



Top quark Physics at the Lepton-Nucleon collider

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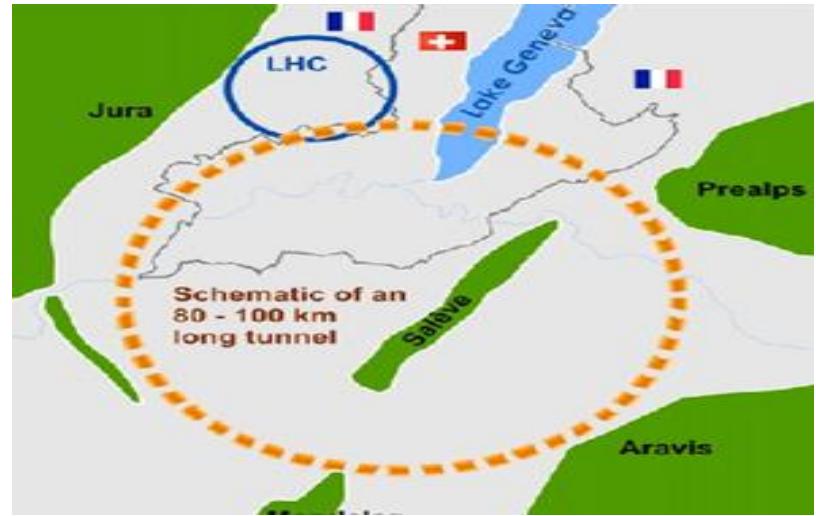
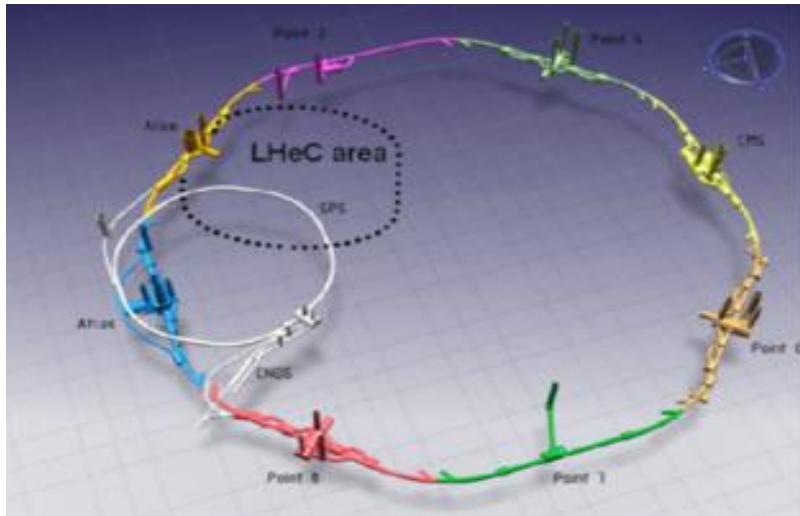
25th International WS on Deep Inelastic Scattering & Related Topics

Outline

1. Future projects of ep colliders: LHeC & FCC-he
2. Top quark Physics at ep colliders
 - Neutral Current(NC) Top quark production
 - Charged Current(CC) Top quark production
 - Top & Higgs production
3. Summary

