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LHeC: probing the HWW vertex

- The WW fusion process at LHC and HWW vertex.
- WW fusion production mechanism at LHeC.
- Probing the new physics contribution to HWW vertex at LHeC.

References:

1) T.Plehn, D.Rainwater and D.Zeppenfeld, PRL **88** (2002) 051801 (LHC : HWW anom. vertex)

2)T. Han and B. Mellado, PRD **D82**, 016009 (2010). [arXiv:0909.2460 [hep-ph]]. (LHeC: $Hb\bar{b}$ coupling.)

3)S. Biswal, R.G., B. Mellado and S. Raychaudhuri, LHeC CDR. (LHeC: HWW anom. vertex.) ArXiv: hep-ph/1203.XXXX

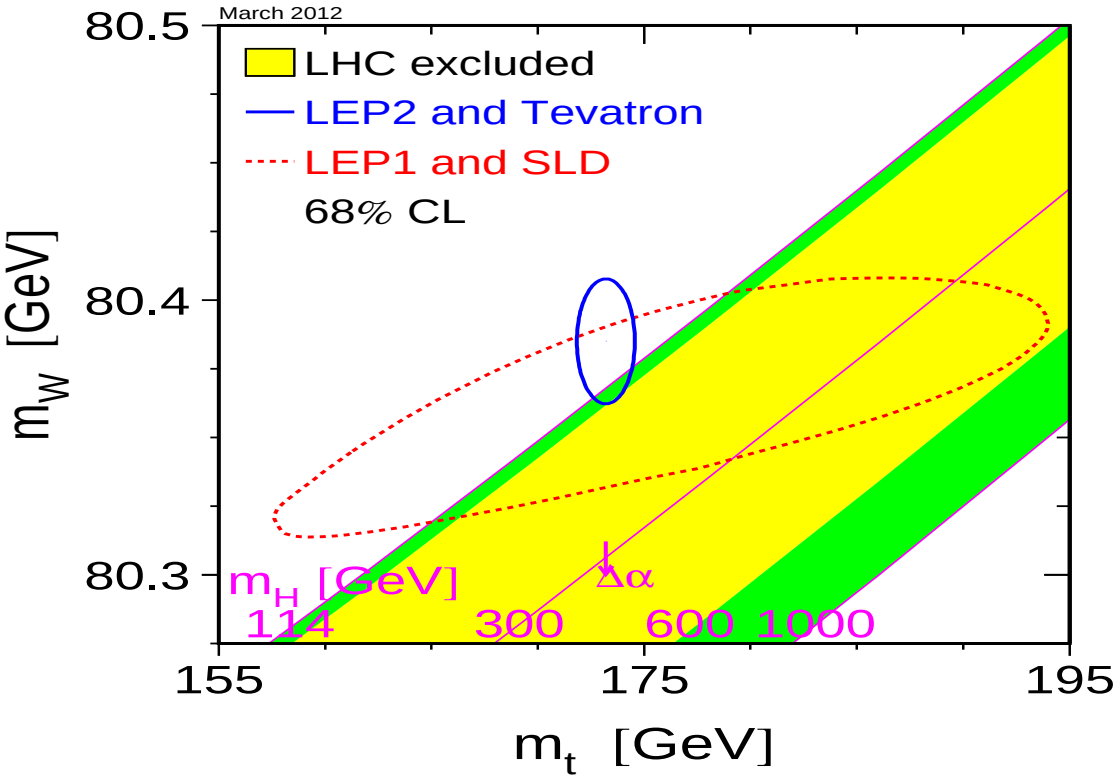
- In SM, the only fundamental neutral scalar is a $J^{PC} = 0^{++}$.

- Various extensions of the SM can have several Higgs bosons with different CP properties : e.g. MSSM has two CP-even and one CP-odd states.

- Therefore, when (and if?) neutral spin-0 particle which looks like a Higgs, is detected, a study of its CP-properties would be essential to establish it as *the* SM Higgs boson.

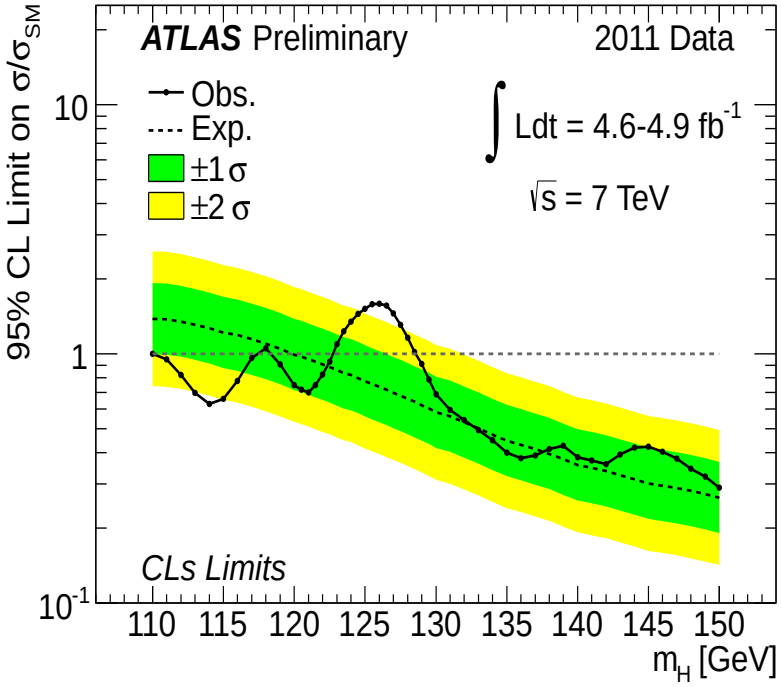
- To study the effects beyond SM, we need to establish the CP eigenvalues for the Higgs states if CP is conserved, and measure the mixing between CP-even and CP-odd states if it is not.

