# Physics BSM II

G. Azuelos, M. D'Onofrio and O. Fischer, for BSM team

ELECTRONS FOR THE LHC: Workshop on the LHeC, FCC-eh and PERLE

24-25 October 2019, Chavannes de Bogis

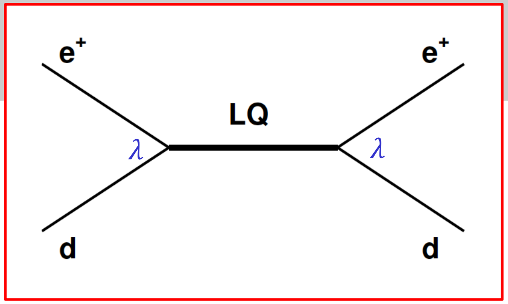
https://indico.cern.ch/event/835947/

# Outline

- Leptoquarks
- Charged Higgs
- SUSY
- Triple Gauge Couplings
- Axion-Like Particles
- Vector-Like Quarks
- heavy fermions
- Anomalous top couplings → see Christian Schwanenberger's talk

*more on backup slides...*

# Leptoquarks




- Large section on LQ's in 2012 CDR
  - produced in s- and t/u channels
    - analyzed with CalcHep model provided by A. Belyaev
    - now complete UFO models for MadGraph, …
      Vector LQ Model, http://feynrules.irmp.ucl.ac.be/wiki/LeptoQuark
      VecLepQrk, http://feynrules.irmp.ucl.ac.be/wiki/VecLepQrk, arXiv:1901.10480
      LQ_NLO: https://lqnlo.hepforge.org, arXiv:1801.07641
  - LQ properties
    - fermion number, charge, *much more sensitive than at LHC, from sign and size of asymmetry (need both $e^+$ and $e^-$, coupling to $q$ or $\bar{q}$)*

$$\mathcal{A}_{ep} = \frac{\sigma_{prod}(e^+p) - \sigma_{prod}(e^-p)}{\sigma_{prod}(e^+p) + \sigma_{prod}(e^-p)}$$

    - spin, *(scalar of vector) from angular distribution*
    - sensitivity to $\lambda$ = LQ-e-q coupling
    - chiral structure, *with polarized beams* ($e_L^- p$ *vs* $e_R^- p$)
  - scalar LQ possible interpretation as R-parity violating squark decay
  - contact term for high mass
  - leptogluons

# Classification of LQ's

I. Doršner et al., 1603.04993

fermion number

| $(SU(3), SU(2), U(1))$ | Spin | Symbol | Type | $F$ |
|---|---|---|---|---|
| $(\overline{\mathbf{3}}, \mathbf{3}, 1/3)$ | 0 | $S_3$ | $LL\,(S_1^L)$ | $-2$ |
| $(\mathbf{3}, \mathbf{2}, 7/6)$ | 0 | $R_2$ | $RL\,(S_{1/2}^L)$, $LR\,(S_{1/2}^R)$ | 0 |
| $(\mathbf{3}, \mathbf{2}, 1/6)$ | 0 | $\tilde{R}_2$ | $RL\,(\tilde{S}_{1/2}^L)$, $\overline{LR}\,(\tilde{S}_{1/2}^L)$ | 0 |
| $(\overline{\mathbf{3}}, \mathbf{1}, 4/3)$ | 0 | $\tilde{S}_1$ | $RR\,(\tilde{S}_0^R)$ | $-2$ |
| $(\overline{\mathbf{3}}, \mathbf{1}, 1/3)$ | 0 | $S_1$ | $LL\,(S_0^L)$, $RR\,(S_0^R)$, $\overline{RR}\,(S_0^{\overline{R}})$ | $-2$ |
| $(\overline{\mathbf{3}}, \mathbf{1}, -2/3)$ | 0 | $\bar{S}_1$ | $\overline{RR}\,(\bar{S}_0^R)$ | $-2$ |
| $(\mathbf{3}, \mathbf{3}, 2/3)$ | 1 | $U_3$ | $LL\,(V_1^L)$ | 0 |
| $(\overline{\mathbf{3}}, \mathbf{2}, 5/6)$ | 1 | $V_2$ | $RL\,(V_{1/2}^L)$, $LR\,(V_{1/2}^R)$ | $-2$ |
| $(\overline{\mathbf{3}}, \mathbf{2}, -1/6)$ | 1 | $\tilde{V}_2$ | $RL\,(\tilde{V}_{1/2}^L)$, $\overline{LR}\,(\tilde{V}_{1/2}^R)$ | $-2$ |
| $(\mathbf{3}, \mathbf{1}, 5/3)$ | 1 | $\tilde{U}_1$ | $RR\,(\tilde{V}_0^R)$ | 0 |
| $(\mathbf{3}, \mathbf{1}, 2/3)$ | 1 | $U_1$ | $LL\,(V_0^L)$, $RR\,(V_0^R)$, $\overline{RR}\,(V_0^{\overline{R}})$ | 0 |
| $(\mathbf{3}, \mathbf{1}, -1/3)$ | 1 | $\bar{U}_1$ | $\overline{RR}\,(\bar{V}_0^R)$ | 0 |

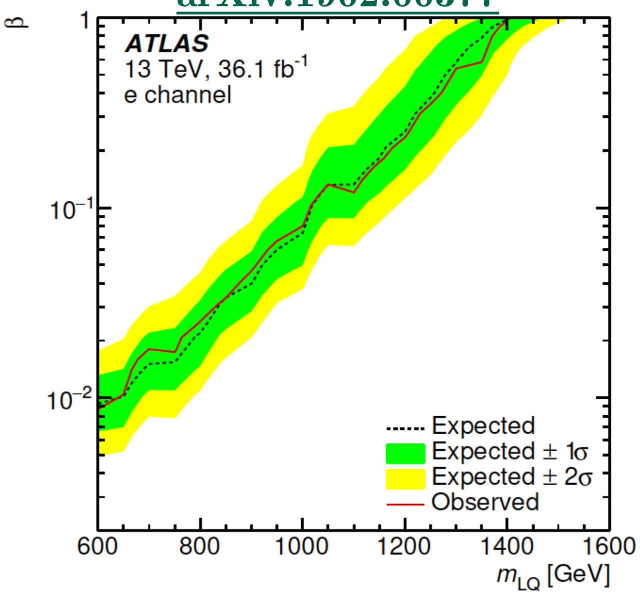
example: doublet in SU(2) ➔ $Q_R$ x $L_L$ ➔ Y= (-2/3, 1/3) -1/2 = (-7/6, -1/6)
or $Q_L$ x $L_R$ ➔ Y = -1/6 + (0, – 1) = (-1/6, -7/6)

$R_2: (3, 2, 7/6)$, $\tilde{R}_2: (3, 2, 1/6)$

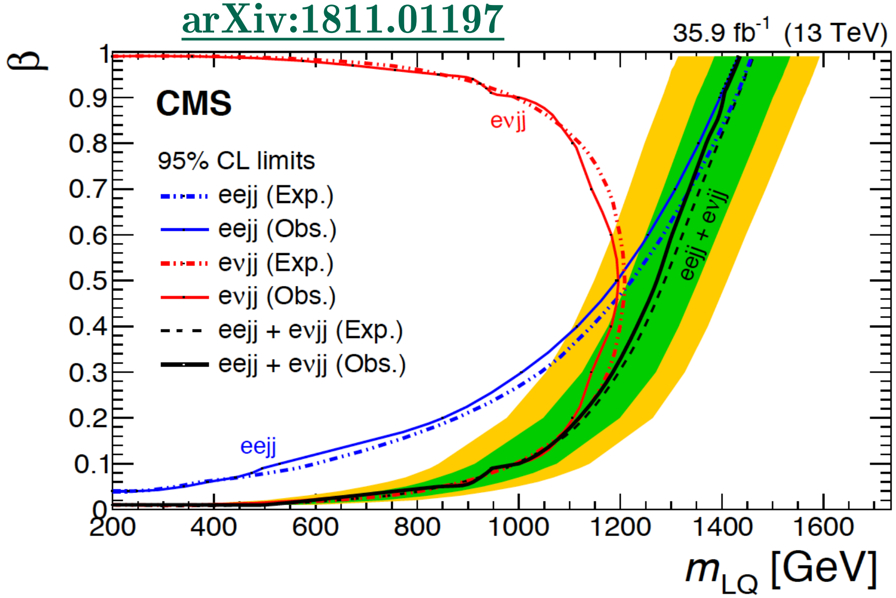
charge of $\tilde{R}_2$ : $Q = I_3 + Y = \left(\frac{1}{2}, -\frac{1}{2}\right) + \frac{1}{6} = \left(\frac{2}{3}, -\frac{1}{3}\right) \Rightarrow \bar{d}_R e_L, \bar{d}_R \nu_L, \bar{u}_L \nu_R, \bar{d}_L \nu_R + anti$

# LHC present limits

arXiv:1902.00377

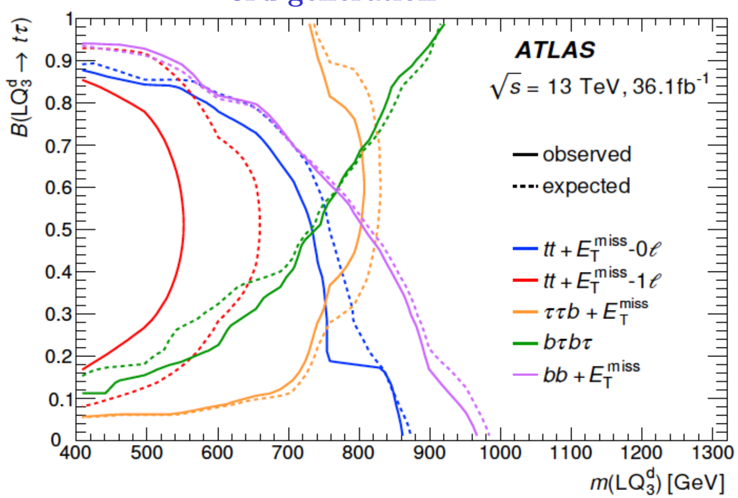



arXiv:1811.01197




arXiv:1902.08103 charge -1/3 (down-type)

