Higgs Physics at the LHeC and the FCC-eh

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on behalf of
the LHeC/FCC-eh Higgs Physics Group

EPS-HEP Conference, Venice, Italy
July 7, 2017

Outline

★ Introduction
- Higgs production @ ep colliders
- Analysis framework

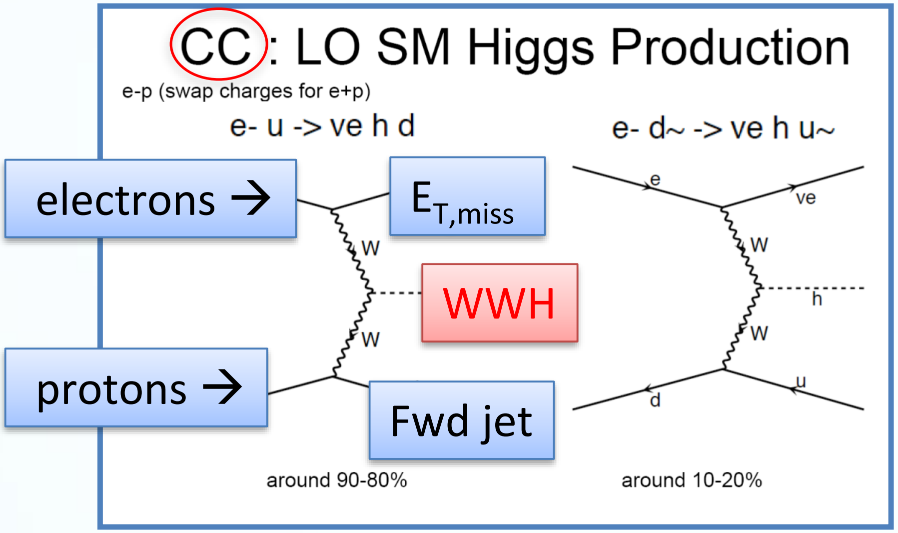
★ SM Higgs
- hbb, hcc coupling
- hcc coupling

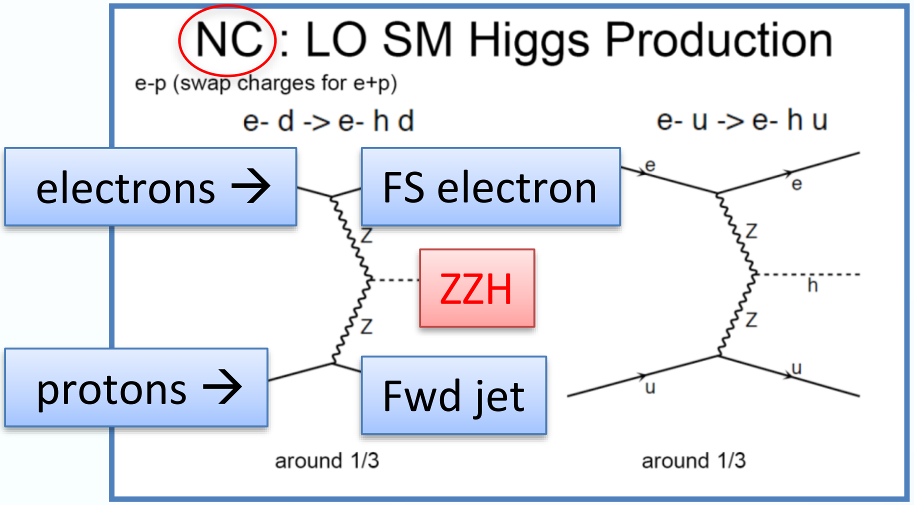
★ Exploring New Physics
- Top Yukawa coupling
- Constraining EFT operators: via di-Higgs Measurements
- Invisible Higgs decay
- Exotic Higgs decay: h->ϕϕ-> 4b

★ Outlook & Summary

More details, see [Uta Klein's talk "FCC-eh SM and BSM Higgs Studies" in the FCC week 2017, https://indico.cern.ch/event/556692/contributions/2510778/attachments/1468874/2272276/FCC_Berlin_UKlein_01.06.2017.pdf]

SM Higgs Production @ ep Colliders





→ In ep, direction of quark (FS?) is well defined.

σ [fb] (LO QCD CTEQ6L1 M_H=125 GeV)

Collider	LHeC	FCC-eh
c.m.s. energy [TeV]	1.3	3.5
NC DIS, unpol.	21	127
CC DIS, unpol.	109	560
CC DIS, P_e =-80%	196	1008

→ Scale dependencies of the LO calculations ~ 5-10%.

→ NLO QCD corrections are small, but shape distortions of kinematic distributions up to 20%.

→ QED corrections up to -5%

[J. Blumlein, G.J. van Oldenborgh , R. Ruckl, Nucl.Phys.B395:35-59,1993]
[B.Jager, arXiv:1001.3789]

Analysis Framework

Event generation

- **SM or BSM production**
- **CC & NC DIS background**

by MadGraph5/MadEvent

- **Fragmentation**
- **Hadronization**

by PYTHIA (modified for ep)

Fast detector simulation

by Delphes

→ test of FCCeh detector

S/B analysis → Cuts or BDT

- Calculate cross section with tree-level Feynman diagrams (any UFO) using pT of scattered quark as scale (CDR ŝ) for ep processes with **MadGraph5**
- Standard HERA tools can NOT to be used !
- Higgs mass **125 GeV** as default
- Fragmentation & hadronisation uses **ep-customised Pythia**.

- **Delphes 'detector'**
  →displaced vertices and signed impact parameter distributions
  →studied for LHeC, and used for FCC-eh SM Higgs extrapolations

→ powerful method to optimize detector tuning and S/N (S/B ?) for various Higgs, top and BSM decays

→ Ongoing: Integration of FCC-eh into FCC simulation framework

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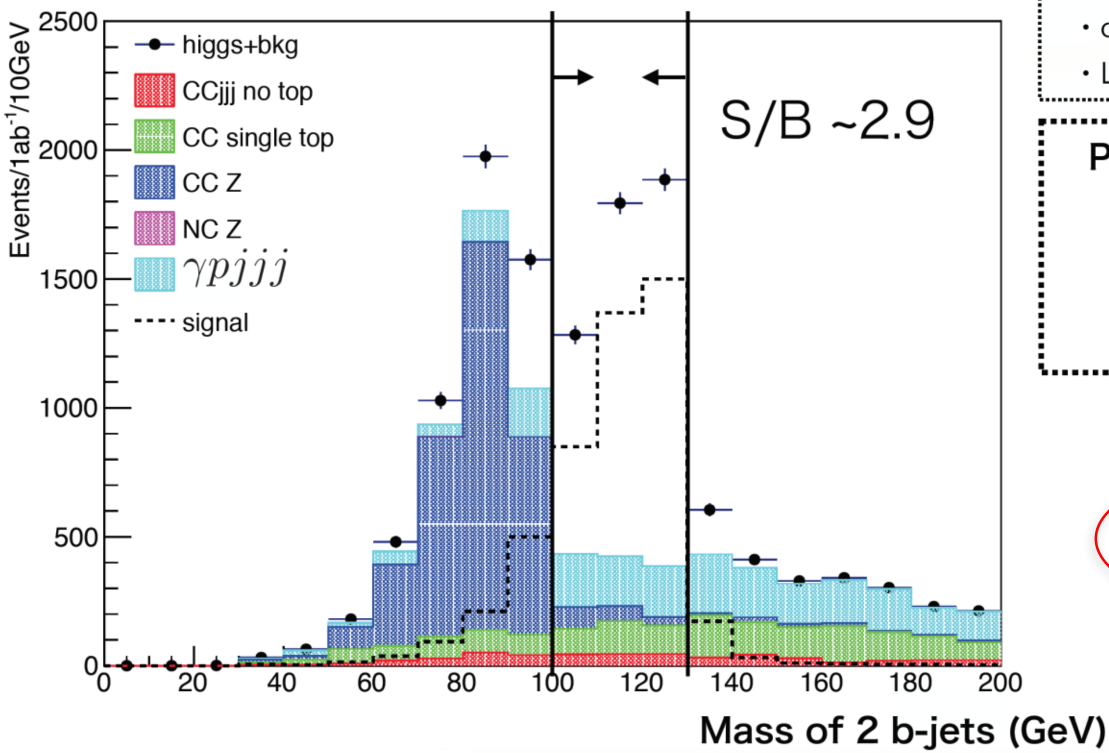
Cut-based Results for Hbb @ LHeC

[Masahiro Tanaka, Masahiro Kuze]

Previous studies pursued since the LHeC CDR
[before the Higgs discovery, see http://cern.ch/lhec]

- Assumed 1000 fb^{-1} of statistics. (~10 years running for LHeC.)
- Veto efficiency of 90% for photo-production background is assumed, using forward electron tagging.

b-tag performance (cut based)
- b-jet: 75%
- c-jet mis-tagging rate: 5%
- Light-jet mis-tagging rate: 1%



Precision of coupling constant (Statistics error only)

