LHeC: probing the HWW vertex

- The WW fusion process at LHC and HVV 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, In prepration. (LHeC: HWW anom. vertex.)

- 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, should a neutral spin-0 particle be 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.

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)

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

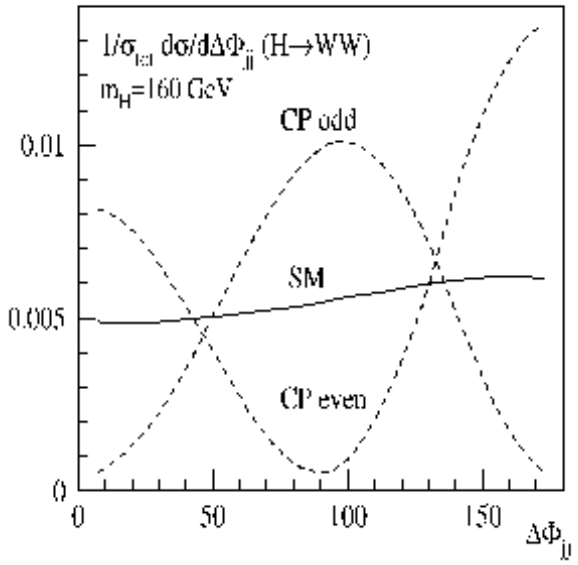
HVV:

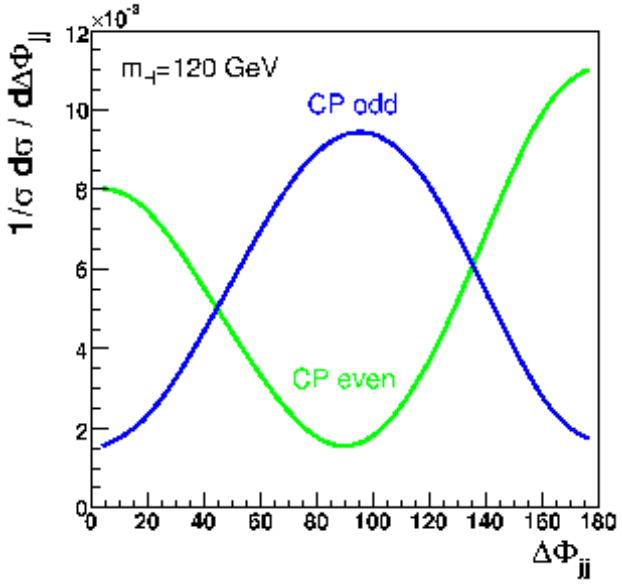
$$V^{\mu\nu}_{HVV} = -ig\left[\, f_1\, g_{\mu\nu} + f_2\,(g_{\mu\nu}k1.k2 - k1_\nu k2_\mu) + f_3\, i\epsilon_{\mu\nu\alpha\beta}\, k_1^\alpha k_2^\beta \,\right],$$

