Higgs CP properties and the LHeC

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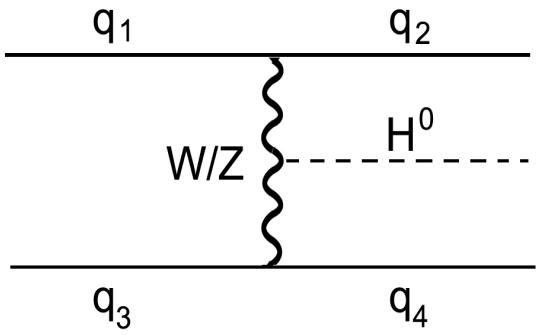
Workshop on the LHeC

Chavannes-de-Bogis, 01-03/09/09

Introduction

- Extensive feasibility studies indicate that the observation of the SM Higgs boson at the LHC will be possible with 1-20 fb^{-1} of integrated luminosity in the entire range of search (M_H=115-1 TeV)
- Once the Higgs is observed emphasis will move towards measuring cross-sections and couplings
- The gg→H production is an indirect test of the Htt coupling and the HTT coupling is reachable.
- The measurement of Hbb coupling is a crucial aspect, but is challenging at the LHC
  - ttH(→bb) and WH(→bb) have been investigated
- Emphasized the use of forward jet tagging for the isolation of the H→bb signal at the LHeC and with this make an attempt at exploring the CP properties of the HVV couplings

Higgs via VBF
Qualitative remarks



$$\sigma(fa \to f'X) \approx \int dx dp_T^2 P_{V/f}(x, p_T^2)\sigma(Va \to X)$$

$$P_{V/f}^T(x, p_T^2) = \frac{g_V^2 + g_V^2}{8\pi^2}\frac{1+(1-x)^2}{x}\frac{p_T^2}{(p_T^2+(1-x)M_V^2)^2}$$

$$P_{V/f}^L(x, p_T^2) = \frac{g_V^2 + g_V^2}{4\pi^2}\frac{1-x}{x}\frac{(1-x)M_V^2}{(p_T^2+(1-x)M_V^2)^2}.$$

- **Unlike QCD partons that scale like $1/P_T^2$, here $P_T \sim \sqrt{(1-x)}M_W$**

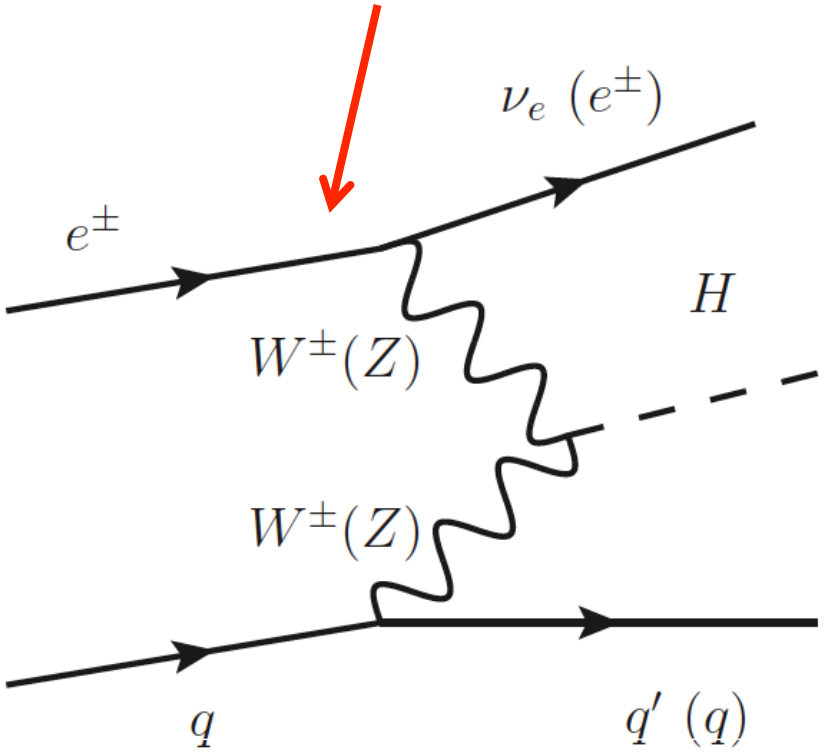
- **Due to the 1/x behavior of the Weak boson the outgoing parton energy (1-x)E is large → forward jets**
- **At high P_T** $P_{V/f}^T \sim 1/p_T^2$ and $P_{V/f}^L \sim 1/p_T^4$

- **Contribution from longitudinally polarized Weak bosons is suppressed (Higgs couples to longitudinally polarized WB)**

Higgs at LHeC

At LHC replace
Lepton line by quark line

- It is remarkable that VBF diagrams were calculated for lepton nucleon collusions before for pp!
  - T.Han was involved in first calculations and a lot of the phenomenology for pp
- Consider feasibility for the following point:

