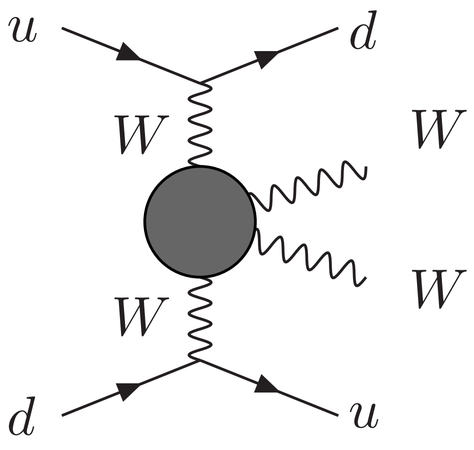
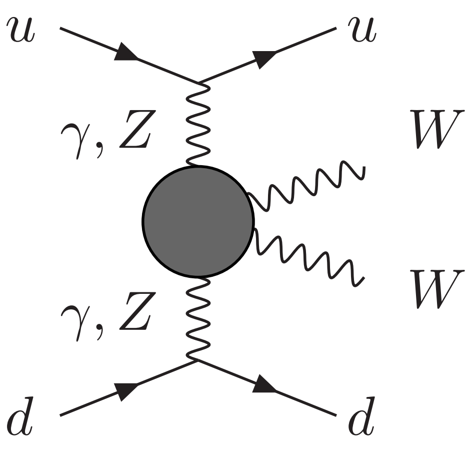
BOSON BOSON SCATTERING AT LHC

E. MAINA

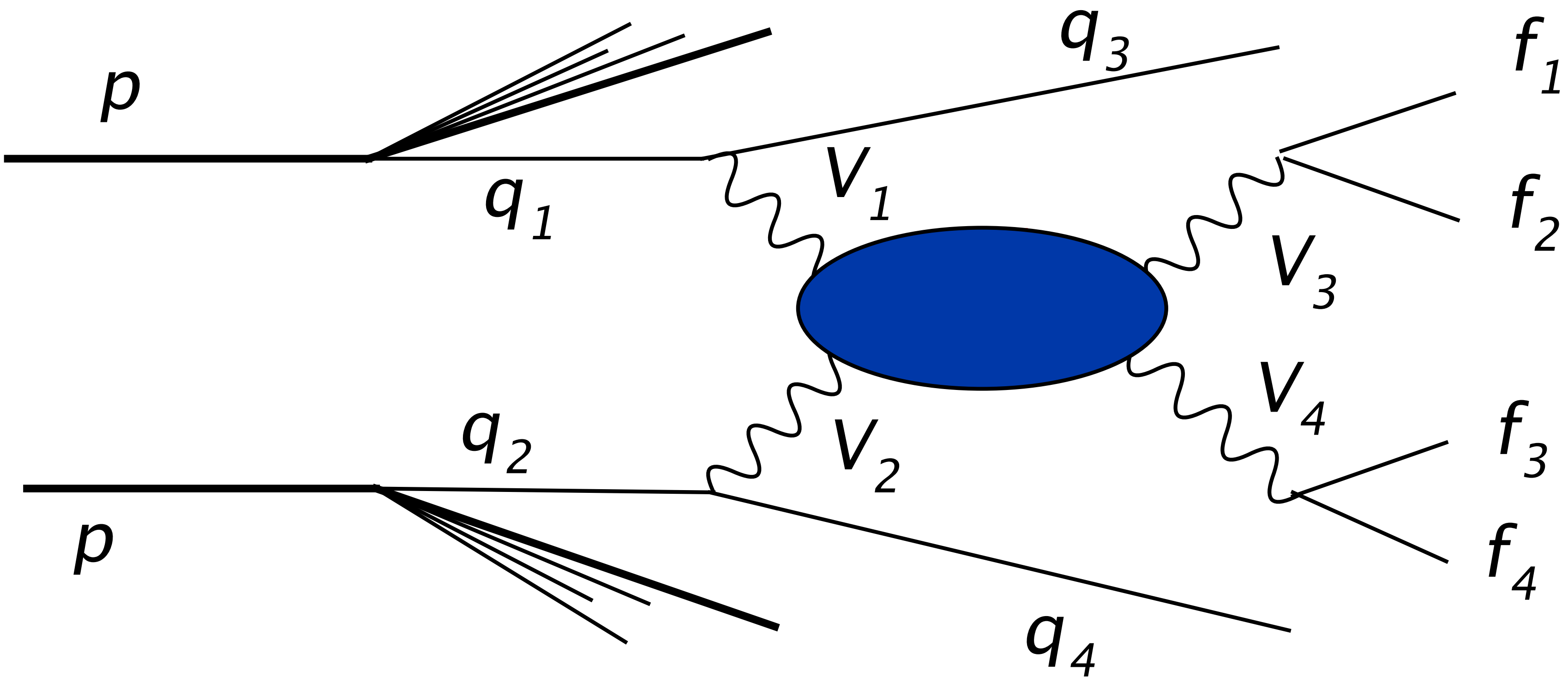
UNIV. OF TORINO AND I.N.F.N. TORINO





TORINO, DECEMBER 16, 2004

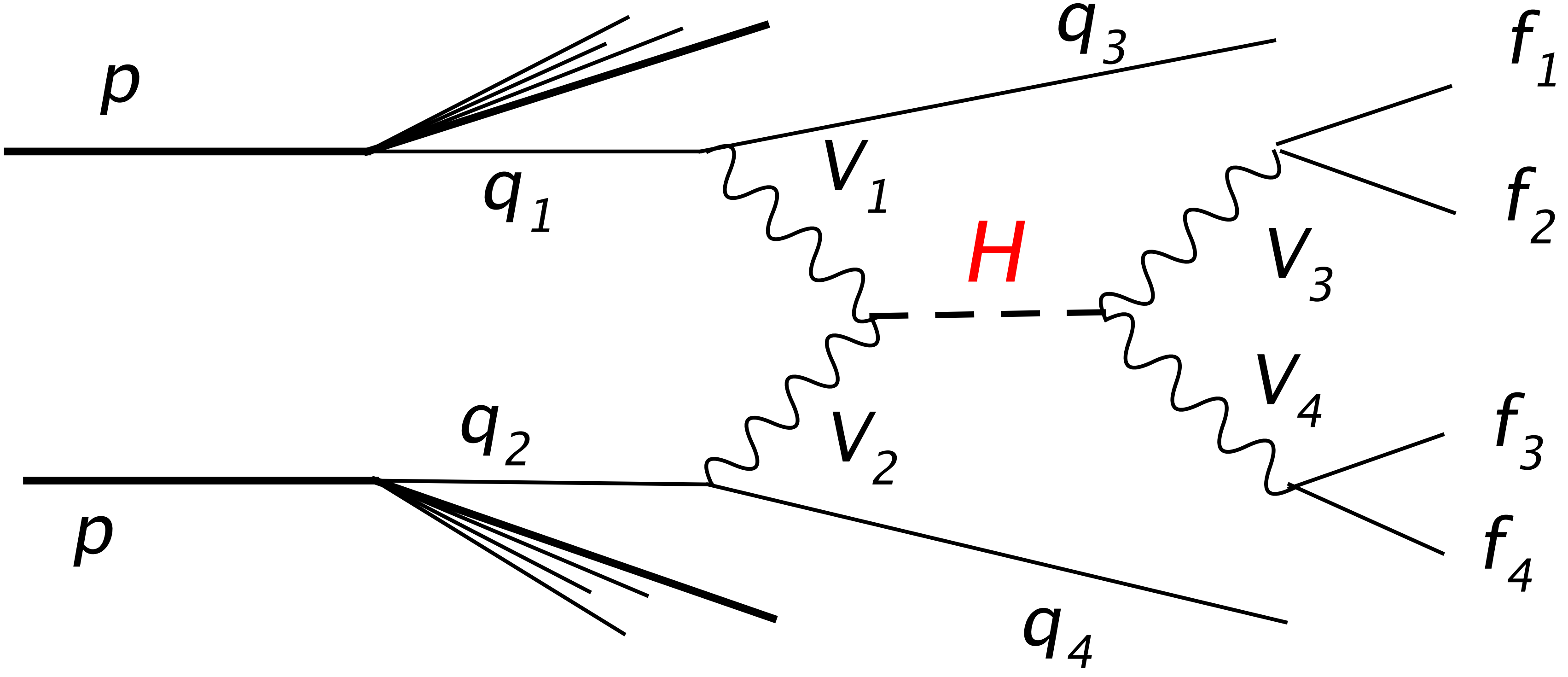
What can we observe at LHC?



- Very energetic isolated leptons in central region
- 2 W, Z-jets + low extra jet activity in central region
- Two highly energetic, low P_T spectator jets, well separated in η
- V_1, V_2 ALWAYS off-shell

WHY DO WE WANT TO OBSERVE IT AT LHC?

