Large Hadron Electron Collider

（LHeC）和其上的物理

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高能物理会，合肥

2016

Outline

- Why LHeC ?
- Physics highlights @ LHeC
- Exotic Higgs decay@ LHeC
  - Invisible Higgs decay at the LHeC
  - Other exotic Higgs decay channels
- Conclusions and discussions

1. Why LHeC?

A Critical Point in Search of New Physics

NP or not ?

- Experimental status:
  - SM+GR consistent with all observations so far.
- Theoretical side:
  - Naturalness is highly debated.
  - ……

A Critical Point in Search of New Physics

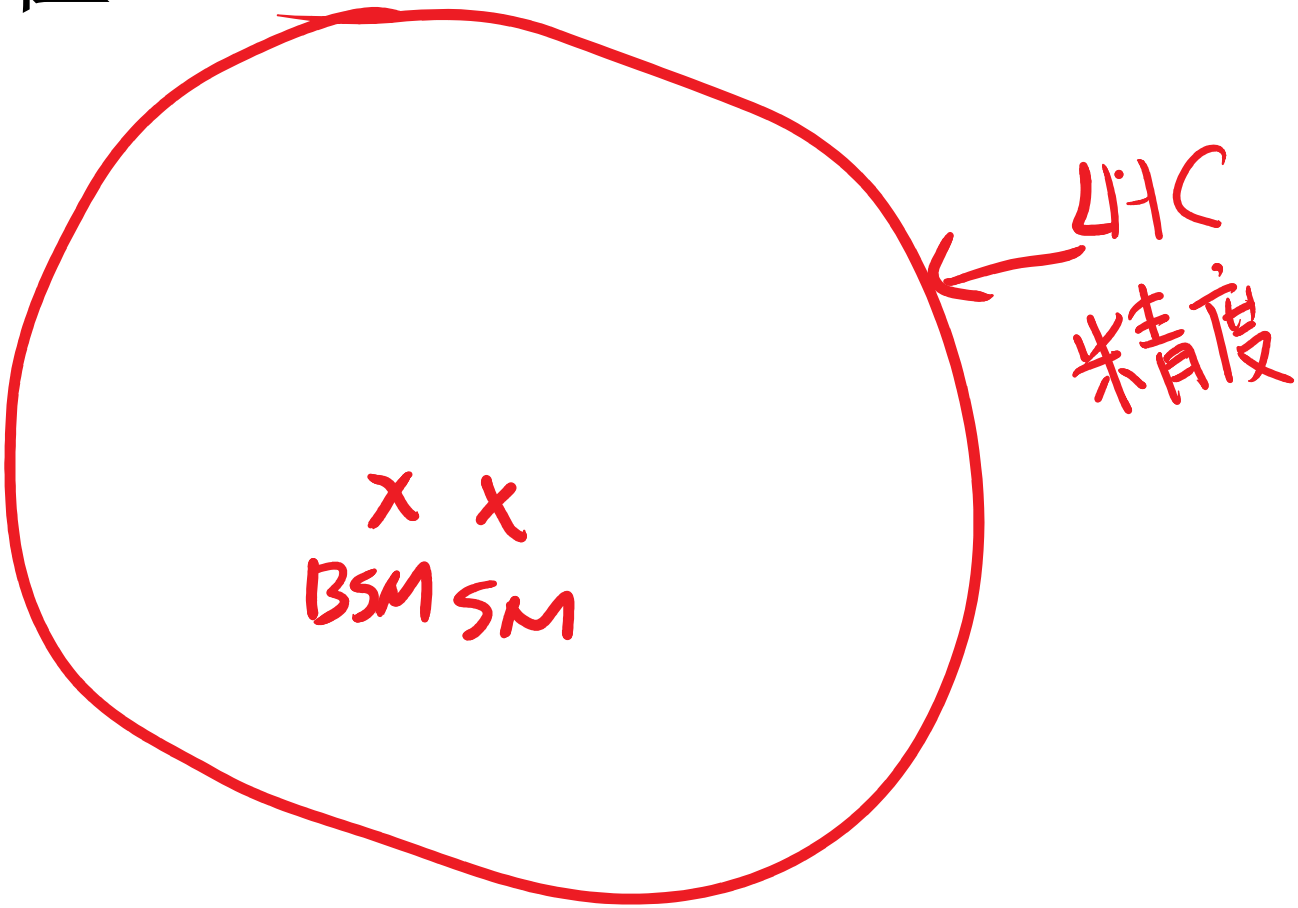
- With no definite experimental clue and irrefutable theoretical guideline at hand, measuring precisely what we already have (eg. Higgs) could become progressively important, both as precision tests of SM and avenues to NP.

The Phenomenological Higgs Landscape

- Mass
- Width
- Spin-Parity
- Coupling
  - hVV, hff, hVff
  - 3h,4h, hhVV
  - FCNC Higgs coupling
- Exotic Higgs Decay
  - h to invisible
  - h to 4b
  - …

D. Curtin et al., Phys.Rev. D90 (2014) no.7, 075004

如何通过精确测量尽快确立BSM存在？



Collider Type Considerations

- (HL-)LHC
  - Large signal cross sections
  - Large backgrounds
  - Large pile-up
    - Higher thresholds needed to control systematics
    - Significant impact on the performance of objects like jet and MET

Significant impact on exotic Higgs decay searches

- Electron-positron collider
  - Small backgrounds
  - Pile-up negligible
  - Small signal cross sections
  - As long as the Br is not too small, e+e- machine will provide an ideal environment for probing exotic Higgs decay.

Electron-Positron collider (CEPC, FCC-ee or ILC) is ideal for studying most of the exotic Higgs decays.

Q:

However, what is the best sensitivity we might achieve if such lepton colliders are not available before the end of HL-LHC? Does there exist any other option?

A: LHeC

HISTORY

eP OPTION PROPOSED SINCE THE BEGINNING OF THE LHC

PHYSICS OF ep COLLISIONS IN THE TeV ENERGY RANGE

G. Altarelli*), B. Mele*) and R. Rückl,
CERN, Geneva, Switzerland
(Presented by G. Altarelli)

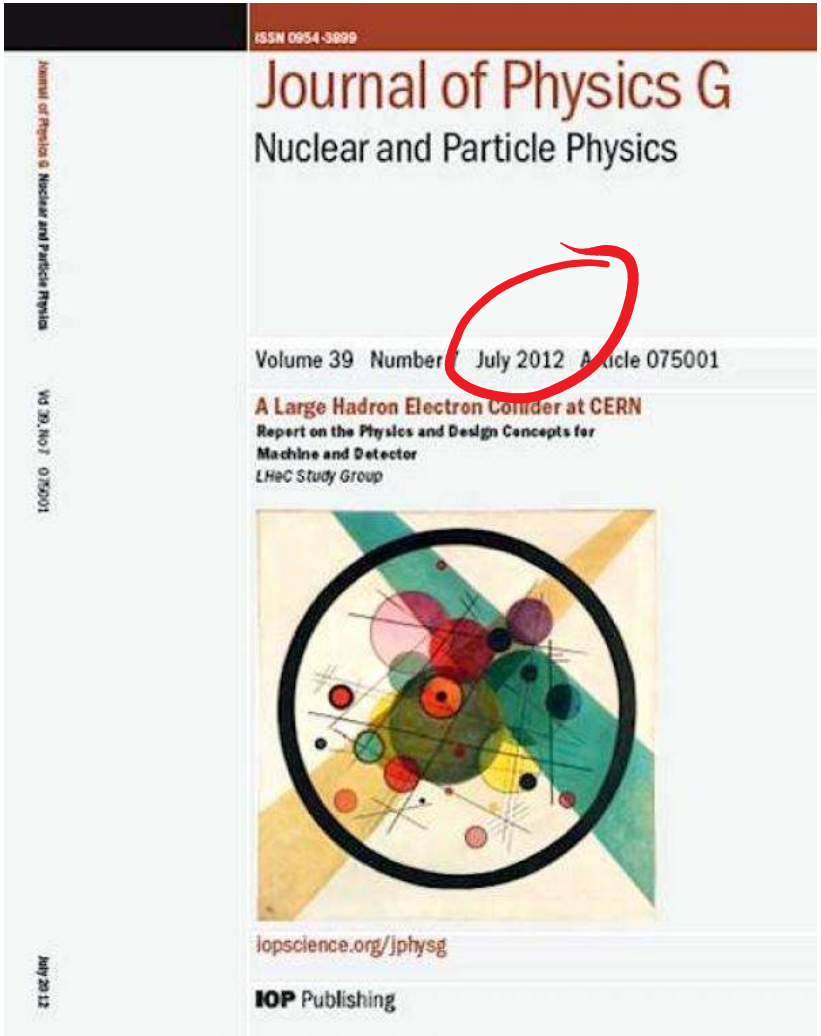
ABSTRACT

We study the physics of electron-proton collisions in the range of centre-of-mass energies between $\sqrt{s}$ = 0.3 TeV (HERA) and $\sqrt{s}$ = (1-2) TeV. The latter energies would be achieved if the electron or positron beam of LEP [E_e = (50-100) GeV] is made to collide with the proton beam of LHC [E_p = (5-10) TeV].

