Search for Flavor Changing Neutral Currents in Top Quark Decays

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October 23, 2012

Outline

- Top Quark Physics
  - Motivation
- ATLAS Detector
- Object and Event Selection
  - Track-Lepton
- Backgrounds
- Systematic Uncertainties
- Limit Calculation
- Conclusions

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Top Quark

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$m_t = 173.2 \pm 0.9$ GeV

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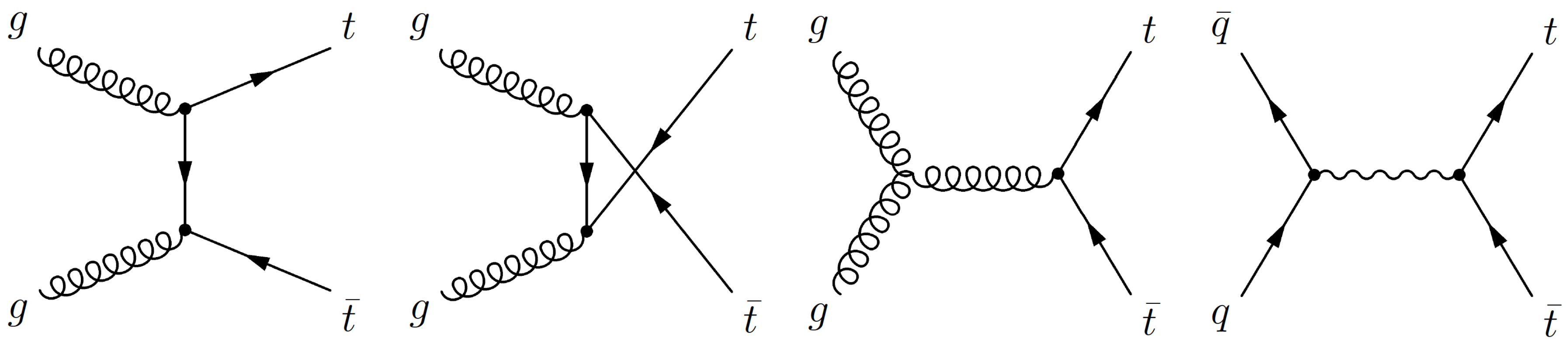
Deviations from the **decay** and **production** predictions from the SM give a model-independent test for physics beyond SM.
In addition to this, it is an important **background** to other searches.

LHC is a Top Quark **Factory**

Top Quark Pair Production

Top quark pairs are produced via:



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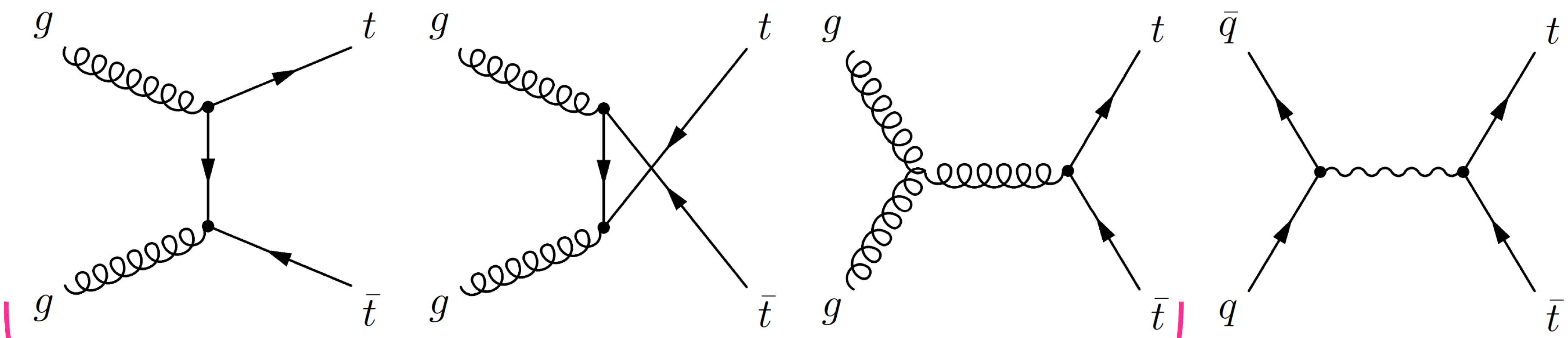

Gluon Fusion
~90% of the time
in the LHC

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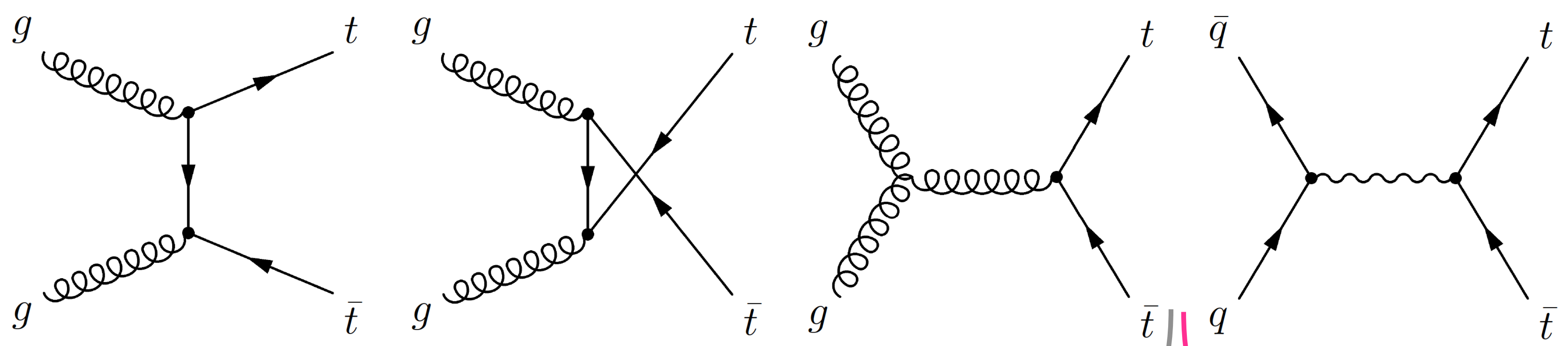

Gluon Fusion
~90% of the time
in the LHC

Quark Annihilation
~85% of the time
in the Tevatron

LHC is a Top Quark **Factory**

Top Quark Pair Production

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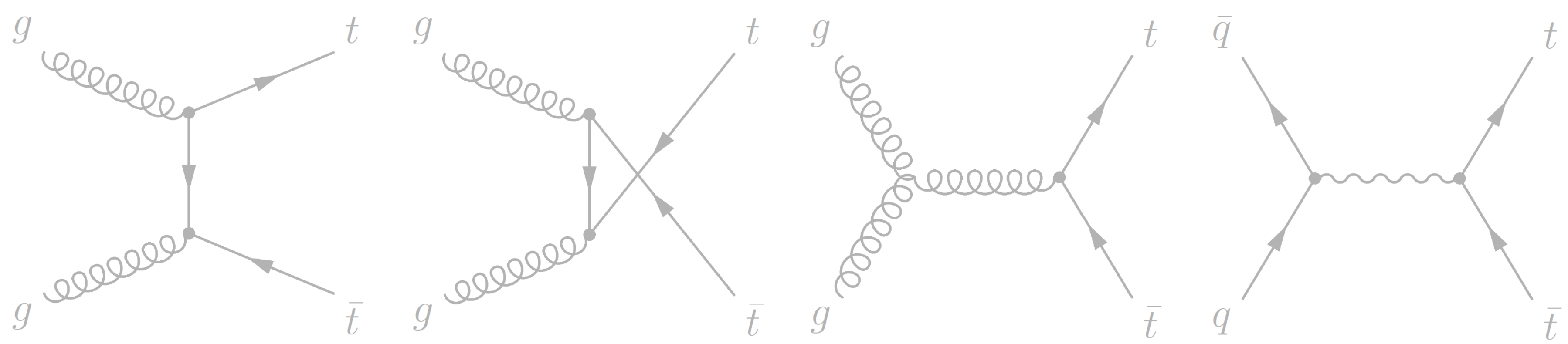
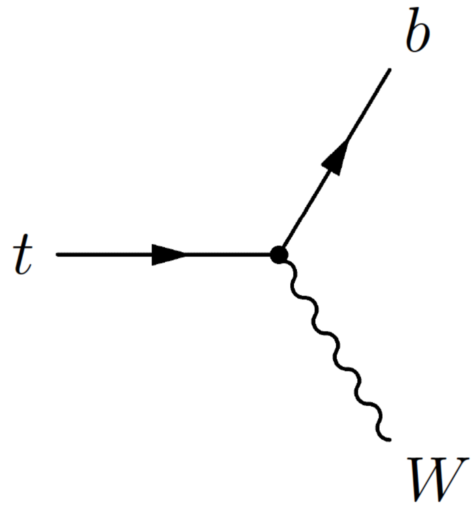
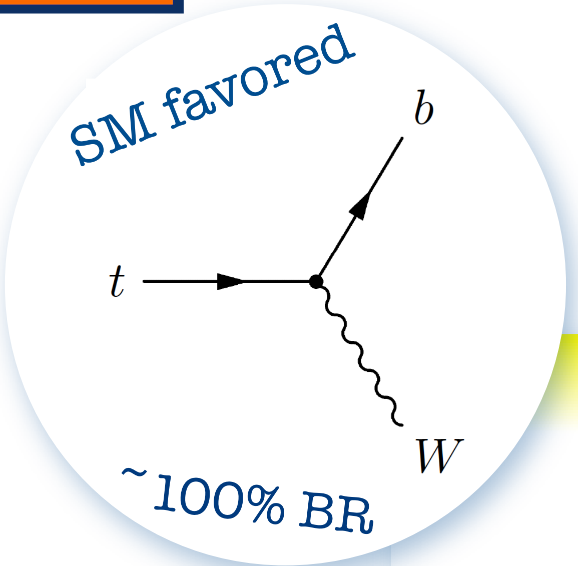


Top Quarks can also be produced via
single-top quark production mechanisms.

Top Quark Decay

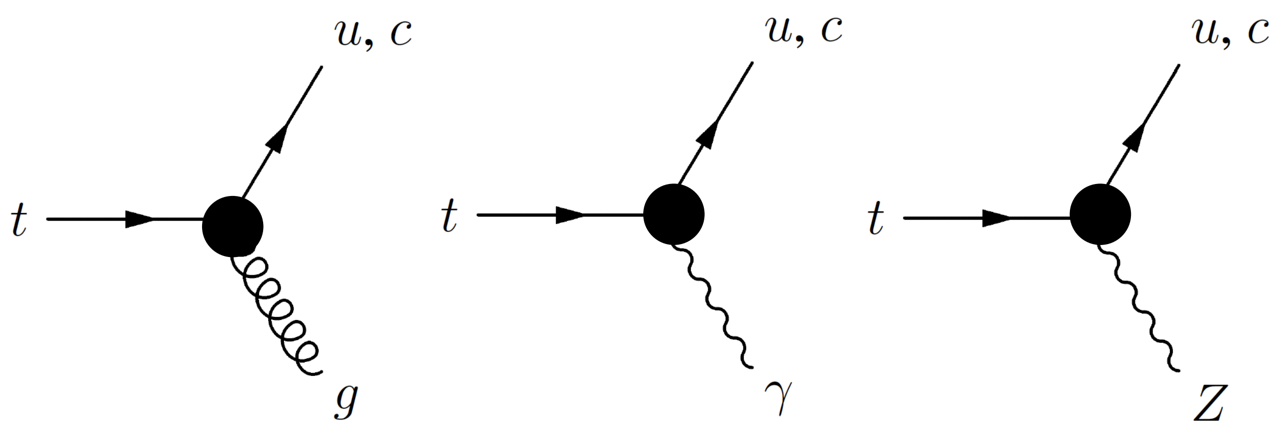


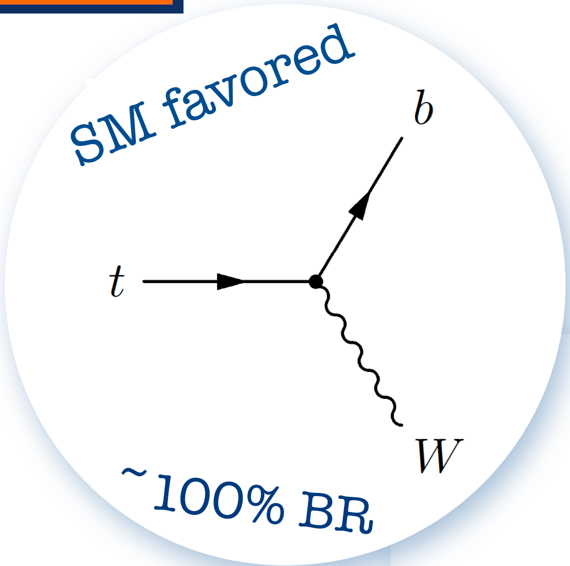
SM favored decay



Top Quark Decay

Other decays are possible via
flavor changing neutral currents





Top Quark Decay

Other decays are possible via
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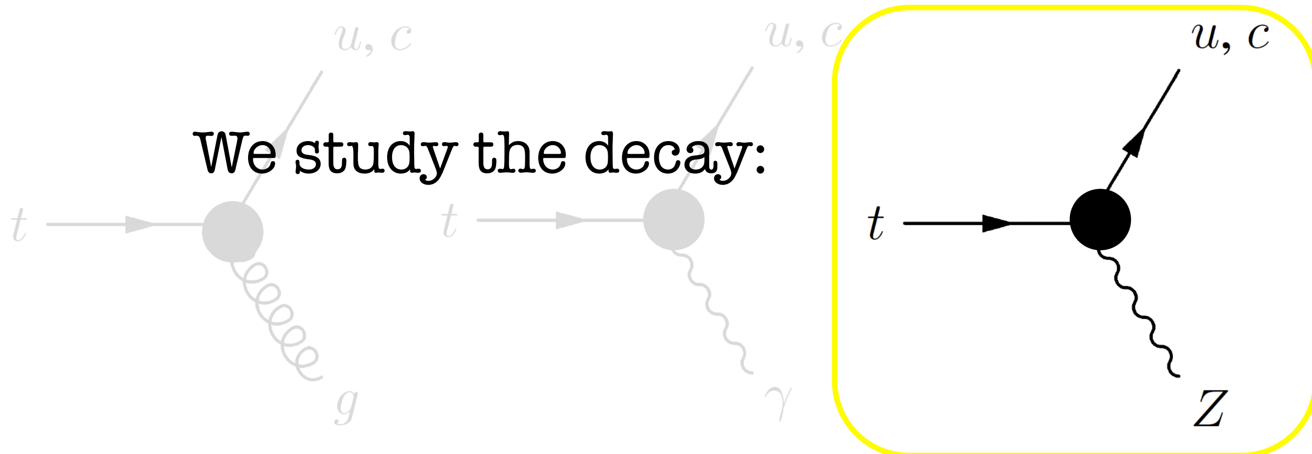
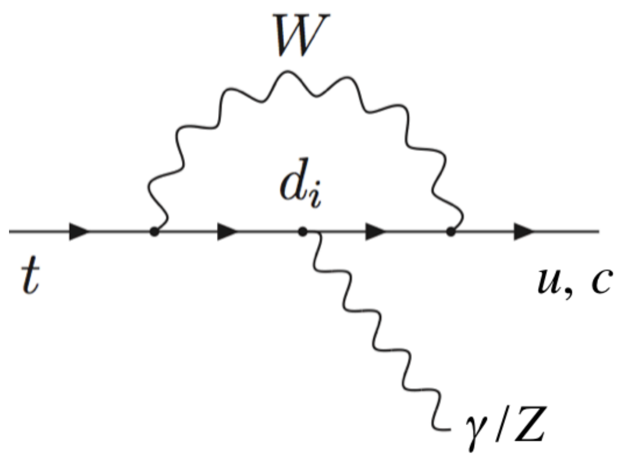
We study the decay:



FCNC

FCNC do not exist at tree level in the SM.

Higher order electroweak interactions do allow FCNC:



FCNC

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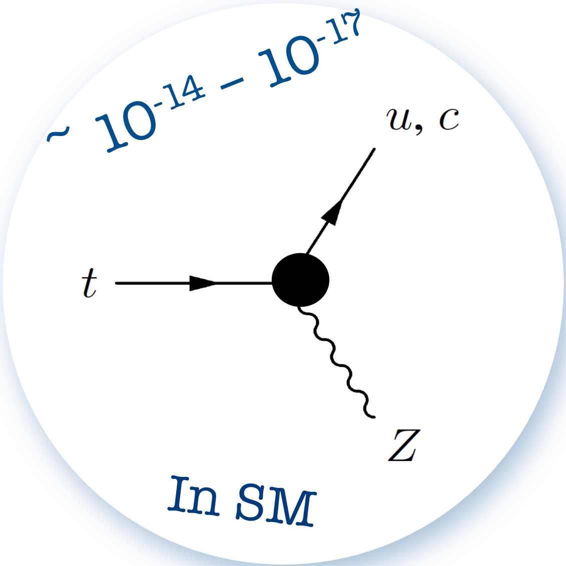
However, the GIM mechanism highly suppresses the contribution from these diagrams...



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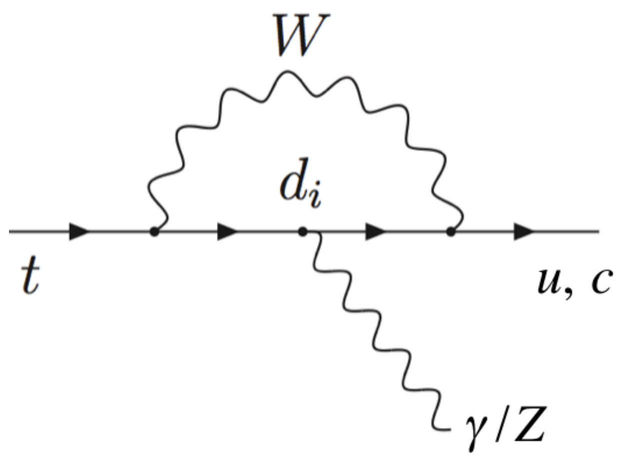

Why is FCNC interesting?

Beyond SM FCNC

SM extensions predict higher branching ratios for top quark FCNC decays:

Process	SM	QS	2HDM	FC 2HDM	MSSM	$\not R$ SUSY
$t \to u\gamma$	3.7×10^{-16}	7.5×10^{-9}	—	—	2×10^{-6}	1×10^{-6}
$t \to uZ$	8×10^{-17}	1.1×10^{-4}	—	—	2×10^{-6}	3×10^{-5}
$t \to ug$	3.7×10^{-14}	1.5×10^{-7}	—	—	8×10^{-5}	2×10^{-4}
$t \to c\gamma$	4.6×10^{-14}	7.5×10^{-9}	$\sim 10^{-6}$	$\sim 10^{-9}$	2×10^{-6}	1×10^{-6}
$t \to cZ$	1×10^{-14}	1.1×10^{-4}	$\sim 10^{-7}$	$\sim 10^{-10}$	2×10^{-6}	3×10^{-5}
$t \to cg$	4.6×10^{-12}	1.5×10^{-7}	$\sim 10^{-4}$	$\sim 10^{-8}$	8×10^{-5}	2×10^{-4}

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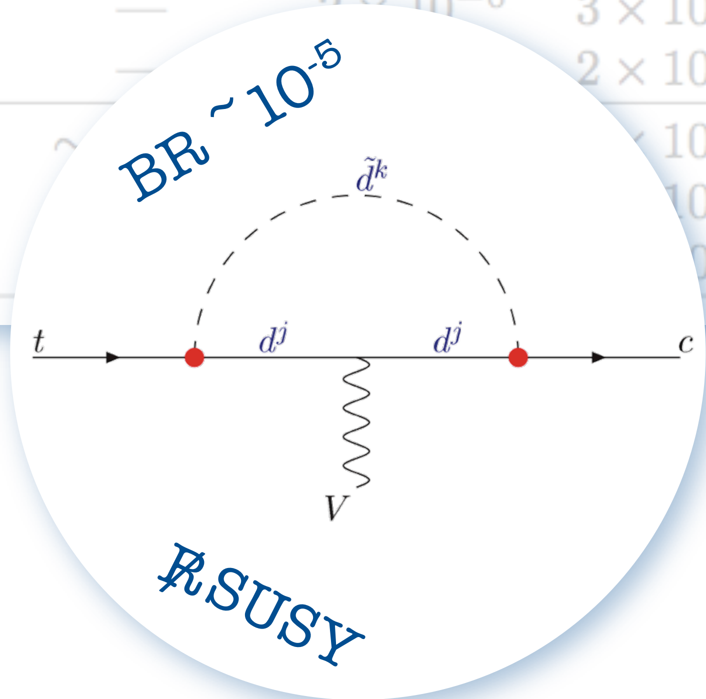
E. g. in some R-parity violating SUSY models, the BR can be enhanced up to ~10^{-5}



Our FCNC Search

Search FCNC in top quark decays

We take top quark pair production events: $t\bar{t} \Rightarrow \begin{array}{l} t \rightarrow bW \\ t \rightarrow qZ \end{array}$

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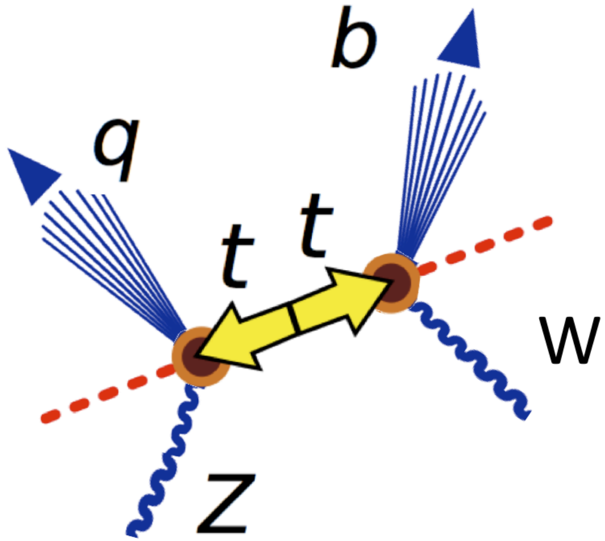

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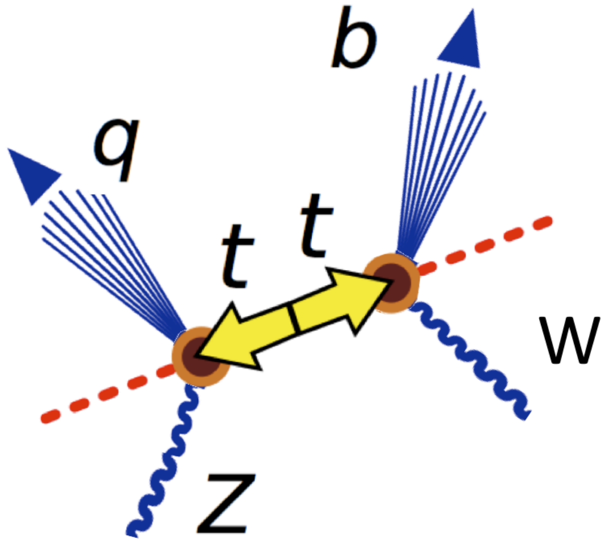

