High energy photoproduction and photon-photon interactions at the LHC

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(on behalf of the Louvain Photon group) :

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$\gamma\gamma$ interactions

Outline :

- Equivalent photon approximation (EPA)
- $\gamma\gamma$ luminosities for the LHC
- Detection and tagging
- Cross section of main interest
  - $\gamma\gamma \to \mu^+\mu^-$ LHC luminosity monitoring
  - $\gamma\gamma \to W^+W^-$ SM
  - new physics

γp interactions

Overview :

- 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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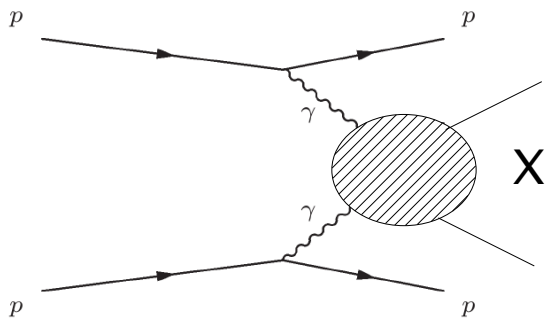
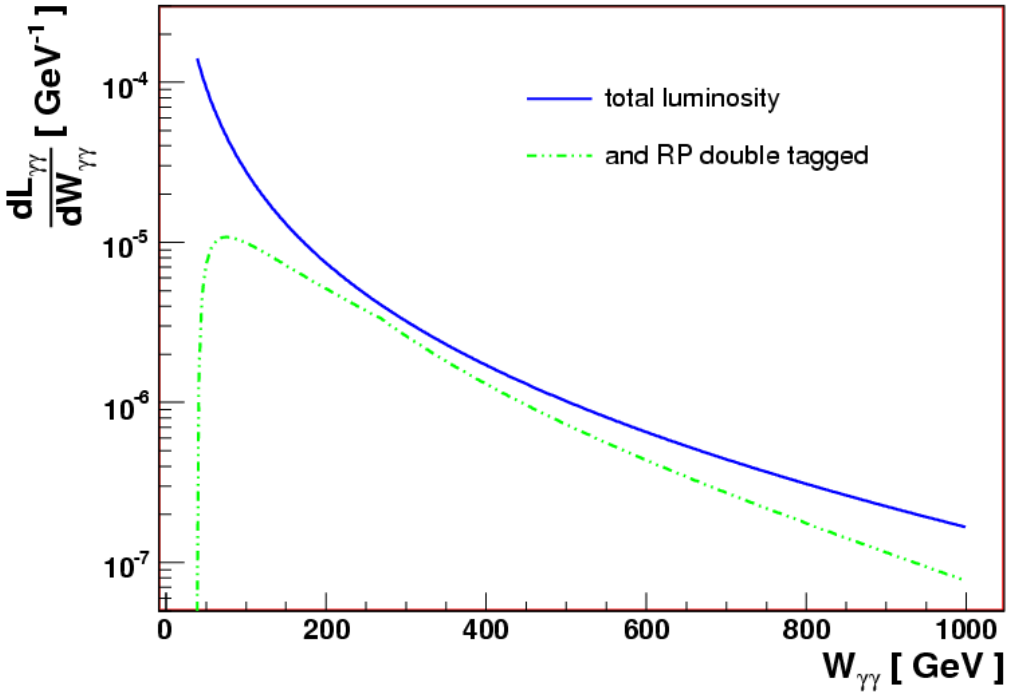
LHC – also a photon-photon collider

γγ luminosities at the LHC

$$pp \to (\gamma\gamma \to X)\, pp$$



$$\sigma_{pp} = \int \sigma(W_{\gamma\gamma}) \frac{d\,L_{\gamma\gamma}}{dW_{\gamma\gamma}}\, dW_{\gamma\gamma}$$



low γ virtuality (typical $q^2 \sim 0.01\,GeV^2$)

- factorization to
  - long distance photon exchange
  - short distance γγ → X interaction
- zero degree scattered angles

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

sizable charged pair production up to $W_{\gamma\gamma} \approx 500$GeV

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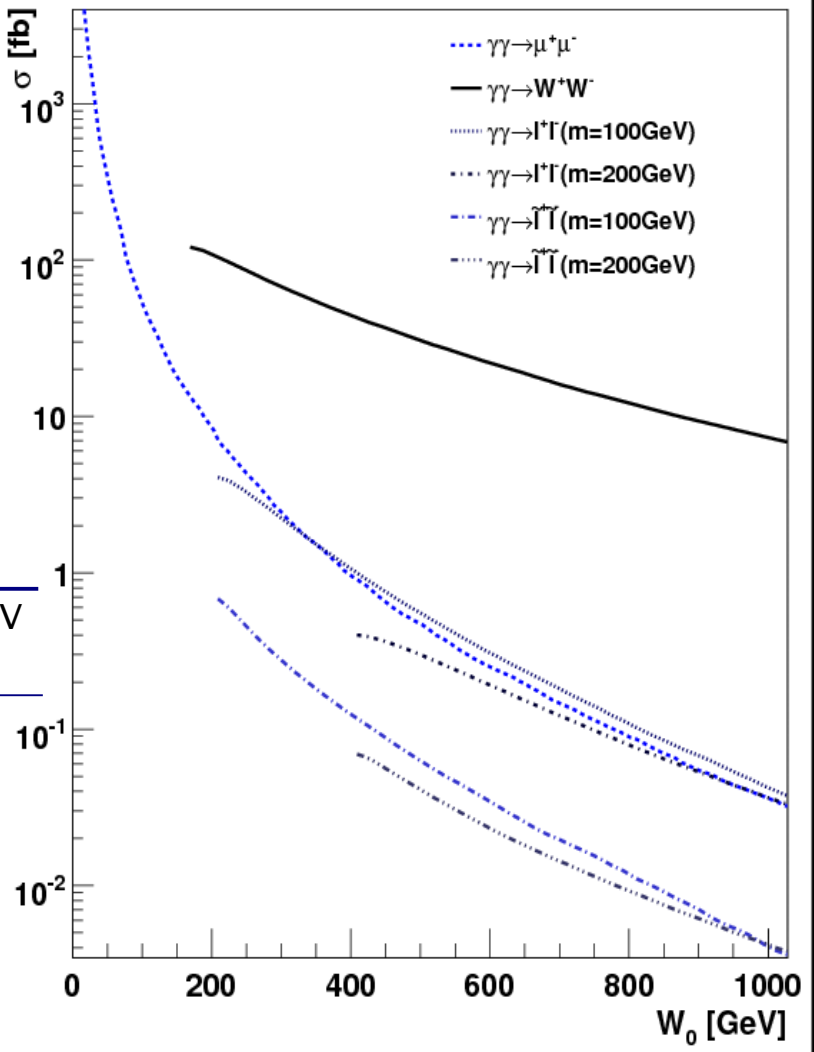
γγ cross sections

- $\gamma\gamma \to \mu\mu$ first γγ process to be seen
- $\gamma\gamma \to W^+W^-$ very interesting SM process 103fb
- New physics !