CERN-ECFA workshop, Lausanne, March 1984:
a Large Hadron Collider in the LEP tunnel

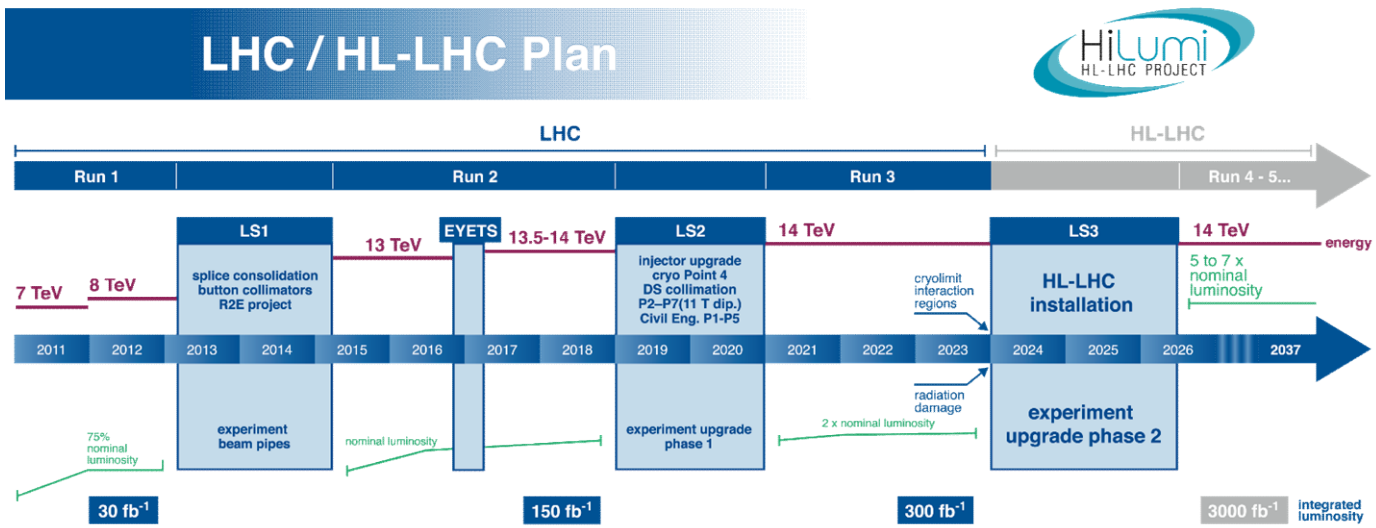
Collider Type Considerations

- LHeC
  - Small backgrounds
  - Pile-up negligible
  - Small signal cross sections


ISSN 0954-3899
Journal of Physics G
Nuclear and Particle Physics
Volume 39 Number 7 July 2012 Article 075001
A Large Hadron Electron Collider at CERN
Report on the Physics and Design Concepts for Machine and Detector
LHeC Study Group
iopscience.org/jphysg
IOP Publishing

LHeC Basic Information

- Time schedule: **expected** to run **synchronously** with HL-LHC (because it has to utilize the proton beam of HL-LHC).



LHeC Basic Information

O. Bruening, LHeC Accelerator Studies and Considerations, talk at LHeC 2015 Workshop
A. Gaddi, LHeC Detector: Preliminary Engineering Study, talk at LHeC 2015 Workshop

- Beam
  - 7 TeV proton (from HL-LHC)
  - 60 GeV electron (Energy limited by power consumption)

    (Electron beam may achieve -80%~-90% polarization)
  - Up to 1ab^{-1} luminosity for precision Higgs studies

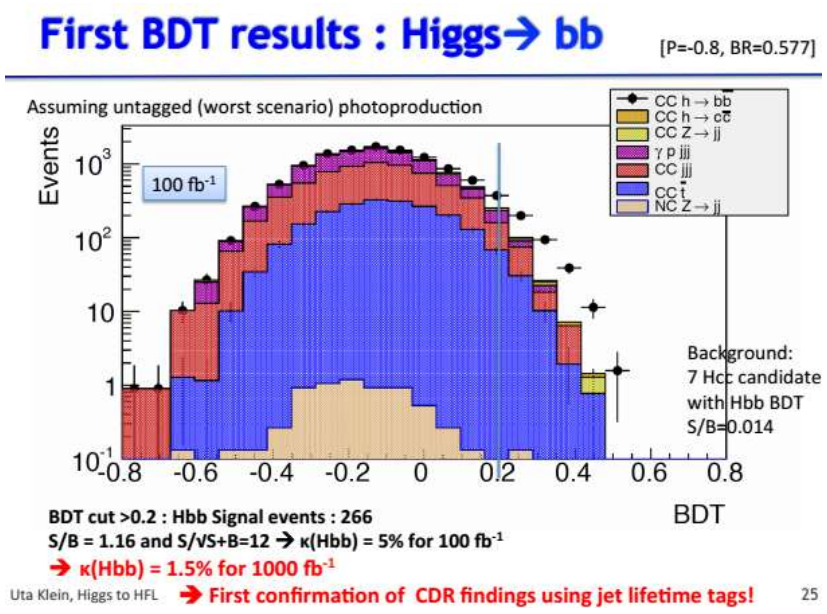
$\sqrt{s} \sim 600$ GeV

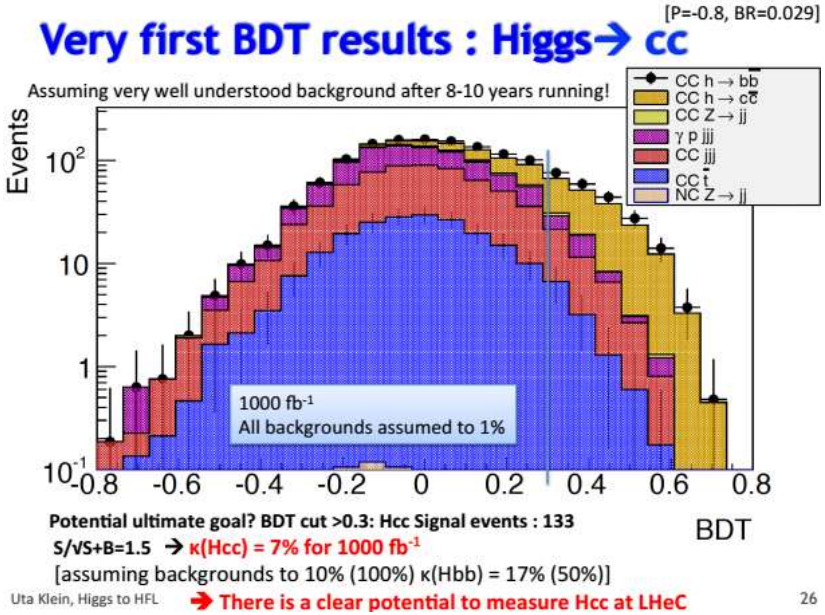
- Detector
  - Very large acceptance (eta coverage up to ~5)

