets ($0 \leq N_{parton} \leq 5$)	ALPGEN 2.13	10.46	NNLO
$Z \to \ell\ell$ + jets ($m_{\ell\ell} > 40$ GeV, $0 \leq N_{parton} \leq 5$)	ALPGEN 2.13	1.07	NNLO
$t\bar{t}$	MC@NLO 3.1.3.1	89.7×10^{-3}	approx. NNLO
Single-top (s-channel)	MC@NLO	4.3×10^{-4}	NLO
Single-top (t-channel)	AcerMC 2.0	6.34×10^{-3}	NLO
Single-top (Wt)	AcerMC 2.0	13.1×10^{-3}	NLO
WW	HERWIG 6.510	44.9×10^{-3}	NLO
WZ	HERWIG 6.510	18.5×10^{-3}	NLO
ZZ	HERWIG 6.510	5.96×10^{-3}	NLO

Tagging a b-jet



Jet Reconstruction

- On 2010 Electromagnetic calibration used
- $anti - k_T$ algorithm used for reconstruction

b-jet tagging

- Relies on b-hadrons properties
  - High mass ($\approx 5\ GeV$)
  - Long life time (fly for $\approx mm$)
  - Semi-leptonic decay
- The long life time makes it possible to reconstruct secondary vertices (ID resolution $\approx 10\mu m$)
- Standard tagger for 2010 = SV (secondary vertex tagger)
- On 2011 data more powerful (and more complex) strategies will be used

- Reconstructed primary vertex with at least 3 tracks
- Events triggered by electron or muon trigger algorithms
- Isolated electron or muon
- $E^T_{miss} > 25\ GeV$, $M^W_T > 40\ GeV$
- 1 or 2 jets with $p_T > 25\ GeV$, $|y| < 2.1$, $> 75\%$ momentum coming from primary vertex
- Exactly 1 b-jet, tagged using secondary vertex association algorithm (50% efficiency working point)

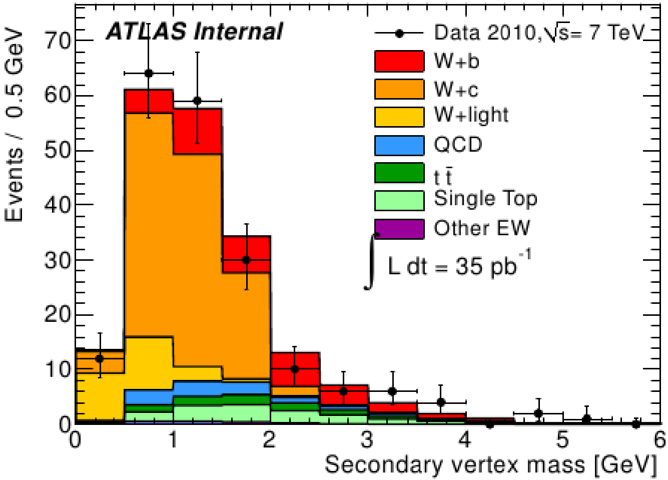
Expected number of events in the muon channel

Source	1-jet	2-jet (1 b-tag)	2-jet (2 b-tag)
W+b	24.8	25.9	1.6
W+c	108.4	44.9	0.4
W+light	38.2	20.2	0
Total W+Jet	171.4	91	2
ttbar	10	39.7	7.4
SingleTop	17.2	23.1	2.5
QCD	8	9.9	-0.1
Z+Jet	3.7	2.4	0.2
Diboson	0.2	0.1	0
Total Predicted	210.6	166.2	12.1
Data	261	217	13