$$\kappa = \frac{\sqrt{N_s + N_b}}{2N_s}$$

Signal: 3600
Bkg: 1250

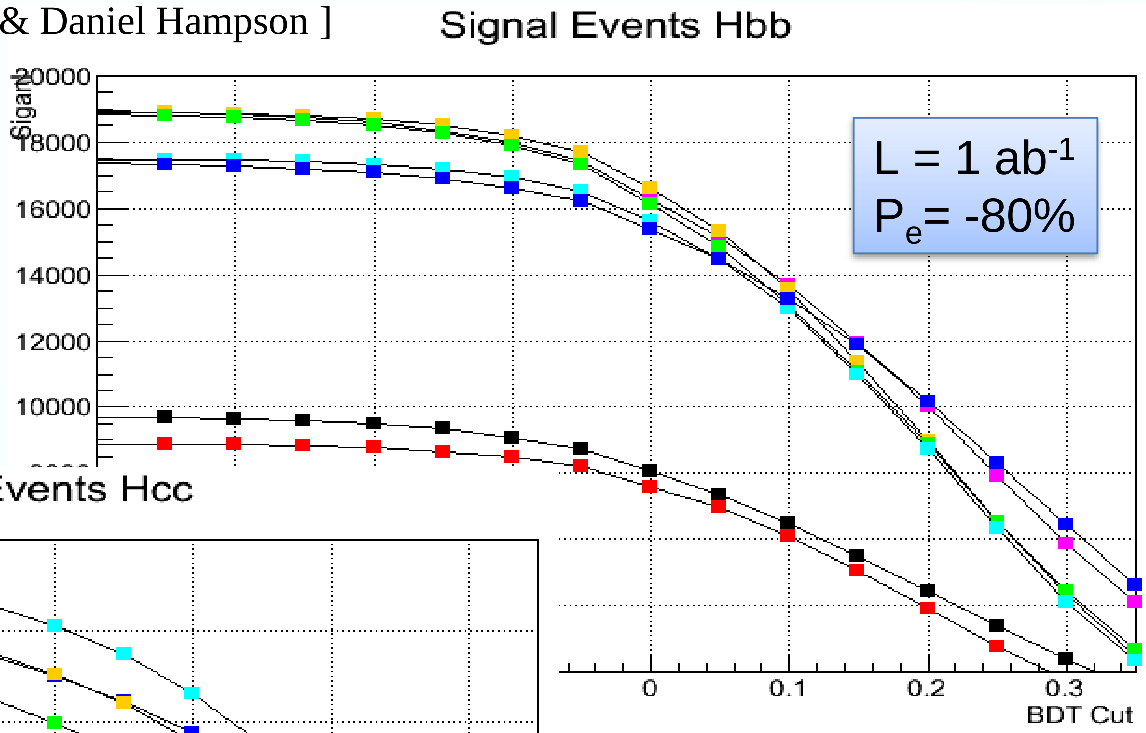
κ (Hbb) ~ 0.97%

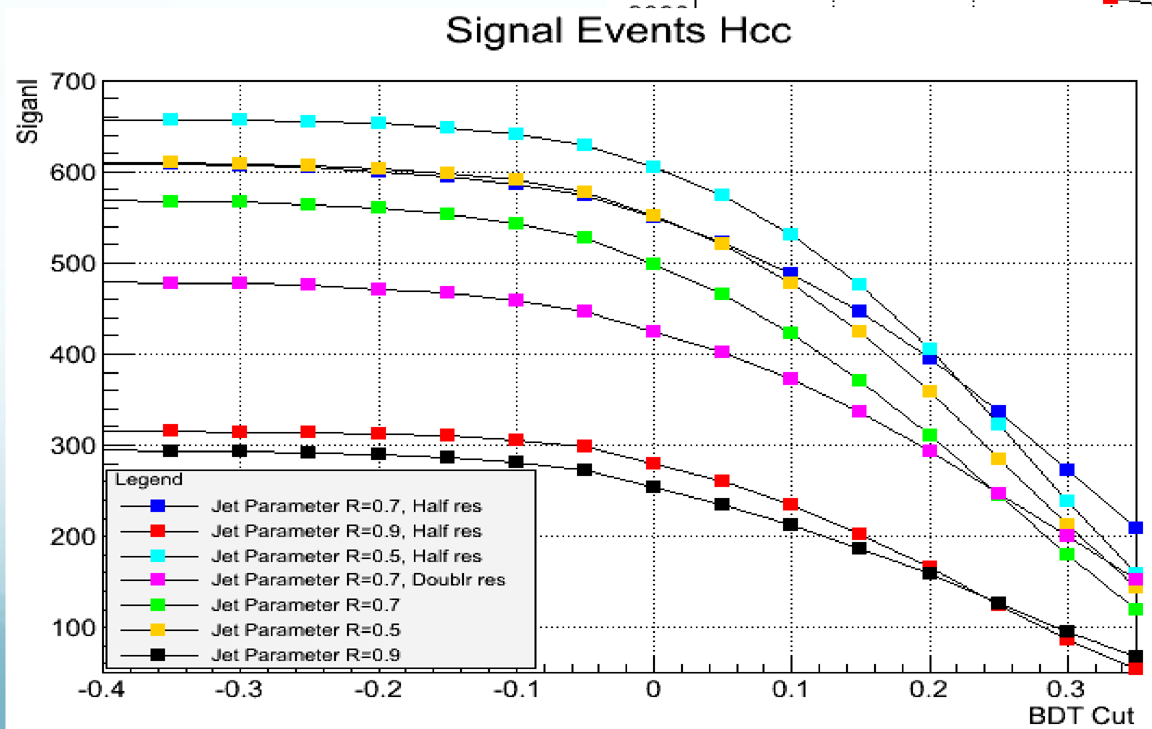
BDT Results for Hbb @ LHeC

[Uta Klein & Daniel Hampson]

Hbb:

→ using same background assumptions as for cut-based analysis
→ A factor 5 more Hbb candidates (~ 15,000) (How?)
=> uncertainty ~ 0.5%





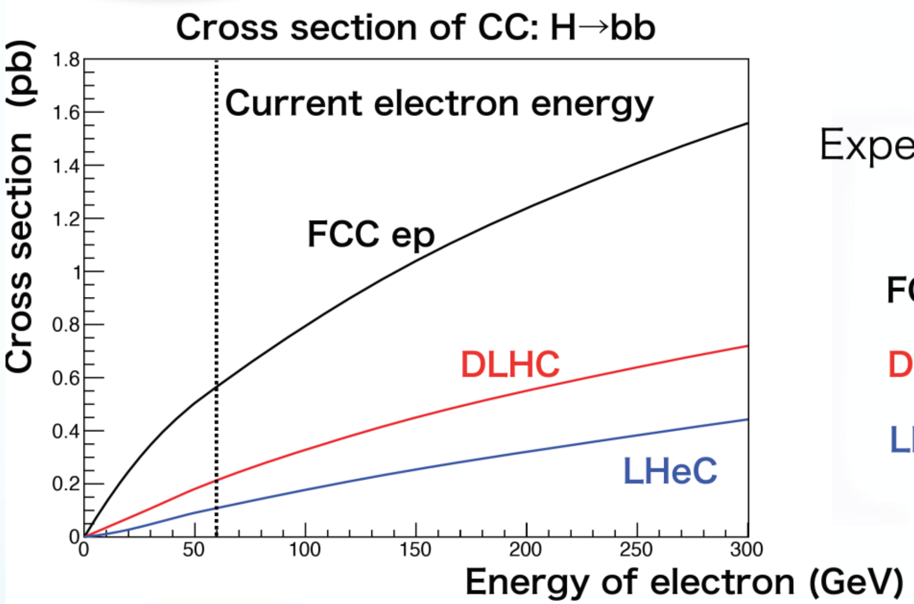
Hcc:

→ High sensitivity to vertex resolution (nominal 10 μm) and jet radius
→ Expect ~ 400-600 Hcc candidates

Hbb & Hcc Summary

- Assume a 60 GeV polarized electron beam and 1000 fb^{-1} (~10 years running)
- Expected number of signal events and error of coupling constant from BDT results.
- Background assumed to be known to ~2%

U Klein (Liverpool)



Expected number of signal events
(E_e = 60 GeV)

FCC ep (~85,000 H→bb events)

DLHC (~35,000 H→bb events)

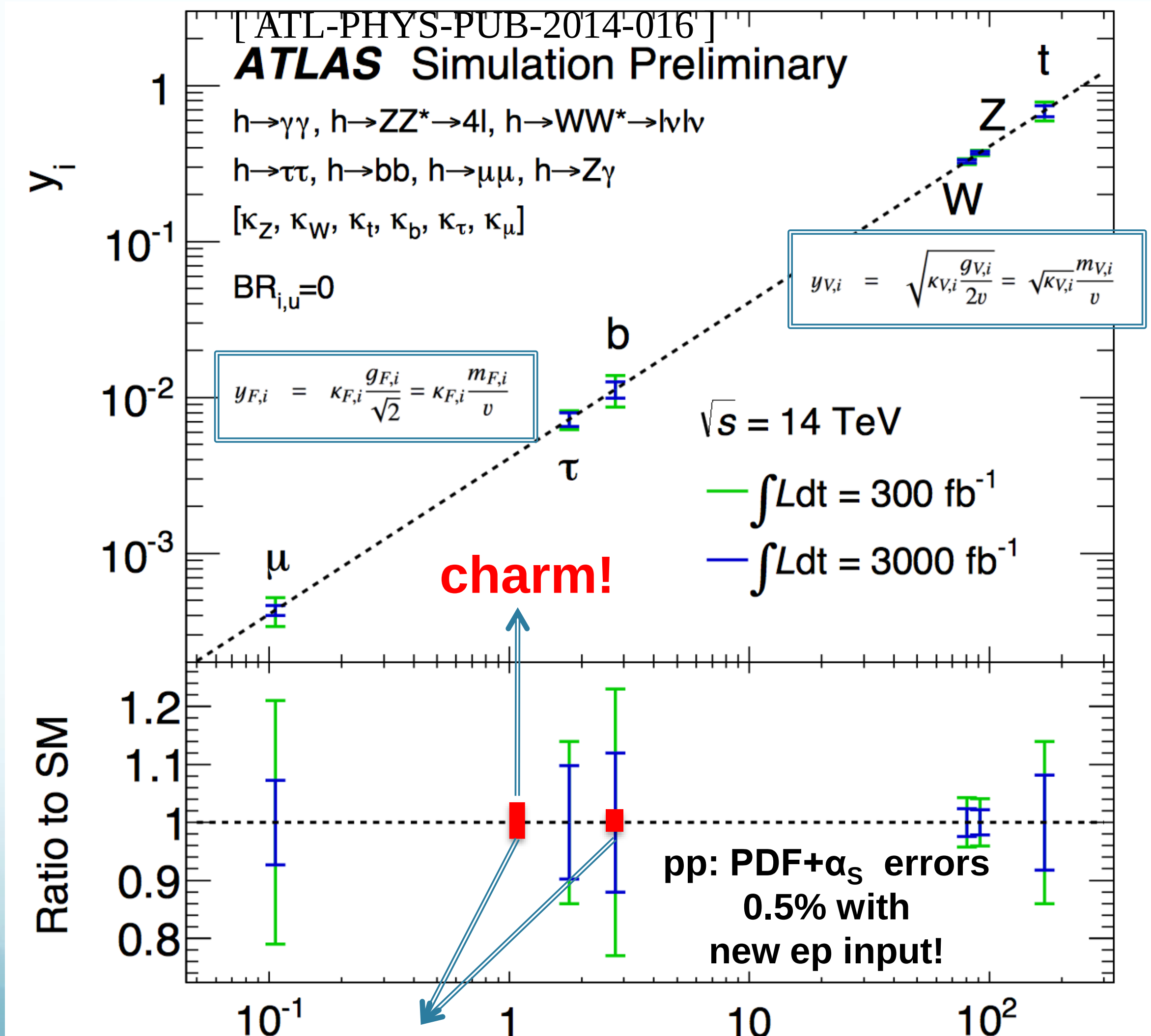
LHeC (~15,000 H→bb events)

	LHeC (E_p = 7 TeV √s ~1.3 TeV)	**DLHC** (E_p = 14 TeV √s ~1.8 TeV)	**FCC ep** (E_p = 50 TeV √s ~ 3.5 TeV)
κ (Hbb)	0.5%	0.3%	0.2%
κ (Hcc)	4%	2.8%	1.8%

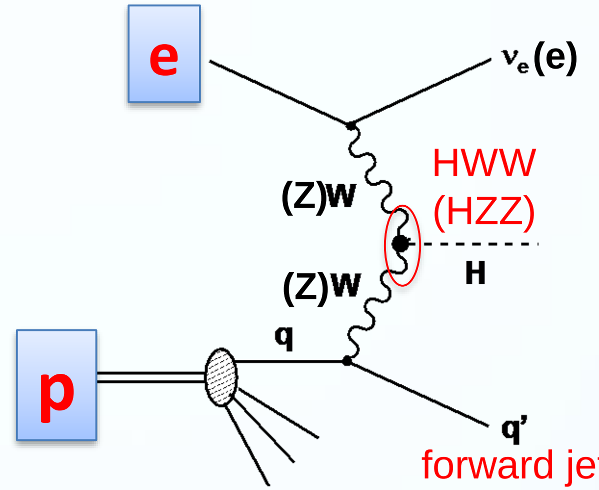
When extracting Hbb, Hcc couplings, assuming SM values of HWW, HZZ couplings.