3rd generation




- exclusion up to ~1-1.4 TeV if BR to charged lepton =1

  → *but poorer mass limit for small β*

*(β normally fixed in standard classification)*

- ✸ Probing Leptoquark and Heavy Neutrino at LHeC,

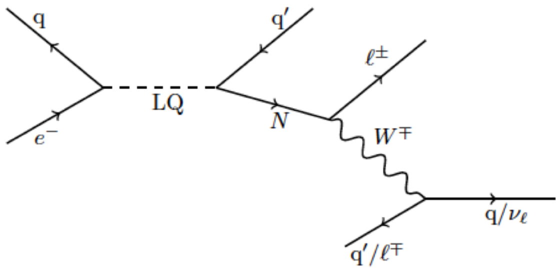
  S. Mandal, N. Sinha and M. Mitra, arXiv:1807.06455

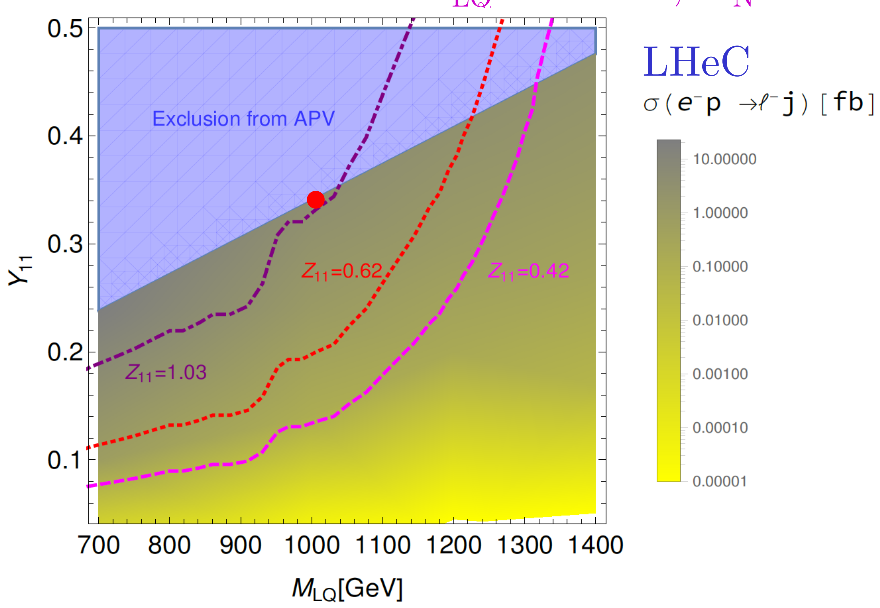
  *analysis based on 150 GeV x 7 TeV,*

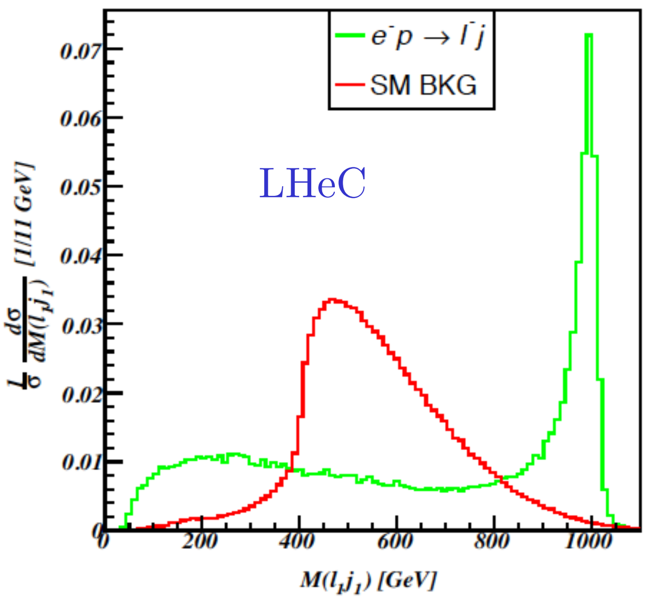
  *authors kindly agreed to update to 60 GeV x 7 TeV and 60 GeV x 50 TeV*

  - include possibility of RH neutrinos (3 generations)
    - LQ can decay to $e+j$, $\nu+j$ or $N+j$

      $$\mathcal{L} = Y_{ij}\bar{d}^i_R \tilde{R}^a_2 \epsilon^{ab} L^{j,b}_L + Z_{ij}\bar{Q}^{i,a}_L \tilde{R}^a_2 N^j_R$$
  - include t-channel production
  - simulation with MadGraph/Pythia6/Delphes
  - benchmark: $M_{LQ}$ = 1 TeV, $m_N$ = 100 GeV, $Y_{11}$ = 0.34, $Z_{11}$ = 1.03



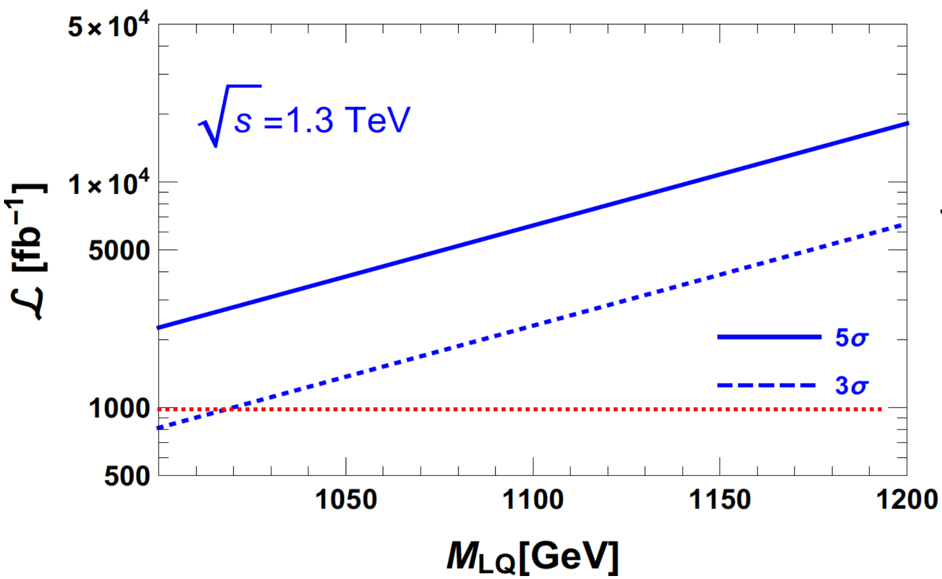
# Sensitivity, lj signal

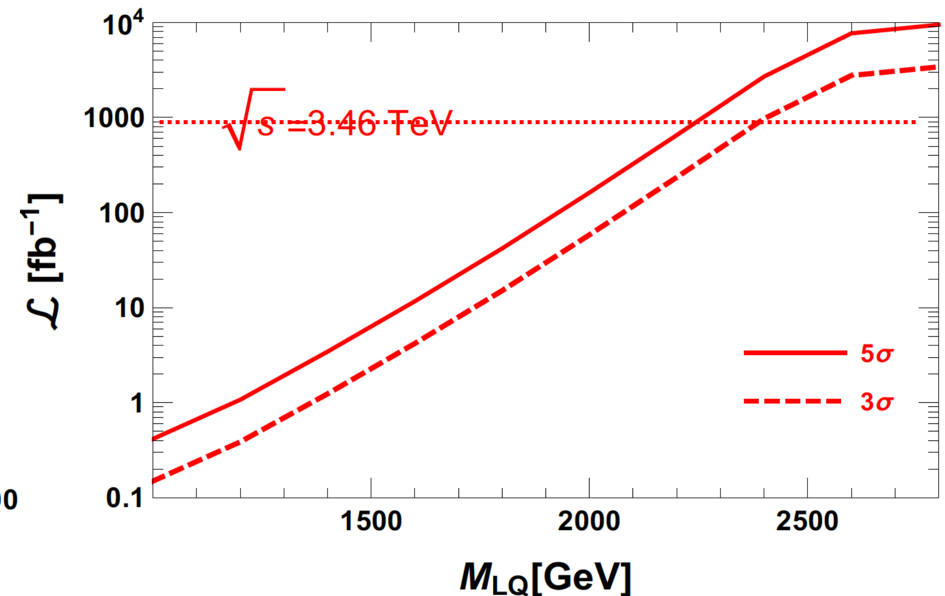
- cuts
  - $N_j > 1$, $N_l > 1$
  - $PT(l) > 400$ GeV
  - $PT(j) > 400$ GeV
  - $|M_{LQ}-M_{lj}| < 100$ GeV

benchmark point

$m_N = 100$ GeV,
$Y_{11} = 0.34$,
$Z_{11} = 1$.