Future projects of ep colliders: LHeC & FCC-he

Both plan to create new electron facility



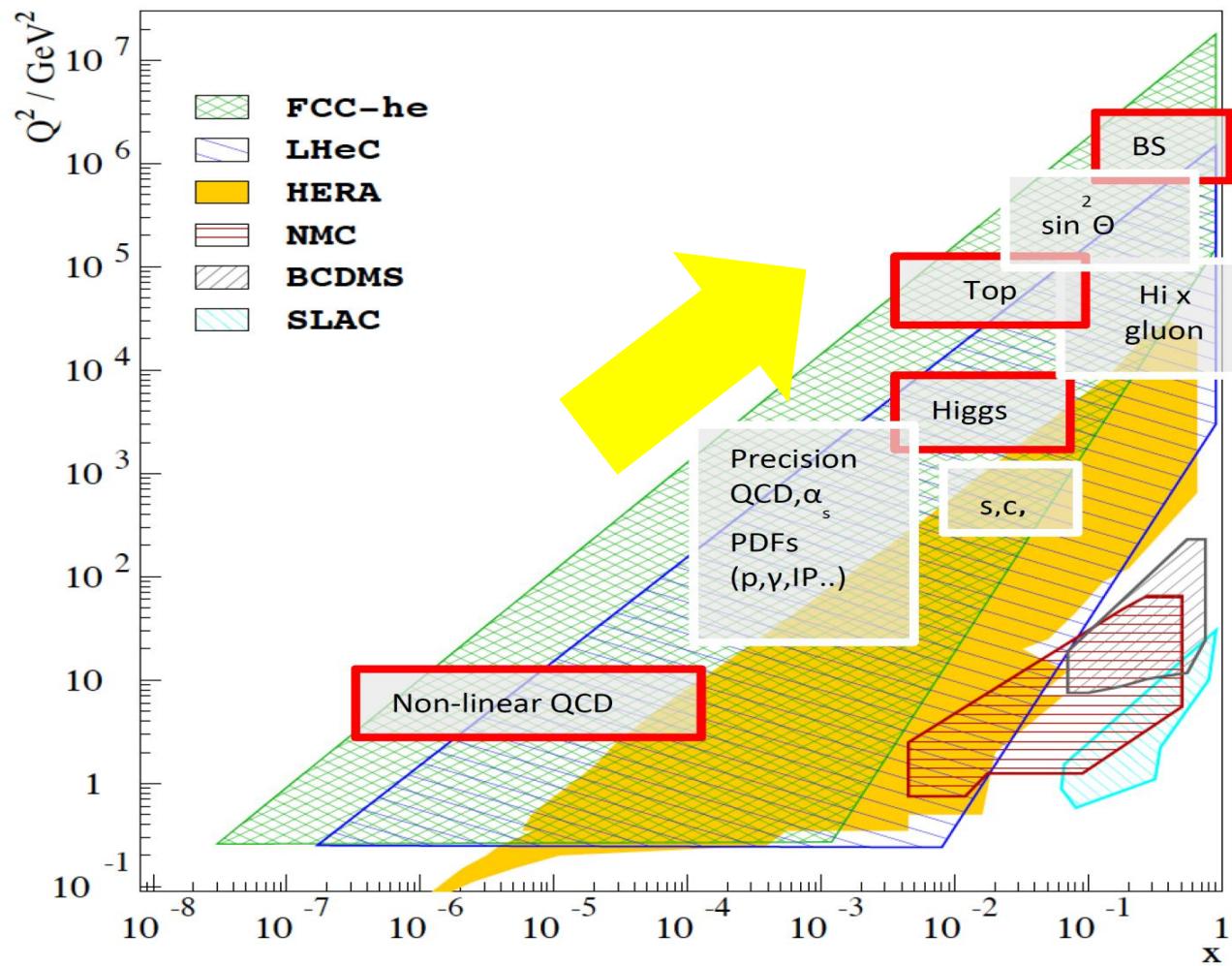
LHeC

7 TeV proton of LHC
and 60 GeV electron
($\sqrt{s} \sim 1.3$ TeV)

FCC-he

50 TeV proton of FCC
and 60 GeV electron
($\sqrt{s} \sim 3.5$ TeV)

Future projects of ep colliders: LHeC & FCC-he

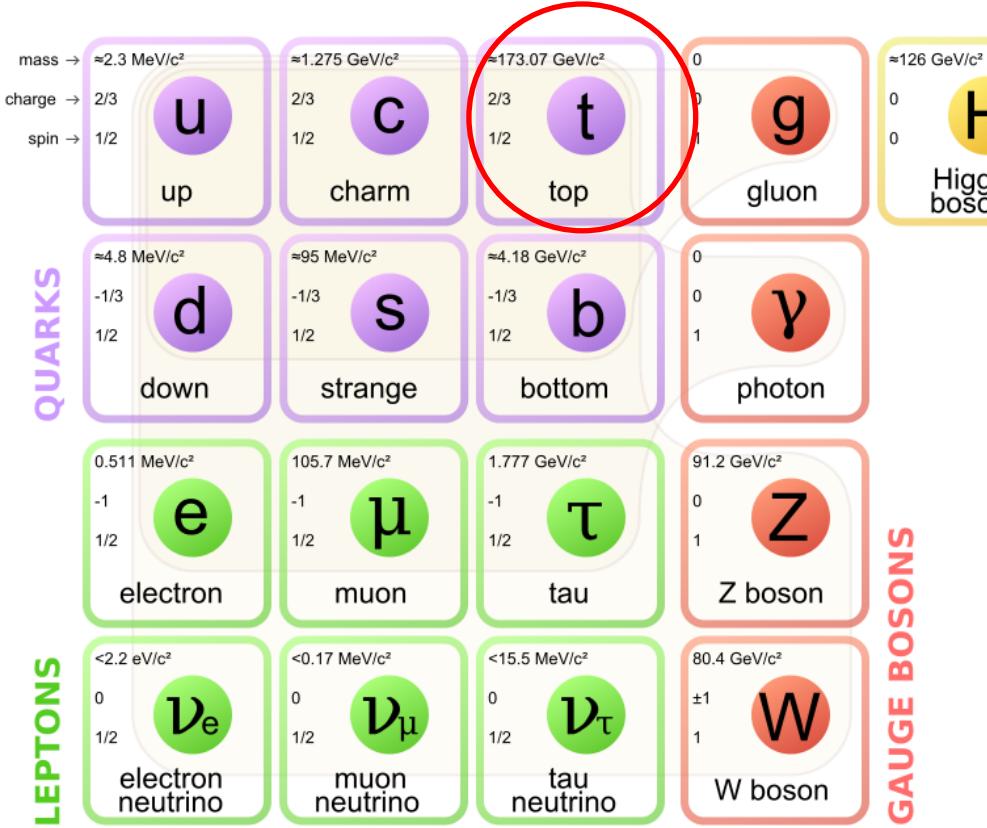


O. Bruning, E. Nissen, D. Pellegrini, D. Schulte, A. Valloni, F. Zimmermann,

A. Bogacz, E. C. Alaniz, M. Klein, PoS EPS-HEP2015 (2015) 520

Top quark Physics at ep colliders

is expected to be sensitive to BSM physics

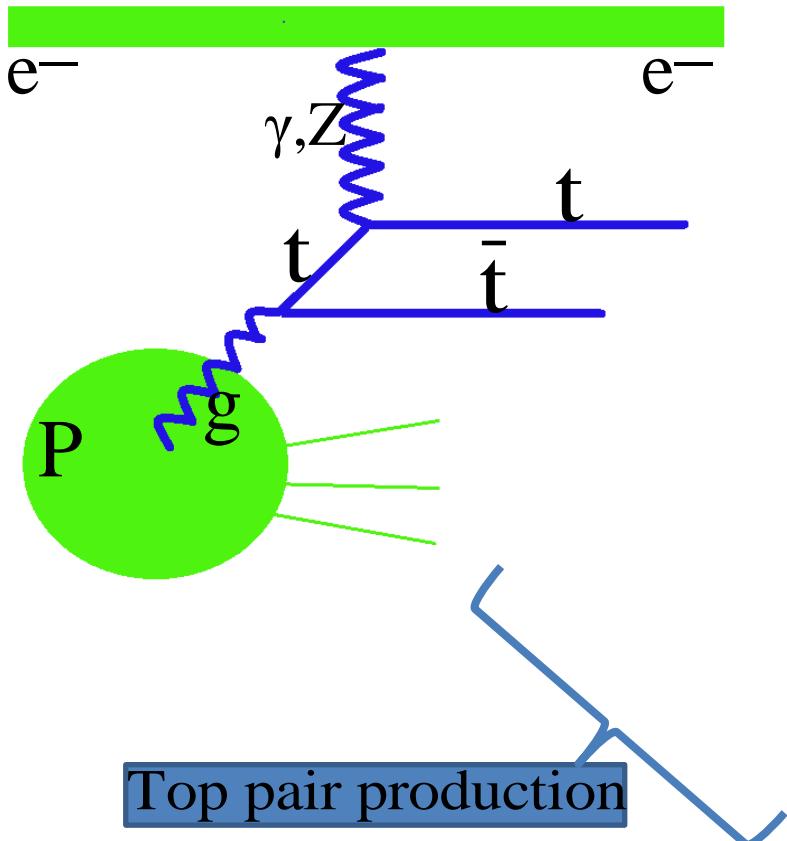


The ep future colliders offers excellent prospects for top physics

Neutral Current (NC) Top quark Production

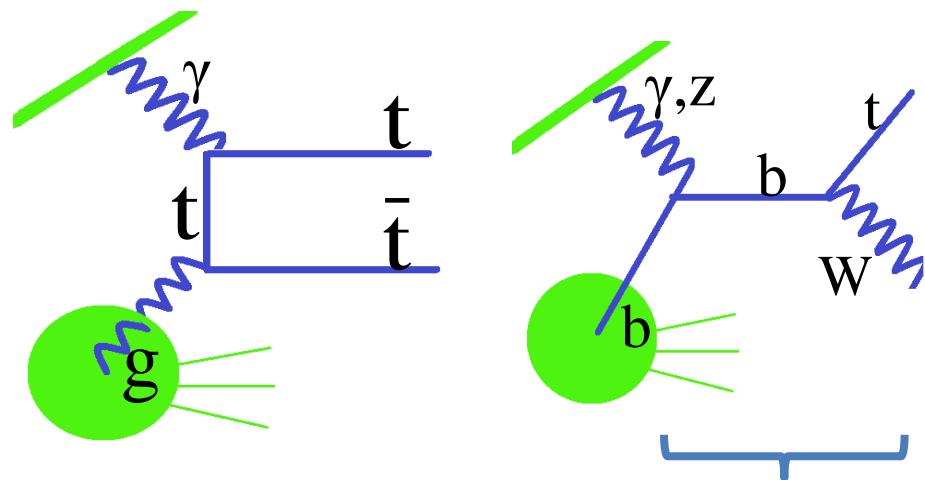


Neutral Current Top quark Production



DIS

photoproduction



e^- beam 60 GeV, proton beam 7 TeV, 100 fb^{-1}

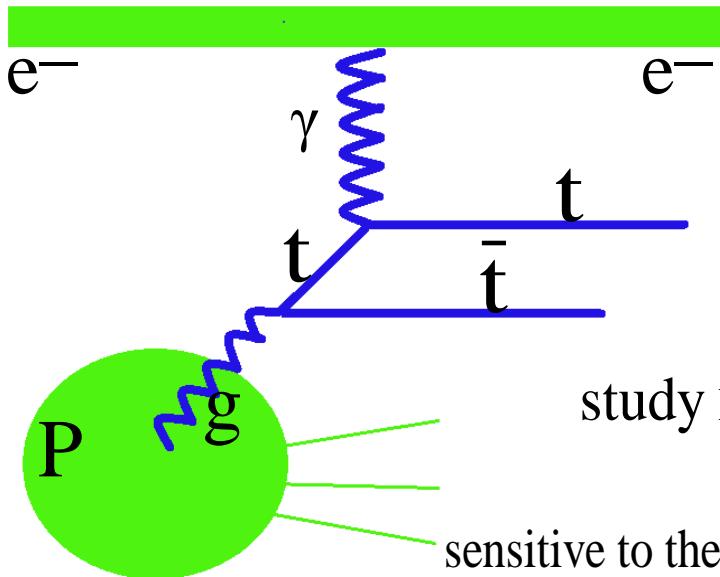
PHP

0.023 pb
 $N_{t\bar{t}} = 2300$

0.70 pb
 $N_{t\bar{t}} = 70,000$

0.031 pb
 $N_t = 3,100$

Neutral Current Top quark Production



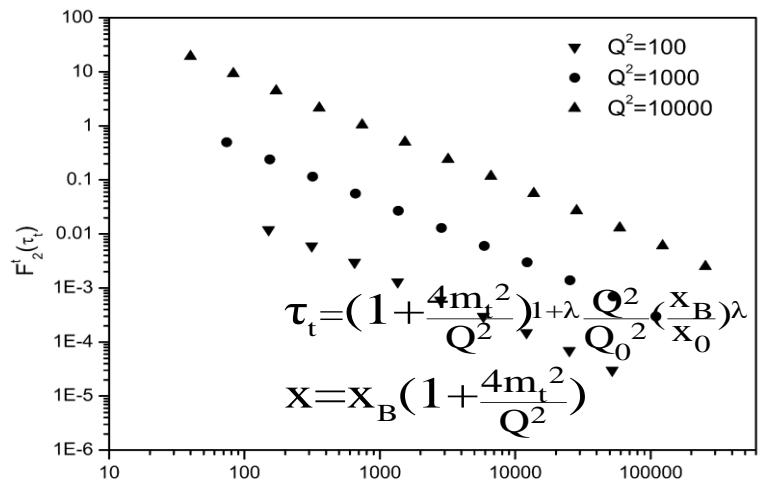
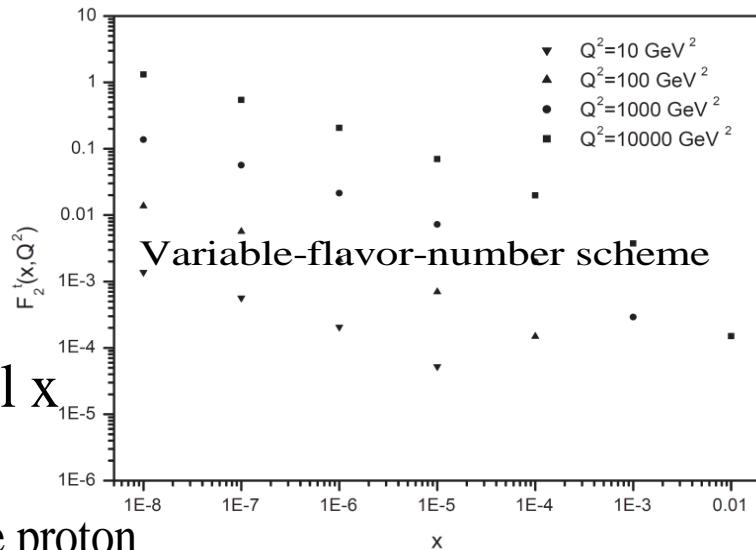
study $F_t^l(x, Q^2)$ at small x

sensitive to the gluon density in the proton

DIS Photon-Gluon-Fusion-model



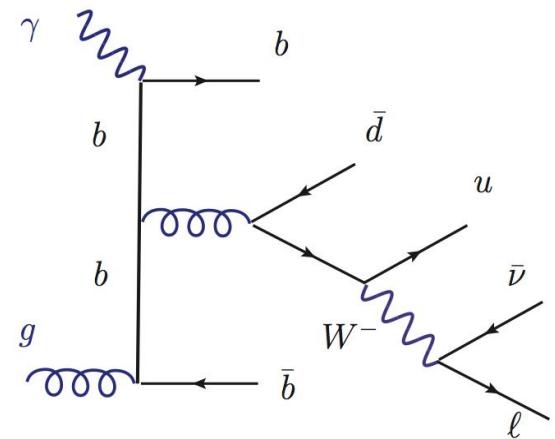
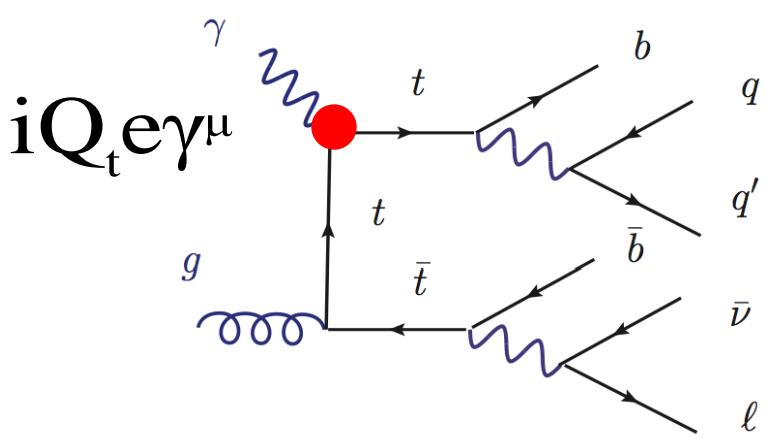
Top Structure Function at LHeC



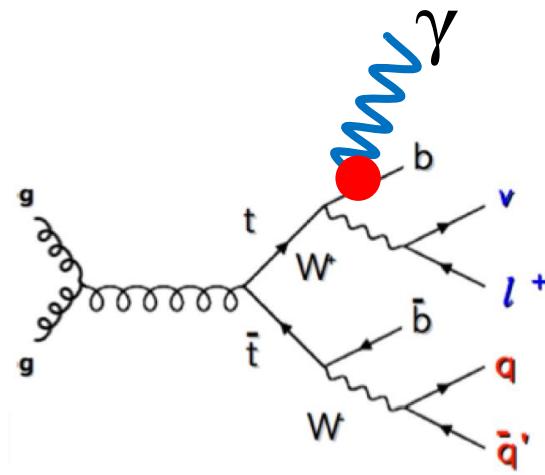
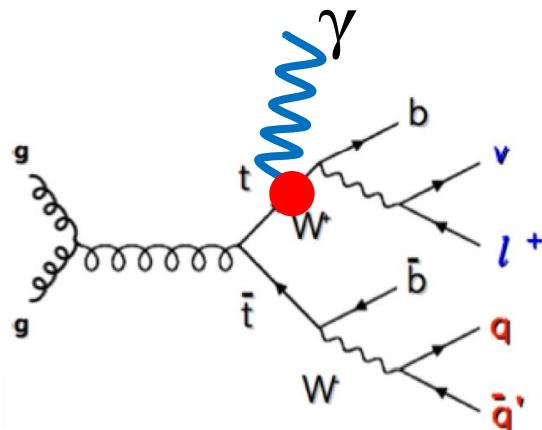
G.R. Boroun Phys.Lett. B744 (2015) 142-145

G.R. Boroun Phys.Lett. B741 (2015) 197-201

Neutral Current Top quark Production



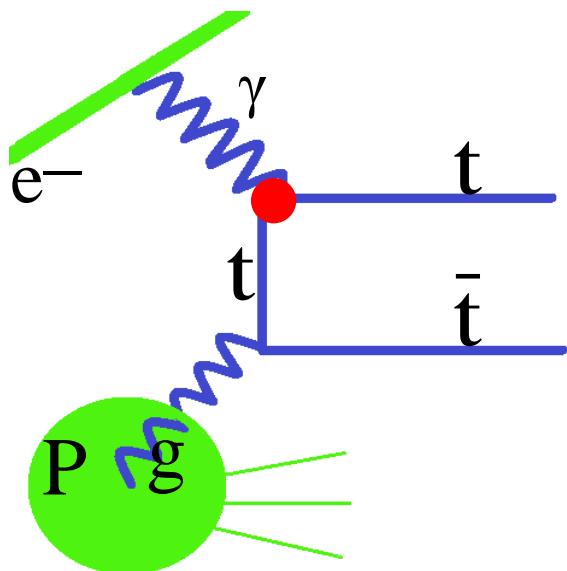
measure top quark electric charge



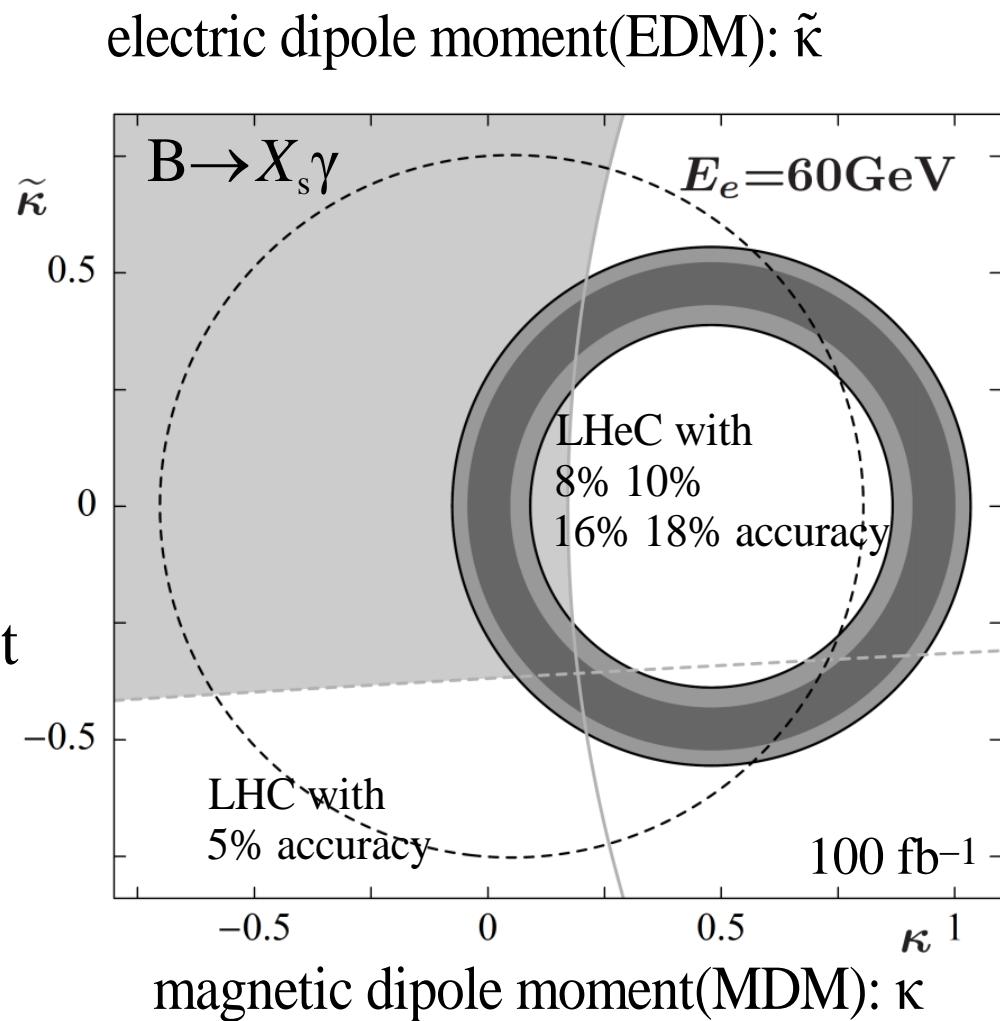
difficult at the LHC

Background

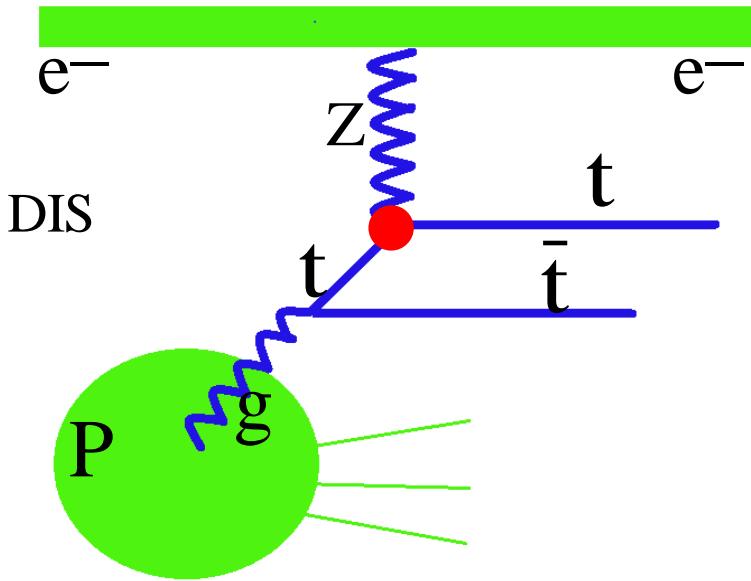
Neutral Current Top quark Production



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



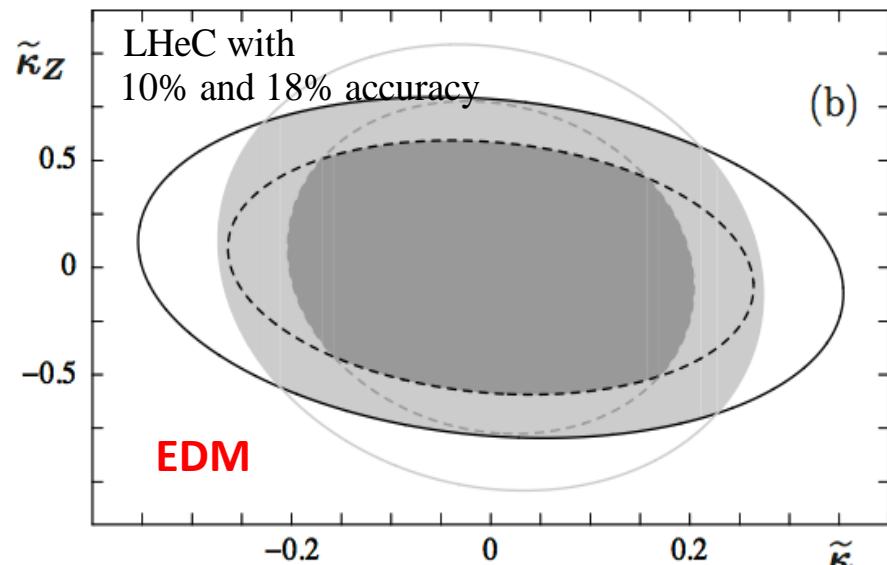
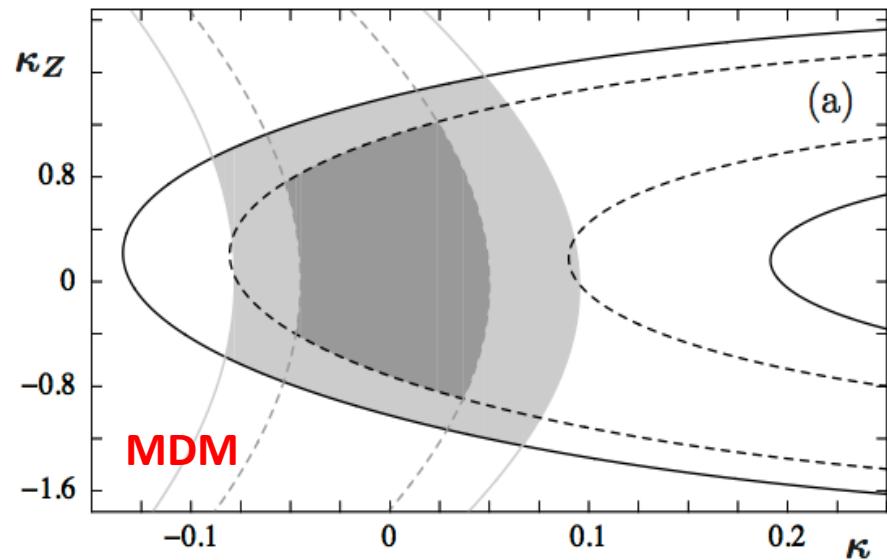
Neutral Current Top quark Production



