PHANTOM at ILC

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ILC Physics in Florence

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It is commonly agreed that the TeV scale holds clues to understand the origin of masses and the mechanism of Electroweak Symmetry Breaking (EWSB).

Tevatron has started exploring the TeV region

LHC and ILC will complete the picture

Physics agenda includes:

- Higgs studies via Vector Boson Fusion
- Vector Boson Scattering
- Triple Gauge Boson production
- $t\bar{t}$ production
- ...

Processes with six partons in the final state will be central to the physics program at next-generation colliders

LHC and ILC will be complementary in many respects

Six-fermion tools for ILC

Current status:

General purpose MC tools

- GRACE
- HELAS/MadGraph/MadEvent
- Whizard+Omega
- Sherpa/AmegiC++
- HELAC/PHEGAS

Dedicated 6f MC tools

- eett6f $e^+e^- \to t\bar{t} \to 6f$, including QCD
- Sixfap $e^+e^- \to 6f$, no QCD
- Sixphact $e^+e^- \to 6f$, naive QCD approach (NQCD)
- Lusifer $e^+e^- \to 6f$, including one-gluon exchange
- Sixrad $e^+e^- \to 6q/4q2g/2q4g$

Six-fermion tools for ILC

The road is still open for progress in several directions...

- improving efficiency
- extending the coverage of final states with *gluon* jets
- facilitating comparative studies between LHC and ILC physics potential

New MC tool for six-parton physics developed in Torino:

PHANTOM – PHAct New TOrino Montecarlo

First dedicated event generator for hadron and e^+e^- colliders

Profits from the experience obtained with PHASE, an event generator dedicated to all processes of type $pp \to 4q + \ell\nu$

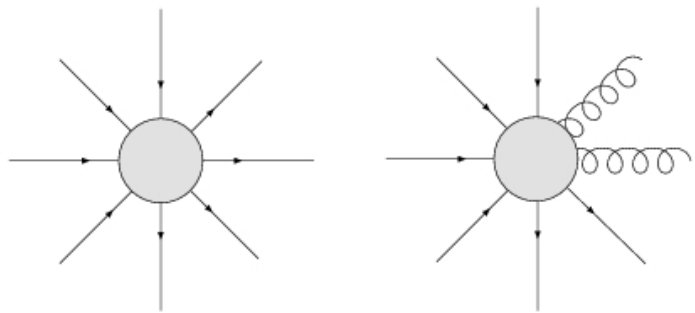
Accomando,Ballestrero,Maina

PHANTOM 1.0

Ballestrero, Belhouari, G.B., Kashkan, Maina

Event generator dedicated to six-fermion physics at pp, $p\bar{p}$ and e^+e^- colliders

- Exact tree-level matrix elements at $\mathcal{O}(\alpha_{EM}^6) + \mathcal{O}(\alpha_{EM}^4 \alpha_S^2)$



- Full coverage of Standard Model processes at fixed order

at e^+e^-:

- Initial-state radiation (ISR) via leading log structure functions
- Interface to CIRCE library (beamstrahlung parameterization)

Main features

Efficient

- fast *modular* evaluation of helicity amplitudes (with PHACT)
- new integration technique merging *multichannel* with an *adaptive* routine (VEGAS): *iterative-adaptive multichannel*

User friendly

- automatic set-up of reactions managed by PERL scripts
- possibility of unweighted generation of any number of processes at the same time (*oneshot* mode)

Les Houches ready

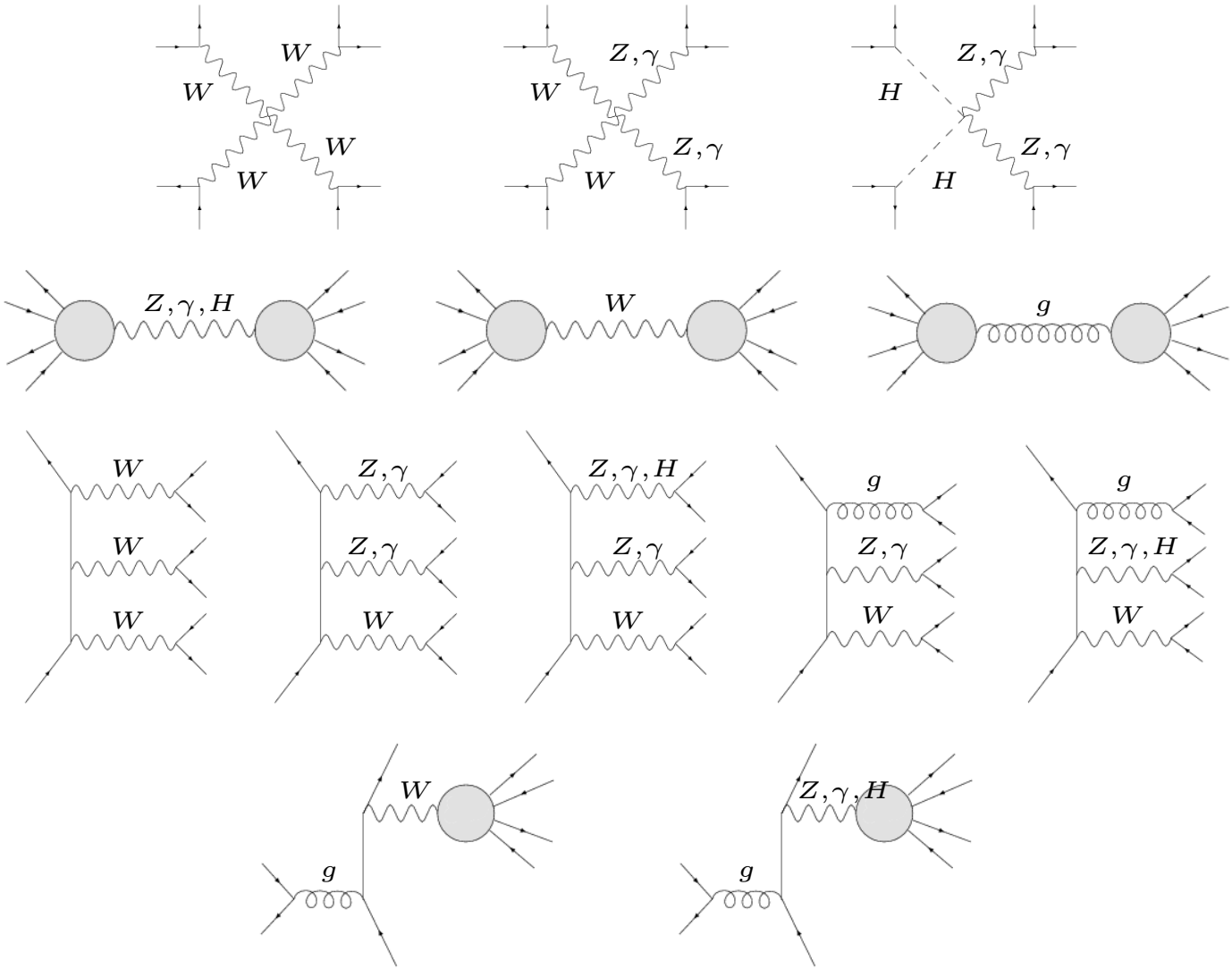
- interface to pdf's and showering/hadronization via Les Houches Accord; new Les Houches Event File (LHEF) format

