Electroweak and Top Physics at Energy Frontier DIS

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on behalf of

LHeC

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MANCHESTER 1824

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Outline

Introduction
Electroweak Physics
Top Quark Physics: CC
Top Quark Physics: NC
Conclusions

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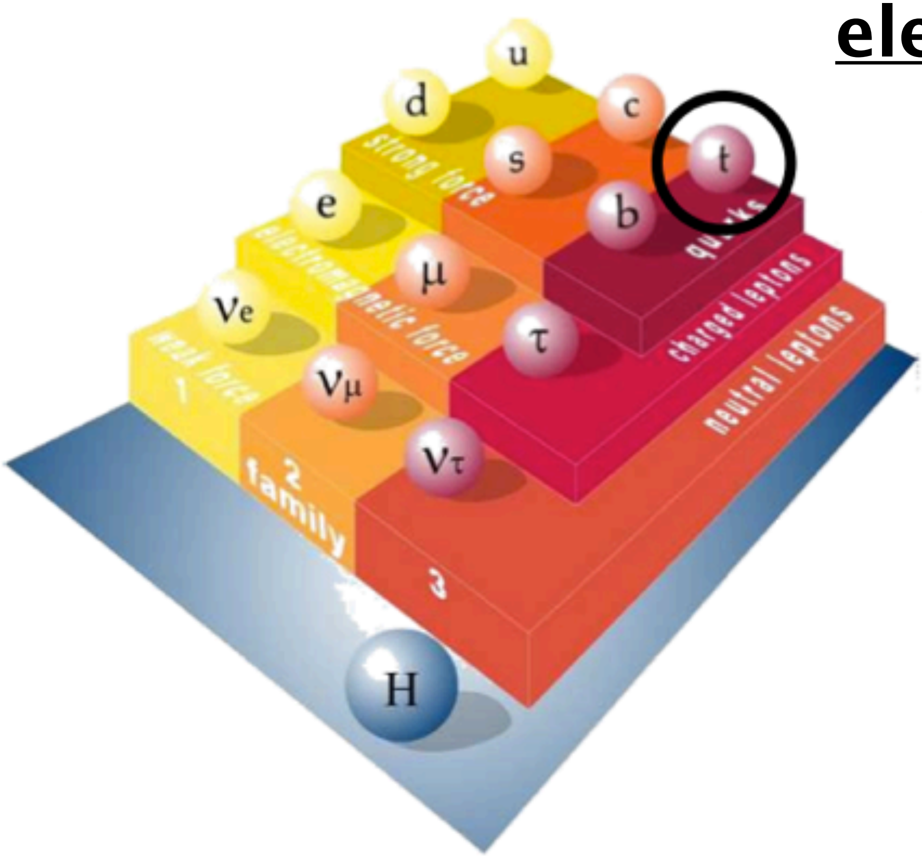
Top Quark Physics: NC

Conclusions

The Standard Model



<u>electroweak symmetry breaking:</u>

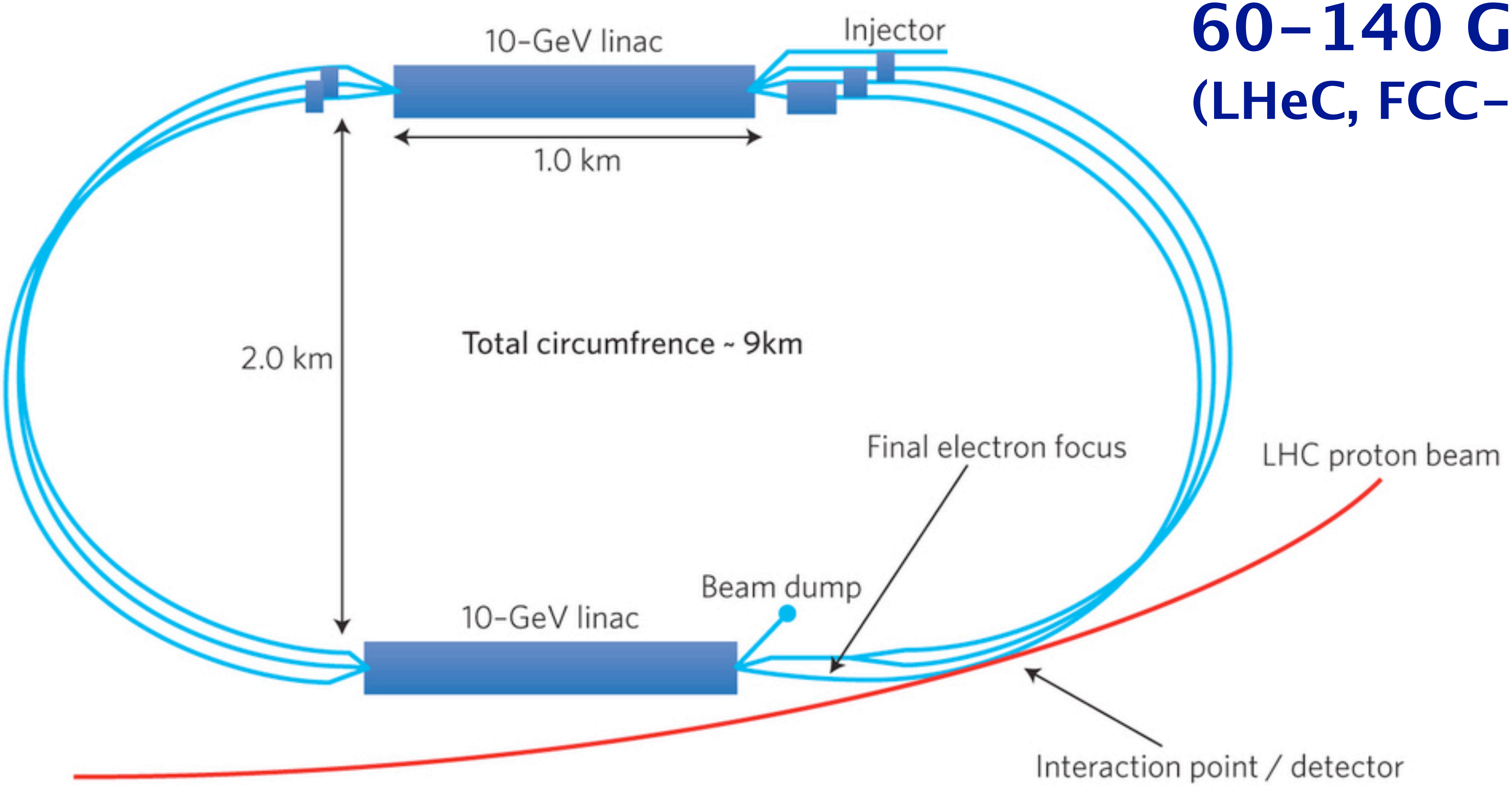
- precision electroweak measurements
- role of the top quark: study EWK interactions with top quarks
- search for new physics

→ ep collider excellent to explore EWK theory

LHeC, Linac-Ring Collider

Energy Recovering Linac

$e^{\pm}$ beam: 60–140 GeV (LHeC, FCC-HE)



$L_{int} \leq 100\ fb^{-1}$

p beam: 7 TeV

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Top Quark Physics: NC

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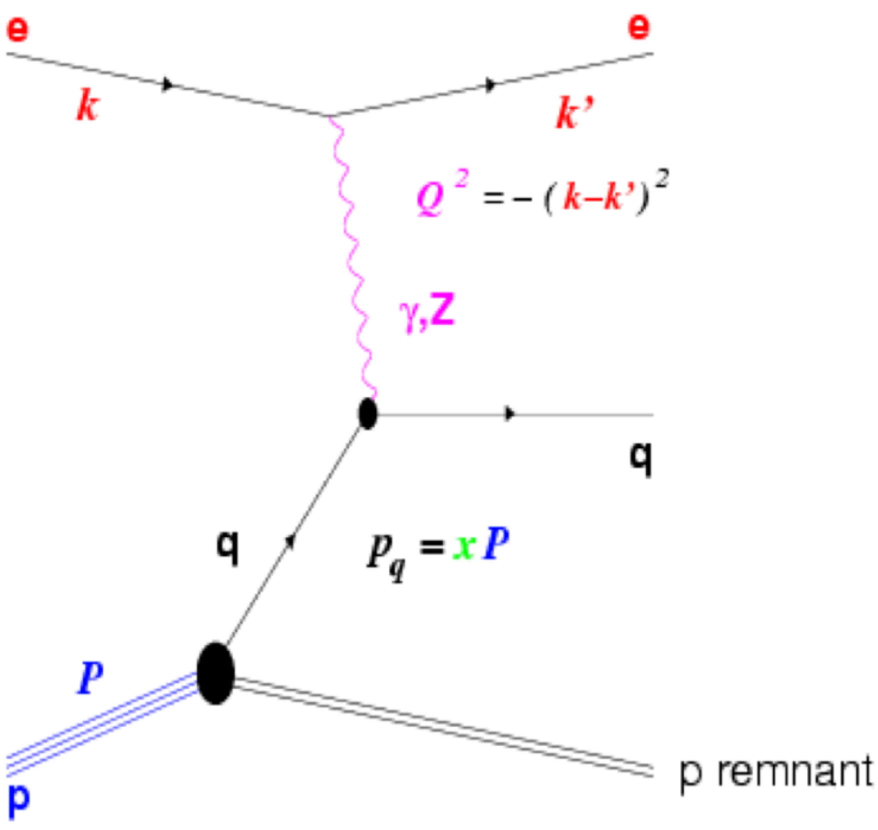
Deep Inelastic Scattering

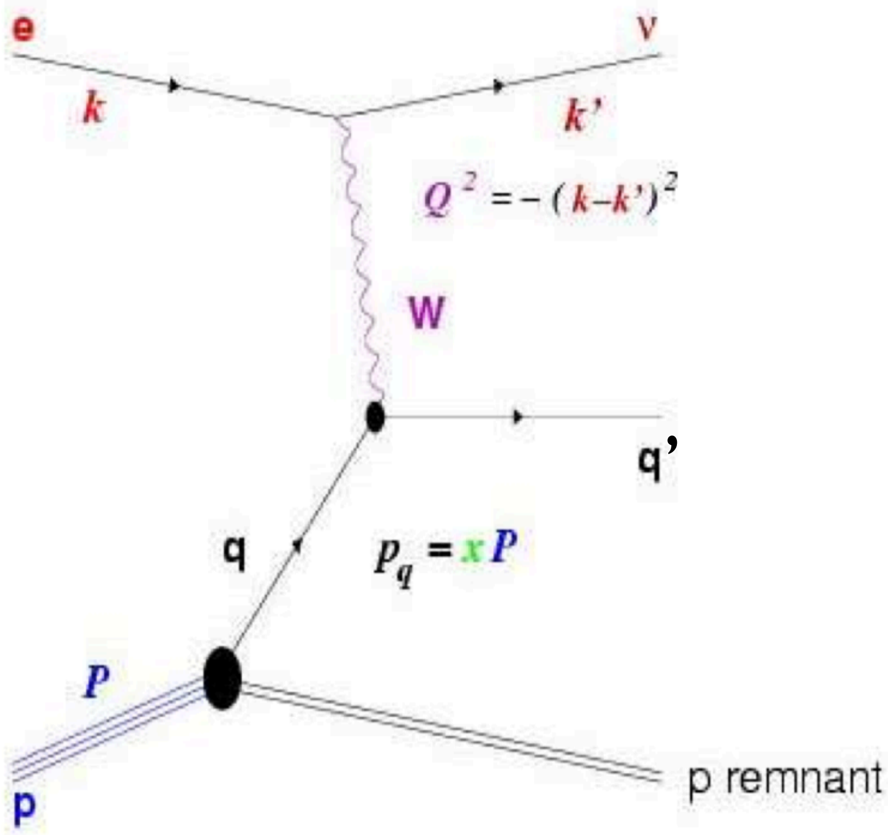
Neutral Current (NC)



Q^2: four-momentum transfer

spatial resolution $\sim 1/Q$

Charged Current (CC)

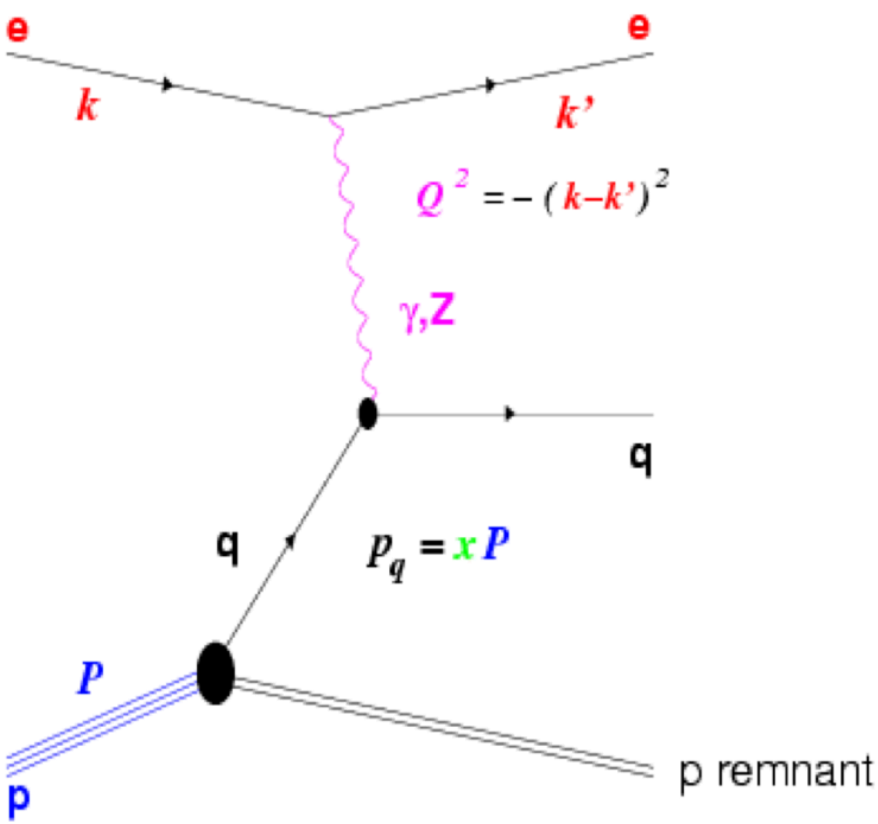


x: fractional momentum of

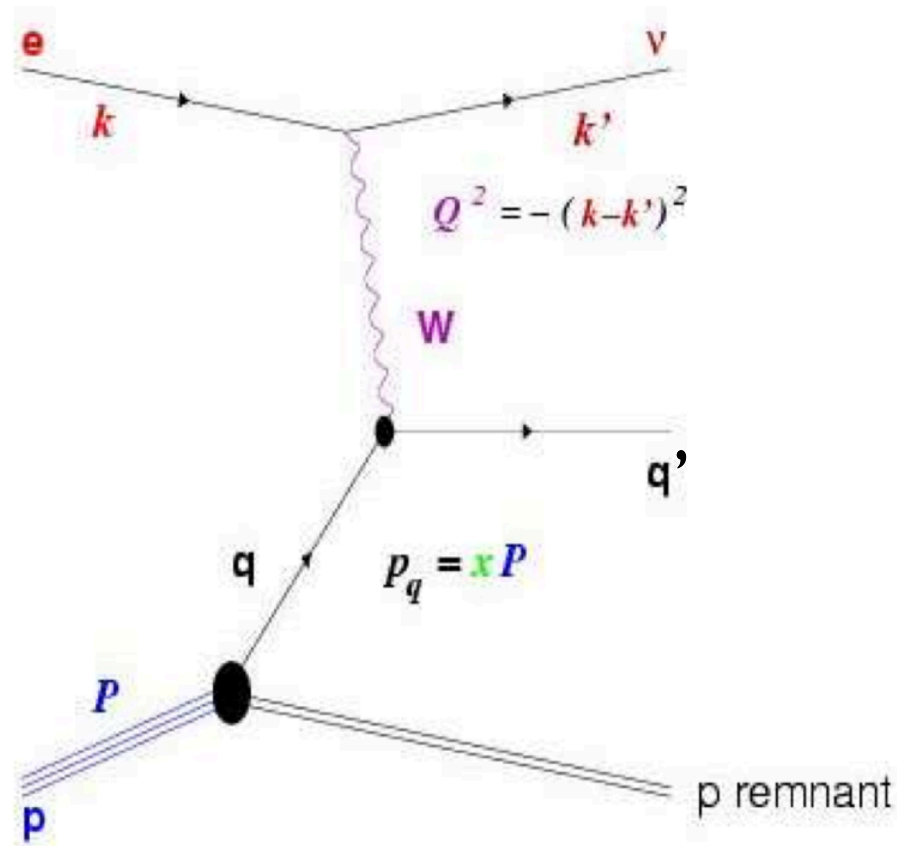
the struck quark

Deep Inelastic Scattering

Neutral Current (NC)



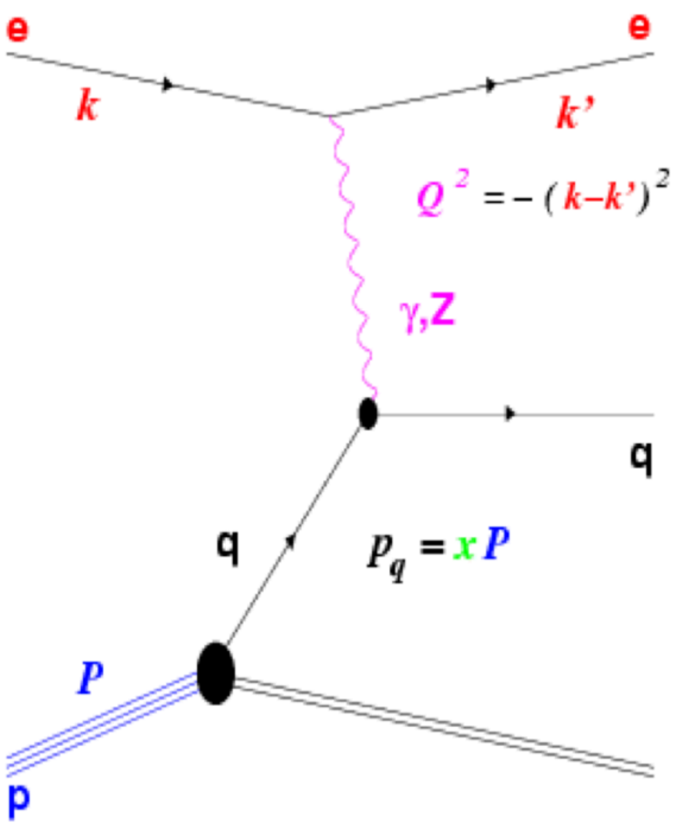
Charged Current (CC)

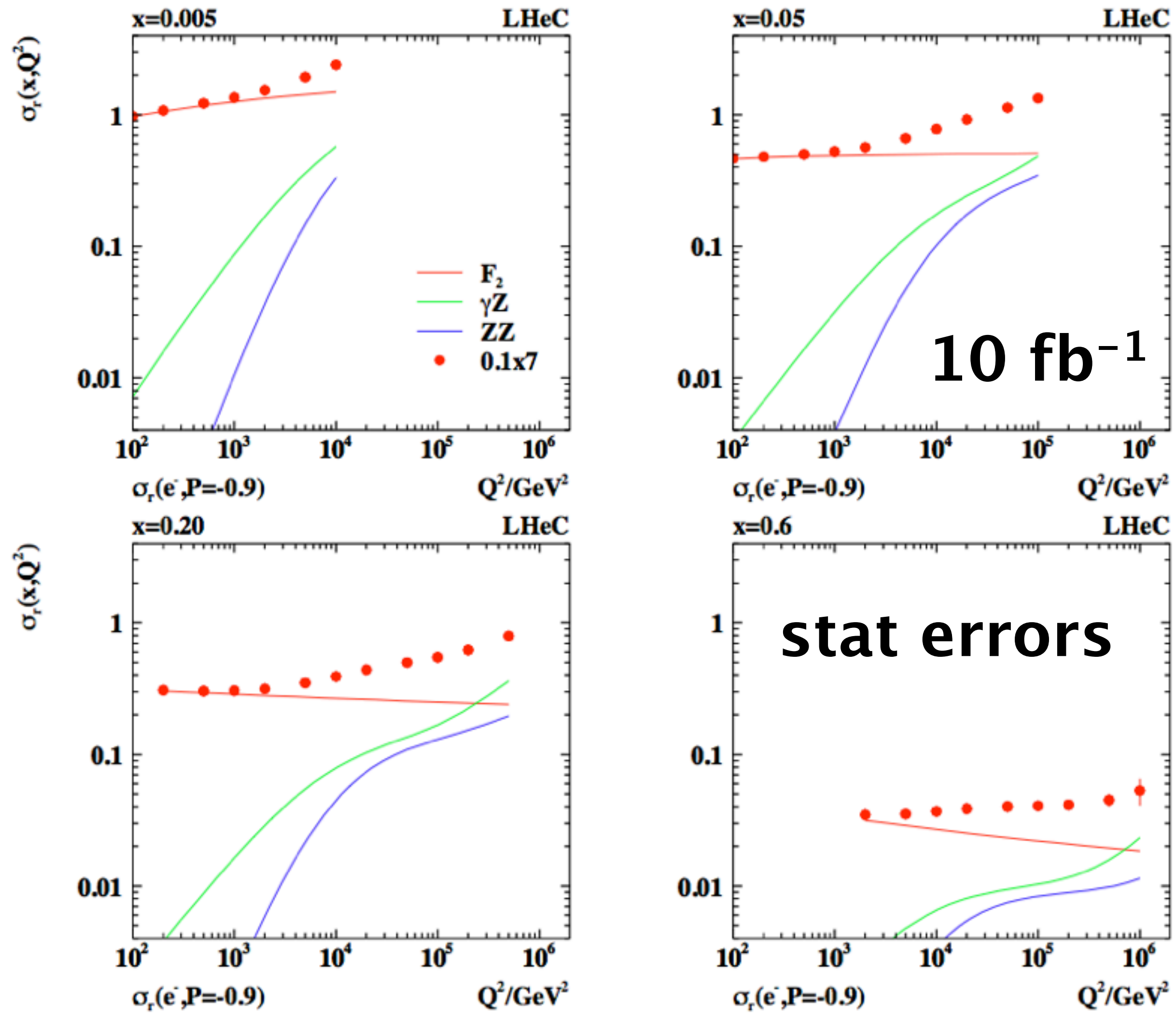


→ **LHeC is unique facility for testing EW theory: two charge states, different polarisation states, NC+CC, p or isoscalar targets**

NC Cross Section Measurement

Neutral Current (NC)



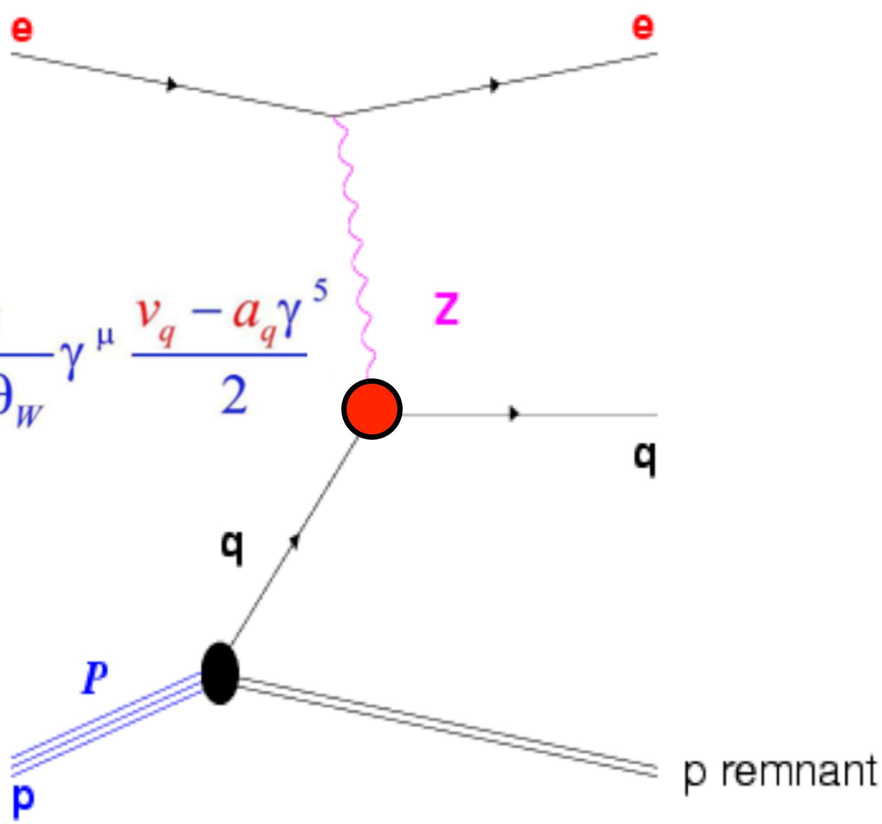


→ **high precision in large range of Bjørken x and Q^2**

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

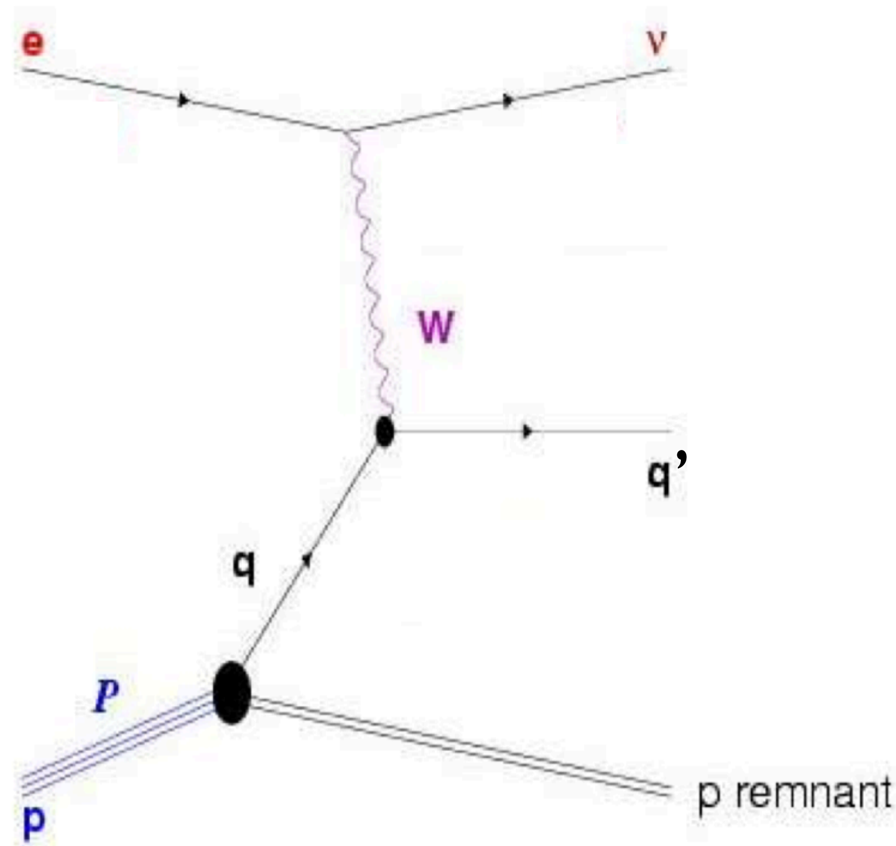
Quark Couplings to the Z boson

Neutral Current (NC)



$$\frac{ig}{\cos\theta_W}\gamma^{\mu}\frac{v_q - a_q\gamma^5}{2}$$

Charged Current (CC)



