

Measurement of the inclusive $t\bar{t}\gamma$ cross section at $\sqrt{s} = 7$ TeV with the ATLAS detector

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German contributions :

- **University of Göttingen**
- **University of Siegen**

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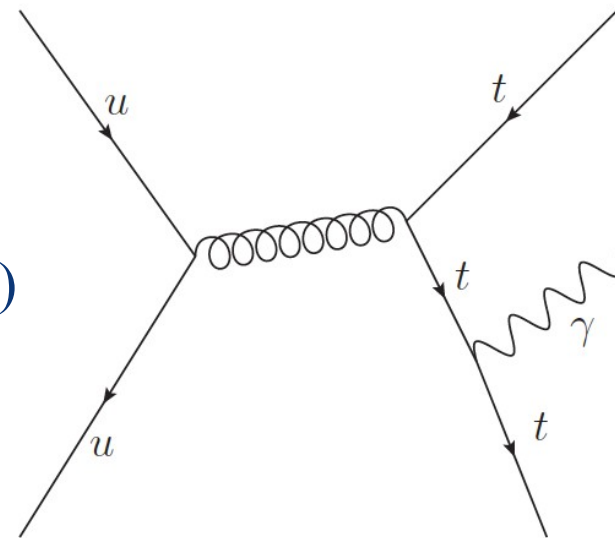
The ATLAS Collaboration

presented at HCP 2011

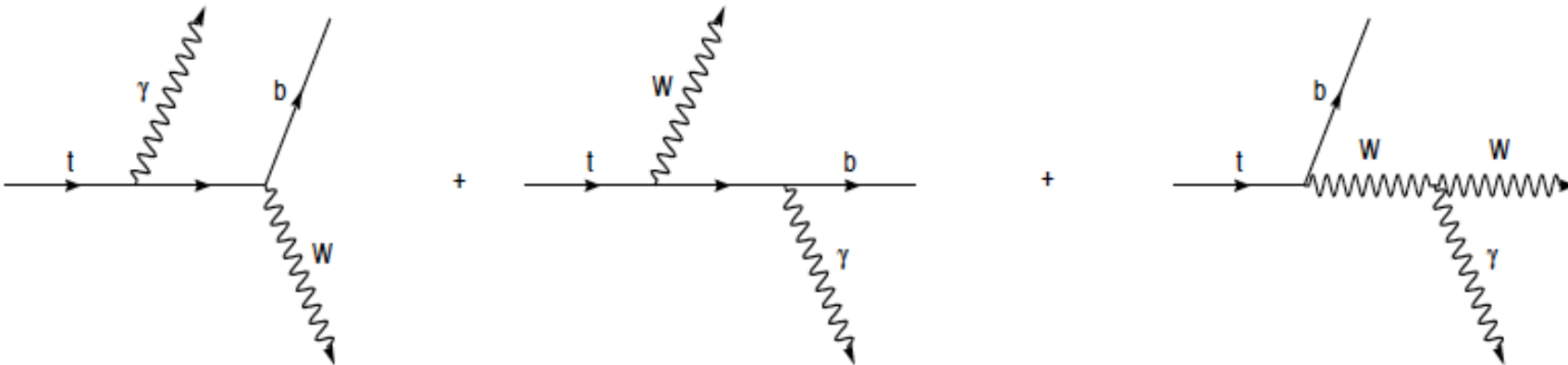
Abstract

Top quark pair events with additional photons in the final state are directly sensitive to the $t\bar{t}\gamma$ vertex. In this note, a first measurement of the $t\bar{t}\gamma$ cross section in pp collisions at $\sqrt{s} = 7$ TeV is presented using 1.04 fb^{-1} of data taken with the ATLAS detector. Events are selected that contain a large transverse momentum electron or muon and a large transverse momentum photon. In the electron and muon samples, 52 and 70 candidate events have been identified, respectively. The resulting cross section times branching ratio into the single lepton and dilepton channels (including τ -leptons) for $t\bar{t}\gamma$ production with a photon with transverse momentum above 8 GeV is $\sigma_{t\bar{t}\gamma} = 2.0 \pm 0.5$ (stat.) ± 0.7 (syst.) ± 0.08 (lumi.) pb, which is consistent with theoretical calculations.

- Many properties of the top already studied
- **However: We do not know much about its couplings ...**
- **ty vertex :**
 - “Exotic” em. charge “-4/3 e” excluded (jet charge analyses)
 - **$t\bar{t}\gamma$ → direct measurement of coupling constant & vertex structure**
- CDF 2011 (Phys. Rev. D 84, 031104(R), hep-ex/1106.3970) :
 - Evidence for $t\bar{t}\gamma$ production + measurement of $\sigma_{t\bar{t}\gamma} / \sigma_{t\bar{t}}$ (3.0 σ evidence, cross section ratio: 0.024 ± 0.009 – consistent with SM)



- Interferences between diagrams with γ s radiated from different particles



Aim with 1.04 fb^{-1} : measure the inclusive $t\bar{t}\gamma$ cross section

- Avoid infrared + collinear divergencies

→ define signal phase space

- $\gamma p_T > 8 \text{ GeV}$

- Invariant mass cuts : $m(q, \gamma) > 5 \text{ GeV}$ + $m(l, \gamma) > 5 \text{ GeV}$

modelled with the
 WHIZARD MC
 generator (LO)

- **Electrons :**

- $p_T > 25 \text{ GeV}$
- $|\eta| < 2.47$
- good shower shapes
- calorimeter isolation

- **Muons :**

- $p_T > 20 \text{ GeV}$
- $|\eta| < 2.5$
- combined ID+MS track
- calorimeter + track isolation