REASON #1: HIGGS



HIGGS PRODUCTION AT LHC

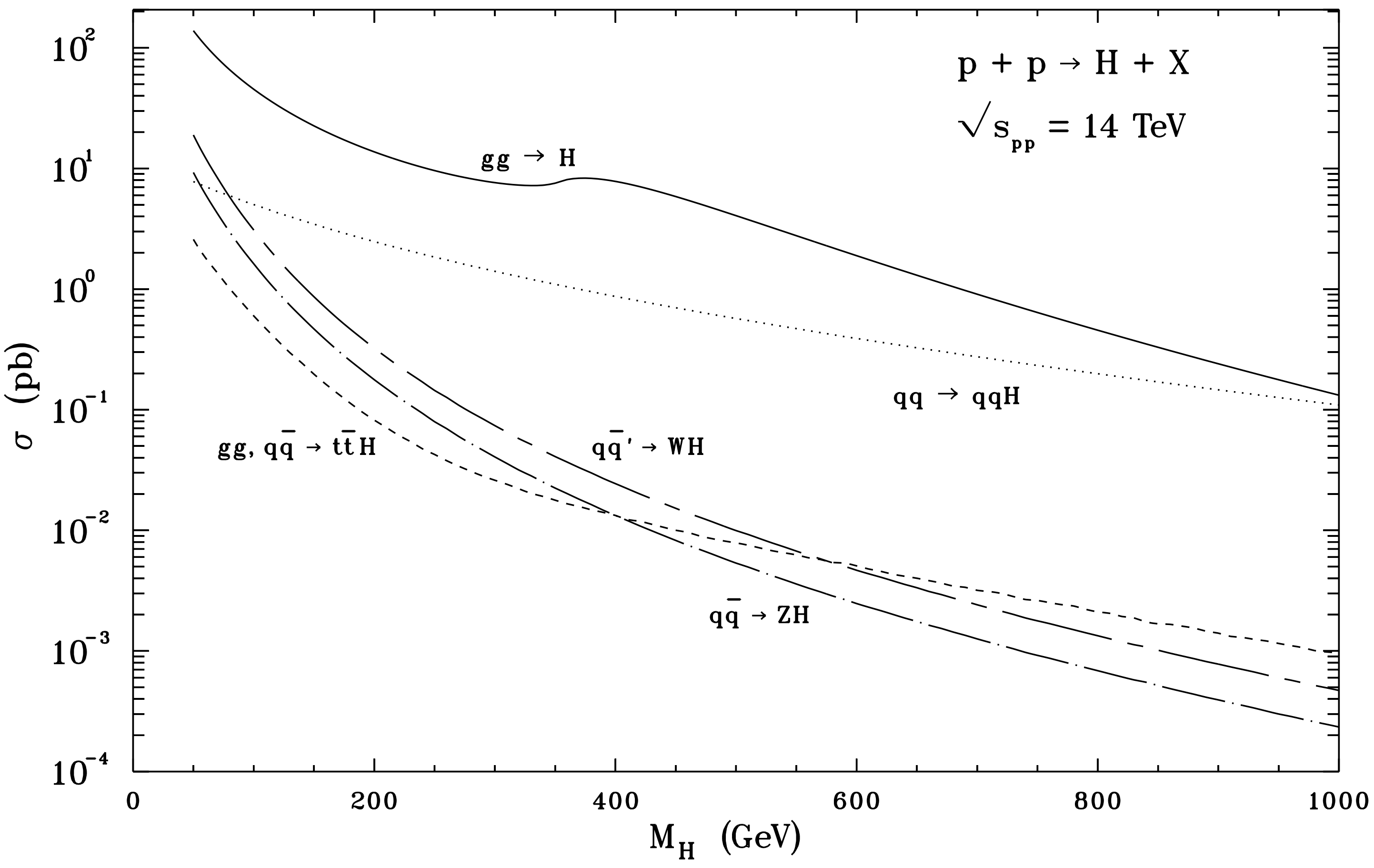


Fig. 5b

HIGGS DECAY

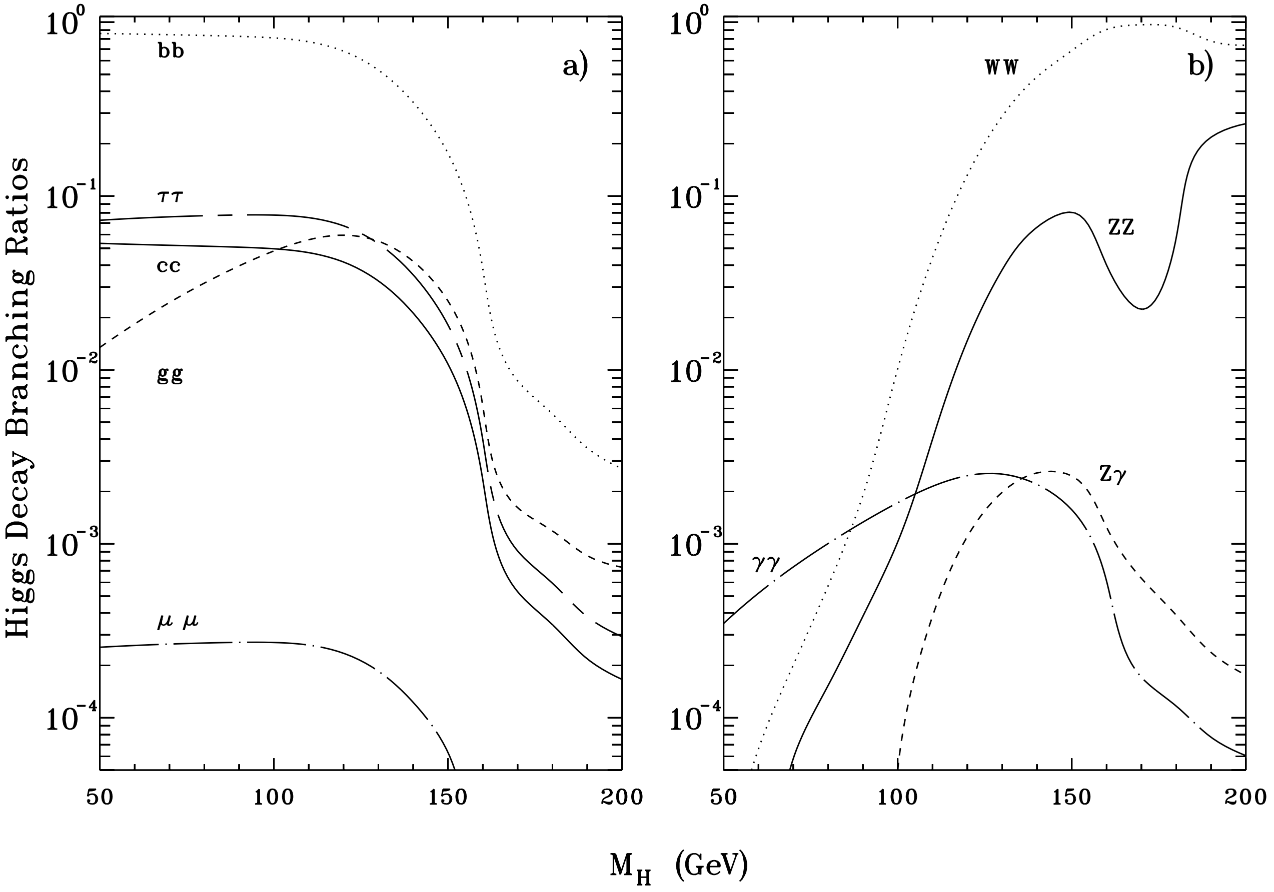
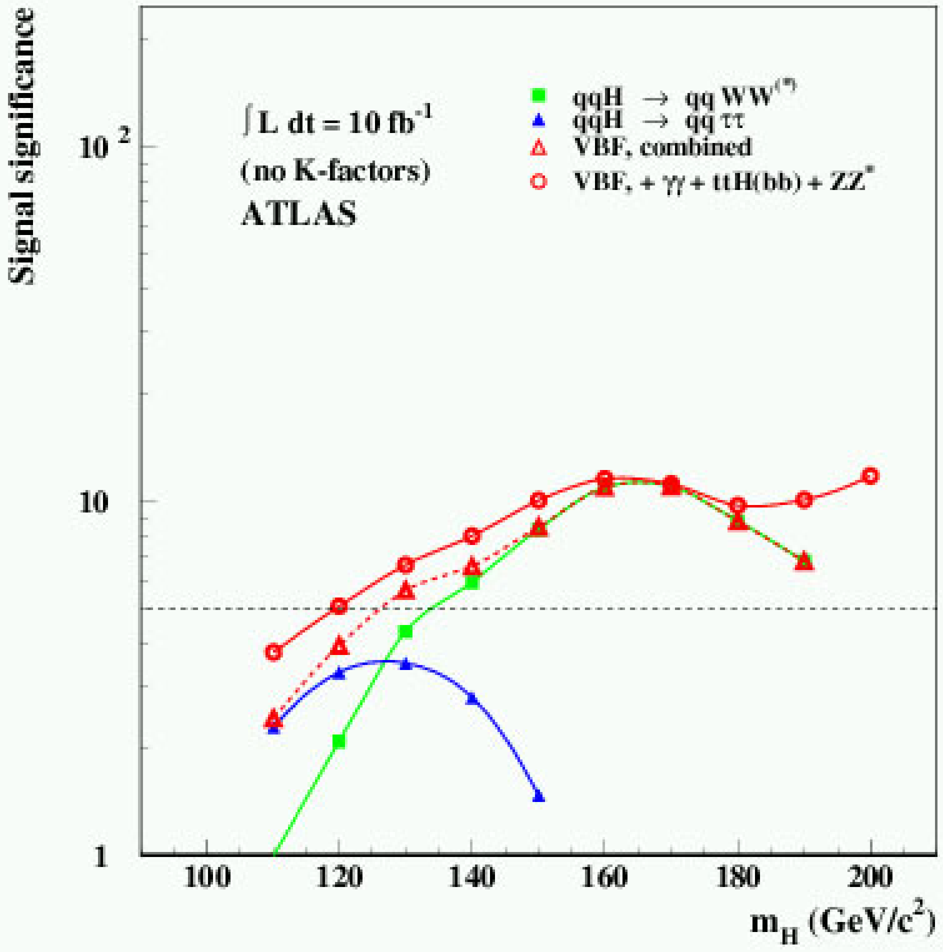
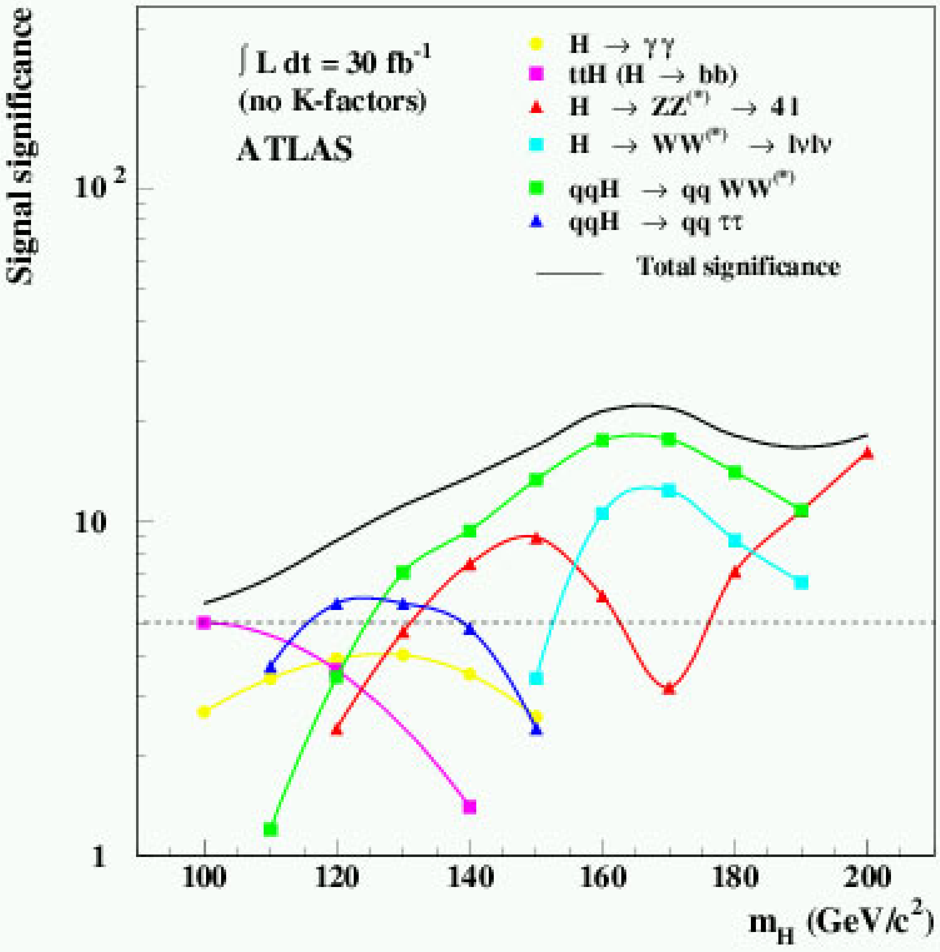