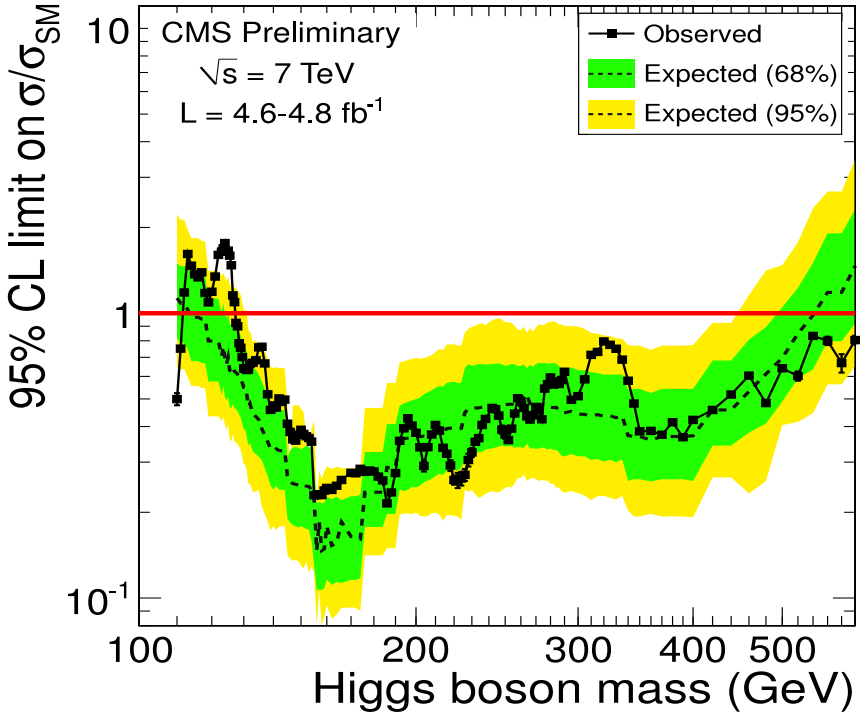
Tevatron: new W mass measurement



SM Higgs pinned to the very narrow range.

ATLAS: ATLAS-CONF-2012-019 , CMS:HIG-12/008





The experiments can not rule out the existence of a Higgs in the same narrow range. Very suggestive..**we need to be patient.**

But many of us start dreaming what after?

Since the BSM has hidden itself very well may be we will have to look for clues about new physics through measurements on the Higgs sector!

One of the most important quantity from the point of EW symmetry breaking to confirm the SM completely: probe VVH coupling.

Higgs Couplings with pair of gauge bosons (ZZ/WW) and the pair of heavy fermions (t/τ) are largest. Study $\not{CP}$ in a model independent way (most studies so far)

$$Hf\bar{f} : -\frac{gm_f}{2M_W}\bar{f}\left(a_f + ib_f\gamma_5\right)fH$$

HVV:

$$V^{\mu\nu}_{HVV} = -ig\left[\, f_1\, g_{\mu\nu} + f_2\,(g_{\mu\nu}k1.k2 - k1_\nu k2_\mu) + f_3\, i\epsilon_{\mu\nu\alpha\beta}\, k_1^\alpha k_2^\beta\,\right],$$

with

$$f1 = mW/2m_H, f2 = \lambda/m_W, f3 = \lambda'/m_W$$

Many studies possible at the ILC: CPNSH report: hep-ph/0608079.

Studies with $t\bar{t}H$ process gives unambiguous information at the ILC (For example: P. S. Bhupal Dev, A. Djouadi, R. M. Godbole, M. M. Muhlleitner and S. D. Rindani, Phys. Rev. Lett. **100**, 051801, 2008)

Studies at the LHC with $H \to ZZ$ and $H \to WW$ (For example: R. M. Godbole, D. J. Miller and M. M. Muhlleitner, JHEP **0712**, 031 (2007) [arXiv:0708.0458 [hep-ph]].)

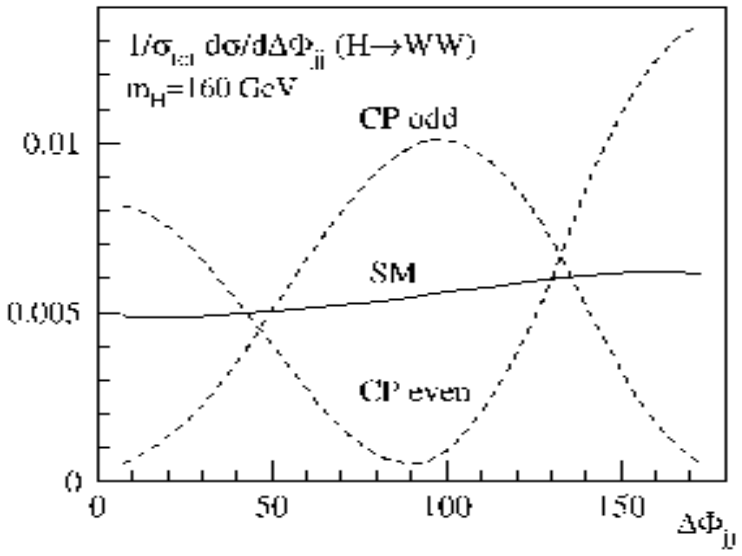
Our observation: With $\sim$ 125 GeV Higgs, width measurements can give 2d limits. Separation of CP even and CP odd cases, a more than demanding task!