- **Jets :**

- anti- k_T algorithm with parameter 0.4
- calibrated to the hadronic scale

- **Photons (unconverted and converted) :**

- $p_T > 15 \text{ GeV}$
- $|\eta| < 2.37$
- good shower shapes
- no isolation criterion : template fit (see later)

Selection for single lepton channels (e+jets and μ +jets)

- Single electron (muon) trigger with $p_T > 20$ (18) GeV
- Exactly 1 electron (muon) with $p_T > 25$ (20) GeV
- e+jets : MET > 35 GeV & $m_T(W) > 25$ GeV
- μ +jets : MET > 20 GeV & MET + $m_T(W) > 60$ GeV
- ≥ 4 jets with $p_T > 25$ GeV
- ≥ 1 b-tag
- ≥ 1 photon with $p_T > 15$ GeV
- e+jets : remove events with $86 \text{ GeV} < m(e, \gamma) < 96 \text{ GeV}$
- Remove events with $\Delta R(\text{jet}, \gamma) < 0.5$

1.04 fb⁻¹ of data :

e+jets : 52 candidates

μ +jets : 70 candidates

- Main γ background : mesons ($\pi^0 \rightarrow \gamma\gamma, \eta \rightarrow \gamma\gamma, \dots$) from jets

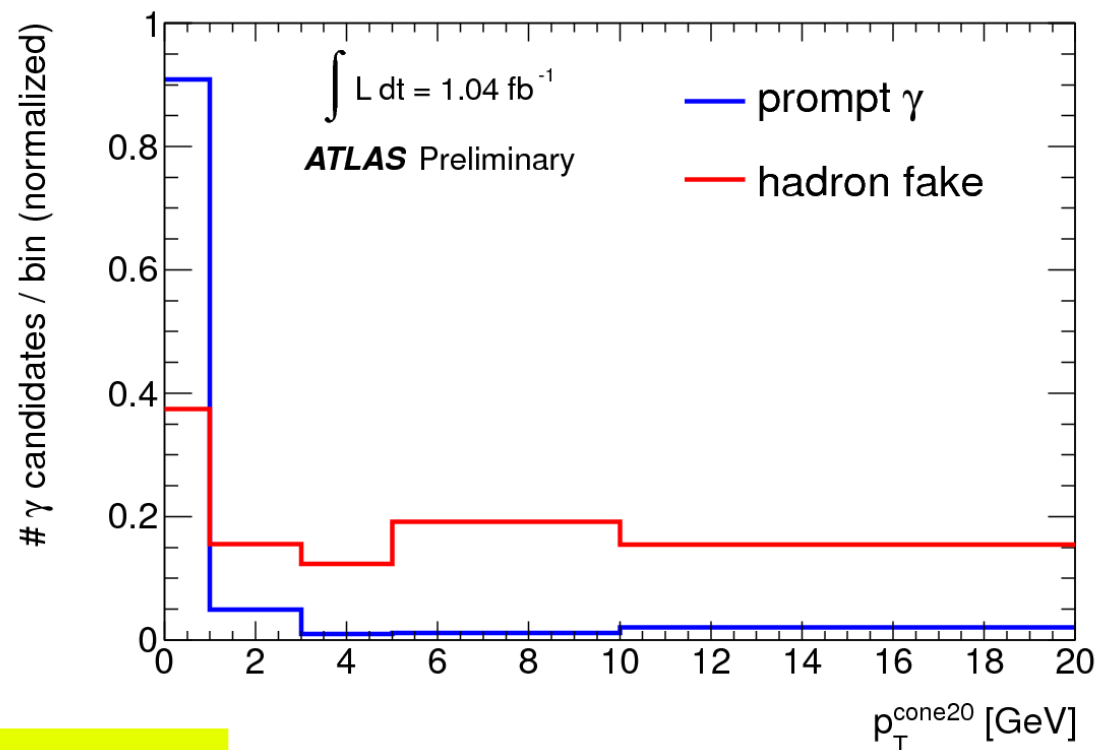
- Don't trust MC \rightarrow set up **data-driven measurement** :

