Higgs physics at the LHeC
and the HE-LHC/FCC-he

Uta Klein
on behalf of
the LHeC/FCC-he Higgs Group

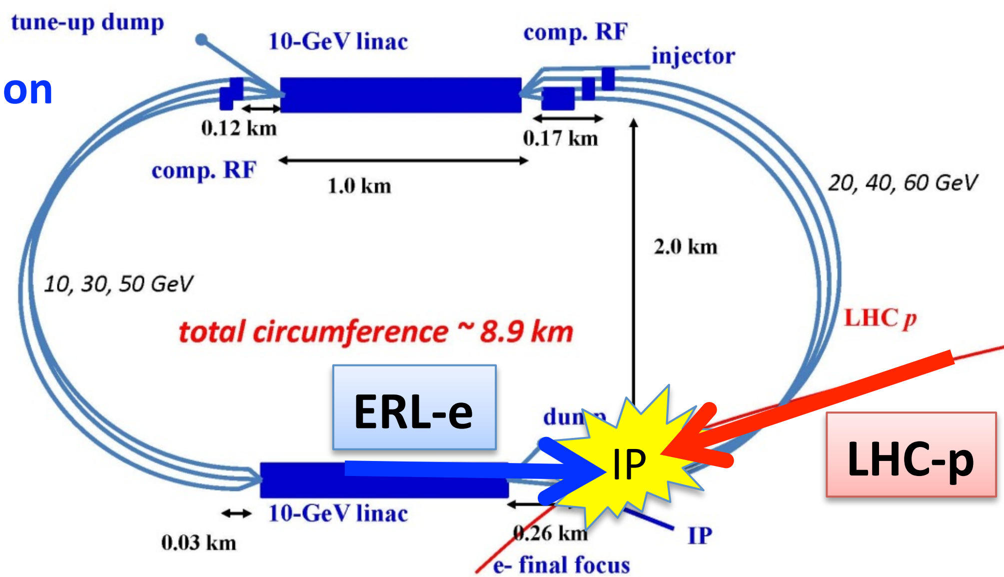
HL-LHC Meeting, CERN, June 19th, 2018

electrons for pp : ERL + LHC

- Two Electron LINACs + 3 return arcs: using energy recovery in same structure: 'green' technology with power consumption < 100 MW : nominal E_e = 60 GeV
- Beam dump: no radioactive waste!
- high electron polarisation of 80-90%
- Installation decoupled from LHC operation

Concurrent ep and HL-LHC operation!

Same idea holds for HE-LHC and FCC-hh for a novel Twin Collider



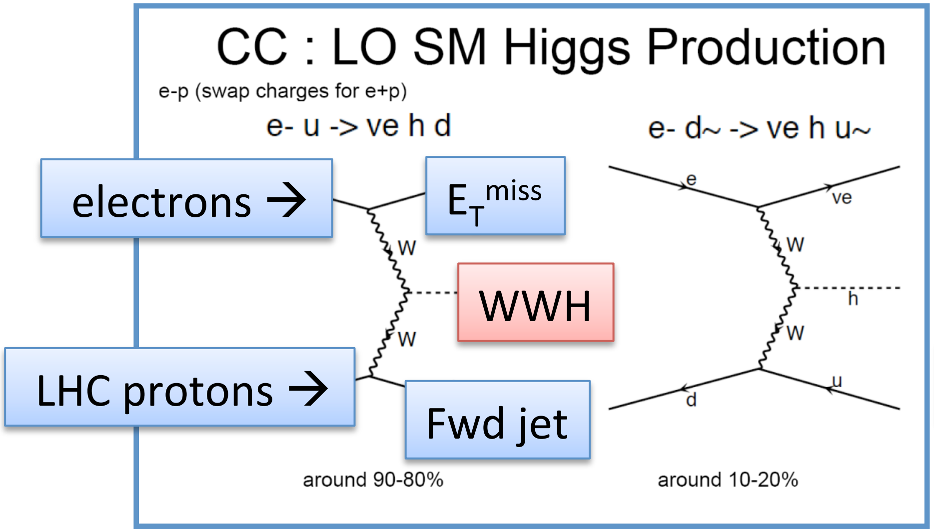
- ep Lumi 10^{34} cm s^{-2} s^{-1} **
- 100 fb^{-1} per year, e.g. ~2030-2040 (HL-LHC)
- L= 1000 fb^{-1} total collected in 10 years
- eA luminosity estimates ~ 10^{33} cm s^{-2} s^{-1} eA

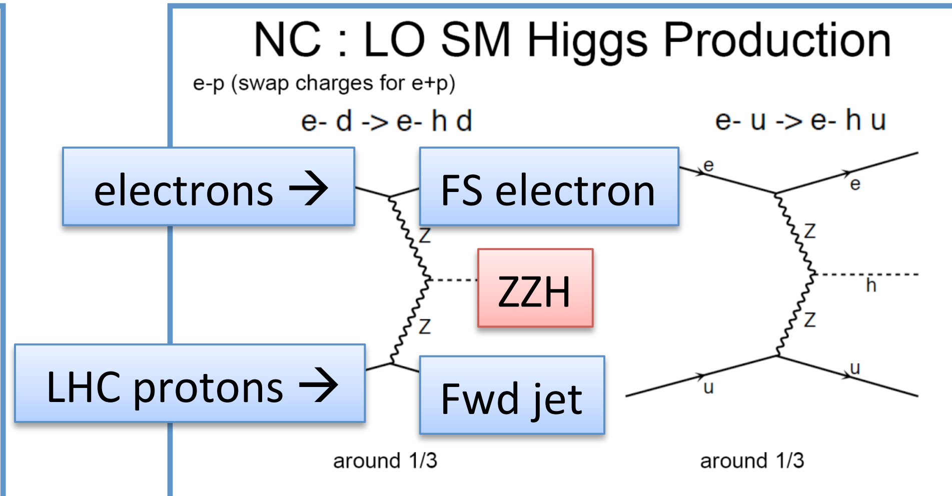
** based on existing HL-LHC proposal

Detector Design
for HL+HE+FCC ep
Peter Kostka et al.
→ installation in 2 years,
e.g. during LS4

LHeC CDR: arXiv:1206.2913 and updates at LheC/FCC-eh WS@CERN, 9/17

SM Higgs Production in ep





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

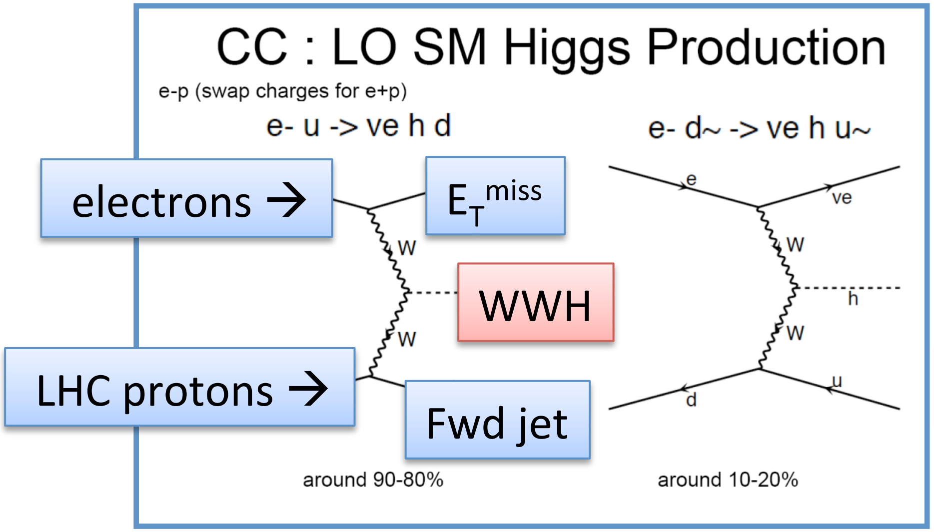
Total cross section [fb]
(LO QCD CTEQ6L1 M_H=125 GeV)

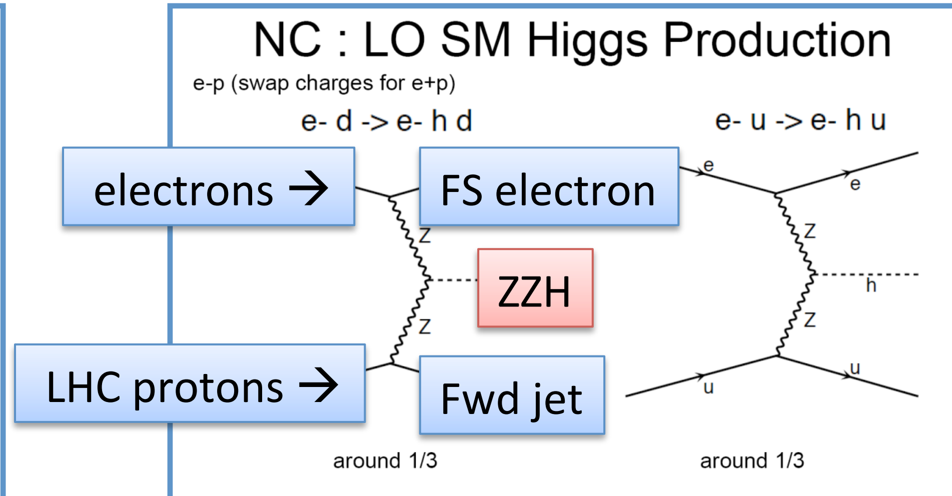
c.m.s. energy	1.3 TeV LHeC	3.5 TeV FCC-he
CC DIS NC DIS	109 21	560 127
P=-80% CC DIS NC DIS	 **196** **25**	 **1008** **148**

- **Scale dependencies of the LO calculations are in the range of 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]

SM Higgs Production in ep





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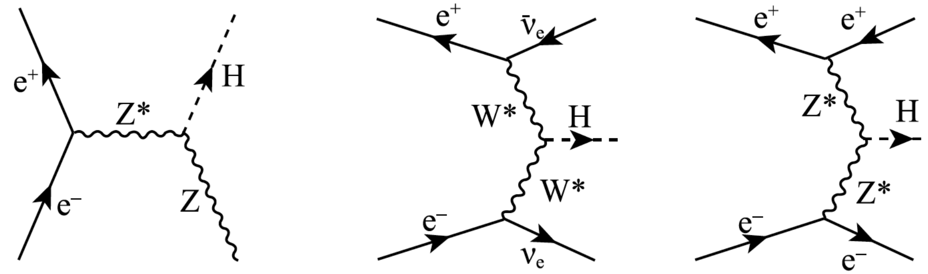
Theory well under control in ep!