with

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

LHC study, Higgs + 2 jets: VBF, Gluon Fusion

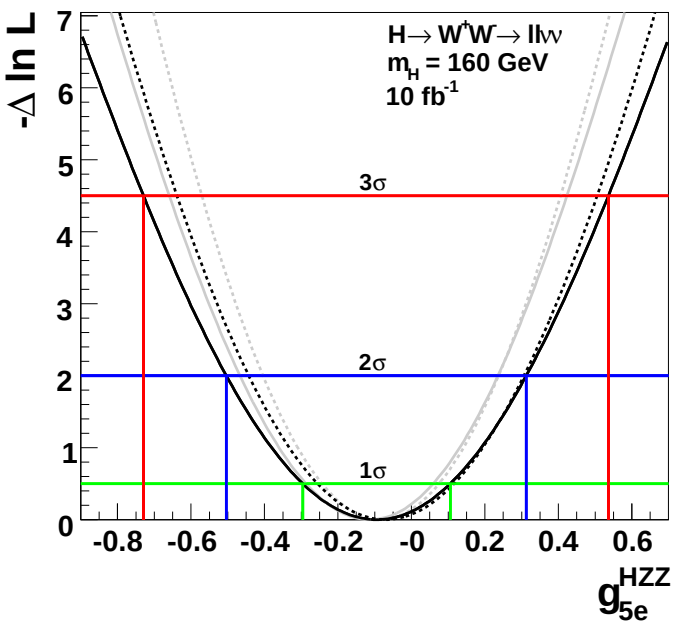


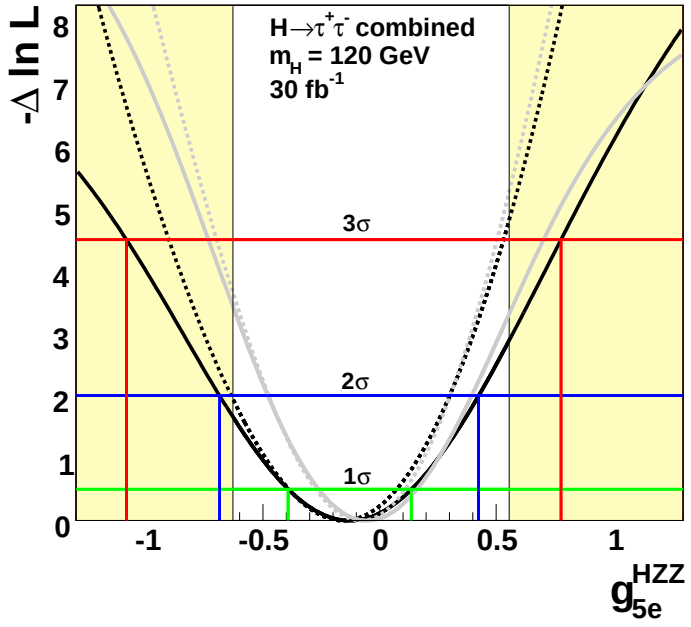


Left plot: VBF, CP even and CP odd refer to the dimension 5 operator.

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.

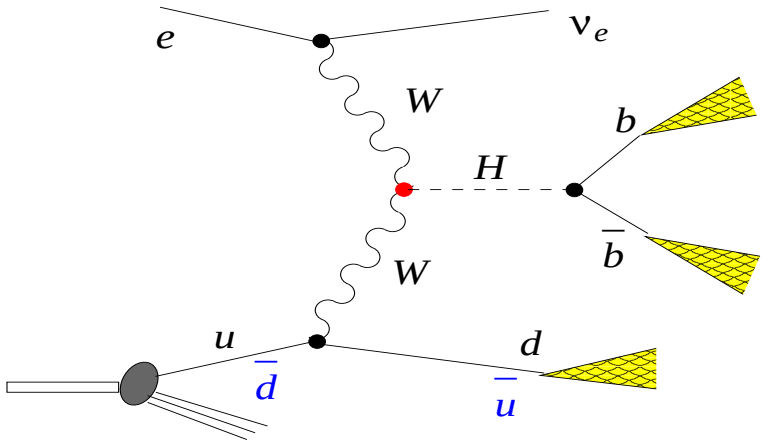
At LHC, For lighter Higgs one needs to use $\tau\tau$ decay mode. and for heavier Higgs, WW decay mode. The BR for the latter, for a CP odd Higgs is very small. The left plot is for WW decay mode and right for $\tau\tau$ decay mode.