- Hadron fakes less isolated than prompt photons

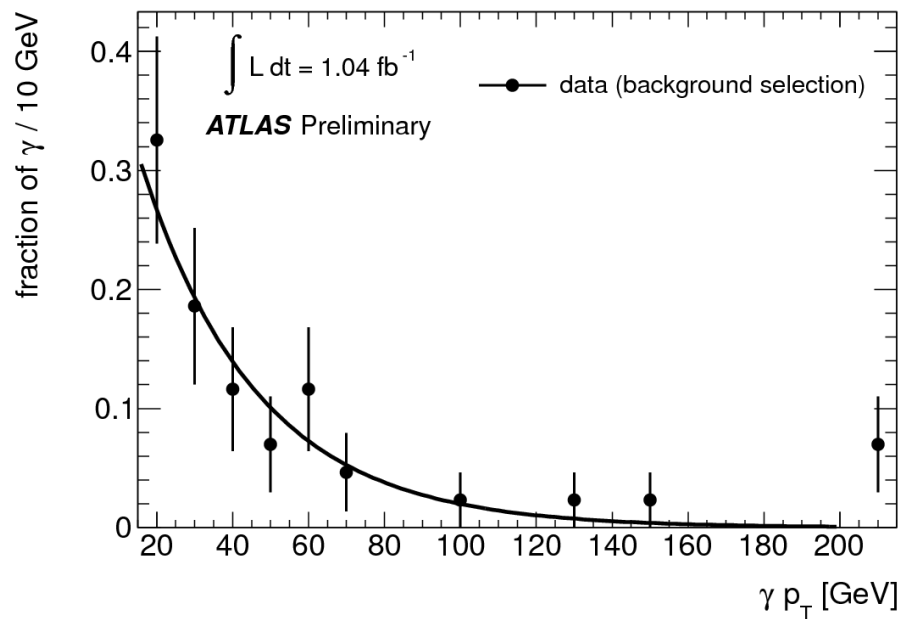
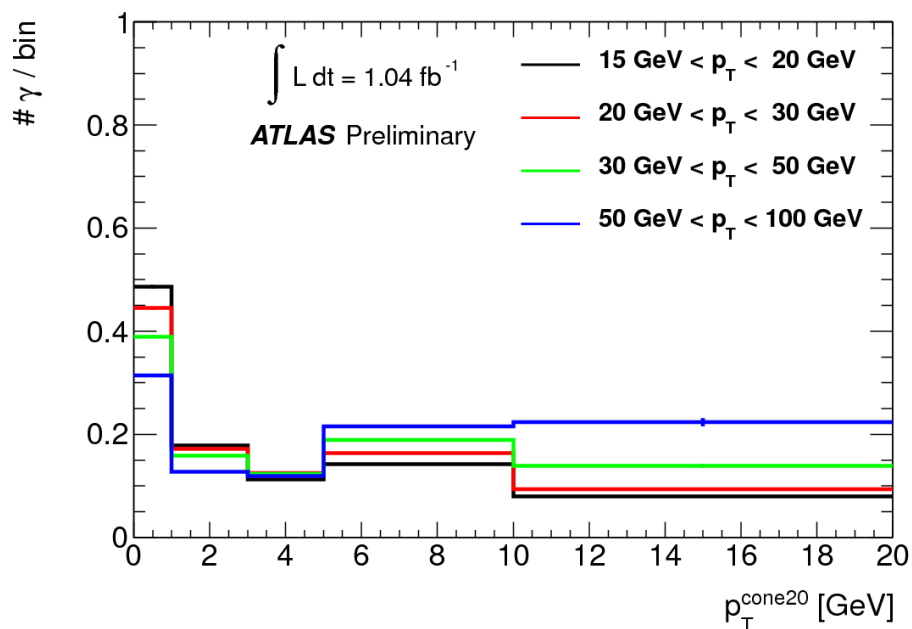
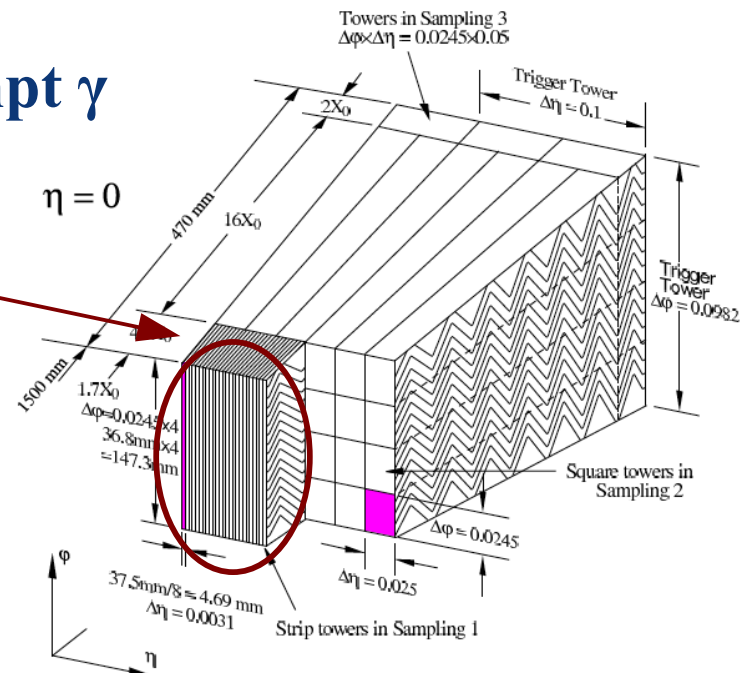
$\rightarrow p_T^{\text{cone20}}$: p_T of tracks in cone
 of radius 0.2 around γ

- γ template from **Z \rightarrow ee data**
- Hadron template from
control region (CR) (next slide)

- **Template fit to p_T^{cone20} of $t\bar{t}\gamma$ candidates**



- 1st calo. layer distinguishes $\pi^0 \rightarrow \gamma\gamma$ and prompt γ
- Define control region dominated by hadron fakes (shower shapes)
- Reweight hadron fake templates in p_T and η

