Associated W and Higgs boson photoproduction and other electroweak photon induced processes at the LHC

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High energy photoproduction at the LHC : introduction

LHC : a new HERA collider !

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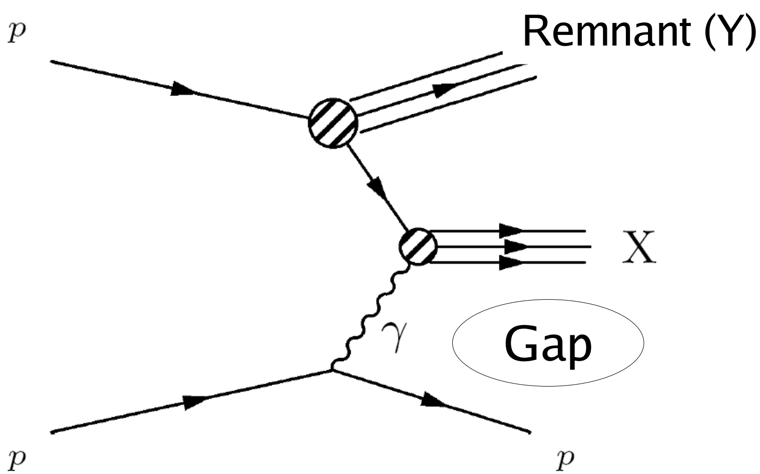
Photoproduction is traditionally studied at e-p collisions

pp (γq/g → XY) p



- γp events can also be tagged at the LHC
  - ➡ e.g. Using Large Rapidity Gaps (LRG)
- Higher luminosity than γγ events
- Probe electroweak sector up to/beyond 2 TeV !

Using EPA

$$\sigma_{pp} = \int \sigma_{\gamma q/g}(\hat{W}_{\gamma q/g}) f_\gamma(x_1) f_{q/g}(x_2, Q^2)\, dx_1\, dx_2$$

where $\hat{W}^2_{\gamma q/g} = 4 E_p x_1 x_2$

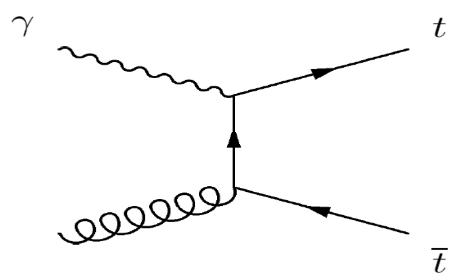
BUT pp events are more dangerous backgrounds than in γγ interactions!

γp cross sections

Obtained using MadGraph/MadEvent

- Large variety of processes
- Significant cross sections up to 2 TeV

e.g.