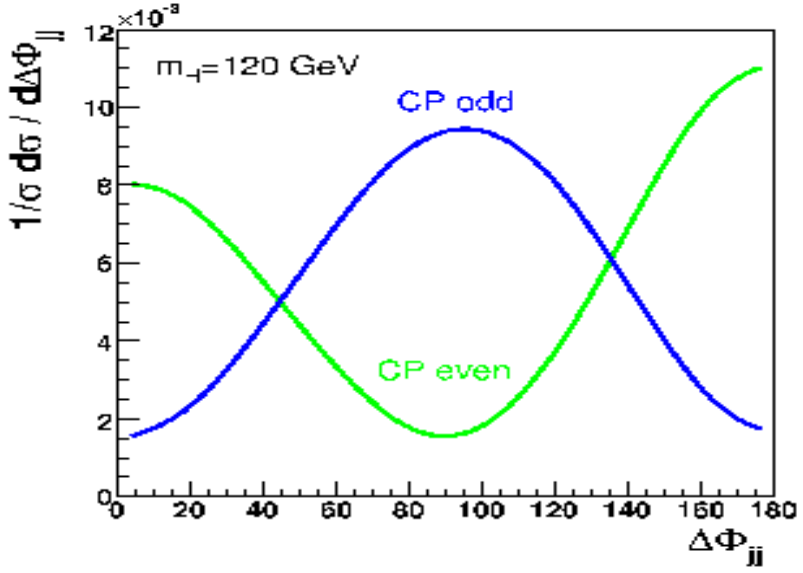
For a light Higgs at the LHC :

a)$t\bar{t}H$: Requires 14 TeV and 100 to 200 fb^{-1}. Demanding.

b) A good chance offered by a study of Higgs + 2 jets: VBF, Gluon Fusion (just today 1203.5788)

Study by Zeppenfeld et al:

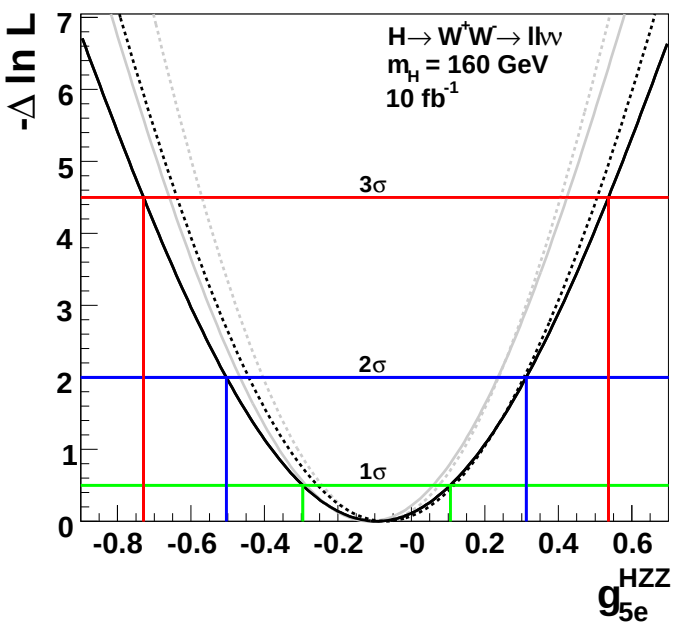


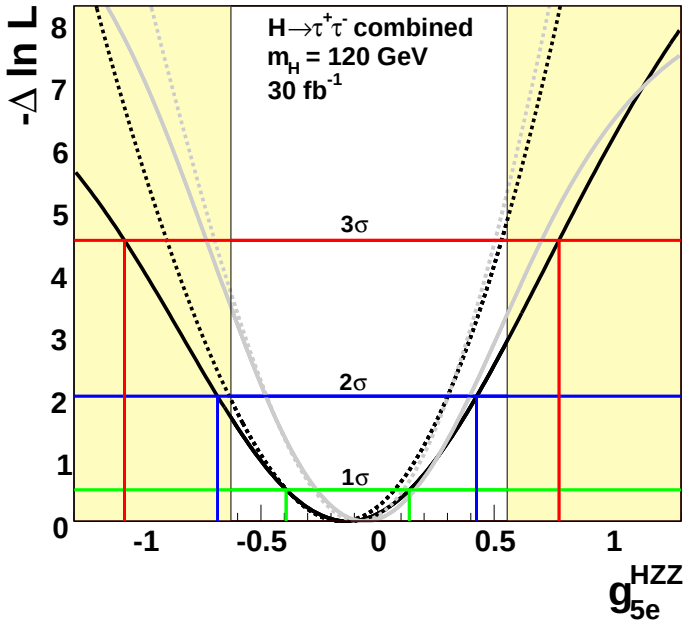


Left plot: VBF, CP even and CP odd refer to the dimension 5 operator.

For gluon fusion the angular distribution is decided by the CP property of the $t\bar{t}H$ coupling.

VBF can probe the anomalous ZZH 5 dimensional vertex. With 10 fb^{-1} one can find good evidence for a purely anomalous CP even or CP odd operators. With 30 fb^{-1} good sensitivity to rule out. The limits on CP even and CP odd operators are corrleated.





One can probe the additional couplings only upto moderate values, independent of H mass. C. Ruwiedel et al, EPJC 51 (2007) 385

Few Comments:

For CP odd Higgs the BR into $b\bar{b}$ is largest.