Higgs Couplings at HL-LHC + LHeC

running concurrently



LHeC @1ab^{-1}
results in 2038, concurrent with HL-LHC end



use ep as the 'near' detector for pp to beat
→ α_s and PDF uncertainties to < ~ 0.5%,
→ δm_b to 10 MeV,
→ δm_c to 3 MeV

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  - Di-Higgs Measurement
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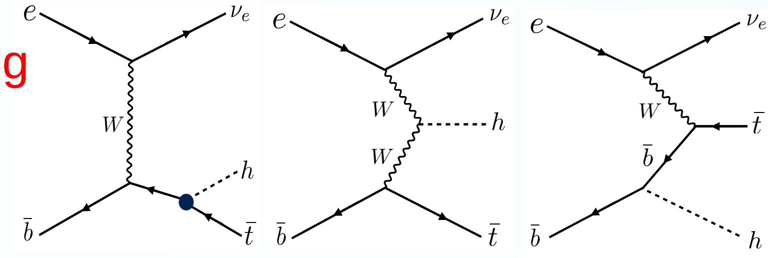
Top Yukawa Coupling @ LHeC

h -> b b
t -> b lν

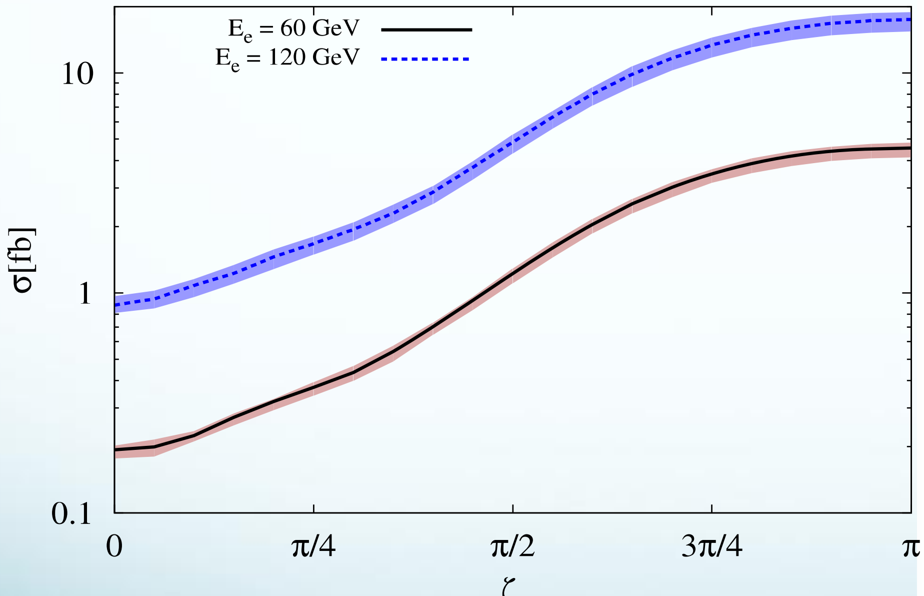
[B.Coleppa, M.Kumar, S.Kumar, B.Mellado, Phys. Lett. B 770 (2017) 335]



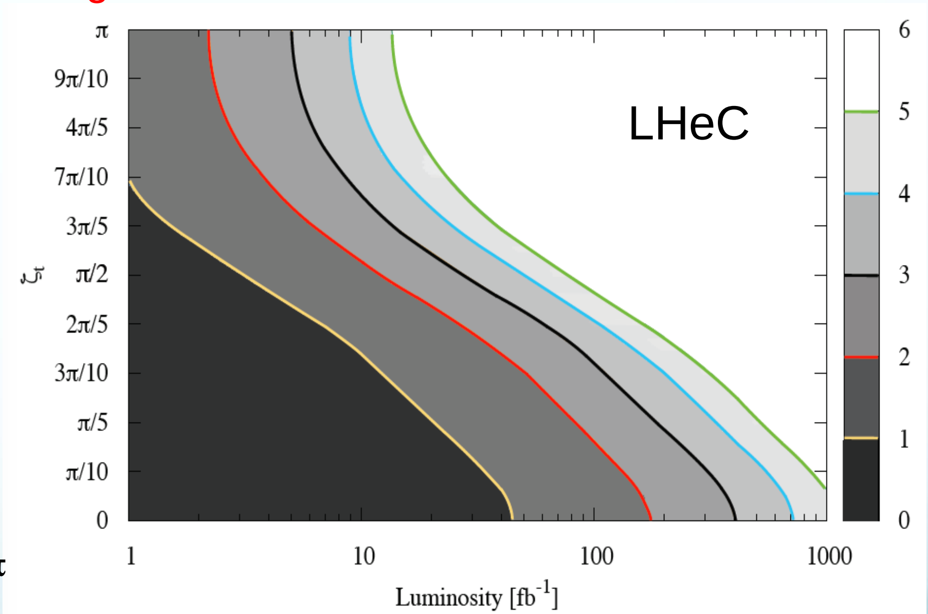
Introduce CP phase dependent top Yukawa coupling

$$\mathcal{L} = -\frac{m_t}{v}\bar{t}\,[\kappa\cos\zeta_t + i\gamma_5\sin\zeta_t]t\,h$$

Total cross-section as a function of phase with scale uncertainties



Significances based on fiducial cross section



→ Test also CP-odd BSM

→ Observe/Exclude non-zero phase to better than 4σ with 1000 fb^{-1}

→ With Zero Phase: Measure coupling κ with 17% accuracy

→ work ongoing on FCC-eh prospects

Double Higgs Production @ FCC-eh

[**“Probing anomalous couplings using di-Higgs production in electron-proton collisions”** by Mukesh Kumar, Xifeng Ruan, Rashidul Islam, Alan S. Cornell, Max Klein, Uta Klein, Bruce Mellado, **Physics Letters B 764 (2017) 247-253,** arXiv:1509.04016]

Introduce EFT operators

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \mathcal{L}^{(3)}_{hhh} + \mathcal{L}^{(3)}_{hWW} + \mathcal{L}^{(4)}_{hhWW} .$$

SM

$$\mathcal{L}^{(3)}_{hhh} = \frac{m_h^2}{2v}(1 - g^{(1)}_{hhh})h^3 + \frac{1}{2v} g^{(2)}_{hhh} h\partial_\mu h \partial^\mu h, \quad (2)$$

$$\mathcal{L}^{(3)}_{hWW} = -g\left[\frac{g^{(1)}_{hWW}}{2m_W} W^{\mu\nu}W^\dagger_{\mu\nu}h + \frac{g^{(2)}_{hWW}}{m_W}(W^\nu\partial^\mu W^\dagger_{\mu\nu}h + \text{h.c}) + \frac{\tilde{g}_{hWW}}{2m_W} W^{\mu\nu}\widetilde{W}^\dagger_{\mu\nu}h\right], \quad (3)$$

$$\mathcal{L}^{(4)}_{hhWW} = -g^2\left[\frac{g^{(1)}_{hhWW}}{4m_W^2} W^{\mu\nu}W^\dagger_{\mu\nu}h^2 + \frac{g^{(2)}_{hhWW}}{2m_W^2}(W^\nu\partial^\mu W^\dagger_{\mu\nu}h^2 + \text{h.c}) + \frac{\tilde{g}_{hhWW}}{4m_W^2} W^{\mu\nu}\widetilde{W}^\dagger_{\mu\nu}h^2\right]. \quad (4)$$

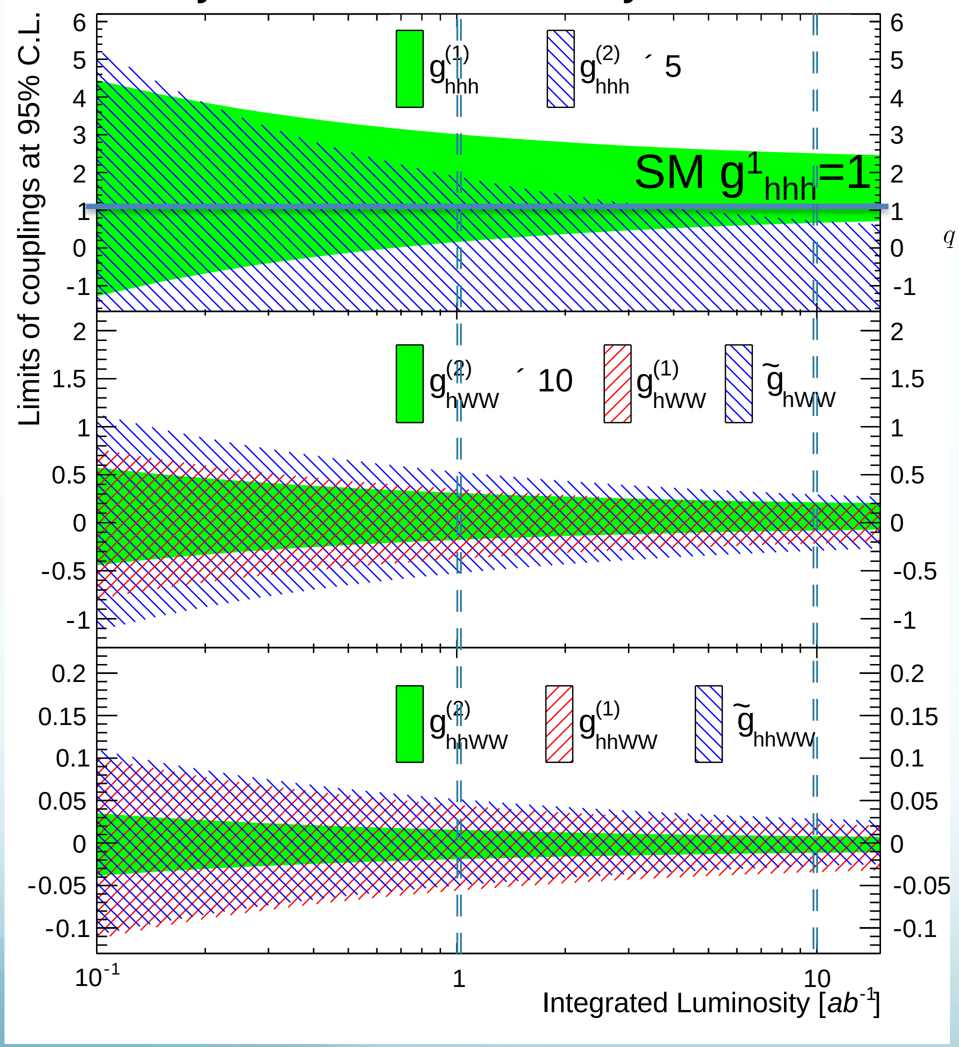
→ All other g coefficients are anomalous couplings to the hhh, hWW and hhWW anomalous vertices

→ those are 0 in SM

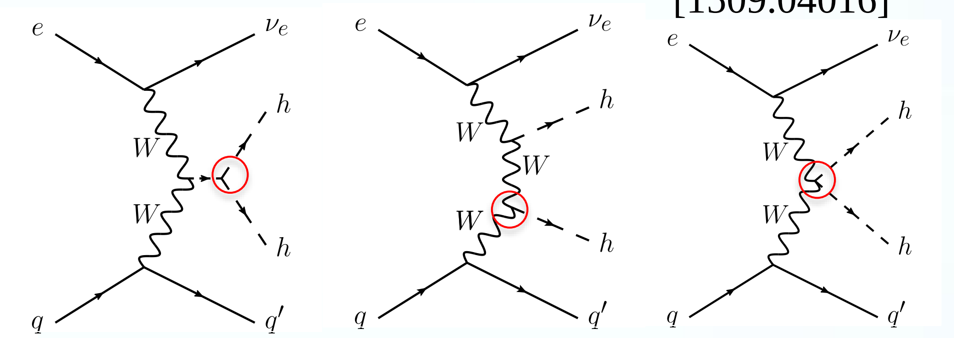
Double Higgs Production @ FCC-eh

95% C.L. Exclusion Limits from $\sigma_{fiducial}$

5% systematic uncertainty included



[1509.04016]



Event Selection using h->bb
Final state: 1 fwd j + 4 b + MET
Cut-based analysis

1σ for SM hhh for E_e, 60 (120) GeV & 10 ab^{-1}

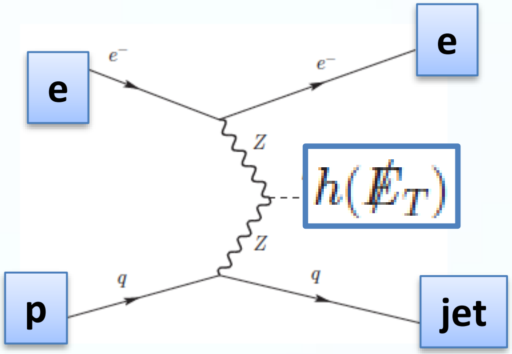
$$g^{(1)}_{hhh} = 1.00^{+0.24(0.14)}_{-0.17(0.12)}$$

→ Limits are obtained by scanning one of the coefficients, while keeping the others couplings to their SM values.