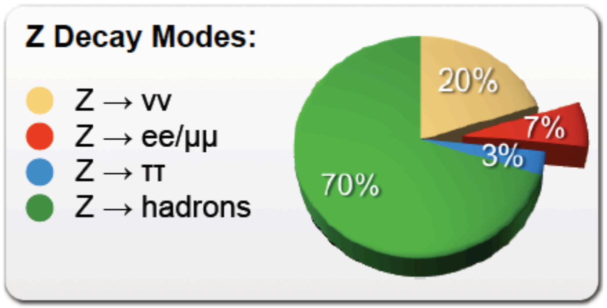

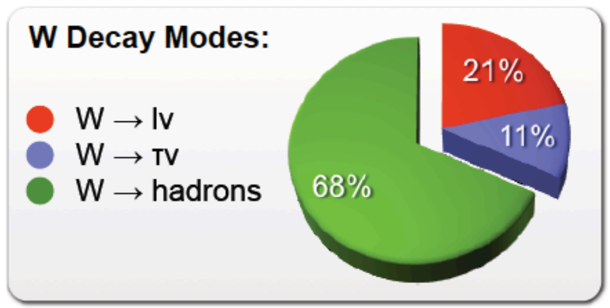

Only leptonic decays of the W- and Z-bosons are considered as signal

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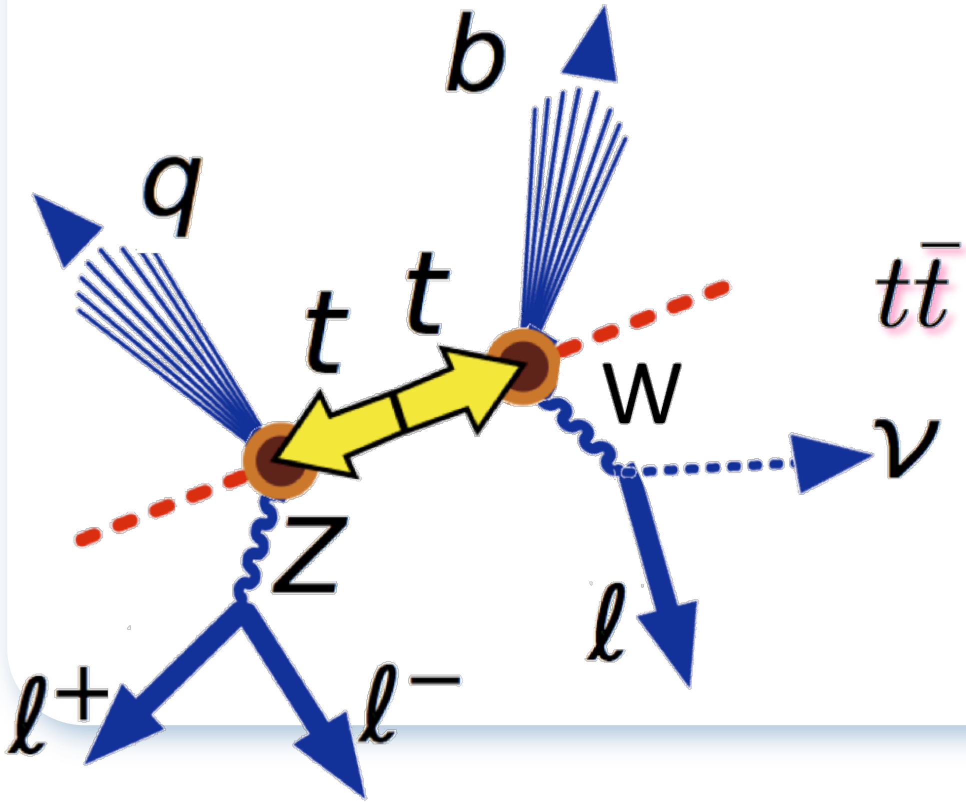

$$t\bar{t} \rightarrow bWqZ \rightarrow b\ell_1\nu q\ell_2\ell_2$$

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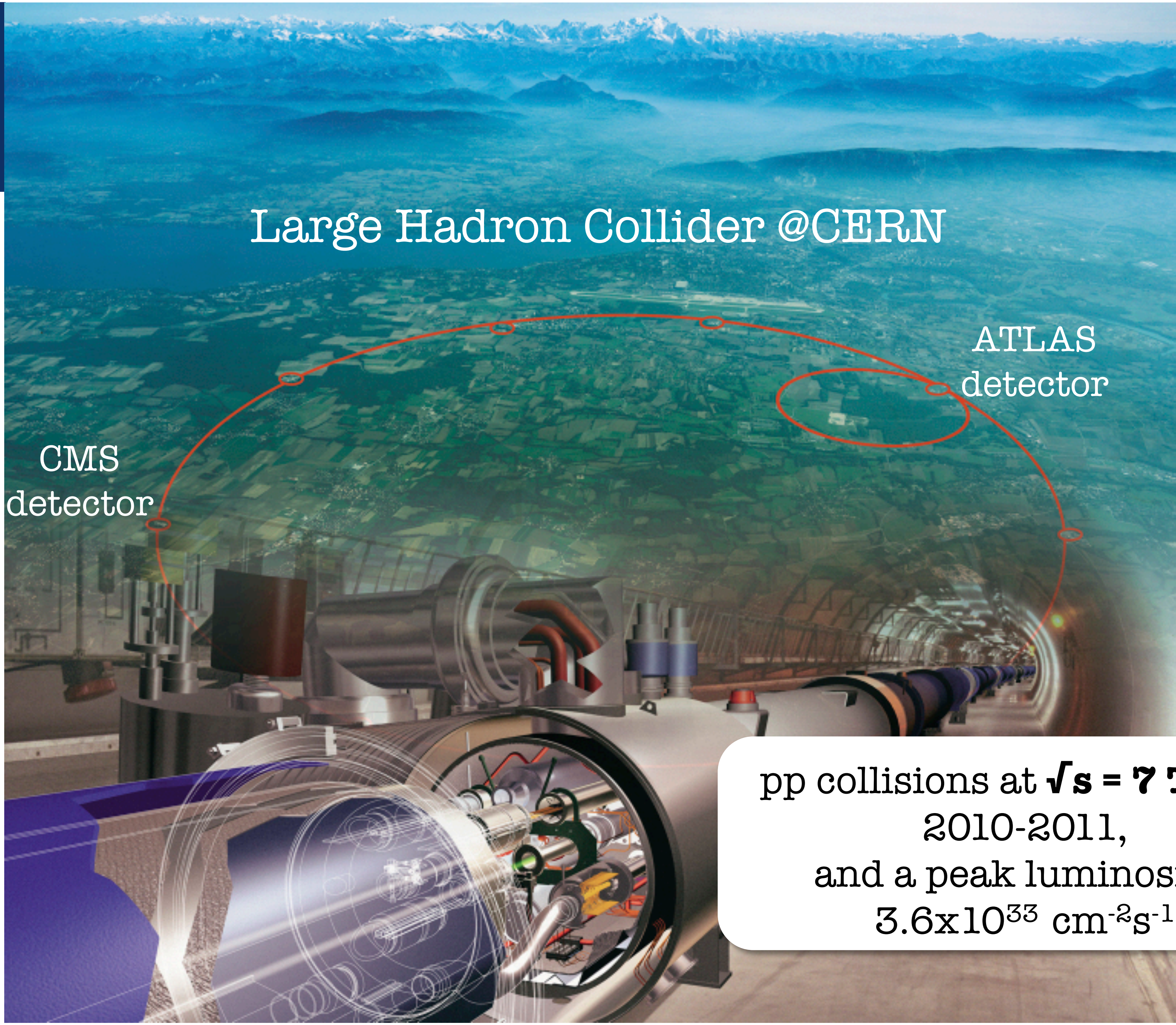
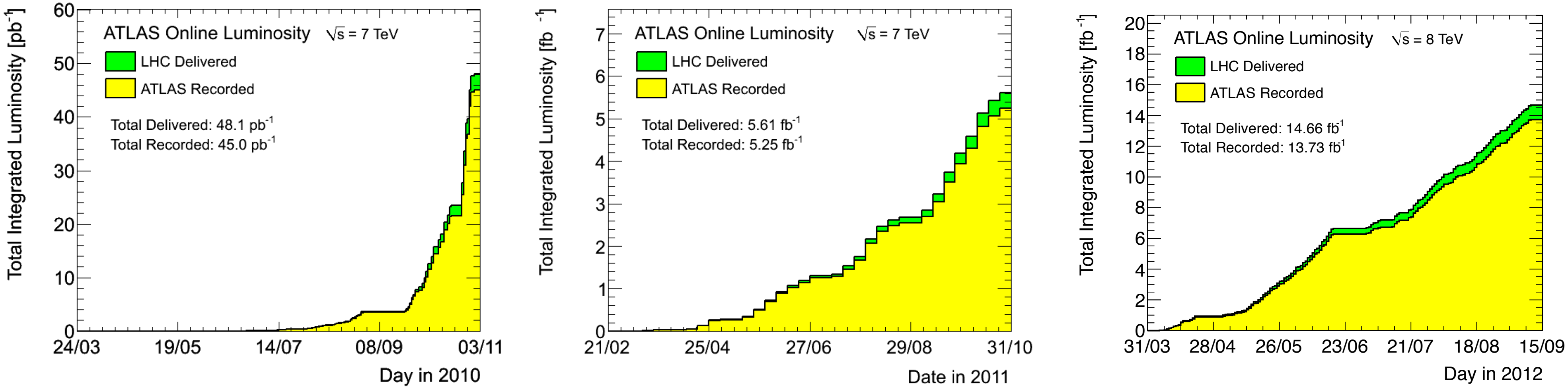


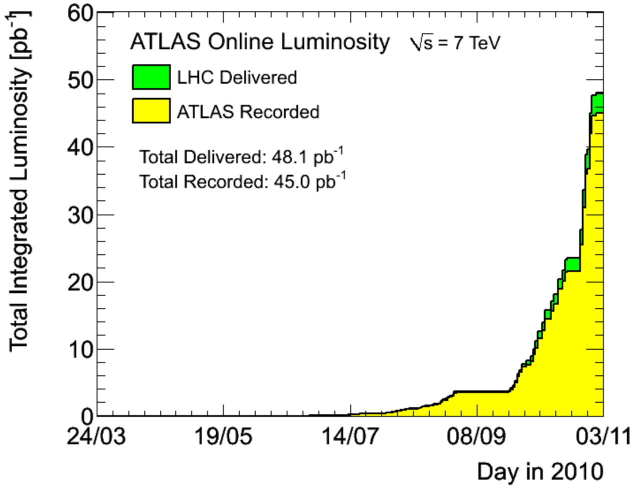
pp collisions at $\sqrt{s}$ = **7 TeV** in 2010-2011,
and a peak luminosity:
3.6×10^{33} $cm^{-2}s^{-1}$

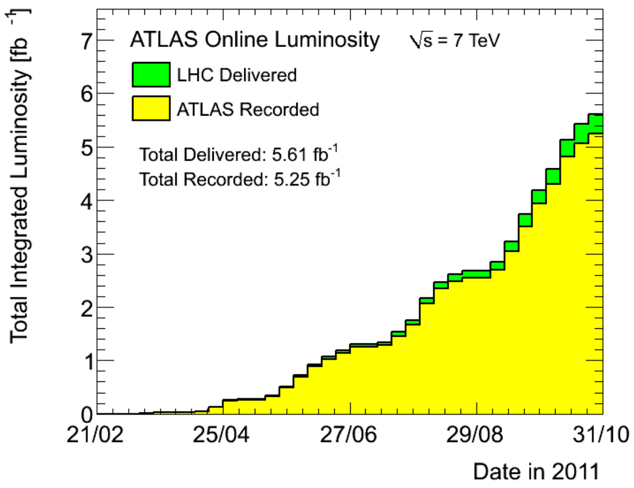
Data Sample

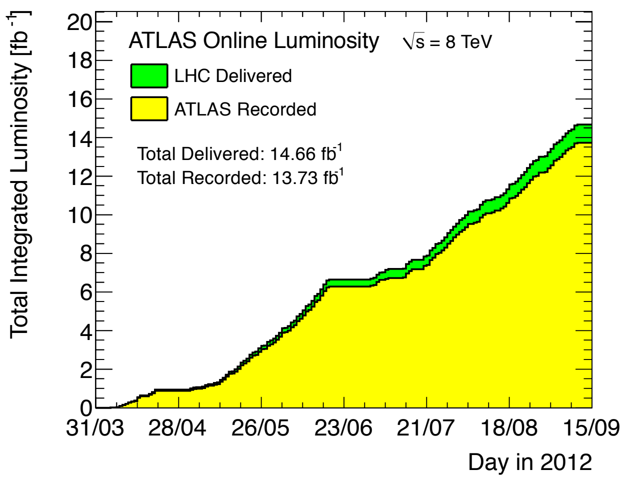


ATLAS Online Luminosity $\sqrt{s}$ = 7 TeV
LHC Delivered
ATLAS Recorded
Total Delivered: 48.1 pb^{-1}
Total Recorded: 45.0 pb^{-1}
Total Integrated Luminosity [pb^{-1}]
Day in 2010
ATLAS Online Luminosity $\sqrt{s}$ = 7 TeV
LHC Delivered
ATLAS Recorded
Total Delivered: 5.61 fb^{-1}
Total Recorded: 5.25 fb^{-1}
Total Integrated Luminosity [fb^{-1}]
Date in 2011
ATLAS Online Luminosity $\sqrt{s}$ = 8 TeV
LHC Delivered
ATLAS Recorded
Total Delivered: 14.66 fb^{-1}
Total Recorded: 13.73 fb^{-1}
Total Integrated Luminosity [fb^{-1}]
Day in 2012

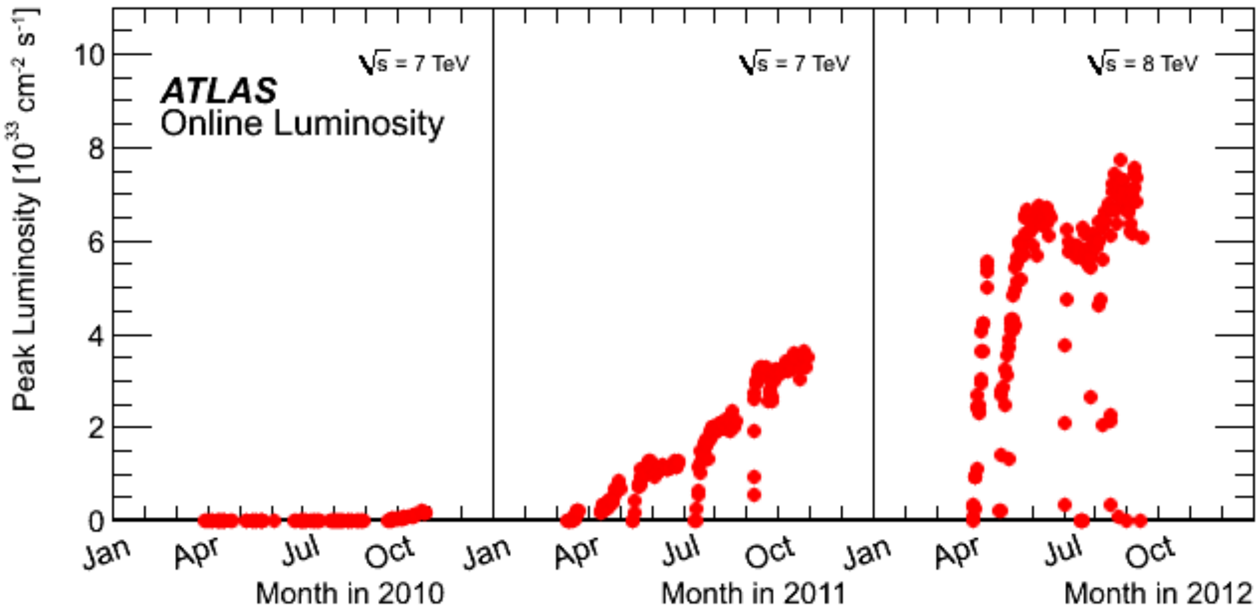
Data Sample







Increasing peak luminosity...



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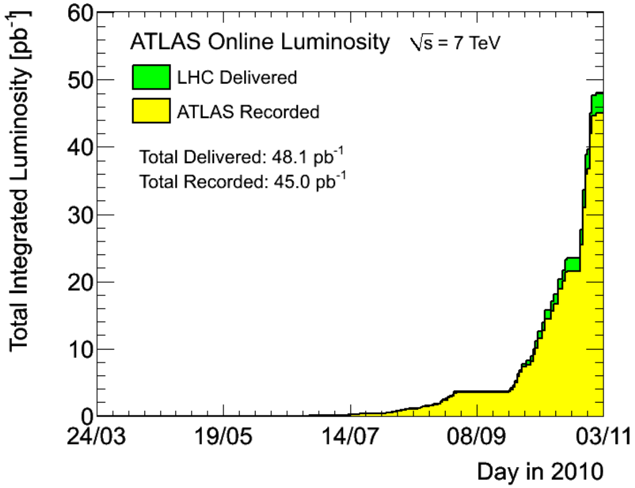
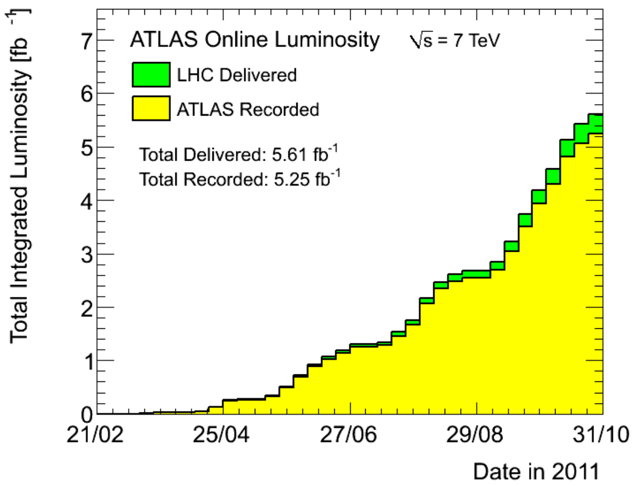
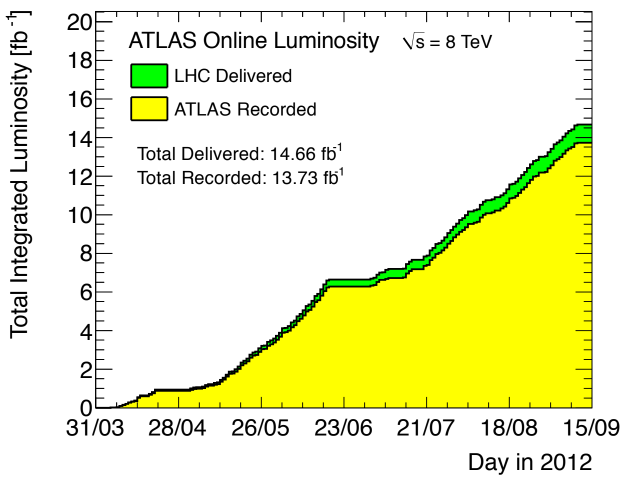
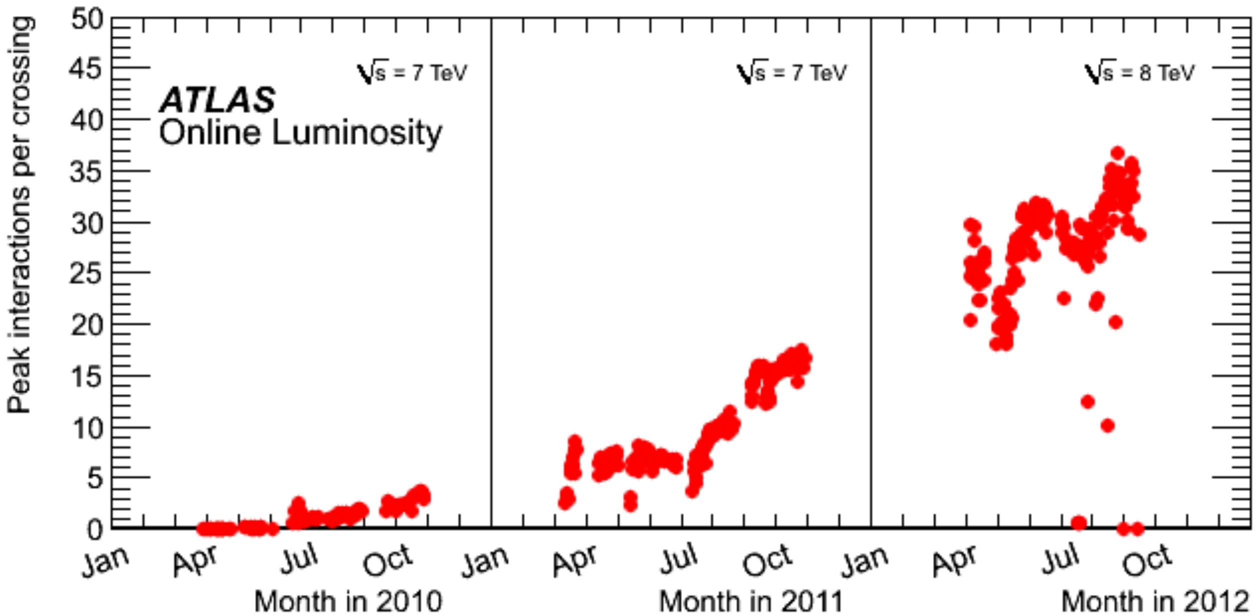


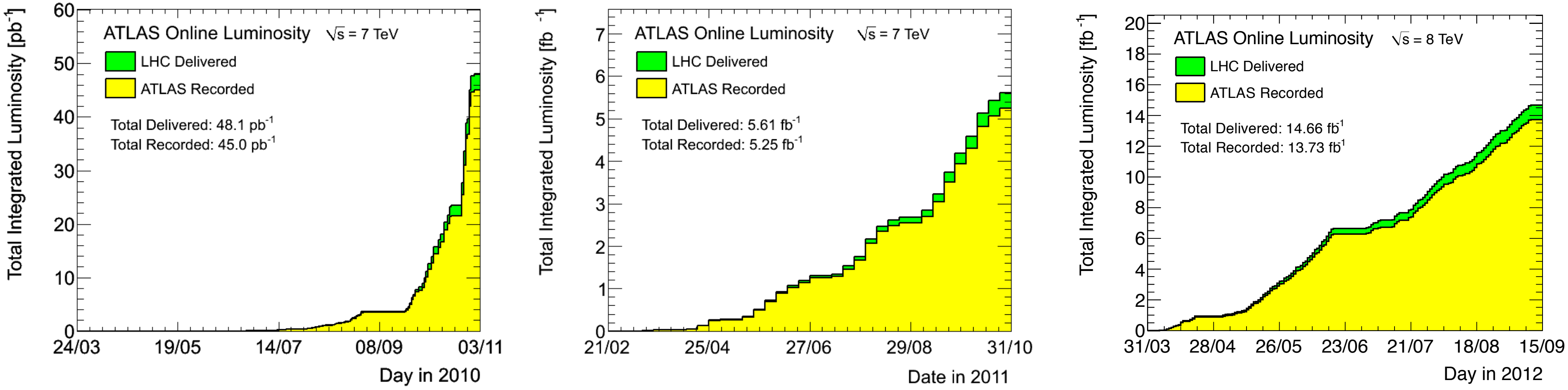




Increasing interactions per crossing...