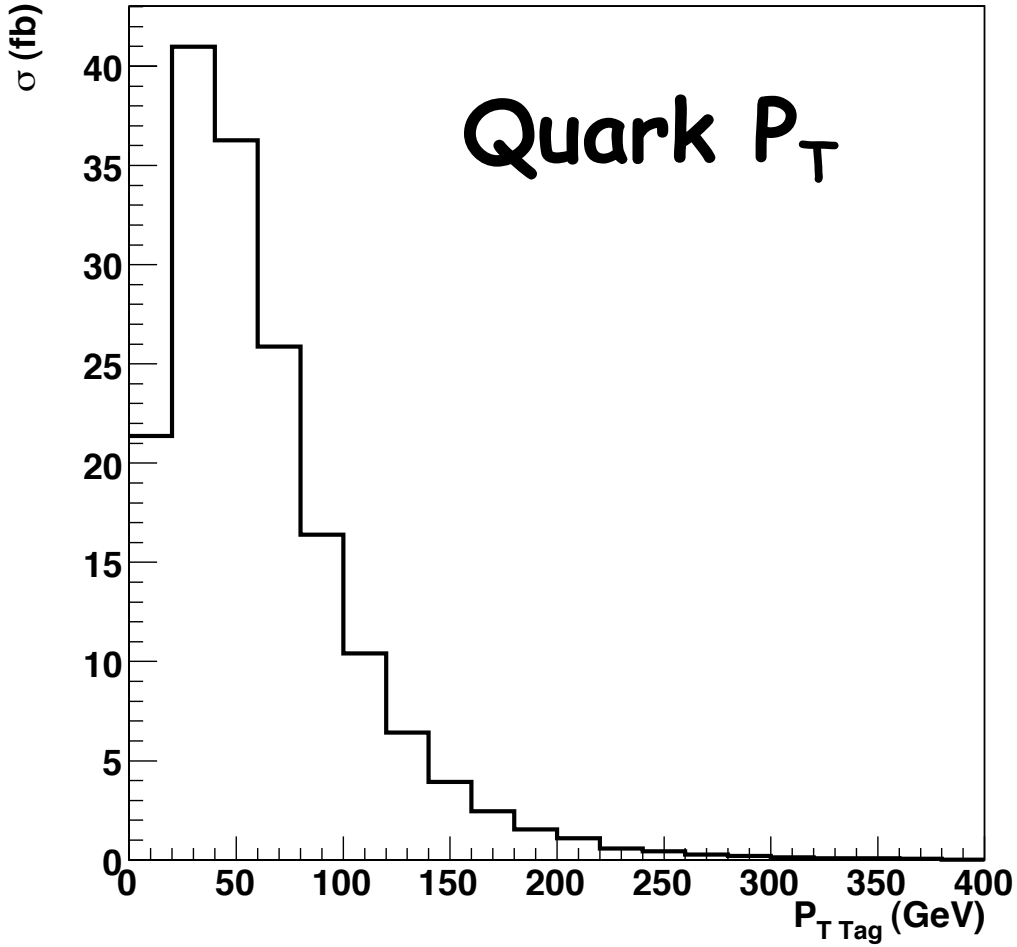


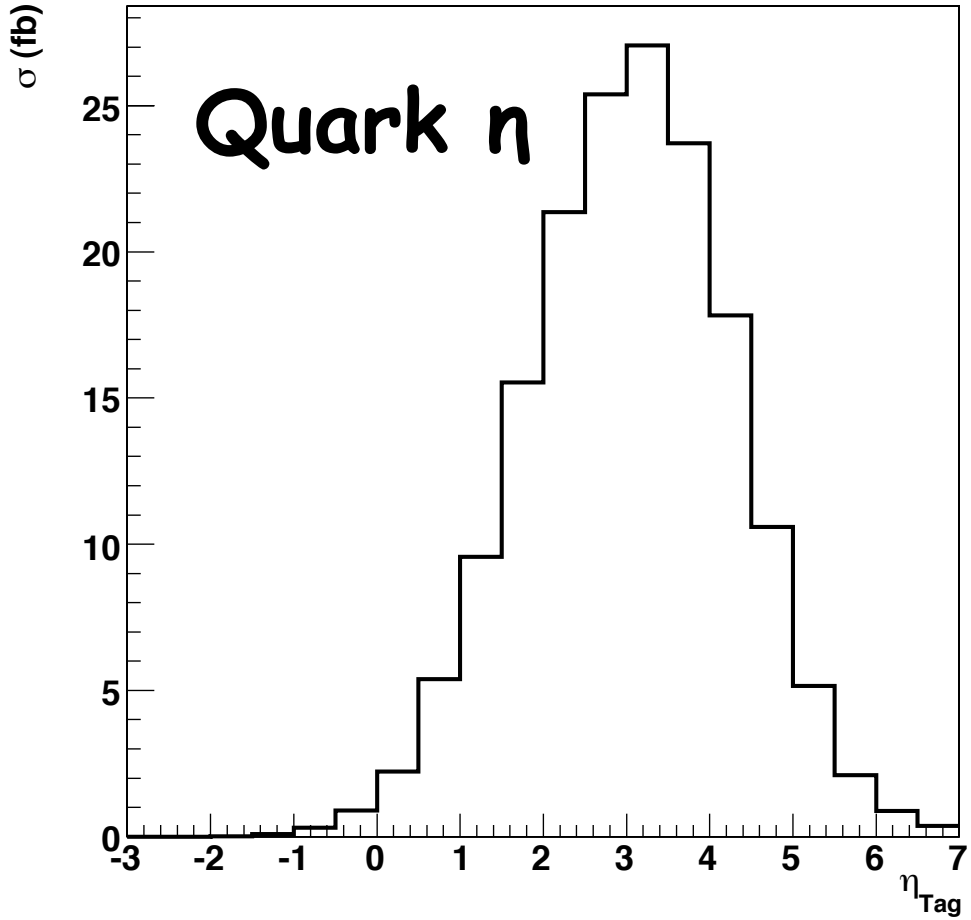
$$E_p = 7 \ \text{TeV}, \quad E_e = 140 \ \text{GeV}, \quad M_H = 120 \ \text{GeV}$$

Forward Jet Kinematics

T.Han, B.M. Phys.Rev. D82 (2010) 016009

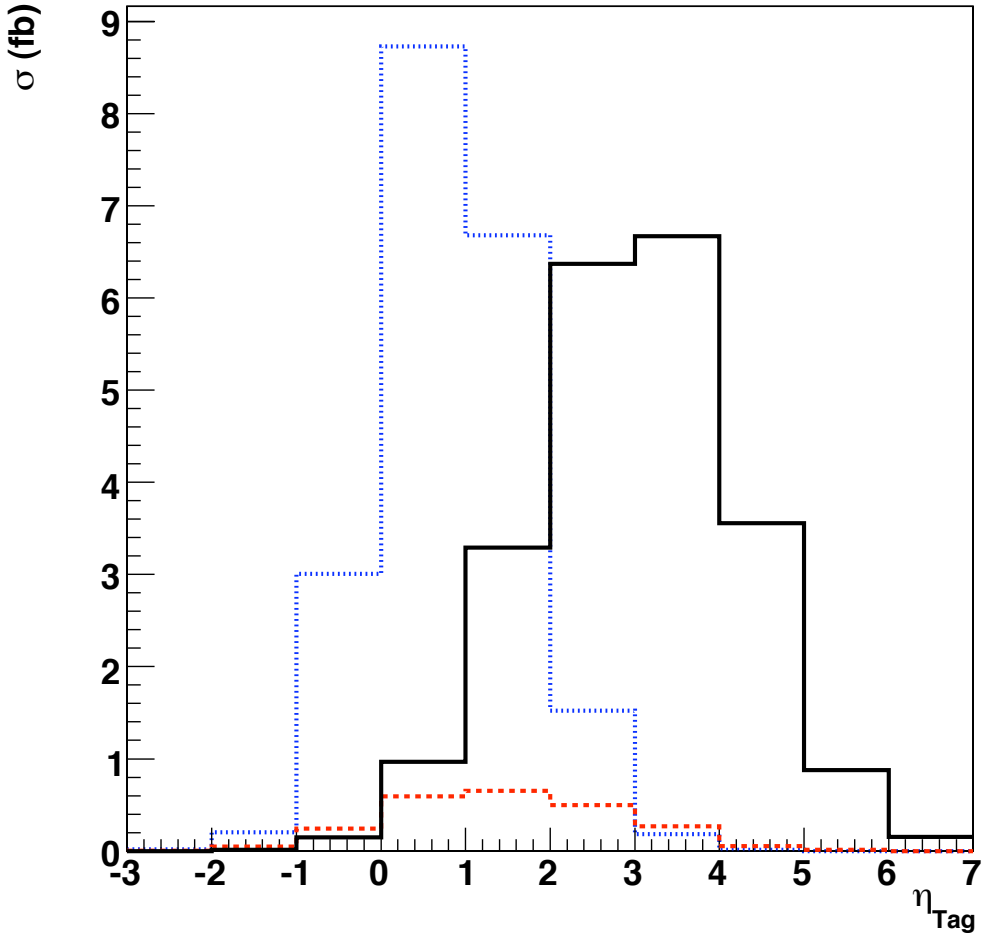
See Masaki Ishitsuka et al. for complete analysis