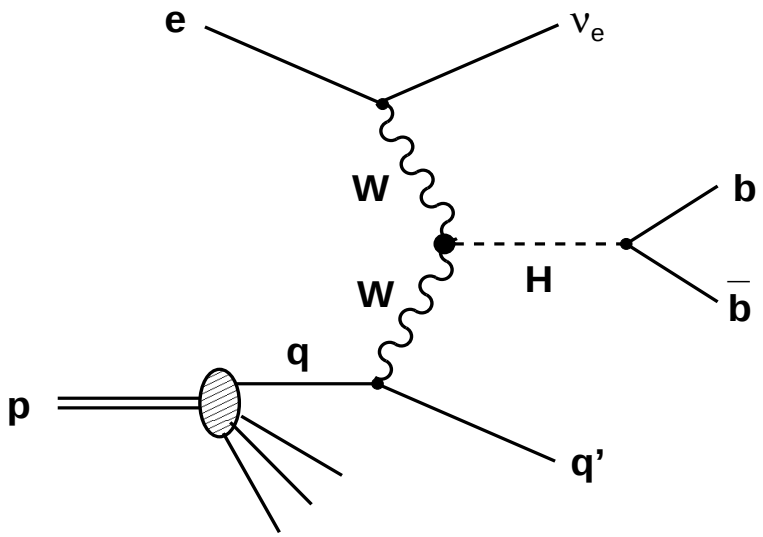
At LHC, For lighter Higgs one needs to use $\tau\tau$ decay mode. The left plot is for WW decay mode and right for $\tau\tau$ decay mode. If the indications are right we are looking at a light higgs! So only left plot is relevant.

If one could use the $b\bar{b}$ mode things would be different.

Han and Mellado: T. Han and B. Mellado, Phys. Rev. **D82**, 016009 (2010

They have studied and shown how at the LHeC one can study the production of Higgs throught WW fusion process to good effect to study $Hb\bar{b}$ coupling.

In fact some of us (RG) had studied this in the inverse reaction (ν induced CC production) for a Higgs mass of < 3–4 GeV ☺ RG, PRD **18**, 95 (1978)



Idea in present study:

What is the potential of LHeC to study the new physics contribution due to the higher dimensional operators and probe whether it is CP conserving or CP violating.Expect improvement, particularly for the latter, due to possible use of large $b\bar{b}$ rates.

What do we know from Mellado-Han study:

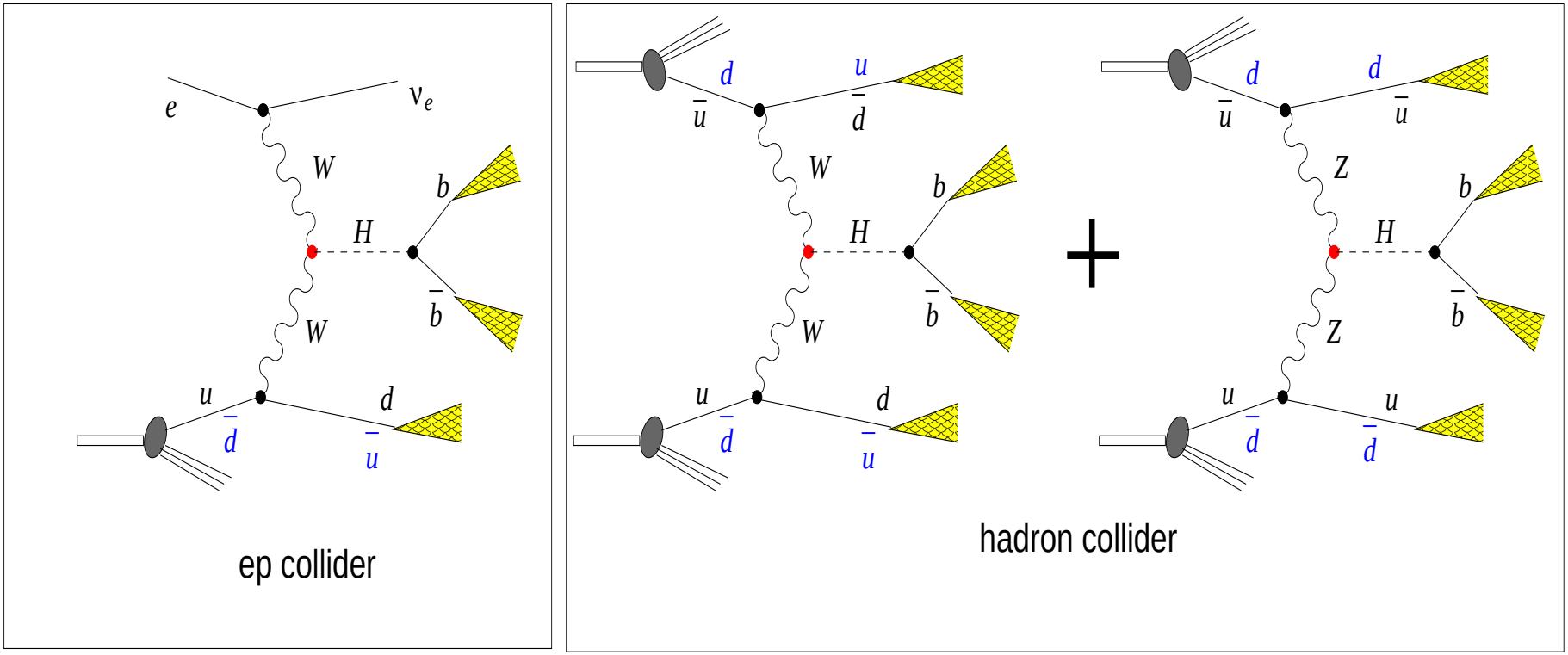
There exist two processes:

$e + p \to \nu + Higgs + jet + X$ (CC) and $e + p \to e + Higgs + jet + X$ (NC).