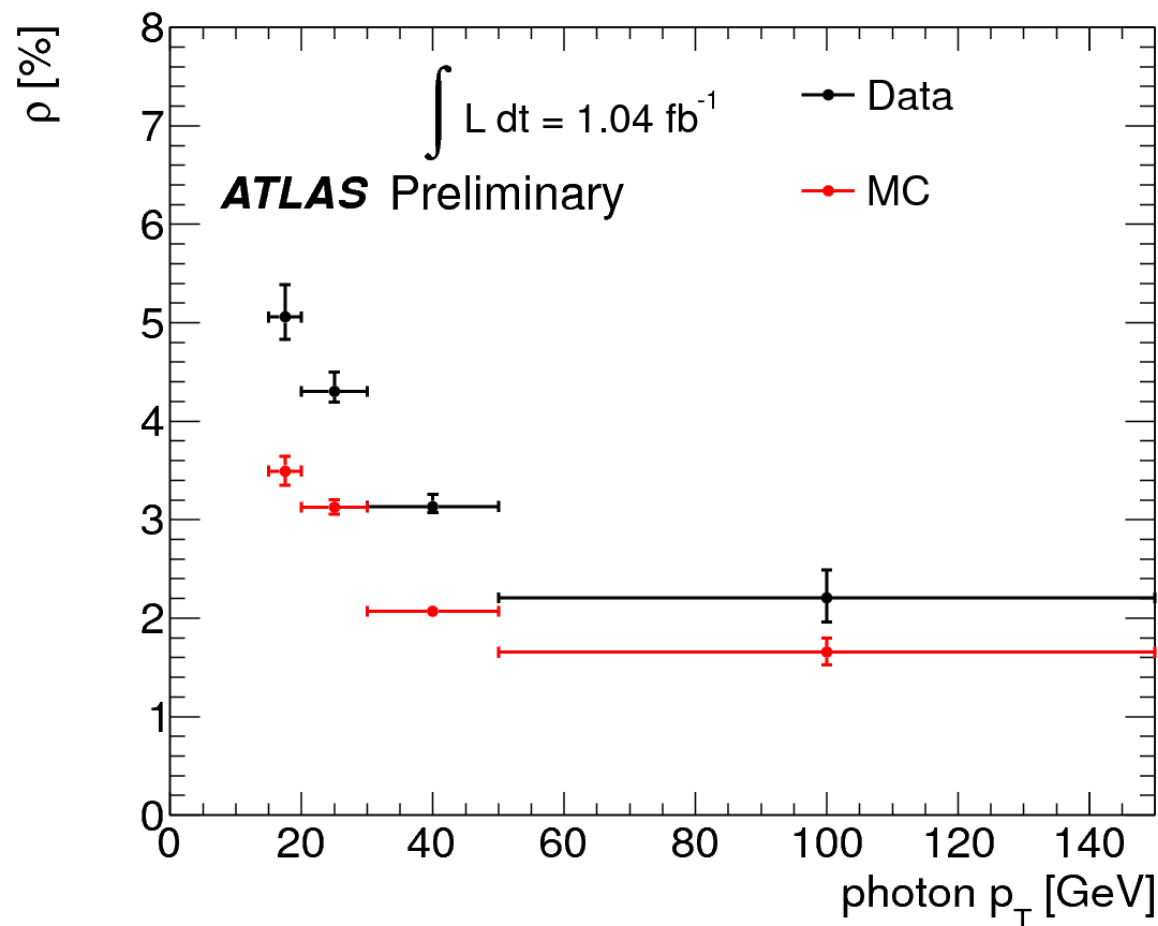


- Background from dileptonic top with $e \rightarrow \gamma$ fake
- Measure $e \rightarrow \gamma$ fake rate from ratio of $Z \rightarrow ee$ and $Z \rightarrow "e\gamma"$ events

Background estimate

(scale factor applied to $t\bar{t}$ MC
 [MC@NLO])

- e +jets : 7.6 ± 1.7 events
- μ +jets : 10.7 ± 2.2 events



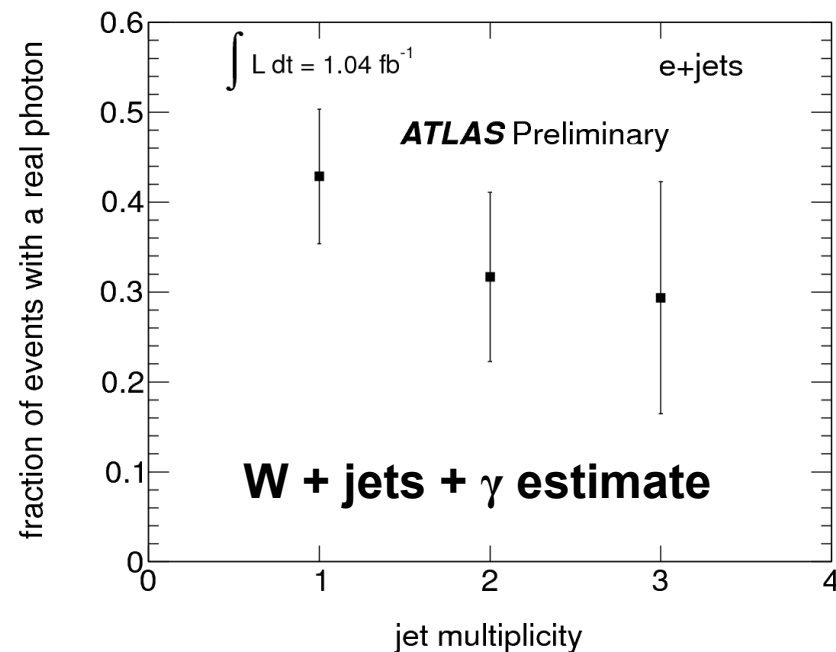
Source	e+jets	μ +jets	Estimate
W + jets + γ	$1.3 + 0.9 - 1.2$	$0.9 + 0.6 - 0.9$	Control region (next slide)
QCD + γ	$0.1 + 0.4 - 0.1$	$0.1 + 0.7 - 0.1$	Control region (next slide)
Z + jets + γ Z + jets ($e \rightarrow \gamma$)	3.9 ± 2.5	1.9 ± 1.8	MC [ALPGEN] SF for $e \rightarrow \gamma$ fake rate
single top + γ	1.3 ± 0.8	0.9 ± 0.5	MC [MC@NLO]
WW/WZ/ZZ + γ	0.21 ± 0.21	$0.04 + 0.09 - 0.04$	MC [HERWIG]
Sum (non-$t\bar{t}$)	6.7 ± 2.8	3.8 ± 2.1	
$t\bar{t}\gamma$ outside of signal phase space	$0.22 + 0.45 - 0.22$	$0.4 + 0.6 - 0.4$	MC [MC@NLO]

