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High energy photoproduction at the LHC

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Overview photon-photon:

- Introduction to photon-photon
- Detection and tagging
- Associated WH
- Single top
- Summary

Overview photoproduction:

- Introduction to photon-proton procedure
- Detection and tagging
- Associated WH
- Single top
- Summary

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High energy photon-photon interactions at the LHC

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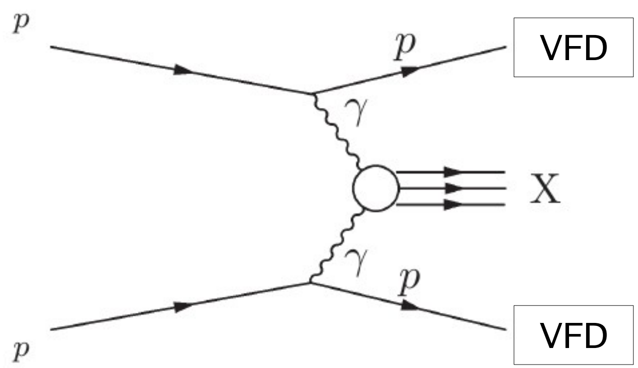
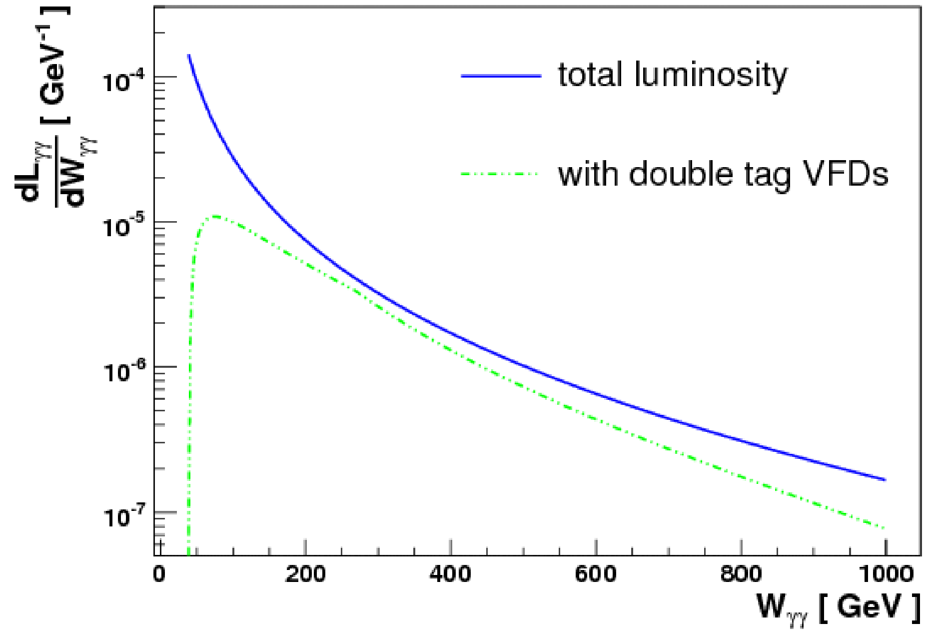
LHC as a photon-photon collider !

pp (γq/g → X) pp





Luminosity peaked at low $W_{\gamma\gamma}$

- Very clean event topologies :
  - centrally produced particles
  - 2 protons measured far away from the IP

Using EPA

$$\sigma_{pp} = \int \sigma_{\gamma\gamma} \frac{dL_{\gamma\gamma}}{dW_{\gamma\gamma}} dW_{\gamma\gamma}$$

- Factorization to
  - long distance photon exchange
  - short distance $\gamma\gamma \rightarrow X$

- Detection and tagging : use of very forward detectors (VFD)

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pp cross sections

- Huge pp background sufficiently suppressed
- Photon momenta precisely measured using VFD
  ➡ reconstruction of the longitudinal degrees of freedom
- Several large inclusive cross sections

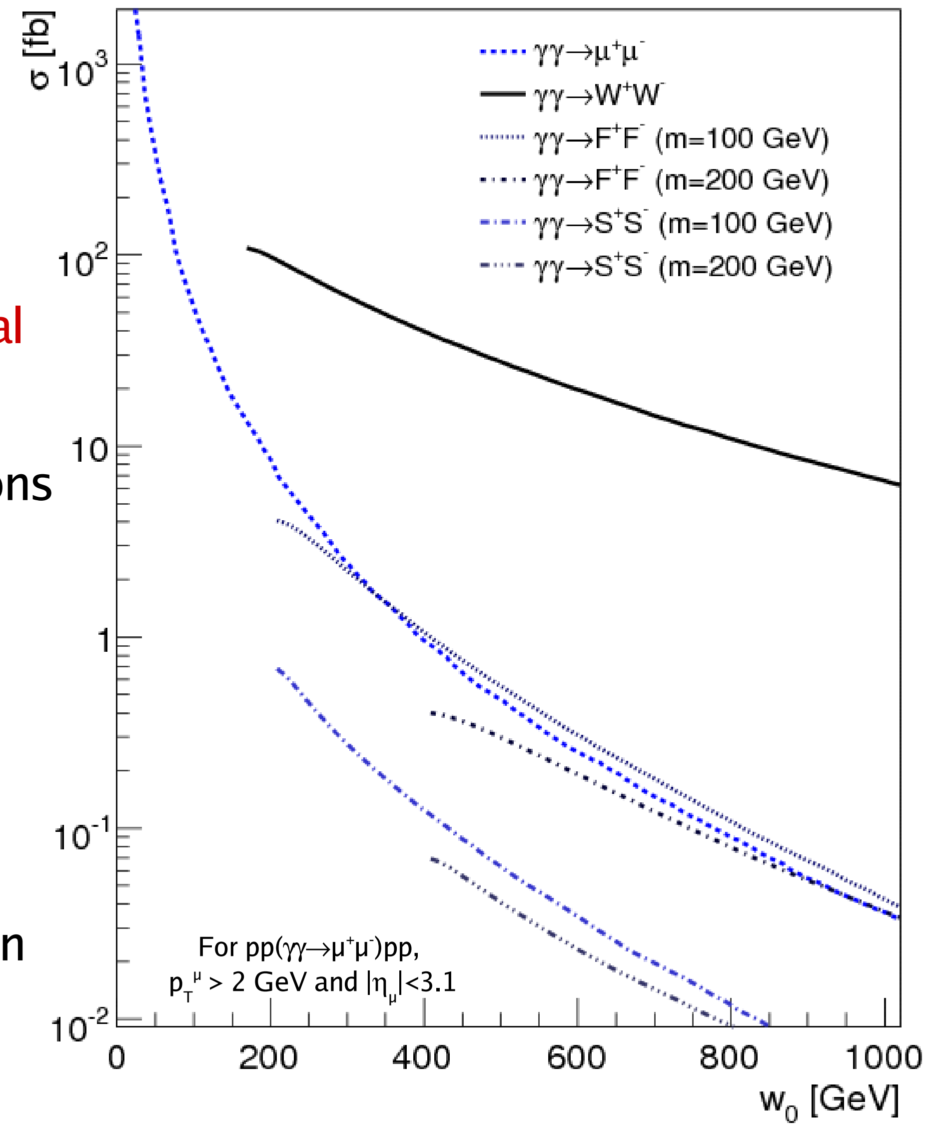
  $\gamma\gamma \rightarrow \mu^+\mu^-$: first $\gamma\gamma$ process to be seen (σ=72.5 pb)