All-in-one

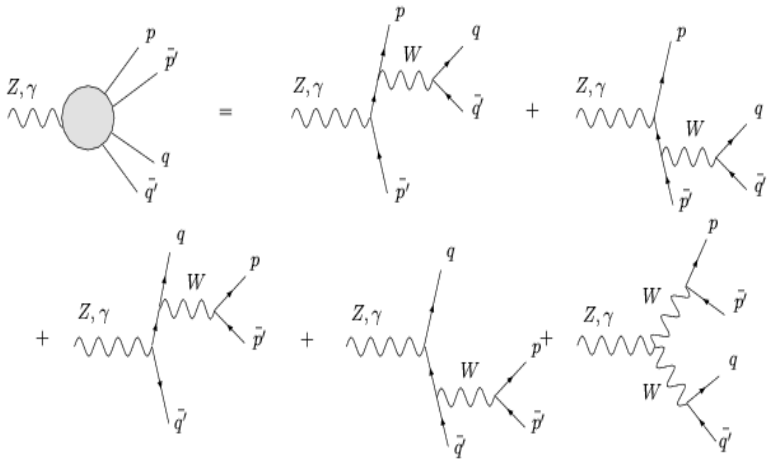
- one dedicated tool for 6f physics at hadron and e^+e^- colliders

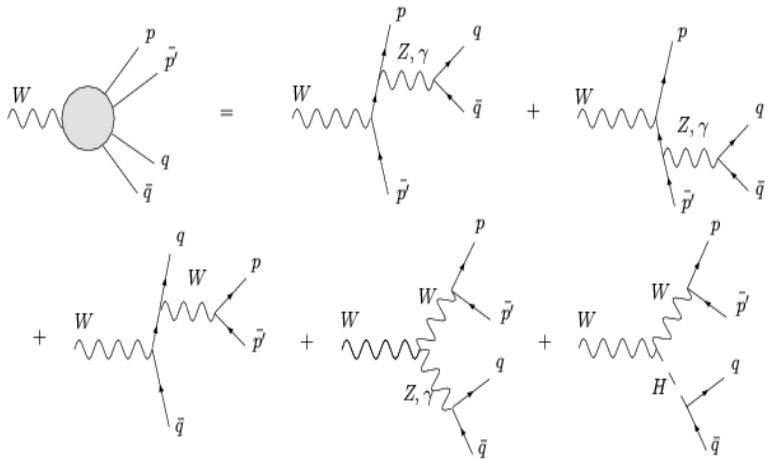
Matrix-element calculation

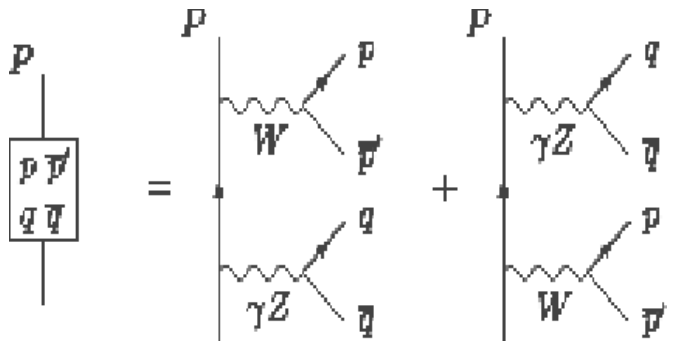
Example: diagrams with 8 external fermions