2. Physics Highlights @LHeC

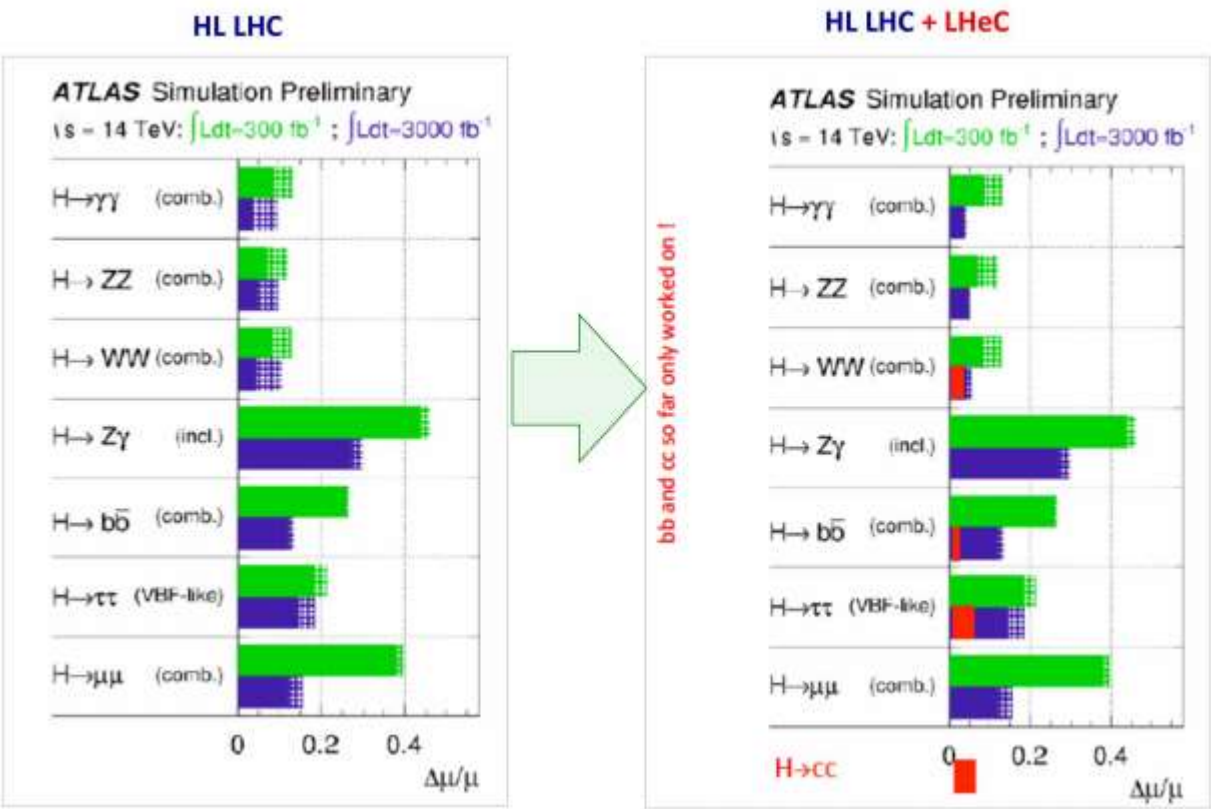
Bottom and Charm Yukawa Measurements

O(1%) determination of Hbb and O(10%) determination of Hcc are possible at the LHeC.





Bottom and Charm Yukawa Measurements



Precision Parton Distribution Functions

(ATLAS 7 & 8 TeV Higgs in diphoton decay channel) Breakdown of systematics

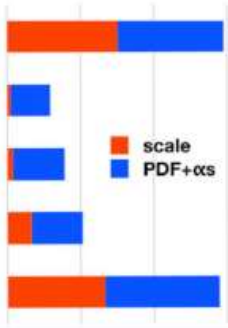
TABLE XIV. Main systematic uncertainties $\sigma_\mu^{\text{syst.}}$ on the combined signal strength parameter μ. The values for each group of uncertainties are determined by subtracting in quadrature from the total uncertainty the change in the 68% CL range on μ when the corresponding nuisance parameters are fixed to their best fit values. The experimental uncertainty on the yield does not include the luminosity contribution, which is accounted for separately.

Uncertainty group	$\sigma_\mu^{\text{syst.}}$
Theory (yield)	0.09
Experimental (yield)	0.02
Luminosity	0.03
MC statistics	< 0.01
Theory (migrations)	0.03
Experimental (migrations)	0.02
Resolution	0.07
Mass scale	0.02
Background shape	0.02

Breakdown of theory systematics for Higgs production

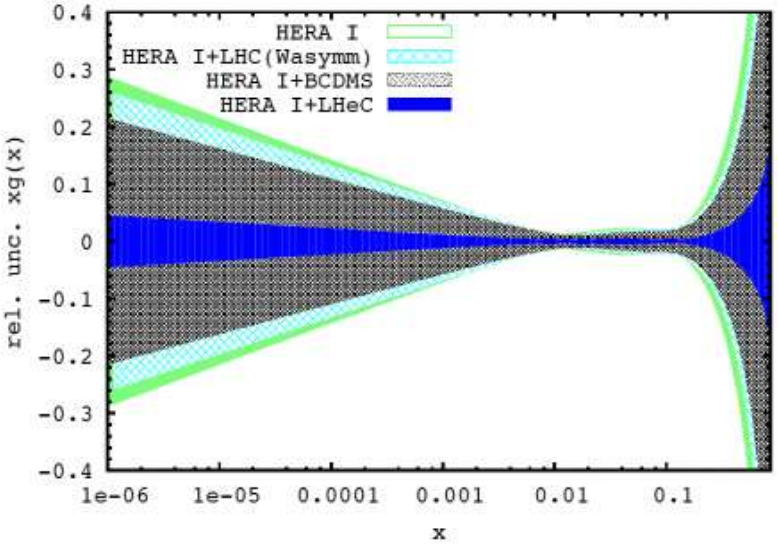
HIGGS PRODUCTION

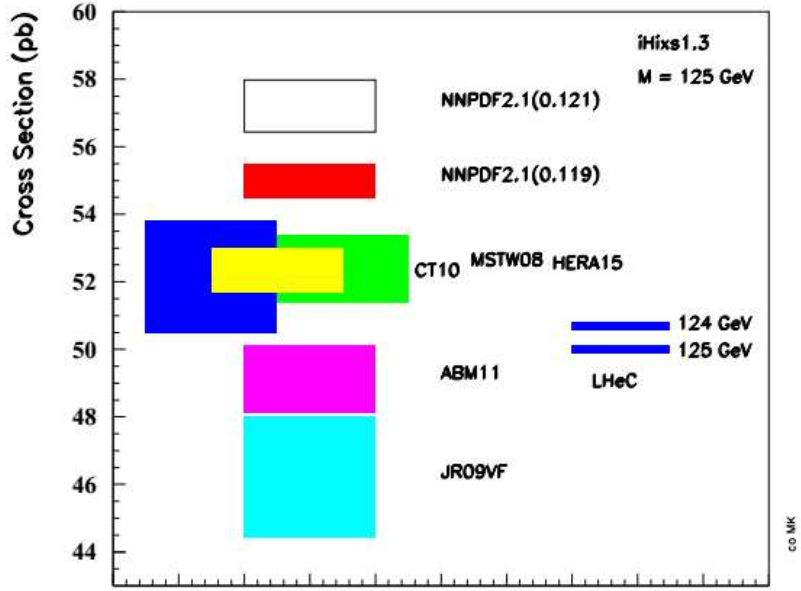
		σ (8 TeV)	uncertainty
NNLL QCD +NLO EW	gg→H	19.5 pb	14.7%
	VBF	1.56 pb	2.9%
NNLO QCD +NLO EW	WH	0.70 pb	3.9%
	ZH	0.39 pb	5.1%
NLO QCD	ttH	0.13 pb	14.4%



Precision PDF

O.Bruening, M. Klein, 1305.2090





$$\sigma = 48.58\,\text{pb}^{+2.22\,\text{pb}\,(+4.56\%)}_{-3.27\,\text{pb}\,(-6.72\%)}\ (\text{theory}) \pm 1.56\,\text{pb}\,(3.20\%)\ (\text{PDF}+\alpha_s)$$

N^{3}LO Higgs cross section(125 GeV, 13 TeV), C. Anastasiou et al., 1602.00695

AlphaS Determination

J. M. Campbell et al., 1310.5189

Method	Current relative precision	Future relative precision
e^+e^- evt shapes	expt $\sim$ 1% (LEP) thry $\sim$ 1–3% (NNLO+up to N^{3}LL, n.p. signif.) [27]	$<$ 1% possible (ILC/TLEP) $\sim$ 1% (control n.p. via Q^2-dep.)
e^+e^- jet rates	expt $\sim$ 2% (LEP) thry $\sim$ 1% (NNLO, n.p. moderate) [28]	$<$ 1% possible (ILC/TLEP) $\sim$ 0.5% (NLL missing)
precision EW	expt $\sim$ 3% (R_Z, LEP) thry $\sim$ 0.5% (N^{3}LO, n.p. small) [9, 29]	0.1% (TLEP [10]), 0.5% (ILC [11]) $\sim$ 0.3% (N^{4}LO feasible, $\sim$ 10 yrs)
τ decays	expt $\sim$ 0.5% (LEP, B-factories) thry $\sim$ 2% (N^{3}LO, n.p. small) [8]	$<$ 0.2% possible (ILC/TLEP) $\sim$ 1% (N^{4}LO feasible, $\sim$ 10 yrs)
ep colliders	$\sim$ 1–2% (pdf fit dependent) [30, 31], (mostly theory, NNLO) [32, 33]	0.1% (LHeC + HERA [23]) $\sim$ 0.5% (at least N^{3}LO required)
hadron colliders	$\sim$ 4% (Tev. jets), $\sim$ 3% (LHC $t\bar{t}$) (NLO jets, NNLO $t\bar{t}$, gluon uncert.) [17, 21, 34]	$<$ 1% challenging (NNLO jets imminent [22])
lattice	$\sim$ 0.5% (Wilson loops, correlators, ...) (limited by accuracy of pert. th.) [35–37]	$\sim$ 0.3% ($\sim$ 5 yrs [38])

Table 1-1. *Summary of current uncertainties in extractions of $\alpha_s(M_Z^2)$ and targets for future (5 – 25 years) determinations. For the cases where theory uncertainties are considered separately, the theory uncertainties for future targets reflect a reduction by a factor of about two.*