  - high statistics for $\gamma\gamma \rightarrow W^+W^-$
    ➡ precise measurement of the $\gamma\gamma WW$ coupling

  - Supersymmetric pair production

- High survival probability factor

Obtained using MadGraph/MadEvent



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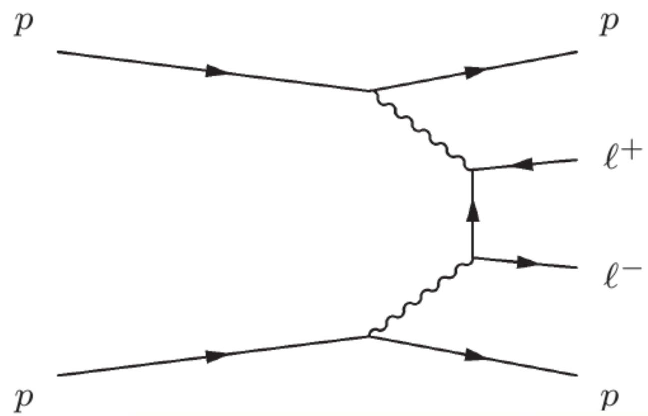
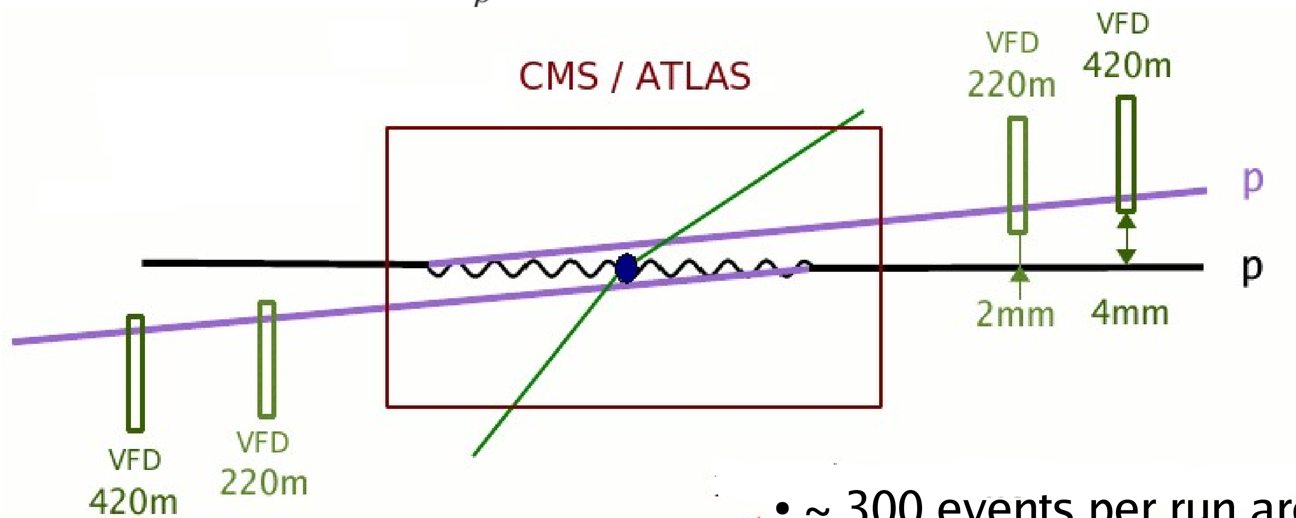
$\gamma\gamma \to \mu^+\mu^-$



- Well known and large cross section
- pp luminosity monitoring : ~ 800 events/12 h ($L = 10^{33}\ cm^{-2}\ s^{-1}$)
- Calibration of very forward detectors
  - VFD acceptance
  - Misalignment of the beam optics



- ~ 300 events per run are selected with at least one VFD tag ➡ run-by-run calibration

	$\|\eta\|<2.5$	
	$p_T^\mu > 3$ GeV	$p_T^\mu > 10$ GeV
σ_{acc}	21600 fb	1340 fb
σ_{acc} (with VFD)	7260 fb	1270 fb

- Require a dedicated trigger with low thresholds

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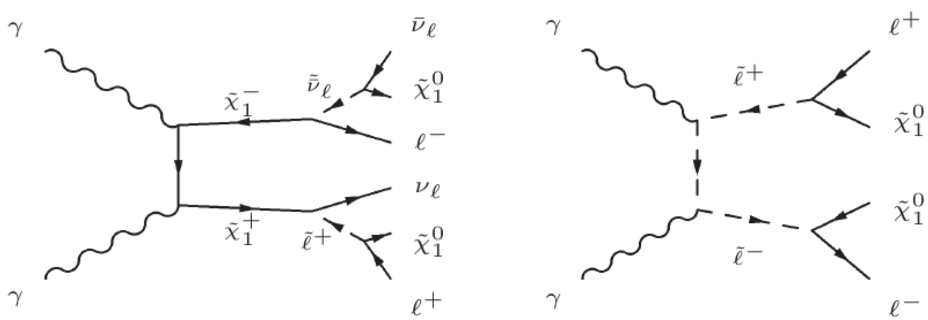
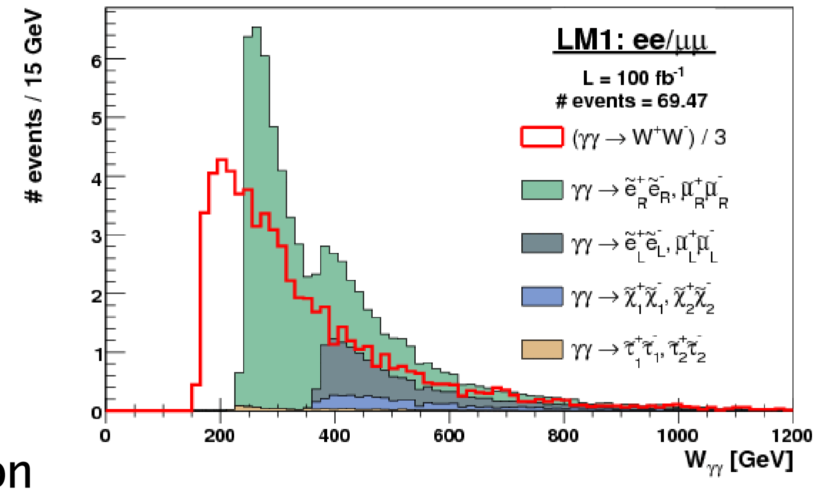
SuSy search...