Dealing with BG

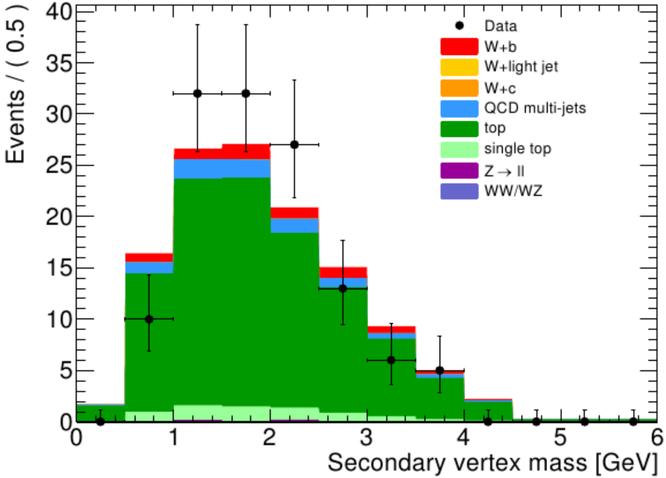
- events with 2 b tagged jets = very low signal due to top bg $\rightarrow$ vetoed
- High light and c background
- The idea: use secondary vertex properties to have a further flavour discrimination

Secondary vertex mass fit in the electron channel, 1 jet bin



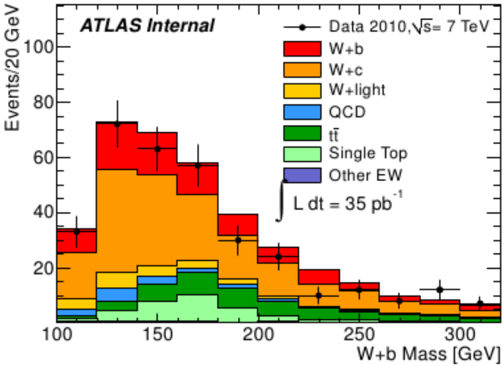
- Secondary vertex invariant mass distribution different for signal and background
- It can be used as a discriminating variable on statistical basis
- Template distributions produced on simulation (for QCD on data)
- Maximum likelihood fit
- Input to the fit: all non W+jet backgrounds normalizations
- Output of the fit: W+jet flavour fractions

The SV0 shapes are taken from simulations, and validated for b, c and light in different control regions.
The QCD shape is taken from data, from an enriched QCD sample.

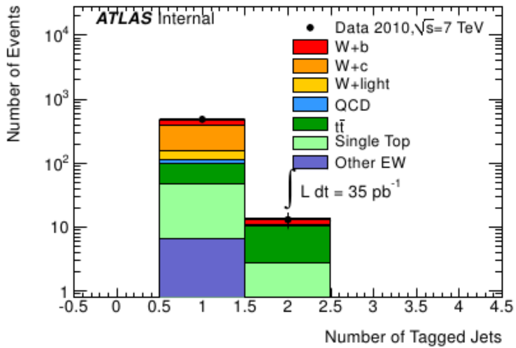


The method

- Select events with ≥ 4 jets, ≥ 1 b-tagged jet
- This defines a control region, dominated by $t\bar{t}$ events
- Apply the secondary vertex mass fit to extract the $t\bar{t}$ fraction
- Extrapolate back to signal region (1 or 2 jets, 1 b-tagged jet) using MC simulations prediction
- Most uncertainties cancels out (b tagging uncertainty above all)
- Alternative method (tag-counting) gives compatible results



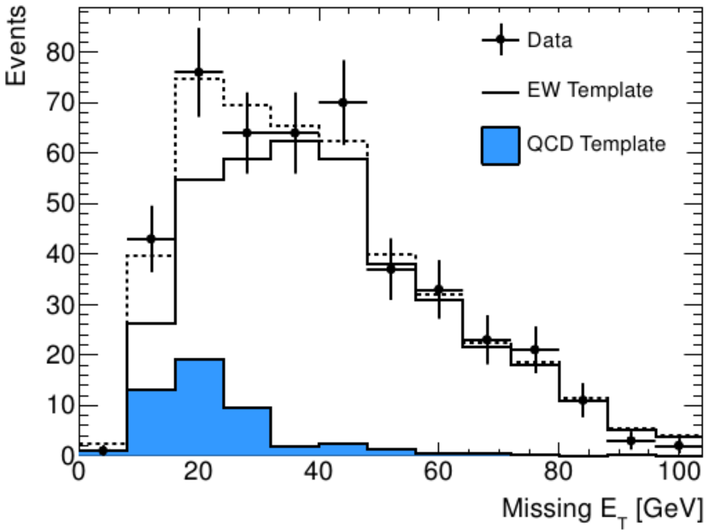
Invariant mass of the W+b-jet system in the electron channel, combined 1+2 jet bins



