Experience w/ Alpgen in CMS: Search for Associated Higgs boson production via $gg/qq \rightarrow ttH(h^0)$, $t \rightarrow l+X$, $H(h^0) \rightarrow \gamma\gamma$

(Alpgen V1.3→PYTHIA 6.227→ORCA 8_7_4)

Robert FRAZIER

University of Bristol

Jean-Laurent AGRAM, Clément BATY, Suzanne GASCON-SHOTKIN Damien MERCIER

Institut de Physique Nucléaire de Lyon/Université Claude Bernard Lyon I

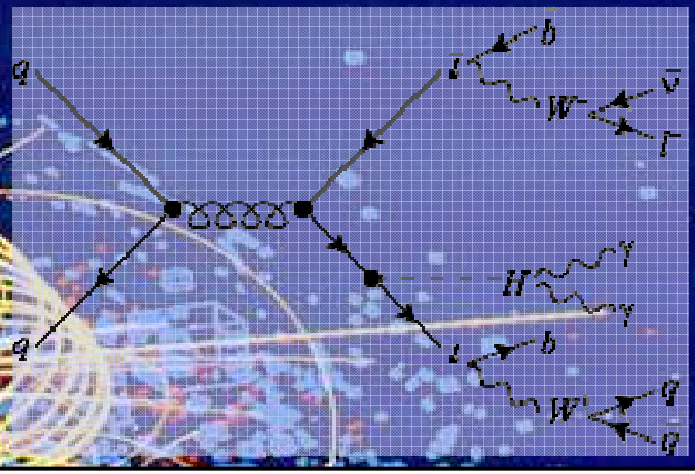
Alexander NIKITENKO

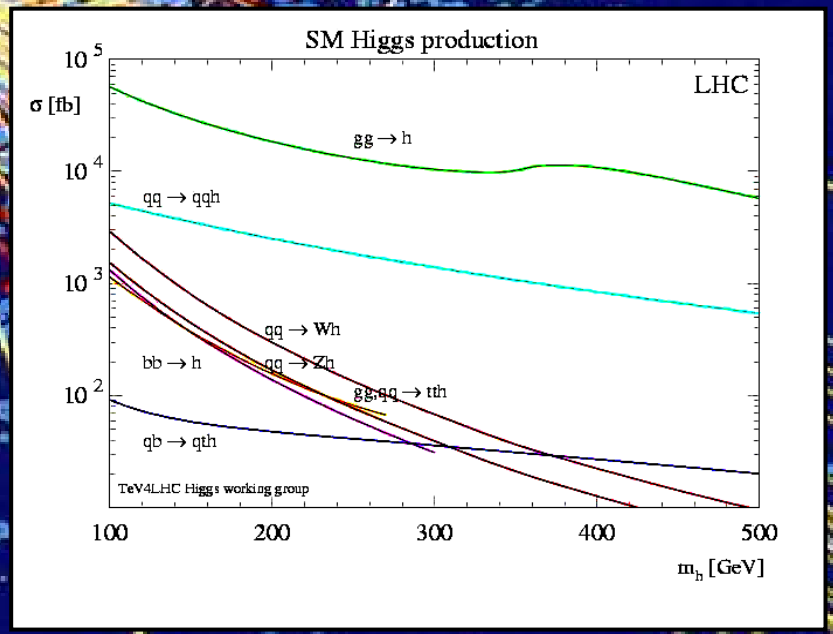
Imperial College London

The channel gg/qq → ttH(h0), t →l+X, H(h0) → γγ

- Unlikely to be discovery channel alone (except in MSSM interpretation) but could be added to other channels to boost visibility.
- Particular 2-doublet case of MSSM (Belanger et al, Nucl.Phys.B568 (2000)): gluon fusion production channel subject to suppression given top-stop degeneracy (maximal mixing) , not true for associated production channels.
- Measure Top-Higgs Yukawa coupling

Signature : 2b,1lepton,2γ, high jet multiplicity





Signal Cross-sections and datasets--SM

Estimated Number of signal events, NLO (M. Spira 'official' CMS nos.), ttH,H→γγ , 1 lepton from a top

mH (GeV)	After 30 (1/fb)	After 100 (1/fb)
115	20.80	69.33
120	19.61	65.36
130	15.96	53.20
140	11.20	37.33