Example for the LM1 parameter space

LM1 : very light LSP, light sleptons, light charginos, tg(β)=10

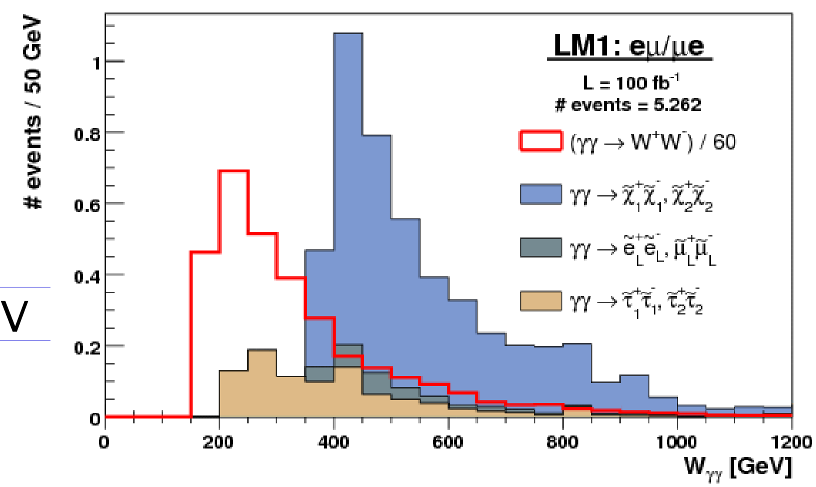




SuSy pairs produced with Calchep, decay with Pythia

- New, complementary and simple production mechanism
- Very simple final state : 2 leptons and E_T^{mis}
- Using double VFD tag : constraint on the SuSy masses

	σ (fb)	σ_{acc} (fb)	
		p_T > 3 GeV	p_T> 10 GeV
$\gamma\gamma \rightarrow \tilde{\ell}_R^+\tilde{\ell}_R^-$	0.798	0.627	0.475
$\tilde{\ell}_L^+\tilde{\ell}_L^-$	0.183	0.142	0.133
$\tilde{\tau}_i^+\tilde{\tau}_i^-$	0.604	0.175	0.146
$\tilde{\chi}_i^+\tilde{\chi}_i^-$	0.642	0.111	0.035
H^+H^-	0.006	-	-
$\gamma\gamma \rightarrow W^+W^-$	108.5	4.257	3.652



Small cross sections, probably not a discovery channel

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γγ processes
Lepton pairs
Susy pairs
W and Z pairs
Summary

- High cross section ~ 100 fb
- Very clean signature
  - ➡ Stringent test of the SM

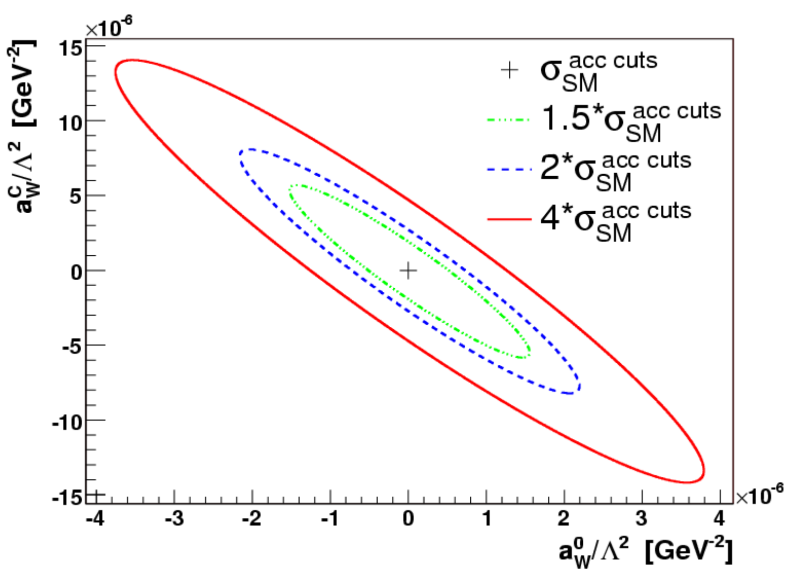
$\gamma\gamma \to W^+W^- \to \mu^+\mu^-$	$\lvert\eta\rvert<2.5$	
	$p_T^{\mu} > 3$ GeV	$p_T^{\mu} > 10$ GeV
σ_{acc}	0.80 fb	0.76 fb
σ_{acc} (with VFD)	0.70 fb	0.66 fb

Anomalous gauge boson couplings

Lagrangian for anomalous quartic vector boson couplings which conserves C, P as well as local $U(1)_{em}$ and SU(2) :

$$L_6^0 = \frac{-e^2}{8}\frac{a_0^W}{\Lambda^2} F_{\mu\nu} F^{\mu\nu} W^{+\alpha} W_\alpha^- - \frac{e^2}{16\cos^2\theta_W}\frac{a_0^Z}{\Lambda^2} F_{\mu\nu} F^{\mu\nu} Z^\alpha Z_\alpha$$

$$L_6^C = \frac{-e^2}{16}\frac{a_C^W}{\Lambda^2} F_{\mu\alpha} F^{\mu\beta} (W^{+\alpha} W_\beta^- + W^{-\alpha} W_\beta^+) - \frac{e^2}{16\cos^2\theta_W}\frac{a_C^Z}{\Lambda^2} F_{\mu\alpha} F_{\mu\, betha} Z^\alpha Z_\beta$$



no other background than SM $\gamma\gamma \to WW$ for 30 fb^{-1} expected 22.8 (18.6) events

while current OPAL limits are:

$$-0.020 \text{ GeV} < a_0^W < 0.020 \text{ GeV}$$

$$-0.052 \text{ GeV} < a_C^W < 0.037 \text{ GeV}$$

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Summary - outlook

- LHC is a γγ collider
- γγ -> μμ : interesting for luminosity monitoring and RP calibration
- γγ -> WW : limits on 4-vector coupling could be really improved
- SUSY pairs could be measured for high luminosity runs

