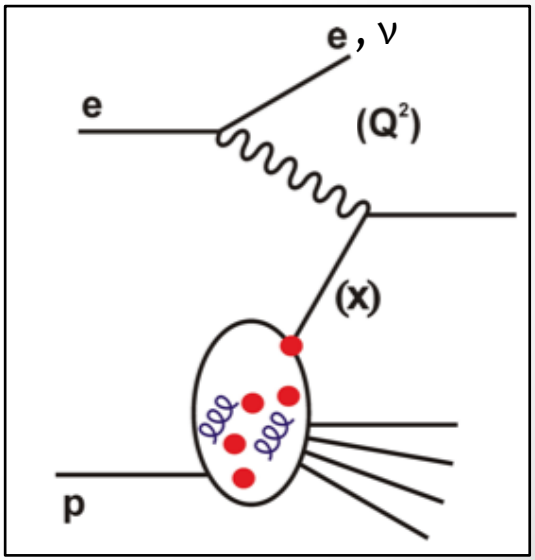
High Q^2 physics at the LHeC and FCC-he (**electroweak, top and BSM**)

Claire Gwenlan, Oxford
for the LHeC and FCC-he study groups

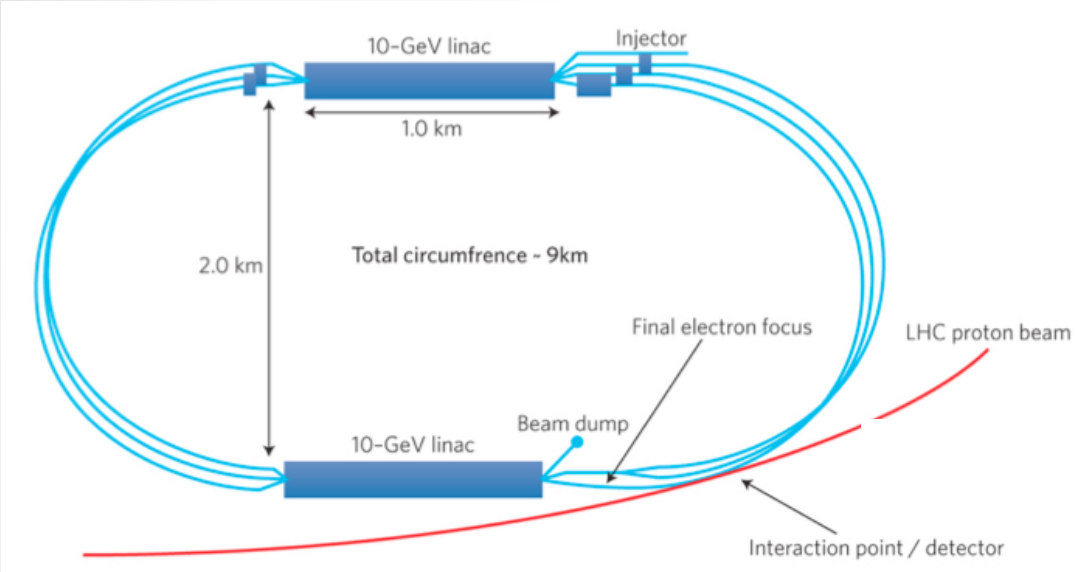
POETIC 7

Philadelphia, USA
14 – 16 November 2016



with thanks to G. Azuelos, O. Cakir, M. Klein, M. Kumar, C. Schwanenberger

LHeC and FCC-he



energy recovery LINAC

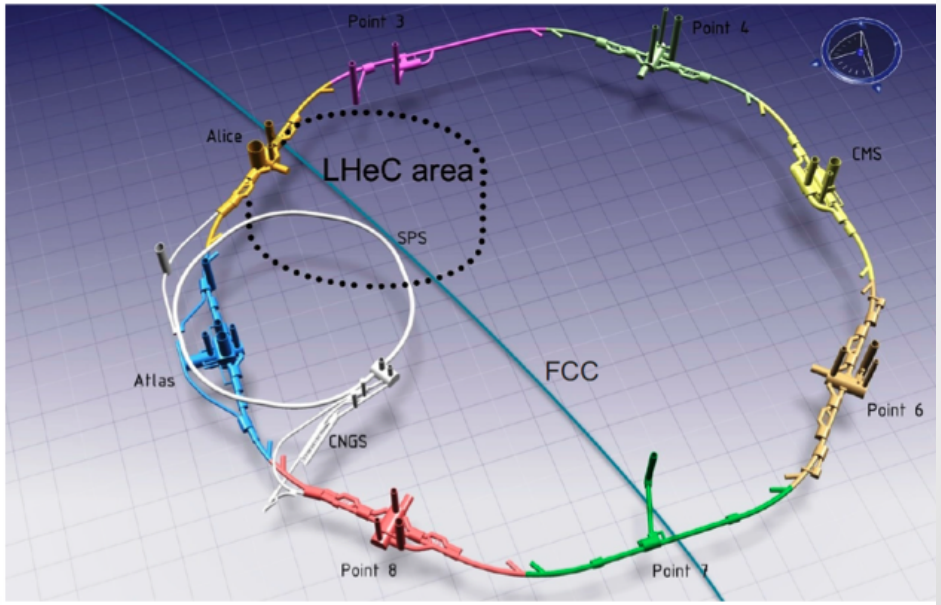
e^- beam: 60 GeV

$L_{int} \longrightarrow 1\ ab^{-1}$

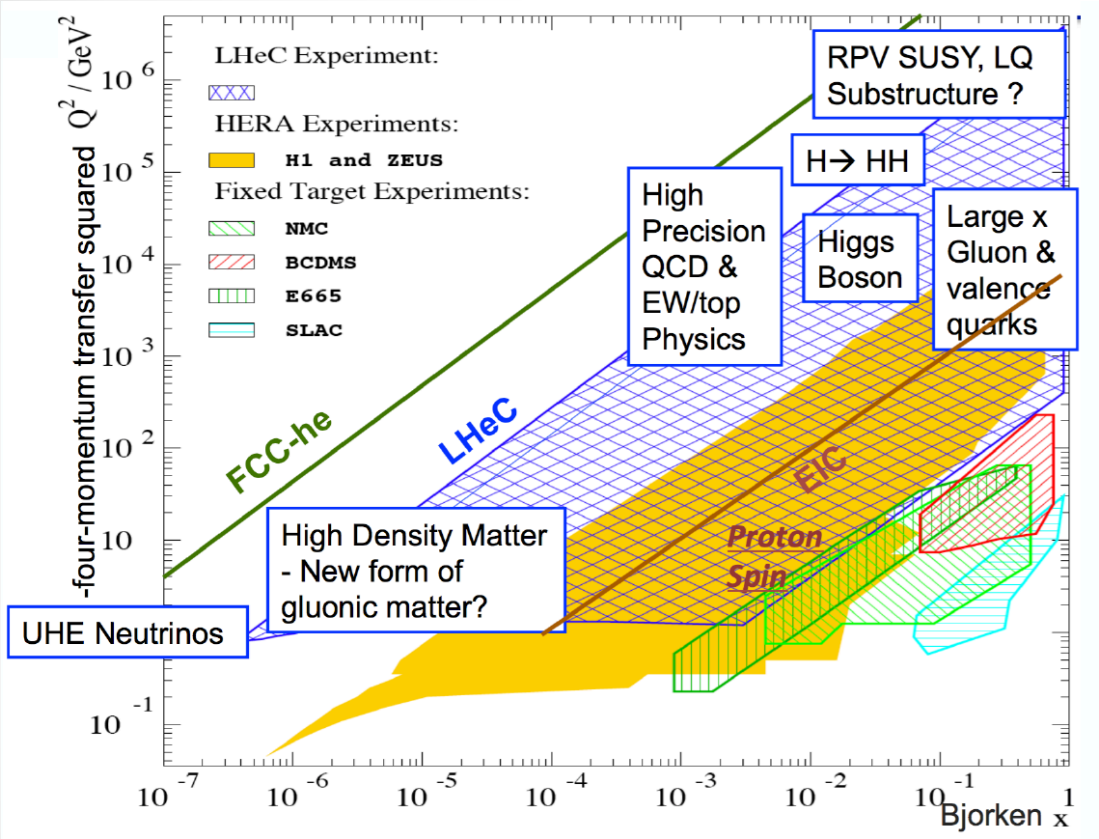
see talk by M. Klein

operating **synchronously**:

- with **HL-LHC**:
  p beam: 7 TeV, $\sqrt{s}$ = 1.3 TeV
- and/or later with **FCC-hh**:
  p beam: 50 TeV, $\sqrt{s}$=3.5 TeV



eh physics at the high energy frontier



- parton distribution functions (A. M. Cooper-Sarkar)
- Higgs (C. Zhang)
- **physics at high pt** (this talk)
- LHeC increases LHC precision (from much improved PDFs, α_s)
- precision electroweak
- electron-quark specific interactions (EG. leptoquarks, compositeness)
- precision top quark studies
- also, eA option (N. Armesto), low x (A. Stasto), …

LHeC (**FCC-he**) complementary to, synchronous with, **HL-LHC** (**FCC**)

potential to improve sensitivity of LHC, to characterise or possibly discover new phenomena

outline

precision electroweak physics

BSM

top quark physics

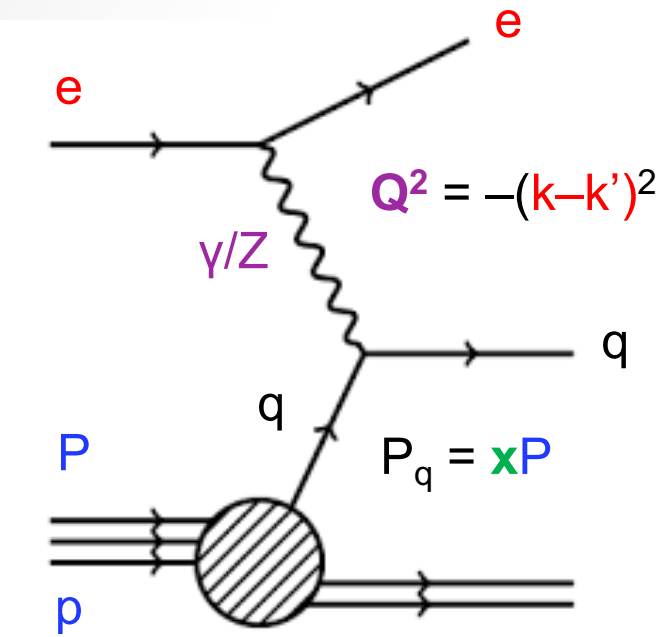
precision electroweak physics

BSM

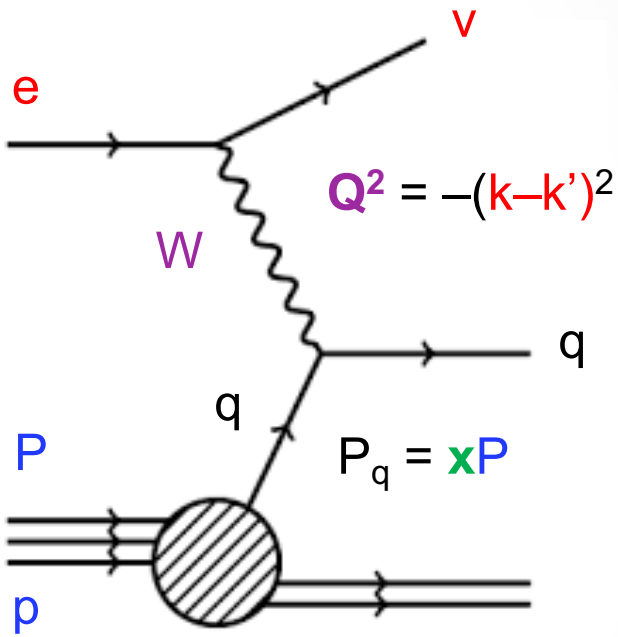
top quark physics

Deep Inelastic Scattering (DIS)

Neutral Current (NC)



Charged Current (CC)



Q^2: four-momentum transfer

spatial resolution ∝1/Q

x: fractional momentum of struck parton

LHeC is a unique facility for testing electroweak theory

(two) e beam charges, two e polarisation states, NC+CC, p or isoscalar targets

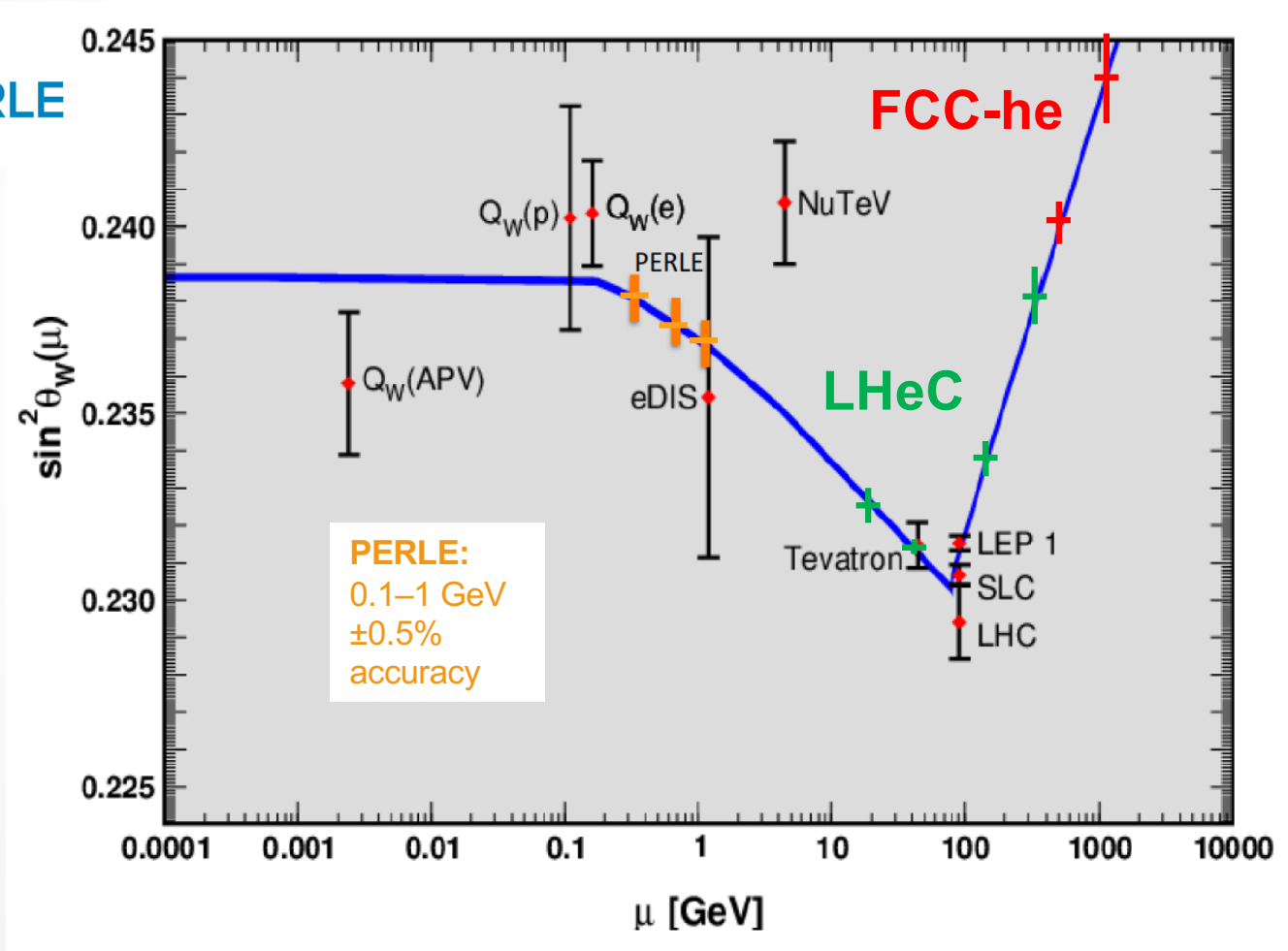
scale dependence of $\sin^2\theta_W$

$$A^- = \frac{\sigma^-_{NC}(P_R) - \sigma^-_{NC}(P_L)}{\sigma^-_{NC}(P_R) + \sigma^-_{NC}(P_L)} \qquad R^- = \frac{\sigma^-_{NC}}{\sigma^-_{CC}}$$

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

PERLE CDR, Arduini et al., to be published

C. Schwanenberger, ICHEP16



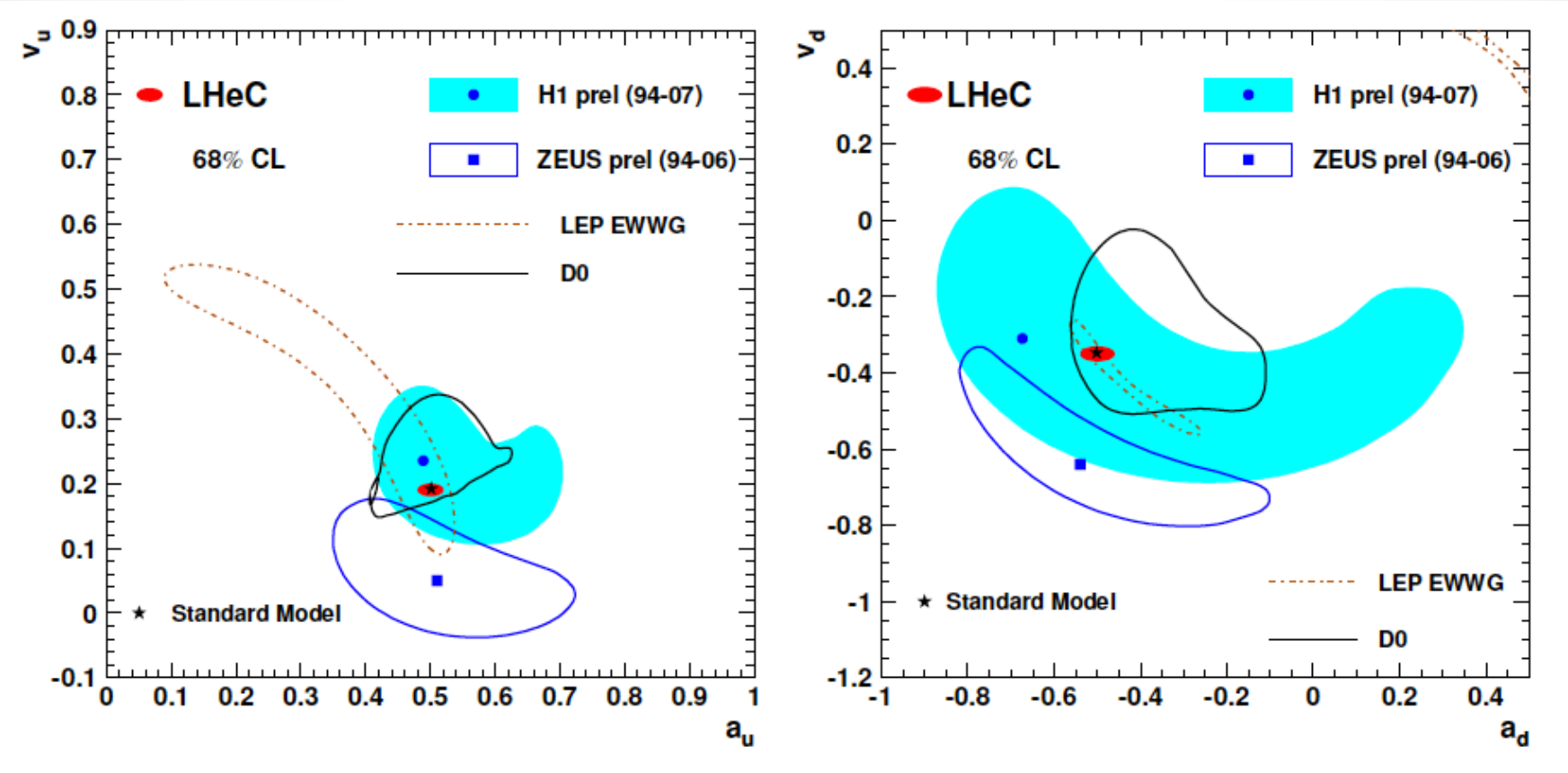
extract $\sin^2\theta_W$ with α, Mz fixed

probe **large range** of scale dependence

NC vector and axial vector couplings

significant improvements expected from higher luminosity and FCC-he

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



very high precision measurement

sensitive to new physics: Z', leptoquarks, R-parity violating SUSY, …

e-beam: 50 GeV

1 fb^{-1} of each of e^-p and e^+p

polarisation: 40%

precision electroweak physics

BSM

LHC (FCC) is/ will be main discovery machine; **LHeC** (**FCC-he**) has potential for improving or possibly discovering new physics

B and **L** quantum numbers in initial state, and very **clean environment** – favourable for specific BSM models; now strong constraints from LHC, and LHeC discovery window remains open only for certain scenarios; FCC-he energy offers more potential; improved PDFs and α_s from **LHeC** transforms LHC into high precision machine

top quark physics

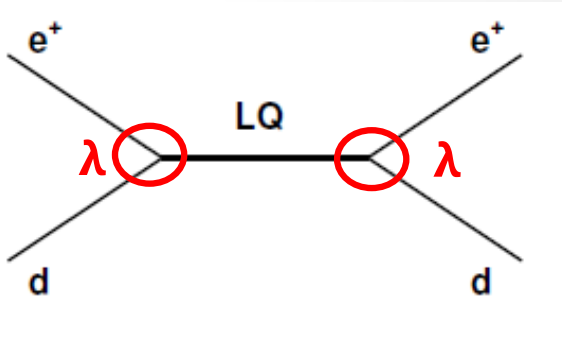
leptoquarks (LQs)

ep collider: both **baryon** and **lepton** quantum numbers in initial state

LHeC (**FCC-he**) ideal to study properties of **new particles** coupling to **eq** pairs

LQs:

- 1st generation leptoquark bosons
  (E6 GUTs, extended technicolor, Pati-Salam model, lepton-quark compositeness models)
- or, squarks in R-parity violating SUSY (see later)



can be **scalar** or **vector**, with fermion number **0** or **2**
Buchmüller classification

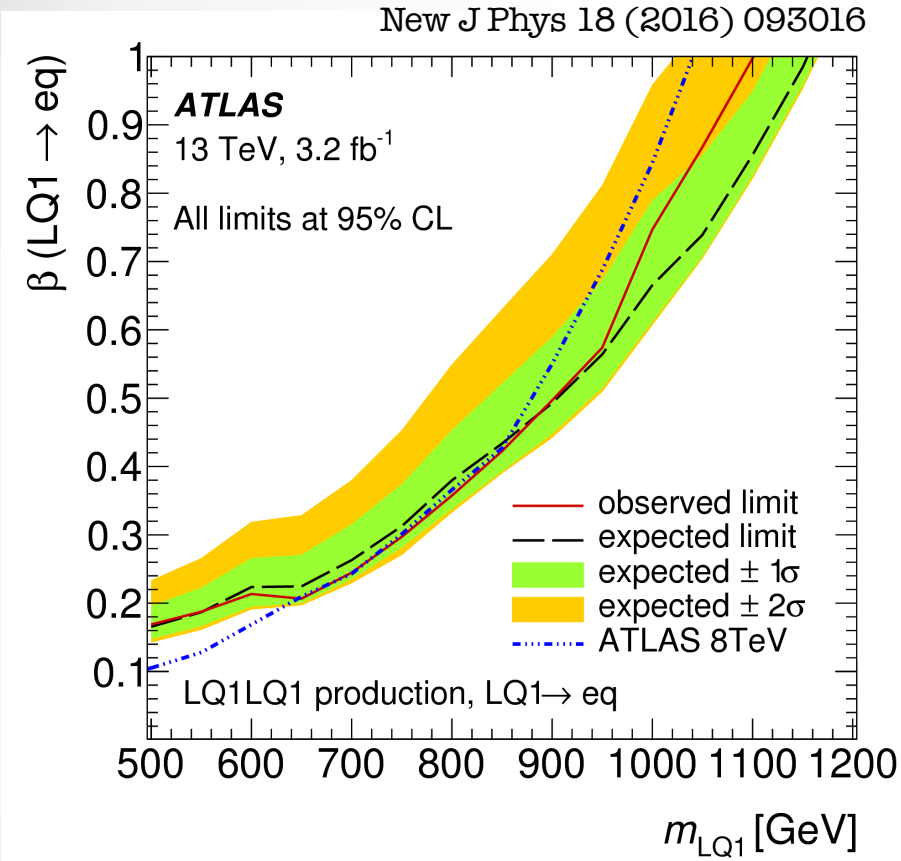
coupling **λ** is unknown parameter of model

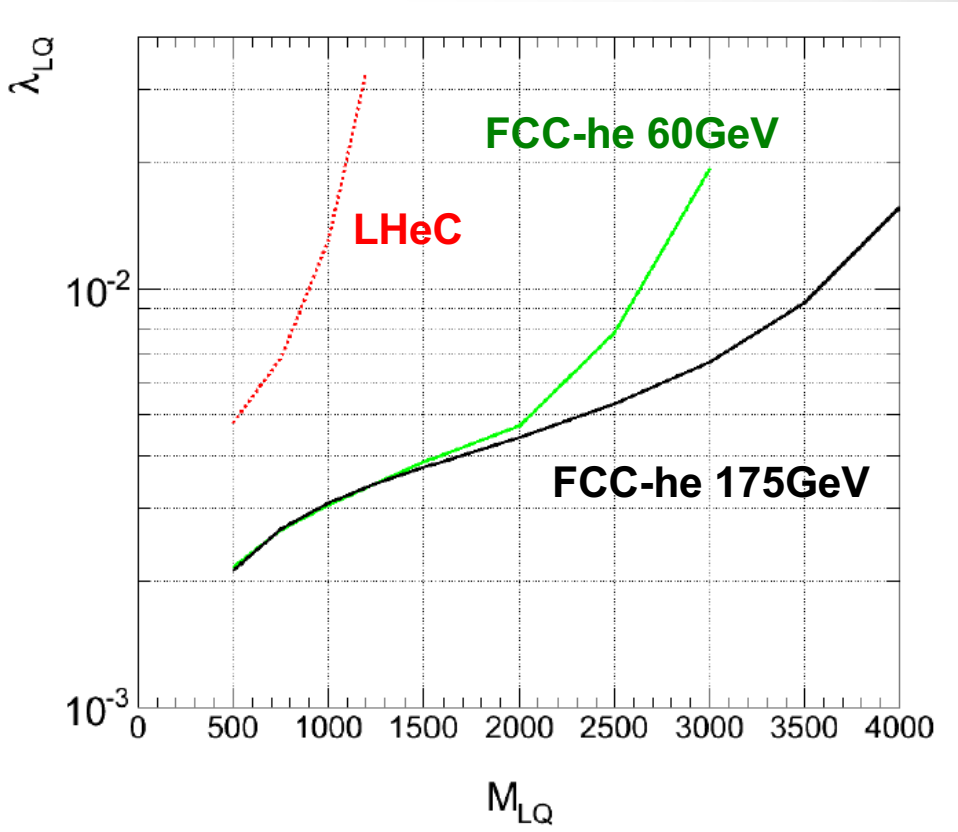
$\sigma \propto \lambda^2 q(x)$ (narrow width approx.)