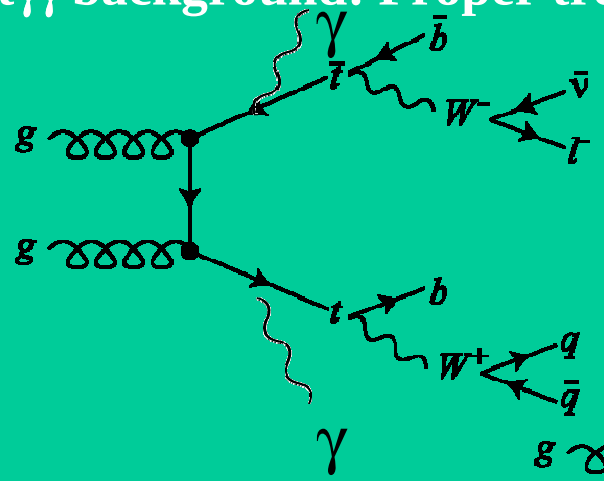
Dataset	SxBR (fb)	Digis	ExRoot	Analyzed
Signal Alpgen				
115 GeV	0.69	21k	± 10k	9500
120 GeV	0.65	30k	± 10k	4470
130 GeV	0.53	30k	± 10k	4460
140 GeV	0.37	29k	± 10k	4190
Signal Madgraph				
115 GeV	-	29k	± 10k	Cross-ch
120 GeV	-	28k	± 3k	
130 GeV	-	30k	± 3k	
140 GeV	-	29k	± 3k	

- Prior work in CMS: Generator-level studies of the SM (Ilyin et al, CMS NOTE 1997/101), and MSSM (R. Kinnunen & D, Denegri, CMS NOTE 1997/057) cases demonstrated S/B~1.
- In ATLAS:Full simulation study in Physics TDR (based on thesis of G. Eymard (LAPP), S/sqrt(B)={4.3-2.8} for mH={100-140} , signal efficiency ~30%. CERN-ATL-COM-PHYS-2004-056 par Beauchemin, P and Azuelos, Georges "Search for the SM Higgs Boson in the gamma gamma + ETmiss channel" For 100fb-1, for ttbarh channel, for mH=120 GeV, S/B of ~2 (10.2 signal events for 5.4 background events).

The channel gg/qq → ttH(h0), t →l+X, H(h0) → γγ

- **Major challenge: Irreducible Standard Model backgrounds: Special collaboration with ALPGEN authors to consider certain processes never before taken into consideration, for example ttγγ types 2,3 (below) and W+2g + 4jets (σ X BR= 11.5 fb)**

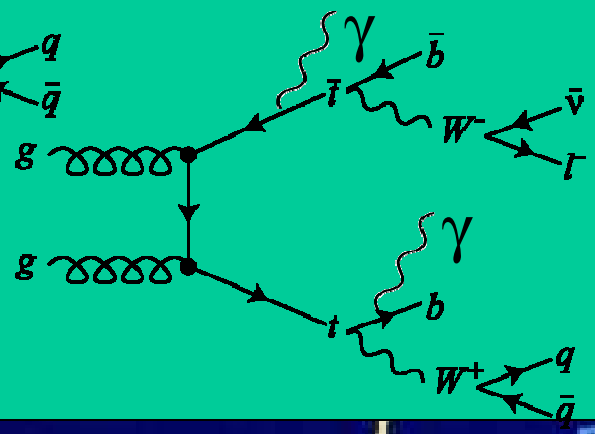
ttγγ background: Proper treatment a priority



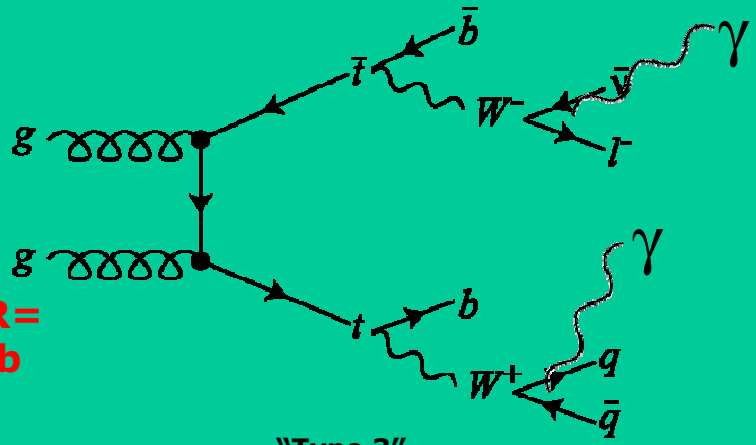
σ X BR= 1.6 fb

"Type 2"

1 Prompt, 1 from t decay prods.



σ X BR= 6.1 fb



"Type 3"

Both from t decay prods.