Charged current(CC) and Neutral current(NC) separation possible

Studied further by U. Klein

higgs + 2jets: VBF (LHC), higgs + jet + missing E_T (LHeC)

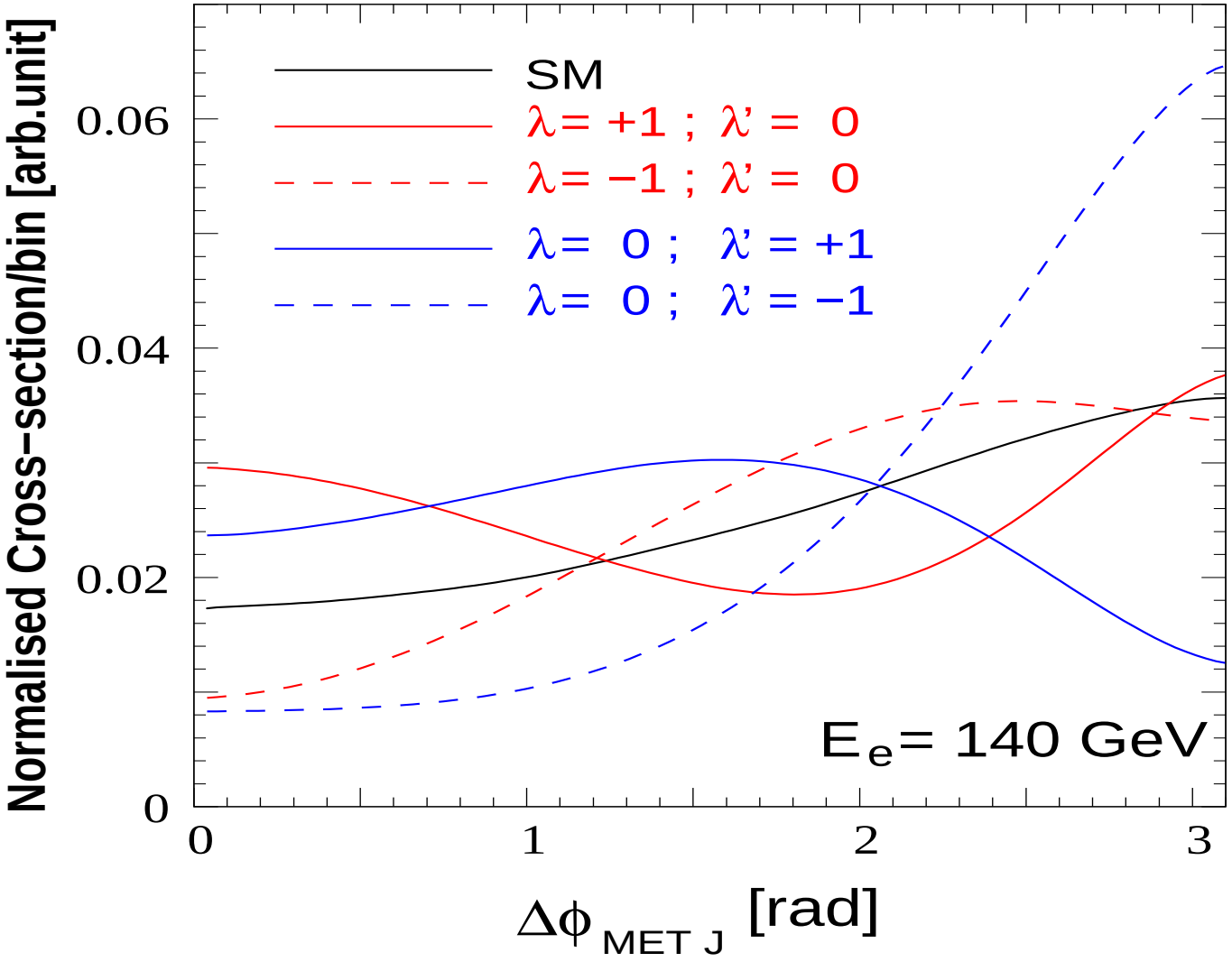


ep process uniquely addresses the HWW vertex.

At the e^+e^- colliders also a clean separation of effects of the anom. HWW vertex, independent of those from HZZ vertex in the H production via VV fusion not possible. (for example, S. Biswal, D. Choudhury, R.G., Mamta, PRD **79**, 035012 (2009), [arXiv:0809.0202 [hep-ph]])

In LHeC CC processes offer the chance of probing WW vertex by itself.

Opens up the possibility of using the large branching ratio $b\bar{b}$.


SM
λ= +1 ; λ' = 0
λ= −1 ; λ' = 0
λ= 0 ; λ' = +1
λ= 0 ; λ' = −1
E_e= 140 GeV
Normalised Cross−section/bin [arb.unit]
0
0.02
0.04
0.06
0
1
2
3
Δφ MET J [rad]

The behaviour very similar to that seen for pp. So the disribution can look at CP property of the Higgs cleanly.