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

Higgs in ee vs ep

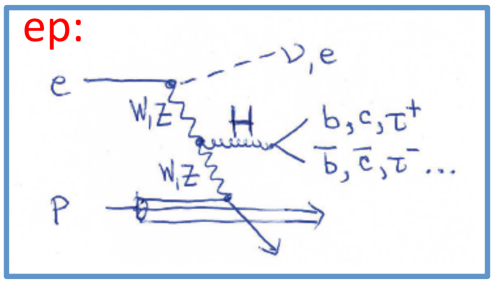
ee: Dominant Higgs productions

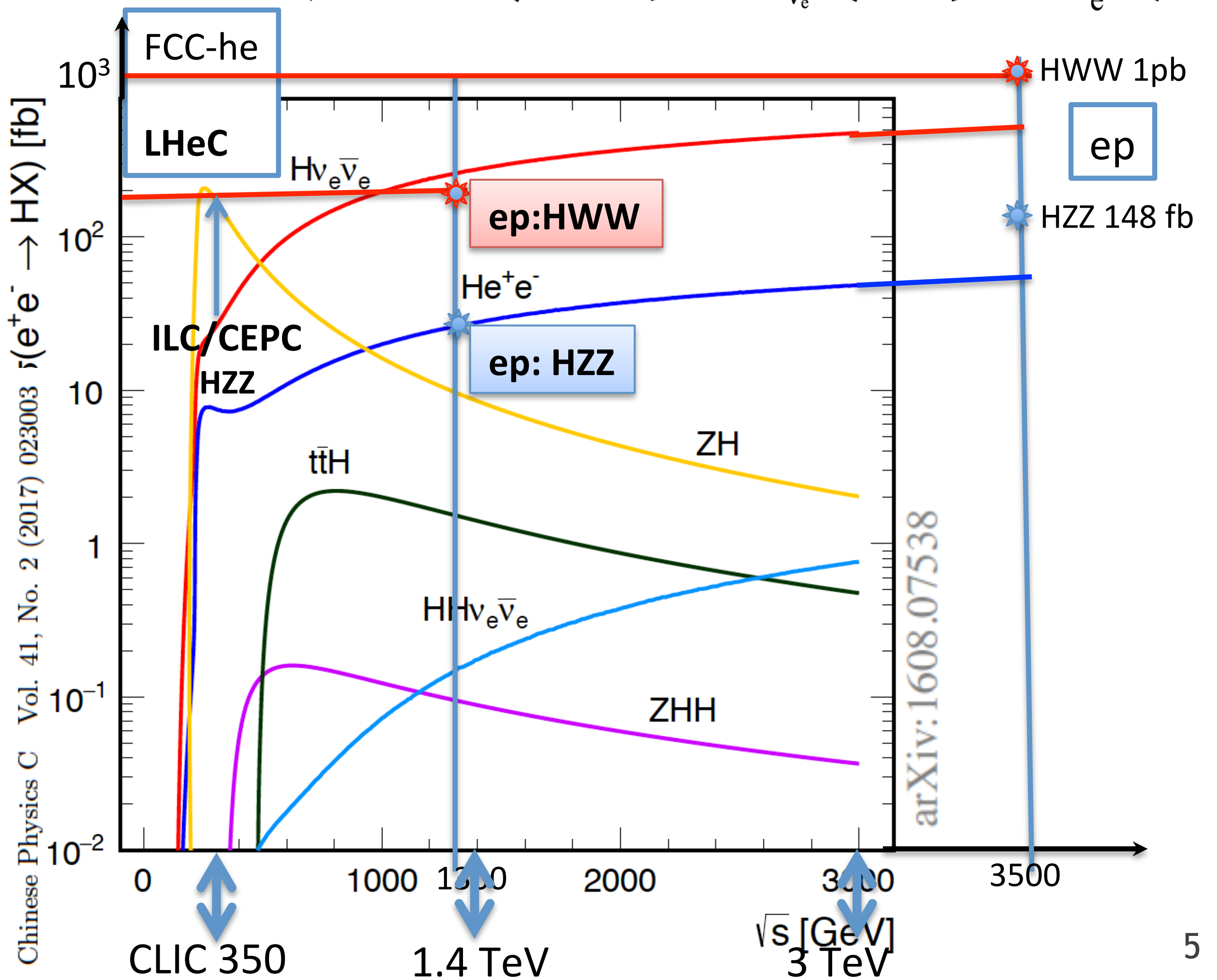


pe vs e+e- Higgs cross sections

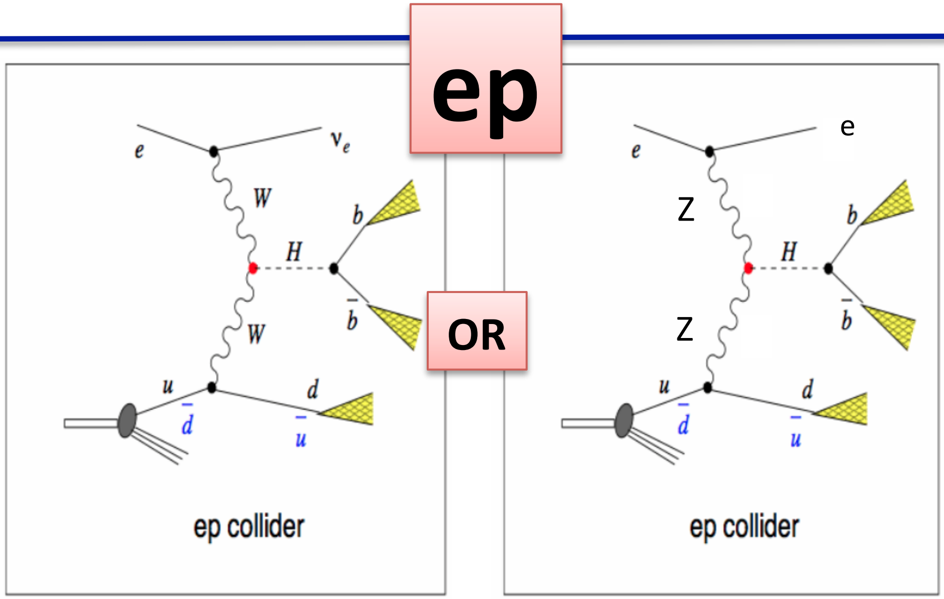
ep:CC DIS WW Fusion

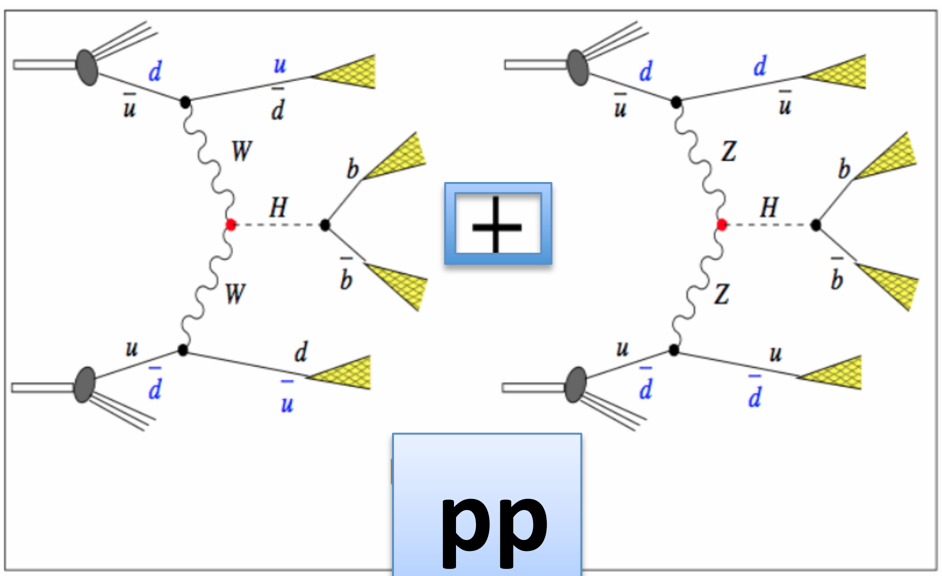
ep: NC DIS ZZ Fusion





VBF Higgs Production in ep (top) and pp (bottom)





ep: Higgs production in ep comes uniquely from either CC or NC DIS via VBF

Clean bb final state, S/B >1
e-h Cross Calibration for Precision ep
Clean, precise reconstruction and easy distinction of ZZH and WWH <u>without pile-up</u>:
<0.1@LHeC up to 1@FCCeh events

<u>VBF: Small theoretical uncertainties!</u>

pp: Higgs production in pp comes predominantly (~80%) from gg→ H :
high rates crucial for rare decays
However, only small VBF fraction

Pile-up in pp at 5 10^{34} cm^{-2} s^{-1} is 150@25ns
FCC-hh: pile-up 500-1000 (!)
S/B very small for bb
Final precision in pp needs accurate N^{3}LO PDFs & α_s

Analysis Framework and 'Detector'

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 LHeC 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**
- **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**
- 'Standard' GPD LHC-style detectors used and further studied based on optimising Higgs measurements, i.e. vertex resolution a la ATLAS IBL of ~ 5 μm, excellent hadronic and elmag resolutions using 'best' state-of-the art detector technologies (no R&D 'needed')

LHeC@HL-LHC: SM Higgs rates

√s= 1.3 TeV

LHeC Higgs		CC (e^-p)	NC (e^-p)	CC (e^+p)
Polarisation		-0.8	-0.8	0
Luminosity [ab^{-1}]		1	1	0.1
Cross Section [fb]		196	25	58
Decay	BrFraction	N^H_{CC} e^-p	N^H_{NC} e^-p	N^H_{CC} e^+p
$H \to b\bar{b}$	0.577	113 100	13 900	3 350
$H \to c\bar{c}$	0.029	5 700	700	170
$H \to \tau^+\tau^-$	0.063	12 350	1 600	370
$H \to \mu\mu$	0.00022	50	5	–
$H \to 4l$	0.00013	30	3	–
$H \to 2l2\nu$	0.0106	2 080	250	60
$H \to gg$	0.086	16 850	2 050	500
$H \to WW$	0.215	42 100	5 150	1 250
$H \to ZZ$	0.0264	5 200	600	150
$H \to \gamma\gamma$	0.00228	450	60	15
$H \to Z\gamma$	0.00154	300	40	10

Ultimate polarised e-beam of 60 GeV and LHC 7 TeV p-beams, 10 years of operation

➔ **Decay to bb is dominating decay mode : 58%**

Higgs decay to charm is factor 20 less likely than Hbb

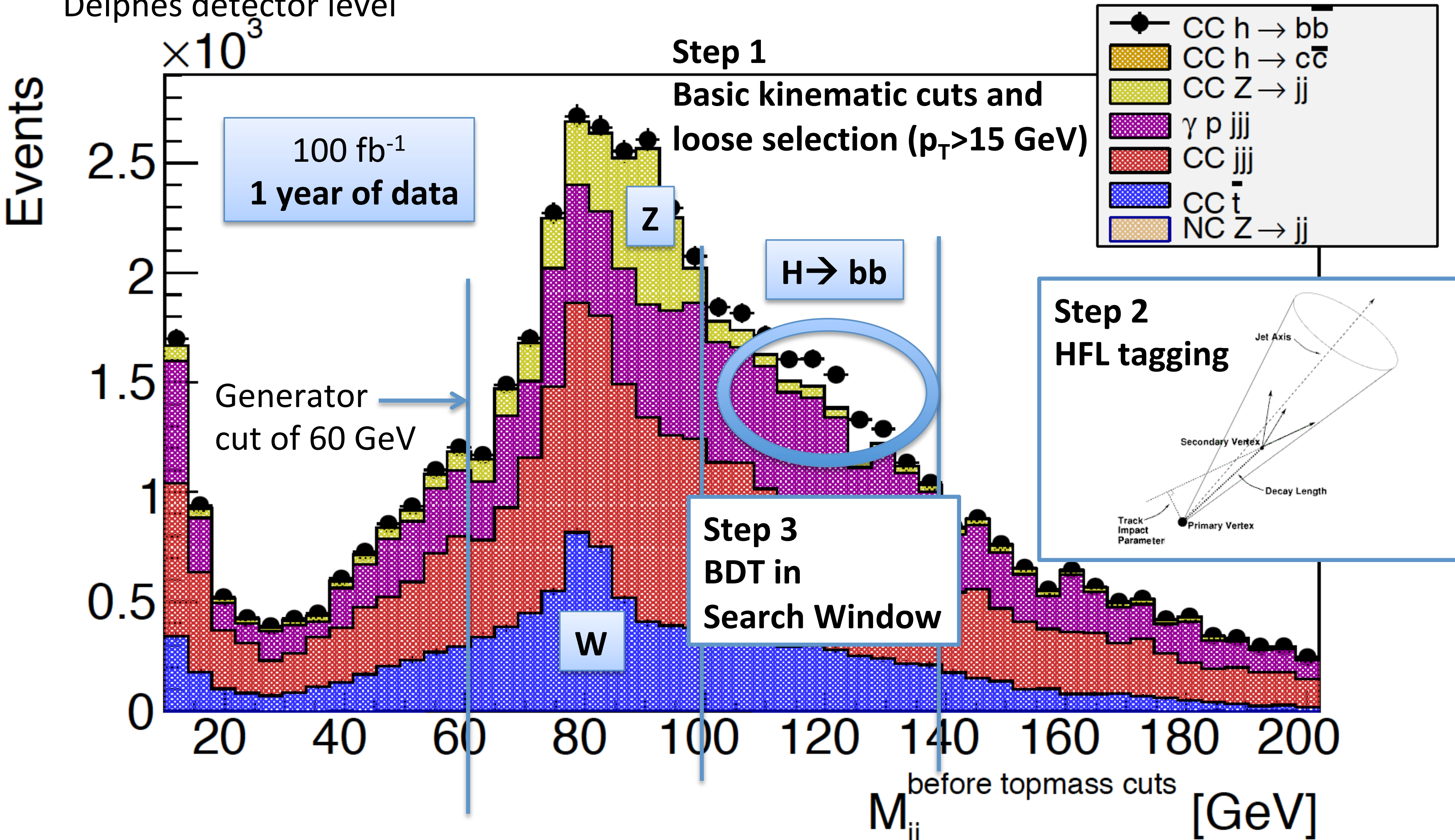
pp: **perfect Higgs factory for gluon-induced rare decays**

https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CERNYellowReportPageBR2014

BDT:U Klein; Cut-based: M Kuze, M Tanaka

Dijet Mass Candidates *HFL untagged*

Delphes detector level

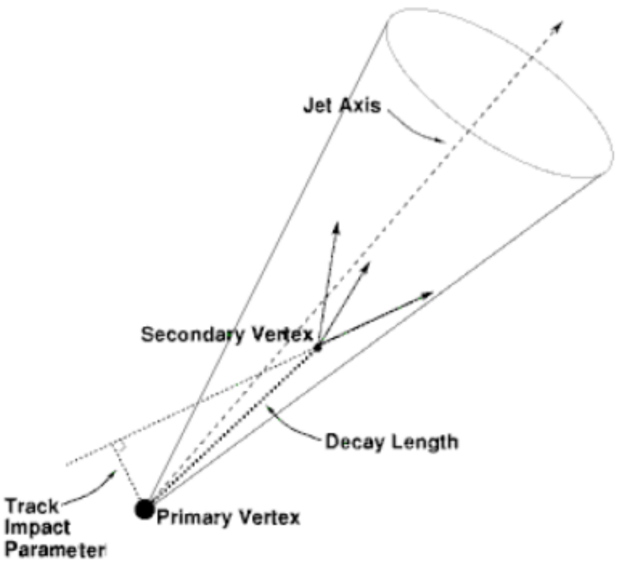


'Worst' case scenario plot : Photoproduction background (PHP) is assumed to be 100%!