Fig. 1


Signal significance
10 ²
10
1
100
120
140
160
180
200
m$_H$ (GeV/c^2)
∫L dt = 10 fb^{-1}
(no K-factors)
ATLAS
qqH → qq WW$^{(*)}$
qqH → qq ττ
VBF, combined
VBF, + γγ + ttH(bb) + ZZ*

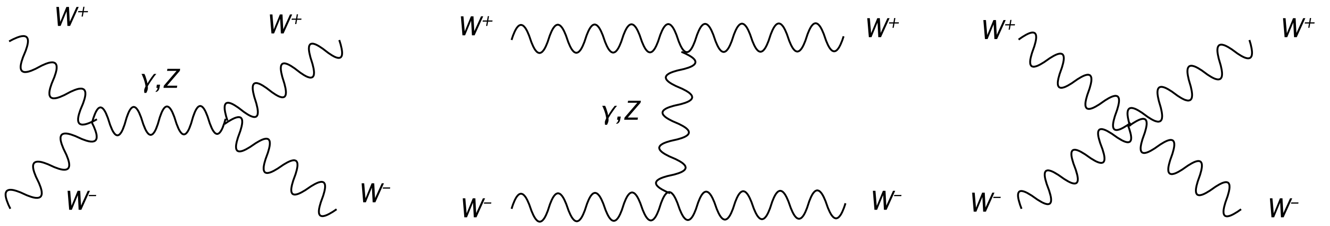

Signal significance
10 ²
10
1
100
120
140
160
180
200
m$_H$ (GeV/c^2)
∫L dt = 30 fb^{-1}
(no K-factors)
ATLAS
H → γγ
ttH (H → bb)
H → ZZ$^{(*)}$ → 4 l
H → WW$^{(*)}$ → lνlν
qqH → qq WW$^{(*)}$
qqH → qq ττ
Total significance

BOSON BOSON SCATTERING AND UNITARITY

$$\epsilon_T = \left(0; \pm\frac{1}{\sqrt{2}}, \frac{-i}{\sqrt{2}}, 0\right) \qquad \epsilon_L = \frac{1}{m_W}\left(|\vec{k}|; 0, 0, E_W\right) \qquad \vec{k}//\hat{z}$$

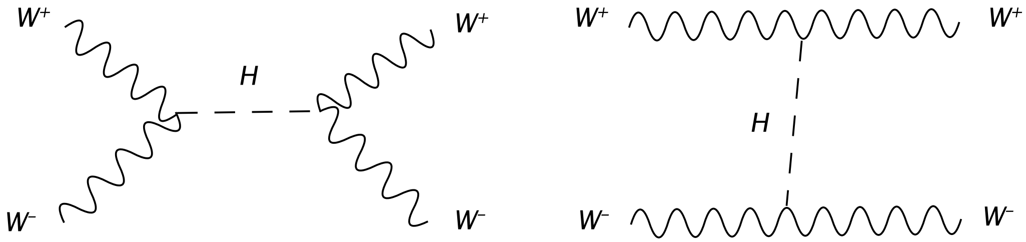
FOR $E_W \gg m_W$ $\quad \epsilon_L^\mu \approx \frac{k^\mu}{m_W}$

$$\epsilon^L_{W^+} \cdot \epsilon^L_{W^-} \approx \frac{k_{W^+} \cdot k_{W^-}}{m_W^2} = \frac{s}{m_W^2} \longrightarrow D_i \propto \frac{k_{W^+} \cdot k_{W^-}}{m_W^2} \frac{k_{W^+} \cdot k_{W^-}}{m_W^2} = \frac{s^2}{m_W^4}$$



$\Sigma \propto s$

GAUGE!