σ X BR= 4.9 fb

ALPGEN V1.3 (LO)(Mangano, M.Moretti, Piccinini, Pittau, Polosa)

LO Background X-sections/Event Generation:

Irreducible: Now full statistics, all of these **produced** /waiting for production

Process	σx BR σ (1 W->l ν)	N_{gen}	N 30fb^{-1}	Wgt 30fb^{-1}	N 100fb^{-1}	Wgt 100fb^{-1}	Generator/Presel
ttγγ 1	1.6 fb (<1/mil)	52202	48	.0009	160	.0031	AL,MG (2) (1)
ttγγ 2	6.1 fb (<1%)	6238	183	.0293	610	.0978	AL(2,4)
ttγγ 3	4.9 fb (<1%)	2967	147	.0495	490	.1651	AL (1,2,4)
bbγγ	318.1 fb (<2/mil)	159829	9543	0.0597	31810	0.1990	MG (1)
Wγγ 4j	11.5 fb (1.2%)	4587	345	0.0752	1150	.2507	AL(2.3)
Zγγ	29.0 fb (<2/mil)	50005	870	0.0174	2900	0.0580	MG (1)
Wγγ	23.6 fb (<2/mil)	112000	708	0.0063	2360	0.0211	MG (1)

- Statistical errors shown as %
- Intersection of preselections applied to all samples before either particle-level or full reconstruction analyses

CTEQ5L, $m_{\gamma\gamma}$>80 GeV +

(1)→$p_{T\gamma}$>20 GeV, η_γ<2.5 (MG)

(2)→$p_{T\gamma}$>15 GeV, η_γ<2.7 (AL)

(3)→$p_{Tj,l,\gamma}$>15 GeV, $\eta_{\gamma,j,l}$<2.7, ΔR(l,j or j,j)>0.3

(4)→p_{Tl}>15 GeV

Particle-Level Results:

Table 4: Estimated number of signal and background events, signal selection efficiency and signal significance for $t\bar{t}H$, $H \rightarrow \gamma\gamma$, after 30 fb^{-1} of integrated luminosity, for the particle-level selection.

Higgs Boson Mass (GeV/c^2)	115	120	130	140
Signal Selection Efficiency (%)	19.09	20.78	24.65	25.58
Number Signal Events	3.96	4.06	3.92	2.86
$t\bar{t}\gamma\gamma$ 1	0.17	0.11	0.14	0.16
$t\bar{t}\gamma\gamma$ 2	0.08	0.16	0.08	0.16
$t\bar{t}\gamma\gamma$ 3	<0.2	0.2	<0.2	<0.2
$Z\gamma\gamma$	0.23	0.21	0.24	0.16
$W\gamma\gamma 4j$	0.4	0.9	1.9	1.4
$bb\gamma\gamma$	< 0.06	0.06	0.06	< 0.06
Total Number Background Events	0.88	1.63	2.42	1.88
Signal Significance Sc_12	2.524	2.217	1.925	1.612
$W\gamma\gamma$	0.37	0.42	0.37	0.39

- **Leading-order inclusive $W\gamma\gamma$ sample seems to strongly underestimate contribution to total background compared to $W\gamma\gamma$ + 4 jets sample→inference of similar situation for $Z\gamma\gamma$**