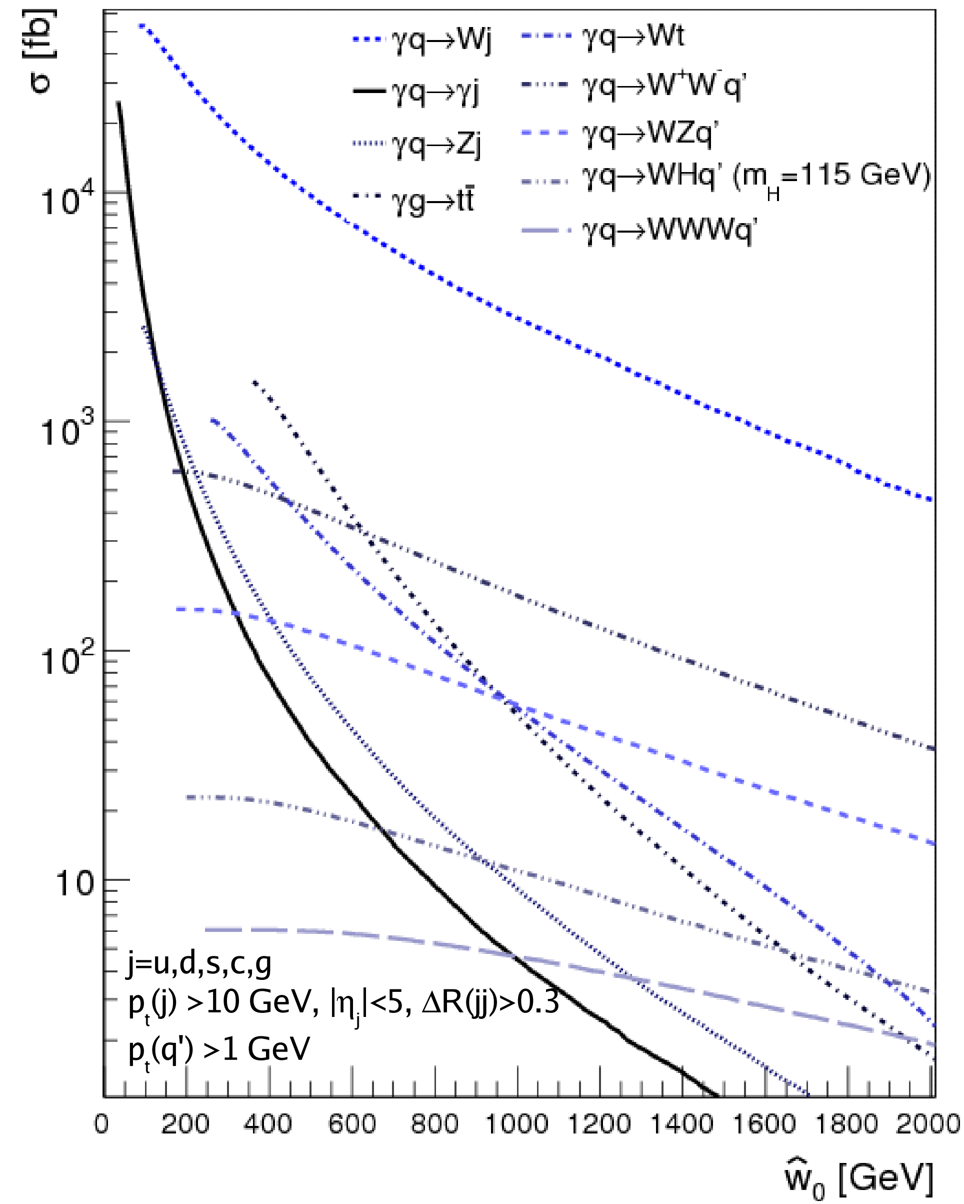


1.5 pb

- Alternative way to pp interactions to study

1. Higgs search
2. Top physics (e.g. $|V_{tb}|$)
3. New phenomena up to 2 TeV

- Very good S/B expected



Experimental aspects

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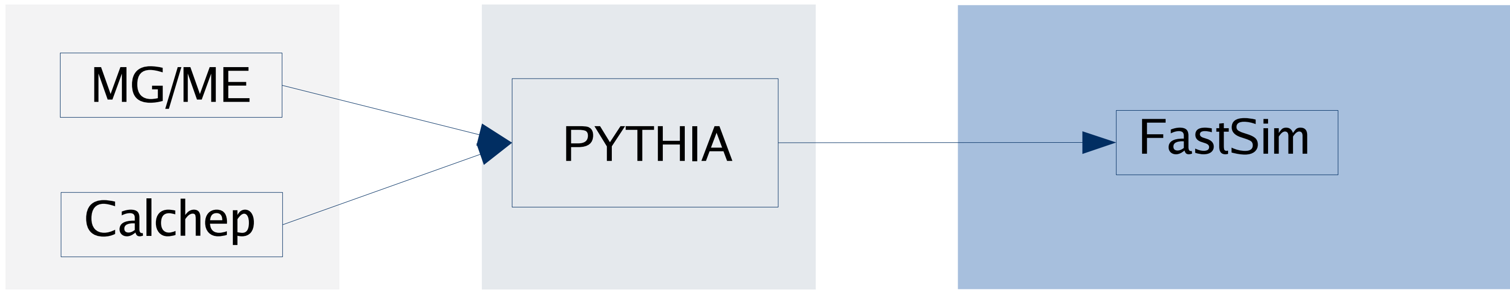
Simulation procedure

- Jets in the final state require careful simulation of acceptance cuts!



Showering,
Hadronization,
Fragmentation,...

Detector simulation of a LHC-like detector :
- infinitely good granular resolution
- finite E resolution depending on η

All results are obtained using LHC detectors with parametrized resolutions and acceptances on generated events

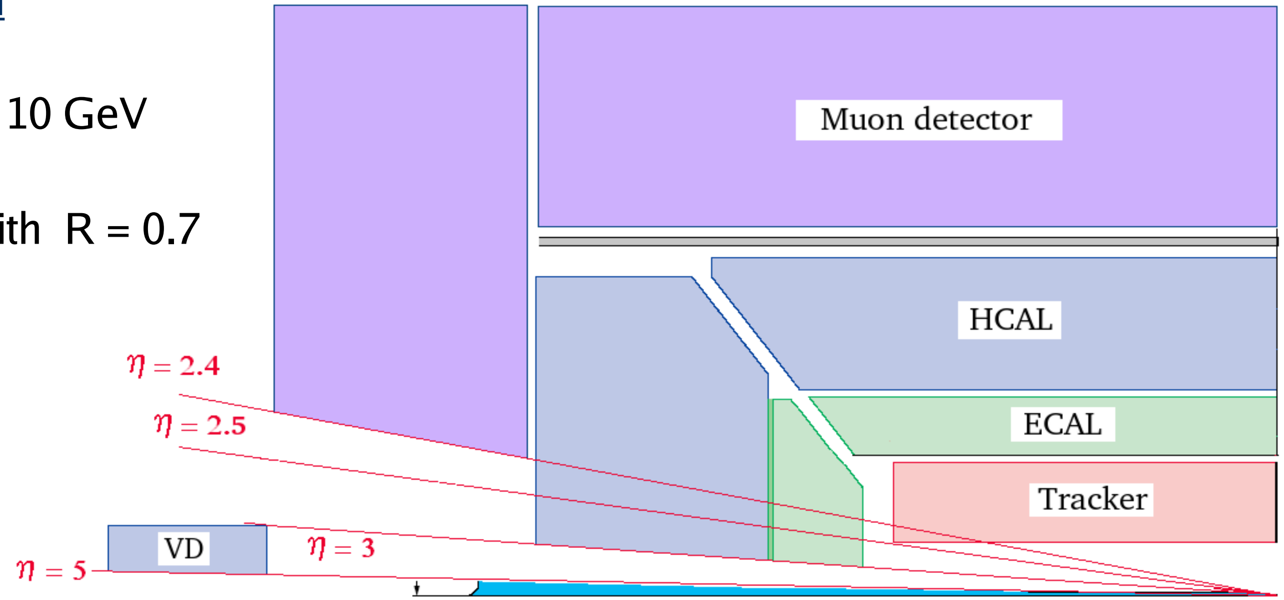
- Only photo-induced backgrounds have been studied in the present analysis

Fast simulation

Object reconstruction

Leptons : $|\eta| < 2.5$, $p_T > 10$ GeV

Jets : cone algorithm with R = 0.7 for $|\eta| < 3$, $p_T > 10$ GeV



- b-tagging : for $|\eta| < 2.5$
- - tagging efficiency : 40%,
- - mistagging of 1% for j=u,d,s,g
- - mistagging of 10% for j=c.

- τ-tagging : for $|\eta| < 2.5$ and $p_T > 10$ GeV
- - typical efficiency : 60%,

- Other jets retained if $p_T > 20$ GeV

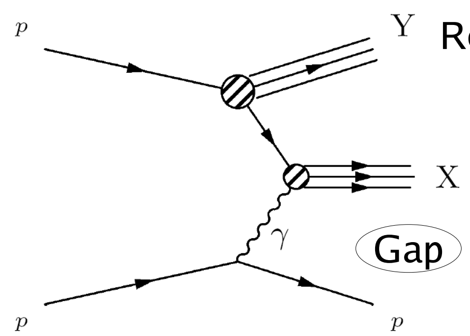
Observability of photo-induced processes is determined using acceptance cuts with these thresholds

Detection and tagging

Potential backgrounds : topologies similar to signal γp events produced from parton-parton collisions

➡ Need a large rejection against pp events

1) Escaping proton signature



- In γp interactions, the proton emitting the photon does not break up
  - no energy in one of the Forward Calorimeter
  - tagging of the escaping proton using very forward detectors

See X. Rouby's talk

2) Use of exclusivity conditions

- In pp interactions, presence of additional particles with low transverse energy due to color flow

➡ The calorimetric and/or the tracking information can be used to look for additional energy in the central detector