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

Han and Mellado:

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)



ep collider

Idea in present study:

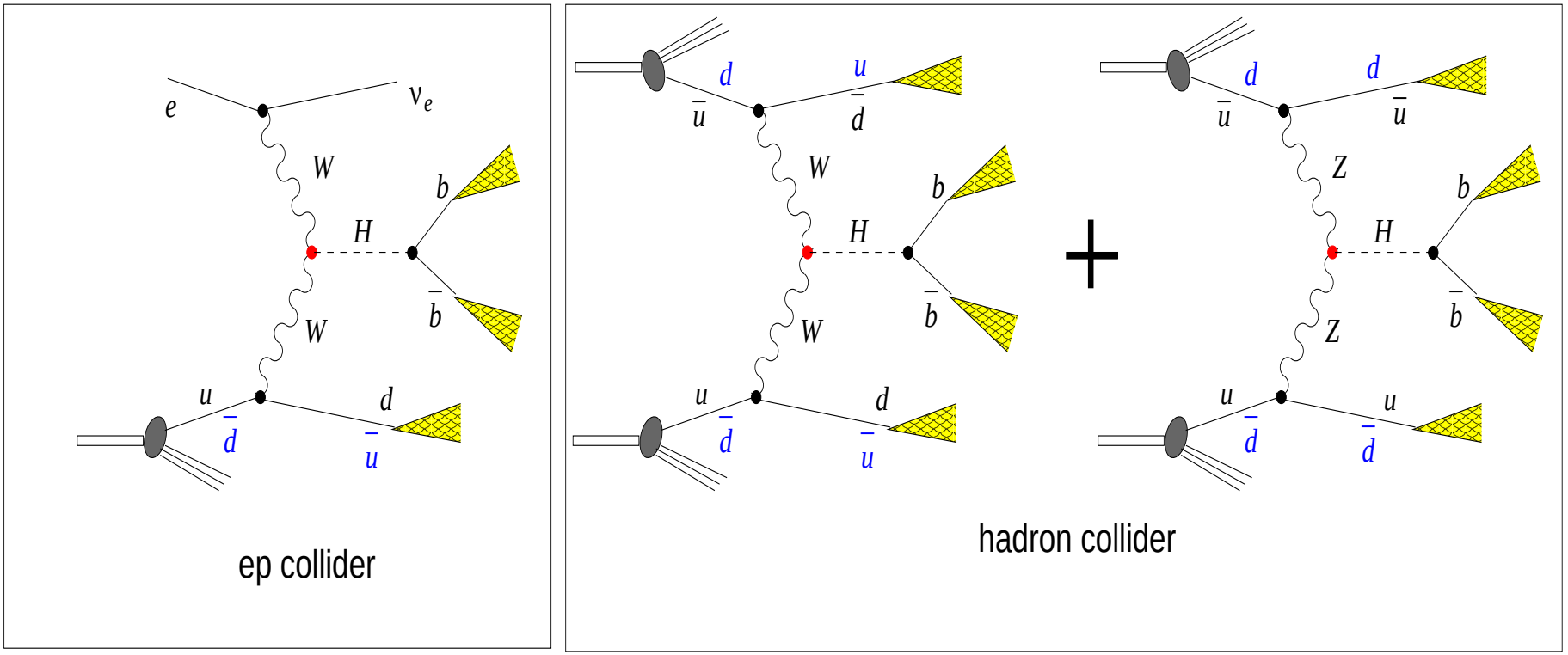
What is the potential of LHeC to study the new physics contribution due to the higher dimensional operators and probe whether it is CP conserving or CP violating. Expect improvement, particularly for the latter, due to possible use of large $b\bar{b}$ rates.

What do we know from Mellado-Han study:

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

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

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

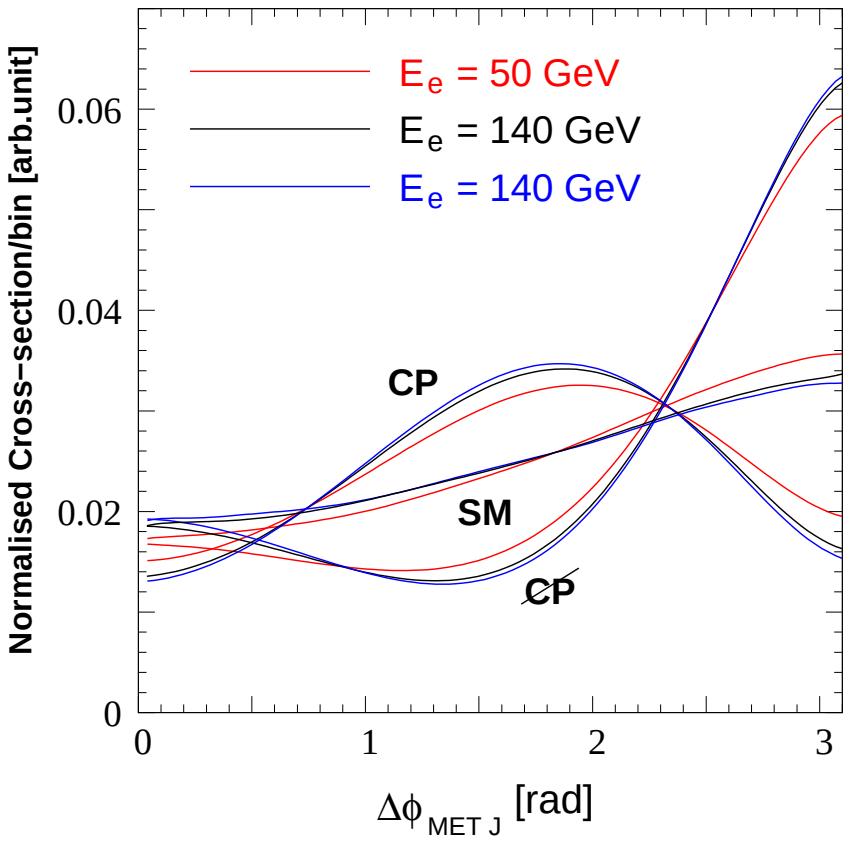


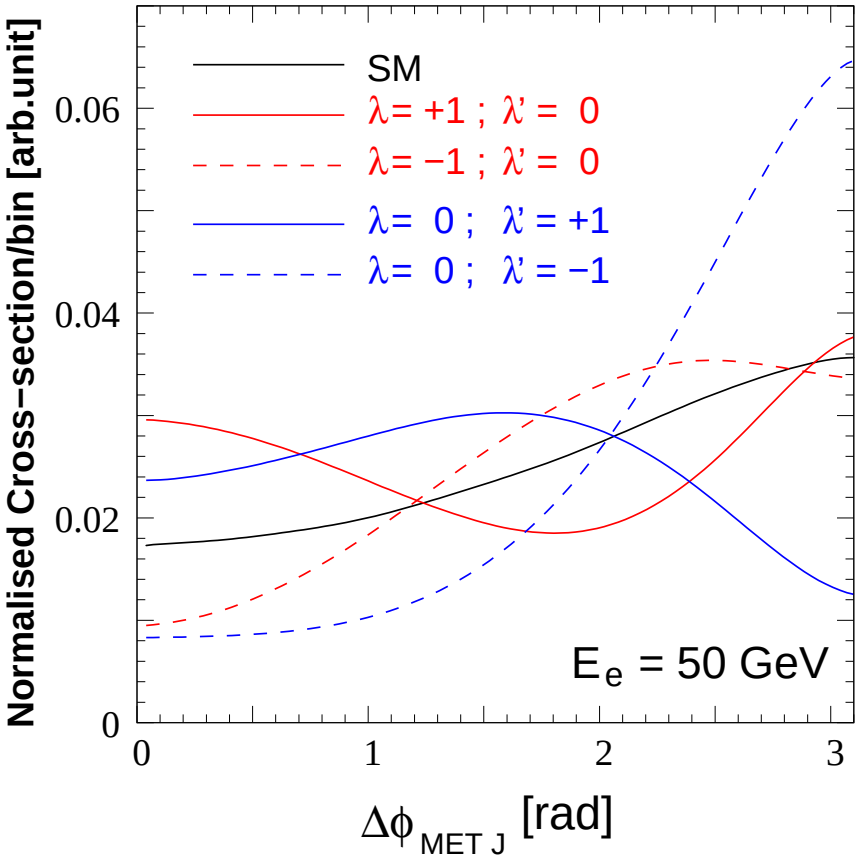
ep process uniquely addresses the HWW vertex.