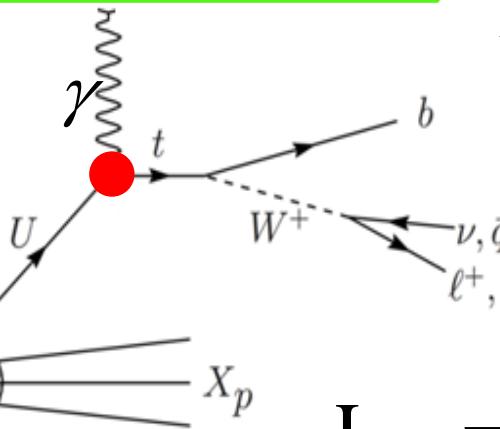
$$L_{t\bar{t}Z} = \frac{g}{2c_w} \bar{t} \left(\frac{1}{4m_t} \sigma^{\mu\nu} Z_{\mu\nu} (\kappa_z + i\tilde{\kappa}_z \gamma_5) \right) t$$



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



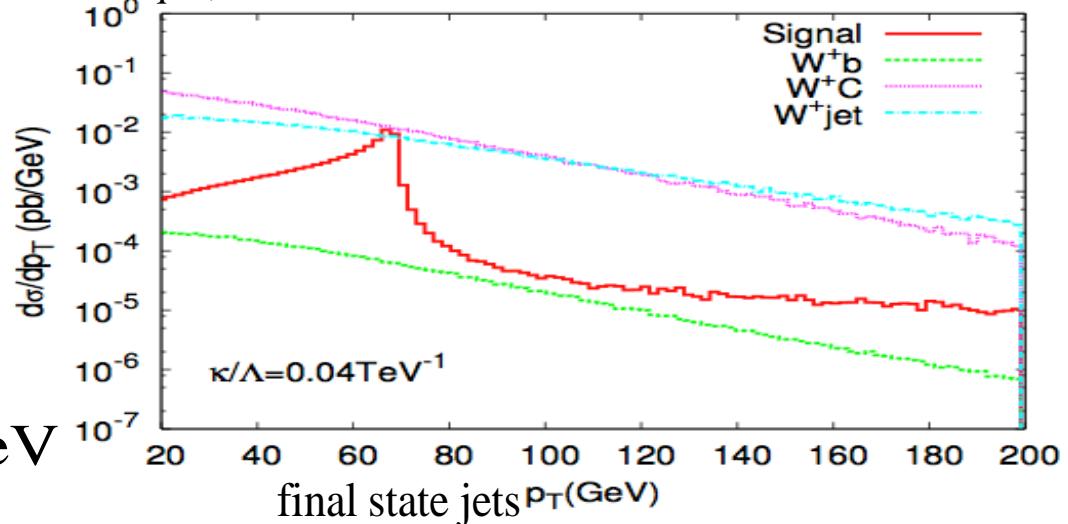
Neutral Current Top quark Production



b-tagging:
60% efficiency

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

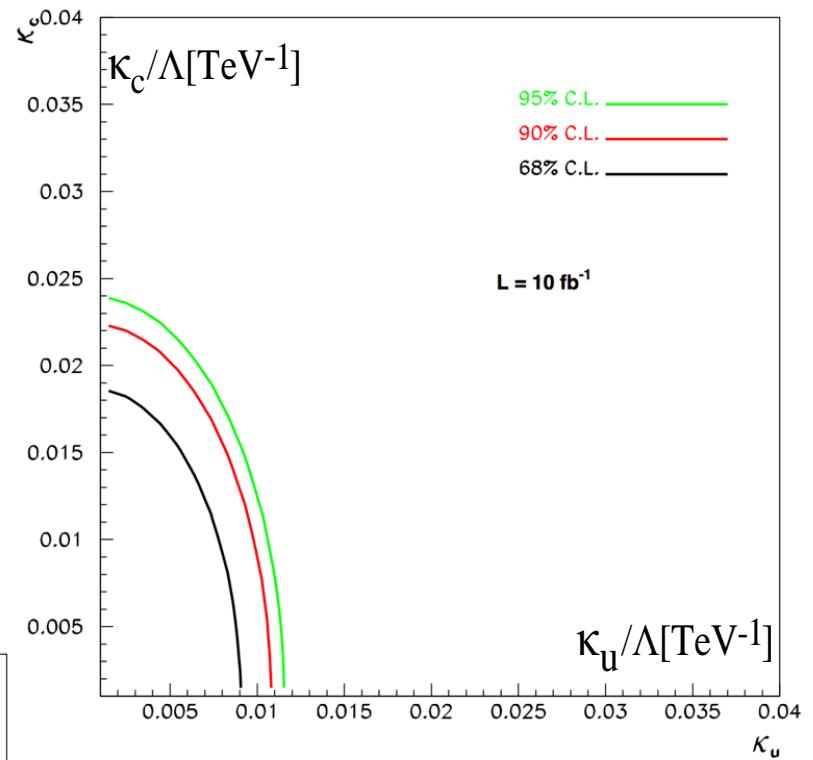
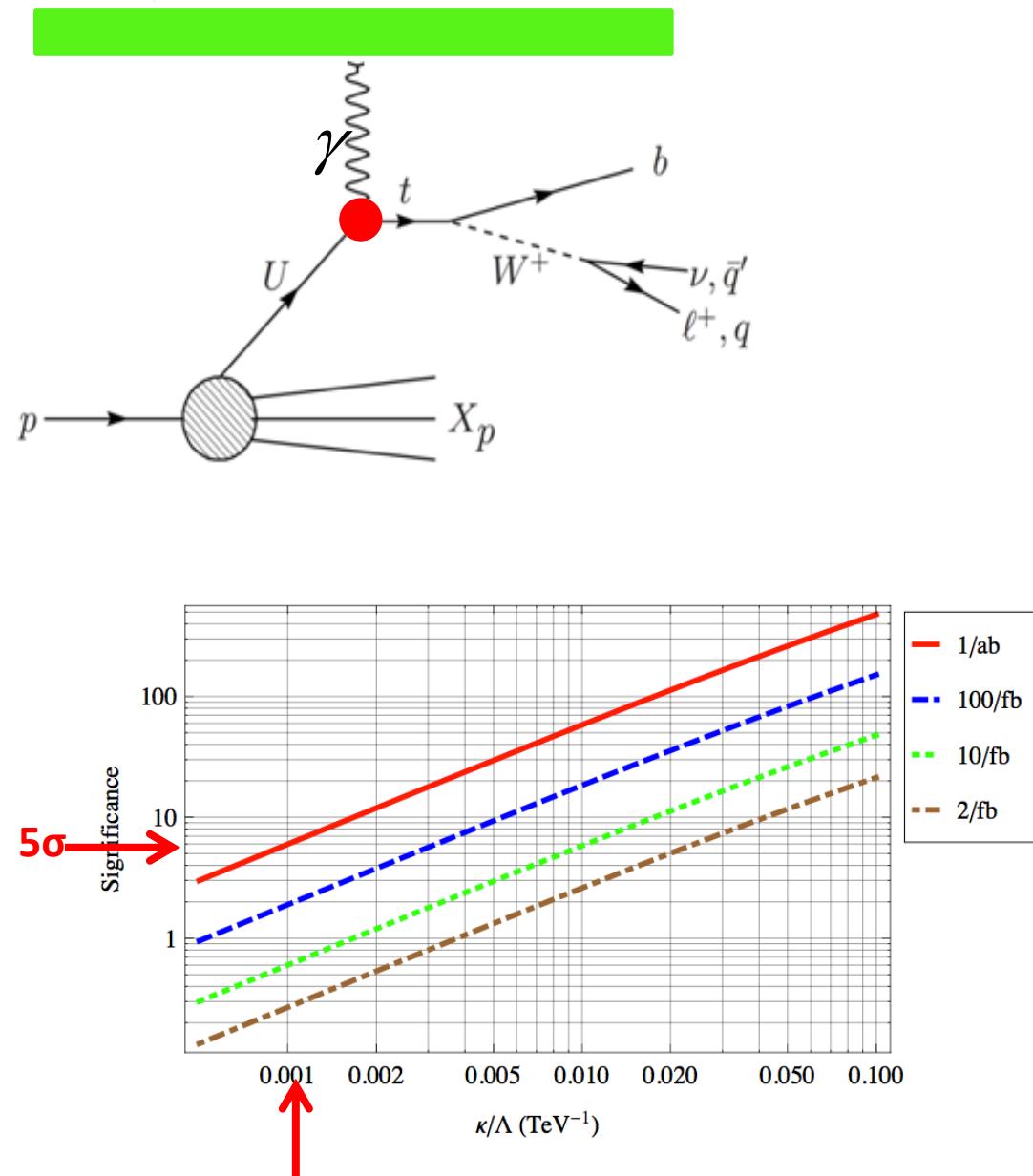
γp collider
e-beam 70GeV



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

AI.T.Cakir, O.Cakir, S.Sultansoy, Phys.Lett.B685:170-173,(2010)

Neutral Current Top quark Production

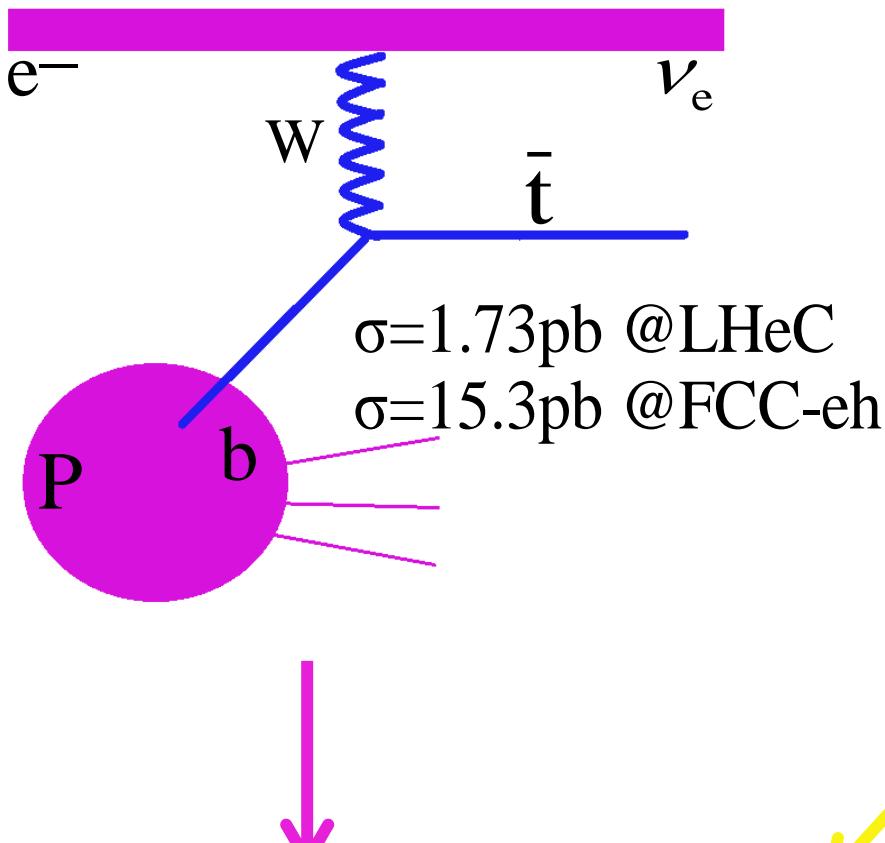


1 ab $^{-1}$
the $tq\gamma$ coupling can be probed up to order of 10^{-3}

Charged Current (CC) Top quark Production

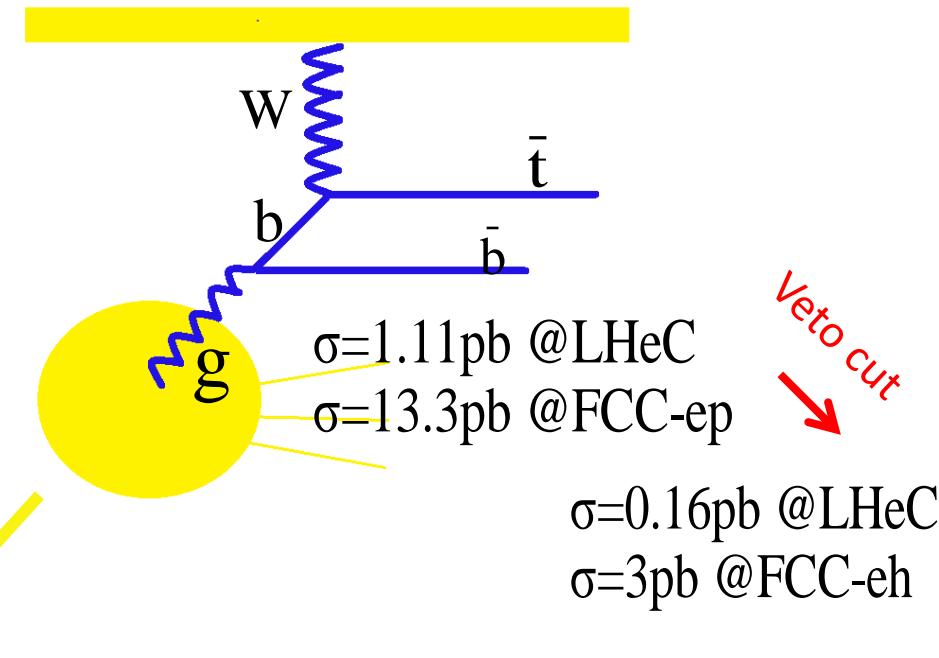


Charged Current Top quark Production

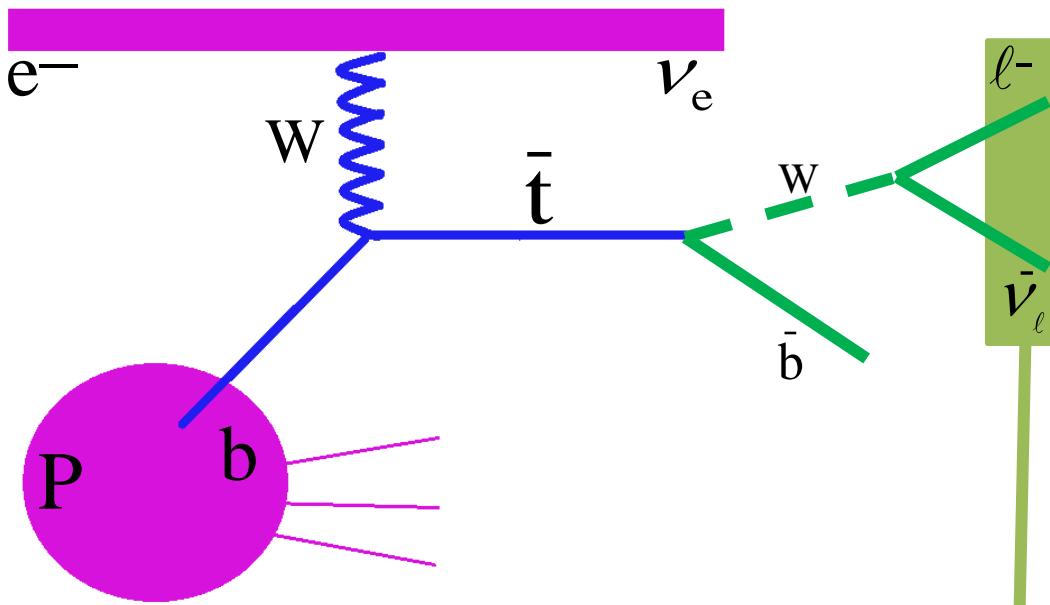


$$\sigma(eb \rightarrow t\bar{v}) + \sigma(eg \rightarrow t\bar{b}\bar{v}) - \sigma(g \rightarrow b\bar{b}^* eb \rightarrow t\bar{v})$$