*Br(N→W) : Br(N→Z) : Br(N→H) ≈ 0.6:0.3:0.1*

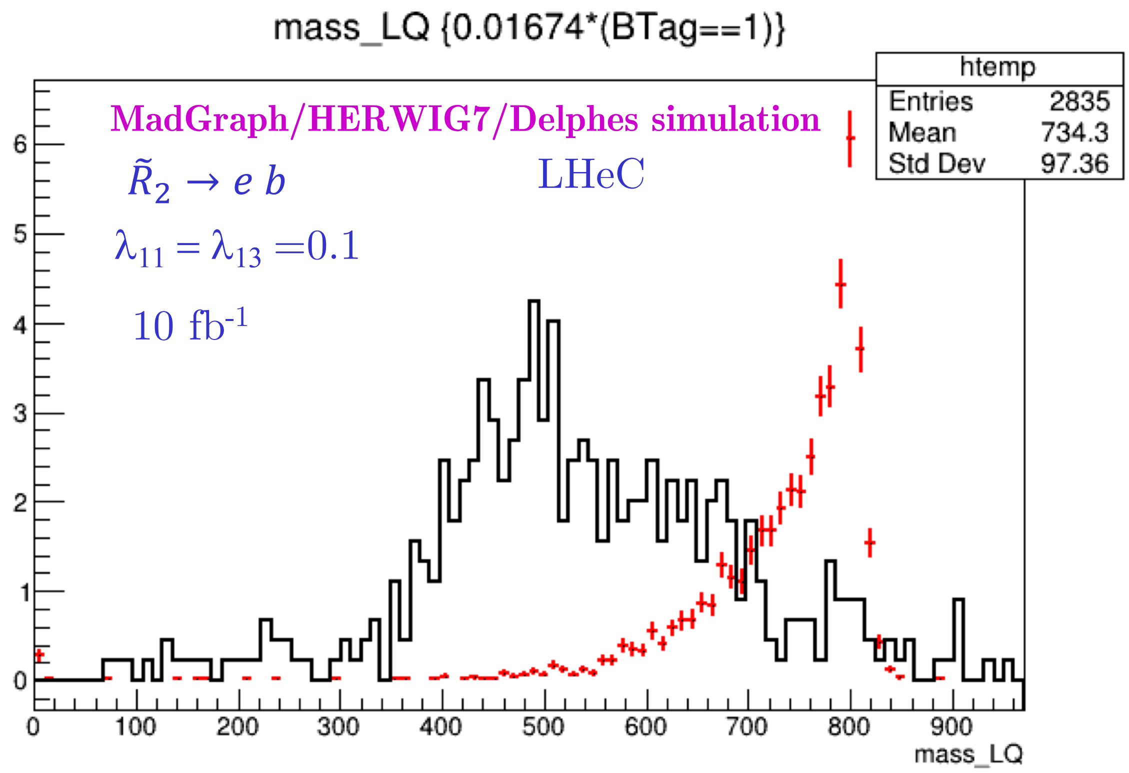



*3σ significance of 1020 GeV at LHeC and 2400 GeV at FCC-eh*

# *Assuming generation crossing: coupling to 1st and 3rd generation*

$\tilde{R}_2$ mass = 800 GeV, → e/b, pt(l)>100 GeV
pt(el)> 200 GeV and pt(jet)>200 GeV for background



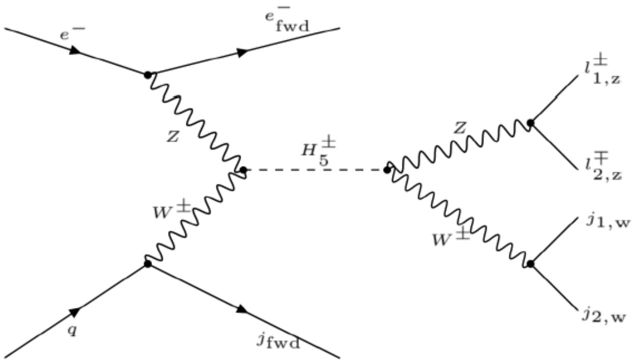

With 1 $ab^{-1}$ at LHeC, and
$750 < |M_{eb}| < 850$

S = 2640
B = 650

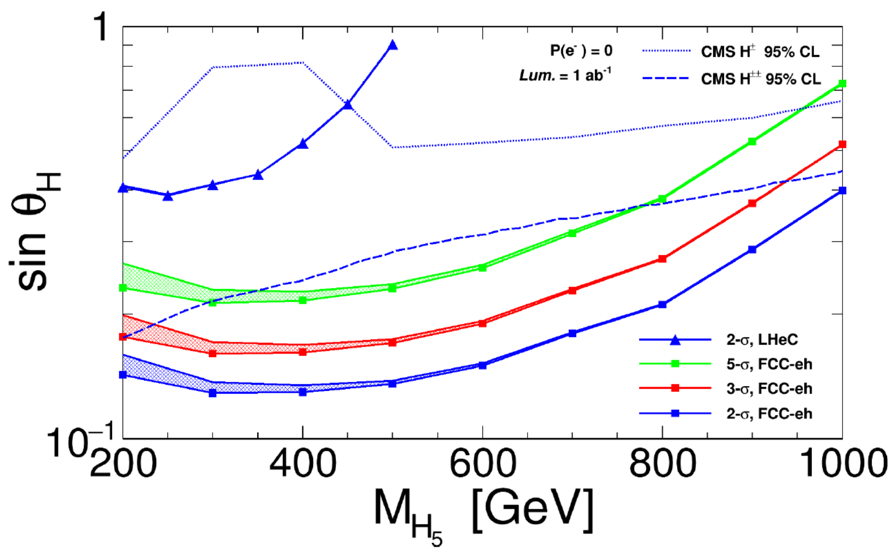
S/sqrt(B) = 103
→ *exclude with 95 % CL up to* $\lambda = 0.014$

# Charged Higgs, Georgi-Machacek model

G.A., H. Sun and K. Wang, arXiv:1712.07505



- Extended Higgs sector, with isospin triplets, satisfying custodial symmetry
  - ➔ $\rho = \frac{M_W^2}{M_Z^2 \cos\theta_W} = 1$ at tree level
- Higgs bidoublet and two triplets (one real and one complex) arranged as a bitriplet
- physical spectrum includes fiveplet $(H_5^{++}, H_5^{+}, H_5^{0}, H_5^{-}, H_5^{--})$ which does not couple to fermions
  - ➔ only produced by VBS
- parameters:
  - mass of $H_5$
  - mixing angle $s_H = \sin\theta_H$



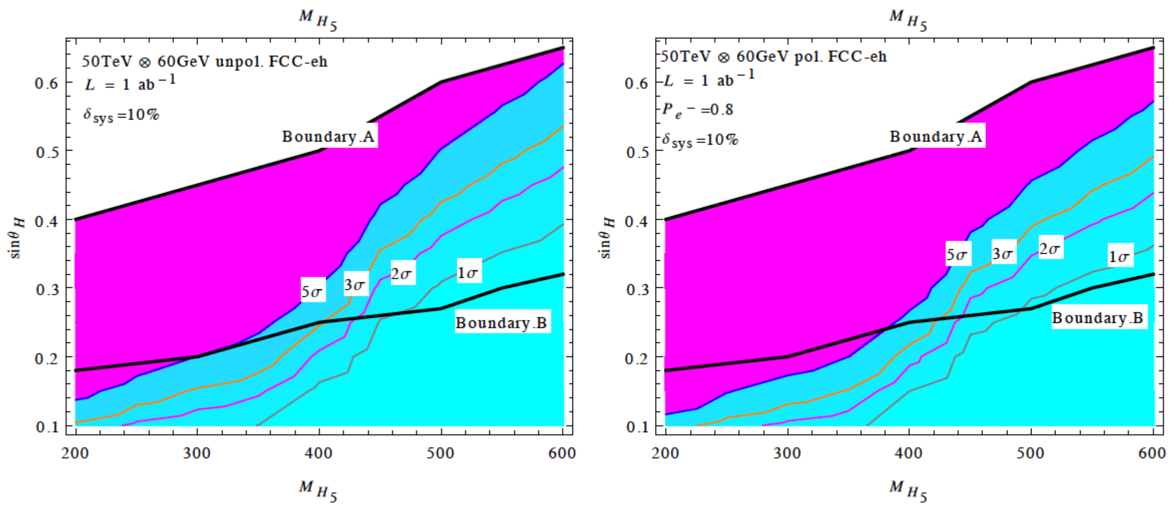

Analysis based on Delphes detector siumlatio[n] and BDT signal optimization

# Charged Higgs

- $e^- p \to \nu H^{\pm\pm} q,\ H^{\pm\pm} \to W^{\pm} W^{\pm}$ in GM model

  **H. Sun, et al., arXiv:1710.06284**

  - LHeC: 2−3σ at LHeC for $M_{H_5} < 300$ GeV and $\sin\theta_H < 0.2$
  - more sensitivity for small $\sin\theta_H$ at FCC−eh, unpolarized and polarized beams




- $e^- p \to \nu H^+ q,\ \ H^+ \to c\bar{b}$ in 2HDM, type III

  **J. Hernandez-Sanchez et al., arXiv:1612.06316**

  - flavour-violating decays, with FCNC's controlled in Yukawa Lagrangian
  - 3σ with 100/fb for mass 100-200 GeV

- $e^- b \to \nu H^+ b,\ \ H^{\pm} \to sc + su$ in NMSSM at FCC-eh

  **A.P. Das et al., arXiv:1806.08361**

  - additional singlet S, looking for light charged Higgs
  - 4.4(2.2)σ with 1/ab for mass of 114(121) GeV

# Electroweakinos in compressed scenarios

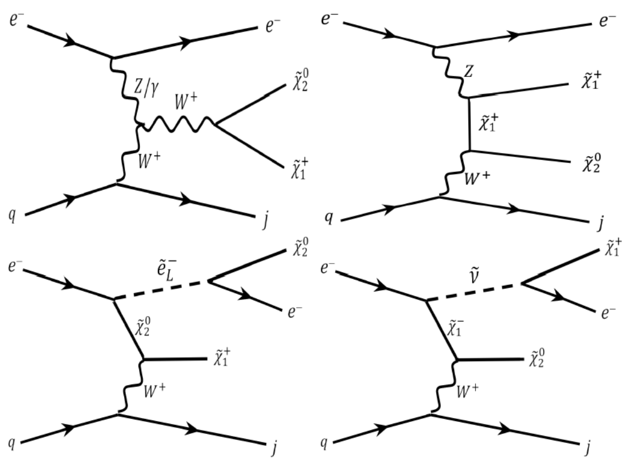
- compressed scenario (small $\Delta m(\tilde{\chi}_1^\pm/\chi_2^0,\ \chi_1^0)$)
  - assume ~ degenerate $\tilde{\chi}_1^\pm/\chi_2^0$
  - difficult to investigate at LHC because of soft decay products and large background
  - sleptons, $\tilde{\ell}$, could be also NLSP