- **Estimate W + jets + γ and QCD + γ from control regions :**

- W + jets + γ : 1 – 3 jet bin before b-tagging
- QCD + γ : low MET

- **Extrapolation to signal region :**

- W + jets + γ : MC [ALPGEN]
- QCD + γ : matrix method



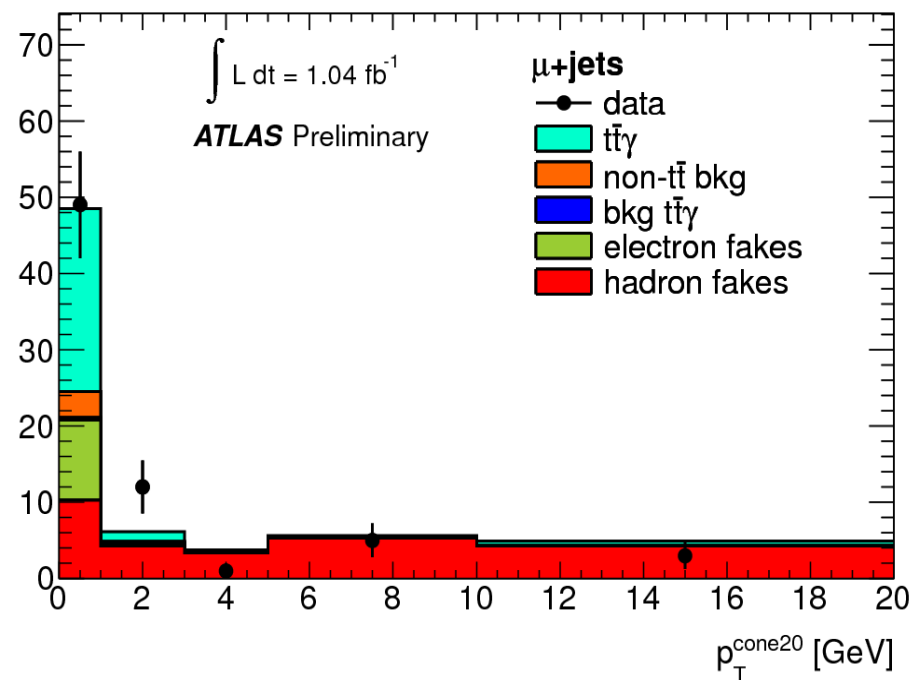
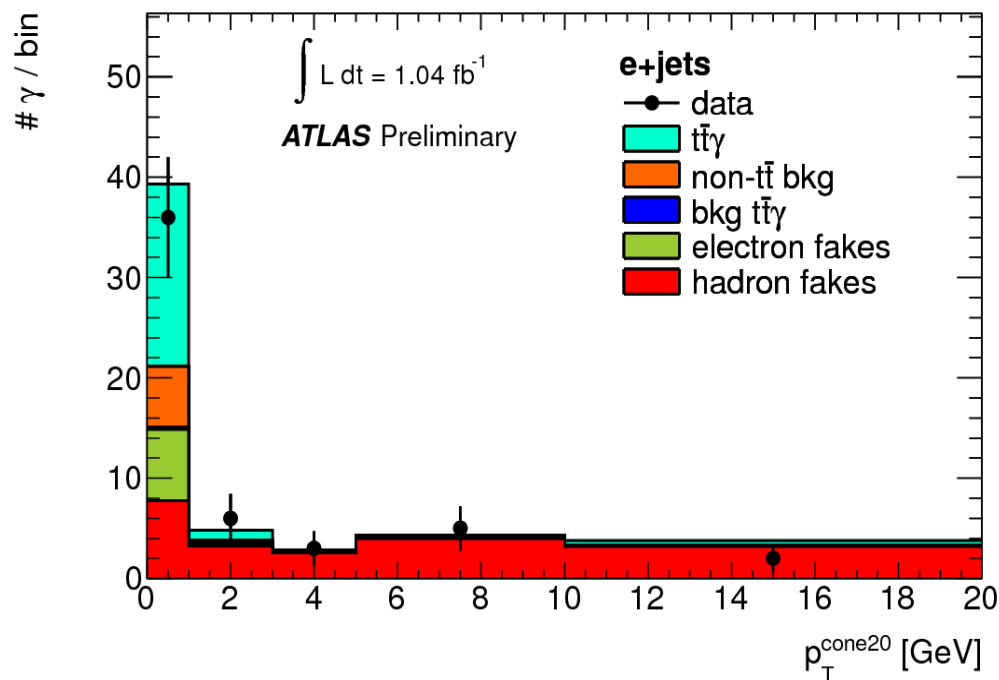
- **γ purity with template fit to p_T^{cone20} (prompt γ + hadron fake templates)**

- Large errors from low statistics in CRs

- W+Jets+ γ background
- QCD+ γ background

	e+jets	μ +jets
- W+Jets+ γ background	$1.3^{+0.9}_{-1.2}$	$0.9^{+0.6}_{-0.9}$
- QCD+ γ background	$0.1^{+0.4}_{-0.1}$	$0.1^{+0.7}_{-0.1}$

	Shape	Yield	Prior probability
$t\bar{t}\gamma$	γ template	free parameter	constant
hadron $\rightarrow \gamma$ fakes	hadron template	free parameter	constant
$e \rightarrow \gamma$ fakes ($t\bar{t}$ dilep.)	e template	estimate	Gaussian
non- $t\bar{t}$ with true γ	γ template	estimate	delta function (fixed)
$t\bar{t}\gamma$ outside of phase space	γ template	estimate	delta function (fixed)



- The fit yields :

total number of background events	78	± 14	events
total number of signal events	46	± 12	events
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$t\bar{t}\gamma$ signal (before selection and acceptance cuts)	2100	± 500	events