LHC: **mostly** pair production (through gg or qq)
if **λ** not too large ($\lesssim e=\sqrt{4\pi\alpha}=0.3$), cross section insensitive to **λ**
determination of QNs impossible, or ambiguous / model dependent

ep: single resonant LQ production (sensitive to **λ**; suited for determination of QNs)

LQ bounds





1st generation LQs, β=BR(LQ⟶eq)=1

ATLAS+CMS: $M_{LQ} \lesssim 1.1$ TeV

can expect up to 1.5 TeV from LHC (pair production) with 300 fb^{-1} at $\sqrt{s}$=14 TeV

ep scenarios:

also sensitive to $\lambda \ll e=\sqrt{4\pi\alpha}=0.3$

(preliminary study, G. Azuelos)

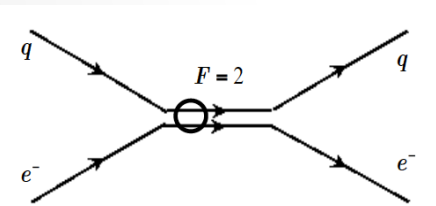
LQ properties

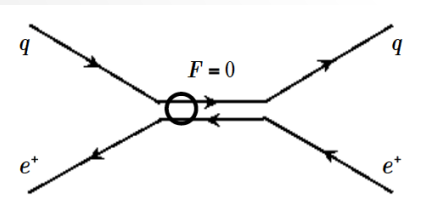
LHeC CDR,
J. Phys. G39
075001 (2012)

- **single LQ production** more powerful for determination of QNs
- **LHeC** (**FCC-he**): much higher cross section for **single production** than **LHC**
- if LQs observed at **LHC**, **future ep collider** could measure **fermion number**, **spin**, **flavour structure**, **chiral structure, coupling**

EG. Fermion Number (e^-p and e^+p)

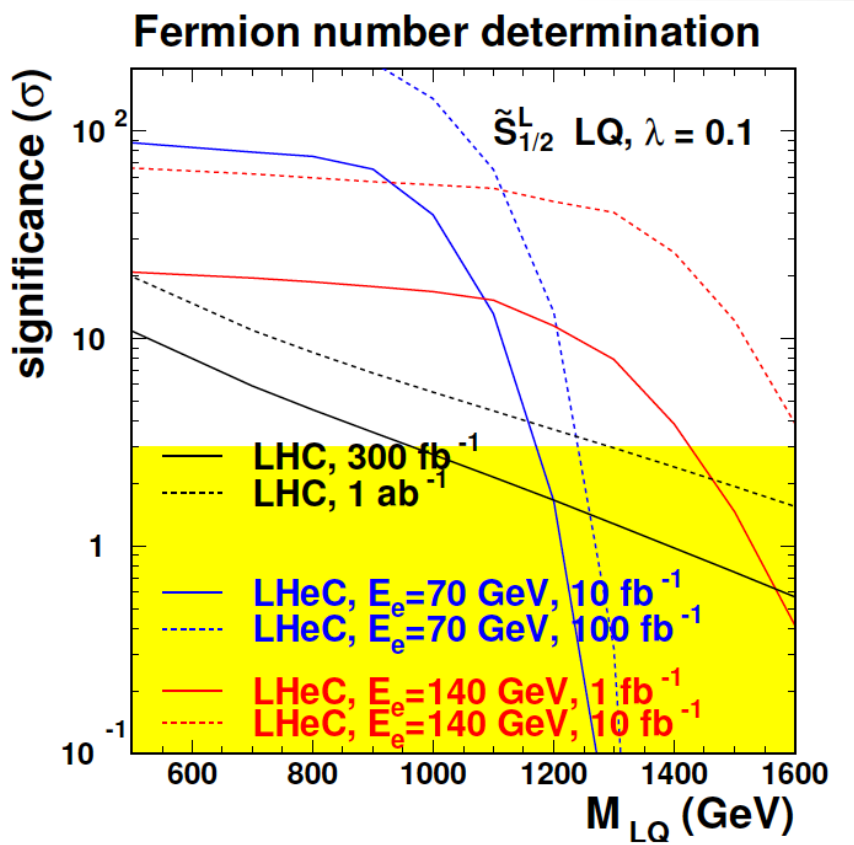
$$A = \frac{\sigma_{e^-} - \sigma_{e^+}}{\sigma_{e^-} + \sigma_{e^+}} \begin{cases} > 0 \text{ for F=2} \\ < 0 \text{ for F=0} \end{cases}$$





asymmetry, A, since u, d ≫ ubar, dbar at high x

asymmetry also sensitive to quark flavour



much of this mass range now excluded but can be extended to **FCC**

new physics in high Q^2 inclusive DIS

- new physics at higher scales $\Lambda \gg \sqrt{s}$, may become observable as **deviations from SM predictions**
- seen as an effective 4-fermion **contact interaction** (CI)

observed as a **modification** of the **Q^2 dependence** – all information contained in $d\sigma/dQ^2$

4-fermion interaction $\Rightarrow M_{eq \to eq} \sim \Lambda^{-2}$

- may be applied very generally to **new phenomena**:

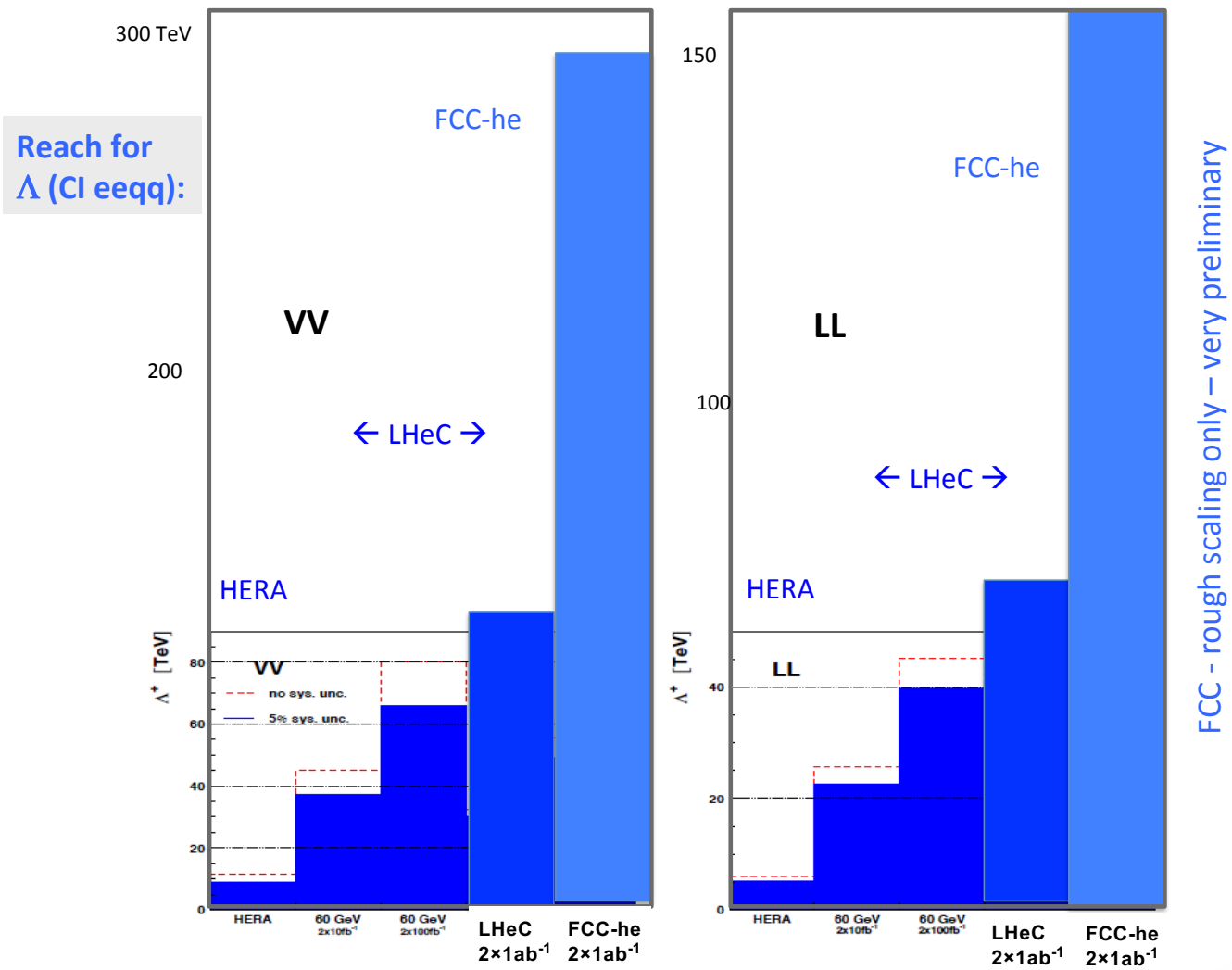
Λ ⎧ LQ, mass $\gg \sqrt{s}$
⎨ Planck scale (M_S) of extra-dimensional models
⎨ compositeness scale
⎩ …

$$\mathcal{L} = \frac{4\pi\,\varepsilon}{\Lambda^2}\, j_\mu^{(e)} j^{\mu(q)}; \quad q = u, d; \quad \varepsilon = \pm 1$$

$$j_\mu^{(f=e,q)} = \eta_L\, \bar{f}_L \gamma_\mu f_L + \eta_R\, \bar{f}_R \gamma_\mu f_R + h.c.$$

$$\Rightarrow \text{ all combinations of couplings } \eta_{ab} = 4\pi\,\varepsilon \frac{\eta_a^{(e)} \eta_b^{(q)}}{\Lambda_{ab}^2}$$

scale of CI at future colliders



present LHC constraints on scale of **qqll** contact interactions: 15–26 TeV, depending on model (expect up to **40 TeV** at LHC at √s=14TeV)

also advantages over, and complementarities with, pp and e^+e^- in characterising nature of new physics

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

(M. Klein)

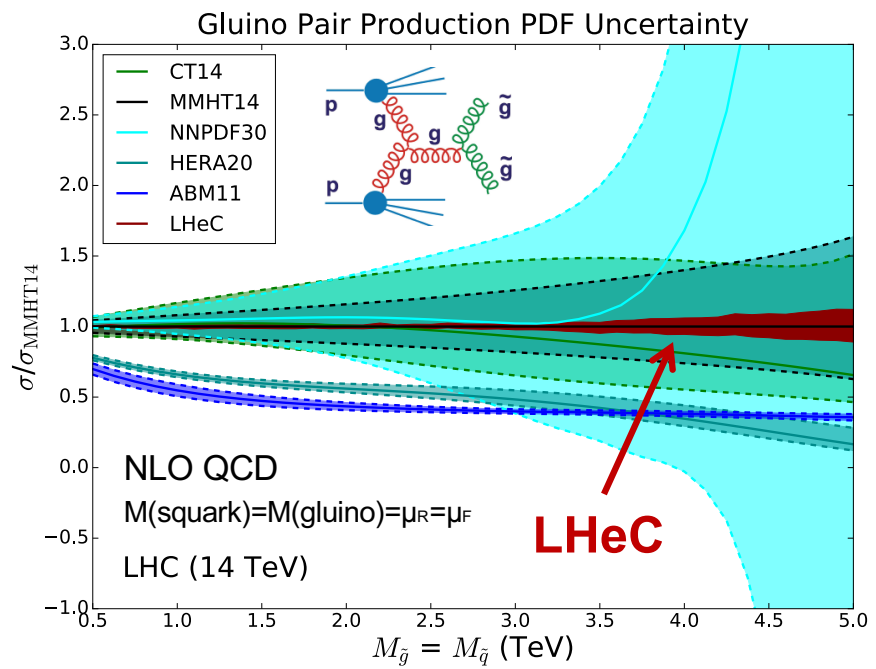
supersymmetry

- **improved sensitivity for HL-LHC**

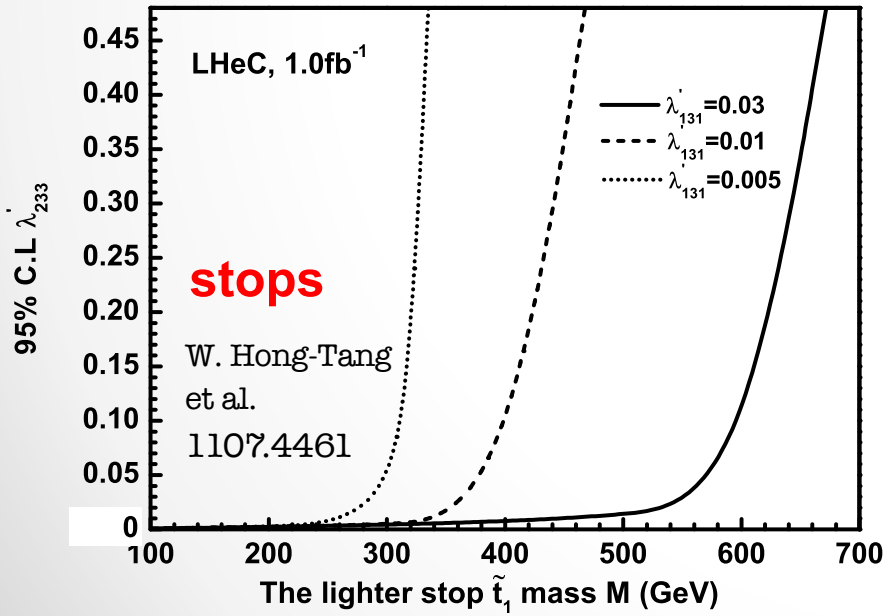
SUSY searches near **HL–LHC** kinematic boundary may be ultimately limited by PDF uncerts., especially high x gluon

LHeC reduces PDF uncertainties considerably

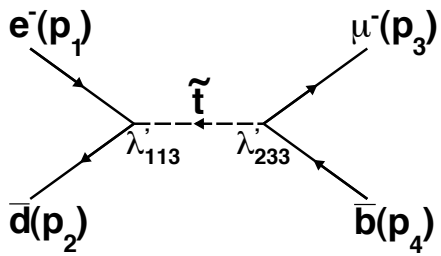
plot by C. Borschensky and M. Kramer; update to LHeC note arXiv:1211.5102



- **R-parity violating supersymmetry**



RPV squark production (like LQs, with generation mixing)



$$P_R = (-1)^{3(B-L)+2s}$$

$$\mathcal{W}_{RPV} = \lambda'_{ijk} L_i Q_j \bar{D}_k$$

(also **sbottoms**: 1401.4266)

with high luminosity, **RPV SUSY** can be probed to unprecedented levels

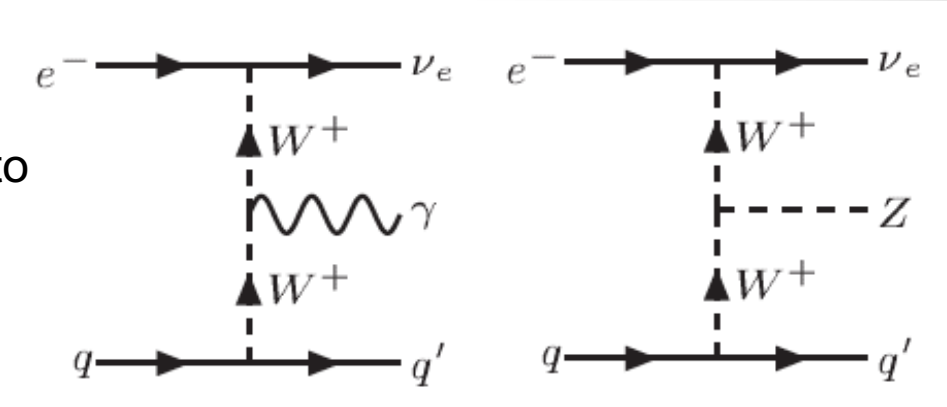
BSM in vector boson scattering

FCC-he: explore **vector boson scattering** at high mass (G. Azuelos)

anomalous TGC, QGC couplings?

LHeC studies show sensitivity comparable to LHC; enhanced sensitivity with polarised e beam

I.T.Cakir et al., arXiv:1406.7696



is unitarity restored only by Higgs? are there new resonances? (EG. composite Higgs)

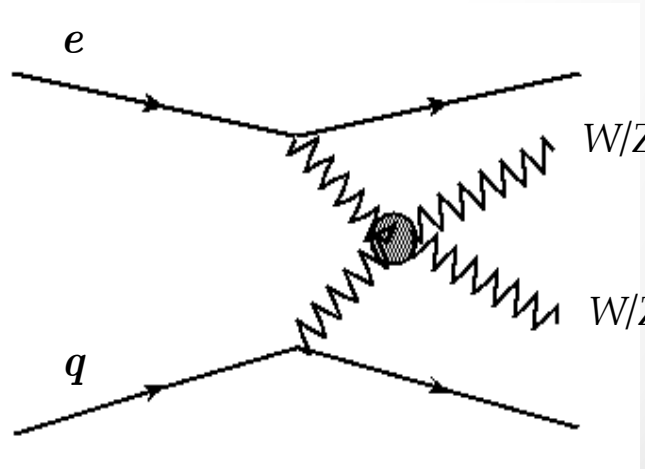
expect below ∽ 2–3 TeV

eq ⟶ (eq)VV, (vq)VV

search for deviations from SM

LHC: hadronic modes challenging

large QCD backgrounds not present in ep, pileup, difficult if no lepton triggers used, …



precision electroweak physics

BSM

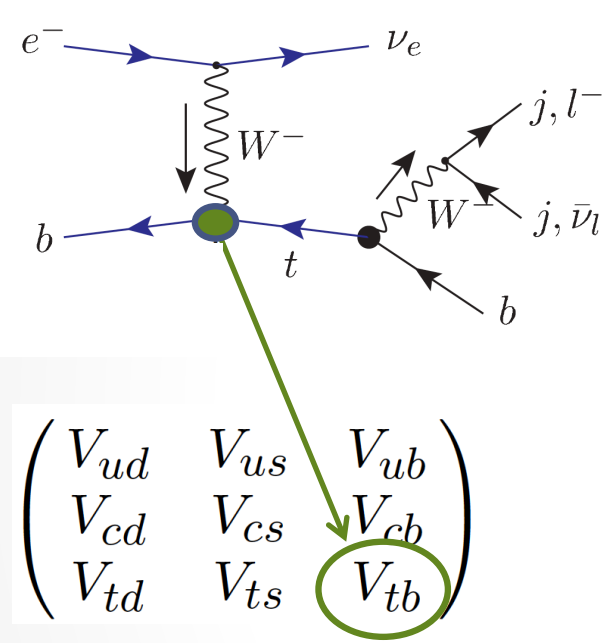
top quark physics

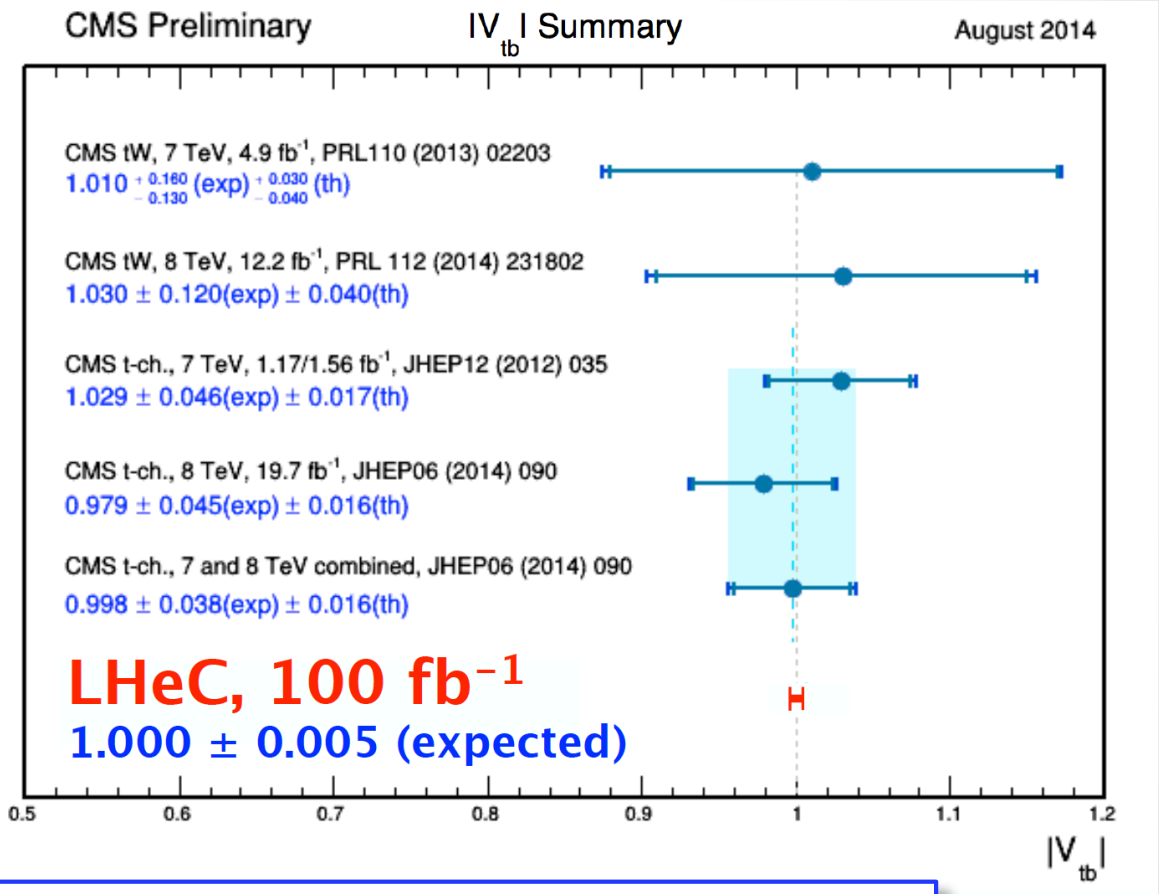
precise measurements of couplings between SM bosons and fermions are sensitive test of new physics (search for deviations); top quark expected to be most sensitive to BSM physics, due to large mass

ep future collider offers excellent prospects for top physics

measurement of |Vtb|

Dutta, Goyal, Kumar, Mellado, arXiv:1307.1688 [hep-ph]





e beam: 60 GeV

L_{int} = 100 fb^{-1} and simple cuts:

HAD: N_t = 22000, S/B=1.2

LEP: N_t = 11000, S/B=11

LHeC: very high precision measurement

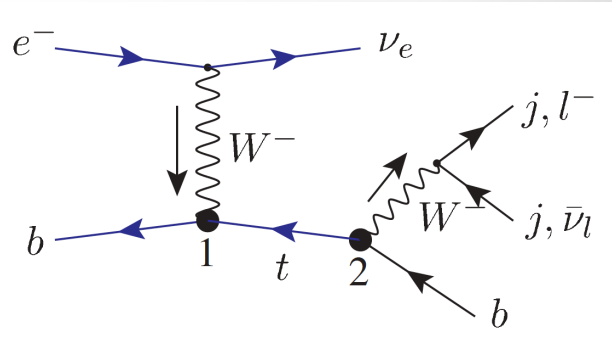
current LHC+Tevatron average: $|V_{tb}|$=1.009 ±0.031 (PDG 2016)

anomalous Wtb couplings

J.A. Aguilar-Saavedra, NP B812 (2009) 181

$$\mathscr{L}_{Wtb} = \frac{g}{\sqrt{2}}\Big[W_\mu \bar{t}\gamma^\mu (V_{tb} f_1^L P_L + f_1^R P_R) b - \frac{1}{2\,m_W} W_{\mu\nu}\bar{t}\sigma^{\mu\nu}(f_2^L P_L + f_2^R P_R) b\Big] + h.c.$$

=1 in SM



anomalous Wtb couplings

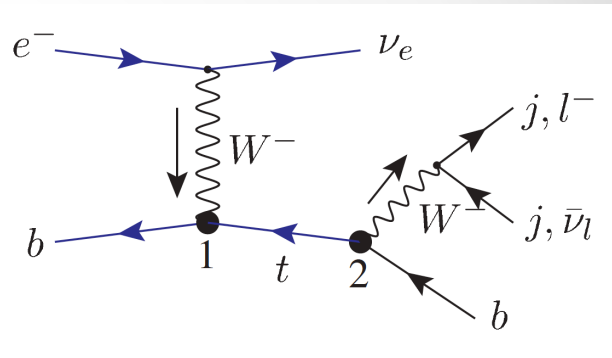
J.A. Aguilar-Saavedra, NP B812 (2009) 181

RH vector

$$\mathscr{L}_{Wtb} = \frac{g}{\sqrt{2}}\Big[W_\mu \bar{t}\gamma^\mu (V_{tb} f_1^L P_L + f_1^R P_R) b - \frac{1}{2\,m_W} W_{\mu\nu}\bar{t}\sigma^{\mu\nu}(f_2^L P_L + f_2^R P_R) b\Big] + h.c.$$

=1 in SM

LH and RH tensor



DELPHES

anomalous Wtb couplings

J.A. Aguilar-Saavedra, NP B812 (2009) 181

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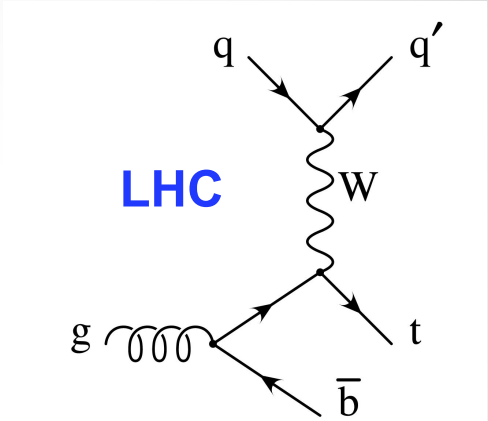
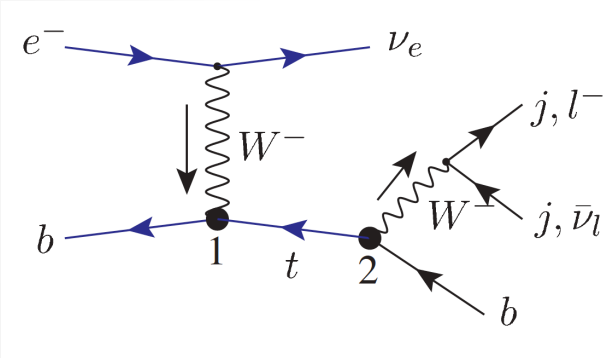
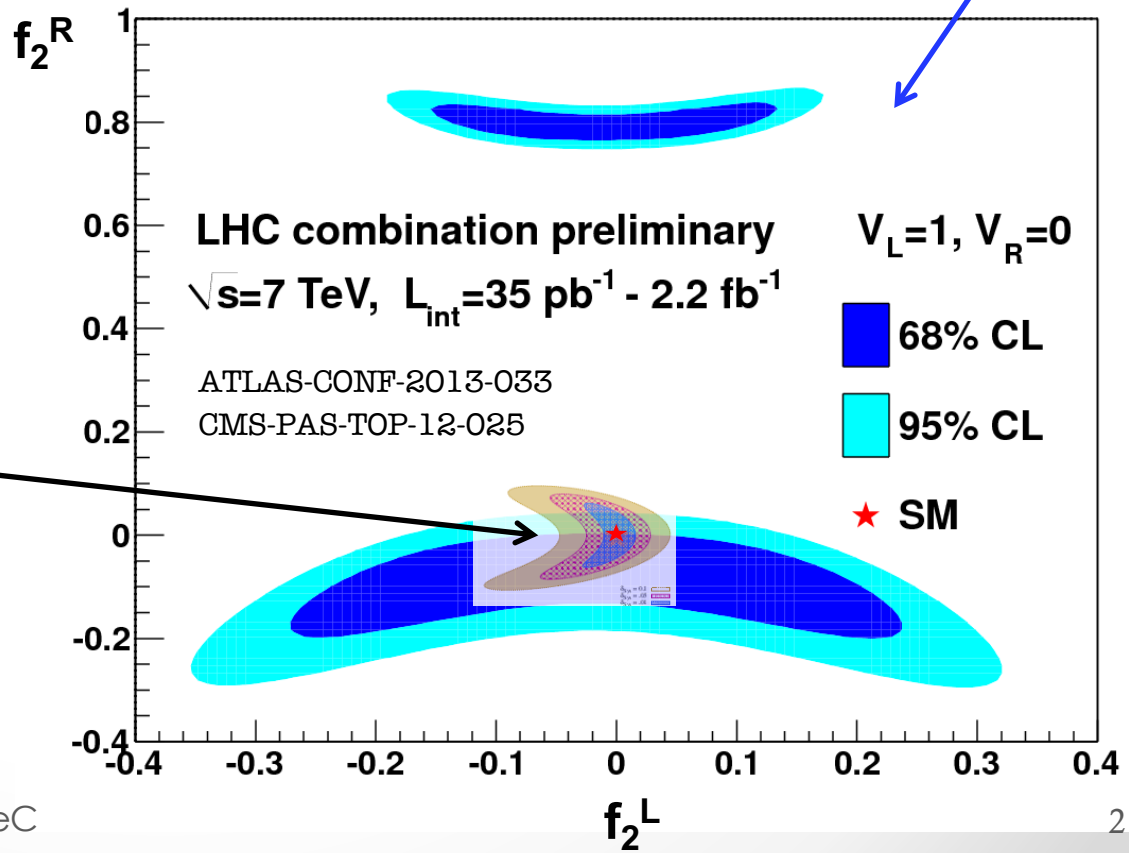
LH and RH tensor







LHeC: 95% CL, hadronic mode

(100 fb^{-1}, systs. 1,5,10%)

similar sensitivity with leptonic mode

from asymmetry of kinematic variable distributions

Dutta, Goyal, Kumar, Mellado, arXiv:1307.1688

anomalous Wtb couplings

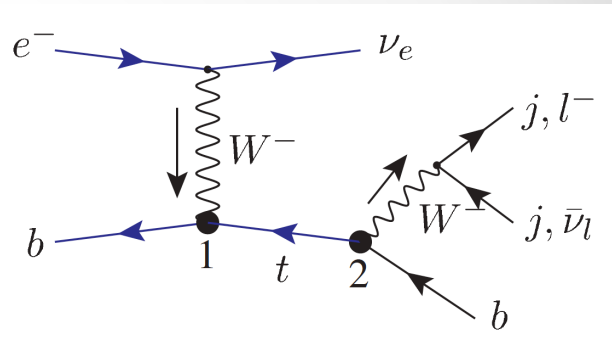
J.A. Aguilar-Saavedra, NP B812 (2009) 181

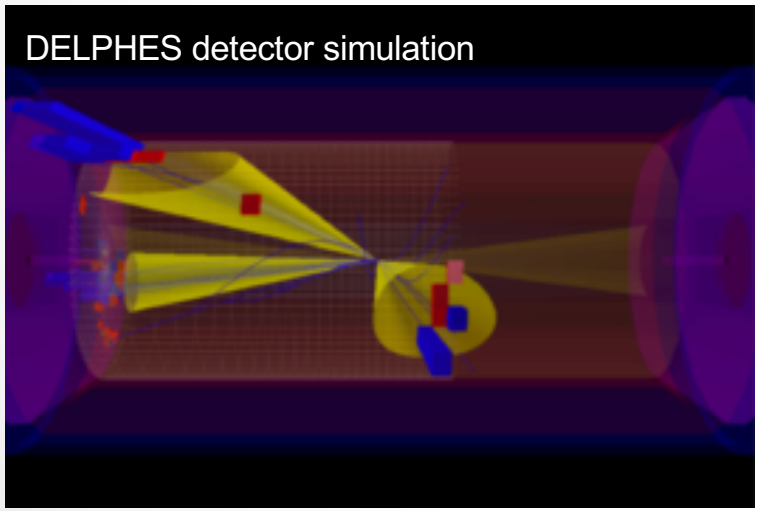
RH vector

$$\mathscr{L}_{Wtb} = \frac{g}{\sqrt{2}}\Big[W_\mu \bar{t}\gamma^\mu (V_{tb} f_1^L P_L + f_1^R P_R) b - \frac{1}{2\,m_W} W_{\mu\nu}\bar{t}\sigma^{\mu\nu}(f_2^L P_L + f_2^R P_R) b\Big] + h.c.$$

=1 in SM

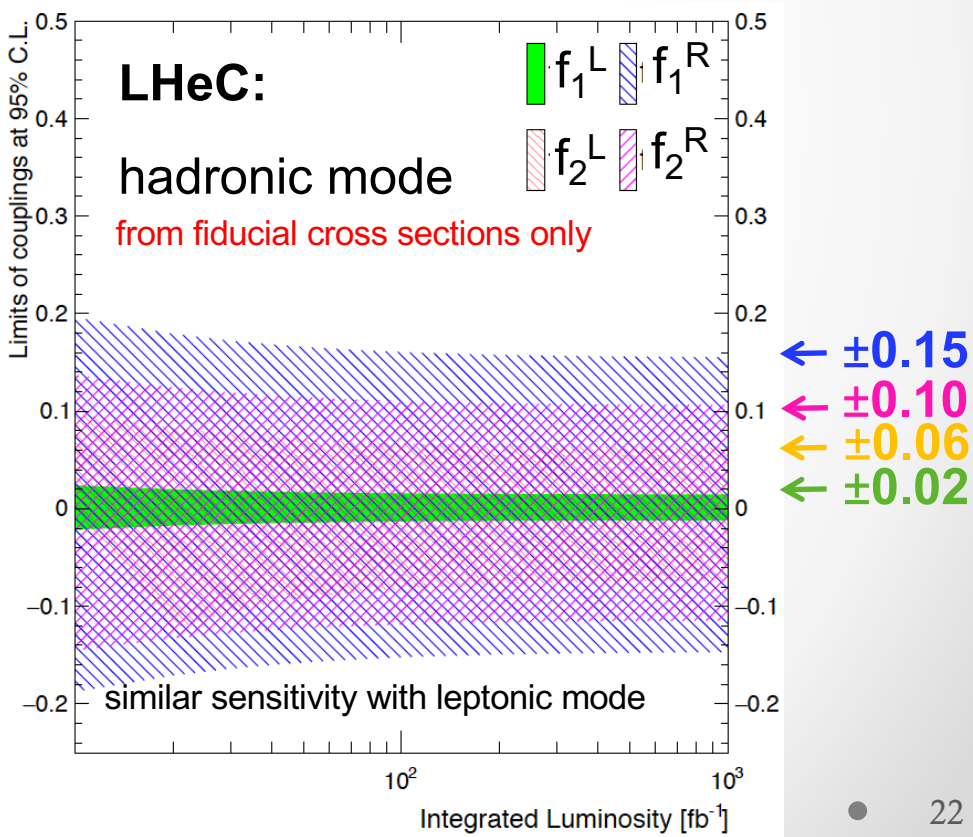
LH and RH tensor





Kumar and Ruan, **work in progress**

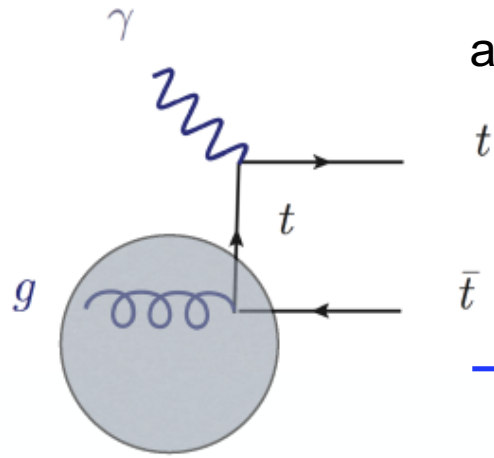
Dutta, Goyal, Kumar, Mellado, arXiv:1307.1688



top quark PDF

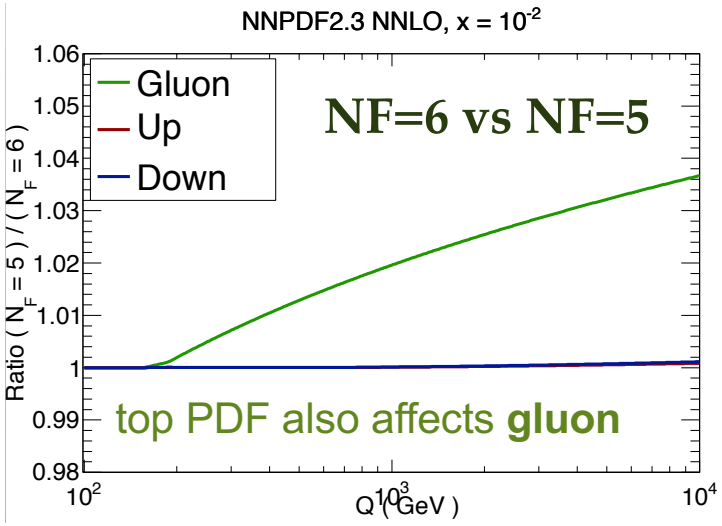
G.R. Boroun,
Phys Lett B744 (2015) 142
Phys Lett B741 (2015) 197

NC: top pair production



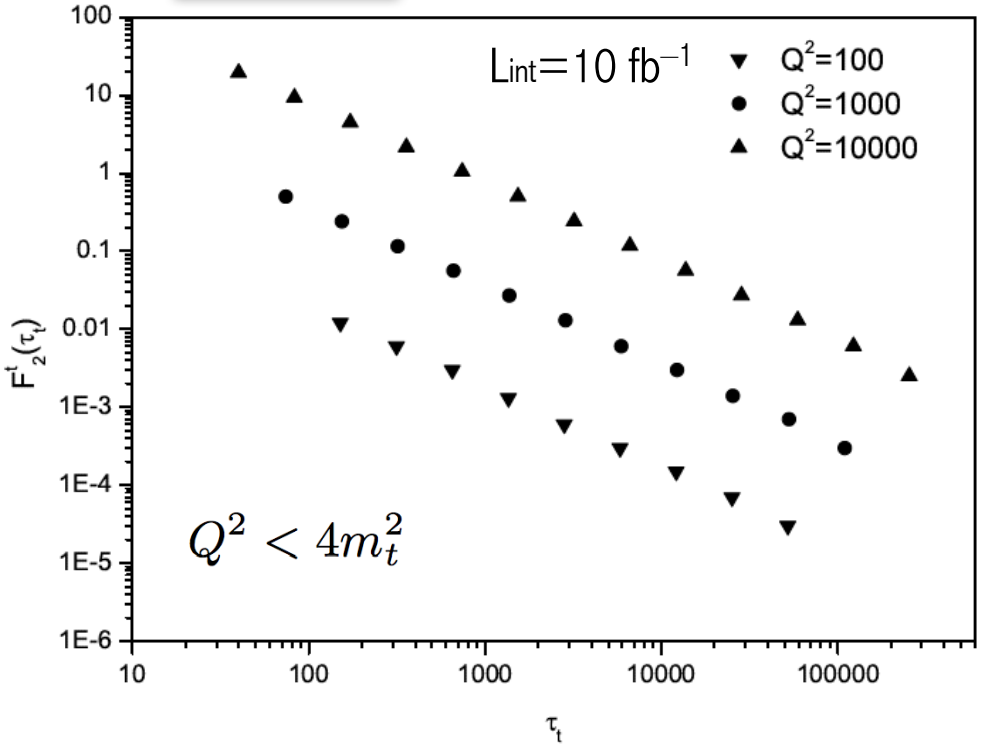
at very high Q^2
top quark
becomes
'light'

⟶ top PDF



LHeC

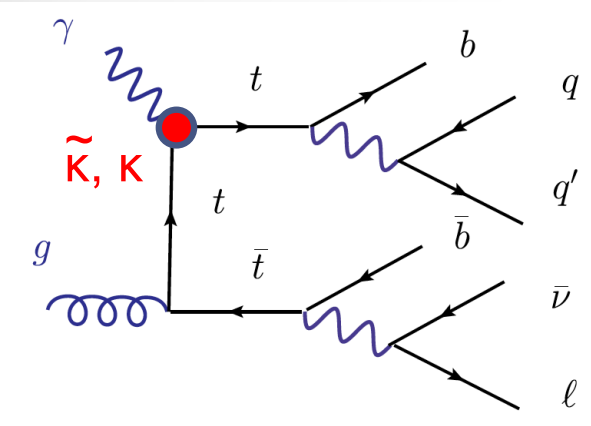
(variable flavour number scheme for top)



LHeC opens up new field of research for **top quark PDFs**

search for anomalous ttγ couplings

A. Bouzas, F. Larios, Phys Rev D88 094007 (2013)

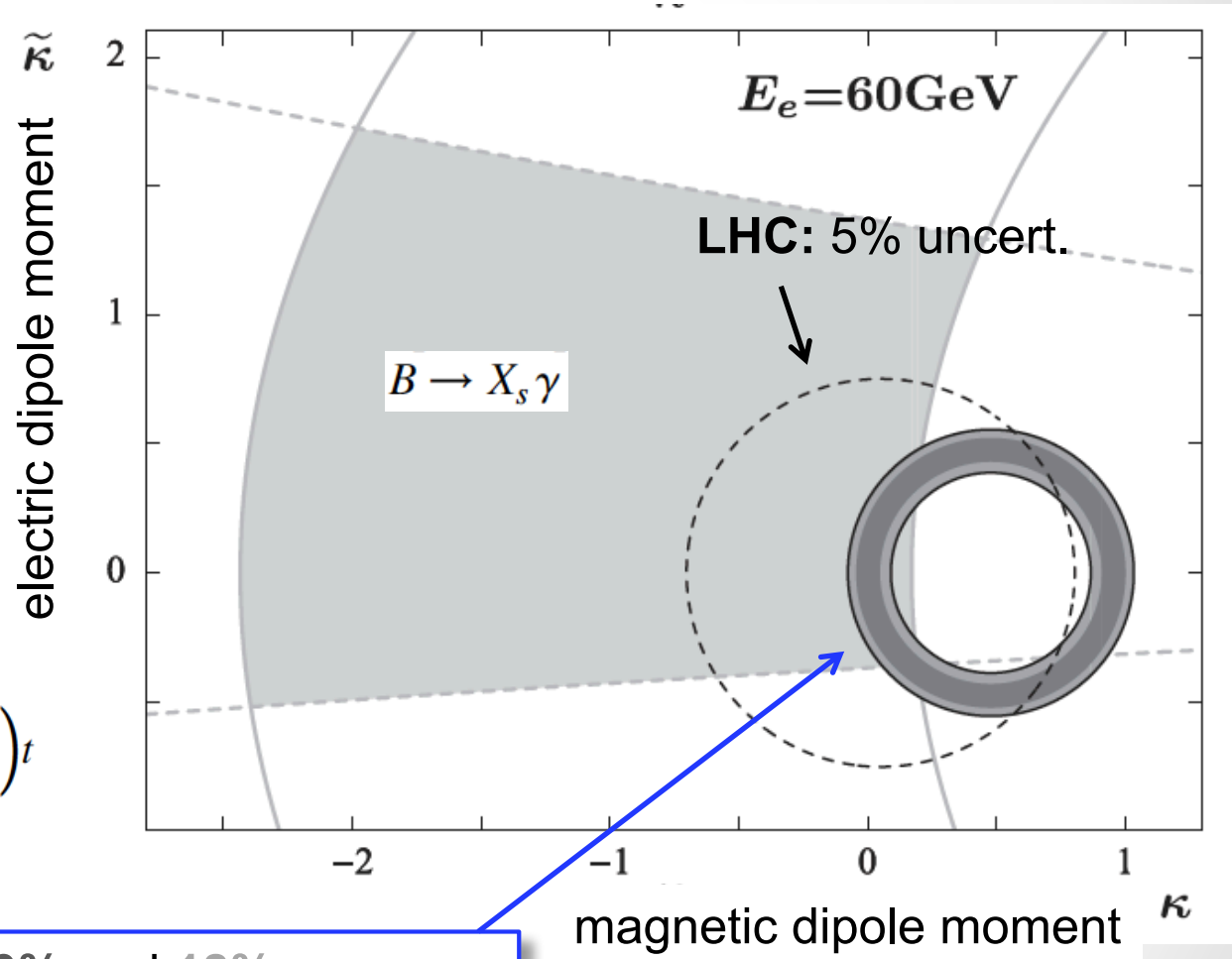


with γp and DIS, sensitivity also to **ttZ**

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

MDM EDM

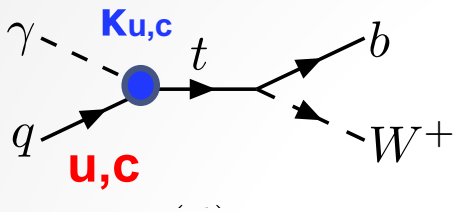
can also measure top quark charge



LHeC: **10%** and **18%** accuracy

27% uncert. (with 4.6 fb^{-1}, 7 TeV)