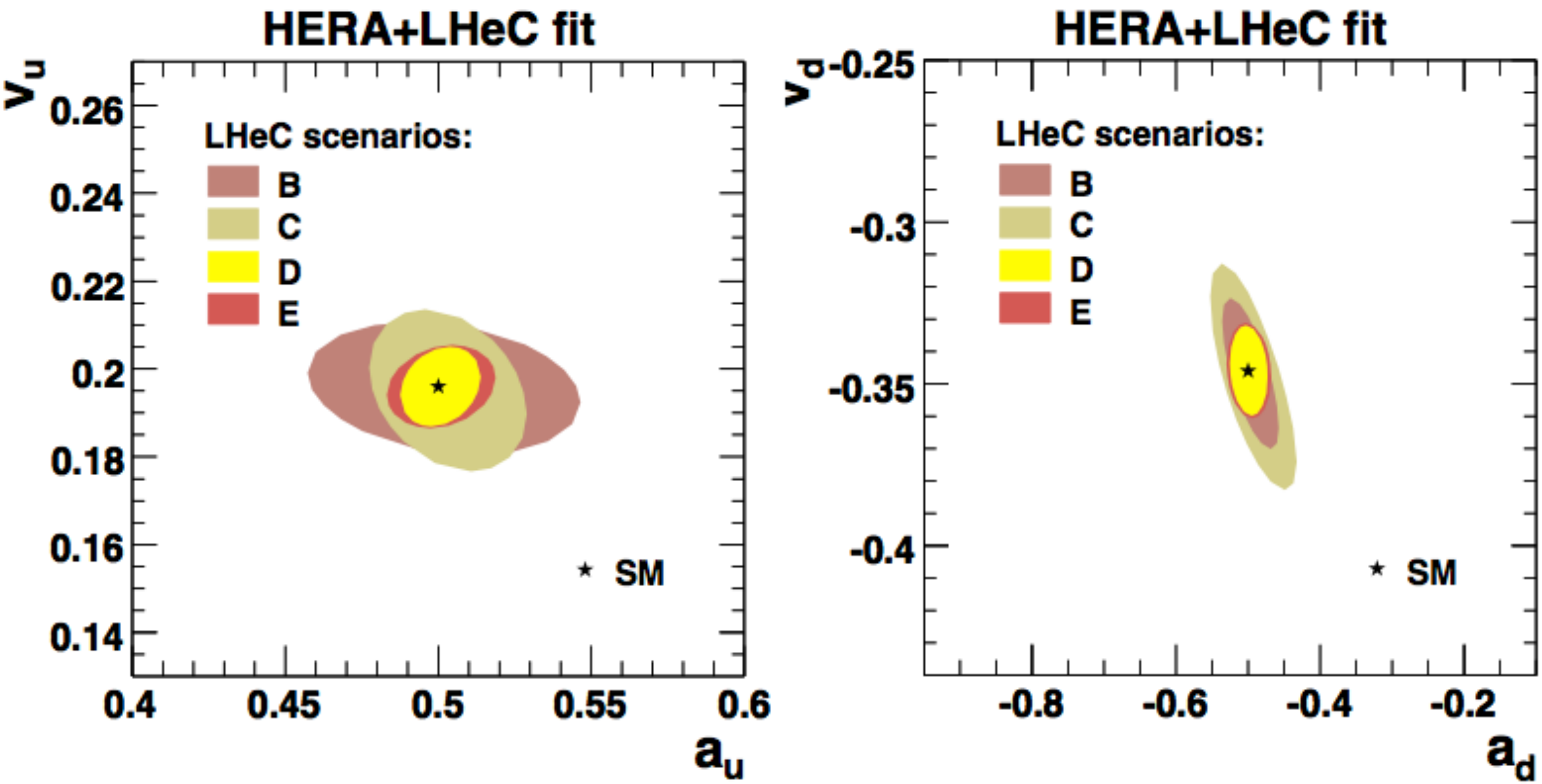
$a_q = I_3^L$ Axial coupling, I³=+1/2 for u, -1/2 for d

$v_q = I_3^L - 2e_q \sin^2\theta_W$ Vector coupling

fit to simulated NC and CC data to extract a_u, a_d, v_u, v_d and PDFs simultaneously

Vector and Axial Vector NC Couplings

C: e beam: 50 GeV, 1 fb^{-1} e^-p, 1 fb^{-1} e^+p, polarisation: 40%

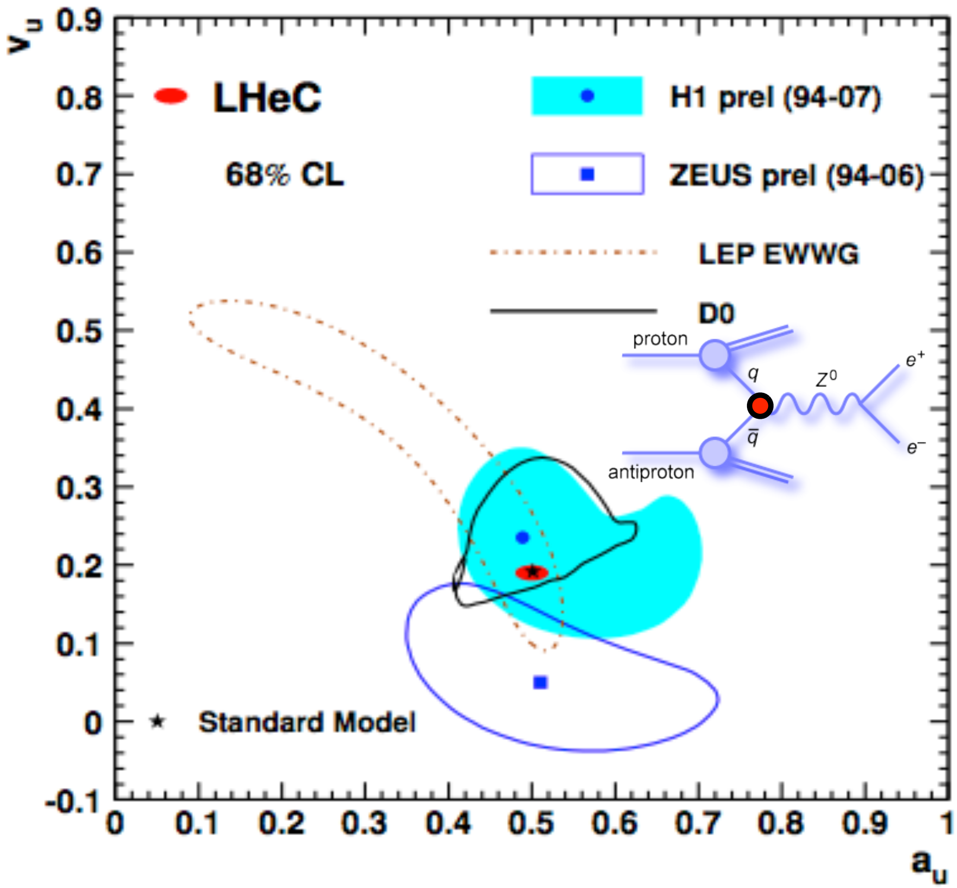


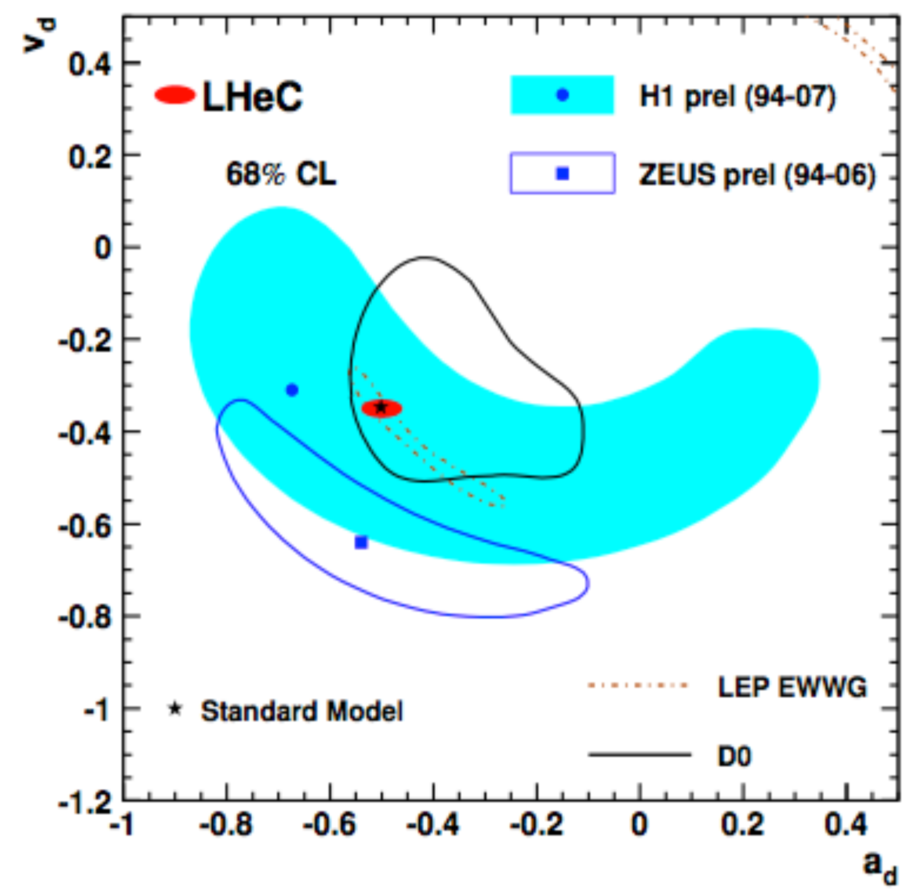
LHeC TDR, J.Phys. G39, 075001 (2012)

Vector and Axial Vector NC Couplings

C: e beam: 50 GeV, 1 fb^{-1} e^{-}p, 1 fb^{-1} e^{+}p, polarisation: 40%

significant improvements for higher luminosity and FCC-HE





→ **high precision measurement**

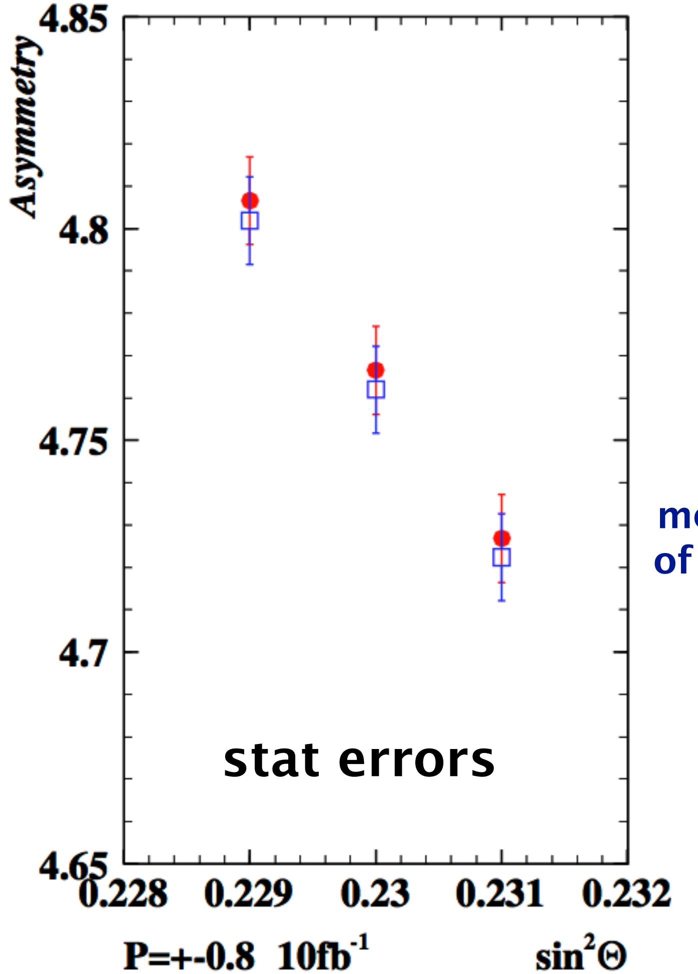
→ **test new physics: Z' boson, R-parity violating SUSY, leptoquarks**

Asymmetry Measurements

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

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

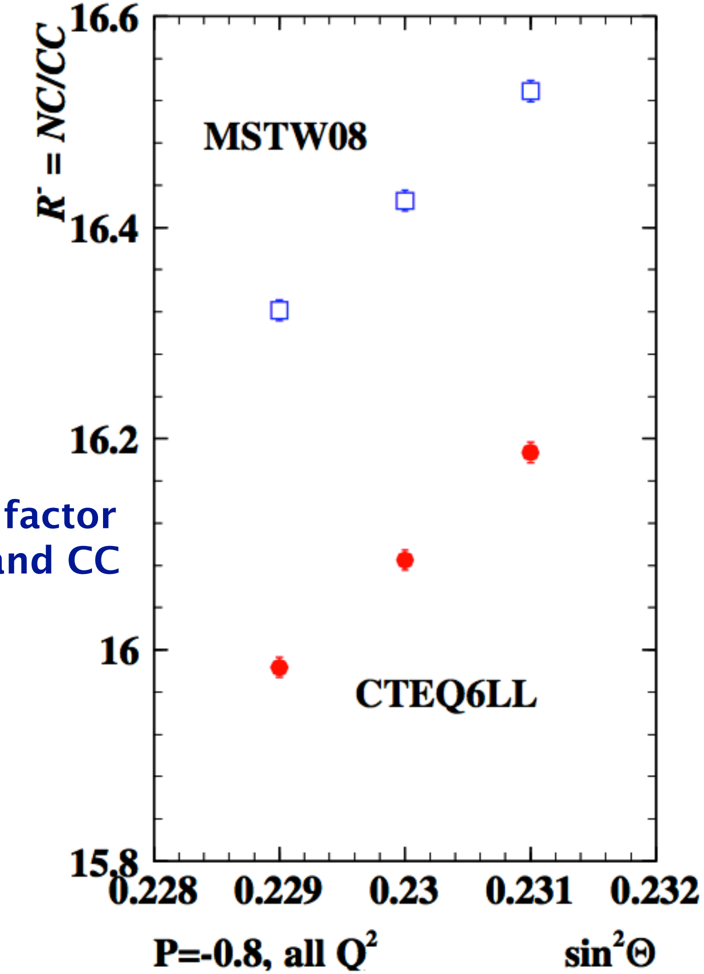
A^-



$10\ fb^{-1}$

e beam: 60 GeV

mean x differs by factor of 6 between NC and CC



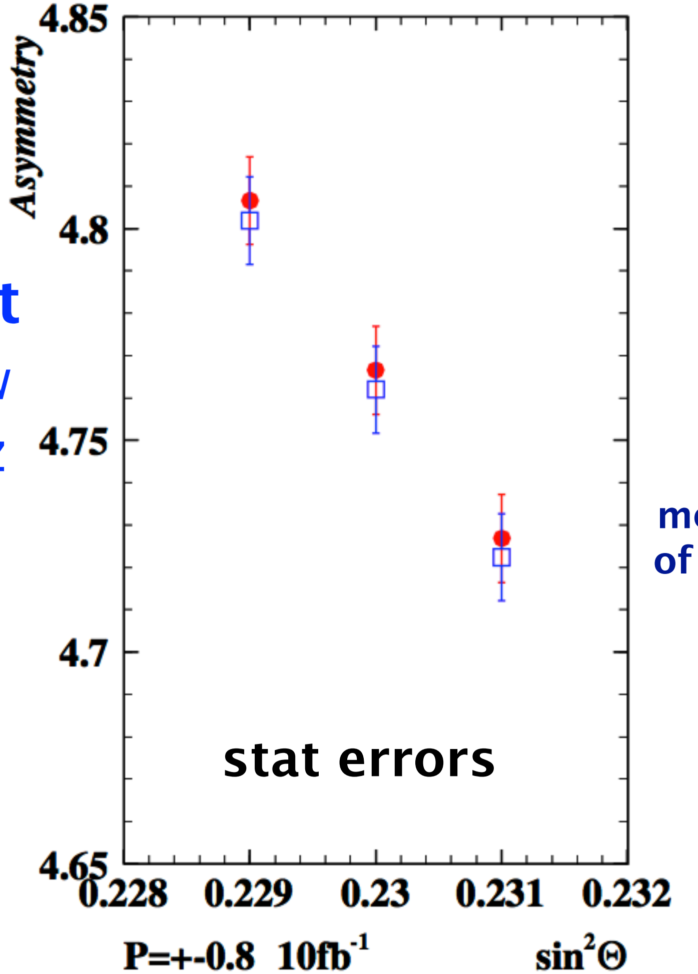
Asymmetry Measurements

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

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

A^-

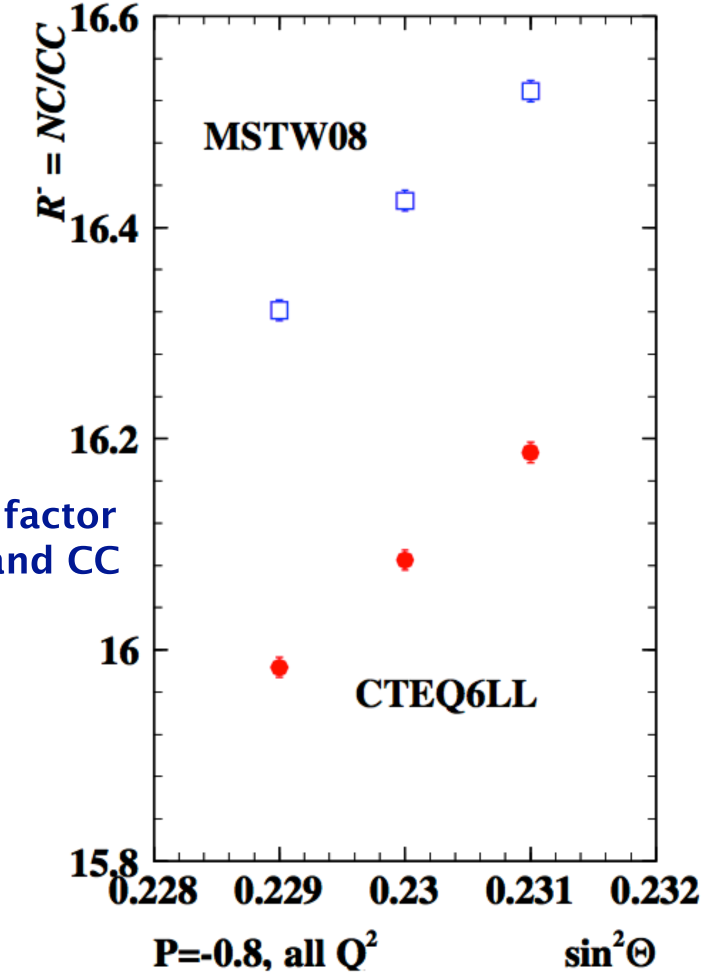
extract $\sin^2\theta_W$ (α, m_Z fixed)



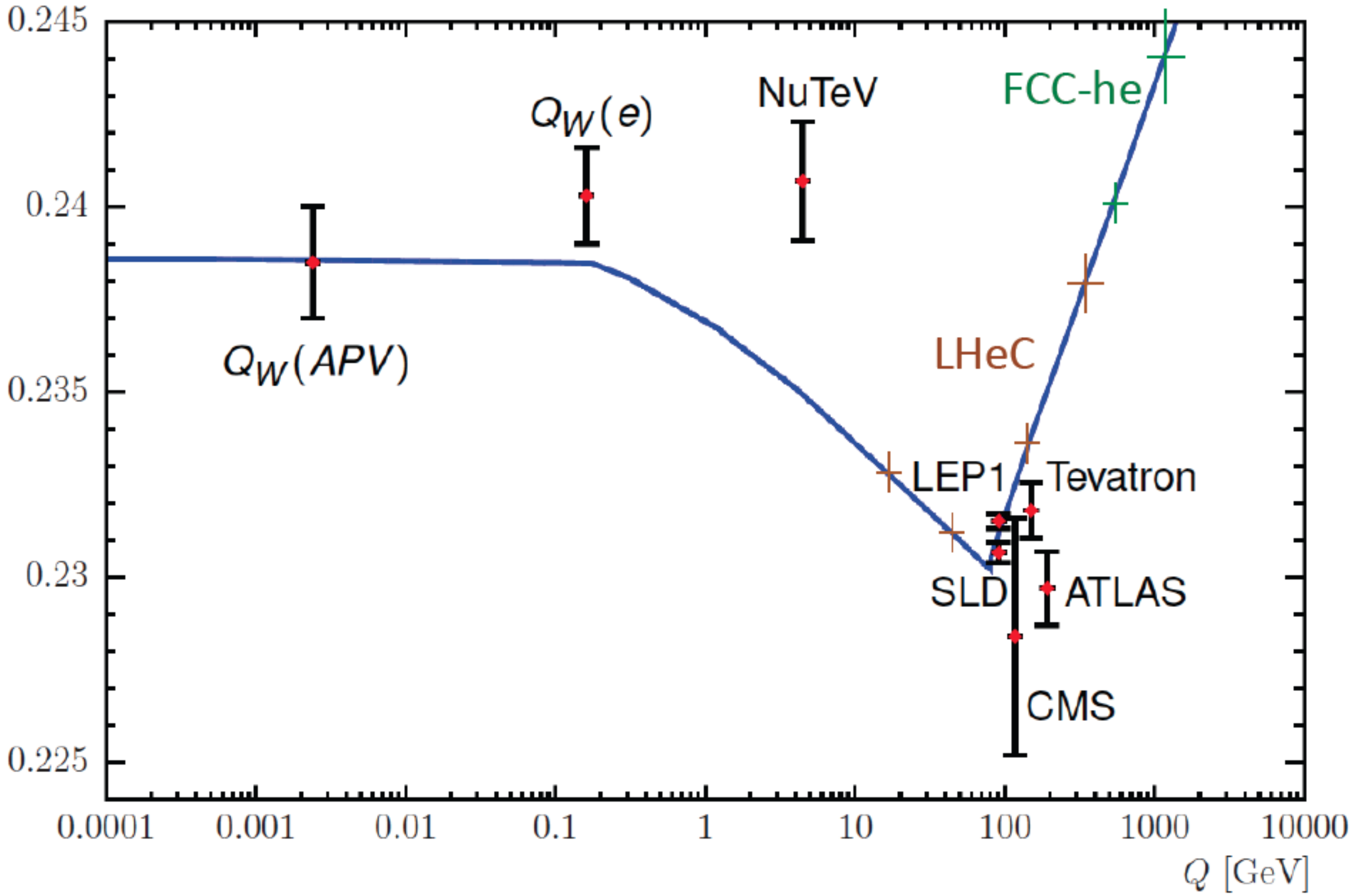
10 fb^{-1}

e beam: 60 GeV

mean x differs by factor of 6 between NC and CC



Scale Dependence of $\sin^2\theta_W$



→ **probe large range of scale dependence**

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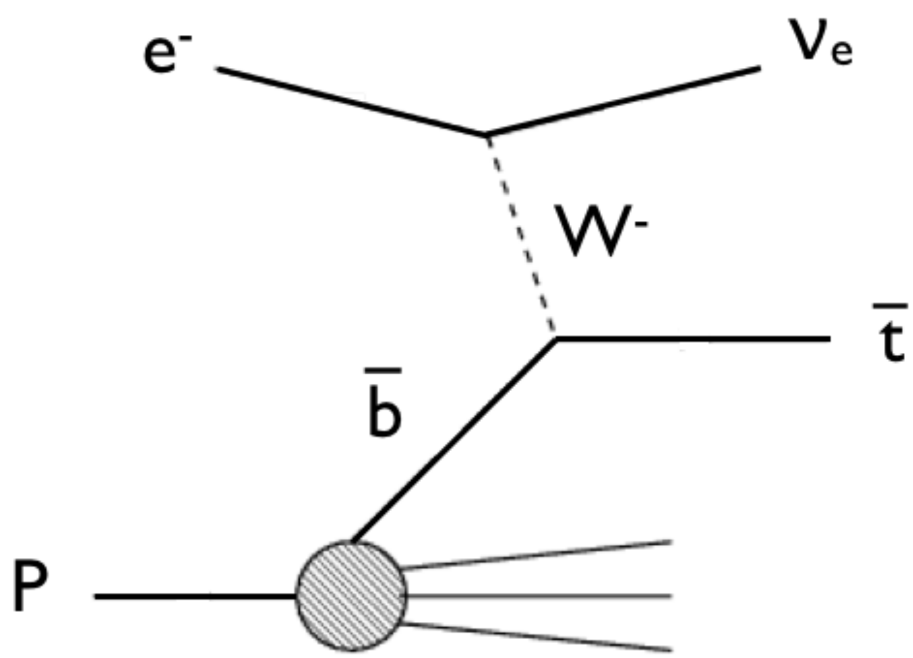
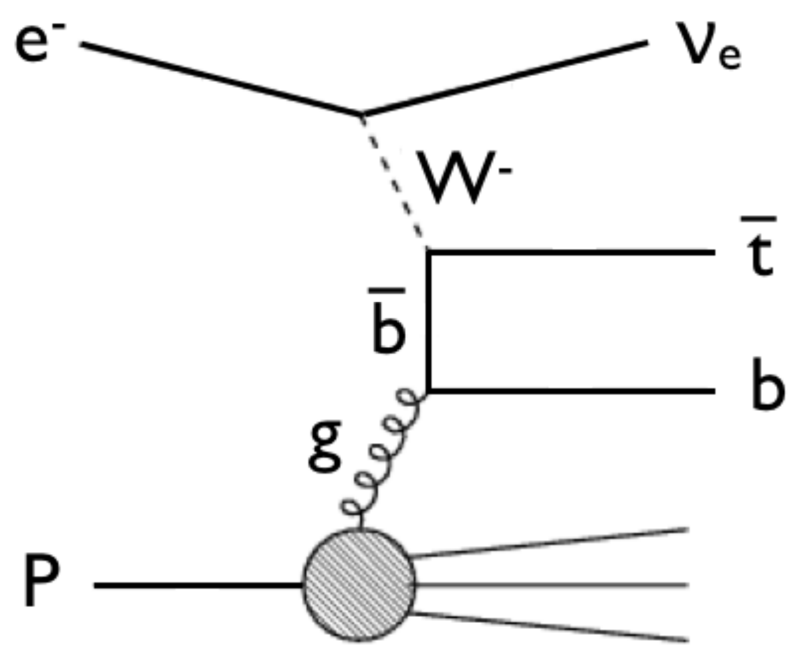
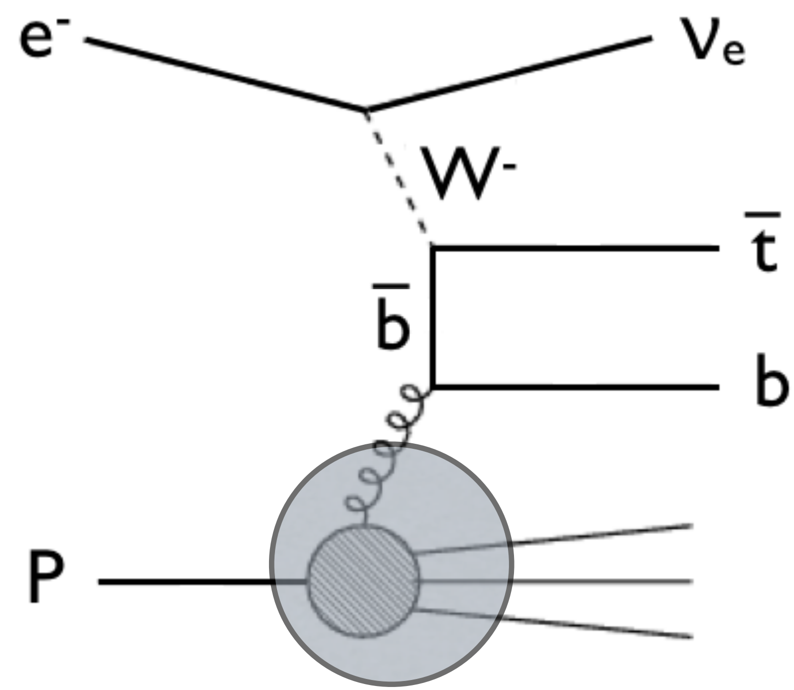
CC Single Top Quark Production