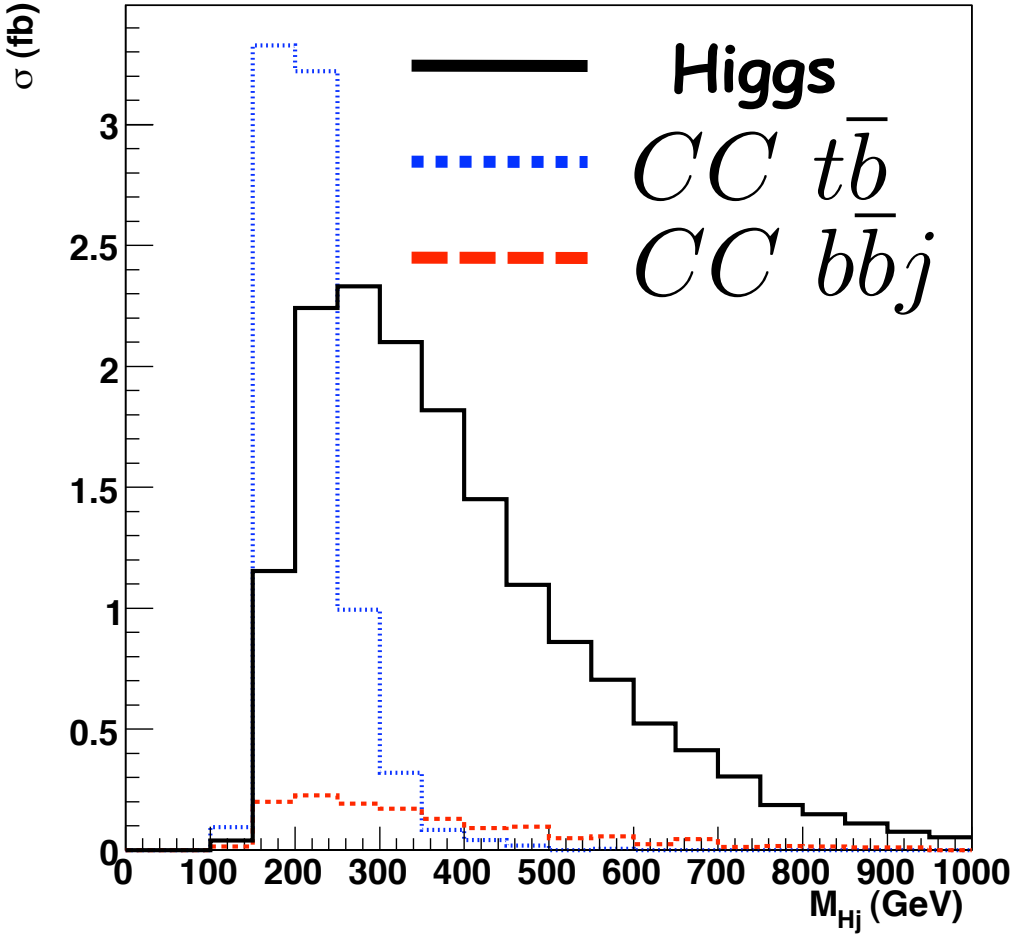




Forward Jet Kinematics

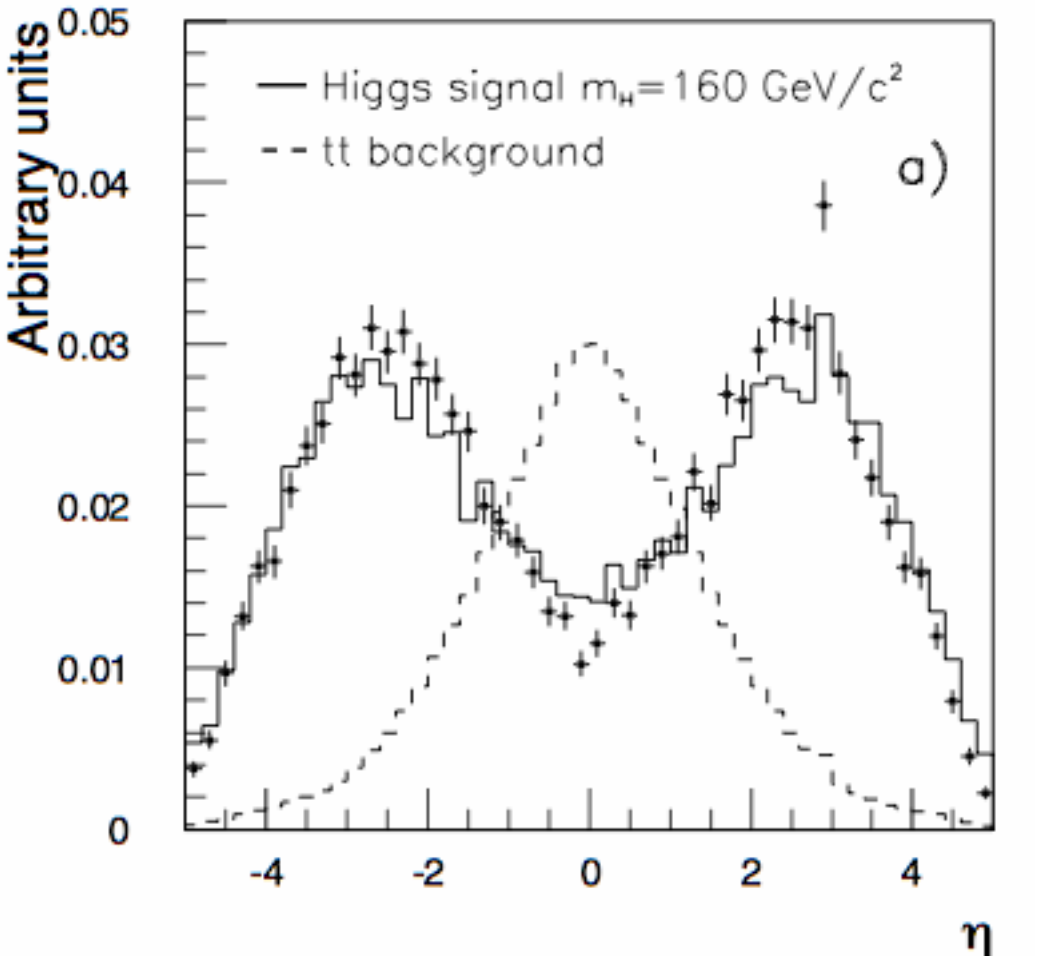
Pointed out in B.M., W.Quayle. S.L.Wu
Phys.Lett. B611 (2005) 60-65

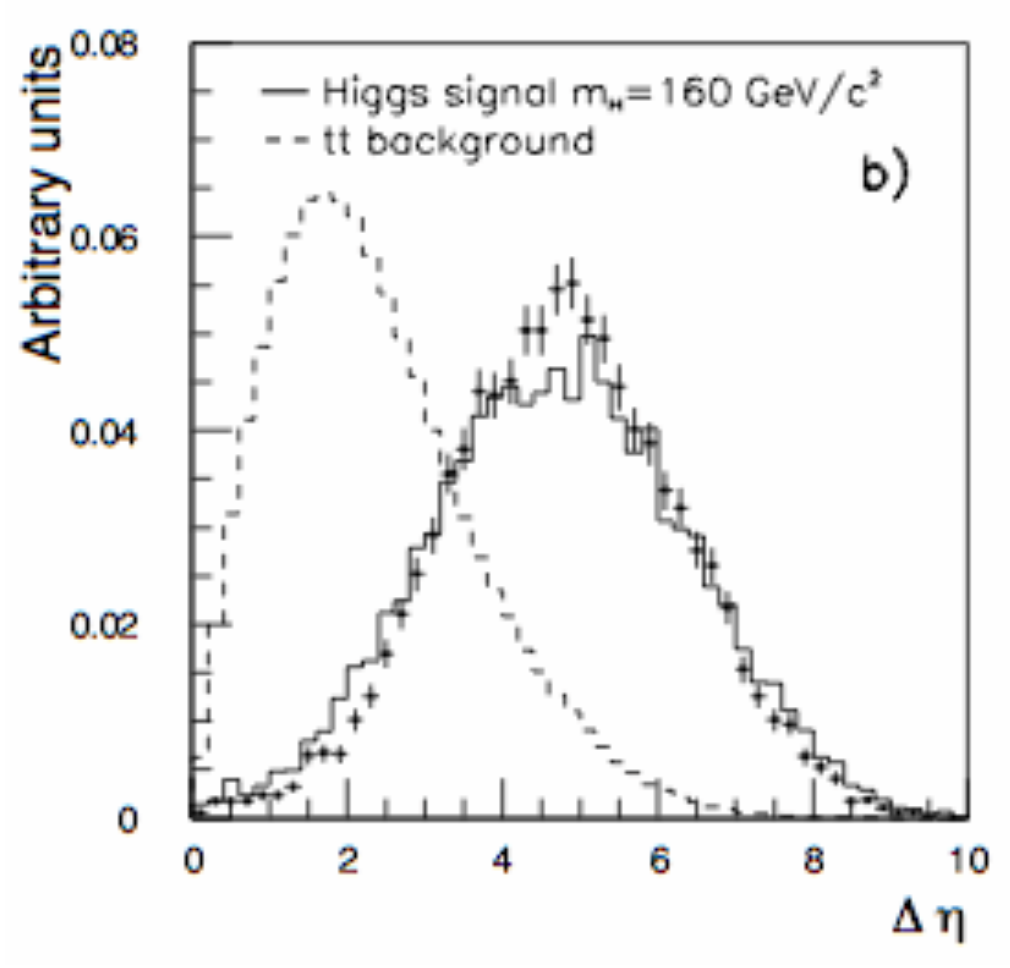




Jets in VBF Higgs

- **ATLAS reported results with studies on forward tagging in full simulation in Eur. Phys J. C 32 (2004) s19**
  - **Histrograms – parton level. Dots - reconstruction**





S. Biswal, R. Godbole, B.M. and a S. Raychaudhuri
arXiv:1203.6285

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)

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

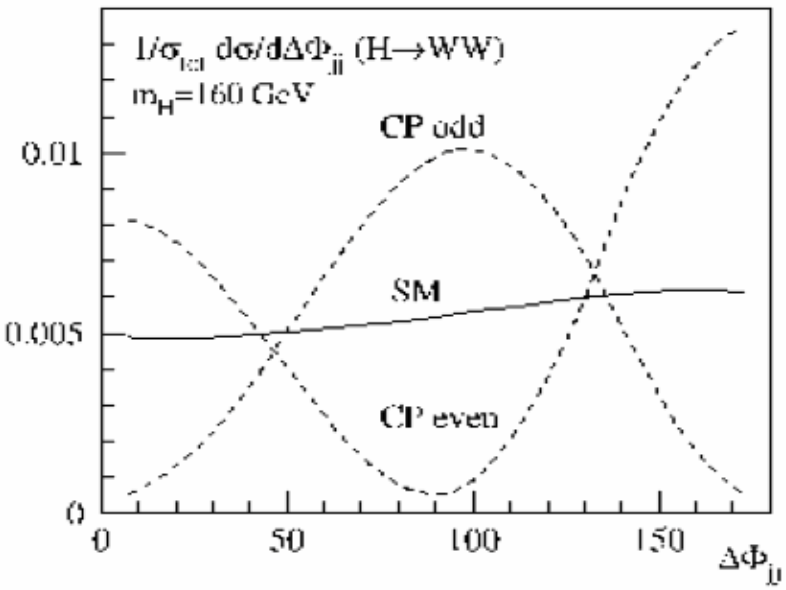
HVV:

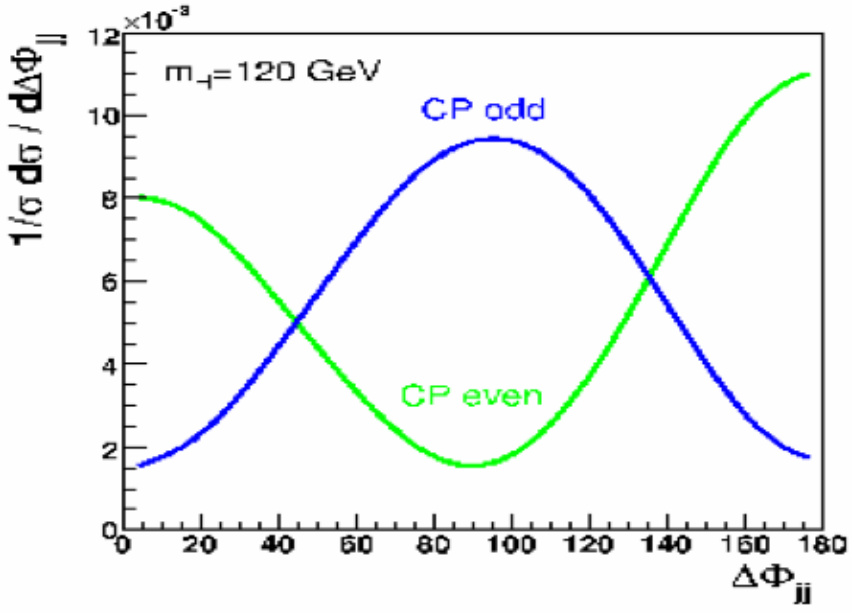
$$V^{\mu\nu}_{HVV} = -ig\left[f_1\, g_{\mu\nu} + f_2\,(g_{\mu\nu}k1.k2 - k1_\nu k2_\mu) + f_3\, i\epsilon_{\mu\nu\alpha\beta}\, k_1^\alpha k_2^\beta\right],$$

with

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

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.