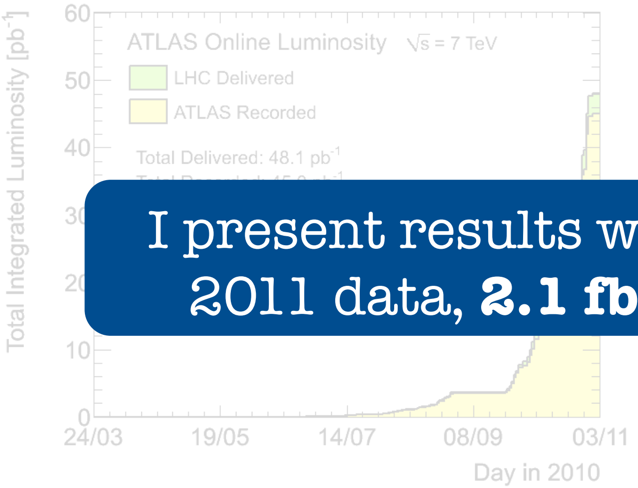


Data Sample

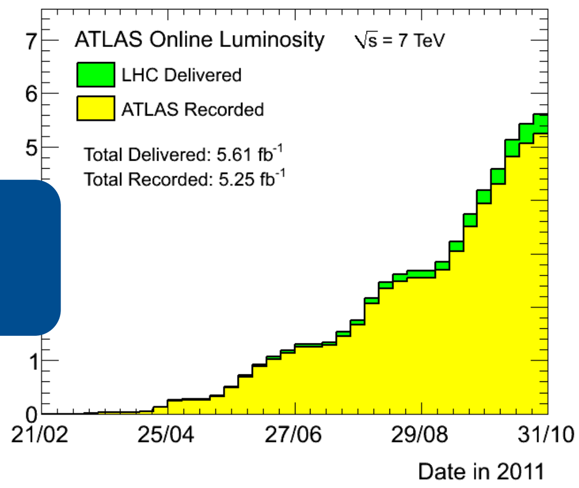


	2010	2011	2012
$\sqrt{s}$	7 TeV	7 TeV	8 TeV
peak luminosity	$2.1\ \times 10^{32}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$	$3.6\times 10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$	$7.7\ \times 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
# interactions per BC	2	6-12	~ 25

Data Sample



I present results with 2011 data, **2.1 fb^{-1}**



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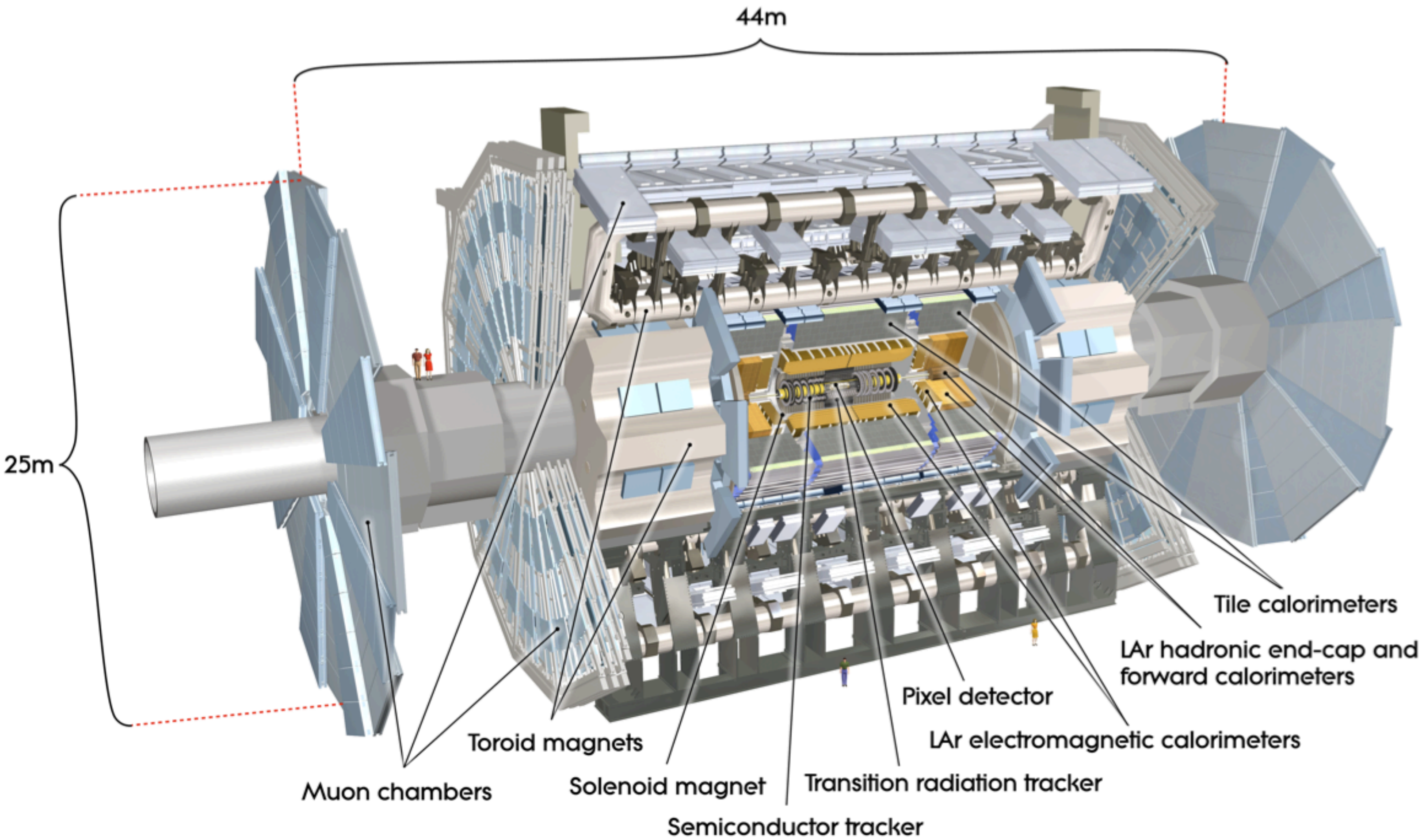
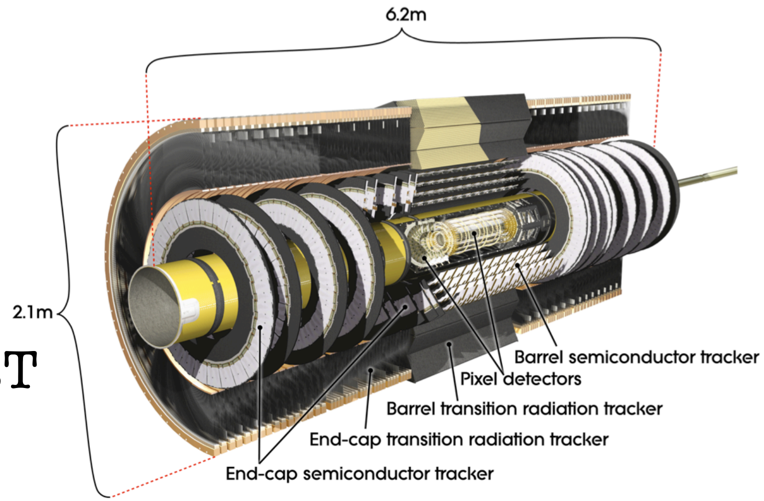
ATLAS Detector

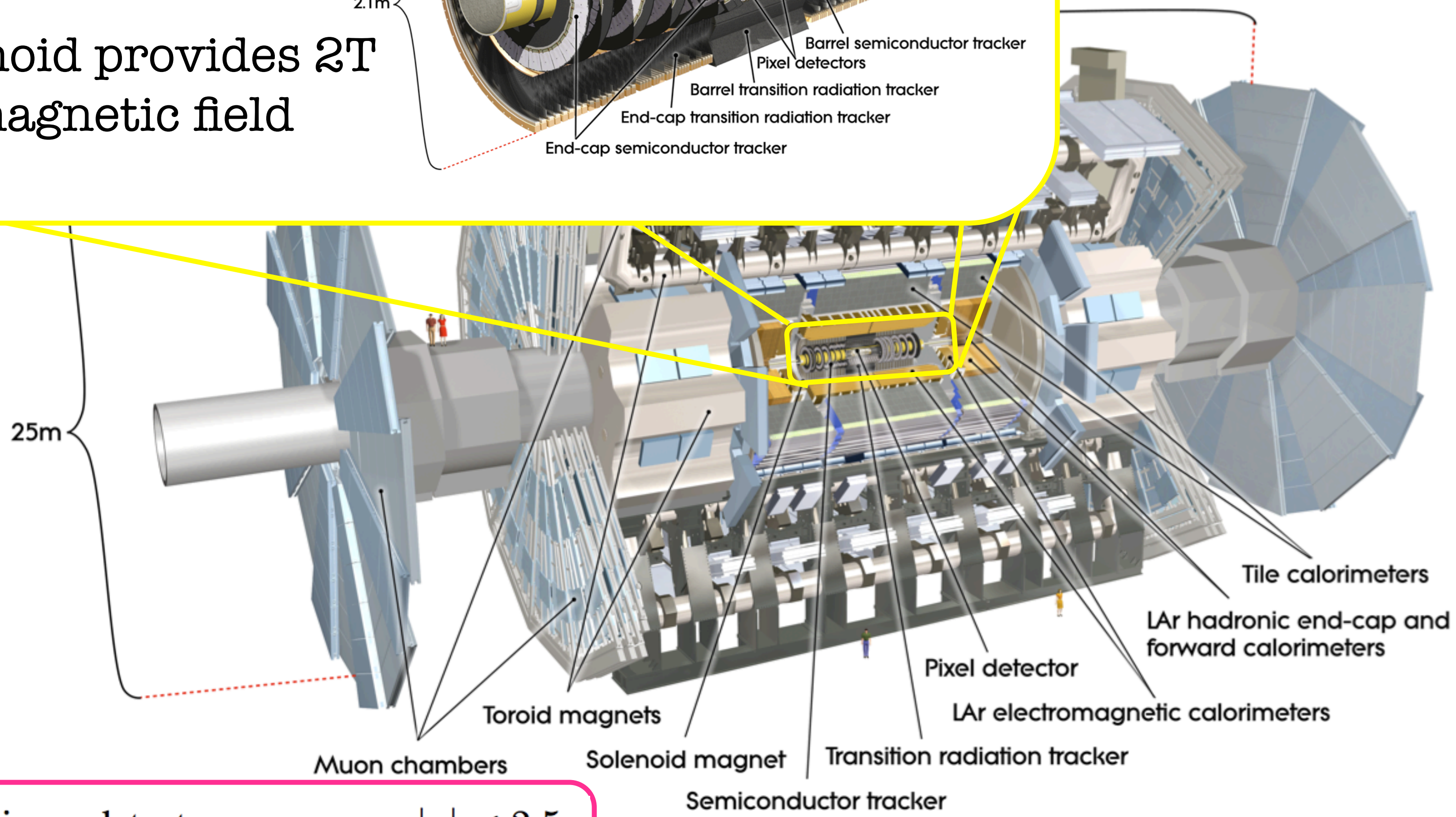


Inner Detector

Silicon pixels and strips, TRT.

Solenoid provides 2T magnetic field





inner detector coverage	$\|\eta\| < 2.5$
$\sigma(p_T)/p_T\ (@p_T = 100GeV)$	3.8%

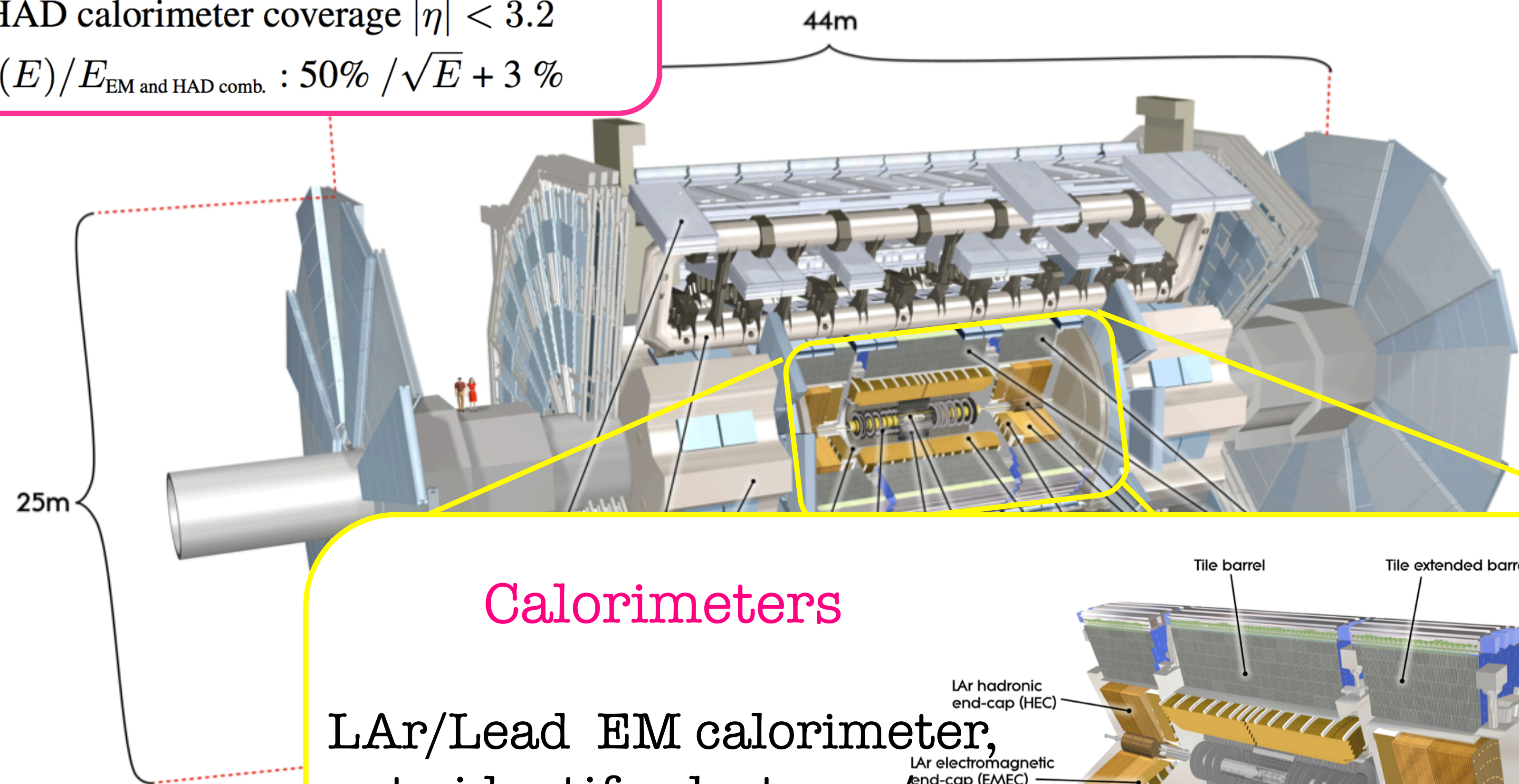
ATLAS Detector

EM calorimeter coverage $|\eta| < 3.2$

$\sigma(E)/E : 10\% \ /\sqrt{E} + 0.7\ \%$

HAD calorimeter coverage $|\eta| < 3.2$

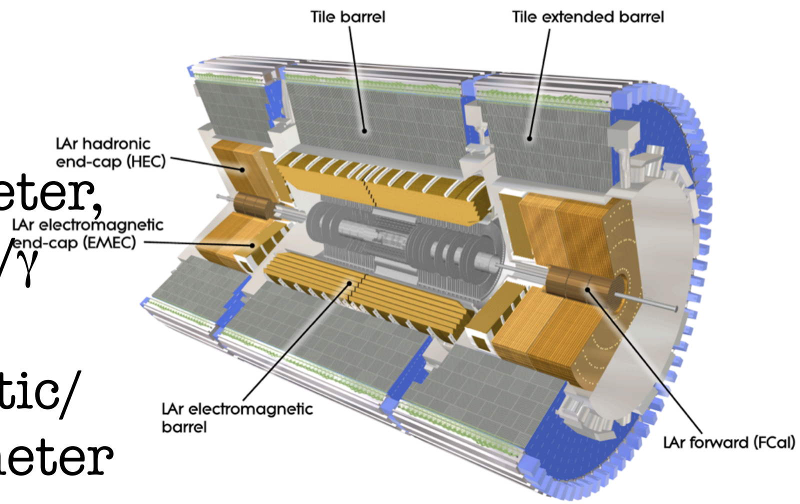
$\sigma(E)/E_{\text{EM and HAD comb.}} : 50\% \ /\sqrt{E} + 3\ \%$



Calorimeters

LAr/Lead EM calorimeter, to identify electrons/γ

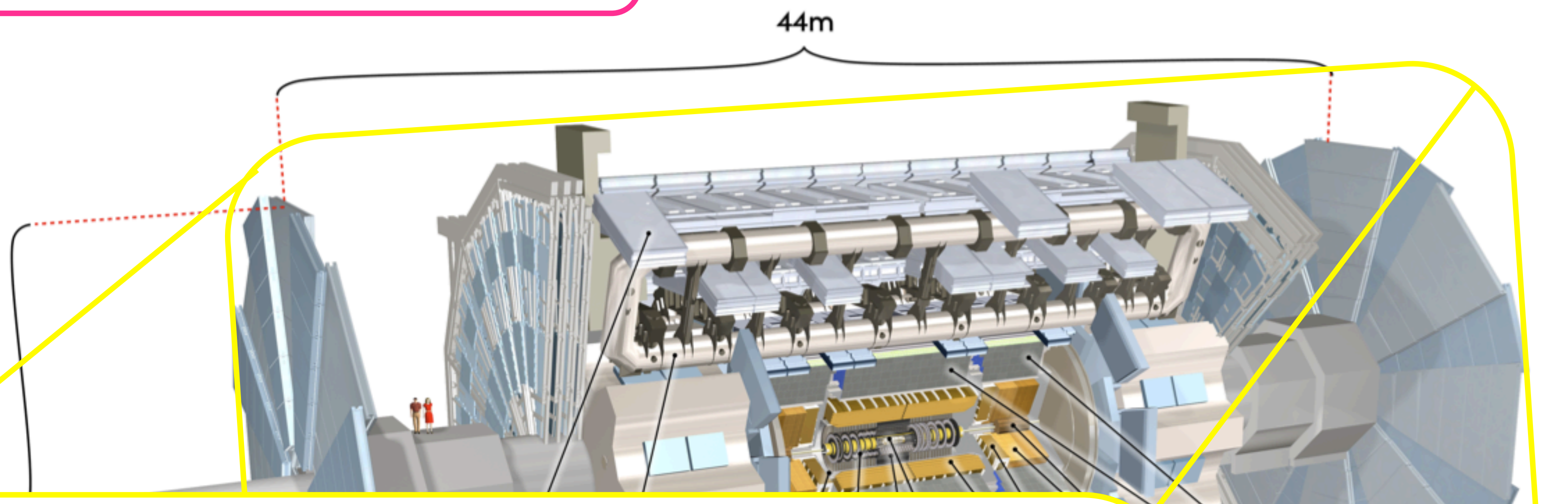
Scintillation-tile (plastic/ steel) hadronic calorimeter



ATLAS Detector

muon spectrometer coverage $|\eta| < 2.7$

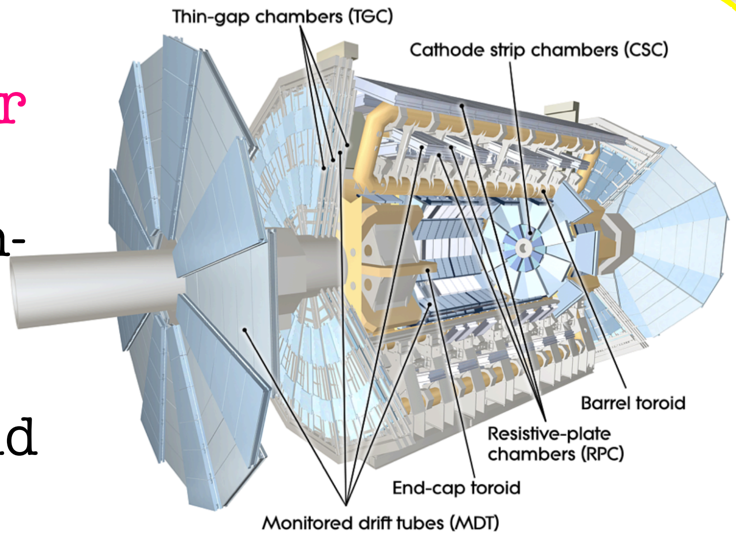
$\sigma(p_T)/p_T\ (@p_T = 1\ \text{TeV})_{\text{stand-alone}}$: $12\%_{\ |\eta|<1.5}$



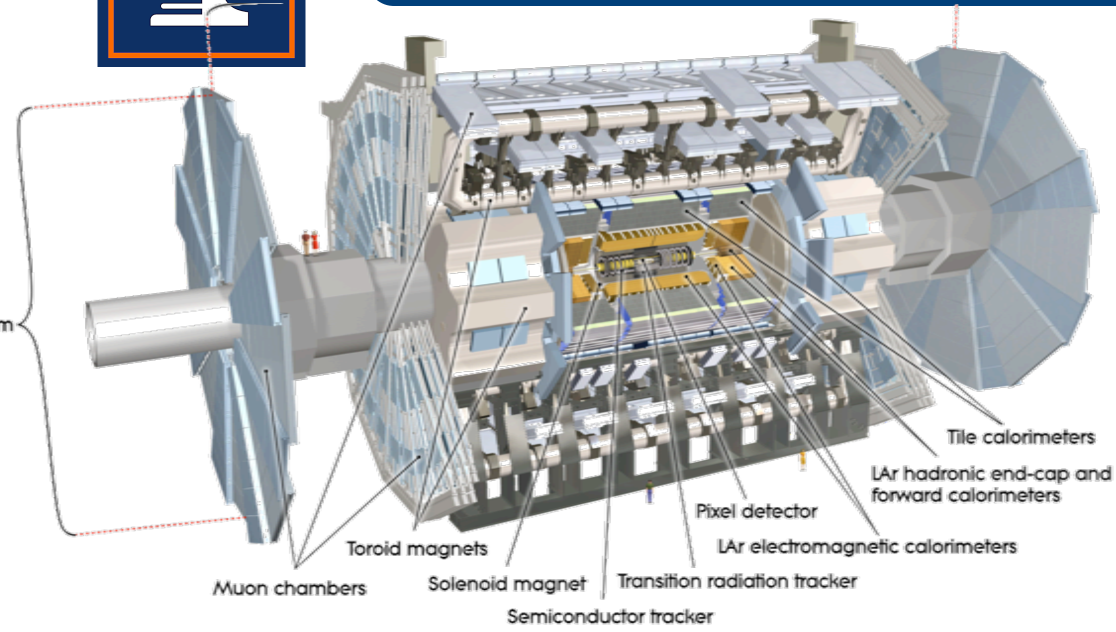
Muon Spectrometer

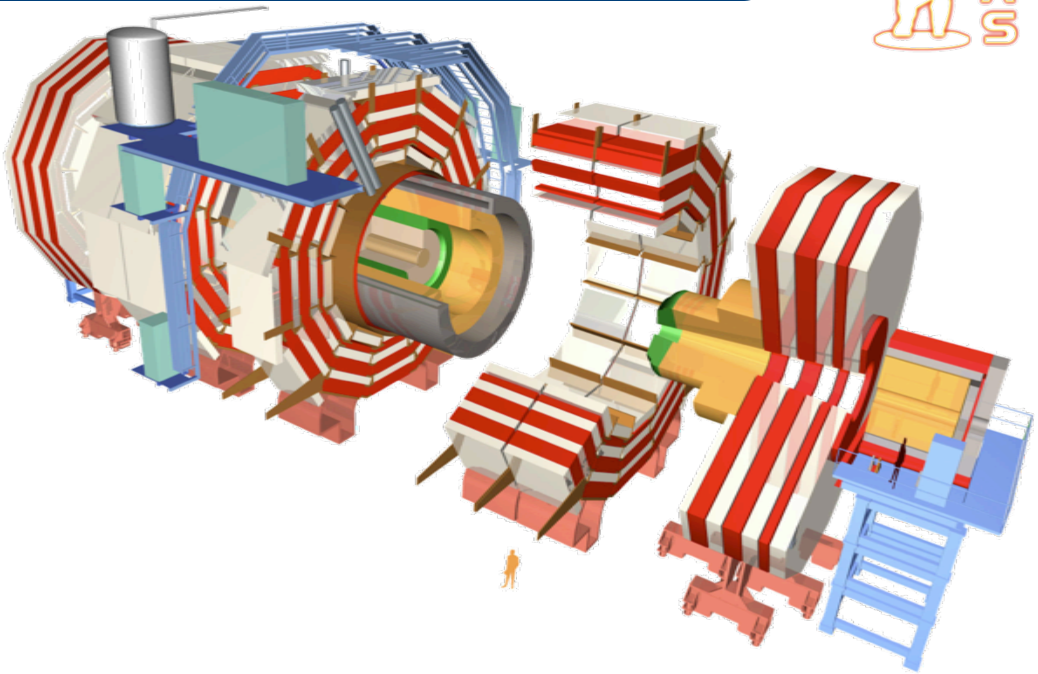
With trigger and high-precision chambers

Toroidal magnetic field



ATLAS & CMS





Super conducting toroid magnets provide magnetic field in the muon spectrometer.