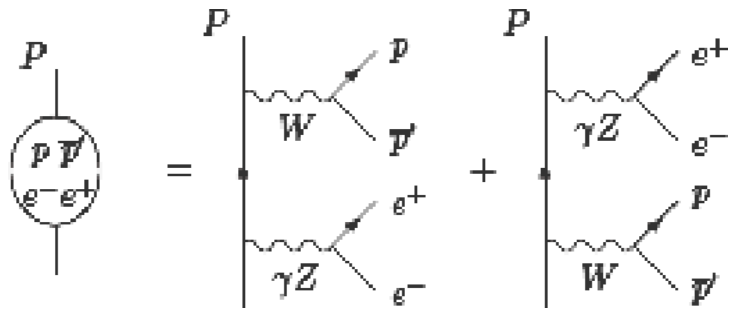


Examples of subdiagrams









Physics potential for ILC studies

$$\mathcal{O}(\alpha_{EM}^6)$$

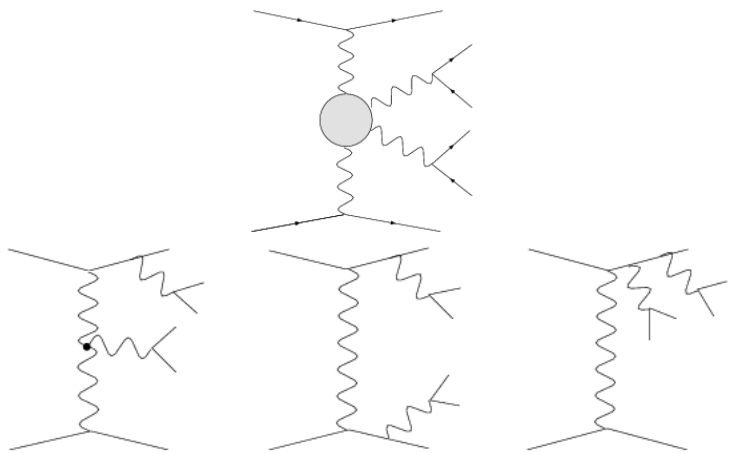
Holds the signal of

- Higgs production via Vector Boson Fusion $\nu_e\bar{\nu}_e H \to \nu_e\bar{\nu}_e VV$ ...
- Vector Boson Scattering (VBS) $WW \to WW, WZ \to WZ$ ...
- Triple Gauge Boson production
- triple/quadruple-vertex EW interactions

together with all possible EW irreducible background from a six-fermion point of view.

example: VBS signal

Possible large interferences and gauge cancellations with *pure EW* irreducible background

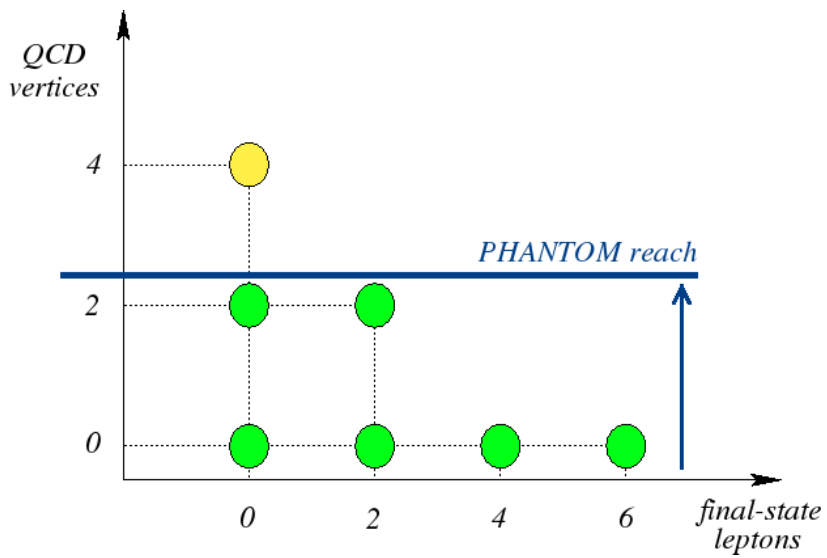


Physics potential for ILC studies

$$+\mathcal{O}(\alpha_{EM}^4 \alpha_S^2)$$

All *EW+QCD* irreducible background to the previous signals with one gluon exchange (and interferences)

Notice: at e^+e^- colliders, $\mathcal{O}(\alpha_{EM}^6) + \mathcal{O}(\alpha_{EM}^4 \alpha_S^2)$ describes completely the tree-level QCD background for final states with at least two leptons



Only for fully hadronic final states PHANTOM needs to be complemented by other MC generators for physics studies at ILC

Physics studies on EWSB at ILC

We are interested in extending to ILC our analyses on Boson-Boson Scattering and alternative EWSB scenarios.

Several studies in this direction have already appeared

Barger, Cheung, Han, Phillips '95 ...

W^+W^- fusion is a sensitive probe of the dynamics of EWSB: different models predict different ratios $\sigma(W^+W^- \to W^+W^-)/\sigma(W^+W^- \to ZZ)$

Principal backgrounds:

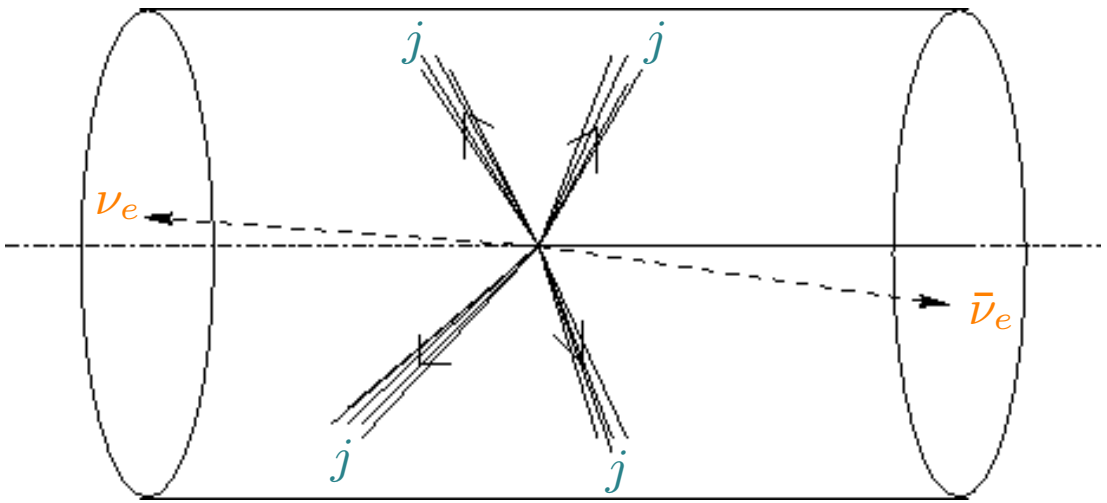
$e^+e^- \to e^+e^-W^+W^-$, e^+e^-ZZ , $e^\pm\nu W^\pm Z$ (with undetected $e^\pm$)