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:

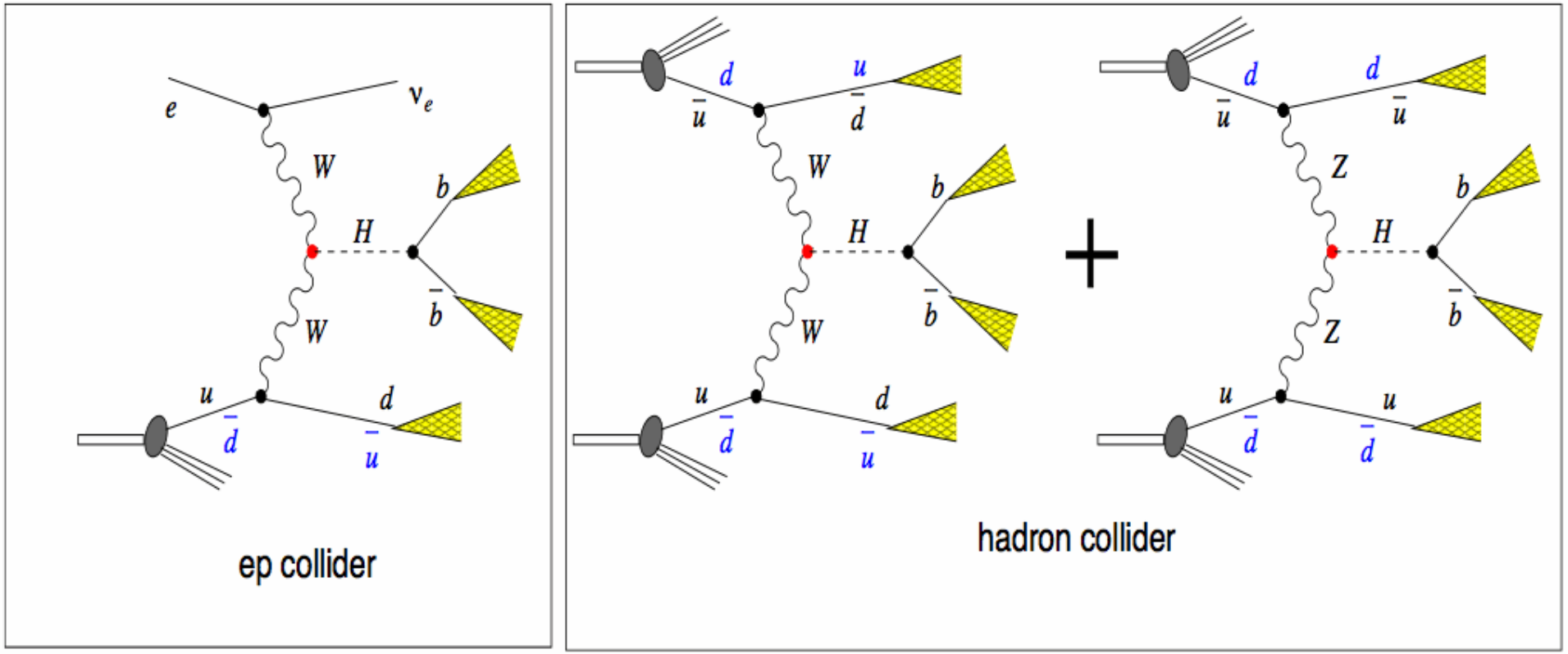
There exist two processes:

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

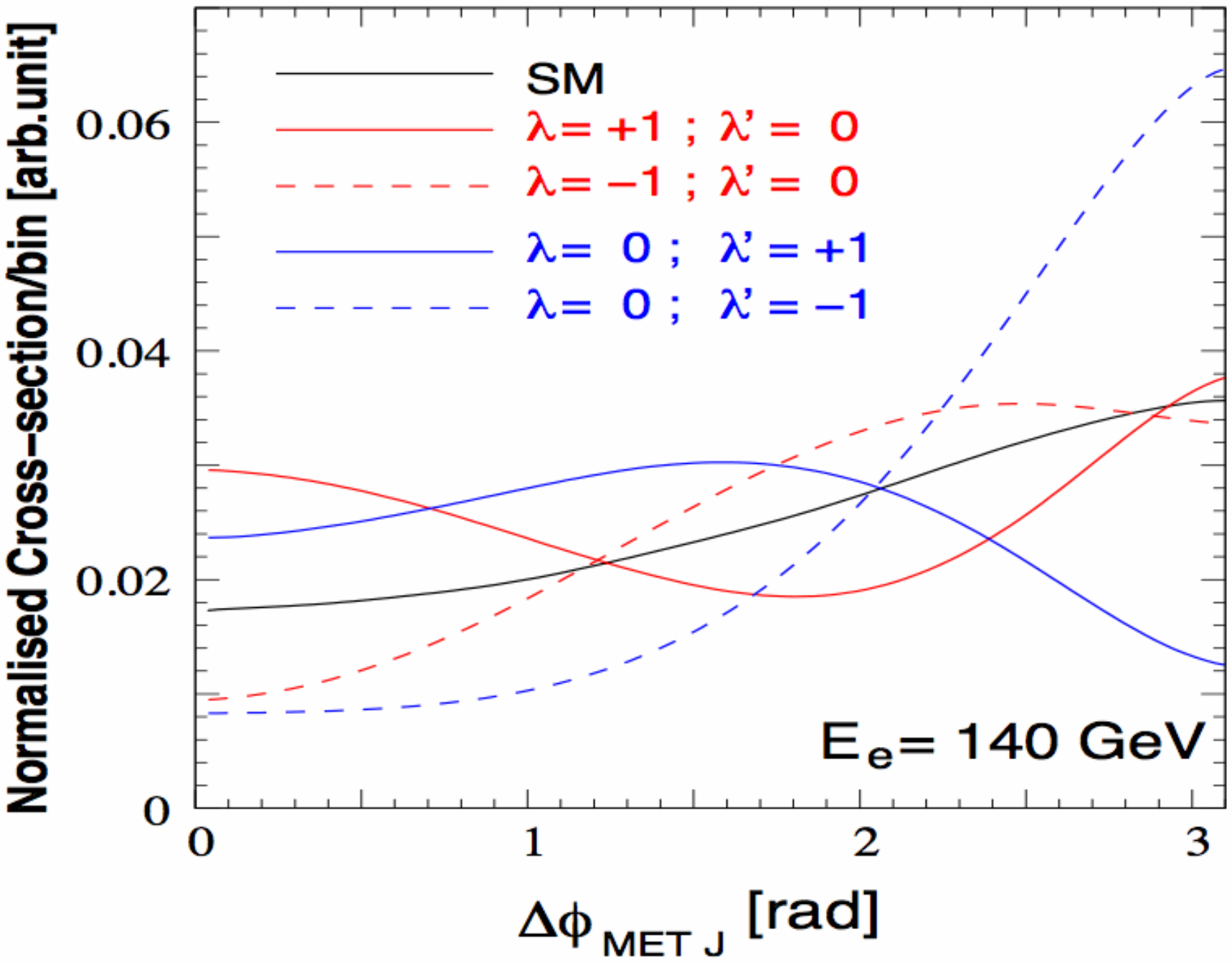
Charged current(CC) and Neutral current(NC) separation possible

Studied further by U. Klein

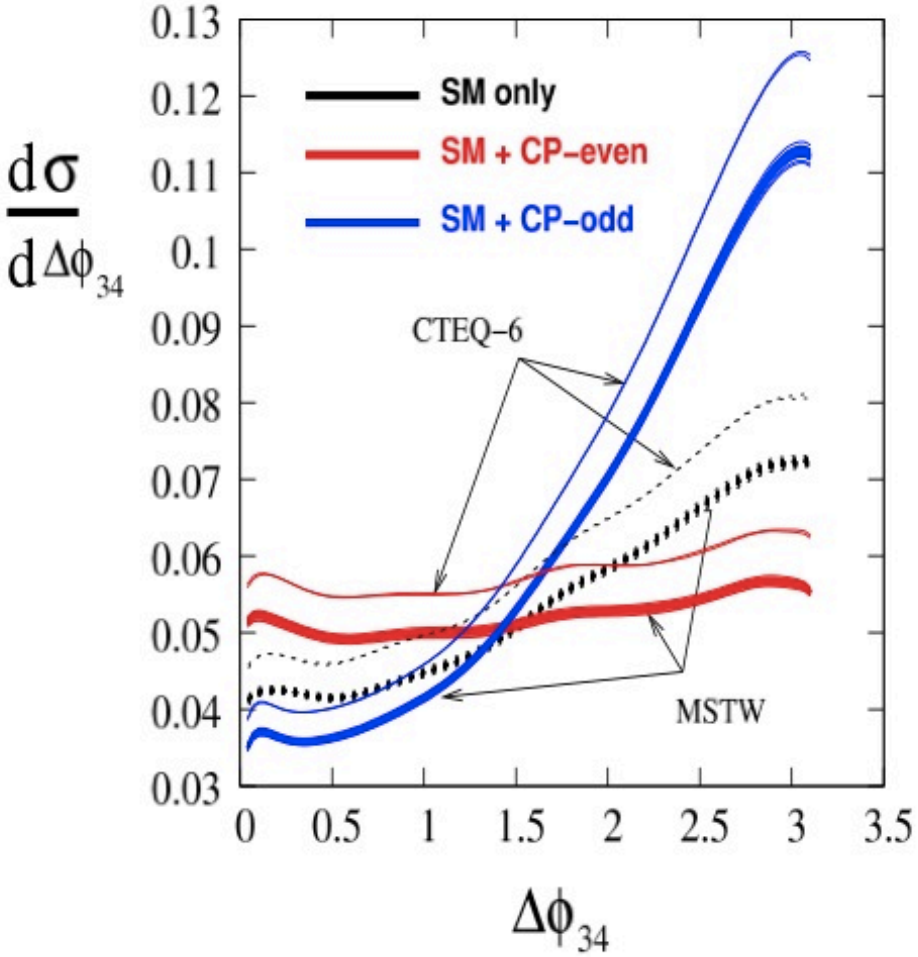
higgs + 2jets: VBF (LHC), higgs + jet + missing E_T (LHeC)