$\Sigma \propto s$

$\Sigma_{all} \approx s^0$

Boson Boson scattering and Unitarity continued

Unitarity is the statement that the total probability of all possible final states is 1 for any given initial state

$$\sum_j < i|S^\dagger|j >< j|S|k >= \delta_{ik}$$

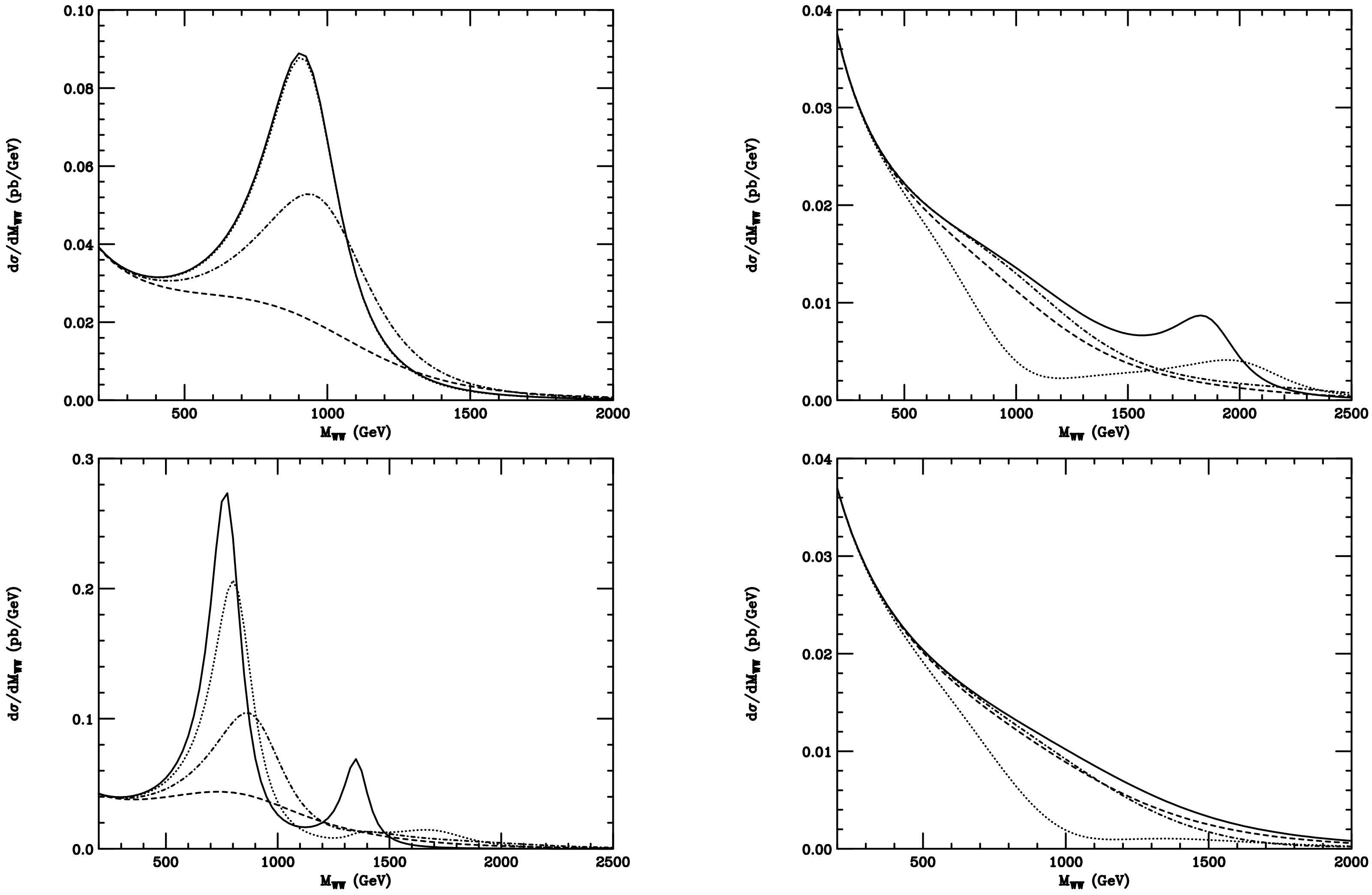
$< j|S|i >$ is the Amplitude to obtain $|j >$ at $t = \infty$ from $|i >$ at $t = -\infty$

No FULL amplitude can grow indefinetly with Energy

We only know the lowest order terms in perturbation theory

THERE ARE DIFFERENT WAYS OF CONSTRUCTING AMPLITUDES WHICH SATISFY UNITARITY CONSTRAINTS FROM LOW ORDER AMPS

BUTTERWORTH,COX,FORSHAW,PRD65(02)96014

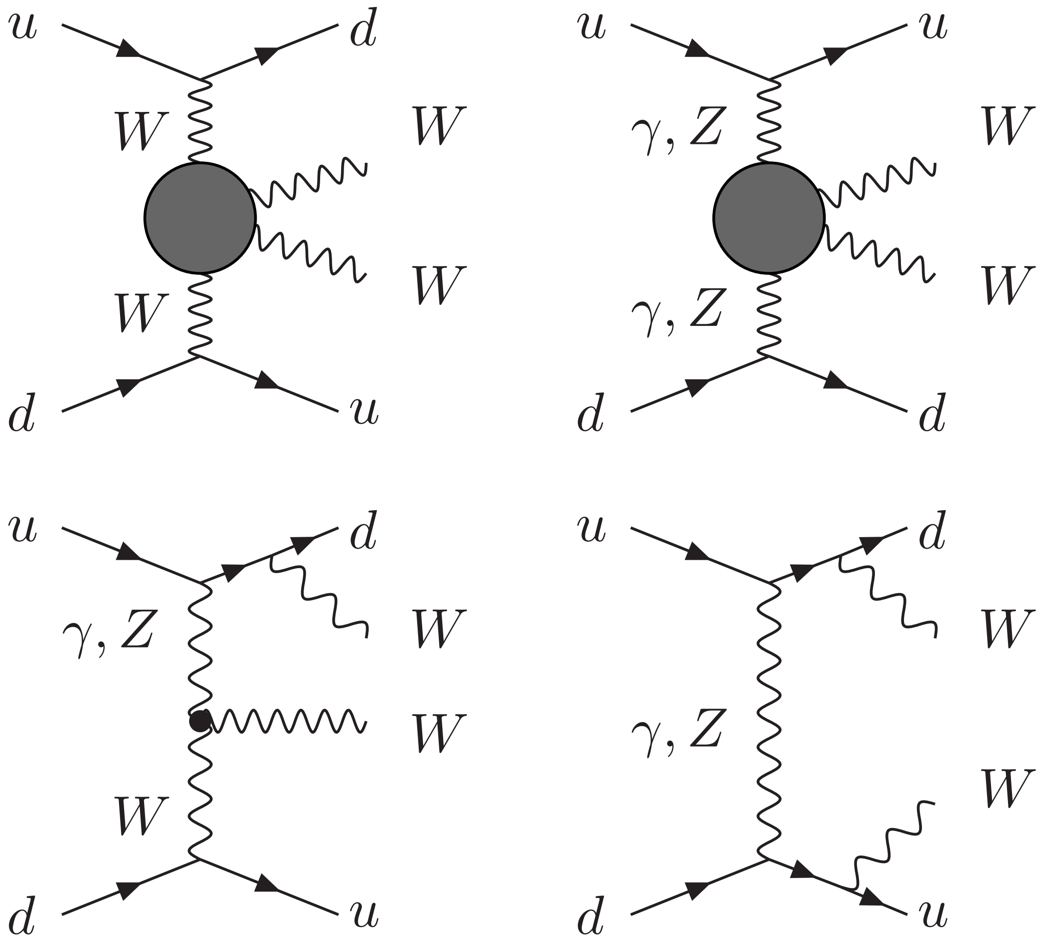


(A4,A5): UL:(0,0.003), UR:(0.002,-0.003), LL:(0.008,0), LR:(0;0)UL=UPLEFT ETC.

PADÉ: CONTINOUS

N/D: $M = 10^3$ DASH, $M = 10^4$ DOTDASH, $M = 10^5$DOT

AT THE LHC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LARGE INTERFERENCES:

WW SCATTERING AND THE REST

KLEISS-STIRLING,PL182B(86)75

$$V_L(q_1^2 = m^2 + 4\sqrt{s}\Delta_1)V_L(q_2^2 = m^2 + 4\sqrt{s}\Delta_2) \to X$$

THE HIGH-ENERGY OFF-SHELL BEHAVIOUR IS WORSE THAN ON-SHELL

PROC	OFF-OFF	ON-OFF	ON-ON
$ZZ \to ee$	$\Delta_1\Delta_2$	$m^2\Delta_1/\sqrt{s}$	m^4/s
$ZZ \to ZZ$	$(m_h^2;\Delta_1\Delta_2)$	m_h^2	m_h^2
$ZZ \to WW$	$\Delta_1\Delta_2 s^2/m^4$	$\Delta_1 s\sqrt{s}/m^2$	$(m_h^2;m^2)$
$WW \to WW$	$\Delta_1\Delta_2 s^2/m^4$	$\Delta_1 s\sqrt{s}/m^2$	$(m_h^2;m^2)$

THE PROBLEM CAN BE TRACED TO TRIPLE AND QUARTIC VERTICES.

WHEN THE INCOMING V'S ARE OFF SHELL VECTOR EMISSION FROM THE FERMION

MUST

BE INCLUDED. DO NOT MAKE APPROXIMATIONS!

AT THE LHC AND LC INCOMING VECTORS ARE BOTH ALWAYS OFF-MASS-SHELL.

(A;B)= LINEAR COMBINATION OF A AND B

Large Interferences:

WW scattering and the rest at LHC

E.Accomando,A.Ballestrero,E.M.