EM-CAL: Accordion shaped LAr/Lead.

Solenoid in front of the EM-CAL: electros have a significant energy loss.

Inner tracker: all silicon detectors, with strong magnetic field provided by a solenoid.

EM-CAL: Crystals.

Most calorimetry insider the solenoid, this worsens the resolution.

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t-tbar Cross Section measurement using track-leptons

Object Selection

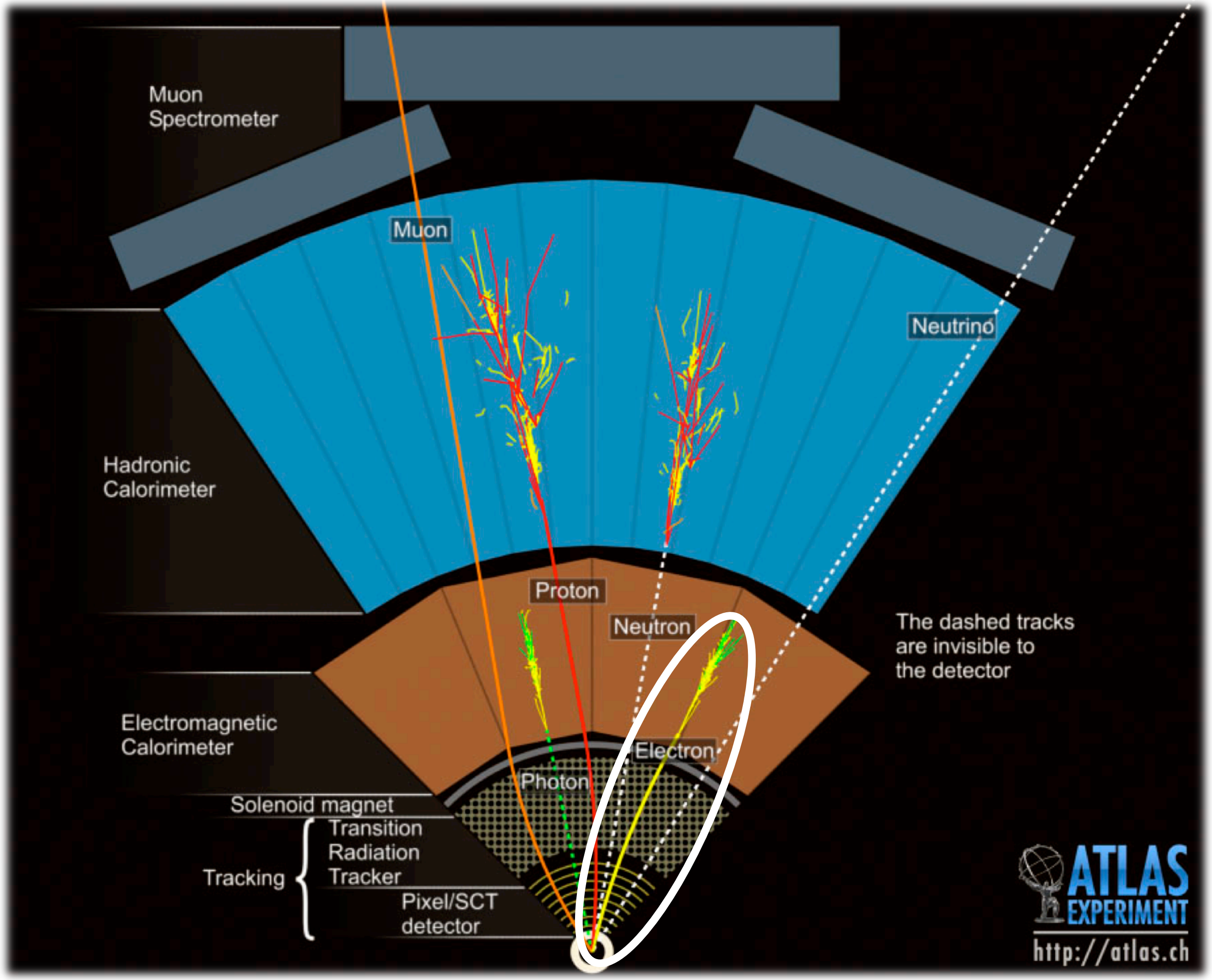
ID electrons

Isolated Electromagnetic clusters associated to Inner Detector track.

$p_T > 20$ GeV, $|\eta| < 2.47$

Exclude transition region between Barrel and End-Cap

Calo-iso($\Delta R < 0.2$) < 3.5GeV



Object Selection

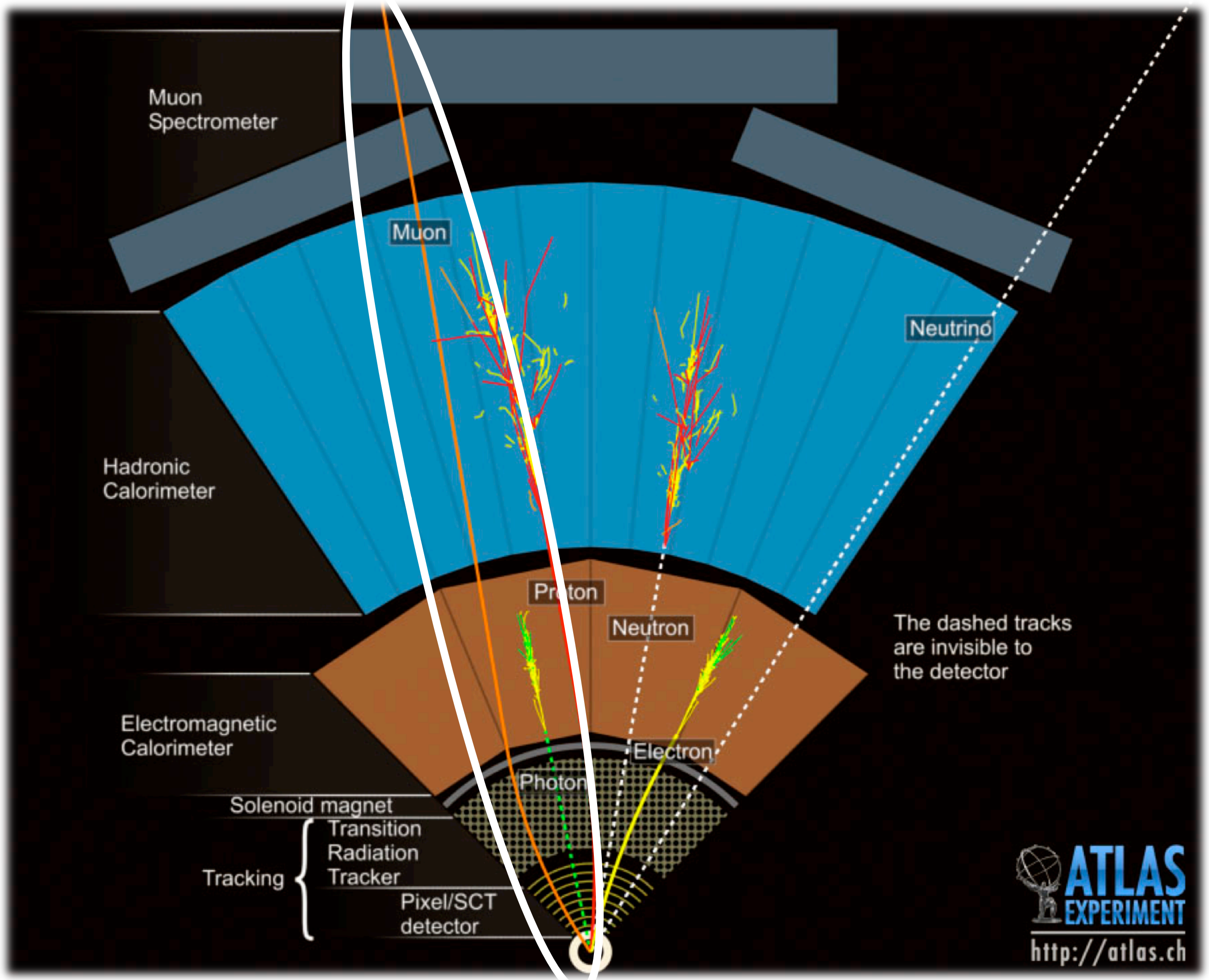
ID muons

Tracks segments from MS matched to tracks from Inner Detector, & refitted.

$p_T > 20$ GeV, $|\eta| < 2.5$

Calo-iso($\Delta R < 0.3$) < 4 GeV
Trk-iso($\Delta R < 0.3$) < 4 GeV

$|d_0| < 0.5$ mm
ΔR(muon, 20 GeV jets) > 0.4



Object Selection

Track-Leptons

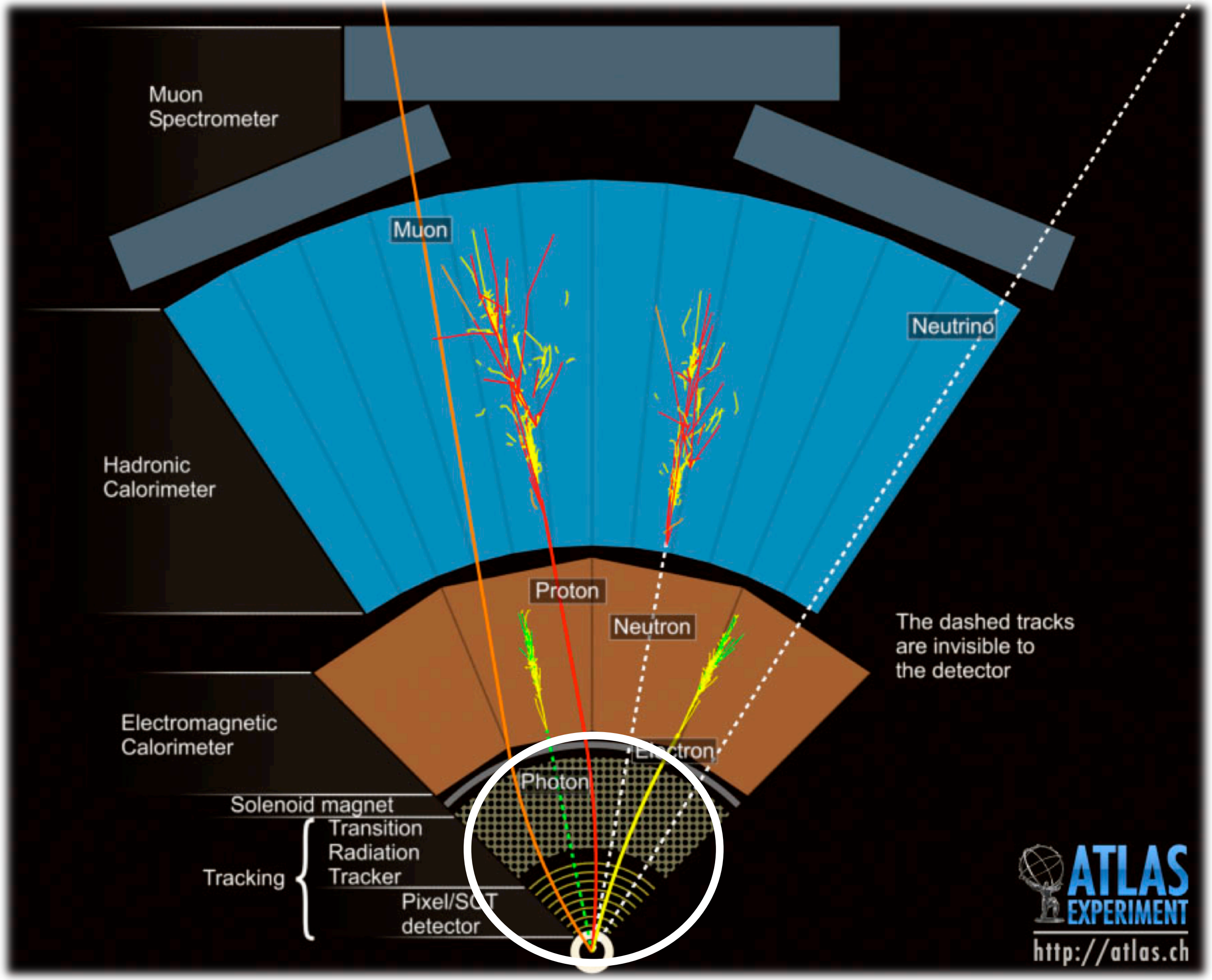
High quality
inner detector tracks

$p_T > 25$ GeV, $|\eta| < 2.4$

Trk-Iso($\Delta R < 0.3$) < 2GeV

Inner detector hit
requirements

$|d_0| < 0.2$ mm



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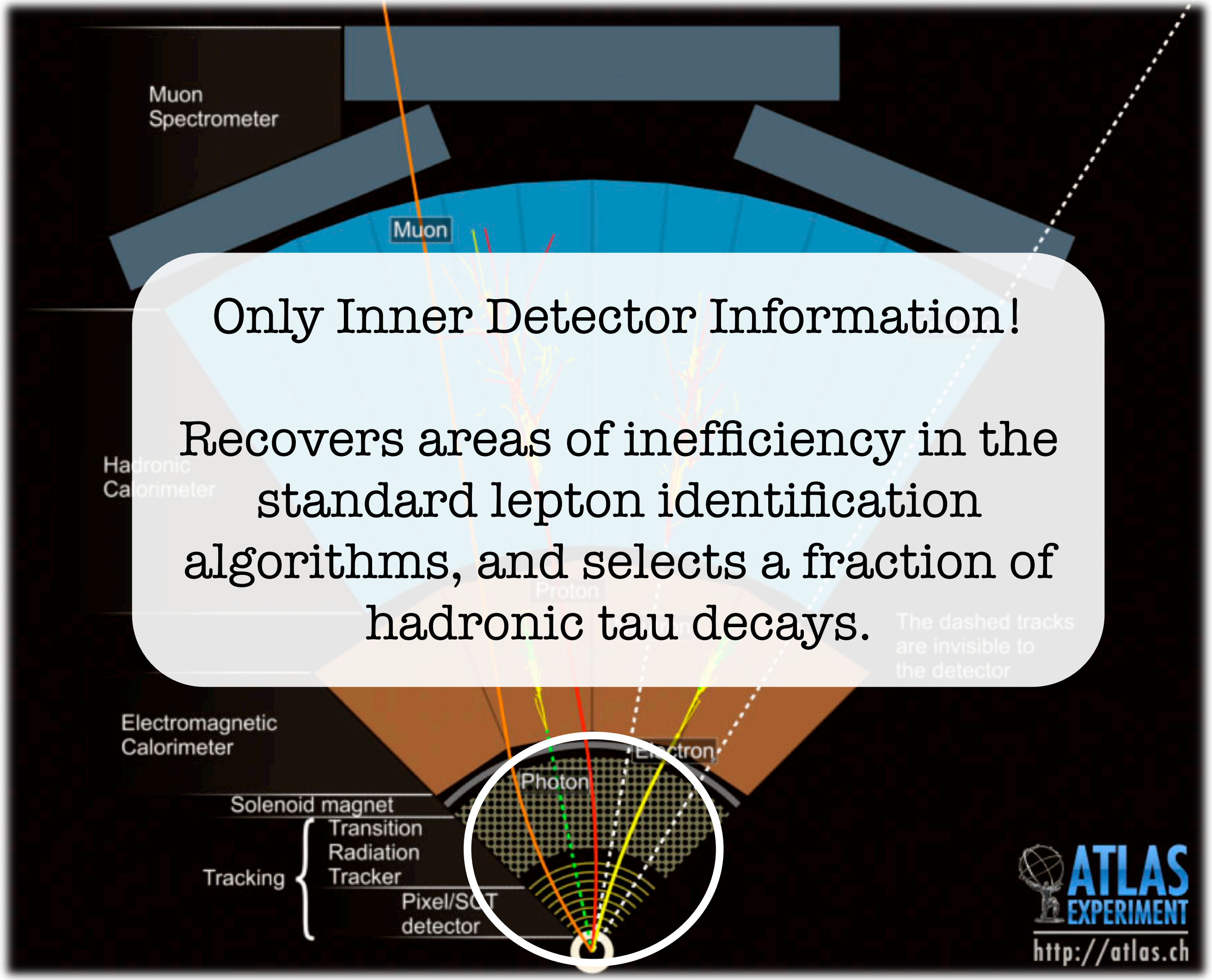


Only Inner Detector Information!

Recovers areas of inefficiency in the standard lepton identification algorithms, and selects a fraction of hadronic tau decays.

Object Selection

ID Jets

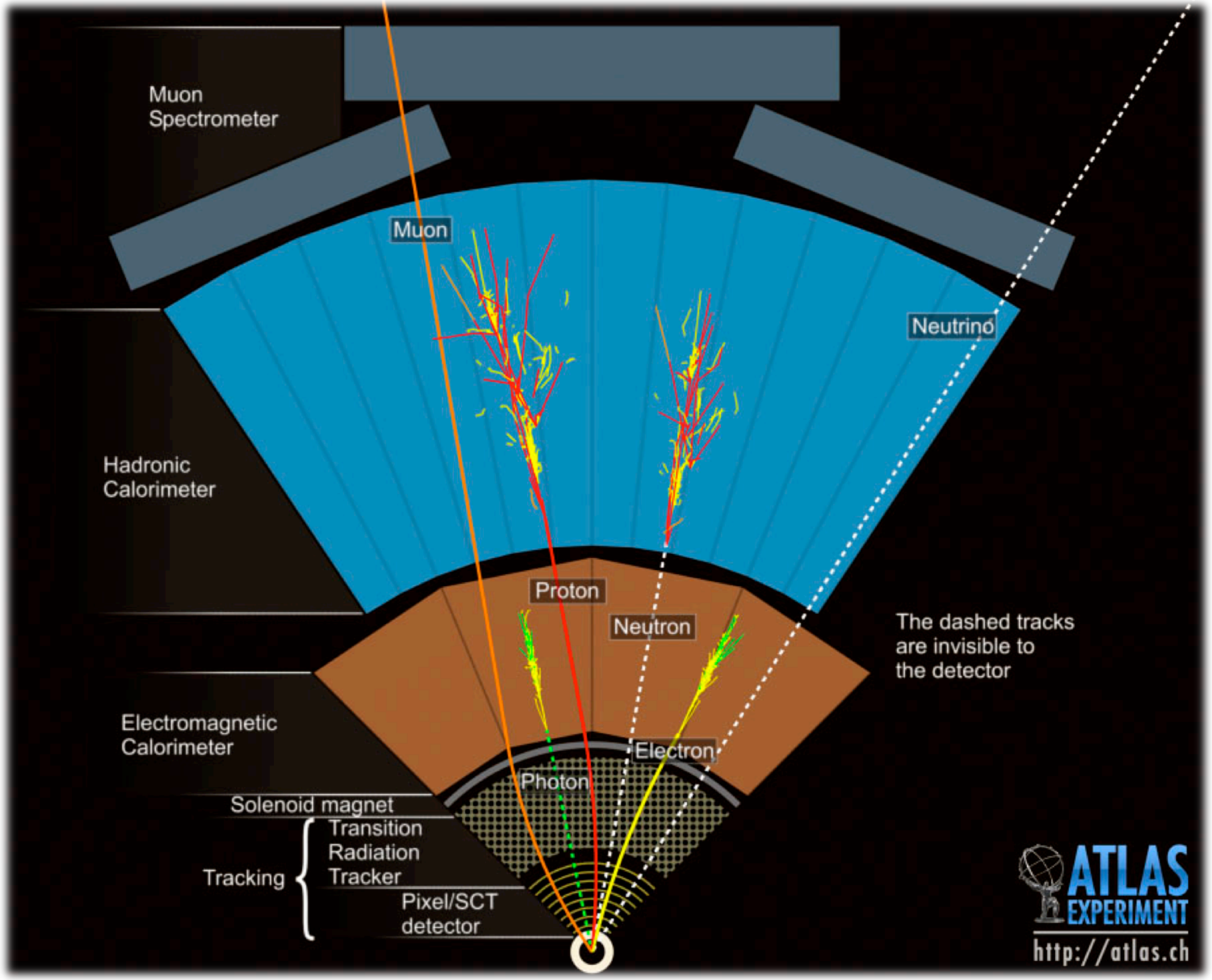
Reconstructed with anti-k_t algorithm (R=0.4), starting from energy clusters in the calorimeter.