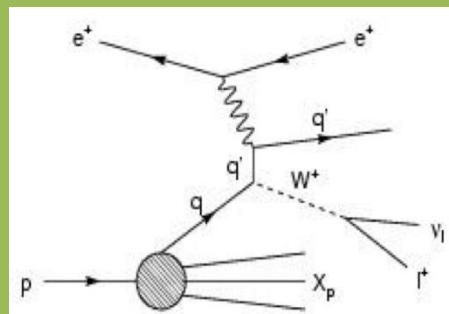
$$\int_{m_t^2/s}^1 \hat{\sigma}(eb \rightarrow \bar{t}v) \left[\frac{\alpha_s(\mu^2)}{2\pi} \ln\left(\frac{\mu^2}{m_b^2}\right) \int_x^1 \frac{dz}{Z} p_{b/g}(z) f_{g/p}\left(\frac{x}{Z}, \mu\right) \right] dx$$



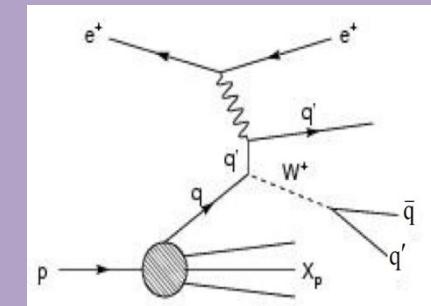
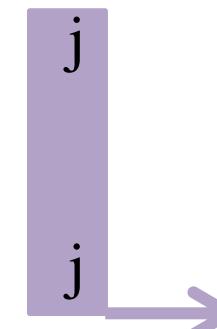
Charged Current Top quark Production



$E_T \geq 25 \text{ GeV}$
 $\Delta\Phi_{E,j} \geq 0.4$
 $\Delta\Phi_{E,b} \geq 0.4$
 $\Delta\Phi_{E,\ell} \geq 0.4$
 $p_{T,j,b,\ell} \geq 20 \text{ GeV}$
 $|\eta^j| \leq 5, |\eta^{b,\ell}| \leq 2.5,$
 $\Delta R_{\ell,b/j} \geq 0.4$



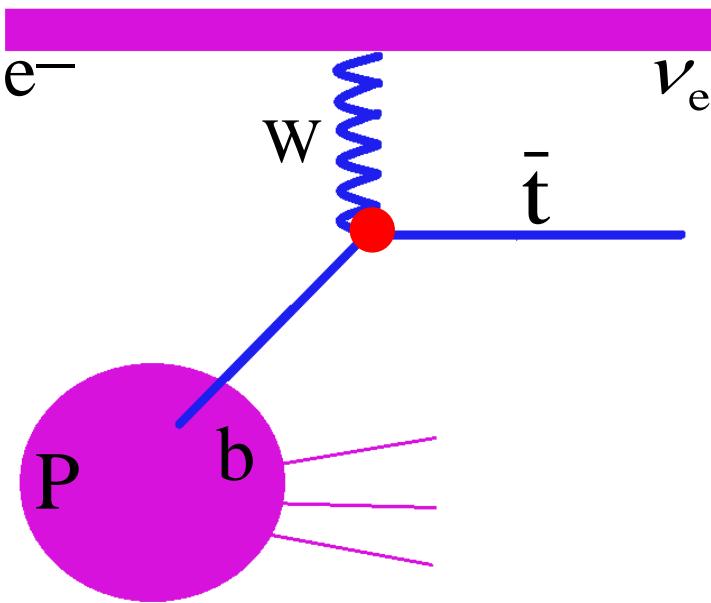
**Nt=11000,
 $S/B=11$**



$E_T \geq 25 \text{ GeV}$
 $\Delta\Phi_{E,j} \geq 0.4$
 $\Delta\Phi_{E,b} \geq 0.4$
 $|m_{j_1,j_2} - m_w| \leq 22 \text{ GeV}$
 $p_{T,j,b} \geq 20 \text{ GeV}$
 $|\eta^j| \leq 5, |\eta^b| \leq 2.5,$
 $\Delta R_{j,b/j} \geq 0.4$

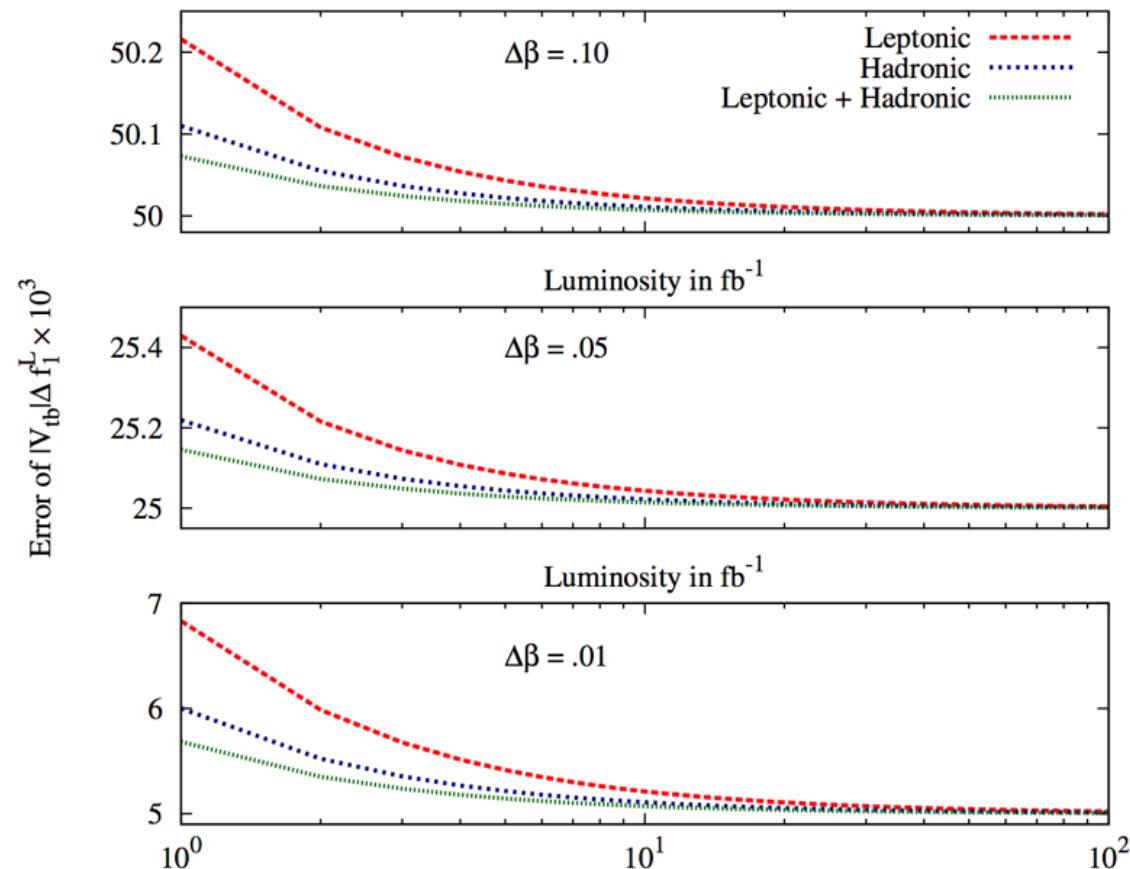
**Nt=22000,
 $S/B=1.2$**

Charged Current Top quark Production



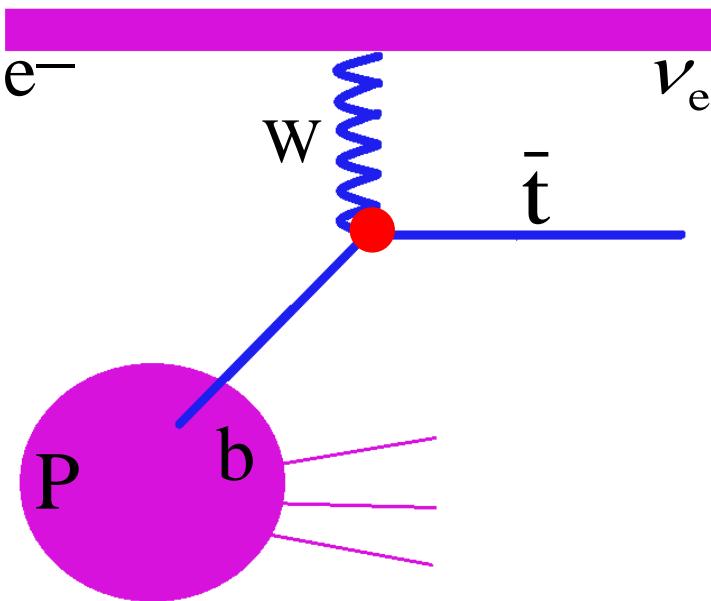
$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$\Delta\beta$: luminosity uncertainty

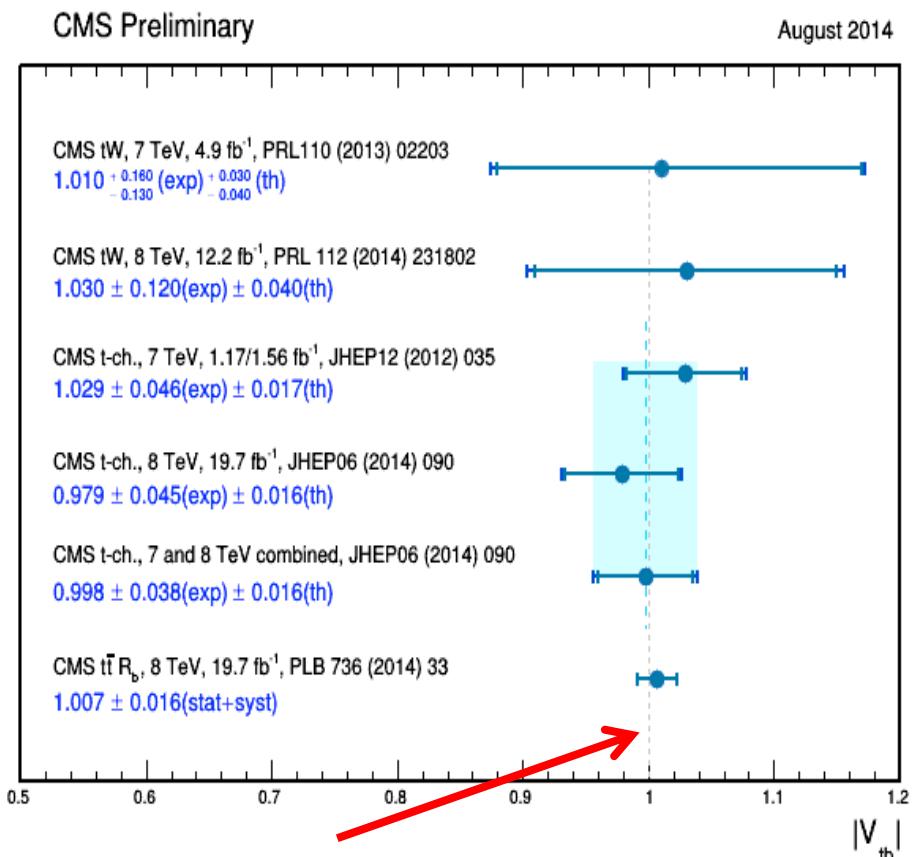


100 fb-1: $\Delta |V_{tb}| = 0.005$

Charged Current Top quark Production

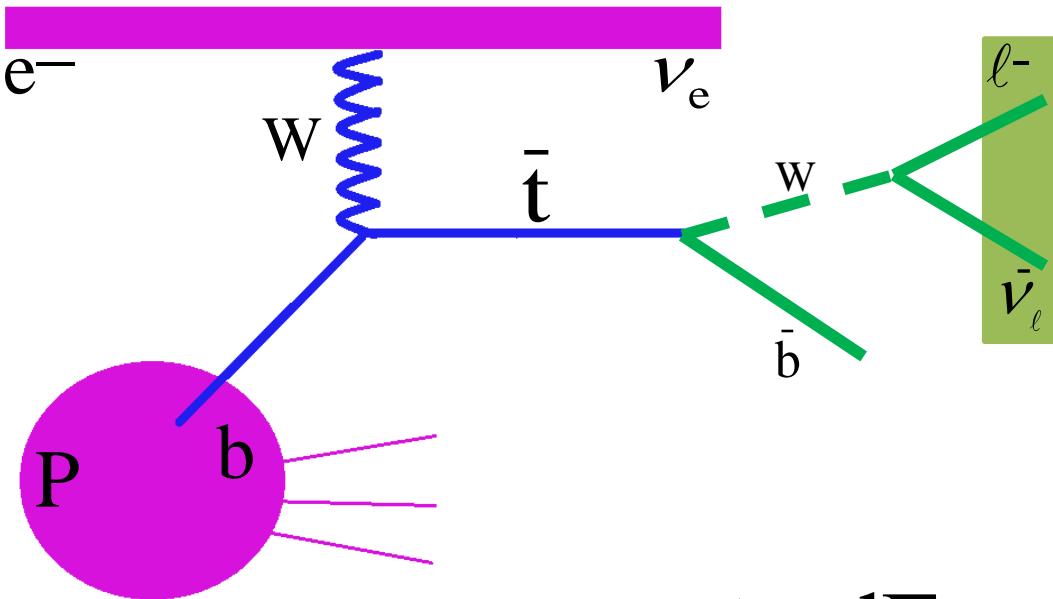


$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$



the CKM matrix element V_{tb}
can be measured with a precision of 0.5%

Charged Current Top quark Production



$\cos\theta$: angle between charged lepton and spin quantisation axis in top rest frame

$$\frac{1}{\Gamma_t} \frac{d\Gamma}{dcos\theta} = \frac{1}{2} (1 + A_{\uparrow\downarrow} \alpha \cos\theta)$$