- Signal efficiency + acceptance from WHIZARD MC

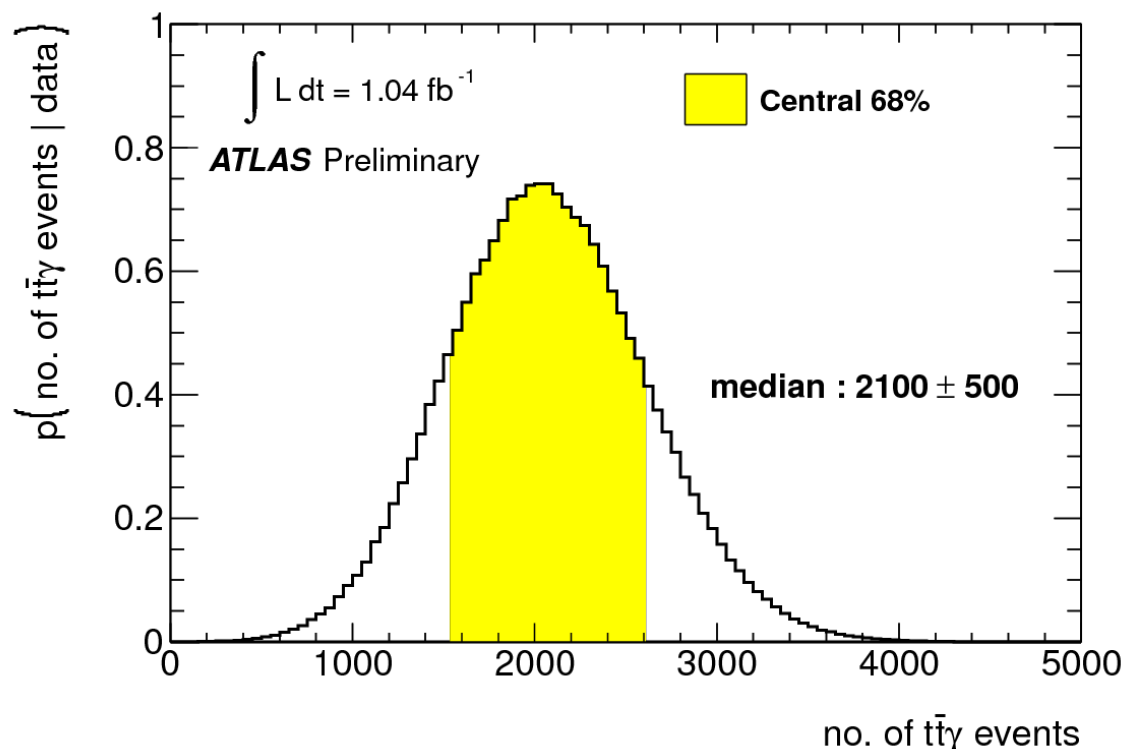
- Resulting cross section (x BR) :

[BR : semilep. + dilep.]

- 2.0 ± 0.5 (stat.) pb

- SM prediction :

- 2.1 ± 0.4 pb



Systematic Uncertainties

Main contributions:

- ISR/FSR
- JES
- b-tagging
- γ identification
- γ purity

Description	Uncertainty on the cross section [pb]
Modelling	± 0.18
Initial and final state radiation	± 0.31
Electron related	± 0.05
Muon related	± 0.08
Jet energy scale	± 0.24
Jet energy scale (pile-up uncertainty)	± 0.28
<i>b</i> -jet energy scale	± 0.06
Jet reconstruction and resolution	± 0.06
E_T^{miss} related	± 0.03
<i>b</i> -tagging performance	± 0.18
Treatment of dead region in LAr calorimeter read-out	± 0.05
Luminosity	+ 0.08
Photon identification efficiency	± 0.33
Photon energy scale	± 0.02
Photon resolution	± 0.01
$t\bar{t}\gamma$ background yield	± 0.03
non- $t\bar{t}$ background yield	± 0.11
Electron to photon extrapolation	± 0.22
Fraction of converted prompt photons	± 0.03
Fraction of converted hadron fakes	± 0.16
Reweighting of the background templates (p_T)	± 0.11
Reweighting of the background templates (η)	± 0.06
Pile-up dependence of the signal templates	± 0.01
Pile-up dependence of the background templates	± 0.05
Sum	± 0.7

- **Final result :**

$$\sigma_{t\bar{t}\gamma} \cdot \text{BR} = 2.0 \pm 0.5 \text{ (stat.)} \pm 0.7 \text{ (syst.)} \pm 0.08 \text{ (lumi.) pb}$$