$p_T > 25$ GeV

$|\eta| < 2.5$

ΔR(jet, TLs) > 0.4

ΔR(jet, ID electron) > 0.2



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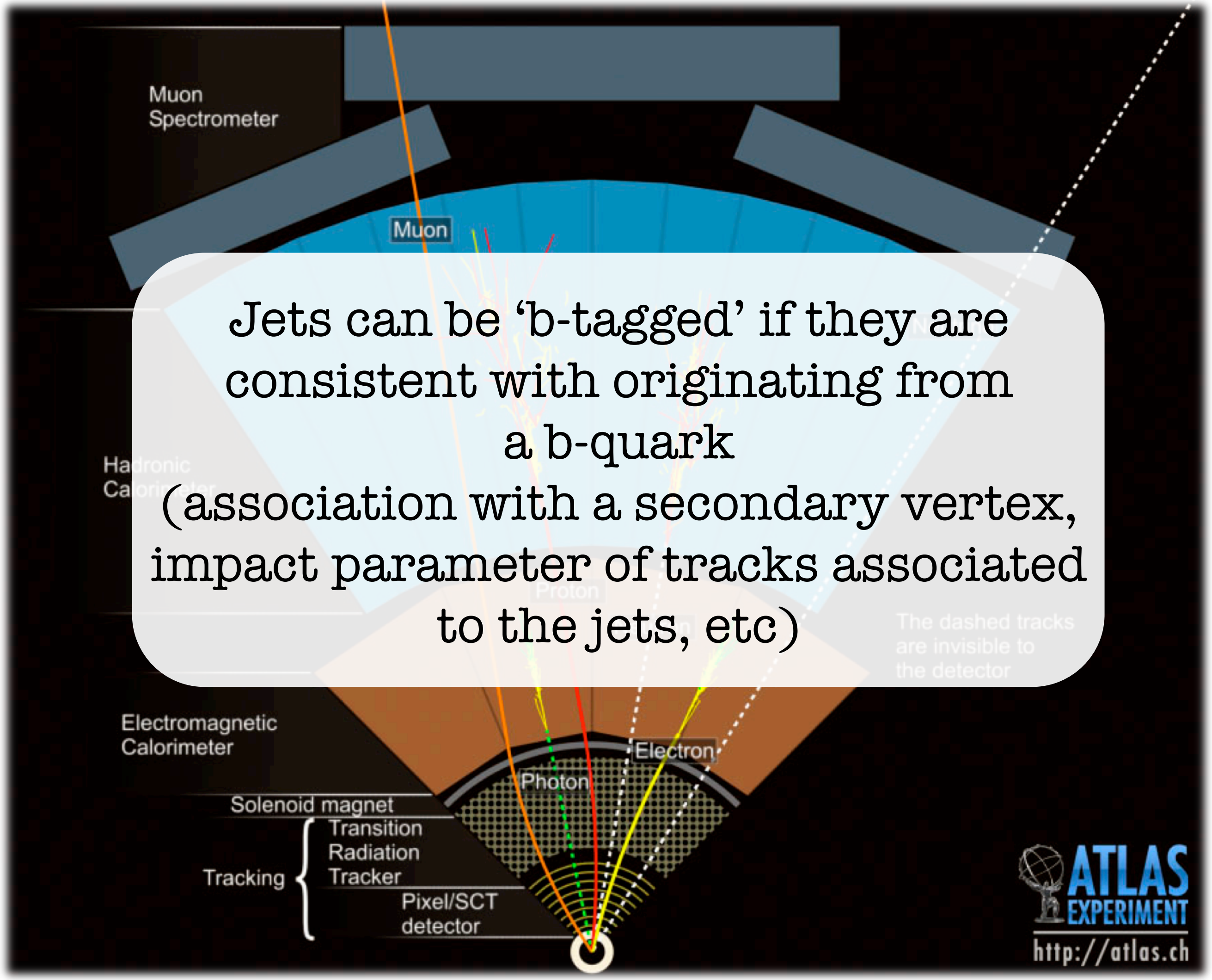
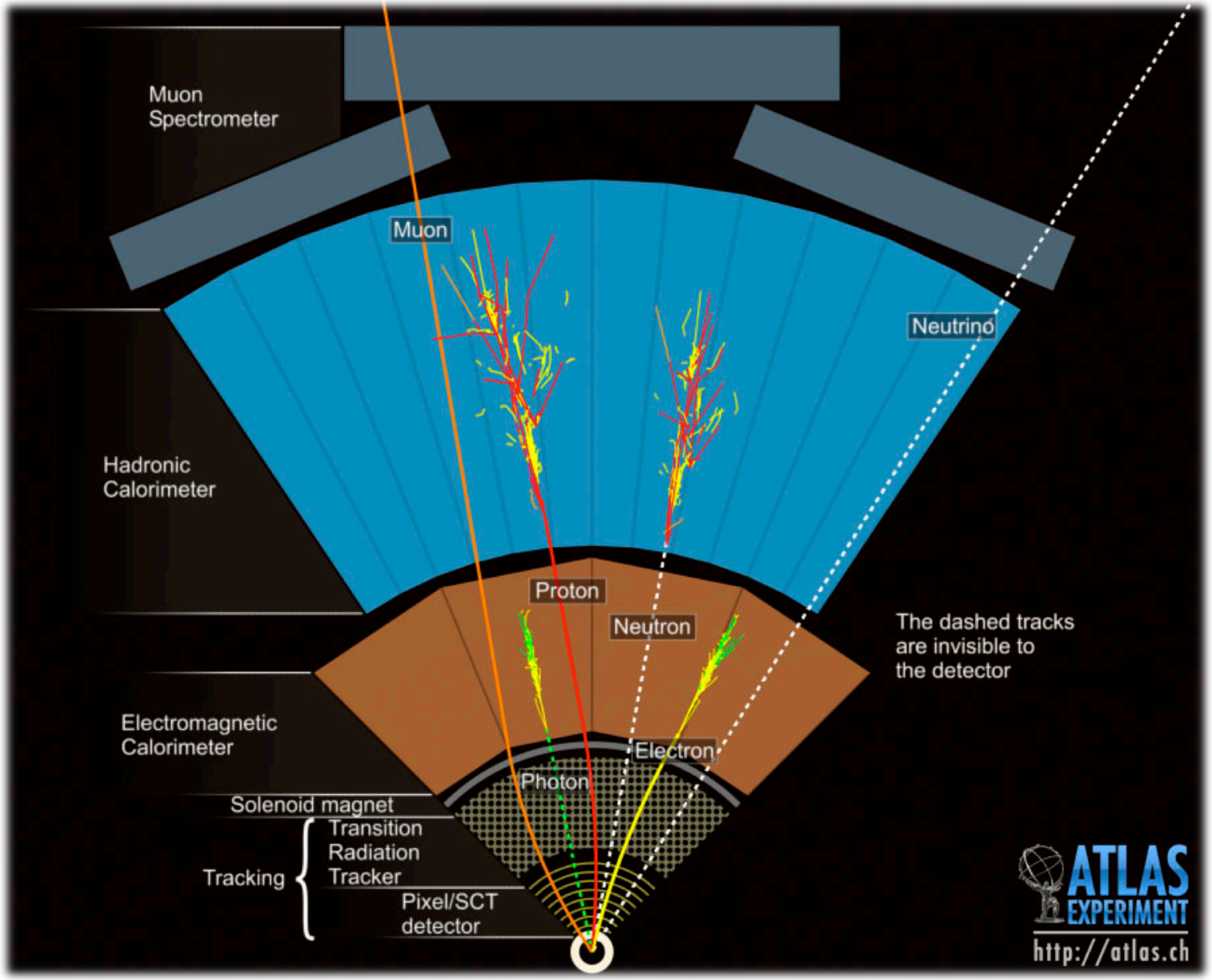


Jets can be 'b-tagged' if they are consistent with originating from a b-quark (association with a secondary vertex, impact parameter of tracks associated to the jets, etc)

Missing Transverse Energy

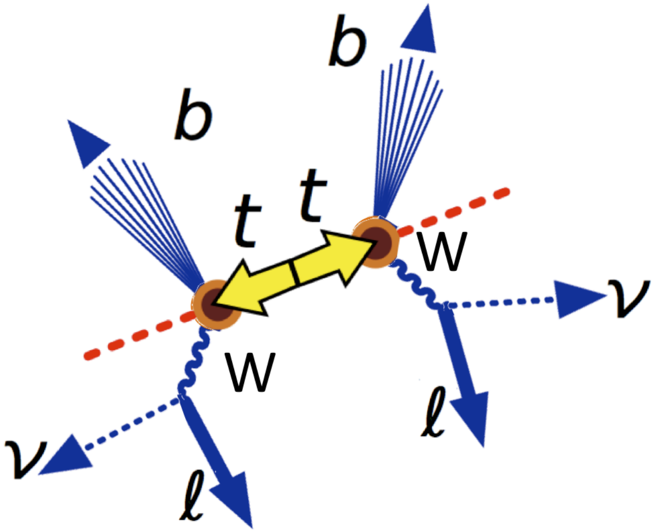
E_T^{miss}: Negative vector sum of the transverse momenta of reconstructed objects



TLs in t-tbar Cross Section Measurement

Cross Section Measurement

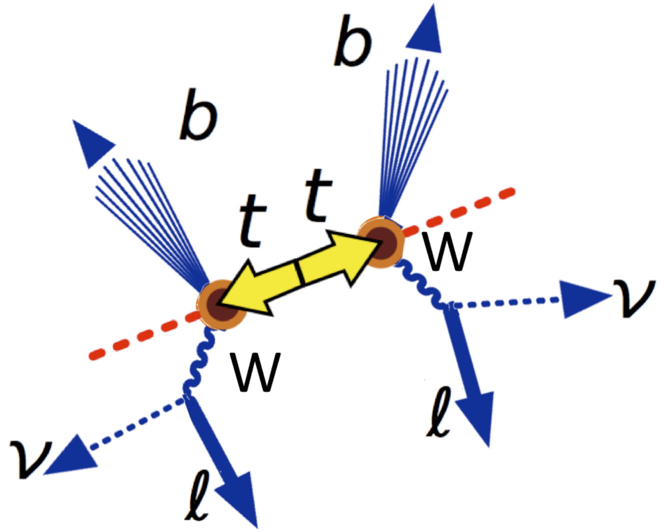
This measurement, in different decay modes, is a sensitive test of the Standard Model description of the Top Quark.



Measured the t-tbar production cross section in dilepton final states

Cross Section: Channels

This measurement, in different decay modes, is a sensitive test of the Standard Model description of the Top Quark.



Measured the t-tbar production cross section in dilepton final states

lepton + TL non b-tagged

e+track, μ+track
pair of opposite signed lepton and track.

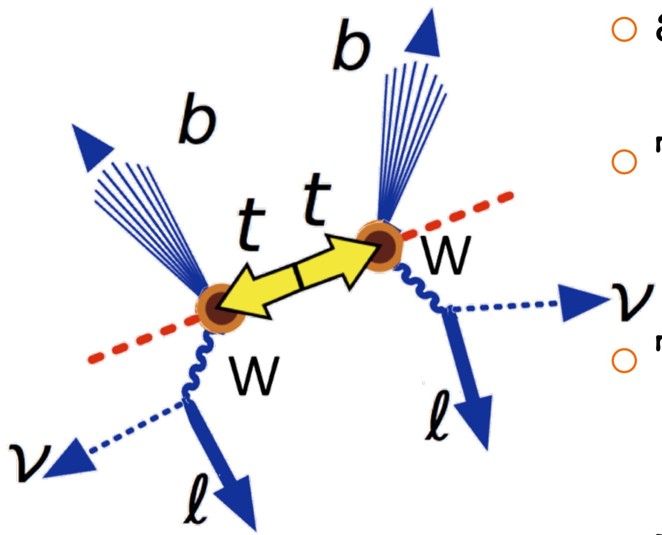
2 leptons non b-tagged

ee, eμ, μμ
pair of opposite signed leptons.

2 leptons b-tagged

ee, eμ, μμ
pair of opposite signed leptons, at least one b-tagged jet

Cross Section: Selection

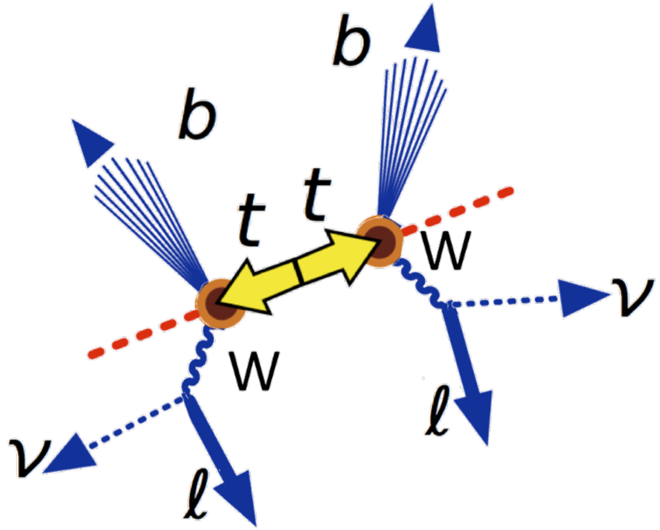


- Select a pair of opposite signed lepton and track.
- at least 2 jets with large transverse momenta
- To reject backgrounds from vector-meson decays:
  invariant mass > 15 GeV
- To suppress background from Z/γ^*+jets :
  $|\text{invariant mass} - m_Z| > 10$ GeV
- Large missing transverse energy (>45 GeV)
- Large scalar p_T sum of selected objects (>150 GeV)

Cross Section: Backgrounds

Monte Carlo
Background

Dibosons (WW, WZ, ZZ)
Single top
$Z/\gamma^* \rightarrow \tau\tau$ + jets

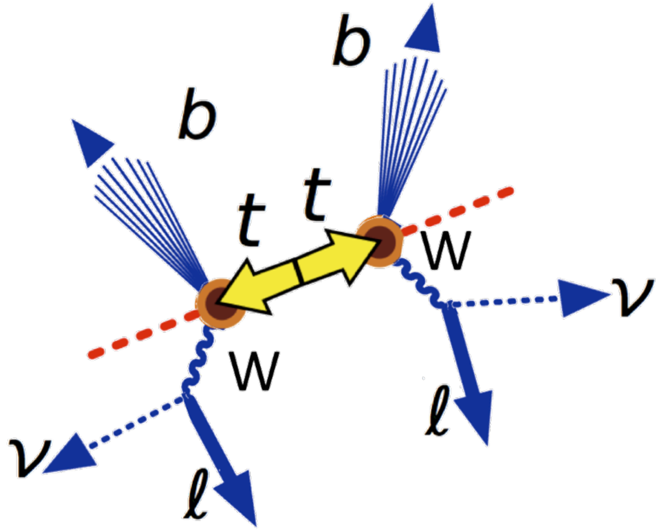


Cross Section: Backgrounds

Monte Carlo Background

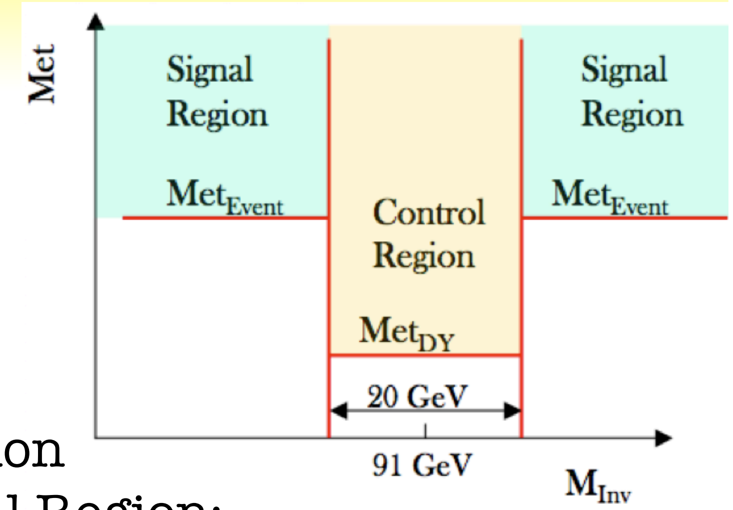
Dibosons (WW, WZ, ZZ)

Single top



Drell-Yan Background

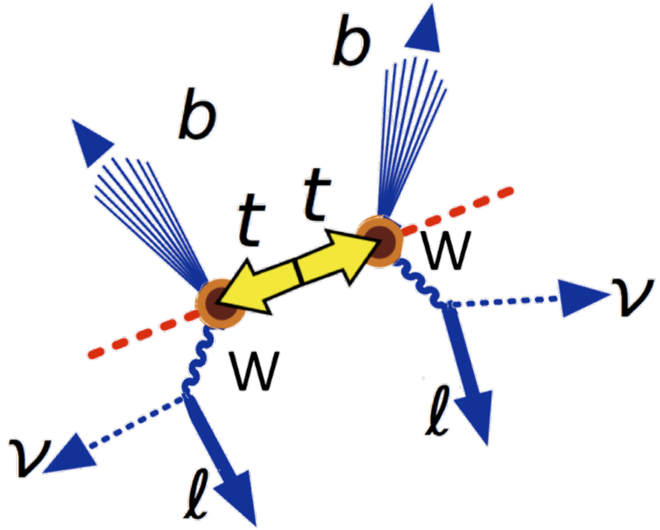
Use a Control Region to compute a normalization factor between data and Monte Carlo



Then apply the normalization factor in Monte Carlo Signal Region:

$$[N^{\rm Data}_{Z+{\rm jets}}]_{\rm SR} = \left[\frac{N^{\rm Data} - N^{\rm MC}_{\rm Other\ \ backgrounds}}{N^{\rm MC}_{Z+{\rm jets}}}\right]_{\rm CR} \cdot [N^{\rm MC}_{Z+{\rm jets}}]_{\rm SR}$$

Cross Section: Backgrounds



Monte Carlo Background

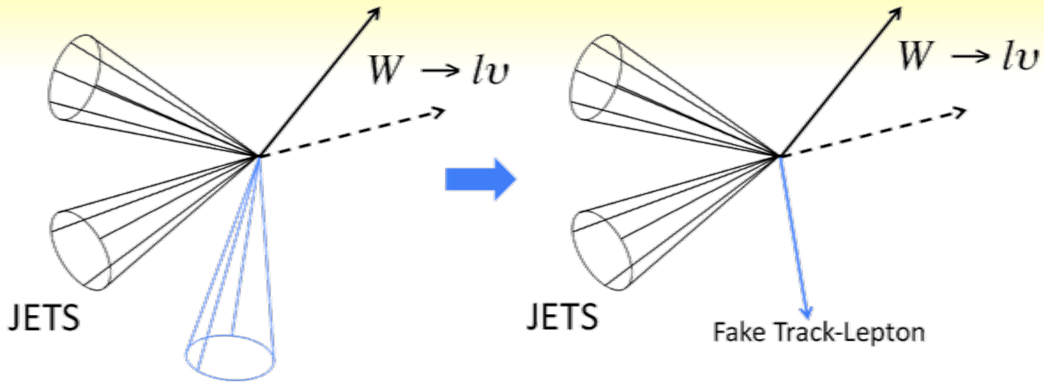
Dibosor…

Drell-Yan Background

Z/…

$[N^{\text{Data}}_{Z+\text{jets}}]_{\text{SR}} = \left[N^{\text{Data}} - N^{\text{MC}}_{\text{Other backgrounds}} \right] \cdot [N^{\text{MC}}_{Z+\text{jets}}]_{\text{SR}}$ …

Fakes Background

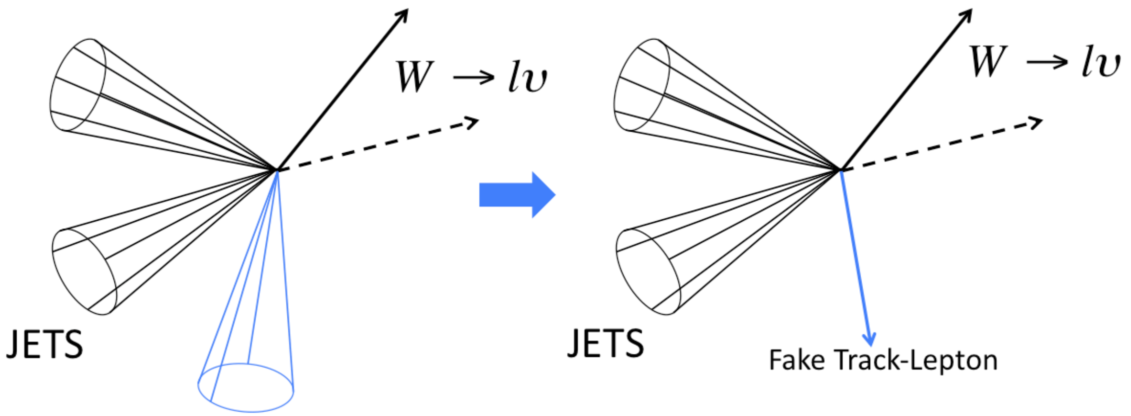


Main background

Fakes Background

Strategy

We measure the probability that a jet fakes a track



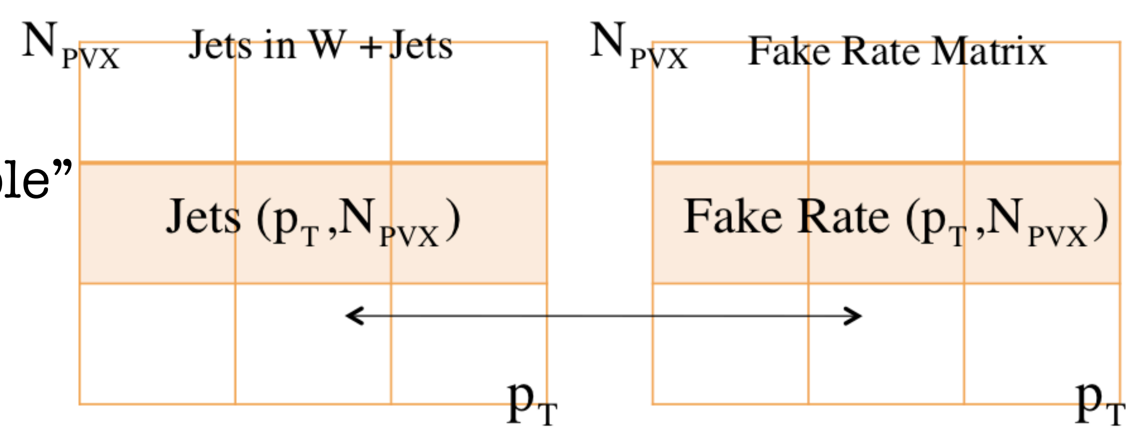
$$\text{Fake Rate}\left(p_T, N_{PVX}\right) = \frac{(p_T, N_{PVX}) \text{ of all selected tracks}}{(p_T, N_{PVX}) \text{ of all ID jets \& jet} - \text{elements}}$$

We do this in γ+jets events from data (Photon trigger, high p_T, isolated photon)

Fakes Background

Strategy

Jets in "parent sample"
(lepton + jets)



$$\text{Prediction} = \sum_{(p_T, N_{PVX})} \text{Jets}_{(p_T, N_{PVX})} \times \text{Fake Rate}_{(p_T, N_{PVX})}$$

Finally, the prediction must be multiplied by the fraction of fake tracks that have opposite charge to the lepton. This fraction is taken from MC in each jet multiplicity.