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High energy photoproduction at the LHC

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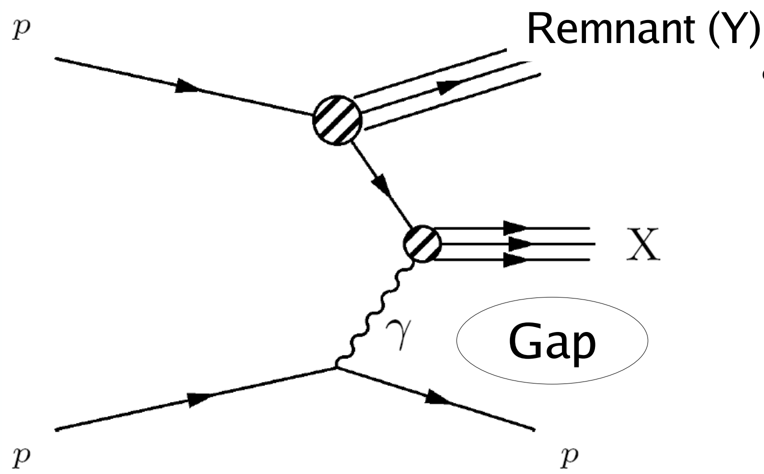
LHC : a new HERA collider !

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!

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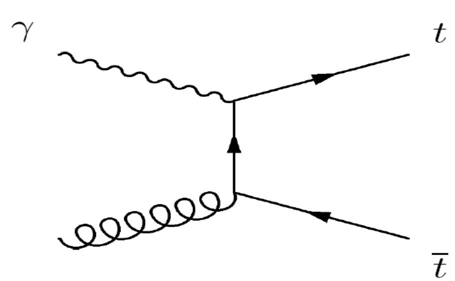
γp cross sections

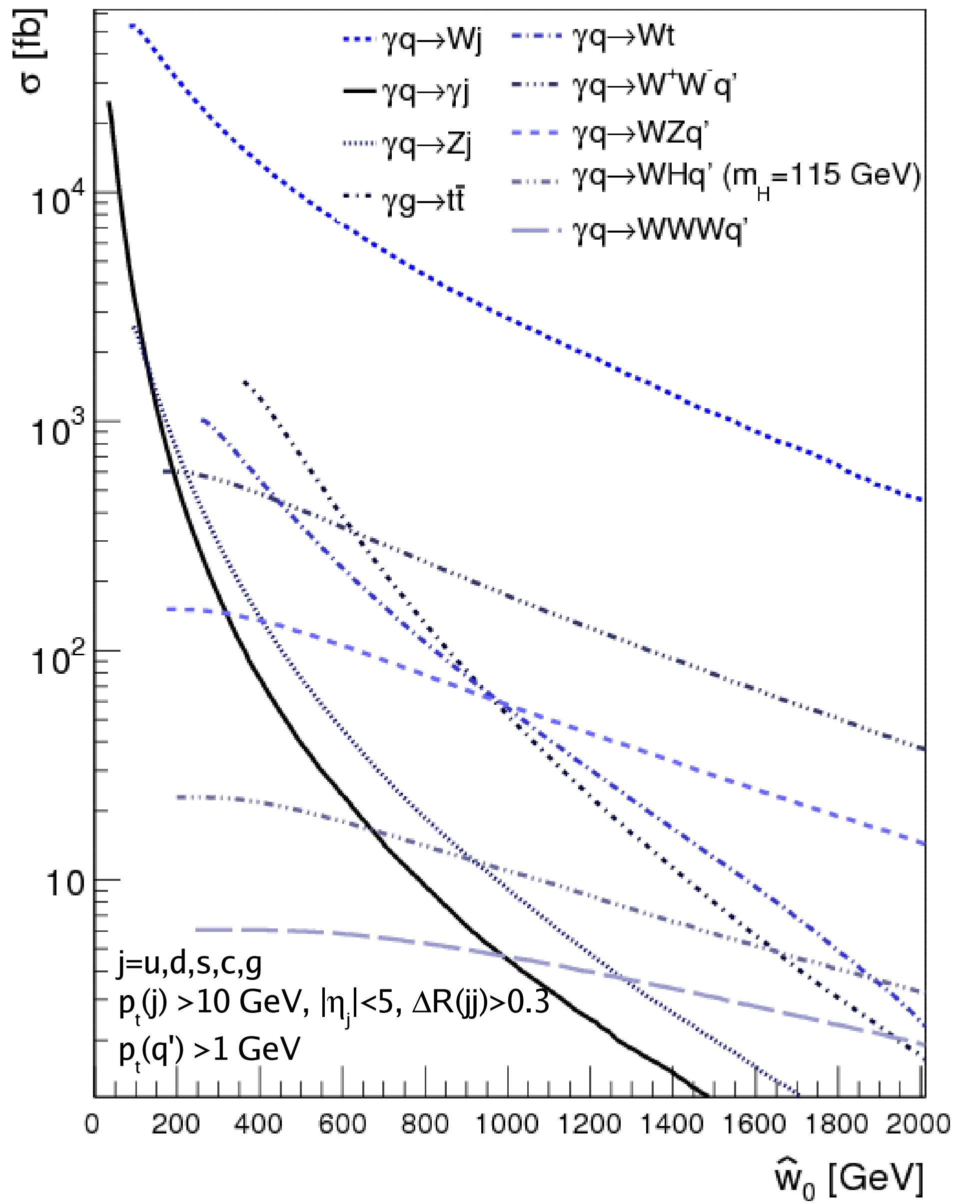
Obtained using MadGraph/MadEvent

- 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

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Simulation procedure

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

MG/ME
Calchep
Generation

→ PYTHIA
Showering
Hadronization
Fragmentation,...