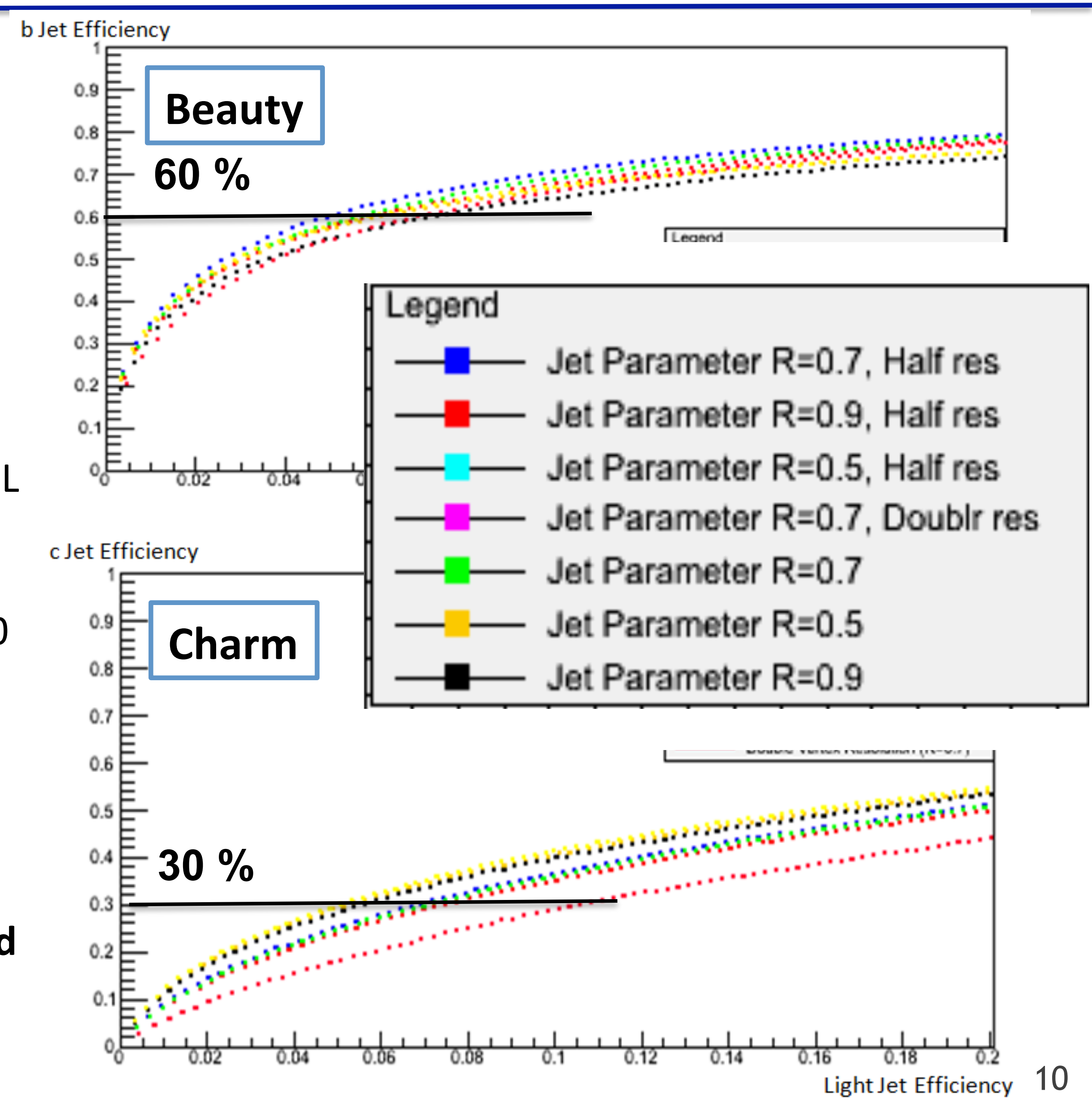
→ However, addition of small angle electron taggers will reduce PHP to ~1-2%

HFL Tagging

Uta Klein &
Daniel Hampson



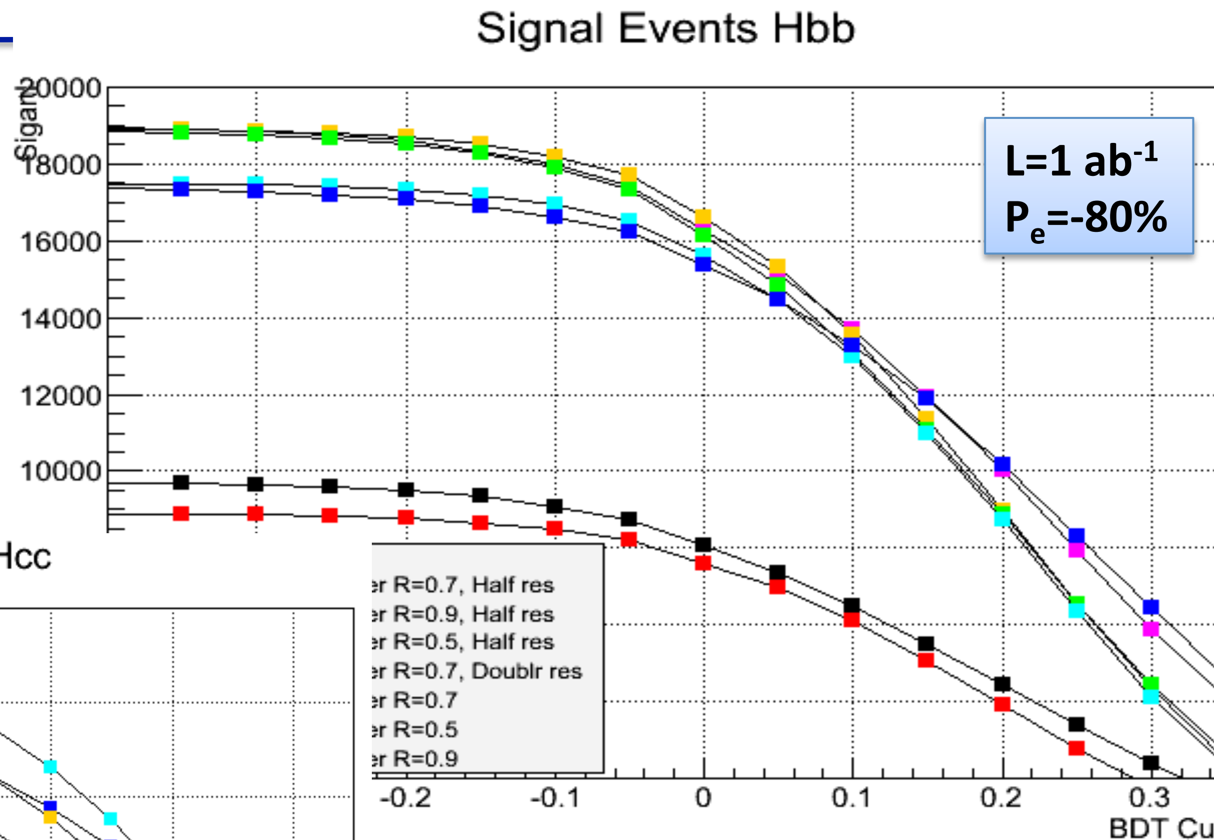
- → Realistic and conservative HFL tagging within Delphes realised, and dependence on vertex resolution (nominal 10 µm) and anti-kt jet radius studied
- → Light jet rejection very conservative, i.e. factor 10 worse than ATLAS
- → **used in full LHeC analysis and for FCC-he extrapolations**

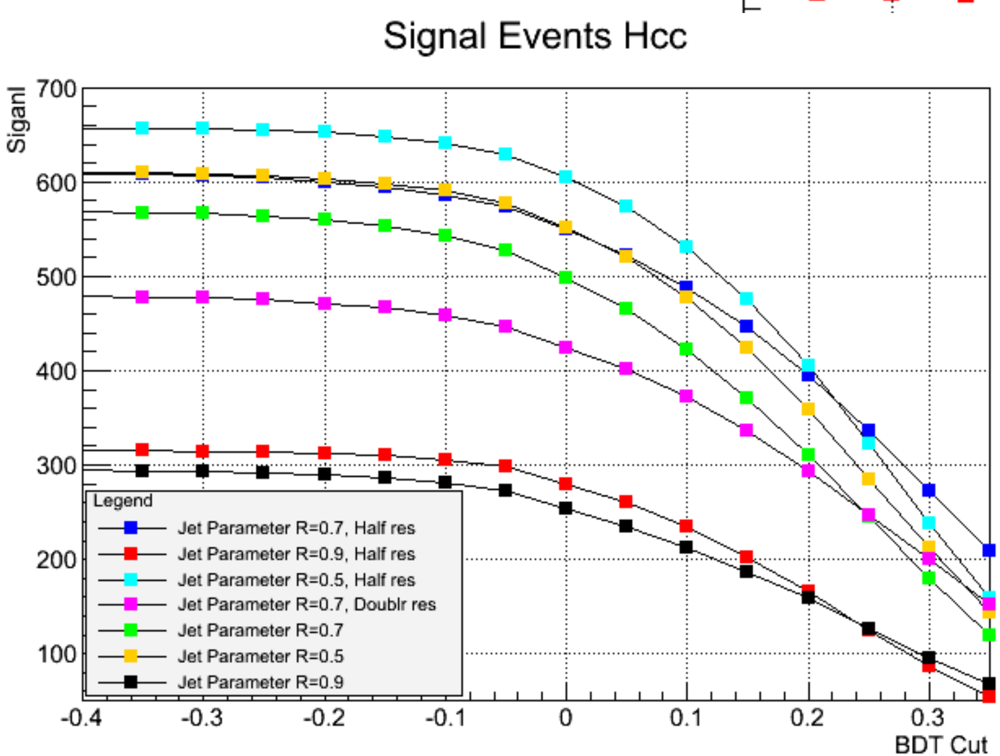


BDT Results for Higgs @ LHeC

Uta Klein &
Daniel Hampson

Hbb : Clear sensitivity to chosen jet radius; rather robust w.r.t. vertex resolution in range of 5 to 20 μm