Fakes Background

Test the method in control regions

Performed test in Z+jets and **W+jets** events

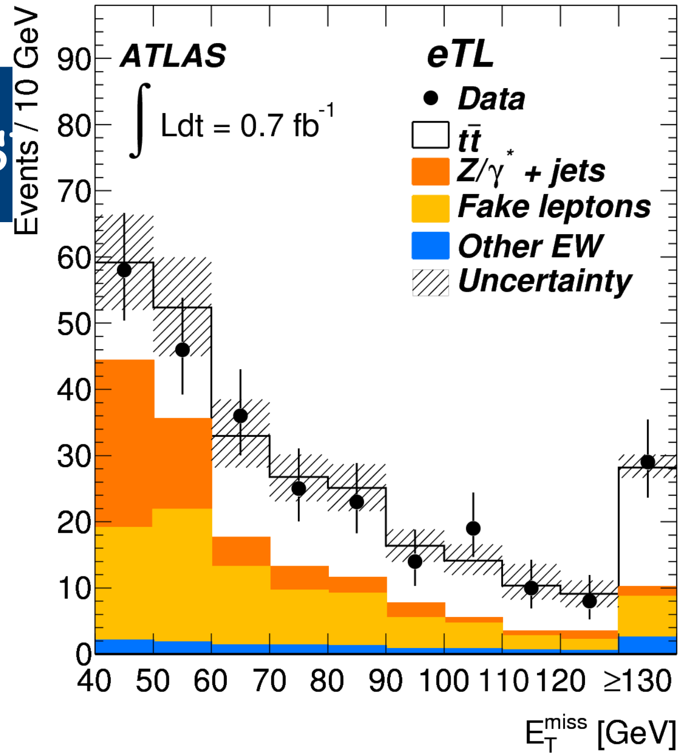
#jets	eTL O	eTL B	eTL P	eTL (B-O)/P [%]	μTL O	μTL B	μTL P	μTL (B-O)/P [%]
0 (OS)	411	$436.3^{+38.4}_{-36.8}$	199.1 ± 9.3		460	$441.1^{+52.9}_{-52.0}$	321.9 ± 48.4	
1 (OS)	201	$207.1^{+16.9}_{-27.3}$	99.0 ± 4.2		247	$270.5^{+17.2}_{-16.5}$	142.5 ± 6.0	
2 (SS)	10	10.7 ± 0.8	7.6 ± 0.7		14	13.9 ± 1.0	11.1 ± 0.9	
3 (SS)	7	6.2 ± 0.5	5.4 ± 0.5		9	8.3 ± 0.7	7.0 ± 0.6	
4 (SS)	4	4.1 ± 0.4	3.8 ± 0.4		1	3.2 ± 0.4	3.1 ± 0.4	
≥ 5 (SS)	2	1.9 ± 0.1	1.8 ± 0.1		0	1.5 ± 0.2	1.4 ± 0.2	
Total	635	$666.4^{+41.9}_{-45.8}$	316.6 ± 10.3	$9.9^{+15.6}_{-16.5}$	731	$738.5^{+55.6}_{-54.6}$	487.0 ± 48.8	$1.5^{+12.7}_{-12.5}$

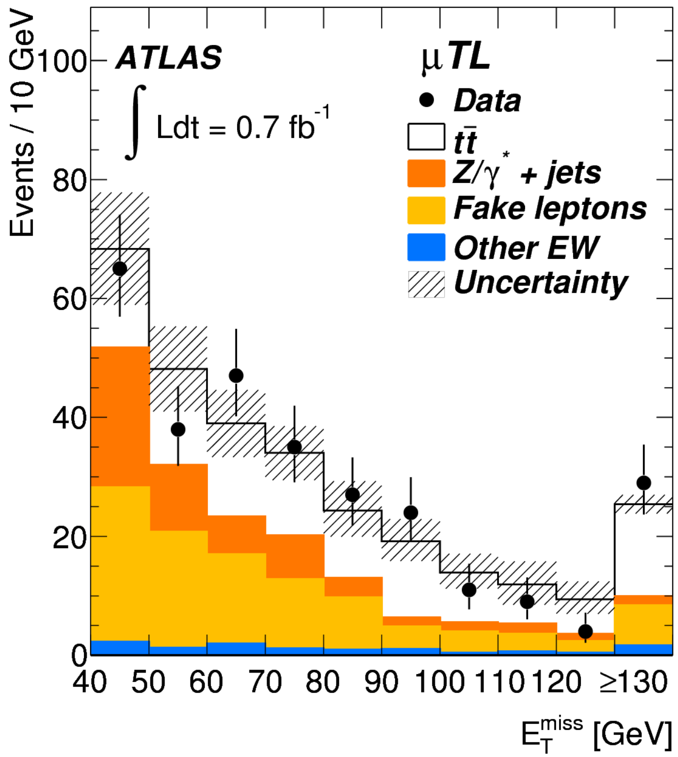
Background: includes the contribution from other sources (Z/γ^*, diboson, single top)
Prediction: contribution from fakes prediction only.

By comparing the agreement between prediction and observation, we estimate a 20% systematic uncertainty on the fake prediction

Cross Section: Res

	eTL	μTL
Z/γ^*+ jets	$24.3^{+10.7}_{-9.4}$	$22.0^{+5.3}_{-5.8}$
$Z/\gamma^* \to \tau\tau$+jets	$17.0^{+8.4}_{-7.6}$	25 ± 11
Fake leptons	74 ± 15	85 ± 17
Single top quark	$5.7^{+1.0}_{-0.9}$	$6.3^{+0.8}_{-1.1}$
Diboson	$5.9^{+0.9}_{-0.8}$	$4.8^{+0.6}_{-0.7}$
Total background	126^{+20}_{-19}	142 ± 21
Predicted $t\bar{t}$	$112\ ^{+16}_{-18}$	$110\ ^{+17}_{-16}$
Total	239 ± 26	253 ± 27
Observed	236	255

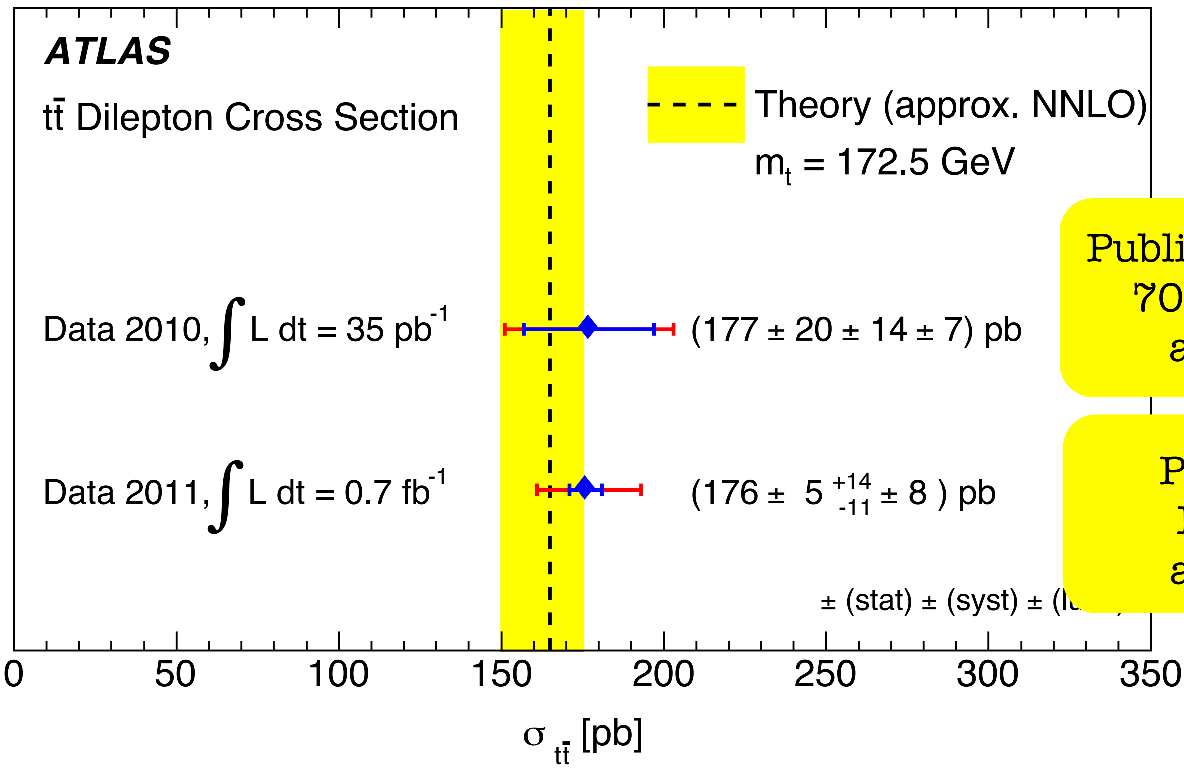




Cross Section: Results

Cut & count study

$$\sigma_{t\bar{t}} = \frac{N_{obs} - N_{bkg}}{A \bullet \varepsilon \bullet \int Ldt}$$



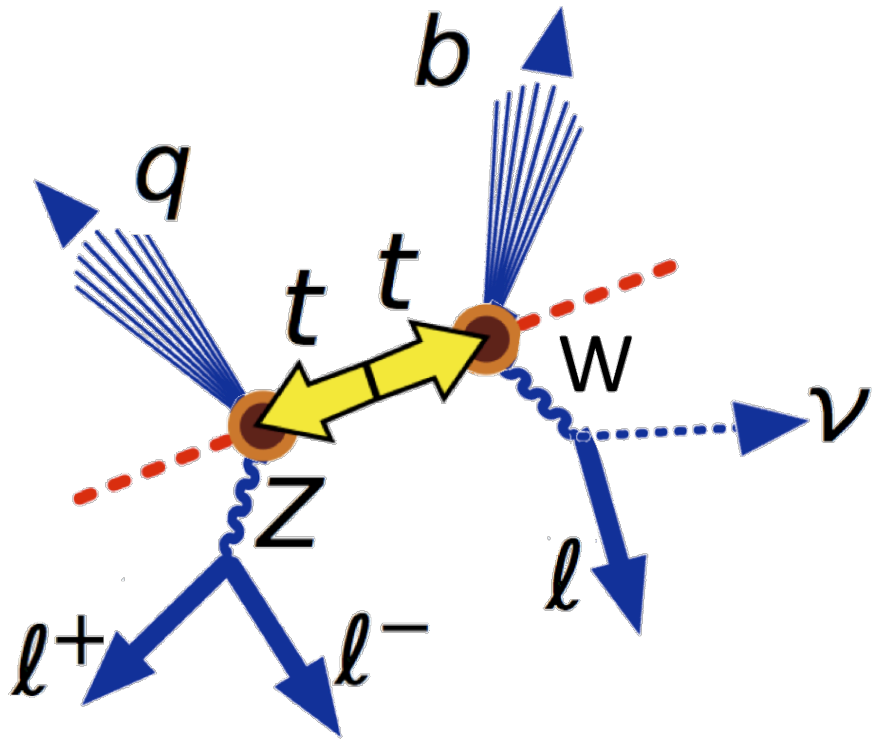
Published in Phys. Lett.B. 707 (2012) 459-477 arXiv:1108.3699

Published in JHEP 1205 (2012) 059 arXiv:1202.4892

Back to FCNC...

FCNC Search: Event Selection

The final state is characterized by three isolated leptons, two of them reconstructing a Z-boson, missing energy, and at least two jets.



Event Selection

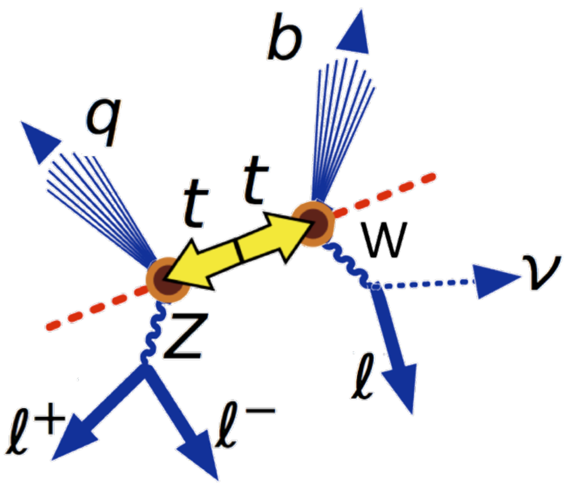
There are two orthogonal channels used for the final result:

2 ID + TL

2 leptons are fully identified, and the third one is allowed to be a high quality inner detector track.

3 ID

Selects 3 fully identified leptons (e, μ).



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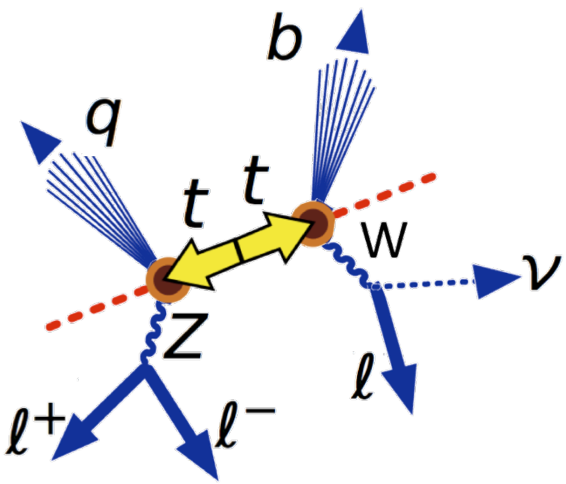


Track-leptons (**TL**) are exclusive of any electrons or muons (**ID** Leptons) selected by the 3ID analysis.

Event Selection

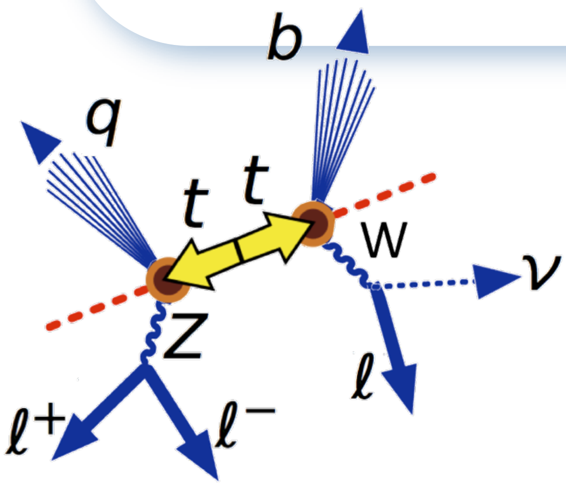
Preselection

- Basic Cuts, Trigger
- Exactly three leptons
  - all matched to the same Primary Vertex

2ID+TL
Two ID leptons + one TL
$P_T^{TL} > 25$ GeV, $P_T^{e,\mu} > 20$ GeV

3ID
Three ID leptons
$P_T^{lead} > 25$ GeV, $P_T^{sublead} > 20$ GeV

- Two leptons of the same flavor and opposite charge
- $E_T^{miss} > 20$ GeV



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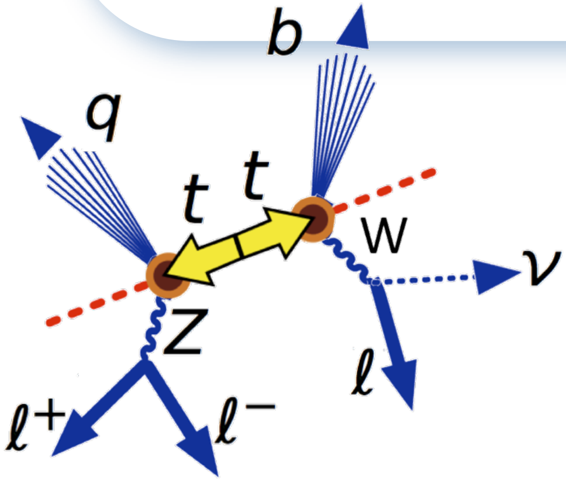
- Two or more ID jets

2ID+TL At least one jet b-tagged



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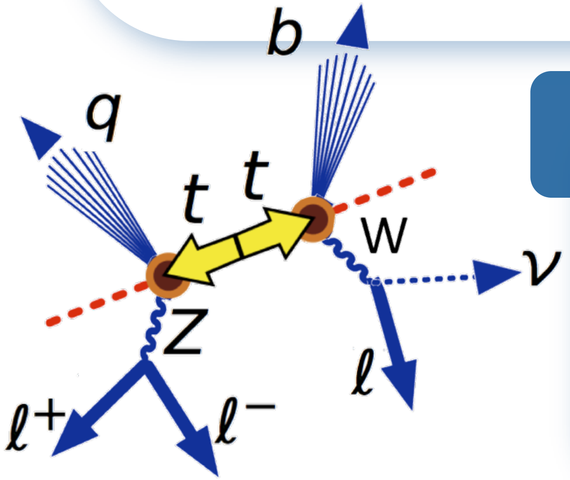

Final Selection

- Event Reconstruction

$$\chi^2 = \frac{\left(m^{reco}_{j_a\ell_a\ell_b} - m_t\right)^2}{\sigma_t^2} + \frac{\left(m^{reco}_{j_b\ell_c\nu} - m_t\right)^2}{\sigma_t^2} + \frac{\left(m^{reco}_{\ell_c\nu} - m_W\right)^2}{\sigma_W^2} + \frac{\left(m^{reco}_{\ell_a\ell_b} - m_Z\right)^2}{\sigma_Z^2}$$

Event Selection

Final Selection

- Event Reconstruction

To reconstruct the mass of the two top quarks and W- and Z-bosons , χ^2 is minimized:

$$\chi^2 = \frac{\left(m^{\mathrm{reco}}_{j_a\ell_a\ell_b} - m_t\right)^2}{\sigma_t^2} + \frac{\left(m^{\mathrm{reco}}_{j_b\ell_c\nu} - m_t\right)^2}{\sigma_t^2} + \frac{\left(m^{\mathrm{reco}}_{\ell_c\nu} - m_W\right)^2}{\sigma_W^2} + \frac{\left(m^{\mathrm{reco}}_{\ell_a\ell_b} - m_Z\right)^2}{\sigma_Z^2}$$

Event Selection

Final Selection

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- j_a, j_b loops over the two leading ID jets

$$\begin{aligned} m_t &= 172.5 \text{ GeV} & \sigma_t &= 14 \text{ GeV} \\ m_W &= 80.4 \text{ GeV} & \sigma_W &= 10 \text{ GeV} \\ m_Z &= 91.2 \text{ GeV} & \sigma_Z &= 3 \text{ GeV} \end{aligned}$$

Event Selection

Final Selection

- Event Reconstruction

To reconstruct the mass of the two top quarks and W- and Z-bosons , χ^2 is minimized:

$$\chi^2 = \frac{\left(m^{\mathrm{reco}}_{j_a\ell_a\ell_b} - m_t\right)^2}{\sigma_t^2} + \frac{\left(m^{\mathrm{reco}}_{j_b\ell_c\nu} - m_t\right)^2}{\sigma_t^2} + \frac{\left(m^{\mathrm{reco}}_{\ell_c\nu} - m_W\right)^2}{\sigma_W^2} + \frac{\left(m^{\mathrm{reco}}_{\ell_a\ell_b} - m_Z\right)^2}{\sigma_Z^2}$$

- j_a, j_b loops over the two leading ID jets
- ℓ_c, $Z \rightarrow \ell_a^+ \ell_b^-$: loop over the three leptons

$$\begin{aligned} m_t &= 172.5\ \mathrm{GeV} & \sigma_t &= 14\ \mathrm{GeV} \\ m_W &= 80.4\ \mathrm{GeV} & \sigma_W &= 10\ \mathrm{GeV} \\ m_Z &= 91.2\ \mathrm{GeV} & \sigma_Z &= 3\ \mathrm{GeV} \end{aligned}$$

Event Selection

Final Selection

- Event Reconstruction

To reconstruct the mass of the two top quarks and W- and Z-bosons , χ^2 is minimized:

$$\chi^2 = \frac{\left(m^{\text{reco}}_{j_a\ell_a\ell_b} - m_t\right)^2}{\sigma_t^2} + \frac{\left(m^{\text{reco}}_{j_b\ell_c\nu} - m_t\right)^2}{\sigma_t^2} + \frac{\left(m^{\text{reco}}_{\ell_c\nu} - m_W\right)^2}{\sigma_W^2} + \frac{\left(m^{\text{reco}}_{\ell_a\ell_b} - m_Z\right)^2}{\sigma_Z^2}$$

- j_a, j_b loops over the two leading ID jets
- ℓ_c, $Z \rightarrow \ell_a^+ \ell_b^-$: loop over the three leptons
- E_T^{miss} is taken to be the transverse component of the neutrino p_T^ν.
- p_Z^ν is the determined by the minimal χ^2

$$m_t = 172.5 \text{ GeV} \qquad \sigma_t = 14 \text{ GeV}$$
$$m_W = 80.4 \text{ GeV} \qquad \sigma_W = 10 \text{ GeV}$$
$$m_Z = 91.2 \text{ GeV} \qquad \sigma_Z = 3 \text{ GeV}$$

Event Selection

Preselection

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2ID+TL Two ID leptons + one TL
$P_T^{TL} > 25$ GeV, $P_T^{e,\mu} > 20$ GeV

3ID Three ID leptons
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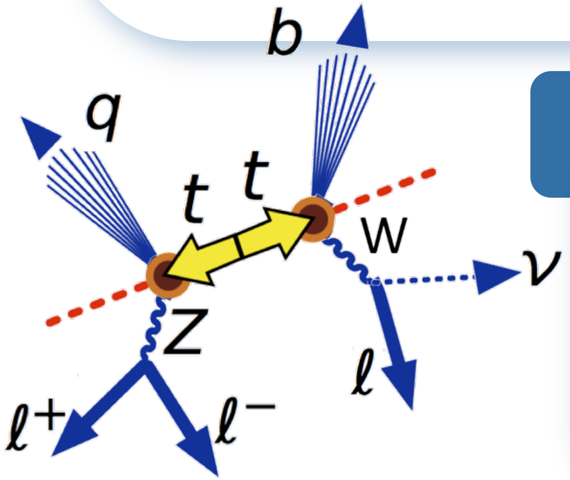
- Two leptons of the same flavor and opposite charge
- $E_T^{miss} > 20$ GeV
- Two or more ID jets

2ID+TL At least one jet b-tagged



Final Selection

- Event Reconstruction
  - $|m_Z - m_Z^{reco}| < 15$ GeV
  - $|m_W - m_W^{reco}| < 30$ GeV
  - $|m_t - m_t^{reco}| < 40$ GeV

Gain from 2ID+TL

The 2ID+TL gives a 22% gain wrt the 3ID channel alone.

Gain

This gain comes mainly from e and μ in the transition regions and gaps in detector coverage.

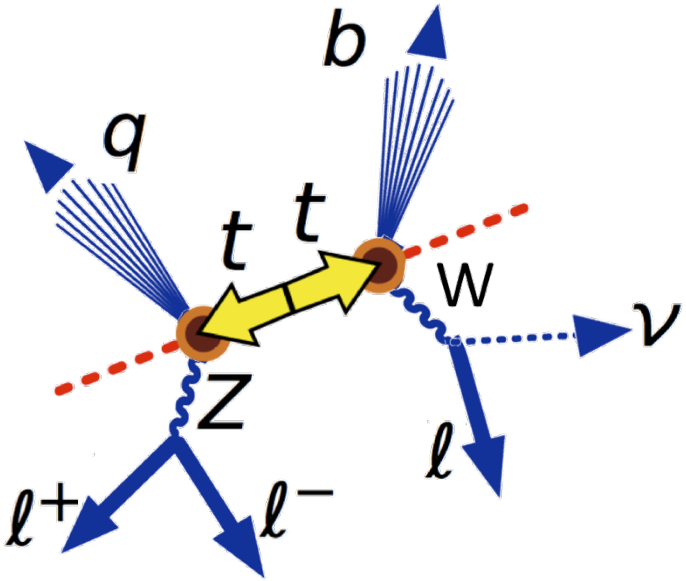
There is also a partial recovery of efficiency losses in the e and μ selection and additional acceptance from hadronic taus.