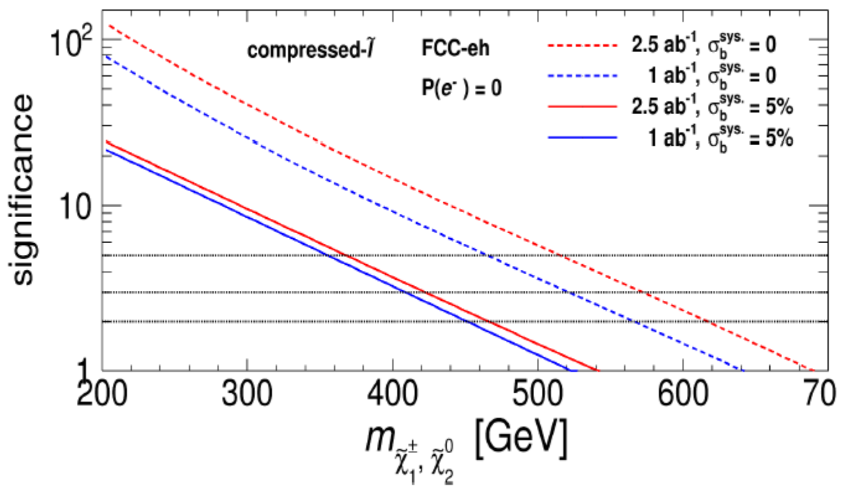
**G.A., M. D'Onofrio, K. Wang, TBP**

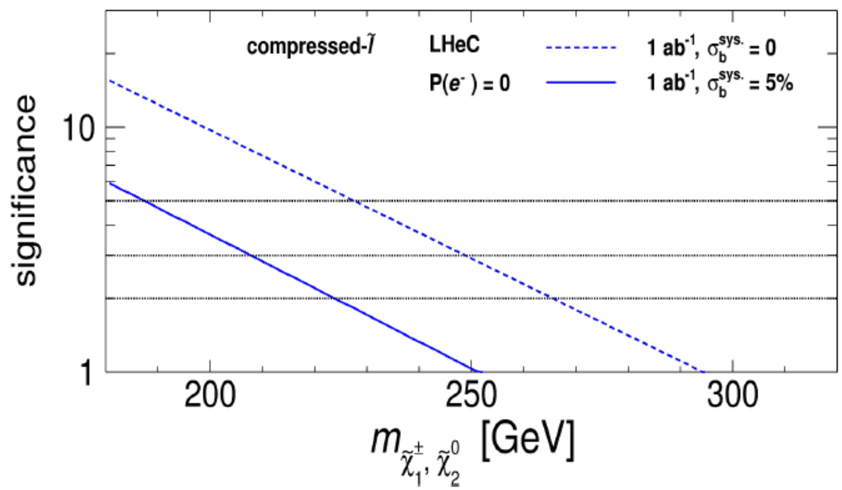
- study based on BDT
  - benchmark: $\Delta m = m_{\tilde{\ell}} - m_{\tilde{\chi}_1^\pm,\tilde{\chi}_2^0} = 35$ GeV

    $m_{\tilde{\chi}_1^\pm,\tilde{\chi}_2^0} - m_{\tilde{\chi}_1^0} = 1$ GeV

    $\tilde{\chi}_1^0$ is Bino, $\tilde{\chi}_1^\pm, \tilde{\chi}_2^0$ are Wino
  - limits on $\tilde{\chi}$ mass
    - LHeC: ~ 220 GeV, with 5% syst. uncertainty
      $\gtrsim$ LHC limit
    - FCCeh: ~ 450 GeV, with 5% syst. uncertainty
    - HL-LHC: ~ 400 GeV





# more SUSY

- Light Higgsinos in compressed spectrum

  **C. Han et al., arXiv:1802.03679**

  - decoupled scenario (heavy slepton)
  - LHeC: $2\sigma$ for mass=115 GeV, 1 $ab^{-1}$
- non-prompt decay, for nearly degenerate $\tilde{\chi}^{\pm} - \tilde{\chi}^{0}$ → see Oliver's talk

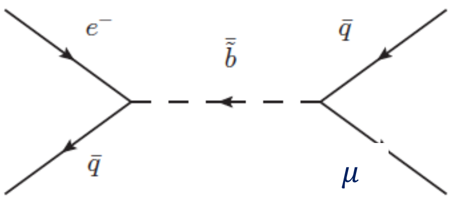
  **D. Curtin, K. Deshpande, O. Fischer and J. Zurita, arXiv:1712.07135**

  - exploit displaced vertex from soft hadronic final state, low background
- RPV, resonant production of $\tilde{b}$

  **S. Kuday, arXiv:1304.2124**

  **(also R. Zhang et al., with 150 GeV e- beam)**

  - constraints on $\hat{L}\hat{Q}\hat{D}$ couplings $\lambda'_{113}$, $\lambda'_{123}$, $\lambda'_{231}$, $\lambda'_{232}$
    - present bounds: 0.18, 0.45 (Barbier et al.)
    - couplings extended to 0.001 with 1/fb for low $\tilde{b}$ mass




$e^- p \to \tilde{b} \to \mu q$

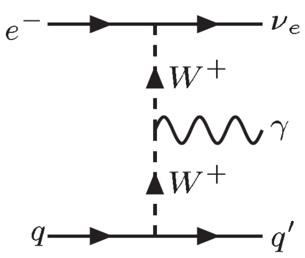
- prompt decay of low mass gluinos: 50-70 GeV

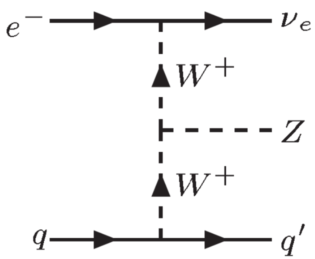
  **D. Curtin, K. Deshpande, O. Fischer and J. Zurita, arXiv:1812.01568**

  - RPV or stealth SUSY, multiple soft jets ➔ hadronic noise at LHC
  - 95% exclusion with simple cuts, at LHeC, 1/ab, with 1% syst. error

# Triple Gauge Couplings

- $WW\gamma$, $WWZ$ coupling with polarized beam
  - **I.T. Cakir et al., arXiv:1406.7696**
  - **S. Biswal, M. Patra and S. Raychaudhuri, arXiv:1405.6056** *(for 140 GeV e beam)*



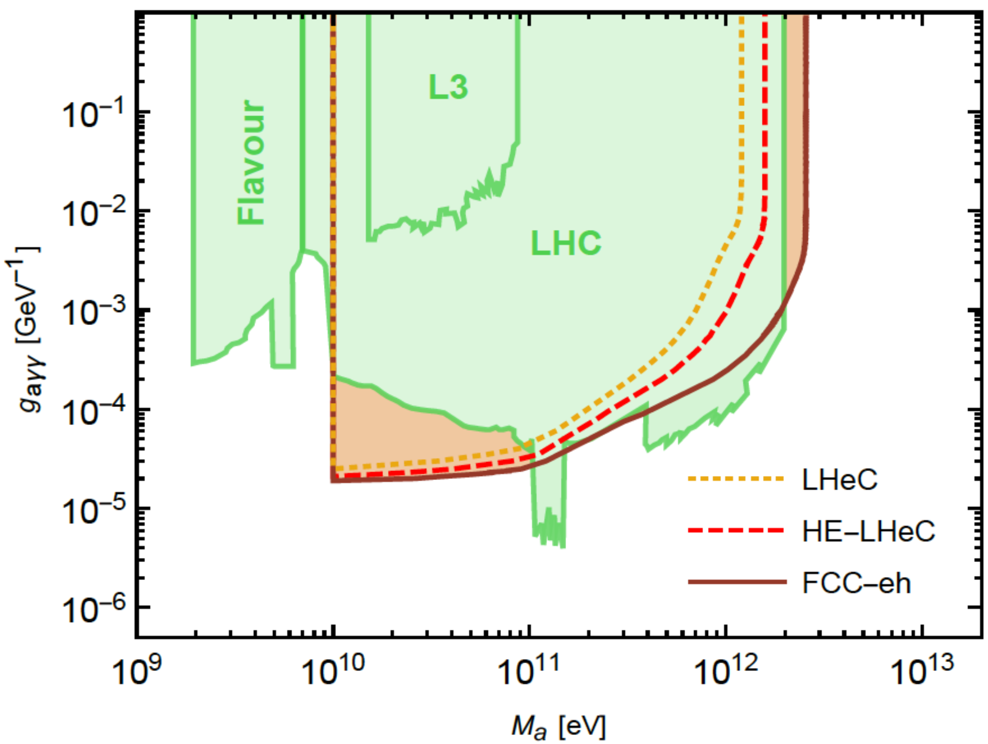

  - in VBF, no interference between the two, *(unlike LHC: $qq \rightarrow Z/\gamma^* \rightarrow WW$)*
  - limits at LHeC, 100/fb comparable to current limits for WWγ
  - improved limits for WWZ coupling
  - $\Delta\phi(jet, MET)$ distribution sensitive to WWγ couplings
- $WW\gamma$ with process $e^- p \rightarrow e^-(W^+ \rightarrow \mu^+\nu)\, j$
  - **R. Li et al., arXiv:1711.05607**
  - exploit azimuthal ang. distributions and W polarization
  - $\lambda_\gamma$ and $\Delta k_\gamma \sim \mathcal{O}(10^{-3})$ for $L = 2 - 3\ ab^{-1}$, comparable or better than LHC and LEP

- ALP: pseudoscalar particles, low mass
  - possible dark matter, or mediator to dark sector
  - pNBG in composite models
  - decay into photons, leptons, hadrons

$$e^-\gamma \to e^- a, \qquad a \to \gamma\gamma$$

**C-X Yue, M-Z liu and Y-C Guo, arXiv:1904.10657**

*exclude 10 GeV – 1(3) TeV at LHeC(FCC-eh)*



# Vector-like quarks

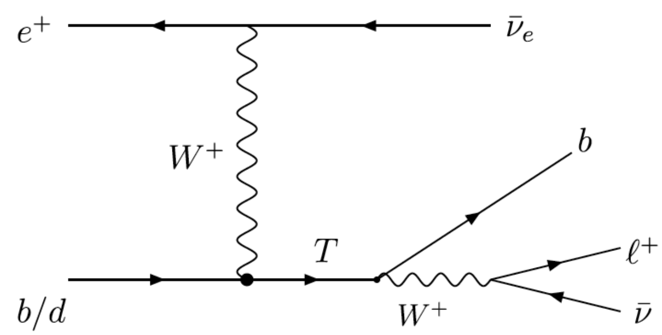
- VLQ's predicted in composite-Higgs models
  - cancel quadratic divergences in Higgs mass (hierarchy problem)
  - third generation coupling most important
  - produced in pair at LHC ➔ independent of coupling
- At LHeC/FCC-eh
  - $e^- p \to T(\to tZ)\nu_e;\quad t \to Wb \to jjb,\ Z \to \ell^+\ell^-$