Invisible Higgs Decay @ LHeC

HL-LHC with 3 ab^{-1} [1411. 7699]

$\mathrm{Br}(h \to \not{E}_T)$ < 3.5% @95% C.L., MVA-based

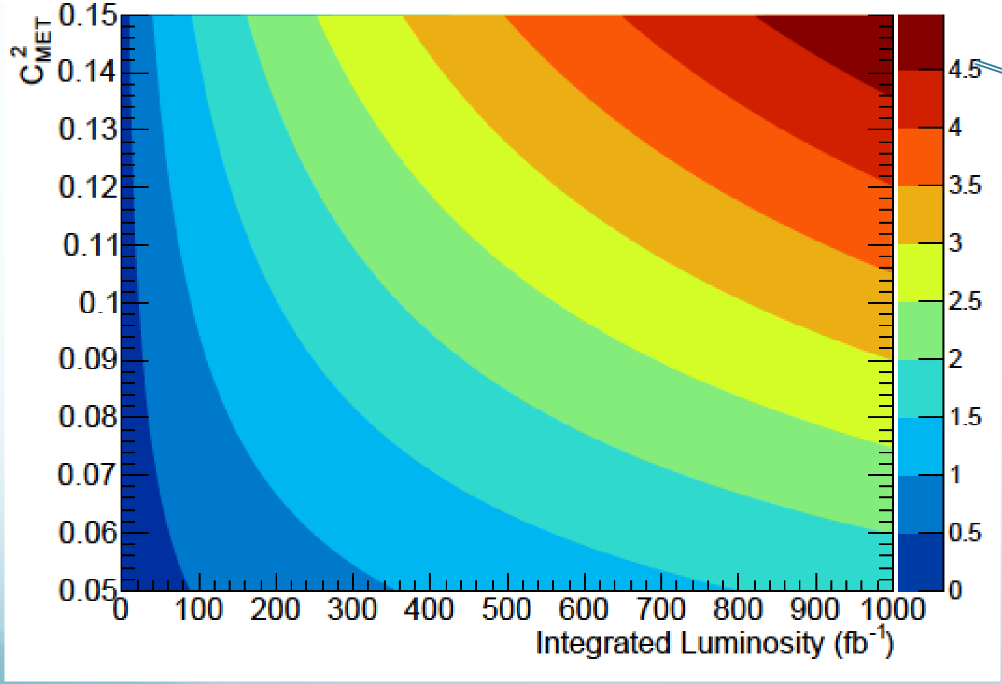


For **LHeC**, with 1ab^{-1}, P_e=-0.9 [Y.-L. Tang et al., 1508.01095]

$\mathrm{Br}(h \to \not{E}_T)$ < 6% @ 95 % C.L., Cut-based

$$C^2_{\mathrm{MET}} = \kappa_Z^2 \times \mathrm{Br}(h \to \not{E}_T)$$

κ_Z: BSM w.r.t. SM HZZ coupling



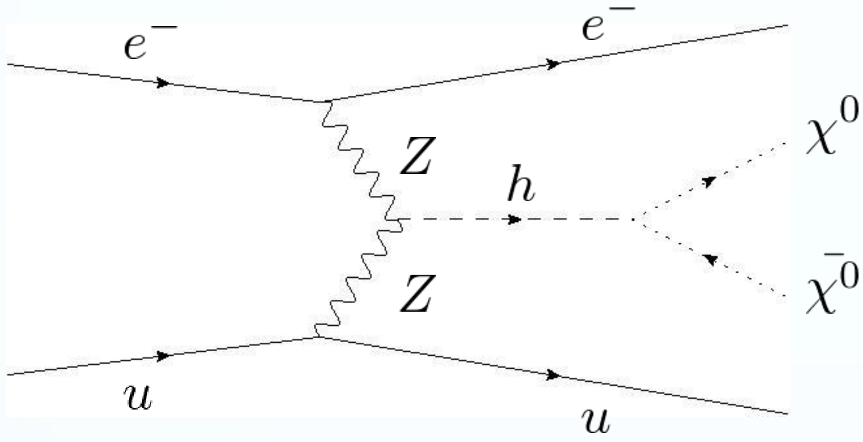
Statistical significance

→ potential much enhanced for FCC-eh @ 3.5 TeV & HE-LHC-eh @ 1.8 TeV

Invisible Higgs Decay @ FCC-eh

[Satoshi Kawaguchi, Masahiro Kuze (Tokyo Inst. of Tech.)]

NC production of an invisible Higgs



Final state: 1 fwd j + 1 e^- + MET

Dominant Background:
W^-(->e^-v) j *v*, Z(->*vv*) j e^-, $W^{+/-}$ j e^-

→ Delphes detector level
→ BDT-based analysis

BR(h -> inv.) at 2σ level

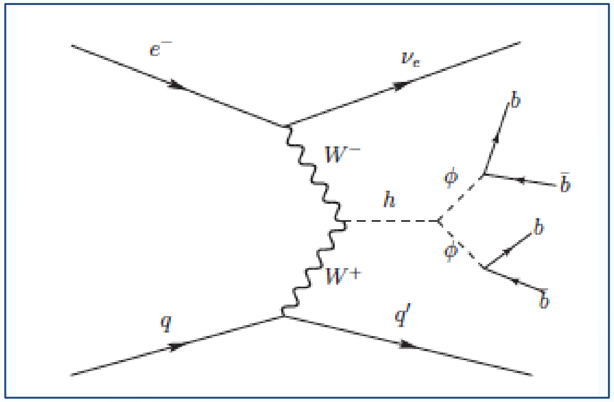
Delphes detector	LHeC	DLHeC	FCC-eh
	1.3 TeV	1.8 TeV	3.5 TeV
LHC-style	4.7%	3.2%	1.9%
First ‘ep-style’	5.7%		2.6%

Exotic Higgs Decays

Cut-based Analysis @ LHeC [S. Liu, Y. Tang, C. Zhang, S. Zhu, 1608.08458]

Introducing a new real scalar ϕ with effective interaction

$$\mathcal{L}_{eff} = \lambda_h v h \phi^2 + \lambda_b \phi \bar{b} b + \mathcal{L}_{\phi\,\mathrm{decay,other}}$$



Final state: 1 fwd j + 4 b + MET

Parton level, 95% C.L.
=> m_ϕ = 20, 40, 60 GeV, 0.3%, 0.2%, 0.1% precisions
for $C_{4b}^2 = \kappa_V^2 \times \mathrm{Br}(h \to \varphi\varphi) \times \mathrm{Br}^2(\varphi \to bb)$

BDT Analysis @ FCC-eh Delphes-detctor level
Significances after BDT > 0. [Uta Klein, Michael o'Keefe (U of Liverpool)]

P_e=-80%, L=1000 fb^{-1}

	M_φ (GeV)					
	20			60		
BR (%)	σ (fb)	Δσ (fb)	Z	σ (fb)	Δσ (fb)	Z
0.2	0.03	0.02	1.14	0.03	0.03	1.17
0.4	0.05	0.02	2.27	0.07	0.03	2.33
0.6	0.08	0.02	3.37	0.10	0.03	3.47
0.8	0.10	0.02	4.46	0.13	0.03	4.59
1	0.13	0.03	5.54	0.17	0.03	5.71

$$Z = \sqrt{2\left[(S+B)\ln\left(1+\frac{S}{B}\right) - S\right]}$$

Discover limits:
BR ~ 1% for 1000 fb^{-1}
BR ~ 10% for 100 fb^{-1}
(within 1 year)

Summary & Outlook

- ★ LHeC/FCC-eh offers a variety of opportunities for Higgs physics
  We explore the potential of SM and BSM Higgs searches

- ★ SM Higgs
  → Hbb
  → Hcc

- ★ Exploring New physics:
  → Top Yukawa coupling
  → Constraining EFT operators via di-Higgs measurements
  → Invisible Higgs decay
  → Exotic Higgs decay: $h \to \phi\phi \to 4b$

- ★ Physics potential yet to be fully exploited
  → Complementary between pp, ep & ee
  → More studies ongoing (Htt, HWW, HZZ, total Higgs decay width, H^{++}, H^{+} ...)
  → You are welcome !!!

More details,

see [Uta Klein's talk "FCC-eh SM and BSM Higgs Studies" in the FCC week 2017, https://indico.cern.ch/event/556692/contributions/2510778/attachments/1468874/2272276/FCC_Berlin_UKlein_01.06.2017.pdf]

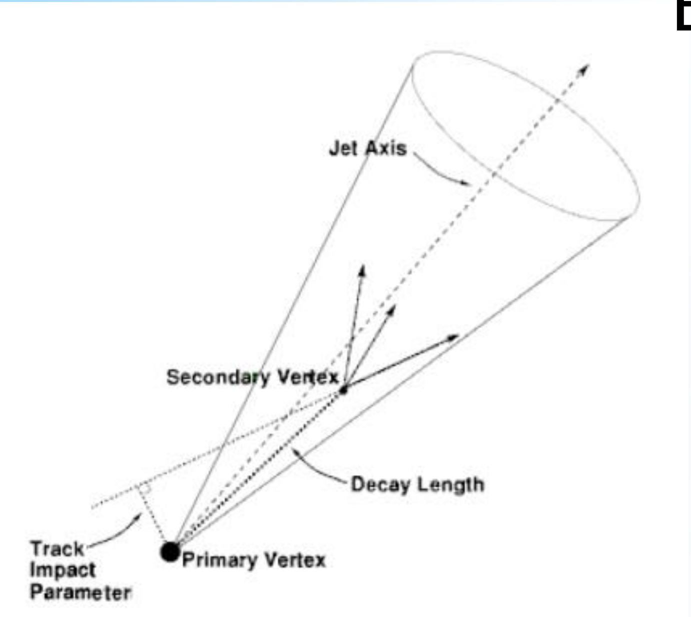
Thank you for your attention !

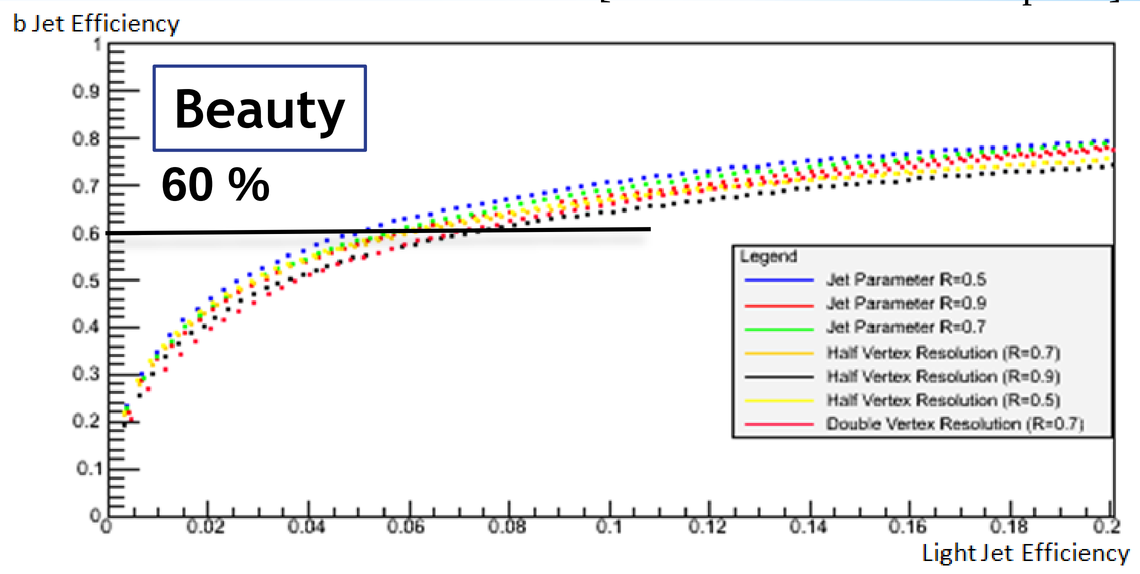
Any Questions ?