Light Quark Weak Neutral Coupling

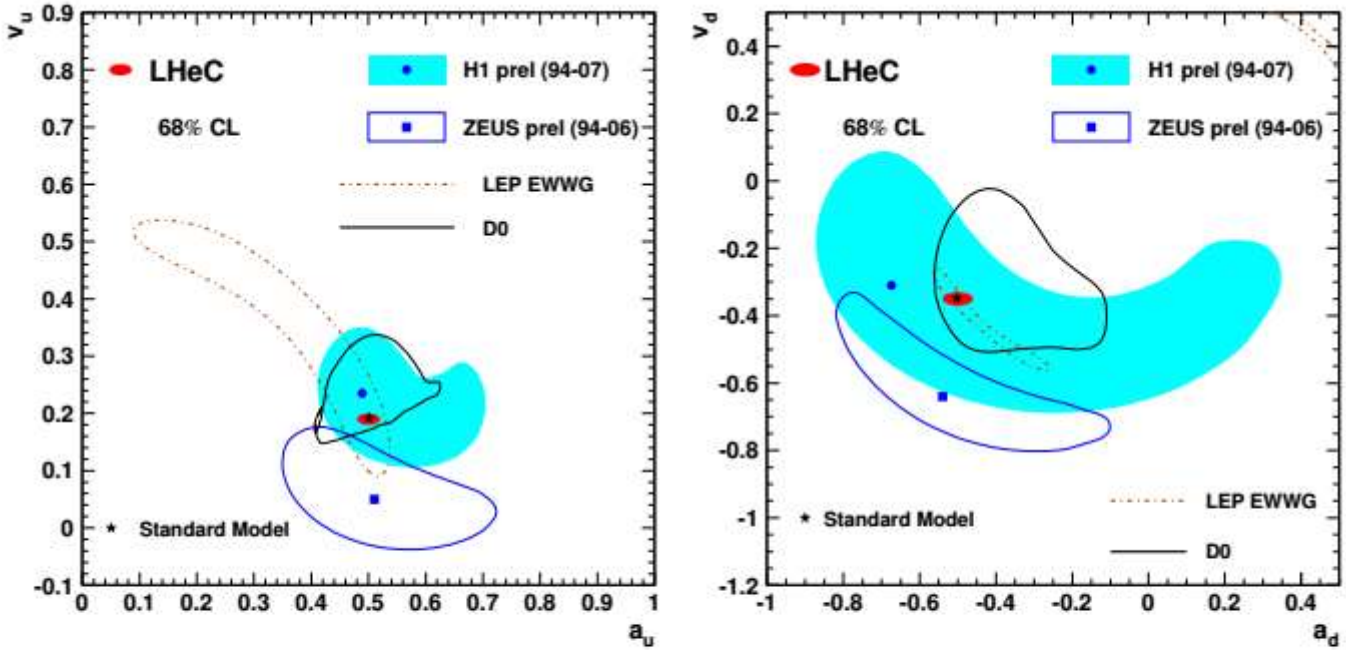
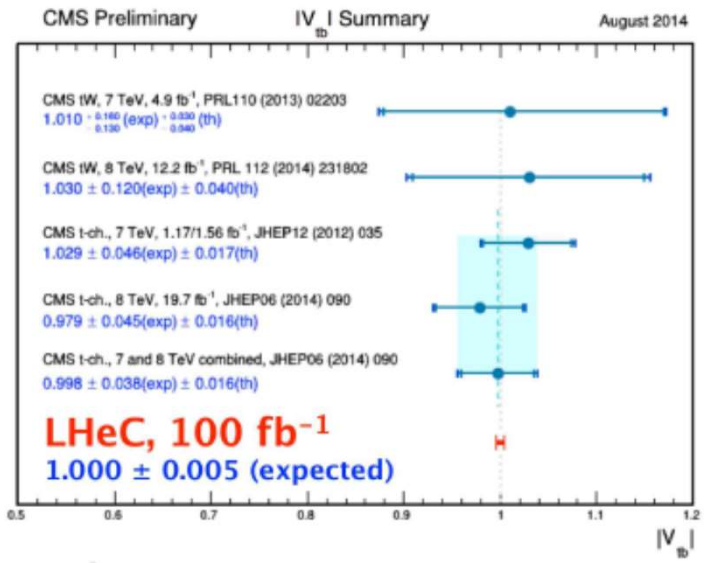


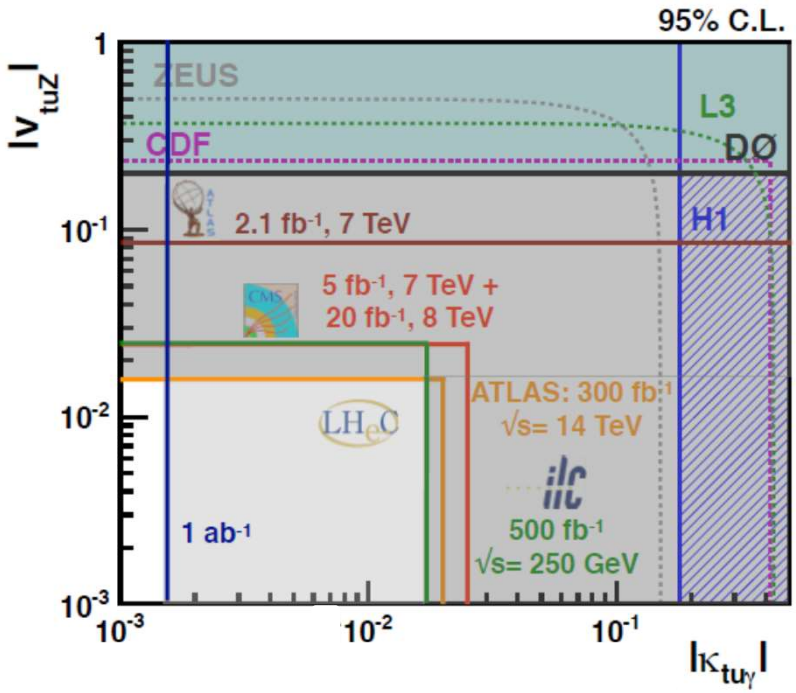
Figure 3.36: Determination of the vector and axial-vector weak neutral current couplings of the light quarks by LEP, DØ, H1 and ZEUS, compared with the simulated prospects for the LHeC.