FCNC in single top quark production



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

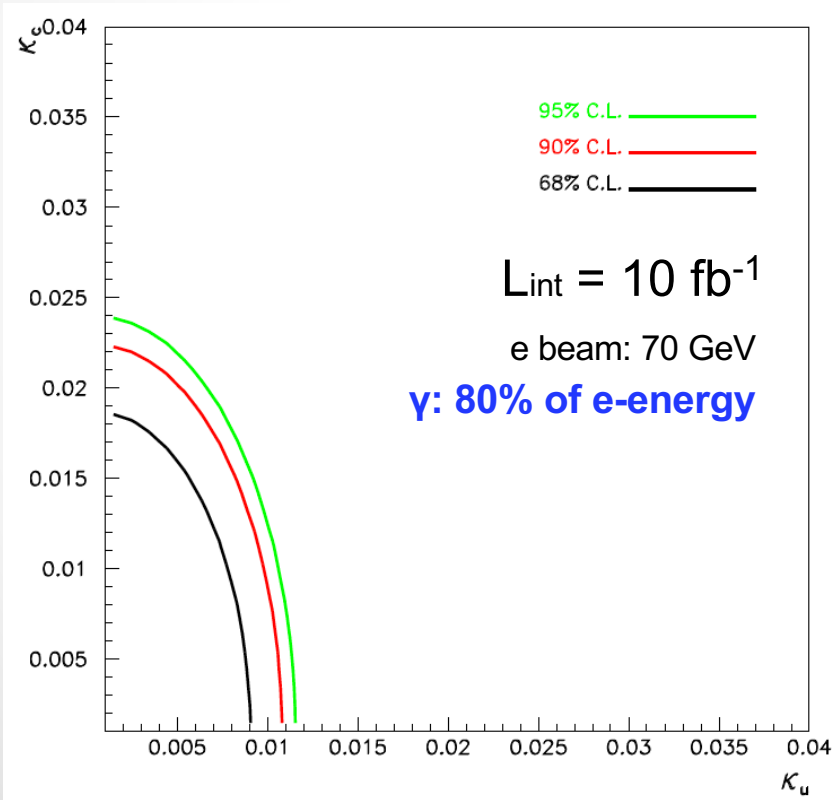
κ= anomolous FCNC coupling

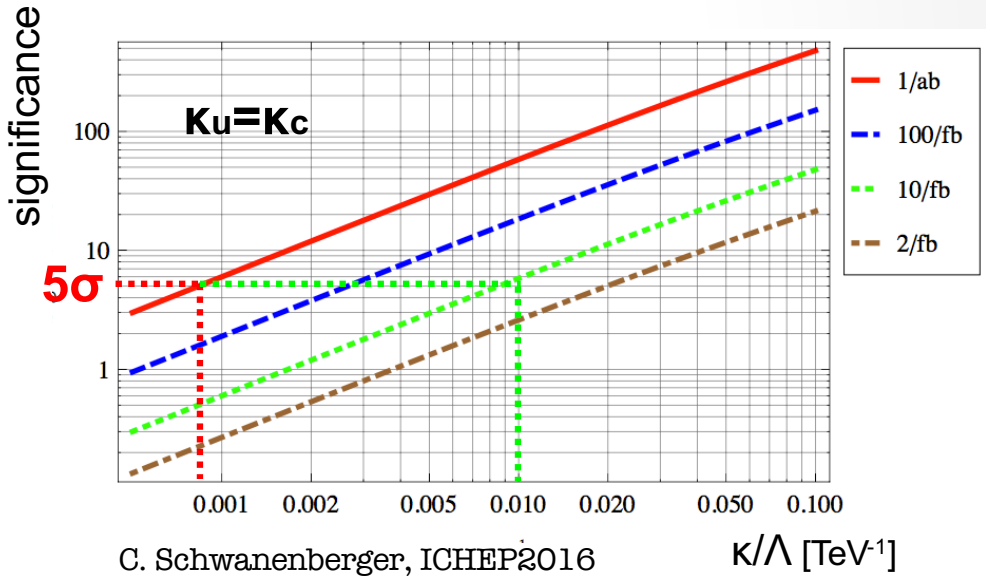
Λ= new physics scale

LHeC: operating as **γp collider**

I.T. Cakir, O. Cakir, S. Sultansoy, Phys Lett B685 (2010) 170

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





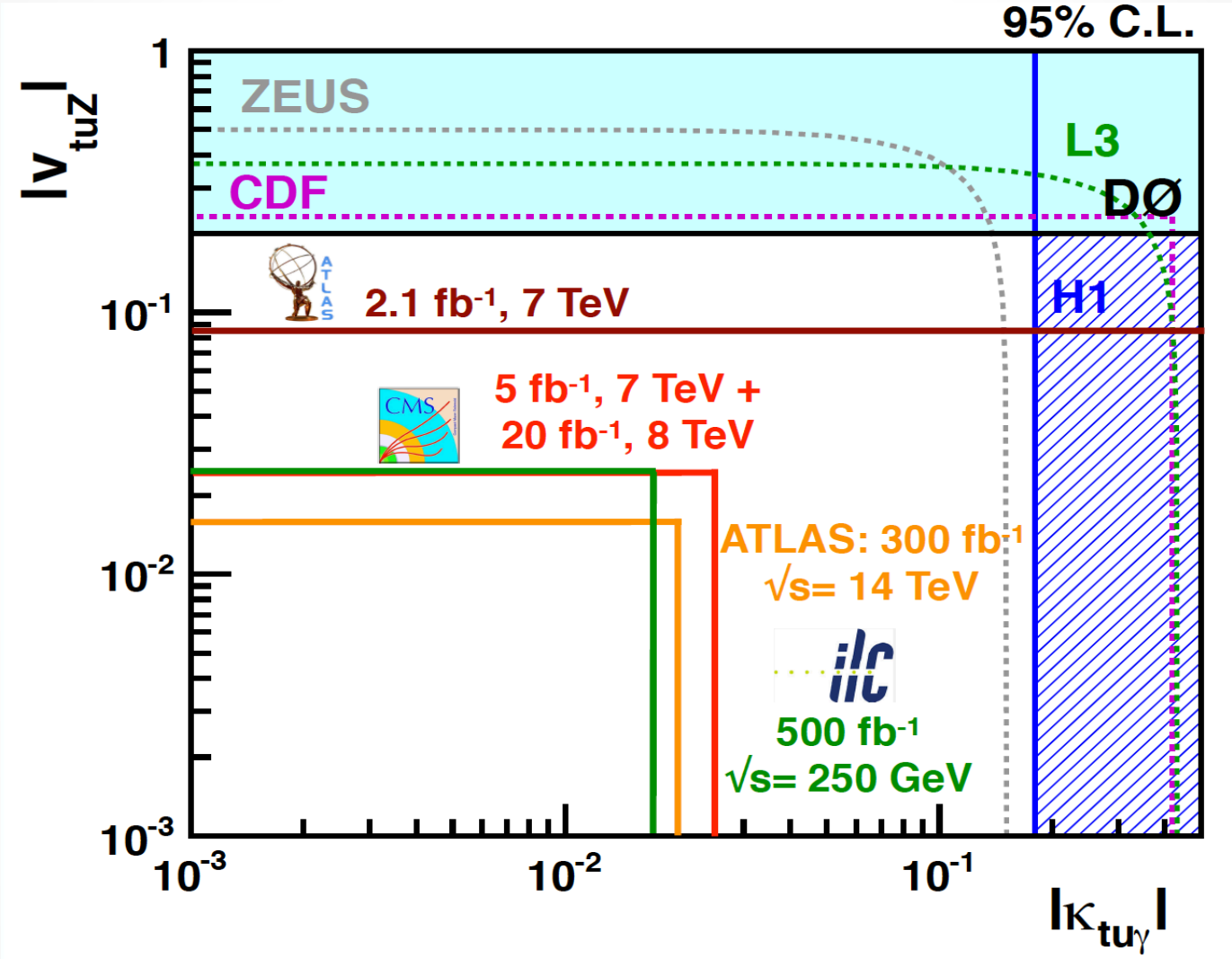
C. Schwanenberger, ICHEP2016

Ref.: κ/Λ= 0.01 ⇔ BR(t⟶uγ) ∽ 2×10^{-6}

(two orders of mag. better than LHC reach with 100 fb^{-1})

can also explore κu≠κc

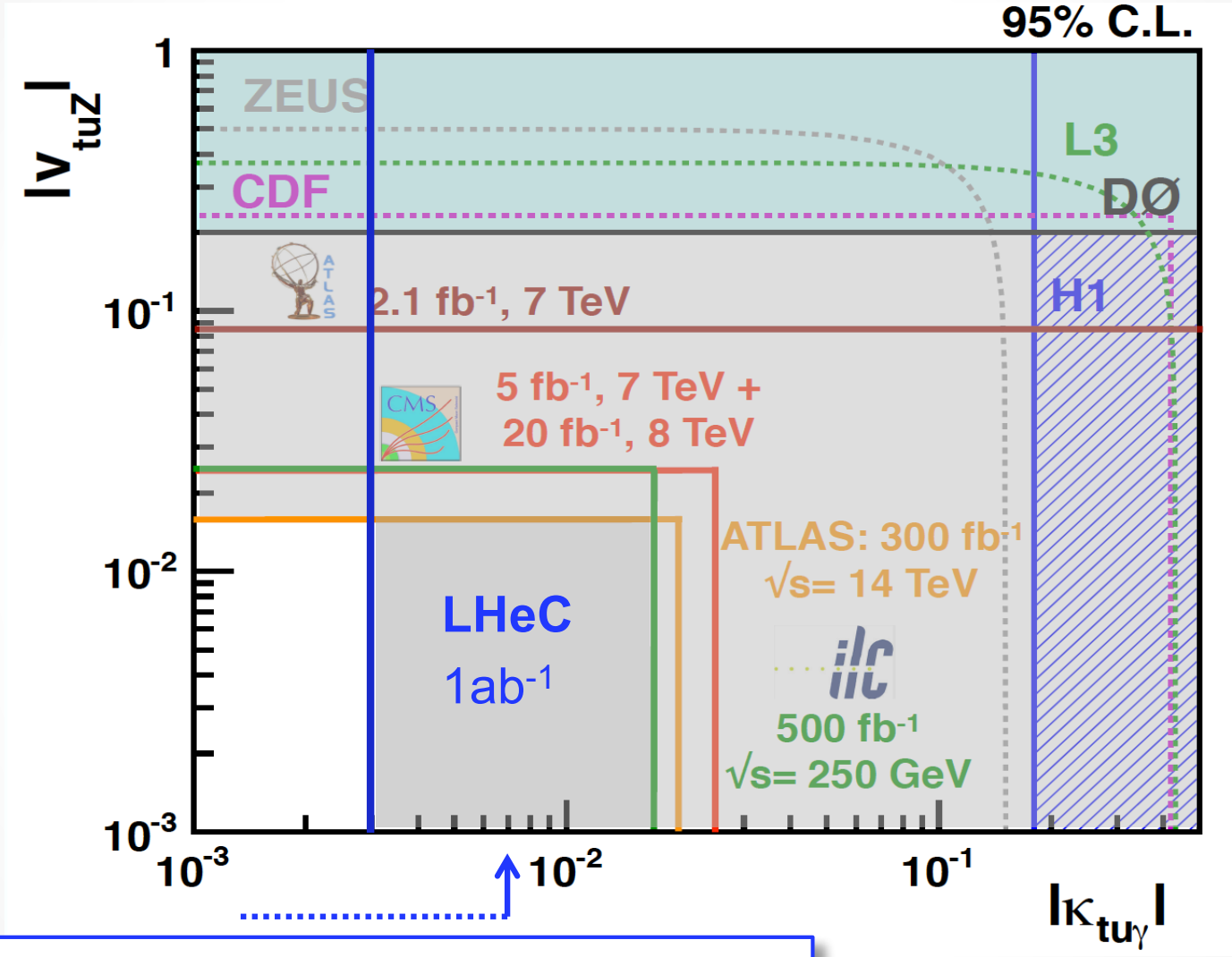
FCNC top couplings at colliders



C. Schwanenberger
ICHEP16

dimensionless coupling ($\Lambda = m_t$)

FCNC top couplings at colliders

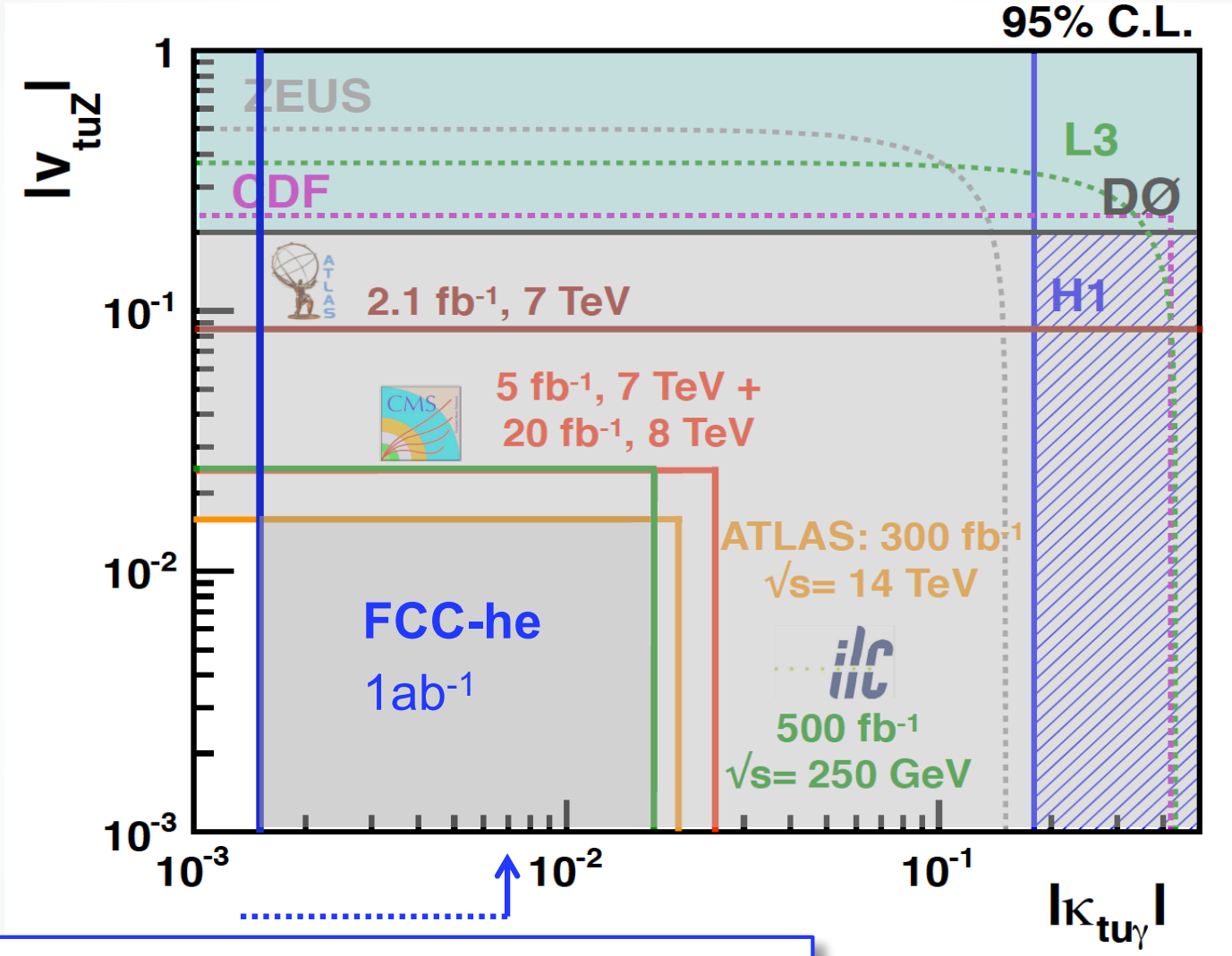


C. Schwanenberger
ICHEP16

test SUSY, technicolor, little Higgs, extra dimensions

dimensionless coupling (Λ=m$_t$)

FCNC top couplings at colliders



C. Schwanenberger
ICHEP16

test SUSY, technicolor, little Higgs, extra dimensions

dimensionless coupling ($\Lambda = m_t$)

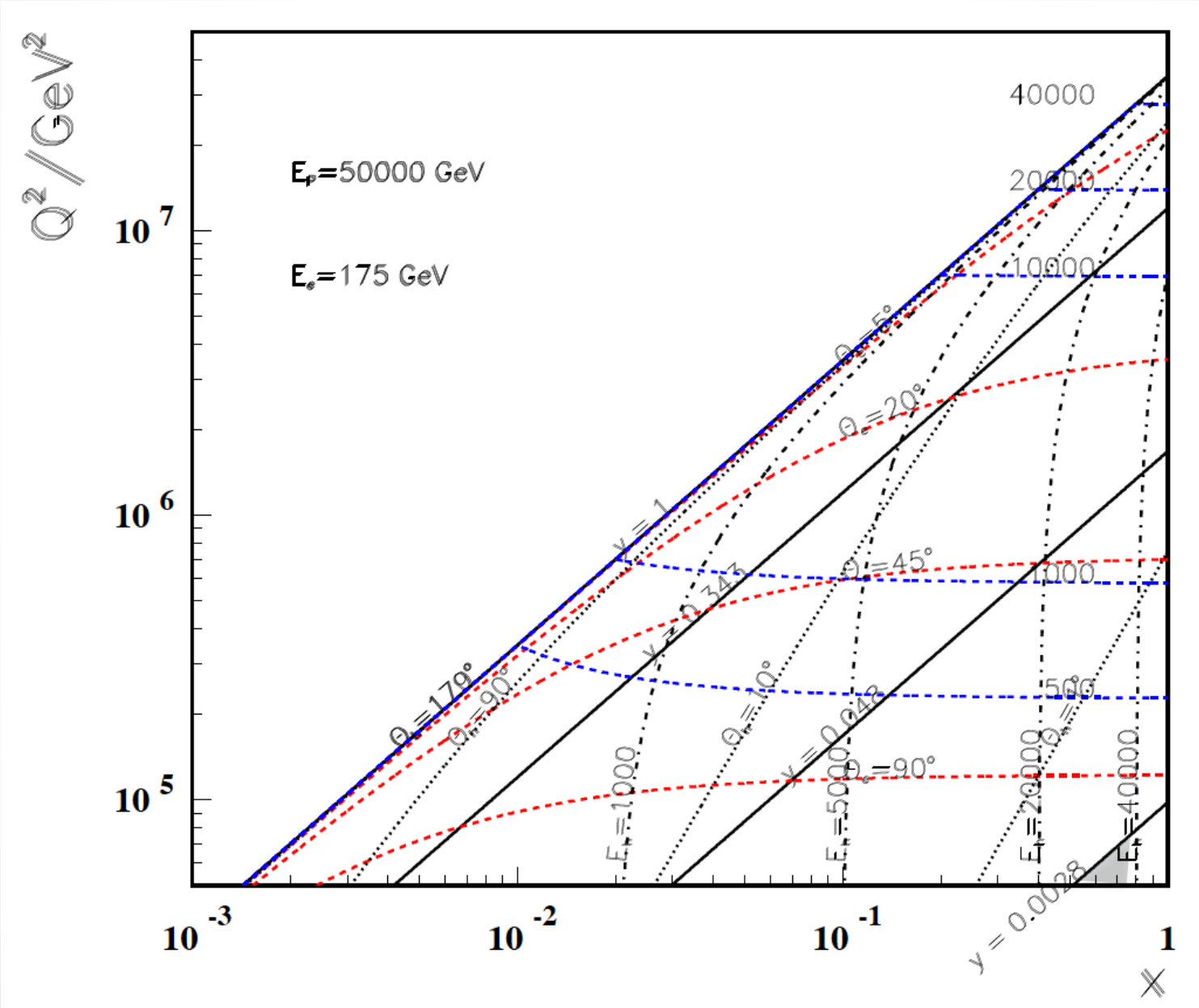
summary

- **ep future collider** has very rich high Q^2 analysis programme
  only selected studies shown here
- precision measurements of **proton** (and **nuclear**) structure are primary goals of **LHeC** (and **FCC-eh**)
- **dramatically improved precision** for LHC and FCC searches and measurements
- precision electroweak measurements (**light quark couplings**, **$\sin^2\theta_W$**)
- new phenomena, discovery, and / or determination of properties
- **LQs**, **contact interactions**, **excited fermions**, **RPV SUSY**, **FCNC**, **anomalous couplings**, **colour octet electron**, **ultra heavy / Majorana neutrinos**, **H+ bosons**, **heavy top**, …
- study top quark in detail for first time at ep collider
- couplings to gauge bosons (EG. **|Vtb|, Wtb**, **ttγ**, **ttZ**, **tH**)
- top quark properties: **top PDF**, **charge**, **polarisation**
- **FCC-he**: higher sensitivity in all channels, studies ongoing

extras

High Q^2

Rutherford backscattering
of dozens of TeV e- energy



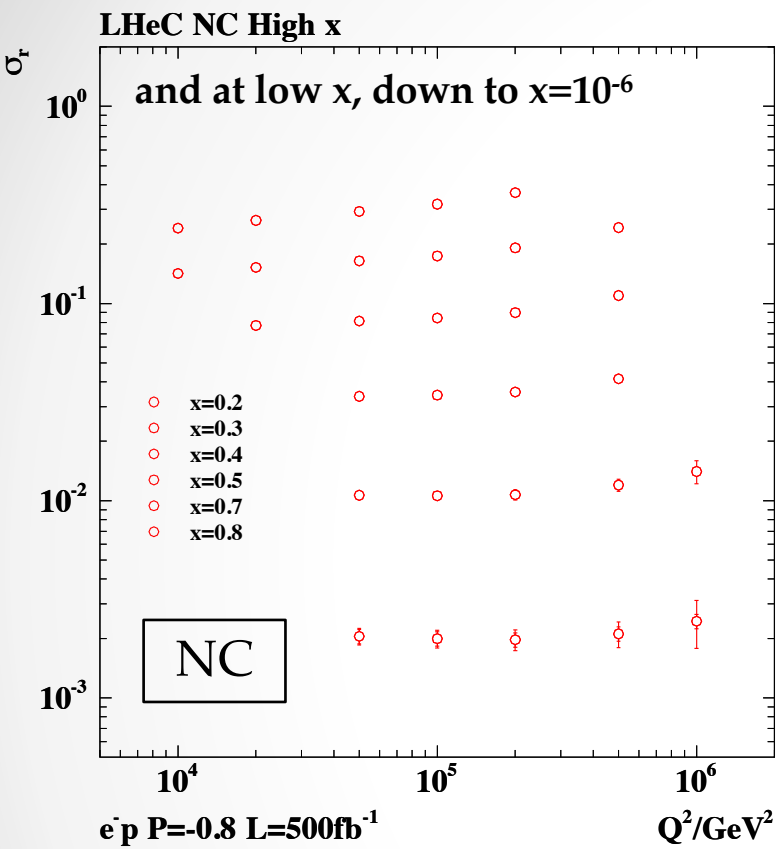
FCC-he
175 GeV
60 GeV

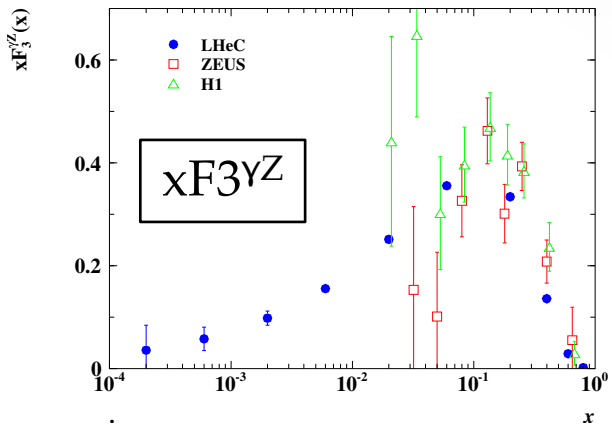
LHeC

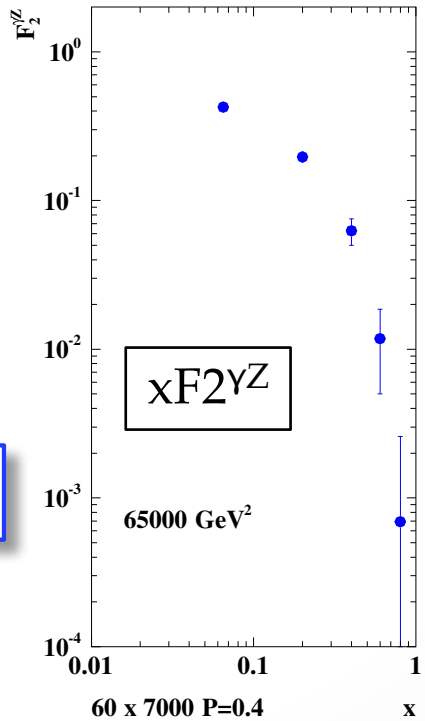
← ϑ_h=1°

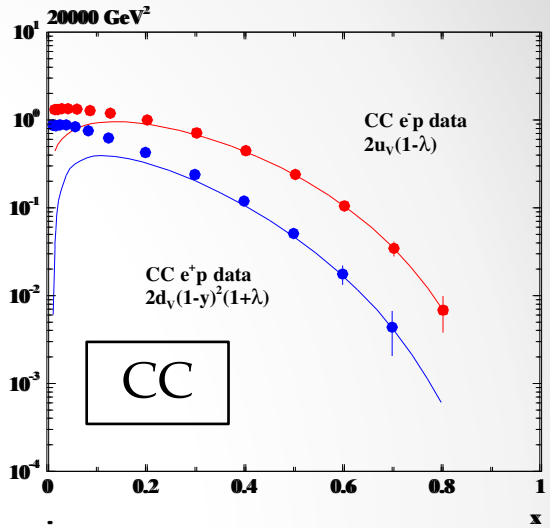
← HERA

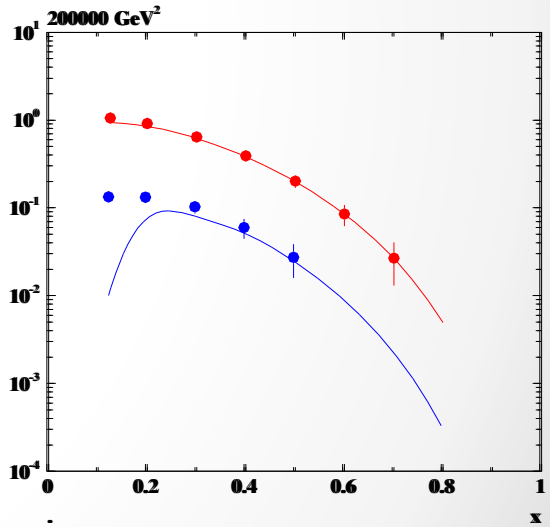
primary measurements at high Q^2











NC+CC cross sections to high precision

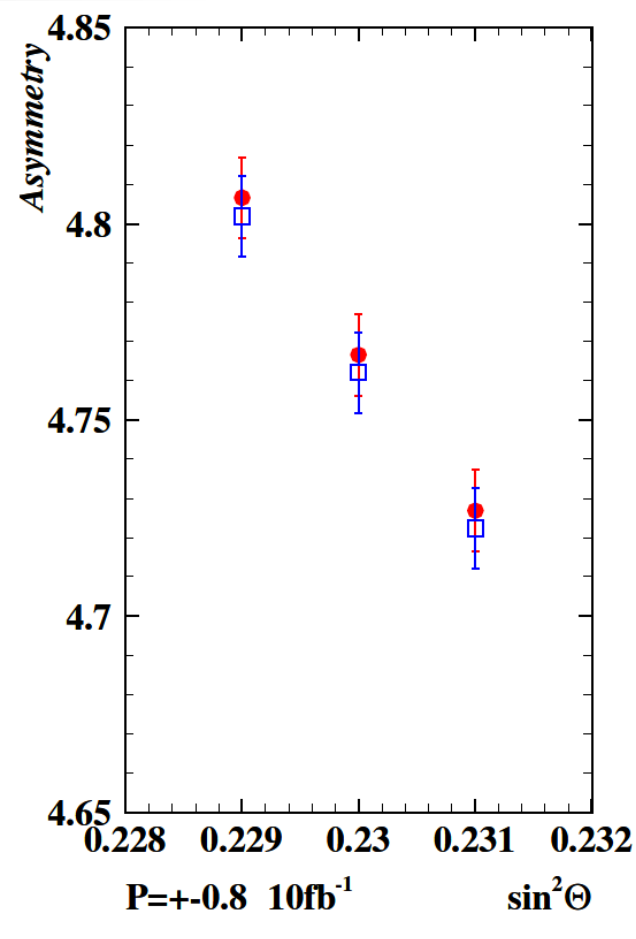
- access high x, free of nuclear corrections
- different beam charge and polarisations:
  determination of all quark types!