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, 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 $b\bar{b}$. Even for heavy Higgs if the Higgs is mostly CP odd, then WW final state BR is small.


Normalised Cross−section/bin [arb.unit]
0.06
0.04
0.02
0
0
1
2
3
$\Delta\phi_{\mathrm{MET\,J}}$ [rad]
E_e = 50 GeV
E_e = 140 GeV
E_e = 140 GeV
CP
SM
CP


Normalised Cross−section/bin [arb.unit]
0.06
0.04
0.02
0
0
1
2
3
$\Delta\phi_{\mathrm{MET\,J}}$ [rad]
SM
λ= +1 ; λ' = 0
λ= −1 ; λ' = 0
λ= 0 ; λ' = +1
λ= 0 ; λ' = −1
E_e = 50 GeV

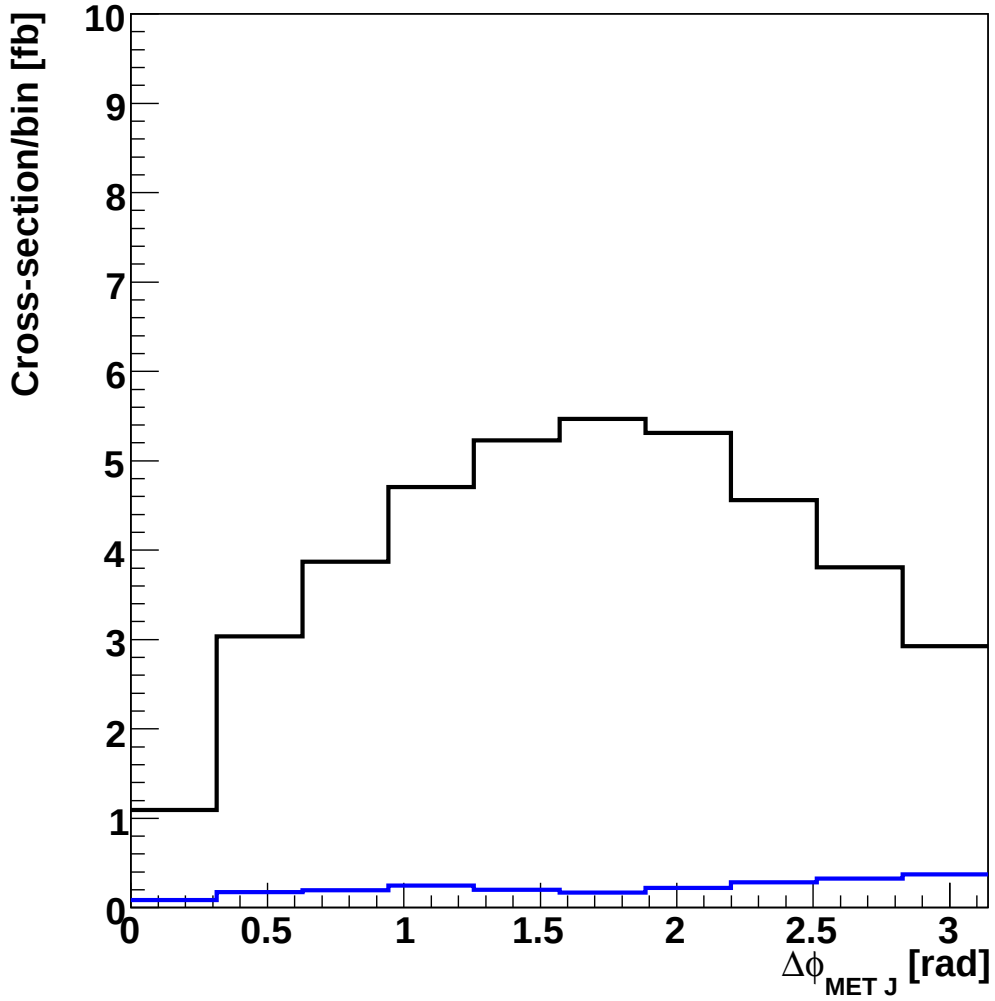
The behaviour very similar to that seen for pp. So the disribution can look at CP property of the Higgs cleanly.