V_{tb} and Top Quark Anomalous Coupling

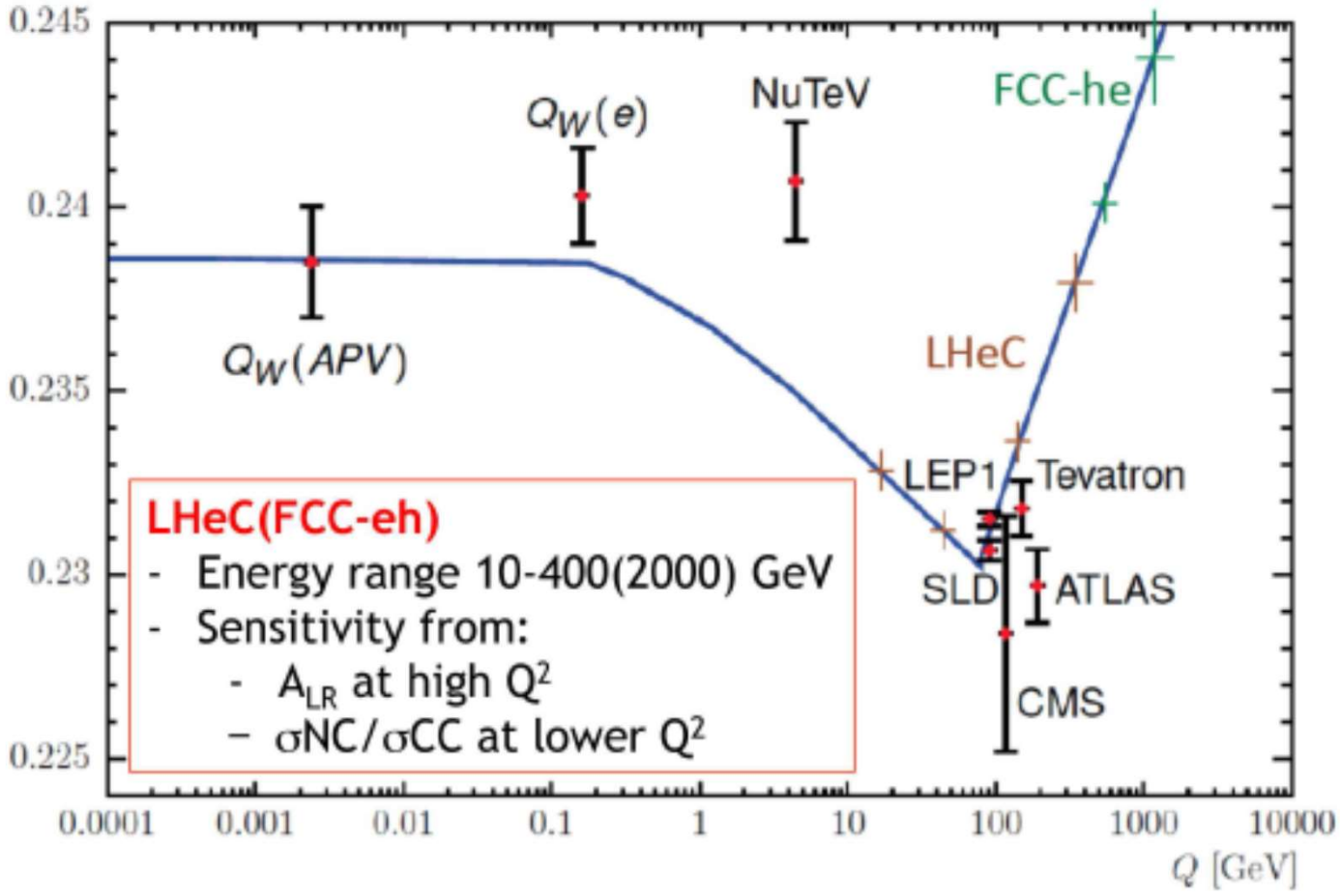
Vtb



Top FCNC



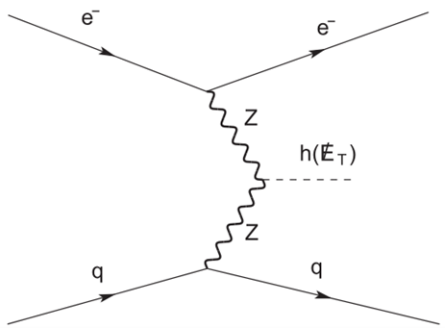
Weak Mixing Angle



3. Exotic Higgs decay @LHeC

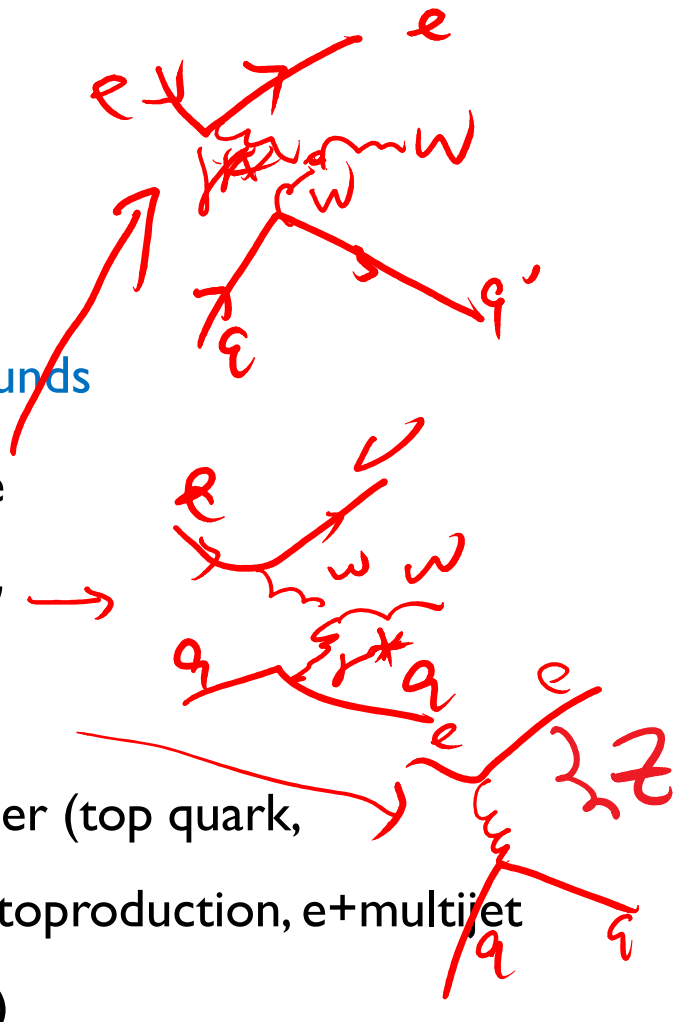
Invisible Higgs Decay @ LHeC

- Motivation: Important and well-motivated signature in many types of BSM & regular constraint on DM models, complementary to DM direct detection.
- Signal



Signal cross section ~ 20fb before Higgs decay & cuts (Assuming -90% electron polarization).

- Backgrounds
  - Wje
  - Wjv
  - Zje
  - Other (top quark, photoproduction, e+multijet etc.)



No Alpha_s @LO!

Invisible Higgs Decay @ LHeC

(parton level analysis)

- Beam
  - 7 TeV proton + 60 GeV electron
  - electron is -90% polarized
- Energy smearing

$$\frac{\sigma}{E} = \frac{\alpha}{\sqrt{E}} \oplus \beta, \alpha = \begin{cases} 0.6\sqrt{GeV} & \text{for jets} \\ 0.05\sqrt{GeV} & \text{for leptons} \end{cases}, \beta = \begin{cases} 0.03 & \text{for jets} \\ 0.0055 & \text{for leptons} \end{cases}$$

- Basic cuts

$$p_{Tj} > 20 \text{ GeV}, |\eta_j| < 5.0,$$
$$p_{Tl} > 20 \text{ GeV}, |\eta_l| < 5.0, \Delta R_{jl} > 0.4$$

LV pT threshold: 5 GeV for muon, 7 GeV for electron and 20 GeV for visible hadronic tau.
LV eta coverage ~ 5.0
Hadronic tau tagging efficiency: 70%
Tau decay treated in collinear approximation.
Assumptions on visible tau momentum:
Leptonic decaying tau: 1/3
Hadronic decaying tau: 1/2

- Cut flow after basic cuts

Convention: Proton direction corresponds to positive pseudorapidity.

(1) $\not{E}_T > 70$ GeV.
(2) Missing energy isolation: $I > 1$ rad.
(3) Pseudorapidity gap of the jet and the electron satisfies $\eta_j - \eta_e > 3.0$.
(4) The azimuthal angle difference of the electron and the jet satisfies $\Delta\phi_{ej} \equiv |\phi_j - \phi_e| < 1.2$.
(5) The pseudorapidity of the electron satisfies $\eta_e \in [-1.2, 0.6]$.
(6) Inelasticity cut: the inelasticity variable y is defined as $y = \frac{p_1 \cdot (k_1 - k_2)}{p_1 \cdot k_1}$, where p_1 is the 4-momenta of the initial proton, k_1 is the 4-momenta of the initial electron, and k_2 is the 4-momenta of the outgoing electron. Then we require $y \in [0.06, 0.5]$.
(7) Lepton veto: additional electron, muon, or tagged hadronic τ are vetoed.

Treatment of tau decay checked with TauDecay package.
(K. Hagiwara, T. Li, K. Mawatari and J. Nakamura, 1212.6247)

Event generation and analysis tools: FeynRules, MG5_aMC@NLO, MadAnalysis
PDF: NNPDF2.3 LO

Invisible Higgs Decay @ LHeC

Statistical Significance

$$Z = \sqrt{2((S+B)\ln(1+S/B)-S)}$$

Signal (100% invisible)~1.8fb

Total background~2.7fb

$$C^2_{\mathrm{MET}} = \kappa_V^2 \times \mathrm{Br}(\mathrm{h} \to invisible)$$

Br(h->inv)=6%@2σ level with 1 ab^{-1}
(Parton level, assuming κ_V=1.0)

Cross Section (fb)	Basic Cuts	$\not{E}_T > 70$ GeV	$I > 1$	$\eta_j - \eta_e > 3.0$	$\Delta\phi_{ej} < 1.2$	$\eta_e \in [-1.2, 0.6]$	$y \in [0.06, 0.5]$	Lepton Veto
Signal ($C^2_{\mathrm{MET}} = 1$)	16.1	8.80	8.23	4.68	2.37	2.16	1.77	1.77
Wje	816	158	143	51.7	13.9	11.3	9.13	1.96
$Wj\nu$	192	102	101	5.68	2.36	1.33	0.387	0.387
Zje	42.7	13.8	12.1	1.64	0.683	0.464	0.326	0.326

TABLE I: The cross section (in unit of fb) of the signal and major backgrounds after application of each cut in the corresponding column. Other backgrounds contribute less than 0.1 fb in total after all cuts and are not displayed in the table.