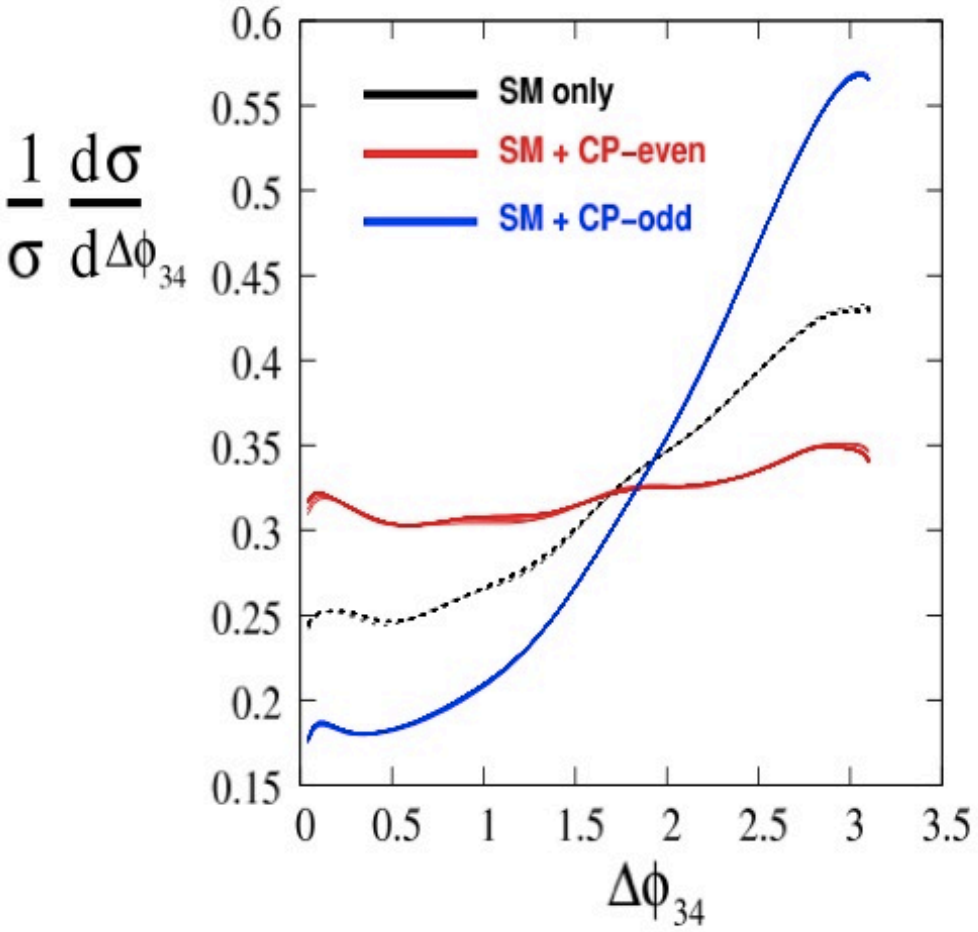


ep process uniquely addresses the HWW vertex.


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]

Effect of PDF uncertainties





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

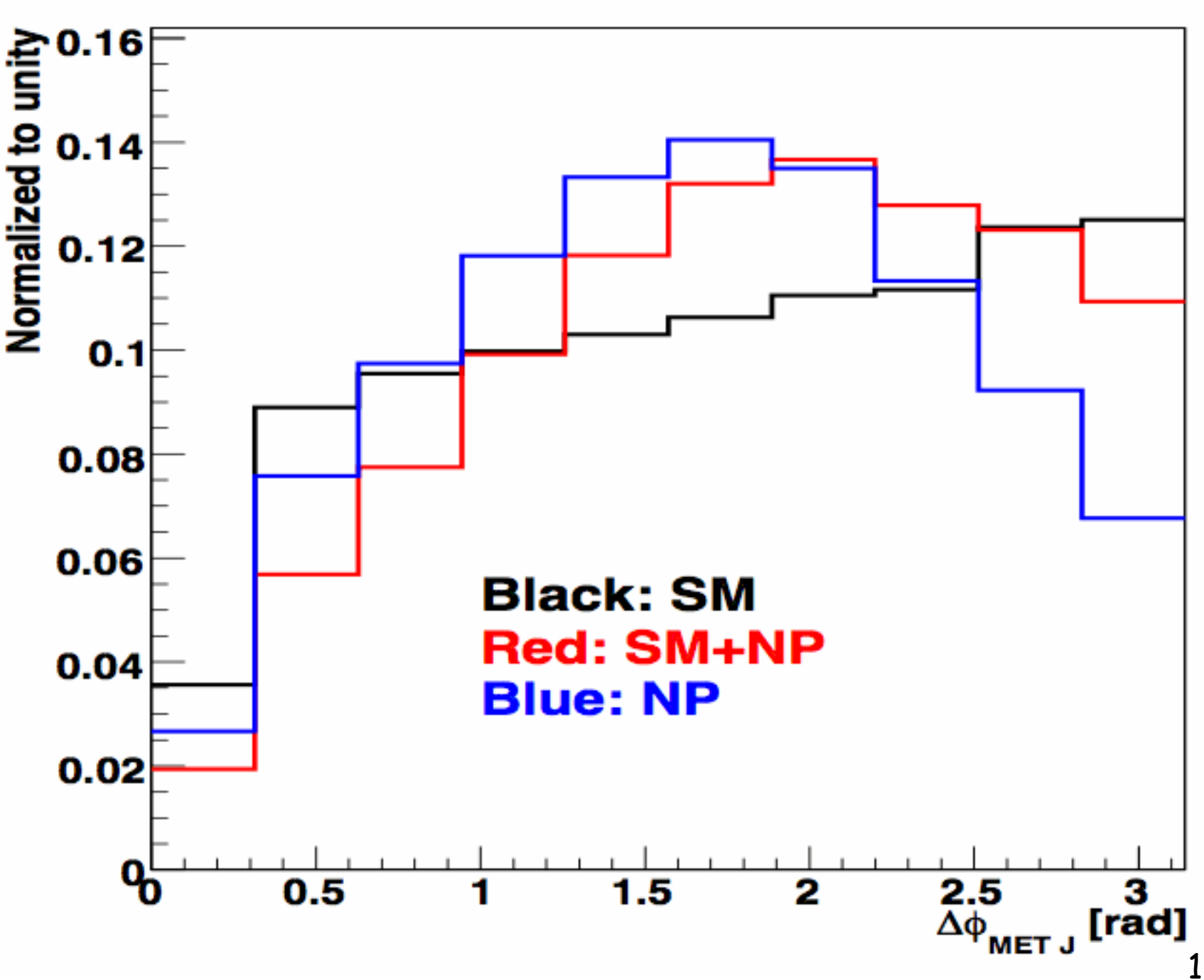
This behaviour essentially follows from the behaviour of matrix element square.

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.