Outline

- Top Quark Physics
  - Motivation
- ATLAS Detector
- Object and Event Selection
  - Track-Lepton
- Backgrounds
- Systematic Uncertainties
- Limit Calculation
- Conclusions

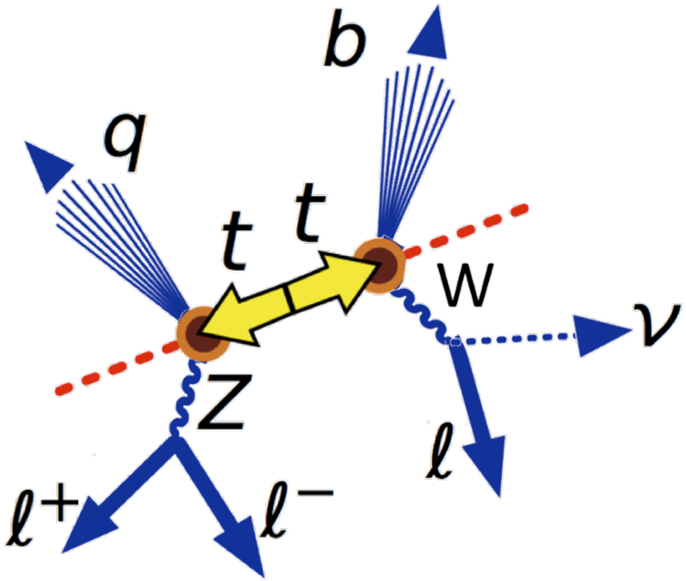
Backgrounds

SM processes that have a similar final state topology



Backgrounds

SM processes that have a similar final state topology



Three real leptons

Dibosons (WZ, ZZ)
t-tbar + W, t-tbar + Z

At least one fake lepton

t-tbar, Z+jets, W+jets,
WW, single top

Three real leptons background

Three real leptons

Dibosons WZ, ZZ
t-tbar+W, t-tbar+Z

Determined using MC samples.

Contributes to ~15% of the 2ID + TL background.
Main background for the 3ID selection

Fake leptons background

Fake leptons

t-tbar, Z+jets, W+jets, WW, single top

Events with at least one fake → any object identified as a lepton that does not come from a W- or Z-boson.

Evaluated with a data-driven (and MC) methods.

Dominant background source of the 2ID + TL.

Fake leptons background

3ID Fake leptons

The background from fake leptons is estimated for events with one fake leptons, and events with 2 or 3 fake leptons.

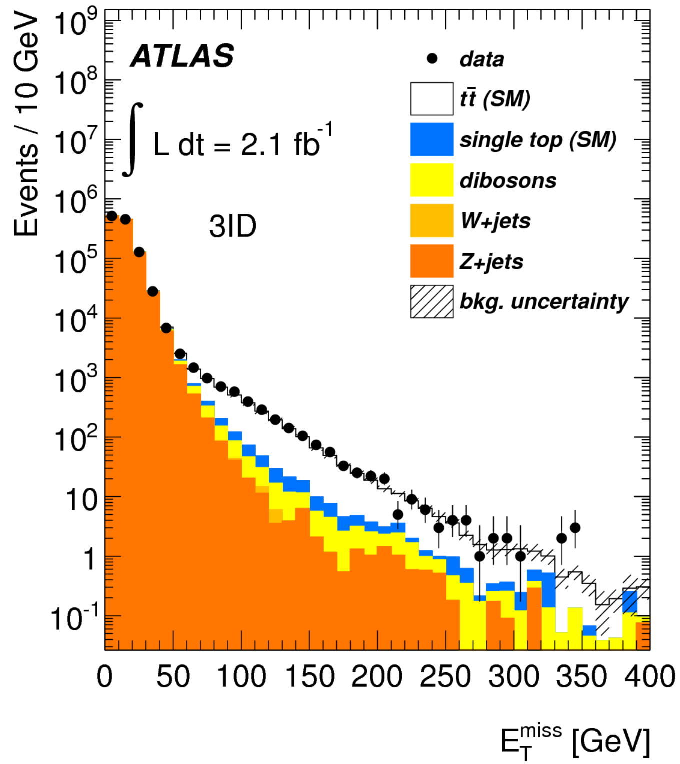
One fake events

- Z+jets

We use a control region to compute a **normalization** between data and MC.
Control region: Events with two leptons and $|m_{\ell\ell}^{reco} - 91.2\text{ GeV}| < 15\text{ GeV}$.

$$[N^{\text{Data}}_{Z+\text{jets}}]_{\text{SR}} = \left[\frac{N^{\text{Data}} - N^{\text{MC}}_{\text{Other backgrounds}}}{N^{\text{MC}}_{Z+\text{jets}}}\right]_{\text{CR}} \cdot [N^{\text{MC}}_{Z+\text{jets}}]_{\text{SR}}$$

A loose lepton selection is used, and a multiplicative factor is applied to the final result: (loose → tight) 0.063 ± 0.013



Fake leptons background

3ID Fake leptons

The background from fake leptons is estimated for events with one fake leptons, and events with 2 or 3 fake leptons.

One fake events

- Z+jets

We use a control region to compute a **normalization** between data and MC.
A loose lepton selection is used, and a multiplicative factor is applied to the final result:
(loose → tight) 0.063 ± 0.013

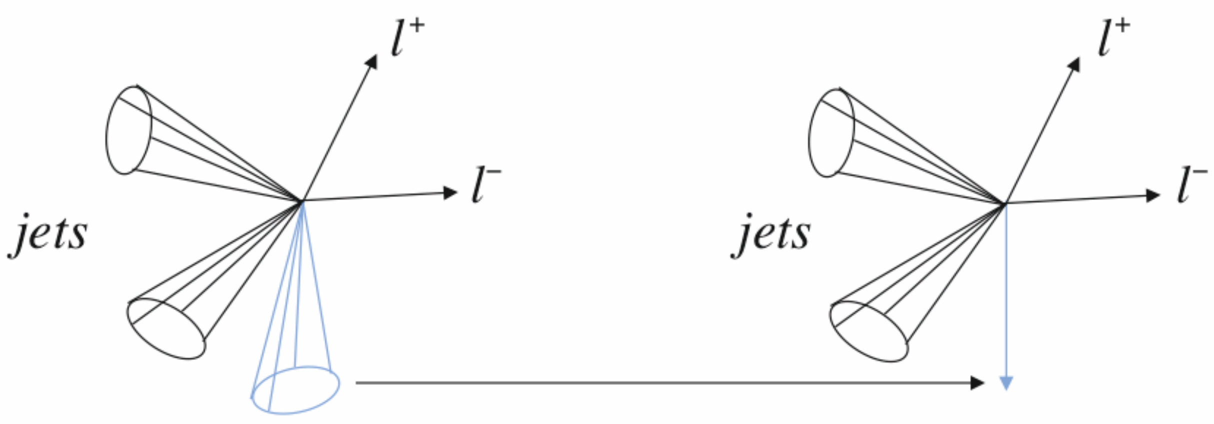
- Dileptonic t-tbar, single top (Wt), WW.

Measured in MC with the loose lepton selection, and scaled down by the same factor.

Fake leptons background

2ID+TL Fake leptons

Same strategy as in the cross section analysis.



$$\text{Fake Rate}\,(p_T, N_{\text{PVX}}) \;=\; \frac{(p_T, N_{\text{PVX}})\ \text{of all selected track leptons}}{(p_T, N_{\text{PVX}})\ \text{of all ID jets \& jet} - \text{elements}}$$

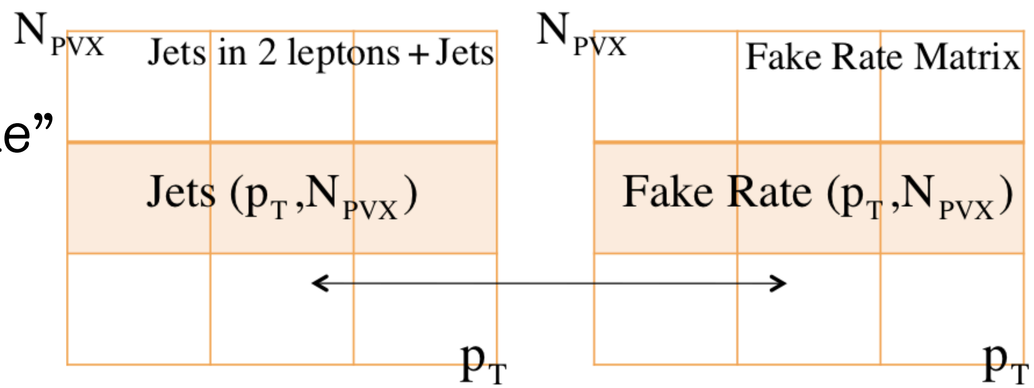
Measure the fake rates in γ+jets events

Fake leptons background

2ID+TL Fake leptons

Same strategy as in the cross section analysis.

Jets in "parent sample"
(2 leptons + jets)



$$\text{Prediction} = \sum_{(p_T, N_{PVX})} \text{Jets}_{(p_T, N_{PVX})} \times \text{Fake Rate}_{(p_T, N_{PVX})}$$

Z-boson candidate? 3 different cases for the parent sample:

- OS ID leptons → $TL^{\pm}$
- SS ID leptons (+) → TL^{-}
- SS ID leptons (−) → TL^{+}

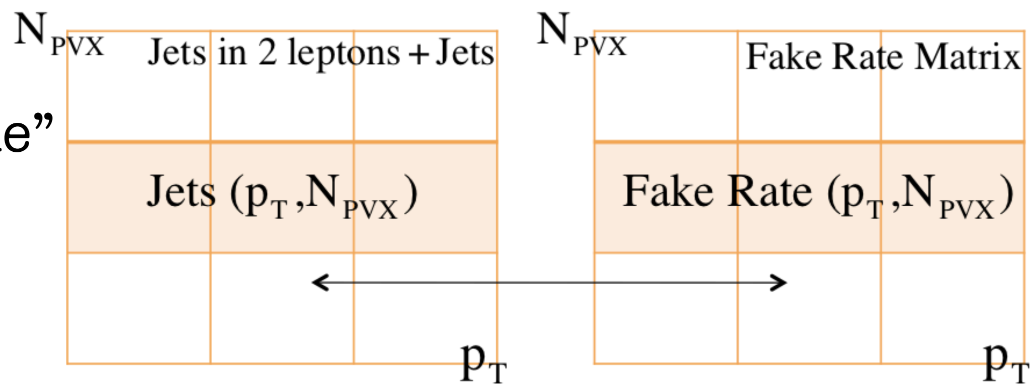
(use corresponding fakes matrix)

Fake leptons background

2ID+TL Fake leptons

Same strategy as in the cross section analysis.

Jets in "parent sample"
(2 leptons + jets)



$$\text{Prediction} = \sum_{(p_T, N_{PVX})} \text{Jets}_{(p_T, N_{PVX})} \times \text{Fake Rate}_{(p_T, N_{PVX})}$$

b-tagging?

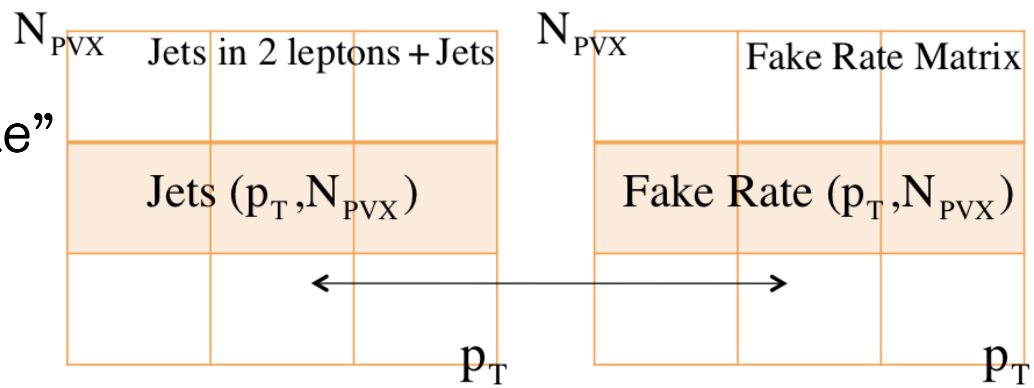
Since a jet within ΔR<0.4 of a TL is removed → a b-jet contributes to the prediction if there's another b-jet.

Fake leptons background

2ID+TL Fake leptons

Same strategy as in the cross section analysis.

Jets in "parent sample"
(2 leptons + jets)

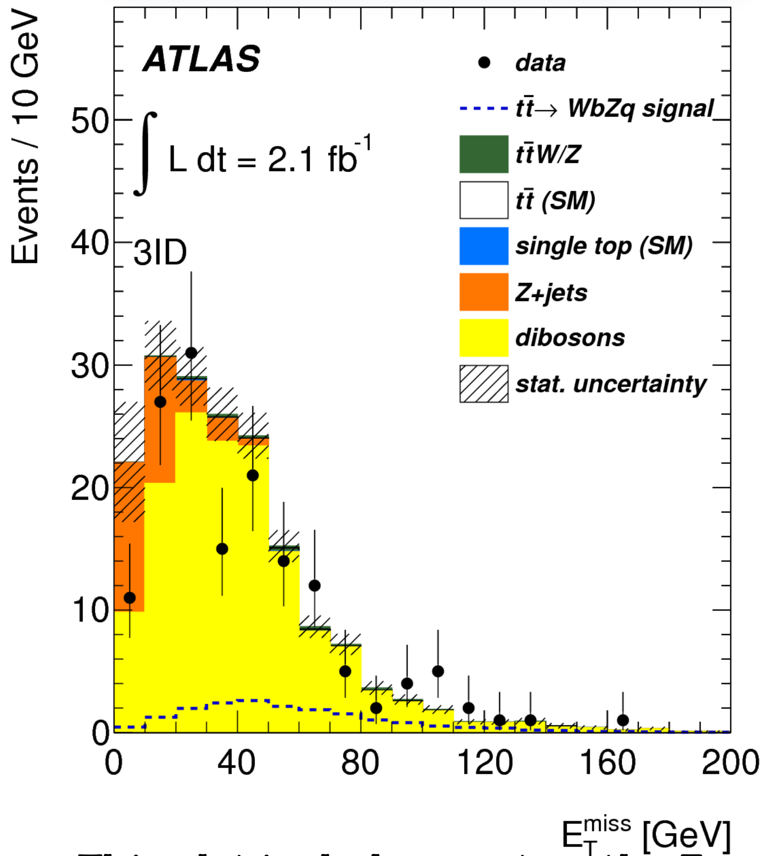


$$\text{Prediction} = \sum_{(p_T, N_{PVX})} \text{Jets}_{(p_T, N_{PVX})} \times \text{Fake Rate}_{(p_T, N_{PVX})}$$

Finally, to account for the mass cuts after the χ^2 minimization, the fake prediction is scaled by (31.2±10.2)%

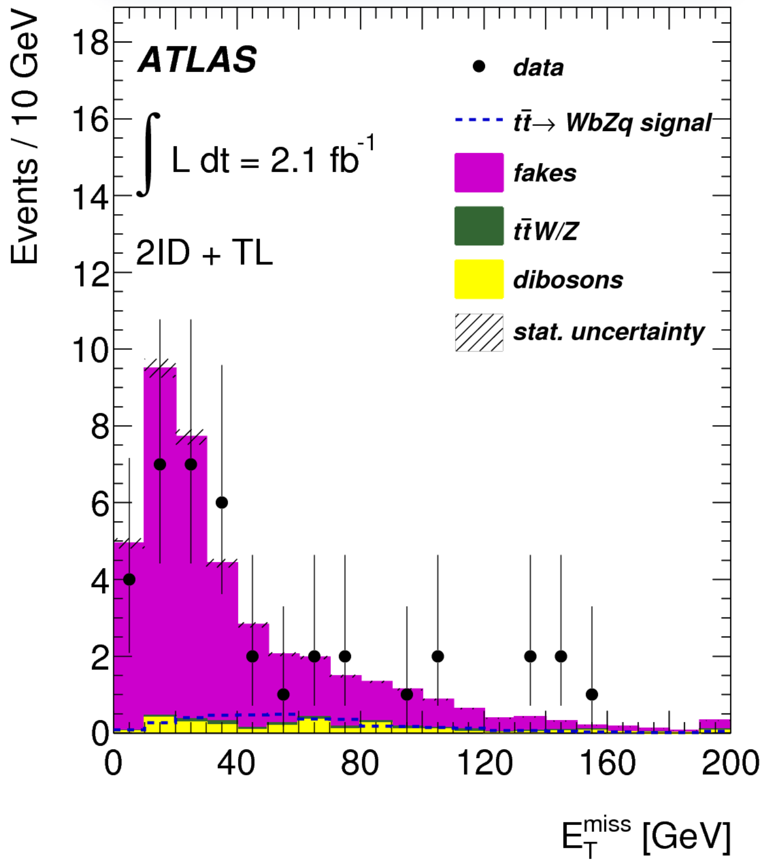
E_T^{miss} at preselection level

3 ID



This plot includes a cut on the Z-boson candidate invariant mass $|m_Z\text{-}91.2|<15$ GeV

2 ID + TL

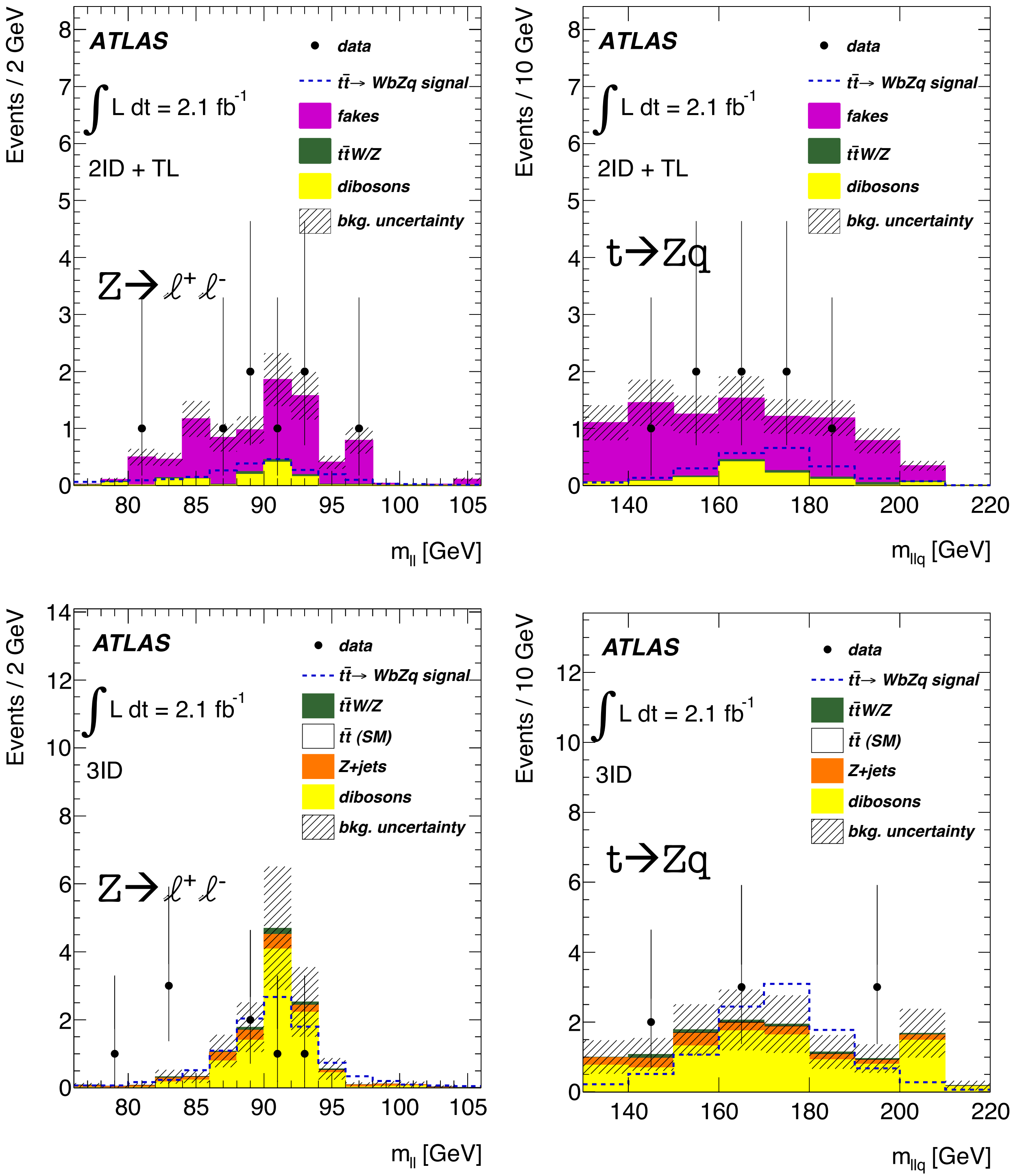


After b-tagging condition

2ID + TL Final Selection	
ZZ and WZ	$1.0\ ^{+0.5}_{-0.6}$
$t\bar{t}W$ and $t\bar{t}Z$	0.25 ± 0.05
fakes	7.6 ± 2.2
expected background	8.9 ± 2.3
data	8

Final Selection

3ID Final Selection	
ZZ and WZ	9.5 ± 4.4
$t\bar{t}W$ and $t\bar{t}Z$	0.51 ± 0.14
$t\bar{t}$, WW	0.07 ± 0.02
Z+jets	1.7 ± 0.7
Single top	0.01 ± 0.01
2+3 fake leptons	$0.0 \pm^{0,2}_{0,0}$
expected background	11.8 ± 4.4
data	8



Outline

- Top Quark Physics
  - Motivation
- ATLAS Detector
- Object and Event Selection
  - Track-Lepton
- Backgrounds
- Systematic Uncertainties
- Limit Calculation
- Conclusions

Systematic Uncertainties

Systematic uncertainties can influence the expected number of signal and/or background events:

Systematic Uncertainties

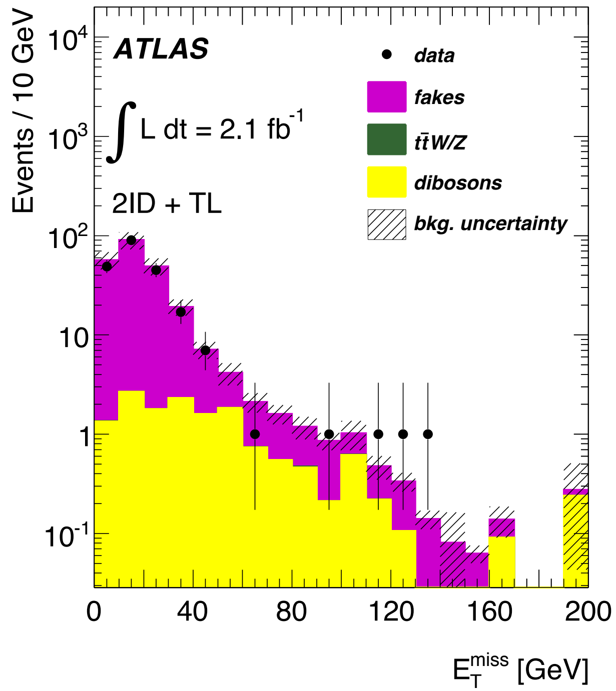
Systematic uncertainties can influence the expected number of signal and/or background events:

Fake TL Prediction

The fake matrix is tested in control regions (orthogonal to signal regions) enriched with fake leptons.

Events with lepton+fake, done in the context of the cross section measurement.

Check two regions of E_T^{miss} for events with: two leptons + fake and one jet events.



A 20% systematic uncertainty is used for the fake leptons prediction.

Systematic Uncertainties

Systematic uncertainties can influence the expected number of signal and/or background events:

WZ, ZZ background

- Cross Section

Include the 5% theoretical uncertainty.

- HF content (when b-agging is used)

Estimate by comparing different MC generators.

- **MC modelling**

Using the Berend-Giele scaling with a 24% uncertainty per jet, added in quadrature (4% is used for the 0-jet bin).

