Higgs and EWK ep Physics at the FCC-eh

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DESY & University of Hamburg
for the LHeC/FCC-eh Study Group

FCC Physics Workshop 2022
Online
8 February 2022

Outline

Introduction
Electroweak Physics
Higgs Physics
Conclusions

Outline

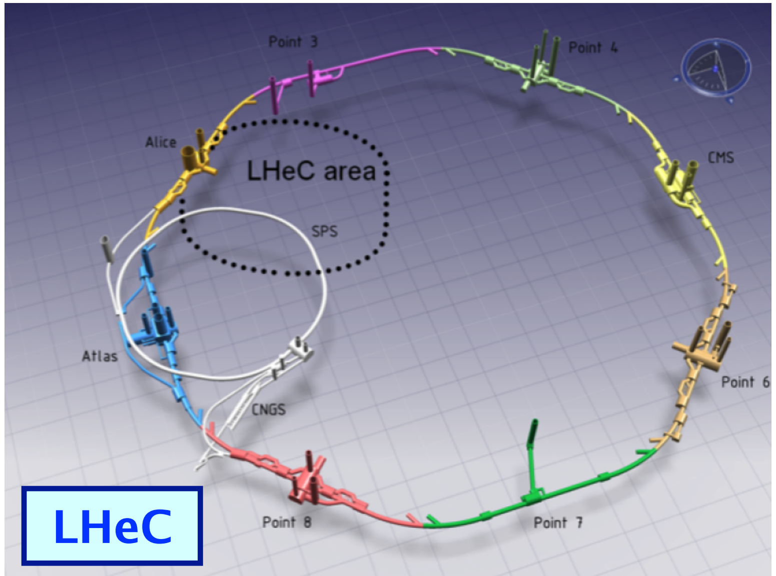
Introduction

Electroweak Physics

Higgs Physics

Conclusions

Linac-Ring Collider, LHeC and FCC-eh



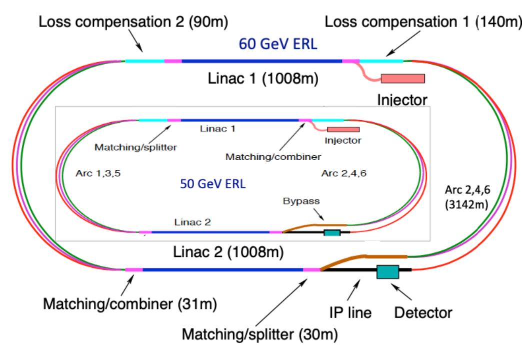
LHeC CDRs:
arXiv:1206.2913, J. Phys. G 39 075001 (2012)
arXiv:2007.14491 (J. Phys. G 48 (2021) 11)

- operated **synchronously** with **HL-LHC:** e beam: 50 GeV × p beam: 7 TeV: $\sqrt{s}$=1.2 TeV
- operation: 2035+
- cost: O(1) BCHF
- luminosity of 10^{34} $cm^{-2}s^{-1}$

FCC CDR:
Eur. Phys. J. C 79, no. 6, 474 (2019) - Physics
Eur. Phys. J. ST 228, no. 4, 755 (2019) - FCC-hh/eh

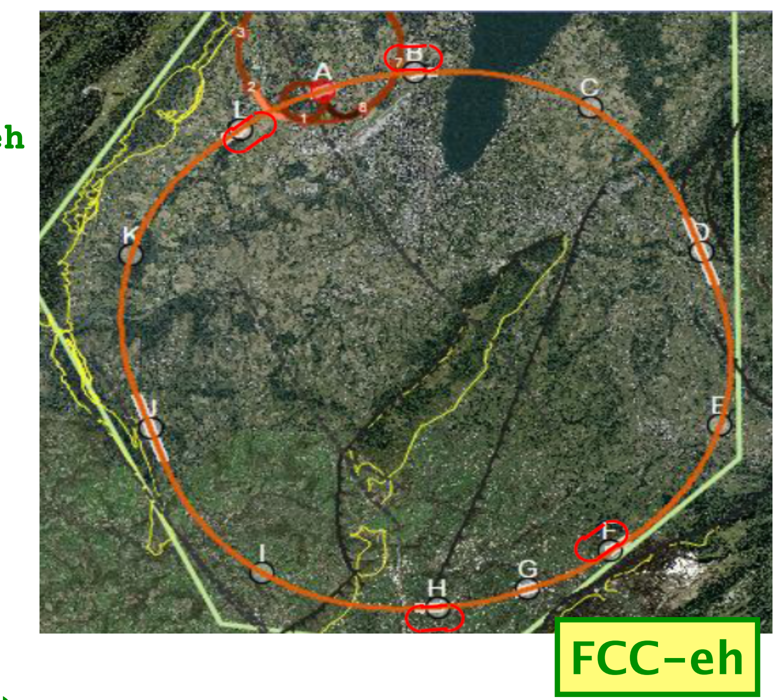
Energy Recovering Linac

e± beam: 50, 60 GeV



L_{int} = 1-3 ab^{-1} (1000×HERA!)

- operated **synchronously** with **FCC-hh:** e beam: 60 GeV × p beam: 50 TeV: $\sqrt{s}$=3.5 TeV
- operation: 2050+
- cost: O(1-2) BCHF

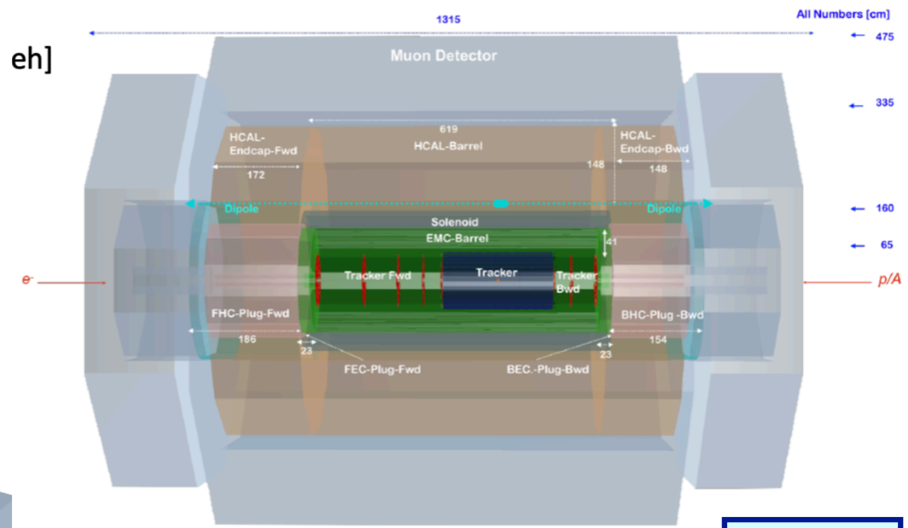


LHeC and FCC-eh Detector Layout

FCC-eh

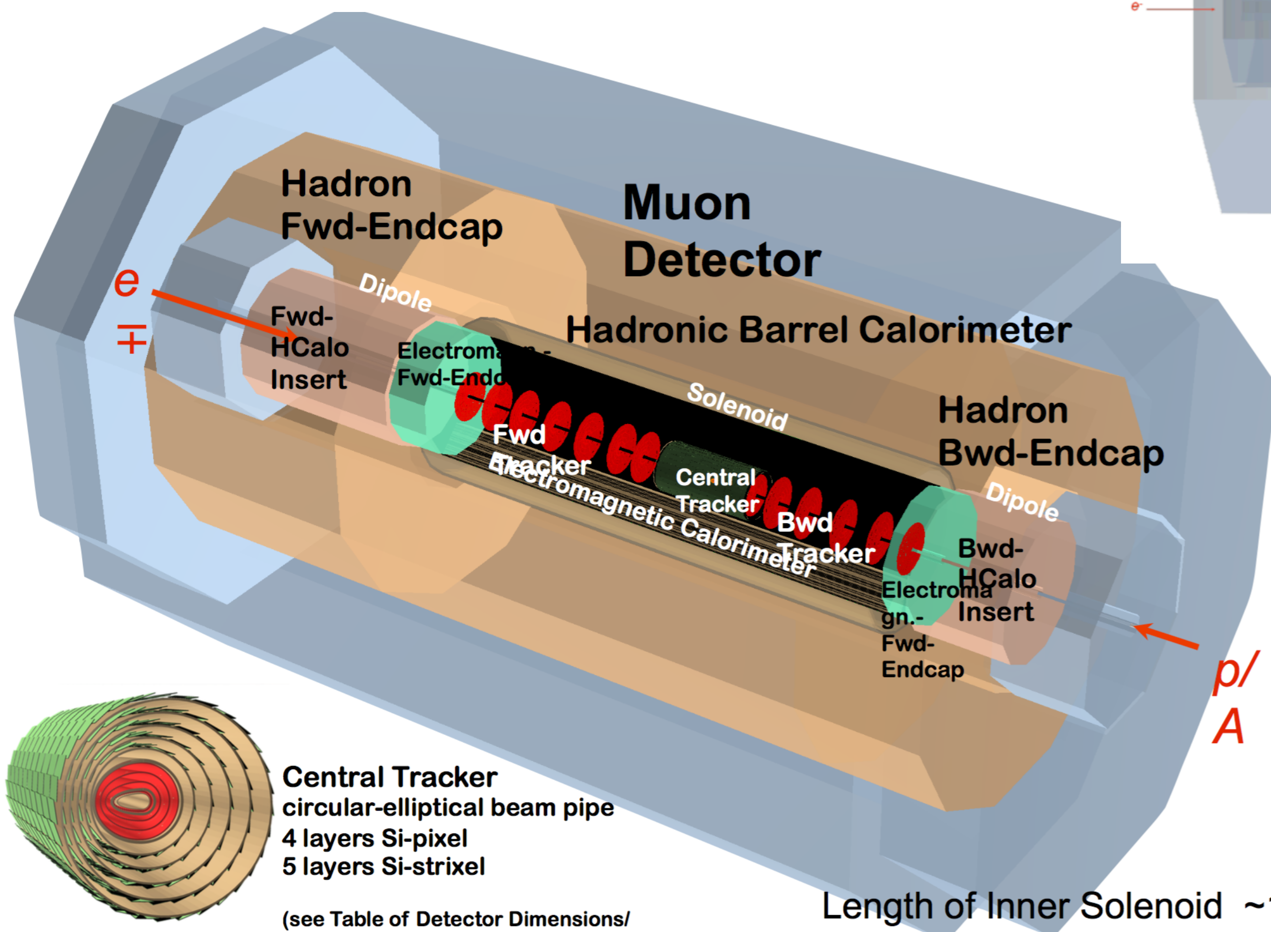
L=19.3m
(about CMS size)

eh]



L=13.2m

LHeC

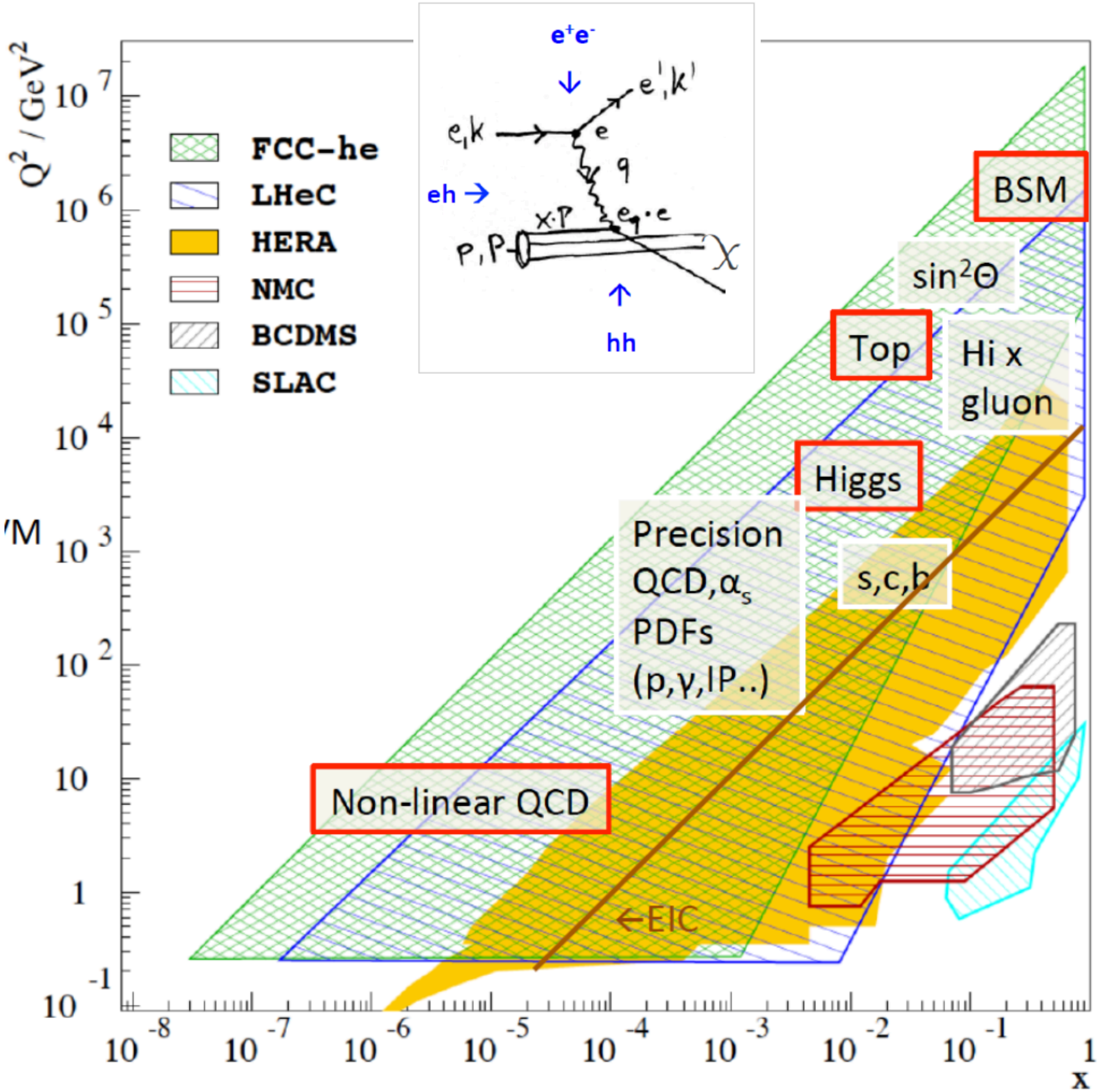


Central Tracker
circular-elliptical beam pipe
4 layers Si-pixel
5 layers Si-strixel

(see Table of Detector Dimensions/ Parameters in backup)

Length of Inner Solenoid ~12m

High energy frontier eh physics



deliveries of ep/eA at the energy frontier

- cleanest high resolution microscope: QCD discovery
- empowering the LHC/FCC search program
- precision Higgs facility together with LHC/FCC-hh
- precision and discovery facility (top, EWK, BSM)
- unique nuclear physics facility

→ **diversity**

→ **ep collider excellent to explore Higgs & EW theory**

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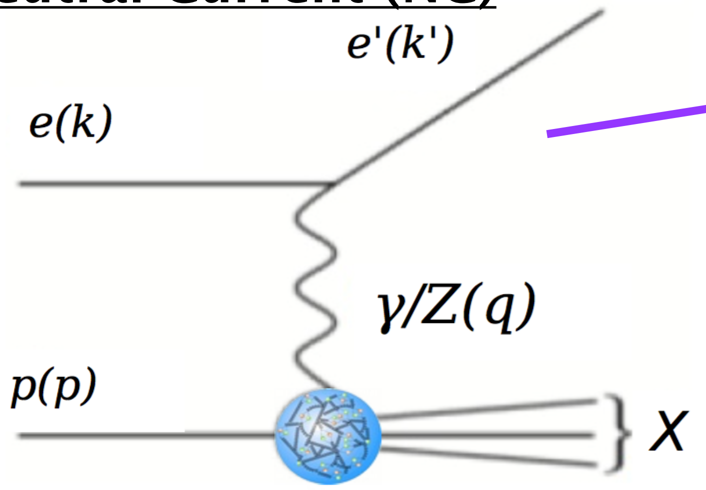
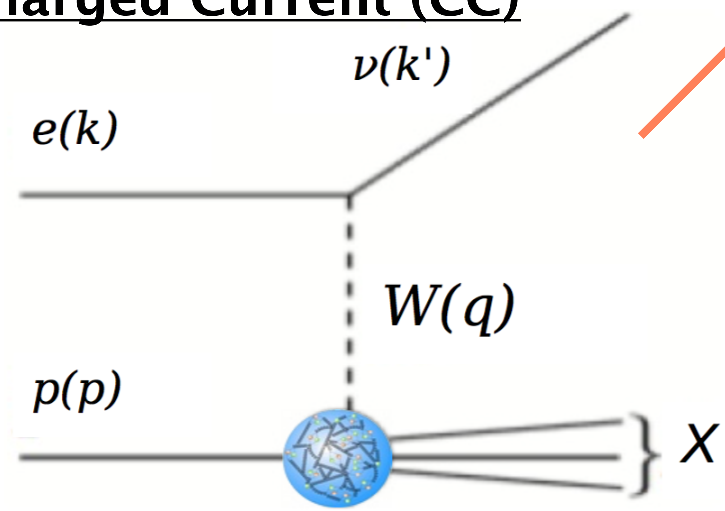
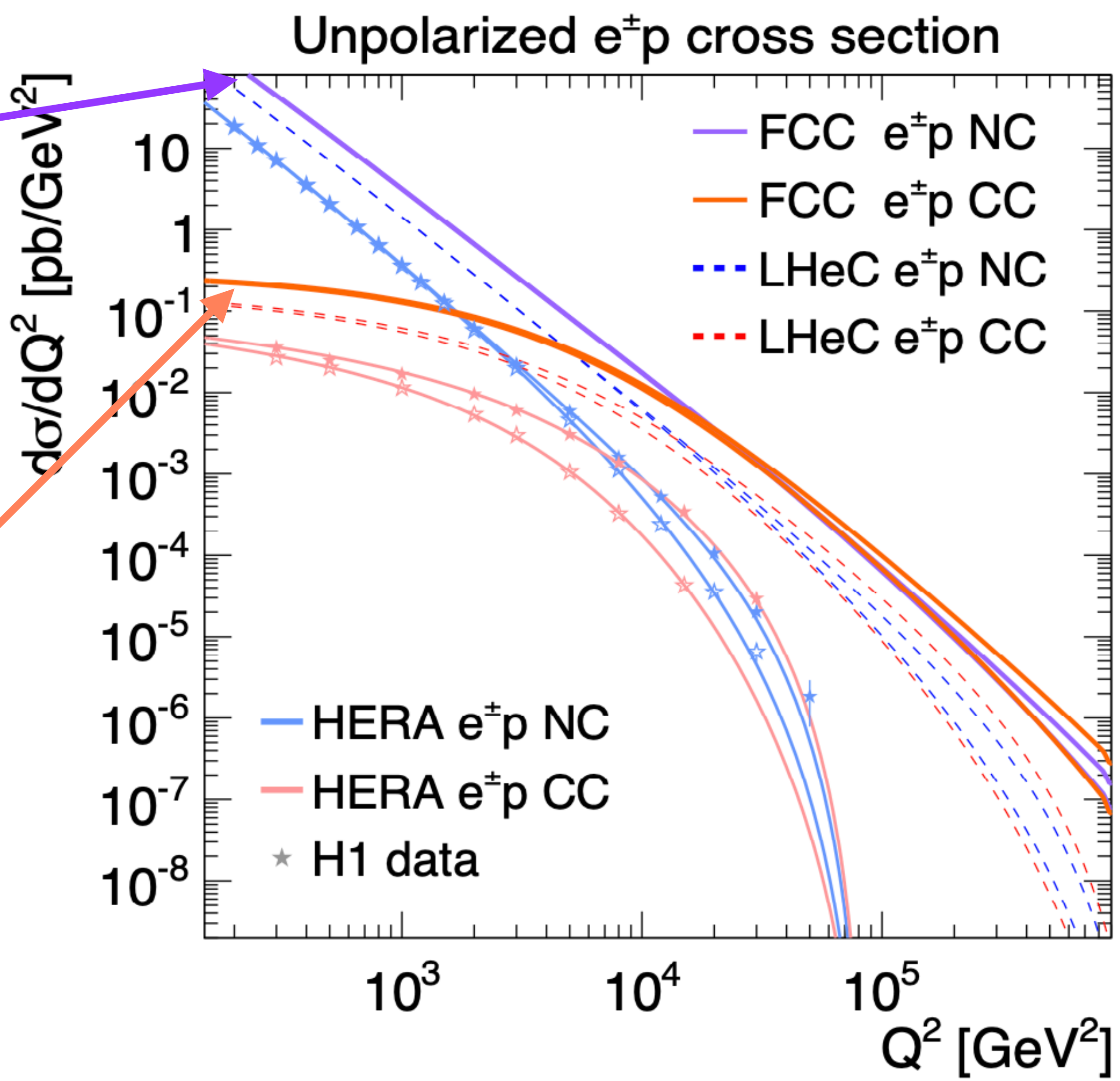
Deep Inelastic Scattering

Neutral Current (NC)



Charged Current (CC)

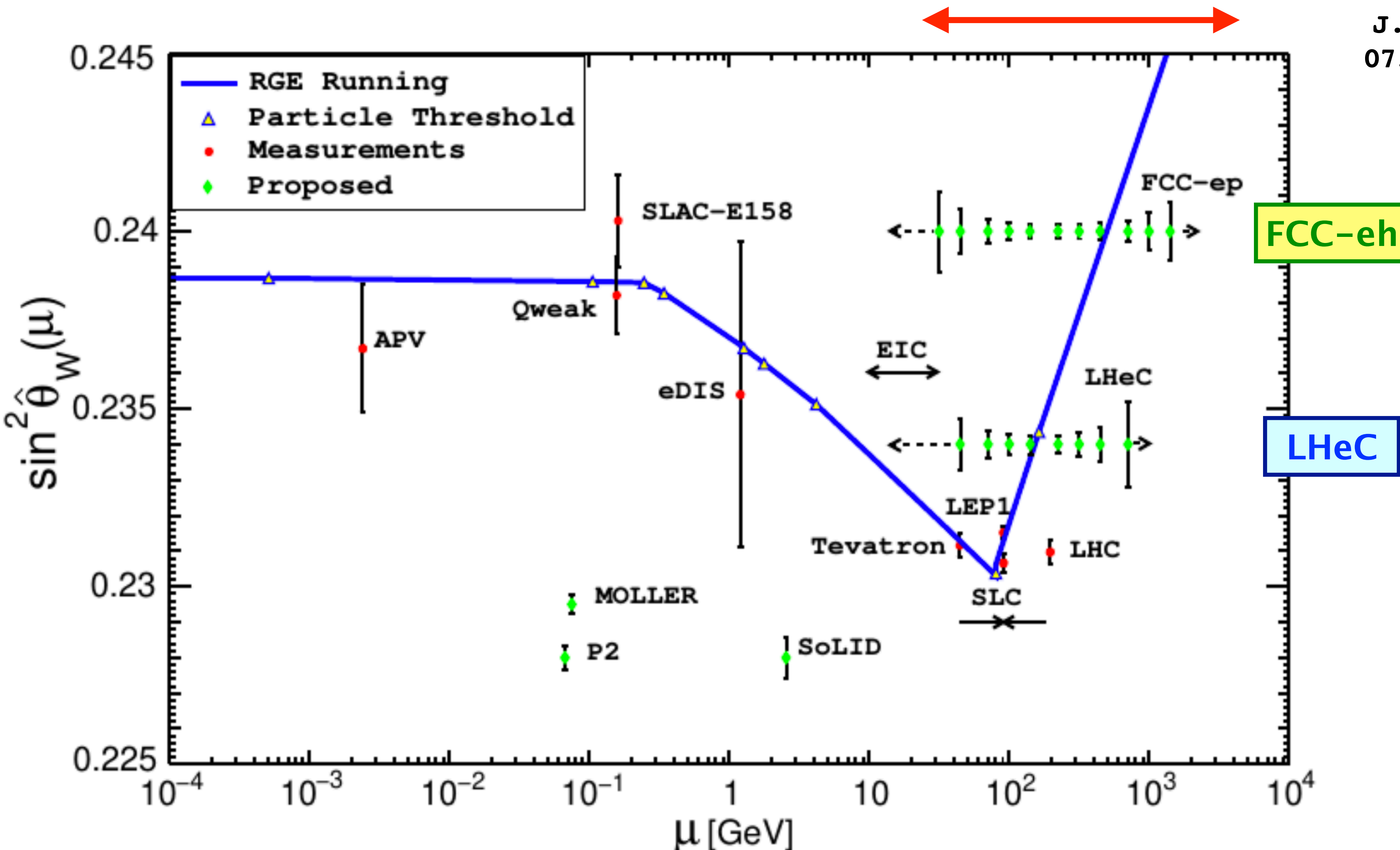




→ **LHeC/FCC-eh are unique facilities for testing EW theory:**
NC+CC, two e-beam charge and polarisation states, p or isoscalar targets

Scale Dependence of $\sin^2\theta_W$

LHeC CDR, J.Phys. G39, 075001 (2012)



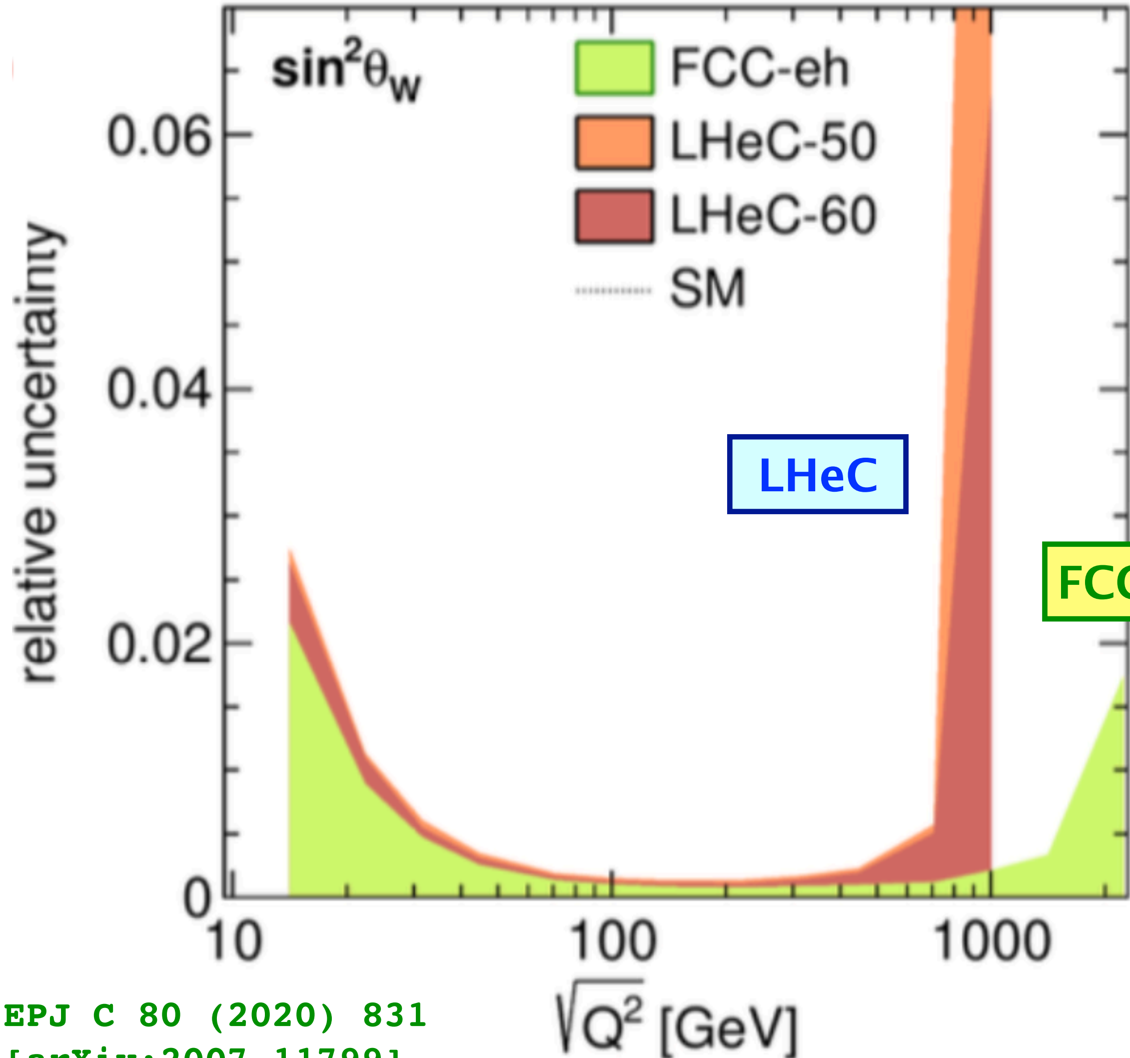
→ **probe large range of scale dependence**

MSbar definition

Scale Dependence of $\sin^2\theta_W$

NC+CC DIS

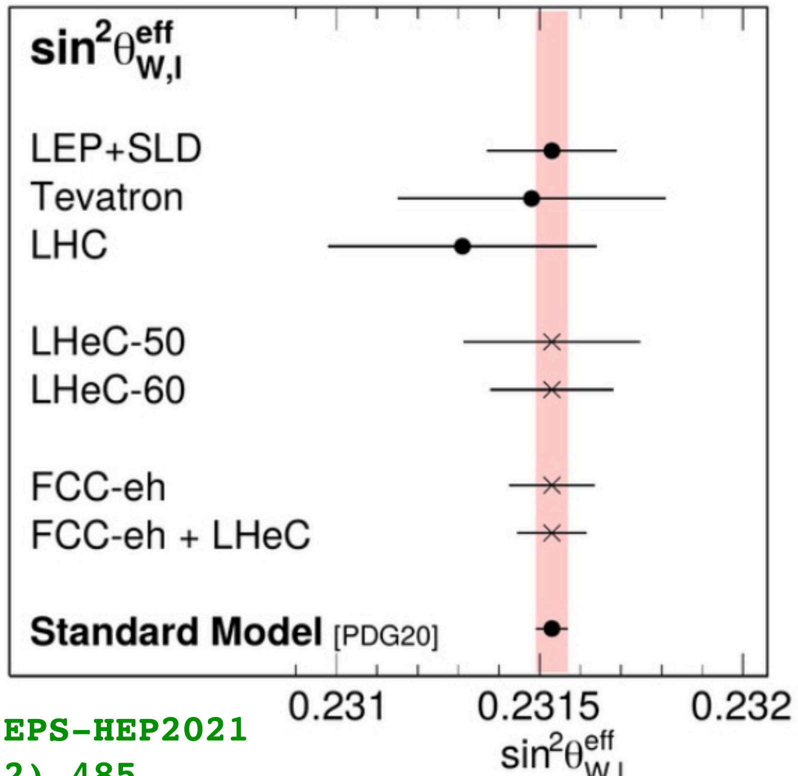
on-shell definition $\sin^2\theta_W = 1 - \frac{m_W^2}{m_Z^2}$



FCC-eh

$\Delta\sin^2\theta_w$ (FCC-eh) = ±0.00011
= ±0.00010$_{(exp)}$ ±0.00004$_{(PDF)}$

→ **precision per mille level**

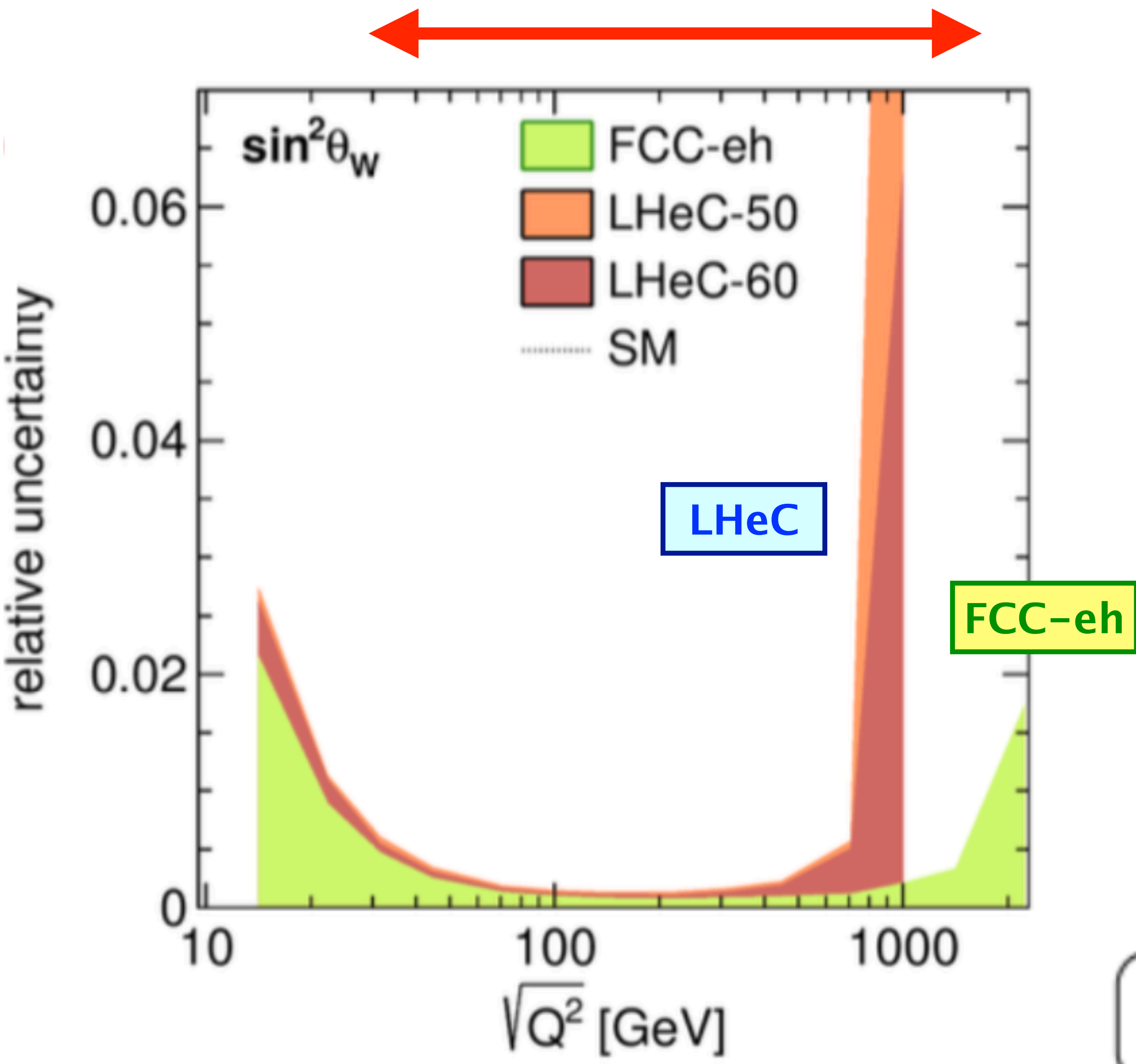


EPJ C 80 (2020) 831
[arXiv:2007.11799]