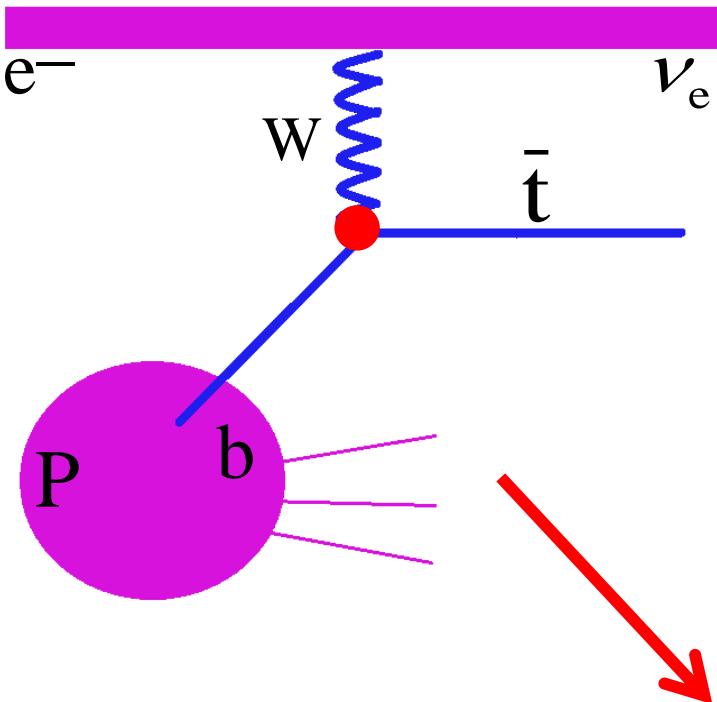
$$A_{\uparrow\downarrow} = \frac{N_\uparrow - N_\downarrow}{N_\uparrow + N_\downarrow}$$

spin asymmetry



Top quark Spin Polarization

Charged Current Top quark Production



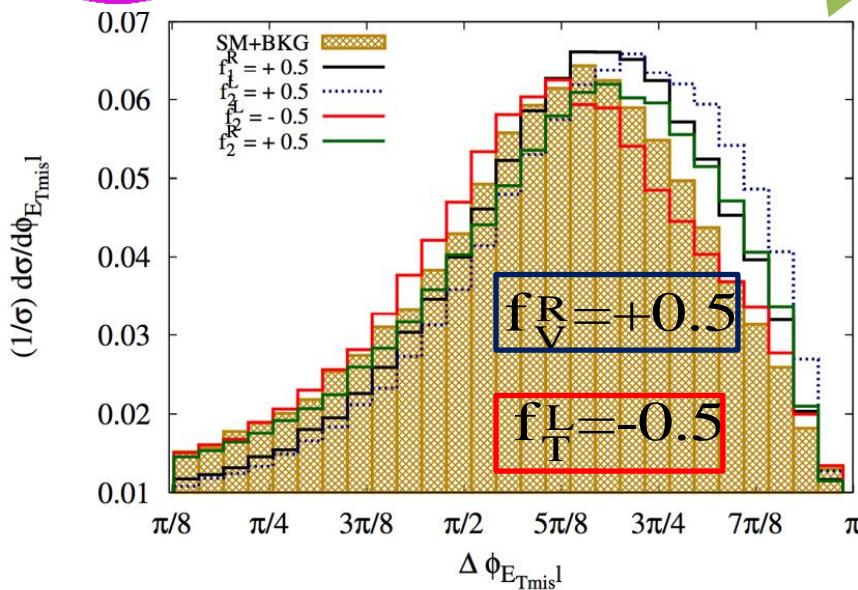
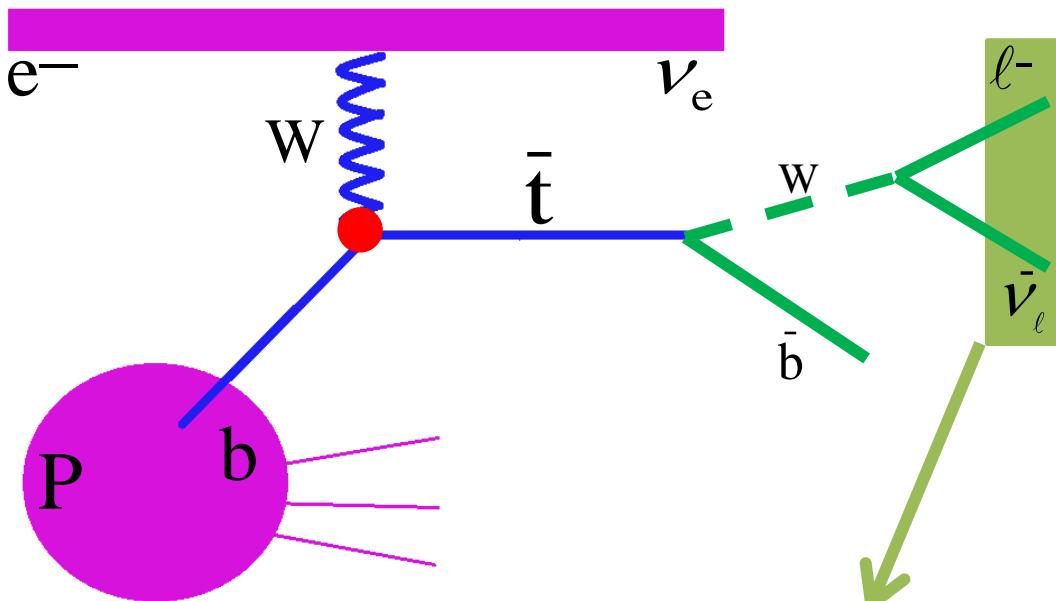
$|V_{tb}|f_L \approx 1, f_R, f_T = 0 \rightarrow \text{SM case}$

$$L_{Wtb} = \frac{g}{\sqrt{2}} \left[-\frac{1}{2m_W} W_{\mu\nu} \bar{t} \sigma^{\mu\nu} (f_L P_L + f_T P_R) b + h.c. \right]$$

\uparrow
f_V
circled

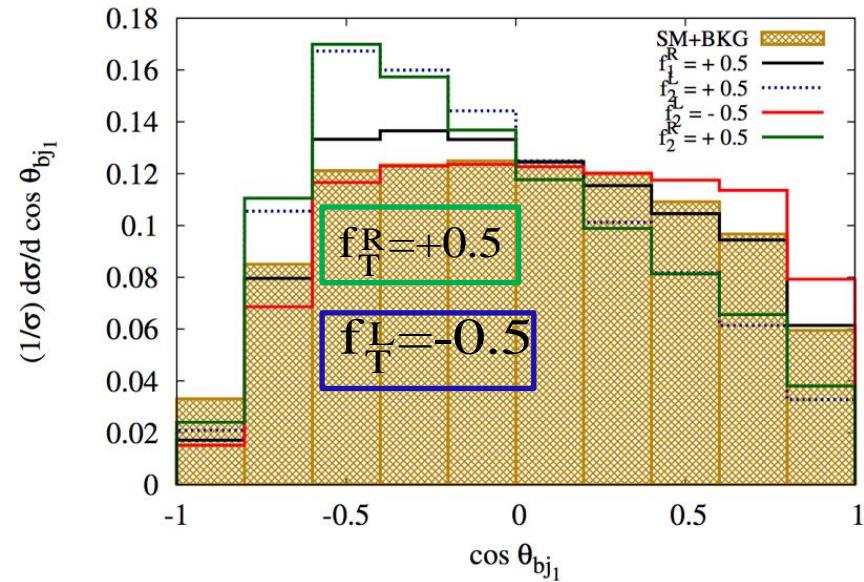
The term $f_L P_L$ is circled in orange.

Charged Current Top quark Production

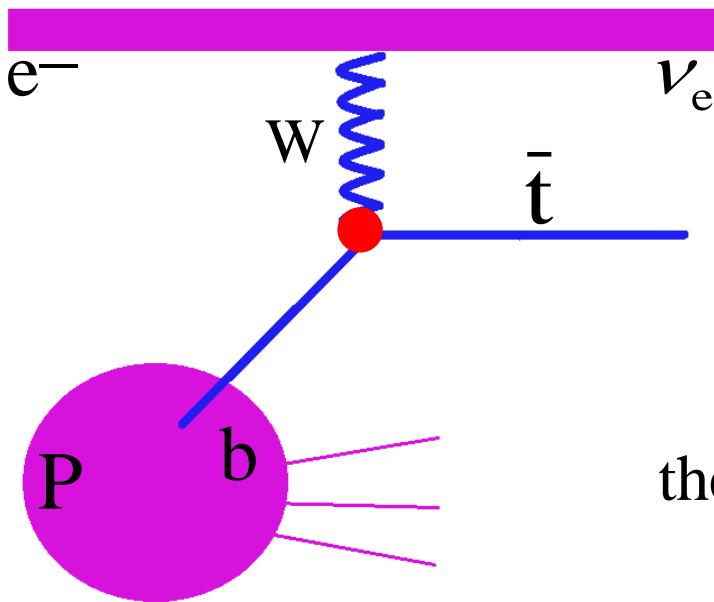


$$L_{Wtb} = \frac{g}{\sqrt{2}} \left[-\frac{1}{2m_W} W_{\mu\nu} \bar{t} \sigma^{\mu\nu} (f_T^L P_L + f_T^R P_R) b + \text{h.c.} \right]$$

$L_{Wtb} = \frac{g}{\sqrt{2}} \left[-\frac{1}{2m_W} W_{\mu\nu} \bar{t} \sigma^{\mu\nu} (f_T^L P_L + f_T^R P_R) b + \text{h.c.} \right]$



Charged Current Top quark Production

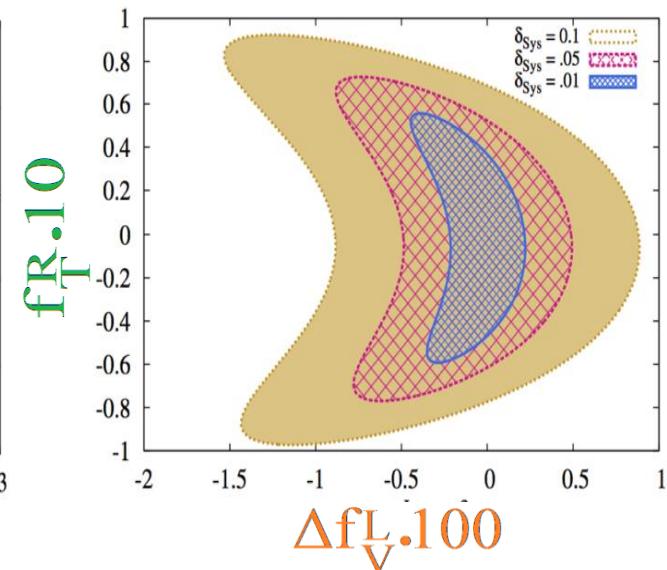
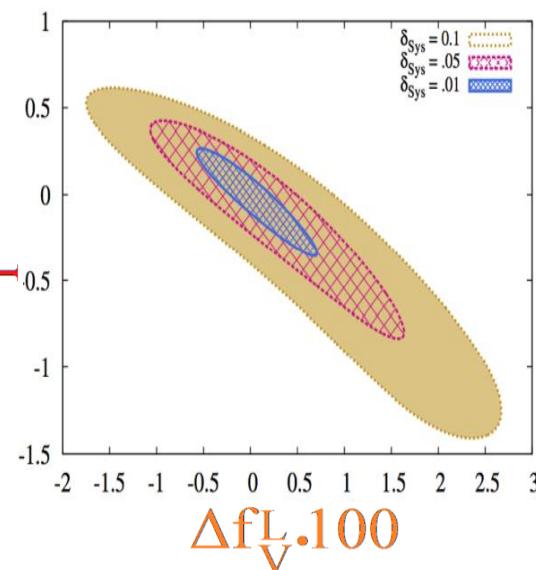
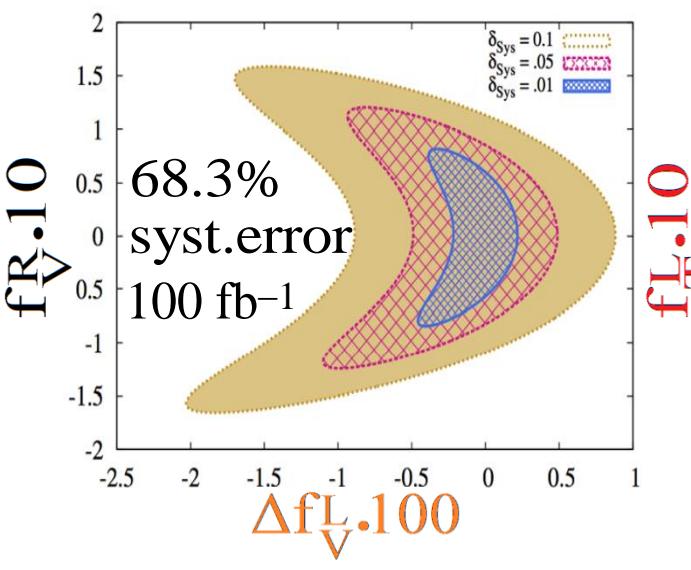


$$L_{Wtb} = \frac{g}{\sqrt{2}} \left[-\frac{1}{2m_W} W_{\mu\nu} \bar{t} \sigma^{\mu\nu} (f_T^L P_L + f_T^R P_R) b \right] + h.c.$$

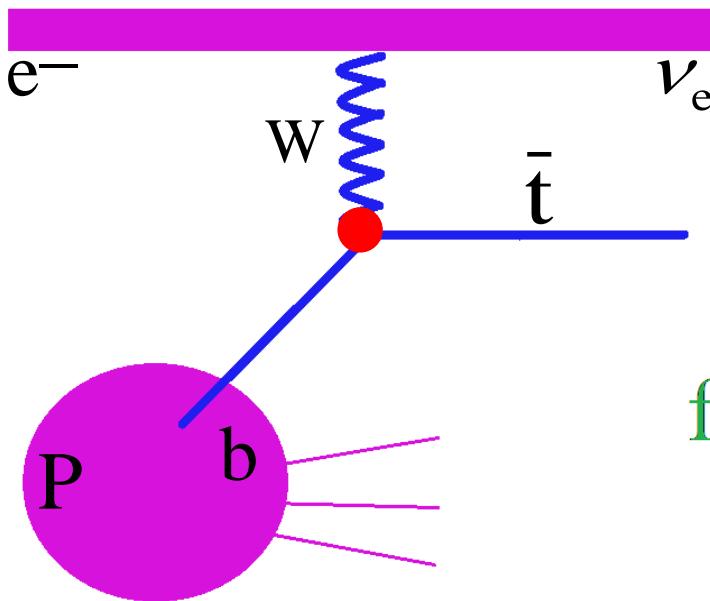
95% C.L.