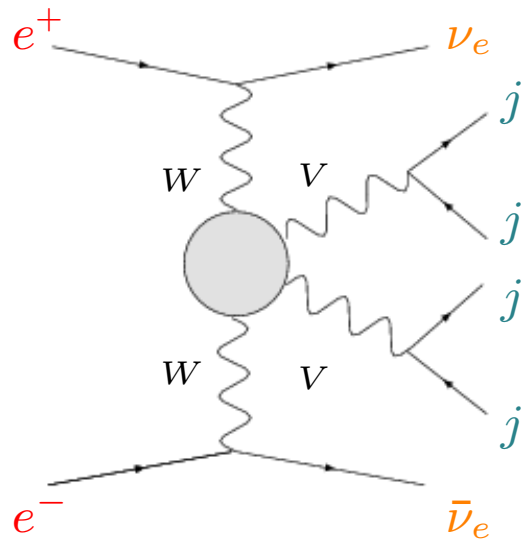
$e^+e^- \to ZW^+W^- \to \nu\bar{\nu}W^+W^-$ (Z-resonant channel)

A case study: $e^+e^- \to \nu_e\bar{\nu}_e\, 4j$

At LHC the selection of events with two tag jets widely separated in η (*forward/backward tagging*) is a well established technique for enhancing the scattering signal.

ILC requires a different selection procedure





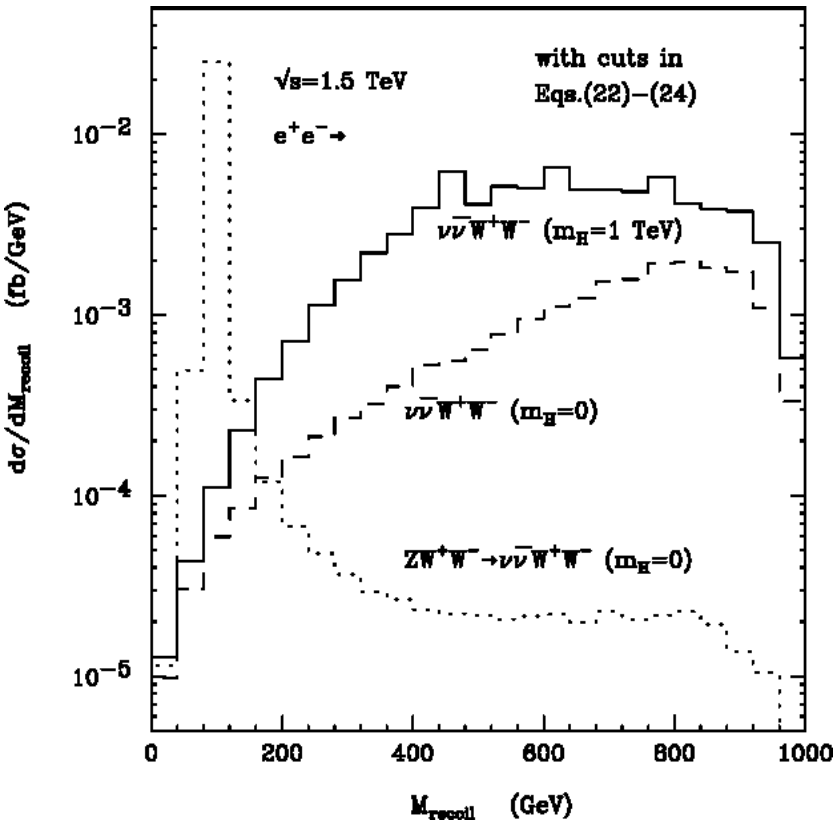
Some interesting observables:

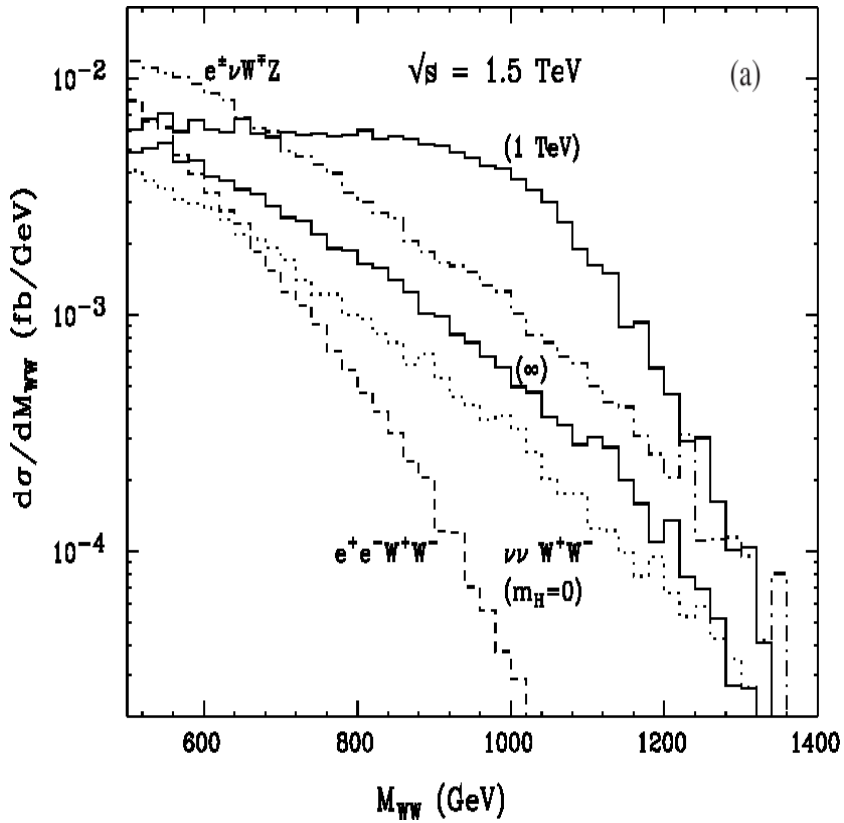
- four-jet invariant mass (M_{4j}): holds information about M_{VV}
- *recoil* four-jet mass (M_{recoil}): complementary to M_{4j}, related to total missing momentum (neutrinos + initial-state radiation)

Barger, Cheung, Han, Phillips '95

$\sqrt{s} = 1.5$ TeV

No ISR/beamstrahlung





Selection cuts:

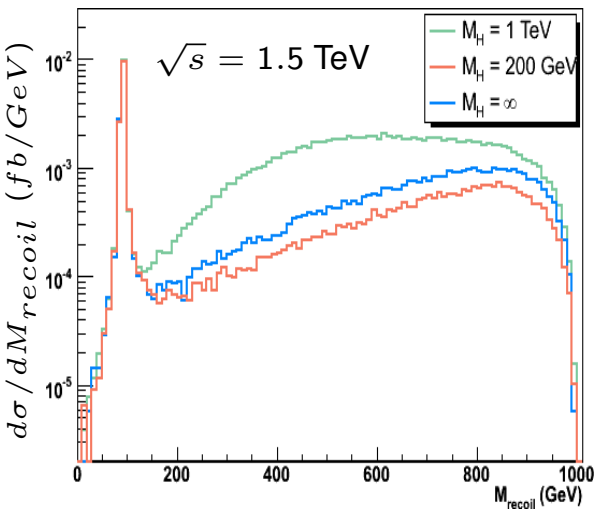
$M_{recoil} > 200$ GeV; $M_{VV} > 500$ GeV; $p_T(V) > 150$ GeV; $|\cos\theta_V| < 0.8$;

50 GeV $< p_T(WW) <$ 300 GeV; 20 GeV $< p_T(ZZ) <$ 300 GeV

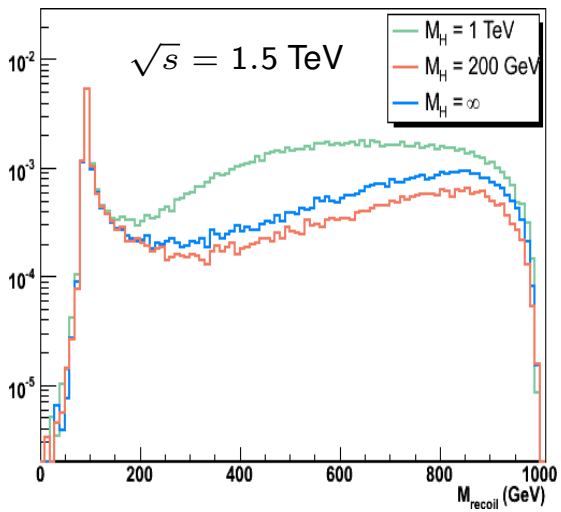
PHANTOM results at $\mathcal{O}(\alpha_{EM}^6)$

Effect of initial-state radiation on *recoil mass* distribution (W^+W^- resonant final states)