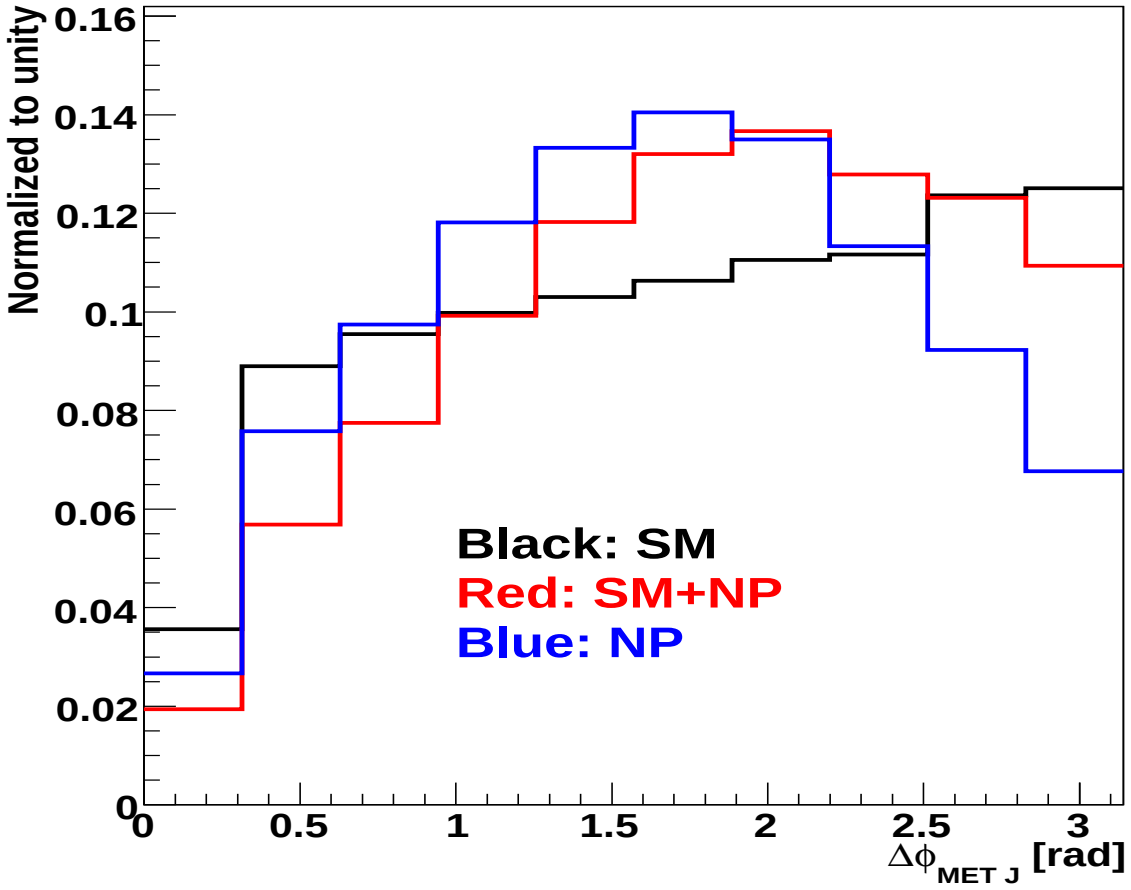
This behaviour essentially follows from the behaviour of matrix element square.

In LHC studies, the modification in the ϕ distribution (dips and peaks) were used with VBF specific cuts. We see that the structure is there even w/out those cuts.

Further no ambiguity about sign of ϕ.

At LHeC the entire range of ϕ is available.

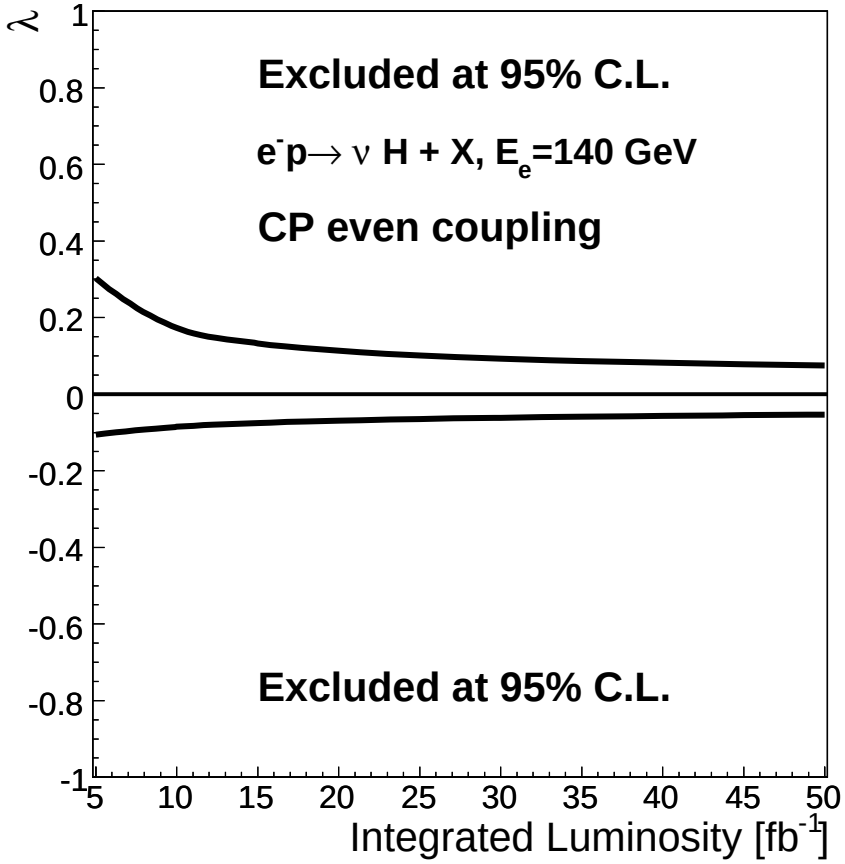
What happens with cuts and reality?