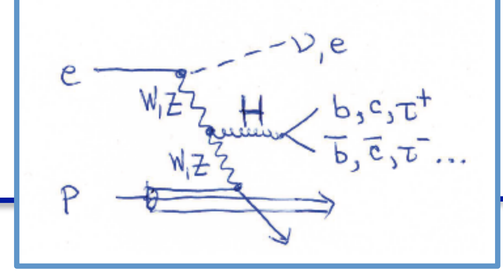




Hcc : High sensitivity to vertex resolution (nominal 10 μm) and jet radius

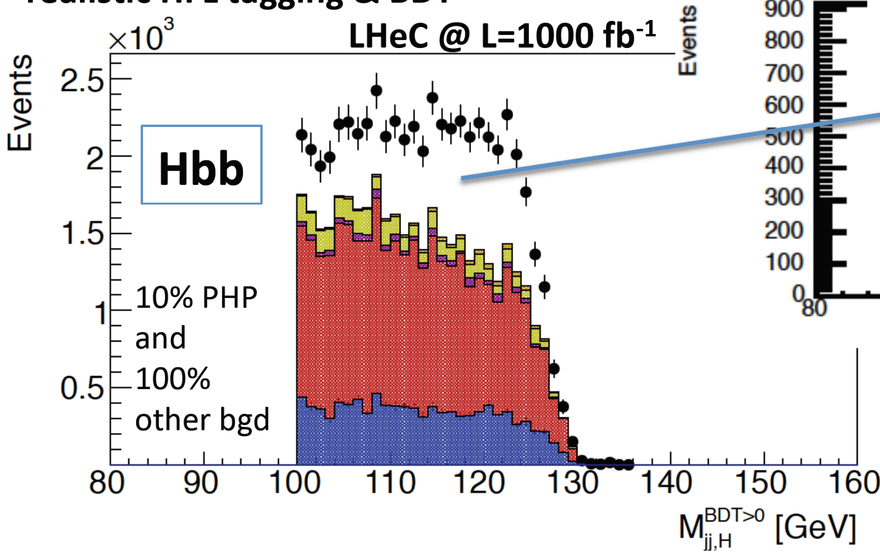
→ expect about 400-600 Hcc candidates

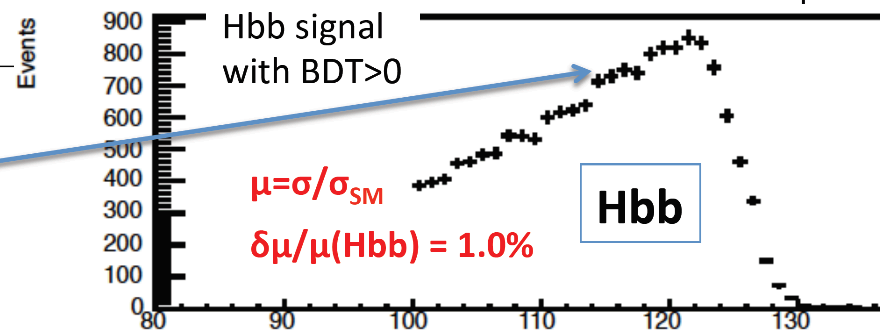
Higgs in ep – clean S/B, no pile-up



Uta Klein & Daniel Hampson

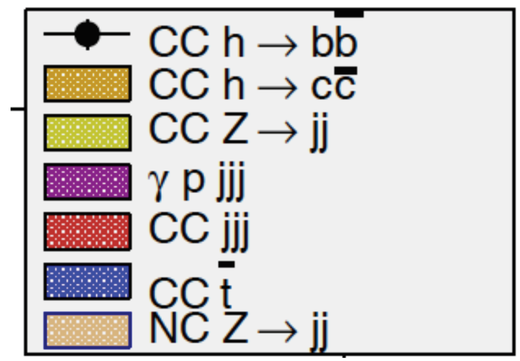
realistic HFL tagging & BDT

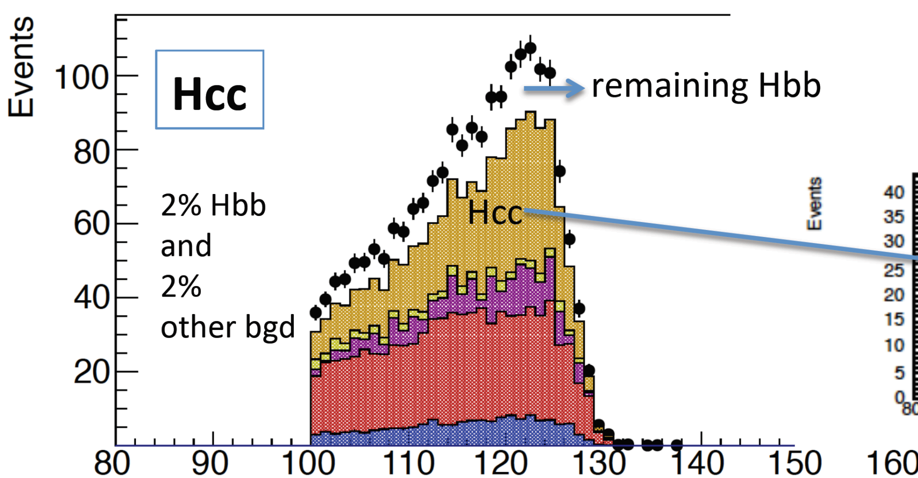


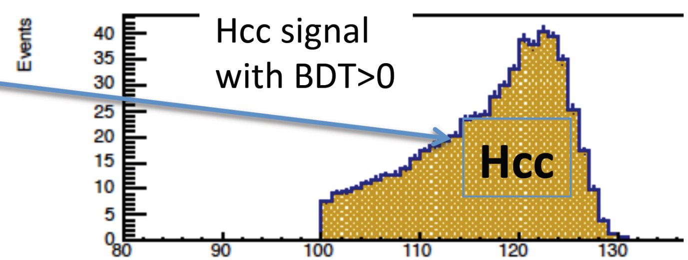


$\mu=\sigma/\sigma_{SM}$

$\delta\mu/\mu(Hbb)$ = 1.0%







→ Hcc signal strength given for assumptions with Hbb background enhanced by factor 2!

$\delta\mu/\mu(Hcc)$ = 7.4 %

→ Main systematic checks: variations of background contribution and tagging efficiencies

New: Estimates of Higgs Prospects

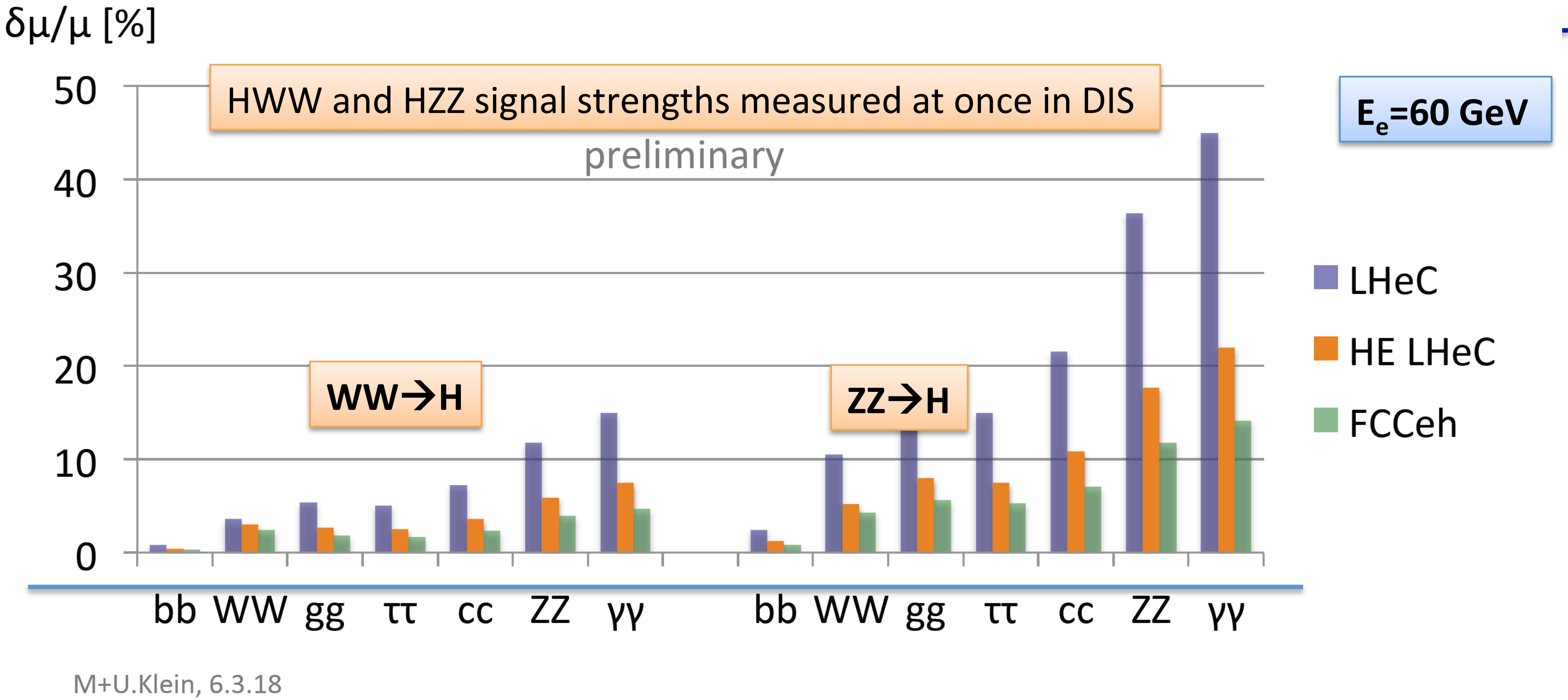
- Use LO Higgs cross sections **σ_H for M_H=125 GeV, in [fb],** and branching fractions BR(H→XX from Higgs Cross Section Handbook (c.f. appendix)
- Apply further branching, BR(X→FS) in case e.g. of W→ 2 jets and use acceptance, Acc, estimates based on MG5, for further decay
- Use reconstruction efficiencies, ε, achieved at LHC Run-1, see e.g. prospect calculations explored in arXiV:1511.05170
- Use fully simulated LHeC Hbb and Hcc results as baseline for S/B ranges
- Use fully simulated Higgs to invisible for 3 ep c.m.s. scenarios as guidance for extrapolation uncertainty (~25%)
- Estimate HIggs events per decay channel for certain Luminosity in [fb^{-1}]

$$N = \sigma_H \bullet BR(H \to XX) \bullet BR(X \to FS) \bullet L$$

- Calculate uncertainties of signal strengths w.r.t. SM expectation $\mu = \frac{\sigma}{\sigma_{SM}}$

$$\frac{\delta\mu}{\mu} = \frac{1}{\sqrt{N}} \bullet f \quad \text{with} \quad f = \sqrt{\frac{1+1/(S/B)}{Acc \bullet \varepsilon}}$$

Signal Strengths @ LHeC - HE-LHeC - FCCeh



Charged Currents: ep → νHX   Neutral Currents: ep → eHX

Note: HWW and HZZ requires different e+e- machine settings / c.m.s. energies for high precision
→NC and CC DIS together over-constrain Higgs couplings in a combined fit.

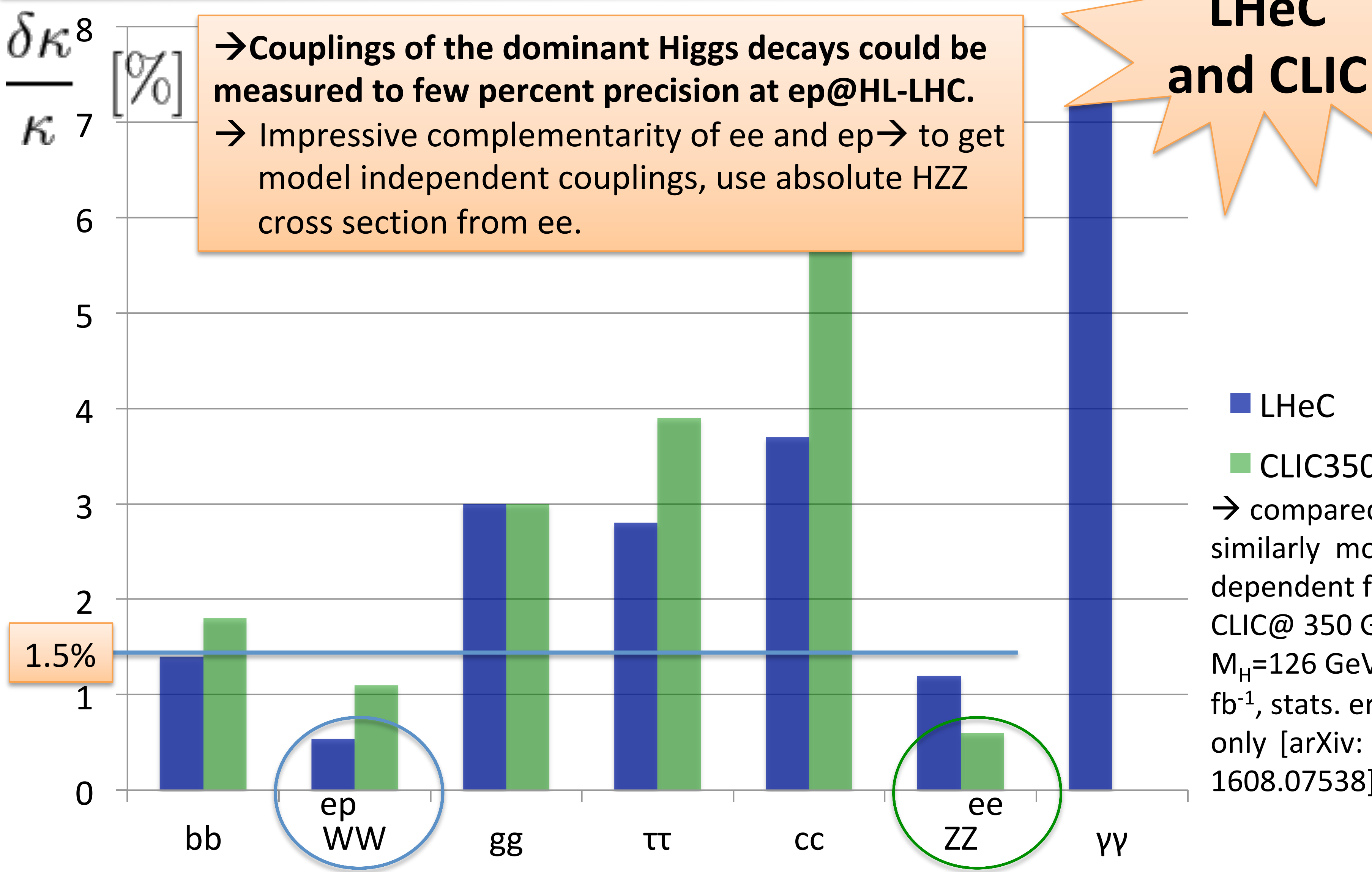
E_e = 60 GeV LHeC E_p = 7 TeV L=1ab^{-1} HE-LHC E_p = 14 TeV L=2ab^{-1} FCC: E_p = 50 TeV L=2ab^{-1}

Model-dependent Coupling Fit

LHeC and CLIC

→Couplings of the dominant Higgs decays could be measured to few percent precision at ep@HL-LHC.