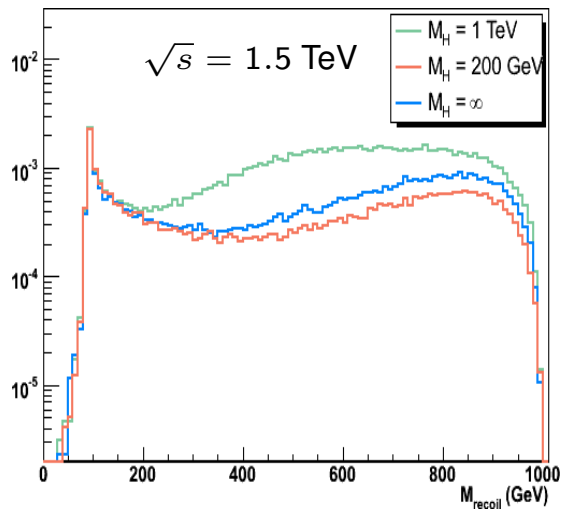
no radiation



ISR



ISR+beamstrahlung

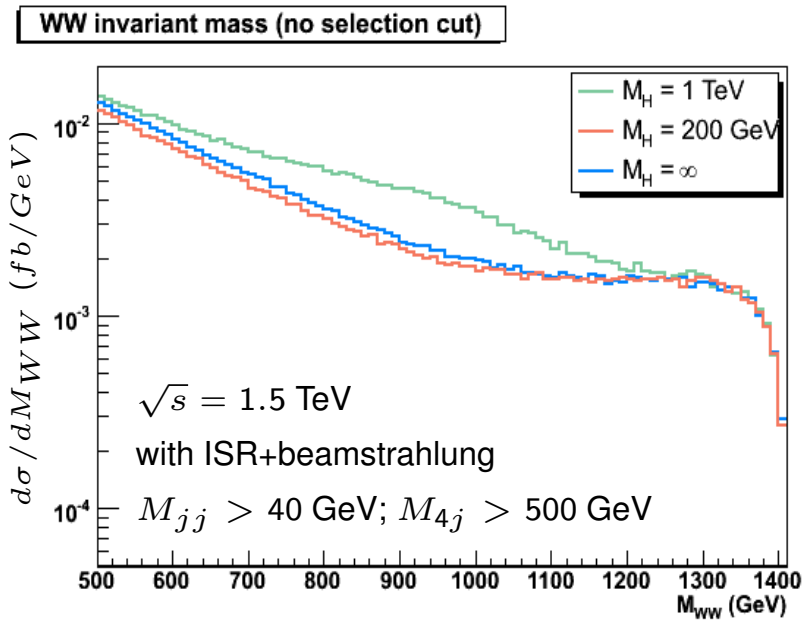


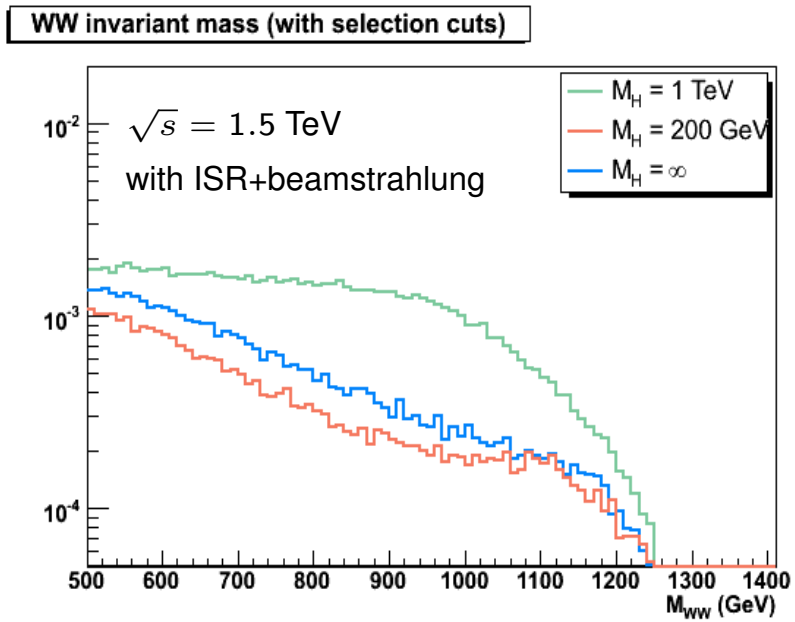
Selection cuts:

$M_{jj} > 40$ GeV; $M_{VV} > 500$ GeV; $p_T(V) > 150$ GeV; $|\cos\theta_V| < 0.8$;

50 GeV $< p_T(WW) <$ 300 GeV; 20 GeV $< p_T(ZZ) <$ 300 GeV

Effect of selection cuts on W^+W^- invariant mass distributions





Selection cuts:

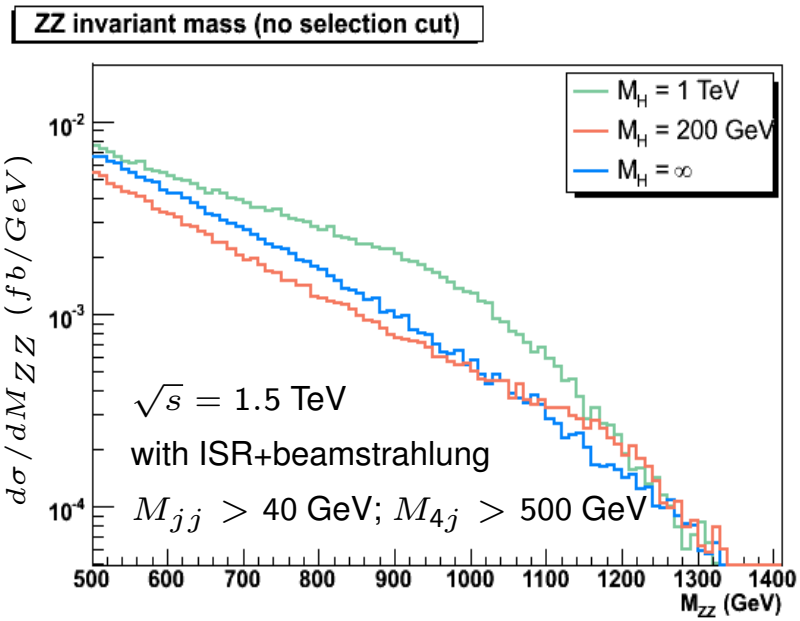
$$M_{jj} > 40 \text{ GeV}; \quad M_{WW} > 500 \text{ GeV}; \quad p_T(W) > 150 \text{ GeV}; \quad |\cos\theta_W| < 0.8;$$