Processes	[fb]	Generator
$\gamma\gamma \to \mu\mu$	72 500	LPAIR pt > 2 GeV $\lvert\eta\rvert$ < 3.1
W^+W^-	103	
f^+f^- (m=100GeV)	4.1	MadGraph
f^+f^- (m=200GeV)	0.41	/
$\tilde{f}^+\tilde{f}^-$ (m=100GeV)	0.69	MadEvent
$\tilde{f}^+\tilde{f}^-$ (m=200GeV)	0.07	



Cross sections for γγ processes as a function of the minimal γγ cms energy W_0

moreover :
lepton final states
clear signature – background suppression

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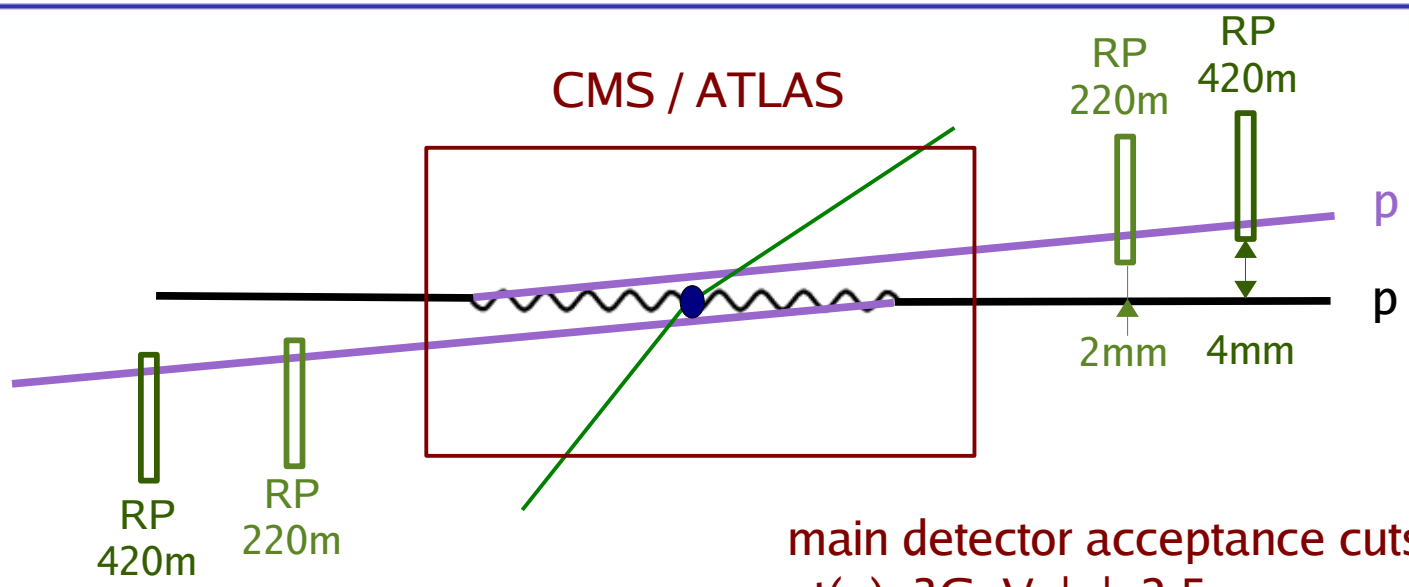
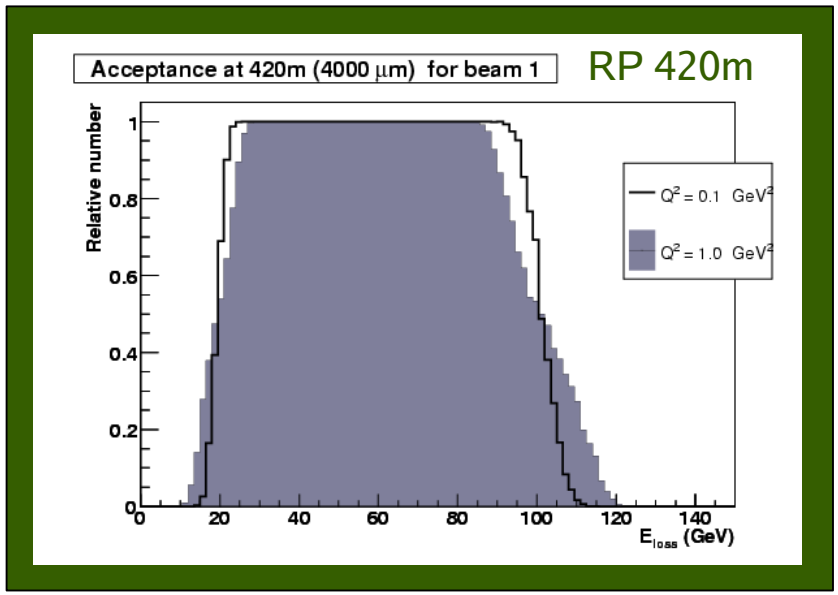


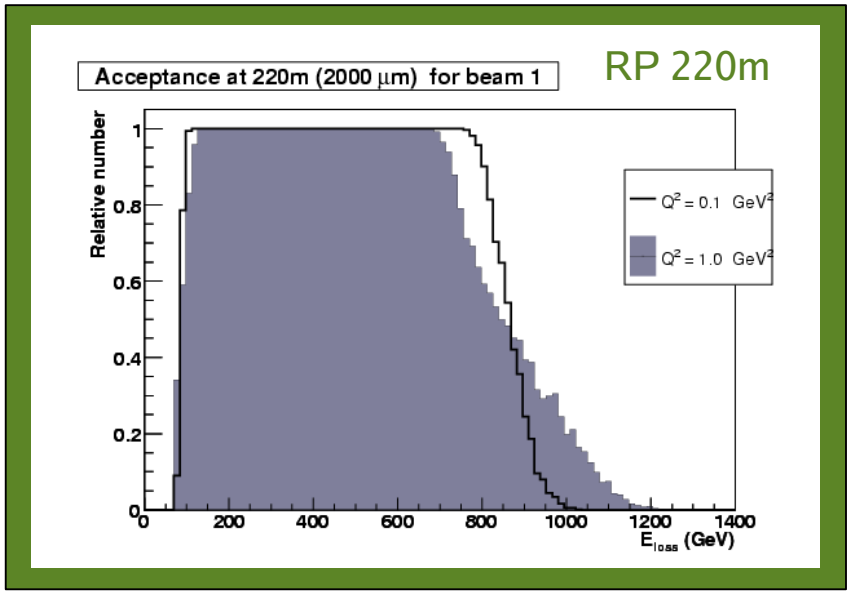
main detector acceptance cuts
pt(μ)>3GeV, |η|<2.5