Experimental aspects

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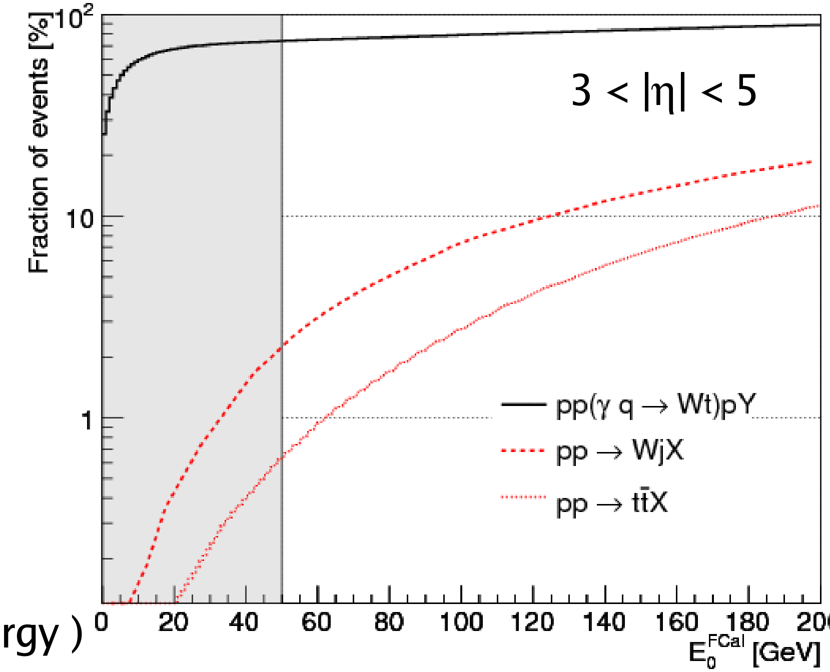
Escaping proton signature



Very low luminosity phase ($<10^{33}$ cm^{-2} s^{-1}) :

- Small event pile-up

➡ Large rapidity gap (LRG) signature can be used

e.g. :

1) choose the « photon-side » (forward calorimeter containing the minimum of energy)

2) cut on the maximum allowed value for this energy

Advantage : independent from very forward detectors features (Roman Pots)

Drawback : - low integrated luminosity expected : 1 fb^{-1}

- kinematics is less constrained

Low luminosity phase (~ 10^{33} cm^{-2} s^{-1})

- Use of very forward detector is mandatory !

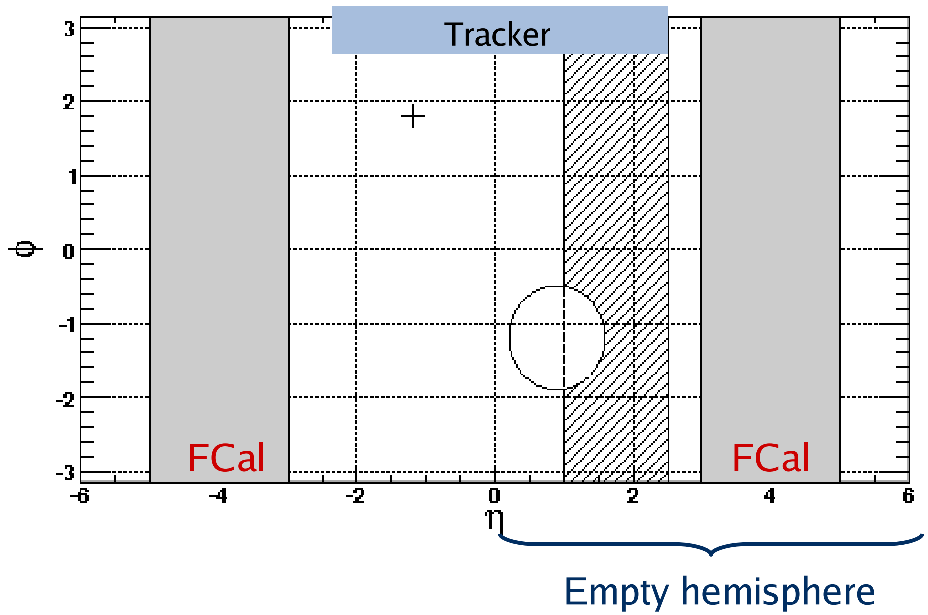
➡ Expected integrated luminosity of 10-30 fb^{-1}

Experimental aspects

Use of exclusivity conditions

Exclusivity based on the tracker

e.g. : 1 lepton and 1 jet expected



- Exclusivity cuts can be applied to reject soft tracks from event vertex

e.g. :

Require no additional track with $p_T >$ 0.5 GeV outside jet cones (R = 0.7) with $1 < \eta < 2.5$

↳ Reduction factor :
- γp events : ~ 0.5
- pp events : ~ 0.001

> After the application of rapidity gap and exclusivity cuts, contribution of pp events is similar to the one from γp events

➡ Only irreducible γp backgrounds have been studied in this presentation

Exclusivity based on the calorimeters

An additional cut based on the energy measured in the central calorimeters can also be applied

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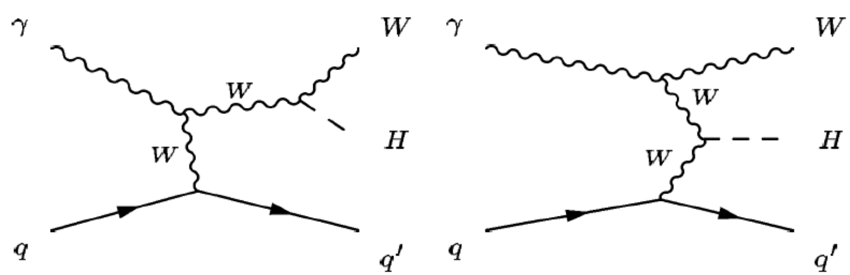
Associated WH photoproduction