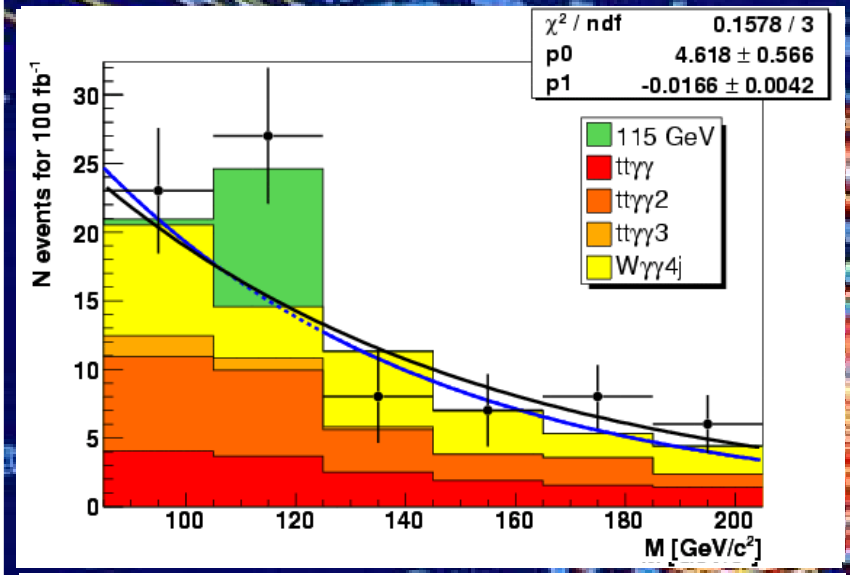
The channel gg/qq → ttH(h0), t →l+X, H(h0) → γγ

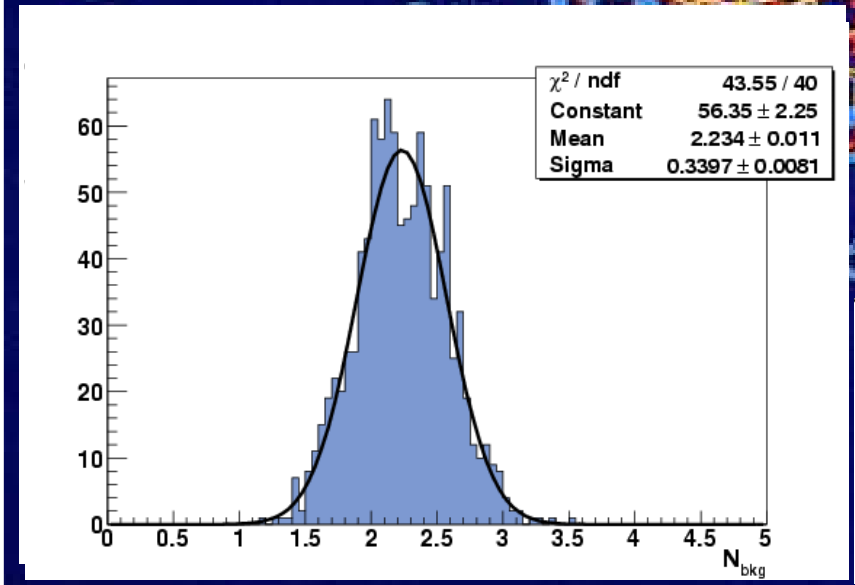
Valeurs requises	$M_H = 115\ GeV$	$tt\gamma\gamma 1$	$tt\gamma\gamma 2$	$tt\gamma\gamma 3$	$W2\gamma 4j$
Avant sélection	0.693 (100.0)	1.59 (100.0)	6.12 (100.0)	4.95 (100.0)	11.4 (100.0)
Présélection	0.533 (76.8)	1.4 (87.9)	5.05 (82.5)	3.94 (79.6)	11.3 (98.9)
L1+HLT	0.517 (97.0)	1.34 (95.4)	4.71 (93.4)	3.36 (85.7)	10.5 (93.0)
HLT $\gamma\gamma$	0.508 (98.3)	1.30 (96.9)	4.57 (96.9)	3.25 (96.6)	10.0 (96.0)

- **Results of sequential selection (effective cross-sections in fb and numbers of expected events) for signal and irreducible backgrounds**