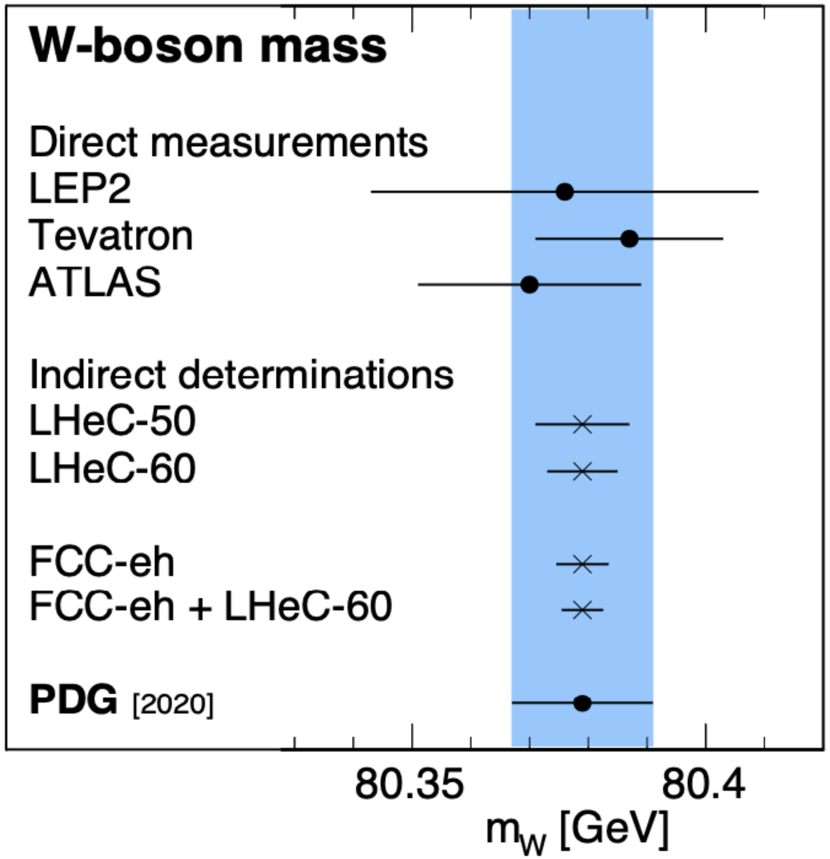
PoS EPS-HEP2021 (2022) 485

→ **probe large range of scale dependence**

Scale Dependence of $\sin^2\theta_W$



on-shell definition $\sin^2\theta_W = 1 - \frac{m_W^2}{m_Z^2}$

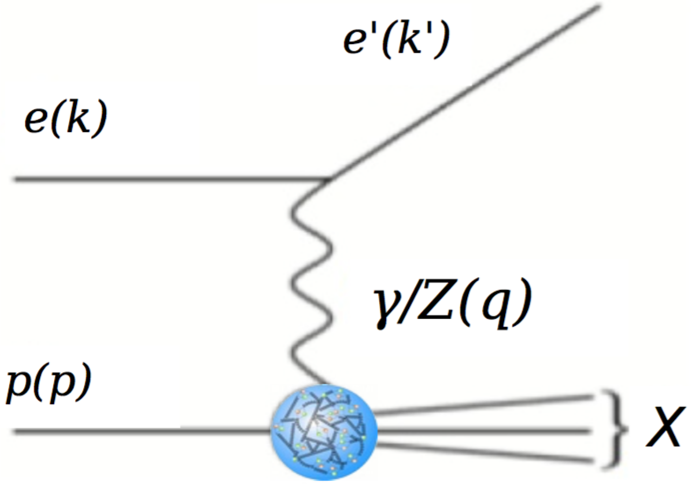


→ **probe large range of scale dependence**

$\Delta m_W = \pm 4.5$ MeV

(includes PDF uncertainty of about ±3.6 MeV)

Electroweak Fermion Couplings



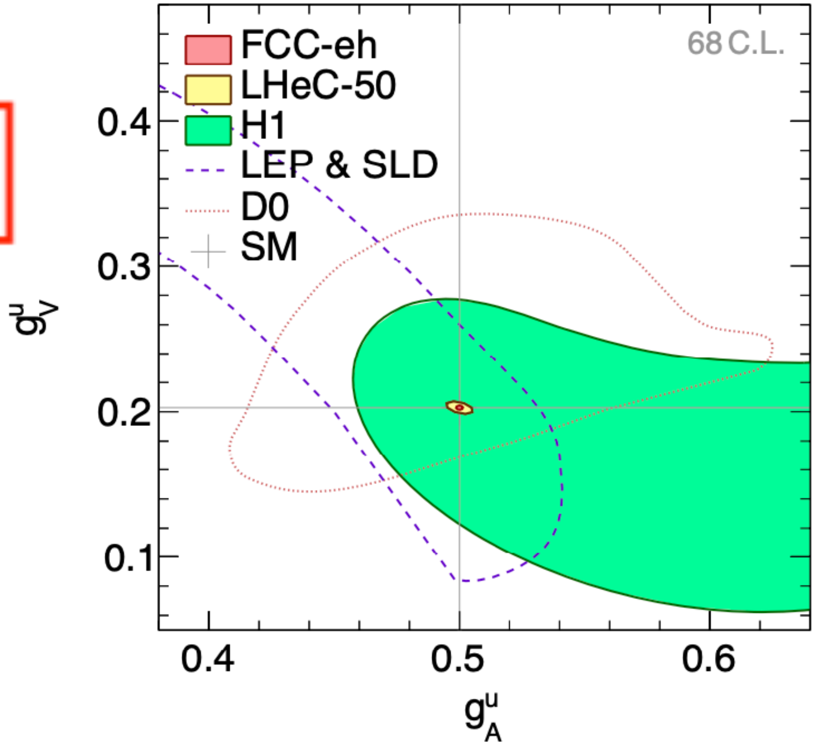
$$g_A^f = \sqrt{\rho_{\mathrm{NC},f}\rho'_{\mathrm{NC},f}}\, I^3_{\mathrm{L},f}\,,$$

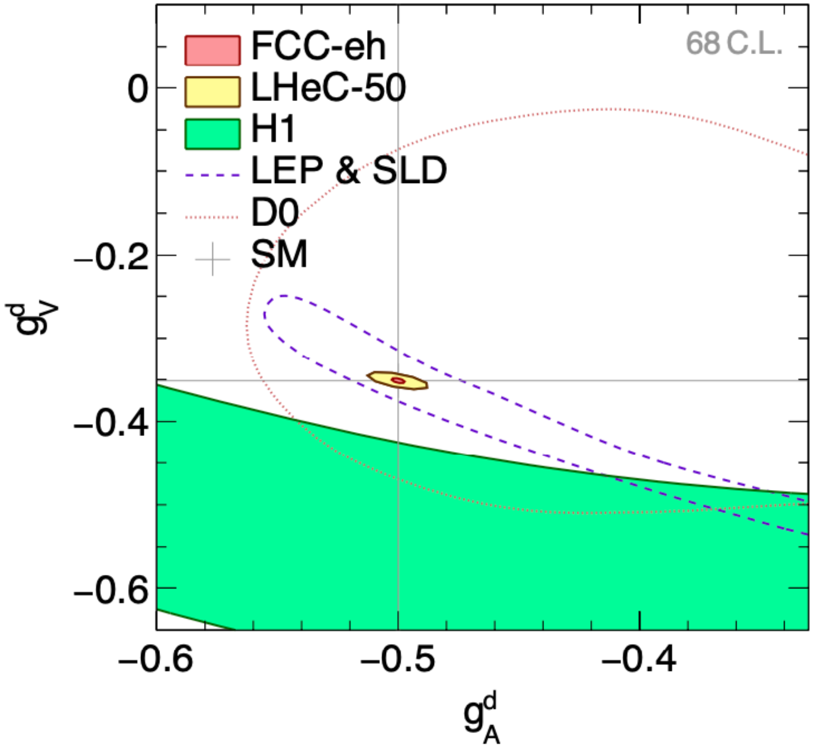
$$g_V^f = \sqrt{\rho_{\mathrm{NC},f}\rho'_{\mathrm{NC},f}}\left(I^3_{\mathrm{L},f} - 2Q_f\kappa_{\mathrm{NC},f}\kappa'_{\mathrm{NC},f}\sin^2\theta_W\right)$$

→ **precision on per mille level**

(largely unaccessible in e^+e^-)

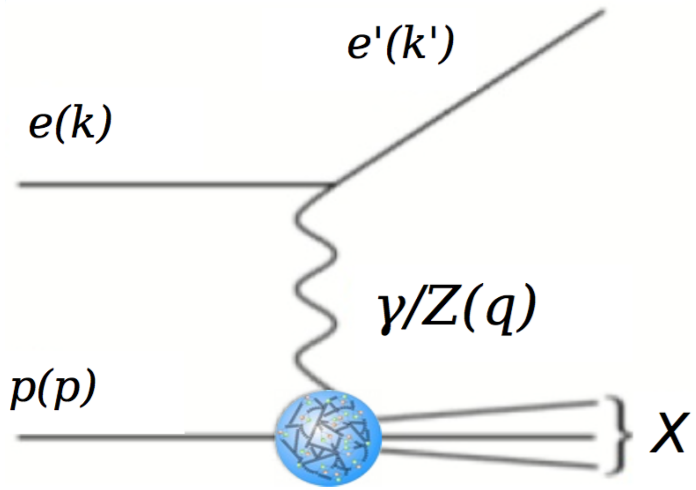
u





d

Electroweak Fermion Couplings



$$g_A^f = \sqrt{\rho_{NC,f}\rho'_{NC,f}}\, I_{L,f}^3 \,,$$

$$g_V^f = \sqrt{\rho_{NC,f}\rho'_{NC,f}}\left(I_{L,f}^3 - 2Q_f\kappa_{NC,f}\kappa'_{NC,f}\sin^2\theta_W\right)$$

→ **precision on per mille level**

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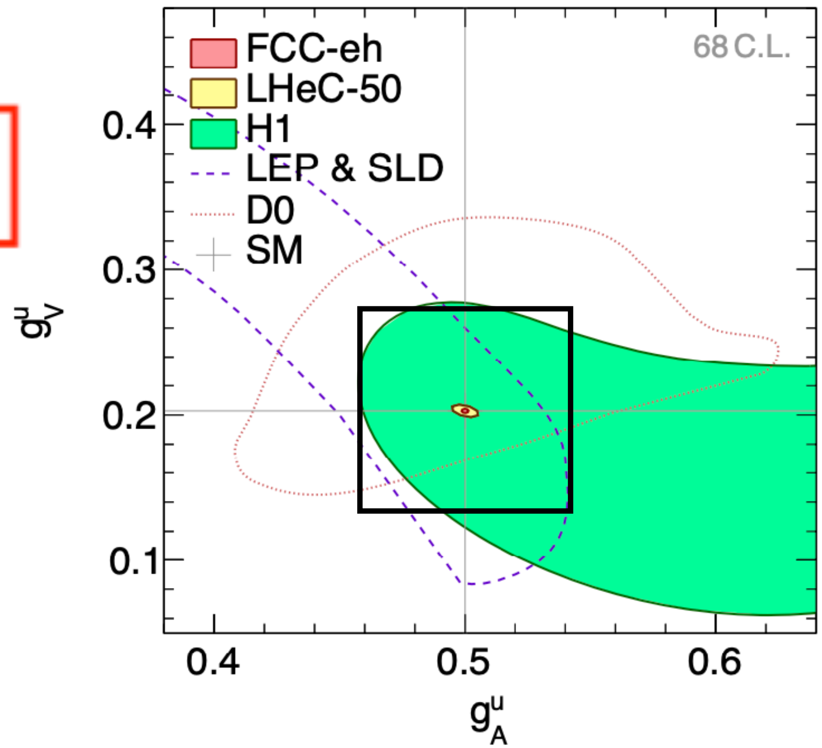

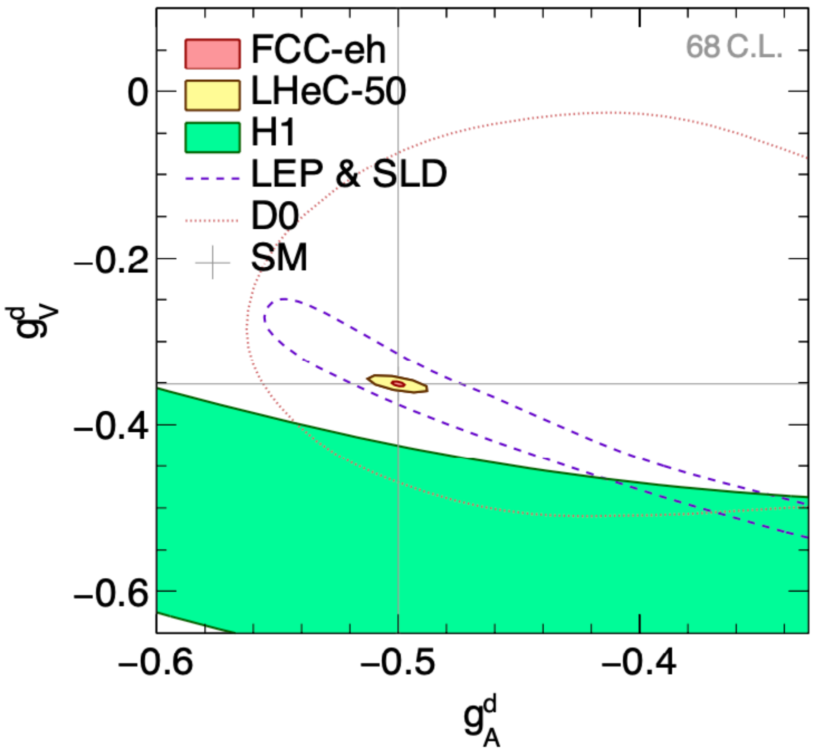

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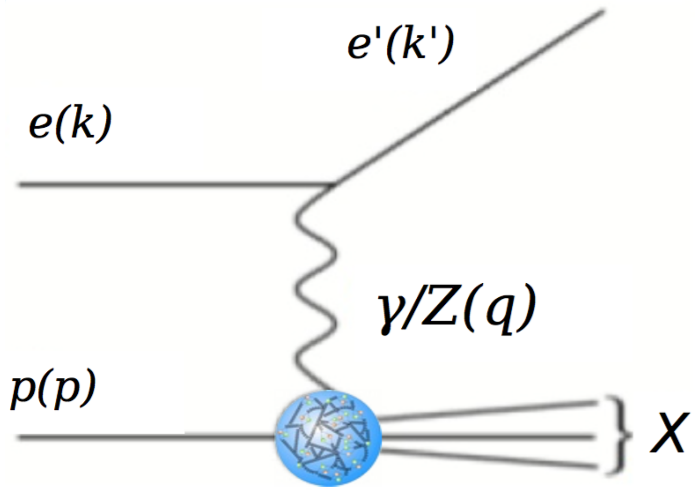
Electroweak Fermion Couplings



$$g_A^f = \sqrt{\rho_{NC,f}\rho'_{NC,f}}\, I^3_{L,f}\,,$$

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→ **precision on per mille level**

(largely unaccessible in e^+e^-)

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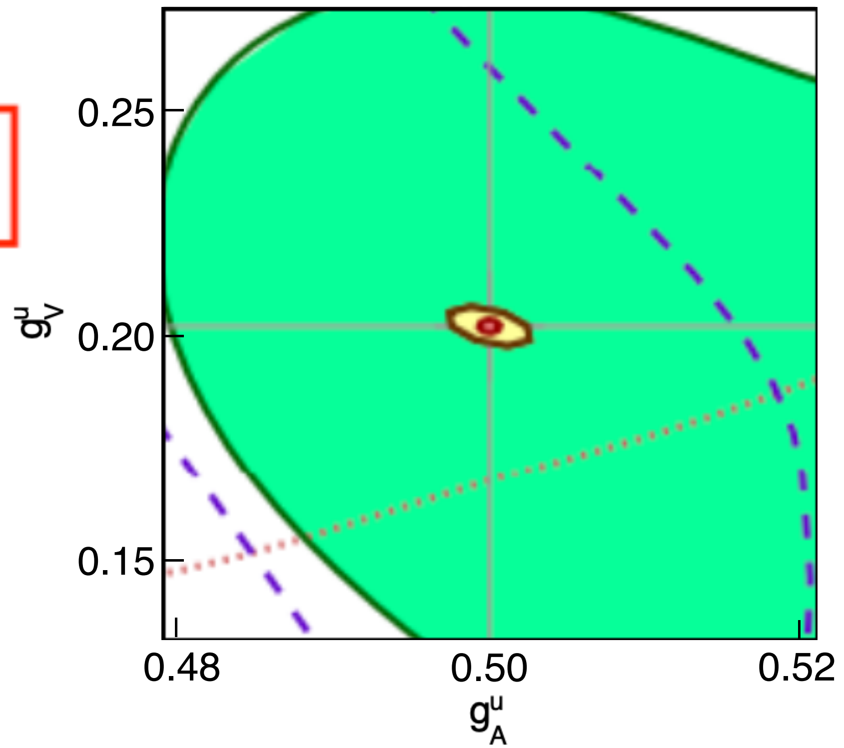

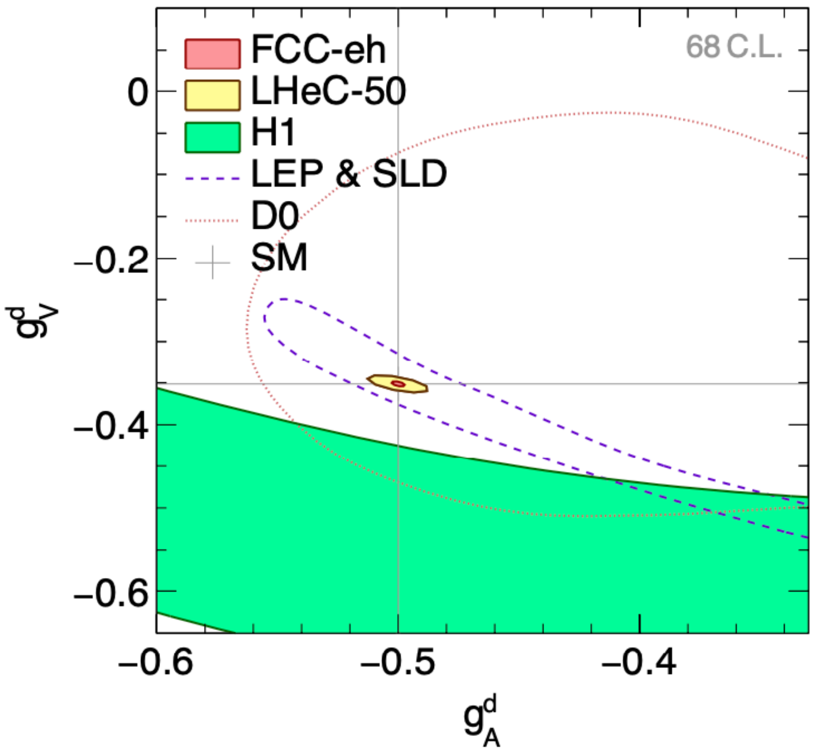

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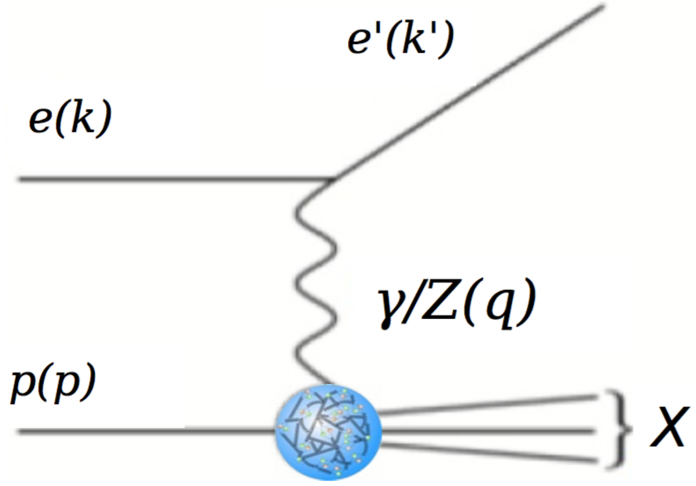
Electroweak Fermion Couplings



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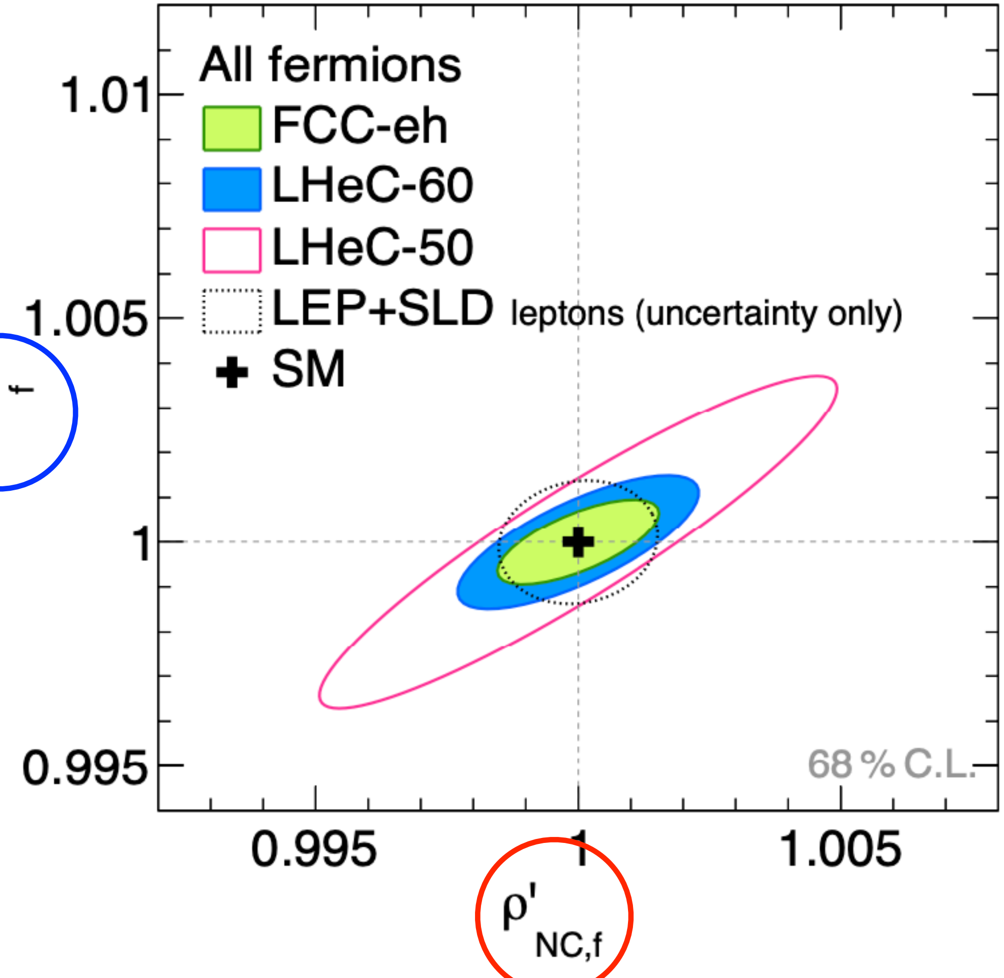
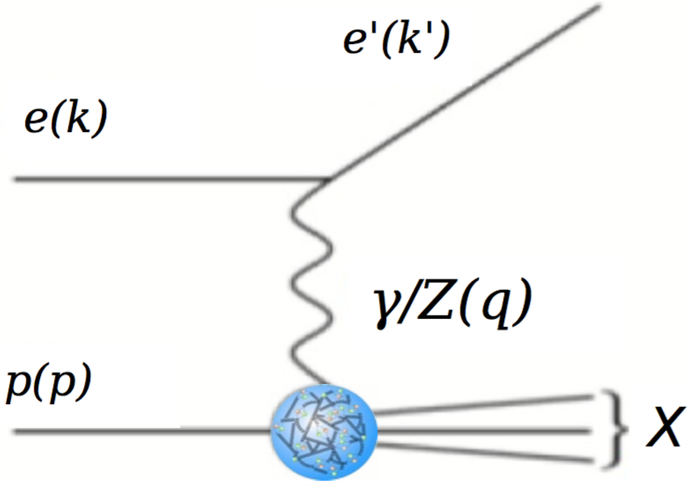
f = fermions



→ **precision on per mille level**

Electroweak Fermion Couplings



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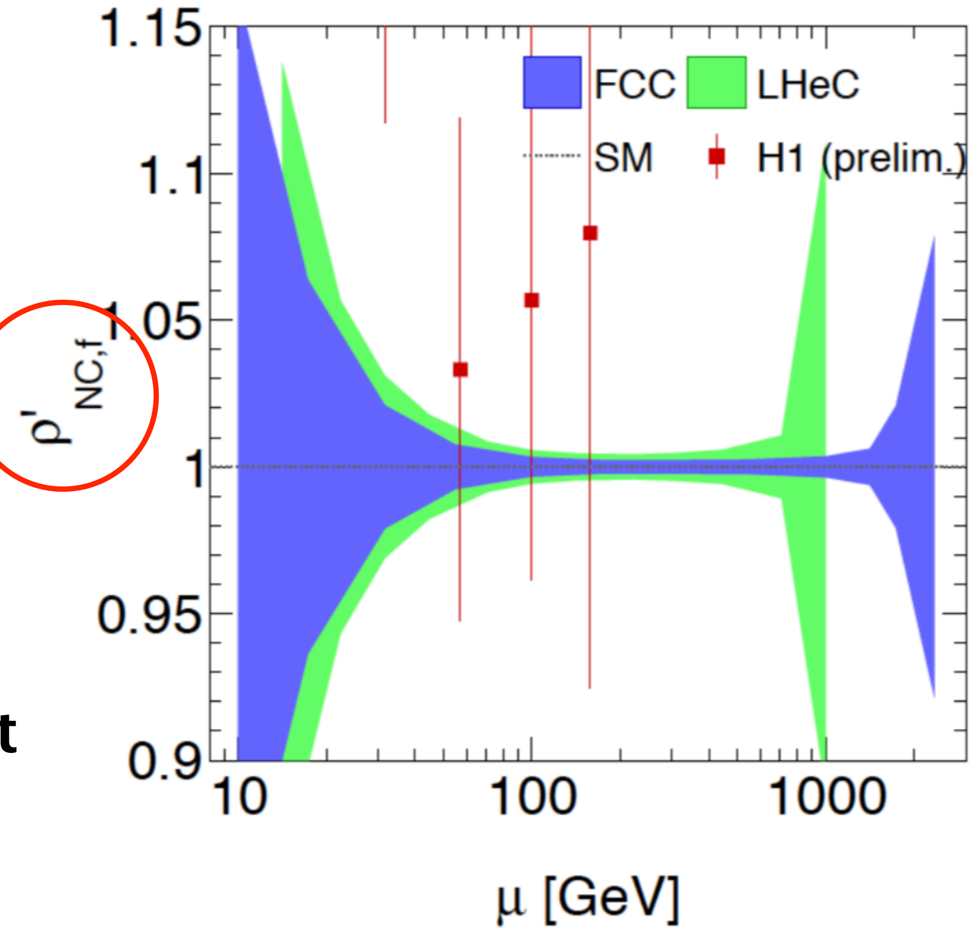
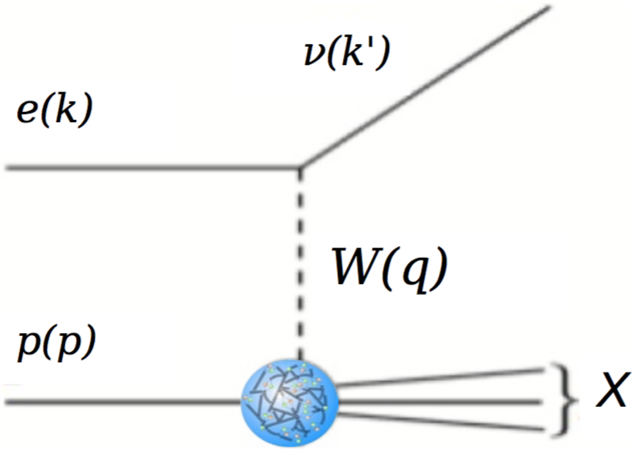


→ **scale dependence on per cent level (mostly per mille level) between 20 < μ < 2000 GeV**

Weak Couplings of W boson



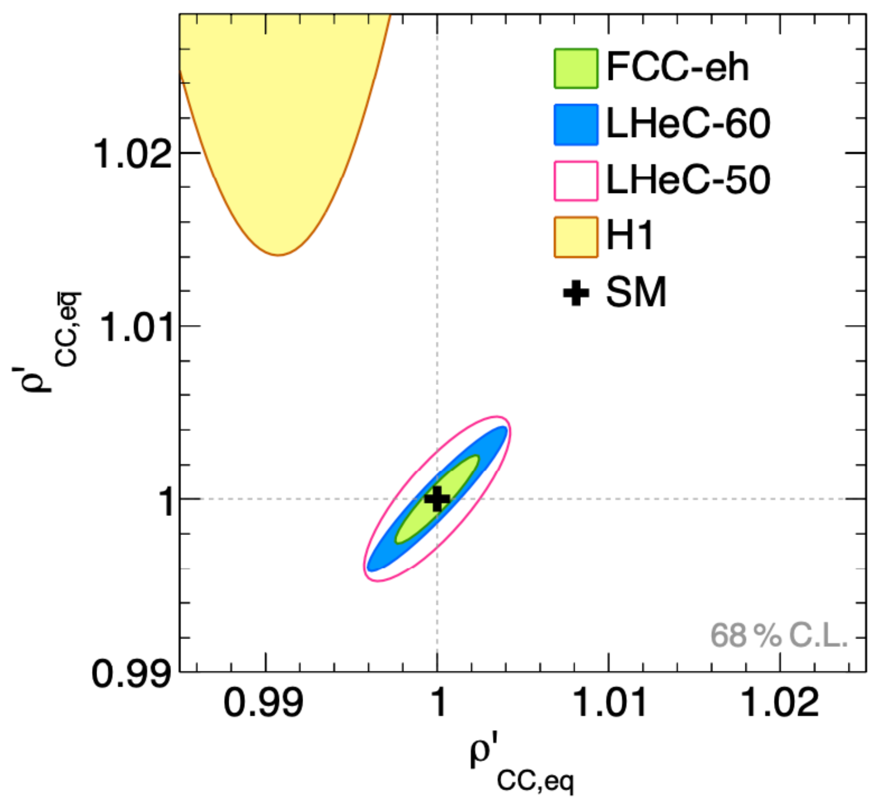
kinematics of CC DIS is completely measured from final state and incoming electron (despite ν)

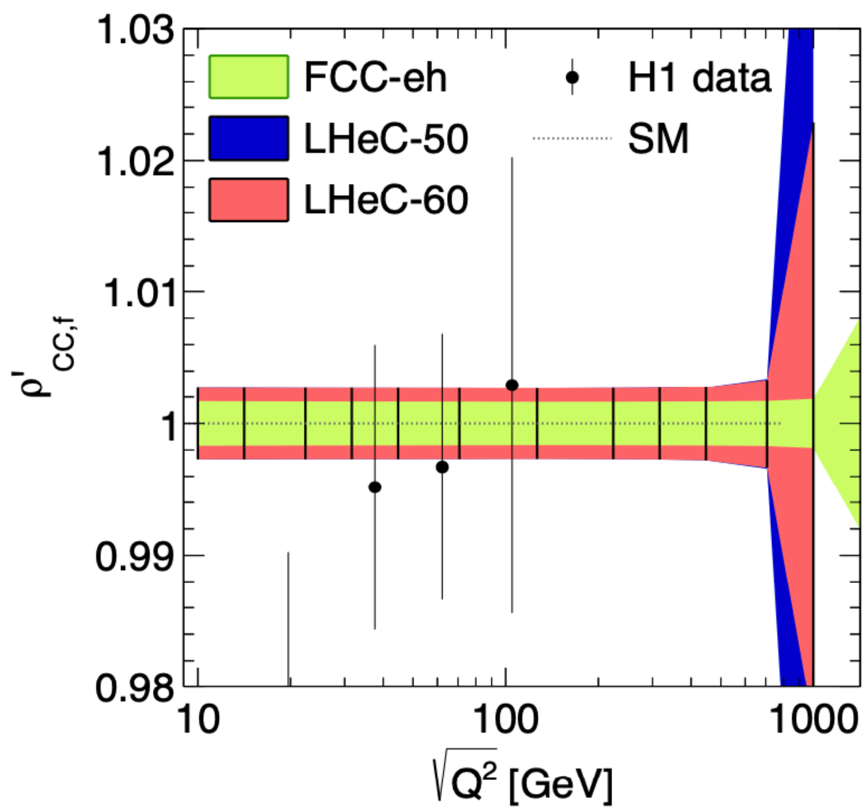
→ **scale uncertainties of a few per mille level**

→ **large range of Q^2, up to the TeV regime**

→ **very unique measurement**

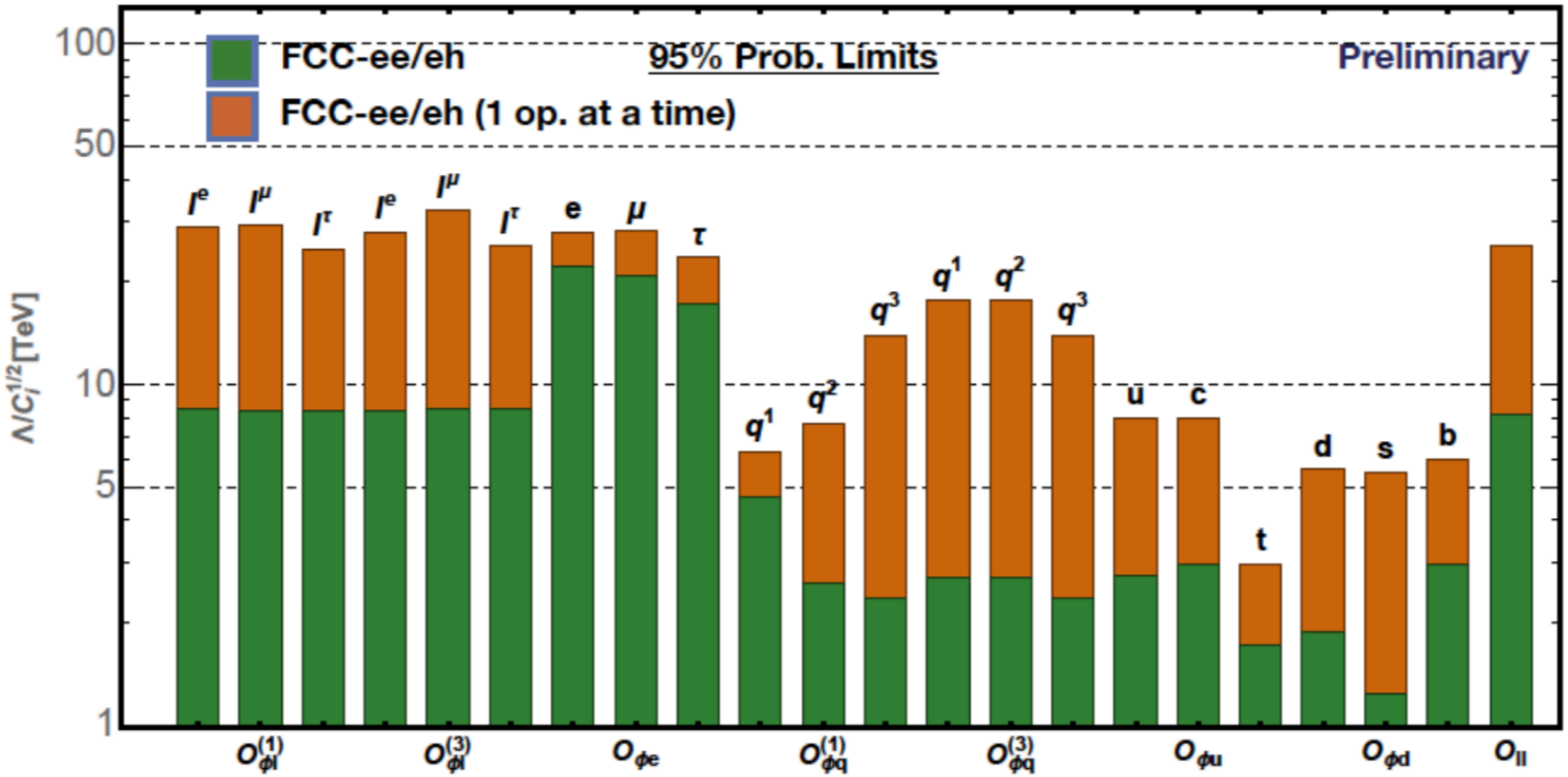
$\rho'_{CC,eq} = \rho'_{CC,e\bar{q}} = \rho'_{CC,f}$