property	precision
f_V^L	0.001-0.01
f_V^R, f_T^L, f_T^R	0.01-0.1

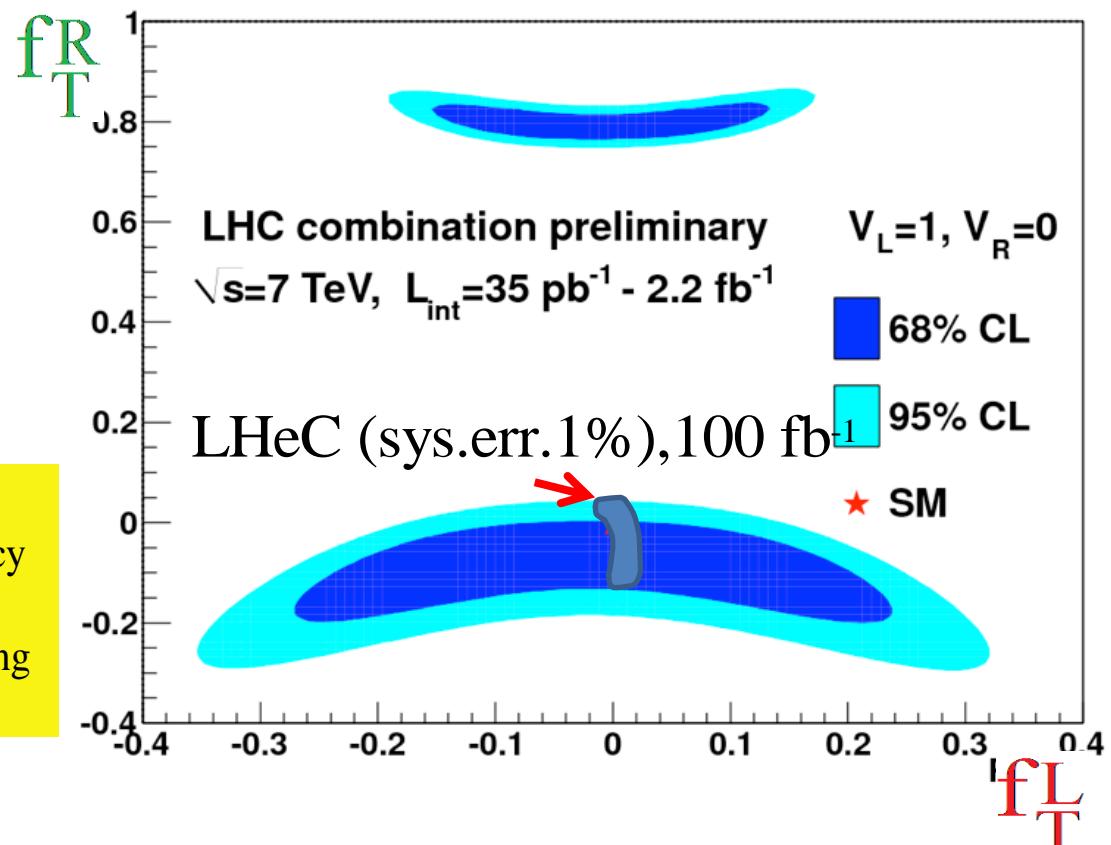
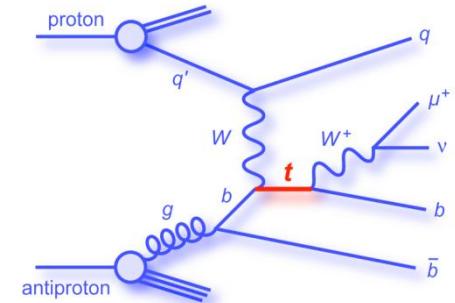
the sensitivity



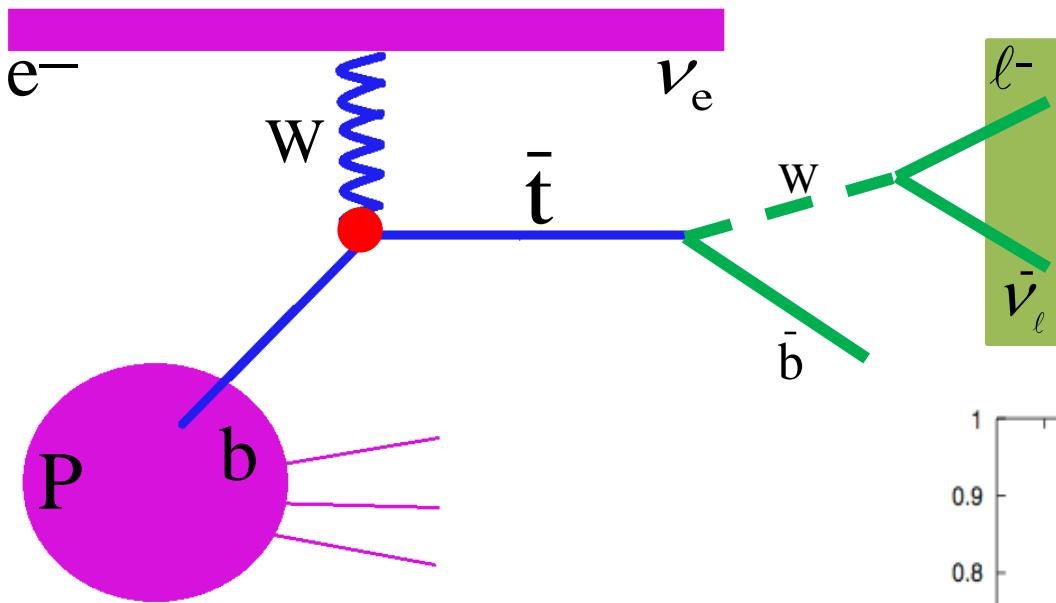
Charged Current Top quark Production



The analysis show that tbW vertex can be probed at the LHeC to a very high accuracy and one can obtain much more stringent upper limits on it, in comparison to existing limits from the LHC



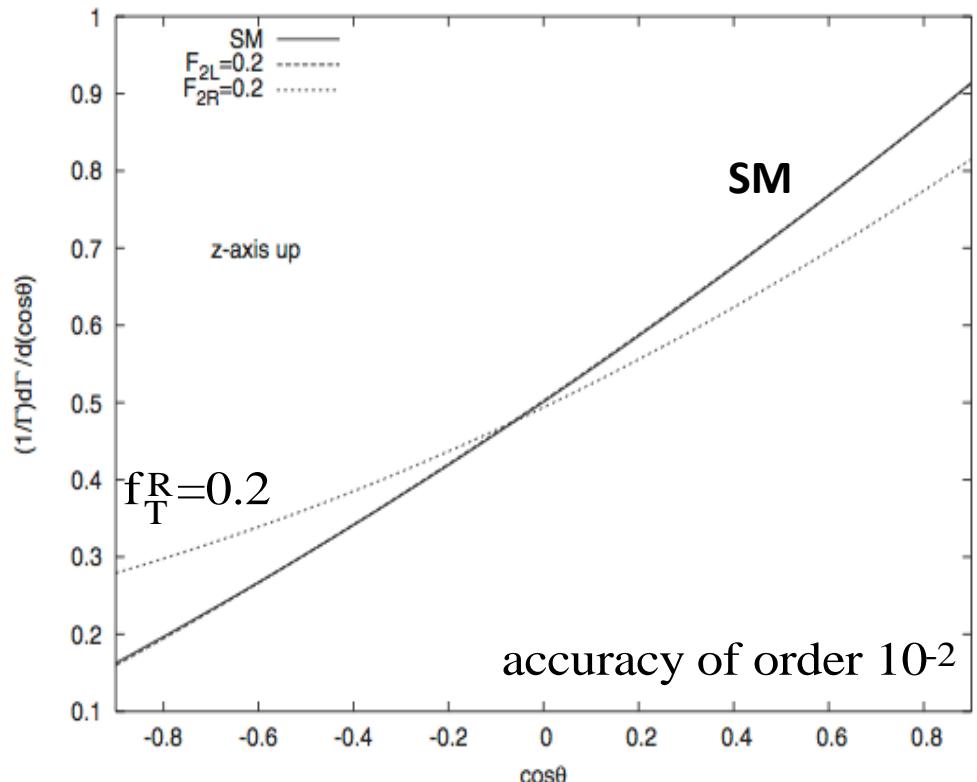
Charged Current Top quark Production



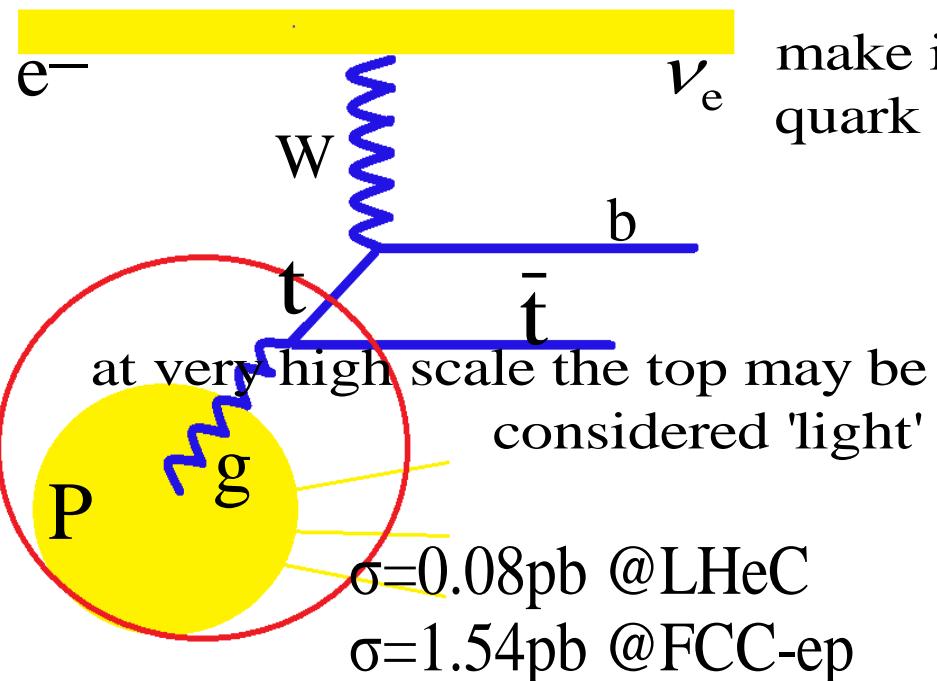
$$\frac{1}{\Gamma_t} \frac{d\Gamma}{d\cos\theta} = \frac{1}{2} (1 + A_{\uparrow\downarrow} \alpha \cos\theta)$$

$$L_{Wtb} = \frac{g}{\sqrt{2}} \left[-\frac{1}{2m_W} W_{\mu\nu} \bar{t} \sigma^{\mu\nu} (f_T^L P_L + f_T^R P_R) b + h.c. \right]$$

$$+ W_\mu \bar{t} \gamma^\mu (V_{tb} f_V^L P_L + f_V^R P_R) b \right]$$

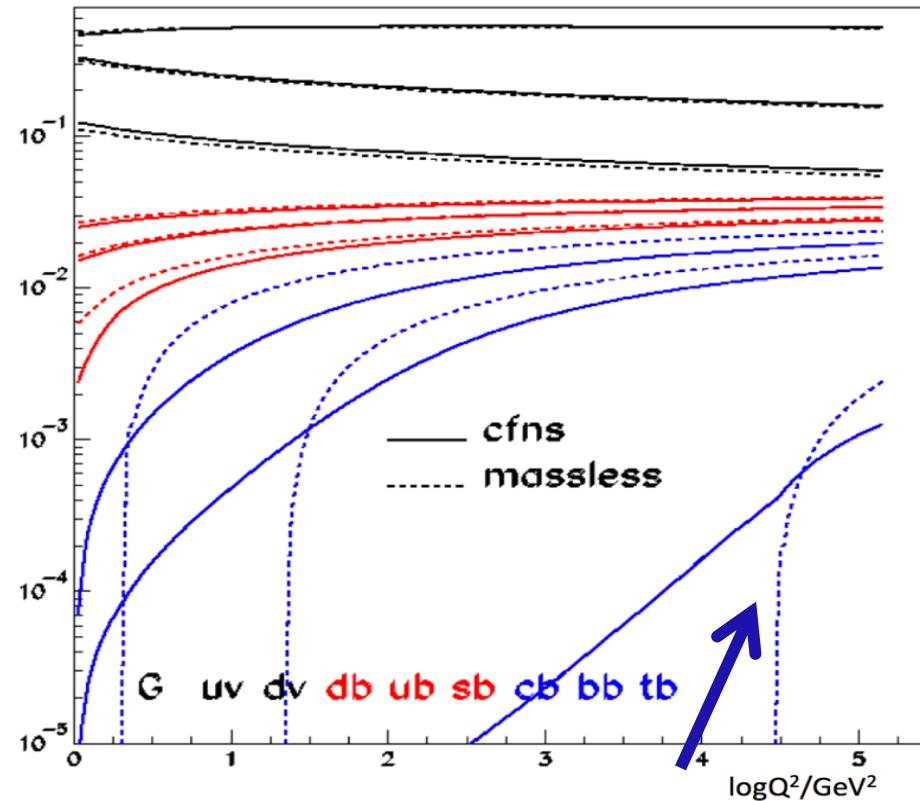


Charged Current Top quark Production



LHeC offers new field of research for top quark pdfs

make it possible to consider quark density for the top quark

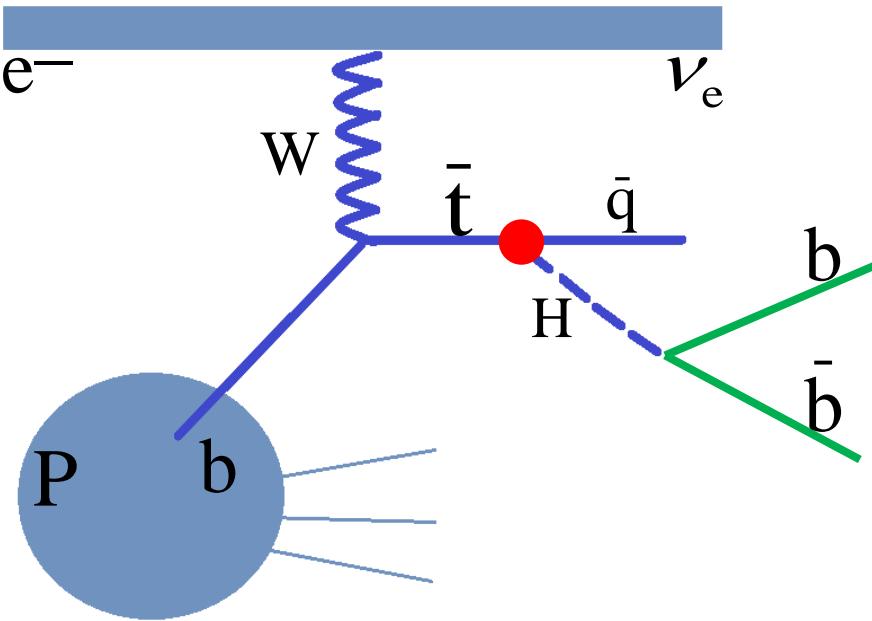


six-flavor-variable-number scheme for top quark can be proposed

Charged Current Top & Higgs Production



Charged Current FCNC Top-Higgs Production



- 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 ($s/\sqrt{S+B}$)
- cut-based and MVA-based analyses

$$L_{tqH} = \underline{\kappa_{tuh}} \bar{t} u H + \underline{\kappa_{tcH}} \bar{t} c H + h.c.$$