- $ud \to udW^+W^- \to ud\mu^-\overline{\nu_\mu}c\bar{s}$
- Initial state: p_u along z, p_d along $-z$,
- $1 < \eta(d) < 5.5,\ -1 > \eta(u) > -5.5$. Selecting WW fusion diagrams.
- $E(u,d) > 20\,\mathrm{GeV},\ P_t(u,d) > 10\,\mathrm{GeV}$
- $70 < M(cs, e\nu) < 90\,\mathrm{GeV}$. Final state W's close to mass-shell.

M_h	WW Signal	Total
120	0.2106672	0.1319138E-02
200	0.2174115	0.7960299E-02
500	0.2114054	0.2804993E-02
2000	0.2100076	0.1490797E-02
noH	0.2099891	0.1468983E-02

σ (pb)

MONTECARLO GENERATORS

MC GENERATORS ARE ESSENTIAL:

- GENERATE REALISTIC SAMPLES TO DEVELOP AND OPTIMIZE SEARCH STRATEGIES
- RELATE MEASURED QUANTITIES TO THEORETICAL (INCLUSIVE) QUANTITIES
- ESTIMATE EXPERIMENTAL EFFICIENCIES

THEY MUST:

- DESCRIBE AS FAITHFULLY AS POSSIBLE ALL RELEVANT PHYSICAL PROCESSES
- ALLOW INTERFACE WITH SHOWERING / HADRONIZATION MC'S

ACTIVITY IN TORINO

THEORY

E.ACCOMANDO, A. BALLESTRERO, E. MAINA, A. BELHOUARI, V. KASHKAN, G. BEVILACQUA

EXPERIMENT: CMS

C. MARIOTTI, G. GERMINARA, R. BELLAN, S. BOLOGNESI

PHASE

PHACT ADAPTIVE SIX-FERMION EVENT-GENERATOR

A DEDICATED EVENT GENERATOR:

- ALL $q_1 q_2 \rightarrow q_3 q_4 q_5 q_6 l \overline{\nu_l}$ PROCESSES AT $\mathcal{O}(\alpha_{em}^6)$
  THIS IS WHERE WW SCATTERING IS!
  $q_1 q_2 \rightarrow q_3 q_4 q_5 q_6 l \bar{l}$ AND $q_1 q_2 \rightarrow q_3 q_4 l_1 \overline{\nu_{l_1}} l_2 \overline{\nu_{l_2}}$ ALSO INTERESTING, τ'S?
  $qq \rightarrow 6q$ HAVE LARGE BACKGROUNDS
- ONE-SHOT: ALL PROCESSES GENERATED SIMULTANEOUSLY.
  SUBSETS POSSIBLE.
- OVER THE FULL PHASE SPACE: EFFICIENCY
- INTERFACED WITH PYTHIA / HERWIG WITH LES HOUCHES PROTOCOL

PROBLEMS

- LARGE NUMBER OF PROCESSES
- LARGE NUMBER OF DIAGRAMS / PROCESS
- LARGE NUMBER OF CHANNELS / ENHANCED REGIONS

WHICH PROCESSES IN $q_1 q_2 \longrightarrow q_3 q_4 q_5 q_6 \mu \overline{\nu_\mu}$ AT $\mathcal{O}(\alpha_{em}^6)$?

- EQUIVALENT PROCESSES WITH ALL FERMIONS OUTGOING: $\sum_{i=1}^{8} Q_i = 0$
- FIX ONE PAIR TO BE $c\overline{s}$
- $q_1 q_2 \rightarrow q_3 q_4 c\overline{s}\mu\overline{\nu_\mu}$ WITH $\sum_{i=1}^{4} Q_i = 0$

PROCESSES

ALL PARTICLES OUTGOING

161 WITH DIFFERENT M.E.

141X2+20=302

WITH DIFFERENT PDF

$(u, d) \leftrightarrow (c, s)$ SYMMETRY

CC SYMMETRY

302X4=1208

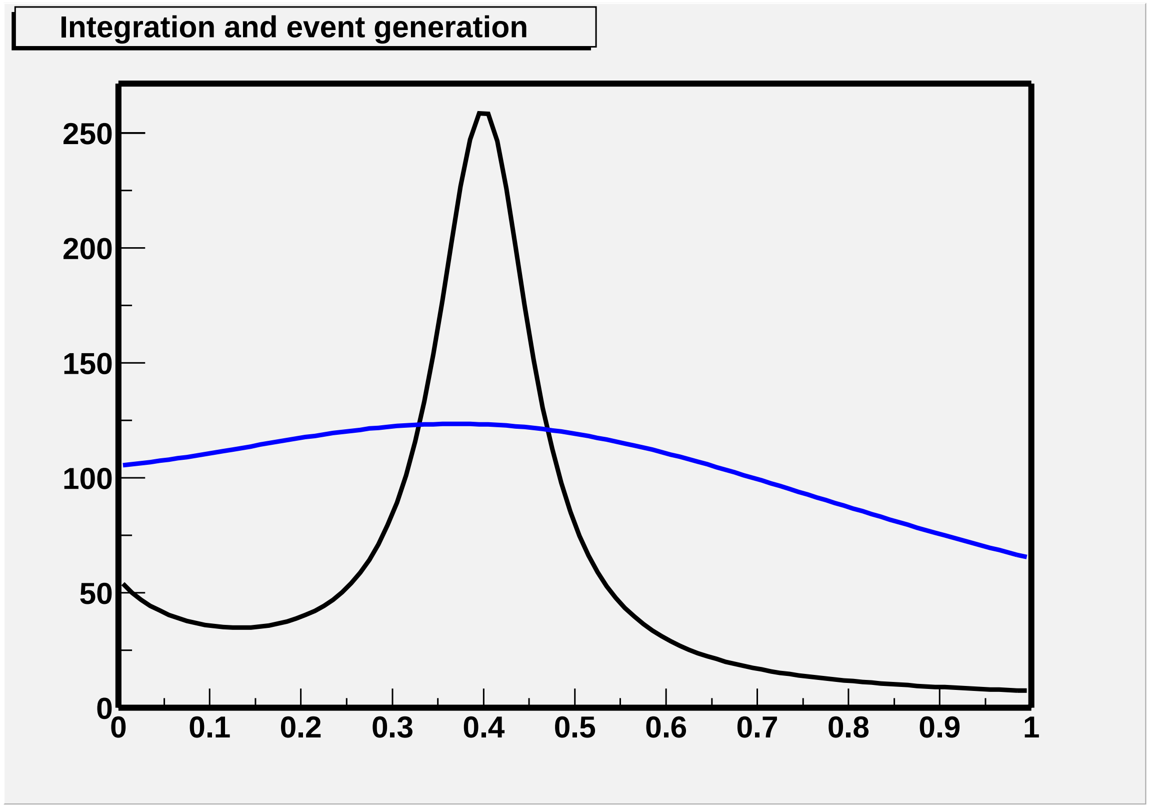
TRIVIAL $(\mu, \nu_\mu) \leftrightarrow (e, \nu_e)$

Particles	type	diag	#proc(2+1)
$c\bar{s}d\bar{u}c\bar{s}\mu\bar{\nu}$	4W	202	6 + 2
$u\bar{u}u\bar{u}c\bar{s}\mu\bar{\nu}$	2Z2W	422	6 + 2
$u\bar{u}c\bar{c}c\bar{s}\mu\bar{\nu}$	2Z2W	422	10 + 1
$u\bar{u}s\bar{s}c\bar{s}\mu\bar{\nu}$	2Z2W	422	10 + 1
$u\bar{u}b\bar{b}c\bar{s}\mu\bar{\nu}$	2Z2W	233	15 + 0
$d\bar{d}d\bar{d}c\bar{s}\mu\bar{\nu}$	2Z2W	422	6 + 2
$d\bar{d}c\bar{c}c\bar{s}\mu\bar{\nu}$	2Z2W	422	10 + 1
$d\bar{d}s\bar{s}c\bar{s}\mu\bar{\nu}$	2Z2W	422	10 + 1
$d\bar{d}b\bar{b}c\bar{s}\mu\bar{\nu}$	2Z2W	233	15 + 0
$c\bar{c}c\bar{c}c\bar{s}\mu\bar{\nu}$	2Z2W	1266	3 + 2
$c\bar{c}b\bar{b}c\bar{s}\mu\bar{\nu}$	2Z2W	466	10 + 1
$s\bar{s}s\bar{s}c\bar{s}\mu\bar{\nu}$	2Z2W	1266	3 + 2
$s\bar{s}b\bar{b}c\bar{s}\mu\bar{\nu}$	2Z2W	466	10 + 1
$b\bar{b}b\bar{b}c\bar{s}\mu\bar{\nu}$	2Z2W	610	6 + 2
$u\bar{u}d\bar{d}c\bar{s}\mu\bar{\nu}$	2Z2W+4W	312	15 + 0
$c\bar{c}s\bar{s}c\bar{s}\mu\bar{\nu}$	2Z2W+4W	1046	6 + 2
TOTAL			141 + 20

INTEGRATION

IT IS ABSOLUTELY NECESSARY TO OBTAIN A PRECISE CROSS SECTION: IT ENSURES THAT THE PHASE-SPACE PARAMETRIZATION MATCHES REASONABLY WELL THE BEHAVIOUR OF THE AMPLITUDE SQUARED.