… and gluon via scaling violations (and F_L)

asymmetry measurements in DIS

$$A^{\pm} = \frac{\sigma^{\pm}_{NC}(P_R) - \sigma^{\pm}_{NC}(P_L)}{\sigma^{\pm}_{NC}(P_R) + \sigma^{\pm}_{NC}(P_L)}$$

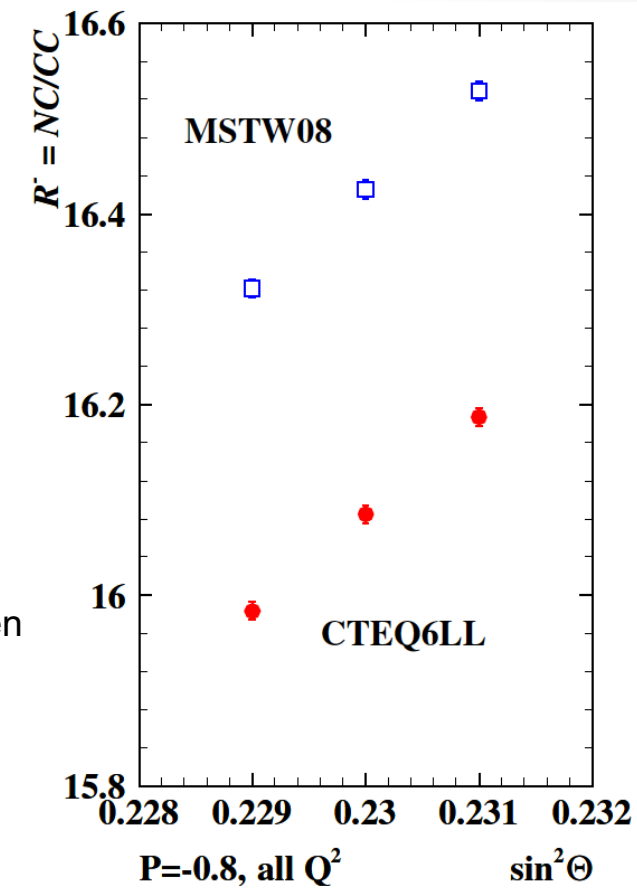
$$R^{\pm} = \frac{\sigma^{\pm}_{NC}}{\sigma^{\pm}_{CC}}$$



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

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

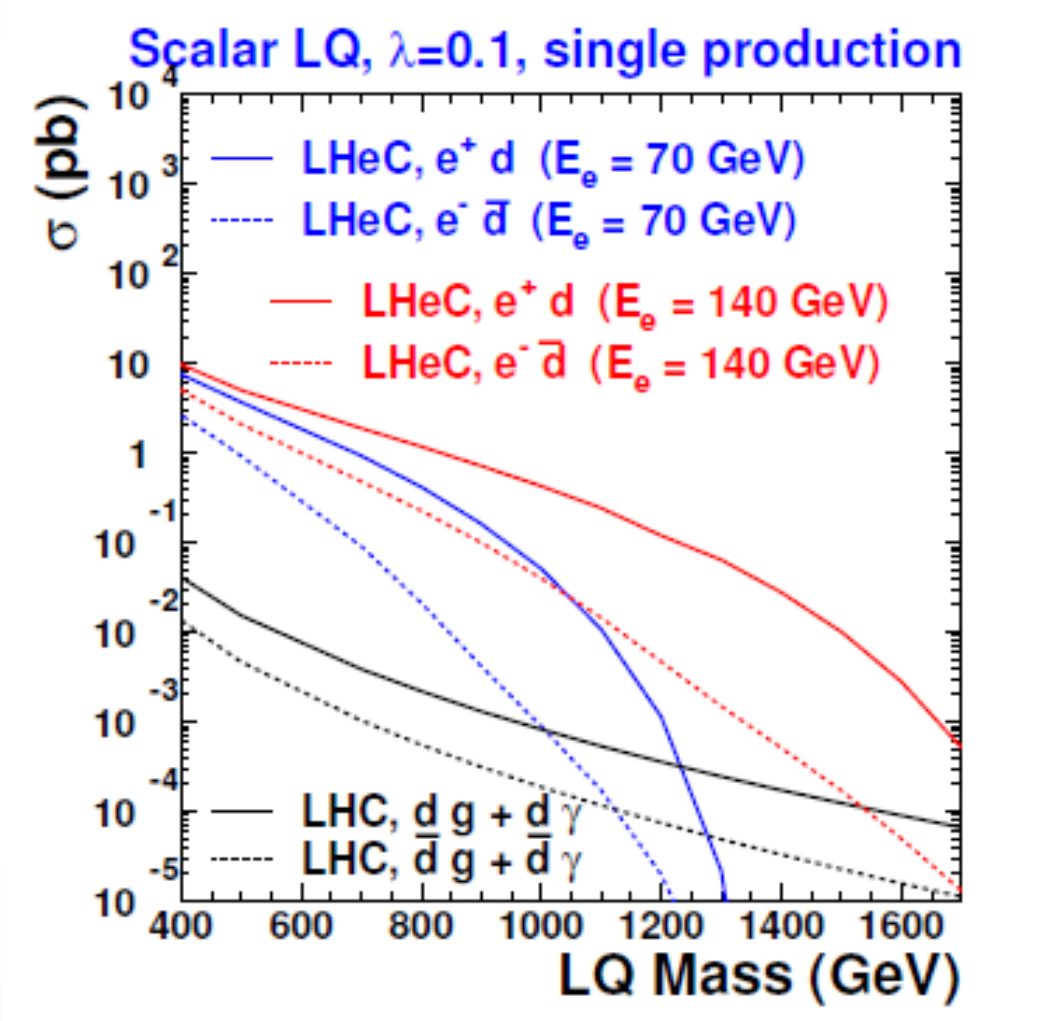
mean x differs by factor of 6 between NC and CC



extract $\sin^2\Theta_W$ (α, Mz fixed)

single LQ production cross sections

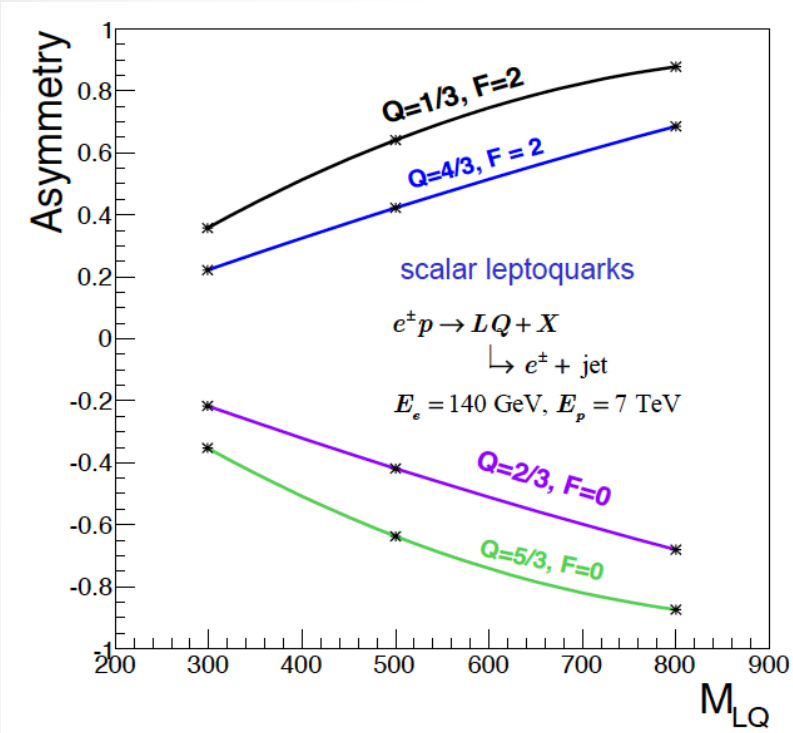
LHeC CDR,
J. Phys. G39
075001 (2012)



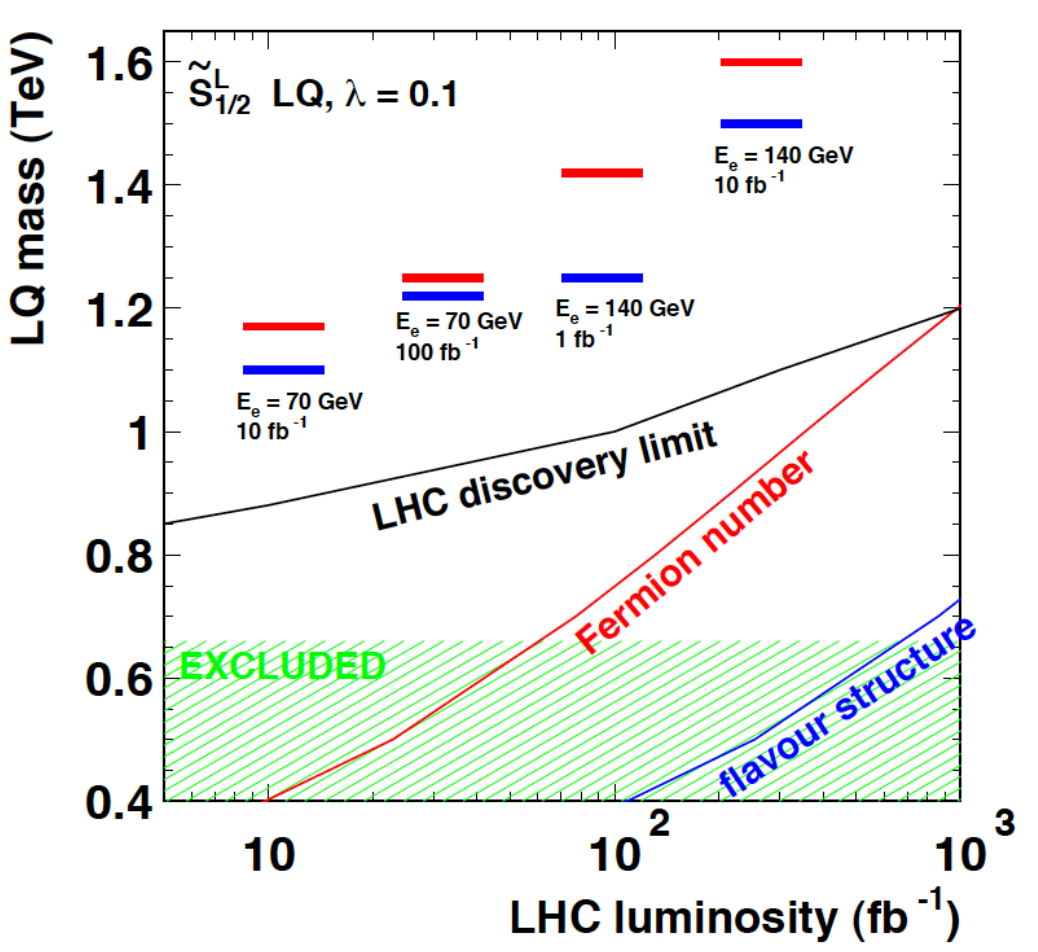
LQ properties with the LHeC

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

- **fermion number** and **flavour structure**



$$A = \frac{\sigma_{e^-} - \sigma_{e^+}}{\sigma_{e^-} + \sigma_{e^+}} \begin{cases} > 0 \text{ for F=2} \\ < 0 \text{ for F=0} \end{cases}$$

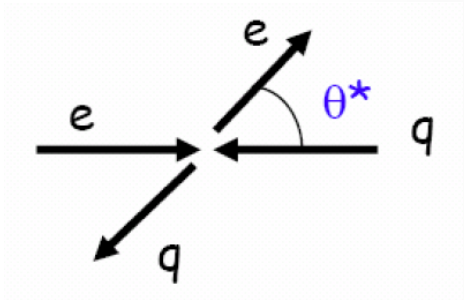


LQ properties with the LHeC

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

- **other properties:**

- **spin**
- **LHC:** pair production of LQ – LQ leads to angular distributions which depend on the g – LQ – LQ coupling
  - may need to look at spin correlations
- **LHeC:** cos**θ*** distribution sensitive to spin
- vector LQs can have anomalous couplings



- **couple chirally** (i.e. to L or R but not both?)
- could be probed by measuring sensitivity of cross sections to polarisation of the electron beam

- **generation mixing?**
- does LQ decay to 2nd generation?
- **BR to neutrino, good S/B in νj channel** $e_L^- u_L \rightarrow S_3 \rightarrow \nu_e d_L$

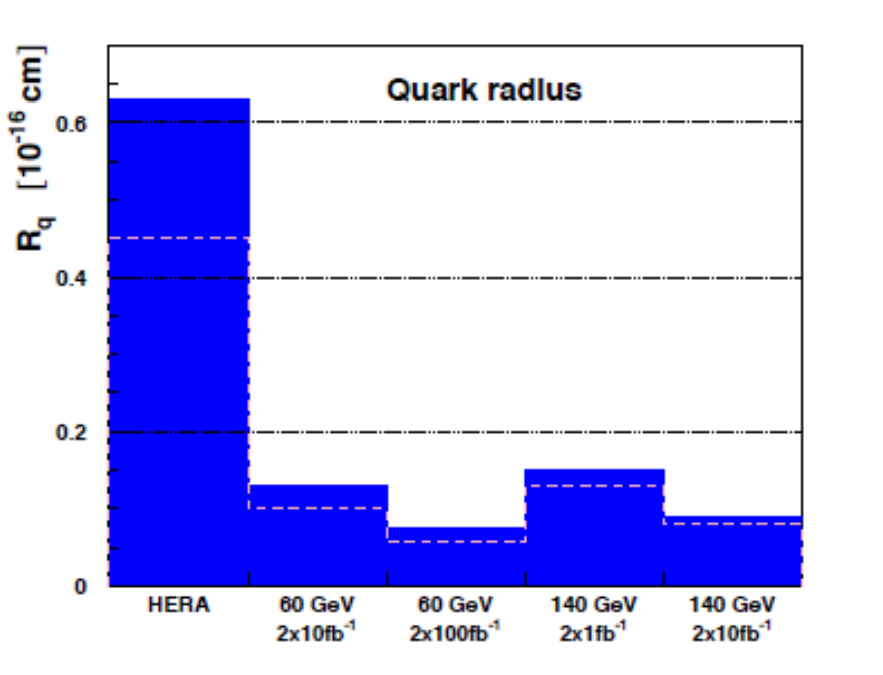
quark substructure

- if contact terms originate from a model where fermions composite, scale proportional to composite object radius

form factor: $f(Q^2) = 1 - \frac{1}{6}\langle r^2 \rangle Q^2$

$$\frac{d\sigma}{dQ^2} = \frac{d\sigma_{SM}}{dQ^2} f_e^2(Q^2) f_q^2(Q^2)$$

sensitive to fermion radius below 10^{-19}–10^{-20} m at LHeC (FCC-eh)

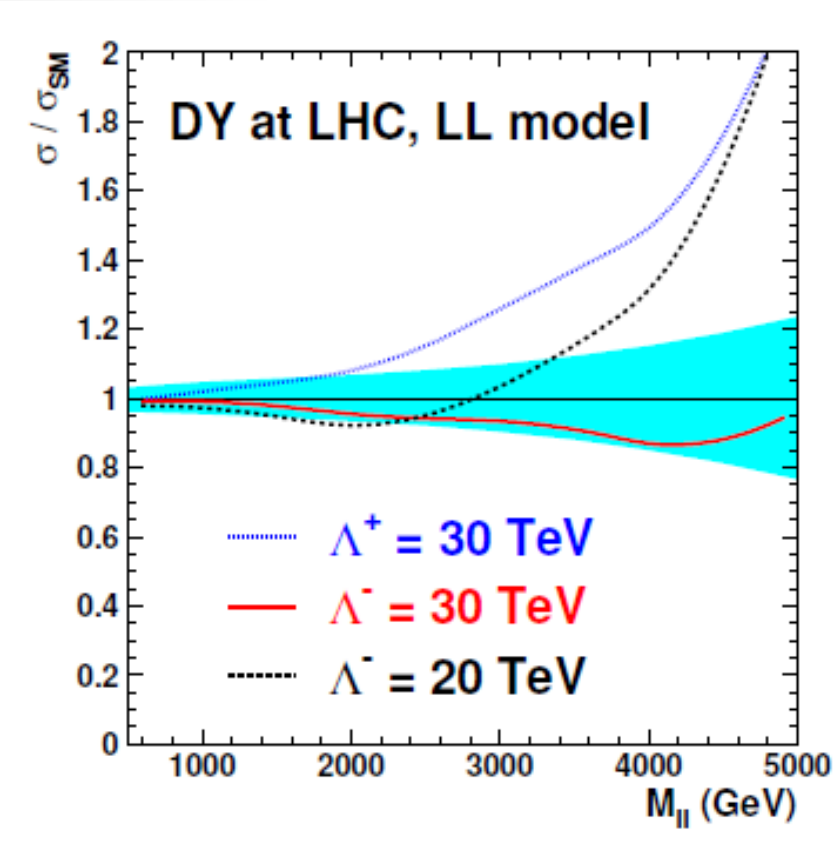


LHeC CDR, J. Phys. G39 075001 (2012)

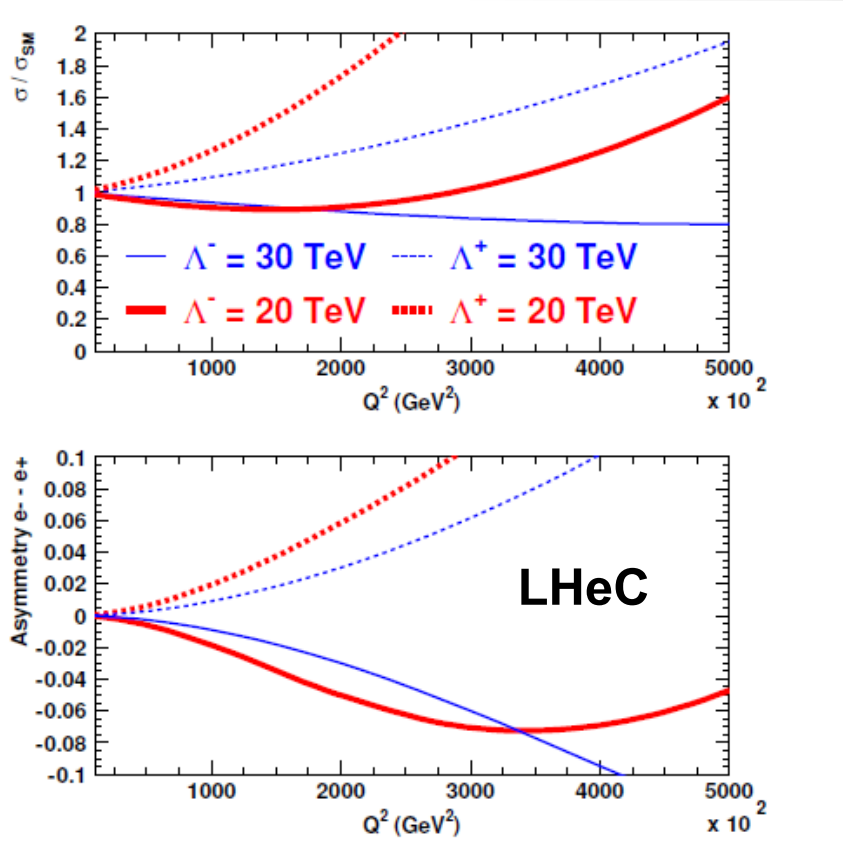
CI at the LHC and LHeC

- **LHC**: variation of Drell-Yan cross section for CI model
- cannot simultaneously determine Λ and sign of interference of new amplitude with respect SM (ε)