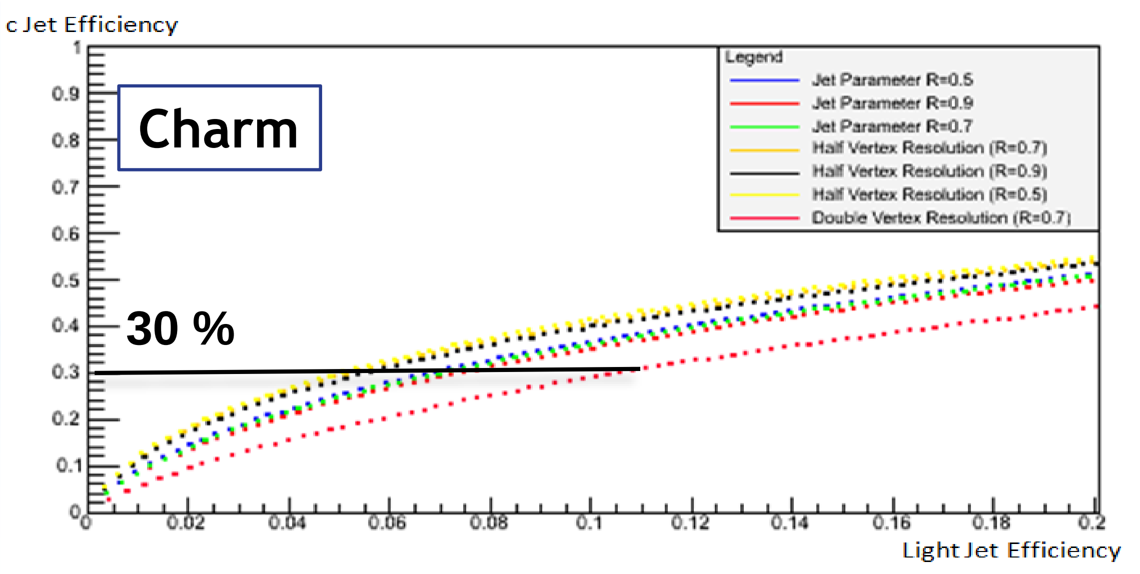
Backup Slides

HFL Tagging

[Uta Klein & Daniel Hampson]

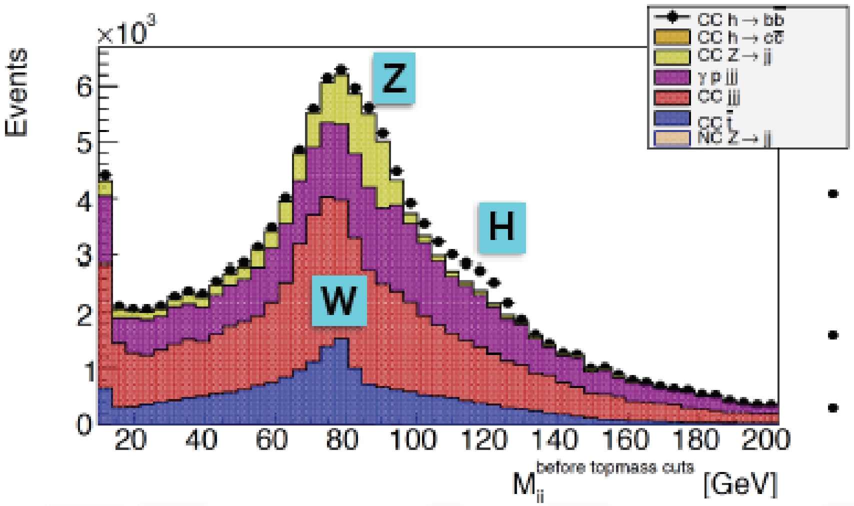




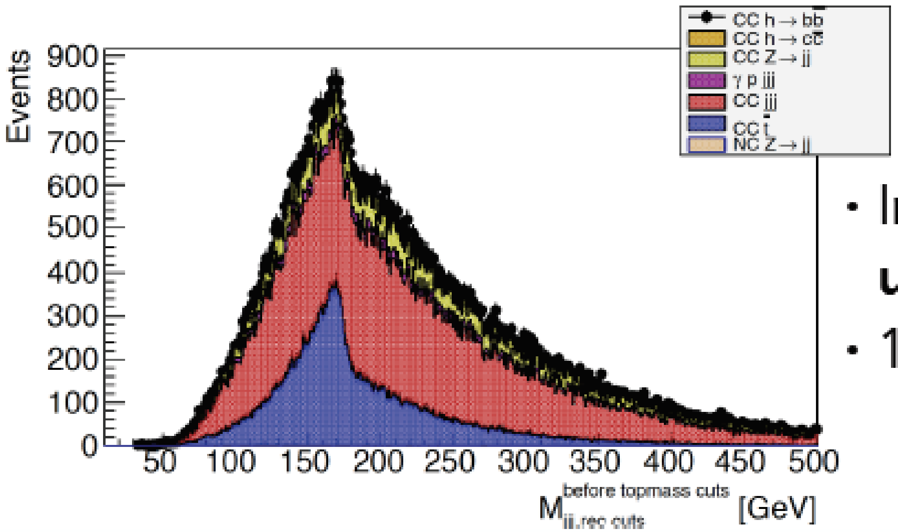


- → Realistic and conservative HFL tagging within Delphes realised, and dependence on vertex resolution (nominal 10 μm) and anti-kt jet radius studied
- → Light jet rejection very conservative, i.e. factor 10 worse than ATLAS
- → **Used in full LHeC analysis and for FCC-eh extrapolations**

Higgs w/o HFL tagging



- Invariant Di-jet Mass using 2 lowest eta **un-tagged** jets.
- 100% photo production background.
- No anti top cut.



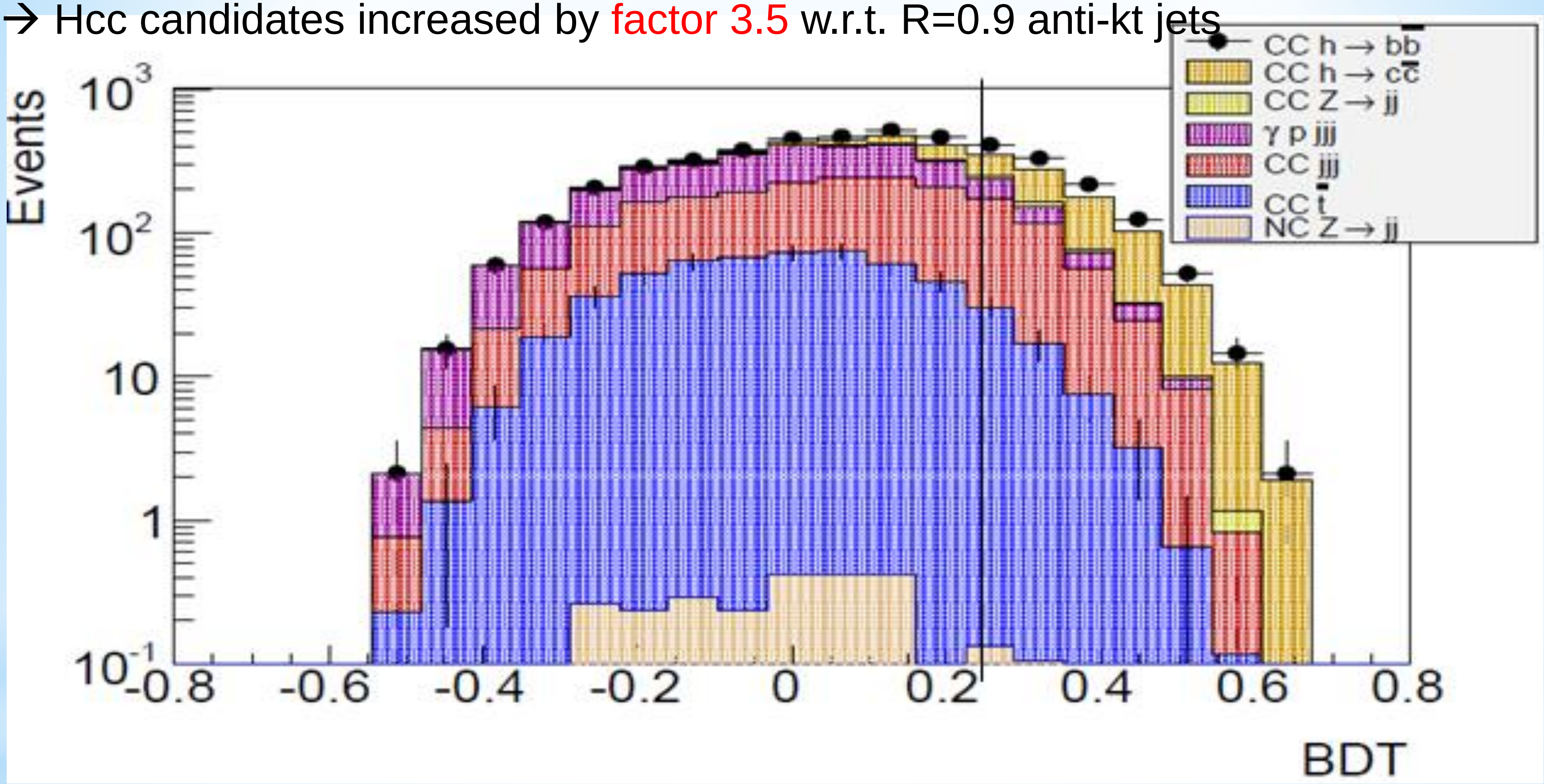
- Invariant Mass of 3 highest p_T **un-tagged** jets.
- 10% photo production background.

BDT Result for Hcc @ LHeC

[Uta Klein & Daniel Hampson]

NEW : Using R = 0.5 anti-kt jets and ATLAS IBL vertex resolution (5 μm)

→ Hcc candidates increased by factor 3.5 w.r.t. R=0.9 anti-kt jets



BDT cut > 0.2

→ Hcc Signal events: ~ 474

→ S/√S+B=12.8

=> κ(Hcc) = 4% for 1000 fb^{-1}

→ Clear potential to access the Higgs to charm decay channel in ep.

Exploring SM EFT

[M. Trott @ LHeC Workshop 2014
http://lhec.web.cern.ch]

In the absence of any explicit new states, or overwhelming theory prejudice, the goal is to systematically study the SM EFT for hints of NP, using all possible future facilities to maximize physics conclusions.