→ Impressive complementarity of ee and ep→ to get model independent couplings, use absolute HZZ cross section from ee.



→ compared to similarly model-dependent fit CLIC@ 350 GeV M_H=126 GeV,500 fb^{-1}, stats. errors only [arXiv: 1608.07538]

… and Consistency Checks of EW Theory

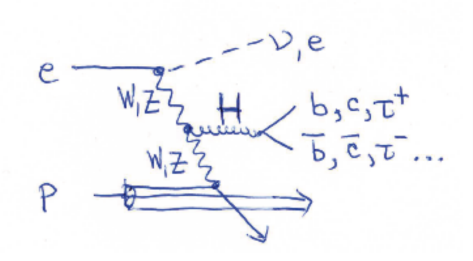
→ similar tests possible using various cms energy CLIC machines, however, in ep, we could perform them with one machine

$$\frac{\sigma_{WW\to H\to ii}}{\sigma_{ZZ\to H\to ii}} = \frac{\kappa_W^2}{\kappa_Z^2}$$

$$\frac{\kappa_W}{\kappa_Z} = \cos^2\theta_W = 1 - \sin^2\theta_W$$

➔ Dominated by H→bb decay channel precision

➢ Very interesting consistency check of EW theory



➢ Values for $\cos^2\Theta$ given here are the PDG value as central value **0.777** and uncertainty from ep Higgs measurement prospects

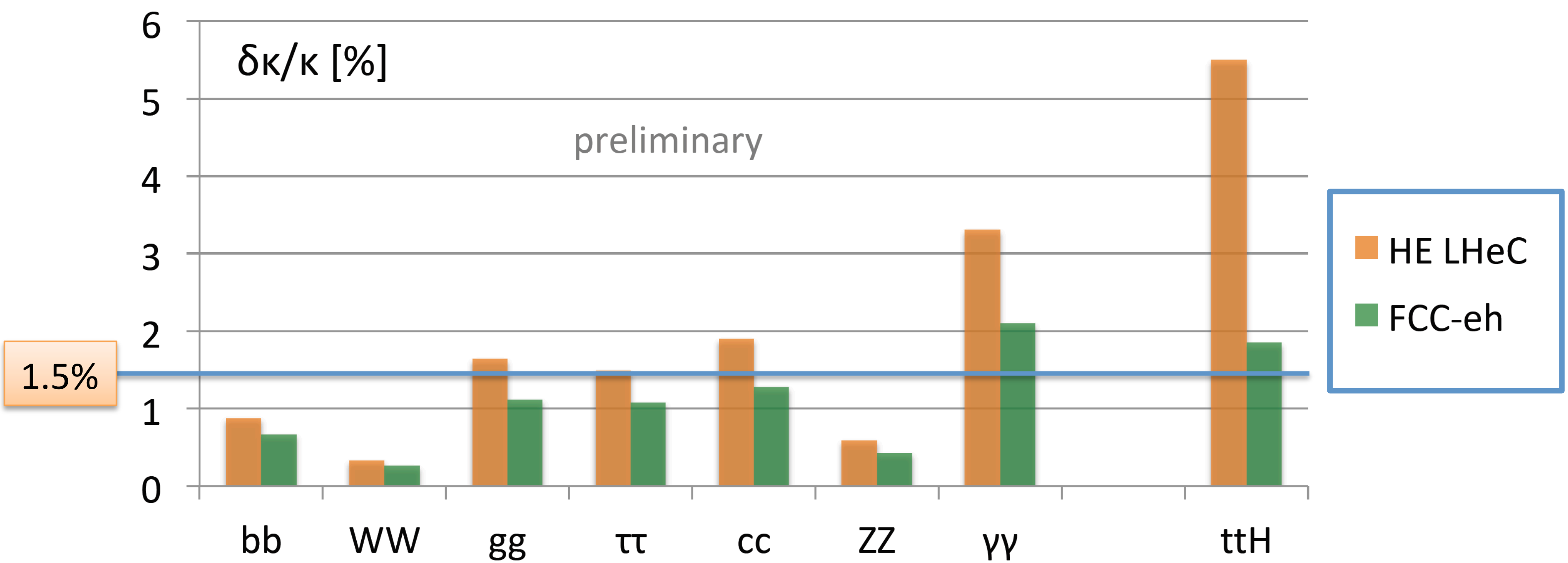
LHeC:	± 0.010
HE-LHeC	± 0.006
FCC-eh	**± 0.004**

➔ Another nice test: **How does the Higgs couple to 3rd and 2nd generation quark?**
b is down-type and c is up-type

$$\frac{\sigma_{WW\to H\to c\bar{c}}}{\sigma_{WW\to H\to b\bar{b}}} = \frac{\kappa_c^2}{\kappa_b^2}$$

Model-dependent Coupling Fit

→ Assuming SM branching fractions weighted by the measured κ values, and Γ_{md} (c.f. CLIC model-dependent method)



M+U.Klein, 5.4.18

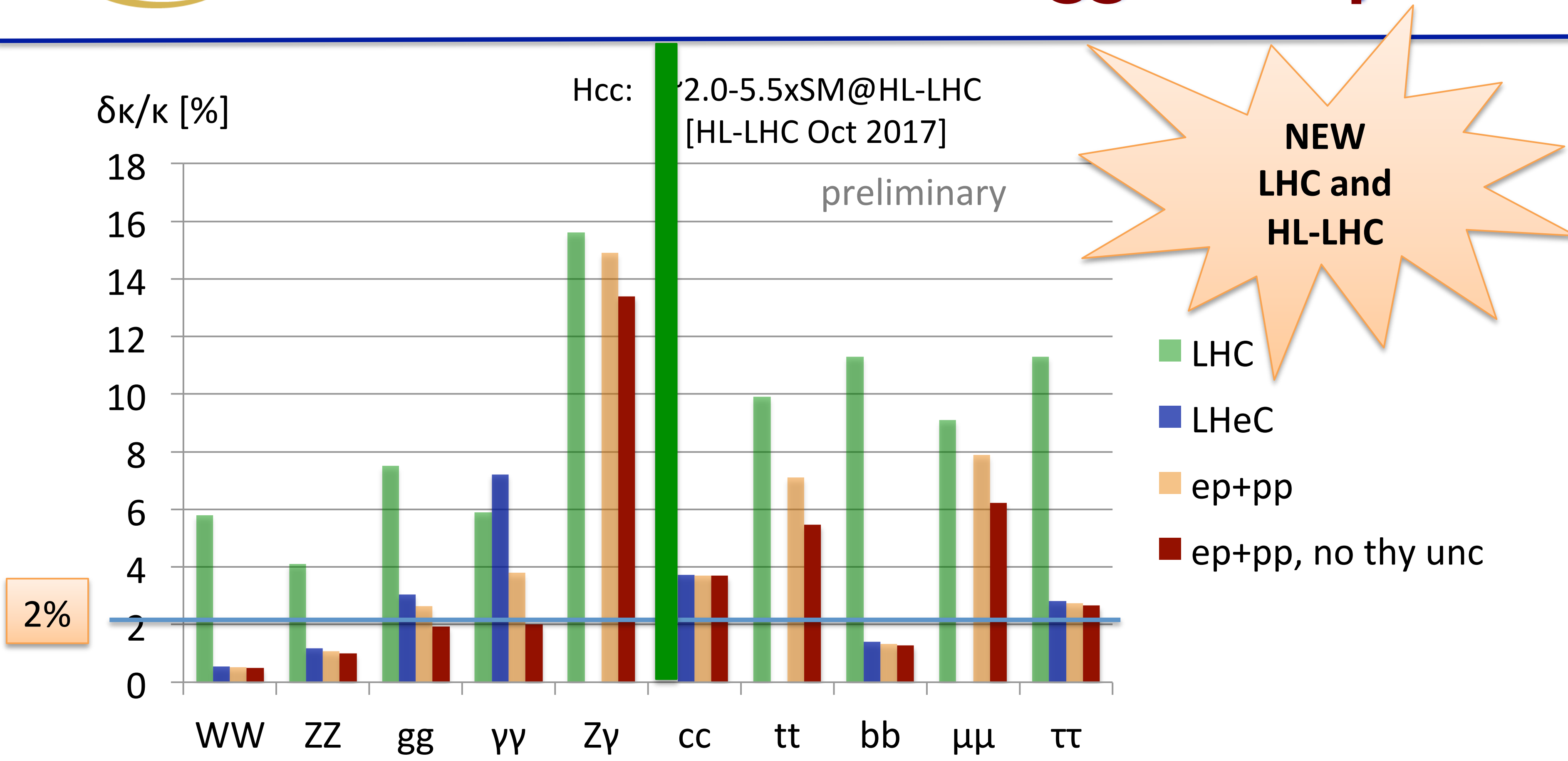
NC+CC Analysis using overconstrained system of couplings

arXiv:1702.03426
Coleppa, Kumar^2, Mellado

E_e = 60 GeV L=2ab^{-1} **HE-LHC E_p = 14 TeV** **FCC: E_p = 50 TeV**

See also talk by Jorge de Blas@FCC-Week2018 for further fits and ep+ee combinations.

LHeC and HL-LHC Higgs Prospects



J. De Blas, M.+U. Klein, 16.4.2018

→ Amazing prospect for measuring fundamental Higgs couplings to high precision (dark red) at LHC with pp + ep using SM assumptions.

HL-LHC prospects using ATLAS 2014 projections ($3ab^{-1}$) w and w/o theoretical uncertainties ('no thy unc') in a SM coupling fit → will be updated with HL-LHC yellow report in preparation

…to take home: ep+pp >~ 2030

- The LHC is fantastic – *let's use it best* by building a Twin Collider!

→ adding electrons for HL-LHC: ep could run in parallel with HL-LHC pp (until ~2040) and for HE-LHC (>2040).

- LHeC (FCC-he) could measure the dominant Higgs couplings, including ttH, to 0.6-17% (0.2-2%) precision [CC+NC DIS, no pile-up, clean final state..]
- ep (>~1 TeV) complements with HWW the ee (250-350 GeV) HZZ coupling measurements: HIGH luminosity is KEY for both machines!
- ep would empower the physics potential of pp (non-resonant searches, EW, Higgs..) through high precision QCD measurements: flavour separated PDFs at N^3LO, α_S to per mille …

Already with the first ~100 fb^{-1} ep data (first few years)

→ use ep as the 'near' detector for pp to beat the α_s and PDF uncertainties for Higgs@HL-LHC from ~3% to <~0.5%, δm_b to 10 MeV; δm_{charm} to 3 MeV

→ $\delta M_{W(pp)}$ to 3 $MeV_{LHeCPDF}$ & $\sin^2\theta$ better than LEP

Workshops

Recent: September 2017

https://indico.cern.ch/event/639067/

Next: 27-29 June 2018 Orsay

https://indico.cern.ch/event/698368/

Preparation for strategy:

Physics, Accelerator, Detector, PERLE

Many eh related workshops

FCC Physics Week CERN Jan 2018

FCC Week:April 2018 (Amsterdam)

DIS 2018 April (Kobe)

HL-HE LHC Physics June 2018 (CERN) which includes ep/eA

Goal by end of 2018: LHeC/FCC-he reports: Physics, Detector, Accelerator

https://lhec.web.cern.ch

+ FCC-he Organisation*)

International Advisory Committee

"..Direction for ep/A both at LHC+FCC"

Sergio Bertolucci (CERN/Bologna)
Nichola Bianchi (Frascati)
Frederick Bordry (CERN)
Stan Brodsky (SLAC)
Hesheng Chen (IHEP Beijing)
Eckhard Elsen (CERN)
Stefano Forte (Milano)
Andrew Hutton (Jefferson Lab)
Young-Kee Kim (Chicago)
Victor A Matveev (JINR Dubna)
Shin-Ichi Kurokawa (Tsukuba)
Leandro Nisati (Rome)
Leonid Rivkin (Lausanne)
Herwig Schopper (CERN) – Chair
Jurgen Schukraft (CERN)
Achille Stocchi (LAL Orsay)
John Womersley (ESS)

We miss Guido Altarelli.