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

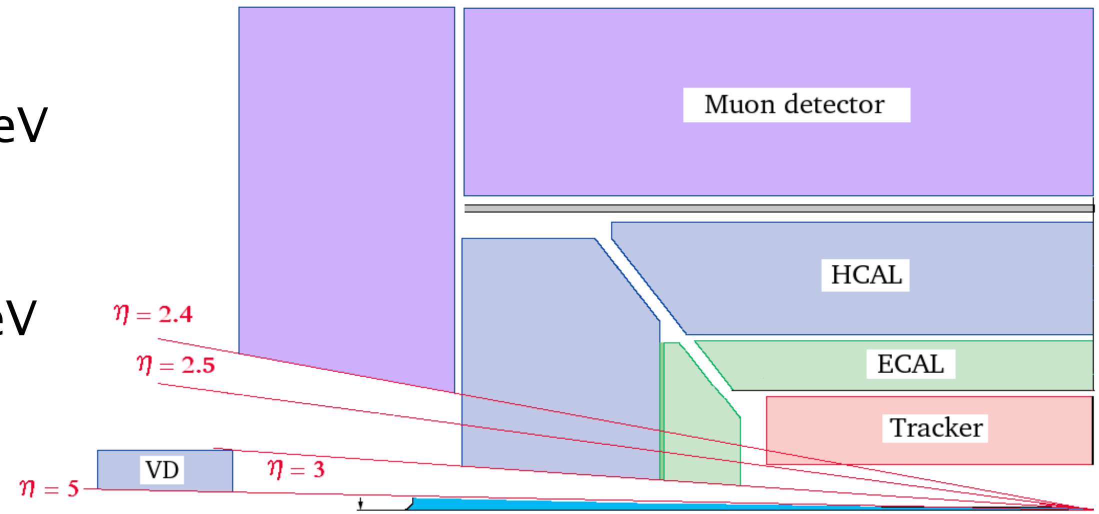
Objects reconstruction

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

Jets : reconstructed in a cone $R = 0.7$ for $|\eta| < 3$, $p_T > 20$ 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.



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

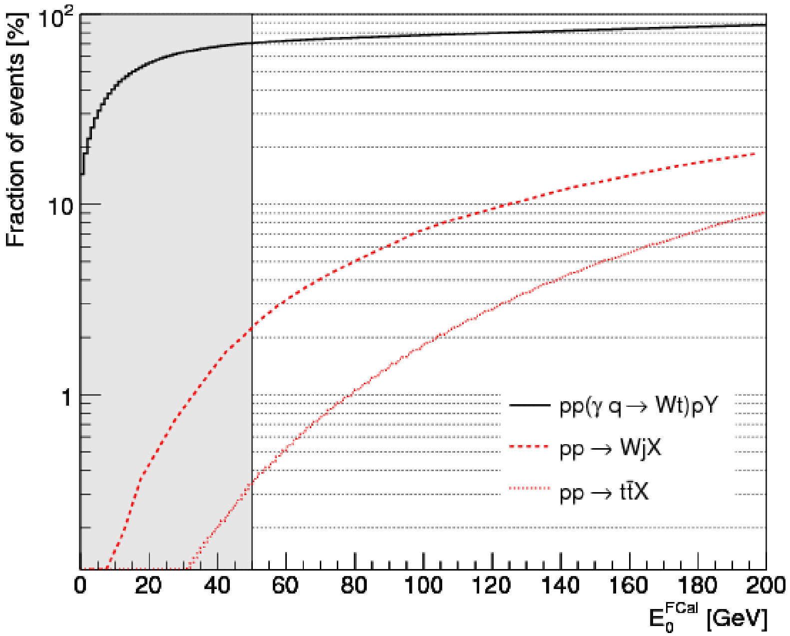
Detection and tagging

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

- Small event pile-up

➡ Large rapidity gap (LRG) signature can be used

- For example, forward energy flows (into $3<|\eta|<5$) in one of the two hemispheres less than 50 GeV



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

Drawback : - low integrated luminosity expected

- kinematics is less constrain

- Expected integrated luminosity of 1 fb^{-1}

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

- Use of very forward detector is mandatory !
- Exclusivity cuts can be applied (e.g. vetoing soft tracks from event vertex)
- Expected integrated luminosity of 10-30 fb^{-1}

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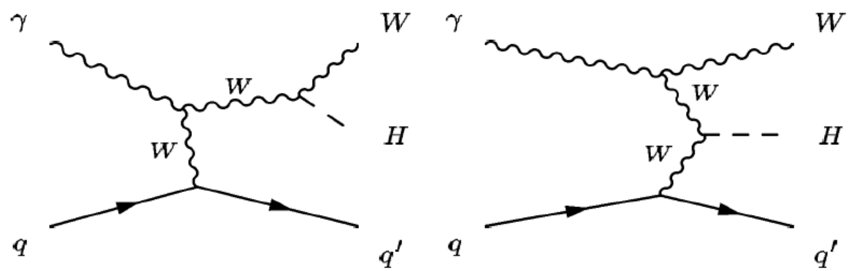
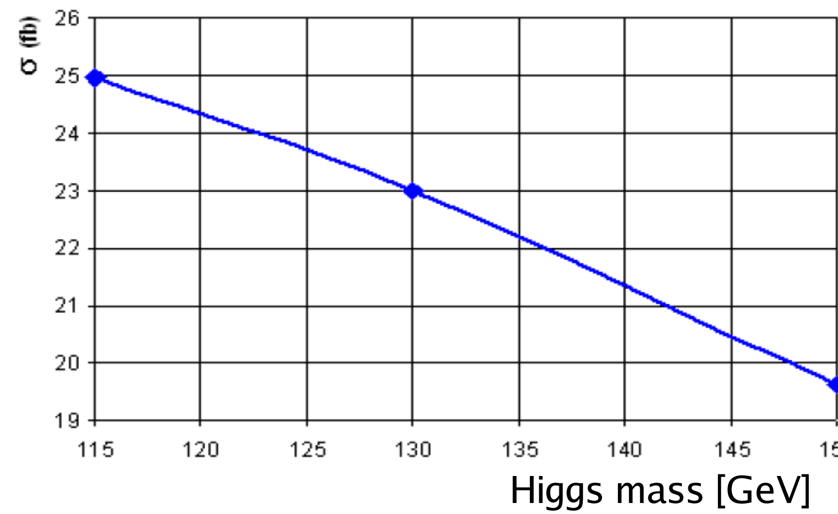
Associated WH production



Obtained using MadGraph/MadEvent



- Associated production of WH has significant cross section at LHC !
- tt less overwhelming than in pp case!

Five topologies where studied

- WH → lνbb, l=e,μ,τ,
- WH → $W\tau^+\tau^-$ → jjl^+l^-, l=e,μ,
- WH → $W\tau^+\tau^-$ → $jjl^+\tau_h$, l=e,μ,
- WH → WW^+W^- → lll, l=e,μ,τ,
- WH → WW^+W^- → $jjl^\pm l^\pm$, l=e,μ,τ.