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

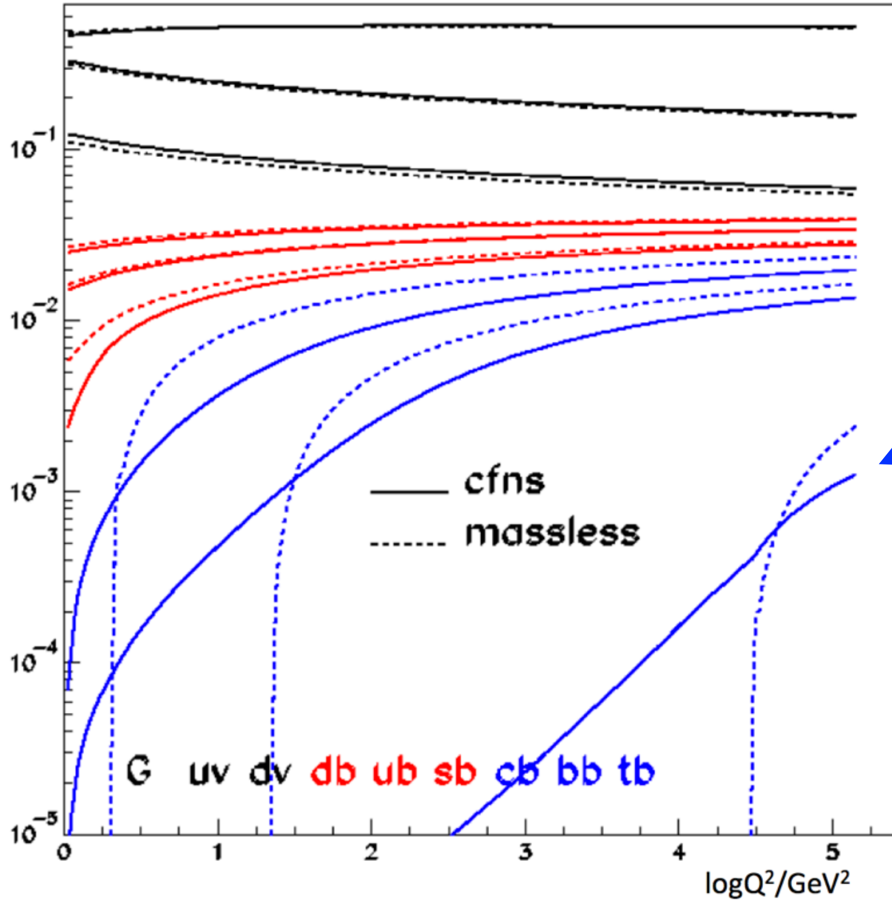
Gluon Parton Density Function



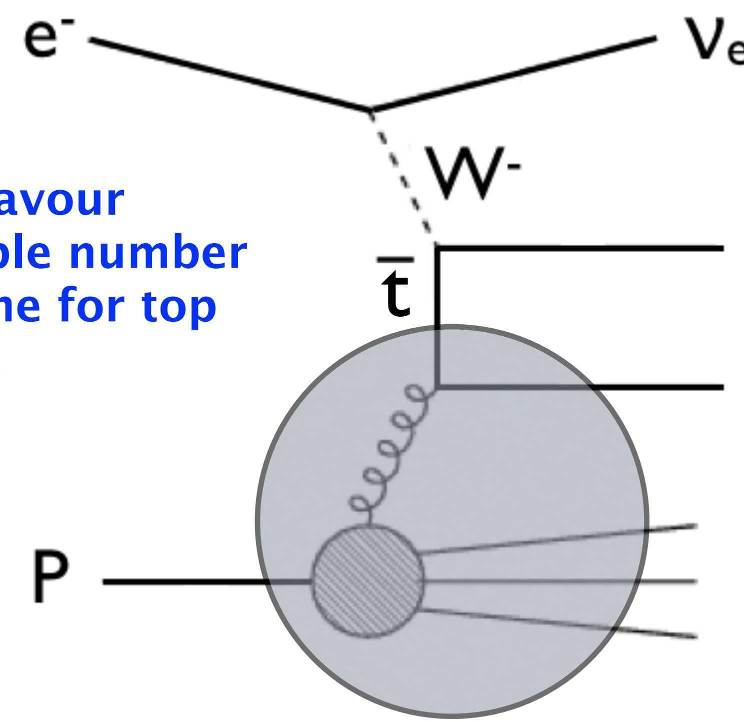
→ **measure gluon density at high x**

Top Quark Parton Density Function

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



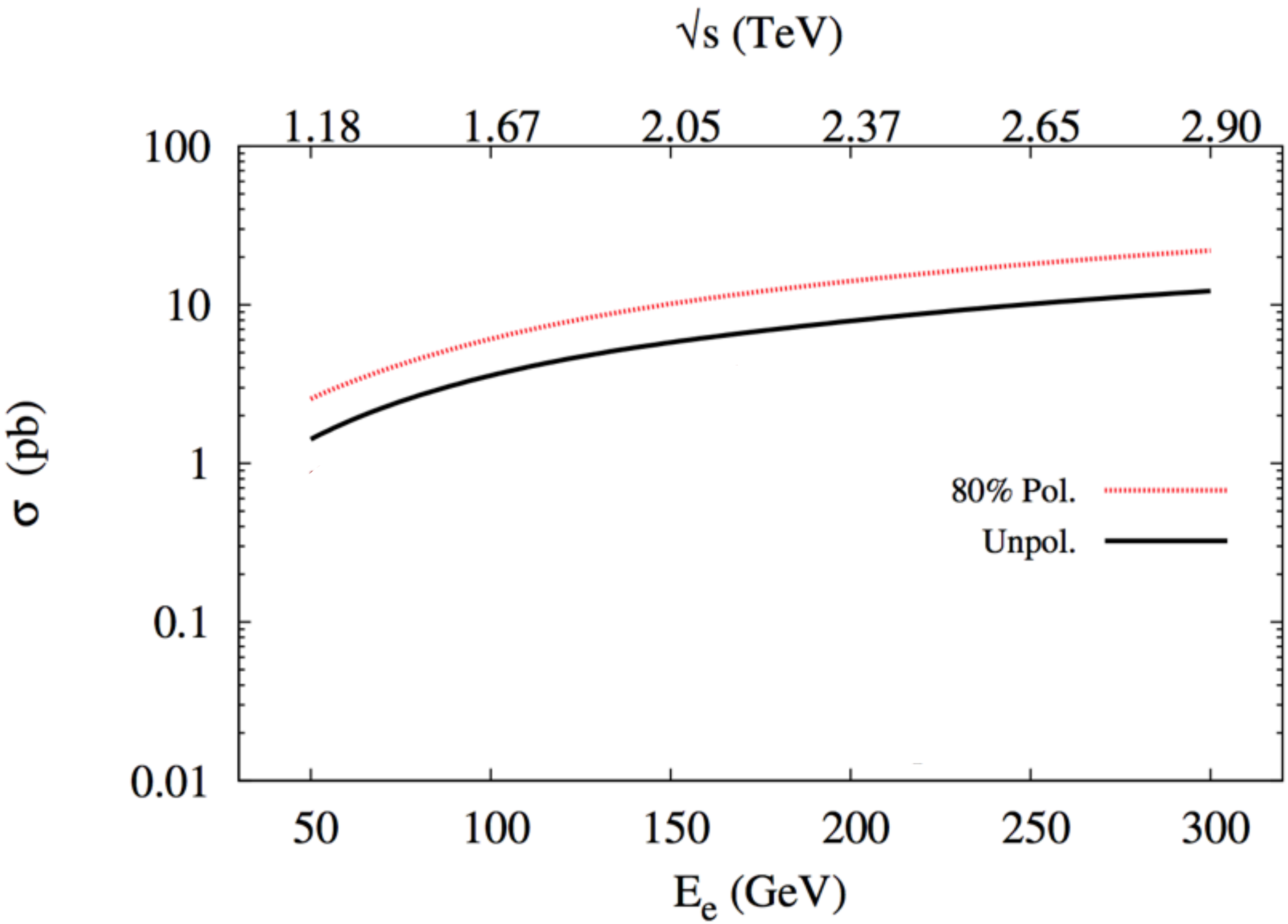
six-flavour variable number scheme for top quark



→ **LHeC offers new field of research for top quark PDF**

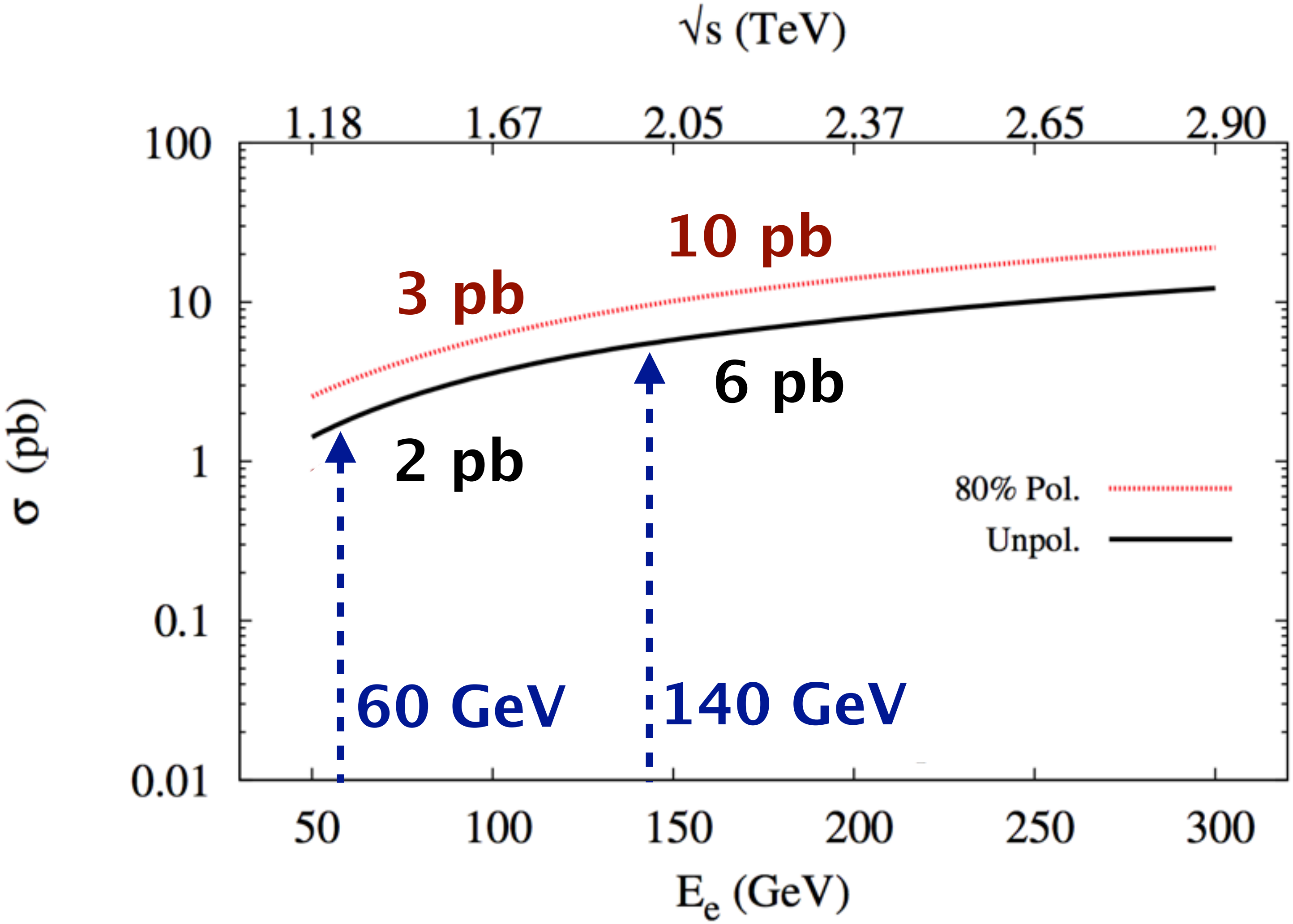
CC Single Top Quark Cross Section

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



CC Single Top Quark Cross Section

100 fb^{-1}:
2–6 · 10^5 events



→ **LHeC offers excellent prospects for top quark physics**

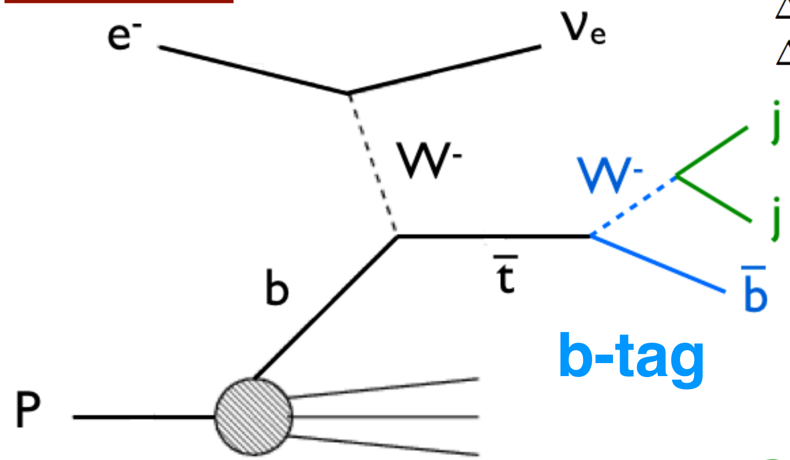
Signal and Backgrounds

signal

background

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

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

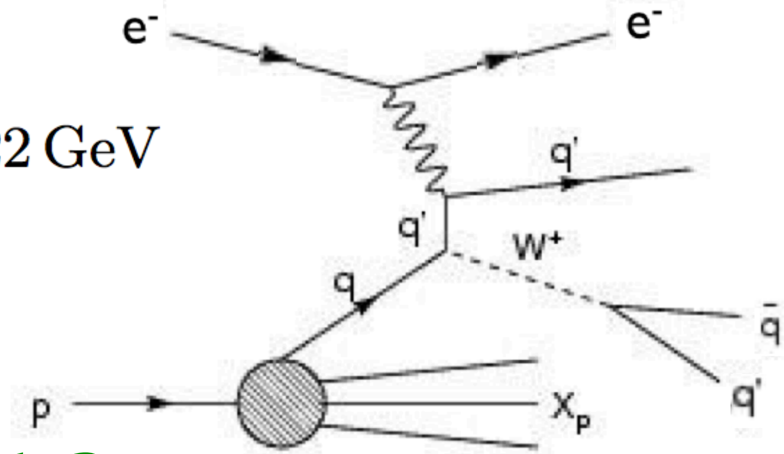


$|m_{j_1 j_2} - m_W| \leq 22\,\mathrm{GeV}$

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

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

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

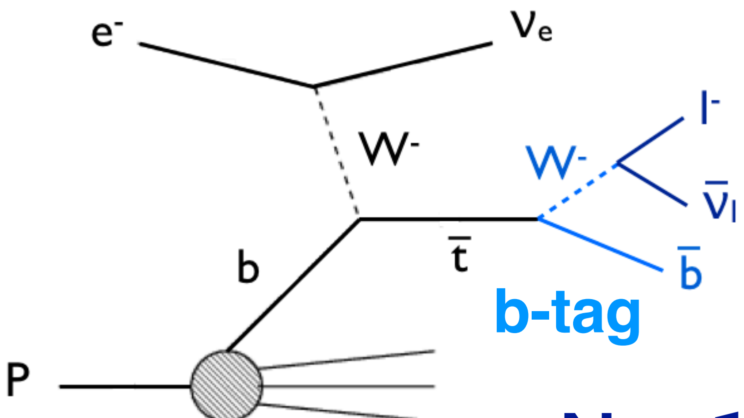


N_t=22000, s/b=1.2

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

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

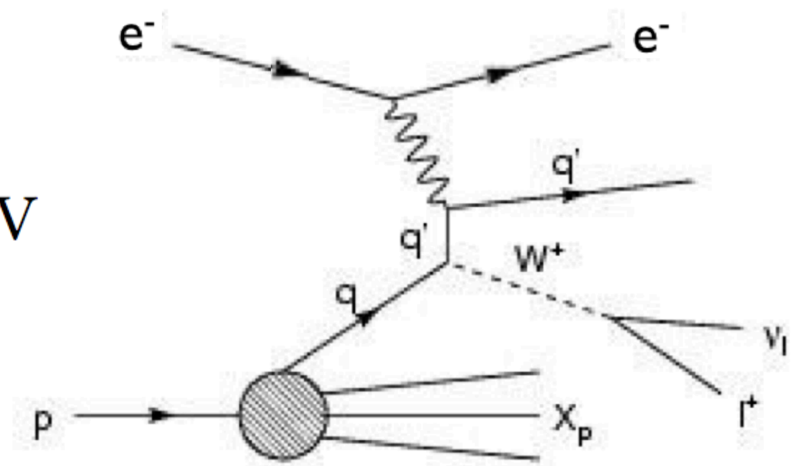
$\Delta\Phi_{\not{E},j} \geq 0.4$
$\Delta\Phi_{\not{E},b} \geq 0.4$
$\Delta\Phi_{\not{E},l} \geq 0.4$



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

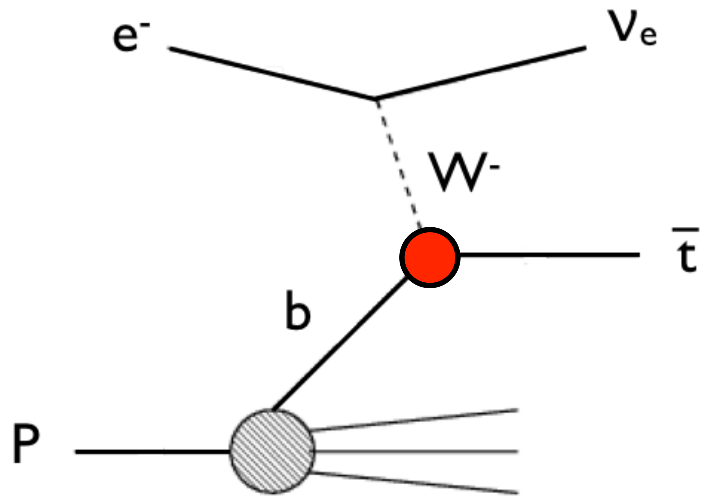
$|\eta_j| \geq 5,\ |\eta_{b,l}| \geq 2.5$

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



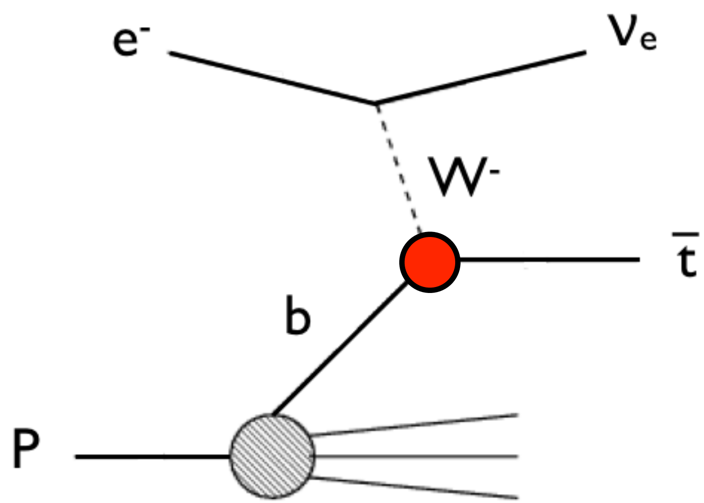
N_t=11000, s/b=11

Direct Measurement of $|V_{tb}|$



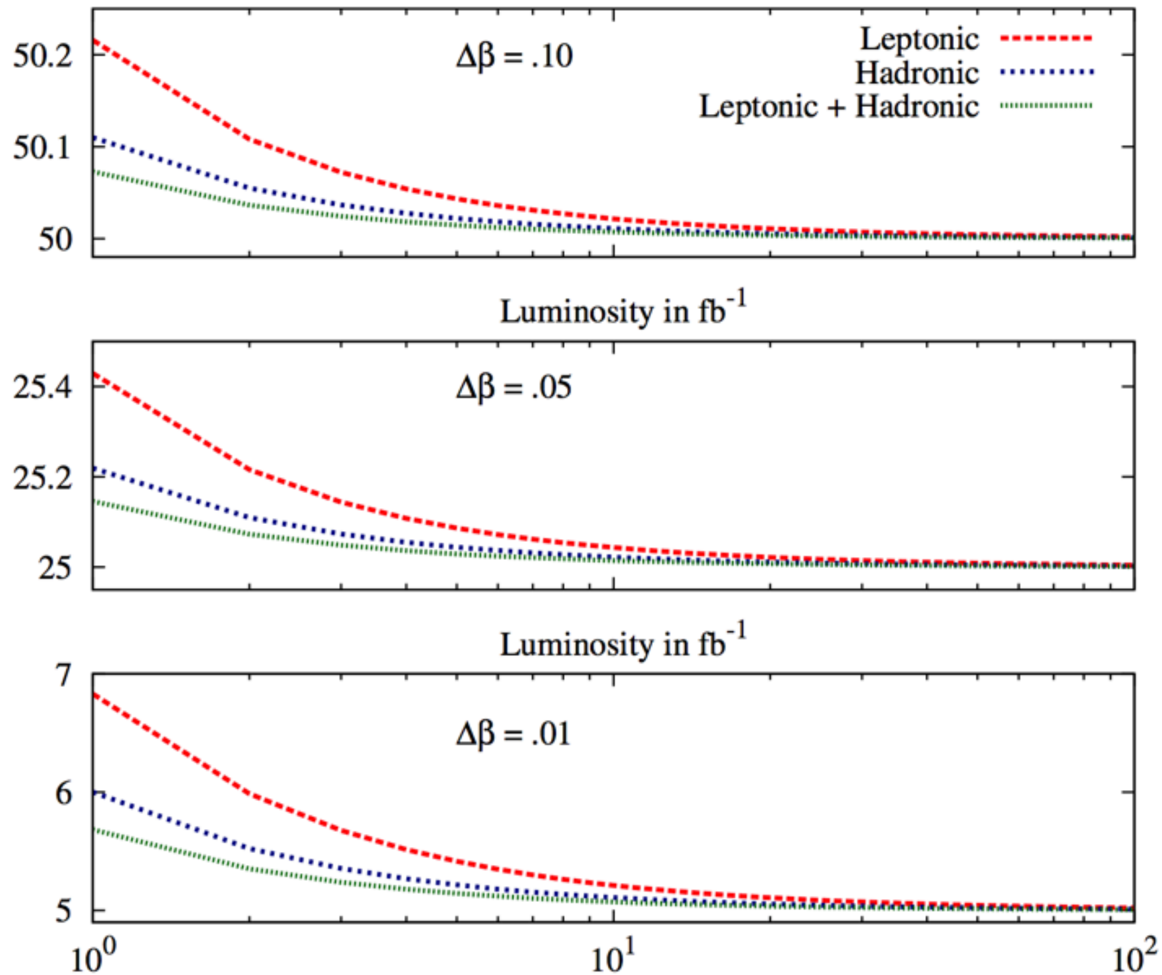
$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

Direct Measurement of $|V_{tb}|$



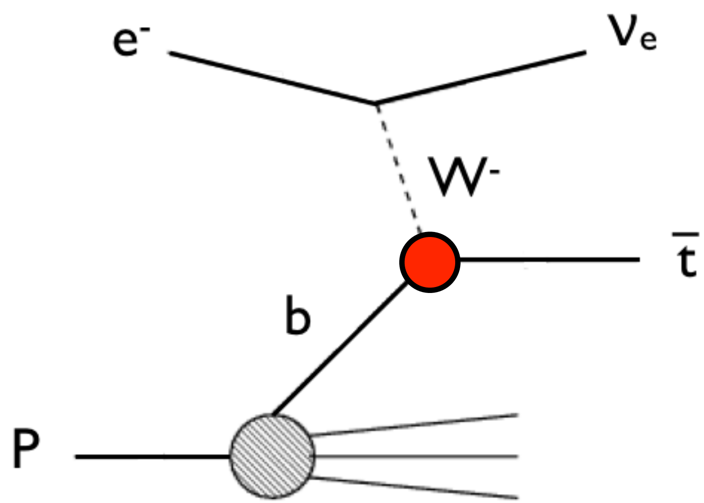
$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$\Delta|V_{tb}| \cdot 1000$