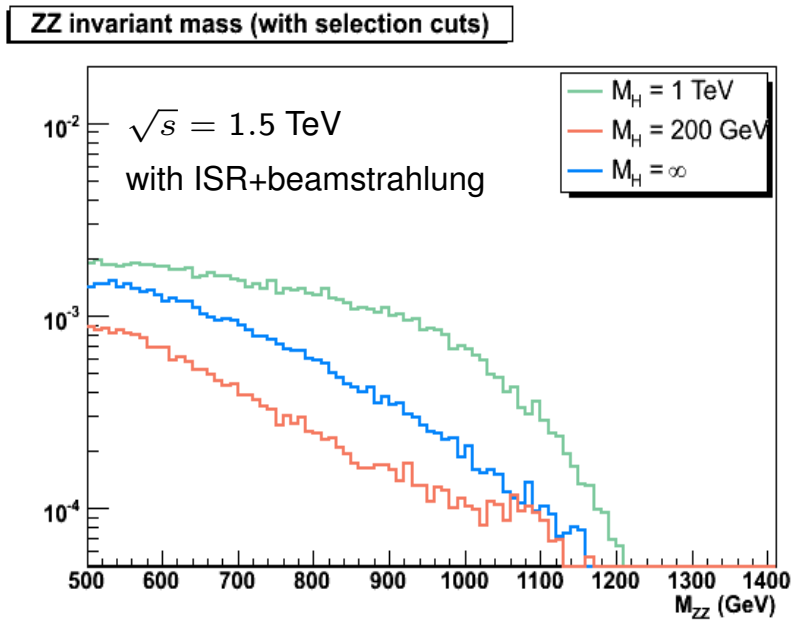
$$M_{recoil} > 200 \text{ GeV}; \quad 50 \text{ GeV} < p_T(WW) < 300 \text{ GeV}$$

W^+W^- cross sections after cuts:

	no radiation	with ISR	with ISR+BMS
$M_H = 200$ GeV	0.269 fb	0.267 fb	0.280 fb
$M_H = 1000$ GeV	1.061 fb	0.936 fb	0.861 fb
$M_H = \infty$	0.413 fb	0.393 fb	0.390 fb

Effect of selection cuts on ZZ invariant mass distributions





Selection cuts:

$$M_{jj} > 40 \text{ GeV}; \quad M_{ZZ} > 500 \text{ GeV}; \quad p_T(Z) > 150 \text{ GeV}; \quad |\cos\theta_Z| < 0.8;$$

$$M_{recoil} > 200 \text{ GeV}; \quad 20 \text{ GeV} < p_T(ZZ) < 300 \text{ GeV}$$

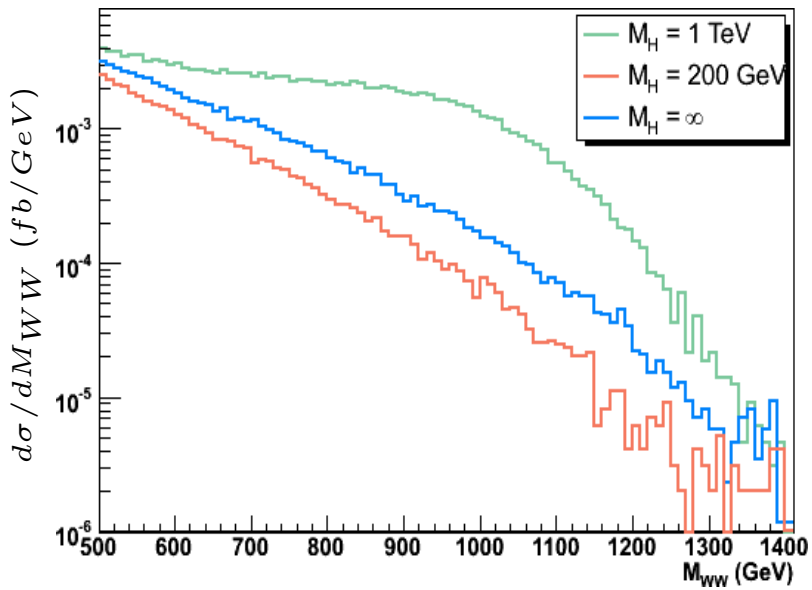
ZZ cross sections after cuts:

	no radiation	with ISR	with ISR+BMS
$M_H = 200$ GeV	0.234 fb	0.217 fb	0.212 fb
$M_H = 1000$ GeV	0.971 fb	0.846 fb	0.760 fb
$M_H = \infty$	0.523 fb	0.459 fb	0.417 fb

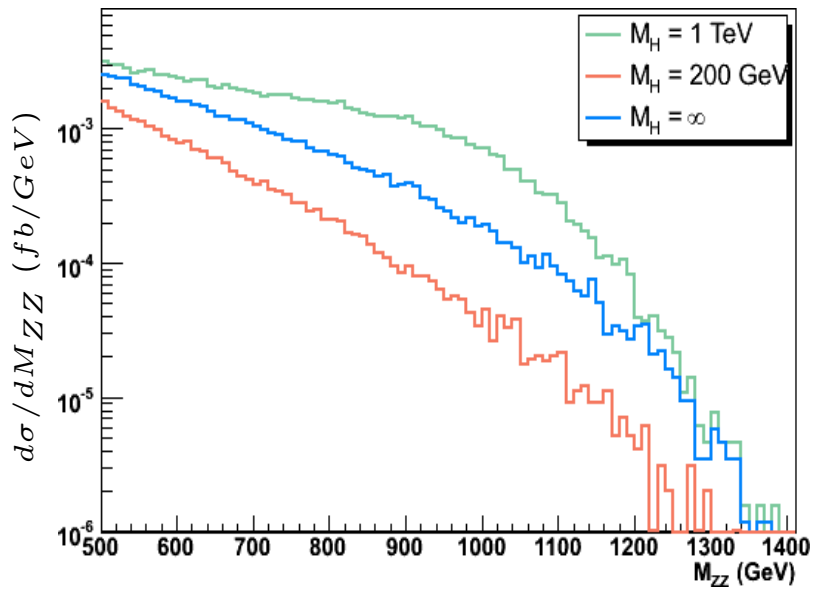
Notice: the previous selection procedure does not ensure a good separation between *light-Higgs* and *no-Higgs* ($M_H \to \infty$) scenarios at high VV invariant masses. Visible effects of non-scattering contributions.