Motivation

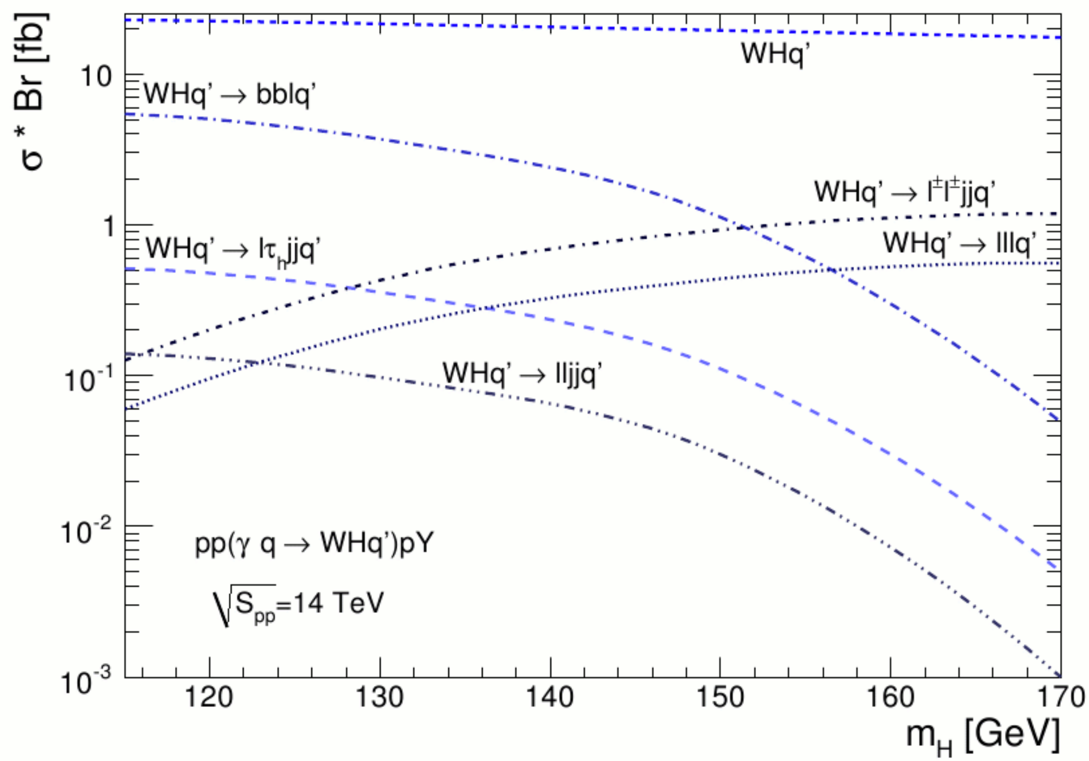


- WH production at LHC challenging due to W+jets, tt, WZ

  ➡ tt less overwhelming than in pp case!

- Associated production of WH has significant cross section at LHC !

Obtained using MadGraph/MadEvent



Five topologies are studied

- WH → lνbb, l=e,μ,τ,
- WH →Wτ+τ− → jjl+l-, l=e,μ,
- WH →Wτ+τ− → jjl+τh, l=e,μ,
- WH →WW+W- → lll,l=e,μ,τ,
- WH →WW+W- → jjl±l±,l=e,μ,τ.

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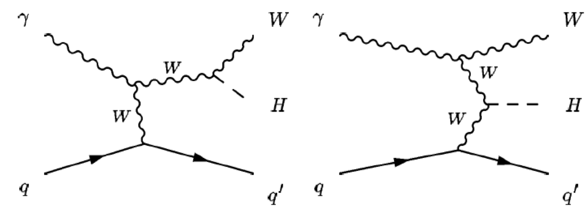
- γp processes
- Experimental
- γp -> WHq’
  - Introduction
  - Acceptance cuts
  - WHq’ → lνbbq'
  - WHq’ → jjl±l±q'
  - WHq’ → lllq'
- Single Top
- Summary

Visible cross section after acceptance cuts

<u>Goal</u> : assess a possible alternative way to observe a light Higgs, in channel with different systematics from H→γγ

<u>pp vs γp cross sections</u>



	pp	γp
WH-channel	~ 1.5 pb	~ 23 fb
tt	~ 730 pb	~ 1.5 pb

S/B improved by more than one order of magnitude

Results after application of acceptance cuts

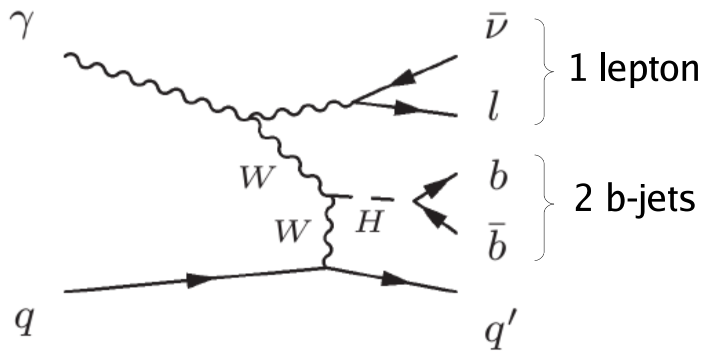
Topology	lνbb (M_H=115 GeV)	jjl^+l^- (M_H=115 GeV)	$jjl^+\tau_h$ (M_H=115 GeV)	lll (M_H=170 GeV)	$jjl^\pm l^\pm$ (M_H=170 GeV)
σ WHq’ [fb]	5.42	0.14	0.52	0.55	1.17
σ_{acc}	0.12	0.01	0.04	0.07	0.22
Irreducible backgrounds (tt, Wt, Wzq', WWW, Wllq' Wbbq')					
σ_{acc} bkg	3.73	30.8	6.68	1.44	0.28

- Very small statistics
  ➡ not a discovery channel
- For analysis, more specific cuts can be applied.
- Interesting sensitivity for 2 topologies : lνbb and $jjl^\pm l^\pm$

Associated WH photoproduction

$\gamma p \to WHq' \to l\nu b\bar{b}q'$ topology

Topology :



Signal selection :

- $E_0^{FCal} < 50$ GeV

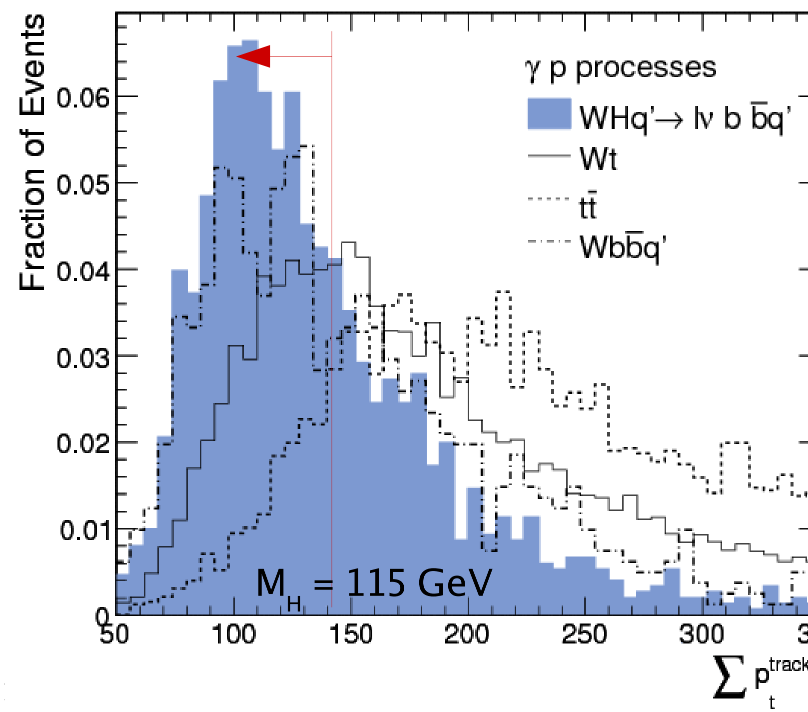
- 1 isolated lepton with $p_t > 15$ GeV
- 2 b-jets with $p_t > 20$ GeV
- No other additional jet with $p_t > 20$ GeV and $|\eta| < 3$