Number of b-tagged jets in the muon channel, combined 1+2 jet bins

Multijet QCD backgrounds

- No intrinsic transverse momentum imbalance
- Contribution due to limited resolution of detector and mis-reconstructed objects



Electron channel

- Look at E^T_{miss} on full range after all other cuts
- Produce one template shape on simulation for EW
- Produce one template shape on data for QCD in a QCD enriched sample (non isolated electrons)
- Fit the templates to obtain QCD normalization on data
- Good agreement between data and fit results

Dealing with the background: QCD

Multijet QCD backgrounds

- No intrinsic transverse momentum imbalance
- Contribution due to limited resolution of detector and mis-reconstructed objects

Muon channel: the matrix method

Two samples defined, with a loose or tight isolation requirement
real= prompt muons from W,Z
fake= non-isolated or mis-identificated muons

$N^{loose} = N^{loose}_{real} + N^{loose}_{fake}$

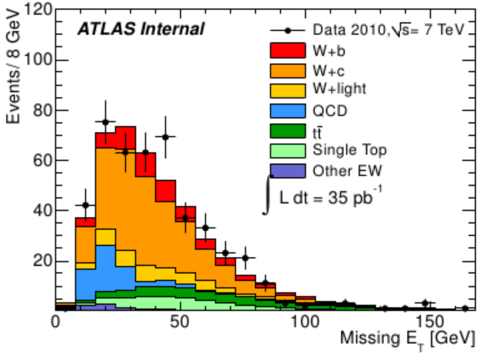
$N^{tight} = N^{tight}_{real} + N^{tight}_{fake} = \epsilon_{real} N^{loose}_{real} + \epsilon_{fake} N^{loose}_{fake}$

Measure ϵ_{real} and ϵ_{fake} on data, calculate

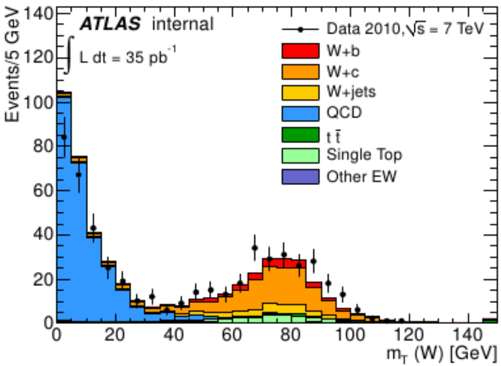
$N^{tight}_{fake} = \frac{\epsilon_{fake}}{\epsilon_{real} - \epsilon_{fake}} (\epsilon_{real} N^{loose} - N^{tight})$

The measurement

- ϵ_{real} measured with tag and probe method on data, using $Z \to \mu\mu$ events
- ϵ_{fake} estimated in a QCD enriched sample, $M_T^W < 20\ GeV$



E^T_{miss} in the electron channel, combined 1+2 jet bins



M_T^W in the muon channel, 1 jet bin

Other backgrounds

Single top

- Statistics too low to perform a measurement on data
- Prediction based on simulations
- Several uncertainties taken into account
  - Luminosity
  - 10% on normalization theory uncertainty
  - Initial/Final State Radiation uncertainties estimated using different Pythia simulation settings

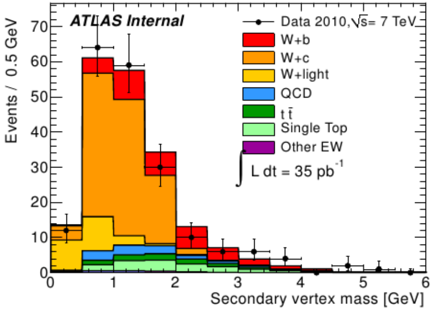
Small backgrounds, estimated with simulations

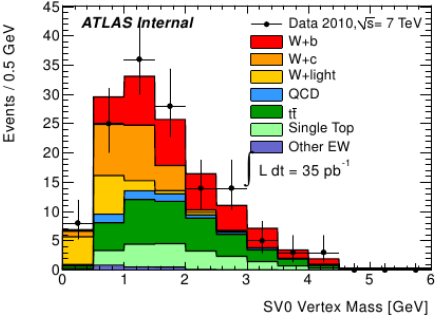
- Z+jets
- WW
- WZ
- ZZ

Now we have all the ingredients needed to perform the fit!