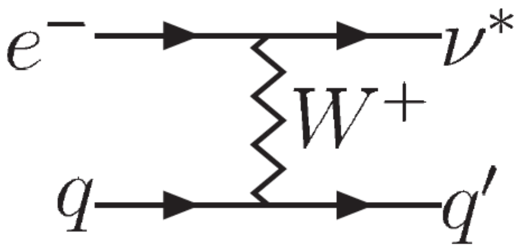
    **Y-J Zhang, L. Han & Y-B Liu, Physics Letters B 768 (2017) 241**
  - $e^- p \to T(\to bW^+)\nu_e;\quad W^+ \to \ell^+\bar{\nu}_\ell$

    **L. Han, Y-J Zhang & Y-B Liu, Physics Letters B 771 (2017) 106**
  - $e^- p \to T(\to th)\nu_e;\quad t \to Wb \to jjb,\ h \to bb$ (also $T \to bW^+$)

    **Y-B Liu, arXiv:1704.02059**

LHeC: (140 GeV polarized e- beam)
- *generation mixing enhances cross section*
- *with 1/ab, $3\sigma$ sensitivity to coupling:*
  *$g^* \sim 0.1$ even with no generation mixing*






- gauge mediated

$$\mathcal{L} = \frac{1}{2\Lambda}\bar{F}_R^*\sigma^{\mu\nu}\left[gf\frac{\vec{\tau}}{2}\overrightarrow{W}_{\mu\nu} + g'f'\frac{Y}{2}B_{\mu\nu}\right]F_L$$

  - typically, take as reference: $m^* = \Lambda$, $f = \pm f'$
  - at FCC-eh, $e^- p \to e^* X \to e\gamma X$,
    - 3σ significance for a mass (e*) of 2.4 TeV, 100 fb$^{-1}$, $f=f'$, $\Lambda=m^*$
      **A. Caliskan & S.O. Kara, arXiv:1806.02037**
  - spin 3/2 $\nu^* \to eW$: consider pseudoscalar and pseudovector fermion
    **A. Ozansoy, V. Arı, & V. Çetinkaya, arXiv:1607.04437**
  - current limit:
    ATLAS, 3-lepton signal: m(ν*) > 1.6 TeV, m(l*) > 3.0 TeV
- contact interaction, lepton-quark compositeness
  - quark radius extracted from measured form factor of charge distribution
    - LHeC: $\leq 10^{-19}$ m with 100 fb$^{-1}$ **(Zarnecki, arXiv:0809.2917)**
  - mass scale of contact interactions
    - LHeC: ~ 65 TeV
    - sign of interference at LHC from asymmetry $e^+p$ vs $e^-p$

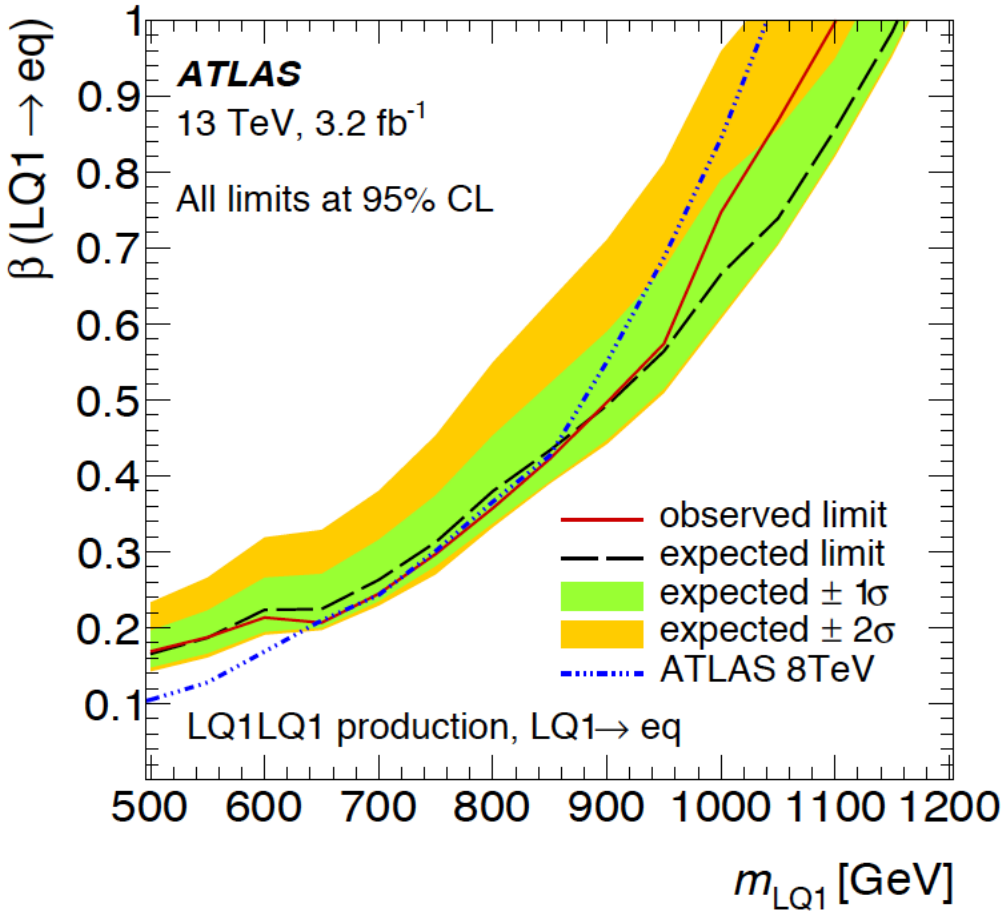
# Conclusion

*Thanks to*
*clean environment, low pileup, no gluon exchange diagrams,*

*LHeC can probe sensitive regions of phase space difficult of access at LHC*
*and complement results from LHC*

*FCC-eh opens higher energy regime*

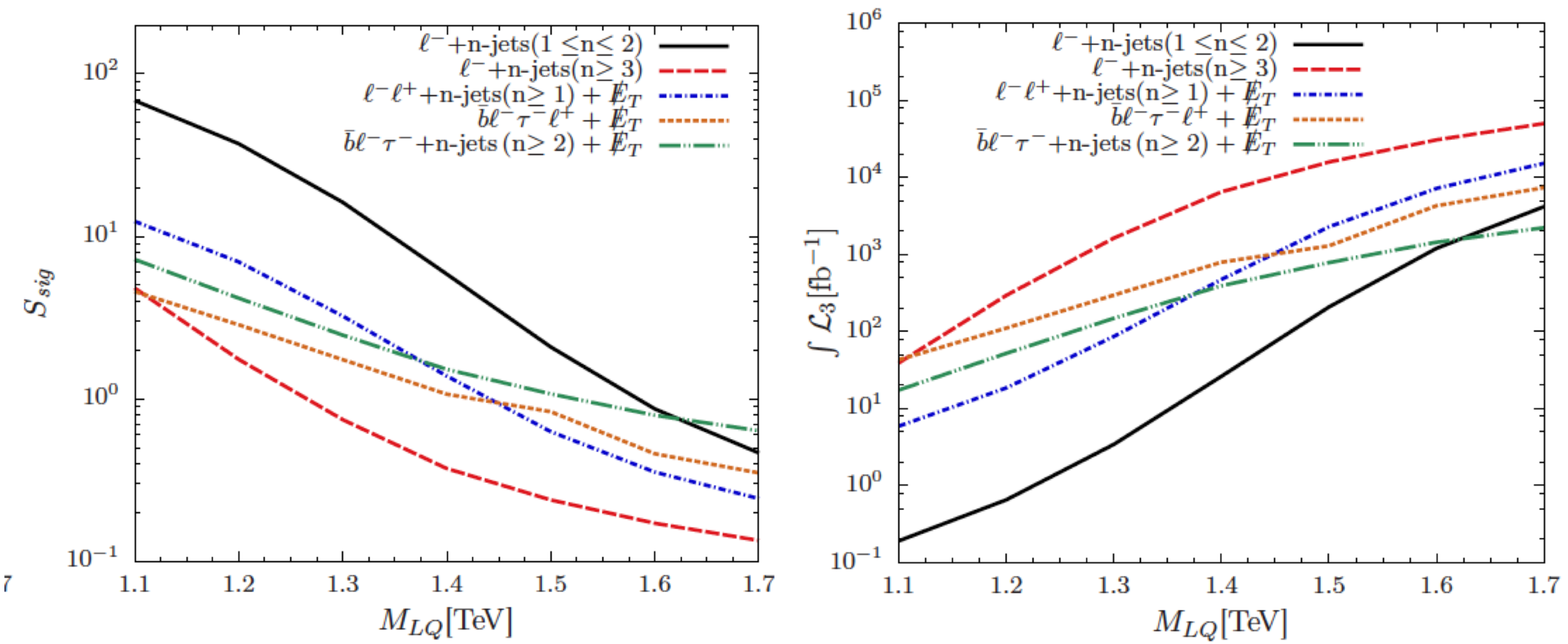
# backup



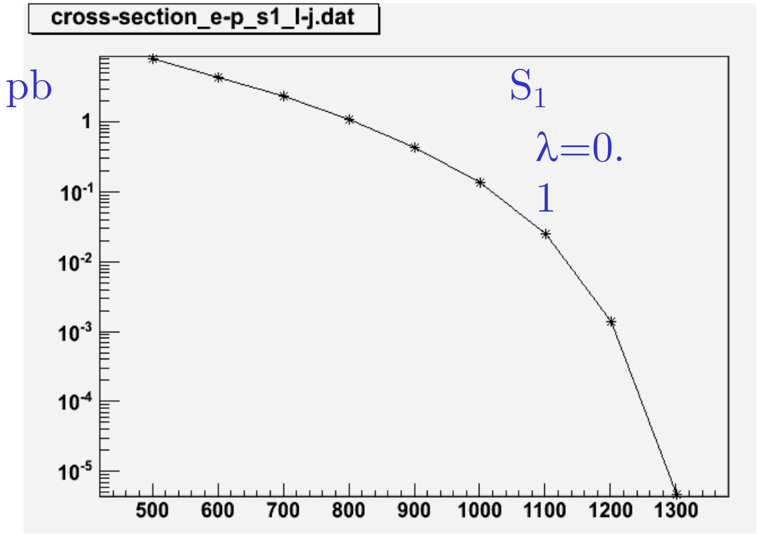
ATLAS
13 TeV, 3.2 fb-1
All limits at 95% CL
observed limit
expected limit
expected ± 1σ
expected ± 2σ
ATLAS 8TeV
LQ1LQ1 production, LQ1→ eq
β (LQ1 → eq)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
500
600
700
800
900
1000
1100
1200
m_LQ1 [GeV]