Cut	Part.	ORCA	MH=115	ttgg1	ttgg2	ttgg3	W2g4j
2 γ (w/o pixel seed)	-	-	0.506 (100.0)	1.29 (100.0)	4.56 (100.0)	3.24 (100.0)	10.0 (100.0)
2 isolated γ (w/o pixel seed)	-	-	0.482 (95.2)	1.22 (94.0)	3.96 (86.8)	2.53 (78.2)	9.58 (95.7)
$pT\gamma_1$ (GeV)	> 50	> 50	0.432 (90.0)	1.04 (85.3)	3.14 (79.4)	1.48 (58.5)	7.90 (82.5)
$pT\gamma_2$ (GeV)	> 20	> 18	0.386 (89.2)	0.88 (84.7)	2.25 (71.6)	1.03 (69.7)	6.72 (85.0)
$pT\gamma_1$+$pT\gamma_2$ (GeV)	> 120	> 85	0.379 (98.2)	0.847 (96.3)	2.17 (96.5)	0.926 (89.8)	6.40 (95.3)
$\Delta R(\gamma_1\gamma_2)$ (GeV)	< 6.4	< 3.2	0.364 (96.4)	0.738 (87.2)	1.86 (85.9)	0.719 (77.7)	5.30 (82.8)
$\cos\theta^*$	< 0.9	< 0.85	0.332 (91.4)	0.589 (79.8)	1.48 (79.5)	0.583 (81.0)	4.36 (82.3)
pT_{lep} isolated (GeV)	> 15	>15	0.238 (72.2)	0.443 (75.2)	0.984 (66.4)	0.387(66.4)	3.15 (72.3)
$\Delta R(\gamma_1 l)$	>0.48	>0.3	0.236 (99.0)	0.441 (99.5)	0.925 (94.0)	0.321 (83.0)	3.14 (99.6)
$\Delta R(\gamma_2 l)$	>0.75	>1.0	0.208 (87.4)	0.389 (88.2)	0.607 (65.7)	0.163 (50.7)	2.34 (74.6)
N jets with p_T >60 GeV	-	≥ 4	0.179 (86.2)	0.338 (87.0)	0.455 (74.9)	0.110 (67.6)	1.79 (76.6)
Max (Btag Disc) of 3 ld jets	-	>0.8	0.110 (61.6)	0.217 (64.0)	0.276 (60.7)	0.051 (46.0)	0.294 (16.4)
Mass Window +/- 1.5 GeV			0.074 (67.1)	0.005 (2.51)	0.011 (3.86)	<0.002 (3.92)	<0.003 (1.02)
N_{evts} 30 fb^{-1}			2.22+/-0.10	0.483 +/-0.158			
N_{evts} 100 fb^{-1}			7.42+/-0.334	1.61+/-0.53			

The channel gg/qq → ttH(h0), t →l+X, H(h0) → γγ





- Technique of background measurement from sidebands: Same procedure as for WH/ZH channels except fit sidebands with decreasing exponential function
- Significance calculated with ScP estimator
- Results for SM Higgs: 3-sigma observability up to mH=130 GeV for 100fb-1
- S/B~4:1 A factor of 2 improvement over prior CMS and ATLAS studies
- Particle-level study done for Les Houches 2005
- Final study included in CMS PTDR2 and CMS AN 2006/064, CMS NOTE submitted

Higgs Boson Mass (GeV)	115	120	130	140
Sig. Selection Eff. (%)	10.7	11.2	11.3	11.3
Number Signal NS	7.42 ±0.33	7.33 ± 0.33	5.96±0.27	4.21±0.19
Total Number Bcgkd	1.61 ±0.53	2.79 ±0.62	1.98±0.66	1.10± 0.51
Total Number Bcgkd from fit w. syst.	2.23±0.34	1.94±0.32	1.60±0.22	1.39±0.22
Signal Significance (ScP)	3.541	3.662	3.257	2.510
Signal Significance (ScP) w. syst.	3.414	3.523	3.184	2.453