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



EG: negative interference too small to be disentangled



LHeC: sign ε from asymmetry of σ/σ_{SM} in e^+p and e^-p

excited fermions

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

- could be produced directly if their mass is below compositeness scale

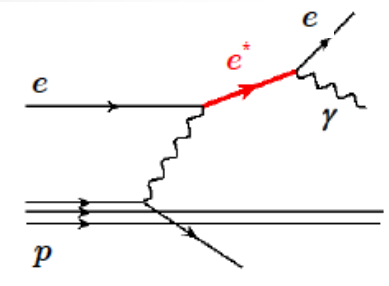
  assume spin= ½, L, R doublets

gauge interaction Lagrangian

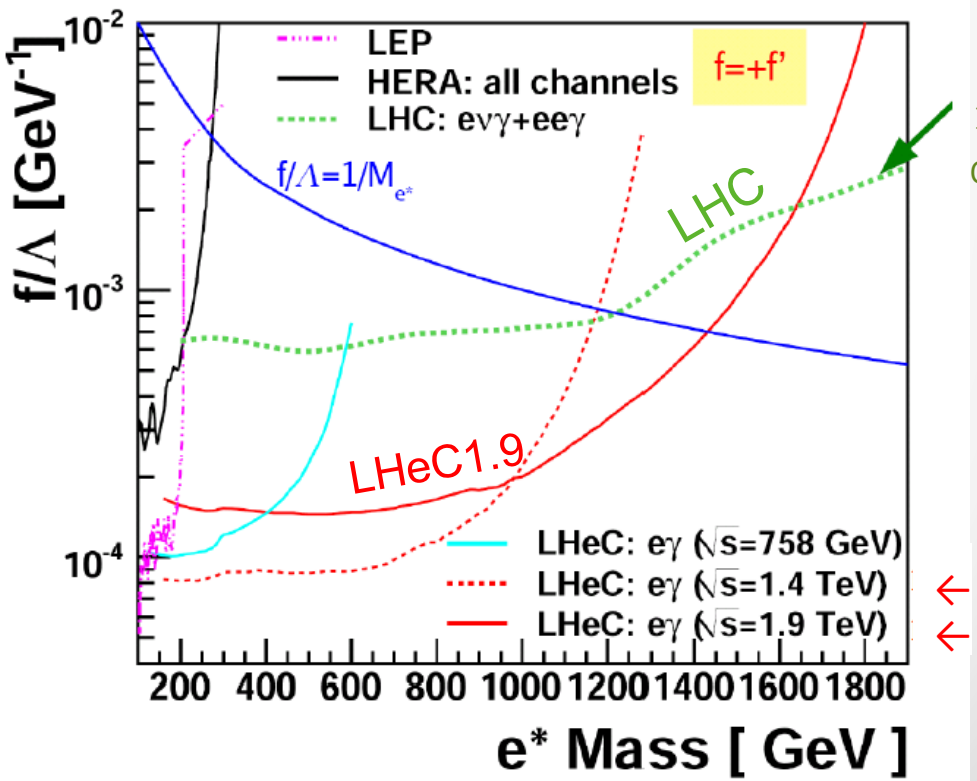
$$\mathcal{L} = \frac{1}{2\Lambda}\bar{f}^*_R \sigma_{\mu\nu}\left[g f \frac{\tau_a}{2} W^a_{\mu\nu} + g' f' B_{\mu\nu} + g_s f_s \frac{\lambda_a}{2} G^a_{\mu\nu} \right] f_L$$

contact interaction Lagrangian

$$\mathcal{L} = \frac{4\pi}{2\Lambda^2} j_\mu j^\mu; \quad j_\mu = \eta_L \bar{f}_L \gamma_\mu f_L + \eta'_L \bar{f}^*_L \gamma_\mu f^*_L + \eta''_L \bar{f}^*_L \gamma_\mu f_L + h.c. + (L \leftrightarrow R)$$



area above curves excluded



LHC: PRD65, 075003 (2002)

← 10 fb⁻¹

← 1 fb⁻¹

LHC could probe up to 1–2 TeV

for f = f' = 1, Λ=m$_{e^*}$ (or f/Λ = 1/m$_{e^*}$)

O. Cakir et al. PRD70 (2004) 075011

A. Belyaev et al., EPJ C41, s02 (2005) 1

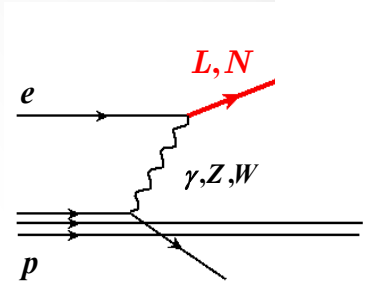
ep colliders could extend sensitivity to f/Λ and mass reach to ≲ CM

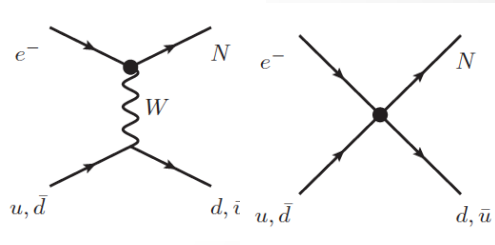
heavy fermions / coloured bosons

G. Azuelos

heavy leptons:

- vector-like leptons: L and R chiralities have same transformation properties
  - predicted in GUT theories (E_6) or in Composite Higgs Models
  - couplings: $eEZ, \nu EW, eEH; \quad \nu NZ, eNW, \nu NH$
- Majorana neutrino production in an effective approach
  (L. Duarte et al. 1412.1433)
  - SM background from $p\gamma \to \ell^+ + 3j + \nu \quad pe^- \to e^+ + 3j + 2\nu_e$
    able to discover Majorana neutrinos up to 700 GeV (for E_e = 50 GeV)

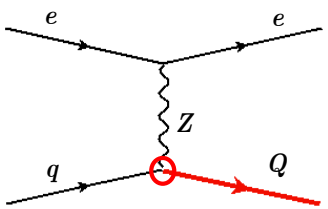




$N \to \ell^+ +$ jets

vector-like quarks?

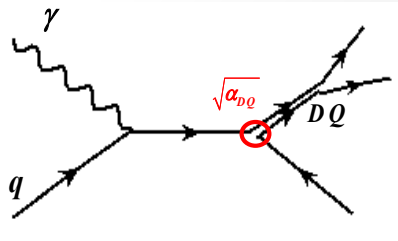
- single production of top partners, sensitive to couplings: $qQZ, qQW, qQH;$
- *(coupling to light quarks)*



diquarks

- predicted in superstring inspired E6 and composite models
- could carry charge 1/3, 2/3, 4/3 and be scalar or vector
- in gp production $\mathcal{L}_{|B|=2/3} = \left(g_{1L}\bar{Q}_L^c i\tau_2 Q_L + g_{1R}\bar{u}_R^c d_R\right) D Q_1^c + \text{h.c.}$

(M Şahin and O. Çakir, arXiv:0911.0496)



LHeC reach excluded; vector and scalar diquarks can be distinguished by the angular distribution of their decays

BSM in vector boson scattering (FCC-eh)

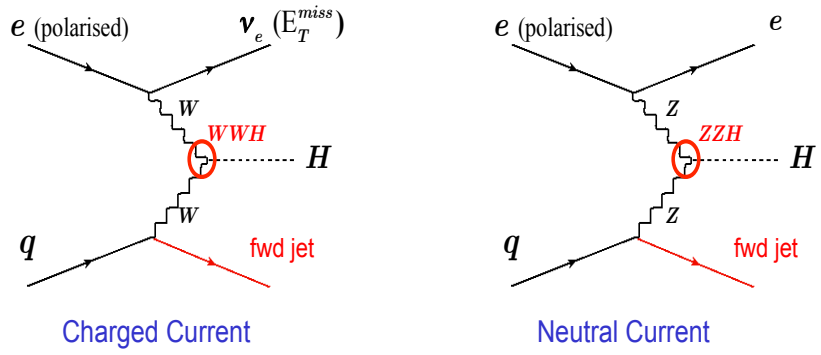
1. VBF Higgs production with BSM decays
   eg. RPV cases $H \rightarrow \chi_1^0 \chi_1^0 \rightarrow 3j\, 3j$ (resonances)
   need to understand backgrounds

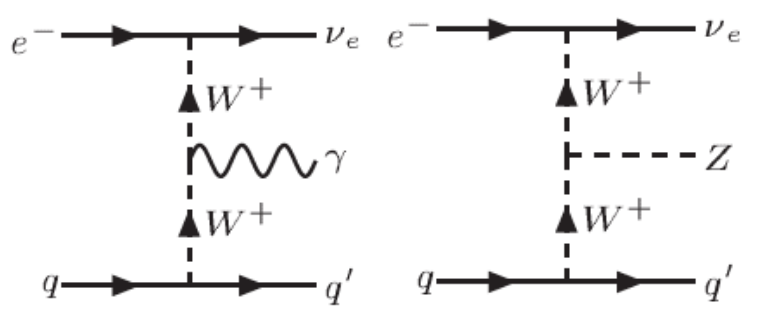
2. **vector boson scattering at high mass**
   mass dependence of cross section

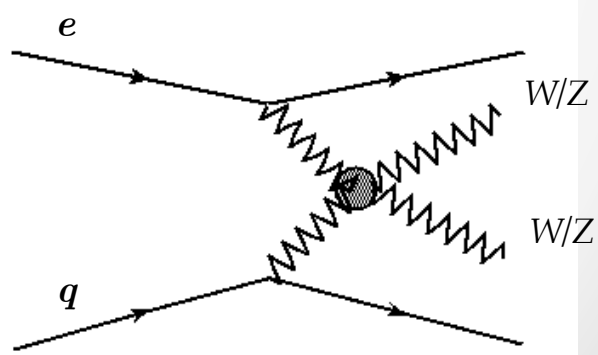
- anomalous TGC, QGC couplings?
  I.T.Cakir et al., arXiv:1406.7697
  studies show sensitivity comparable to LHC

- is unitarity restored only by Higgs?
  are there new resonances (composite Higgs model)?
  expect below about 2–3 TeV:
  e-q ⟶ e-qWZ, vqWZ
  search for deviations from SM predictions

- **LHC**: hadronic modes challenging (high QCD backgrounds not present in ep, pileup, difficult if no lepton triggers used, …)



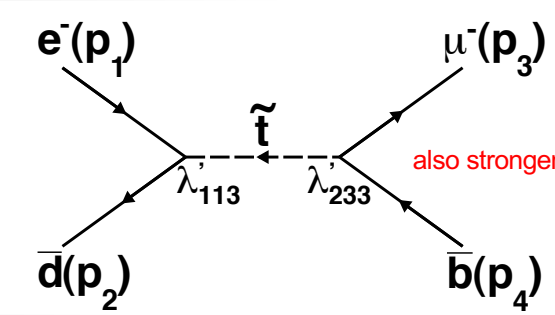




RPV SUSY

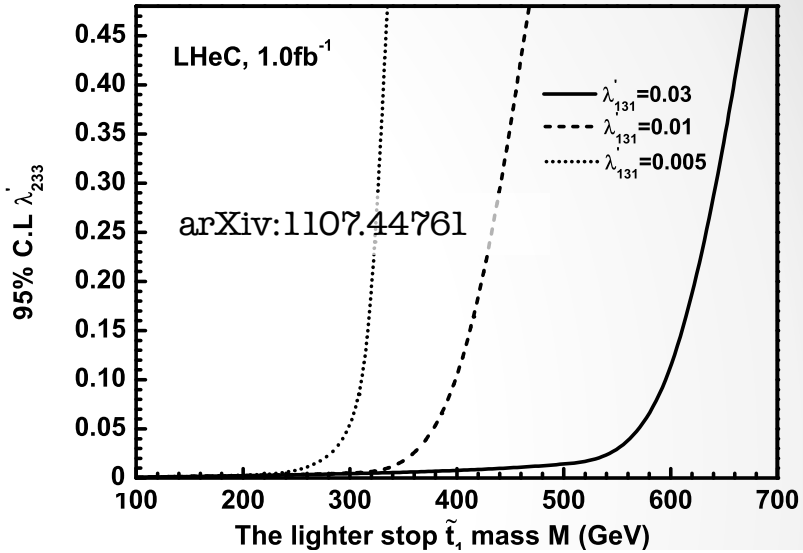
single squark production, in RPV SUSY (signal like LQs, with generation mixing)

stop



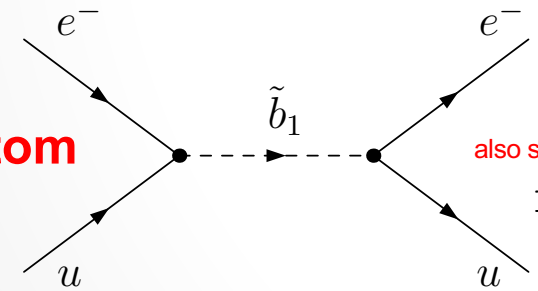
$\Lambda'_{131} < 0.03$

also stronger bounds from ββ0ν



- sensitivity up to 700 – 800 GeV with only 1fb^{-1}
- LHC will also provide constraints
- very promising with high luminosity, 100 fb^{-1}
- requires good b-tagging

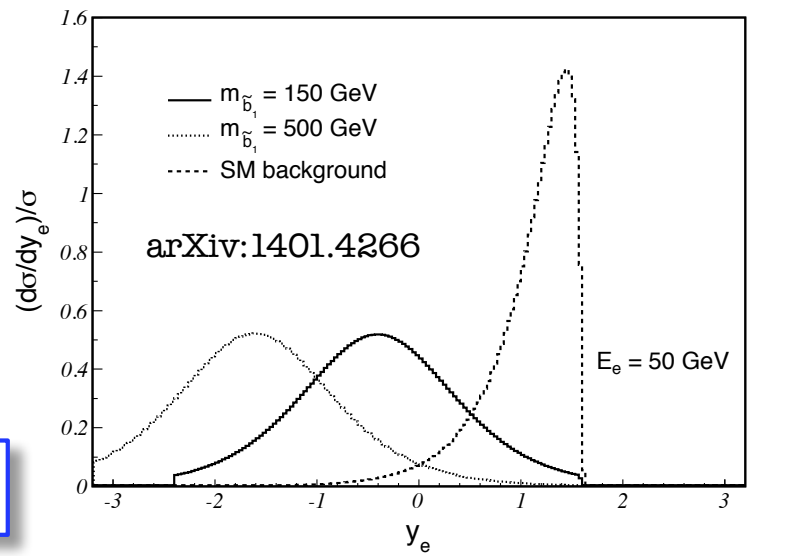
sbottom



$\Lambda'_{131} < 0.02$

also stronger bounds from ββ0ν

Barbier hep-ph/0406039

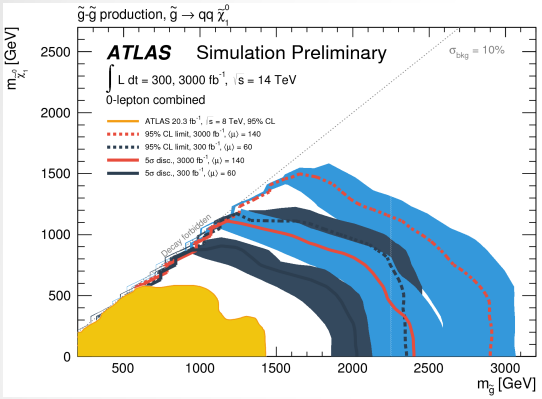


- < 100 fb^{-1} needed for 1TeV RPV sbottom discovery

RPV SUSY can be probed at unprecedented levels

SUSY – PDF impact on searches

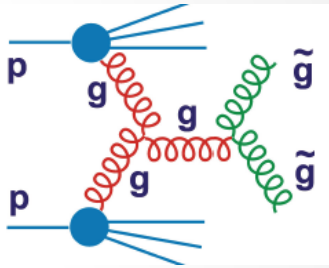
- **SUSY** – searches near **HL–LHC** kinematic boundary may ultimately be limited by knowledge of PDFs (esp. gluon at high x)

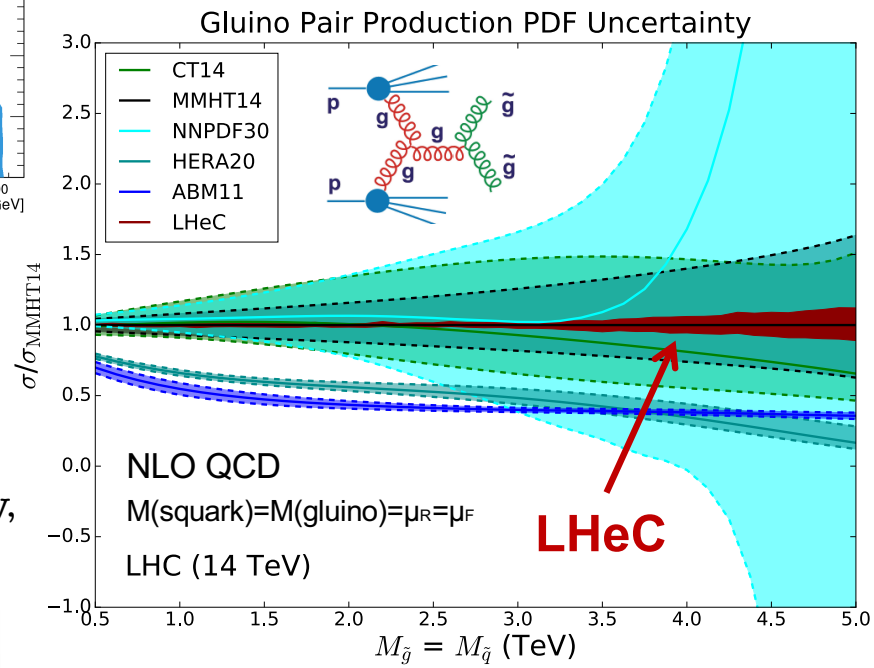


effect could be up to 1 TeV

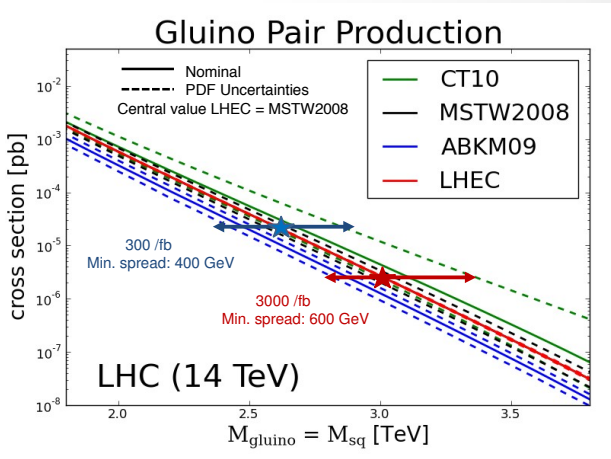
ATL-PHYS-PUB-2014-010

EG: gluino production at the LHC





plot by C. Borschensky, M. Kramer; update to arXiv:1211.5102



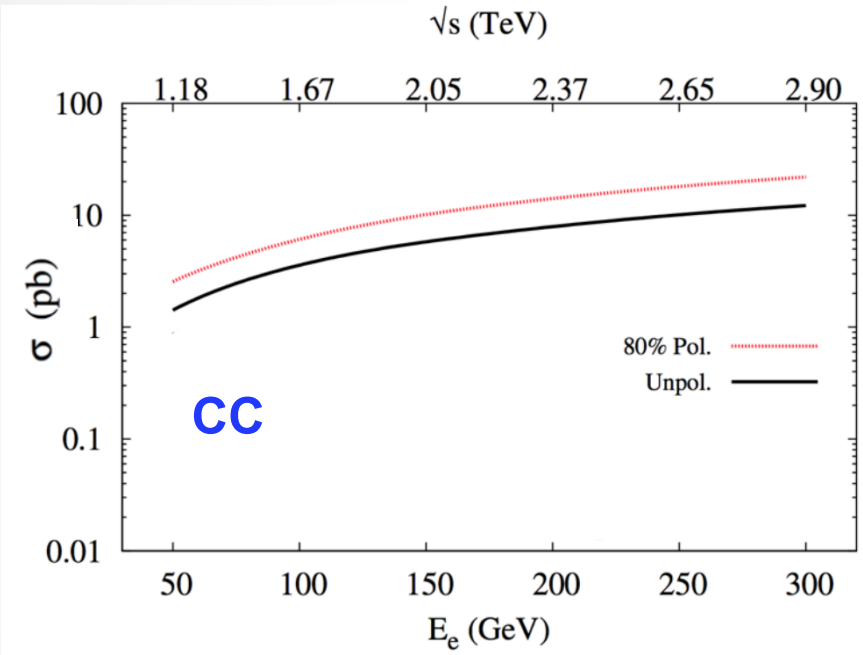
also NNPDF3.0

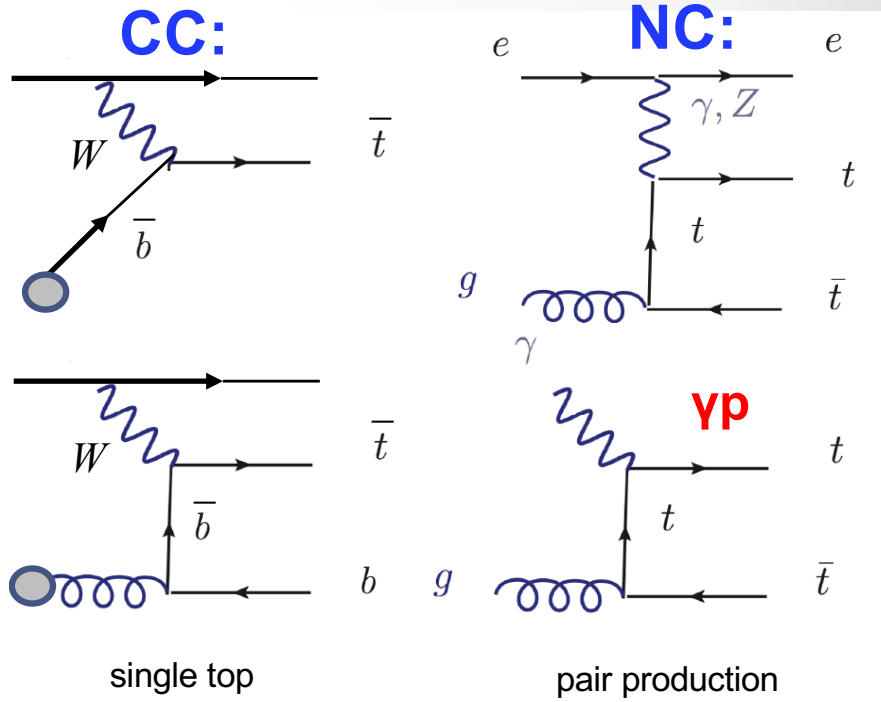
arXiv:1410.8849

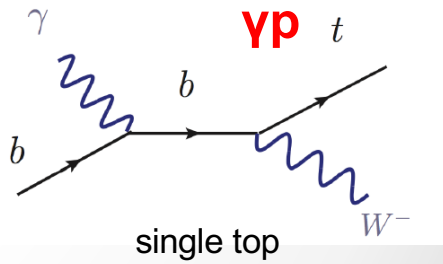
LHeC improves sensitivity for HL-LHC

top quark production

Dutta, Goyal, Kumar, Mellado, arXiv:1307.1688







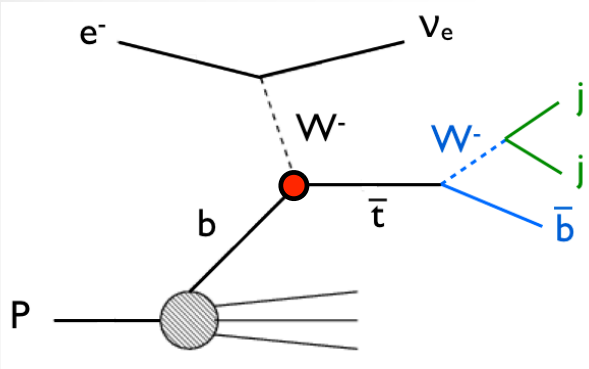
EG. **CC with L_{int} = 100 fb^{-1}** (e: 60–140 GeV):

2–6 × 10^5 events

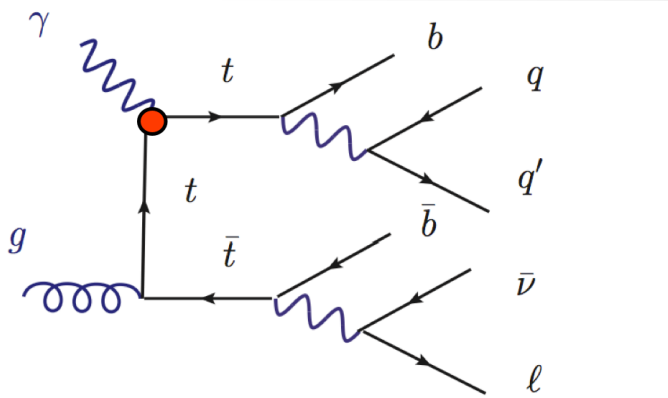
3–10 × 10^5 events

ep future collider offers excellent prospects for top quark physics

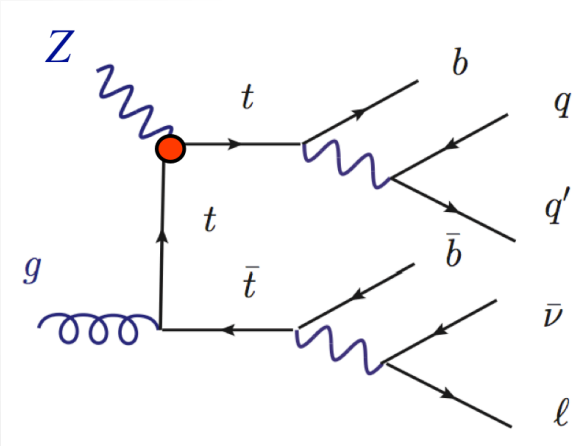
top quark electroweak interactions



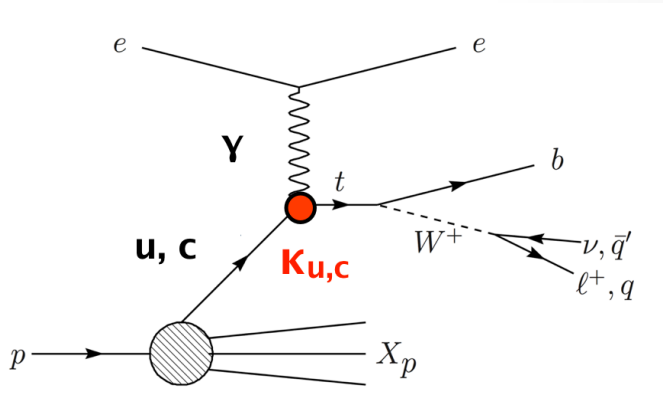
- high precision measurements of Vtb and search for anomalous Wtb couplings