Constraints on New Physics

- Global fit to electroweak precision measurements at FCC-ee + FCC-eh



No Fermion flavour universality assumed

Independent info about all 3 SM fermion families

→ **high sensitivity to NP**

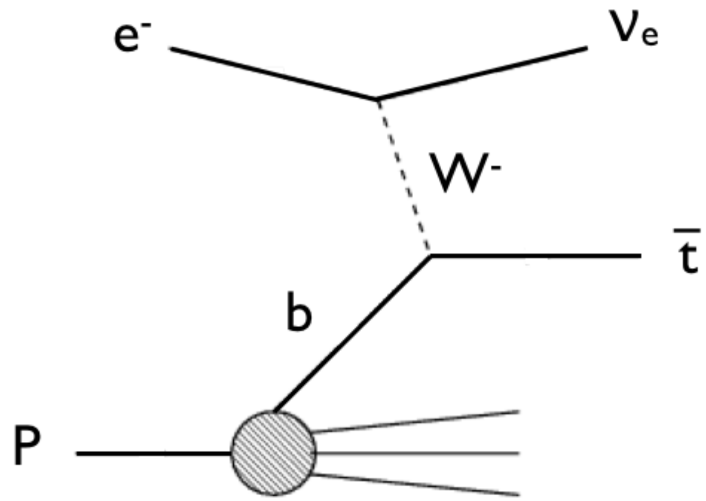
Electroweak Top Quark Production

σ=1.89pb @ LHeC

σ=15.3pb @ FCC-eh

E_e=60 GeV

CC DIS top production



Direct Measurement of $|V_{tb}|$

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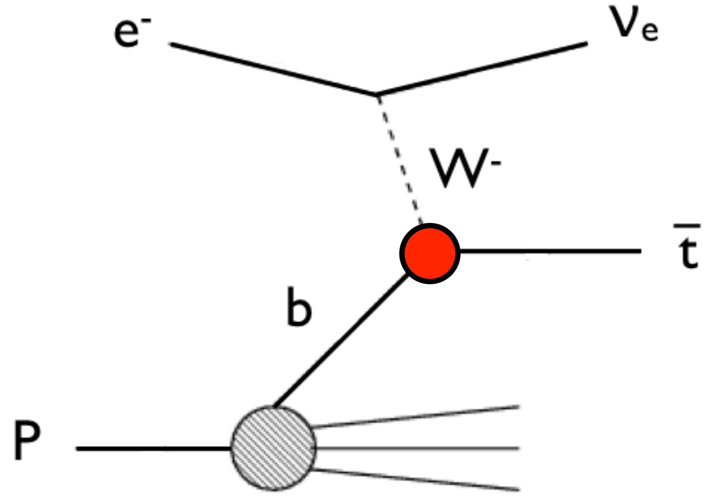
E_e=60 GeV

CC DIS top production



$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

Limits on Anomalous Wtb Couplings

$$L = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}V_{tb}\left(f_V^L P_L + f_V^R P_R\right)tW_\mu^- - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_\nu}{M_W}\left(f_T^L P_L + f_T^R P_R\right)tW_\mu^- + h.c.$$

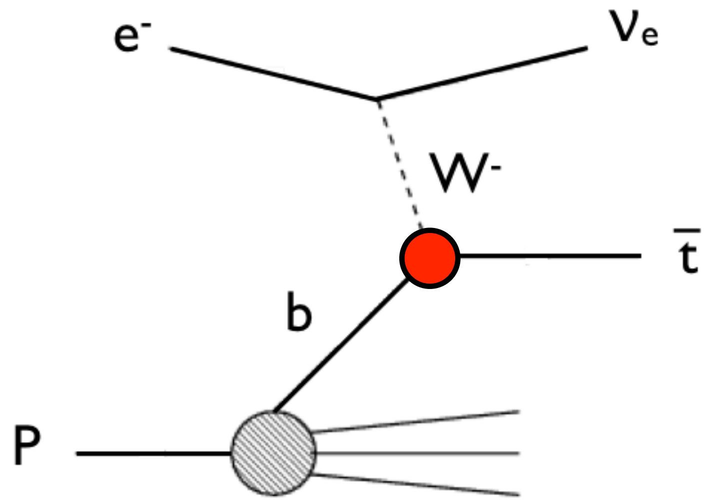
= 1 in SM (f_V^L)

σ=1.89pb @ LHeC

σ=15.3pb @ FCC-eh

E_e=60 GeV

CC DIS top production



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= 1 in SM

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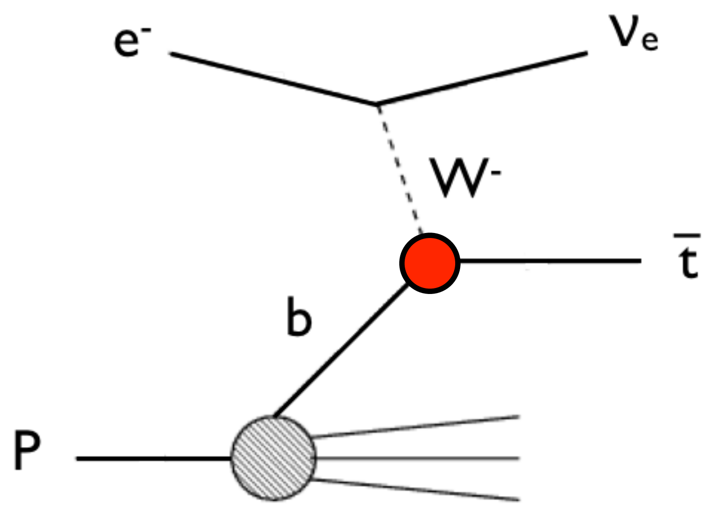
CC DIS top production



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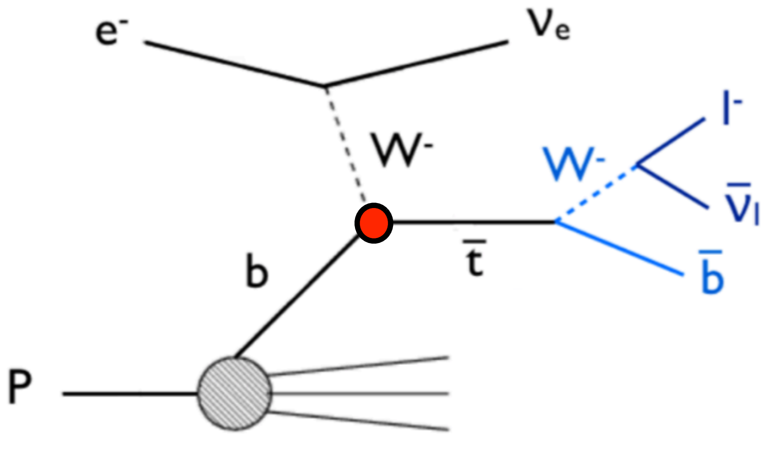
= 1 in SM

σ=1.89pb @ LHeC

σ=15.3pb @ FCC-eh

E_e=60 GeV

CC DIS top production



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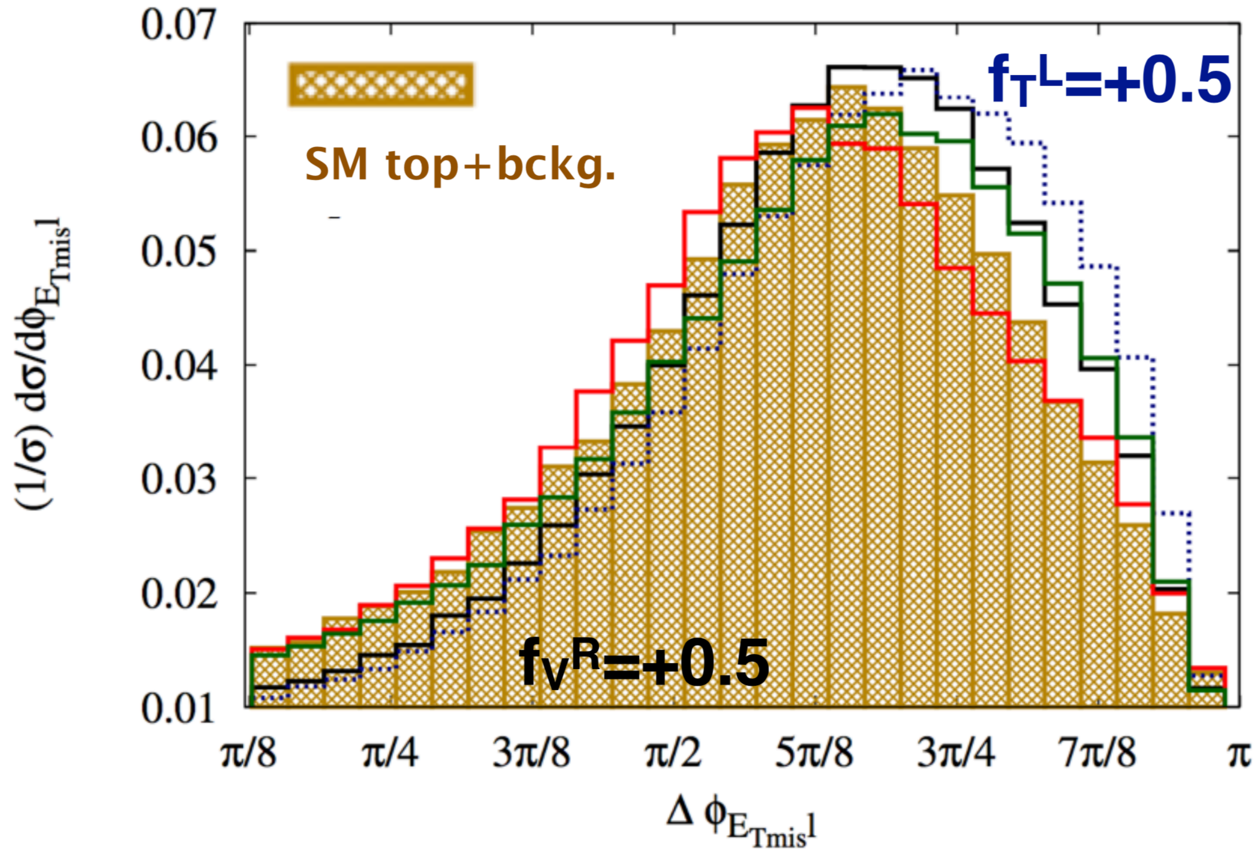


+ other variables sensitive on W helicity

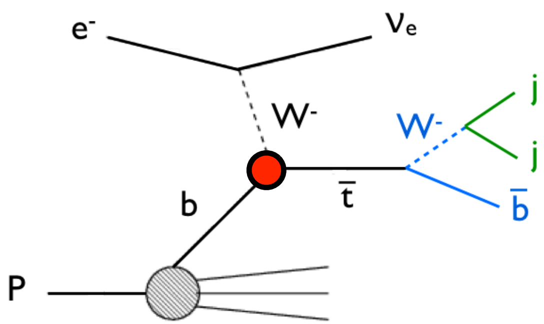
Limits on Anomalous Wtb Couplings

$$L = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}V_{tb}\left(f_V^L P_L + f_V^R P_R\right)tW_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}\left(f_T^L P_L + f_T^R P_R\right)tW_{\mu}^{-} + h.c.$$

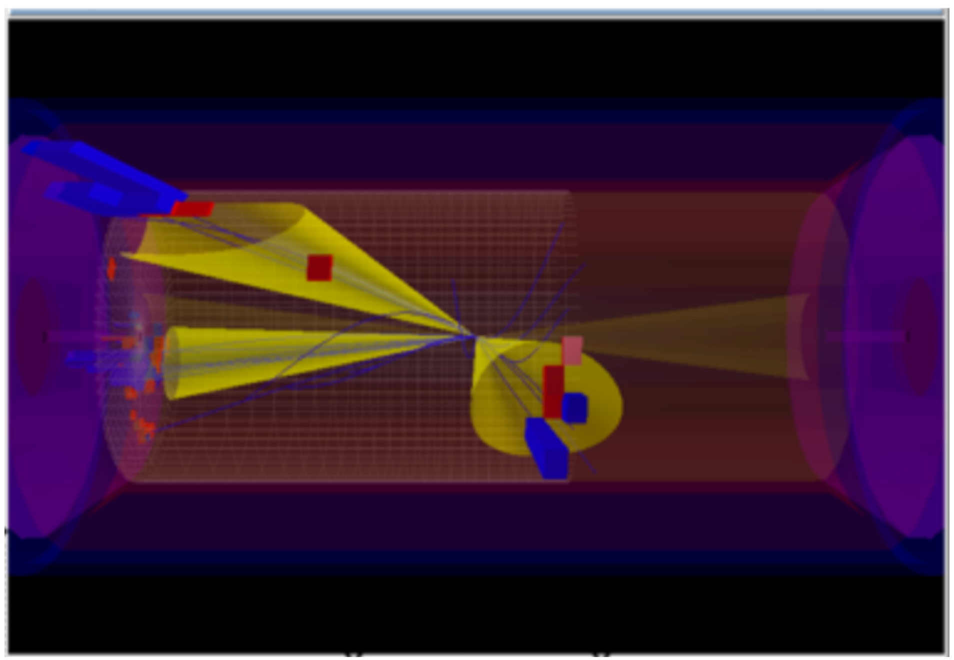
Dutta, Goyal, Kumar, Mellado, arXiv:1307.1688
Kumar, Ruan, to be publ.

= 1 in SM

95% C.L.



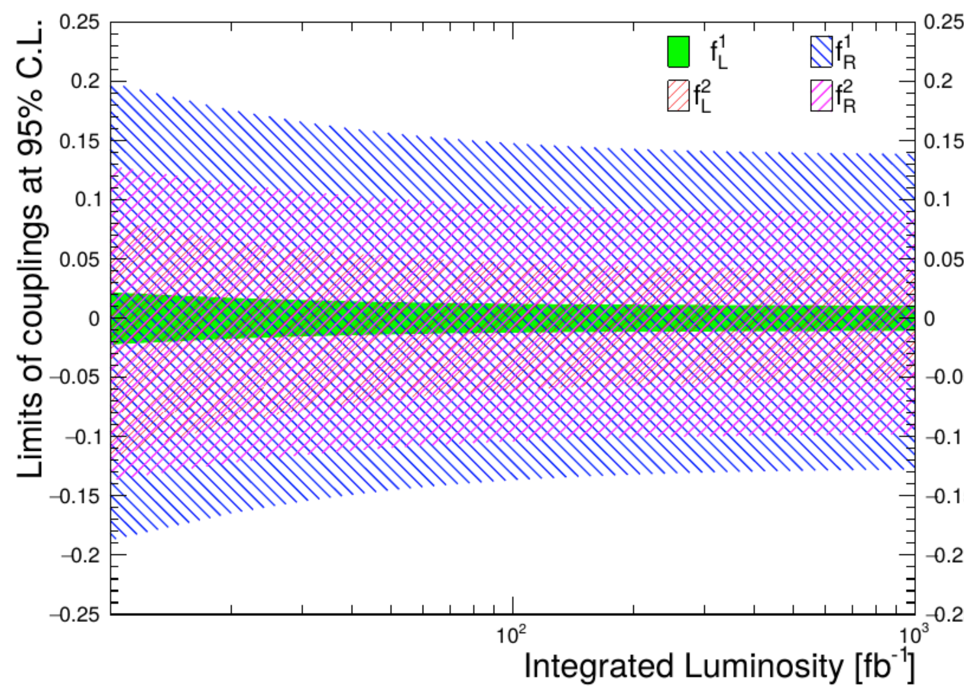
DELPHES



including detector simulation (Delphes)

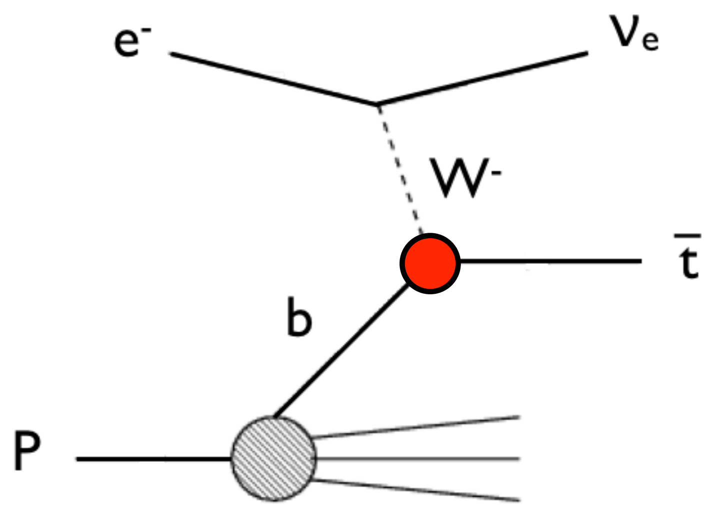
LHeC

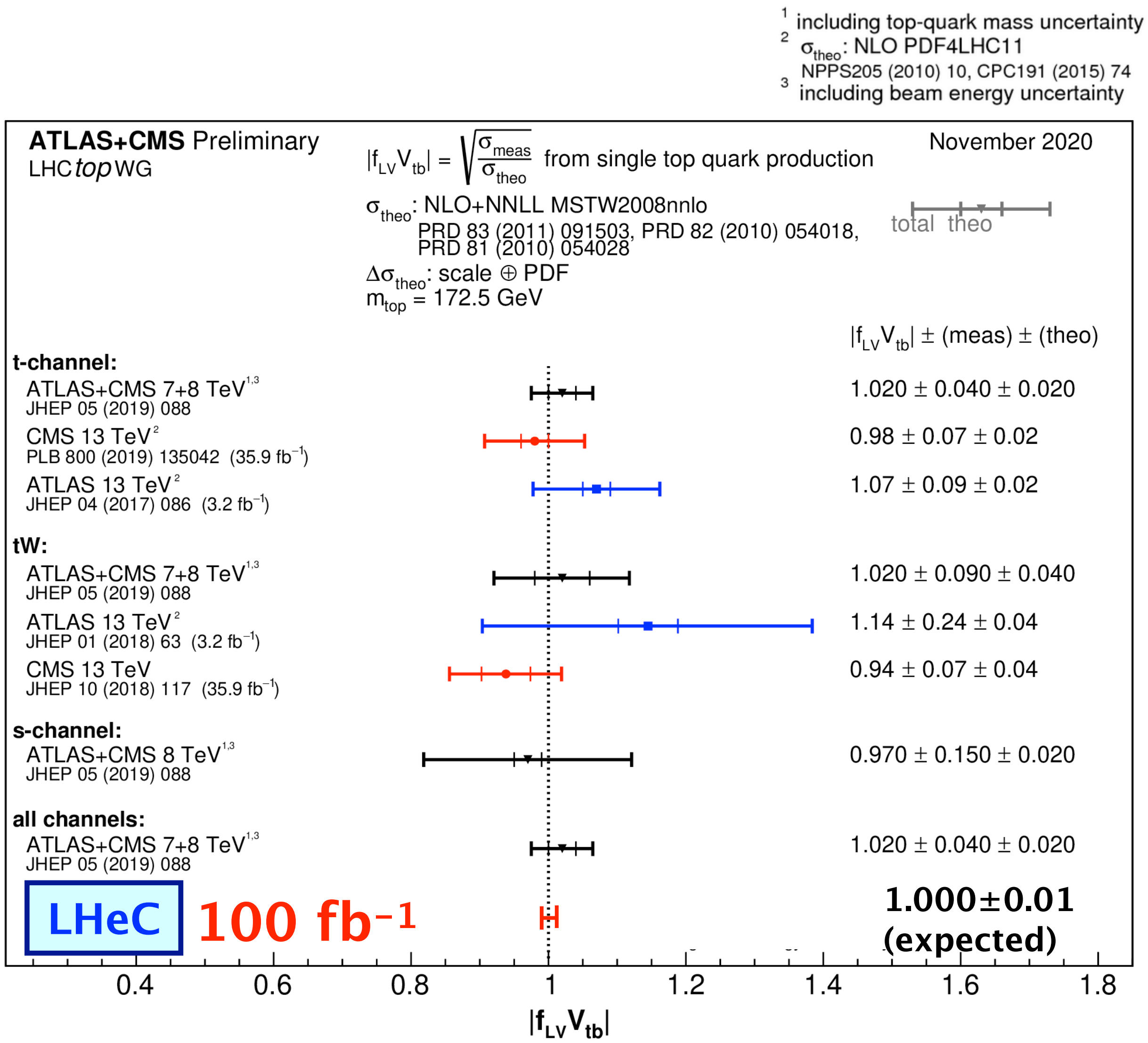
hadronic channel:



<0.14
<0.09
<0.04
<0.01

Direct Measurement of $|V_{tb}|$





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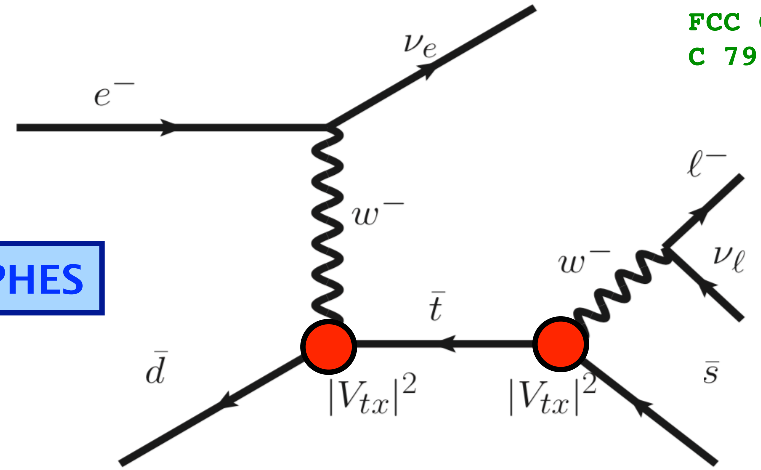
Measurement of $|V_{ts}|$

$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

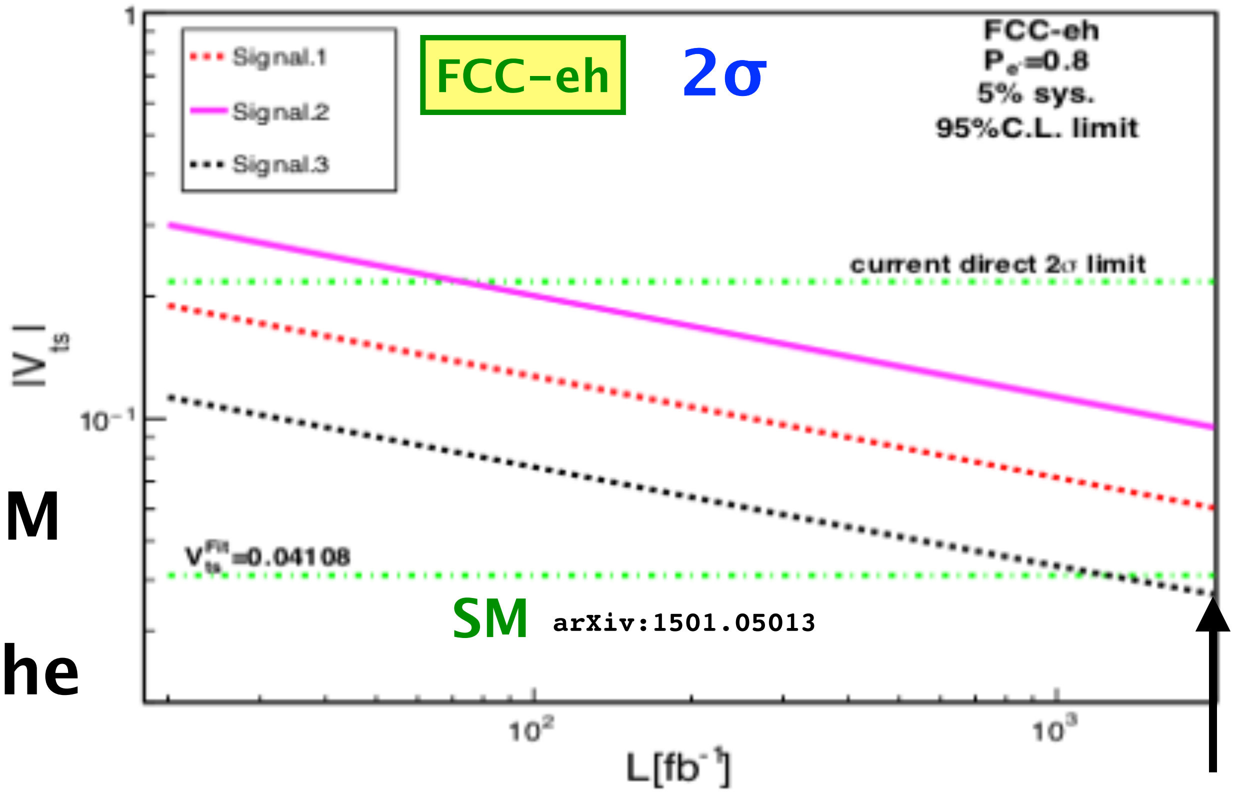
arXiv:1709.07887

DELPHES



FCC CDR, Eur. Phys. J. C 79, no. 6, 474 (2019)

H. Sun PoS DIS 2018, 167 (2018)



LHC

→ $|V_{ts}| < 0.037$

→ probing SM prediction directly for the first time

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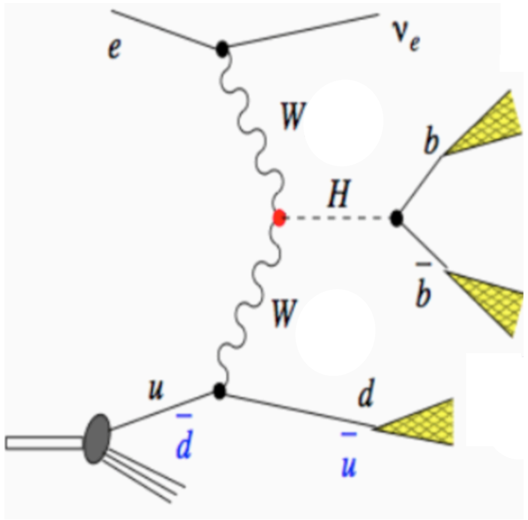
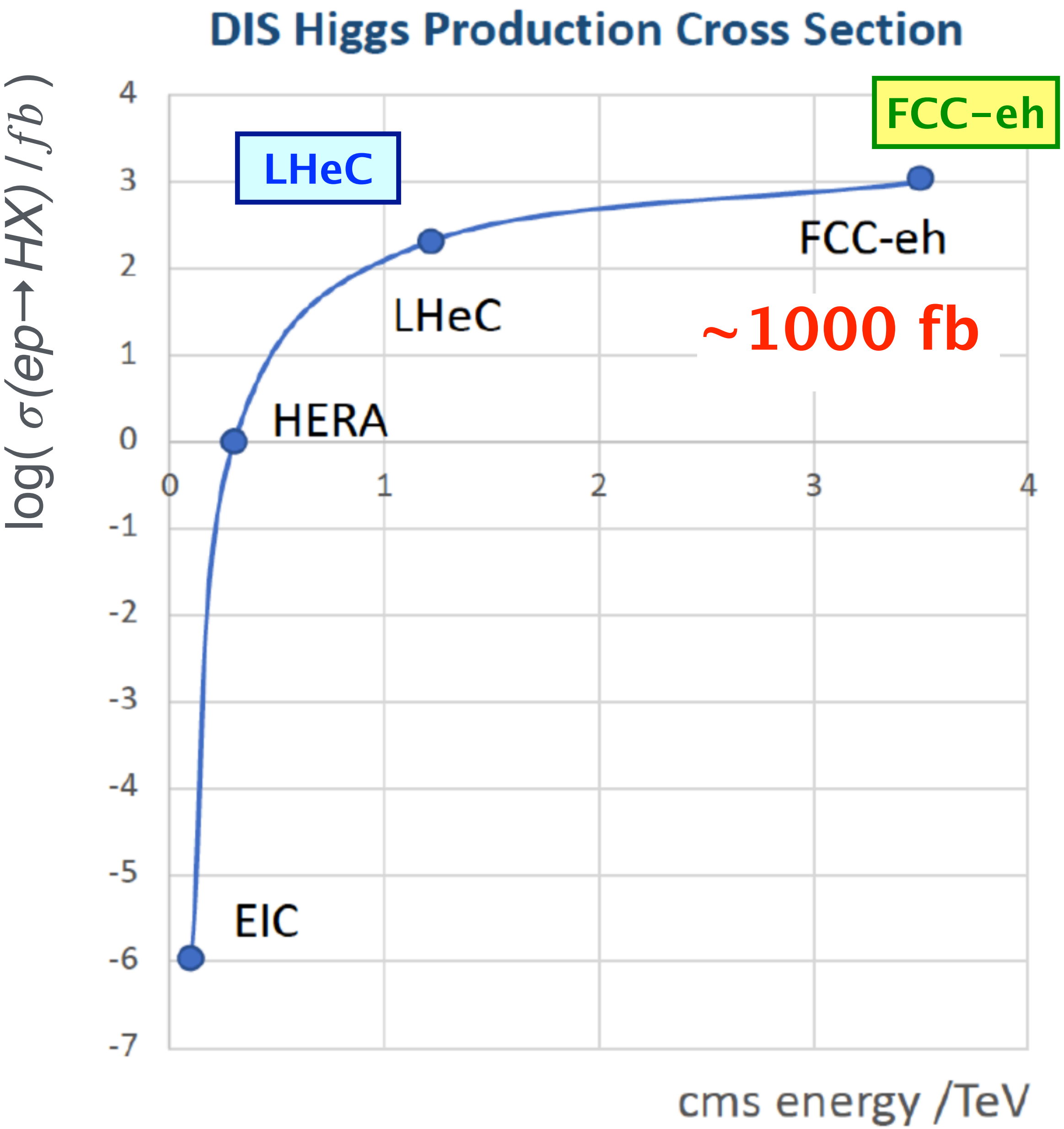
Higgs Production Cross Section

CC(e⁻p): 196 fb (LHeC)

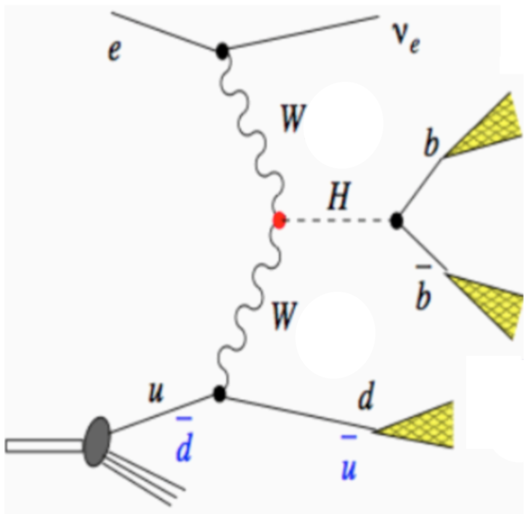


- no pile-up
- clean final state
- small systematic uncertainties

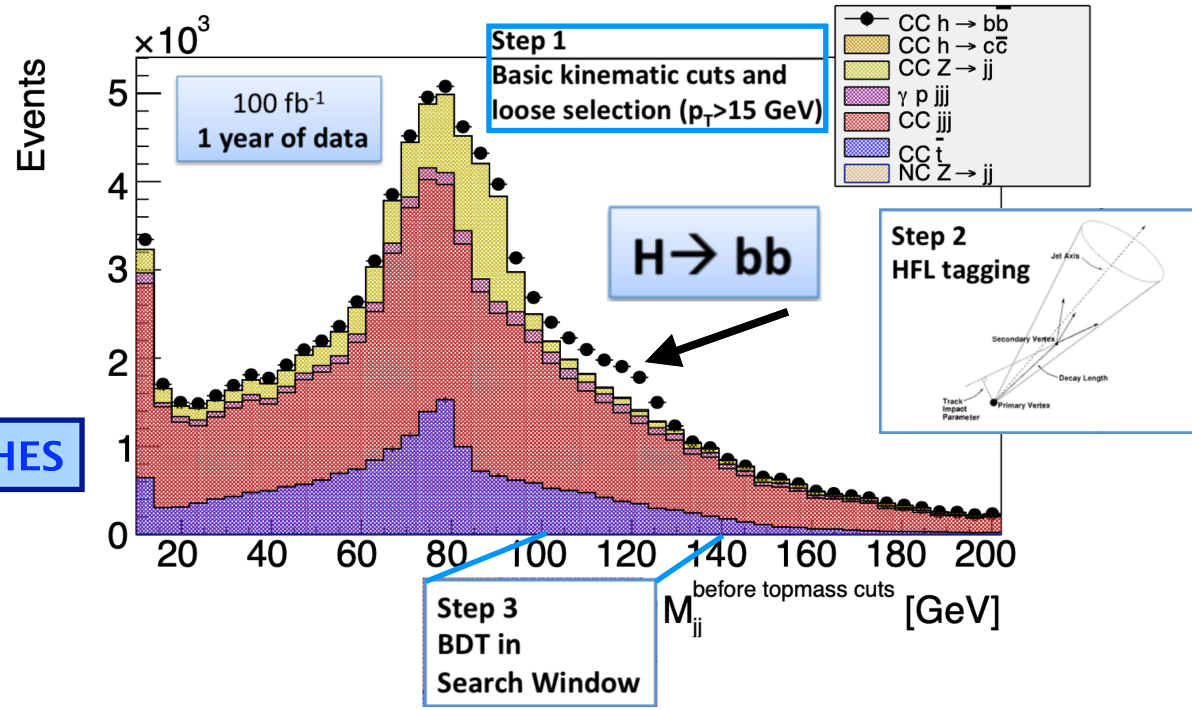


Higgs Analyses

CC(e⁻p): 196 pb (LHeC)



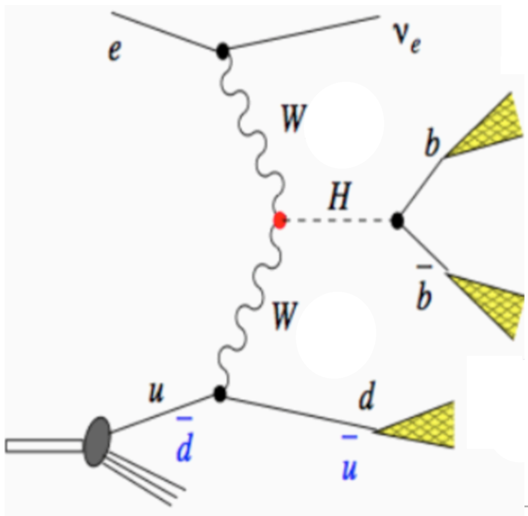
DELPHES



- no pile-up
- clean final state
- small systematic uncertainties

Higgs Couplings (κ–framework)

CC(e⁻p): 196 pb (LHeC)