Coordination Group

Accelerator+Detector+Physics

Nestor Armesto
Oliver Brüning – Co-Chair
Andrea Gaddi
Erk Jensen
Walid Kaabi
Max Klein – Co-Chair
Peter Kostka
Bruce Mellado
Paul Newman
Daniel Schulte
Frank Zimmermann

5(11) are members of the FCC coordination team

OB+MK: FCC-eh responsibles
MDO: physics co-convenor

Working Groups

PDFs, QCD
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Claire Gwenlan
Higgs
Uta Klein,
Masahiro Kuze
BSM
Georges Azuelos,
Monica D'Onofrio
Top
Olaf Behnke,
Christian Schwanenberger
eA Physics
Nestor Armesto
Small x
Paul Newman,
Anna Stasto
Detector
Alessandro Polini
Peter Kostka

*)September 2017

Additional Sources & Thanks to

- Much more material can be found here: LHeC and FCC-eh Workshop, September 2017, CERN https://indico.cern.ch/event/639067/
- **The LHeC/FCC-eh study group, http://cern.ch/lhec.**
- "On the Relation of the LHeC and the LHC" [arXiv:1211.5102]
- 1st FCC Physics Workshop, 16.1.-20.1.2017, CERN https://indico.cern.ch/event/550509/
- Before April 2018: Higgs branching fractions and uncertainties taken from https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CERNYellowReportPageBR2014
- Update used from April 2018 https://twiki.cern.ch/twiki/bin/view/LHCPhysics/CERNYellowReportPageBR
- FCC Week 2018, Amsterdam, https://indico.cern.ch/event/656491/

Special thanks to my colleagues in the LHeC/FCC-he Higgs group and to Jorge de Blas for the discussion of model-dependent coupling fits.

Additional material

pp+ep: HL-LHC δM_W and weak mixing angle

Stefano Camarda, Ludovica Aperio Bella, Bruno Lenzi

The measurement of $\sin^2\theta_W$ tests this relation:

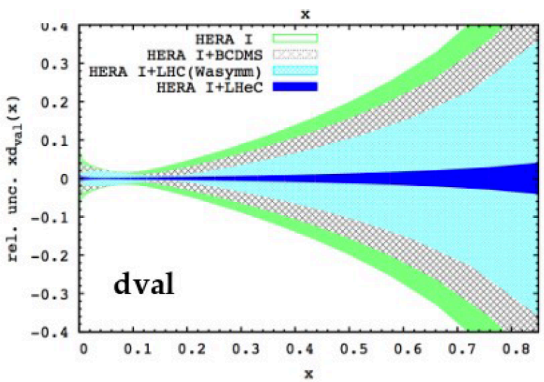
$$\sin^2_{\text{eff}}\theta_W = \left(1 - \frac{m_W^2}{m_Z^2}\right)\kappa$$

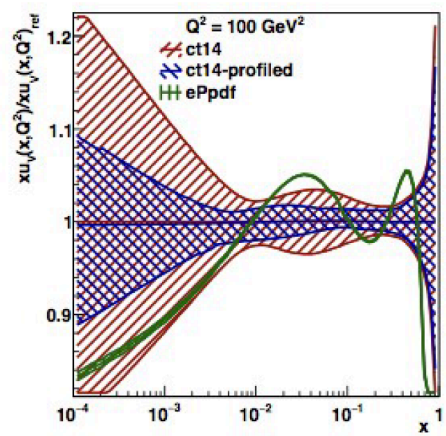
e+e- LEP+SLD uncertainty of 16 x 10^{-5}

Goal HL-LHC ± 20×10^{-5} error in $\sin^2\theta_{\text{eff}}$ corresponds to ±10MeV error in M_W

ATLAS Run 1 : ±19 MeV

- For the HL/HE-LHC Yellow report we would like to extend the study including a LHeC and a HL-LHC PDF scenario





- Using LHeC prospect PDFs we expect the PDF uncertainties to be reduced by a factor of ~10, and the total uncertainty by a factor of ~5 (→ 4 x 10^{-5})

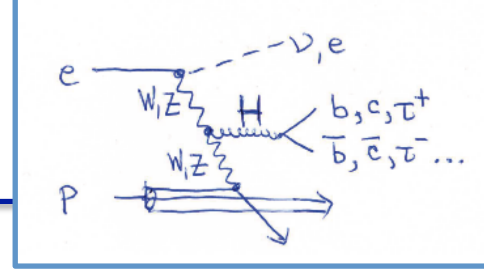
➔ **Better than LEP!!**

➔ **NEW PDFs free from assumptions** & testing PDF paradigms

- Using HL-LHC prospect PDF we expect at maximum a factor of 2 improvement

➔ using mainly **existing assumptions / paradigms in PDF fits** on the composition of sea quarks & gluon at small/high x

Higgs Couplings



M_H=125 GeV
Γ_H=4.088 MeV

	bb	WW	gg	ττ	cc	ZZ	γγ
BR 2016 (BR2014)	0.5824 (0.577)	0.2137 (0.215)	0.08187 (0.086)	0.06272 (0.0632)	0.02891 (0.0291)	0.02619 (0.0264)	0.00227 (0.00228)

CC DIS: ***WW→H → i i*** (decay into FS i as listed in the table)

$$\sigma_{WW\to H\to ii} = \sigma_{WW\to H}\cdot br_i \propto \sigma_H^{SM}\cdot br_i^{SM}\cdot \kappa_W^2\cdot\kappa_i^2\cdot\frac{\Gamma^{SM}}{\sum_j \kappa_j^2\Gamma_j}$$

NC DIS: ***ZZ→H → i i*** (decay into FS i as listed in the table)

$$\sigma_{ZZ\to H\to ii} = \sigma_{ZZ\to H}\cdot br_i \propto \sigma_H^{SM}\cdot br_i^{SM}\cdot \kappa_Z^2\cdot\kappa_i^2\cdot\frac{\Gamma^{SM}}{\sum_j \kappa_j^2\Gamma_j}$$

$$\sum_i \kappa_i^2 br_i = \frac{\Gamma_{H,md}}{\Gamma_H^{SM}}$$ =1 ?

➔ allows a model-dependent fit of coupling uncertainties, see next slide

→ **assuming SM or combination with ee absolute Higgs cross section would enable to measure sum of the 7 branching fractions to**

LHeC : 0.99 +- 0.02 **FCC-he : 0.998 +- 0.010**

Higgs precision observables at FCC ee and eh

Talk by J deBlas @ FCC Week

- Fit to modified Higgs couplings (assuming no extra invisible decays)

NEW

FCC-ee	
Coupling	Relative precision
κ_b	0.58%
κ_t	–
κ_τ	0.78%
κ_c	1.05%
κ_μ	9.6%
κ_Z	0.16%
κ_W	0.41%
κ_g	1.23%
κ_γ	2.18%
$\kappa_{Z\gamma}$	–

FCC-eh	
Coupling	Relative precision
κ_b	0.74%
κ_t	–
κ_τ	1.10%
κ_c	1.35%
κ_μ	–
κ_Z	0.43%
κ_W	0.26%
κ_g	1.17%
κ_γ	2.35%
$\kappa_{Z\gamma}$	–

Summary by J deBlas@FCC-Amsterdam2018

$\equiv g_{hi}/g_{hi}^{SM}$

Higgs→ invisible: 1.2%
ttH: 1.85%

- **All three FCC options complement each other very well:**
  - **FCC-ee allows not only very precise measurements of the Higgs and EWPO but also provides the normalization for more precise measurements at the FCC-eh and FCC-hh**
  - **FCC-eh complements FCC-ee providing information about light quark EW couplings. Similar precision in the Higgs sector**
  - **FCC-hh fills gaps in precision Higgs measurements for rare decays, top and the Higgs self-coupling**

NEW
ee+ep+pp

Talk by J deBlas@FCC-Week2018

Higgs complementarities: Global fit to Higgs couplings at FCC

- **All single Higgs couplings can be determined below the 1%**

FCC-ee/FCC-eh
Precise determinations for the leading couplings

HZZ Crucial for normalization of FCC-hh results

FCC-hh
Completes the picture with precise determinations of Top and coupling associated to rare decays

NOT MODEL-INDEPENDENT:
Results assume that, if there is New physics, it can only be in the Higgs couplings

HLLHC + FCC	
Coupling	Relative precision
κ_b	0.38%
κ_t	0.51%
κ_τ	0.58%
κ_c	0.79%
κ_μ	0.42%
κ_Z	0.14%
κ_W	0.17%
κ_g	0.74%
κ_γ	0.40%
$\kappa_{Z\gamma}$	0.52%

$$\kappa_i \equiv g_{hi}/g_{hi}^{SM}$$

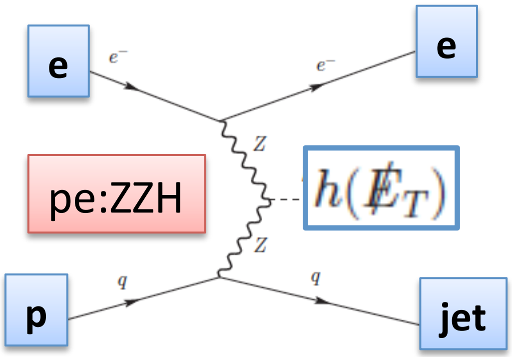
→ Combine the complementary measurements for best physics outcome!
→ Next: joint EFT fits

Branching for invisible Higgs

Satoshi Kawaguchi,
Masahiro Kuze
Tokyo Tech

Values given in case of 2σ and L=1 ab^{-1}

Delphes detectors	LHeC / HL-LHC 1.3 / 1.8 TeV	FCC-he 3.5 TeV
LHC-style	4.7% / 3.2%	1.9%
First 'ep-style'	5.7%	2.6%
+BDT Optimisation	5.5% (4.5%*)	1.7% (2.1%*)



PORTAL to Dark Matter ?

LHeC parton-level, cut based <6% [arXiv: 1508.01095]
HL-LHC @ 3 ab^{-1} < 3.5% [arXiv:1411. 7699]

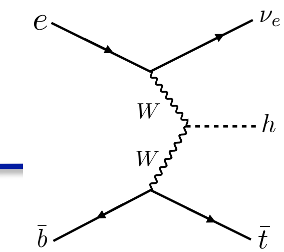
- ✓ **Uses ZZH fusion process to estimate prospects of Higgs to invisible decay using *standard cut/BDT analysis techniques***
- ✓ **Results for full MG5+Delphes analyses, done for 3 c.m.s. energies → very encouraging for a measurement of the branching of Higgs to invisible in ep down to 1.2% (1.7%) for 2 (1) ab^{-1}**

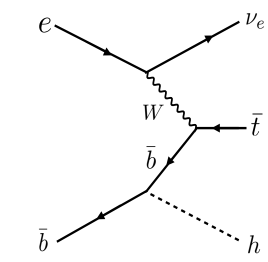
- ✓ We also checked LHeC ←→ FCC-he scaling with the corresponding cross sections (* results in table) : Downscaling FCC-he simulation results to LHeC would give 4.5%, while up-scaling of LHeC simulation to FCC-he would result in 2.1% → all well within uncertainties of projections of ~25%

→ further detector and analysis details have certainly an impact on results

Top Yukawa Coupling @ LHeC

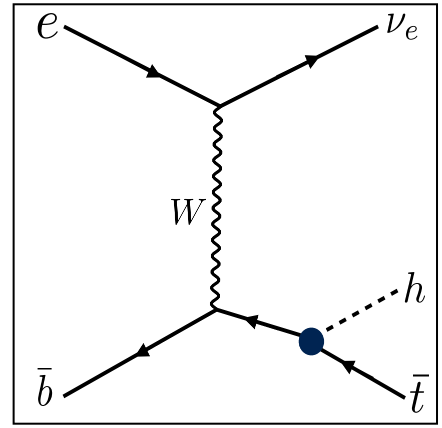
B.Coleppa, M.Kumar, S.Kumar, B.Mellado, Phys. Lett. B770 (2017) 335