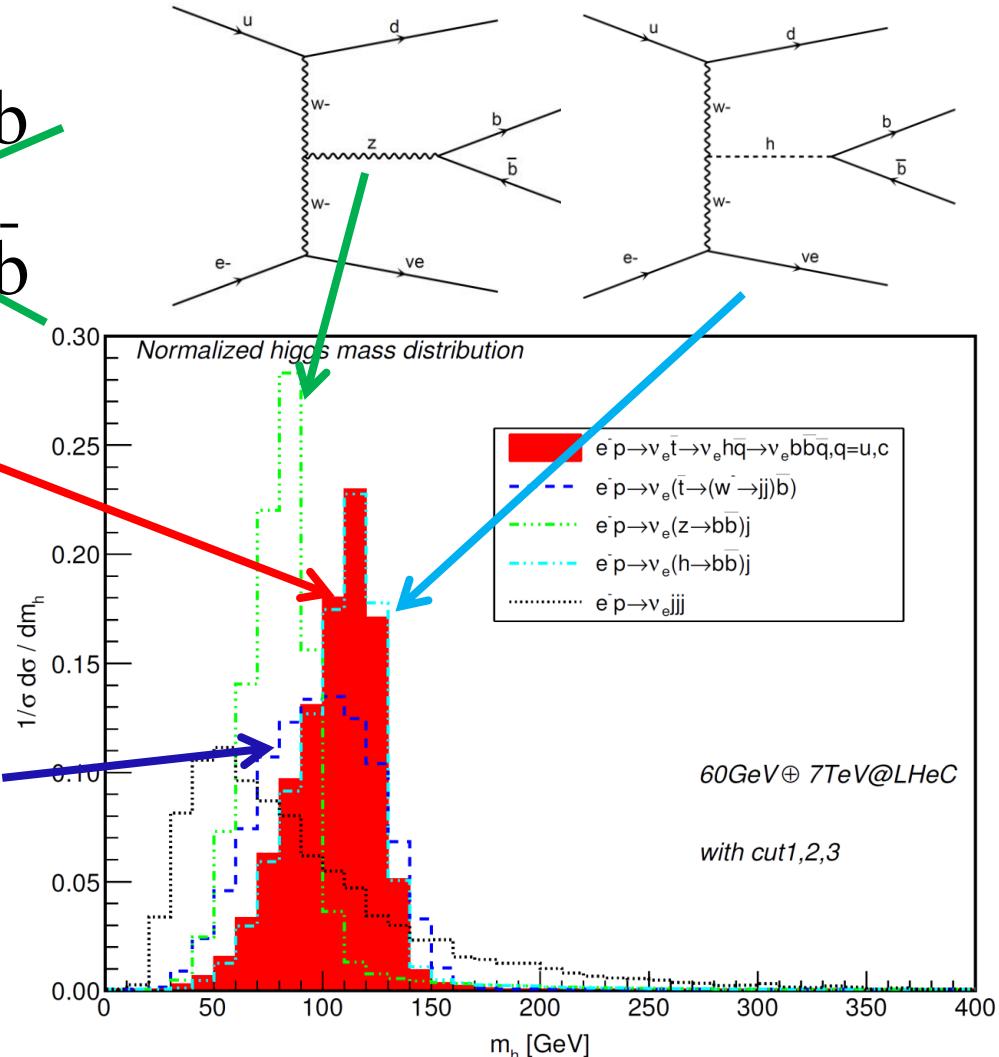
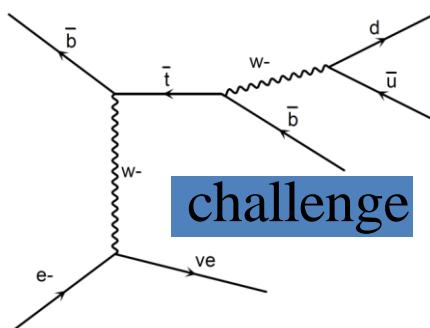
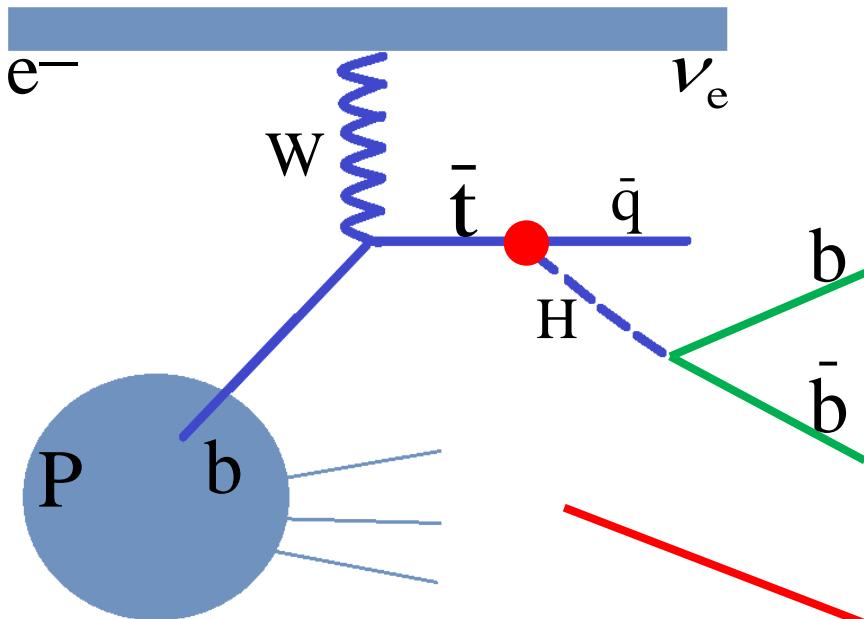
irreducible backgrounds:

$$\begin{aligned} e^- p \rightarrow & \nu_e (H \rightarrow b\bar{b}) j \\ e^- p \rightarrow & \nu_e (Z \rightarrow b\bar{b}) j \\ e^- p \rightarrow & \nu_e (g \rightarrow b\bar{b}) j \end{aligned}$$

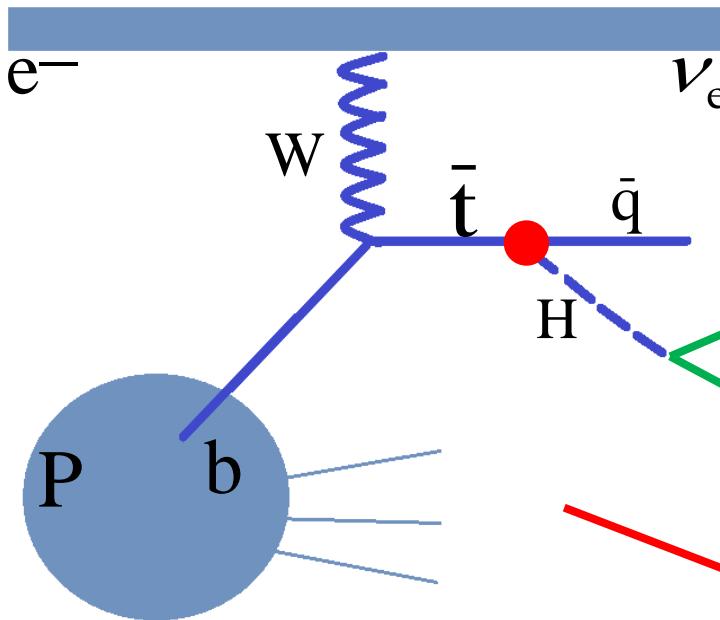
reducible backgrounds:

$$\begin{aligned} e^- p \rightarrow & \nu_e jjj \\ e^- p \rightarrow & \nu_e jjb/\bar{b} \\ e^- p \rightarrow & \nu_e \bar{t} \\ e^- p \rightarrow & e^- (g \rightarrow b\bar{b}) j \end{aligned}$$

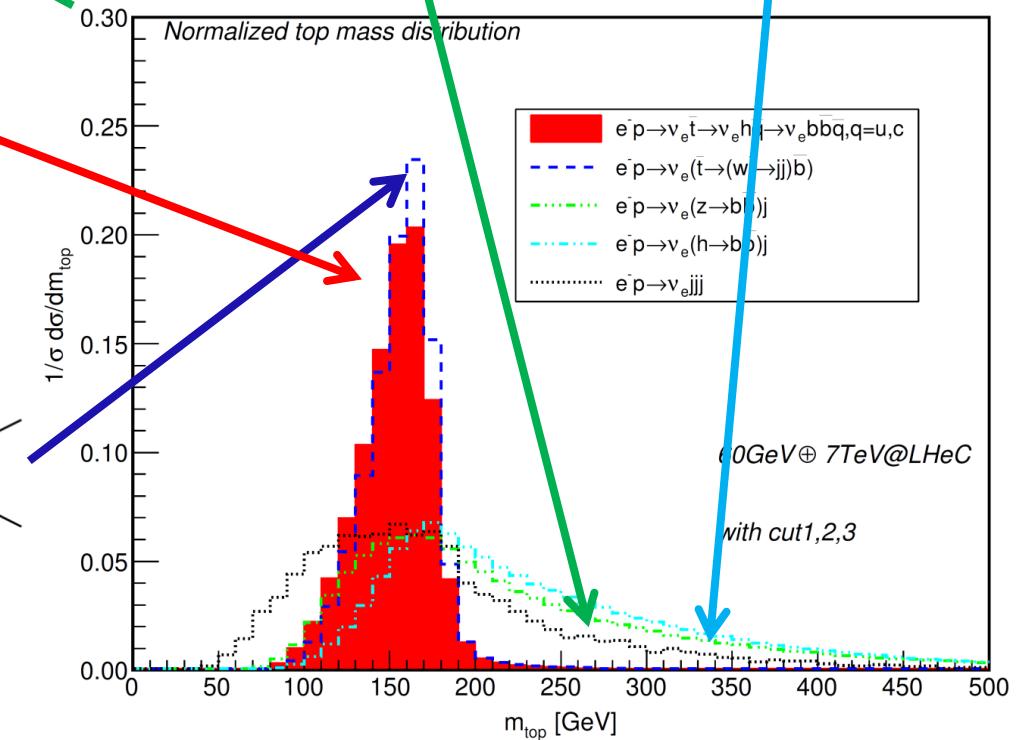
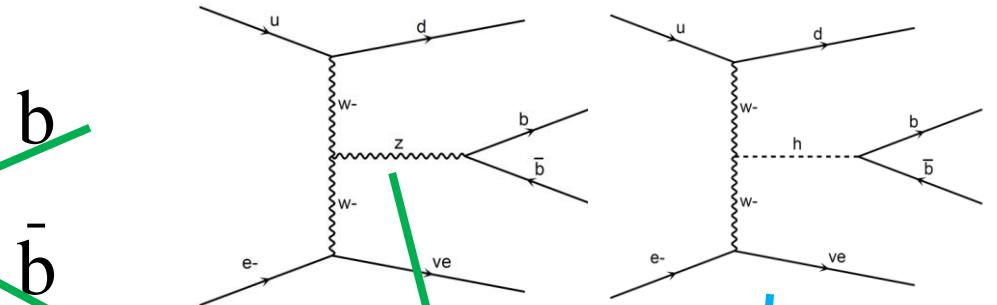
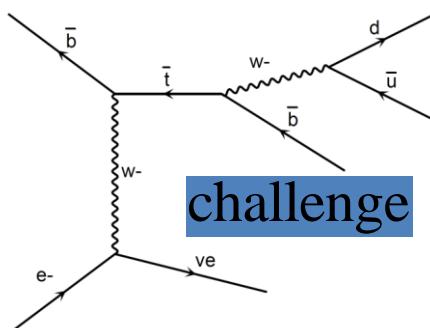
Charged Current FCNC Top-Higgs Production



Charged Current FCNC Top-Higgs Production

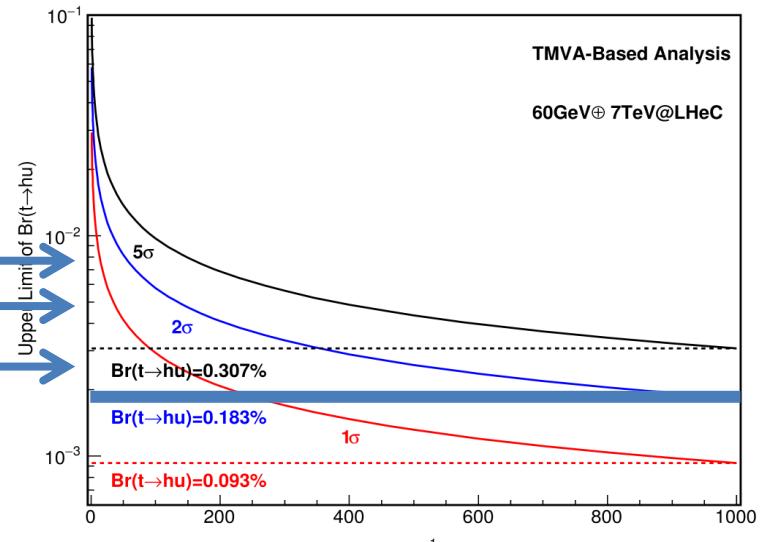


reconstruct Top

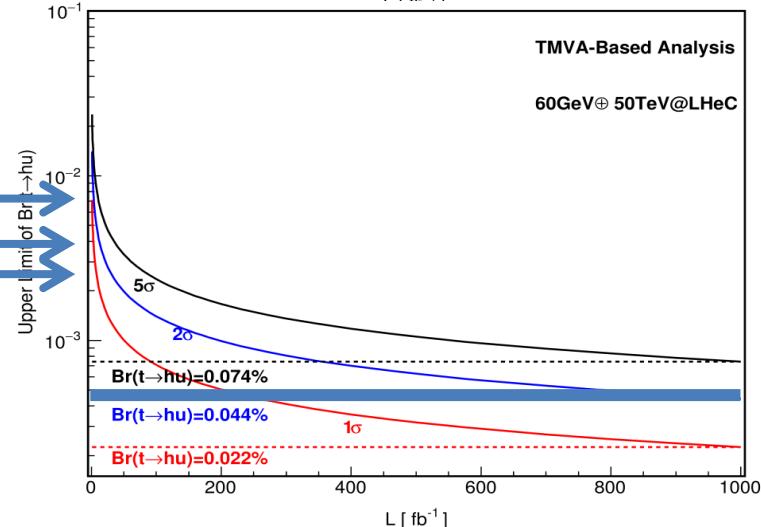


Charged Current FCNC Top-Higgs Production

ATLAS, 4.7(20.3) fb^{-1} @7(8) TeV
CMS, 19.5 fb^{-1} @8 TeV
LHC, 3000 fb^{-1} @8 TeV