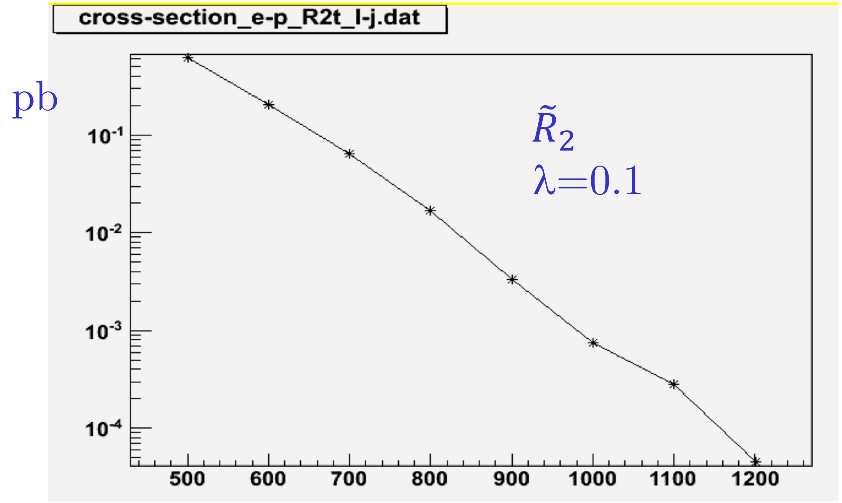

1605.06035

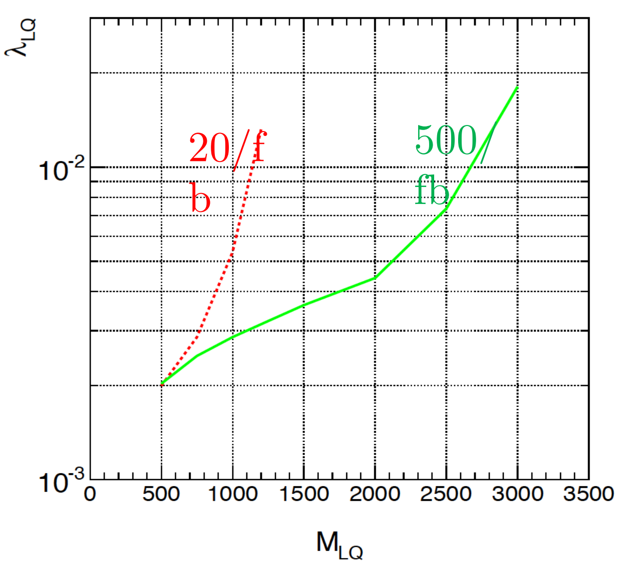
# Results




S. Mandal, N. Sinha and M. Mitra, arXiv:1807.06455 s-channel cross sections

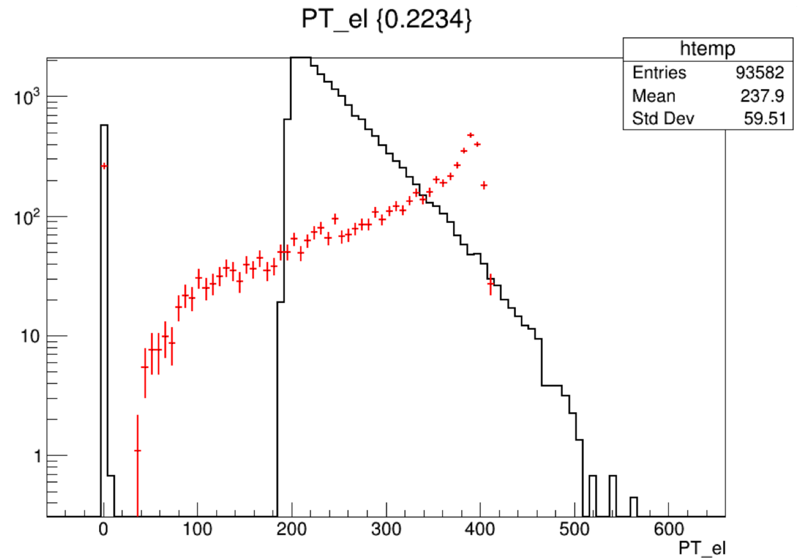


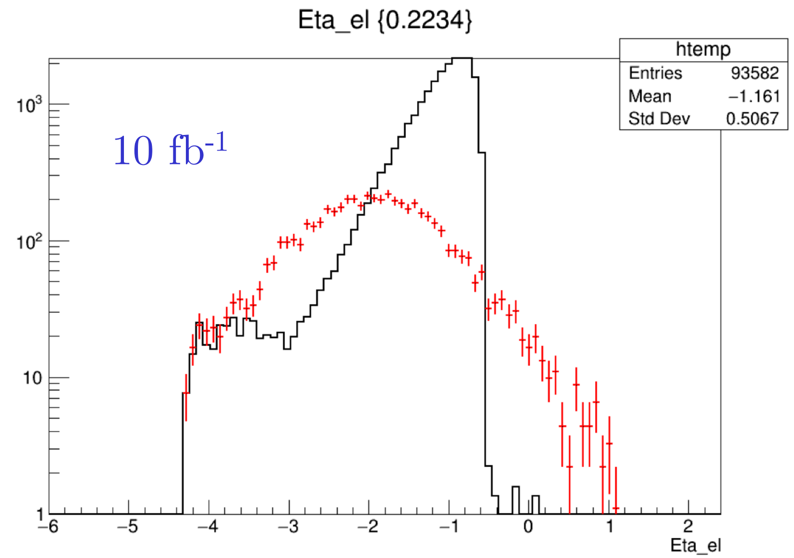



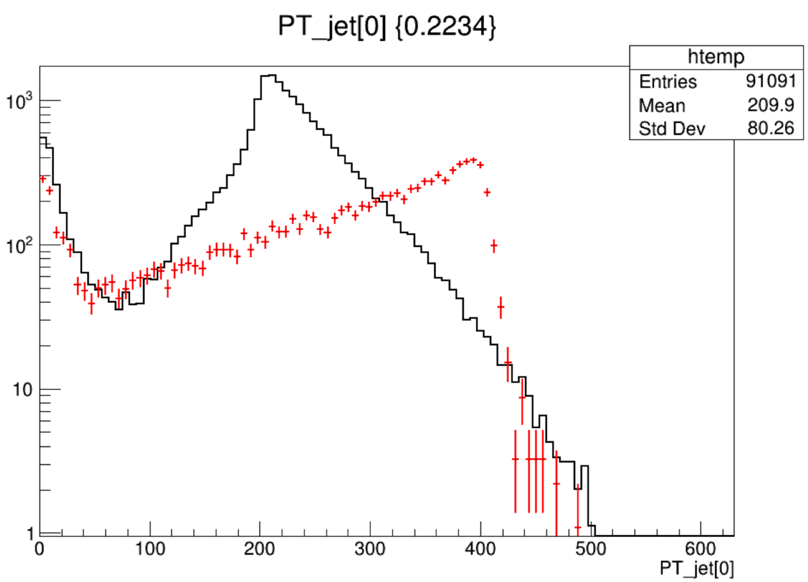



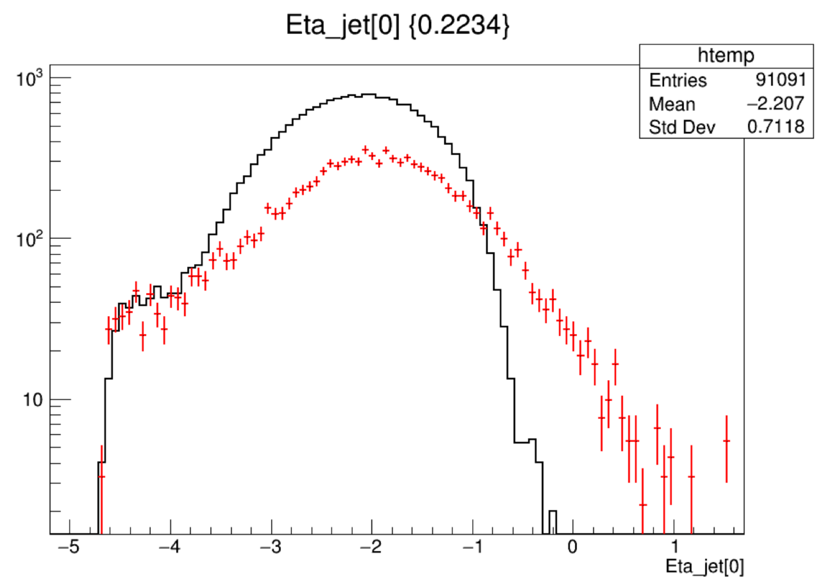
$S_1$ mass = 800 GeV, $S_1 \rightarrow e/\mu$