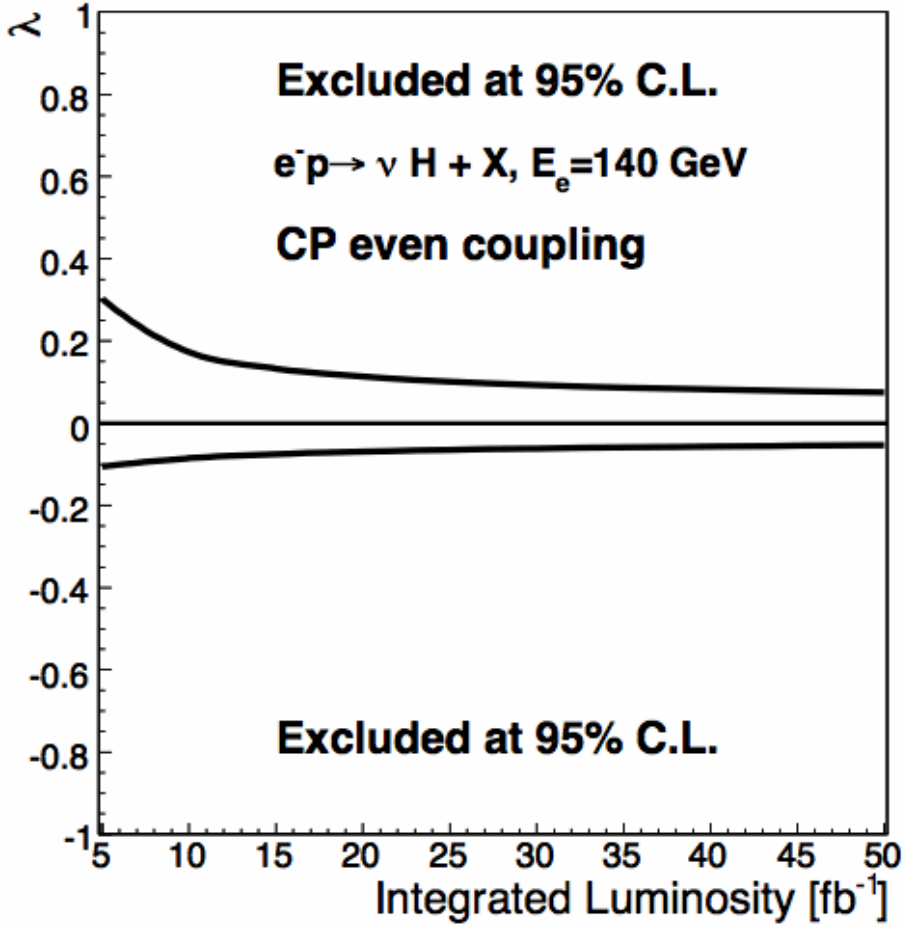
At LHeC the entire range of ϕ is available.

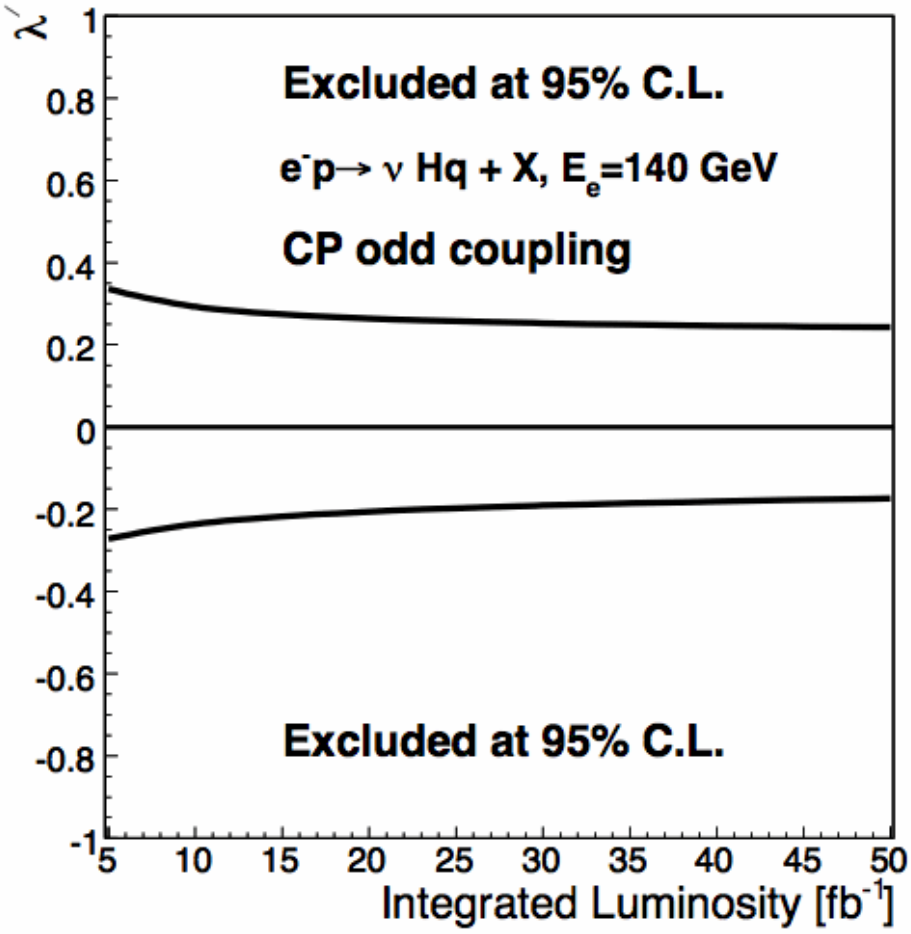
What happens with cuts and reality?


Normalized to unity
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0
0.5
1
1.5
2
2.5
3
Black: SM
Red: SM+NP
Blue: NP
$\Delta\phi_{\text{MET J}}$ [rad]

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





Signal Efficiency for Different E_e

- First row: Cumulative efficiency
- Second row: Efficiency w.r.t. previous cut

Cut	$E_e = 50$	$E_e = 100$	$E_e = 140$	$E_e = 200$
a	0.129 -	0.157 -	0.166 -	0.171 -
b	0.109 0.84	0.127 0.81	0.132 0.80	0.136 0.80
c	0.076 0.70	0.090 0.71	0.093 0.70	0.095 0.70
d	0.050 0.66	0.067 0.75	0.073 0.79	0.078 0.82

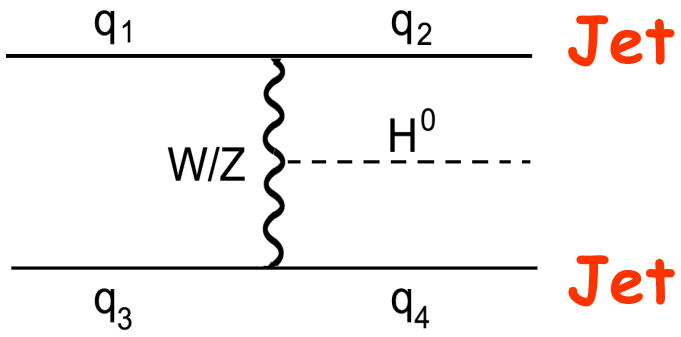
Outlook and Conclusions

- The Higgs can be discovered at the LHC. However, the measurement of the Hbb coupling is challenging
- We believe that forward jet tagging secures the feasibility of the Higgs search in CC and NC
  - Forward jet tagging is now well established at the LHC
- With the isolation of the H→bb signal at the LHeC a window of opportunity opens for the exploration of the CP properties of the HVV vertex
- The LHeC offers a number of advantages
  - Separation of HWW and HZZ couplings
  - Excellent signal to background ratio
  - Identificaiton of backward forward directions

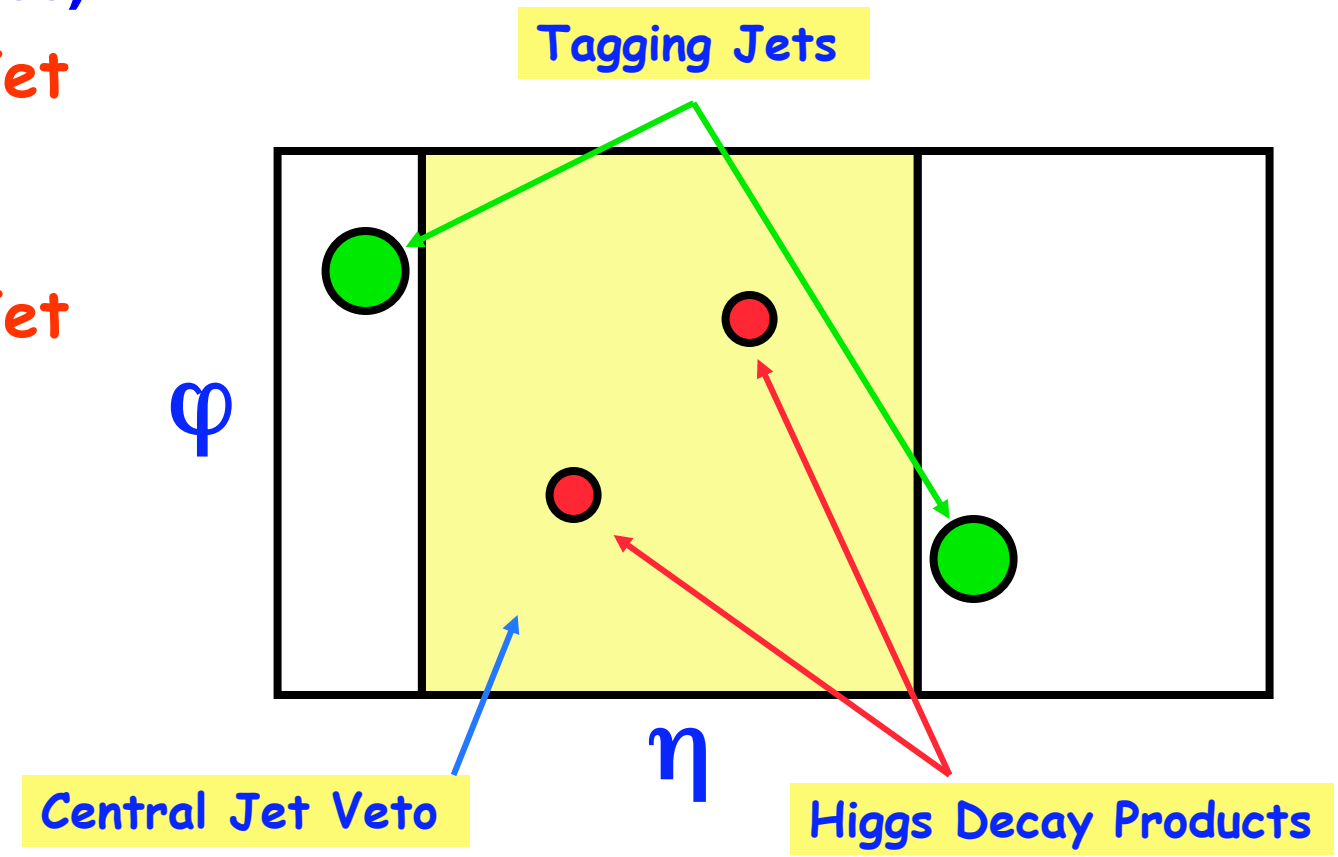
Extra Slides

SM Higgs + 2jets at the LHC

- **Wisconsin Pheno (D.Zeppenfeld, D.Rainwater, et al.) proposed to search for a Low Mass Higgs in association with two jets with jet veto**
  - **Central jet veto initially suggested in V.Barger, K.Cheung and T.Han in PRD 42 3052 (1990)**