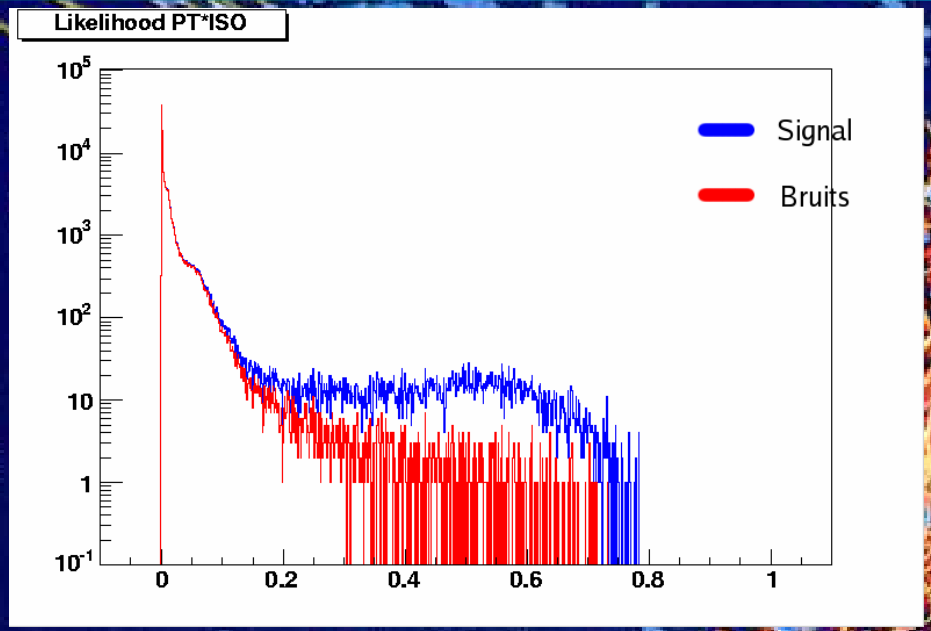
Generation Technical Points

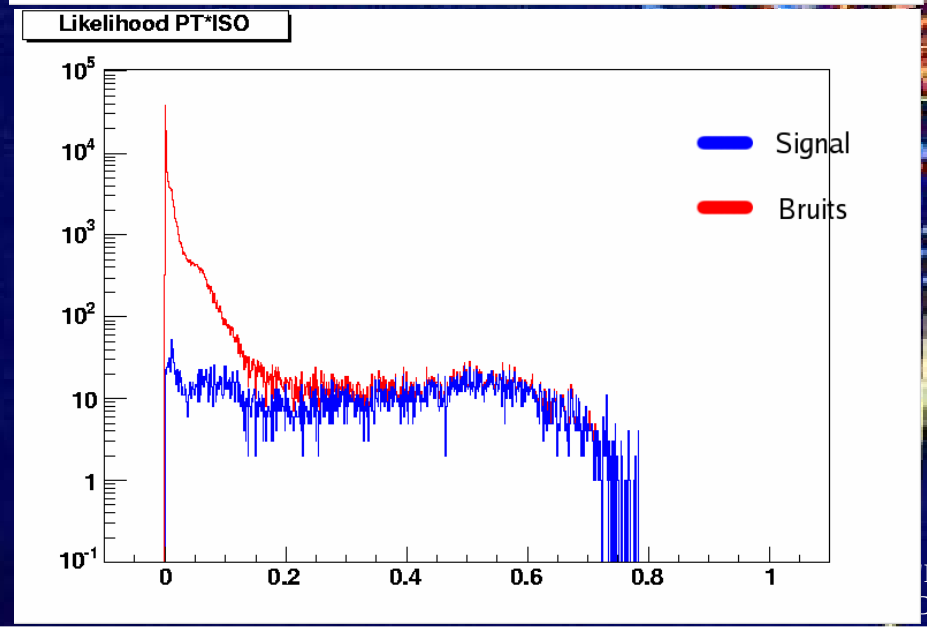
- All generation of weighted event files done at CCIN2P3 on normal batch queues

(Special case: Low-efficiency $W\gamma\gamma$ + 4 jets needed ~20 jobs on exceptionally long queue [3-4 days])

- Subsequent generation of unweighted event files done interactively
- Unweighted event files turned over to CMS production team for fragmention/hadronisation with standard CMS tool (CMKIN), simulation (OSCAR) and digitisation/reconstruction (ORCA)
- Analysis ntuples fabricated from digis with ExRootAnalysis (P. Demin/G. Bruno)