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

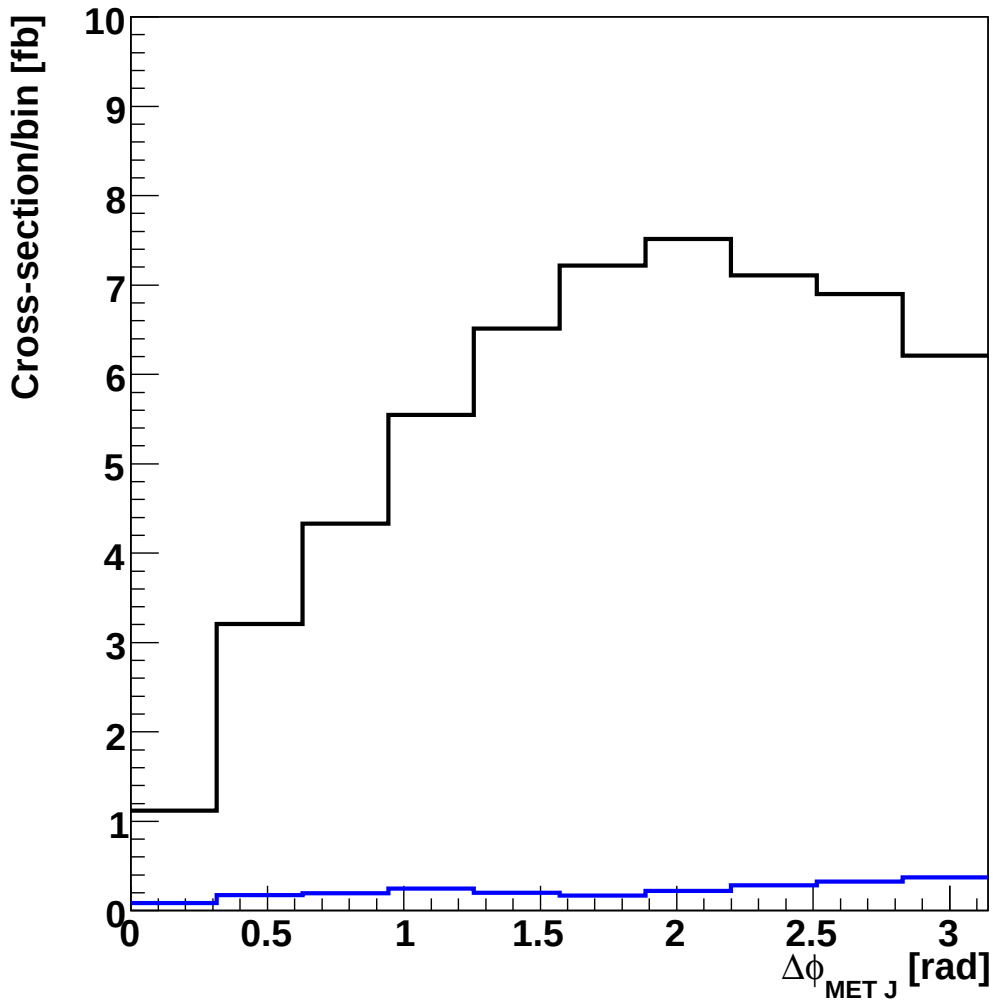
In LHC studies, the modification in the ϕ distribution (dips and peaks) were used with VBF specific cuts. We see that the structure is there even w/out those cuts.

Further no ambiguity about sign of ϕ.