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

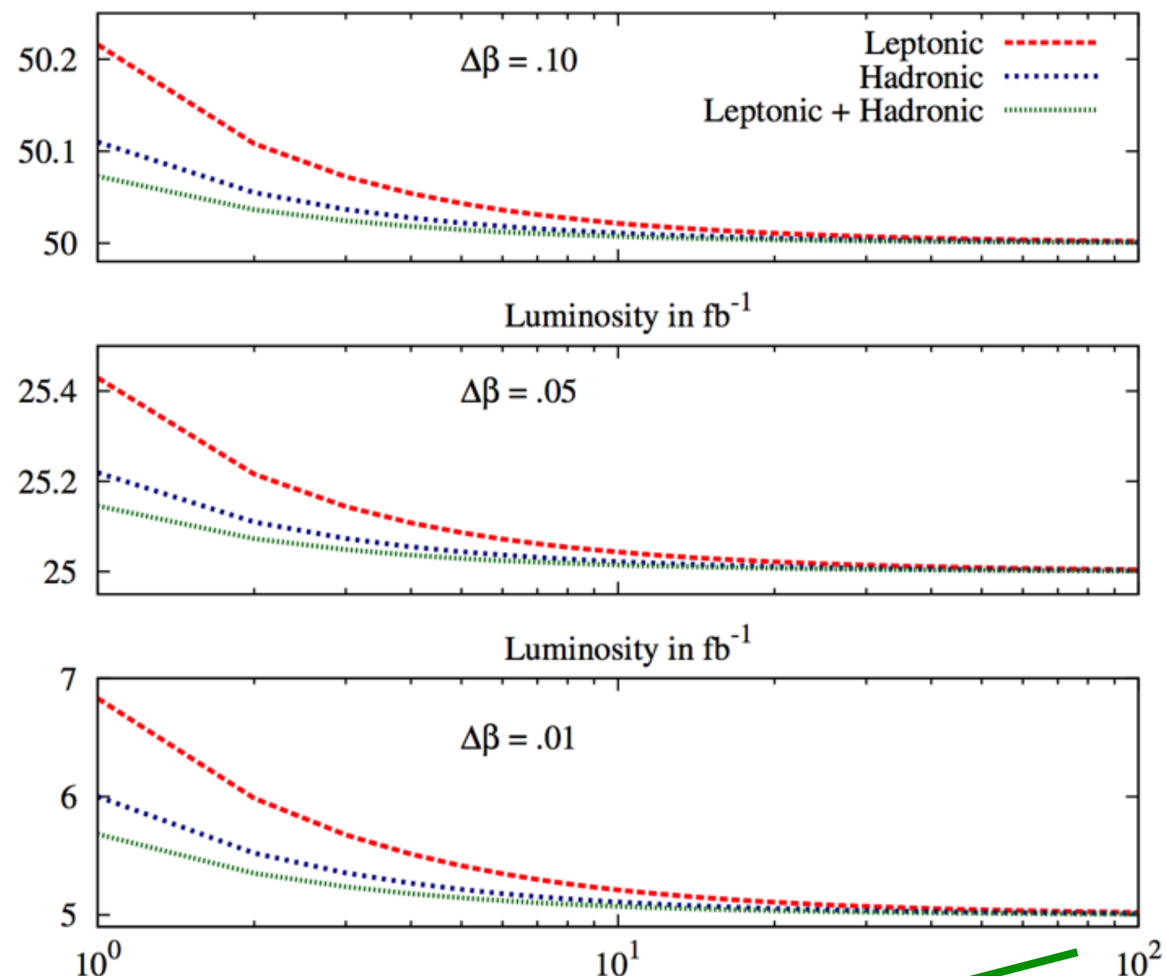
Direct Measurement of $|V_{tb}|$



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

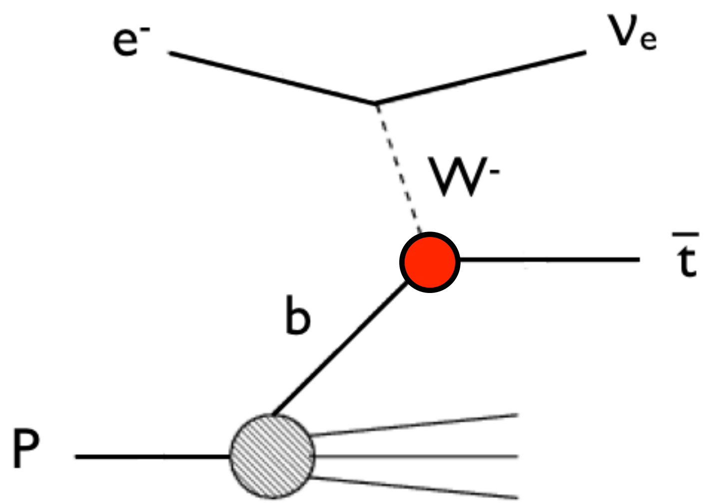
Dutta, Goyal, Kumar, Mellado, arXiv:1307.1688 [hep-ph]

$\Delta|V_{tb}| \cdot 1000$

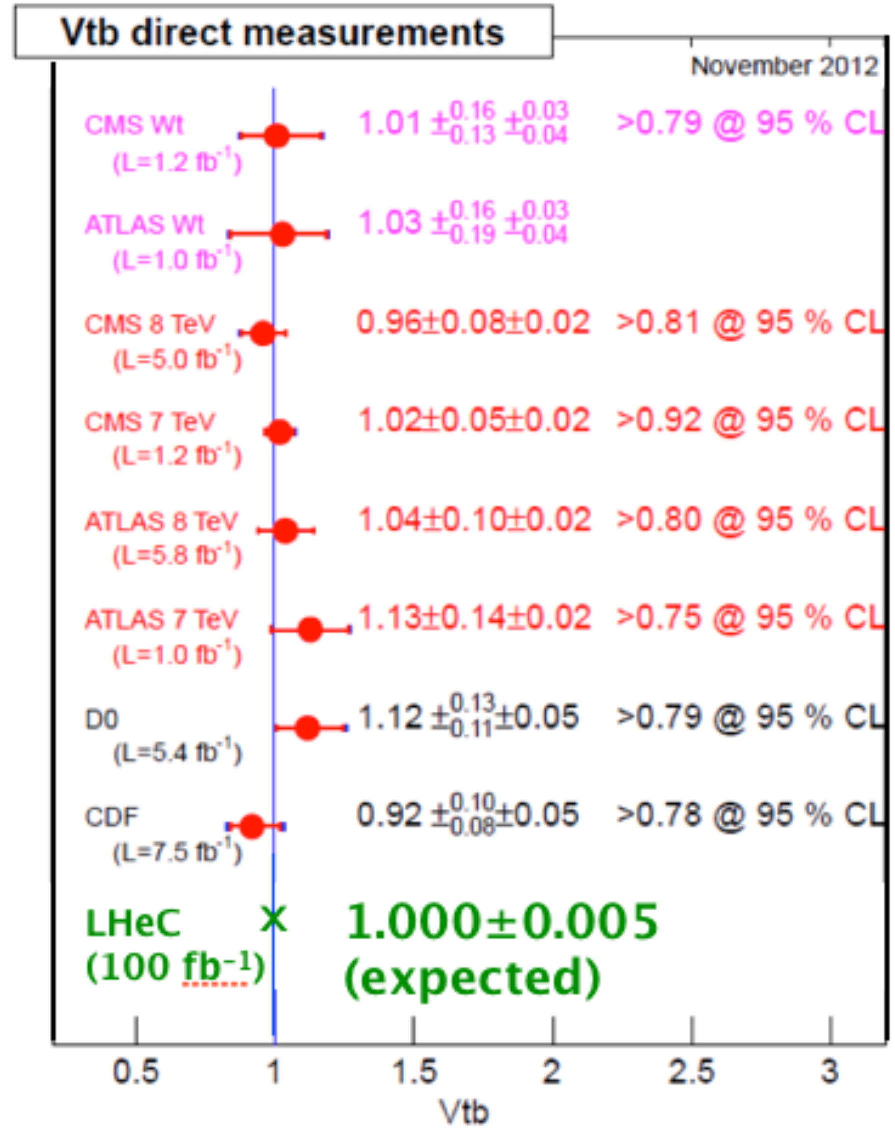


100 fb^{-1}: $\Delta|V_{tb}|$=0.005

Direct Measurement of $|V_{tb}|$



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



→ **high precision measurement**

Search for Anomalous Wtb Couplings

= 1 in SM

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

Search for Anomalous Wtb Couplings

= 1 in SM

$$L = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}V_{tb}\left(f_V^L P_L + f_V^R P_R\right)tW_\mu^-$$
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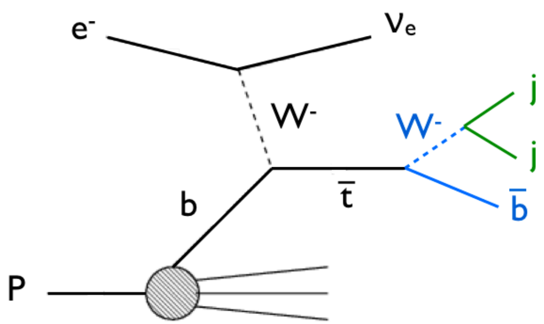
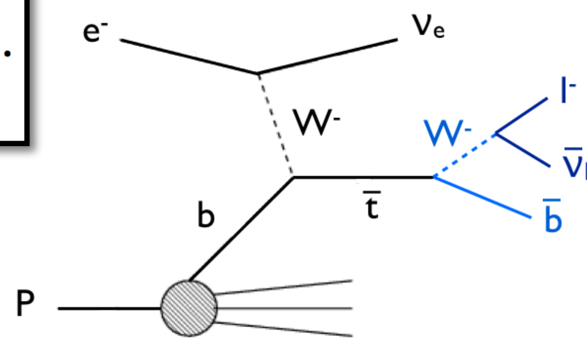
Search for Anomalous Wtb Couplings

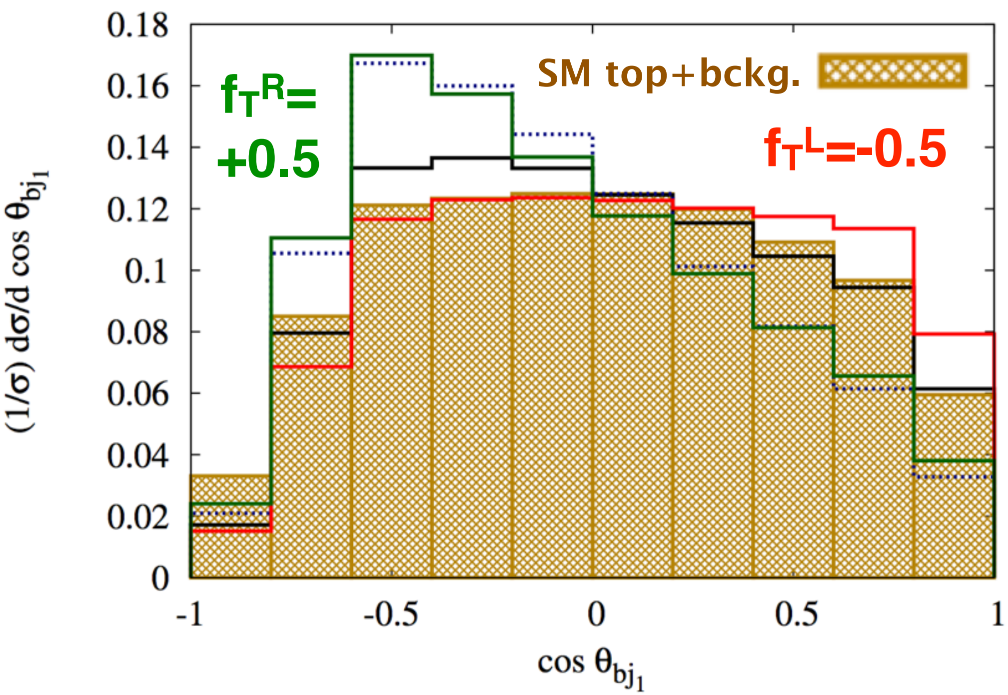
$$L = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}V_{tb}\left(f_V^L P_L + f_V^R P_R\right)tW_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}\left(f_T^L P_L + f_T^R P_R\right)tW_{\mu}^{-} + h.c.$$

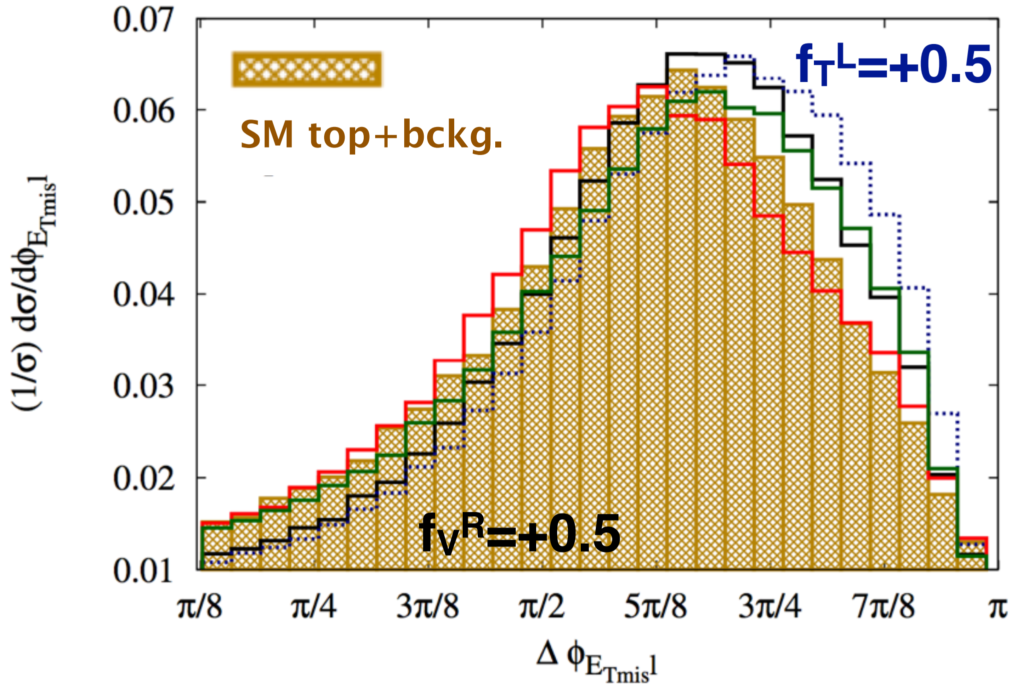
= 1 in SM

Dutta, Goyal, Kumar, Mellado, arXiv:1307.1688









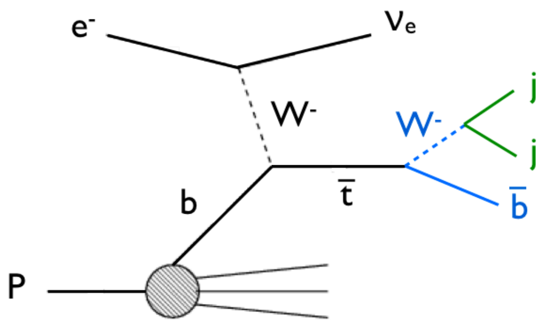
+ other variables sensitive on W helicity

Search for Anomalous Wtb Couplings

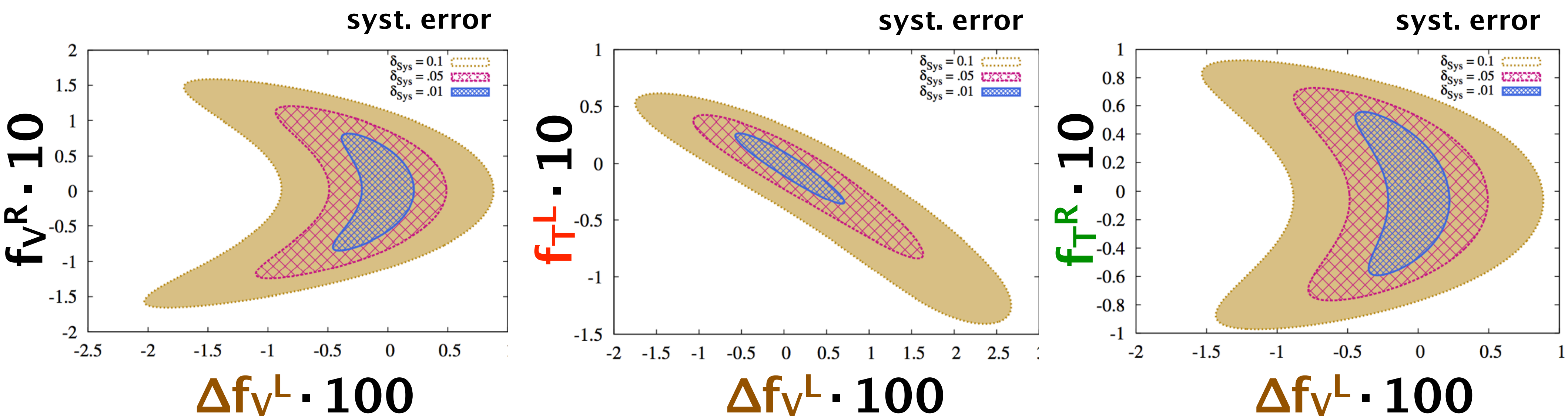
$$L = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}V_{tb}\left(f_V^L P_L + f_V^R P_R\right)tW_{\mu}^{-} - \frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}\left(f_T^L P_L + f_T^R P_R\right)tW_{\mu}^{-} + h.c.$$

= 1 in SM

Dutta, Goyal, Kumar, Mellado, arXiv:1307.1688



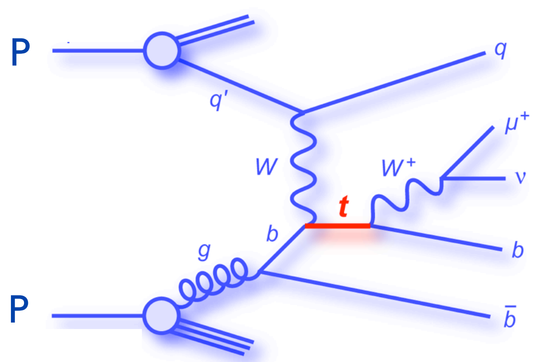
68% C.L.