RP acceptance :

20GeV < tagged photon E < 120GeV



120GeV < tagged photon E < 900GeV



-> talk on Hector by J. de Favereau

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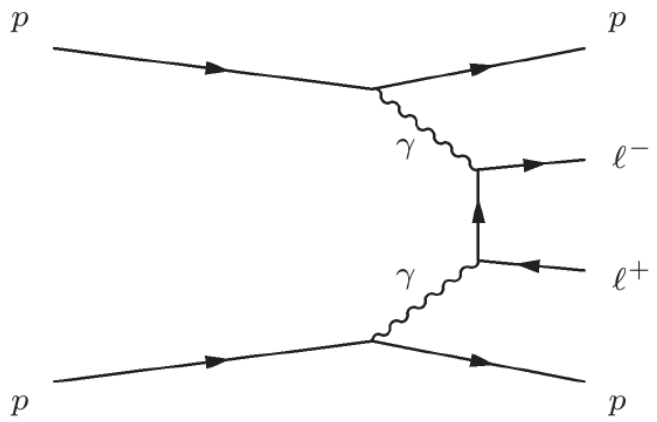
γγ → μμ



	|η| < 2.5	
	pt(μ)>3 GeV	pt(μ)>10 GeV
σ_{acc}	21600 fb	1340 fb
σ_{acc} (with RP)	7260 fb	1270 fb

γγ → μμ will be used for:

- pp luminosity monitoring ~ 800 events/12h (for L= $10^{33} cm^{-2} s^{-1}$)
- calibration of RP – to set photon energy scale
  and RP acceptance
  including misalignment of beam optics

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γγ → WW probing anomalous couplings

γγWW

$$L_6^0 = \frac{-e^2}{8}\frac{a_0^W}{\Lambda^2} F_{\mu\nu} F^{\mu\nu} W^{+\alpha} W^-_{\alpha}$$

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

$$L_6^C = \frac{-e^2}{16}\frac{a_C^W}{\Lambda^2} F_{\mu\alpha} F^{\mu\beta} (W^{+\alpha} W^-_{\beta} + W^{-\alpha} W^+_{\beta})$$

investigating $\gamma\gamma \to W^+W^- \to \mu^+\mu^-\bar{\nu}_\mu\nu_\mu$ effective cross sections (σ_{acc}) are:

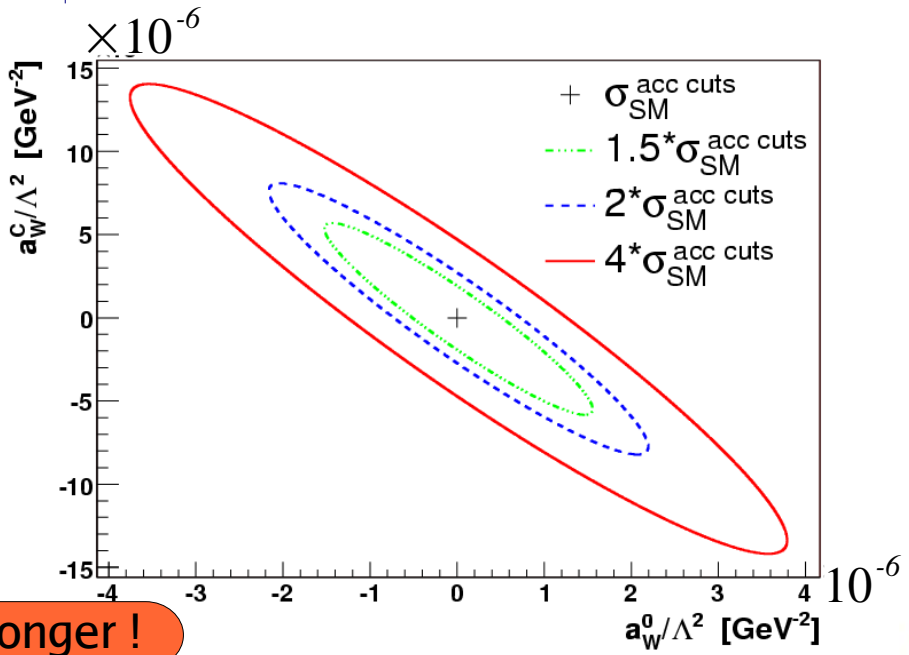
SM here background	pt(μ)>3 GeV	pt(μ)>10 GeV
σ_{acc}	0.76 fb	0.72 fb
σ_{acc} (with RP)	0.66 fb	0.62 fb

no other background than SM γγ→WW
for 30 fb^{-1} expected 22.8 (18.6) events

while current OPAL limits are:

-0.020 GeV < a_0^W < 0.020 GeV

-0.052 GeV < a_C^W < 0.037 GeV



we expect limits to be ~ 10 000 times stronger !