What is the SM EFT? A linear realization of gauge symmetry and the new state is a 0+ scalar:

Four fermion operators with leptons and quark fields:

$8:(\bar{L}L)(\bar{L}L)$	
Q_{ll}	$(\bar{l}_p\gamma_\mu l_r)(\bar{l}_s\gamma^\mu l_t)$
$Q_{qq}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{q}_s\gamma^\mu q_t)$
$Q_{qq}^{(3)}$	$(\bar{q}_p\gamma_\mu\tau^I q_r)(\bar{q}_s\gamma^\mu\tau^I q_t)$
$Q_{lq}^{(1)}$	$(\bar{l}_p\gamma_\mu l_r)(\bar{q}_s\gamma^\mu q_t)$
$Q_{lq}^{(3)}$	$(\bar{l}_p\gamma_\mu\tau^I l_r)(\bar{q}_s\gamma^\mu\tau^I q_t)$

$8:(\bar{R}R)(\bar{R}R)$	
Q_{ee}	$(\bar{e}_p\gamma_\mu e_r)(\bar{e}_s\gamma^\mu e_t)$
Q_{uu}	$(\bar{u}_p\gamma_\mu u_r)(\bar{u}_s\gamma^\mu u_t)$
Q_{dd}	$(\bar{d}_p\gamma_\mu d_r)(\bar{d}_s\gamma^\mu d_t)$
Q_{eu}	$(\bar{e}_p\gamma_\mu e_r)(\bar{u}_s\gamma^\mu u_t)$
Q_{ed}	$(\bar{e}_p\gamma_\mu e_r)(\bar{d}_s\gamma^\mu d_t)$
$Q_{ud}^{(1)}$	$(\bar{u}_p\gamma_\mu u_r)(\bar{d}_s\gamma^\mu d_t)$
$Q_{ud}^{(8)}$	$(\bar{u}_p\gamma_\mu T^A u_r)(\bar{d}_s\gamma^\mu T^A d_t)$

$8:(\bar{L}L)(\bar{R}R)$	
Q_{le}	$(\bar{l}_p\gamma_\mu l_r)(\bar{e}_s\gamma^\mu e_t)$
Q_{lu}	$(\bar{l}_p\gamma_\mu l_r)(\bar{u}_s\gamma^\mu u_t)$
Q_{ld}	$(\bar{l}_p\gamma_\mu l_r)(\bar{d}_s\gamma^\mu d_t)$
Q_{qe}	$(\bar{q}_p\gamma_\mu q_r)(\bar{e}_s\gamma^\mu e_t)$
$Q_{qu}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{u}_s\gamma^\mu u_t)$
$Q_{qu}^{(8)}$	$(\bar{q}_p\gamma_\mu T^A q_r)(\bar{u}_s\gamma^\mu T^A u_t)$
$Q_{qd}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{d}_s\gamma^\mu d_t)$
$Q_{qd}^{(8)}$	$(\bar{q}_p\gamma_\mu T^A q_r)(\bar{d}_s\gamma^\mu T^A d_t)$

$8:(\bar{L}R)(\bar{R}L)+\text{h.c.}$	
Q_{ledq}	$(\bar{l}_p^j e_r)(\bar{d}_s q_{tj})$

$8:(\bar{L}R)(\bar{L}R)+\text{h.c.}$	
$Q_{quqd}^{(1)}$	$(\bar{q}_p^j u_r)\epsilon_{jk}(\bar{q}_s^k d_t)$
$Q_{quqd}^{(8)}$	$(\bar{q}_p^j T^A u_r)\epsilon_{jk}(\bar{q}_s^k T^A d_t)$
$Q_{lequ}^{(1)}$	$(\bar{l}_p^j e_r)\epsilon_{jk}(\bar{q}_s^k u_t)$
$Q_{lequ}^{(3)}$	$(\bar{l}_p^j\sigma_{\mu\nu}e_r)\epsilon_{jk}(\bar{q}_s^k\sigma^{\mu\nu}u_t)$

Number of 4 fermion parameters with lepton-quark: $13\,n_g^4$ *or* 1053 *of* 2499

- ➔ 59 operators or 2499 parameters experimentally to constraint!
- ➔ where nearly 50% of the parameters (1053) are sensitive to lepton-quark interactions – not just about lepto-quarks

Effective vertices

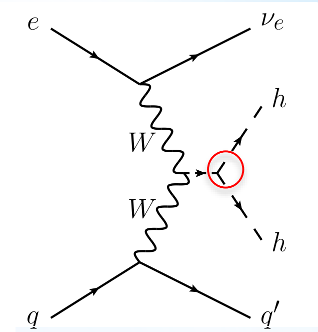
[1509.04016]

FCC-eh SM(P_e=-0.8) σ(HH)=430 ab in VBF !

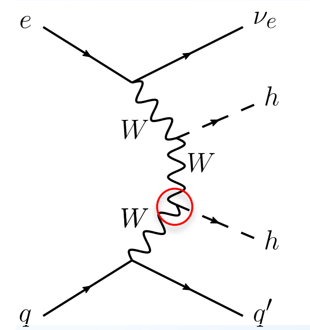
$$\Gamma_{hhh} = -6\lambda v\left[g^{(1)}_{hhh} + \frac{g^{(2)}_{hhh}}{3m_h^2}(p_1\cdot p_2 + p_2\cdot p_3 + p_3\cdot p_1)\right], \qquad (6)$$

$$\Gamma_{hW^-W^+} = g m_W\left[\left\{1 + \frac{g^{(1)}_{hWW}}{m_W^2}p_2\cdot p_3 + \frac{g^{(2)}_{hWW}}{m_W^2}(p_2^2 + p_3^2)\right\}\eta^{\mu_2\mu_3} - \frac{g^{(1)}_{hWW}}{m_W^2}p_2^{\mu_3}p_3^{\mu_2} - \frac{g^{(2)}_{hWW}}{m_W^2}(p_2^{\mu_2}p_2^{\mu_3} + p_3^{\mu_2}p_3^{\mu_3}) - \mathrm{i}\frac{\tilde{g}_{hWW}}{m_W^2}\epsilon_{\mu_2\mu_3\mu\nu}p_2^{\mu}p_3^{\nu}\right], \qquad (7)$$

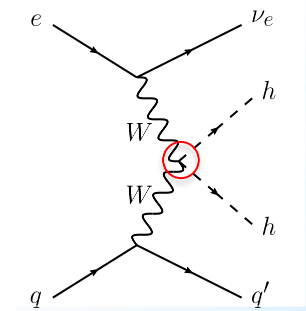
$$\Gamma_{hhW^-W^+} = g^2\left[\left\{\frac{1}{2} + \frac{g^{(1)}_{hhWW}}{m_W^2}p_3\cdot p_4 + \frac{g^{(2)}_{hhWW}}{m_W^2}(p_3^2 + p_4^2)\right\}\eta^{\mu_3\mu_4} - \frac{g^{(1)}_{hhWW}}{m_W^2}p_3^{\mu_4}p_4^{\mu_3} - \frac{g^{(2)}_{hhWW}}{m_W^2}(p_3^{\mu_3}p_3^{\mu_4} + p_4^{\mu_3}p_4^{\mu_4}) - \mathrm{i}\frac{\tilde{g}_{hhWW}}{m_W^2}\epsilon_{\mu_3\mu_4\mu\nu}p_3^{\mu}p_4^{\nu}\right]. \qquad (8)$$



1,2,3= h,h,h



1,2,3 = h,W-,W+

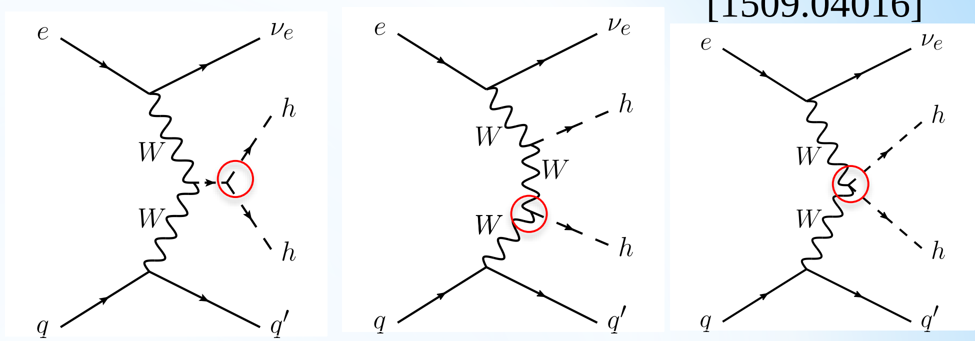


1,2,3,4 = h,h,W-,W+

Note the dependence on momenta in non-SM vertices. This induces significant impact on scattering kinematics.

Double Higgs Production @ FCC-eh

[1509.04016]



Event Selection using h->bb

1 fwd j + 4 b + MET

Assumptions:
P_e=-0.8, anti-kt jets with R=0.4 ;
b-tagging efficiency for |η| < 5 ~ 70%,
misidentification rate ~ 10% for charm and 1% for light quarks /gluons .

Delphes detector-level

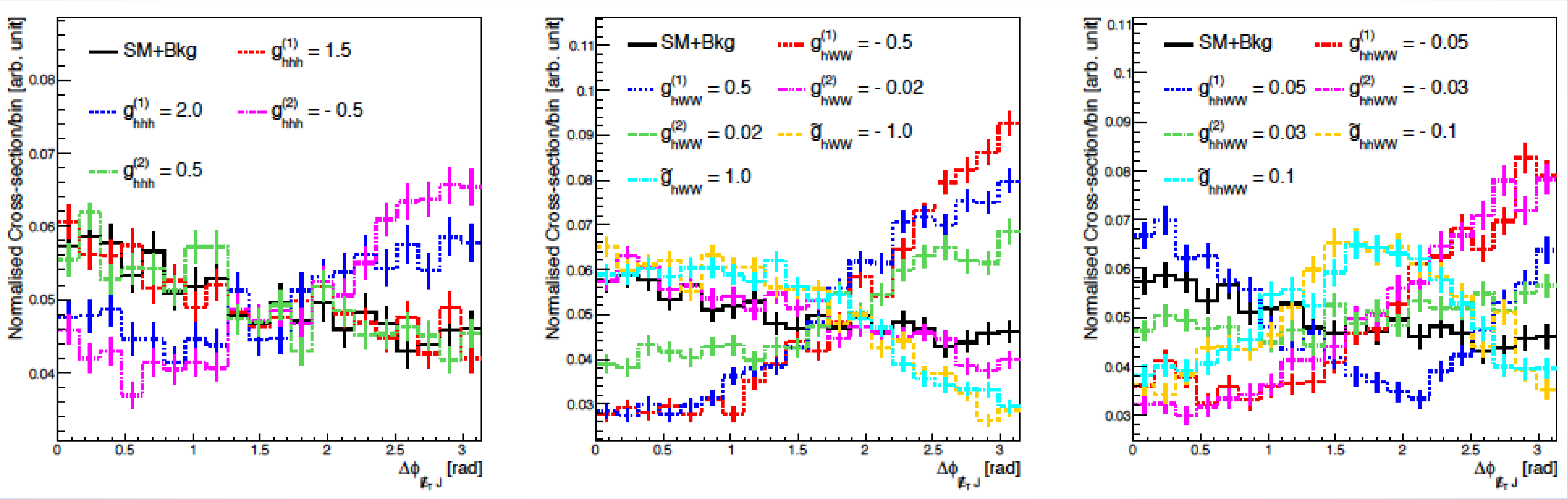
$$S = \sqrt{2[(S+B)\log(1+S/B) - S]}$$

Cuts / Samples	Signal	4b+jets	2b+jets	Top	ZZ	$b\bar{b}H$	ZH	Total Bkg	Significance
Initial	2.00×10^3	3.21×10^7	2.32×10^9	7.42×10^6	7.70×10^3	1.94×10^4	6.97×10^3	2.36×10^9	0.04
At least $4b + 1j$	3.11×10^2	7.08×10^4	2.56×10^4	9.87×10^3	7.00×10^2	6.32×10^2	7.23×10^2	1.08×10^5	0.94
Lepton rejection $p_T^\ell > 10$ GeV	3.11×10^2	5.95×10^4	9.94×10^3	6.44×10^3	6.92×10^2	2.26×10^2	7.16×10^2	7.75×10^4	1.12
Forward jet $\eta_J > 4.0$	233	13007.30	2151.15	307.67	381.04	46.82	503.22	16397.19	1.82
$\not{E}_T > 40$ GeV	155	963.20	129.38	85.81	342.18	19.11	388.25	1927.93	3.48
$\Delta\phi_{\not{E}_T j} > 0.4$	133	439.79	61.80	63.99	287.10	14.53	337.14	1204.35	3.76
$m_{bb}^1 \in [95, 125]$, $m_{bb}^2 \in [90, 125]$	54.5	28.69	5.89	6.68	5.14	1.42	17.41	65.23	6.04
$m_{4b} > 290$ GeV	49.2	10.98	1.74	2.90	1.39	1.21	11.01	29.23	7.51

Azimuthal Angle Distributions

[1509.04016]

between missing transverse energy and forward jet, at Delphes detector-level, including background : bbbbj, bbjjj, Z(bb)h(bb)j, ttj, h(bb)bbj
→ For signal, we consider hh→ bbbb decays motivated by h→bb studies.