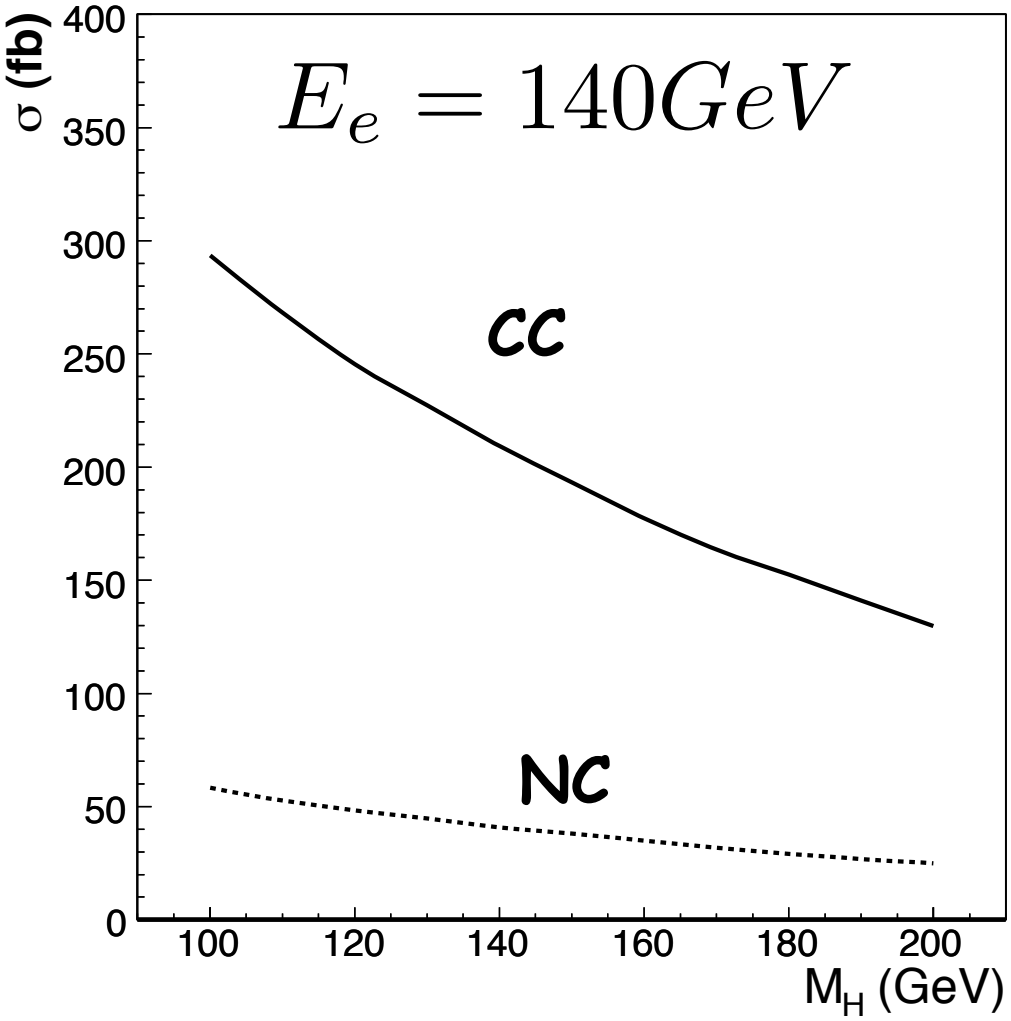


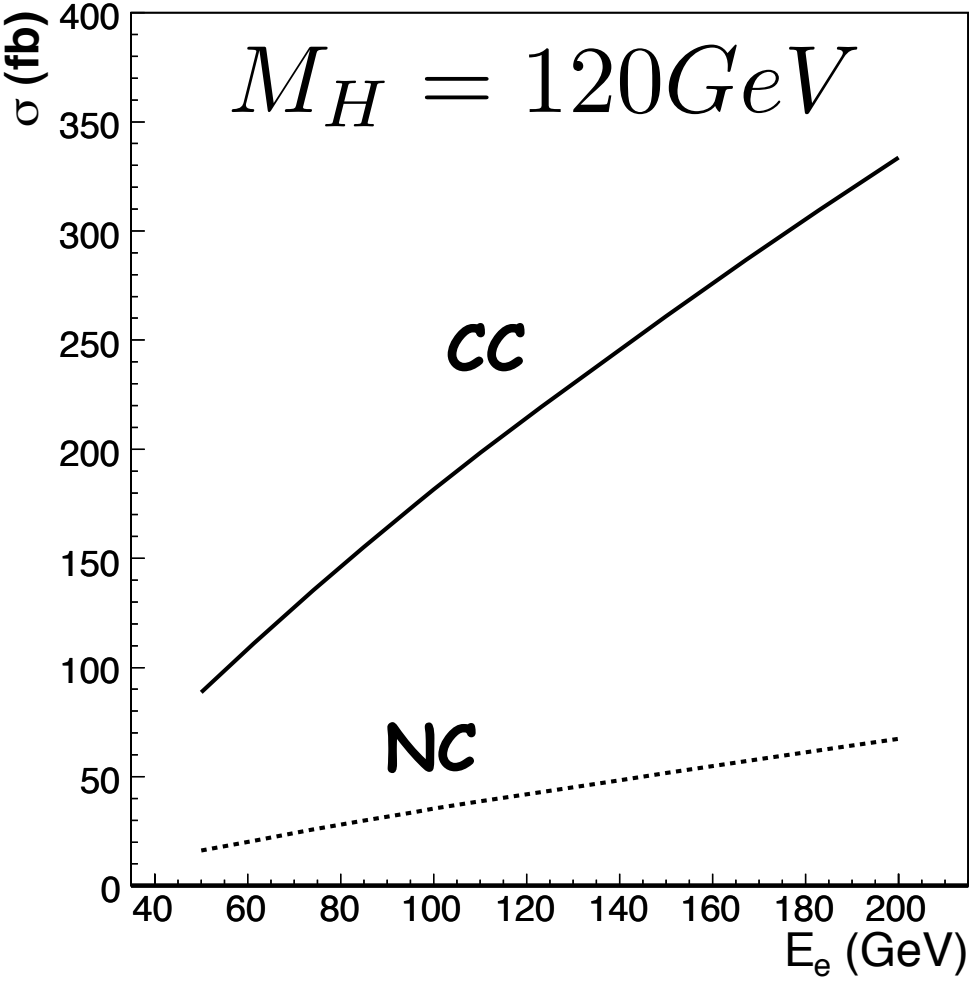
$$\eta_{J1} \cdot \eta_{J2} < 0$$
$$\Delta\eta_{JJ} > 3.5 \div 4$$
$$M_{JJ} > 500 \div 700\text{GeV}$$
c.j.v.



Cross-Sections

- Used Madgraph and CTEQ6L for e^-p scattering
  - Set scales to M_H. Little scale dependence