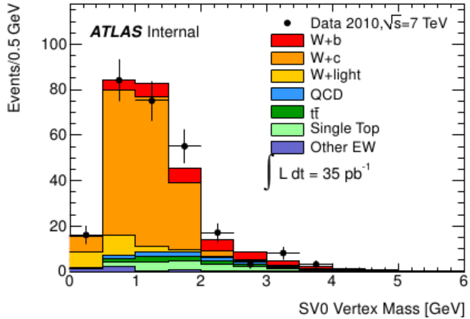
Fit results -1

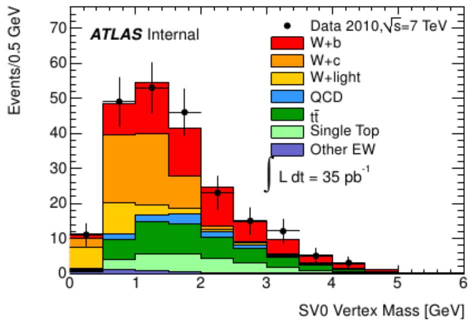
Electron channel, 1 (top) and 2 (bottom) jets





Muon channel, 1 (top) and 2 (bottom) jets





Given the non W-jets background normalizations as input, the secondary vertex mass fit extracts the W+b, W+c, W+light fractions

	μ				e			
	1-jet		2-jet		1-jet		2-jet	
	MC	Fit result	MC	Fit result	MC	Fit result	MC	Fit result
QCD multi-jet	-	8	-	9.9	-	10.4	-	5.8
W+b	24.8	28.4 ± 13.0	25.9	62.4 ± 17.7	17.9	32.6 ± 13.1	18.9	37.7 ± 14.4
W+c	108.4	169.6 ± 19.5	44.9	54.1 ± 18.6	84.3	104.7 ± 17.5	35.5	24.0 ± 14.7
W+light	38.2	21.9 ± 10.4	20.2	21.2 ± 9.9	30.3	22.3 ± 10.1	17.2	14.4 ± 7.6
$t\bar{t}$	10.0	11.0	39.7	43.7	7.6	8.1	31.6	33.4
single top	17.2	-	23.1	-	13.6	-	18.4	-
WW/WZ	0.2	-	0.1	-	1.3	-	1.6	-
$Z \rightarrow \ell\ell$	3.7	-	2.4	-	0.6	-	0.5	-

The results of the fit is used to evaluate an event-level cross section:

$$\sigma_{W+b-\mathrm{jet}} \times \mathscr{B}(W \to \ell\nu) = \frac{(n^{tag} - n_{\mathrm{non-WBG}}) \cdot f_{W+b-\mathrm{jet}}}{\int \mathscr{L} \cdot \mathscr{U}}.$$

The unfolding factor at denominator is the W+b reconstruction efficiency divided by the truth level acceptance in the fiducial region.
All data-driven corrections to simulations applied: reconstruction efficiency, b-jet calibration, momentum smearing...