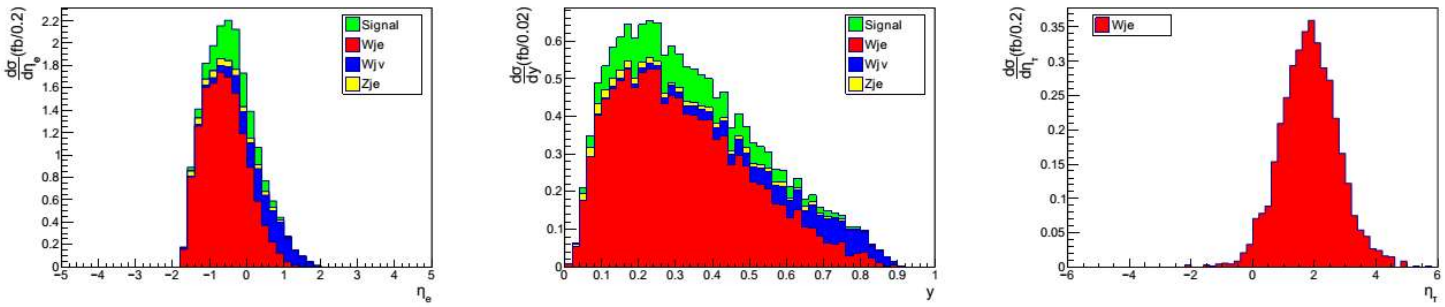


FIG. 2: Left: η_e distribution of the signal and major backgrounds just before the η_e cut. Middle: y distribution of the signal and major backgrounds just before the y cut. Right: τ lepton pseudorapidity distribution of the $Wje(W \to \tau\nu)$ background just before the lepton veto.

Invisible Higgs Decay @ LHeC

- Checks and more realistic simulation (preliminary results by Satoshi Kawaguchi and Masahiro Kuze (LHeC Study Group) from Tokyo Institute of Technology)
  - Cuts are found to be sufficient to suppress e+multijet background. (At least via a fitting function approach)
  - After MadGraph+Pythia+Delphes with Pythia and Delphes customized according to LHeC study, it is found that Br(h->inv)=7.5% can be probed at 2σ level with 1 ab^{-1}, which shows no substantial degradation compared to parton level analysis.
  - With Br(h->inv)=7.5%, S/B approaches 3.3%.

Invisible Higgs Decay @ LHeC

(Rough) Estimation of systematic uncertainties (for Wje background)

Item		Key Parameter (KP)	KP Value	$\delta_{BP,Item}$
CRS		Delta phi	2.5	0.4%
JES		Uncertainty	1%	0.02%
TES		Uncertainty	1%	0.5%
EES		Uncertainty	0.5%	N/A
LID1		Uncertainty	0.5%	0.6%
LID3		Uncertainty	3%	0.9%
RES	JER	Res. Par.	0.45, 0.03	0.7%
	EER	Res. Par.	0.10, 0.02	
	MMR	Res. Par.	0.05	
	TER	Res. Par.	0.45, 0.03	
MCF		-	-	0.8%
Total		-	-	1.4%

The sensitivity is not expected to be significantly degraded by the inclusion of systematic uncertainties. Minor degradation of sensitivity due to inclusion of systematics is expected to be compensated by further analysis improvement (e.g. MVA).

Sensitivity Comparison

- By "sensitivity" I mean sensitivity of direct search rather than the bound derived from global fit of Higgs signal strength.
- Current bounds from LHC ATLAS, 1509.00672 CMS-PAS-HIG-16-006 Sensitivity mainly from VBF channel.
  - ATLAS Combination: Br(h->inv)<25% @95%CL
  - CMS Combination: Br(h->inv)<24% @95%CL

→ Comparable to coupling fit

Sensitivity Comparison

- Ideal sensitivity for the invisible Higgs search can be reached at a high energy electron-positron collider:
  - ILC: Br(h->inv)<0.9% (0.4% for LumiUp) @95%CL
  - CEPC: Br(h->inv)<0.28% @95%CL
  - FCC-ee: Br(h->inv)<0.19% @95%CL

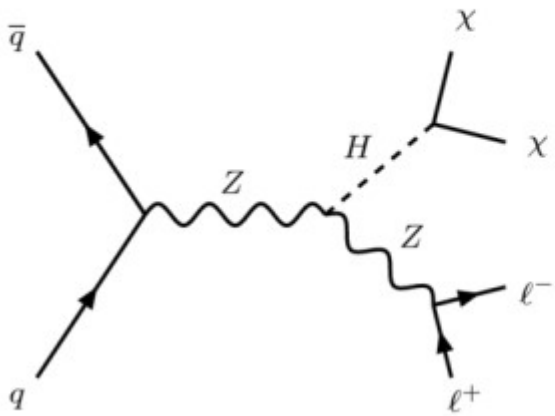
Higgs Working Group Report, 1310.8361

CEPC-SppC PreCDR

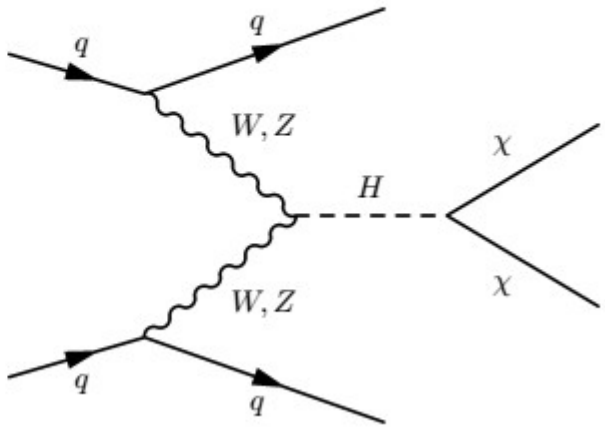
Sensitivity Comparison

At (HL-)LHC, an invisible Higgs can be searched for via ZH and VBF channels.

ZH, H→invisible,
Z→leptons and Z→jets



Vector Boson Fusion (VBF),
H→invisible



O. J. P. Eboli, D. Zeppenfeld, hep-ph/0009158

H. Davoudiasl, T. Han, H. E. Logan, hep-ph/0412269

Y. Bai, P. Draper, J. Shelton, 1112.4496

D. Ghosh, R. Godbole, M. Guchait, K. Mohan, D. Sengupta, 1211.7015

C. Bernaciak, T. Plehn, P. Schichtel, J. Tattersall, 1411.7699

J. Brook, M. R. Buckley, P. Dunne, B. Penning, J. Tamanas, M. Zgubic, 1603.07739

Sensitivity Comparison

- ZH with Z to ll: ATLAS simulation ATL-PHYS-PUB-2013-014

Cut variables	Thresholds
E_T^{miss}	> 180 GeV
$d\phi(\ell,\ell)$	< 1.2
$d\phi(\vec{p}_T^{\ell,\ell}, \vec{E}_T^{miss})$	> 2.7
$\lvert E_T^{miss} - p_T^{\ell,\ell}\rvert / p_T^{\ell,\ell}$	< 0.6
Jet veto	> 25 GeV

Table 14: Cut thresholds optimized for the high pile-up scenarios.

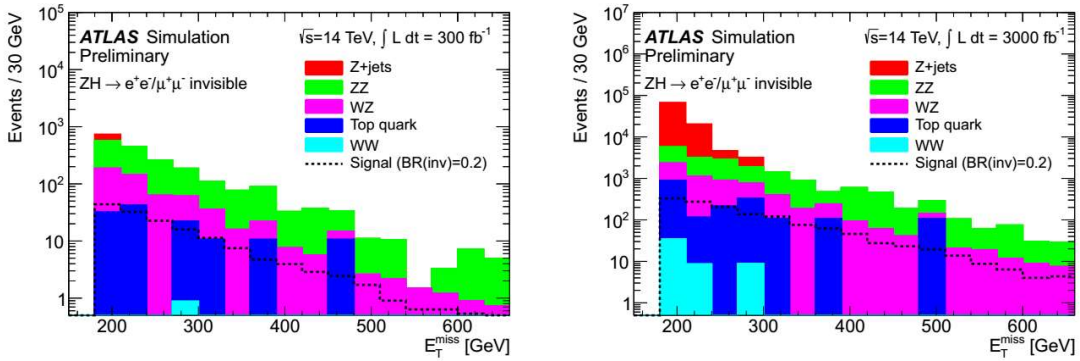


Figure 18: E_T^{miss} distributions for 300 and 3000 fb^{-1} 14 TeV data samples.

BR(H →inv.) limits at 95% (90%) CL	300 fb^{-1}	3000 fb^{-1}
Realistic scenario	23% (19%)	8.0% (6.7%)
Conservative scenario	32% (27%)	16% (13%)

Table 16: Expected limits with 95% (90%) CL on the invisible branching ratio of the Higgs boson are shown. The Standard Model cross section for ZH production is assumed.