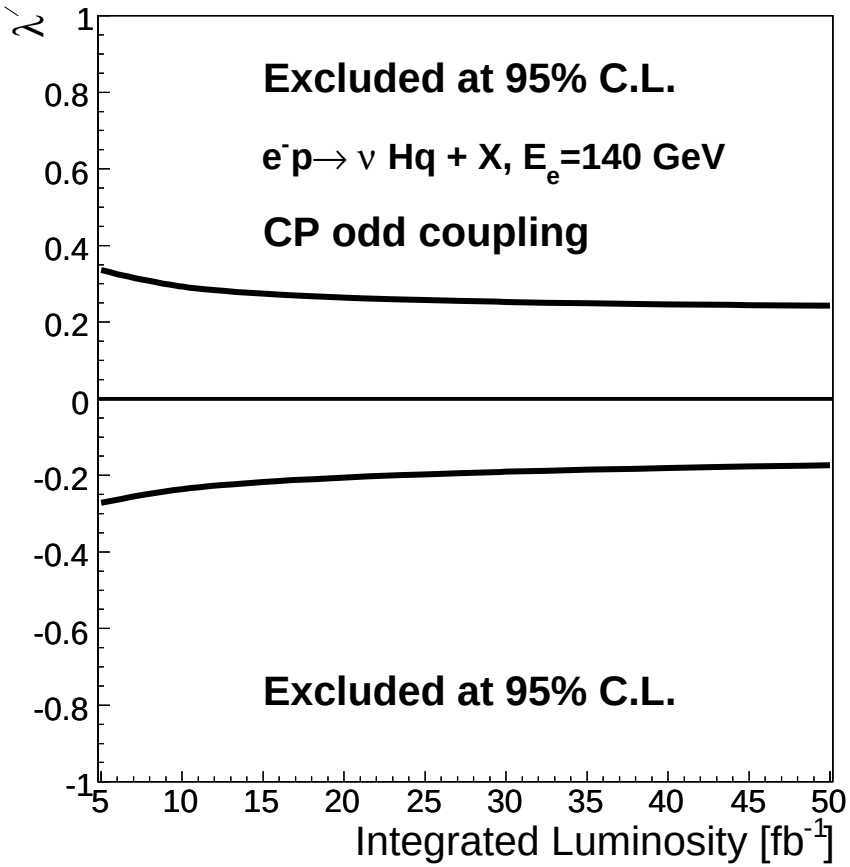


Everything put together: Things look interesting.

Results on the sensitivity with updated background as per the simulations of U. Klein (DIS 2011)

URL: http://www.ep.ph.bham.ac.uk/exp/LHeC/talks/DIS11.Klein2.pdf





Cuts used same as Han-Mellado analysis:

1. All 3 jets have $p_T > 30$ GeV.

2. b-tagged jets must have $|\eta| < 2.5$

3. remaining jet must have $1 < |\eta| < 5$

4. inv. mass of remaining jet and reconstructed Higgs > 250 GeV (at parton level, just the 3-jet invariant mass)

5. MET > 25 GeV

6. $\Delta\phi$ between reconstructed MET and each jets > 0.2.

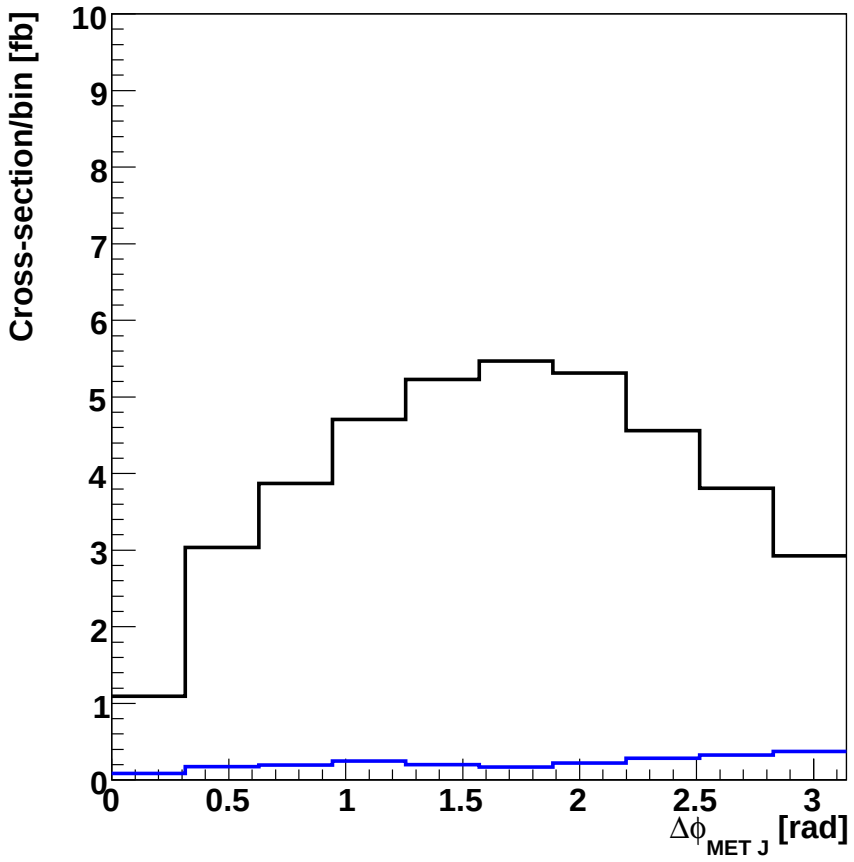
Interesting possiblity offered by LHeC for studying the anom. HWW vertex, unambiguously, with the $b\bar{b}$ final state.

Note that separation of HZZ contamination of the HWW vertex is difficult even for the ILC! Needs longitudinal and transverse polarisation.

For the LHC this separation not possible even in principle.