- direct measurement of top quark charge and search for anomalous ttγ couplings (EG. EDM, MDM)



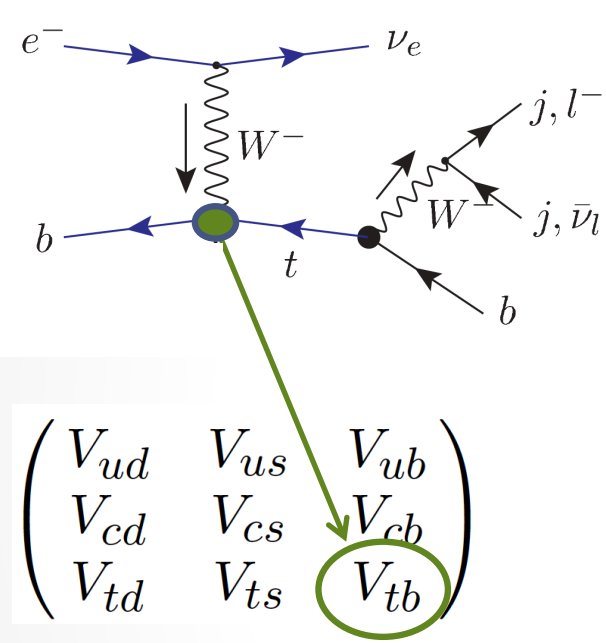
- measurement of top isospin and search for anomalous ttZ couplings (EG. EDM, MDM)



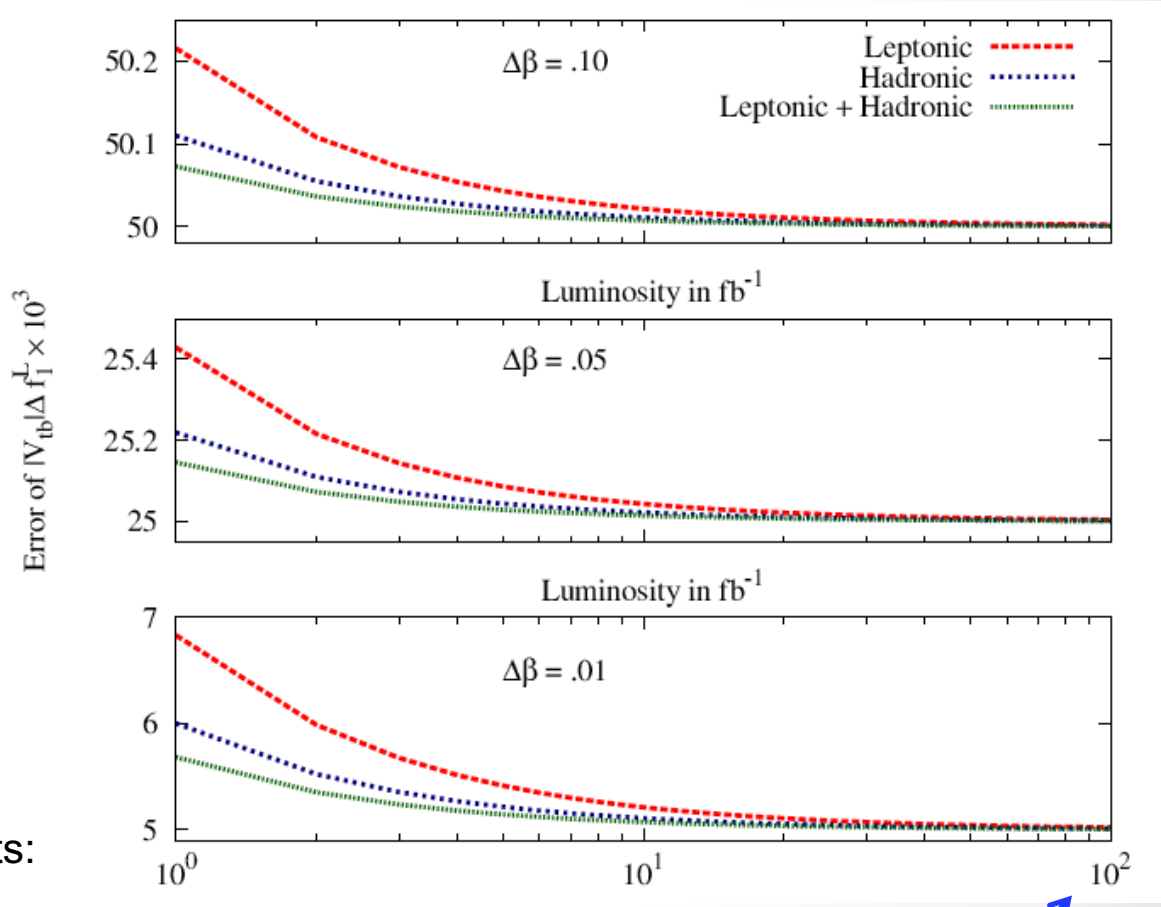
- sensitive search for FCNC couplings will constrain BSM models that predict FCNC (EG. SUSY, little Higgs, technicolour)

measurement of |Vtb|

Dutta, Goyal, Kumar, Mellado, arXiv:1307.1688 [hep-ph]



Δβ: luminosity uncertainty



e beam: 60 GeV

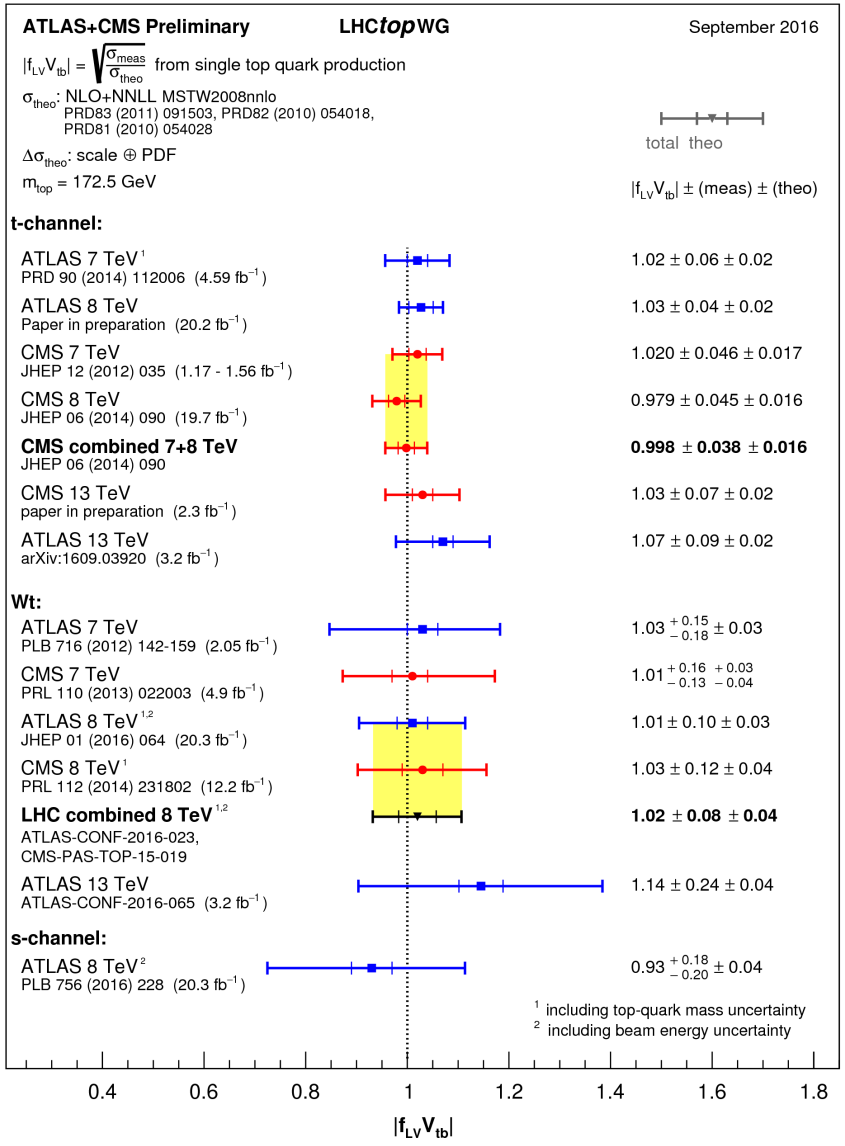
with L_{int} = 100 fb^{-1}, with simple cuts:

hadronic: N_t = 22000, S/B=1.2

leptonic: N_t = 11000, S/B=11

LHeC: **Δ**$|V_{tb}|$ = 0.005 with L_{int}=100 fb^{-1}

LHC measurements of |Vtb|



anomalous Wtb couplings

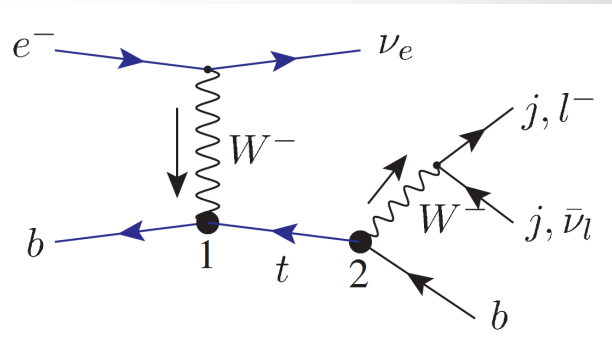
J.A. Aguilar-Saavedra, NP B812 (2009) 181

RH vector

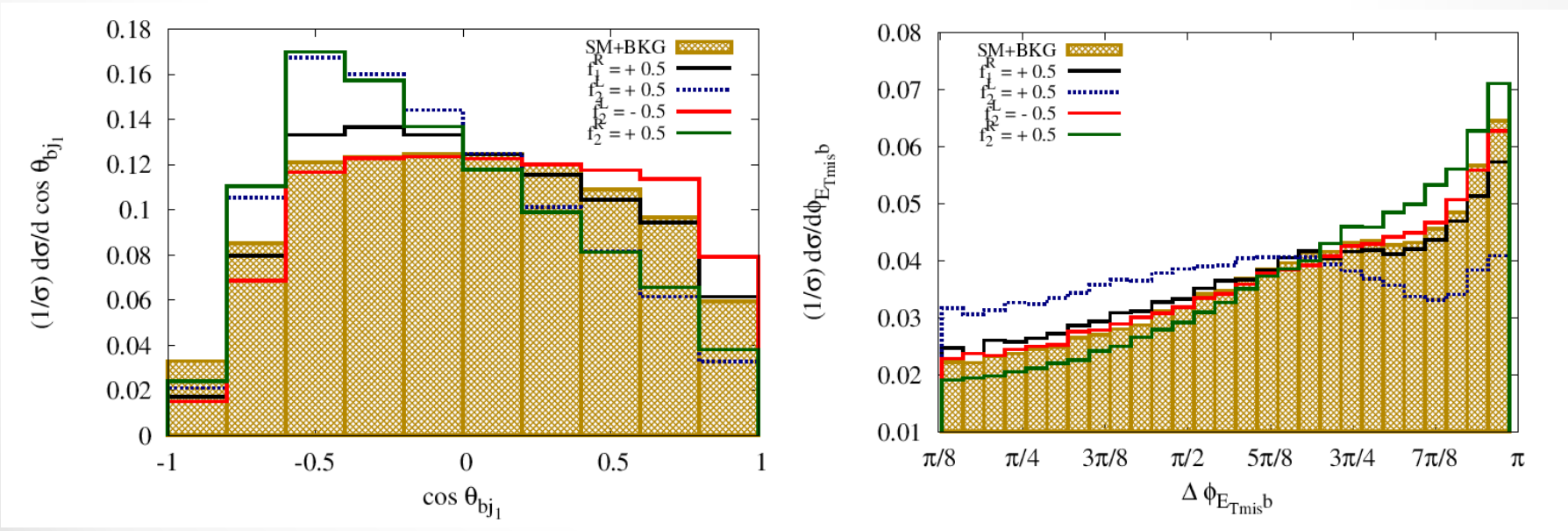
$$\mathscr{L}_{Wtb} = \frac{g}{\sqrt{2}}\Big[W_\mu \bar{t}\gamma^\mu (V_{tb} f_1^L P_L + f_1^R P_R) b - \frac{1}{2\,m_W} W_{\mu\nu}\bar{t}\sigma^{\mu\nu}(f_2^L P_L + f_2^R P_R) b\Big] + h.c.$$

=1 in SM

LH and RH tensor



kinematic observables sensitive to the couplings
free two couplings at a time



anomalous Wtb couplings

Dutta, Goyal, Kumar, Mellado, arXiv:1307.1688 [hep-ph]

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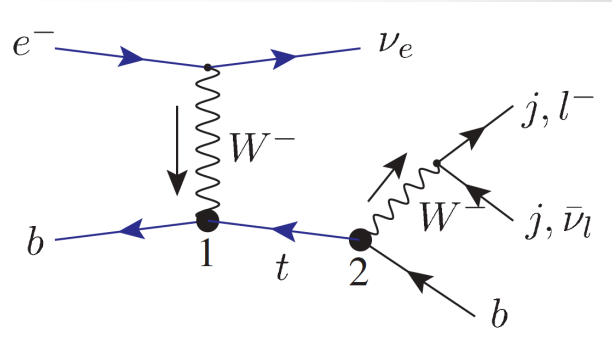
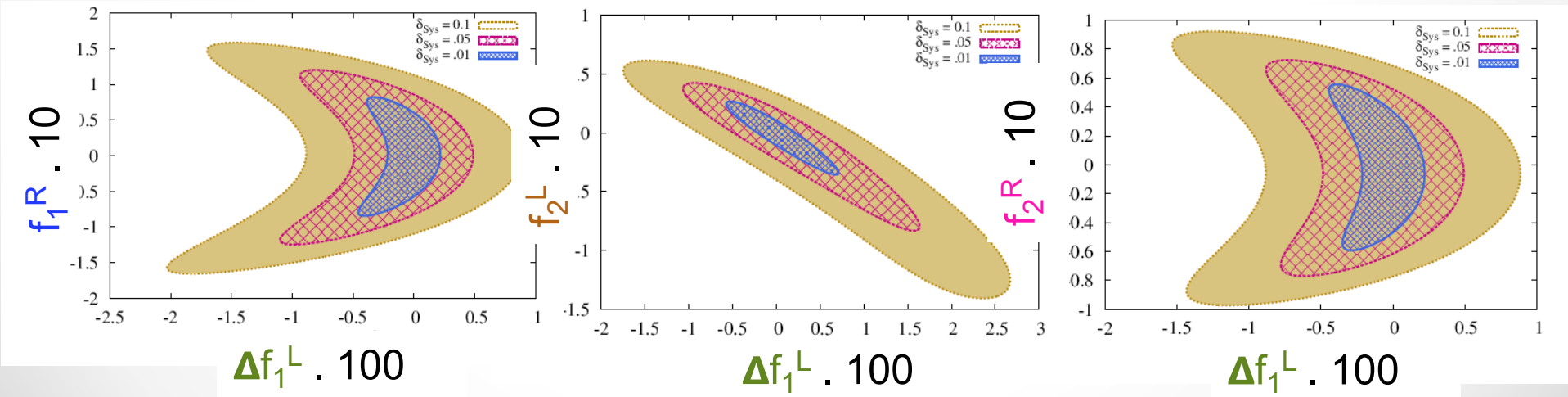
LH and RH tensor



property	precision
f_1^L	0.001 – 0.01
f_1^R, f_2^L, f_2^R	0.01– 0.1

68% CL syst. (1– 10%)

from asymmetry of distributions of kinematic variables

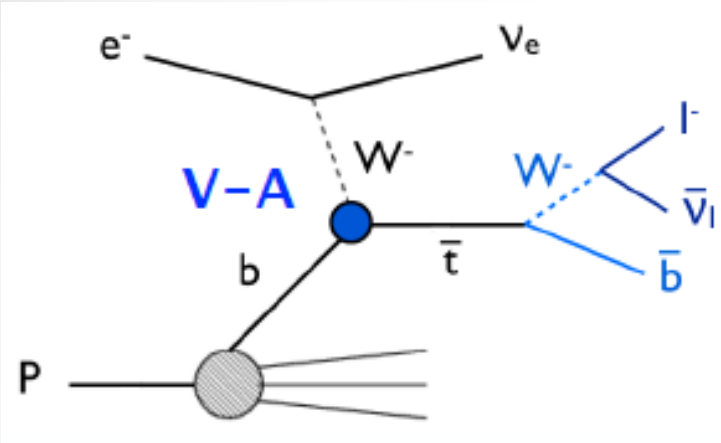


LHeC: hadronic mode

similar sensitivity with leptonic mode

top quark polarisation

Atag, Sahin, PRD 73, 074001 (2006)