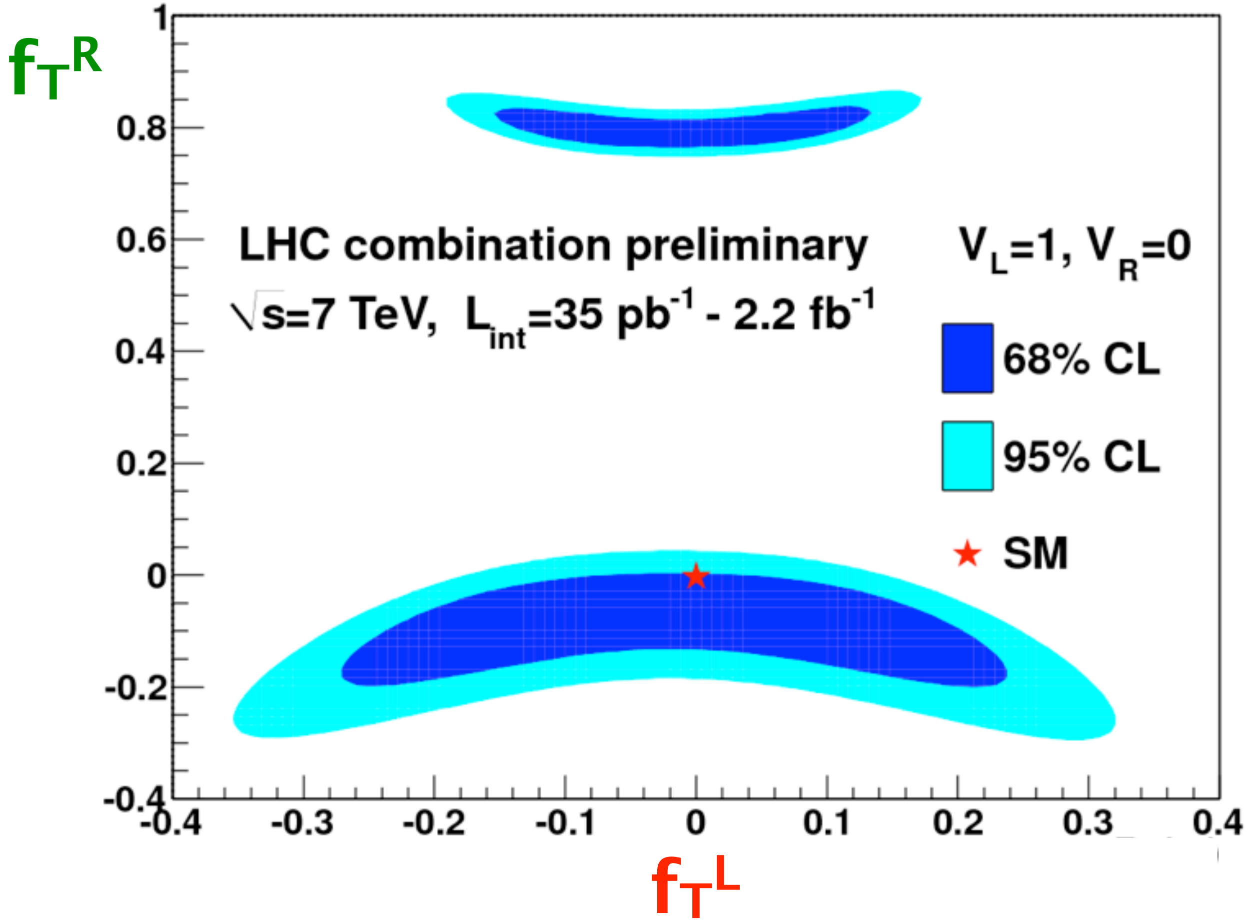


Search for Anomalous Wtb Couplings

= 1 in SM

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

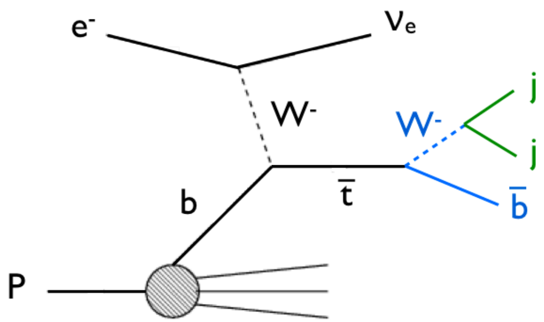


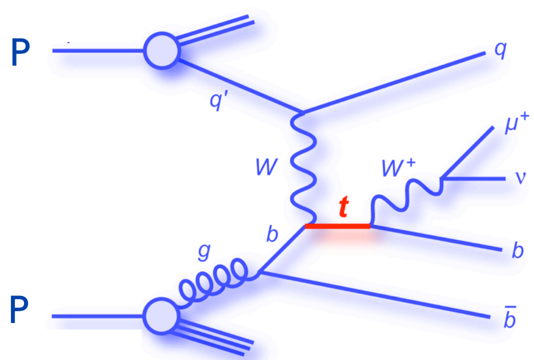


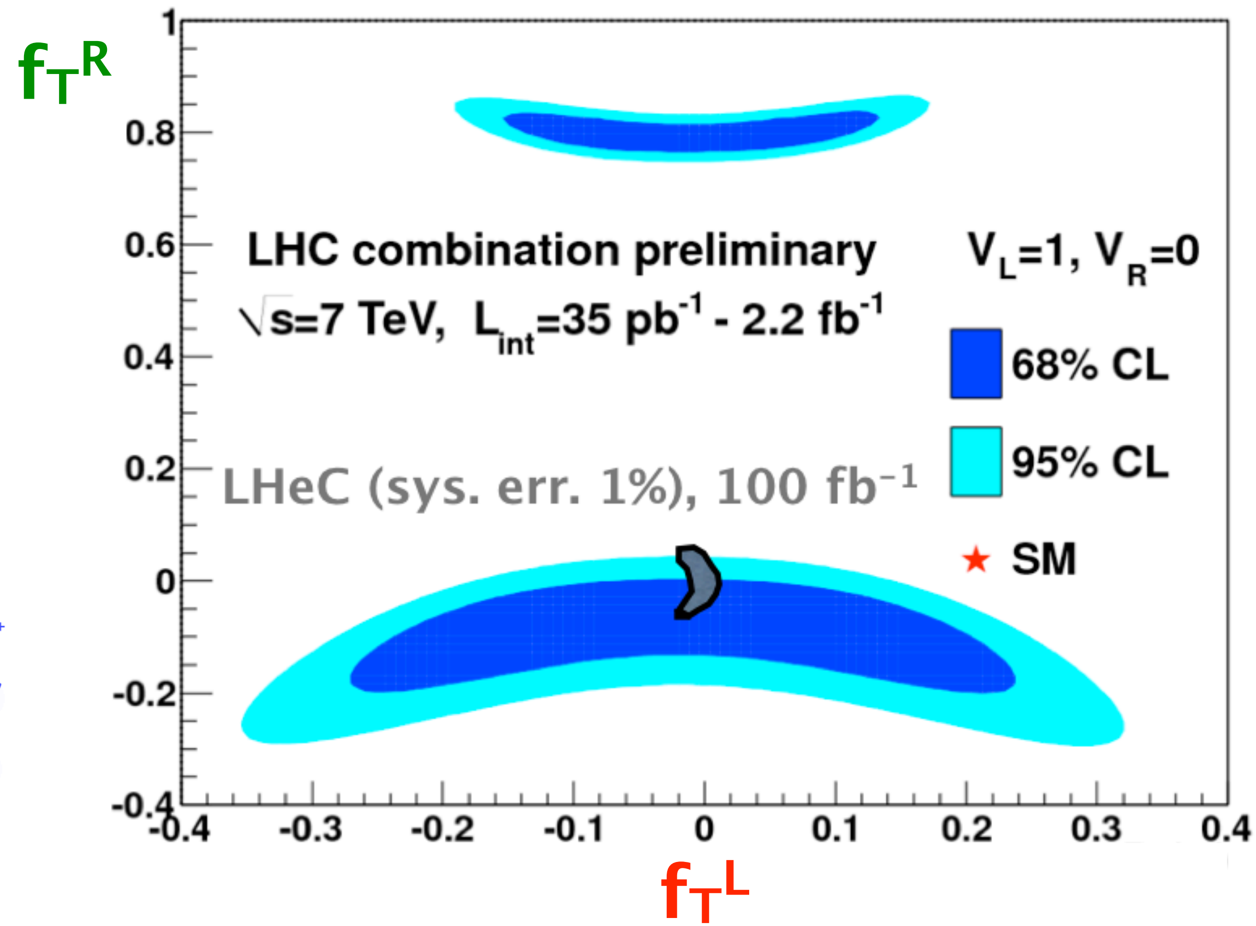
Search for Anomalous Wtb Couplings

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

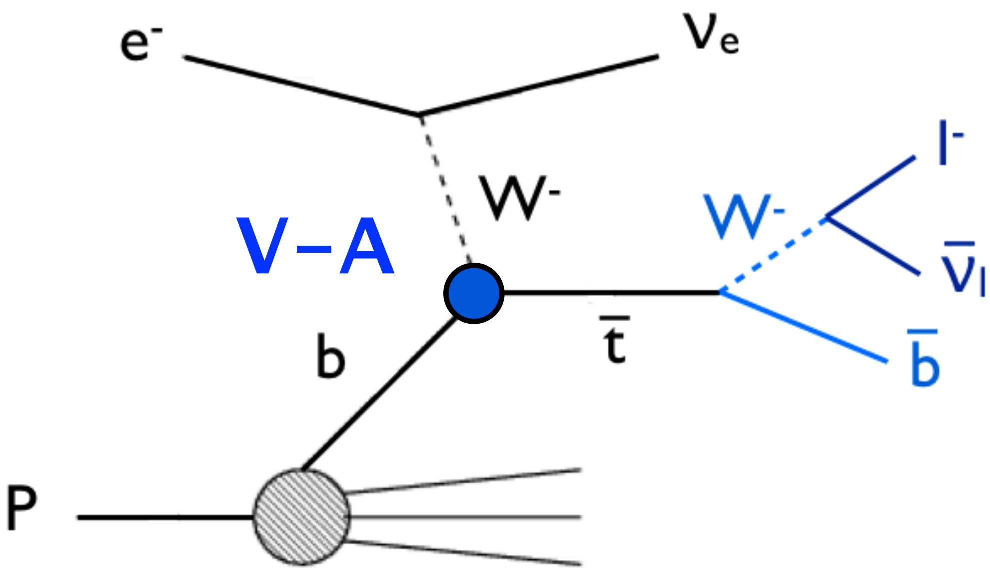
= 1 in SM







Top Quark Polarisation



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

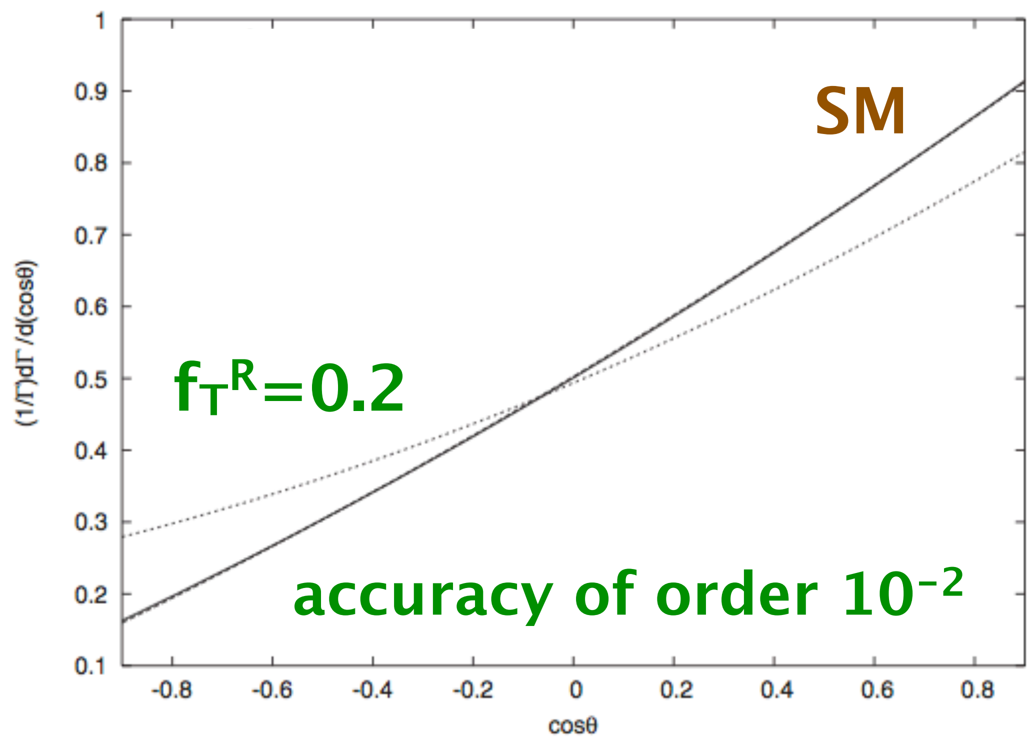
CMS 20 fb^{-1}: $P_t = 0.82 \pm 0.34$

CMS-PAS-TOP-13-001

Atag, Sahin,
PRD 73, 074001 (2006)

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

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



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Top Quark Physics: NC
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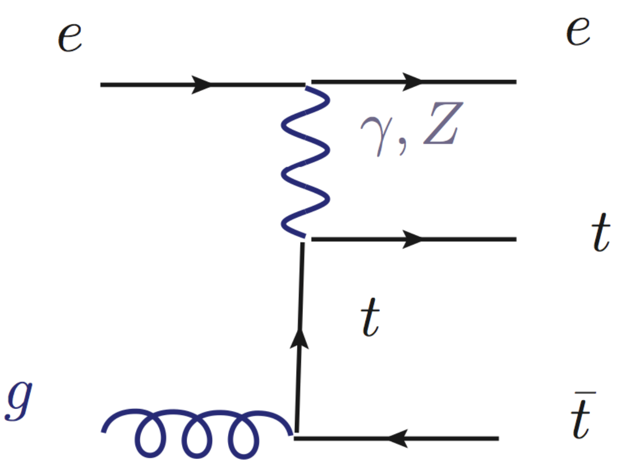
NC Top Quark Production

Bouzas, Larios,
arXiv:1308.5634

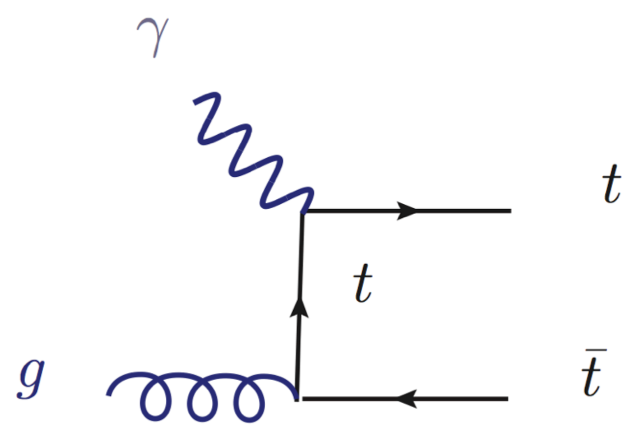
top pair production

single top production

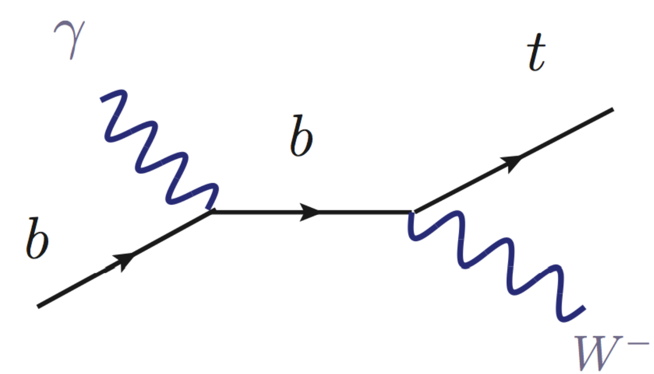
DIS



photoproduction



photoproduction



e−beam 140 GeV, 100 fb^{-1}:

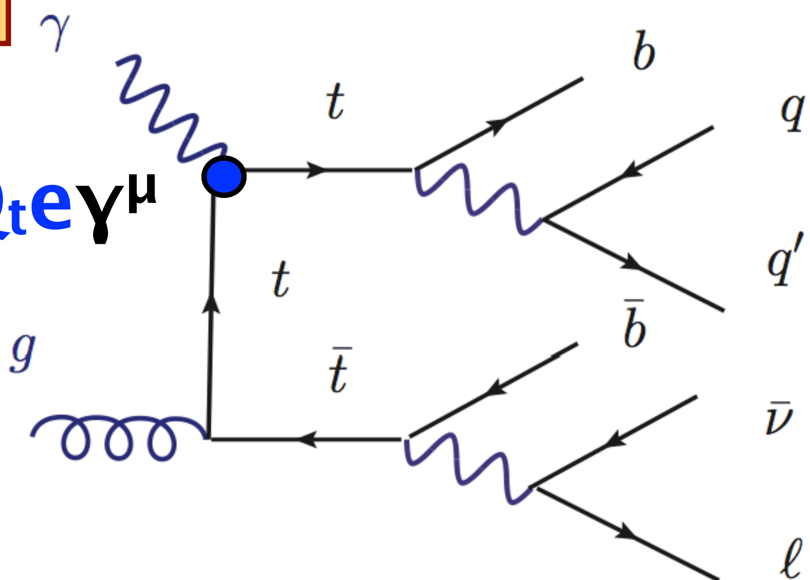
0.12 pb
$N_{t\bar{t}}$=12,000

3.2 pb
$N_{t\bar{t}}$=320,000

0.143 pb
N_t=14,300

Analysis of the ttγ Vertex

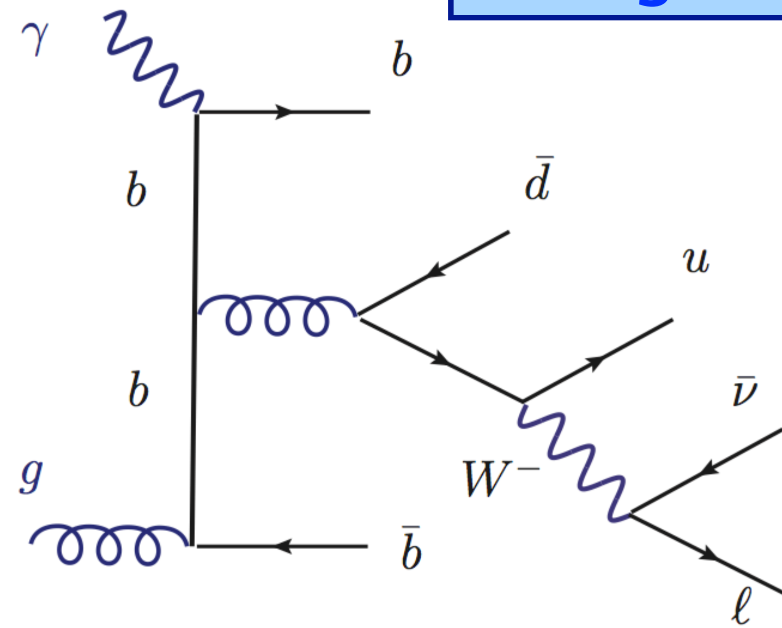
signal



$iQ_t e\gamma^\mu$

→ **measure top quark charge**

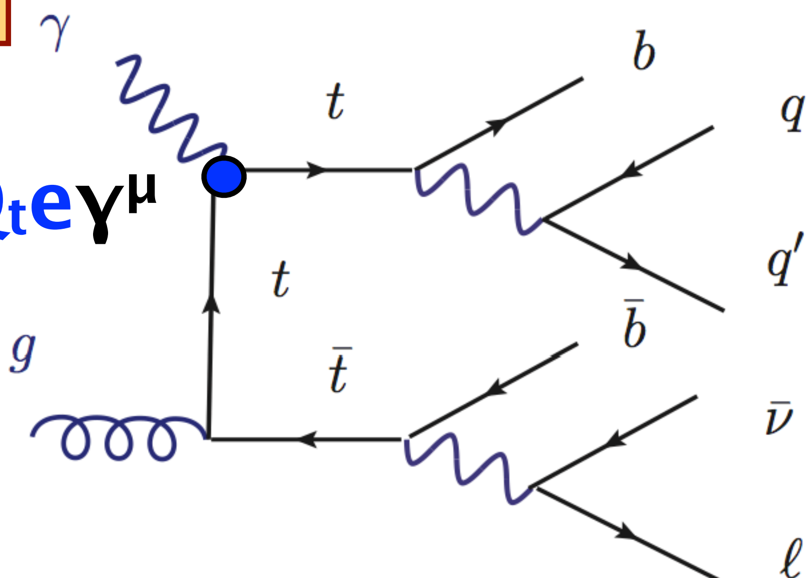
background



Analysis of the ttγ Vertex

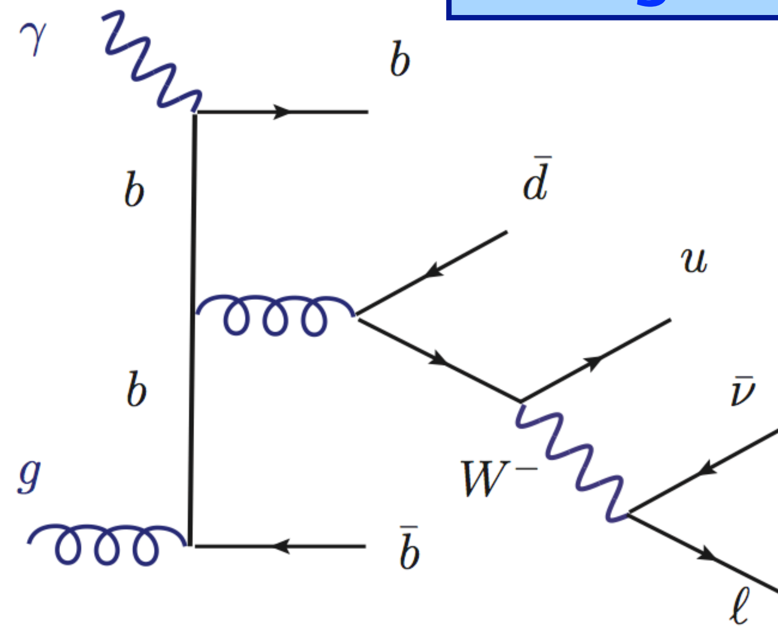
signal

$iQ_t e\gamma^{\mu}$



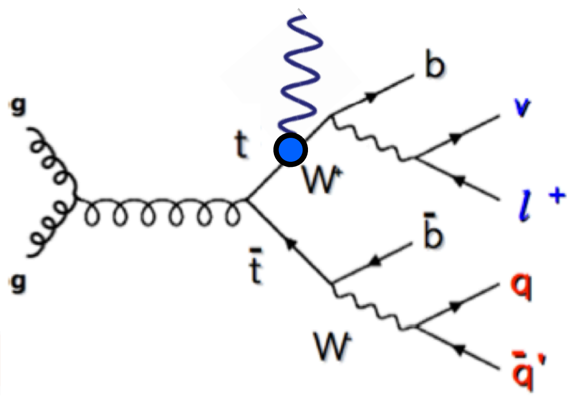
→ measure **top quark charge**

background



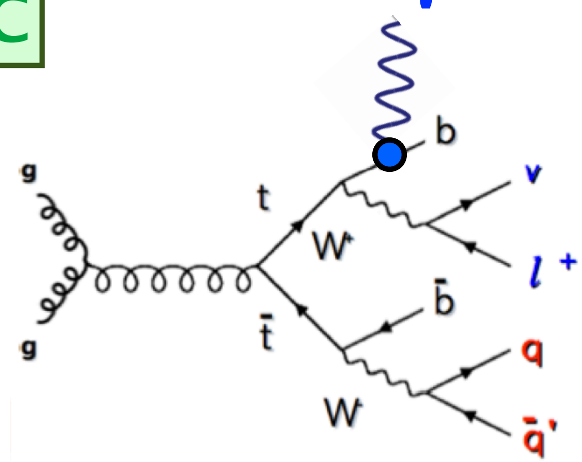
LHC

γ



OR

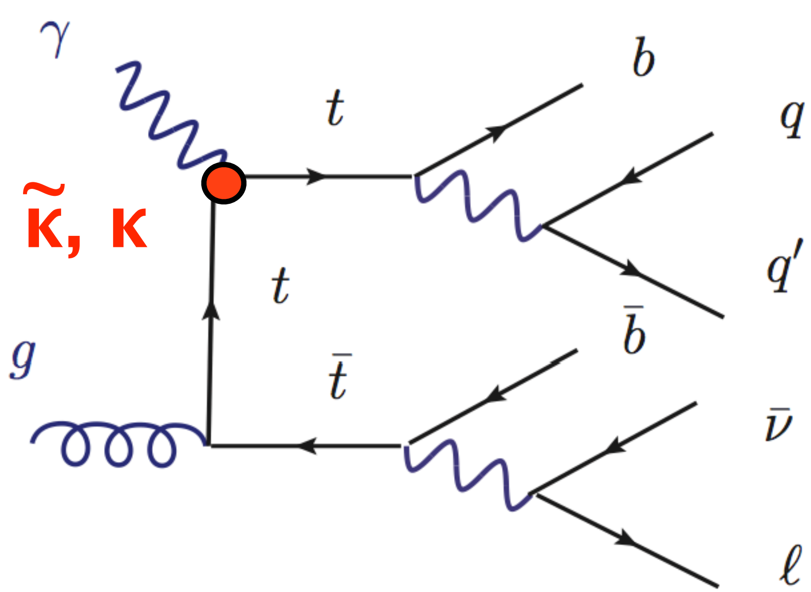
γ



?

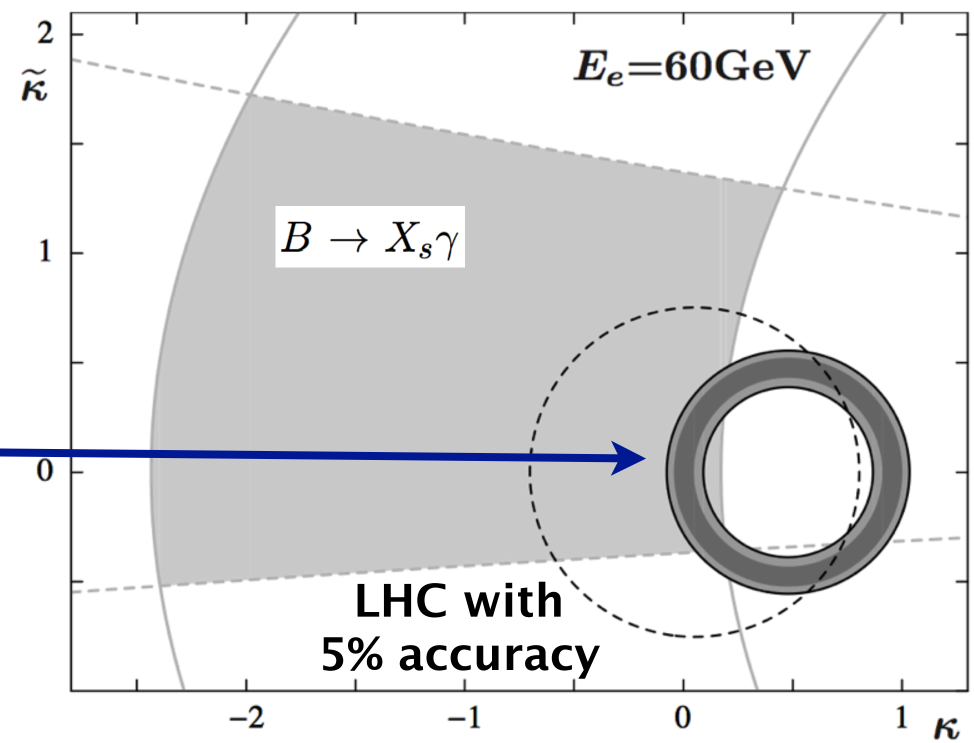
→ difficult at the LHC

Search for Anomalous ttγ Couplings



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

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

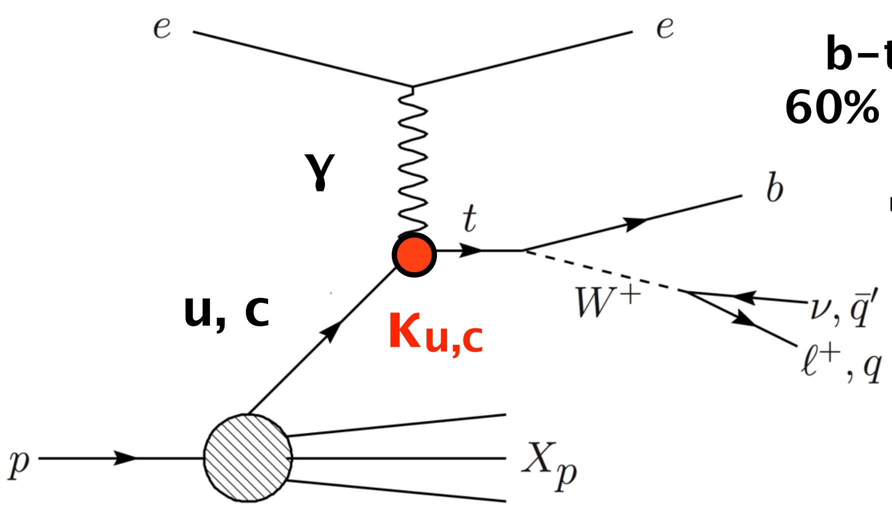


LHeC:
10% and 18% accuracy

magnetic dipole moment: κ

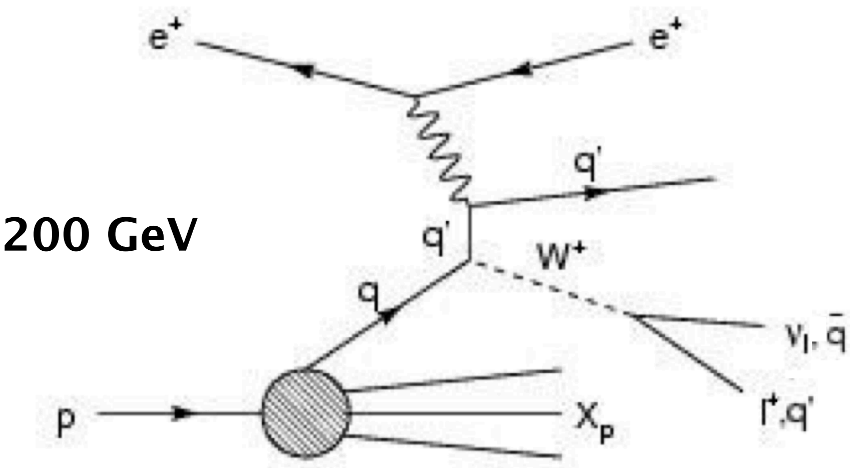
Bouzas, Larios,
arXiv:1308.5634

Single Top Quark Production: FCNC

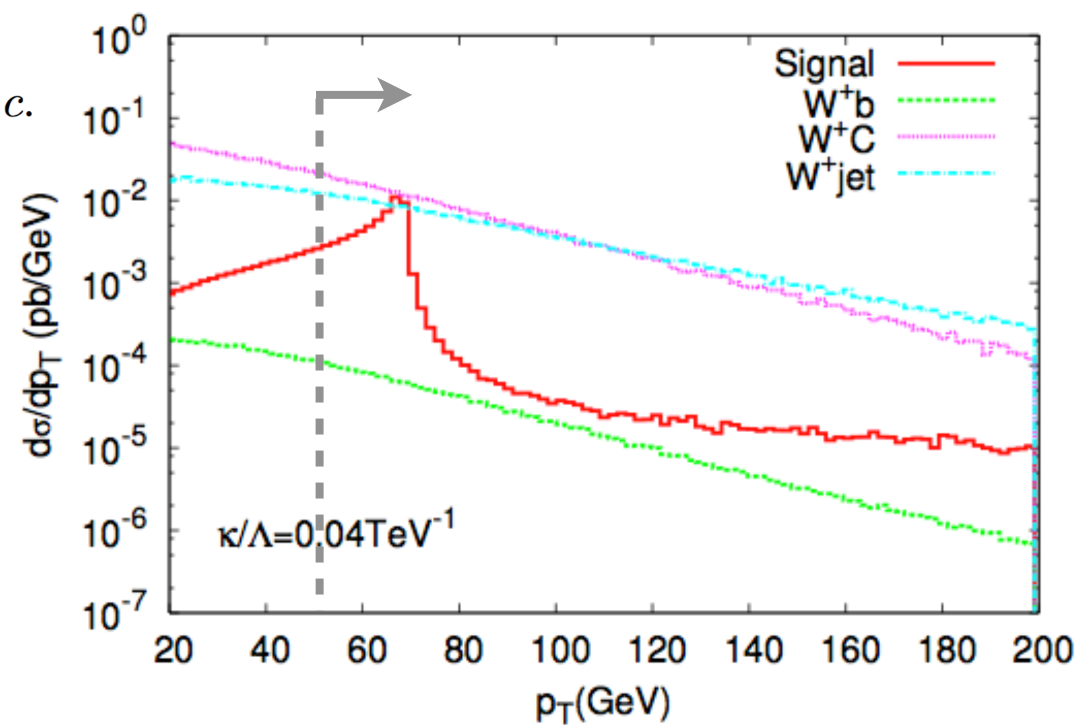


b-tagging:
60% efficiency

150<M_{Wb}<200 GeV



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

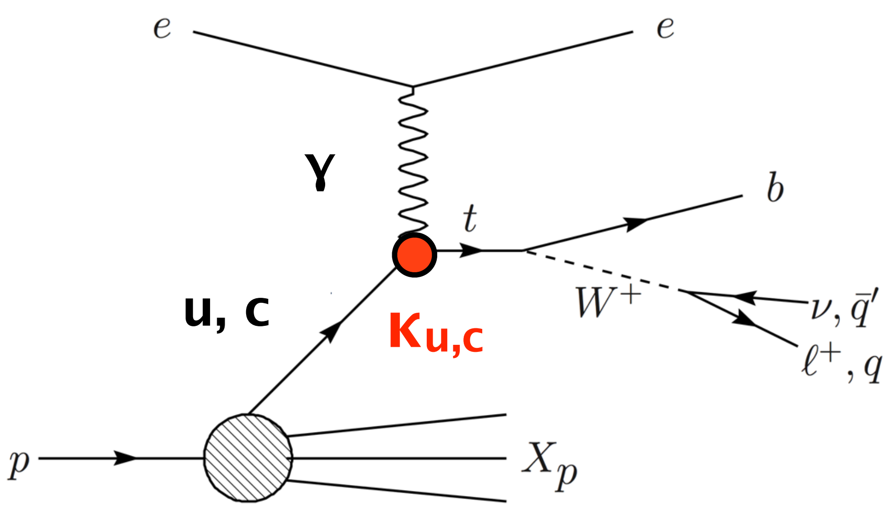


LHeC TDR,
J.Phys. G39,
075001 (2012)

γp collider:

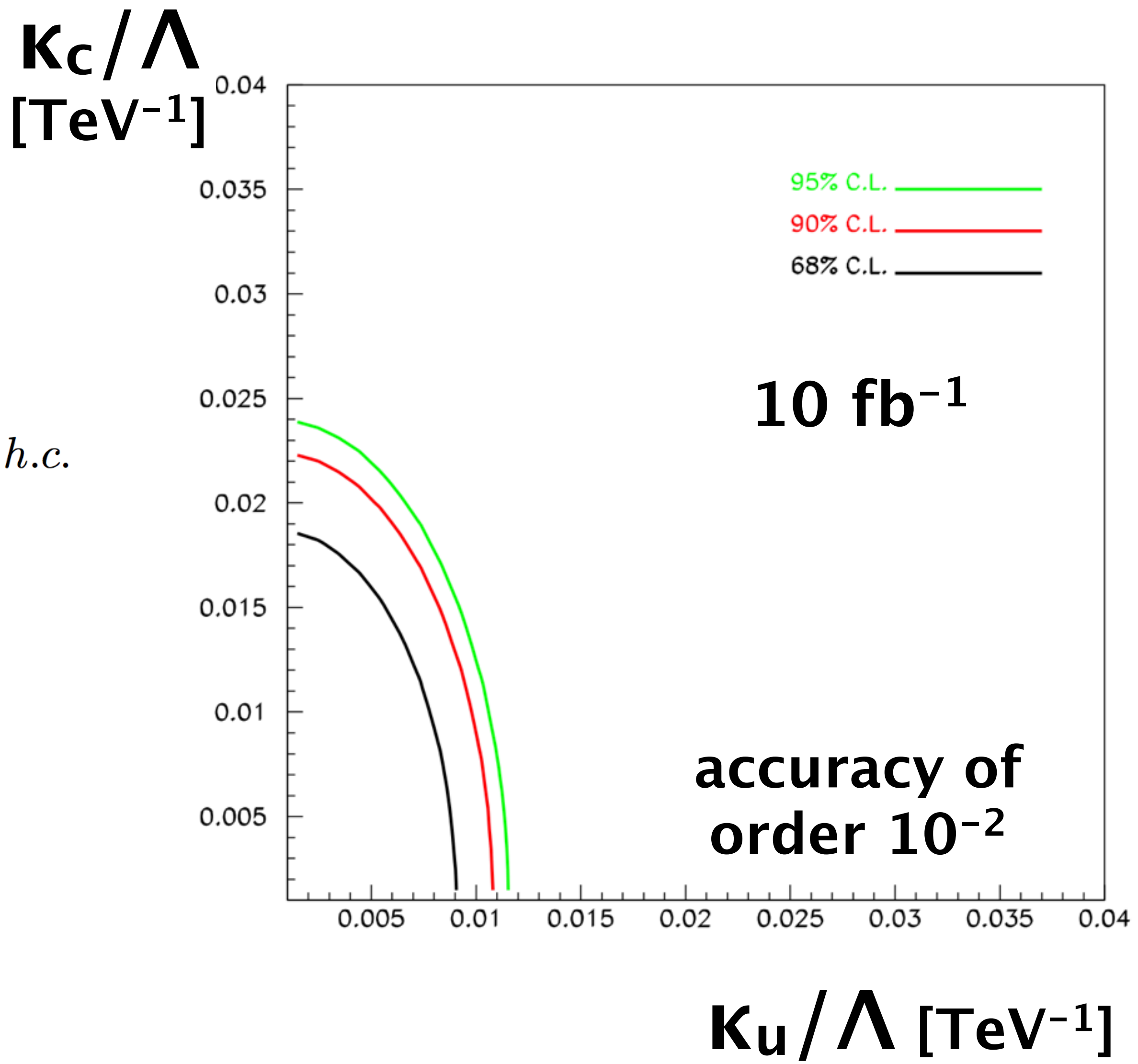
e-beam 70 GeV
γ: 80% of e-energy

Single Top Quark Production: NC

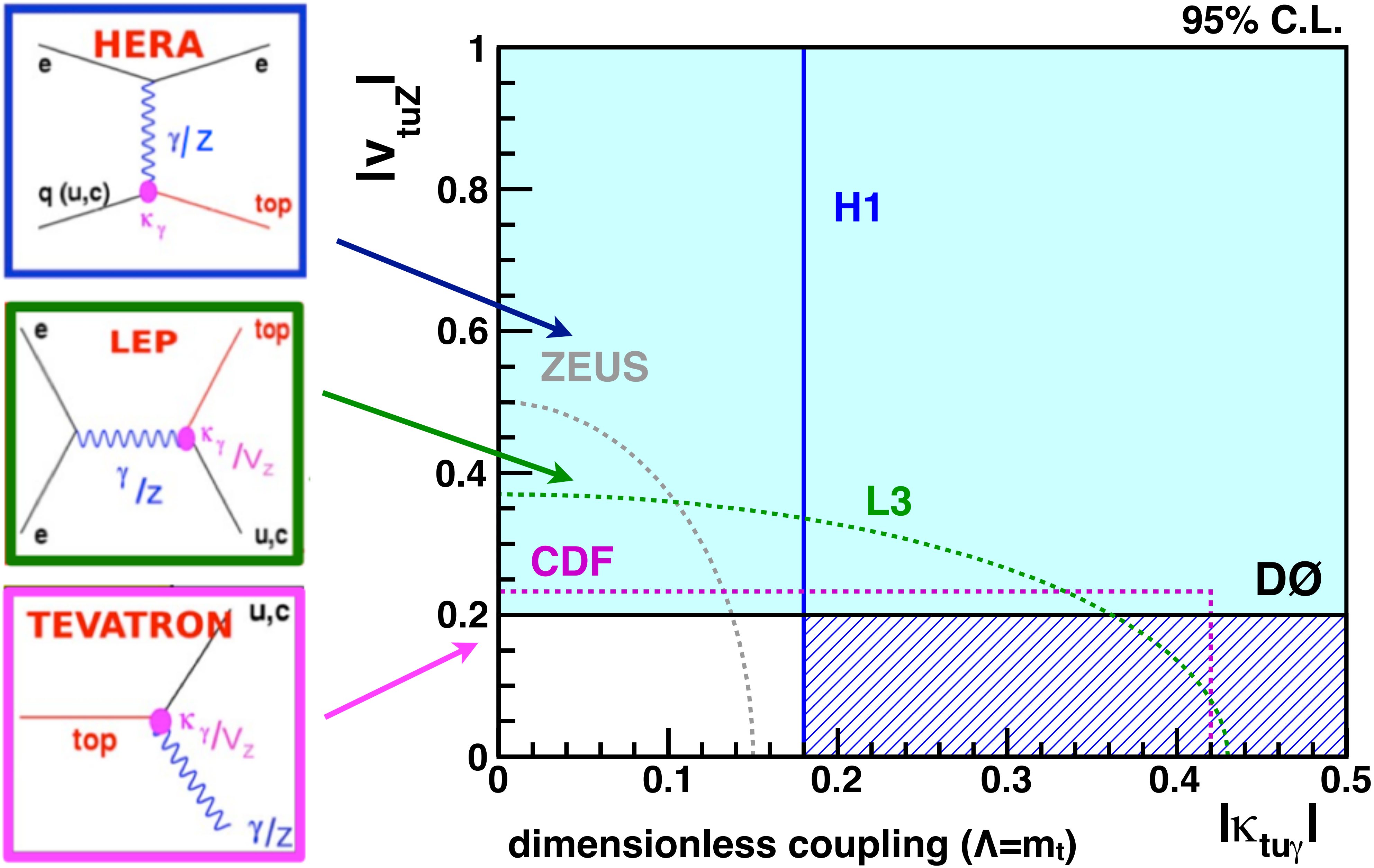


$$L = -g_e \sum_{q=u,c} Q_q \frac{\kappa_q}{\Lambda} \bar{t} \sigma^{\mu\nu} (f_q + h_q \gamma_5) q A_{\mu\nu} + h.c.$$

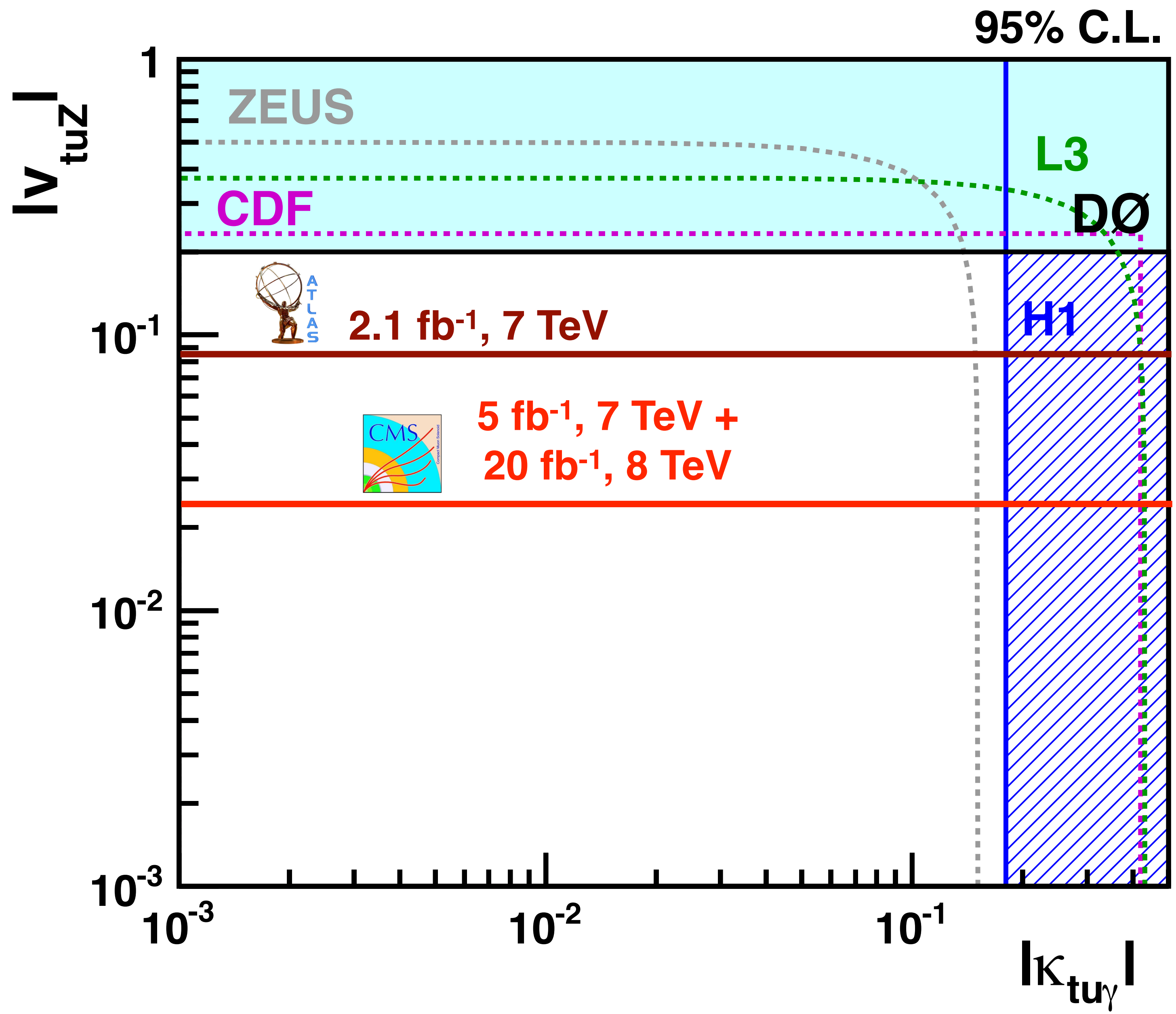
LHeC TDR, J.Phys. G39, 075001 (2012)

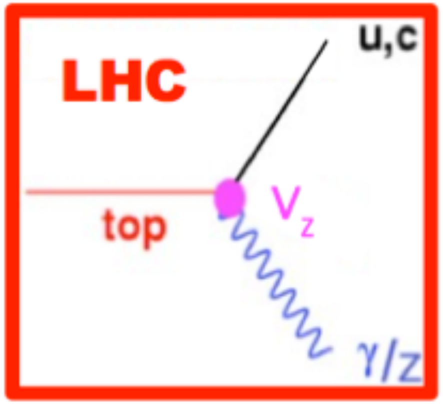


FCNC Top Couplings at Colliders



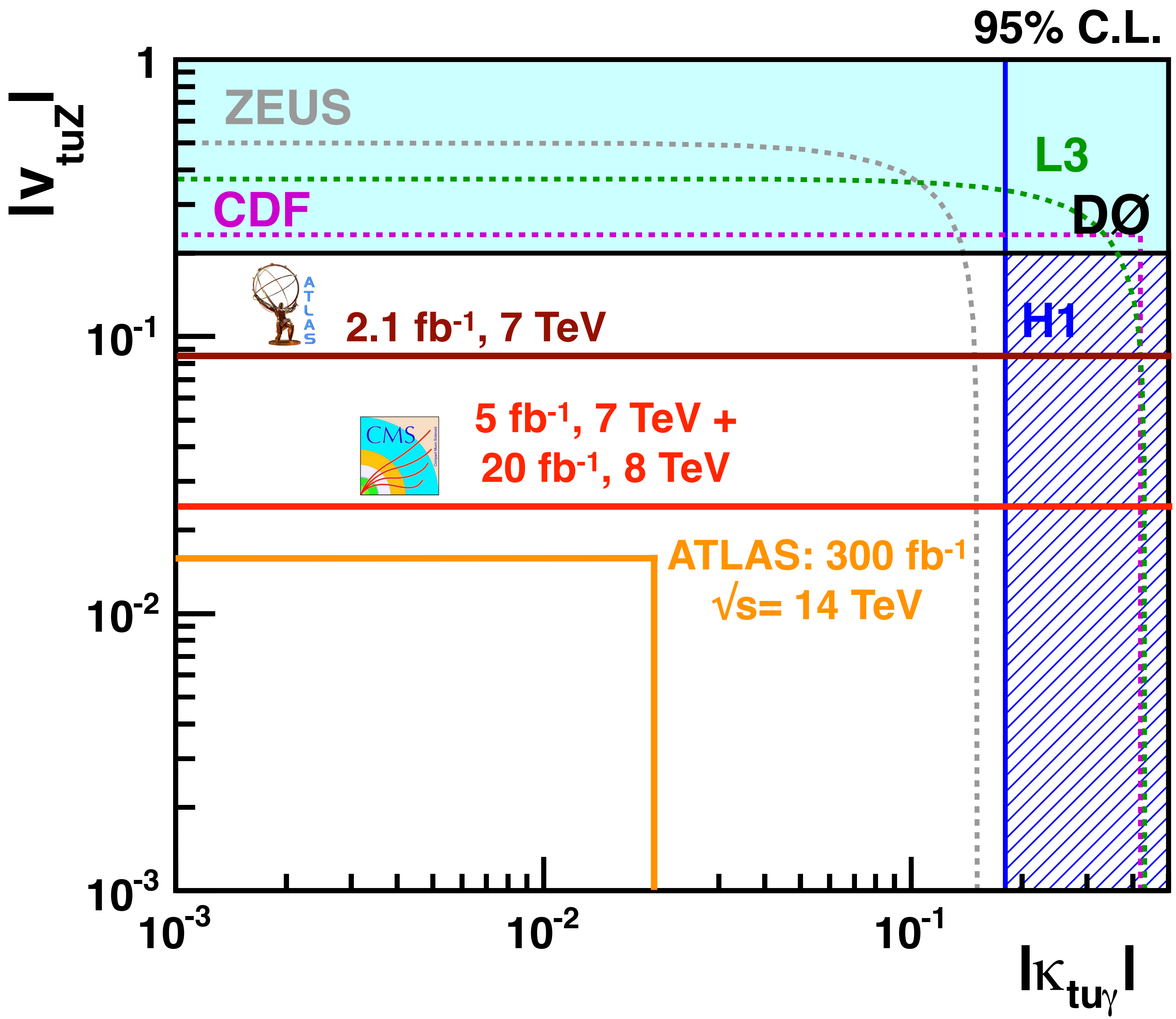
FCNC Top Couplings at Colliders

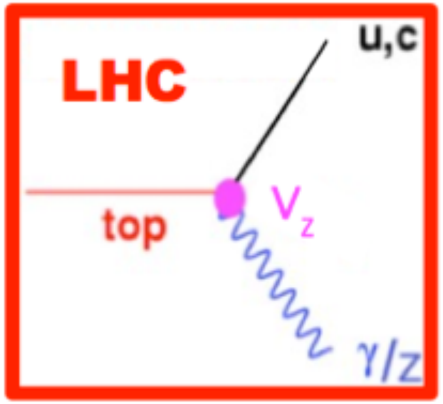




FCNC Top Couplings at Colliders

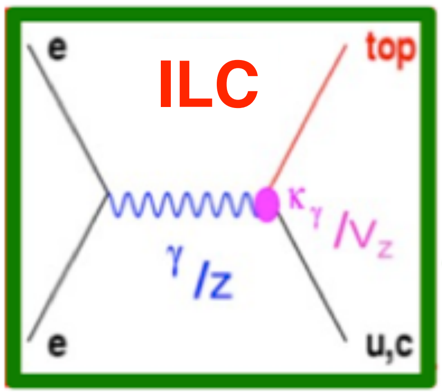
Top Quark Working Group Collaboration, arXiv:1311.2028 [hep-ph]

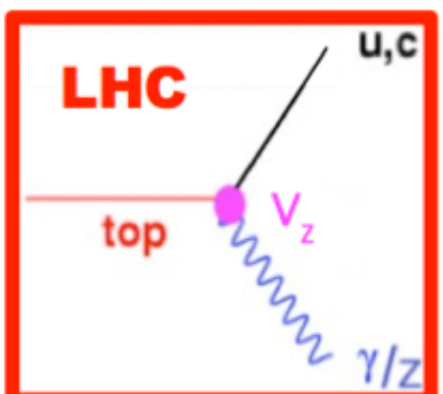


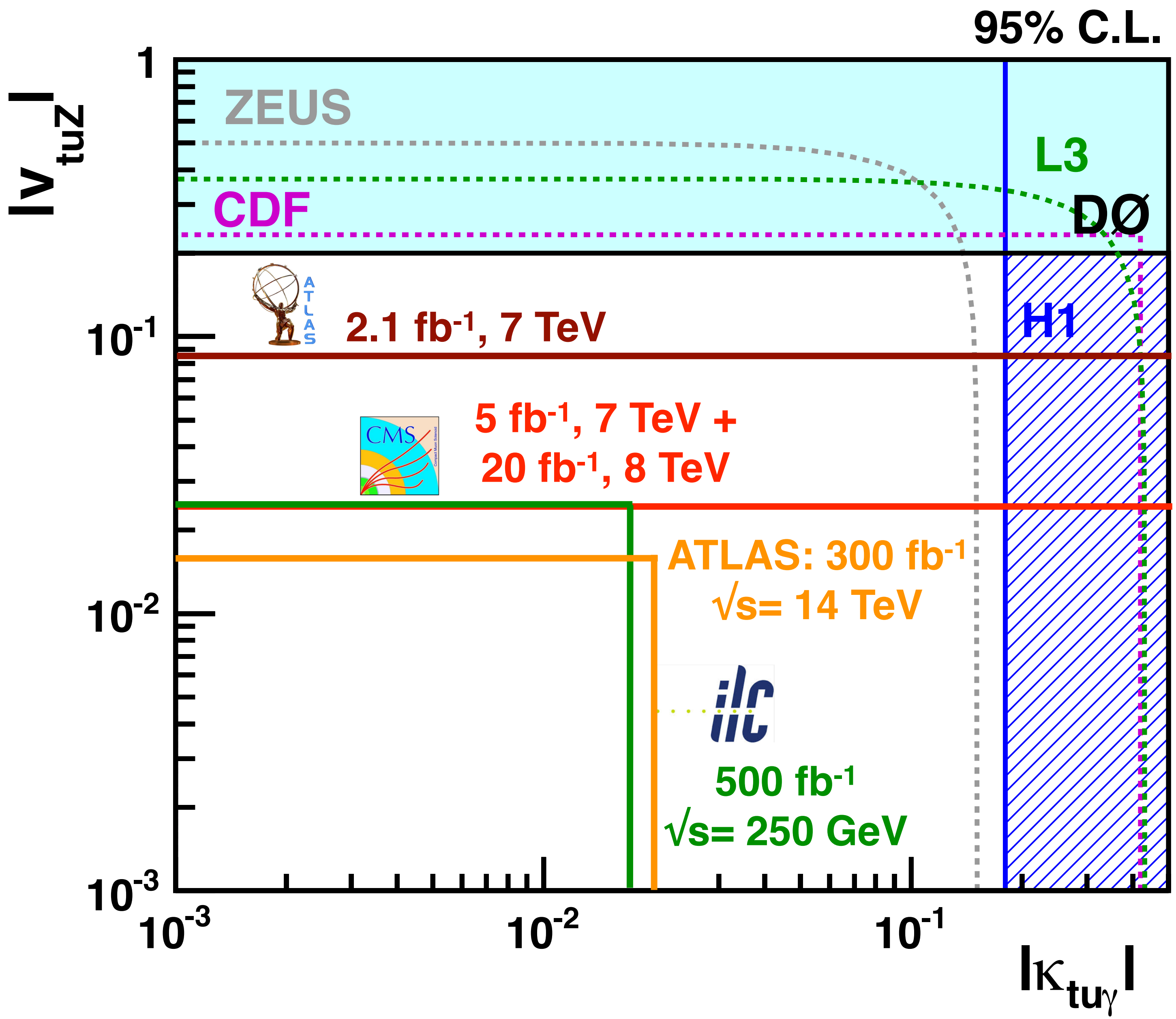


FCNC Top Couplings at Colliders

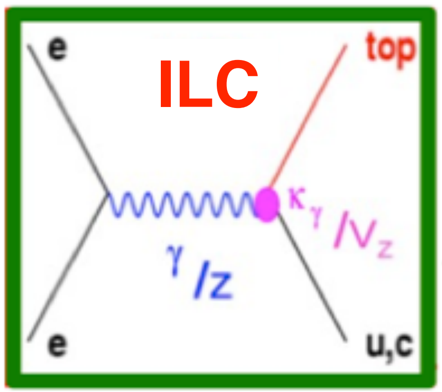
Top Quark Working Group Collaboration, arXiv:1311.2028 [hep-ph]