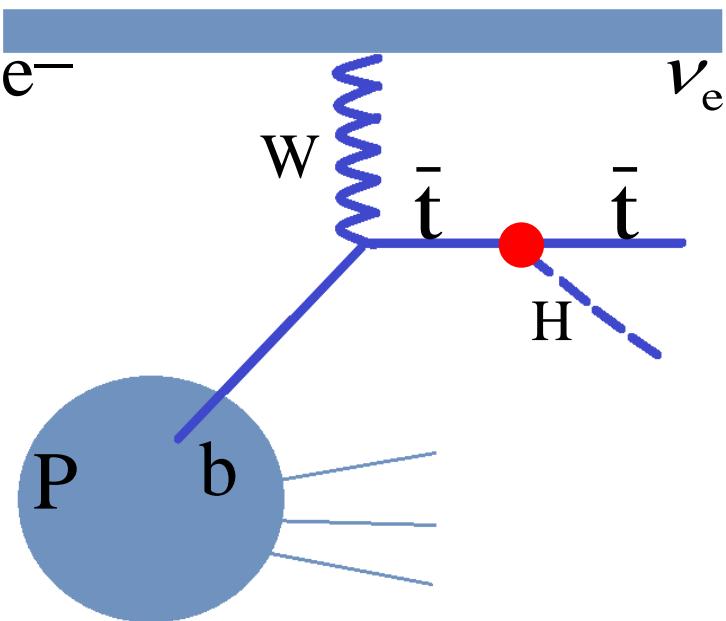


ATLAS, 4.7(20.3) fb^{-1} @7(8) TeV
CMS, 19.5 fb^{-1} @8 TeV
LHC, 3000 fb^{-1} @8 TeV



the potential to probe the tqH coupling can be very much improved compare to the ATLAS and CMS experiments, and even improve the theoretical sensitivity of HL-LHC.

Charged Current Top-Higgs associated Production



CP nature of the $t\bar{t}H$ coupling

$$L_{t\bar{t}H} = -i \frac{m_t}{v} \bar{t} [\kappa \cos \zeta_t + i \gamma_5 \sin \zeta_t] t H$$



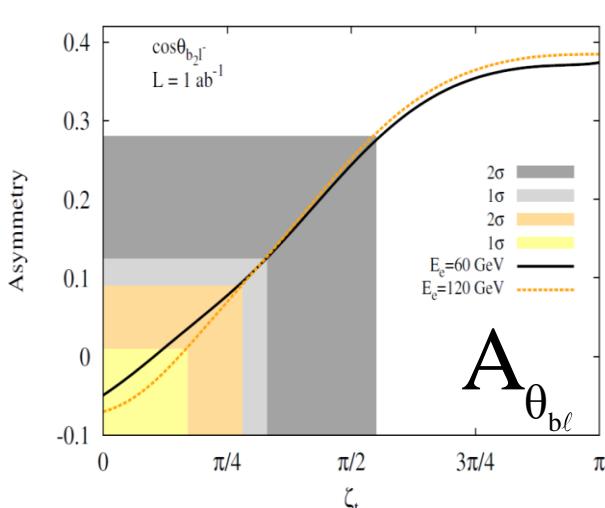
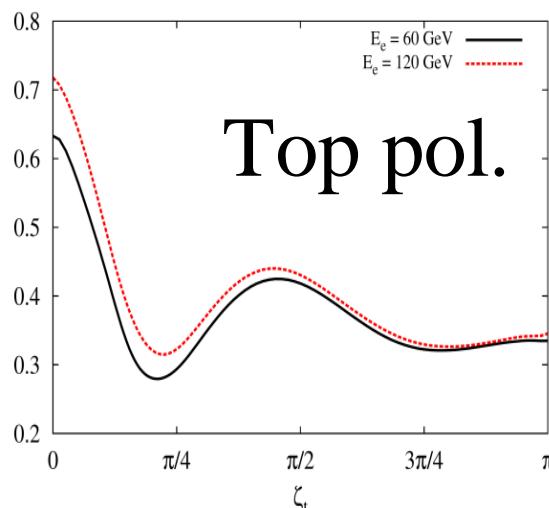
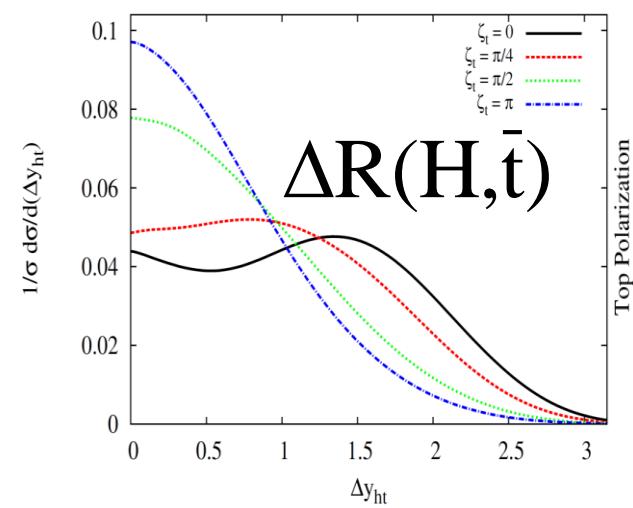
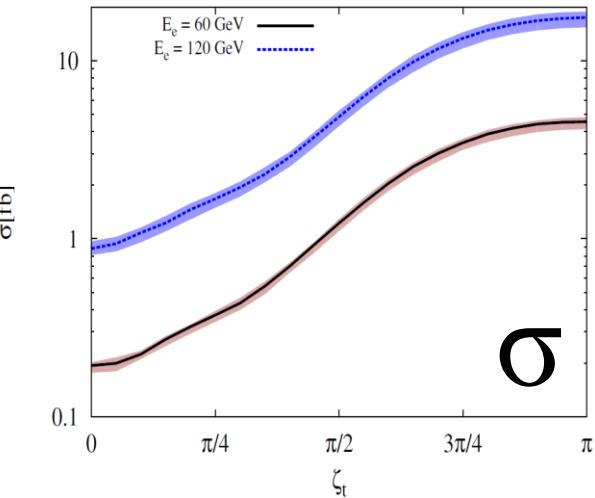
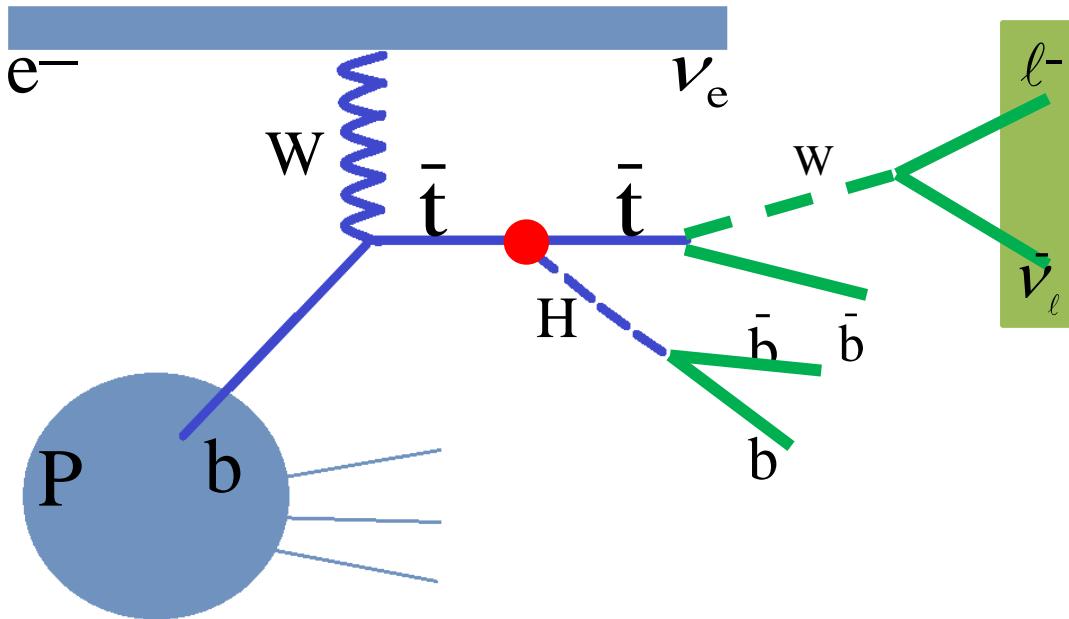
$\zeta_t = 0, \kappa = 1 \rightarrow$ SM case

$\zeta_t = 0$ or $\zeta_t = \pi \rightarrow$ pure scalar state

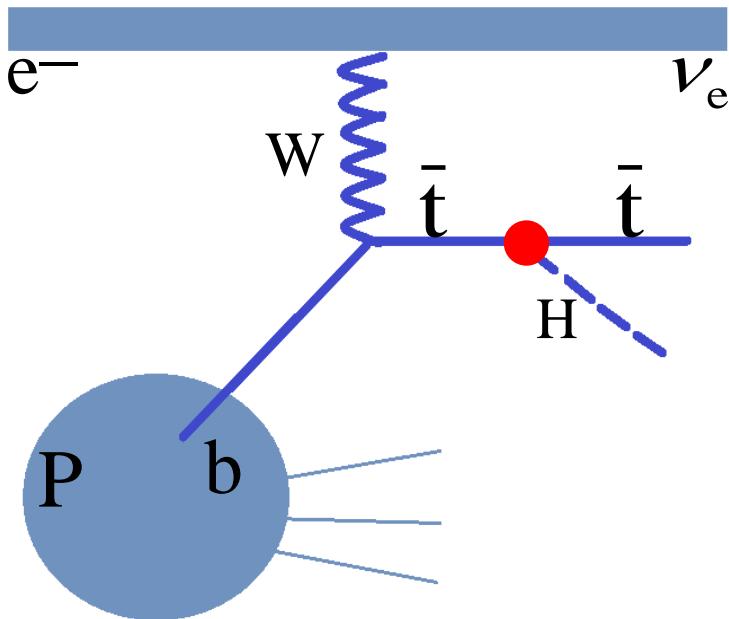
$\zeta_t = \pi/2 \rightarrow$ pure pseudo scalar state

$0 < \zeta_t < \pi/2$ or $\pi/2 < \zeta_t < \pi \rightarrow$ mixture CP-states

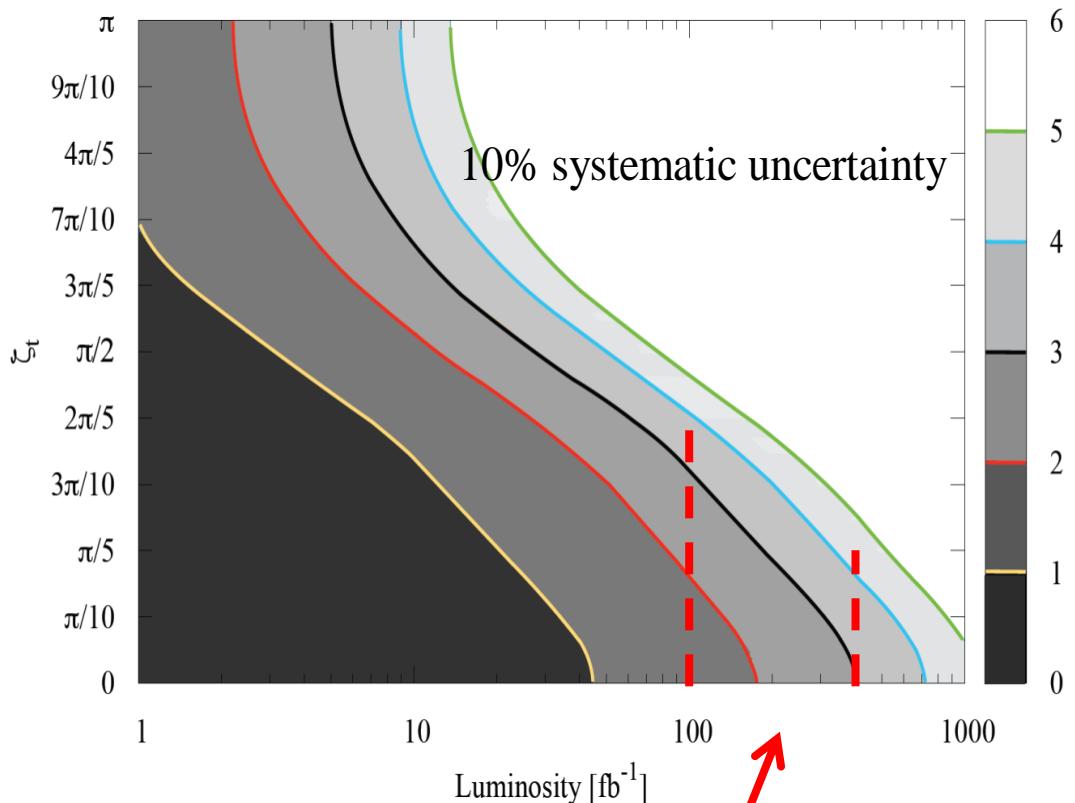
Charged Current Top-Higgs associated Production



Charged Current Top-Higgs associated Production



LHeC provides
a better environment
to test the CP nature
of ttH couplings



$\left\{ \begin{array}{l} 100 \text{ fb}^{-1}: \pi/5 < \zeta_t < \pi \text{ (2}\sigma\text{)} \text{ and } 3\pi/10 < \zeta_t < \pi \text{ (3}\sigma\text{)} \text{ Exc.} \\ 400 \text{ fb}^{-1}: \pi/6 < \zeta_t < \pi \text{ (4}\sigma\text{)} \text{ and } \pi/4 < \zeta_t < \pi \text{ (5}\sigma\text{)} \text{ Exc.} \\ \text{HL-LHC } 3\text{ ab}^{-1} \text{ probe up to } \zeta_t = \pi/6 \end{array} \right.$

Summary

1. In this talk we present a short overview of the top physics at the ep collider.
2. Selected topics include, but not limited to:
 - top structure function
 - top PDFs, top spin polarization
 - $|V_{tb}|$, Q_t measurement
 - anomalous $t\bar{t}\gamma$, $t\bar{t}Z$, $t\bar{b}W$ couplings
 - FCNC $t\bar{q}\gamma$, $t\bar{q}H$ couplings
 - CP nature of $t\bar{t}H$ couplings
3. Some of these topics are being studied with the updated LHeC(FCC-eh) Delphes detector simulation.



A black and white photograph of a bare tree with many branches, standing on a rocky outcrop. The background consists of a cloudy, overcast sky.

Thanks!