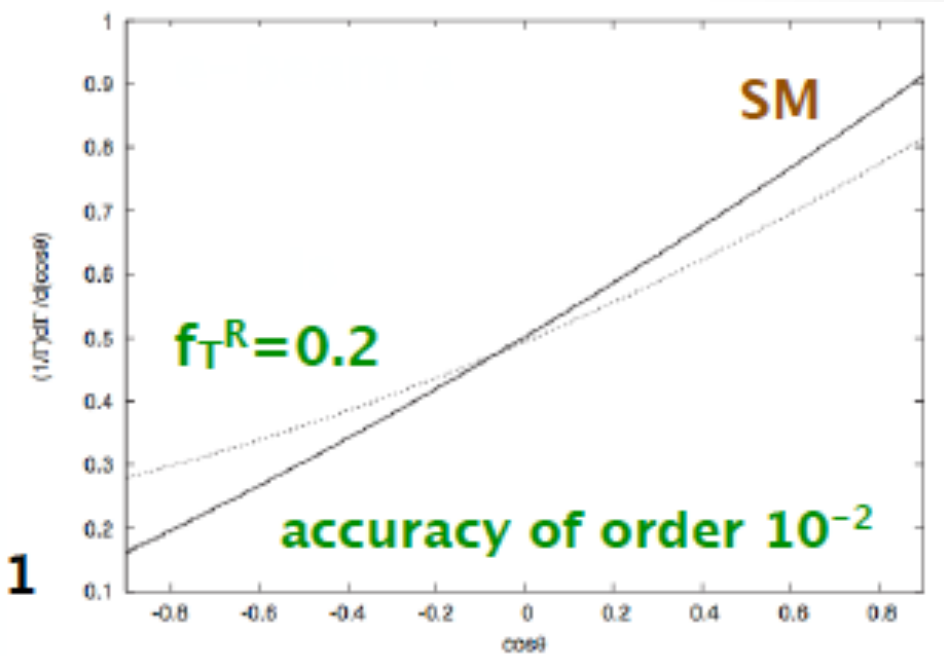


cosθ: angle between charged lepton and spin quantisation axis in top frame

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

using simple e-beam axis

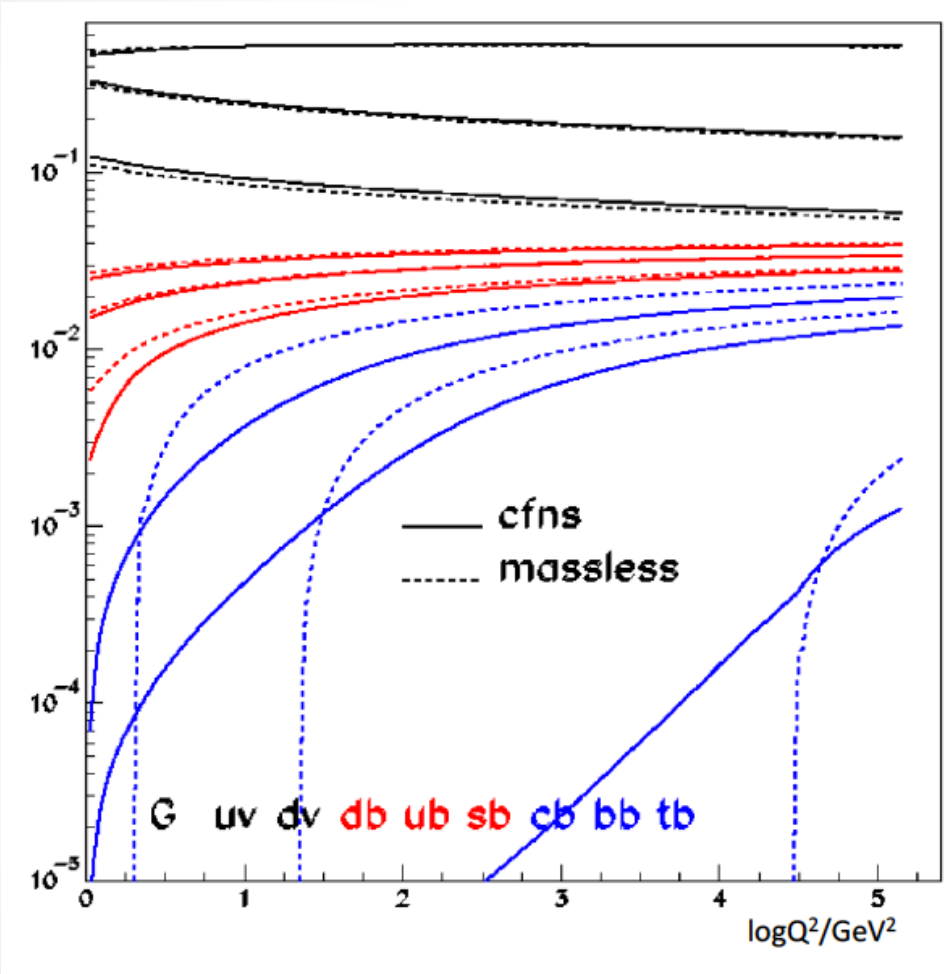
polarisation Pt = 96%

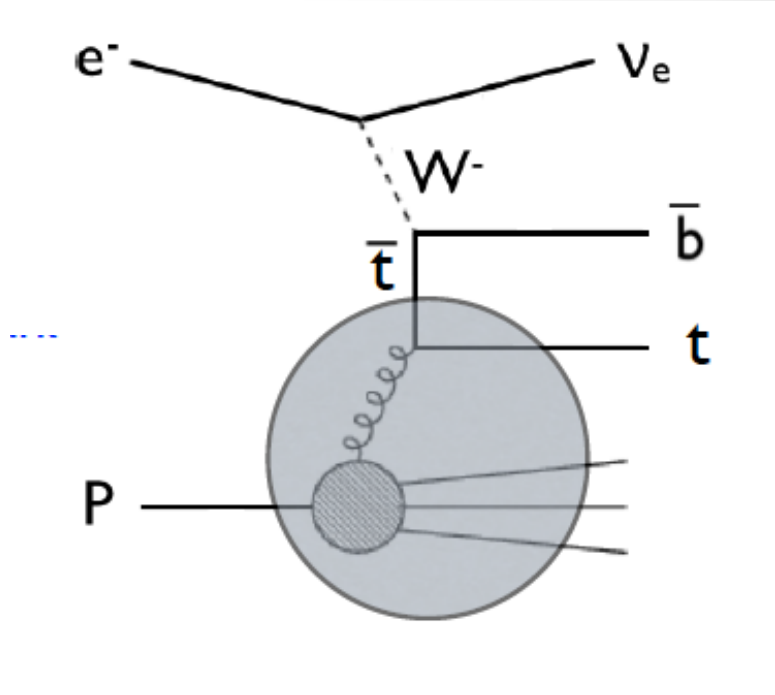


19.7 fb^{-1}: $A_{\uparrow\downarrow}$ = 0.26 ± 0.11

JHEP 04 (2016) 073

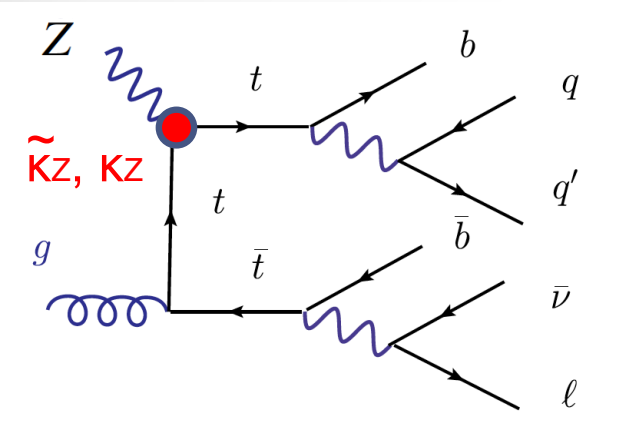
top quark PDF



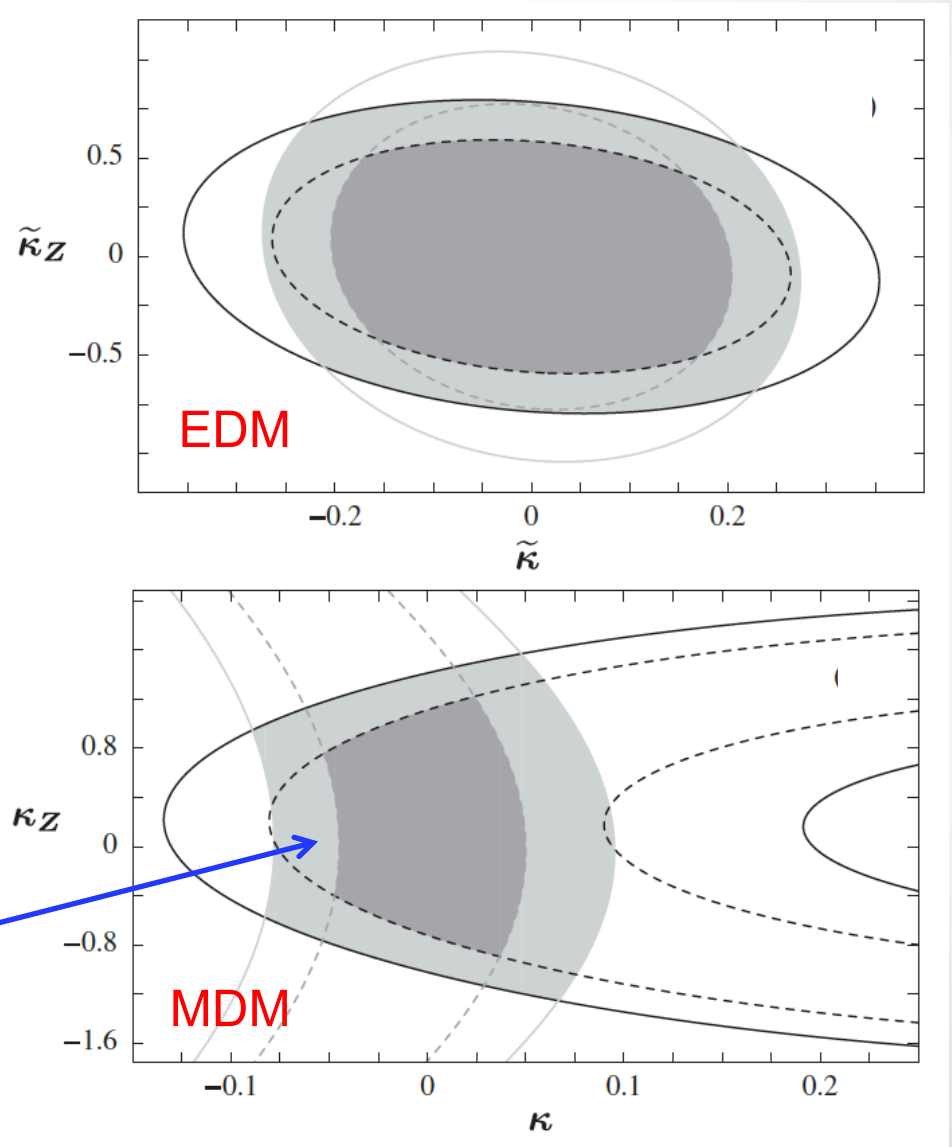


LHeC opens up new field of research for **top PDFs**

search for anomalous ttZ couplings



A. Bouzas, F. Larios, Phys Rev D88 094007 (2013)



property	10% (18%) accuracy
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

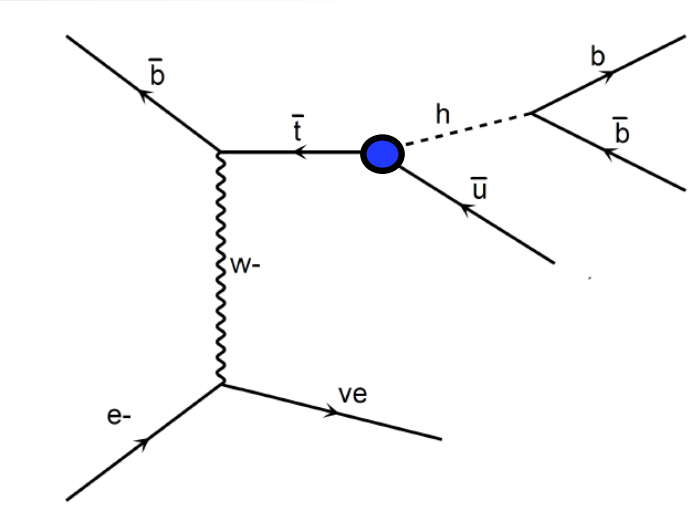
tt photoproduction (grey lines)

tt DIS (black lines)

LHeC: 10% and 18% accuracy

anomalous FCNC tHu coupling

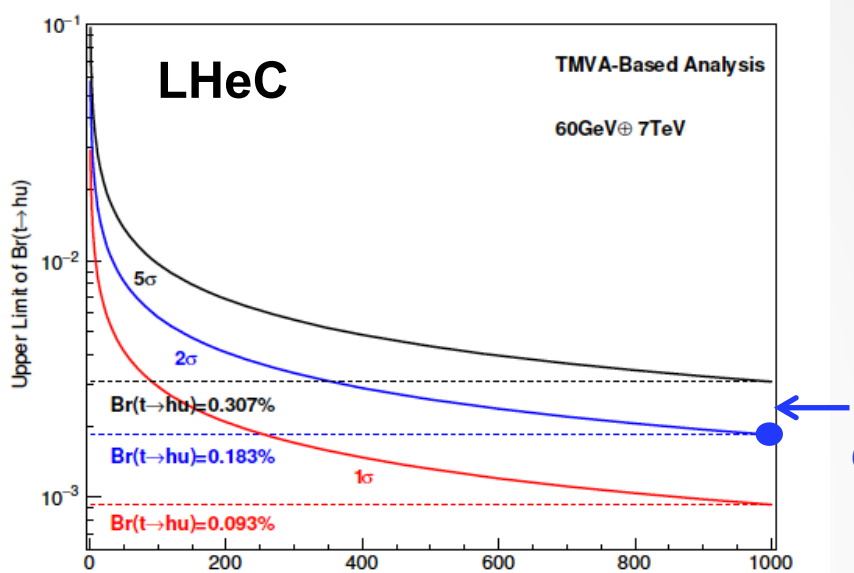
H. Sun, X. Wang, arXiv:1602.04670



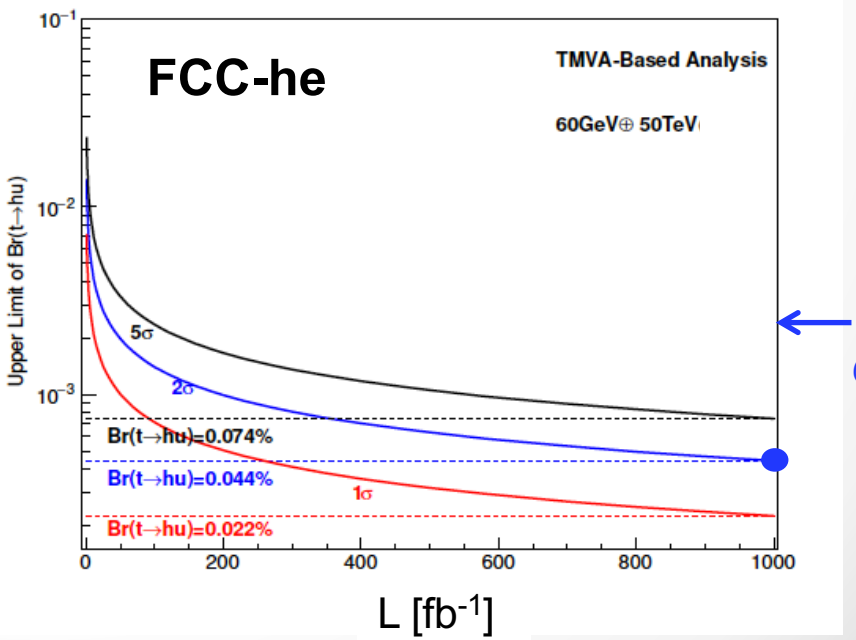
$$e^- p \to \nu_e \bar{t} \to \nu_e h \bar{q} \to \nu_e b \bar{b} \bar{q} \quad q=u,c$$

- object resolutions taken as ATLAS values
- b-tag rate (60%), c- and light-tag fake rates (10% and 1%)
- S/(S+B)$^{1/2}$ optimised for LHeC and FCC-he scenarios
- cut- and MVA-based analyses

improves sensitivity c.f. HL–LHC

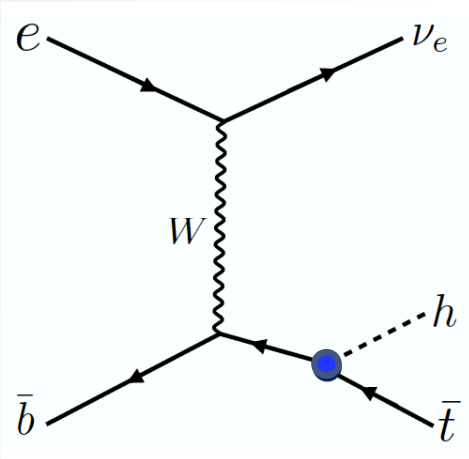


LHC, 3000 fb^{-1} @ 14 TeV



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

CP nature of tH coupling



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

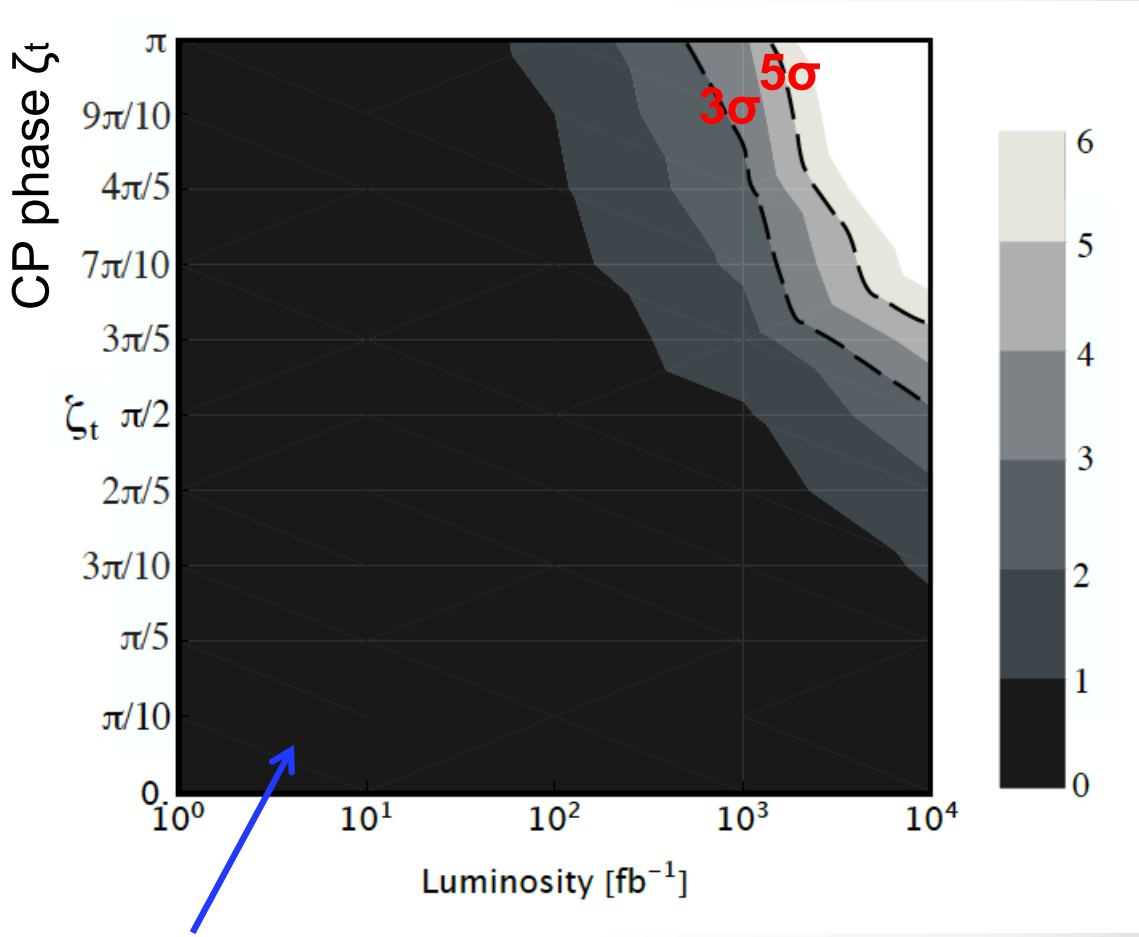
ζ_t = phase of ttH coupling

EG. $\zeta_t = 0, \pi$ (pure scalar); $\zeta_t = \pi/2$ (pure pseudo-scalar)

channel: H⟶bb, t⟶leptonic

LHeC: study new physics contributions to **tH** coupling

Coleppa, S. Kumar, M. Kumar, Mellado (in preparation)



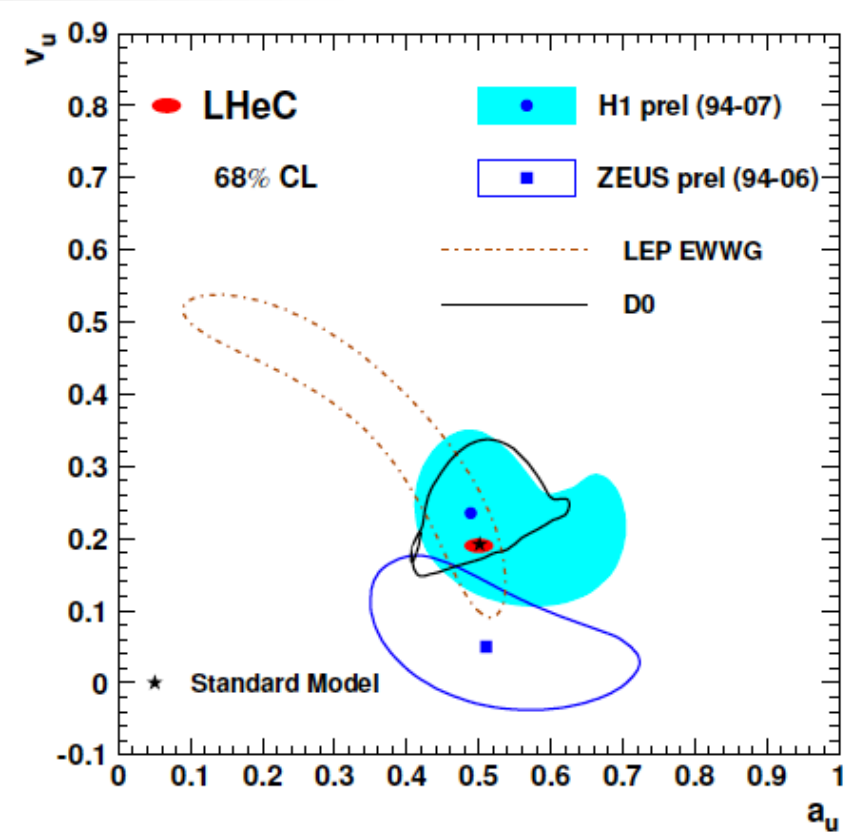
exclusion contour (region above curves excluded)

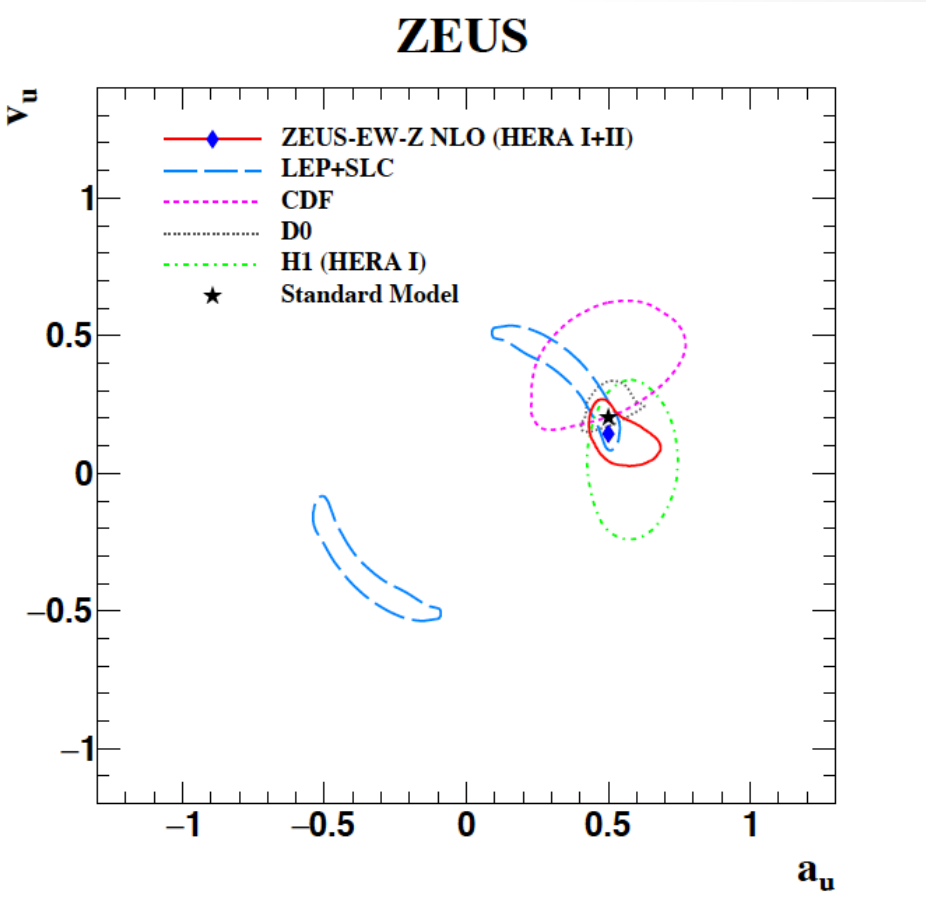
$S/(S+B)^{1/2}$, cross section depends on ζ_t

also studies of ζ_t dependence of various observables

NC vector and axial vector couplings

- most recent constraints from combined analysis of HERA I + II data





ZEUS coll.,
Phys Rev D93 (2016) no.9 092002

NC vector and axial vector couplings

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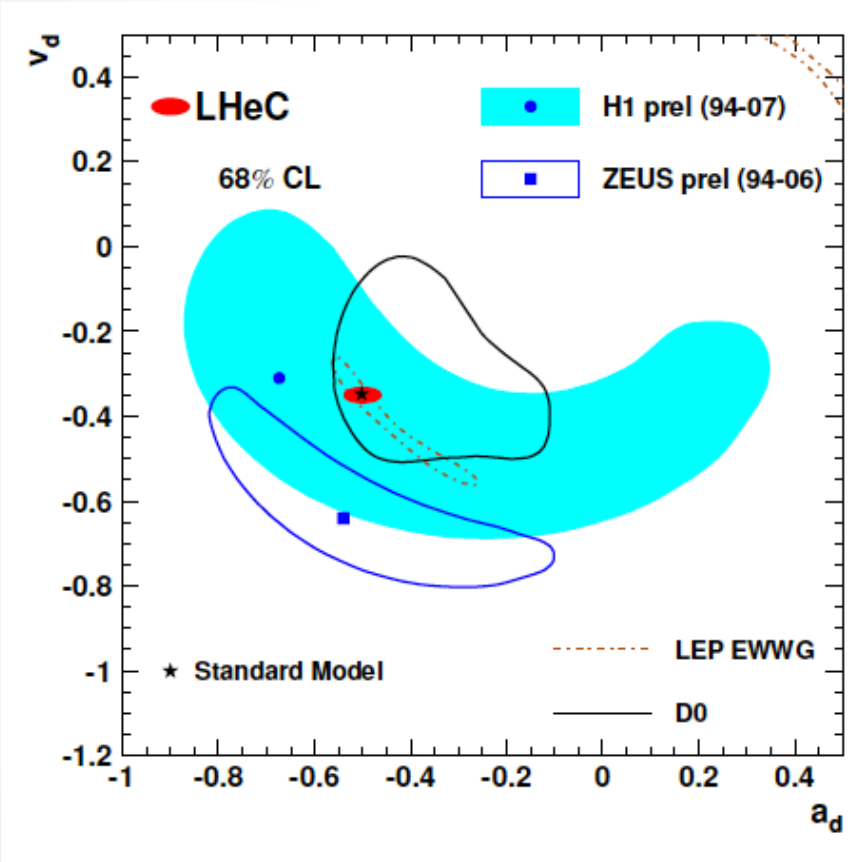

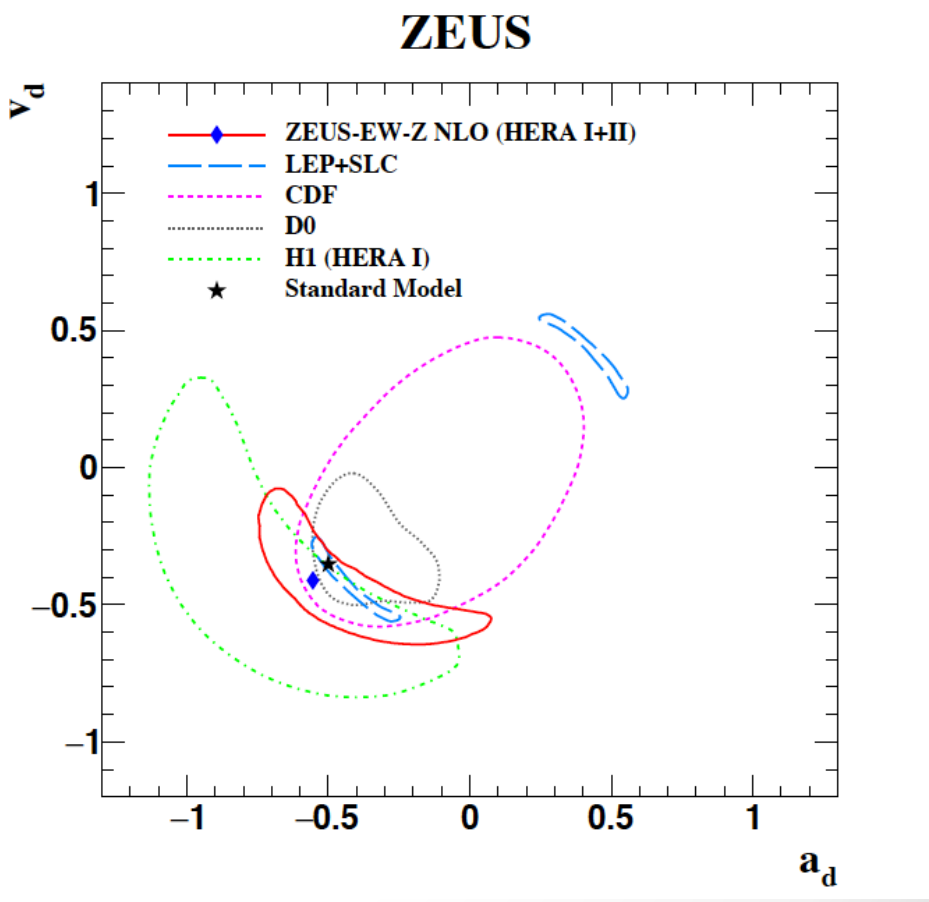

ZEUS coll.,
Phys Rev D93 (2016) no.9 092002