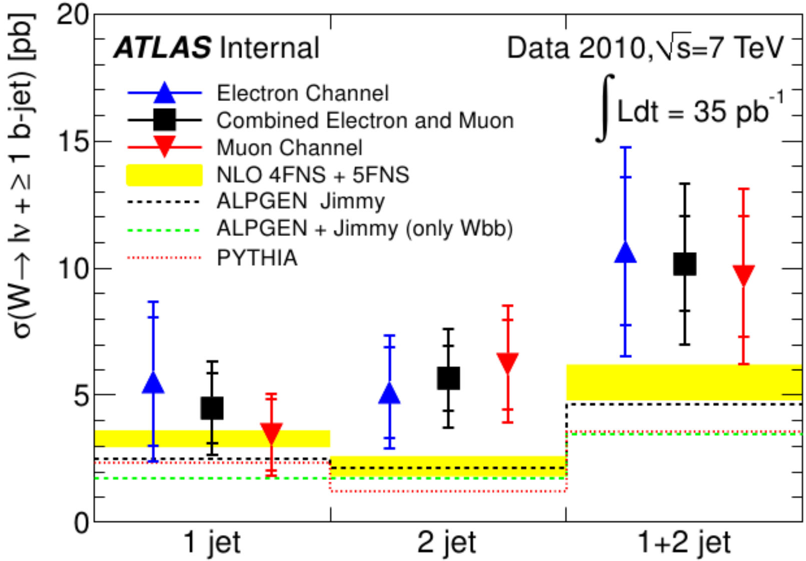
Channel	Jet bin	$n^{e(\propto)}_{Reco\ b-jets}$	$n^{\tau}_{Reco\ b-jets}$	$n^{FiducialW}_{True\ b-jets}$	$\tilde{\mathscr{U}}_{e(\propto)}$ (%)
Electrons	1	17.64±0.84	0.276±0.078	108.1±2.2	16.32±0.84
	2	18.15±0.69	0.73±0.15	91.05±1.6	19.94±0.83
Muons	1	24.2±1.0	0.61±0.16	107.0±2.1	22.6±1.0
	2	25.53±0.84	0.374±0.091	91.7±1.6	27.8±1.0

Cross Section [pb]									
	1 jet			2 jet			1+2 jet		
	μ	e	μ & e	μ	e	μ & e	μ	e	μ & e
Measured	3.5	5.5	4.5	6.2	5.1	5.7	9.7	10.7	10.2
Syst. $\oplus$ Stat.	1.9	2.7	1.8	2.3	2.4	1.9	3.4	4.1	3.2
Statistical	1.6	2.1	1.3	1.8	1.9	1.3	2.4	2.8	1.9
Systematic	1.1	1.7	1.3	1.5	1.5	1.4	2.4	3.0	2.6
Systematics breakdown %									
b-tag efficiency & template shape	22	19	19	14	16	14	16	16	16
Jet uncertainties	9	6	7	7	10	8	7	7	7
QCD background	7	18	11	4	8	4	5	13	7
Missing Energy	1	1	1	2	2	1	1	1	1
$t\bar{t}$ & single top	14	9	11	12	17	14	12	12	12
Lepton uncertainties	3	5	3	2	5	3	2	5	3
Model dependence	9	8	9	10	10	10	9	9	9
Pile-up	5	4	5	3	3	3	3	4	3
Luminosity	5	5	5	4	5	5	5	5	5

Systematics

- For each systematic variation considered, the full chain of the analysis is repeated
- Main systematics
  - b-jet efficiency: the limiting systematics. It affects W+b unfolding and single top estimate in correlated way. It is reduced thanks to the data driven $t\bar{t}$ estimate.
  - jet energy scale has the biggest impact in the $t\bar{t}$ estimate.
  - single top and top pair theory uncertainties are significant
- Signal modeling systematics were taken into account
- b tagging efficiency, therefore the unfolding, depends strongly
  - on b-jet momentum
  - on the angle between the two b partons (if they end in the same jet, the efficiency is higher)
- An estimate on this was produced varying the contribution to signal of
  - $g \to b\bar{b}$
  - $q\bar{q} \to Wb\bar{b}$

Theory prediction by theorists [3]



- The analysis is becoming a paper right now [4]
- The measured cross section suggests an excess wrt predictions
- The measurement is limited by statistics, but in 2011 available already more than 30 times more statistics
- No trivial extension: better b-tagging algorithms available, need to update data driven correction to simulations, ...

1 "Phenomenology of the left-right twin Higgs model"; PHYS. REV. D 75, 075010 (2007)

2 First Measurement of the b-jet Cross Section in Events with a W Boson in p-pbar Collisions at $\sqrt{s} = 1.96 TeV$; arXiv:0909.1505

3 NLO QCD predictions for W + 1 jet and W + 2 jet production with at least one b jet at the 7 TeV LHC; arXiv:1107.3714

4 The article that will be published sooner or later