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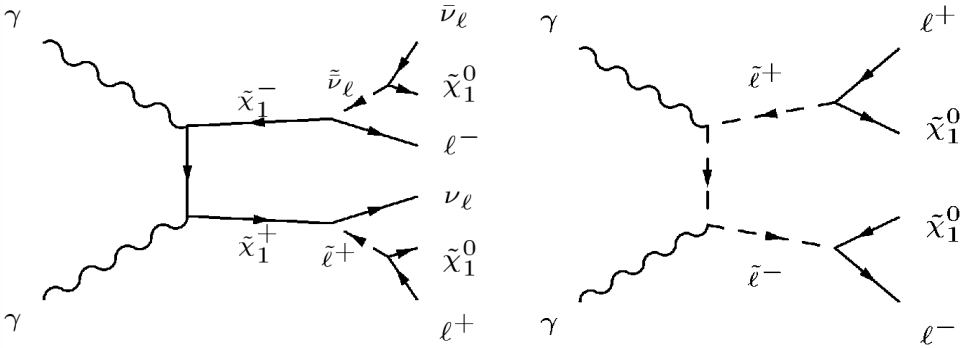
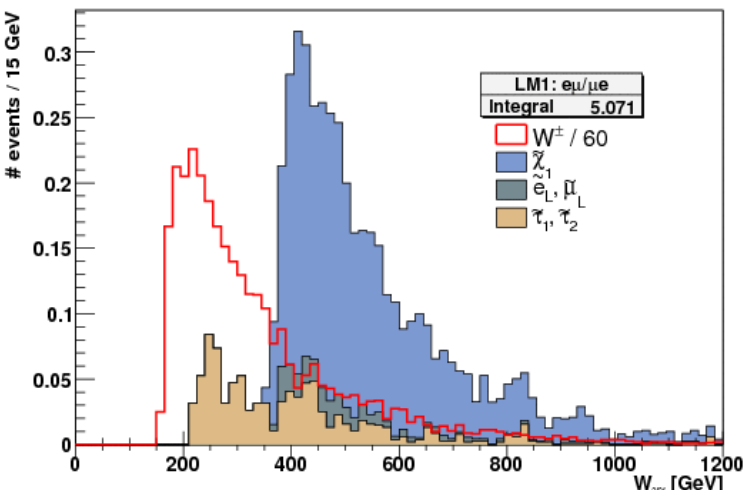
SUSY pairs

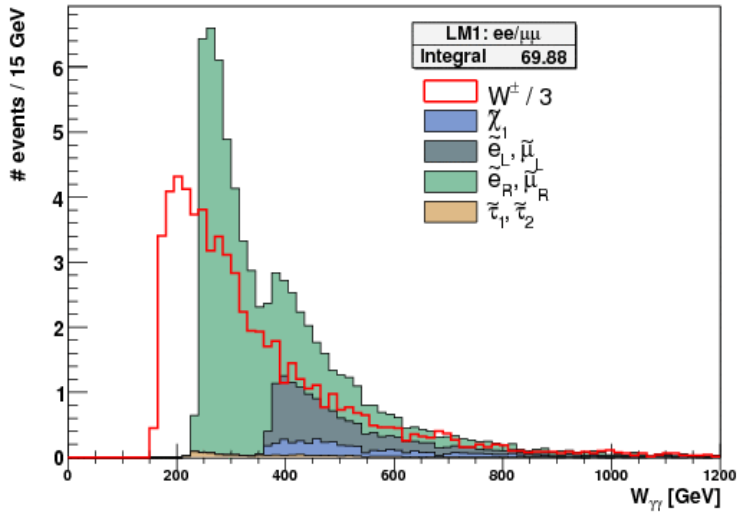
massive SUSY pairs have very clean signature
- pair of charged leptons and large missing E_t -



LM1 – very light LSP, light sleptons and light chargino, tg(β)=10

LM1	m [GeV]
$\tilde{\chi}_1^0$	97
$\tilde{l}_R^+$	118
$\tilde{l}_L^+$	184
$\tilde{\tau}_1^+$	109
$\tilde{\tau}_2^+$	188
$\tilde{\chi}_1^+$	180
H^+	386





100fb^{-1}

γγ → SUSY pairs with CalcHEP; decays with Pythia

acceptance cuts pt^{lep} > 3GeV (10GeV), |η|<2.5

here γγ → WW as an irreducible background

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Summary - outlook

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

High energy photoproduction at the LHC

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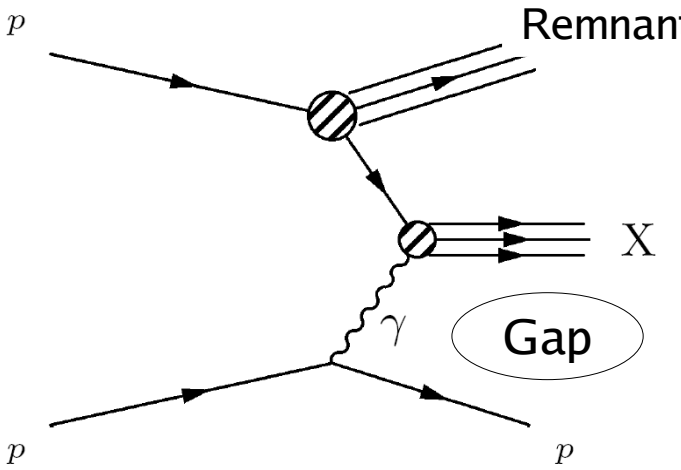
LHC : a new HERA collider !

Photoproduction is traditionally studied at e-p colliders

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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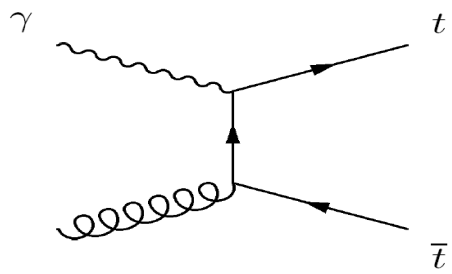
γp cross sections