- $\sum(P^T_{tracks}) < 140$ GeV

- Considered backgrounds : tt, Wt, Wbbq'

[fb]	WHq'	Bkg
σ	5.42	1051
σ_{acc} (HF tag)	4.77	822.9
σ_{acc} (topology)	0.10	1.85
σ_{acc} (final cuts)	0.06	0.31

Signifiance after 100 fb^{-1} : 1.5 σ



Physics goal :

- sensitive to g_{Hbb} which is very difficult to measure in pp collisions

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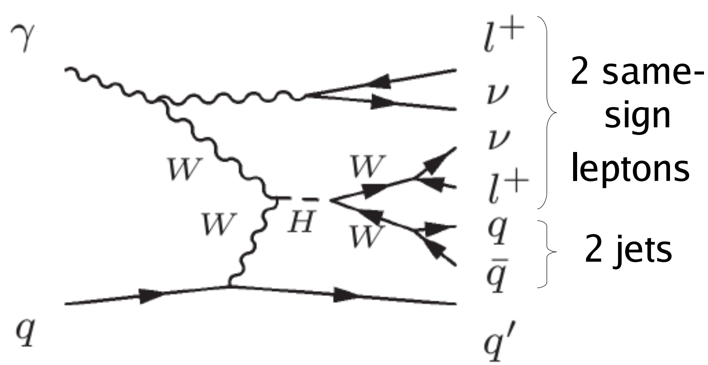
$\gamma p \to WHq' \to jjl^{\pm}l^{\pm}q'$ topology

Topology :



Signal selection :

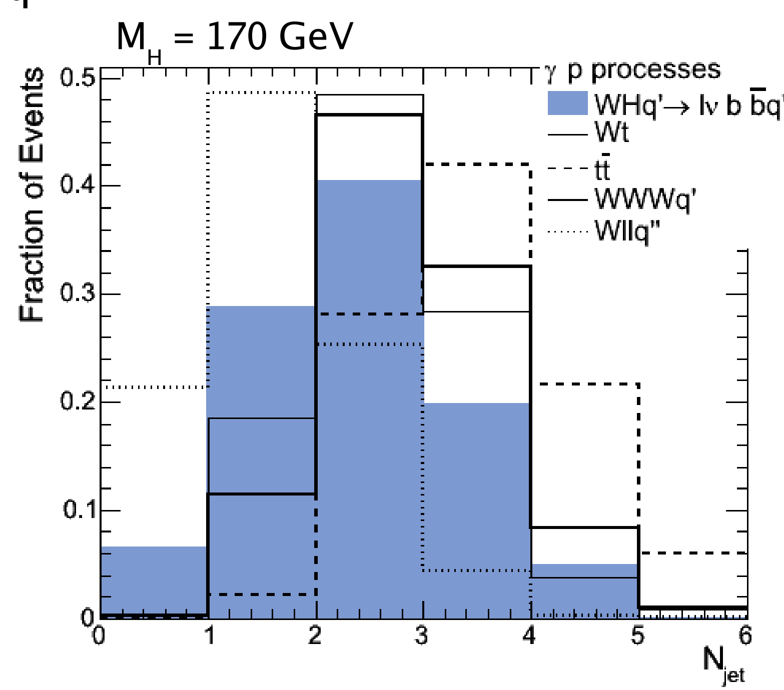
- $E_0^{FCal} < 50$ GeV

- 2 same sign isolated leptons with $p_t > 10$ GeV
- ≥ 2 jets with $p_t > 20$ GeV and $|\eta| < 3$
- No τ-jets with $p_t > 10$ GeV and $|\eta| < 2.5$
- No b-jets with $p_t > 20$ GeV

- Considered backgrounds : tt, Wt, Wllq', WWWq'

[fb]	WHq'	Bkg
σ	1.17	1041
σ_{acc} (HF tag)	0.73	805
σ_{acc} (topology)	0.19	0.80

Signifiance after 100 fb^{-1} : 2.3 σ



Physics goal :

- sensitive to g_{HWW}
- crucial for a fermiophobic Higgs

Associated WH photoproduction

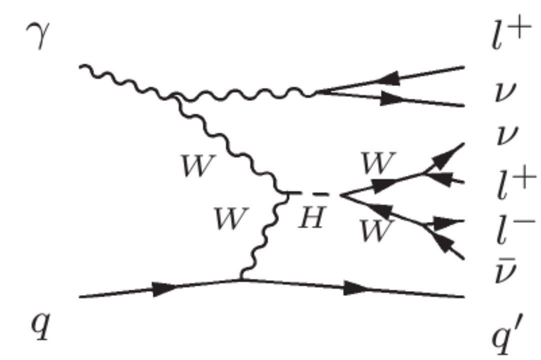
$\gamma p \to WHq' \to lllq'$ topology

<u>Signal selection</u> :

- $E_0^{FCal} < 50$ GeV

- 3 isolated leptons with $p_t > 10$ GeV
- « Z boson veto » : veto if 2 same sign leptons with $60\ \text{GeV} < M_{ll} < 120$ GeV
- « HWW tag » : presence of 2 opposite sign leptons with $\Delta\eta < 1$
- « 2nd jet veto » : veto if 3 jets with $p_t > 20$ GeV and $|\eta| < 3$
- No b-jets with $p_t > 20$ GeV
- $\eta_{jet} > 1$

<u>Topology</u> :

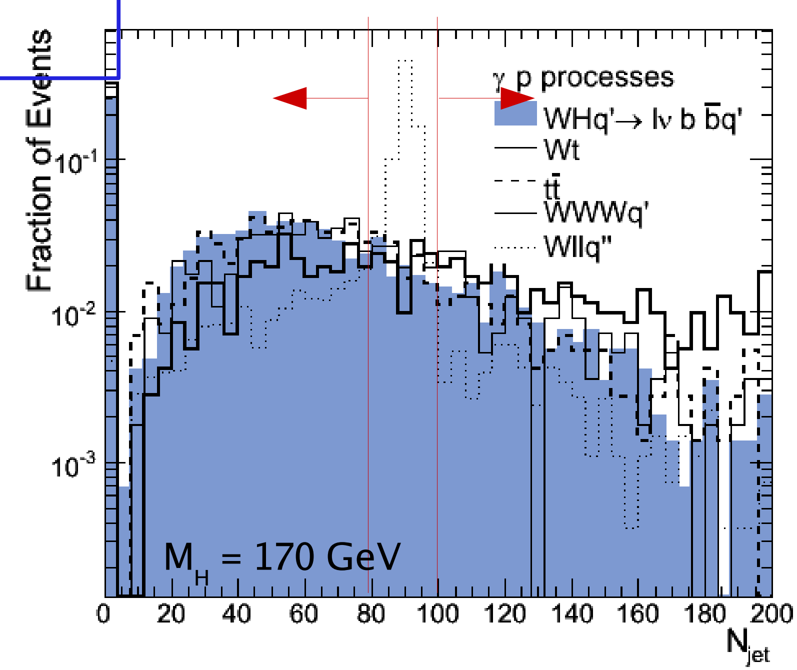


3 isolated leptons

- Considered backgrounds : tt, Wt, Wllq', WWWq'