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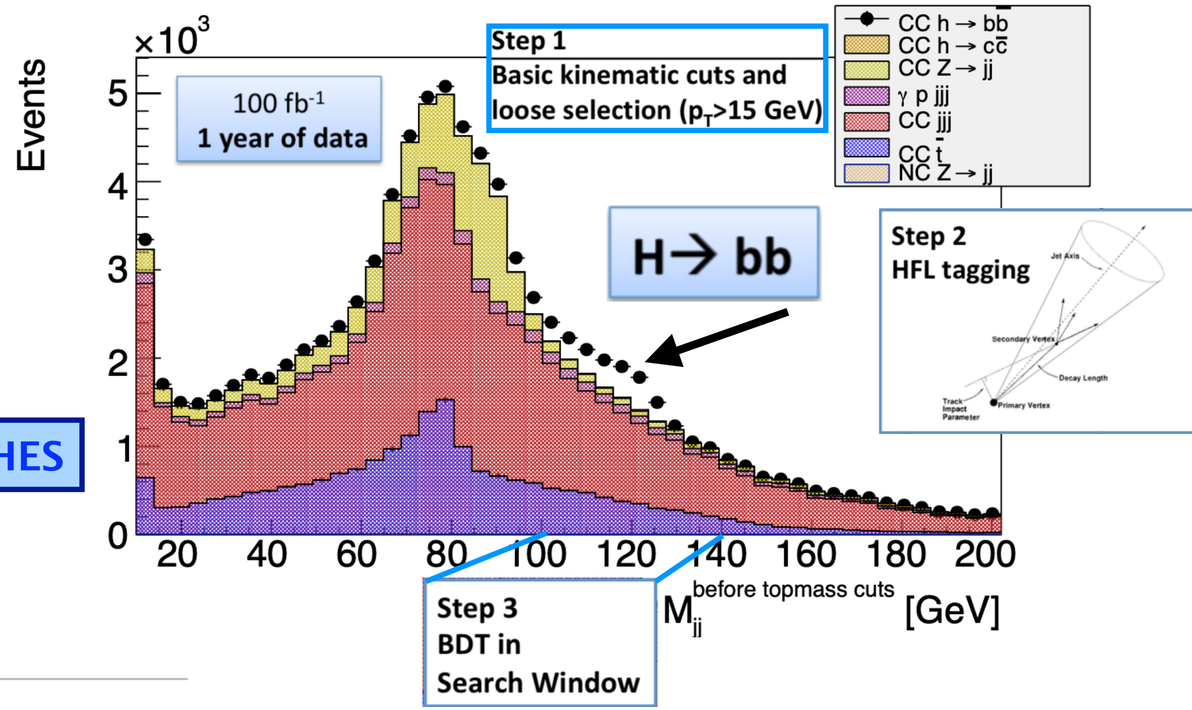
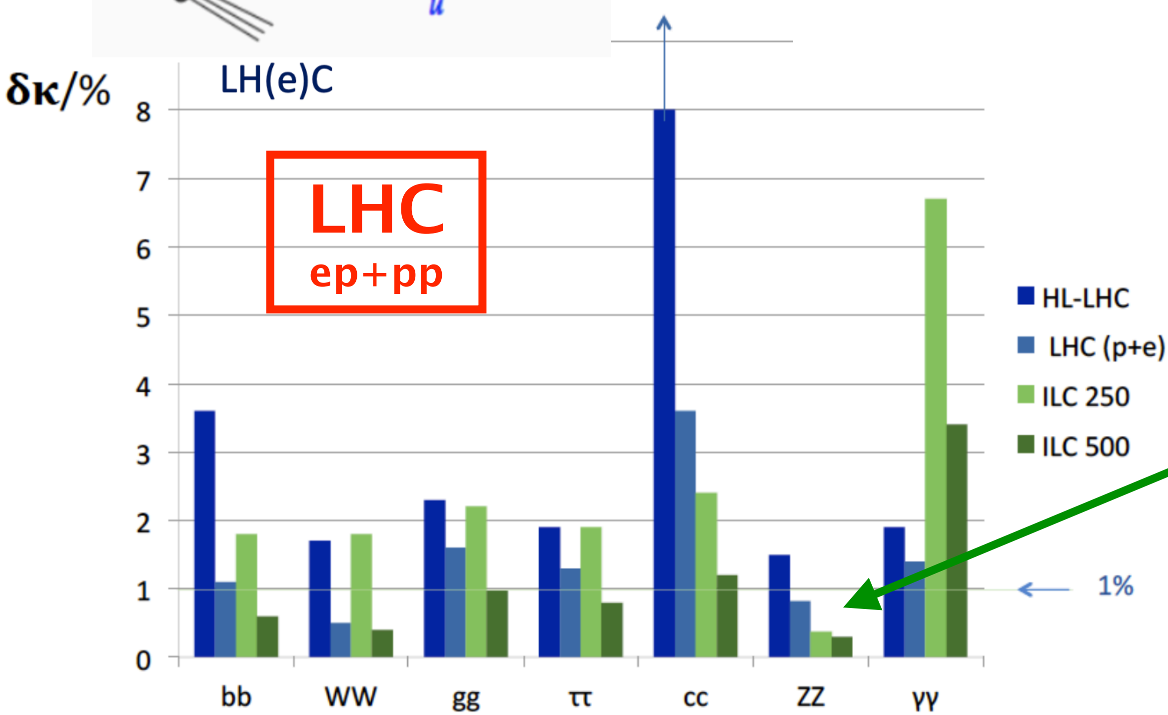
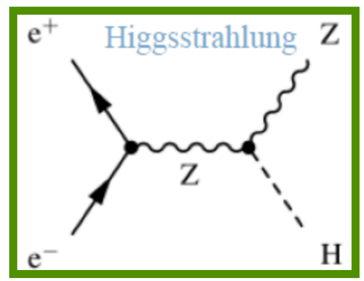




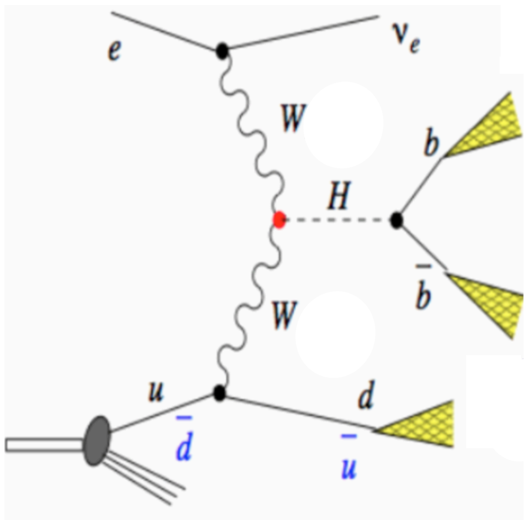


we profit from
diversity through
complementarity

→ adding electrons
makes the LHC a Higgs
precision facility

SM Higgs Signal Strengths

CC(e⁻p): 196 pb (LHeC)



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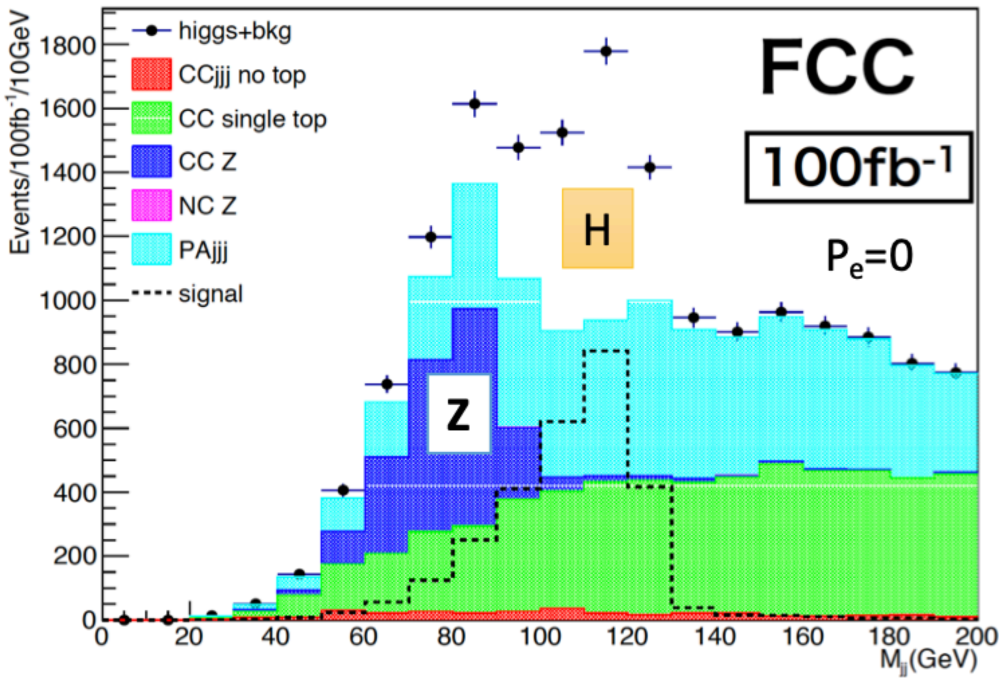
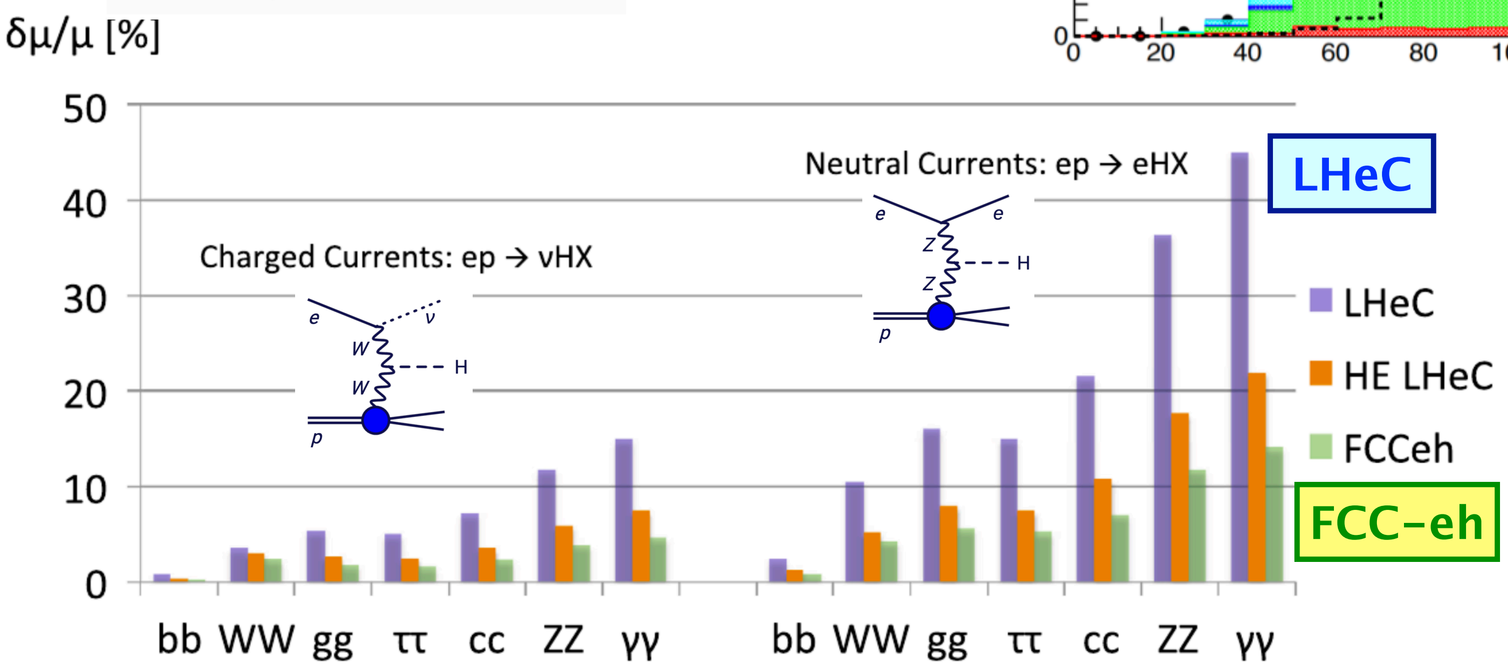




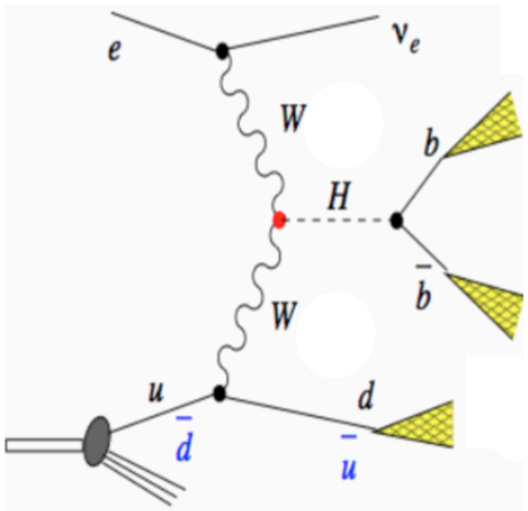
→ improvement for FCC-eh compared to LHeC by factor ~3-3.5

→ good sensitivity to many decay channels

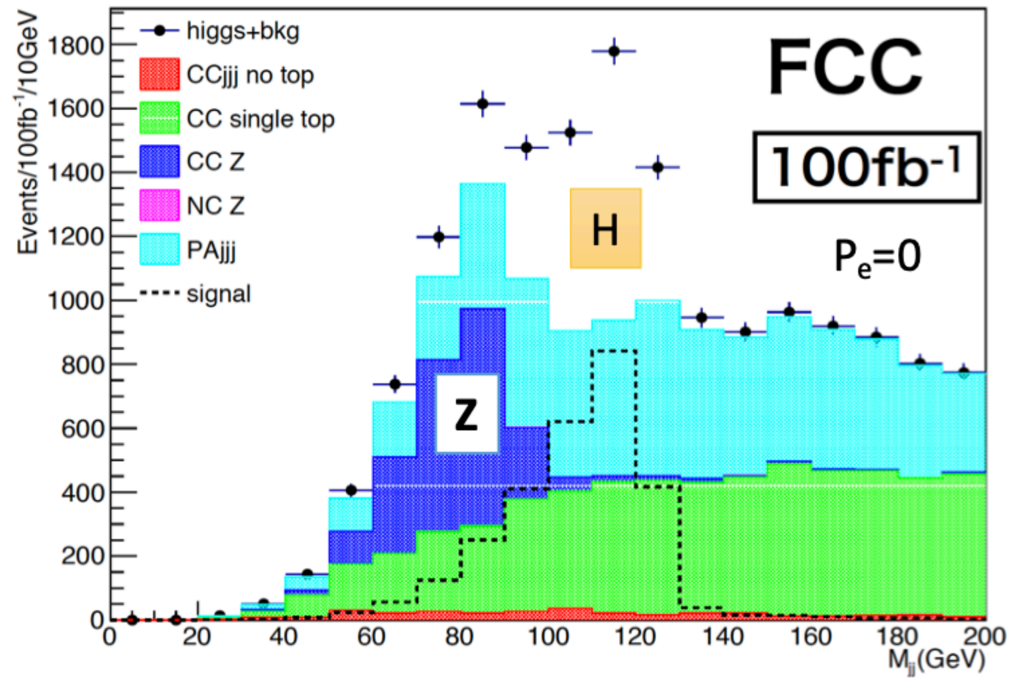
→ NC+CC DIS over-constrain Higgs couplings in combined SM fit

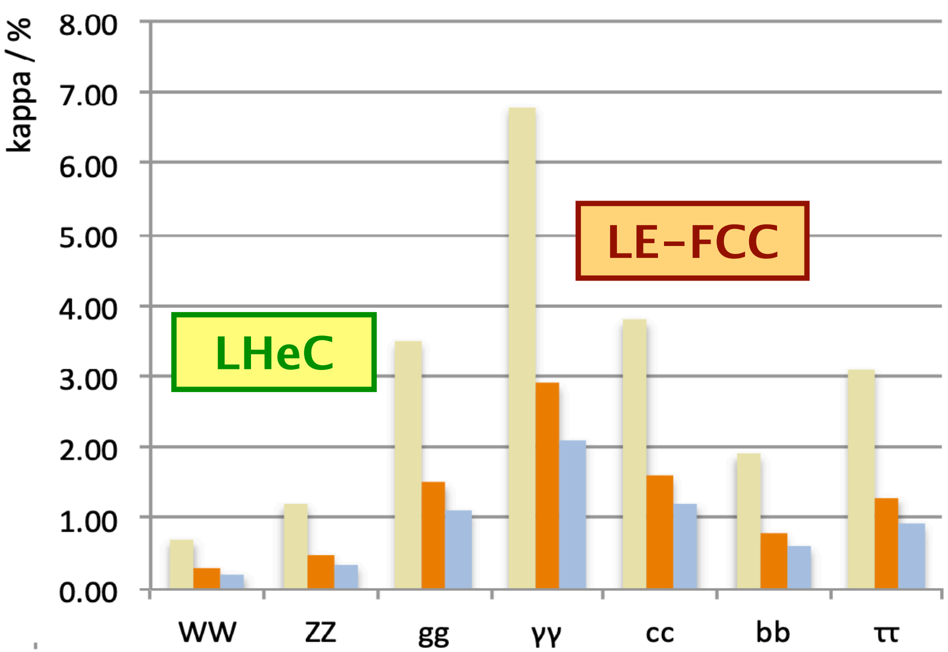
Higgs Couplings (κ–framework)

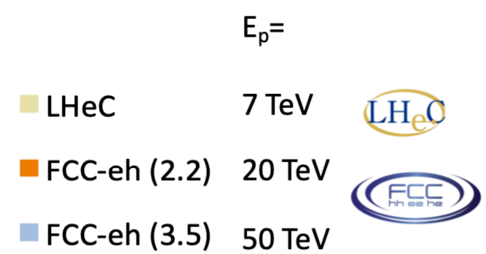
CC(e^-p): 196 pb (LHeC)



DELPHES







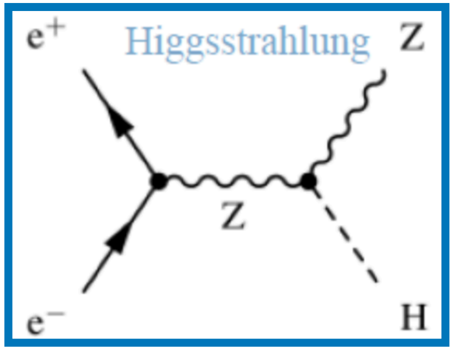
FCC-eh

→ **improvement for FCC-eh compared to LHeC by factor ~3-3.5**

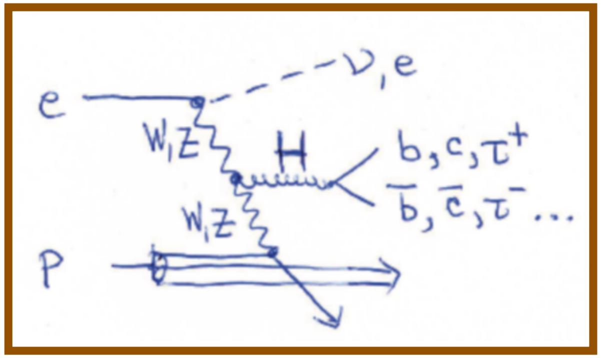
→ **high precision to many decay channels by CC+NC DIS**

Higgs Couplings at FCC-ee and FCC-eh

Collider	FCC-ee	FCC-eh
Luminosity (ab^{-1})	+1.5 @ 365 GeV	2
Years	3+4	20
$\delta\Gamma_H/\Gamma_H$ (%)	**1.3**	SM
$\delta g_{HZZ}/g_{HZZ}$ (%)	**0.17**	0.43
$\delta g_{HWW}/g_{HWW}$ (%)	**0.43**	0.26
$\delta g_{Hbb}/g_{Hbb}$ (%)	**0.61**	0.74
$\delta g_{Hcc}/g_{Hcc}$ (%)	**1.21**	1.35
$\delta g_{Hgg}/g_{Hgg}$ (%)	**1.01**	1.17
$\delta g_{H\tau\tau}/g_{H\tau\tau}$ (%)	**0.74**	1.10
$\delta g_{H\mu\mu}/g_{H\mu\mu}$ (%)	**9.0**	n.a.
$\delta g_{H\gamma\gamma}/g_{H\gamma\gamma}$ (%)	**3.9**	2.3
$\delta g_{Htt}/g_{Htt}$ (%)	–	1.7
BR_{EXO} (%)	< **1.0**	n.a.

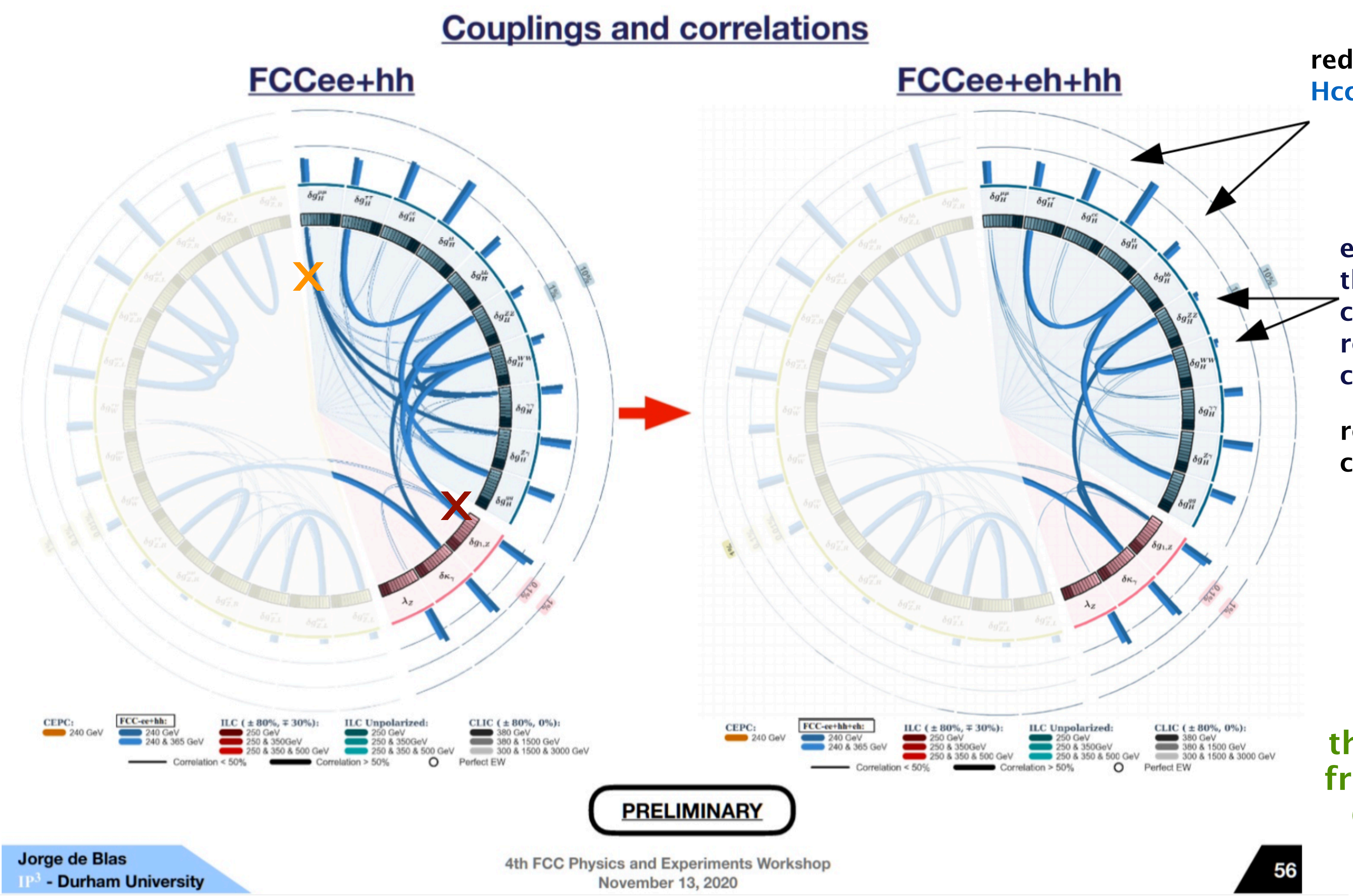


- **gets width with Z recoil**



→ **high precision measurements**

SMEFT fit results after FCC era



reduction for **Hcc** and **Hbb**

eh contributes to the **HWW** and **HZZ** couplings and resolves their correlation X

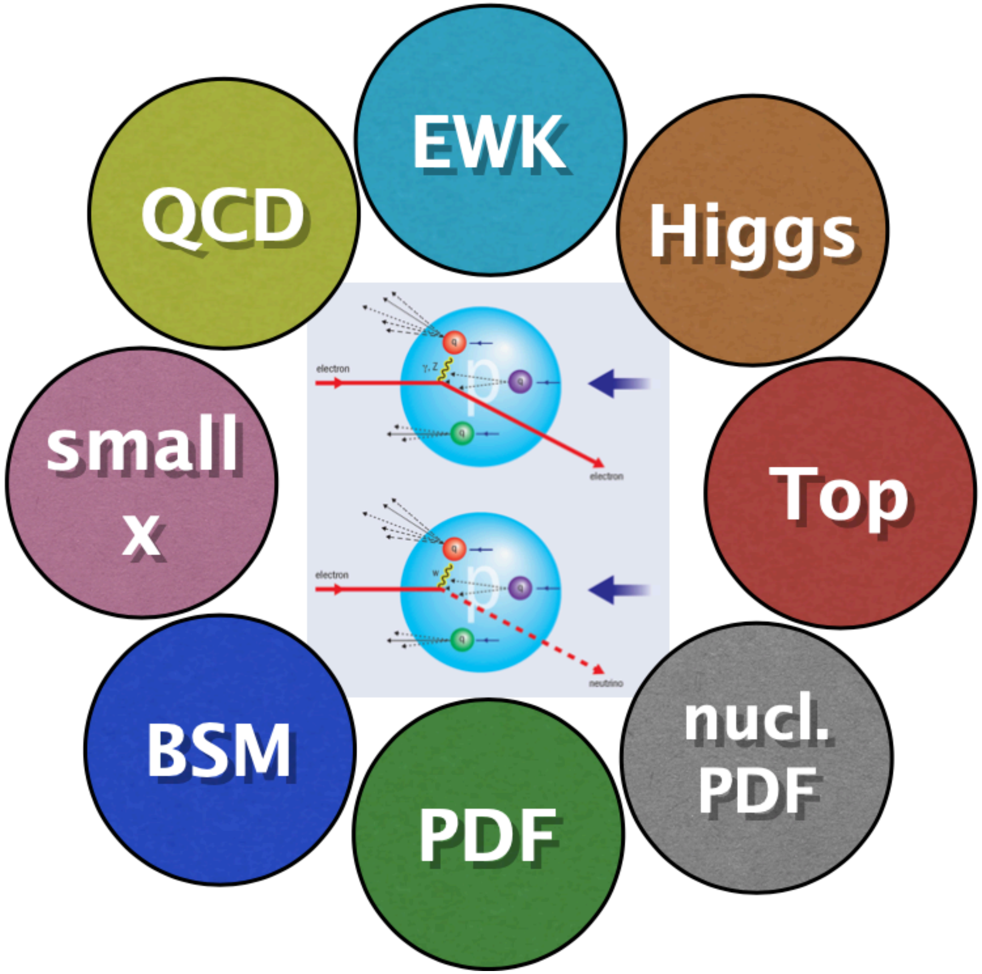
reduces further correlations X

theory profits from diversity (ee, ep, pp)

Outline

Introduction
Electroweak Physics
Higgs Physics
Conclusions

Conclusions



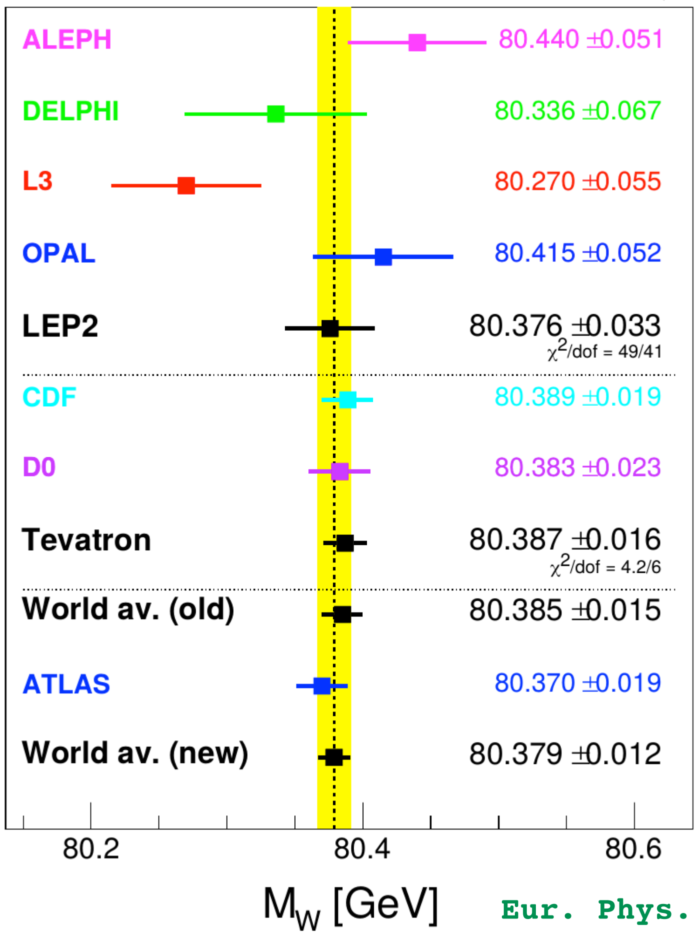
we profit from diversity through complementarity (ee, ep, pp)

future ep collider has a rich analysis programme – in particular for electroweak interactions of light and heavy quarks, and Higgs physics!

Backup

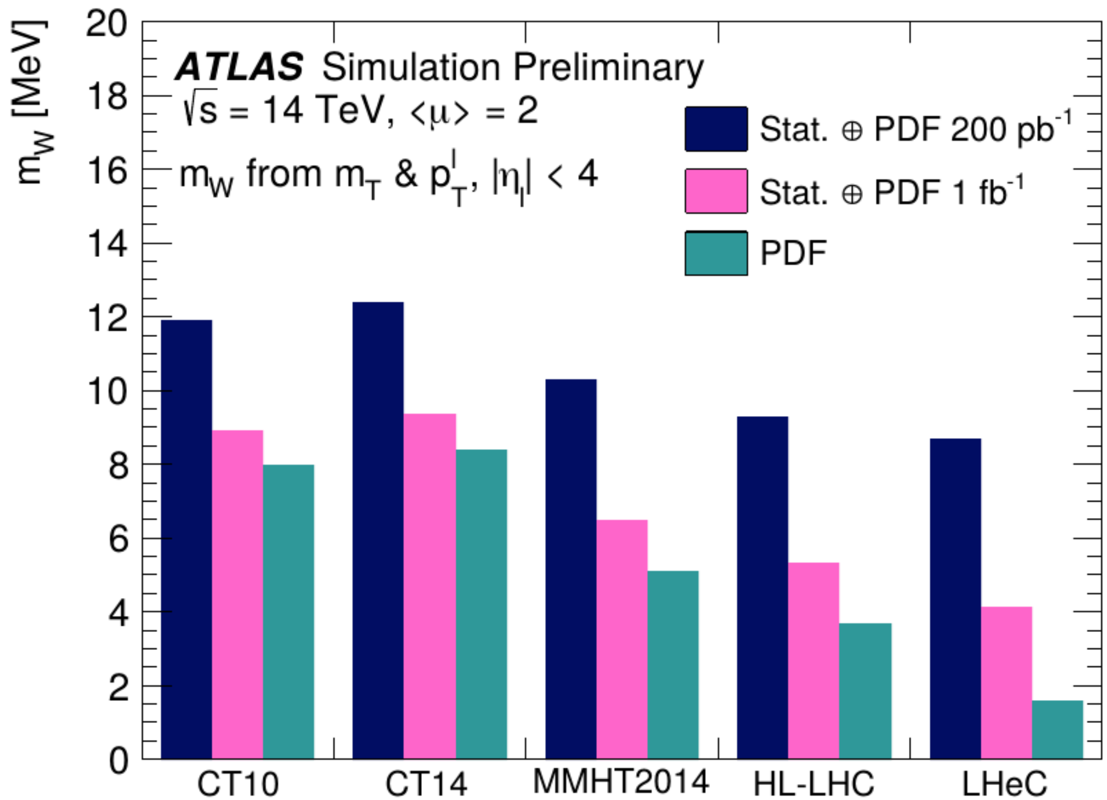
W mass measurements at HL-LHC

- @LHC: precision limited by PDFs (Δm_W^{PDF}~9.2 MeV)



Eur. Phys. J. C 78 (2018) 110; PDG (2017)

- @HL-LHC: major reduction of PDF uncertainty with LHeC PDFs (Δm_W^{PDF}~2 MeV)



ATL-PHYS-PUB-2018-026

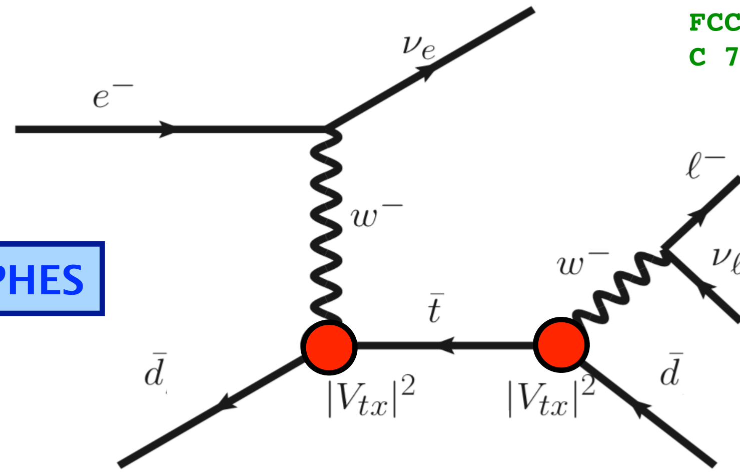
Combined categories	Value [MeV]	Stat. Unc.	Muon Unc.	Elec. Unc.	Recoil Unc.	Bckg. Unc.	QCD Unc.	EW Unc.	PDF Unc.	Total Unc.	χ^2/dof of Comb.
m_T-p_T^ℓ, $W^\pm$, e-μ	80369.5	6.8	6.6	6.4	2.9	4.5	8.3	5.5	9.2	18.5	29/27

Measurement of $|V_{td}|$

$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

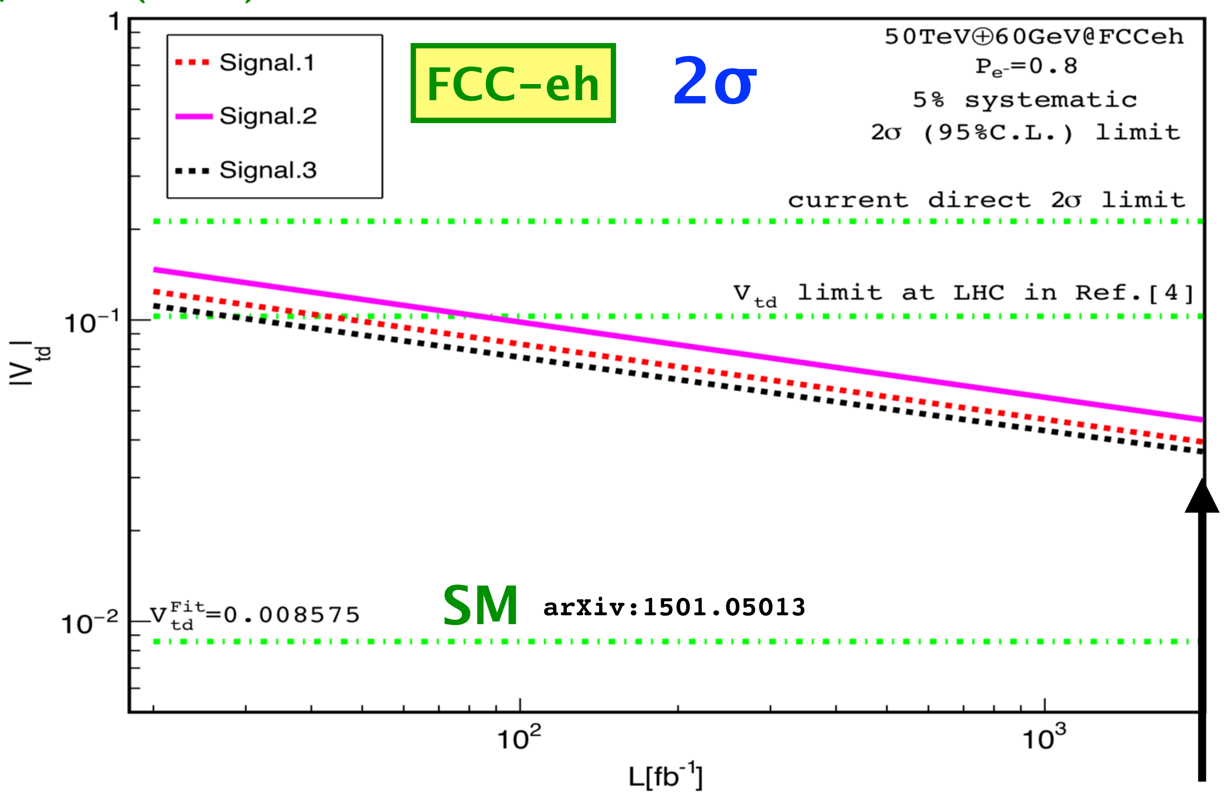
arXiv:1709.07887

DELPHES



FCC CDR, Eur. Phys. J. C 79, no. 6, 474 (2019)