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

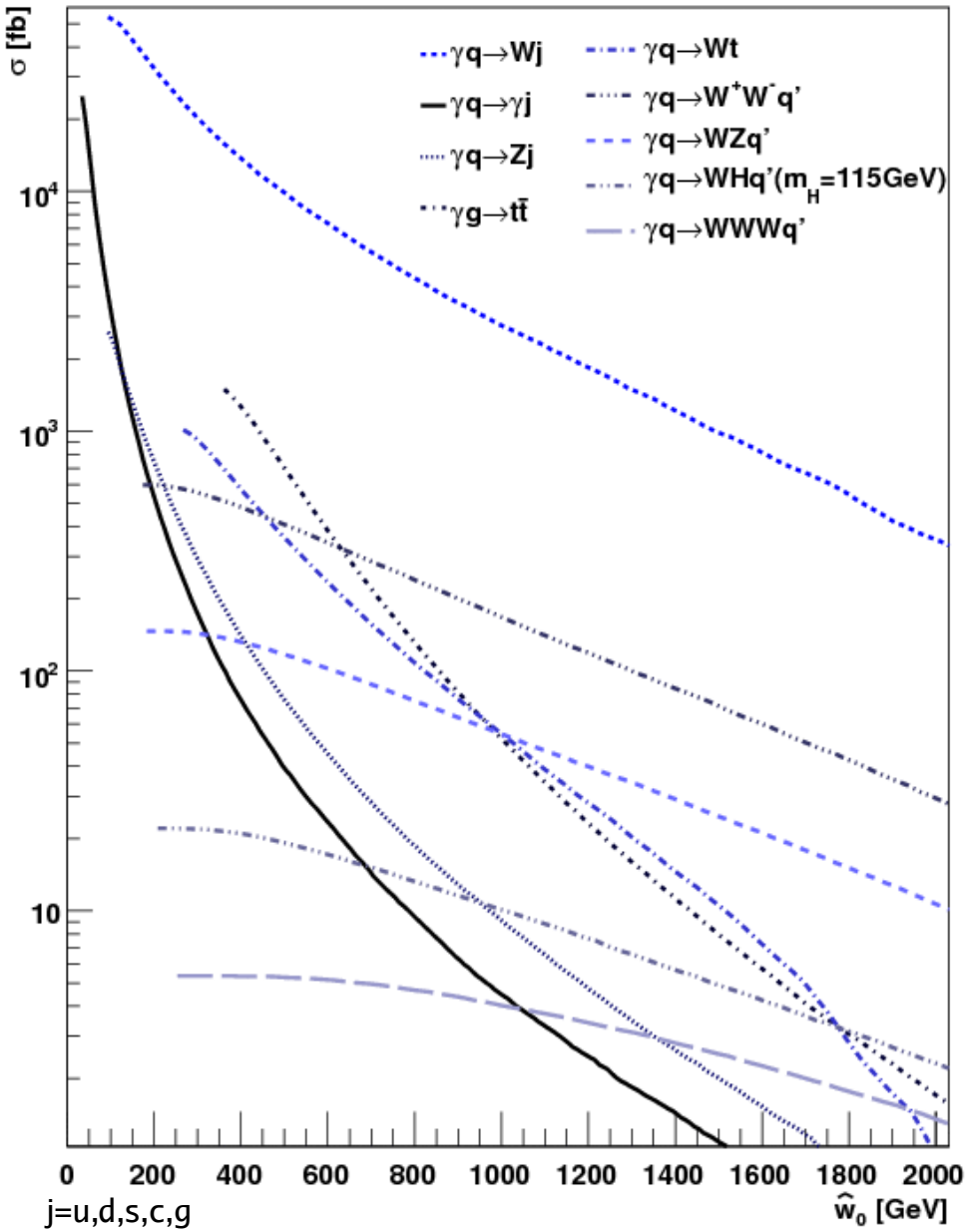
e.g.



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

Obtained using MadGraph/MadEvent



j=u,d,s,c,g
p_t(j) >10 GeV, |η|<5, ΔR>0.3
p_t(q') >1 GeV

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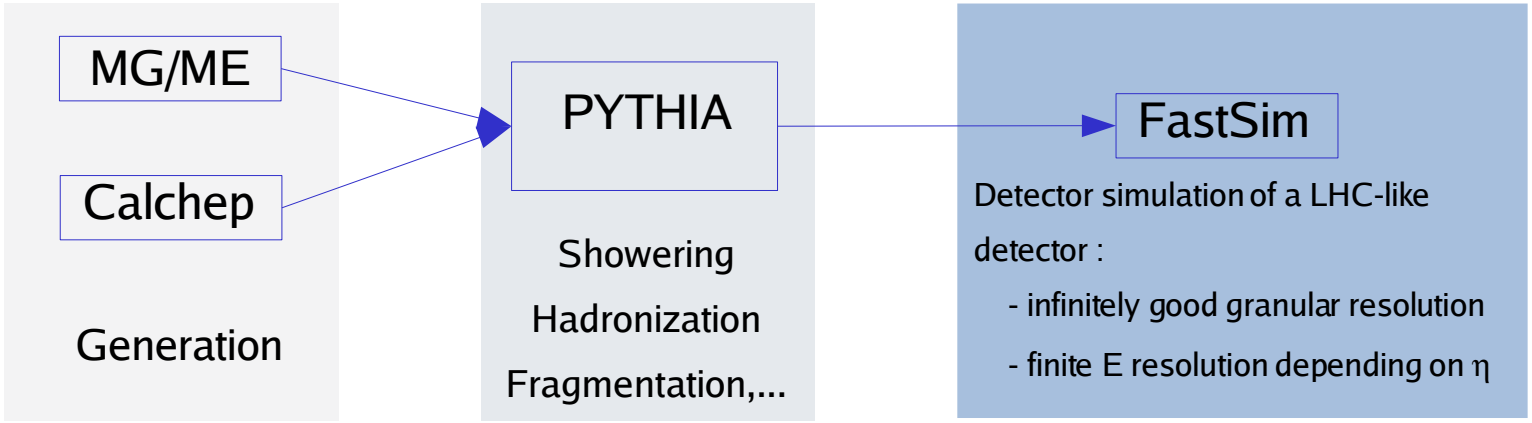
Simulation procedure