[fb]	WHq'	Bkg
σ	1.17	276
σ_{acc} (HF tag)	0.50	238
σ_{acc} (topology)	0.02	0.02

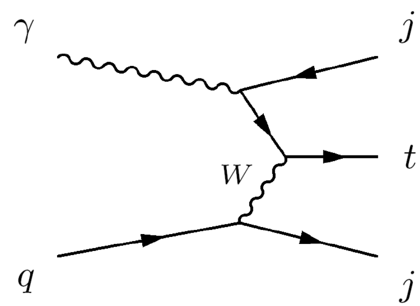
Significance after 100 fb^{-1} : 1.6 σ



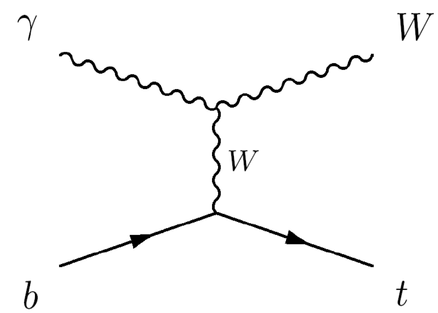
γp processes
Experimental
γp -> WHq'
Introduction
Acceptance cuts
WHq' → lνbbq'
WHq' → jjl±l±q'
WHq' → lllq'
Single Top
Summary

High energy single top photoproduction at the LHC

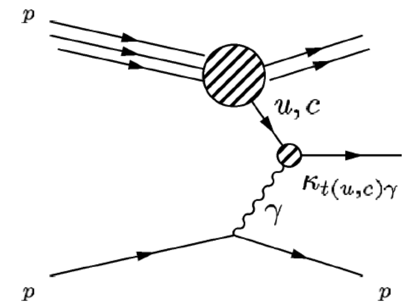
The LHC is a Top factory!



t-channel



Wt-channel



Anomalous top

Physics highlights

- Wt and t-channel related to V_{tb}
- Sensitivity to new physics : FCNC
- Possibility to study top properties (mass, charge,...)

pp vs γp cross sections

pb	pp	γp
Wt-channel	~ 60	~ 1
t-channel	~ 245	~ 0.006
Wjjj	~ 35000	8.7
tt	~ 720	1.5

- Wt-channel : more favorable background condition than pp case
- What kind of uncertainty is reachable on $|V_{tb}|$?

$$\frac{\sigma_{Wt}}{\sigma_{tt}} \simeq 0.7$$

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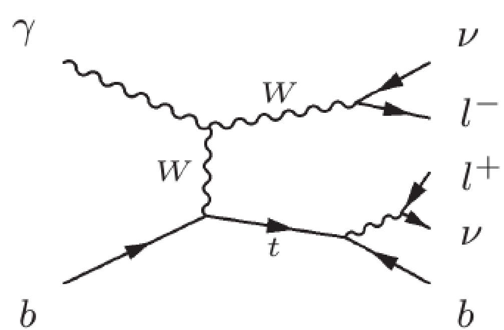
W associated single top production

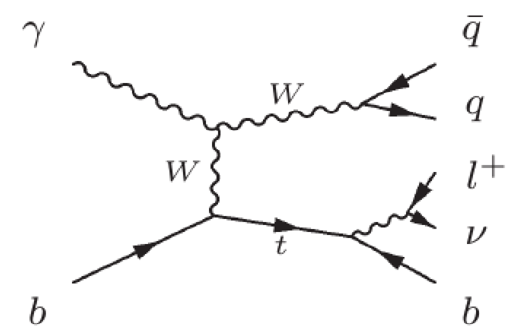
SM single top production : γp events : Wt / total top production = ~50% ➡ Ideal to study $|V_{tb}|$

pp events : Wt / total top production = ~5%

Semi and di-leptonic topologies are studied :



2 leptons and 1 b-jet



1 lepton, 2 jets and 1 b-jet

Results after acceptance cuts

Topology	lbjj	llb
σ Wt [fb]	440	103.7
σ_{acc}	34.1	8.69
Irreducible backgrounds (Wjjj,Wbbq', WWq',tt)		
σ_{acc} bkg	63.0	3.00

Measurement of V_{tb} after 10 fb^{-1} :

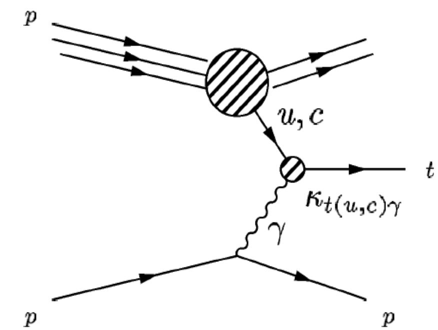
- $\Delta|V_{tb}|/|V_{tb}| \approx 10\%$ in the di-lepton Wt channel
- $\Delta|V_{tb}|/|V_{tb}| \approx 16\%$ in the semi-lepton Wt channel

See J. de Favereau's talk

- Assuming V_{tb}, one can also measure the top electric charge

Anomalous top production

See J. de Favereau's talk



Effective Lagrangian for anomalous coupling :

$$L = ie_t \, t \frac{-\sigma_{\mu\nu} q^{\nu}}{\Lambda} k_{tu\gamma} \, u A^{\mu} + ie_t \, t \frac{-\sigma_{\mu\nu} q^{\nu}}{\Lambda} k_{tc\gamma} \, c A^{\mu} + h.c.$$

Where $\sigma^{\mu\nu} = \frac{\gamma^{\mu}\gamma^{\nu} - \gamma^{\nu}\gamma^{\mu}}{2}$