H. Sun PoS DIS 2018, 167 (2018)



LHC

HL-LHC

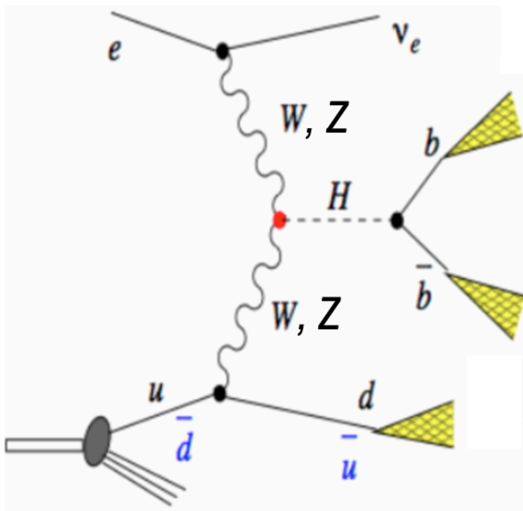
LHC, 3000 fb^{-1}@14TeV

→ $|V_{td}|<0.037$

→ extend HL-LHC limits

Higgs Couplings (κ–framework)

CC(e⁻p): 196 pb (LHeC)



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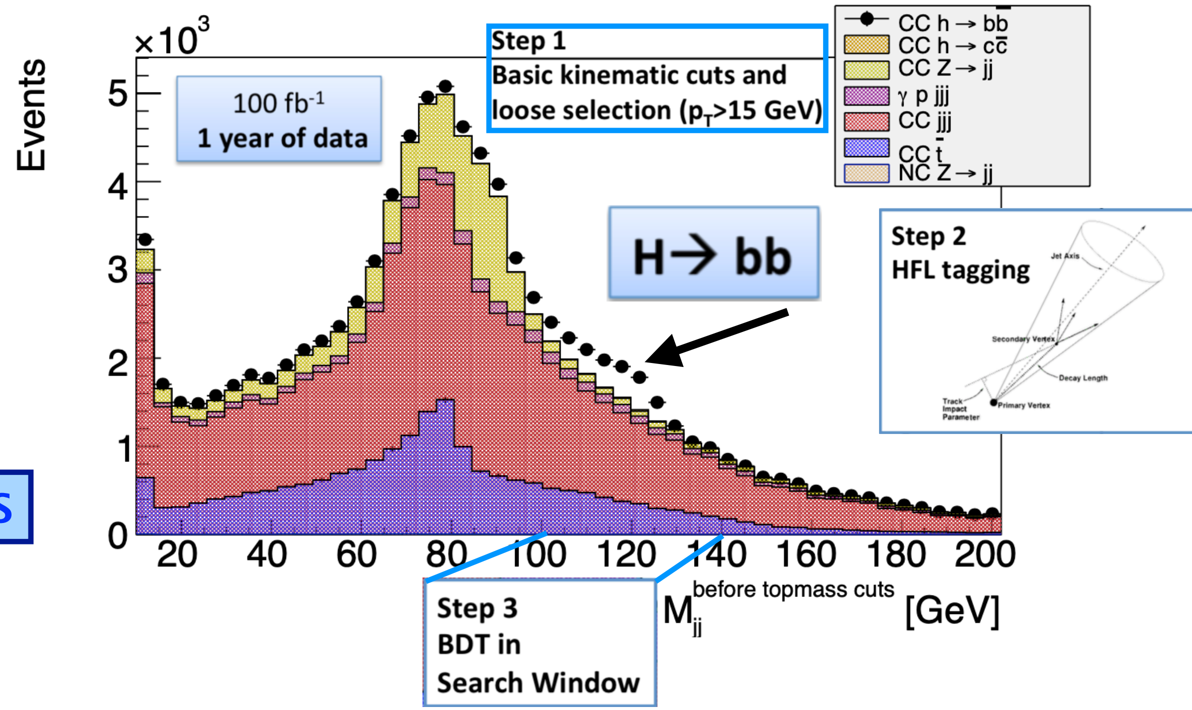
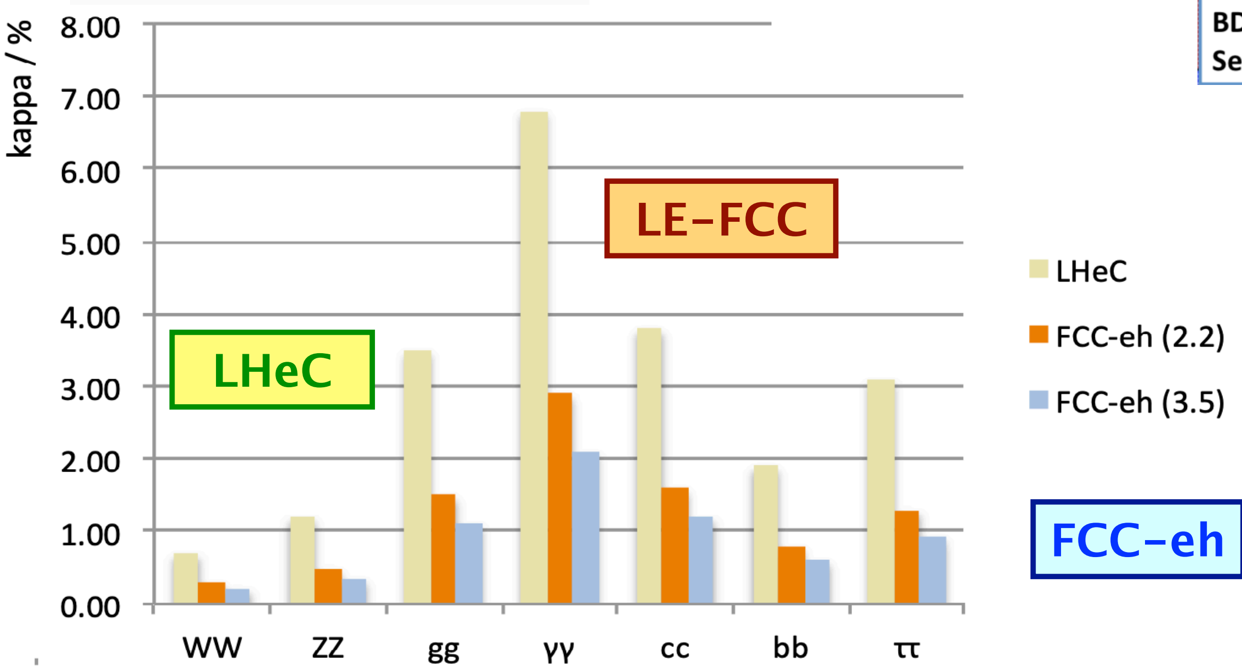
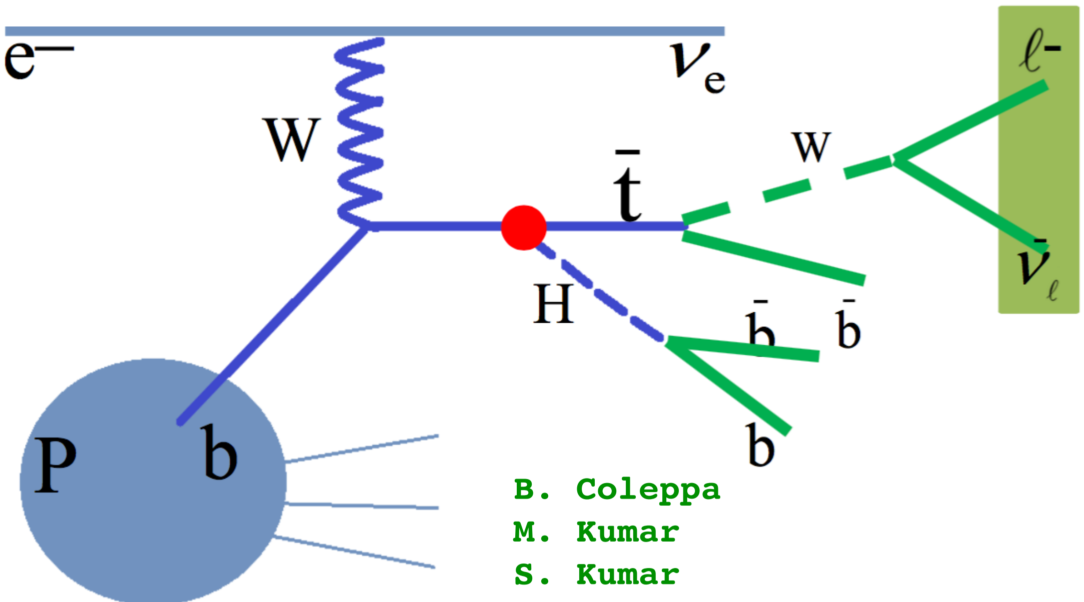




→ improvement for FCC-eh compared to LHeC by factor ~3-3.5

CP Nature of Top-Higgs Coupling

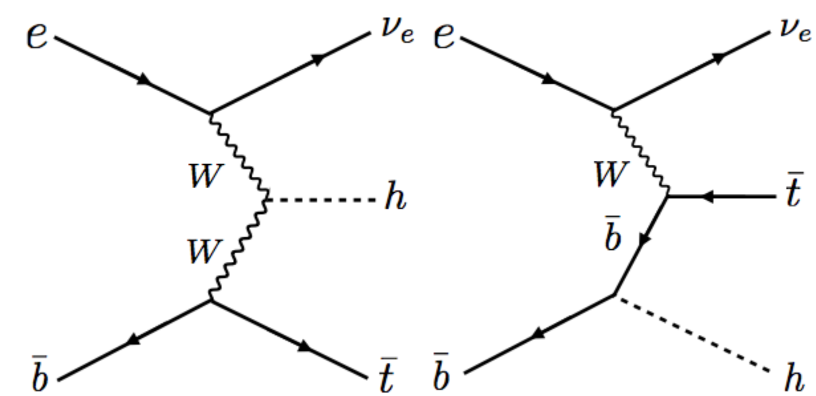


B. Coleppa
M. Kumar
S. Kumar
B. Mellado

parton level

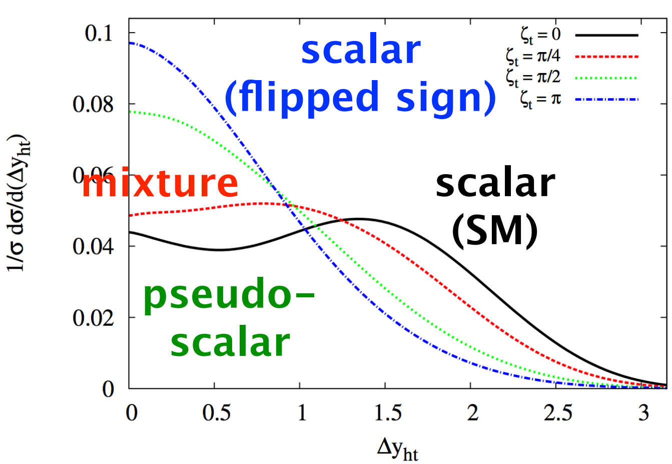
Phys. Lett. B770 (2017) 335

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

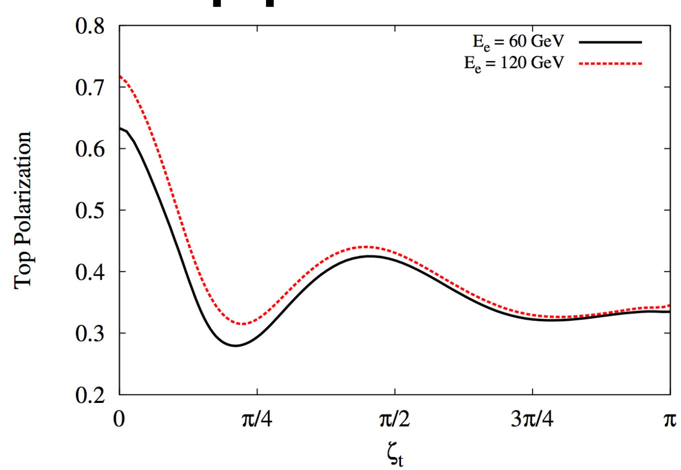


LHeC

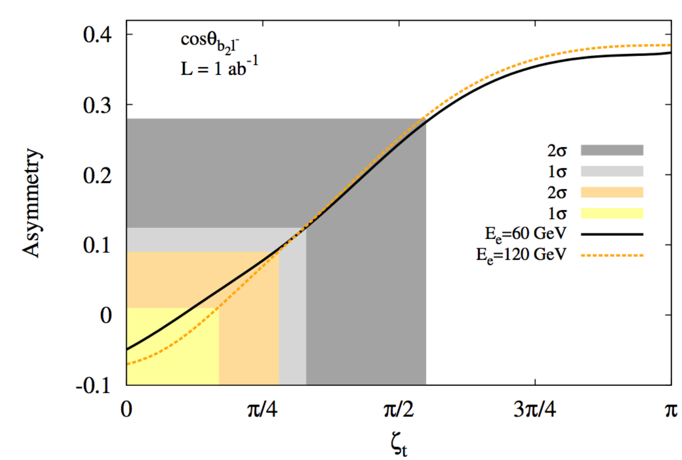
rapidity difference (H,$\bar{t}$)



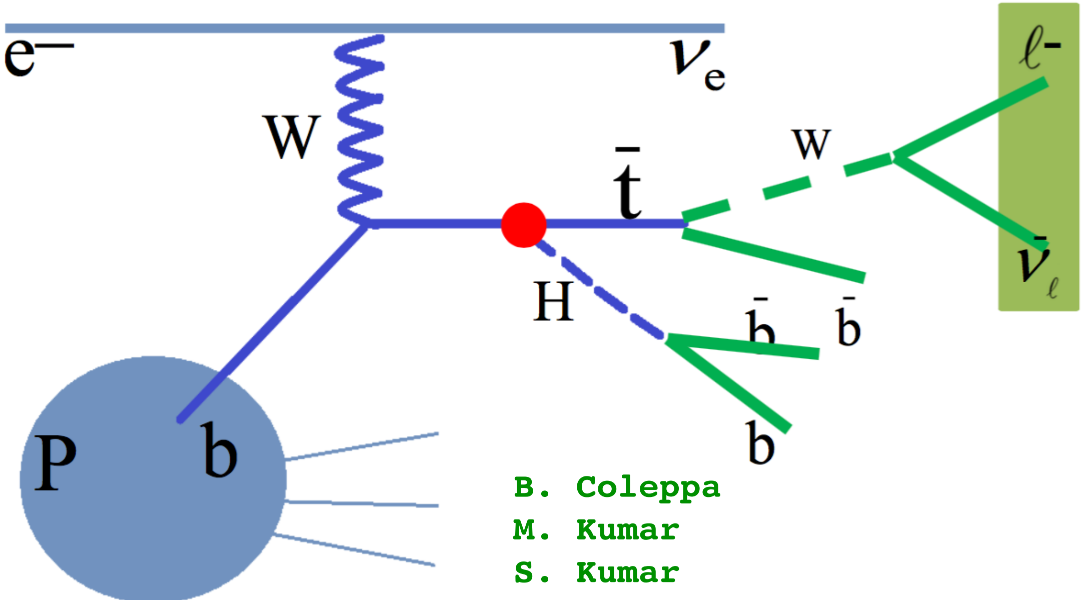
top polarisation



angular asymmetries (b_2,l^-)



CP Nature of Top-Higgs Coupling

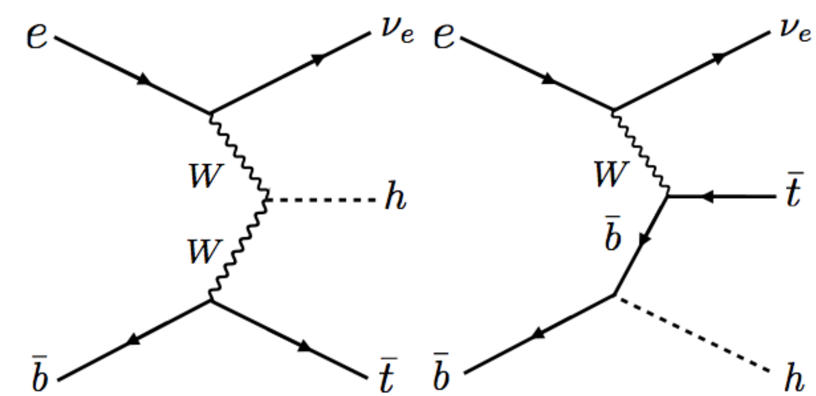


B. Coleppa
M. Kumar
S. Kumar
B. Mellado

parton level

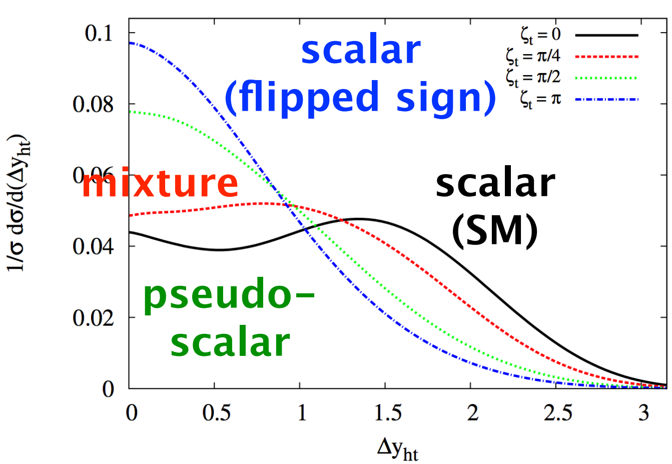
Phys. Lett. B770 (2017) 335

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

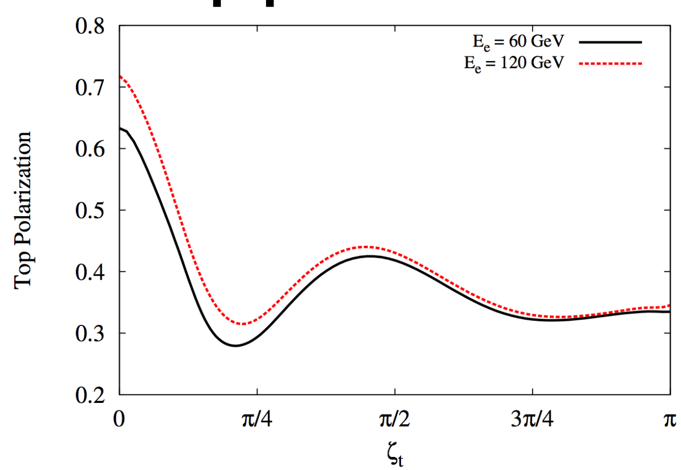


LHeC

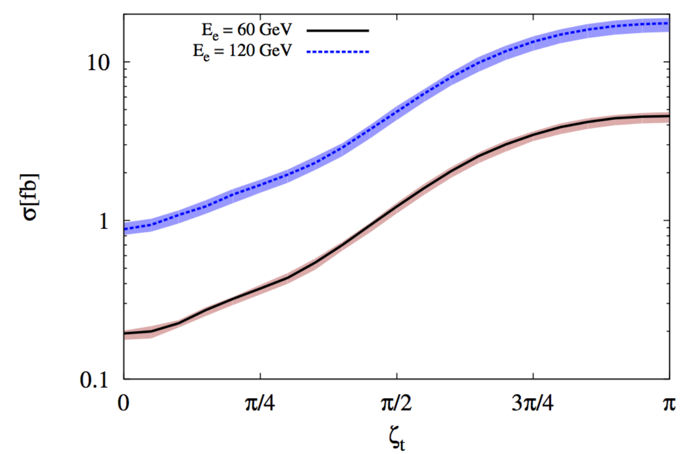
rapidity difference (H,t̄)



top polarisation



fiducial incl. cross-section



Exclusion Contours (fiducial cross section)

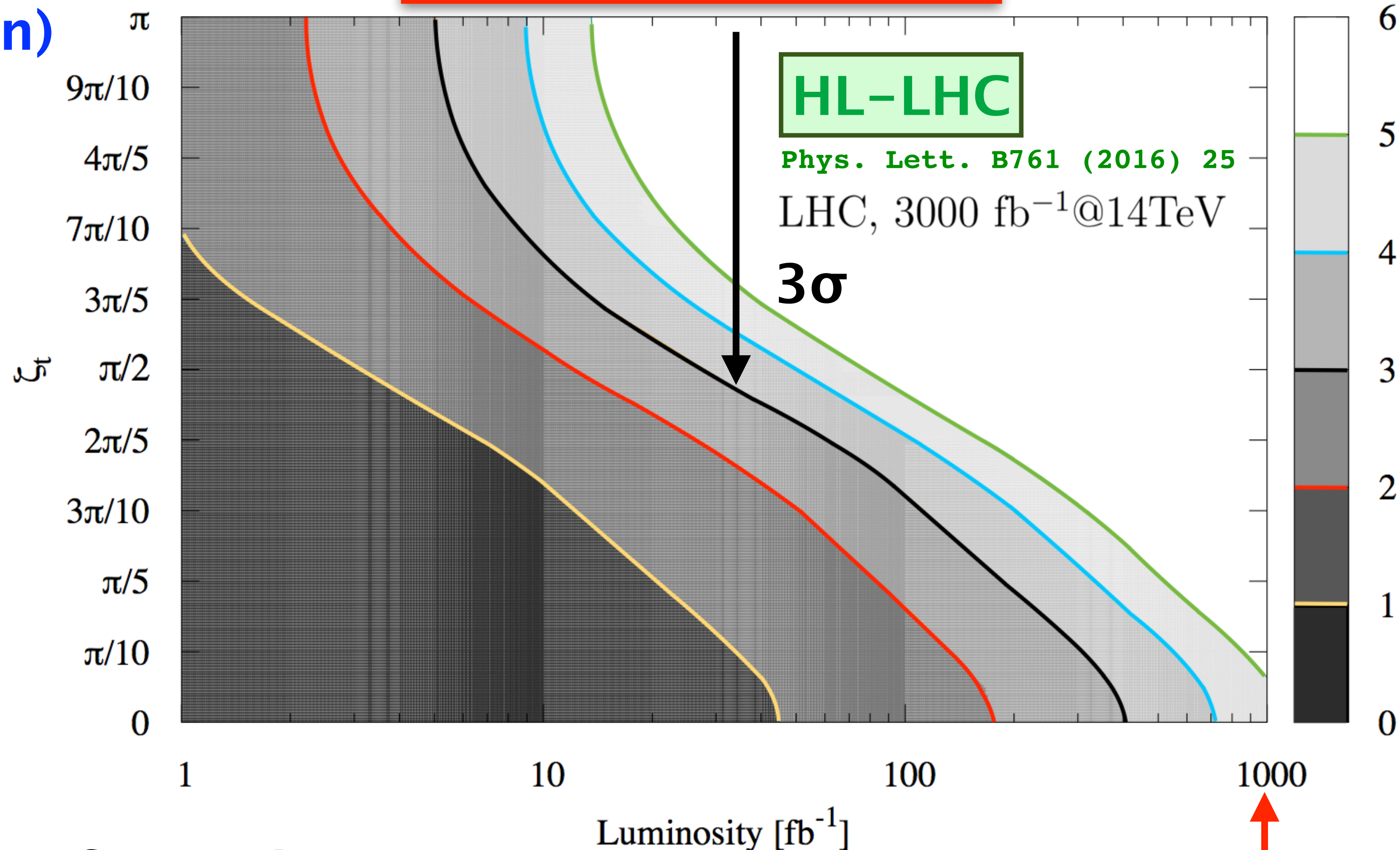
$$\mathcal{L} = -\frac{m_t}{v}\bar{t}\,[\kappa\cos\zeta_t + i\gamma_5\sin\zeta_t]t\,h$$

LHeC

CP-even (flipped sign)

CP-odd

CP-even (SM)



→ **powerful probe of ttH coupling**

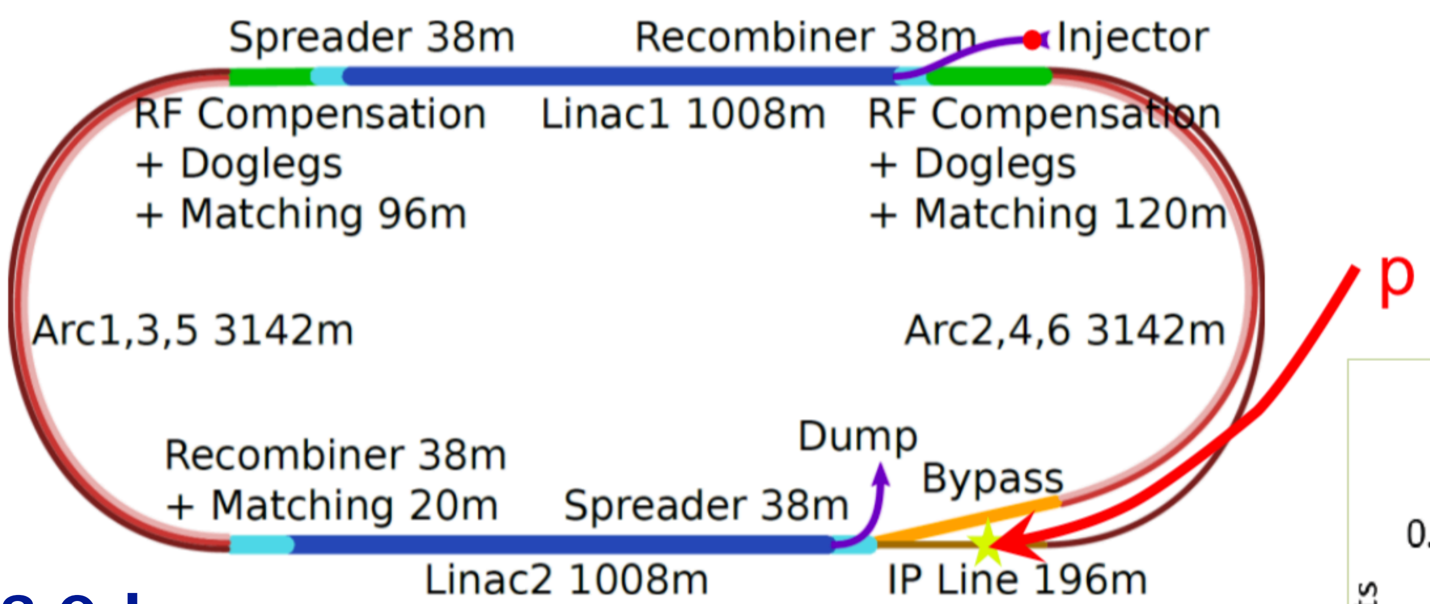
10% uncertainty on background yields

$\kappa = 1.00 \pm 0.17$

Energy Recovering Linac

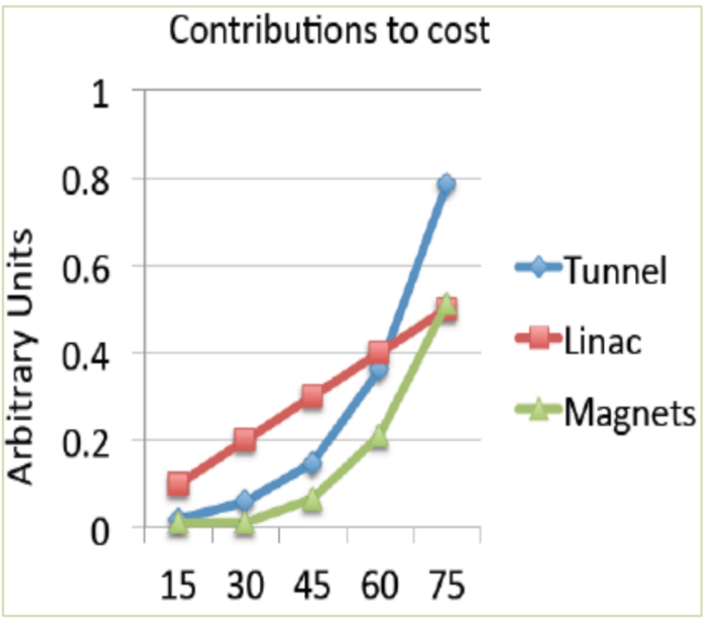
Energy Recovering Linac (ERL):

E_e=60 GeV



8.9 km

- **power limit: 100 MW**
- **luminosity: 10^{34} cm^{-2} s^{-1}**
- **factor of 15/120 (LHeC/FCC-eh) extension of Q^2, 1/x reach**

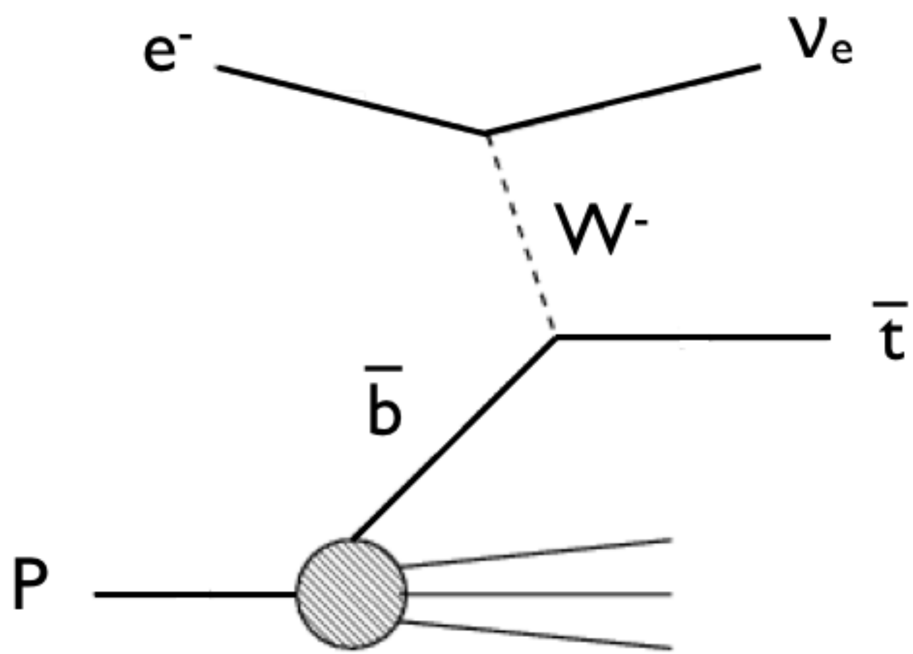


M. Klein, F. Zimmermann

Initial, tentative, rough scaling estimate of basic cost (tunnel, linac (XFEL), magnets

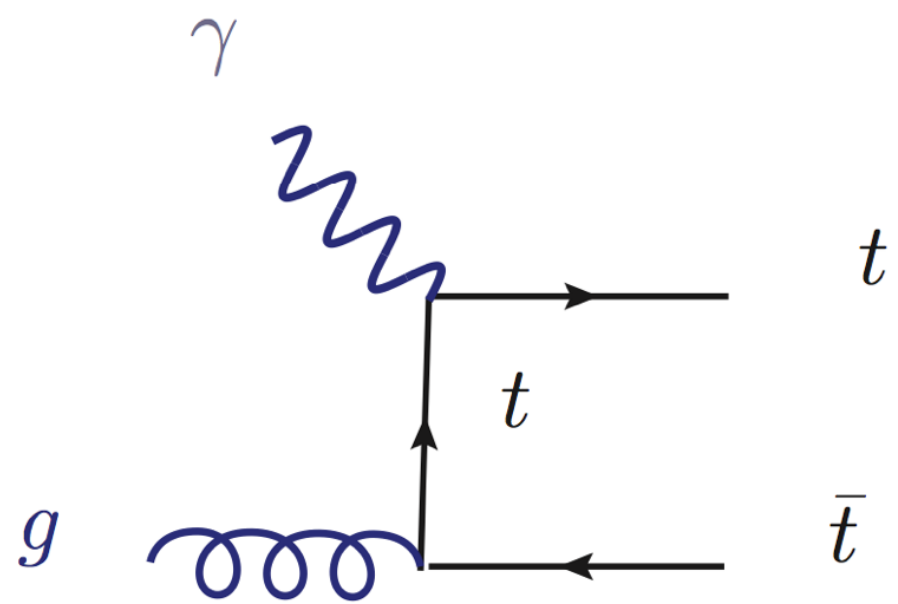
Electroweak Top Quark Production

<u>CC DIS top production</u>



σ=1.89pb @ LHeC
σ=4.46pb @ HE-LHC
σ=15.3pb @ FCC-eh

<u>NC top photoproduction</u>



σ=0.05pb @ LHeC
σ=0.??pb @ HE-LHC
σ=1.14pb @ FCC-eh

E_e=60 GeV

→ future ep collider is ideal to study EWK interactions of the top quark

Signal and Backgrounds

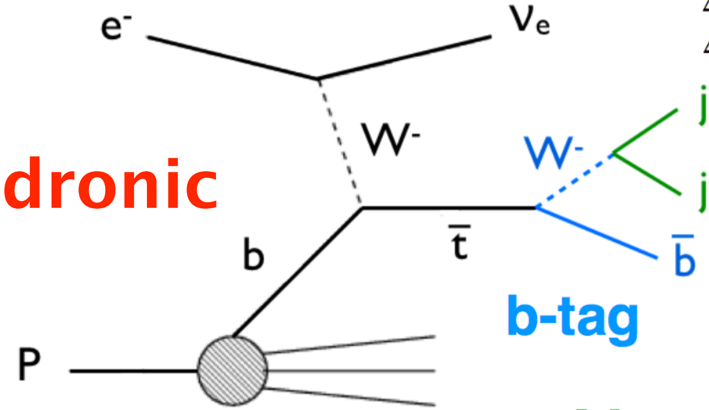
LHeC

signal

background

Dutta, Goyal, Kumar, Mellado, Eur. Phys. J. C75 (2015) no.12, 577

hadronic



$\not{E}_T \geq 25$ GeV

$\Delta\Phi_{\not{E},j} \geq 0.4$

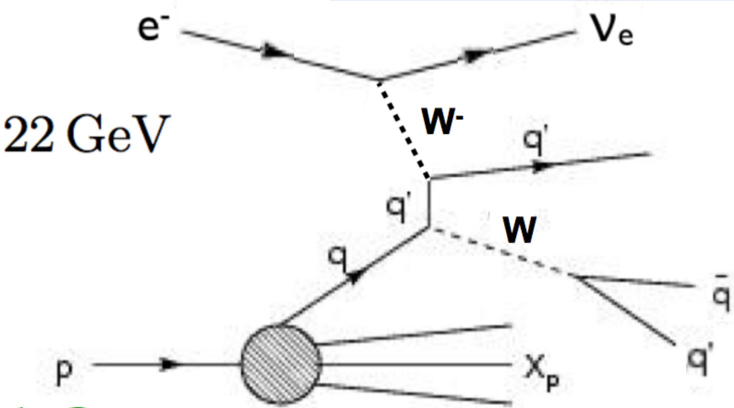
$\Delta\Phi_{\not{E},b} \geq 0.4$

$|m_{j_1 j_2} - m_W| \leq 22$ GeV

$p_{T\,j,b} \geq 20$ GeV

$|\eta_j| \leq 5, |\eta_b| \leq 2.5$

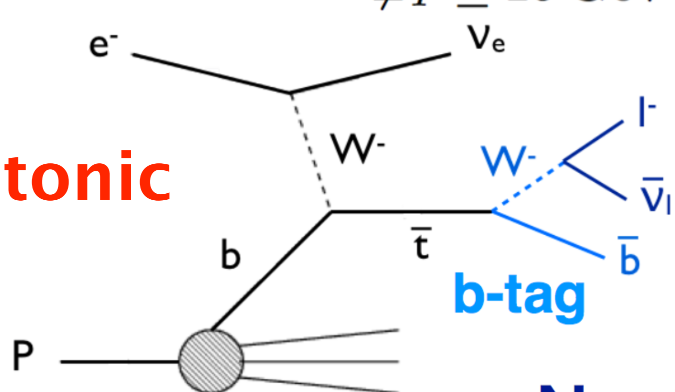
$\Delta R_{j,b/j} \geq 0.4$



N_t=220k, s/b=1.2

e beam: 60 GeV
1000 fb^{-1}

leptonic



$\not{E}_T \geq 25$ GeV

$\Delta\Phi_{\not{E},j} \geq 0.4$

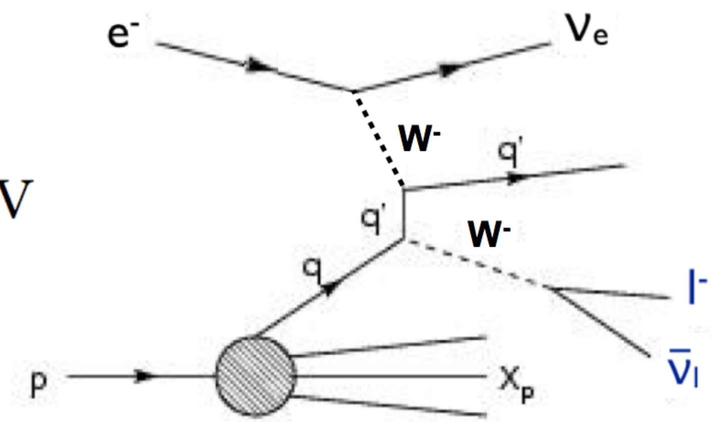
$\Delta\Phi_{\not{E},b} \geq 0.4$

$\Delta\Phi_{\not{E},l} \geq 0.4$

$p_{T\,j,b,l} \geq 20$ GeV

$|\eta_j| \leq 5,\ |\eta_{b,l}| \leq 2.5$

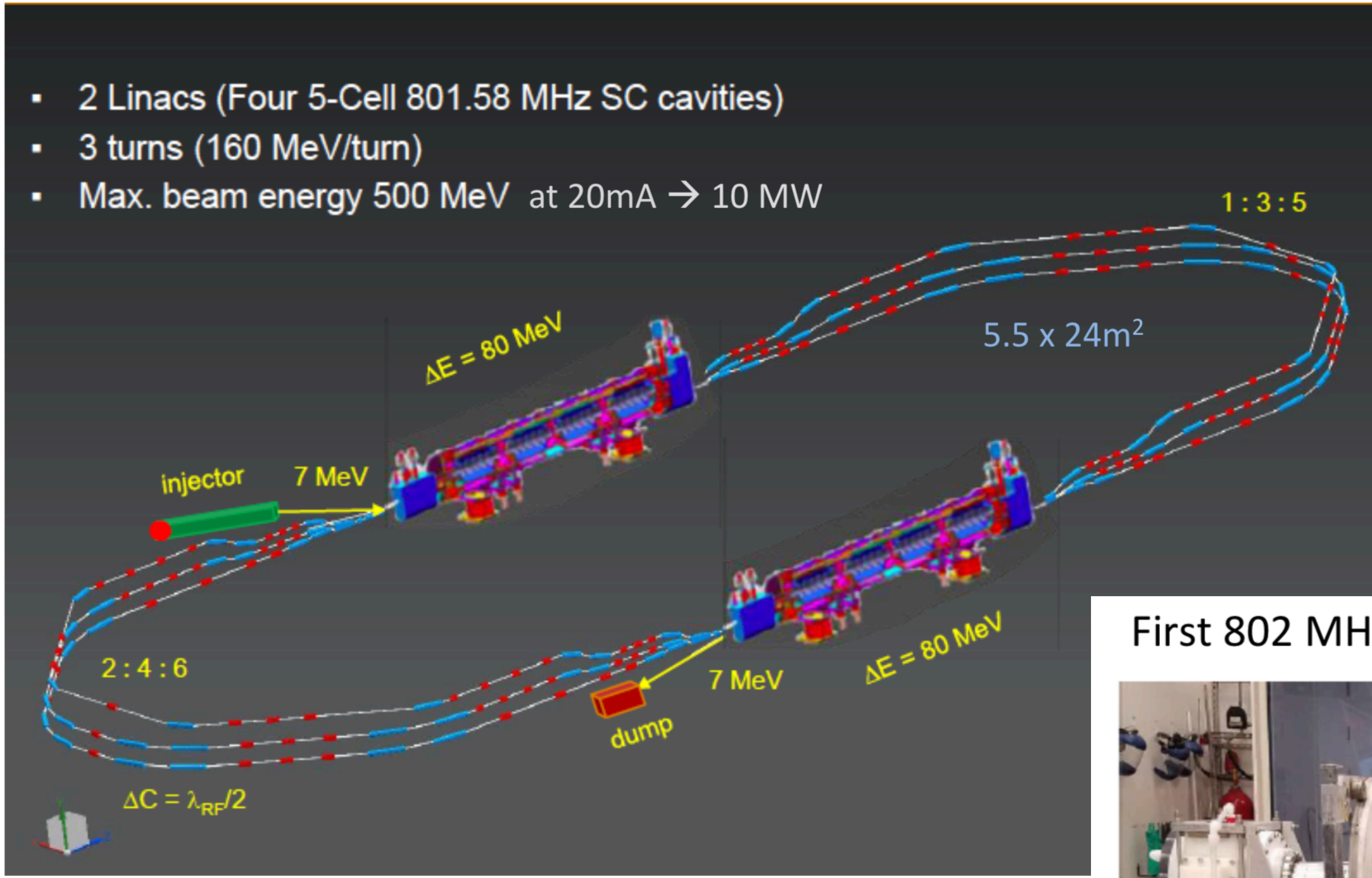
$\Delta R_{j,b/j} \geq 0.4$



N_t=110k, s/b=11

→ top quark factory (with low backgrounds)