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



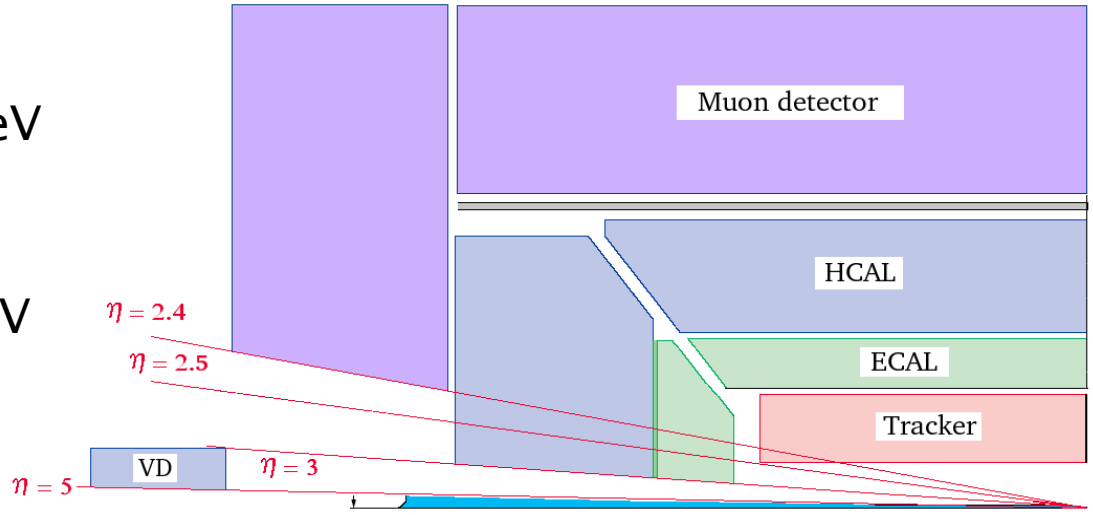
Objects reconstruction

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

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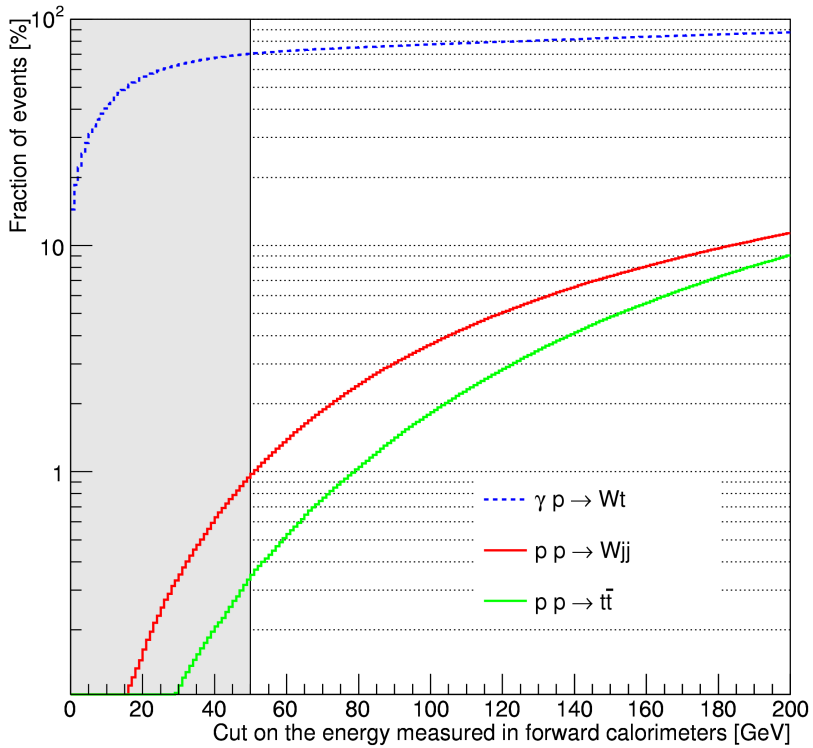
Detection and tagging



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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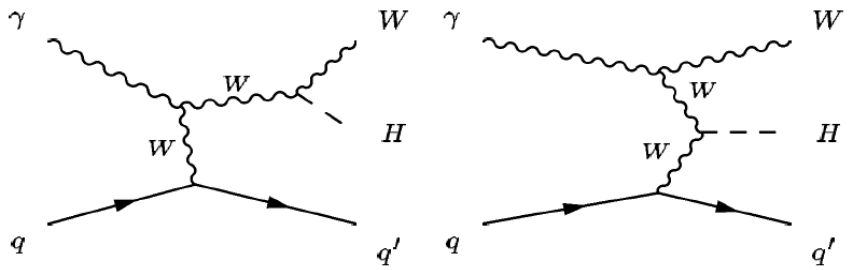
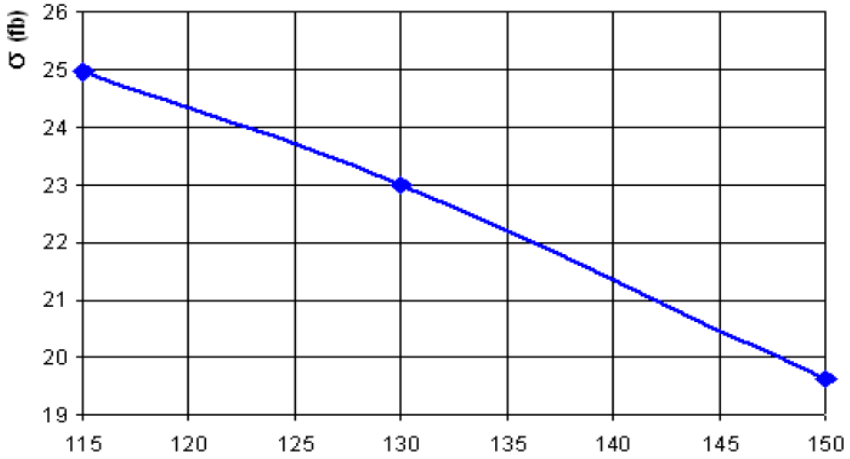
Associated WH production



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

Topology		M_H=115 GeV			M_H=170 GeV	
	lνbb	jjl⁺l⁻	jjl⁺τ_h	lll	jjl±l±
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±l±
- For analysis, more specified cuts can be applied.

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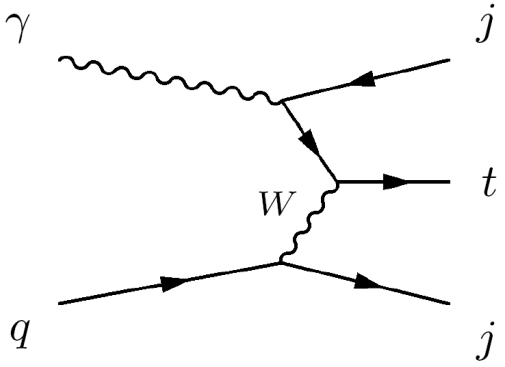
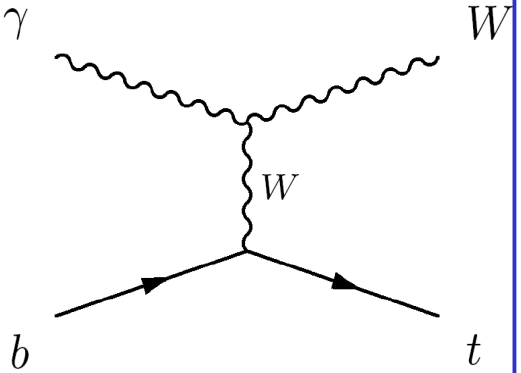
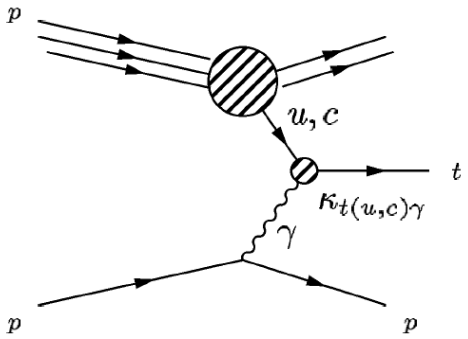
The LHC is a Top factory!



t-channel



Wt-channel



Anomalous top

[pp vs γp cross sections]

[Physics highlights]