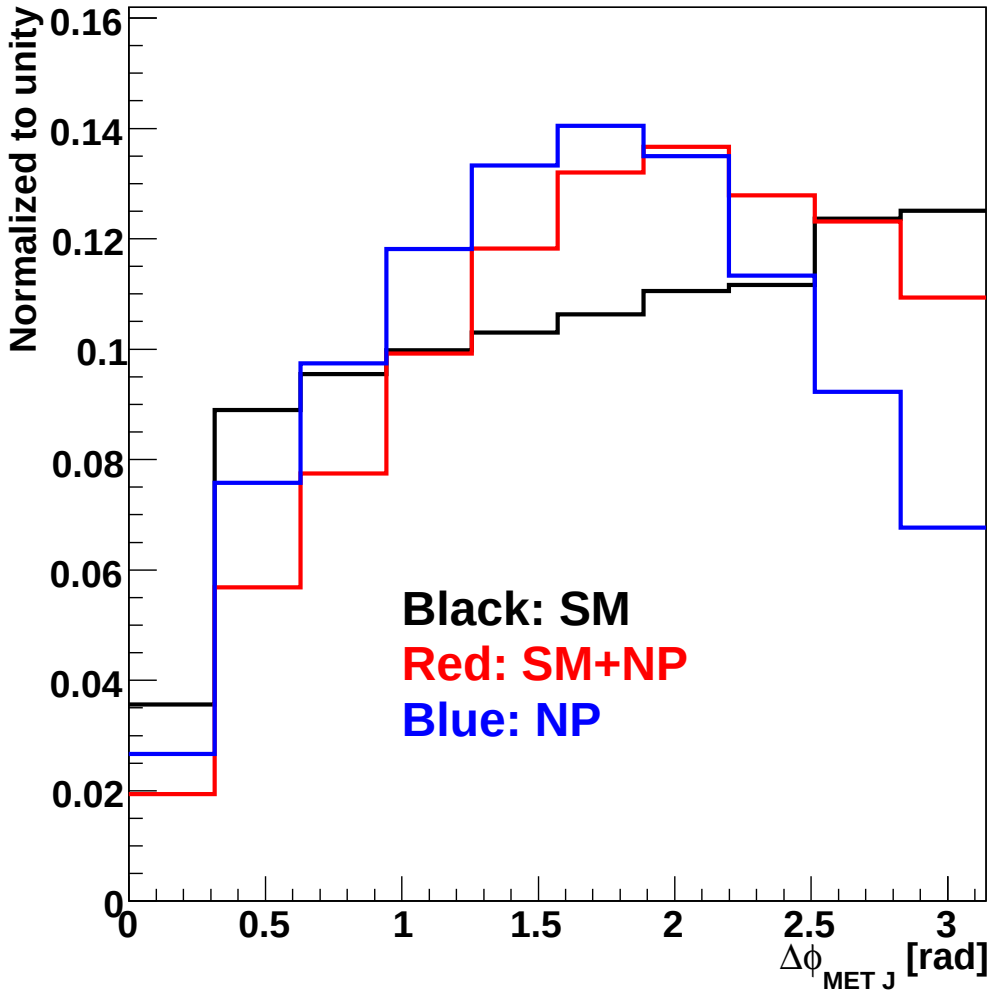
What happens with cuts and reality?