Powerful ERL for Experiments (PERLE)



cf Walid Kaabi at Amsterdam FCC

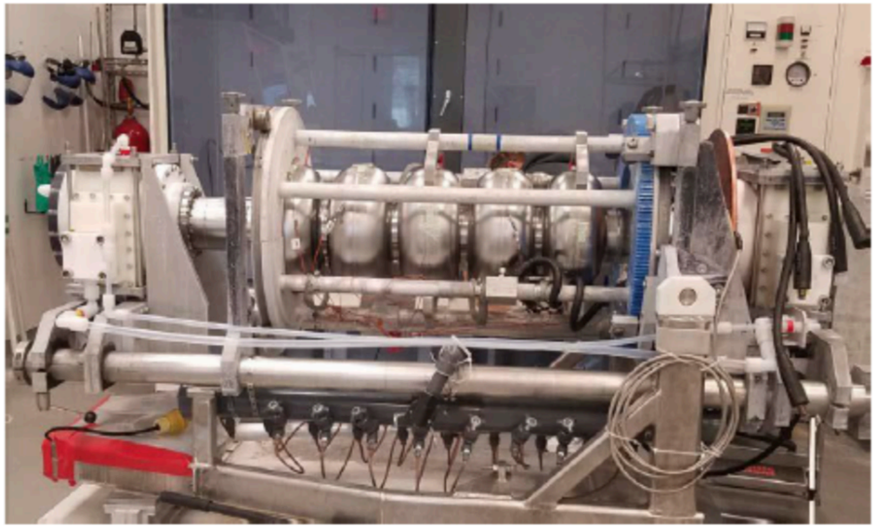
in Orsay

- BINP
- CERN
- Daresbury/Liverpool
- Jlab
- Orsay

→ CDR 1705.08783 [J. Phys G]

→ TDR in 2019

First 802 MHz cavity successfully built (Jlab)

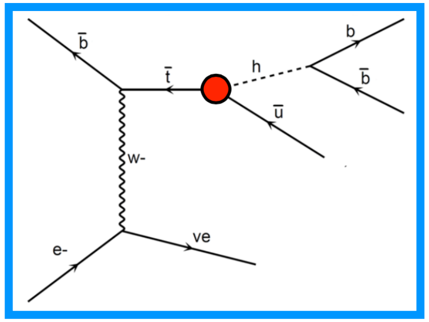


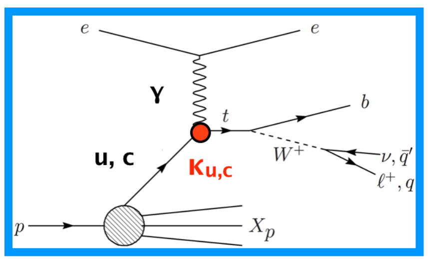
→ **ERL demonstrator**

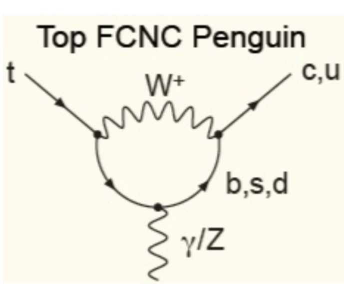
→ **O(10 MeV) physics**

FCNC Top Quark Couplings

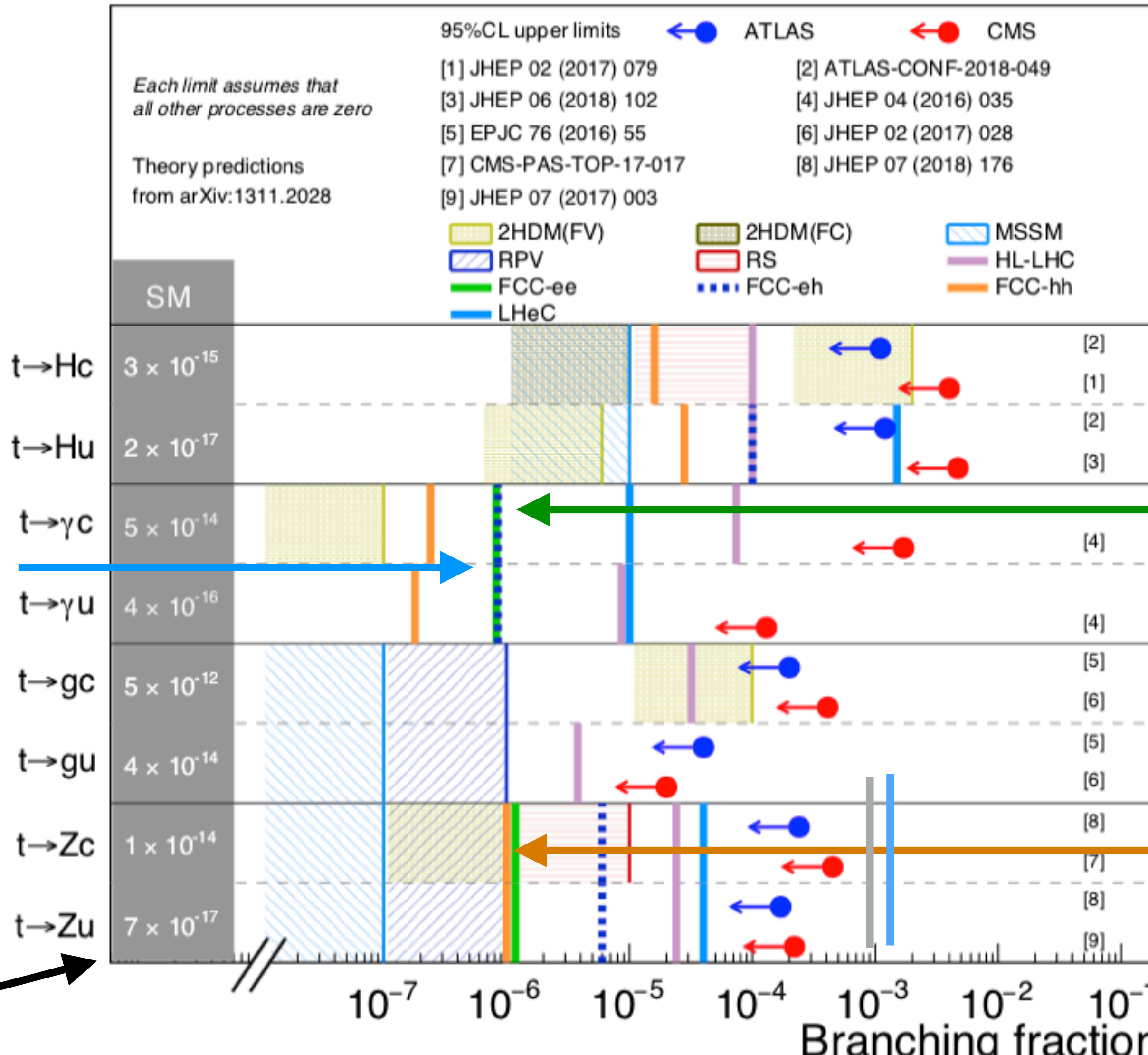
LHeC FCC-ep

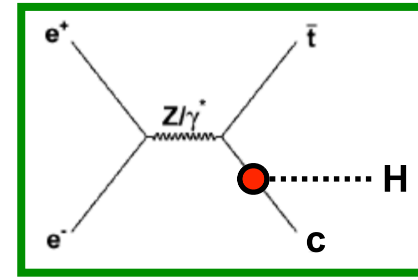


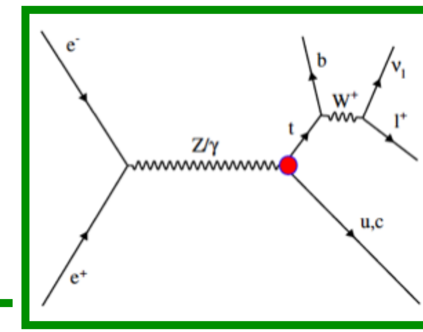




FCC CDR, Eur. Phys. J. C 79, no. 6, 474 (2019)

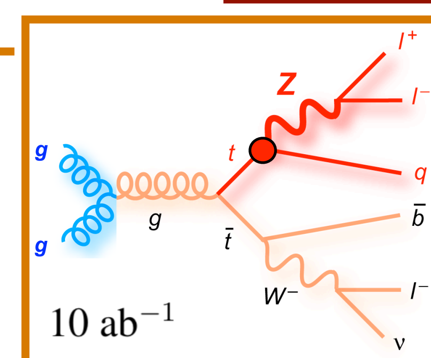






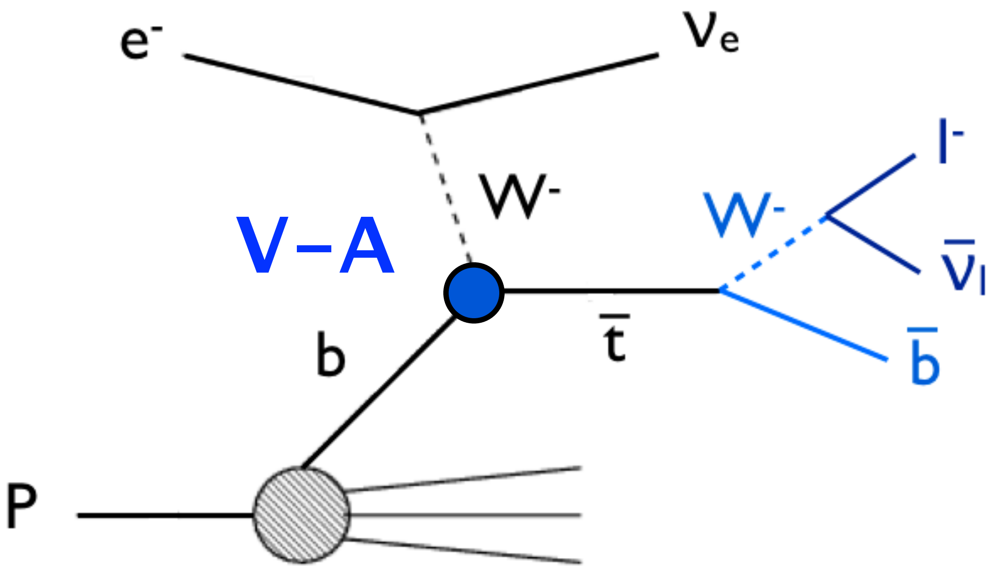
CLIC FCC-ee

FCC-pp



→ **complementarity of colliders**

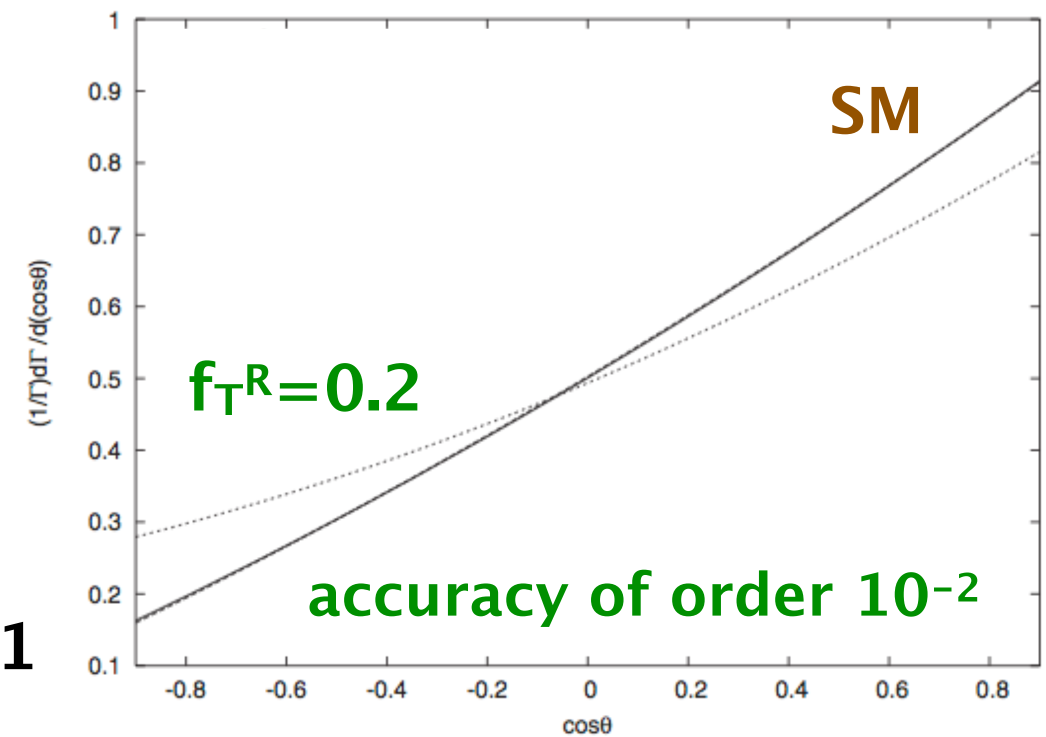
Top Quark Polarisation



Atag, Sahin,
PRD 73, 074001 (2006)

cosθ: angle between charged lepton and spin quantisation axis in top rest frame

$$\frac{1}{\Gamma_T}\frac{d\Gamma}{d\cos\theta} = \frac{1}{2}(1 + A_{\uparrow\downarrow}\alpha\cos\theta) \qquad A_{\uparrow\downarrow} = \frac{N_\uparrow - N_\downarrow}{N_\uparrow + N_\downarrow}$$



using simply e−beam axis:
polarisation: P_t = 96%

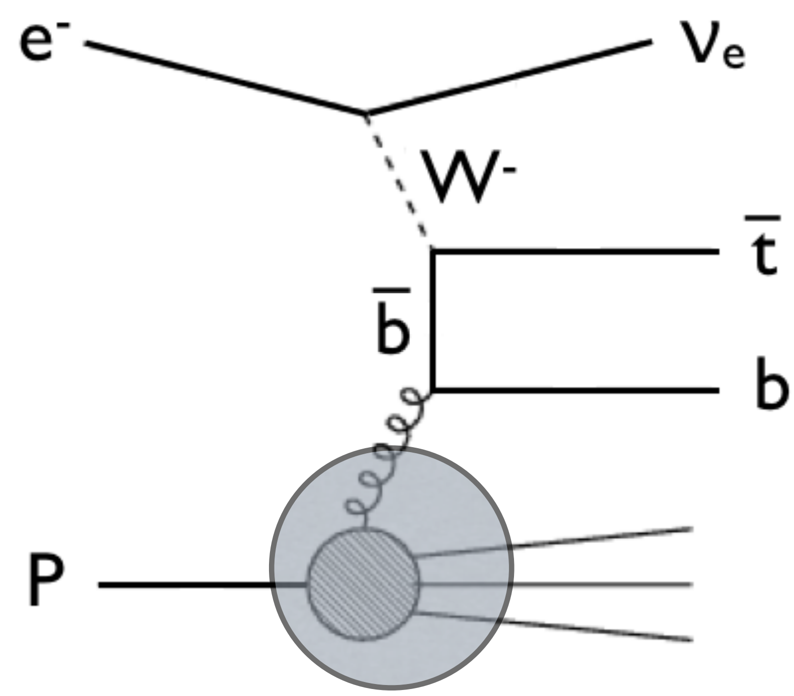
TESLA+HERAp:

$\sqrt{s}$=1.6 TeV
L_{int}=20 fb^{-1}

19.7 fb^{-1}: $A_{\uparrow\downarrow}$ = 0.26±0.11

JHEP 04 (2016) 073

Gluon Parton Density Function



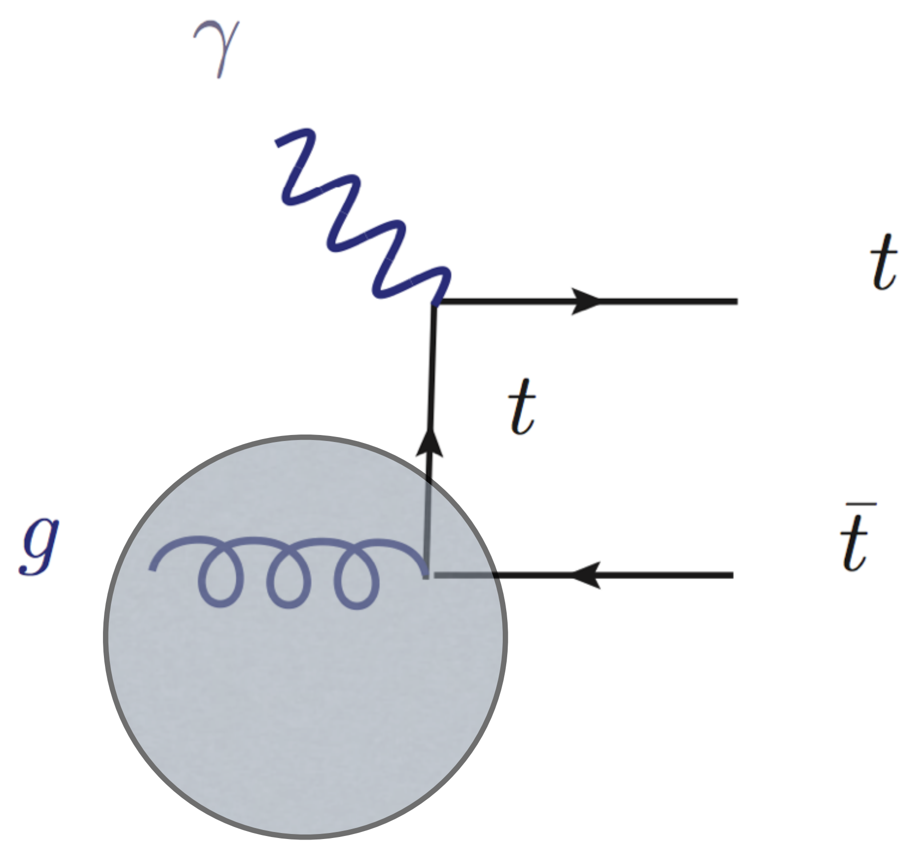
→ **measure gluon density at high x**

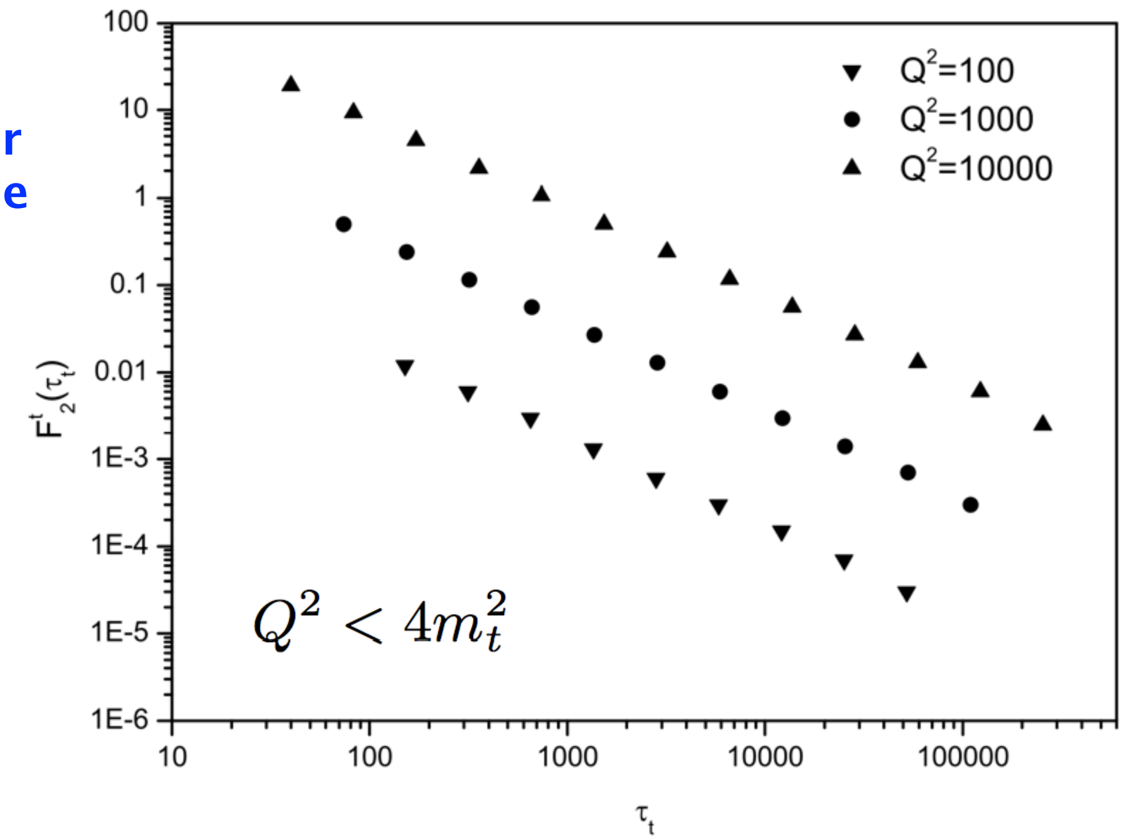
Top Quark Structure Function

Boroun, Phys. Lett. B744, 142 (2015)

L_{int}=10 fb^{-1}

variable flavour number scheme for top quark





$$\tau_t = (1 + \frac{4m_t^2}{Q^2})^{1+\lambda} \frac{Q^2}{Q_0^2} (\frac{x_B}{x_0})^\lambda$$

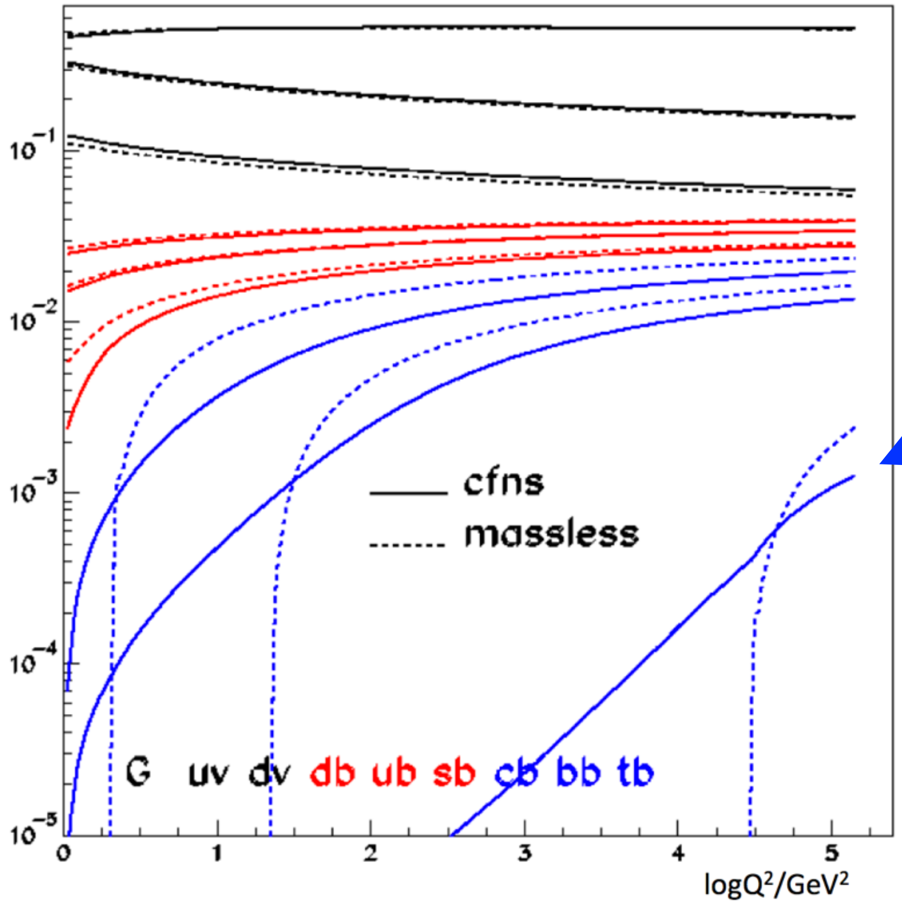
$$x = x_B (1 + \frac{4m_t^2}{Q^2})$$

→ **LHeC opens up a new field of top quark PDFs**

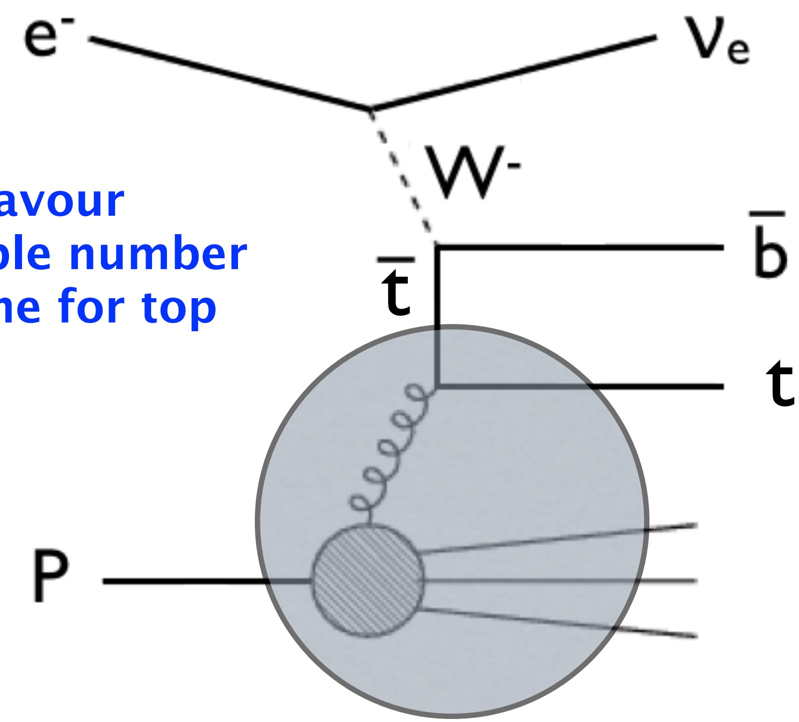
Top Quark Parton Density Function

LHeC CDR, J.Phys. G39, 075001 (2012)

parton momentum fraction



six-flavour variable number scheme for top quark



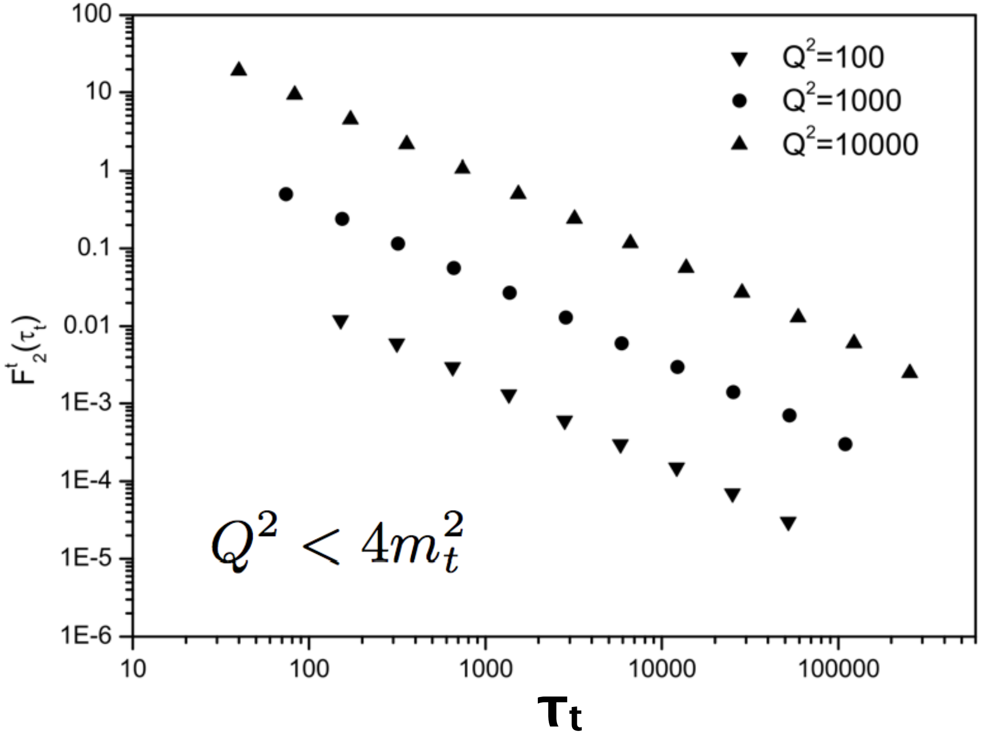
→ LHeC offers new field of research for top quark PDF

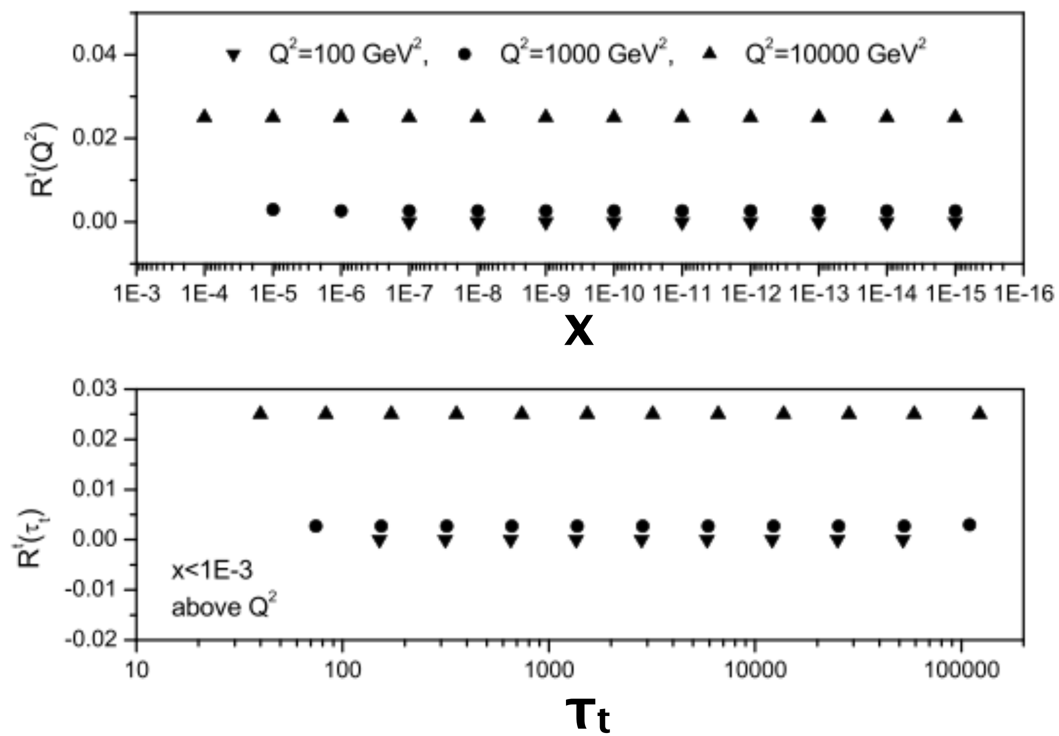
Top Quark Structure Function

Boroun, Phys. Lett. B744, 142 (2015)

$$\tilde{\sigma}^{t\bar{t}}(\tau_t) \rightarrow F_2^t(\tau_t)[1 - R^t(\tau_t)]$$

variable flavour
number scheme
for top quark





→ approximately: $1/\tau_t$

→ independent of x and τ_t

→ **longitudinal top structure function component could be good to probe top quark density in proton at $Q^2 \simeq 4m_t^2$**