OTHERWISE GENERATION EFFICIENCY WILL BE EXTREMELY POOR.

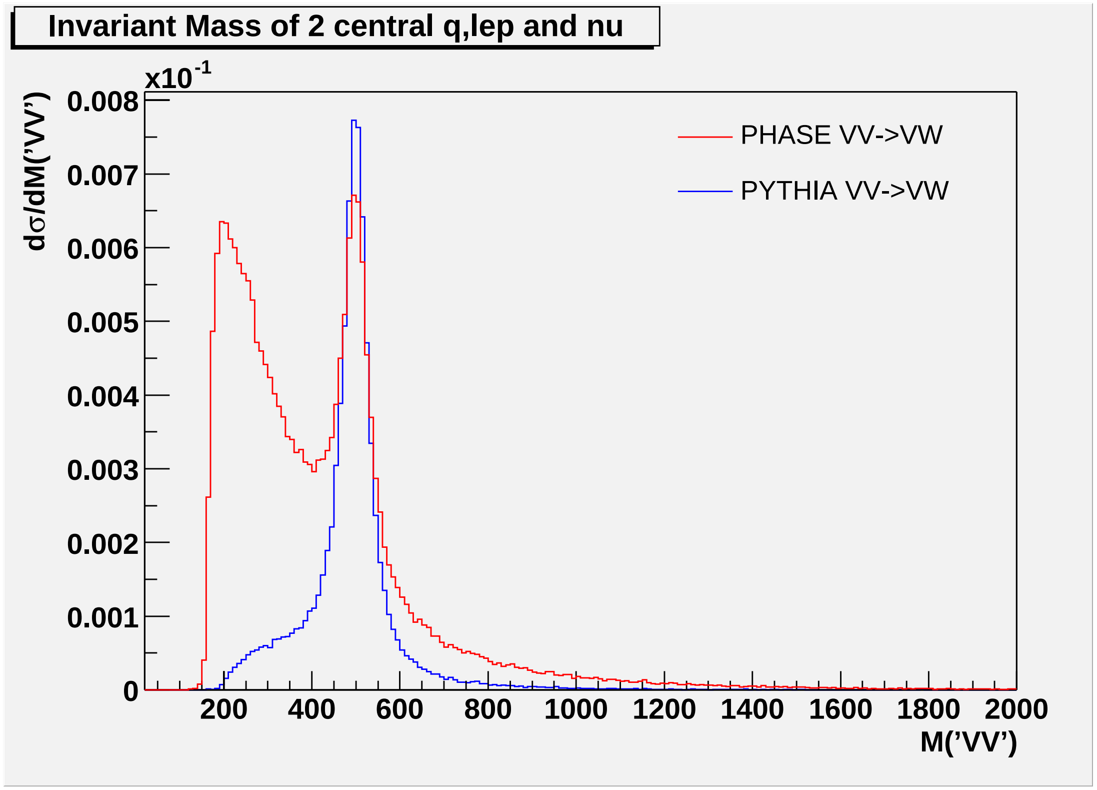


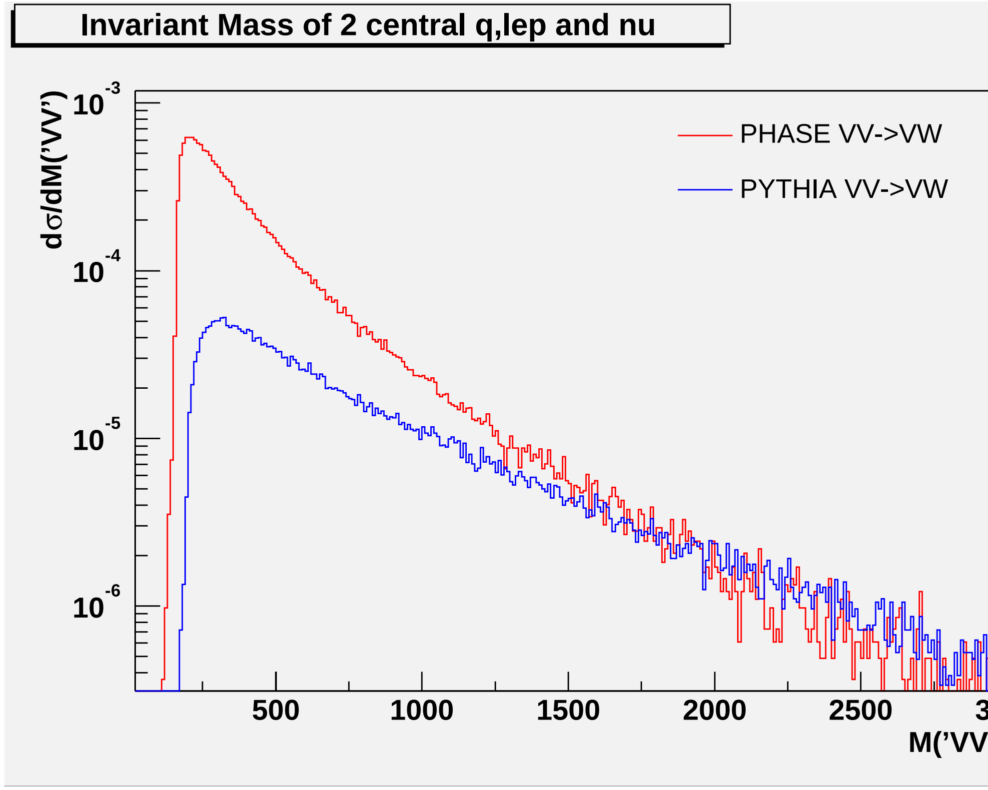
INTEGRATION CAN BE USED TO ADAPT MORE CLOSELY TO THE INTEGRAND

POSSIBLE STRATEGIES:

- ADAPTIVE INTEGRATION (VEGAS)
  - ADAPTS WELL TO CUTS
  - A ROUGH ESTIMATE OF MAPPING PARAMETERS IS USUALLY SUFFICIENT
  - FAILS IF SEVERAL SETS OF ENHANCEMENTS IN $|Amp|^2$ OR ALONG DIAGONALS ☹
- MULTICHANNEL
  - REQUIRES A LARGE NUMBER OF CHANNELS (EASY TO ADD)
  - ALL CHANNELS ARE INTEGRATED OVER SIMULTANEOUSLY
  - SENSITIVE TO CUTS, EFFICIENCY GENERALLY SMALL ☹
  - MAPPING PARAMETERS TO BE DETERMINED WITH HIGH ACCURACY ☹
- ADAPTIVE+MULTICHANNEL
  - ADAPTS WELL TO CUTS
  - A ROUGH ESTIMATE OF MAPPING PARAMETERS IS USUALLY SUFFICIENT
  - ALL CHANNELS HAVE TO BE INTEGRATED SEPARATELY ☹