	M_H=115 GeV			M_H=170 GeV	
Topology	lνbb	jjl^+l^-	$jjl^+\tau_h$	lll	$jjl^\pm l^\pm$
σ WHq' [fb]	5.42	0.14	0.52	0.55	1.17
σ_{acc}	0.12	0.01	0.03	0.07	0.22
Irreducible backgrounds (tt, Wt, Wzq', WWW, Wllq' Wbbq')					
σ_{acc} bkg	3.69	29.9	7.35	1.26	0.27

Results after application of acceptance cuts

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

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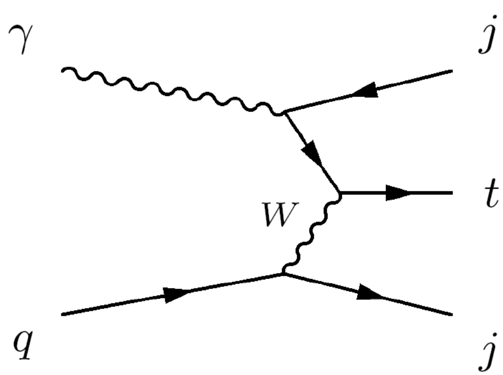
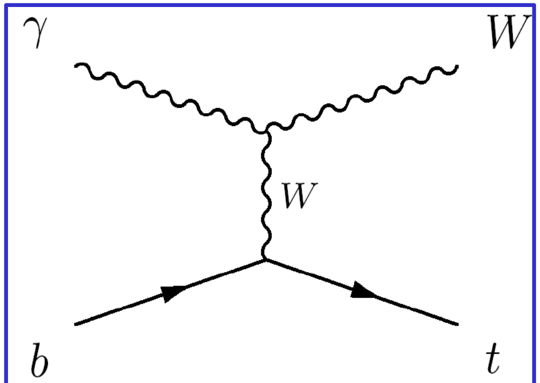
γ p processes
Experimental
γp -> WHq'
Single Top
Introduction
Wt-channel
Anomalous top
Summary

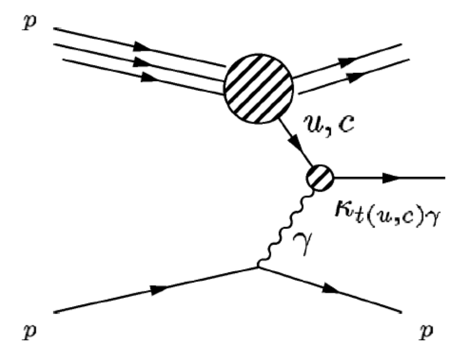
The LHC is a Top factory!



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

	pp	γp
Wt-channel	~ 60 pb	~ 1pb
t-channel	~ 245 pb	~ 6.2 fb
Wjjj	~ 35 nb	8.7 pb
tt	~ 720 pb	1.5 pb

- Wt-channel : more favorable background condition than pp case

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

- What kind of uncertainty is reachable on $|V_{tb}|$?

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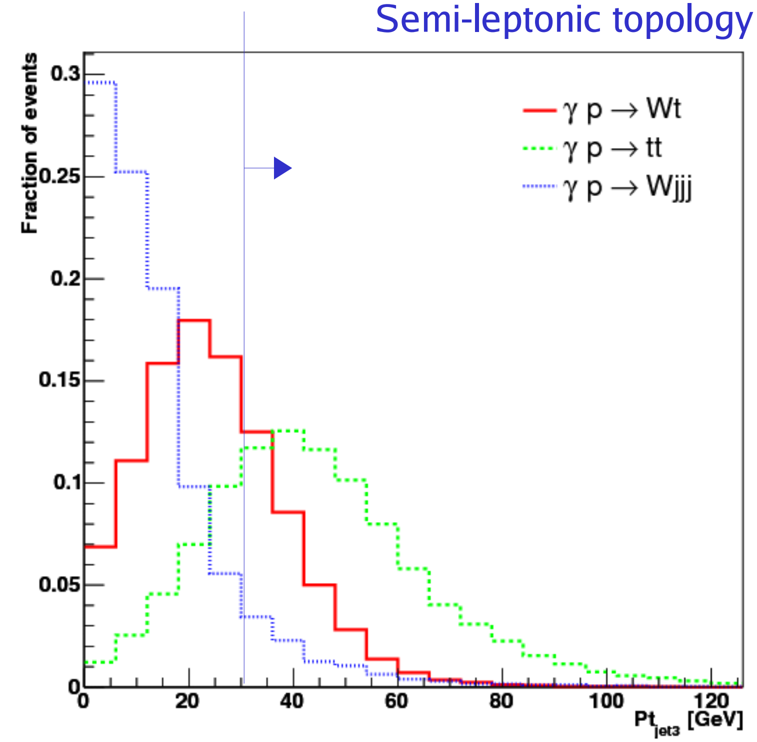
Typical analysis cuts

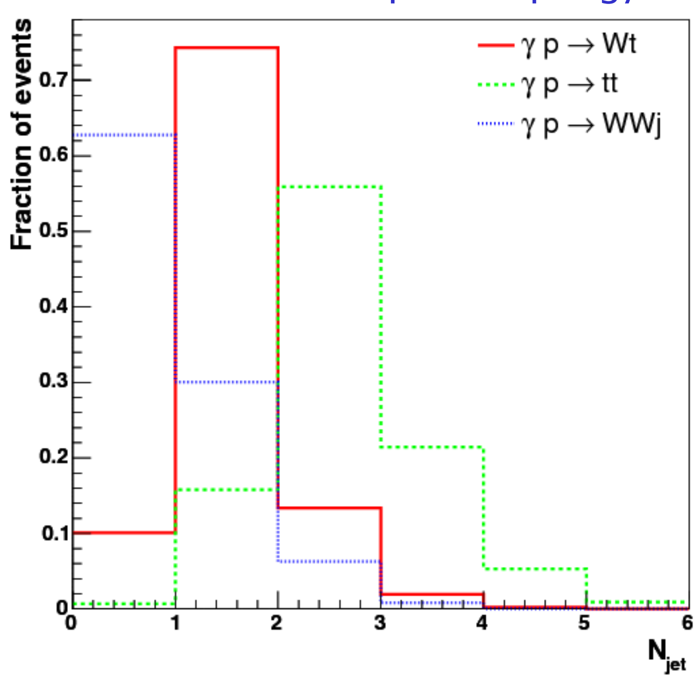
Semi-leptonic topology

- 1 isolated lepton with p_t > 20 GeV
- 3 jets with p_t > 30 GeV
- 1 tagged b-jet
- H_t (scalar sum of all visible E_t's) < 230 GeV
- M(bb) in a window of 20 GeV around M_W

Semi-leptonic topology



Di-leptonic topology



Di-leptonic topology

- 2 isolated leptons with p_t > 20 GeV
- 1 jet with p_t > 30 GeV
- jet tagged as b-jet
- Missing E_t > 20 GeV

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σ uncertainty : semi-leptonic topology

- Cross sections after analysis cuts

		γp backgrounds				pp backgrounds				
	Wt	tt(1l)	tt(2l)	W3j	Wbbj	tt(1l)	tt(2l)	W+jets	Wbbj	tj
σ [fb]	440.6	671.75	159.08	2792.97	55.22	328025	77680	3261000	266587	67005
σ_{acc}	7.35	3.39	0.63	0.79	0.04	8.3	1.76	9.65	2.73	0.56

- Uncertainties after 10 fb^{-1}

Source	Uncertainty	Δσ/σ (semi-lept)
Statistical uncertainty	-	25.5%
Integrated luminosity	5%	10.5%
Theoretical uncertainty	-	9.7%
Jet energy Scale	5% (20 GeV) 3% (50 GeV)	23.4%
b-tagging efficiency	5%	24.0%
Total systematic uncertainty		34.9%

- This result can be improved (e.g. : tagging, exclusivity,...)
- More efficient suppression of pp backgrounds is mandatory!