	3ID		2ID+TL	
Source	Background	Signal	Background	Signal
Luminosity	4%	4%	<1%	4%
Electron trigger	4%	1%	<1%	<1%
Electron reconstruction modelling	10%	3%	<1%	2%
Muon trigger	3%	1%	<1%	<1%
Muon reconstruction modelling	7%	1%	<1%	1%
TL reconstruction modelling	—	—	2%	1%
Jet energy scale	11%	1%	1%	1%
Jet reconstruction efficiency	5%	2%	<1%	<1%
Jet energy resolution	1%	3%	1%	4%
E_T^{miss} modelling	4%	1%	<1%	<1%
LAr readout problem	3%	1%	<1%	1%
Pile-up	4%	<1%	<1%	<1%
b-tagging	—	—	1%	6%
Top quark mass	<1%	2%	—	3%
$\sigma_{t\bar{t}}$	<1%	8%	—	8%
ISR/FSR	<1%	3%	—	6%
PDFs	—	3%	—	3%
ZZ and WZ shape	33%	—	5%	—
ZZ and WZ cross section	4%	—	<1%	—
ZZ and WZ heavy-flavour content	—	—	<1%	—
Fake leptons	1%	—	17%	—
Total	38%	12%	18%	15%

Relative changes on the expected number of total background events and signal yield from different sources of systematic uncertainty.

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Why compute a limit?

Final Selection

	3ID	2ID+TL
ZZ and WZ	9.5 ± 4.4	$1.0 \pm ^{0.5}_{0.6}$
$t\bar{t}W$ and $t\bar{t}Z$	0.51 ± 0.14	0.25 ± 0.05
$t\bar{t}$, WW	0.07 ± 0.02	
Z+jets	1.7 ± 0.7	7.6 ± 2.2
Single top	0.01 ± 0.01	
2+3 fake leptons	$0.0 \pm ^{0.2}_{0.0}$	
Expected background	11.8 ± 4.4	8.9 ± 2.3
Data	8	8
Signal efficiency	$(0.205 \pm 0.024)\%$	$(0.045 \pm 0.007)\%$

Good agreement between data observation and expected Standard Model background.
No evidence for flavor changing neutral currents is found.

Limit calculation

- We derive 95% CL limits on the BR for this FCNC decay using the modified frequentist (CL_s) likelihood method.
  - CL_s is used for small signals.

- Statistical and Systematic uncertainties are taken into account (Gaussian distributions).

- For the combination: systematic uncertainties of the MC-backgrounds and signal samples are taken to be fully correlated between 3ID and 2ID+TL. Other sources (statistical and systematic) are considered uncorrelated.

Limit calculation

- 10^5 pseudo experiments are performed to compare the *background-only* and the *signal+background* hypotheses to the data.
  - The statistical fluctuations of the pseudo –experiments are implemented using Poisson distributions.

- This gives a limit on the number of signal events.
  - Converted into upper limits on the corresponding BRs using the approximate NNLO calculation of the cross section:

$$\sigma_{t\bar{t}} = 165^{+11}_{-16}\ \mathrm{pb}$$

Limit Calculation

Limit

channel	observed	(-1σ)	expected	$(+1\sigma)$
3ID	0.81%	0.63%	0.95%	1.42%
2ID+TL	3.18%	2.15%	3.31%	4.86%
Combination	0.73%	0.61%	0.93%	1.36%

Observed in data

Expected sensitivity, assuming that the data are described correctly by the SM

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FCNC Searches

Current Experimental Limits

	LEP	HERA	Tevatron	ATLAS	CMS
$BR(t \to q\gamma)$	2.4 %	0.64 % $(tu\gamma)$	3.2 %	—	—
$BR(t \to qZ)$	7.8 %	49 % (tuZ)	3.2 %	0.73 %	0.24 %
$BR(t \to qg)$	17 %	13 %	2.0×10^{-4} (tug) 3.9×10^{-3} (tcg)	5.7×10^{-5} (tug) 2.7×10^{-4} (tcg)	—

Before the LHC searches, best limit from DO Collaboration:

$$BR(t \to Zq) < 3.2\%$$

using top quark pairs, with W- and Z-bosons decay leptonically.

FCNC Searches

Current Experimental Limits

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Result from CMS:

- Uses 5 fb^{-1}, full 2011 dataset.
- 3-leptons final state, with two different selections:
  - "S_T" and "b-tag".
  - Best result from S_T selection (no orthogonal).
- Main background: WZ, ZZ (MC with data-normalization).

Conclusions

FCNC in top quark decays

- A search for flavor changing neutral currents in top quark decays has been presented.

- The search was performed in 2.1 fb^{-1} of 2011 *pp* collision data.

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FCNC in top quark decays

- A search for flavor changing neutral currents in top quark decays has been presented.

- The search was performed in 2.1 fb^{-1} of 2011 *pp* collision data.

- Two orthogonal channels were introduced: 2ID+TL and 3ID, and their results combined.
    - Analysis published in JHEP.

2.1 fb^{-1}
arxiv: 1206.0257

Conclusions

FCNC in top quark decays

- A search for flavor changing neutral currents in top quark decays has been presented.

- The search was performed in 2.1 fb^{-1} of 2011 *pp* collision data.

- Two orthogonal channels were introduced: 2ID+TL and 3ID, and their results combined.

- No evidence for FCNC signal has been found, and an upper limit on the $t \rightarrow qZ$ branching ration of

  BR < 0.73%

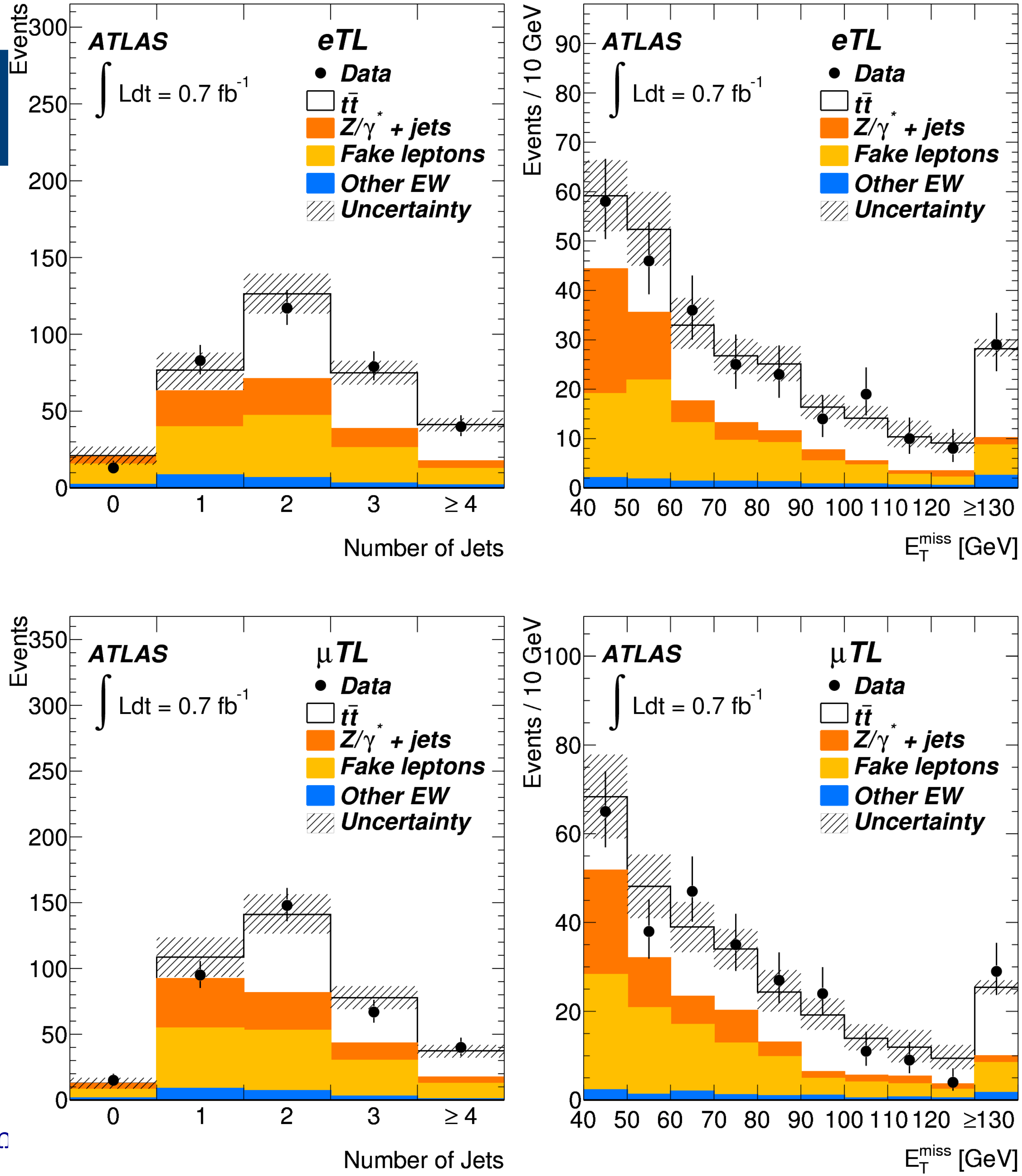
  is set at 95% CL. This observed limit is in agreement with the expected limit of BR < 0.93%

Thank you!

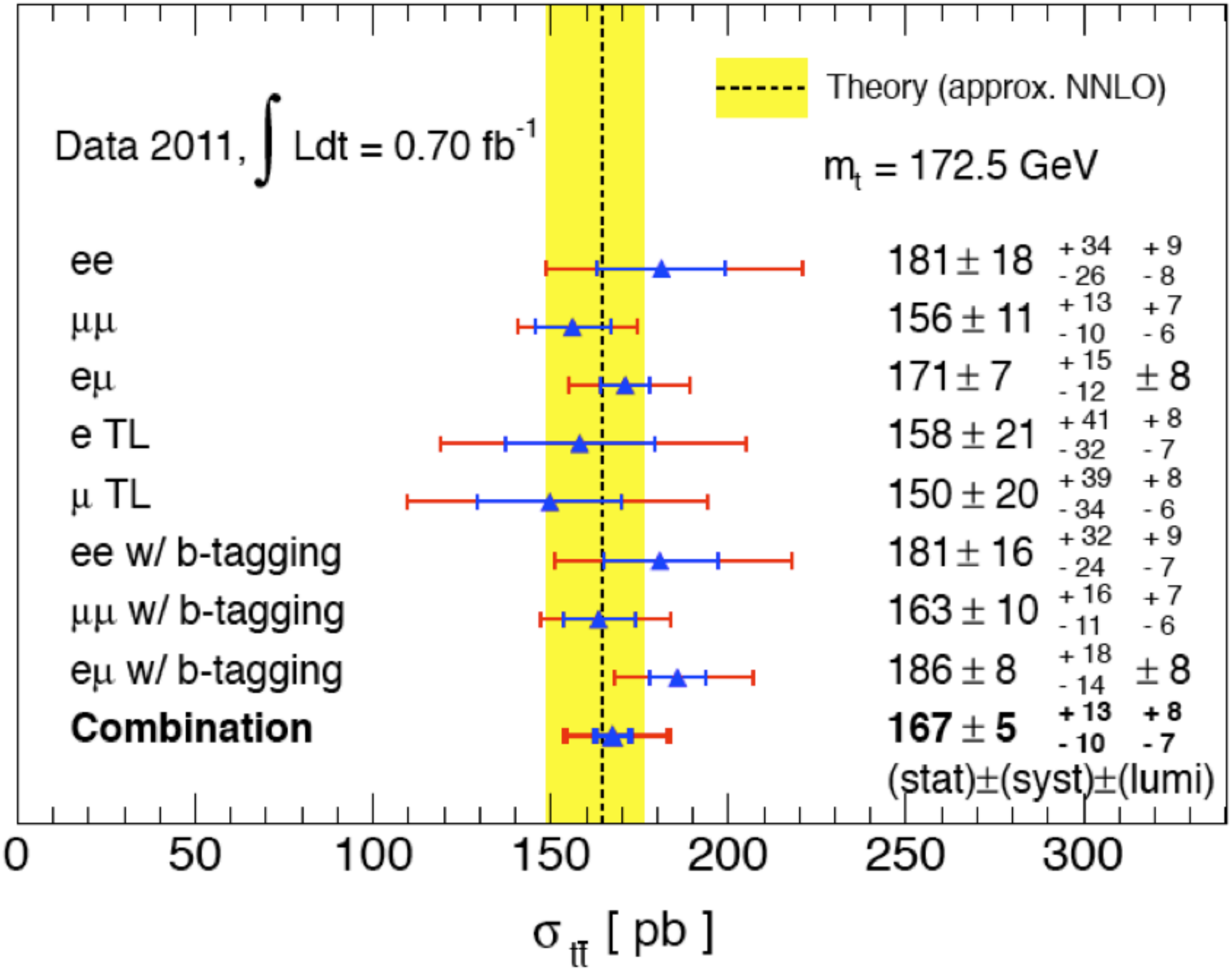
Links to Publications

- Top Quark Pair Production Cross Section
  - 2010 data, 35 pb^{-1},
    Phys. Lett. B 707 (2012) 459-477,
    http://arxiv.org/abs/1108.3699
  - 2011 data, 0.7 fb^{-1},
    JHEP 1205 (2012) 059,
    http://arxiv.org/abs/1202.4892

- FCNC in Top Quark Decays
  - 2011 data, 2.1 fb-1,
    JHEP 09 (2012) 139,
    http://arxiv.org/abs/1206.0257


ATLAS
∫ Ldt = 0.7 fb-1
eTL
μTL
Data
tt̄
Z/γ* + jets
Fake leptons
Other EW
Uncertainty
Events
Events / 10 GeV
Number of Jets
E_T^miss [GeV]

Cross Section: Results



FCNC in R-parity violating SUSY

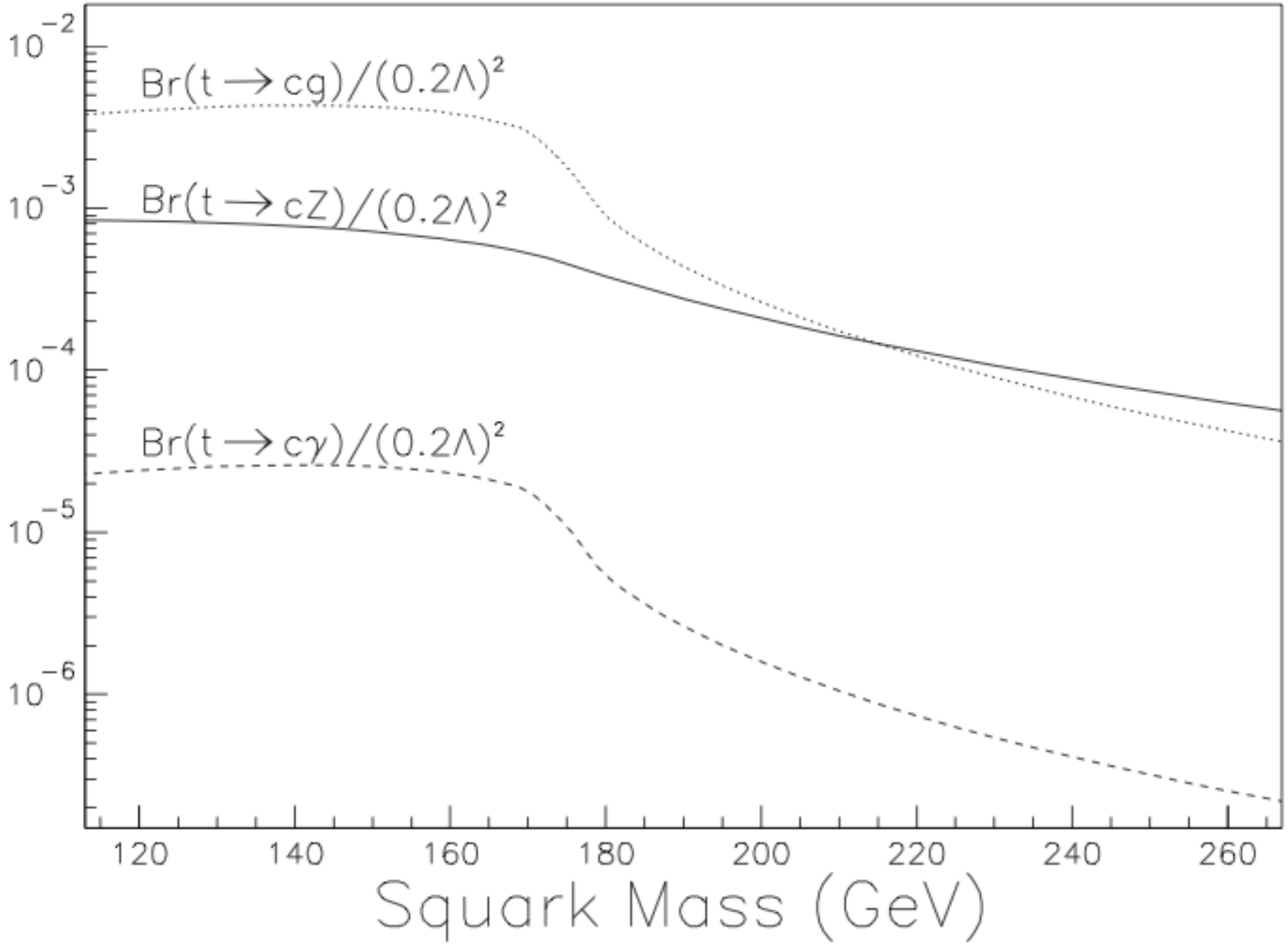


FIG. 3. The plot of $Br(t \to cV)/(0.2\Lambda)^2$ as a function of squark mass.

Λ being the product of the baryon number violating couplings.

Λ = 1, and masses as high as 170 GeV, for the values quoted before

Systematic Uncertainties

Systematic uncertainties can influence the expected number of signal and/or background events:

Miscellaneous

- Luminosity
  Estimated to be 3.7%.

- b-tagging
  MC modelling of the b-tagging efficiency.

- ISR/FSR, Top quark mass, PDF used for signal generation, t-tbar cross section.

Systematic Uncertainties

Systematic uncertainties can influence the expected number of signal and/or background events:

Object Specific

- Muons, Electrons, TL

  MC modelling of Trigger (e, μ), reconstruction and identification efficiencies and of the energy/momentum scale and resolution.

- Jets

  Energy scale of light-quark jets and b-jets (including pile-up). MC modelling of jet energy resolution. Jet reconstruction efficiency.

- E_T^{miss}

  Corrections on the leptons and jets are propagated to the E_T^{miss}. Effect of energy in calorimeter not associated to reconstructed objects, low momentum jets, and MC modelling of pile-up.

Simulated Samples

All MC samples are processed with the GEANT4 simulation of the ATLAS detector.

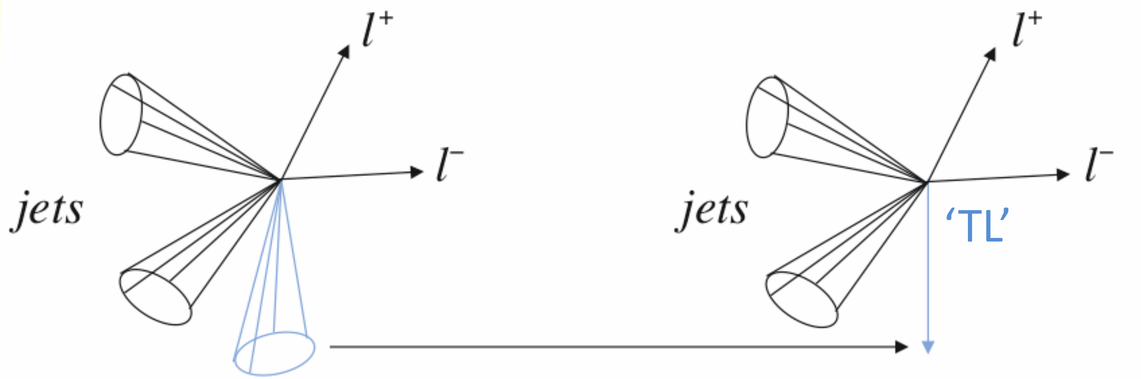
Process	Generator	PDF	Hadronization
FCNC $t\bar{t} \to WbZq$	TopReX	MRST2007 LO*	PYTHIA 6.421
Diboson (WW, WZ and ZZ)	ALPGEN 2.13	CTEQ6L1	HERWIG showering, JIMMY event model
$t\bar{t}+W$ and $t\bar{t}+Z$	MadGraph 4.4.62		PYTHIA
$t\bar{t}$, single top-quark	MC@NLO	CTEQ6.6	HERWIG showering, JIMMY event model

$$m_t = 172.5 \text{ GeV}$$
$$m_W = 80.4 \text{ GeV}$$
$$m_Z = 91.2 \text{ GeV}$$

- t-tbar production was normalized to the NNLO prediction of 164.6 pb.
- single-top cross sections were normalized to the NNLO predictions of 64.9 pb, 4.6 pb, 15.7 pb fpr the t-channel, s-channel and associated Wt production, respectively.

Fake Leptons

Strategy



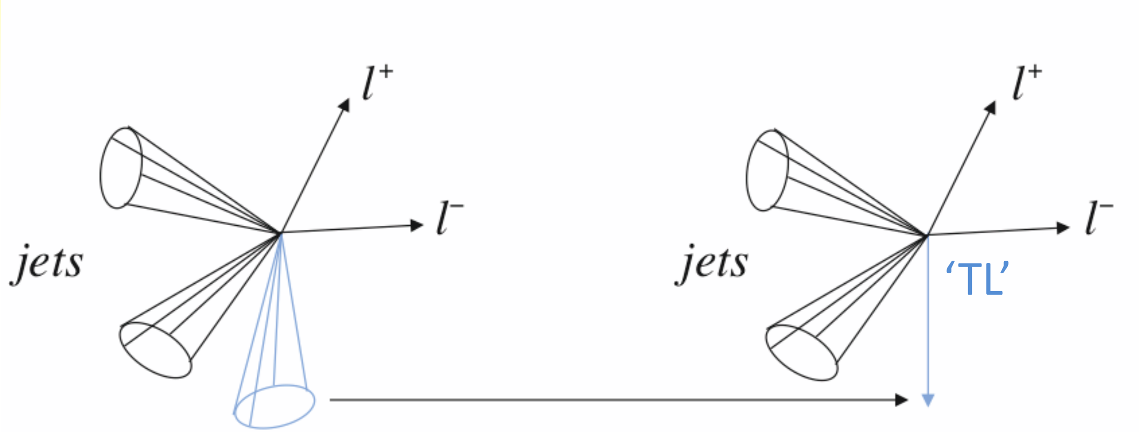
Parent sample
Events with two leptons (passing other event selection cuts)

→

Used to predict events with two leptons + one fake

Fake Leptons

Strategy



Parent sample
Events with two leptons (passing other event selection cuts) → Used to predict events with two leptons + one fake

Since we remove ID jets within $\Delta R<0.4$ of a TL

two leptons events with N jets → Two lepton events + fakes with (N-1) jets

Fake leptons background

3ID Fake leptons

The background from fake leptons is estimated for events with one fake leptons, and events with 2 or 3 fake leptons.

2+3 fakes events

- QCD, W+jets ,s ingle top, single lepton t-tbar

Due to the requirements of two leptons with same charge and opposite sign (36 combinations), this background is extrapolated from the data events with 3 leptons of any flavor, but same charge (16 combination).

$$f = 36/16 = 2.25$$