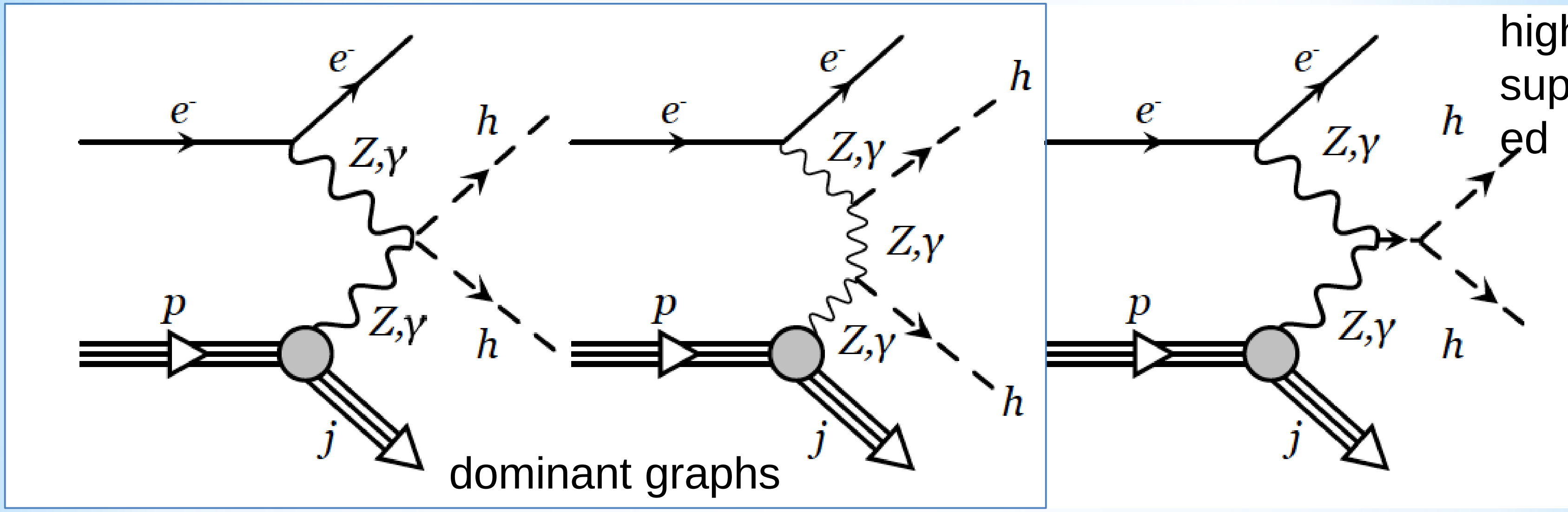


→ normalized DIS cross sections (kinematical distributions) are sensitive to non-BSM vertices
→ initial study published for this novel variable
→ potential for a deeper analysis and interpretation

Double Higgs Production @ FCC-eh

Limits on Di-Boson & Di-Higgs Interactions

[S. Kuday, H. Saygin, I. Hos, F. Cetin, 1702.00185]



- Vertices for Neutral Current DIS (Z, γ) and Photoproduction (γ) studied in Higgs Effective Langrangian Model : parametrise hhZZ and hhγγ in 4-point interactions in terms of CP-even and CP-odd Wilson coefficients (and Higgs self coupling and Yukawa coupling)
- Study at Delphes-detector level (FCC-hh) azimuthal dependencies between scattered lepton and forward jet
- hh : 4b final states investigated using a very first version of FCC-hh detector
- Promising sensitivity found while scanning parameter space for Wilson coefficients

Invisible Higgs Decay @ FCC-eh

Dominant Background

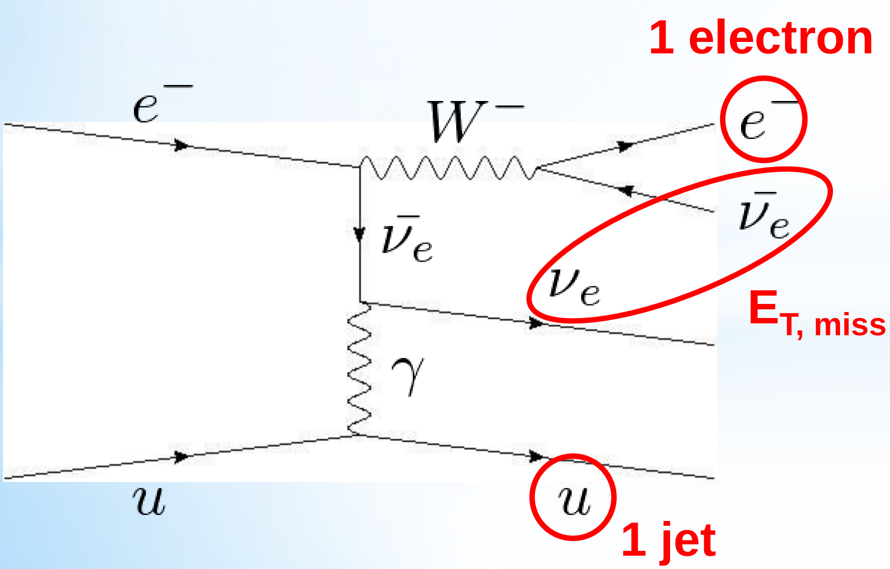
[Satoshi Kawaguchi, Masahiro Kuze (Tokyo Inst. of Tech.)]

W^+je^- and W^-je^- backgrounds and

background

$$p + e^- \to W^- + j + \nu_e$$

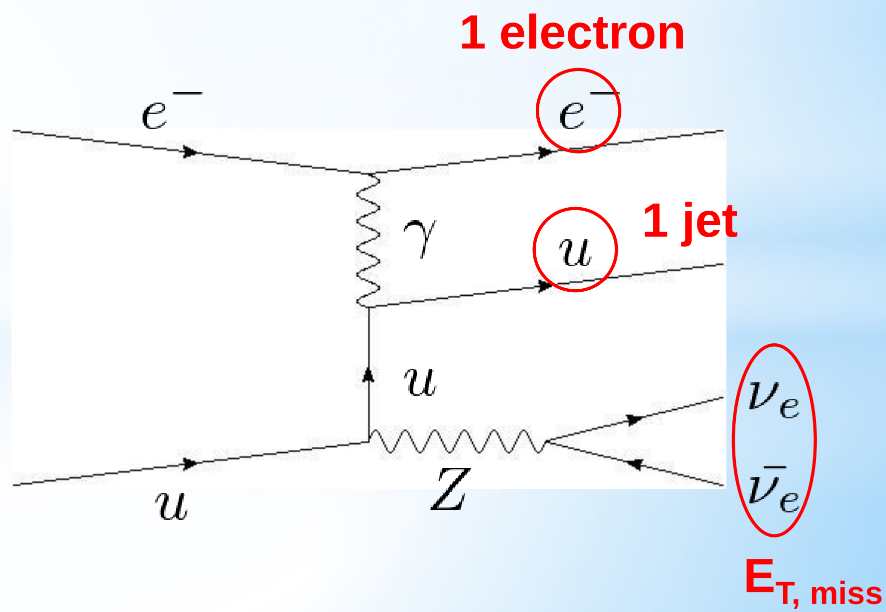
$$W^- \to e^- + \nu_e$$



background

$$p + e^- \to Z + j + e^-$$

$$Z \to \nu + \bar{\nu}$$

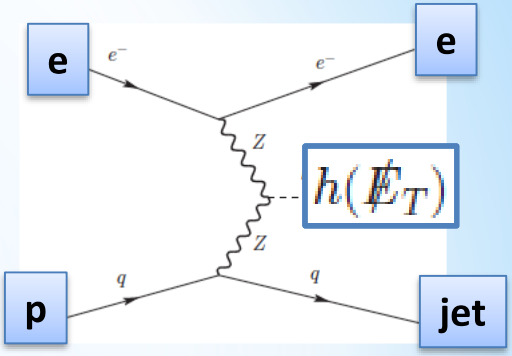


Invisible Higgs Decay @ FCC-eh

Selection Requirements

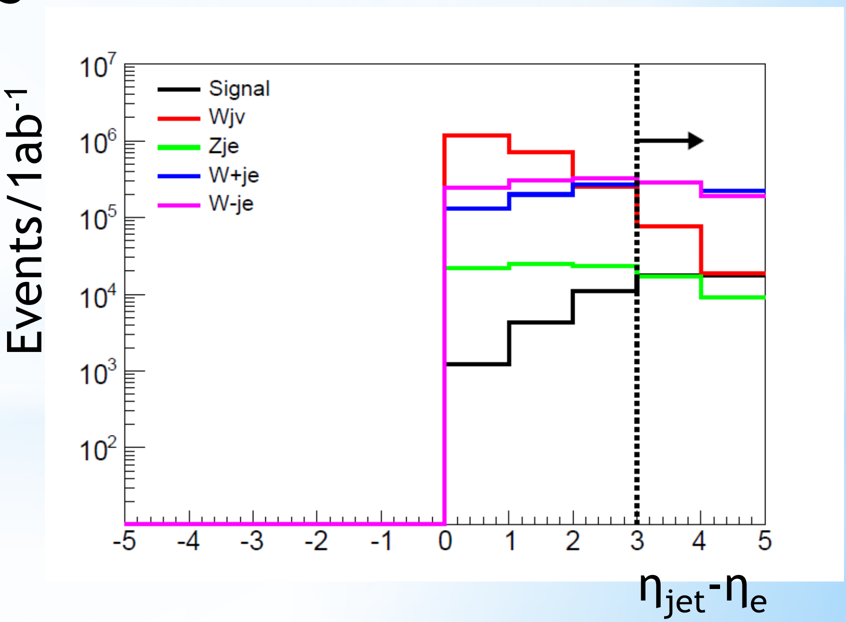
[Satoshi Kawaguchi, Masahiro Kuze (Tokyo Inst. of Tech.)]

Basic cuts (Cut 0)



- N(jets) for the jet and the electron
- pT for the leading jet and the leading electron
- for the leading jet and the leading electron
- for the leading jet and the leading electron

Cut 1 : $|\Delta\phi_{jet,Etmiss}| > 1$ rad
Cut 2 : Etmiss > 50 GeV
Cut 3 : $\eta_{jet}-\eta_e > 3$
Cut 4 : $\phi_{jet} - \phi_e < 2.4$
Cut 5 : $-1.3 < \eta_e < 1.1$
Cut 6 : $0.08 < y_e < 0.55$
Cut 7 : require 1 electron, 1 jet,
and veto tau's and muons



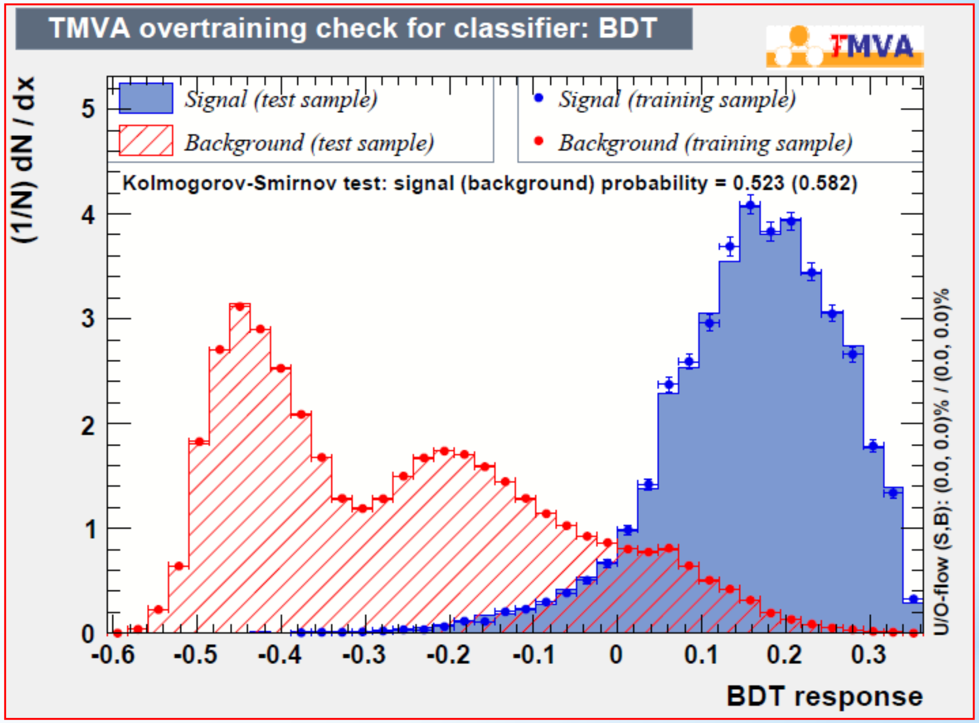
Invisible Higgs Decay @ FCC-eh

Results

[Satoshi Kawaguchi, Masahiro Kuze (Tokyo Inst. of Tech.)]