σ uncertainty di-leptonic topology

- Cross sections after analysis cuts

		γp bkg		pp bkg	
	Wt	tt	WWq'	tt	WWj
σ [fb]	104.33	159.1	62.5	77680	5234
σ_{acc}	5.8	1.97	0.12	2.55	0.23

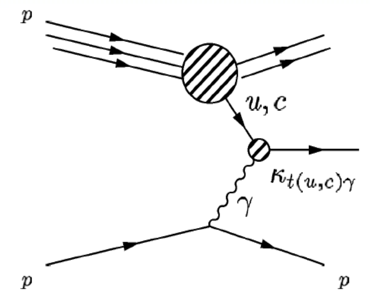
- Uncertainties after 10 fb^{-1}

Source	Uncertainty	Δσ/σ (di-lept)
Statistical uncertainty	-	17.6%
Integrated luminosity	5%	5.7%
Theoretical uncertainty	-	2.75%
Jet Energy Scale	5% (20 GeV) 3% (50 GeV)	10.7%
Btagging efficiency	5%	9.1%
Total systematic uncertainty		14.3%

Uncertainty on $|V_{tb}|$: 12.1%

➡ di-leptonic topology is competitive !

Anomalous top production

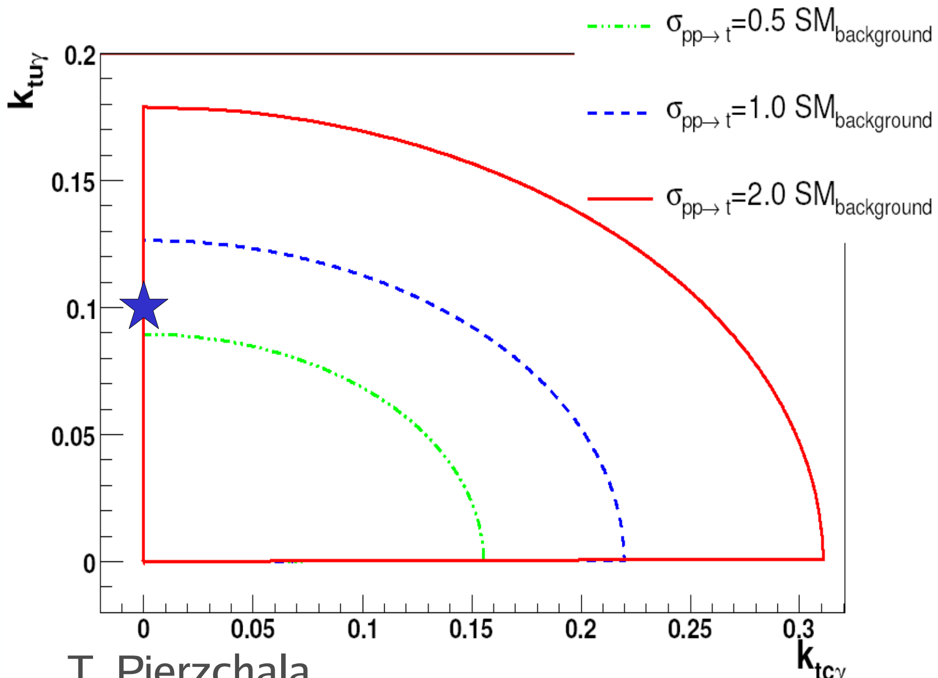


Effective Lagrangian for anomalous coupling :

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

- Current limit obtained by Zeus : $k_{tu\gamma} \approx 0.14$
- At HERA only u-quark relevant, at LHC also c-quark contributes

$$\Rightarrow \quad \sigma_{pp\to t} = \alpha_u k_{tu\gamma}^2 + \alpha_c k_{tc\gamma}^2$$



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

Topology	IE^T_{mis} b
σ t [fb]	3680
σ_{acc}	123.8
Irreducible backgrounds (Wj, Wc)	
σ_{acc} bkg	198.1

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

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Summary - outlook

- High energy γp interactions have significant cross section at the LHC
- γ p -> WHq' (100 fb^{-1}) events only sensitive for 2 topologies : lνbb and $jjl^{\pm}l^{\pm}$
  - Analysis are ongoing for those 2 cases, using analysis cuts.
- Wt-channel (10 fb^{-1}) seems very promising
  - For the di-leptonic topology, $|V_{tb}|$ uncertainty is similar to the one obtained using pp->Wt
  - The sensitivity at reconstructed level has to be evaluated
  - For the semi-leptonic topology, one needs to tackle pp backgrounds
- Anomalous top (1 fb^{-1}) can also be probed using very low integrated luminosity