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

	pp	γp
Wt-channel	~ 60 pb	~ 1pb
t-channel	~ 245 pb	~ 6.2×10^{-3} pb
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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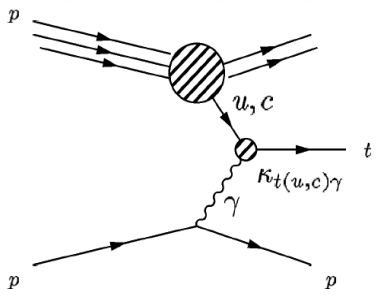
Anomalous top production

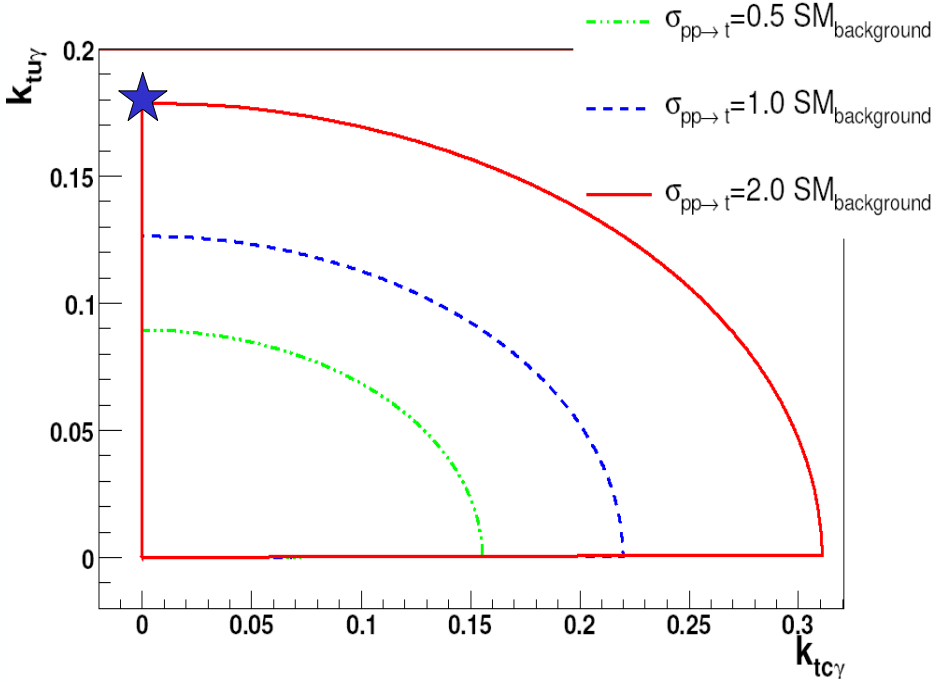


Effective Lagrangian for anomalous coupling :

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

- Current limit obtained by Zeus : $k_{tu\gamma} \approx 0.18$
- At HERA only u-quark relevant, at LHC also c-quark contribute

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



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

Topology	$\not{E}_T^{mis}$ 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 very low 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±l±
  - Analysis are ongoing for those 2 cases, using analysis cuts.

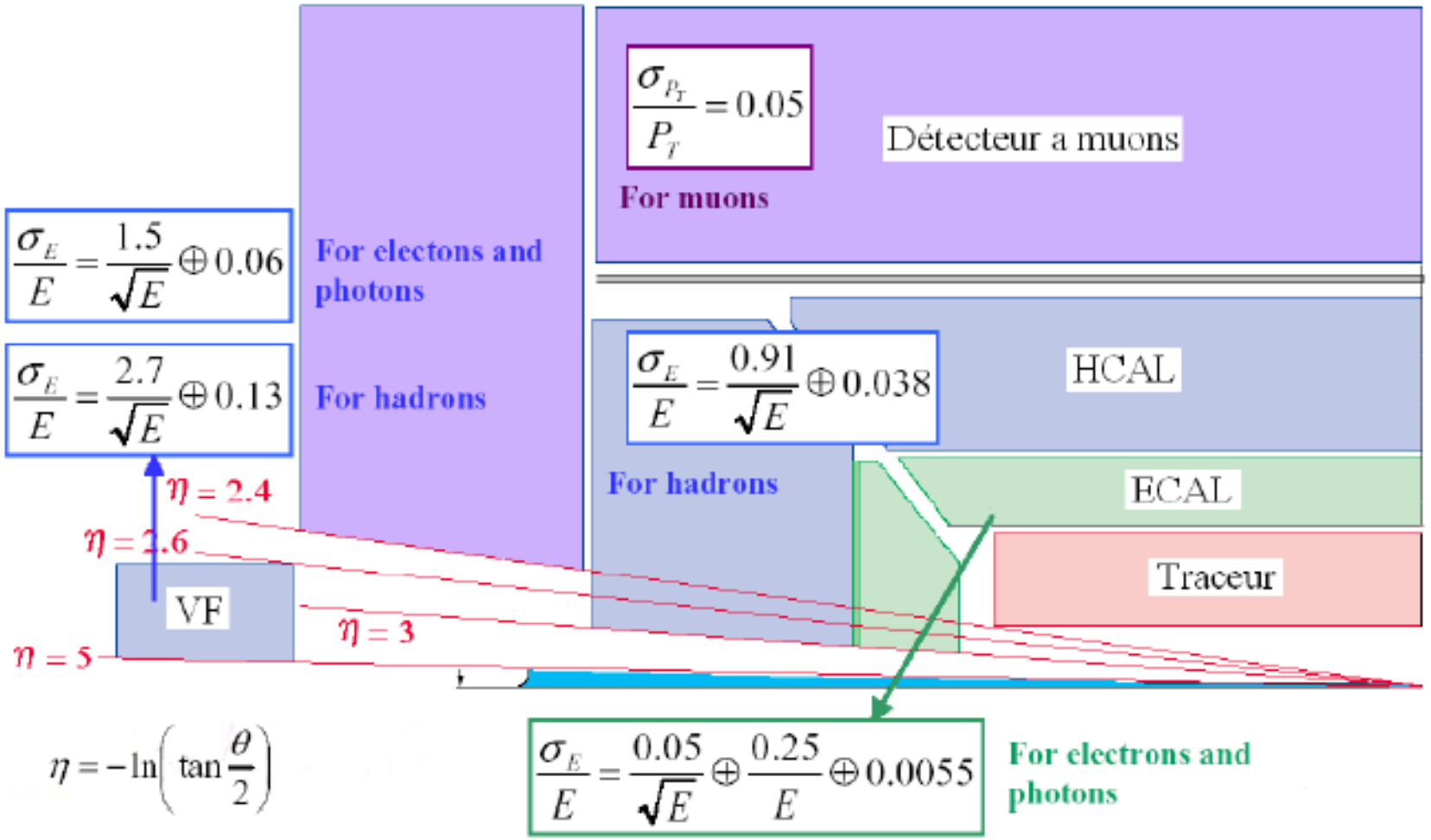
- Wt-channel (10 fb^{-1}) seems very promising
  - For the di-leptonic topology, $|V_{tb}|$ uncertainty is similar to the one obtained using pp->Wt
  - For the semi-leptonic topology, one needs to tackle pp backgrounds