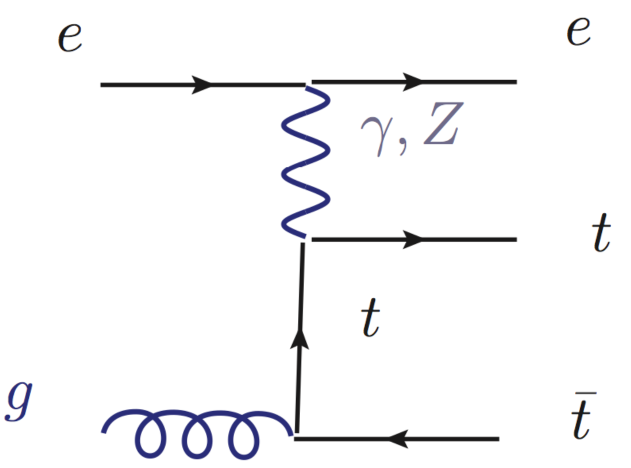
NC Top Quark Production

Bouzas, Larios,
Physical Review D 88, 094007 (2013)

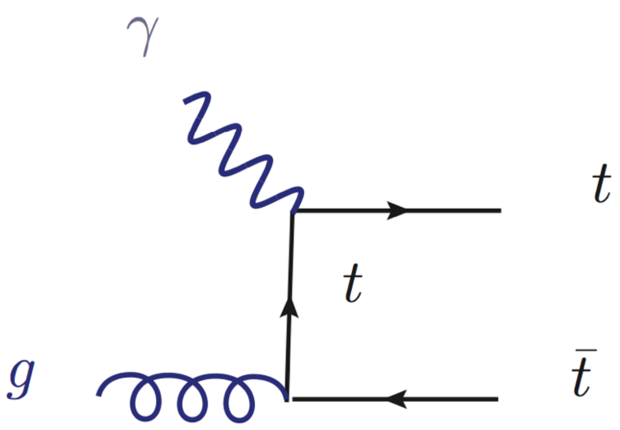
top pair production

single top production

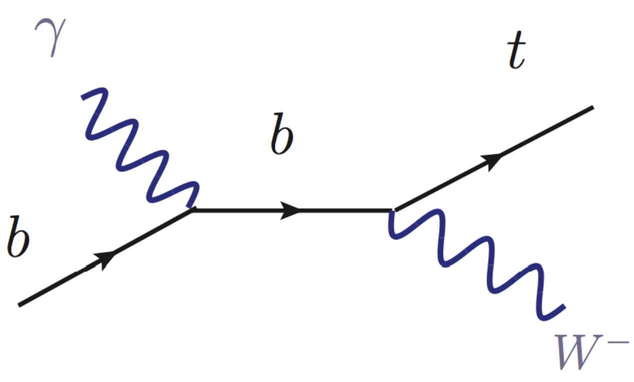
DIS



photoproduction



photoproduction



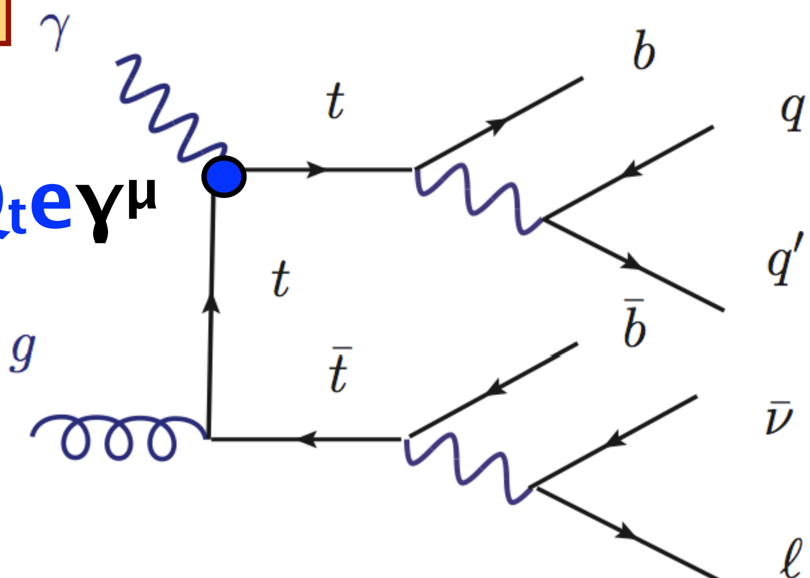
e−beam 60 GeV, 100 fb^{-1}:

DIS	photoproduction	photoproduction
0.023 pb	**0.70 pb**	**0.031 pb**
$N_{t\bar{t}}$=2,300	**$N_{t\bar{t}}$=70,000**	**N_t=3,100**

Analysis of the $t\bar{t}\gamma$ Vertex

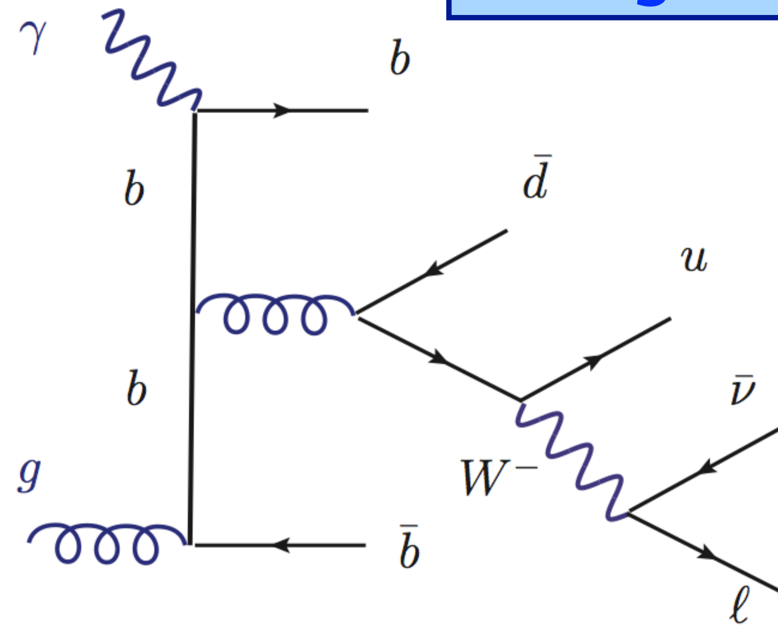
signal

$iQ_t e\gamma^\mu$

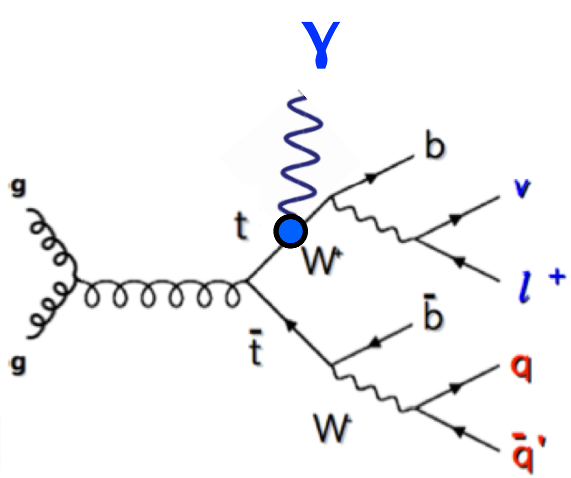


→ **measure top quark charge**

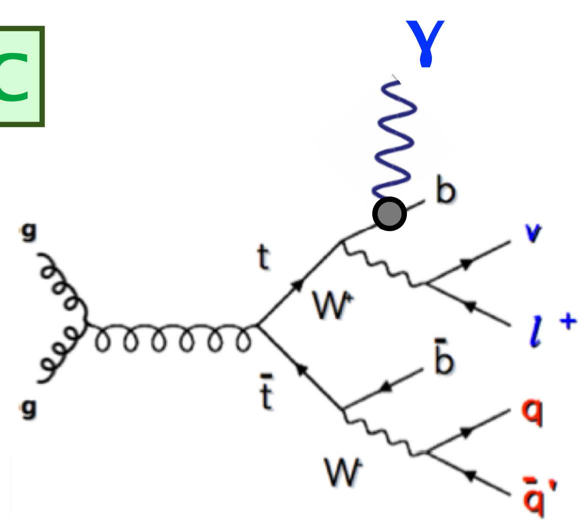
background



LHC



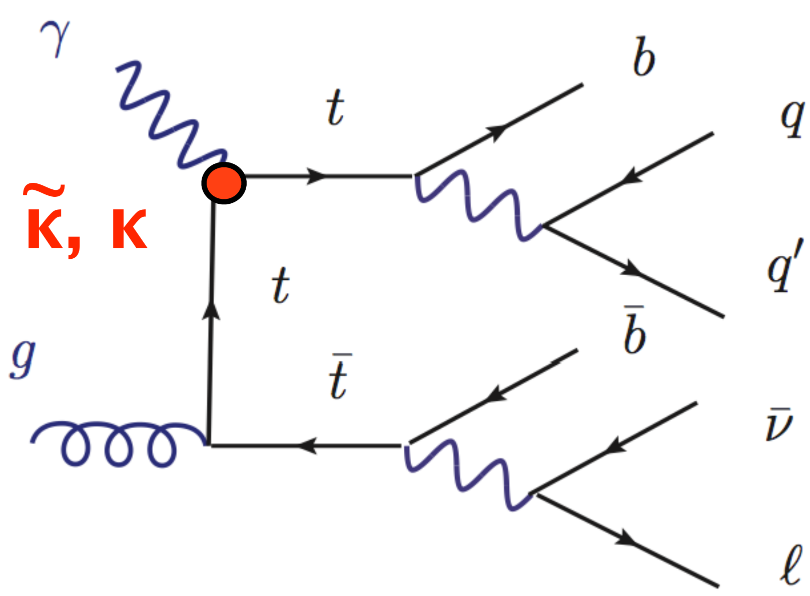
OR



?

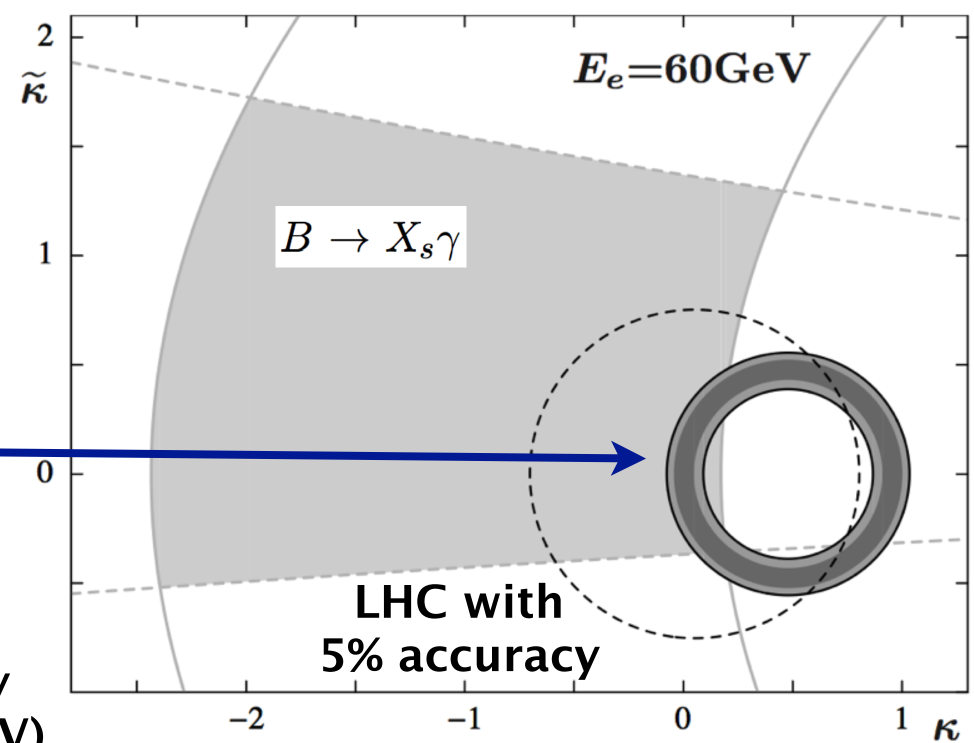
→ **difficult at the LHC**

Search for Anomalous $t\bar{t}\gamma$ Couplings



$$\mathcal{L}_{t\bar{t}\gamma} = e\bar{t}\left(Q_t\gamma^\mu A_\mu + \frac{1}{4m_t}\sigma^{\mu\nu}F_{\mu\nu}(\kappa + i\tilde{\kappa}\gamma_5)\right)t$$

electric dipole moment: $\tilde{\kappa}$



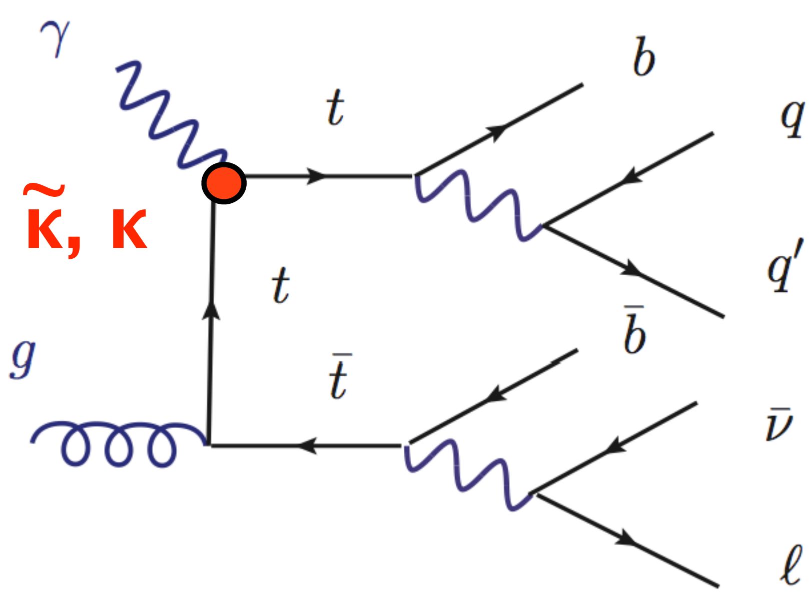
LHeC:
10% and 18% accuracy

27% accuracy
(4.59fb[-1], 7 TeV)

magnetic dipole moment: κ

Bouzas, Larios,
Physical Review D 88, 094007 (2013)

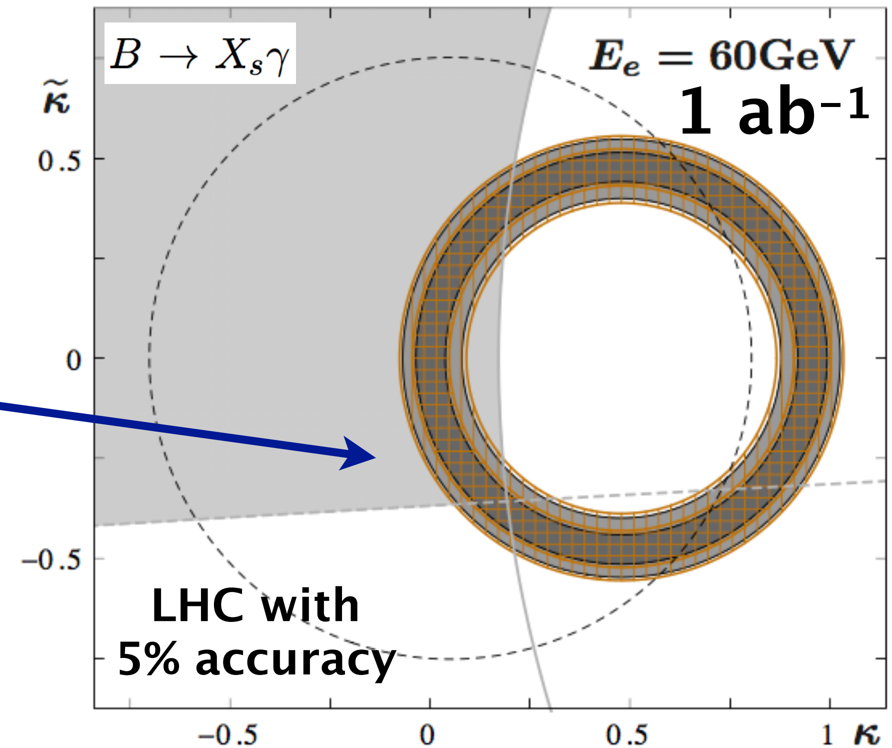
Search for Anomalous $t\bar{t}\gamma$ Couplings



$$\mathcal{L}_{t\bar{t}\gamma} = e\bar{t}\left(Q_t\gamma^\mu A_\mu + \frac{1}{4m_t}\sigma^{\mu\nu}F_{\mu\nu}(\kappa + i\tilde{\kappa}\gamma_5)\right)t$$

electric dipole moment: $\tilde{\kappa}$

LHeC:
8% and 16% accuracy
10% 18%
→ systematically limited



magnetic dipole moment: κ

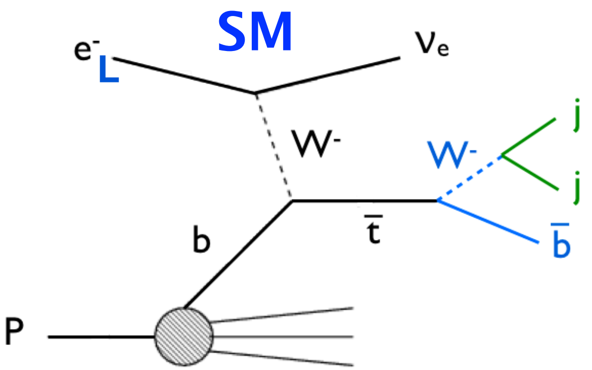
27% accuracy
(4.59fb^{-1}, 7 TeV)

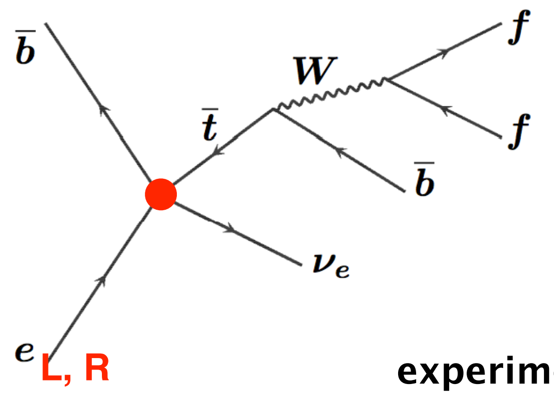
Bouzas, Larios,
Physical Review D 88, 094007 (2013)

Top Quark Dimension 6 Operators

$$\Lambda^2\mathcal{L}_{4f} = C_1(\bar{\nu}_L\gamma^\mu t_L \bar{b}_L\gamma_\mu e_L + h.c.) + [C_2\bar{\nu}_L e_R \bar{b}_R t_L + C_3 \bar{b}_L e_R \bar{\nu}_L t_R + C_4 \bar{\nu}_L e_R \bar{b}_L t_R + h.c.]$$

Λ=1TeV





property	precision
C_1	0.50−0.85
C_2^r	2.2−5.0
C_3^r	1.4−2.9
C_4^r	2.2−4.9

Sarmiento-Alvarado, Bouzas, Larios, arXiv:1412.6679

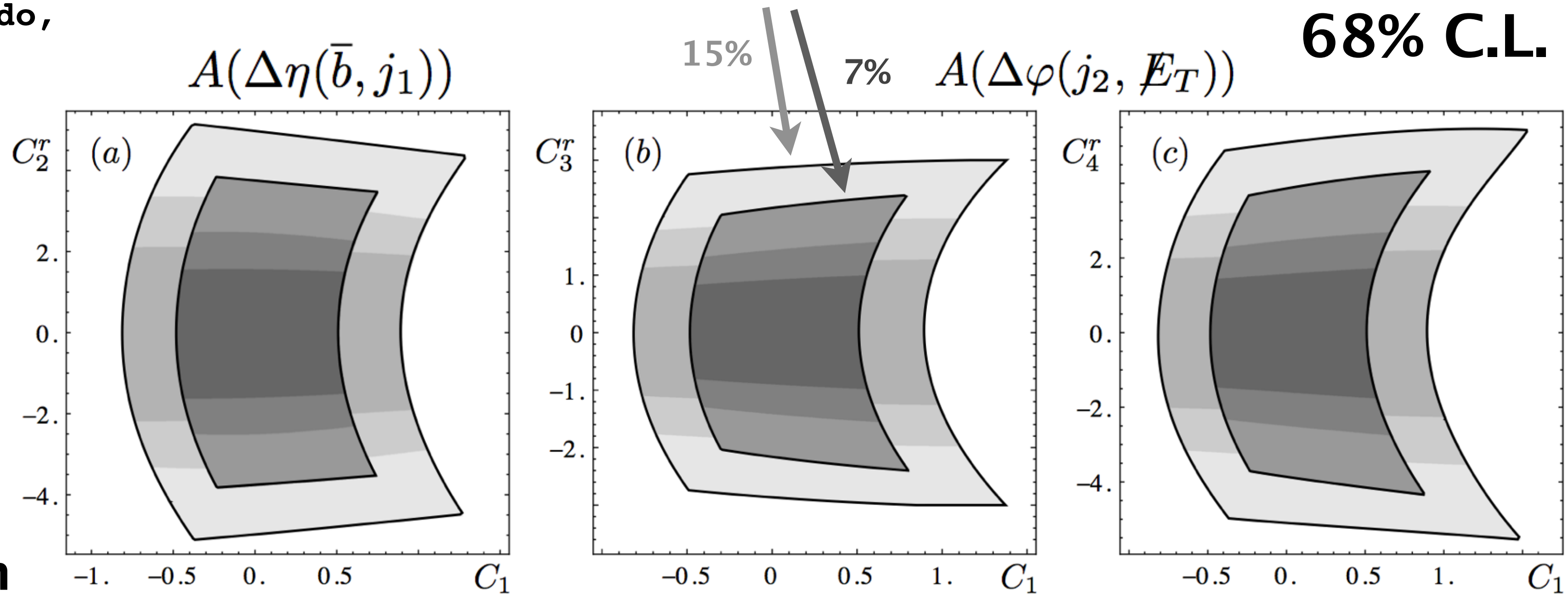
experimental error

68% C.L.

$\mathcal{P}_e = 0$

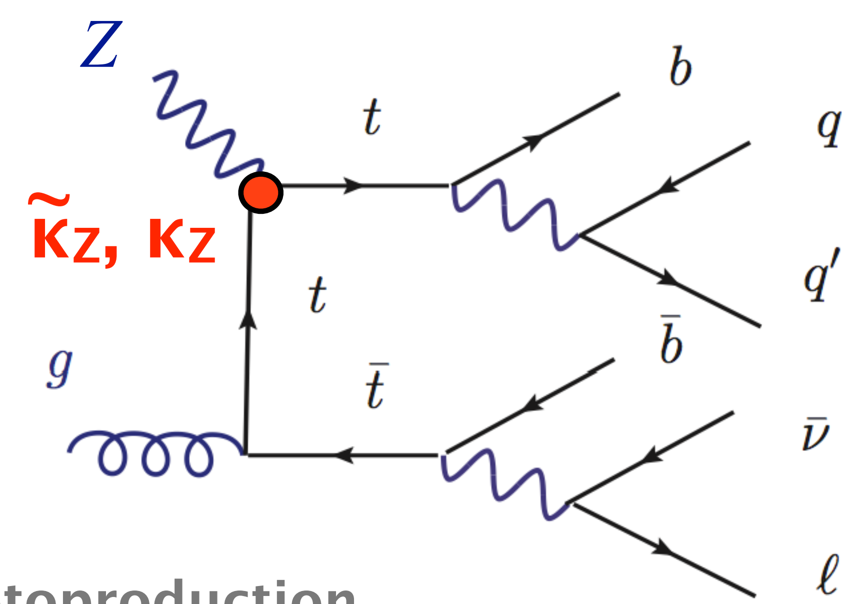
$\mathcal{P}_e = 0.4$

$\mathcal{P}_e = 0.7$



cross section

Search for Anomalous $t\bar{t}Z$ Couplings

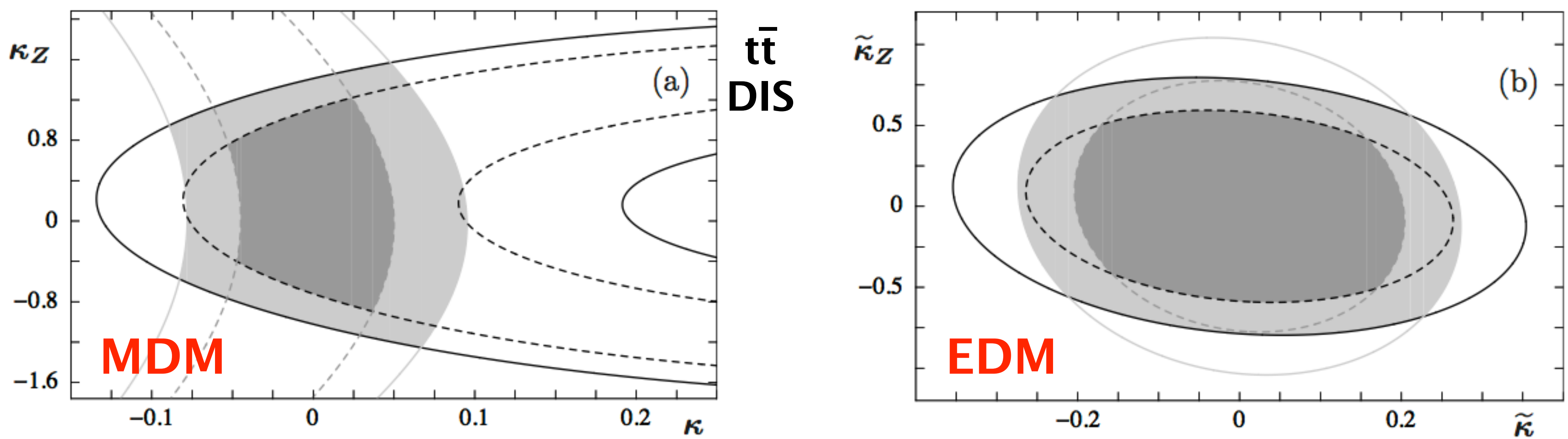


Bouzas, Larios,
Physical Review D 88, 094007 (2013)

property	precision
EDM: $\tilde{\kappa}$ / $\tilde{\kappa}_Z$	0.20–0.28/0.6–0.8
MDM: κ / κ_Z	0.05–0.09/0.9–1.3

$t\bar{t}$ photoproduction

LHeC:
10% and 18% accuracy

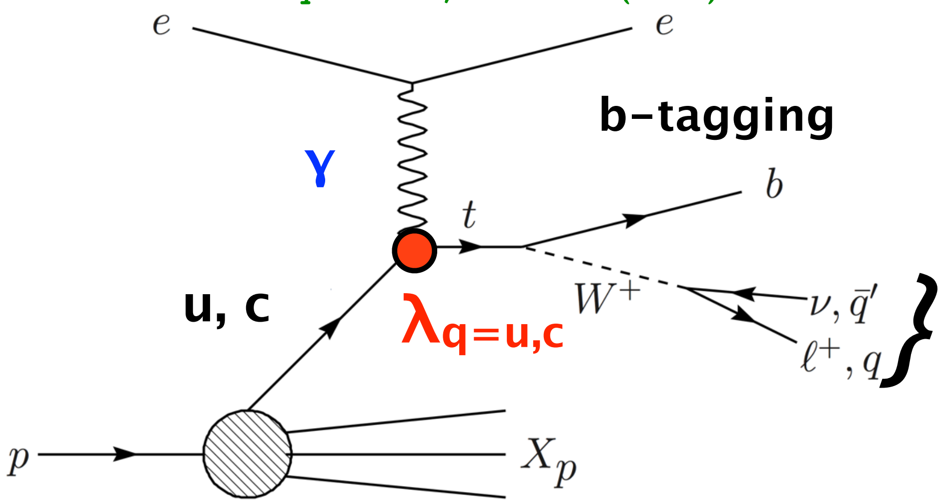


Search for Anomalous FCNC tuγ Coupling

signal

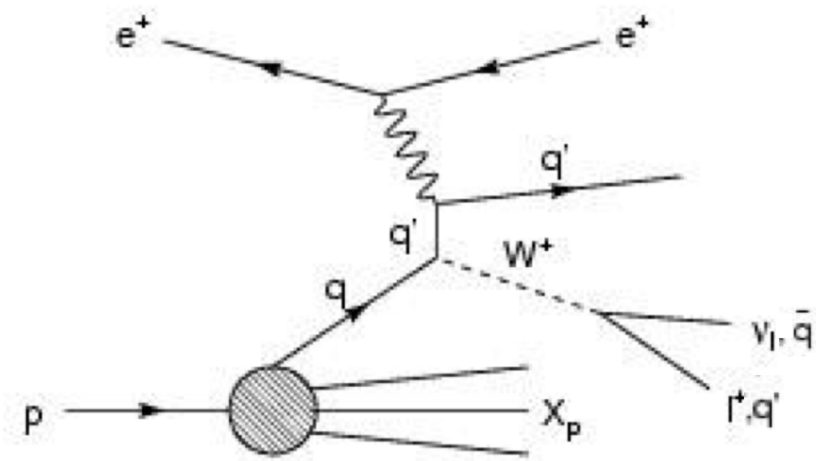
I. Cakir, Yilmaz, Denizli, Senol, Karadeniz, O. Cakir, Adv. High Energy Phys. 2017, 1572053 (2017)

$$L = -g_e \sum_{q=u,c} Q_q \frac{\lambda_q}{\Lambda} \bar{t}\sigma^{\mu\nu}(f_q + h_q\gamma_5)qA_{\mu\nu} + h.c.$$



50<M_{jj}<100 GeV

background



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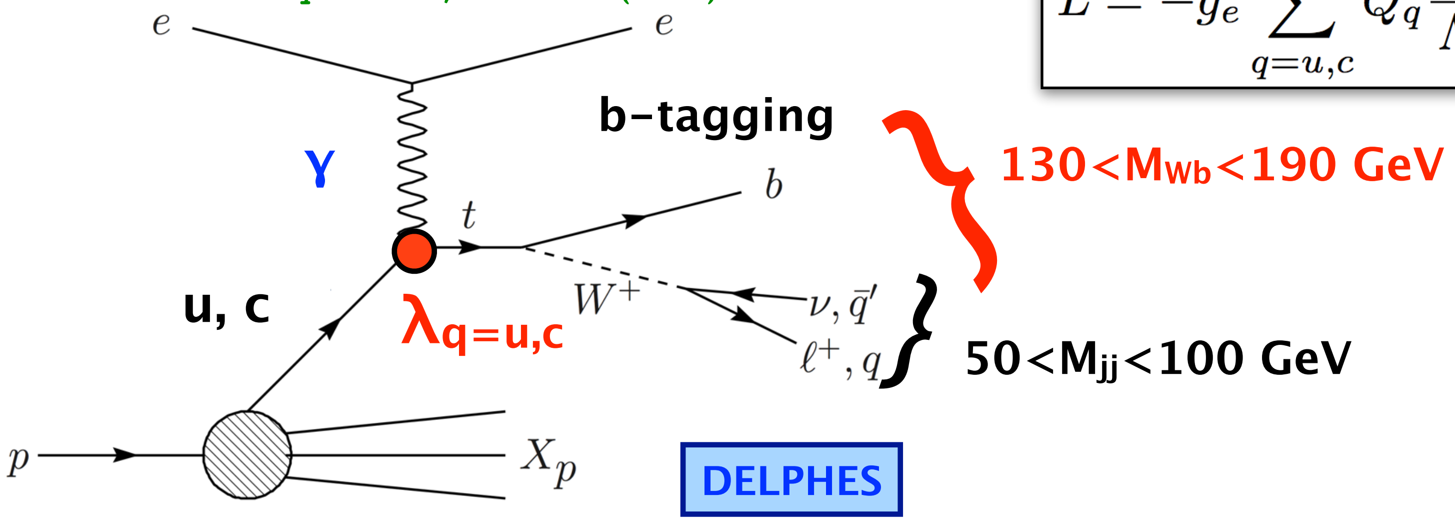
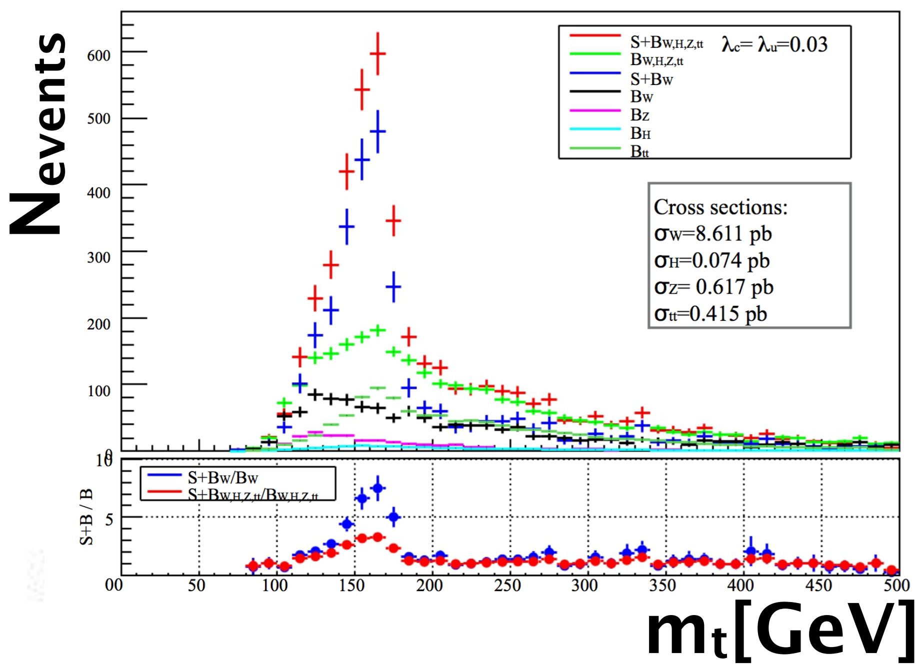


DELPHES



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signal

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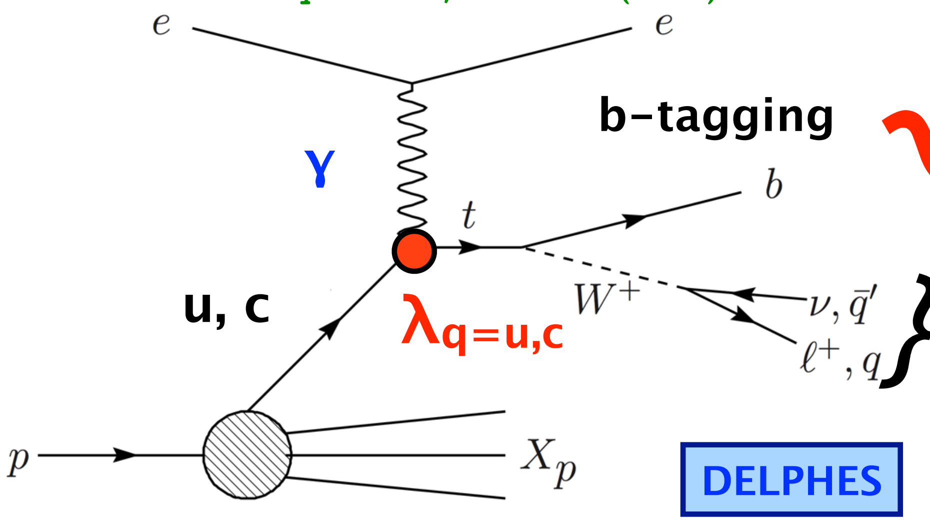
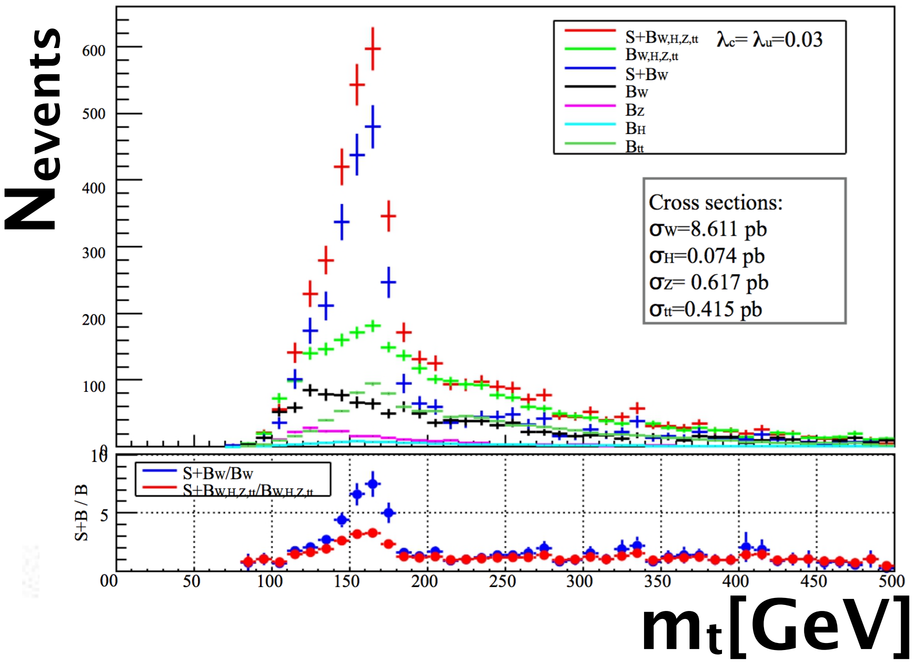