- **Observed : 122 events**

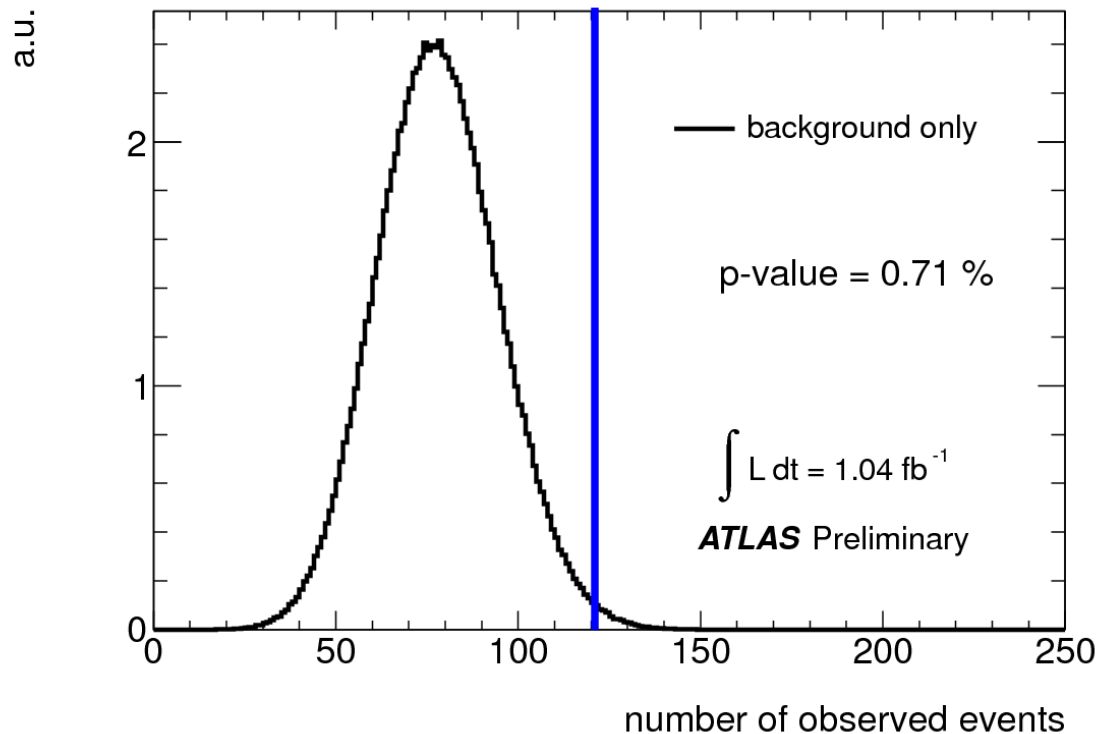
- **Bkg : 78 ± 14**

(stat. + syst. + lumi.)

- **p-value for null**

hypothesis : 0.71 %

- **$\sim 2.7 \sigma$ significance**



- **Measurement of the $t\bar{t}\gamma$ cross section in semilep. + dilep. channel :**

$$\sigma_{t\bar{t}\gamma} \cdot \text{BR} = 2.0 \pm 0.5 \text{ (stat.)} \pm 0.7 \text{ (syst.)} \pm 0.08 \text{ (lumi.) pb}$$

- **Significance : $\sim 2.7 \sigma$**
- **Large data-driven**
- **Consistent with standard model prediction**

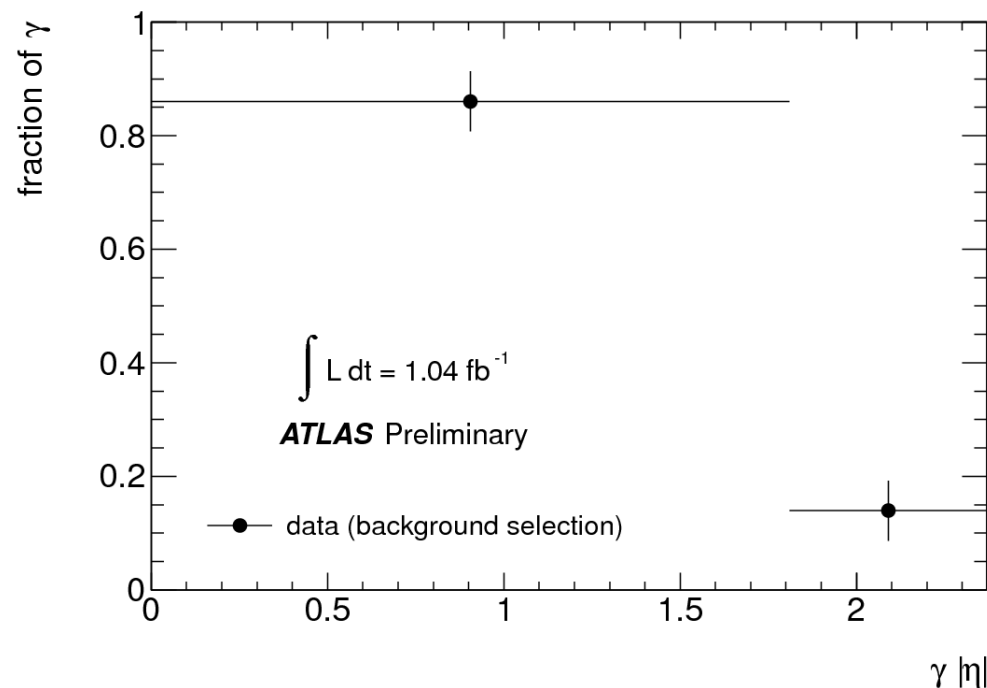
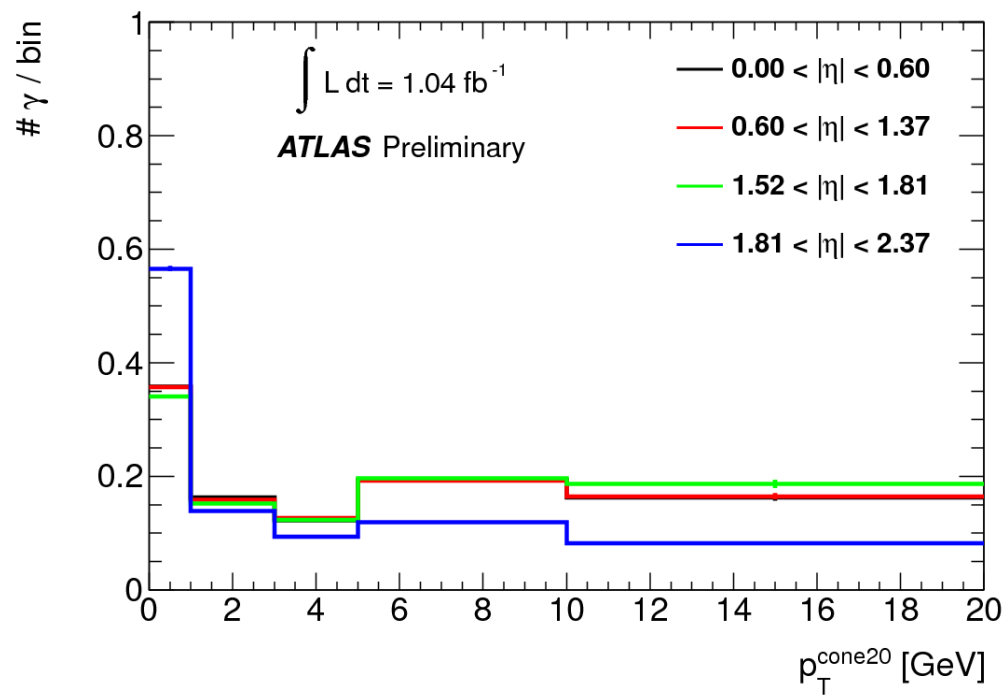
- **Main systematics : γ ID, γ purity, JES, b-tagging, ISR/FSR**
- **Systematics dominate, but:**
 - **in particular photon syst. will decrease with more statistics in the side bands**