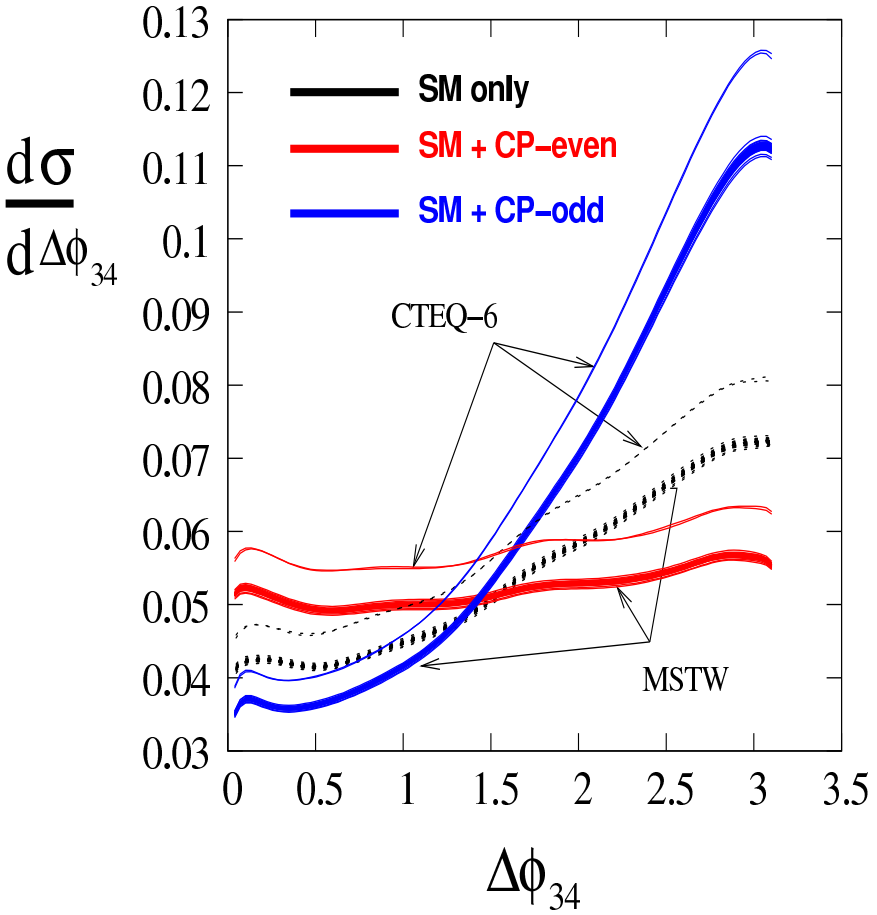
This is quite a unique feature!

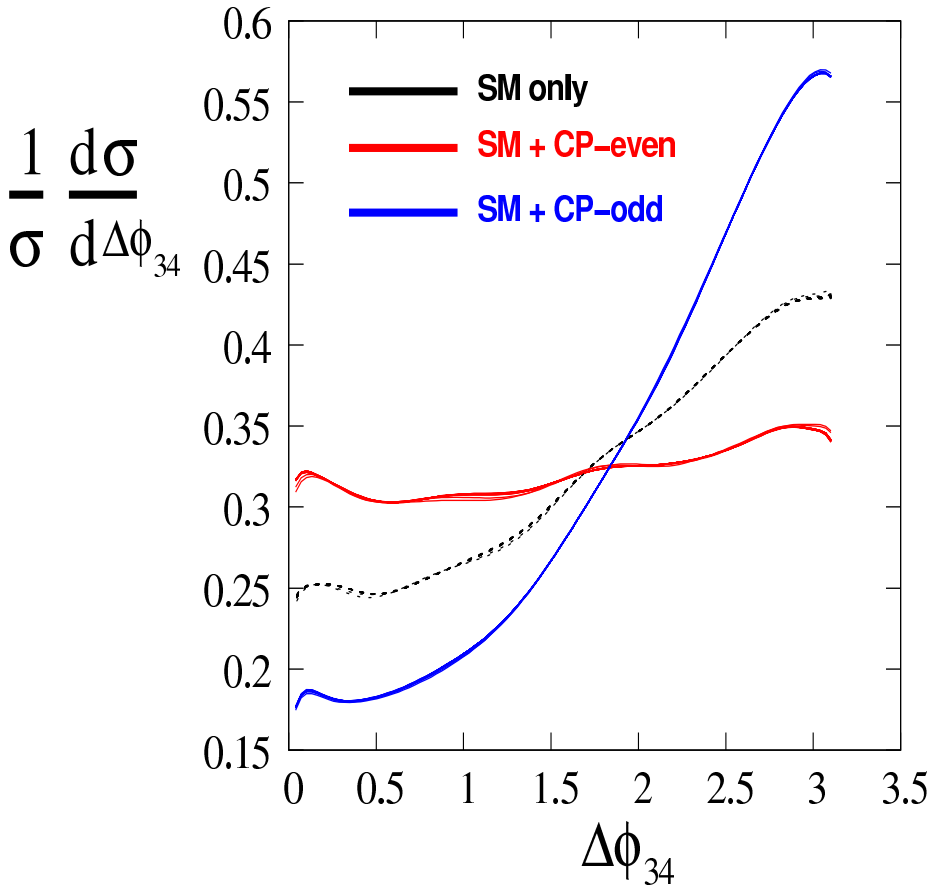
BACKUP SLIDES



So the bkgd is small, as seen in Han-Mellado study as well.

This was our original study. In the results presented here background is updated as per the simulations of U. Klein (DIS 2011)a


dσ/dΔφ34
SM only
SM + CP–even
SM + CP–odd
CTEQ–6
MSTW
0.13
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0
0.5
1
1.5
2
2.5
3
3.5
Δφ34


1/σ dσ/dΔφ34
SM only
SM + CP–even
SM + CP–odd
0.6
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0
0.5
1
1.5
2
2.5
3
3.5
Δφ34