The channel gg/qq → ttH(h0), t →l+X, H(h0) → γγ

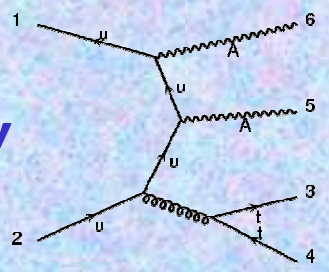
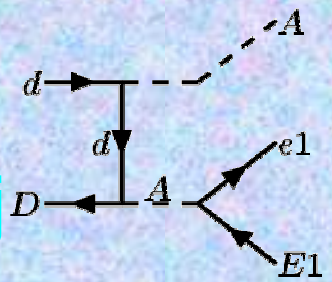




Future Plans

- Remains to be done: Likelihood analysis (premier pas [ci-contre]): choice of pair of Higgs photon candidates via lh including p_t and ISO variable values for each pair member
- MSSM interpretation (CMS Higgs summary note end 2006)
- Incorporation of all reducible backgrounds (continued work with ALPGEN authors)
- Combination with VH, H→γγ via anti-selection on number of jets
- Evaluation of sensitivity to CP nature of Higgs boson (Gunion et al) via examination of certain kinematical variables: Collaboration with COMPHEP authors for code to produce signals of all CP states

Status of Backgrounds I

	Process:	Generators (All LO):
Irreducible:		
lγγ 	ttγγ (+ njets)*,	ALPGEN, MADGRAPH
	bbγγ + (njets)	MADGRAPH, COMPHEP
	Wγγ (+ njets)*, Zγγ (+ njets)**	MADGRAPH, ALPGEN
Reducible:		
llγ 	llγ(γ),	PYTHIA, COMPHEP
	W(Z)+tt (+njets), W(Z)+bb (+njets)	ALPGEN
ljj,llj	kW+mZ (+njets) ,tbbar (W) + j, t + jets, Wtbbar + jets	ALPGEN

ALPGEN (Mangano,Moretti, Piccinini, Pittau, Polosa) '*'➔processes specially added for this analysis '**'➔ processes to be added for this analysis

MADGRAPH (Maltoni, Stelzer)

COMPHEP (Boos, Dubinin, Ilyin, Pukhov, Savrin)

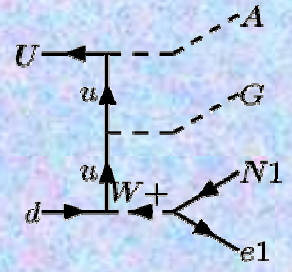
PYTHIA (Lonnblad, Mrenna, Sjostrand,Skands), also used for PS, fragmentation and hadronization for all proc. PHOTOS (Barberio, Was) for radiation photons where not provided

Status of Backgrounds II

- **Reducible:**

Process:	Generators:
$W\gamma$ (+ njets)**, $Z\gamma$ (+ njets)**	MADGRAPH, ALPGEN
kW+mZ (+njets)	ALPGEN
W(Z)+tt (+njets), W(Z)+bb (+njets)	ALPGEN
$bb\gamma$ (+njets), $tt\gamma$ (+njets) **,	MADGRAPH, ALPGEN
bbtt (+njets), bbbb (+njets), tttt (+njets)	ALPGEN
$m\gamma$+njets, tbbar (W) + jets, t + jets, Wtbbar + jets	ALPGEN, (PYTHIA)

$l\gamma j$



$\gamma\gamma j$, γjj,

jjj

- **Note: Several processes could contribute as both irreducible and reducible background and/or to several reducible 'signals'. Virtually any high-multiplicity process could be a reducible background.**
- **Must watch out for double-counting of background (ALPGEN V2.0 available for some processes)!**

ALPGEN V2.11 Jan 15 2007

•NEW: multiple final state **photons can now be included in the vbjet process**

•Q Qbar plus up to 6 jets

•Q Qbar Q' Qbar' plus up to 4 jets

•Q Qbar Higgs plus up to 4 jets

•Inclusive N jets, with N up to 6

ALPGEN V2.11
Jan 15 2007

•N photons + M jets, with N larger than 0, N+M up to 8 and M up to 6

•Higgs + N jets, with N<5

•Single top: tq, tb, tW, tbW. No extra jets.

•NEW: W + photons + jets (up to nph=2, see documentation for details)

•NEW: W Q Qbar + photons + jets (up to nph=2, see documentation for details)

•NEW: Q Qbar + m-photons + N-jets (m+N <= 6, see documentation for details)

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