➡ Therefore, the cross section takes the form : $\sigma_{pp\to t} = \alpha_u k_{tu\gamma}^2 + \alpha_c k_{tc\gamma}^2$

with $\alpha_u = 368\ pb$ and $\alpha_c = 122\ pb$, computed using CalcHEP

Physics highlights

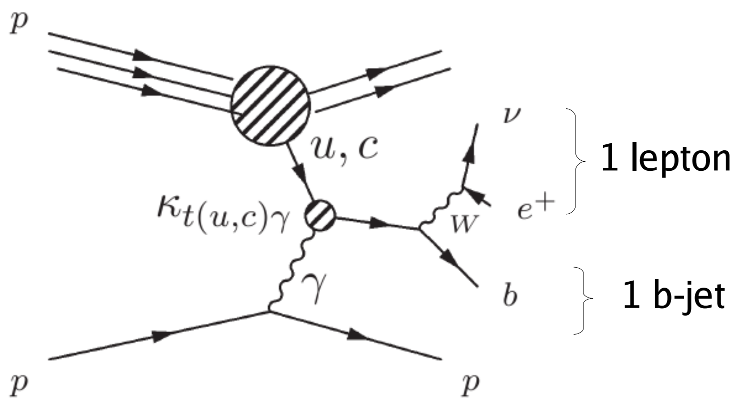
- Sensitivity to new physics : FCNC
- Current limit obtained by Zeus : $k_{tu\gamma} \approx 0.17$
- At HERA only u-quark relevant, at LHC also c-quark contributes

Limit on $k_{tu\gamma}$ could be significantly improved even at start-up luminosity !

- γp processes
- Experimental
- γp -> WHq’
- Single Top
  - Introduction
  - Wt-channel
  - Anomalous top
- Summary

Limits for anomalous couplings

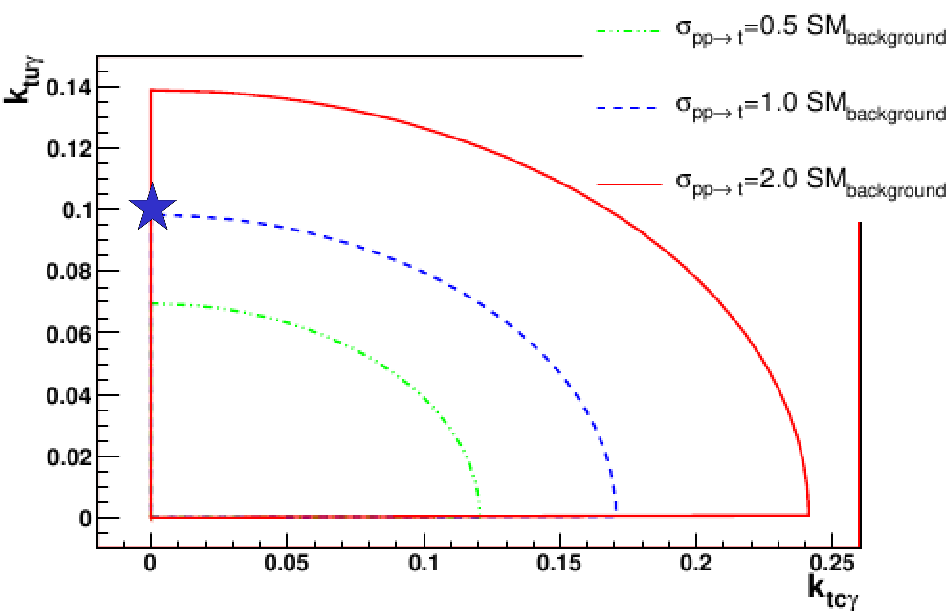
Topology :



Results after acceptance cuts ($k_{tu\gamma}$ = 0.1, $k_{tc\gamma}$ = 0)

Topology	lb
σ t [fb]	769
σ_{acc}	144
Irreducible backgrounds (Wj, Wc)	
σ_{acc} bkg	139

Cross section contours as a function of anomalous couplings :



Expected limits at 95% CL

Coupling	Limits	
	L = 1 fb^{-1}	L = 10 fb^{-1}
$k_{tu\gamma}$	0.043	0.024
$k_{tc\gamma}$	0.074	0.042

~ factor 10 wrt Zeus limits

See J. de Favereau's talk

Summary - outlook

- High energy γp interactions have significant cross section at the LHC
- γ p -> WHq' (100 fb^{-1})
  - $\gamma p \rightarrow WHq' \rightarrow l\nu bbq'$ topology : sensitive to g_{Hbb} which is very difficult to assess in pp events
  - $\gamma p \rightarrow WHq' \rightarrow jjl^{\pm}l^{\pm}q'$ topology
  - $\gamma p \rightarrow WHq' \rightarrow lllq'$ topology

  For m_H = 170 GeV a combined significance close to 3 σ is achieved
- Wt-channel (10 fb^{-1})
  - Wt related to V_{tb} ➡ seems very promising even after 10 fb^{-1}
  - Possibility to study top properties (mass, charge,...)
- Anomalous top
  - Large improvement of sensitivity is expected on current searches for anomalous couplings (FCNC) with 1 fb^{-1}

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Backup slides

Photon-proton cross sections

Processes		σ [pb]		Generator	Cut
γg	$\rightarrow t\bar{t}$	1.54		MG/ME	-
γq	$\rightarrow Wt$	1.01		//	-
	$WWWq'$	6.04	$\times 10^{-3}$	//	-
	W^+W^-q'	0.605		//	-
	$W\gamma q'$	0.349		//	cut 1
	WZq'	0.151		//	-
	Wc	11.4		//	-
	W^+j	28.1		//	-
	W^-j	25.0		//	-
$\gamma q/g$	$\rightarrow Wjj$	19.2		//	-
	$Wjjj$	8.68		//	-
γq	$\rightarrow Zj$	2.62		CalcHEP	-
$\gamma q/g$	$\rightarrow Zjj$	1.34		MG/ME	-
	$Zjjj$	0.827		//	-
γq	$\rightarrow ZZq'$	1.73	$\times 10^{-3}$	//	-
	γj	25.3		CalcHEP	cut 2
$\gamma q/g$	$\rightarrow \gamma jj$	12.9		MG/ME	cut 2
	γjjj	8.48		//	cut 2
γq	$\rightarrow \gamma\gamma q'$	30.4	$\times 10^{-3}$	//	cut 2
	$Wb\bar{b}q'$	45.8	$\times 10^{-3}$	//	cut 3
	$W\tau^+\tau^-q'$	1.62	$\times 10^{-3}$	//	cut 4
	$W\ell^+\ell^-q'$	19.6	$\times 10^{-3}$	CalcHEP	cut 5
	$W\ell^+\ell^-q'$	4.43	$\times 10^{-3}$	//	cut 4