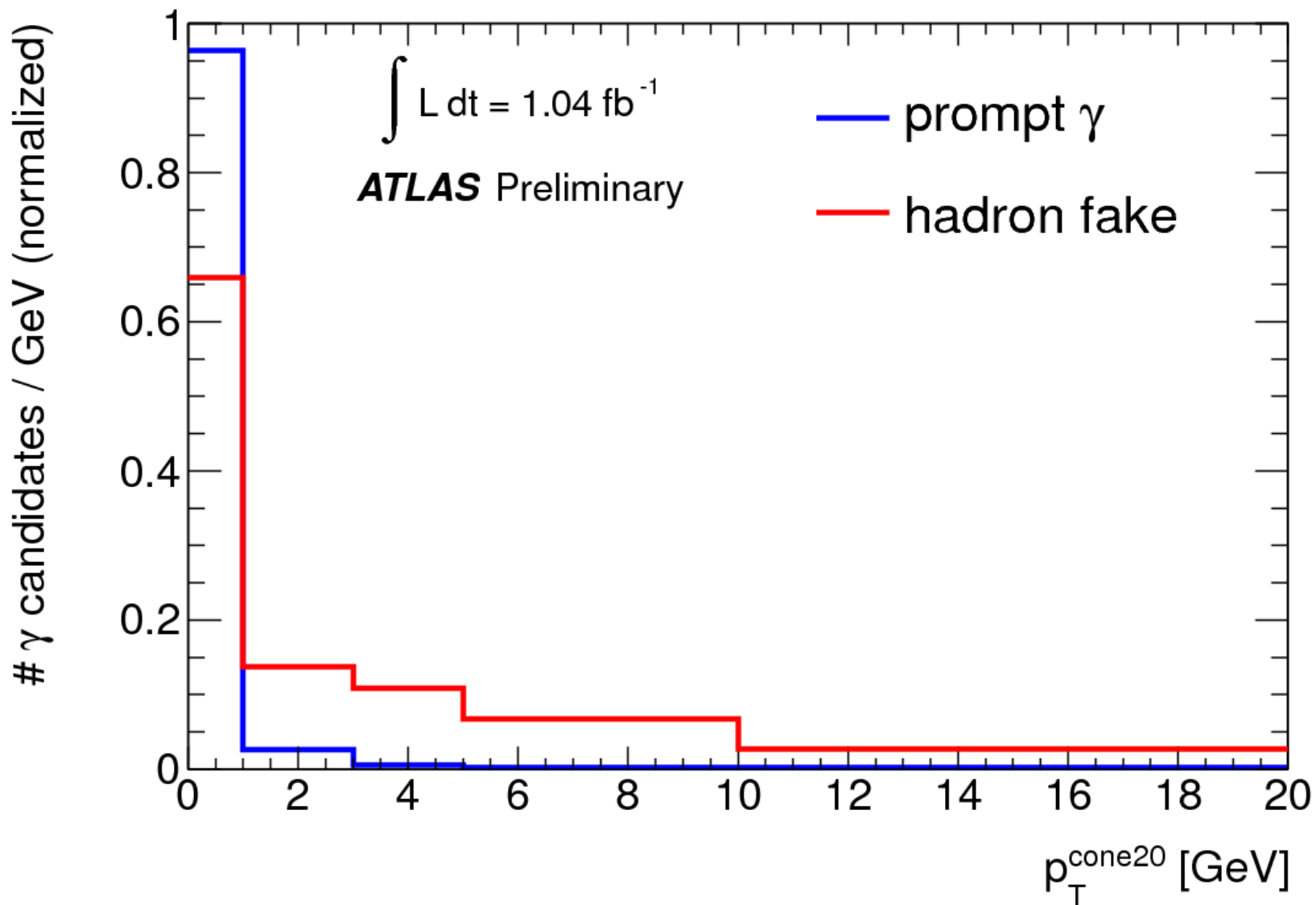
BACKUP



- Hadron fake template : η reweighting



- Alternative template normalization : # candidates / GeV



- Fit both channels separately (cross-check) :

$$\sigma_{t\bar{t}\gamma} \cdot \text{BR} = 1.6 \pm 0.8 \text{ (stat.) pb}$$

$$\sigma_{t\bar{t}\gamma} \cdot \text{BR} = 2.3 \pm 0.7 \text{ (stat.) pb}$$

electron channel

muon channel

- Consistent with simultaneous fit ! (2.0 ± 0.5 pb)