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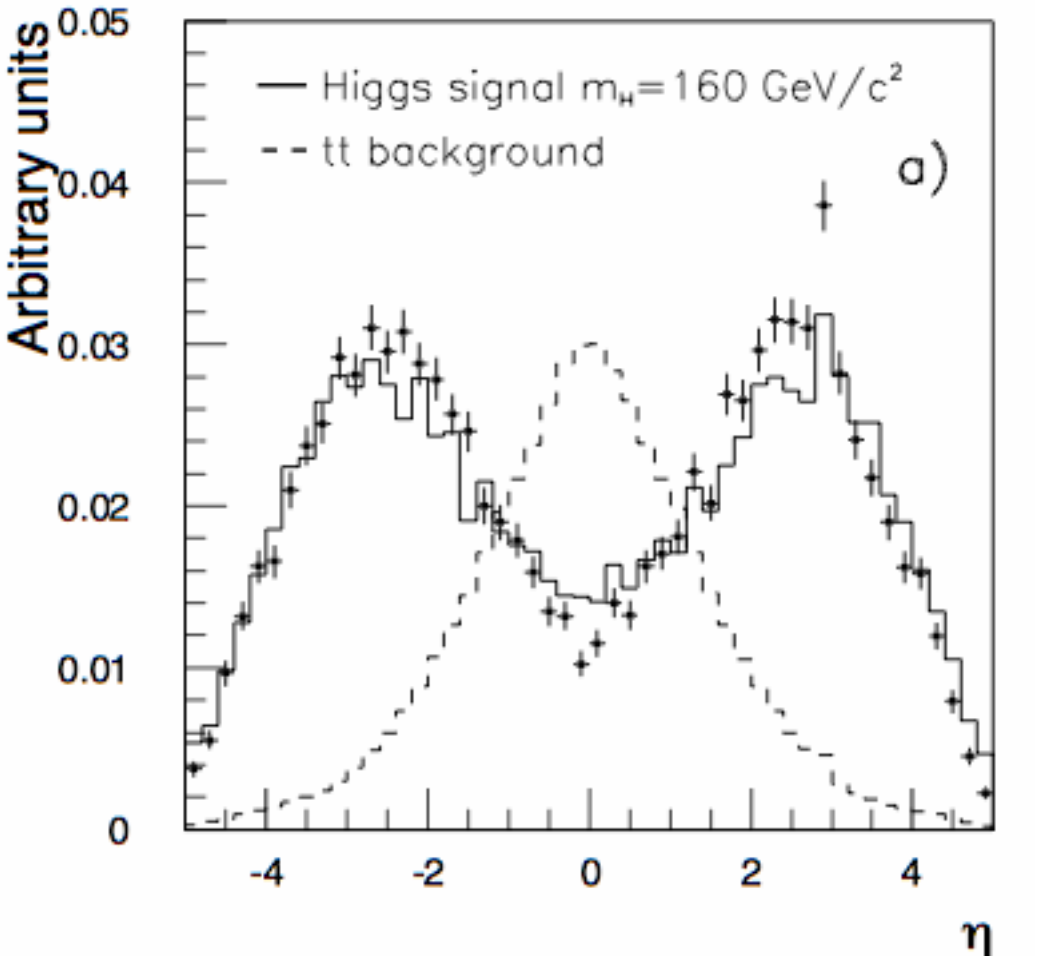
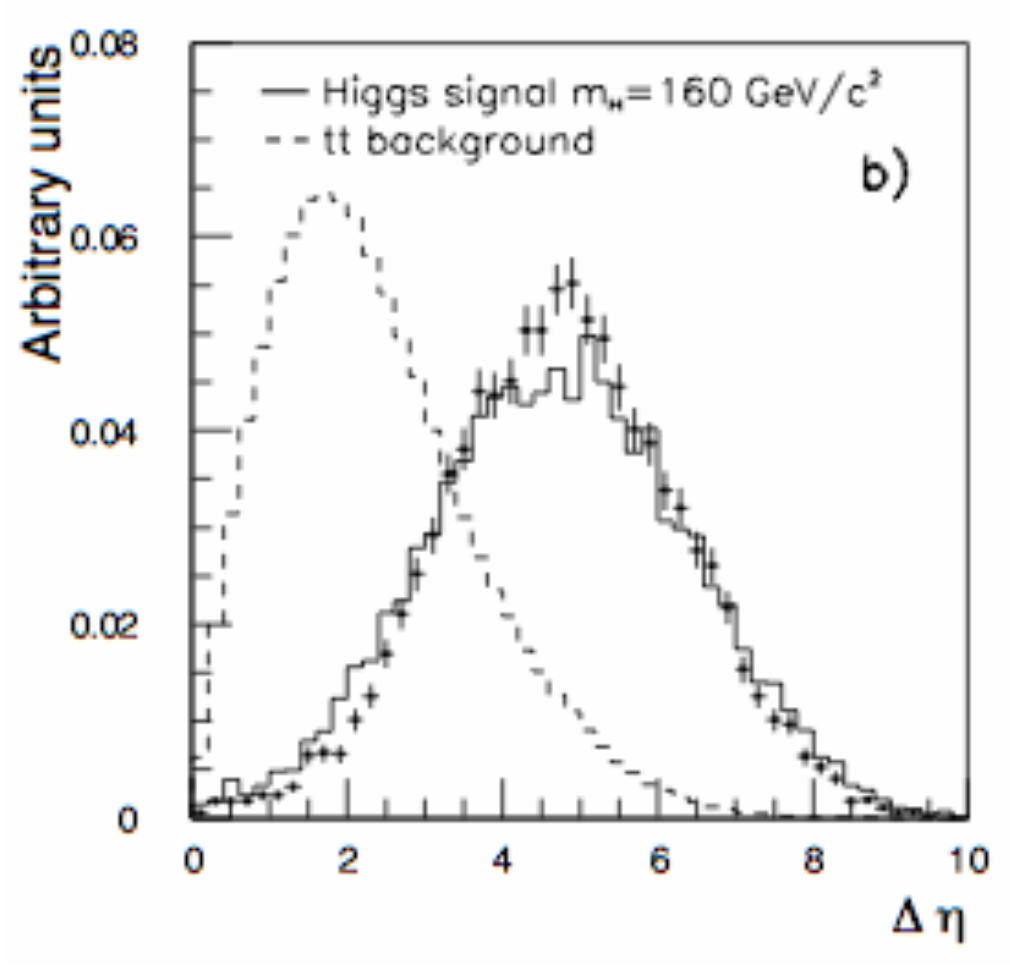
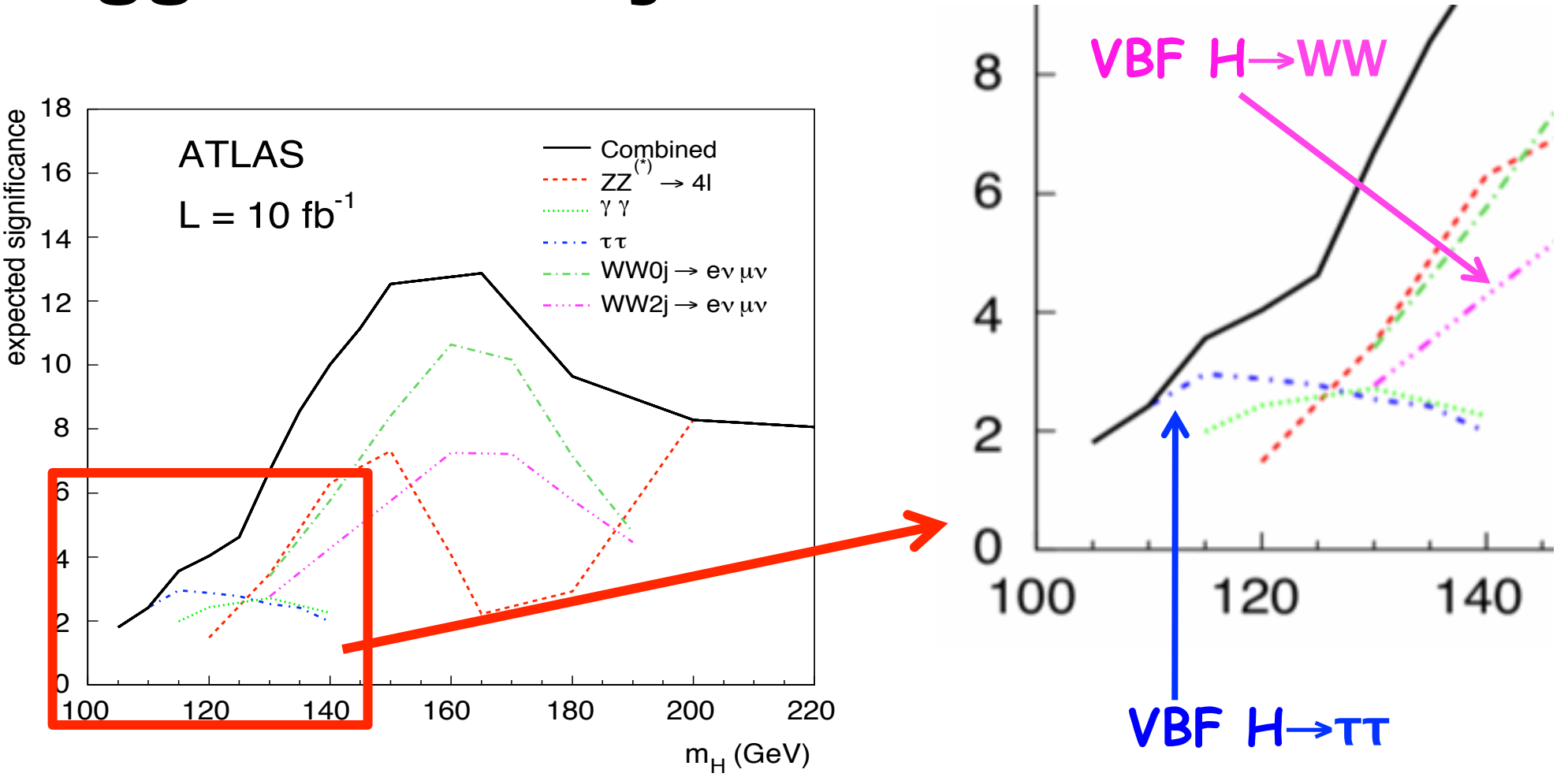




Higgs Discovery Potential with ATLAS



- VBF plays very important role in Higgs discovery
  - CMS and ATLAS prepared for meet the challenges of tagging forward jets