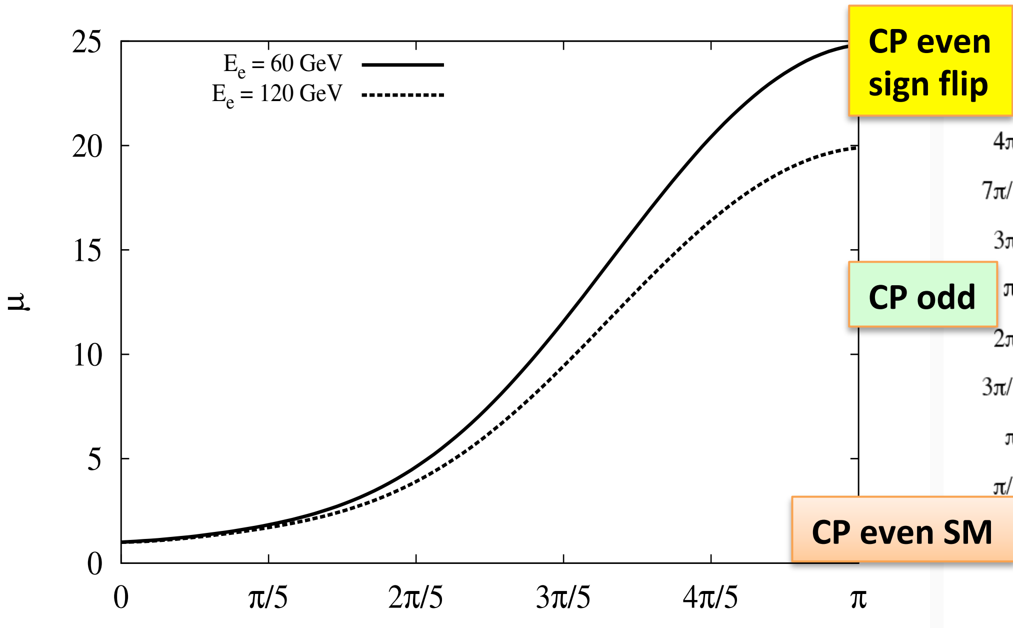


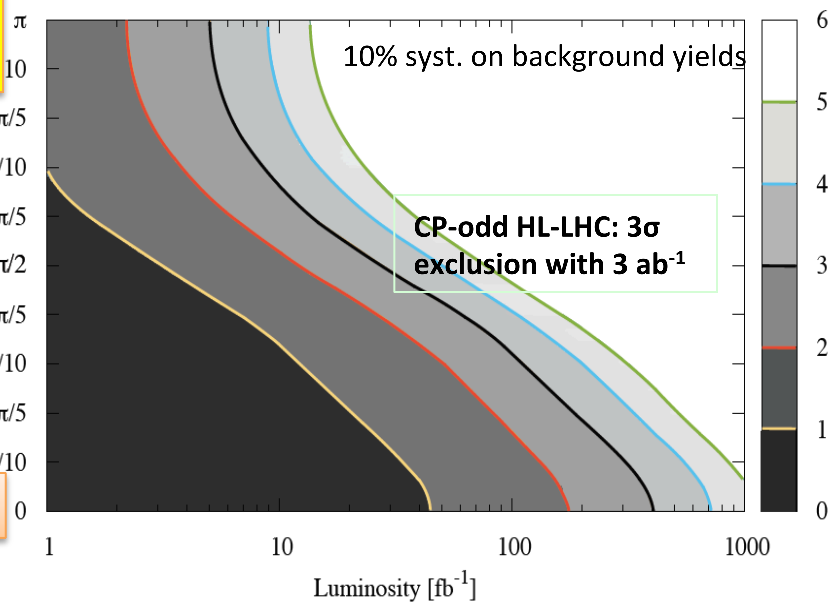
Introduce phase dependent top Yukawa coupling

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



Enhancement of the DIS cross-section as a function of phase





Observe/Exclude non-zero phase to better than 4σ ➔ With Zero Phase: Measure **ttH** coupling with **17% accuracy at LHeC** ➔ **extrapolation to FCCeh: ttH to 1.85%**

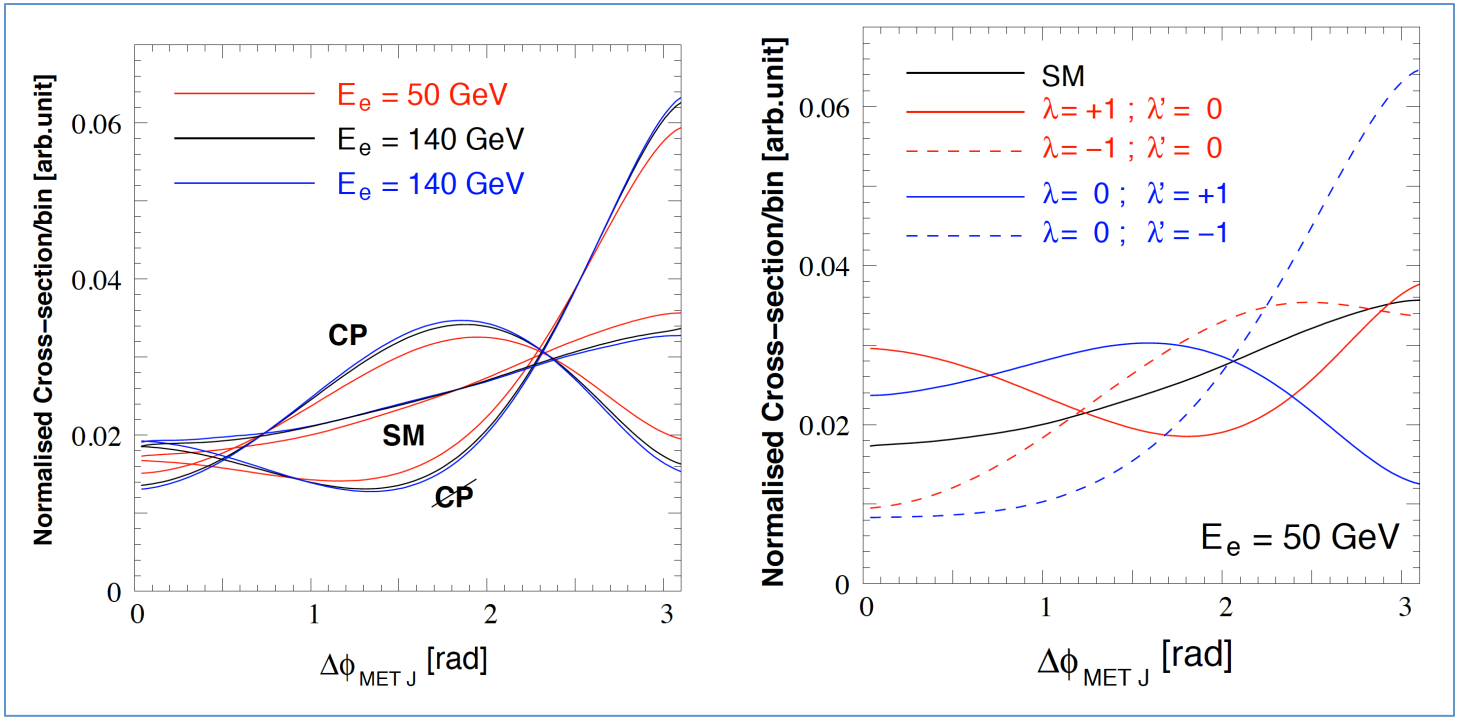
Measure CP Properties of Higgs

[CDR before Higgs discovery M_H=120 GeV, E_p=7 TeV]

- Higgs couplings with a pair of gauge bosons (WW/ZZ) and a pair of heavy fermions (t/b/τ) are largest.
- Higgs@LHeC allows uniquely to access HWW vertex → explore the CP properties of HVV couplings: BSM will modify CP-even (λ) and CP-odd (λ') states differently

$$\Gamma^{\mu\nu}_{(\mathrm{SM})}(p,q) = g M_W\, g^{\mu\nu} \quad \rightarrow \quad \Gamma^{(\mathrm{BSM})}_{\mu\nu}(p,q) = \frac{-g}{M_W}\left[\lambda\,(p.q\, g_{\mu\nu} - p_\nu q_\mu) + i\,\lambda'\,\epsilon_{\mu\nu\rho\sigma} p^\rho q^\sigma\right]$$

- Study ***shape changes*** in DIS normalised CC Higgs→ bb cross section versus the azimuthal angle, $\Delta\phi_{MET,J}$, between $E_{T,miss}$ and forward jet.



CDR initial study of HWW vertex:

CP couplings probed to

λ~0.05

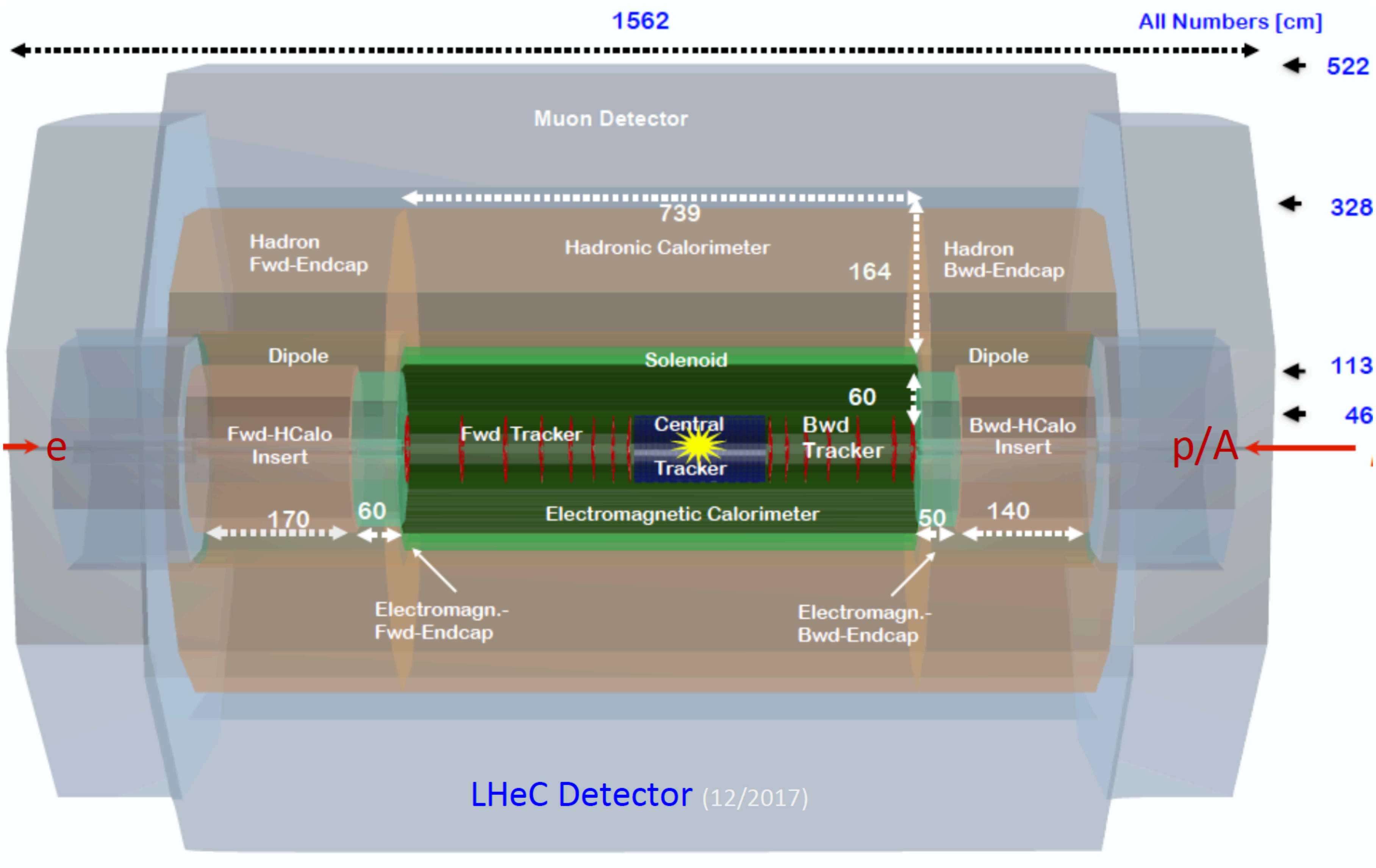
λ'~0.2

based on 50 fb^{-1}

→ Todo: full detector, 125 GeV Higgs study

LHeC Detector for the HL/HE-LHC

[arXiv:1802.04317]



Length x Diameter: LHeC (13.3 x 9 m^2) HE-LHC (15.6 x 10.4) FCCeh (19 x 12)

ATLAS (45 x 25) CMS (21 x 15): [LHeC < CMS, FCC-eh ~ CMS size]