- Anomalous top (1 fb^{-1}) can also be probed using very low integrated luminosity

Back-up slides

Fast simulation of a LHC-like detector

Longitudal view of the detector



UCL

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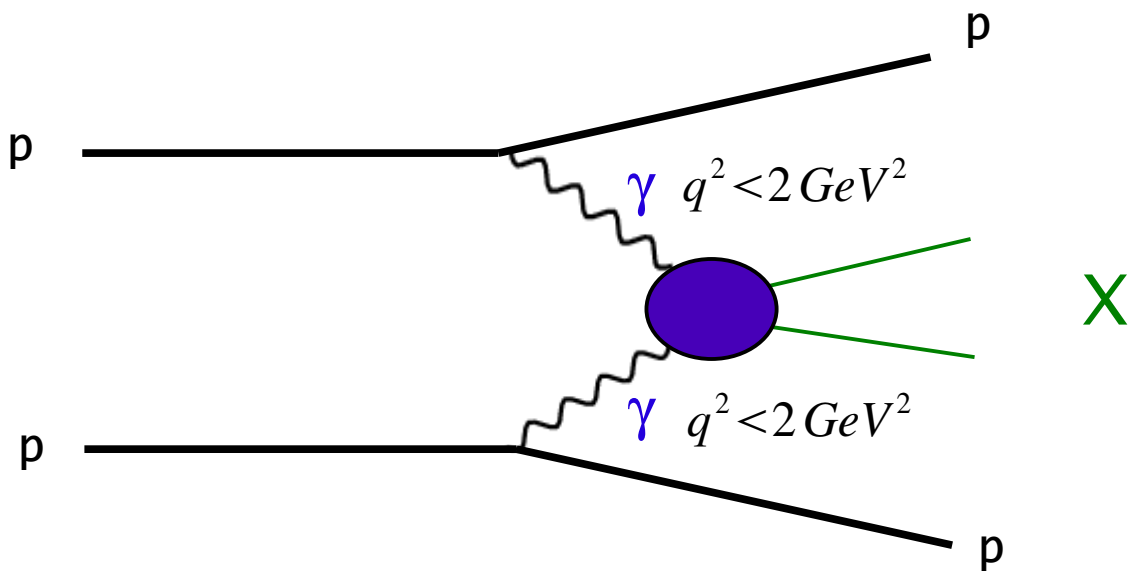
EPA

LHC – also a photon-photon collider



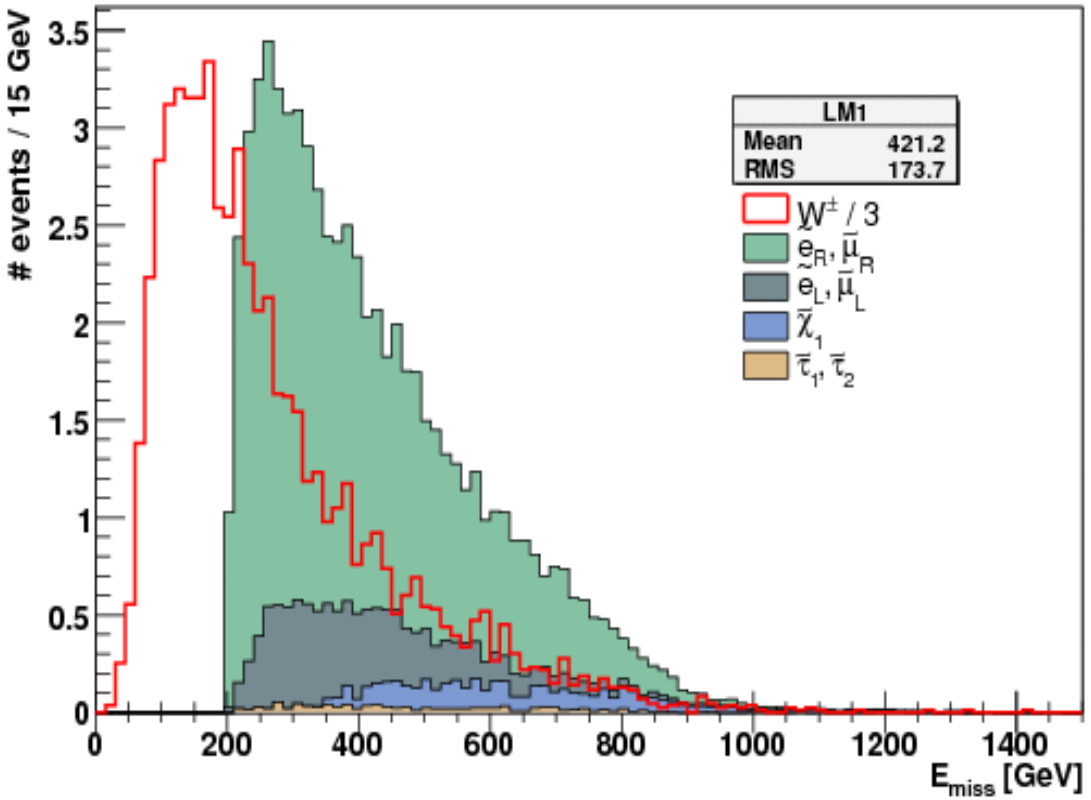
low γ virtuality (typical $q^2 \sim 0.01\,GeV^2$) ⇒

- factorization to
  - → long distance photon exchange
  - → short distance $\gamma\gamma \rightarrow$ X interaction
- zero degree scattered angles

$$\sigma_{pp} = \int \sigma(W_{\gamma\gamma}) \frac{d\,L_{\gamma\gamma}}{dW_{\gamma\gamma}} dW_{\gamma}$$

$$\sigma(\ pp \rightarrow (\gamma\gamma \rightarrow X)\, pp\ )$$

UCL


LM1
Mean 421.2
RMS 173.7
$\tilde{W}^{\pm}$ / 3
$\tilde{e}_R, \tilde{\mu}_R$
$\tilde{e}_L, \tilde{\mu}_L$
$\tilde{\chi}_1$
$\tilde{\tau}_1, \tilde{\tau}_2$
events / 15 GeV
E_{miss} [GeV]
0
0.5
1
1.5
2
2.5
3
3.5
0
200
400
600
800
1000
1200
1400