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



CP odd NP + SM this time

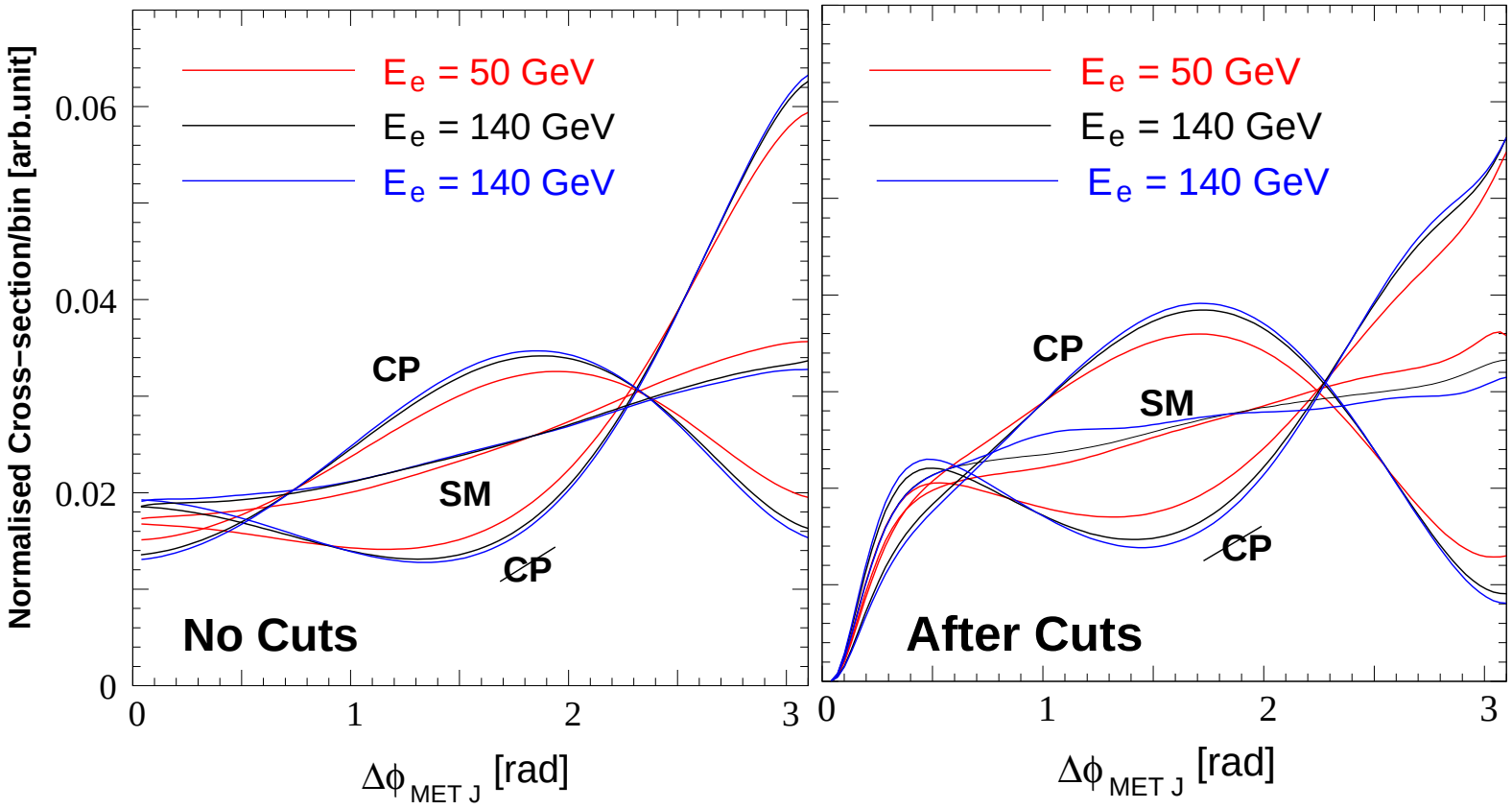


Everything put together: Things look interesting. (CP odd case)

Interesting possiblity offered by LHeC for studying the CP odd case, with the $b\bar{b}$ final state.

Study of sensitivity, with realistic values of λ', λ is on.

Backup, PURE PHENO Plots.


Normalised Cross−section/bin [arb.unit]
0.06
0.04
0.02
0
E_e = 50 GeV
E_e = 140 GeV
E_e = 140 GeV
CP
SM
CP
No Cuts
0
1
2
3
Δφ MET J [rad]
E_e = 50 GeV
E_e = 140 GeV
E_e = 140 GeV
CP
SM
CP
After Cuts
0
1
2
3
Δφ MET J [rad]

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.