Sensitivity Comparison

- VBF Channel: As far as I know, no publicly available projection from experimental groups exists. Two studies done by theorists:
  - (BPST) C. Bernaciak, T. Plehn, P. Schichtel, J. Tattersall, 1411.7699
  - J. Brook, M. R. Buckley, P. Dunne, B. Penning, J. Tamanas, M. Zgubic, 1603.07739

Sensitivity Comparison

BPST basic cuts

$$p_{T,j} > 20(10)\ \text{GeV} \qquad |\eta_j| < 4.5$$
$$\not{p}_T > 100\ \text{GeV} \qquad \Delta\phi_{\not{p}_T,j} > 0.4. \qquad (1)$$

BPST VBF cuts

$$p_{T,j} > 40\ \text{GeV} \qquad \not{p}_T > 100\ \text{GeV} \qquad m_{j_1 j_2} > 1200\ \text{GeV}$$
$$|\eta_j| < 4.5 \qquad |\eta_{j_1} - \eta_{j_2}| > 4.4 \qquad \eta_{j_1} \cdot \eta_{j_2} < 0. \qquad (3)$$

BPST 2-jet analysis BDT variables

$$\{p_{T,j_1}, \eta_{j_1}, p_{T,j_2}, \eta_{j_2}, \Delta\phi_{j_1,j_2}, \not{p}_T\} \quad \text{(2-jet)}. \qquad (5)$$

Assumptions on systematic uncertainties: Only CRS & LID included, assuming scaling with the square root of luminosity.

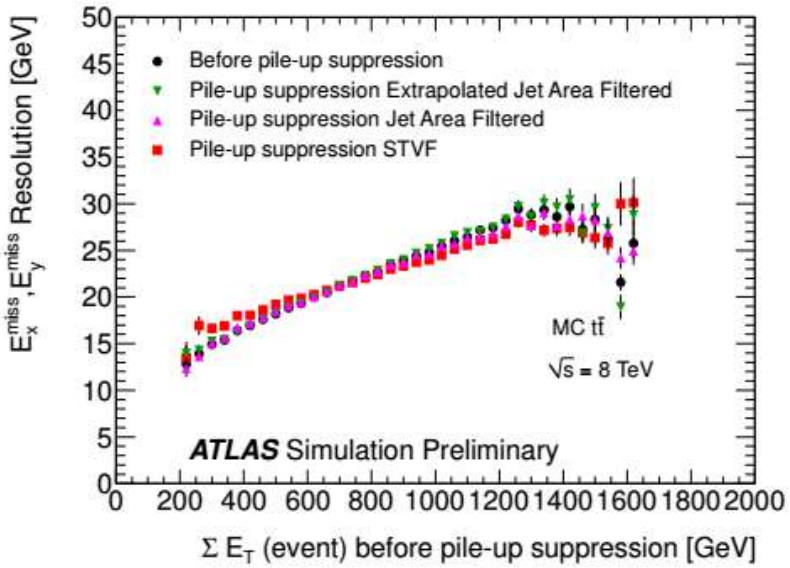
TABLE I. Exclusion reach in $\text{BR}_{\text{inv}} = \Gamma_{\text{inv}}/\Gamma_H$ at 95% CLs to an invisible Higgs width at various luminosities and different combinations of cuts and multivariate analyses. Here, Γ_H is defined to be the width of the Higgs Boson in the Standard Model without the additional invisible component due to new physics.

	$p_{T,j} > 20$ GeV				$p_{T,j} > 10$ GeV	
$\mathcal{L}[\text{fb}^{-1}]$	Eq. (3)	+ jet veto	$+\Delta\phi_{jj}$	BDT 2-jets	BDT 2-jets	+ BDT 3-jets
10	1.02	0.49	0.47	0.28	0.18	0.16
100	0.49	0.20	0.18	0.10	0.07	0.061
3000	0.25	0.094	0.069	0.035	0.025	0.021

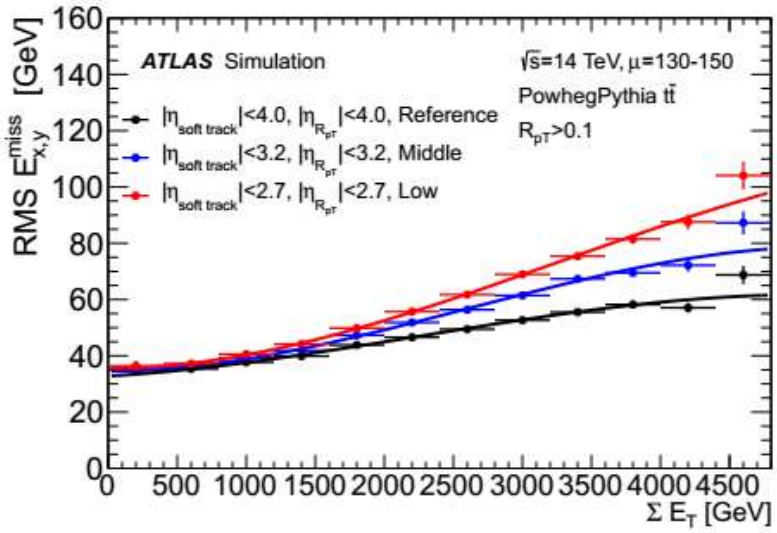
$\Delta\phi_{j_1,j_2} < 1$

Sensitivity Comparison

ATL-CONF-2013-082



ATLAS Phase II Upgrade Scoping Document



$$E_{x,y}^{\text{miss}} = E_{x,y}^{\text{miss,true}} + \text{Gaussian}(0, \sigma(\mu))$$

Sensitivity Comparison

Table 7: Detector and theory uncertainties (%) after all SR or CR selections. For each source of uncertainty, where relevant, the first and second rows correspond to the uncertainties in SR1 and SR2 respectively. The ranges of uncertainties in the Z or W column correspond to uncertainties in the Z+jets and W+jets MC yields in the SR or CR. The search uses the uncertainties in the ratios of SR to CR yields shown in the last column.

Uncertainty	VBF	ggF	Z or W	Z_{SR}/W_{CR} or W_{SR}/W_{CR}
Jet energy scale	16 9	43 12	17–33 0–11	3–5 1–4
Jet energy resolution	Negligible 3.1	Negligible 3.2	Negligible 0.2–7.6	Negligible 0.5–5.8
Luminosity	2.8	2.8	2.8	Irrelevant
QCD scale	0.2	7.8	5–36 7.5–21	7.8–12 1–2
PDF	2.3 2.8	7.5	3–5 0.1-2.6	1–2
Parton shower	4.4	41 29	9–10	5
Veto on third jet			Negligible	Negligible
Higgs boson p_T	Negligible	9.7	Irrelevant	Irrelevant
MC statistics	2 0.6	46 13	2.3–6.4 0.8–4.5	3.3–6.6

ATLAS, 1508.07869

Sensitivity Comparison

- Summary of sensitivity comparison in VBF channel of HL-LHC:
  - Current HL-LHC sensitivity estimation has large uncertainties due to to-be-considered pile-up effects and systematic uncertainties.
    - LHeC has negligible pile-up and should also have better control on systematics.
  - With an improved analysis (e.g. with MVA) in the future, the LHeC sensitivity to an invisible Higgs is expected to be comparable (or even better) than that of HL-LHC (in VBF channel).

More General Considerations

- Lepton-hadron colliders are suited to studying those exotic Higgs decays which suffer from large backgrounds at hadron-hadron colliders.
- More generally, lepton-hadron colliders are suited to precision study of new resonances after their discovery in hadron-hadron collisions, if a lepton-lepton collider with enough center-of-mass energy is not available.

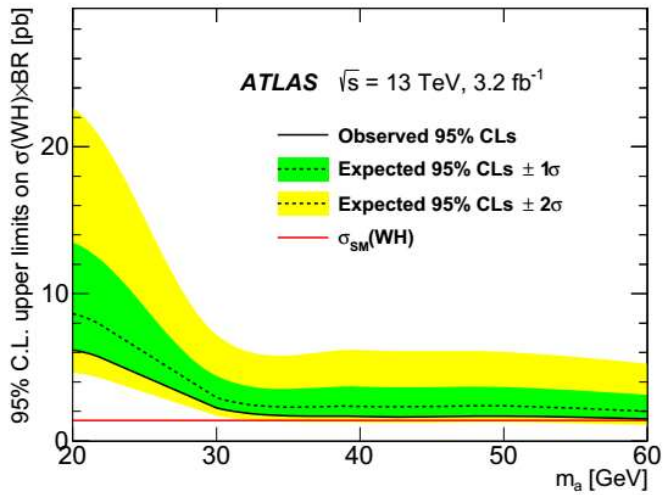
More General Considerations

- Exotic Higgs decay: h to 4b
  - At the (HL-)LHC, this process can be probed via WH associated production.
  - Top-quark background is large and jet pT threshold is crucial.
  - Sensitivity at current and future (HL-)LHC is not satisfactory.