If CERN decides that the HE LHC comes, the LHeC detector should anticipate that

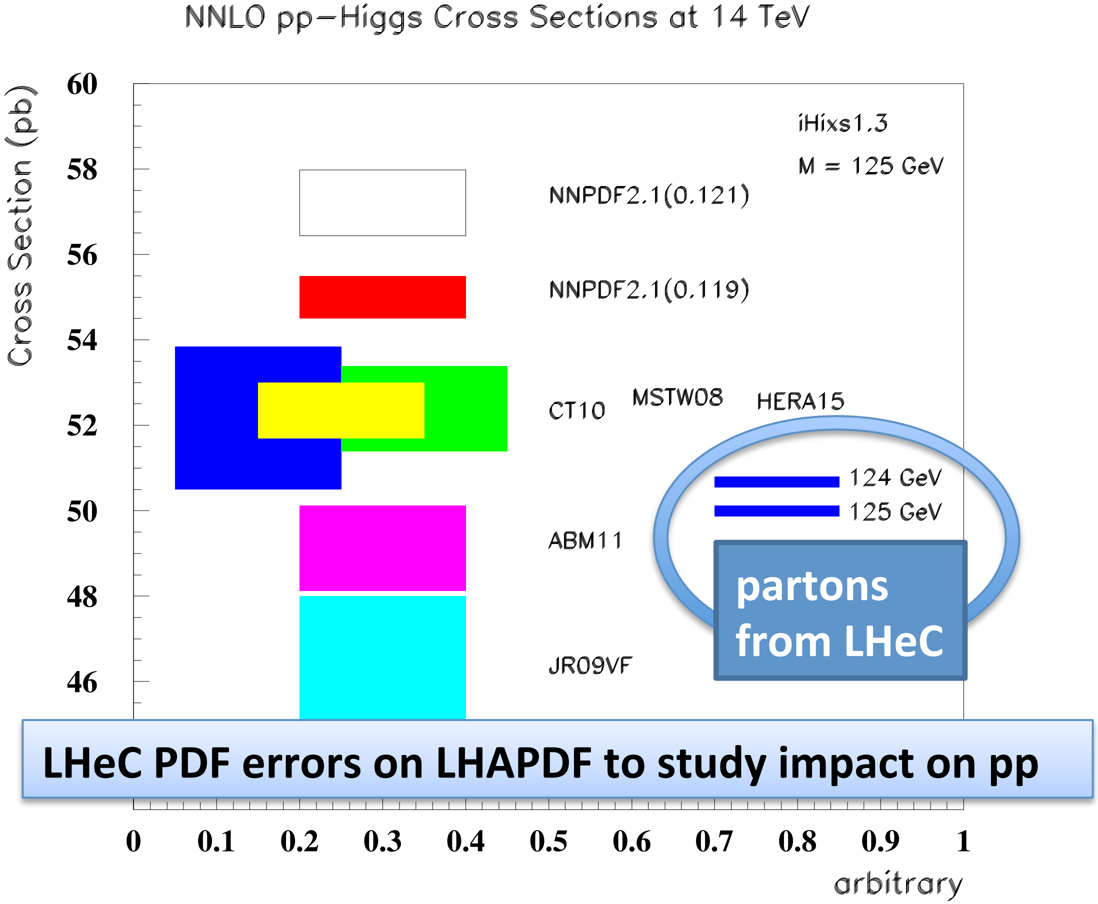
See also talk by C Gwenlan

LHeC Precision Partons for Higgs@pp

→ **<u>Using LHeC input</u>**: experimental uncertainty of predicted **LHC Higgs cross section due to PDFs and α_s** is strongly **reduced to <~0.5%**

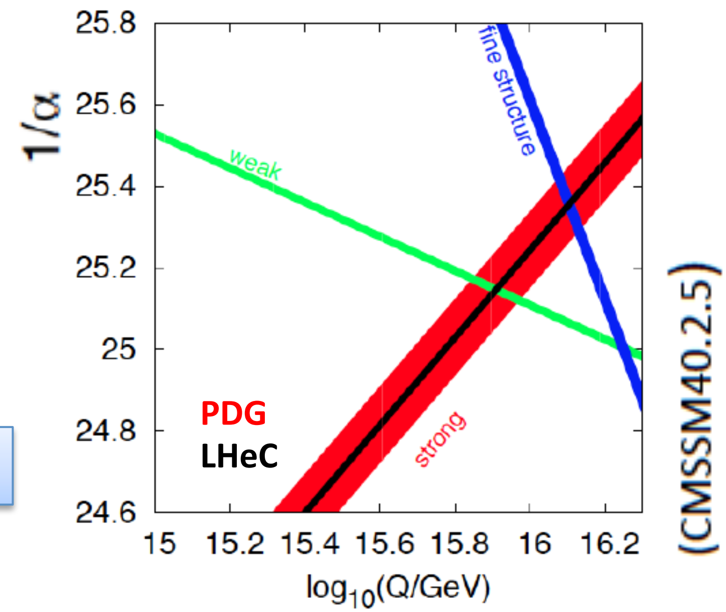
→ ***theoretically clean path to determine N³LO PDFs*** using ep DIS

→ ***ALL those 'benefits' for pp within the first few years, using ~100 fb^{-1} ep data***



LHeC PDF errors on LHAPDF to study impact on pp

→ **precision from LHeC can add a very significant constraint on the Higgs mass** *and challenge Lattice QCD calculations for α_S:*



Invisible Higgs@LHeC

relating the Higgs and the 'dark' sectors

Y.-L. Tang et al., arXiv: 1508.01095

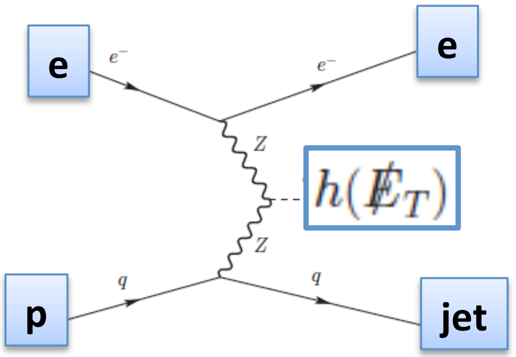
HL-LHC @ 3 ab^{-1} [arXiv:1411. 7699]

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

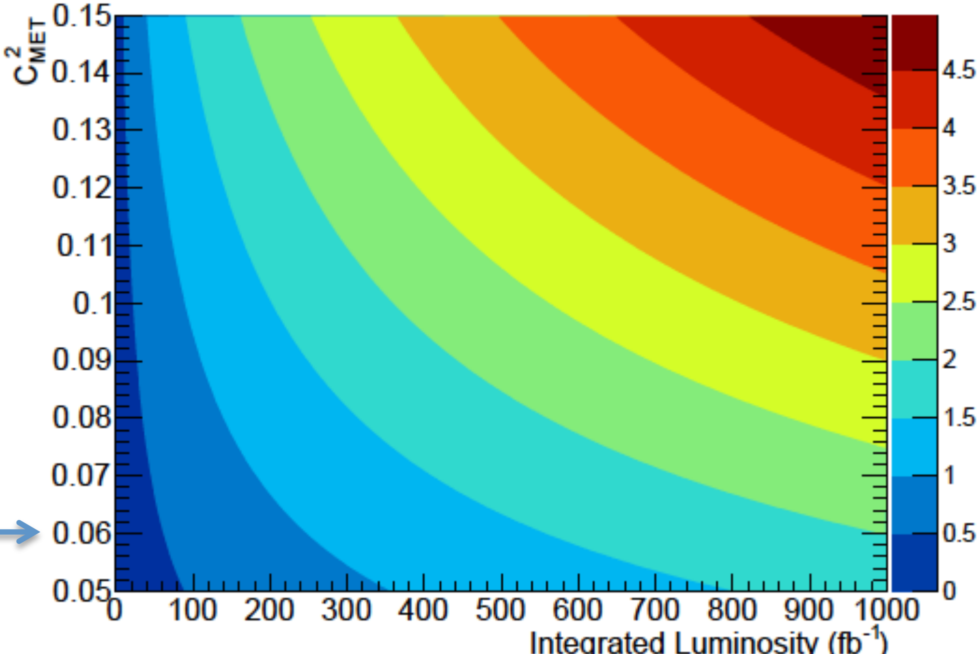
For **LHeC**, assume : 1ab^{-1}, P_e=-0.9, <u>cut based</u>

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

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



κ_Z : BSM w.r.t. SM HZZ coupling



Colours: expected statistical significance

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

→ NEW studies performed on Delphes detector-level using our Madevent framework

Exotic Higgs Decays

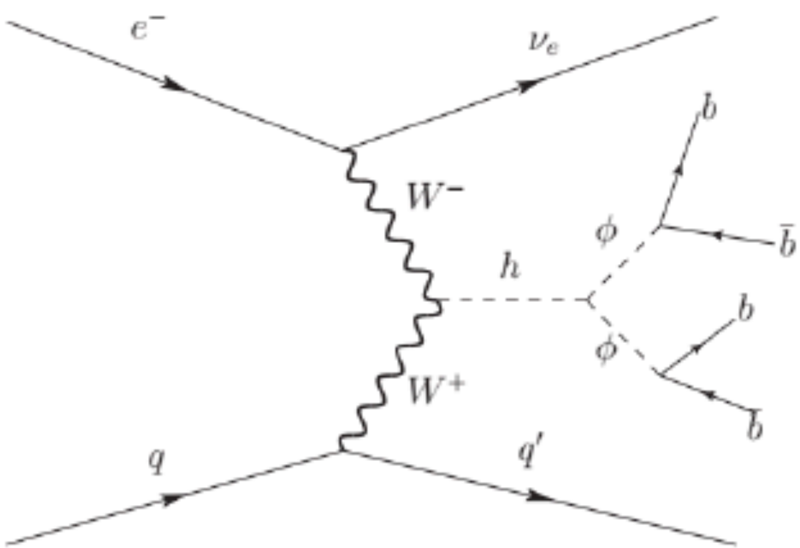
$$\mathcal{L}_{eff} = \lambda_h v h \phi^2 + \lambda_b \phi \bar{b} b + \mathcal{L}_{\phi\,\mathrm{decay,other}}$$

$$h \to \phi\phi \to 4b$$

ϕ: a spin-0 particle from new physics.

S. Liu, Y. L. Tang, C. Zhang, S. Zhu, 1608.08458

$$eq \to \nu_e h q' \to \nu_e \phi\phi q' \to \nu_e b\bar{b}b\bar{b}q'$$

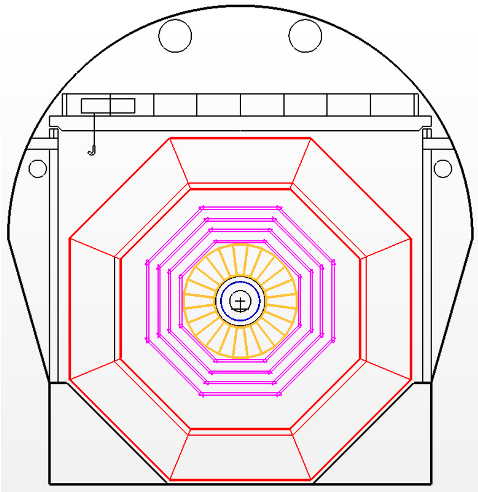


$$C_{4b}^2 = \kappa_V^2 \times \mathrm{Br}(h \to \phi\phi) \times \mathrm{Br}^2(\phi \to b\bar{b})$$

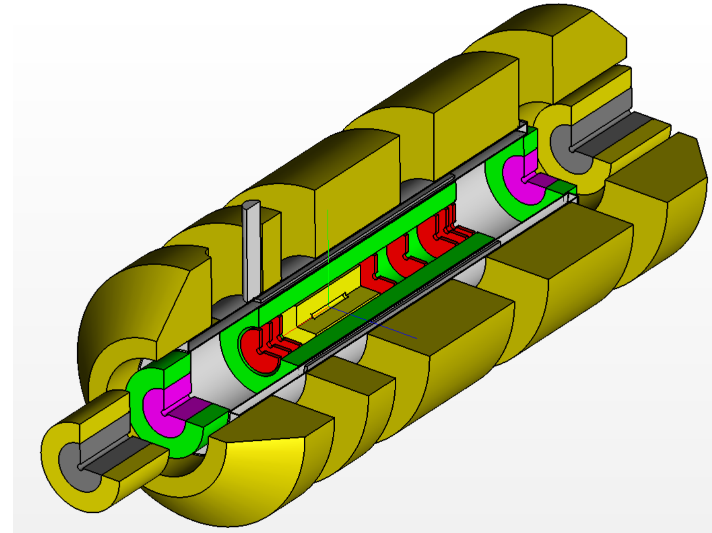
- Well motivated signature in extended Higgs sector.
- Difficult to probe at hadron colliders.
- LHeC signal: here using CC channel.
- Backgrounds: CC multijet, CC t/h/W/Z+jets, PHP multijet.
- PHP backgrounds assumed to be negligible after MET requirements and electron tagging.
- Current analysis is done at parton level.

@LHeC: 95% C.L. for m_ϕ of 20, 40, 60 GeV is 0.3%, 0.2% and 0.1% for C_{4b}^2

Installation Study
to fit into LHC shutdown needs directed to IP2
Andrea Gaddi et al



Detector fits in L3 magnet support



Modular structure

LHeC INSTALLATION SCHEDULE