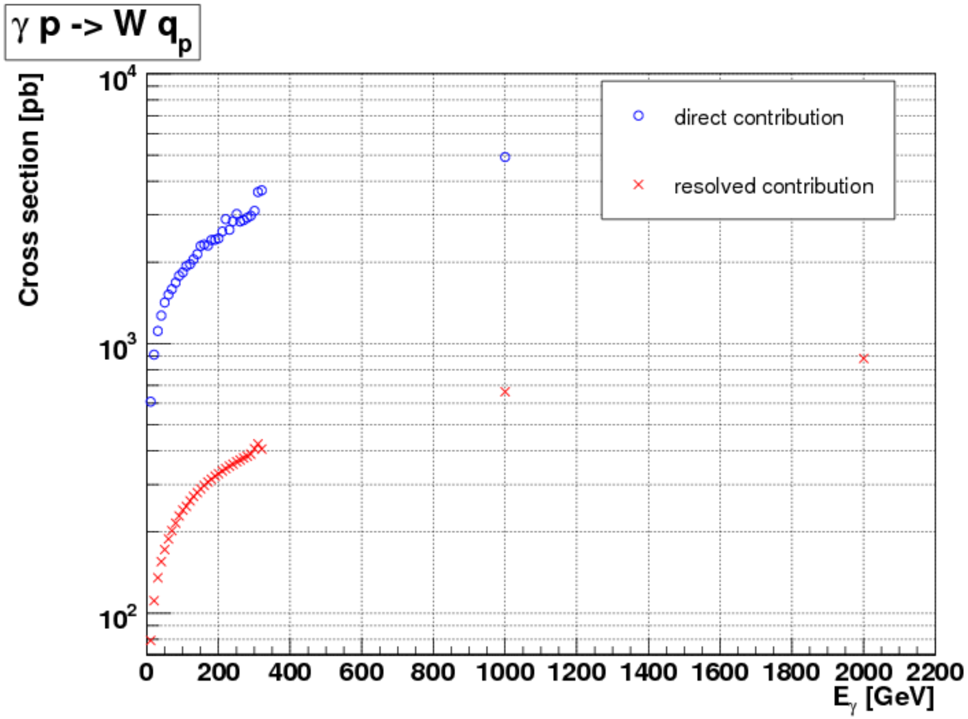
cut 1 : $p_T^\gamma > 20$ GeV,

cut 2 : $p_T^\gamma > 20$ GeV, $|\eta^\gamma| < 5$, $\Delta R(\gamma, j) > 0.3$ and $\Delta R(\gamma, \gamma) > 0.3$

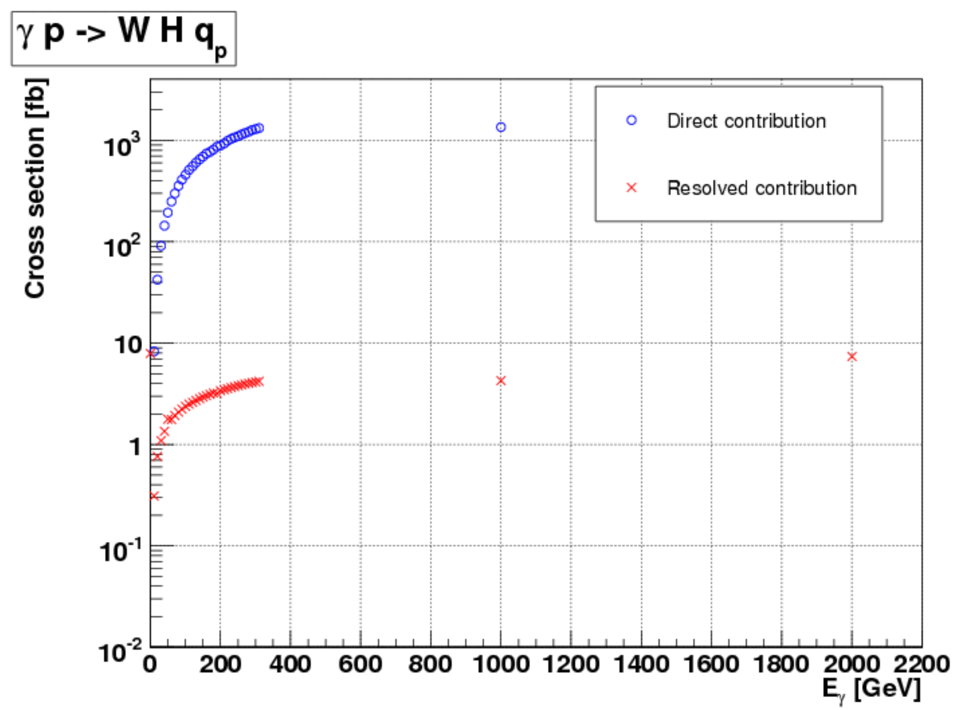
cut 3 : $M_{b\bar{b}} > 80$ GeV,

cut 4 : $M_{\ell^+\ell^-} > 110$ GeV,

cut 5 : 10 GeV $< M_{\ell^+\ell^-} <$ 70 GeV,



Obtained using MG/ME



WH and Wt acceptance cuts

Cross section [fb]	ℓbjj	$\ell\ell b$
σ Wt	440	103.7
σ_{acc}	34.1	8.69
Irreducible processes		
σ_{acc} $t\bar{t}$	46.37	2.80
$Wjjj$	15.61	-
$Wb\bar{b}q'$	1.01	-
W^+W^-q'	-	0.18
σ_{acc} total	62.99	2.99

Wt events

Acceptance cut	ℓbjj	$\ell\ell b$
N_ℓ	1	2
N_{jet}	2 + 1 b-tag	1 b-tag
$\lvert\eta^{jet}_{max}\rvert$	3	2.5

Acceptance cut	$\ell b\bar{b}$	$jj\ell\ell$	$jj\ell\tau_h$	$\ell\ell\ell$	$\ell^\pm\ell^\pm jj$
N_ℓ	1	2	1	3	2
N_{τ_h}	-	-	1	-	-
N_{jet}	2 b-tag	2	2	≤ 1	≥ 2
$\lvert\eta^{jet}_{max}\rvert$	3	3	3	3	3

WHq' events

Cross section [fb]	$\ell b\bar{b}$	$jj\ell^+\ell^-$	$jj\ell\tau_h$	$\ell\ell\ell$	$jj\ell^\pm\ell^\pm$
	m_H = 115 GeV			m_H =170 GeV	
σ WHq'	5.42	0.14	0.52	0.55	1.17
σ_{acc}	0.12	0.01	0.04	0.07	0.22
Irreducible processes					
σ_{acc} Wt	1.18	4.25	0.98	-	-
$t\bar{t}$	2.47	24.7	6.40	-	-
$Wb\bar{b}q'$	0.19	-	-	-	-
$W\ell\ell q'$	-	0.42	0.07	0.43	0.11
WZq'	-	1.51	0.12	0.98	0.06
$WWWq'$	-	0.25	0.08	0.03	0.10
σ_{acc} total	3.84	31.2	7.63	1.44	0.28

Fast simulation of a LHC-like detector

Longitudal view of the detector