130<M_{Wb}<190 GeV

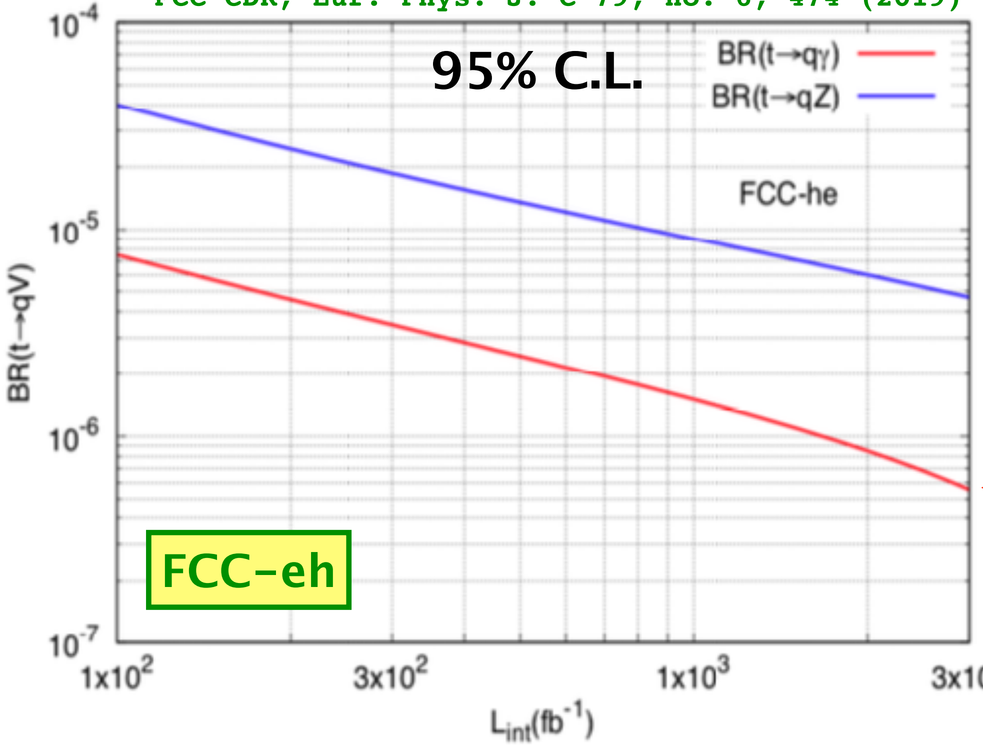
50<M_{jj}<100 GeV

→ **test exotic models leading to FCNC**

DELPHES



FCC CDR, Eur. Phys. J. C 79, no. 6, 474 (2019)



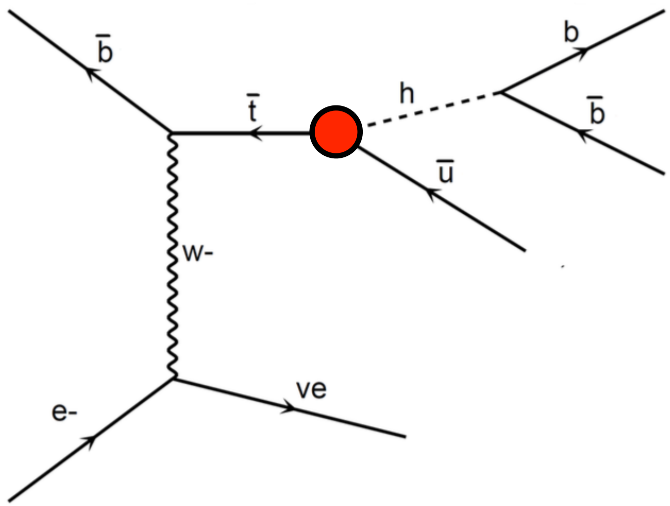
<5·10^{-6}

<6·10^{-7}

Search for Anomalous FCNC tHu Coupling

signal

Sun, Wang,
arXiv:1602.04670 [hep-ph]



$$e^{-}p \to \nu_e \bar{t} \to \nu_e h\bar{q} \to \nu_e b\bar{b}\bar{q}, \quad q = u, c$$

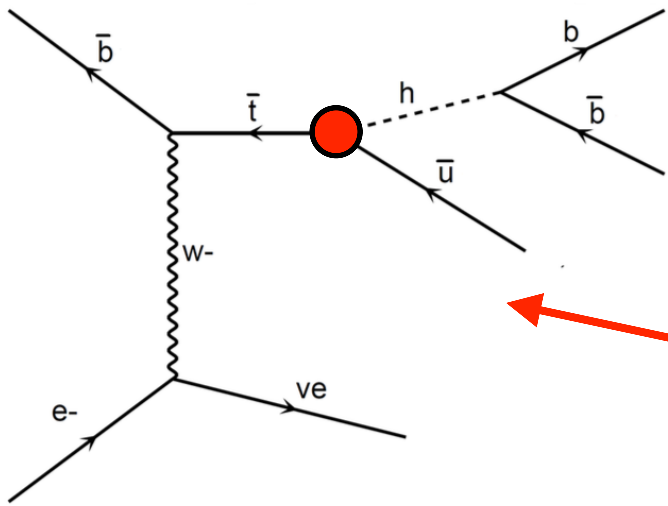
$$\mathcal{L} = \kappa_{tuh}\bar{t}uh + \kappa_{tch}\bar{t}ch + h.c.$$

Search for Anomalous FCNC tHu Coupling

signal

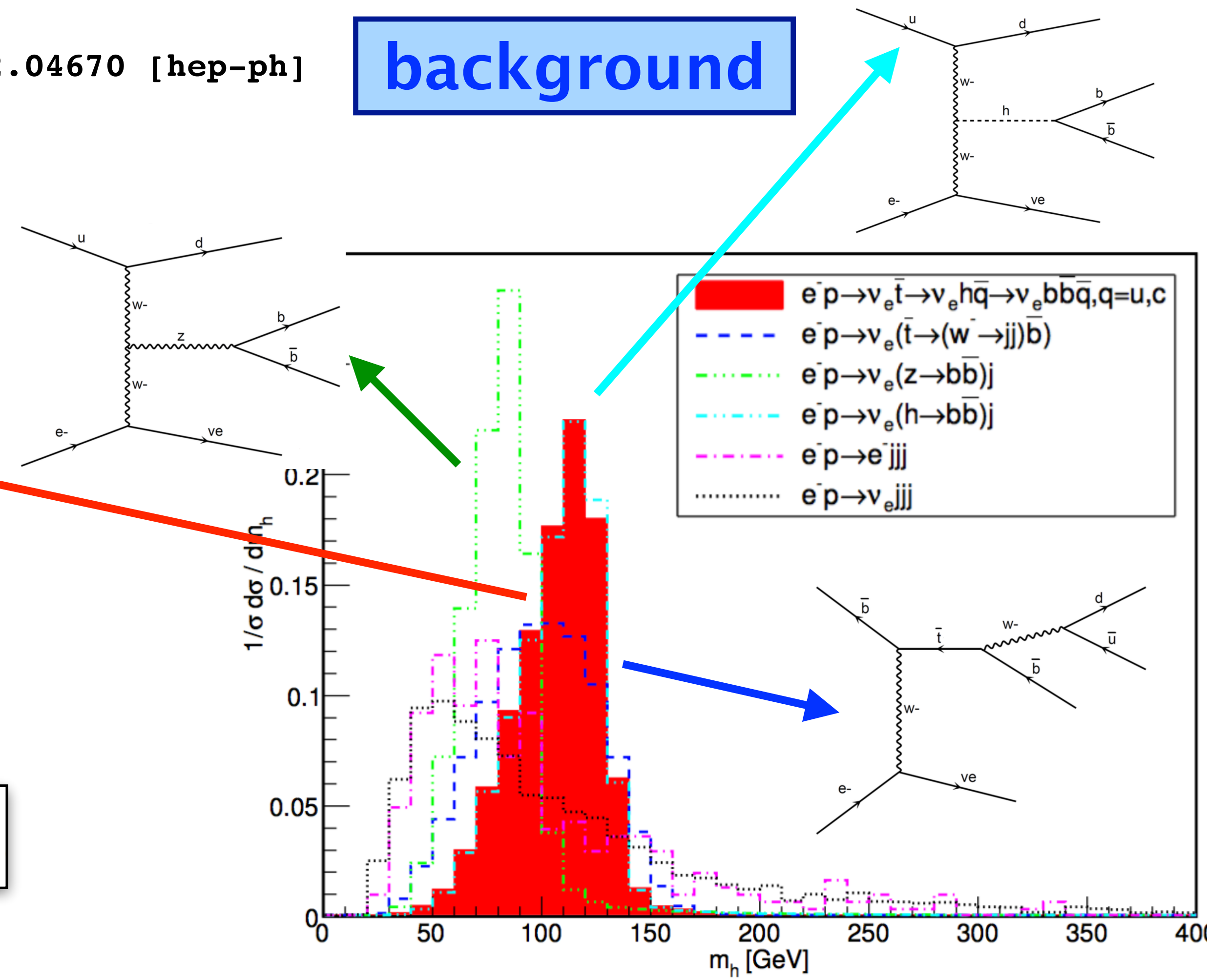
Sun, Wang,
arXiv:1602.04670 [hep-ph]

background



$$e^- p \to \nu_e \bar{t} \to \nu_e h \bar{q} \to \nu_e b \bar{b} \bar{q}, \quad q = u, c$$

$$\mathcal{L} = \kappa_{tuh} \bar{t} u h + \kappa_{tch} \bar{t} c h + h.c.$$

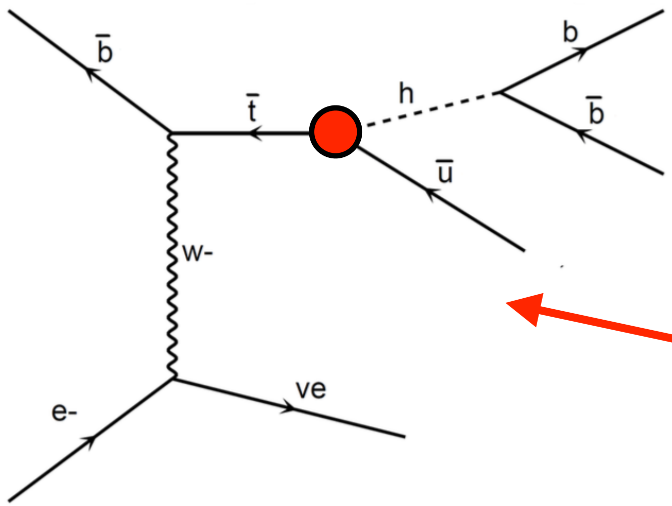


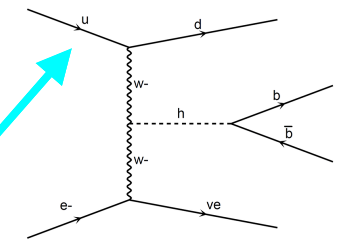
Search for Anomalous FCNC tHu Coupling

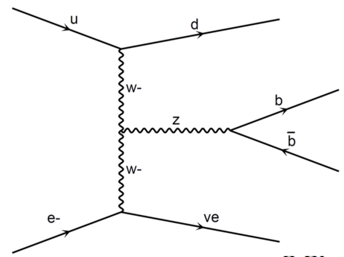
signal

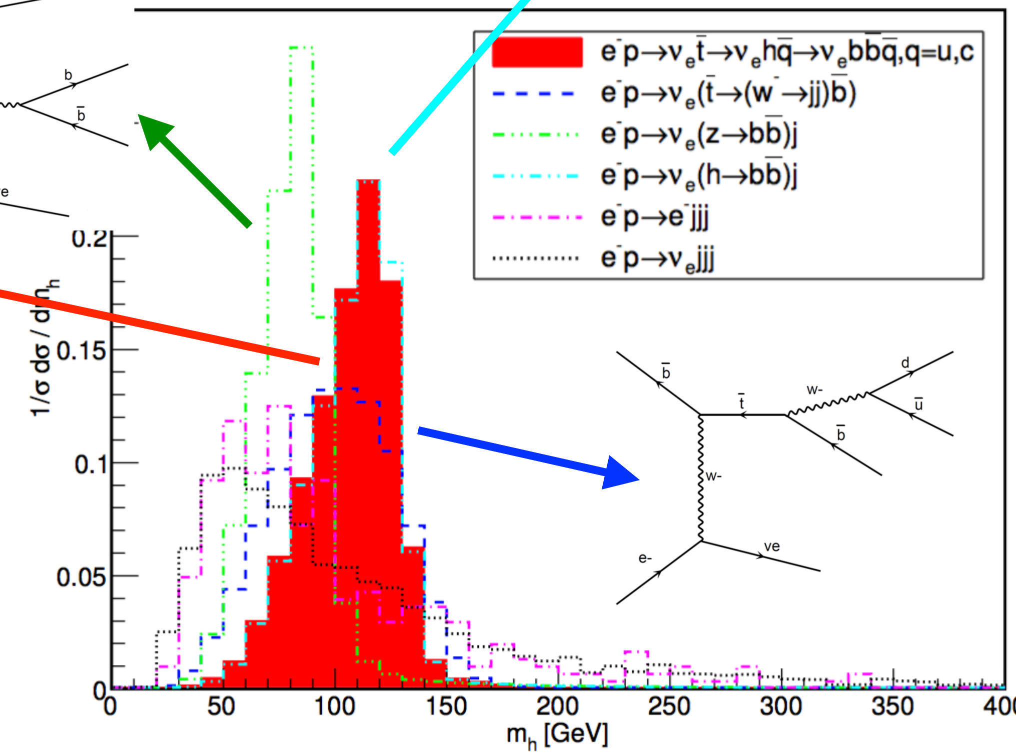
Sun, Wang, arXiv:1602.04670 [hep-ph]

background









$$e^- p \to \nu_e \bar{t} \to \nu_e h \bar{q} \to \nu_e b \bar{b} \bar{q}, \quad q = u, c$$

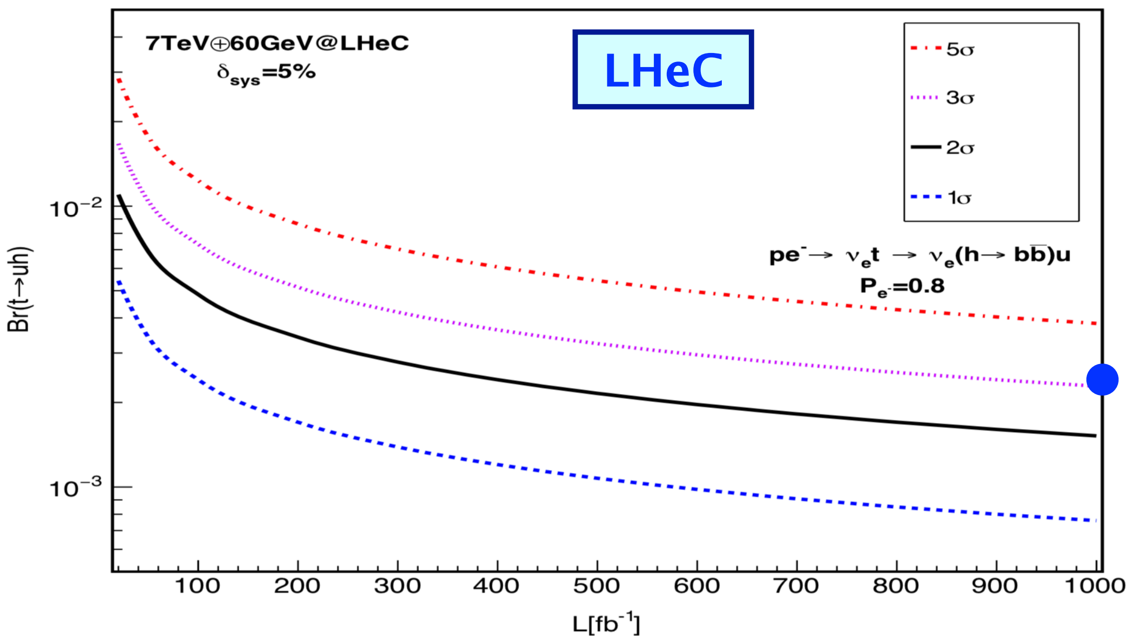
$$\mathcal{L} = \kappa_{tuh} \bar{t} u h + \kappa_{tch} \bar{t} c h + h.c.$$

- **parametrised assumed resolutions for electrons/photons, muons, jets and unclustered energy using ATLAS values**
- **b-tag rate of 60%, c-jet fake rate of 10%, light-jet fake rate of 1%**
- **selections optimized for LHeC and FCC-ep scenarios (s/√(S+B))**
- **cut-based and MVA-based analyses**

Upper Limit on Br(t→uH) in MVA analysis

Sun, Wang, arXiv:1602.04670 [hep-ph]

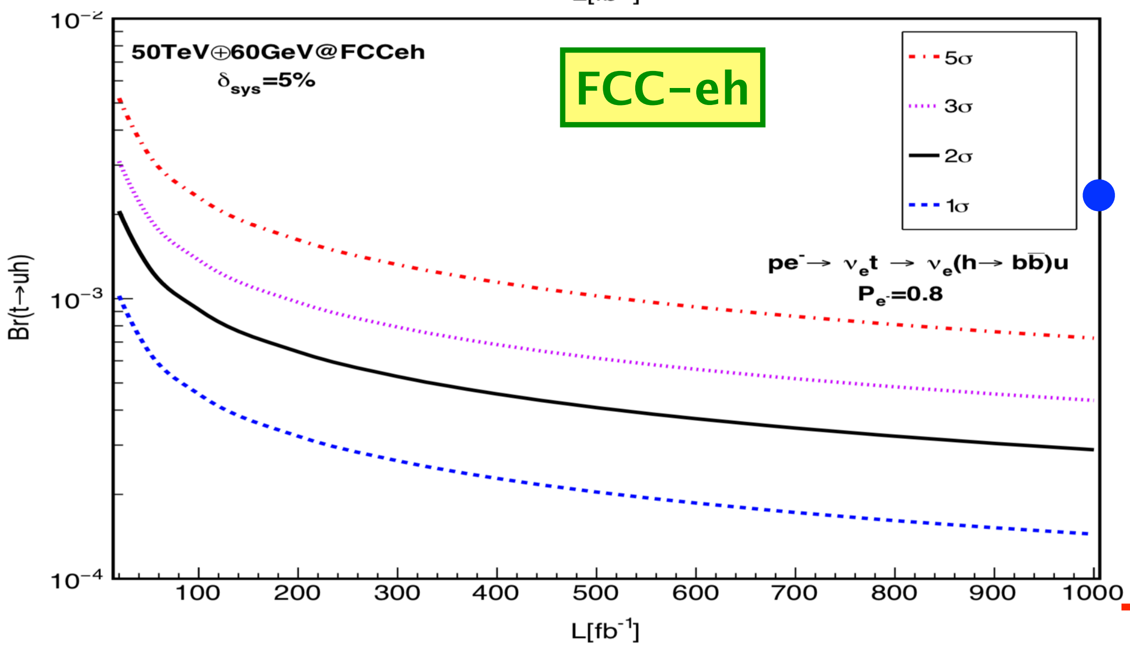
parametrisation



HL-LHC

LHC, 3000 fb^{-1}@14TeV

2σ <0.0015 (1ab^{-1})



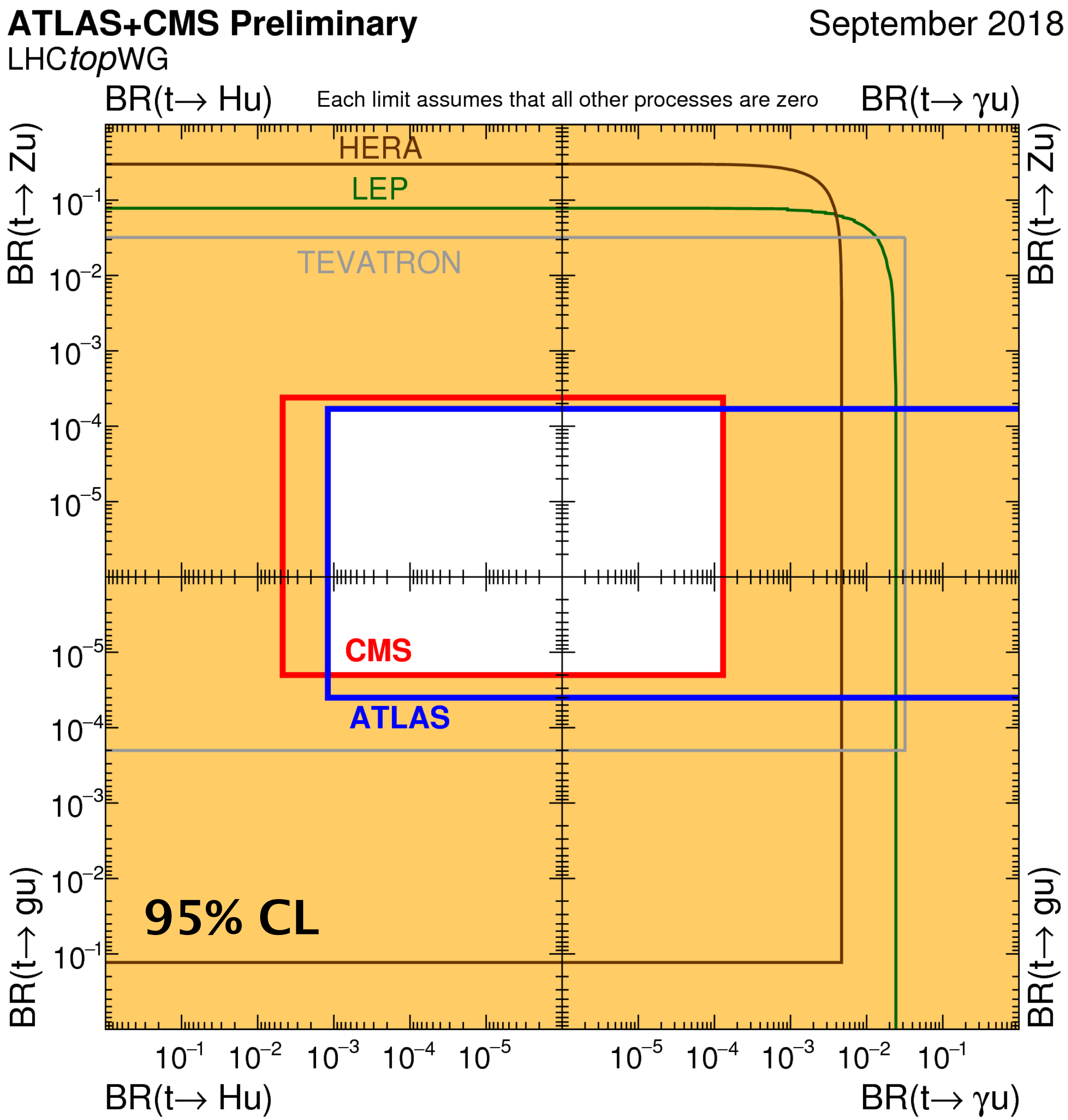
HL-LHC

LHC, 3000 fb^{-1}@14TeV

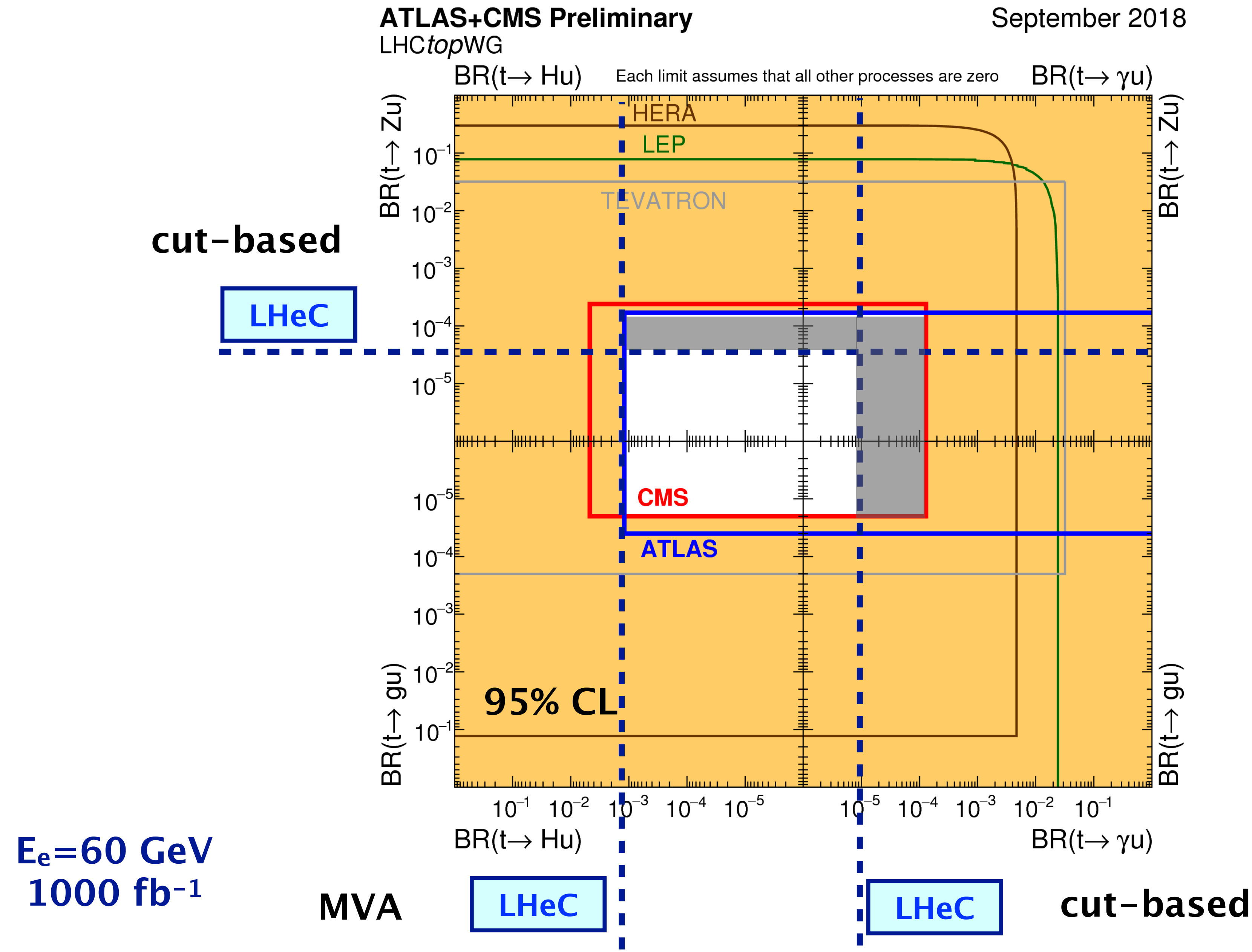
2σ <0.0002 (2ab^{-1})

→ improves HL-LHC sensitivity

FCNC Branching Ratios at Colliders



FCNC Branching Ratios at Colliders

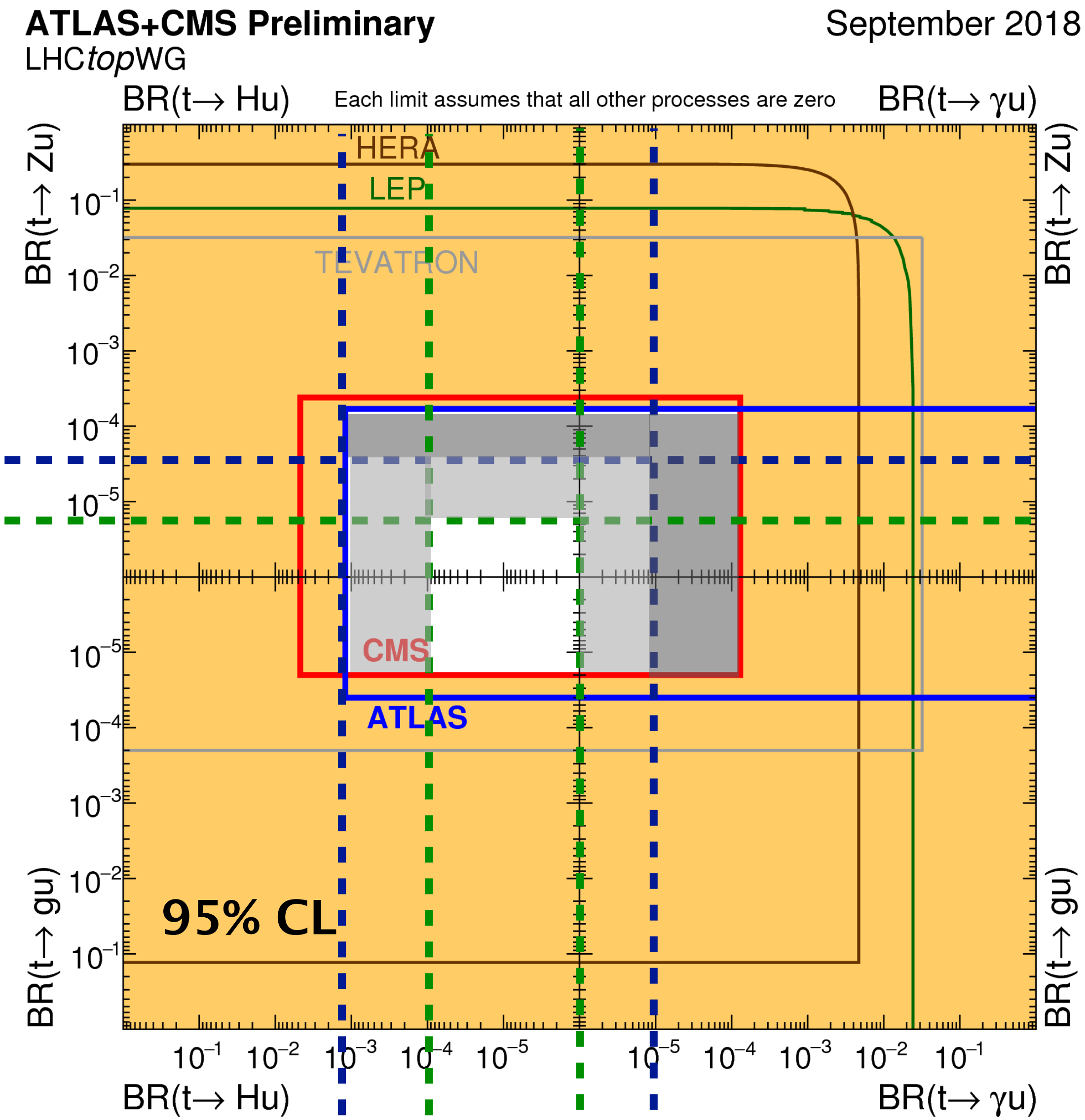


FCNC Branching Ratios at Colliders

cut−based

LHeC

FCC −ep



E_e=60 GeV
1000 fb^{-1}
2000 fb^{-1}

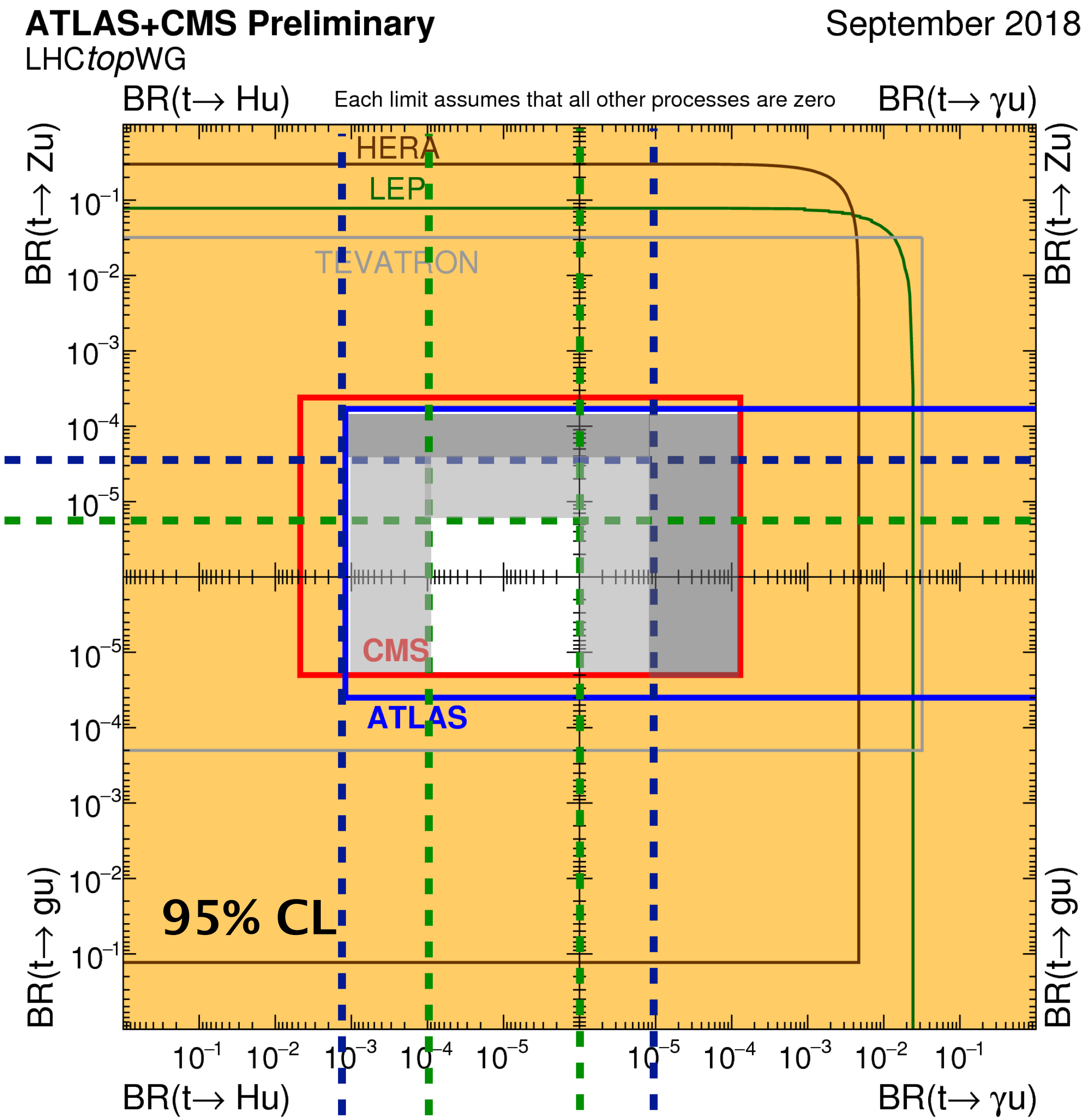
MVA LHeC FCC −ep LHeC cut−based

FCNC Branching Ratios at Colliders

cut-based

LHeC

FCC -eh



- improve limits on BR(t→γu), BR(t→Zu), BR(t→Hu) considerably

→ test SUSY, little Higgs, technicolor...

E_e=60 GeV
1000 fb^{-1}
2000 fb^{-1}

MVA LHeC FCC -eh LHeC cut-based