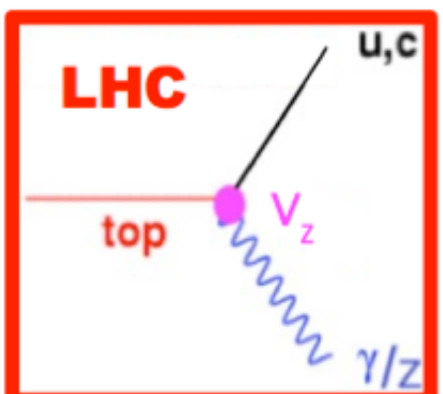


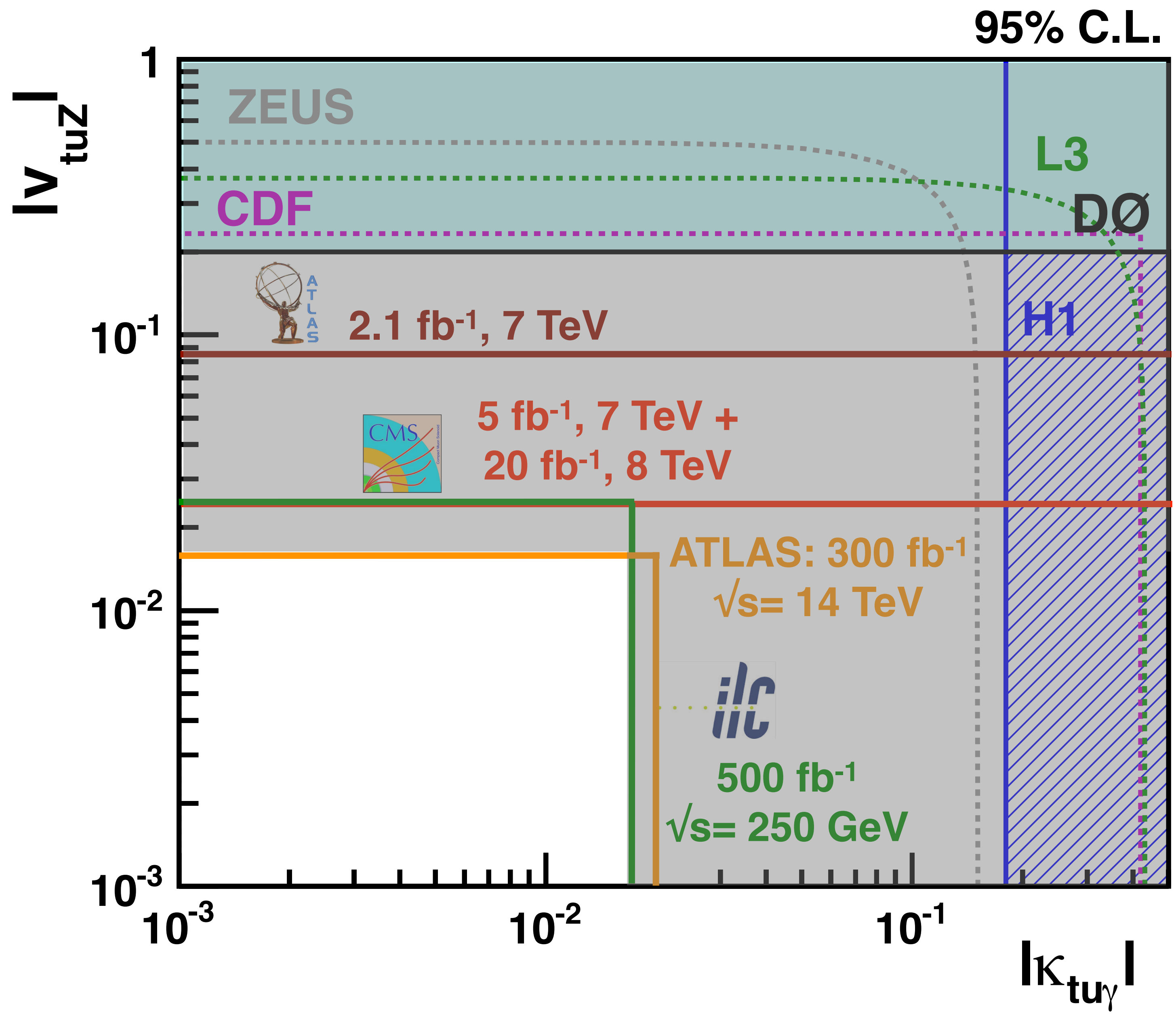




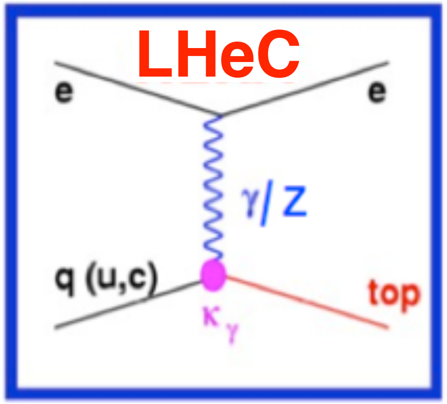
FCNC Top Couplings at Colliders

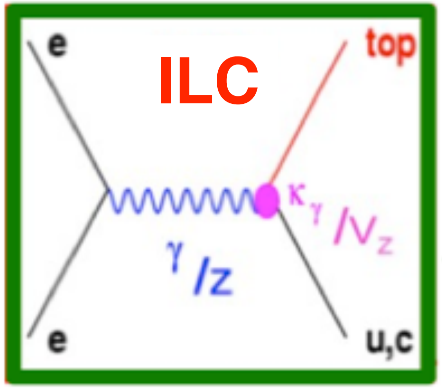


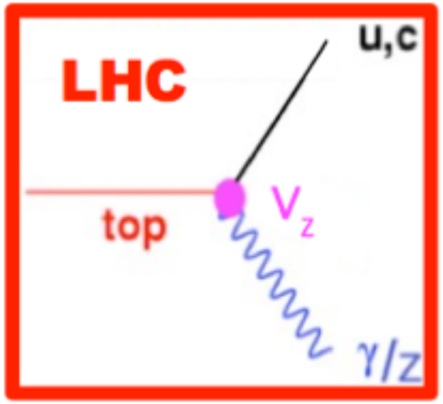


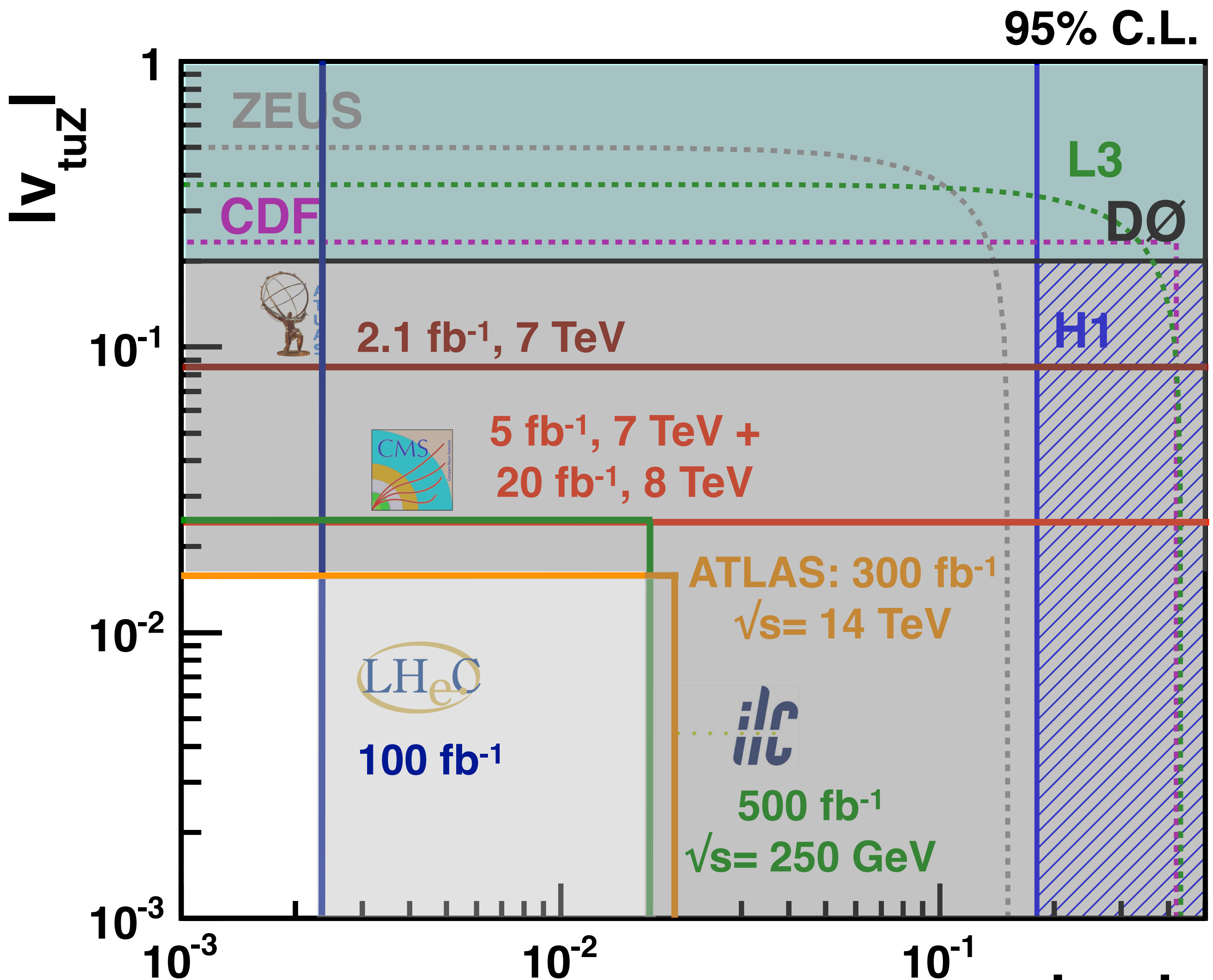


FCNC Top Couplings at Colliders









→ test SUSY, little Higgs, technicolor...

Outline

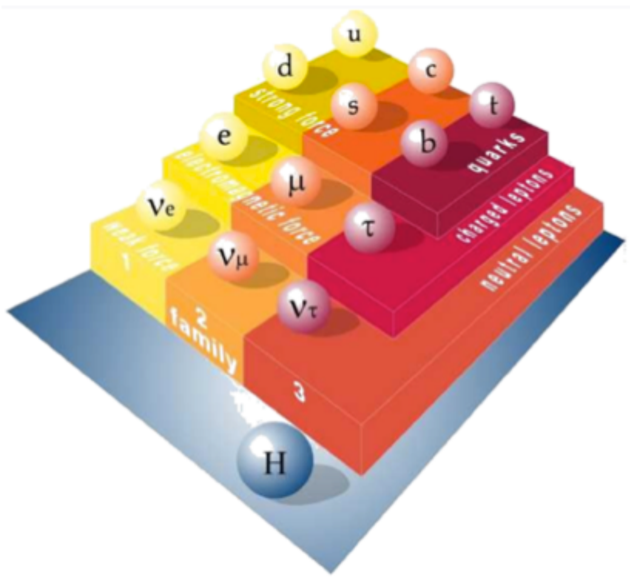
Introduction
Electroweak Physics
Top Quark Physics: CC
Top Quark Physics: NC
Conclusions

Summary

- future ep collider has a rich analysis programme for electroweak interactions of light and heavy quarks
- study top at ep collider for the first time
- high precision measurements of light (v_u, a_u, v_d, a^d) and top quark couplings to gauge bosons (mainly $|V_{tb}|$, Wtb, ttγ, ttZ)
- analyse top quark properties: polarisation, charge, PDFs of tops, ...
- many stringent searches for new physics:

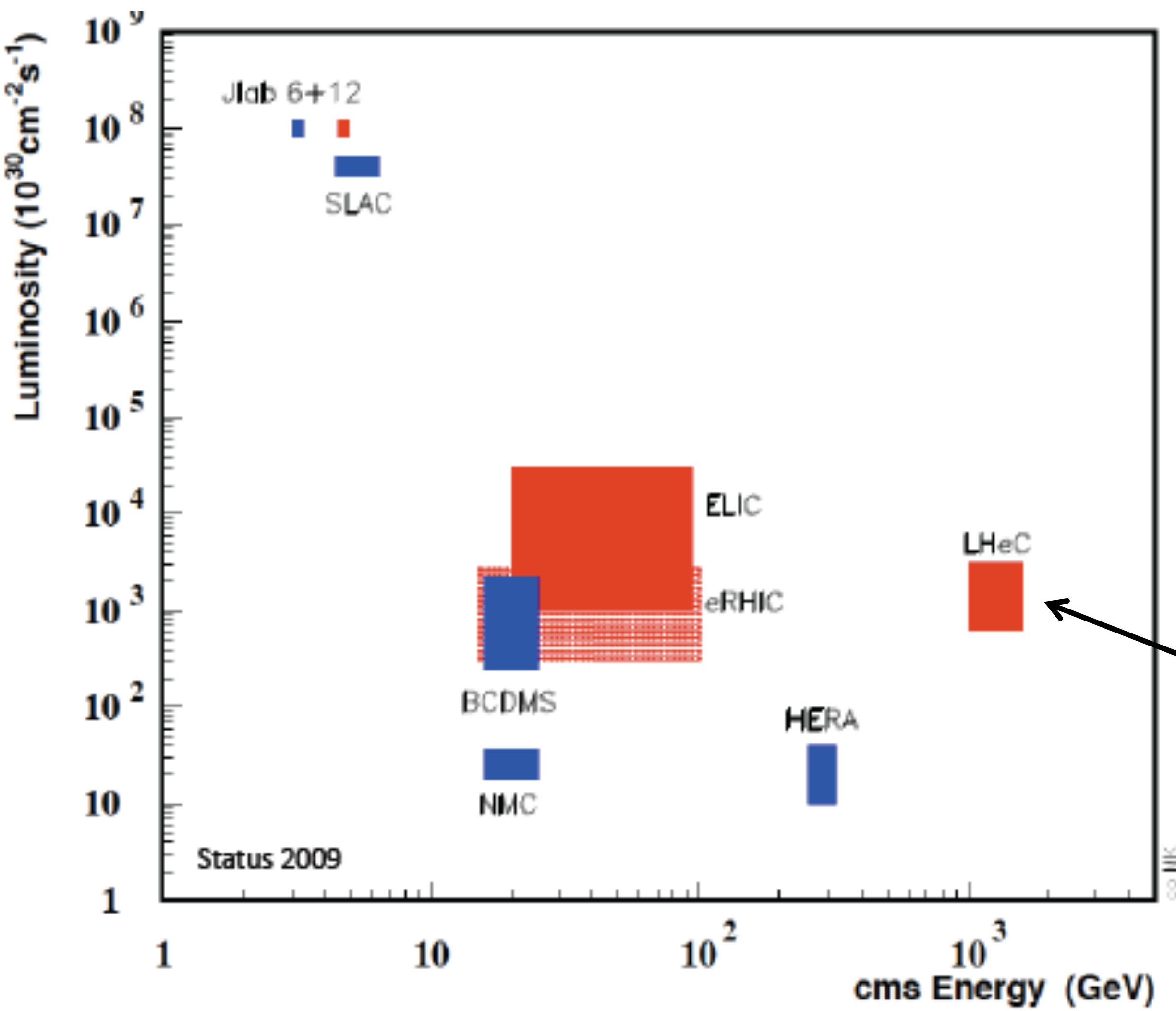
  anomalous couplings, FCNC, H^+ bosons, heavy top, SUSY, technicolor, ...

→ more exciting studies to come



Backup

Lepton Scattering Experiments



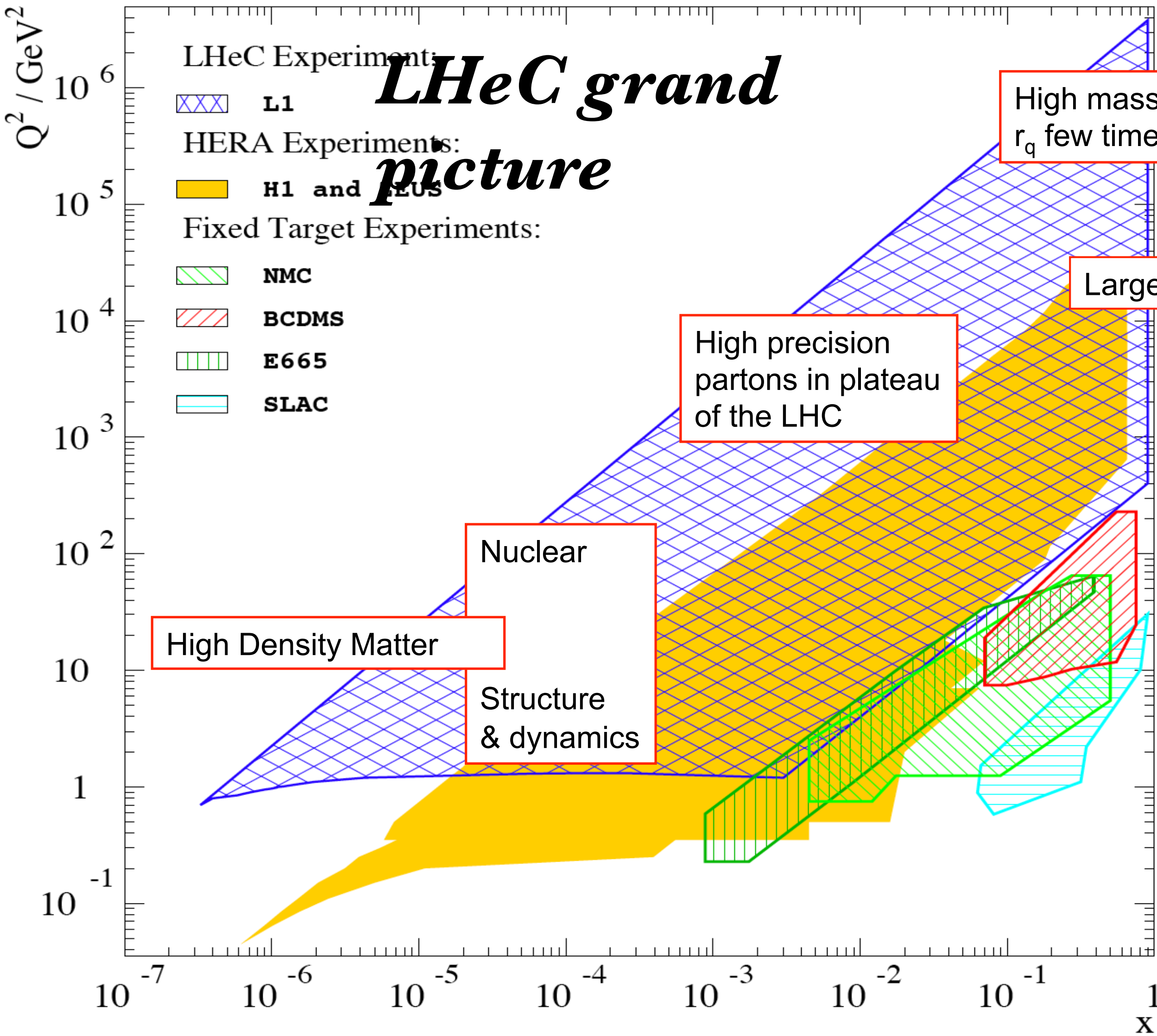
done

planned

LHeC = highest energy and high lumi

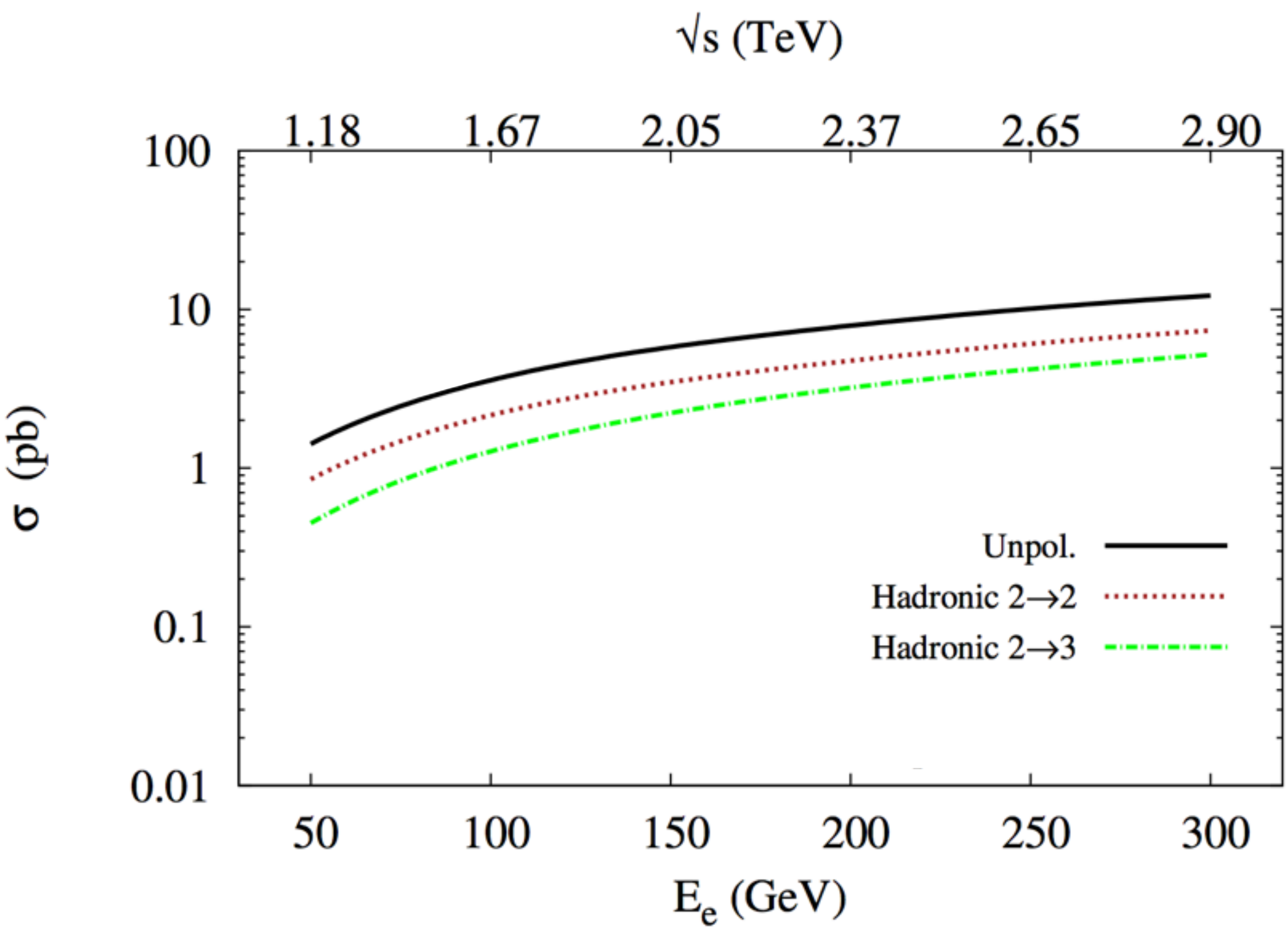
3

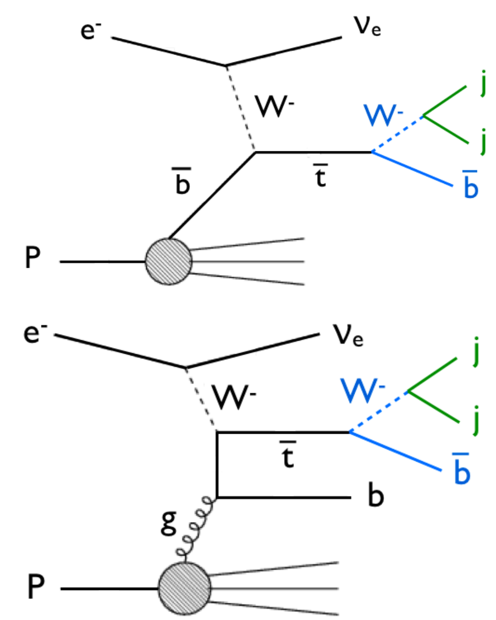
LHeC Overview



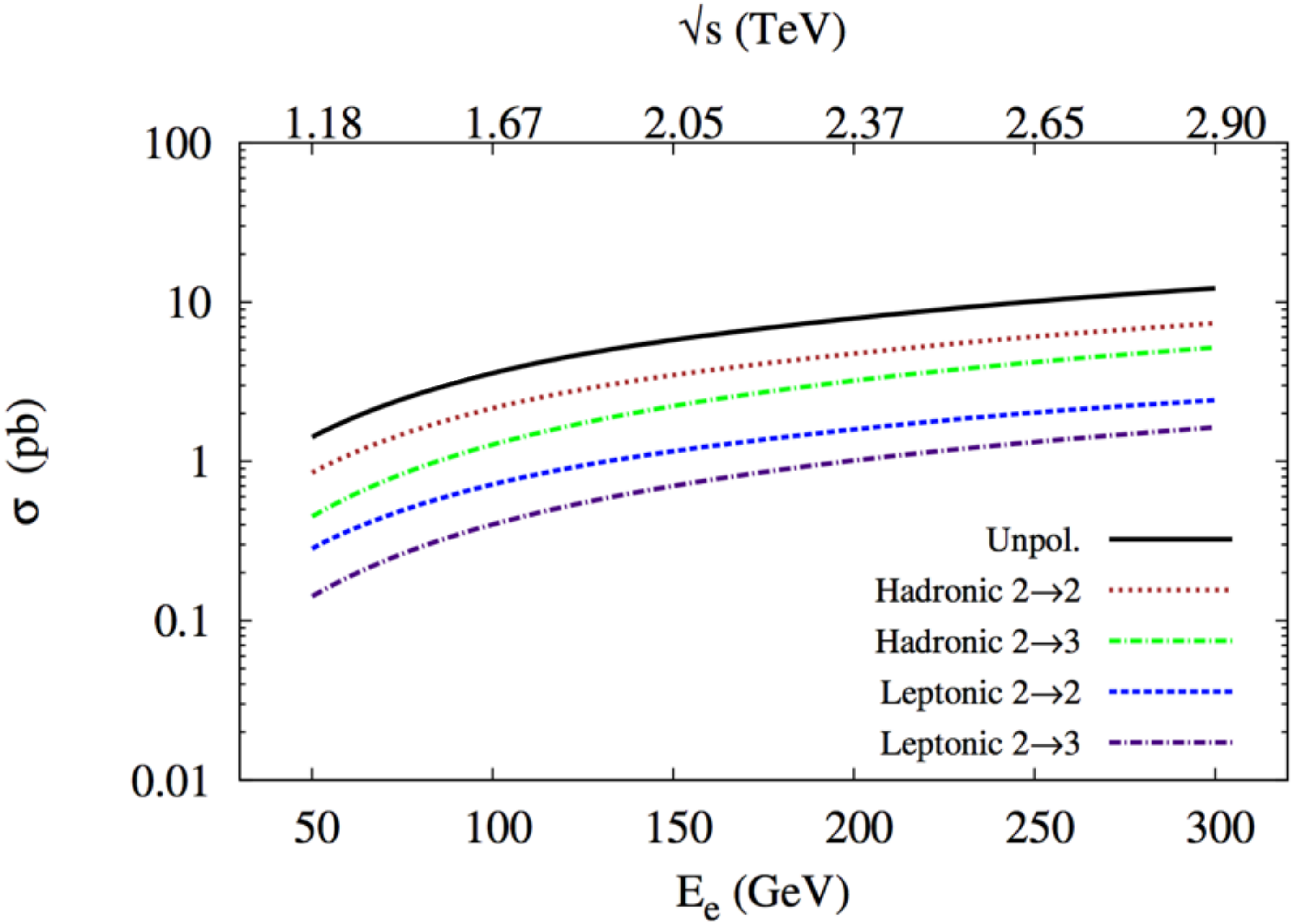
Talk Content:
Accelerator
1. Inclusive DIS & PDFs
2. Jets, c,b,t
3. Low x, saturation
4. EW and BSM

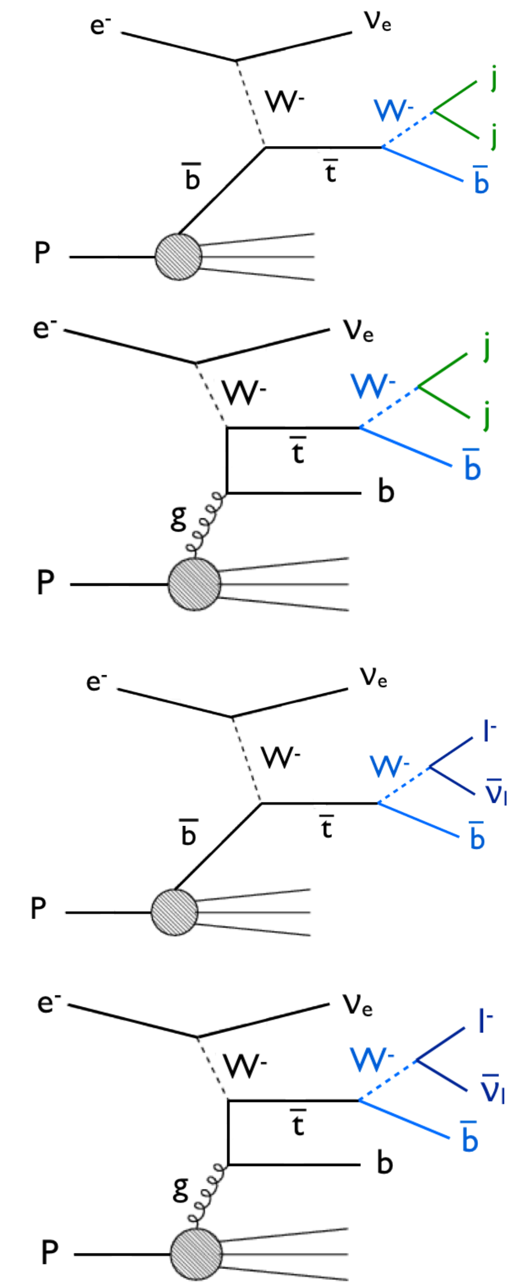
CC Single Top Quark Cross Section





CC Single Top Quark Cross Section





Backgrounds: Hadronic Channel

No.	Background Process	$p_{T\,j,b} \geq 20$ GeV $\lvert\eta_j\rvert \leq 5, \lvert\eta_b\rvert \leq 2.5$ $\Delta R_{j,b/j} \geq 0.4$ $\not{E}_T \geq 25$	$\Delta\Phi_{\not{E},j} \geq 0.4$ $\Delta\Phi_{\not{E},b} \geq 0.4$	$\lvert m_{j_1 j_2} - m_W\rvert \leq 22$ GeV	$\sigma_{\text{eff.}}$
1	$e^- p \to \nu_e W^- \bar{b}$ without anti-top line	7.5×10^{-3}	6.8×10^{-3}	4.5×10^{-3}	2.7×10^{-3}
2	$e^- p \to \nu_e jjj$	4.2×10^{0}	3.6×10^{0}	2.4×10^{0}	7.2×10^{-2}
3	$e^- p \to \nu_e c jj$ & $e^- p \to \nu_e \bar{c} jj$	1.5×10^{0}	1.2×10^{0}	8.6×10^{-1}	8.6×10^{-2}
4	$e^- p \to \nu_e c\bar{c} j$	5.8×10^{-2}	5.0×10^{-2}	3.2×10^{-2}	6.7×10^{-3}
5	$e^- p \to \nu_e b\bar{b} j$	2.5×10^{-2}	2.2×10^{-2}	5.6×10^{-3}	1.3×10^{-3}
6	$e^- p \to \bar{c} \nu_e$ $(\bar{c} \to W^- \bar{s})$	2.5×10^{-2}	2.2×10^{-2}	1.5×10^{-2}	1.5×10^{-4}