K. Cheung, J. Song, Q. S. Yan, hep-ph/0703149

M. Carena, T. Han, G. Y. Huang, C. E. Wagner, 0712.2466

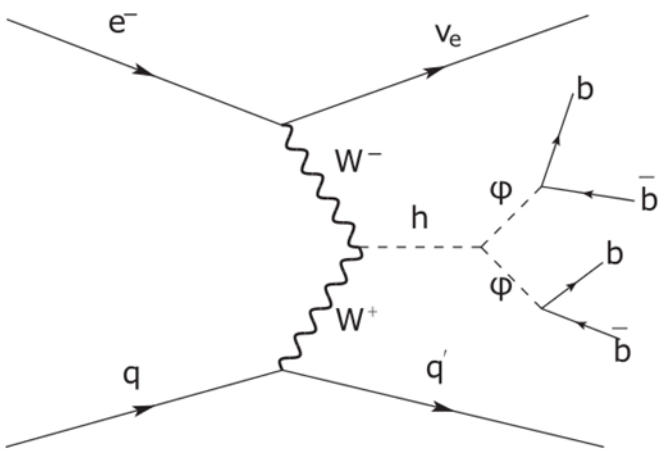
J. Cao, F. Ding, C. Han, J. M. Yang, J. Zhu, 1309.4939

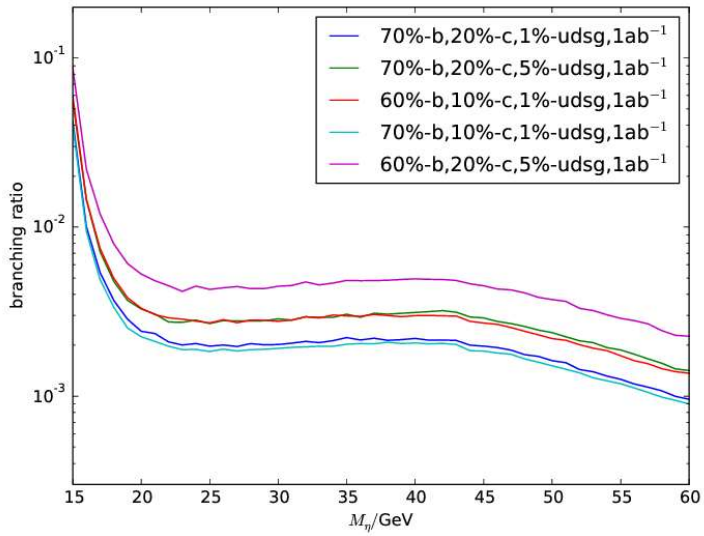


ATLAS, 1606.08391

More General Considerations

- Preliminary study of h to 4b at the LHeC, which is well-motivated in SM+S, 2HDM(+S) and NMSSM. (S. Liu, Y. Tang, C. Zhang and S. Zhu, work in progress)





And many more channels are worth considering, such as bb+ditau, 4tau, bb+MET, photon+MET, Z+MET,etc.,

4. Conclusions and discussions

- With no definite experimental clue and irrefutable theoretical guideline at hand, measuring precisely what we already have (eg. Higgs) could become progressively important, both as precision tests of SM and avenues to NP.
- High energy DIS can play an important role in probing a wide class of exotic Higgs decays. We demonstrate this point by study the sensitivity for an invisible Higgs at the proposed LHeC and compare it with the HL-LHC, which shows that the LHeC is promising in offering a comparable (or even better) sensitivity. We also display very promising results in h to 4b decay channel.
- If a lepton collider with sufficient c.m.s energy is not available, a best precision for studying newly discovered resonance in hadron-hadron collisions might be achieved through a synchronous lepton-hadron collider.
- The LHeC has an extremely rich physics program which optimally uses the LHC infrastructure and will enable the LHC to be transformed into a precision physics facility of increased value.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$e^+e^-, ep, pp?$

Back Up

Pile-up estimate for LHeC

- high luminosity option using $L=10^{34}$ $cm^{-2}s^{-1}$ (LHeC) and $L=5x10^{34}$ $cm^{-2}s^{-1}$ (HL-LHC) with 150 pile-up events (25 ns)
  [calculations by M. Klein]

➔ Pile-up events expected for LHeC <~0.1

Using pp LHC pile-up estimates

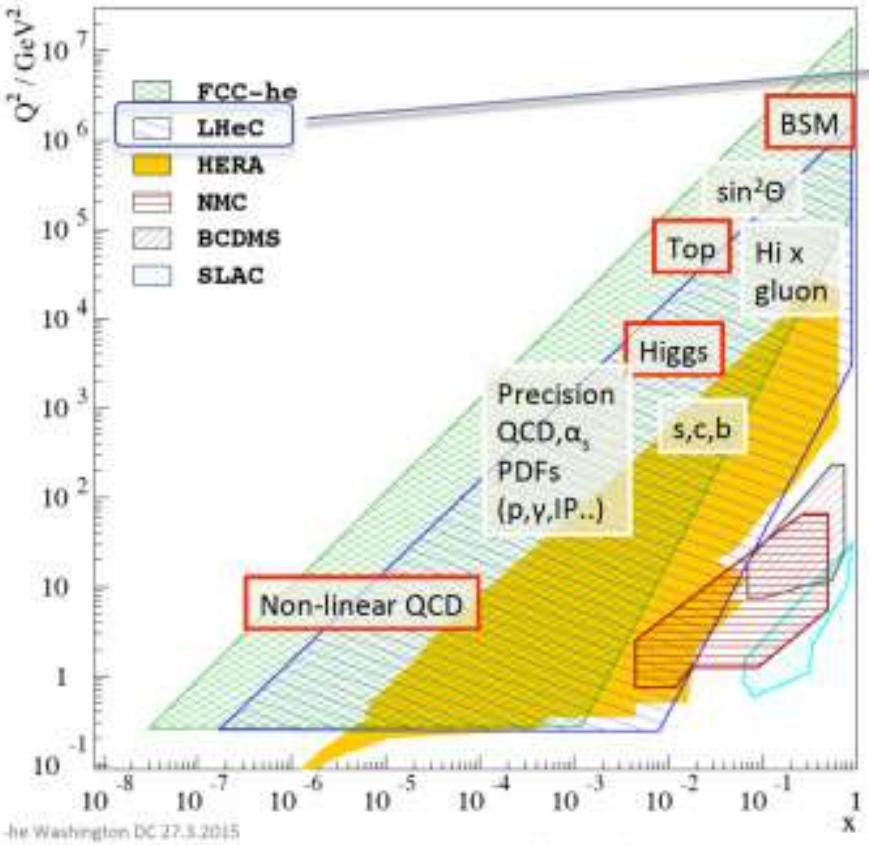
$$N(ep)=N(pp) \times s(yp)/s(pp) \times L(ep)/L(pp)$$
$$= 150 * 0.003 * 0.2$$
$$= 0.1$$

Direct calculation using total gamma-proton cross section of 300 μb

$$N(ep) = 300\ 10^{-6}\ 10^{-24}\ cm^2 \times 10^{34}\ cm^{-2}s^{-1} \times 25\ 10^{-9}s$$
$$= 0.075$$

The LHeC as electron-proton Collider

- Unique opportunity to take lepton-hadron physics to the TeV centre-of-mass scale at high luminosity



Designed to exploit intense **hadron beams** in high luminosity phase of LHC:

→ Use 7 TeV protons

→ Add an **electron beam** to the LHC

transforms p-p machines into high precision facilities

Plus, wealth of 'new' physics in its own right

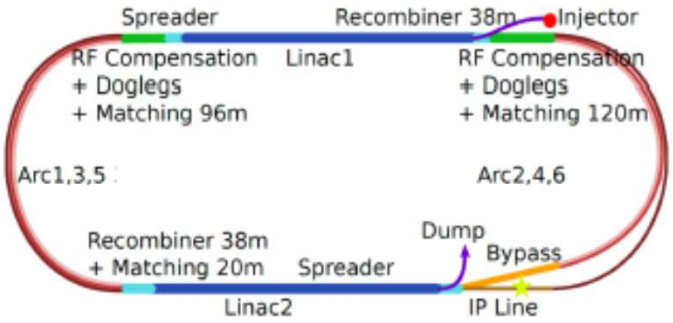
4 Monica D'Onofrio, LHeC Workshop, CERN/Chavannes 6/24/2015

THE LHEC

- RECIRCULATING LINAC WITH ENERGY RECOVERY
  → THREE ACCELERATING PASSES THROUGH EACH OF TWO 10 GeV LINACS
  ⇒ 60 GeV ELECTRON BEAM

- COLLISIONS WITH ONE HL-LHC BEAM (PROTON OR ION)

LAYOUT



BASELINE PARAMETERS

10^{34} cm^{-2} s^{-1} Luminosity reach	PROTONS	ELECTRONS
Beam Energy [GeV]	7000	60
Luminosity [10^{33}cm^{-2}s^{-1}]	16	16
Normalized emittance $\gamma\varepsilon_{x,y}$ [μm]	2.5	20
Beta Funtion $\beta^*_{x,y}$ [m]	0.05	0.10
rms Beam size $\sigma^*_{x,y}$ [μm]	4	4
rms Beam divergence $\sigma'^*_{x,y}$ [μrad]	80	40
Beam Current @ IP[mA]	1112	25
Bunch Spacing [ns]	25	25
Bunch Population	$2.2*10^{11}$	$4*10^{9}$
Bunch charge [nC]	35	0.64