$d\sigma/dM_{VW}$:PHASE vs PYTHIA

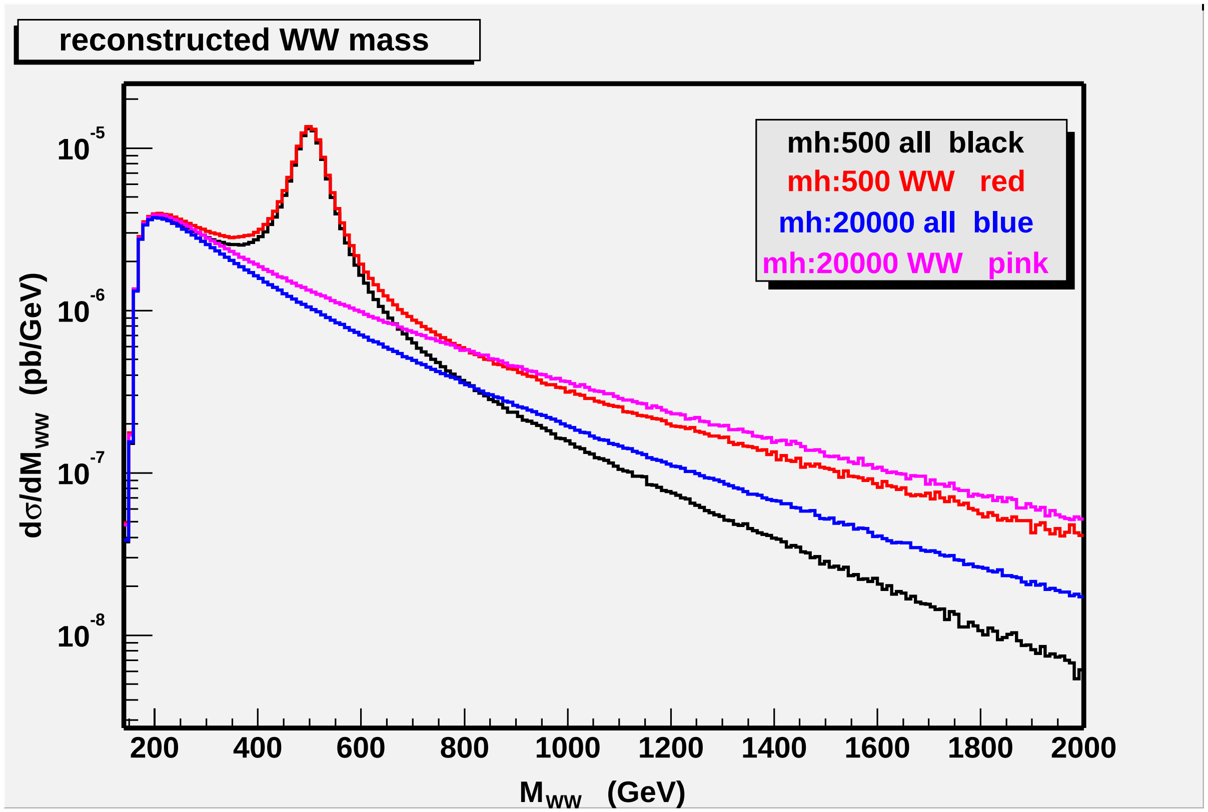




- CUTS: TOP REJECTION, W MASS
- BIG DIFFERENCES OVER THE WHOLE RANGE
- GOOD KNOWLEDGE OF BACKGROUND NECESSARY FOR DISCOVERY

$d\sigma/dM_{VW}$:PRODUCTION×DECAY VS FULL

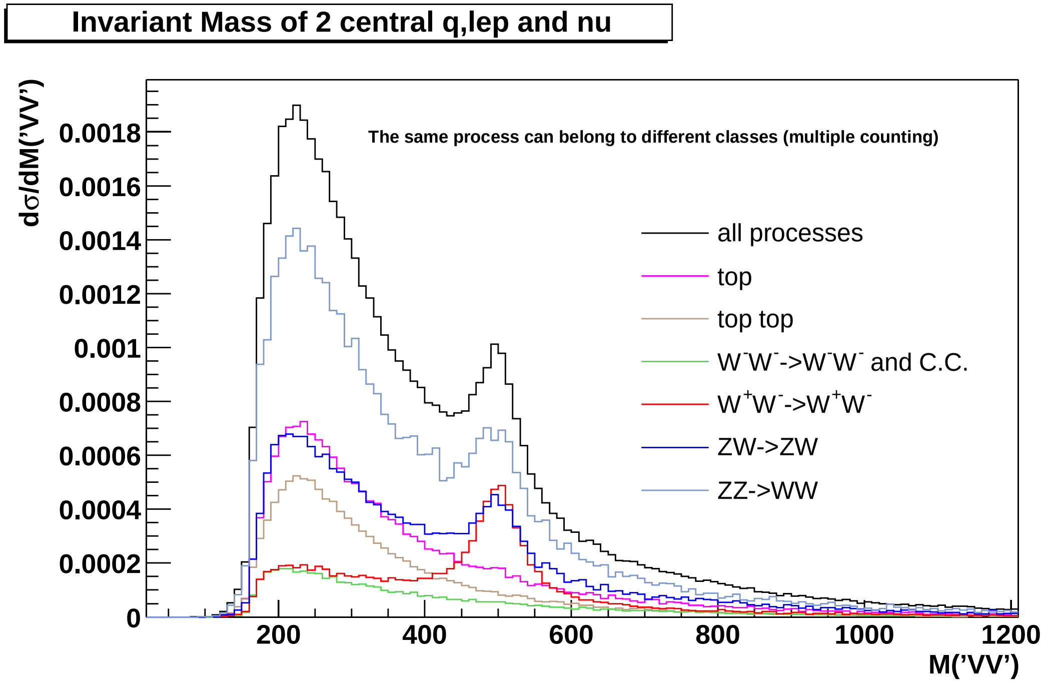
$ud \to udc\bar{s}\mu\bar{\nu}$ VS $ud \to udW^+W^- \to udc\bar{s}\mu\bar{\nu}$ (ALPGEN-LIKE)



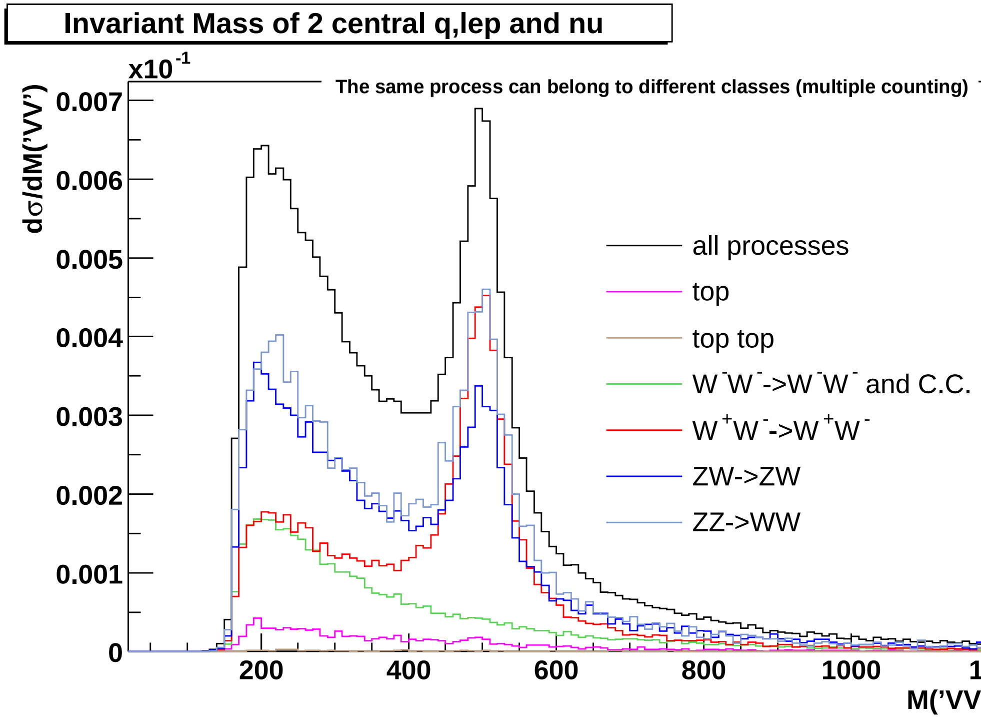
- $|\eta(j)| < 6.5$, $2 < \eta(j_f) < 6.5$, $-6.5 < \eta(j_b) < -2$
- $E(j,\mu) > 20\,\mathrm{GeV}$, $P_t(j,\mu) > 10\,\mathrm{GeV}$
- $M(jj) > 20\,\mathrm{GeV}$, $|M(j_c j_c) - M_W| < 20\,\mathrm{GeV}$, $M_T(\mu\bar{\nu}) < M_W + 20\,\mathrm{GeV}$

DIFF HIGGS-NOHIGGS LARGER BUT σ LOWER FOR FULL CALCULATION

PHYSICAL SUBPROCESSES



Invariant Mass of 2 central q,lep and nu



Invariant Mass of 2 central q,lep and nu

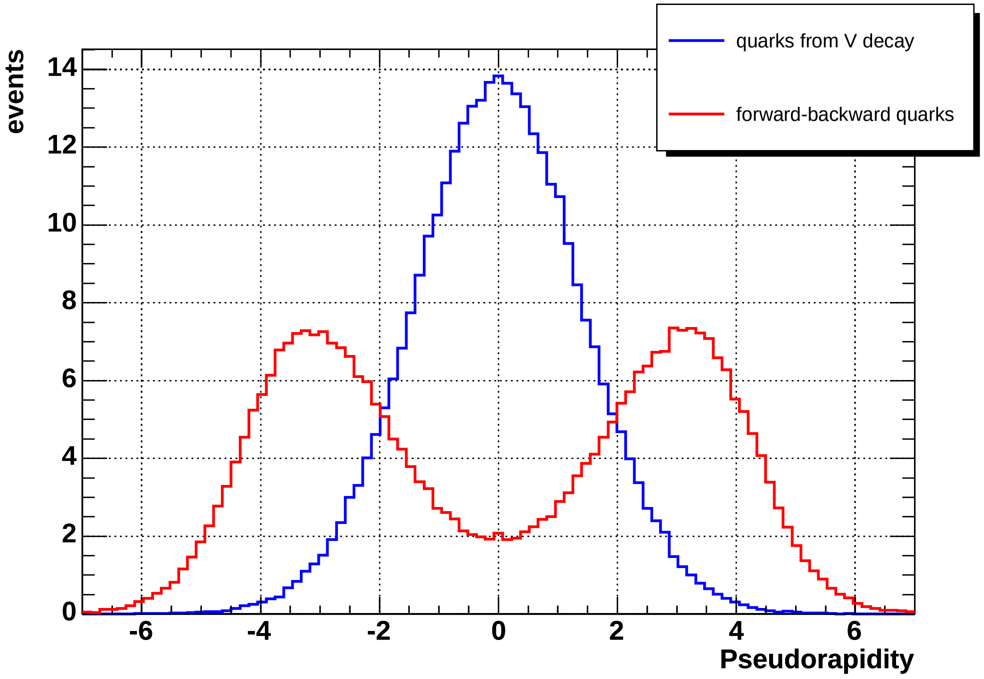
CUTS:

- TOP-TOP AND SINGLE TOP REJECTION
- $60 < M(qq) < 100$ GEV
- $M_T(\mu\overline{\nu}) < 100$ GEV

VV–fusion in CMS

- We want to determine
  - resolution on $M(WW)$ and $M(ZZ)$ that is the energy scale
  - largest $M(VV)$ measurable at LHC
  - luminosity requirements
- Since σ is small efficiency must be kept high and S/B small

Preliminary studies have shown that VV–fusion can be studied in CMS up to ≈2 TeV



Signal vs Background

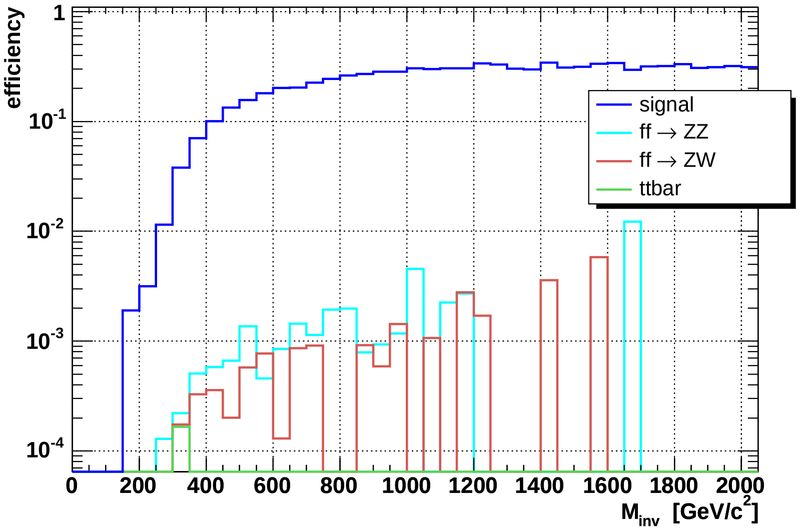
WW	
Signal	
$M_h = 500$ GeV	$\sigma = 60$ fb
$No - Higgs$	$\sigma = 20$ fb
Background	
top–top	$\sigma = 6.2 \times 10^5$ fb
W+jets	$\sigma = 7.7 \times 10^4$ fb
WW	$\sigma = 1.1 \times 10^3$ fb

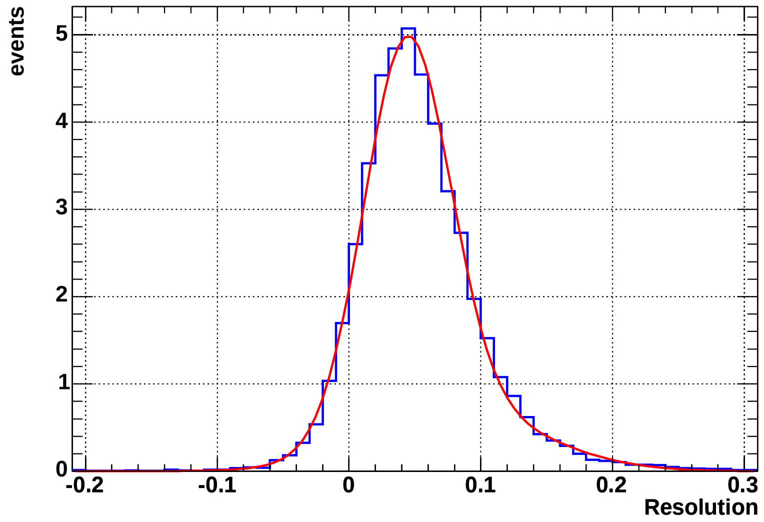
ZZ+ZW	
Signal	
$M_h = 500$ GeV	$\sigma = 9.1$ fb / 0.7 fb
$No - Higgs$	$\sigma = 1.7$ fb / 1.4 fb
Background	
top–top	$\sigma = 6.2 \times 10^5$ fb
Z+jets	$\sigma = 1.4 \times 10^7$ fb
ZZ	$\sigma = 6.6 \times 10^5$ fb
WZ	$\sigma = 6.6 \times 10^5$ fb

Analysis

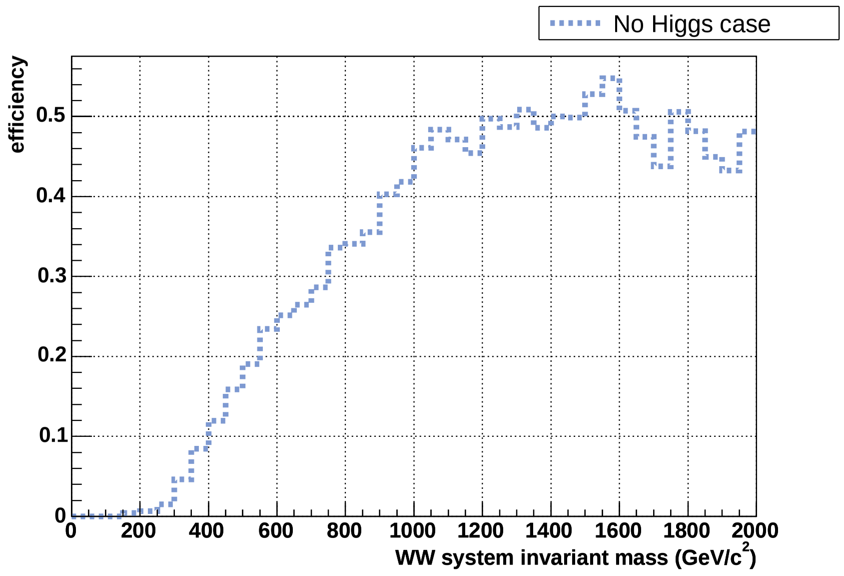
- To enhance signal and suppress bkg, cuts are applied, based on the different kinematics
  - High p_t muons
  - 2 jets with $M(jj) = M_{\mathrm{Z,W}}$
  - High p_t Z,W
  - 1 forward, 1 backward jets, high p_t, E, large $\Delta\eta$ and $M(jj)$
- Signal efficiency is high $\approx$ 35-50%
- $M(VV)$ resolution is good (4% ZZ and 10% WW)
- High $S/\sqrt{B}$; 3-11

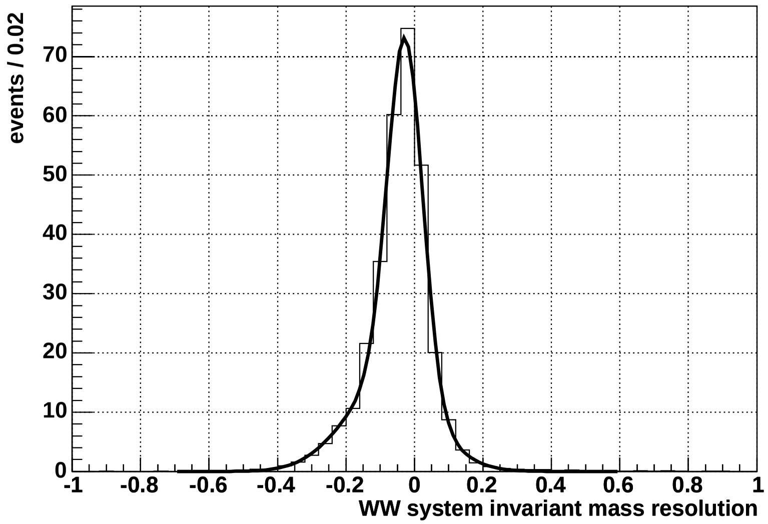
ZZ+WZ FINAL STATE





WW FINAL STATE





PYTHIA(PROCESES 71-77) + CMSJET

CONCLUSIONS

- WW SCATTERING IS MOST SIGNIFICANT HIGGS DISCOVERY CHANNEL FOR $M_h < 190$ GEV
- WW SCATTERING HOLDS THE KEY TO THE EWSB MECHANISM
- EXCITING PHENOMENA COULD TAKE PLACE. SM PREDICTION MUST BE PRECISELY KNOWN
- PHASE IS AT PRODUCTION STAGE

A LOT MORE WORK LIES AHEAD!

FRUITFUL COLLABORATION BETWEEN

THEORY AND EXPERIMENT HAS STARTED

IN TORINO