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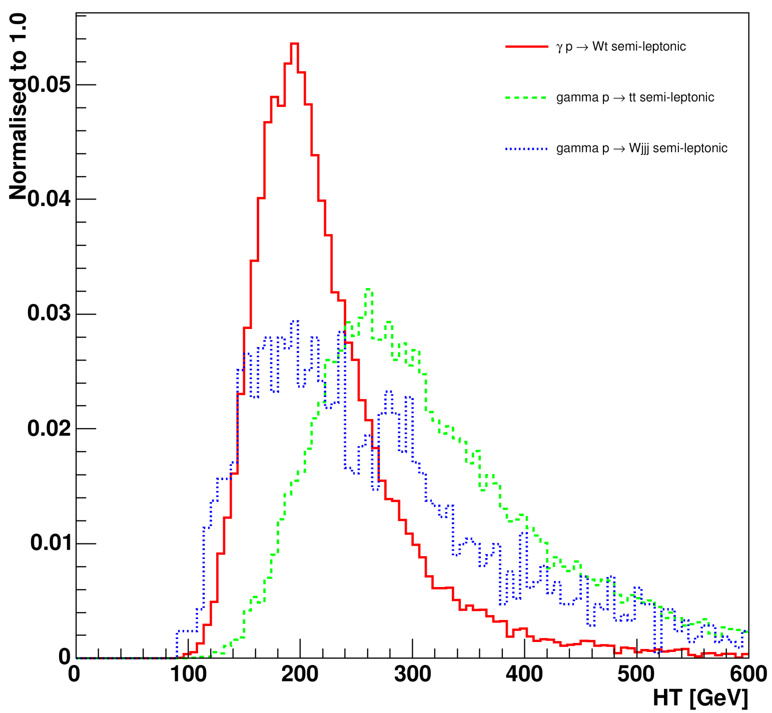
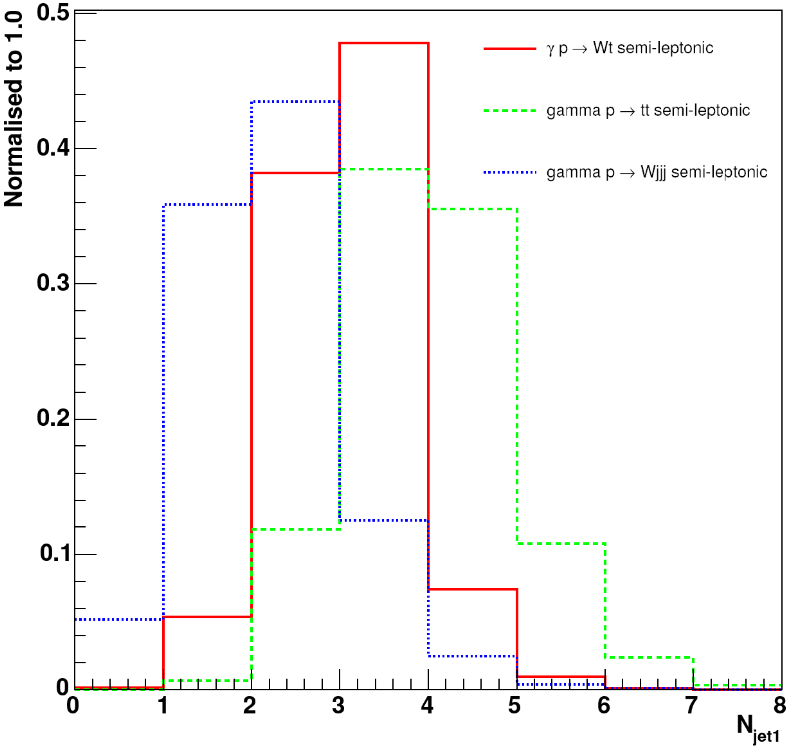
Backup slides





<u>Theoretical errors</u>

single top events : 6%
tt events : 5%
Wjjj events : 3%
Wbbj events : 17%
WWj : 6%

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	Wt	γp backgrounds $t\bar{t}(1\ell)$	$t\bar{t}(2\ell)$	W3j	Wbbj	pp backgrounds tj.	$t\bar{t}(1\ell)$	$t\bar{t}(2\ell)$	Wjets	Wbbj
$E_{\gamma Hem}$	309	489	131	2301	47	536	1095	291	28508	3901
$N_{lept} = 1$	146.7	229	64.0	1111	22.9	261	474	148.8	13347	1661
$N_{jet} = 3$	37.6	95.4	13.6	66.1	1.58	14.0	188	35.9	851	55.5
HT sum	22.0	18.2	3.82	17.7	0.32	5.36	47.1	11.9	343.4	22.22
b-tagging	9.05	8	1.78	2.14	0.15	2.21	20.7	5.53	29.8	9.5
RecW	7.35	3.39	0.63	0.79	0.04	0.56	8.3	1.76	9.65	2.73
Expected for 10/fb	73	34	6	8	negl.	1	83	18	96	27

	sample	selected	$\Delta\sigma$	JES	ΔN_{b-tag}	ΔN_{Lum}	ΔN_{stat}
	S: Wt	73	4.38	3.72	3.65	3.65	8.5
γp proces	B: $t\bar{t}(1l)$	33	1.65	1.51	1.65	1.65	5.7
	B: $t\bar{t}(2l)$	6	0.3	0.37	0.3	0.3	2.4
	B: Wjjj	8	0.24	0	0.4	0.4	2.8
	B: Wbbj	0	0	0.03	0.	0	0
pp proces	B: $t\bar{t}(1l)$	83	4.15	1.98	4.15	4.15	9.1
	B: $t\bar{t}(2l)$	18	0.9	2.1	0.9	0.9	4.2
	B: W+jets	96	2.88	5.41	4.8	4.8	9.79
	B: tj	6	0.36	0.29	0.3	0.3	2.4
	B: Wbbj	27	4.59	1.65	1.35	1.35	5.2

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	Wt	γp backgrounds			pp backgrounds	
		$t\bar{t}(2\ell)$	$WW(2\ell)$	$WW(1\ell)$	$t\bar{t}(2\ell)$	$WW(2\ell)$
$E_{\gamma Hem}$	89.0	130.6	58.0	222.8	291	105.9
$N_{lept} = 2$	21.3	31.6	14.7	0.01	57.9	22.3
$N_{jet} = 1$	15.8	5.2	4.4	0.01	7.17	8.36
$b - tagged$	6.37	2.1	0.13	0.00	2.71	0.27
E^T_{miss}	5.84	1.97	0.12	0.00	2.55	0.23
Expected in 10 fb^{-1}	58	20	1	0	25	2

	sample	selected	$\Delta\sigma$	JES	ΔN_{b-tag}	ΔN_{Lum}	ΔN_{stat}
	S: Wt	58	3.48	0.5	2.9	2.9	7.6
γp	B: $t\bar{t}(2l)$	20	1	1.06	1	1	4.5
	B: WWj (2l)	1	0.06	0.01	0.05	0.05	1
pp	B: $t\bar{t}(2l)$	25	1.25	4.39	1.25	1.25	5
	B: WWj (2l)	2.26	0.14	0.27	0.11	0.11	1.5
	ΔN_b	-	1.6	5.73	2.41	1.55	-

$$\frac{\Delta|V_{tb}|}{|V_{tb}|} = \frac{1}{2}\frac{\Delta|V_{tb}|^2}{|V_{tb}|^2} = \frac{1}{2}\left[\frac{\Delta\sigma_{obs}}{\sigma} \oplus \frac{\Delta\sigma_{th}}{\sigma}\right]$$

UCL

S.Ovyn

Fast simulation of a LHC-like detector

Longitudal view of the detector