How much is *forward/backward tagging* relevant to suppressing non-scattering contributions?

W^+W^- resonant final states



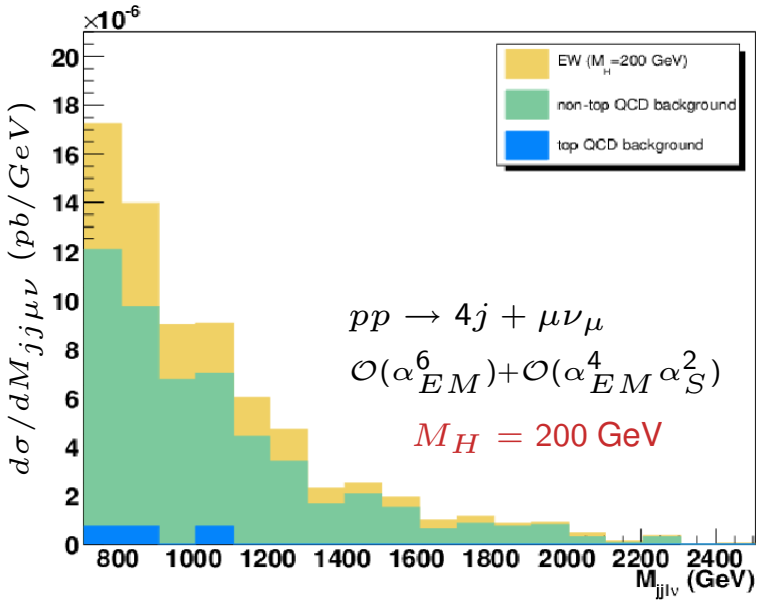
ZZ resonant final states

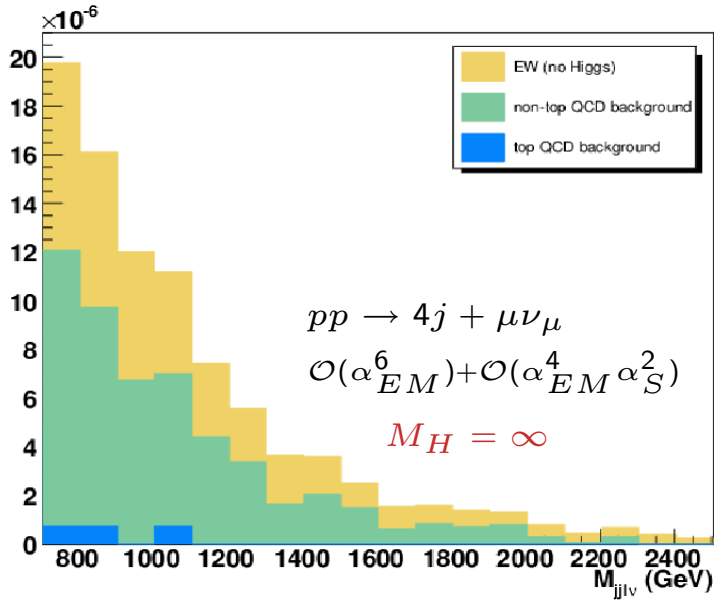


Selection cuts:

$$M_{jj} > 40 \text{ GeV};\ M_{ZZ} > 500 \text{ GeV};\ |\Delta\eta(\nu_e\bar{\nu}_e)| > 3.8;\ |\eta(V)| < 2$$

A comparison with LHC results





A caveat for LHC results: QCD $\mathcal{O}(\alpha^2_{EM}\alpha^4_S)$ background ($V + 4\,jets$) has not been included yet (under study).

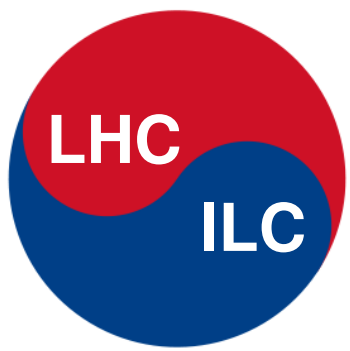
Number of expected events for $M_{VV} > 800$ GeV:

ILC ($\sqrt{s} = 1.5$ TeV) $\mathcal{O}(\alpha^6_{EM})$ $\mathcal{L} = 200$ fb^{-1}		**LHC** $\mathcal{O}(\alpha^6_{EM})$ $\mathcal{L} = 100$ fb^{-1}		**LHC** $\mathcal{O}(\alpha^6_{EM}) + \mathcal{O}(\alpha^4_{EM}\alpha^2_S)$ $\mathcal{L} = 100$ fb^{-1}	
$M_H = 200$	$M_H = \infty$	$M_H = 200$	$M_H = \infty$	$M_H = 200$	$M_H = \infty$
26 ± 5	41 ± 6	145 ± 12	319 ± 18	514 ± 23	761 ± 28

Conclusions

- PHANTOM is the first *dedicated* event generator for six-parton final states at hadron and e^+e^- colliders
- It has features and efficiency competitive with the other six-fermion MC for ILC
- It will be particularly suitable for comparative studies between LHC and ILC physics potential

We have started to use PHANTOM to investigate the sensitivity to strong scattering effects at LHC. We plan to extend our complete studies to ILC with the aim of comparing the reach of the two machines in this field and others connected with 6f physics.



The two colliders yield complementary results
Mutual benefits are envisaged from the physics interplay