MVA (BDT) using samples with 1 jet and $1e^-$ with high p_T
other variables as a BDT input.

BDT >	Signal	Bkg	Z[%]
0	31961	267904	3.25
0.05	29932	176439	2.81
0.1	25686	94138	2.40
0.15	19898	42439	2.08
0.2	13020	15562	1.93
0.25	6998	4969	2.04
0.3	2320	1003	2.82



In the case of 2σ

Branching ratio calculated by :

BR(h -> inv.) ~ 1.93%

Exotic Higg Decay @ FCC-eh

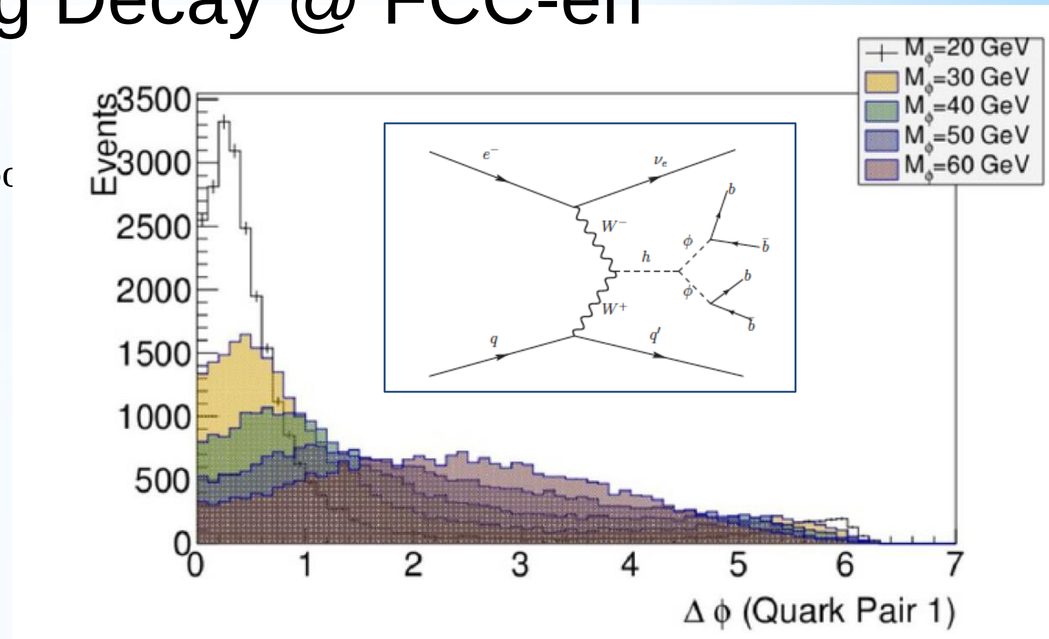
Kinematics @ Quark-level

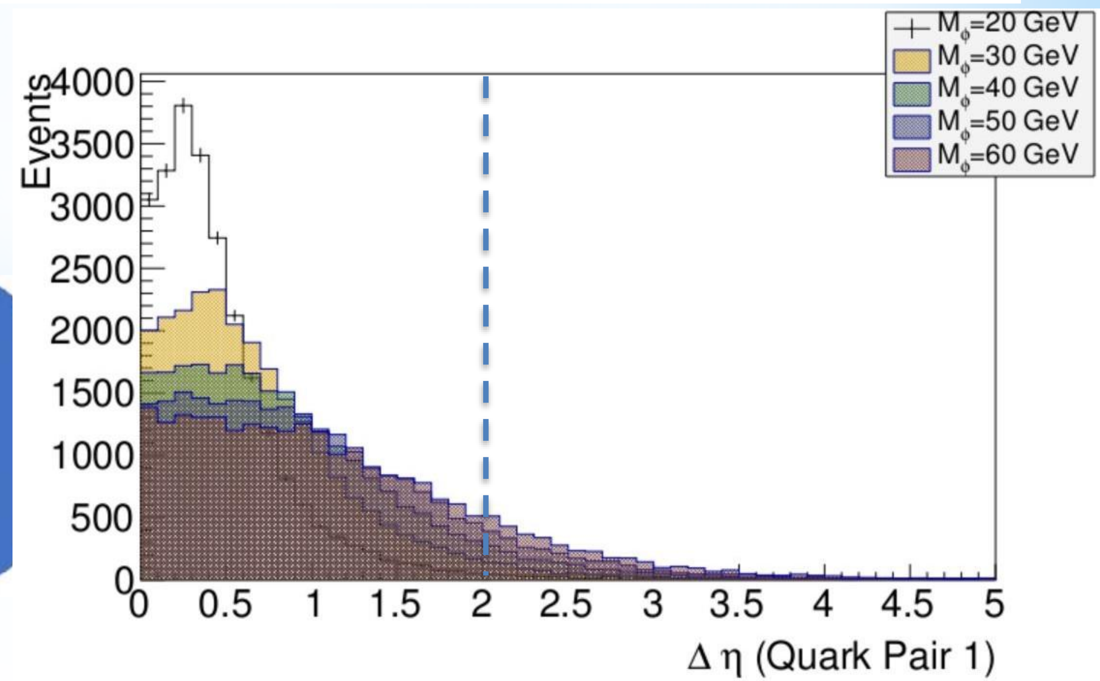
[Uta Klein, Michael o'Keefe (U of Liverpoo

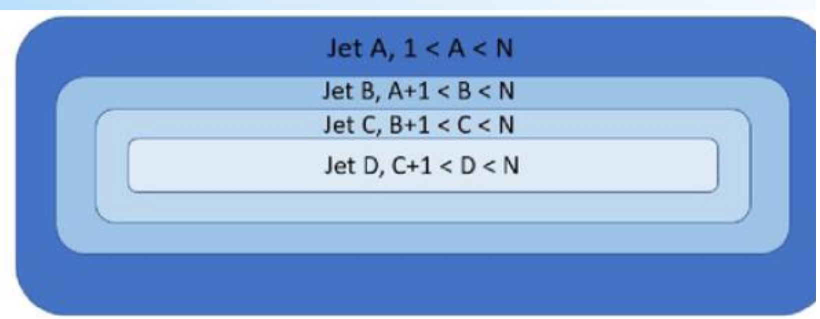
Δφ between b quarks in the scalar (parton level)

Δη between b quarks in the scalar (parton level)

→ use Δη<2 for finding two scalars with mass within $2m_b$ and $m_H/2$ looping over N jets minimising Δm



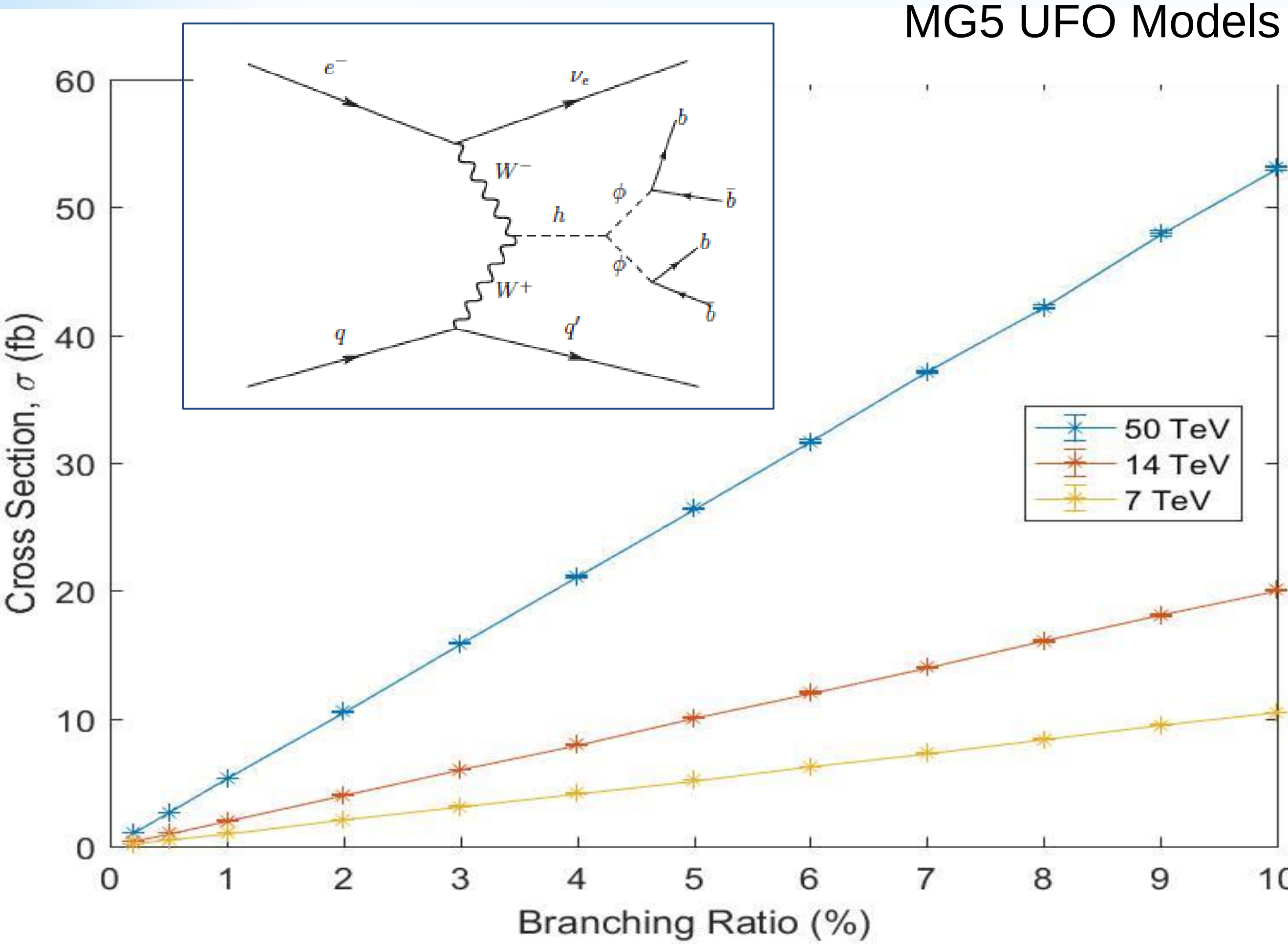




Exotic Higg Decay @ FCC-eh

[Uta Klein, Michael o'Keefe (U of Liverpool)]

MG5 UFO Models from [1608.08458]



FCC-eh @ 3.5TeV

DLHeC @ 1.8 TeV

LHeC @ 1.3 TeV

Values for P_e=0

→ reflecting coupling of new scalar to 125 GeV higgs

Background for H->bb

Typical background processes and assumptions about b-tagging for cut-based study