pt(el)> 200 GeV and pt(jet)>200 GeV for background



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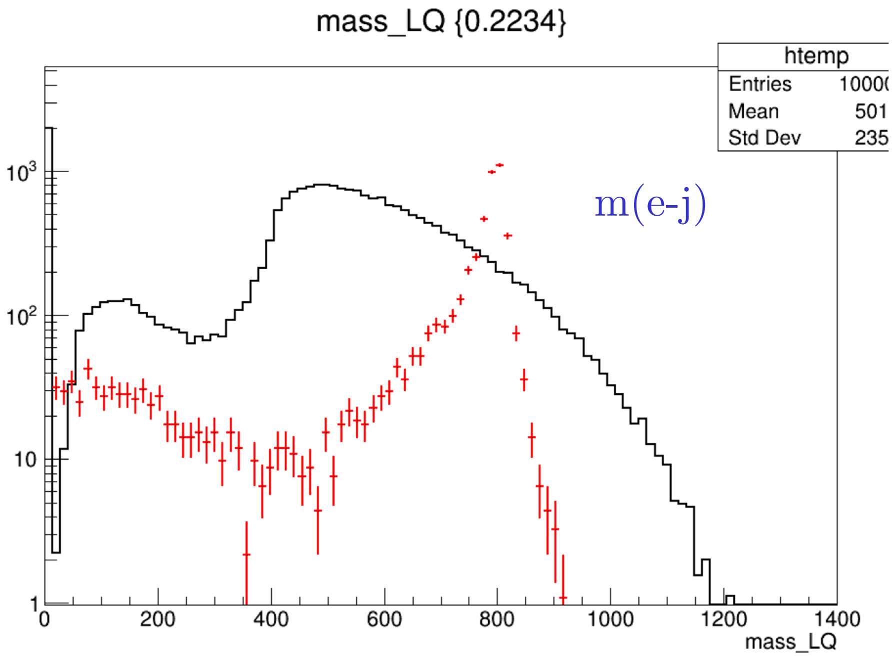
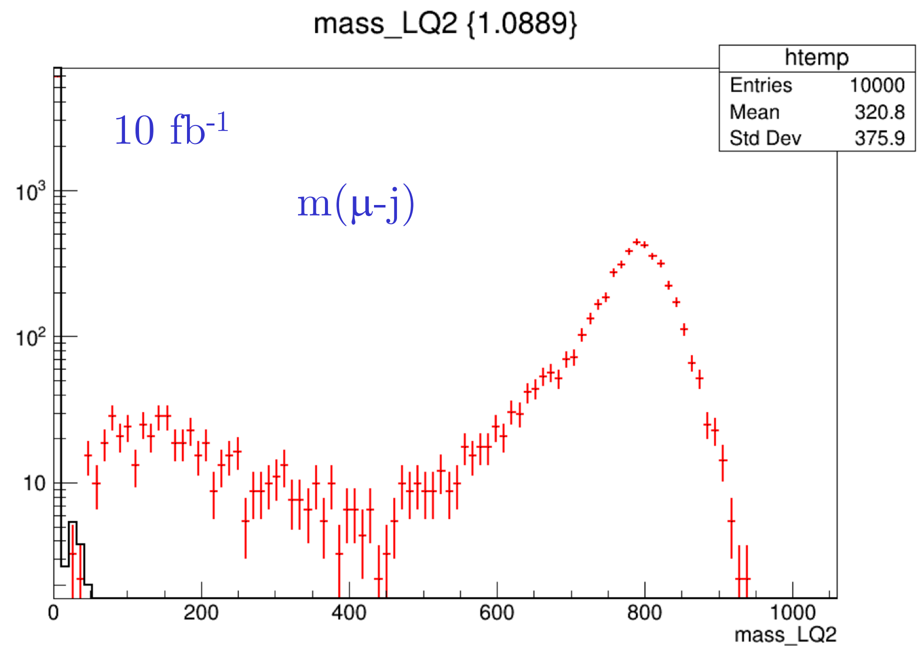
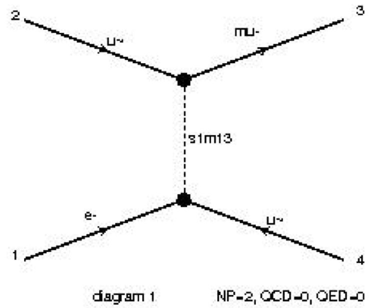
pt(el)> 200 GeV and pt(jet)>200 GeV for background



# non-resonant channel, (mass above cm energy)

*allow couplings* $e/\mu + j$




- LHeC
  - $S_1$ mass 1500 GeV, $p_T$ = 30 GeV ➔ 901 pb
    - also for background
    - 5.13 pb with μ in final state
  - mass 1500 GeV, $p_T$ = 200 GeV ➔ 2.25 pb
    - 2.18 fb with μ in final state

    *Hard to extract from background!*
- FCCeh
  - pT > 100 GeV ➔ 83 pb *150/100000 = 124 fb
    - low pT muons
    - same for signal and background

# Georgi-Machacek model

- Higgs bidoublet and two isospin-triplets (one real, one complex) in a bitriplet

$$\Phi = \begin{pmatrix} \phi^{0*} & \phi^{+} \\ -\phi^{+*} & \phi^{0} \end{pmatrix} \quad (\mathrm{SU(2)_L}\rightarrow,\ \mathrm{SU(2)_R}\downarrow)$$

$$X = \begin{pmatrix} \chi^{0*} & \xi^{+} & \chi^{++} \\ -\chi^{+*} & \xi^{0} & \chi^{+} \\ \chi^{++*} & -\xi^{+*} & \chi^{0} \end{pmatrix} \quad (\mathrm{SU(2)_L}\rightarrow,\ \mathrm{SU(2)_R}\downarrow)$$

  - custodial symmetry by construction
  - bidoublet responsible for fermion masses (SM)
  - vev's $v_\phi$ and $v_\chi$ must sum to

$$v_\phi^2 + 8v_\chi^2 \equiv v^2 = \frac{1}{\sqrt{2}G_F} \approx (246\ \mathrm{GeV})^2$$

parametrized in terms of mixing angle

$$c_H \equiv \cos\theta_H = \frac{v_\phi}{v}, \qquad s_H \equiv \sin\theta_H = \frac{2\sqrt{2}\,v_\chi}{v}$$

**Georgi H, Machacek M., Nucl Phys B. 1985;262(3):463–77**
**Logan HE, Reimer MB., 1709.01883**
**Hartling K, Kumar K, Logan HE., 1410.5538**
**Logan HE, Zaro M., https://cds.cern.ch/record/2002500**

# Georgi-Machacek model

- Physical spectrum
  - $4 + 9 = 13$ components
    - 3 Goldstone bosons give mass to W and Z
    - 2 singlets h and H mix
    - 1 triplet $(H_3^+, H_3^0, H_3^-)$
    - 1 fiveplet$\left(H_5^{++}, H_5^+, H_5^0, H_5^-, H_5^{--}\right)$
      - does not couple to fermions!
      - couple only to gauge bosons ➔ only VBS
- parameters
  - mass of $H_5$
  - mixing angle $s_H = \sin\theta_H$
    - cross section of VBS and widths are proportional to $s_H^2$ (assuming $H_5$ is lighter than $H_3$)
  - other parameters related to $H_3$ and scalar potential

# WW EFT couplings of Higgs, H self-coupling

- HWW and HZZ couplings with higher dimensional operators

  **H. Hesari, H. Khanpour and M.M. Najafabadi, arXiv:1805.04697**

  - LHeC: azimuthal probe, sensitivities $\mathcal{O}(0.1)$

    **S.S. Biswal et al., arXiv:1203.6285**

  - HZZ couplings

    **I.T. Cakir et al., arXiv:1304.3616**

- HHH couplings through di-Higgs production → **see Bruce's talk**

  - LHeC, 2/ab: $\kappa_\lambda = [-0.28,4.25]$ $\left(\lambda_3 = \kappa_\lambda \lambda_3^{SM}\right)$

    **R. Li et al., arXiv:1910.09424**

  - FCC-eh, 10/ab : $g_{hhh}^{(1)} = 1.00^{+0.24}_{-0.17}$ (CP even)

    **M. Kumar et al., arXiv:1509.04016**

- Exotic Higgs Decay $\boldsymbol{h \rightarrow \phi\phi \rightarrow 4b}$ at the LHeC

  - $C^2_{4b} \equiv \kappa^2_V \times \mathrm{Br}(h \rightarrow \phi\phi) \times \mathrm{Br}^2(\phi \rightarrow b\bar{b})$ ~ per mille with 1 $ab^{-1}$, $m_\phi$ = 20-60 GeV

    - much better than HL-LHC

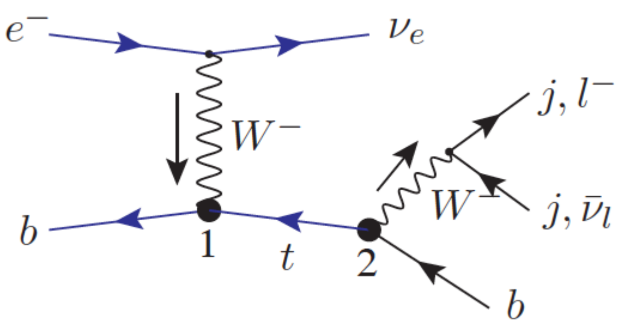
      **S., Liu et al., arXiv:1608.08458**

# anomalous top coupling $V_{tb}$

- single top production by $e^-p \to \nu_e \bar{t}$
  - from most general CP-conserving Lagrangian

    S. Dutta et al., arXiv:1307.1688

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




  - or from dimension-6 operator approach, including 4-fermion contact int'n

    I. A. Sarmiento-Alvarado, A. O. Bouzas & F. Larios, arXiv:1412.6679

$$\mathcal{L} = \mathcal{L}_{\text{SM}} + \frac{1}{\Lambda^2}\sum_k \left(C_k O_k^{(6)} + \text{h.c.}\right) + \cdots$$

| |
|---|
| $\mathcal{O}_{\ell q'}^{1331} = \bar{\ell}_{L1}\gamma^\mu q_{L3}\, \bar{q}_{L3}\gamma_\mu \ell_{L1}$ |
| $\mathcal{O}_{qde}^{1133} = \bar{\ell}_{L1} e_{R1}\, \bar{d}_{R3} q_{L3}$ |
| $\mathcal{O}_{q\ell\epsilon}^{3113} = \bar{q}_{L3} e_{R1}\, (\bar{\ell}_{L1}\epsilon)^T u_{R3}$ |
| $\mathcal{O}_{\ell q\epsilon}^{1133} = \bar{\ell}_{L1} e_{R1}\, (\bar{q}_{L3}\epsilon)^T u_{R3}$ |

  - conclusion:
    *much higher sensitivity than at LHC for vector couplings $|V_{tb}|\ \Delta f_1^L \sim 0.01$, and some improvement on other coupling*
  - present value:

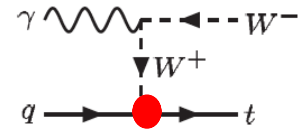
**ATLAS+CMS combination 7+8 TeV**
JHEP 05 (2019) 088

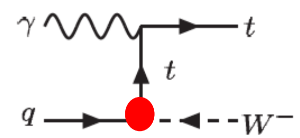
$$|f_{LV} V_{tb}| = 1.020\ \pm 0.040(exp.) \pm 0.020(th.)$$

- single top production by $\gamma\, p \rightarrow t\, W$

  **I.T. Cakir, A. Senol and A.T. Tasci, arXiv:1301.2617**

  - with anomalous $Wtb$ and $Wtb\gamma$ couplings

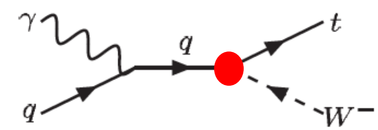


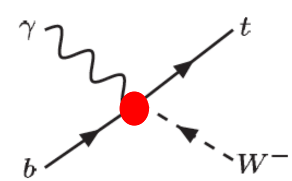




$$L = -\frac{g_W}{\sqrt{2}}\bar{b}\left[\gamma^\mu\left(F_{1L}P_L + F_{1R}P_R\right)W^-_\mu + \frac{i\sigma^{\mu\nu}}{2m_W}\left(F_{2L}P_L + F_{2R}P_R\right)\left(q_\nu W^-_\mu - q_\mu W^-_\nu + g_e\left(A_\mu W^-_\nu - A_\nu W^-_\mu\right)\right)\right]t + h.c.$$

Table I: Sensitivity (95% C.L.) to anomalous $Wtb$ couplings at the LHeC based $\gamma p$ collider with electron beam energy of 60 GeV for various integrated luminosities.

| $L(fb^{-1})$ | $\Delta F_{1L}$ | $F_{1R}$ | $F_{2L}$ | $F_{2R}$ |
|---|---|---|---|---|
| 1 | -0.1088: +0.1318 | -0.5258: +0.5328 | -0.3010: +0.2995 | -0.2903: +0.3106 |
| 10 | -0.0187: +0.055 | -0.3350: +0.3422 | -0.1923: +0.1901 | -0.1802: +0.2035 |
| 100 | -0.0065: +0.0314 | -0.1082: +0.1188 | -0.0601: +0.0626 | -0.1233: +0.1579 |



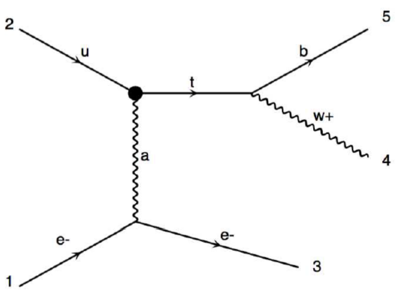



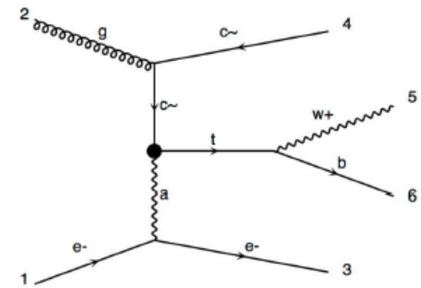

  - same conclusion:

*much improved sensitivity for $F_{1L}$ and $F_{2L}$, compared to LHC, by ~ 1 order of magnitude*

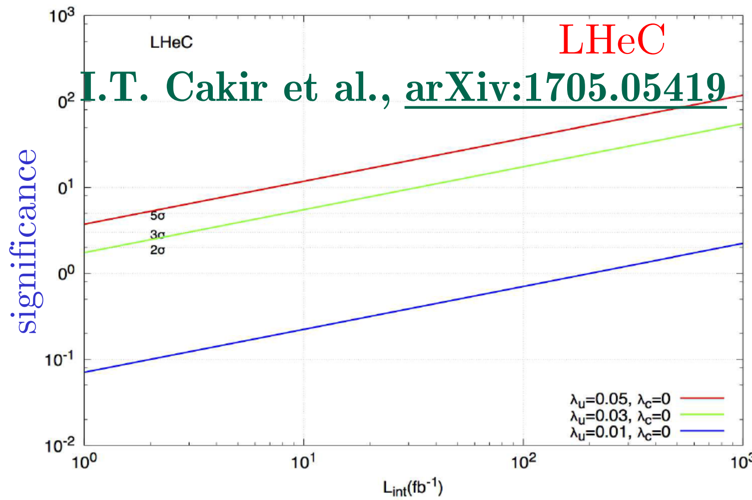
# limits on FCNC top coupling

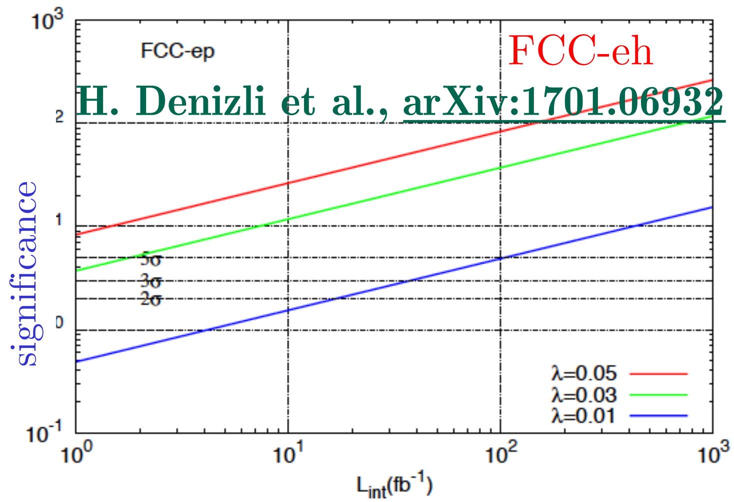
- signal: $e^- p \to e^- W^\pm q, e^- p \to e^- W^\pm qb$



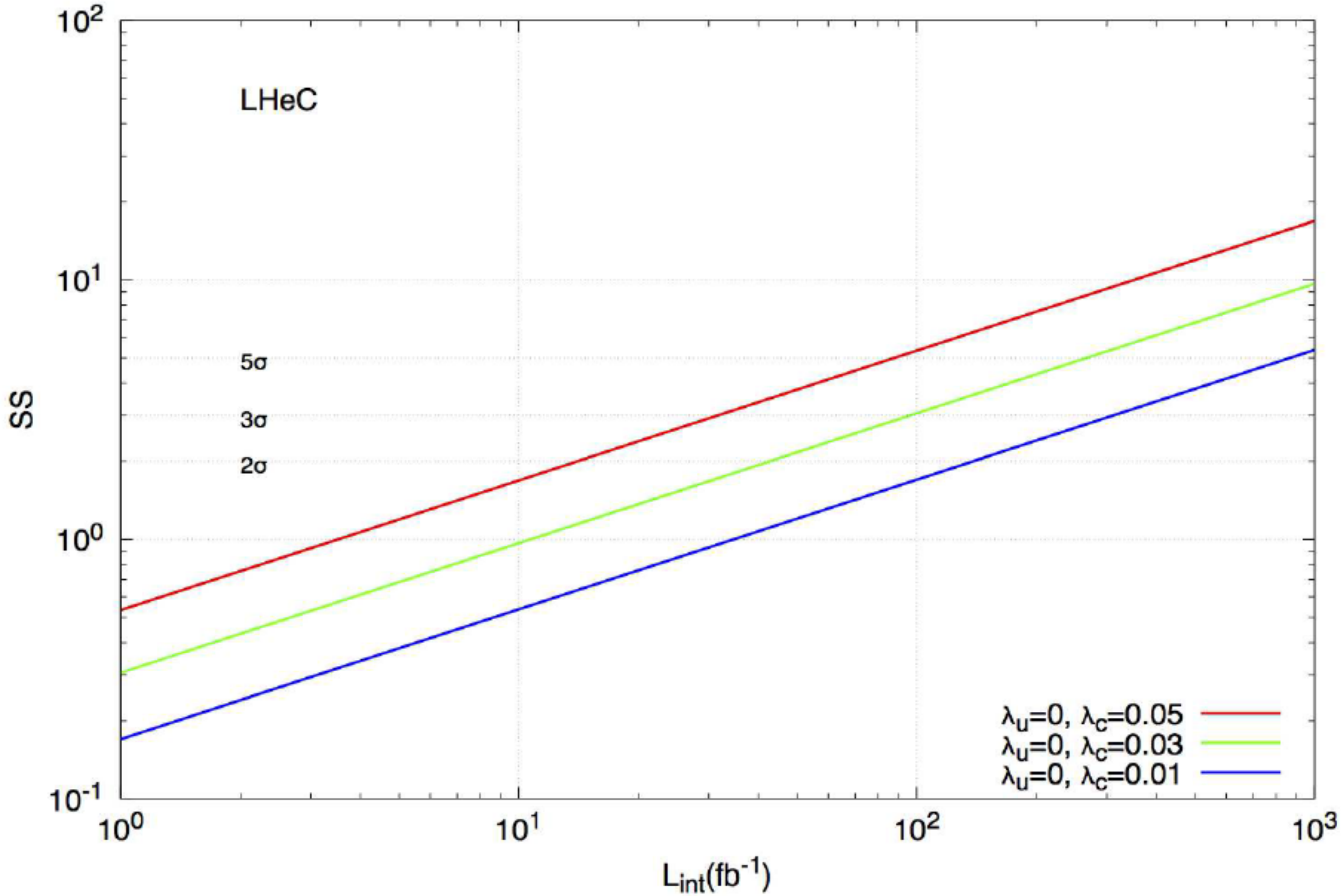




  - fast simulation, b-tagging efficiency of 75% with misID of 1%, 5% for light q and c




  - limit on FCNC coupling to c-quark about 5x higher
  - λ = 0.01 corresponds to $BR(t \to q\gamma) = 2 \times 10^{-5}$
    - CMS: $BR(t \to u\gamma) < 1.61 \times 10^{-4}$, $BR(t \to c\gamma) < 1.82 \times 10^{-3}$




I.T. Cakir et al., arXiv:1705.05419