Event Selection	$p_{T\,j,b} \geq 20$ GeV $\lvert\eta_j\rvert \leq 5, \lvert\eta_b\rvert \leq 2.5$ $\Delta R_{j,b/j} \geq 0.4$ $\not{E}_T \geq 25$	$\Delta\Phi_{\not{E},j} \geq 0.4$ $\Delta\Phi_{\not{E},b} \geq 0.4$	$\lvert m_{j_1 j_2} - m_W\rvert \leq 22$ GeV	Fiducial Efficiency	$S/\sqrt{S+B}$
SM	3.2×10^{4}	2.3×10^{4}	2.2×10^{4}	66.7 %	–
SM+$\sum_i$ Bkg$_i$	6.5×10^{4}	5.0×10^{4}	4.0×10^{4}	61.5 %	
$\lvert V_{tb}\rvert\, \Delta f_1^L = .5$	7.3×10^{4}	5.0×10^{4}	5.0×10^{4}	68.0 %	1.92
$f_1^R = .5$	4.6×10^{4}	3.2×10^{4}	3.2×10^{4}	69.7 %	1.43
$f_2^L = .5$	4.9×10^{4}	3.6×10^{4}	3.6×10^{4}	73.2 %	1.55
$f_2^L = -.5$	3.4×10^{4}	2.3×10^{4}	2.3×10^{4}	69.6 %	1.40
$f_2^R = .5$	5.7×10^{4}	4.1×10^{4}	4.1×10^{4}	72.3 %	1.69

Backgrounds: Leptonic Channel

No.	Background Process	$p_{T\,j,b,l} \geq 20$ GeV, $\Delta R_{j,b/j} \geq 0.4$, $\not{E}_T \geq 25$ $\lvert\eta_j\rvert \geq 5$, $\lvert\eta_{b,l}\rvert \geq 2.5$	$\Delta\Phi_{\not{E},j} \geq 0.4$ $\Delta\Phi_{\not{E},b} \geq 0.4$ $\Delta\Phi_{\not{E},l} \geq 0.4$	$\sigma_{\text{eff.}}$
1	$e^-p \to l^-\bar{\nu}_l\nu_e j$	1.5×10^{-1}	1.4×10^{-1}	1.4×10^{-3}
2	$e^-p \to l^-\bar{\nu}_l\nu_e c$ & $e^-p \to l^-\bar{\nu}_l\nu_e \bar{c}$	6.6×10^{-3}	6.1×10^{-3}	6.1×10^{-4}
3	$e^-p \to l^-\bar{\nu}_l\nu_e b$ & $e^-p \to l^-\bar{\nu}_l\nu_e \bar{b}$ Without top line	3.6×10^{-3}	3.2×10^{-3}	1.9×10^{-3}
4	$e^-p \to e^-l^-\bar{\nu}_l c$	1.5×10^{-2}	6.9×10^{-3}	6.9×10^{-4}
5	$e^-p \to e^-l^-\bar{\nu}_l j$	1.2×10^{-1}	5.5×10^{-2}	5.5×10^{-4}

Event Selection	$p_{T\,j,b} \geq 20$ GeV $\lvert\eta_j\rvert \leq 5$, $\lvert\eta_b\rvert \leq 2.5$ $\Delta R_{j,b/j} \geq 0.4$ $\not{E}_T \geq 25$	$\Delta\Phi_{\not{E},j} \geq 0.4$ $\Delta\Phi_{\not{E},b} \geq 0.4$ $\Delta\Phi_{\not{E},l} \geq 0.4$	Fiducial Efficiency	$S/\sqrt{S+B}$
SM	1.2×10^4	1.1×10^4	92.0 %	–
SM+$\sum_i$ Bkg$_i$	1.3×10^4	1.2×10^4	92.0 %	–
$\lvert V_{tb}\rvert\, \Delta f_1^L = .5$	4.5×10^4	2.5×10^4	92.6 %	1.55
$f_1^R = .5$	2.8×10^4	1.6×10^4	94.1 %	1.23
$f_2^L = .5$	3.1×10^4	1.7×10^4	89.5 %	1.27
$f_2^L = -.5$	1.8×10^4	1.0×10^4	90.9 %	0.95
$f_2^R = .5$	3.6×10^4	2.0×10^4	90.9 %	1.38

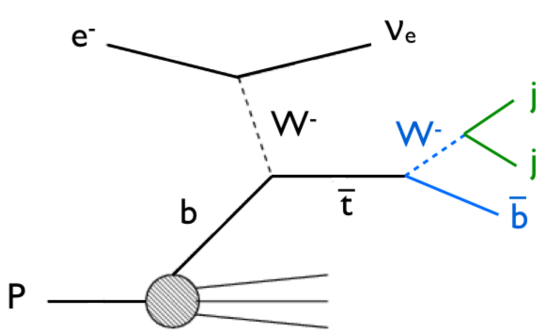
Search for Anomalous Wtb Couplings

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

= 1 in SM

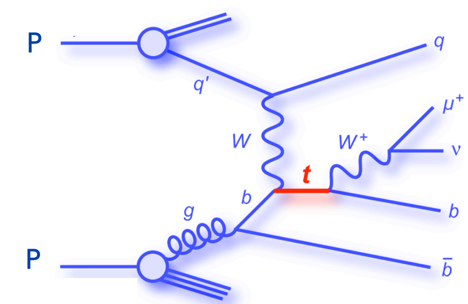
Dutta, Goyal, Kumar, Mellado, arXiv:1307.1688

68% C.L.

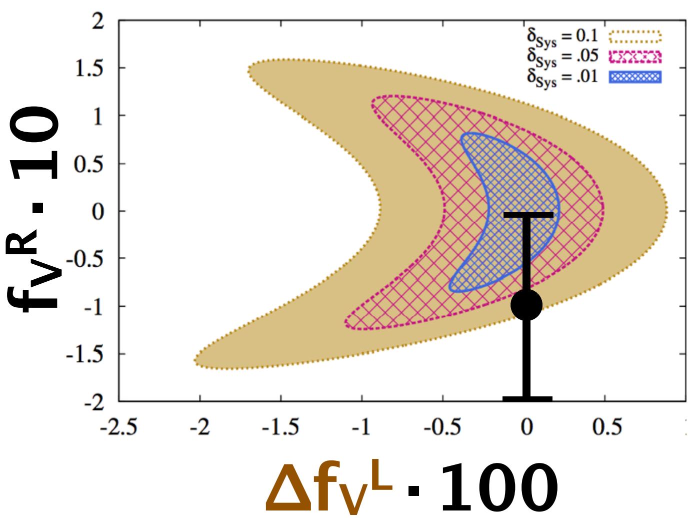


LHC combination preliminary

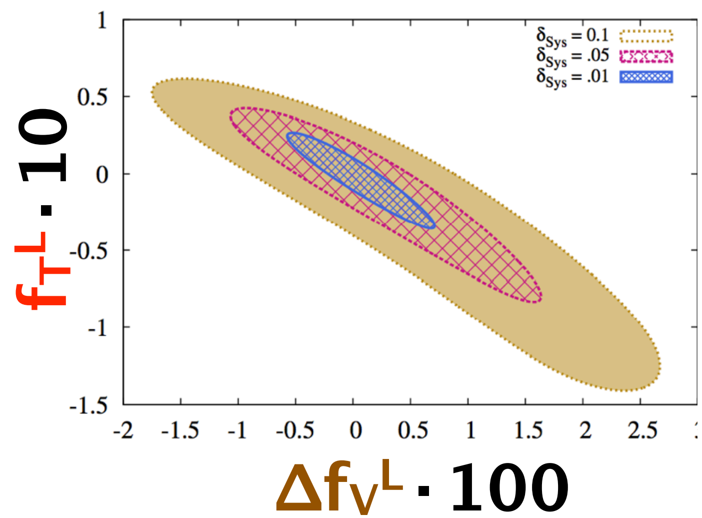
$\sqrt{s}$=7 TeV, L_{int}=35 pb^{-1} - 2.2 fb^{-1}



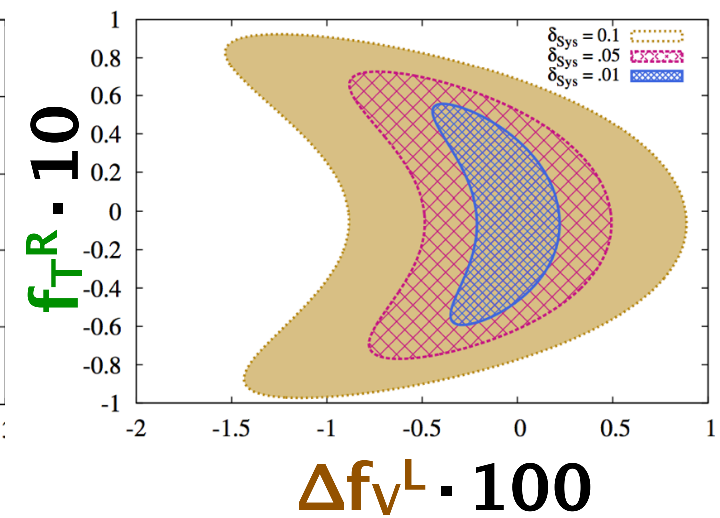
syst. error



syst. error



syst. error

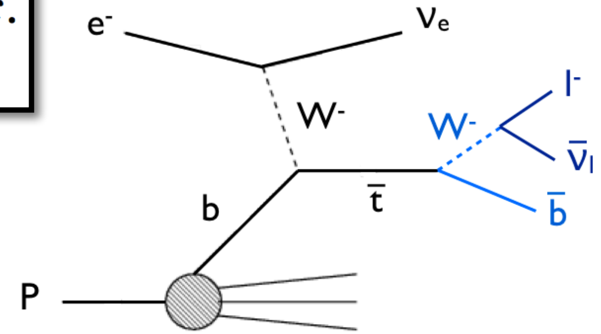


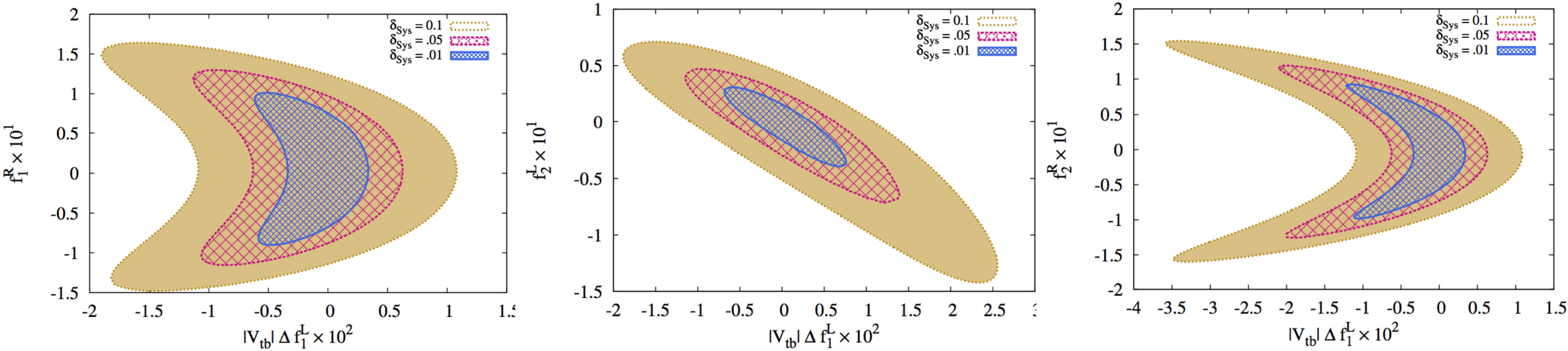
Search for Anomalous Wtb Couplings

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

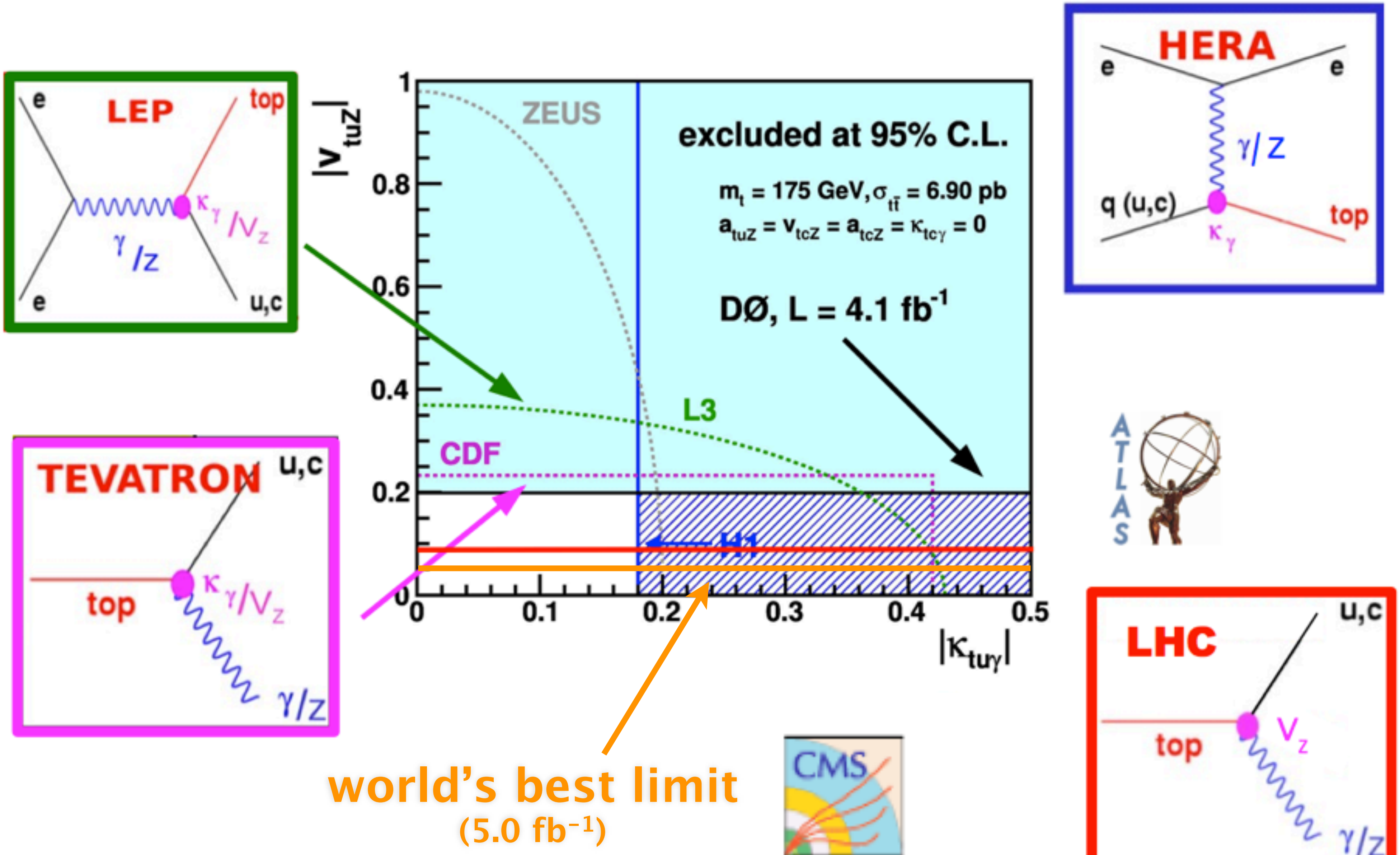
= 1 in SM

68% C.L.



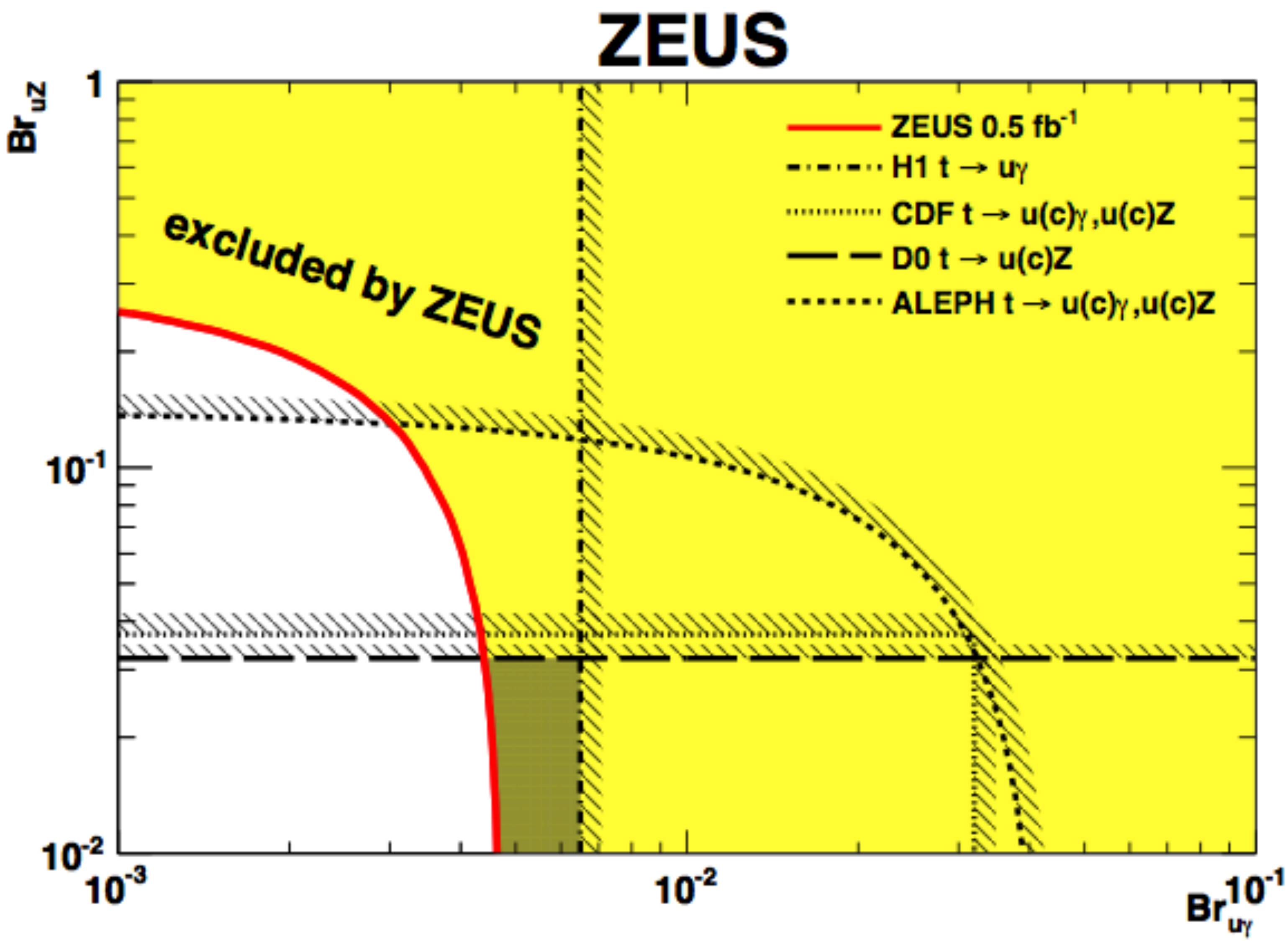


Search for FCNC in Top Quark Decays



arXiv:1208.0957 [hep-ex]

Search for FCNC in Top Quark Decays



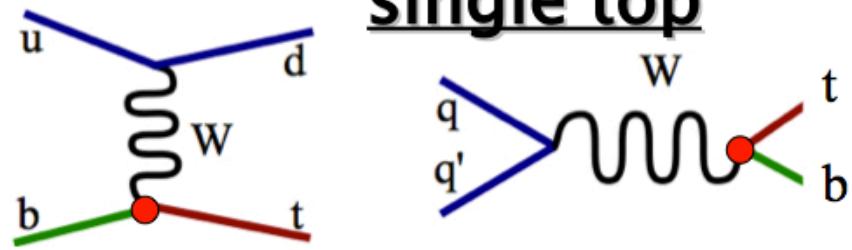
Search for Anomalous Wtb Couplings

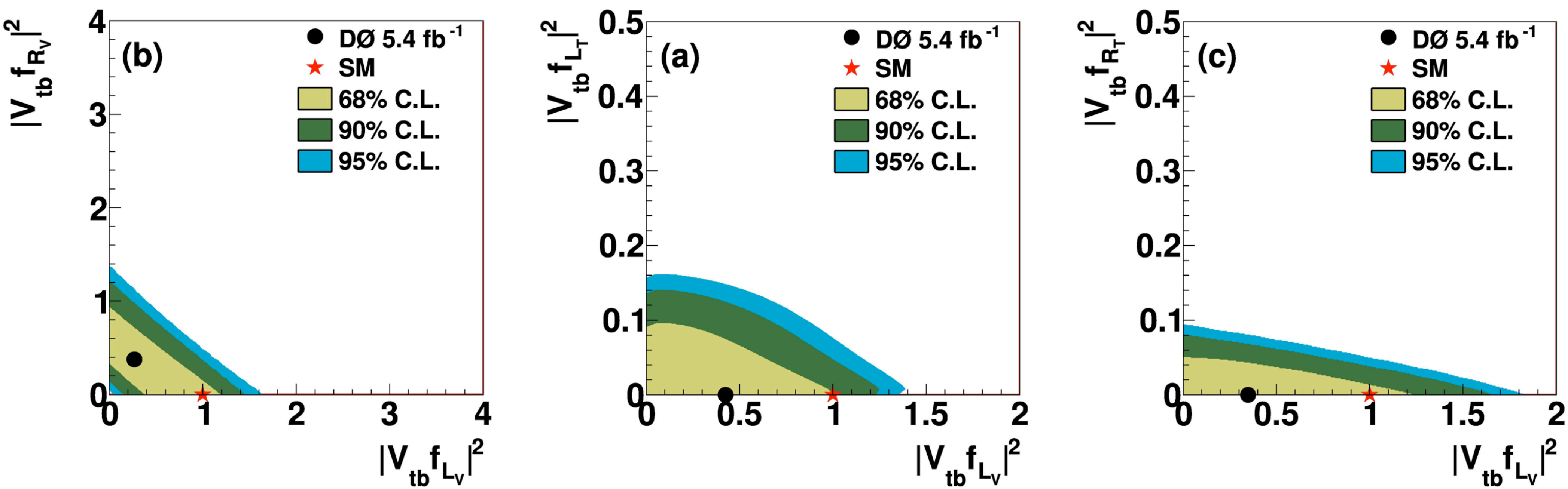
PLB 708, 21 (2012)

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

= 1 in SM

single top





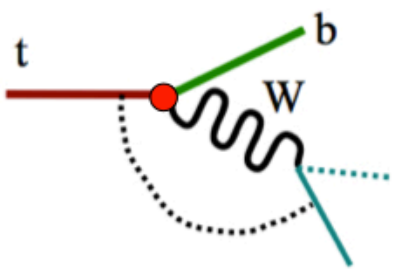
Search for Anomalous Wtb Couplings

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

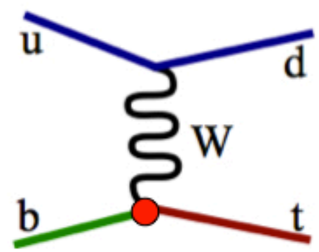
= 1 in SM

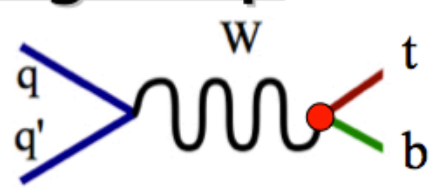
PLB 713, 165 (2012)

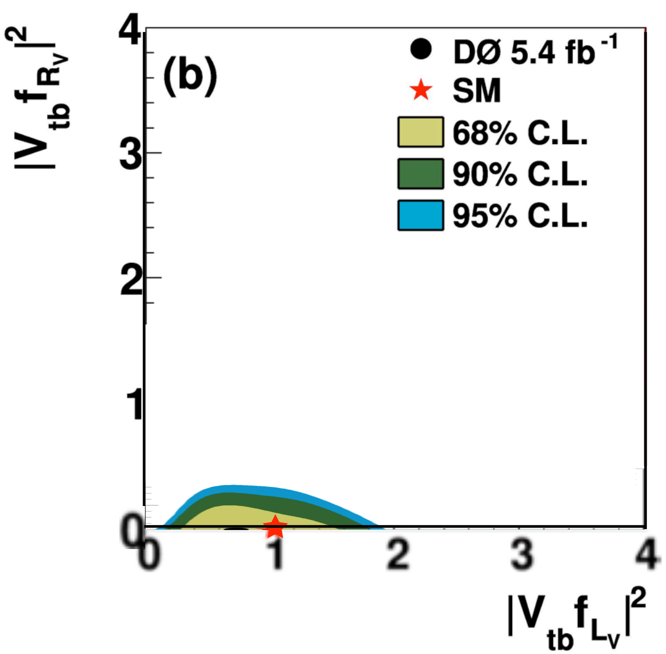
W helicity

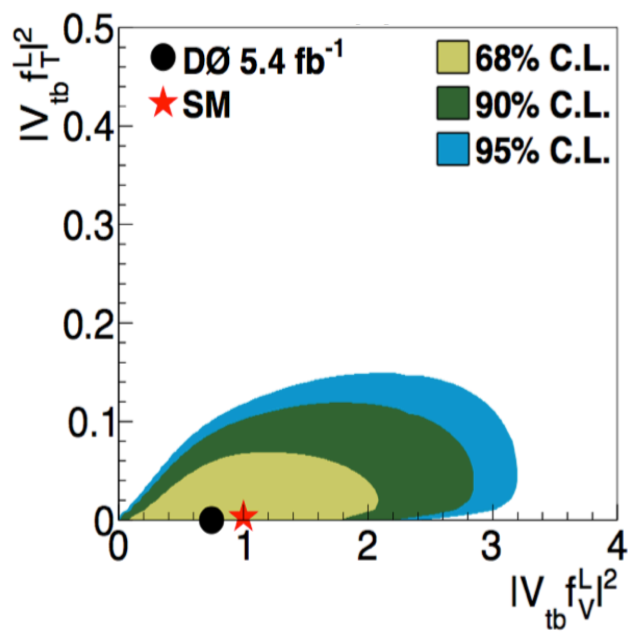


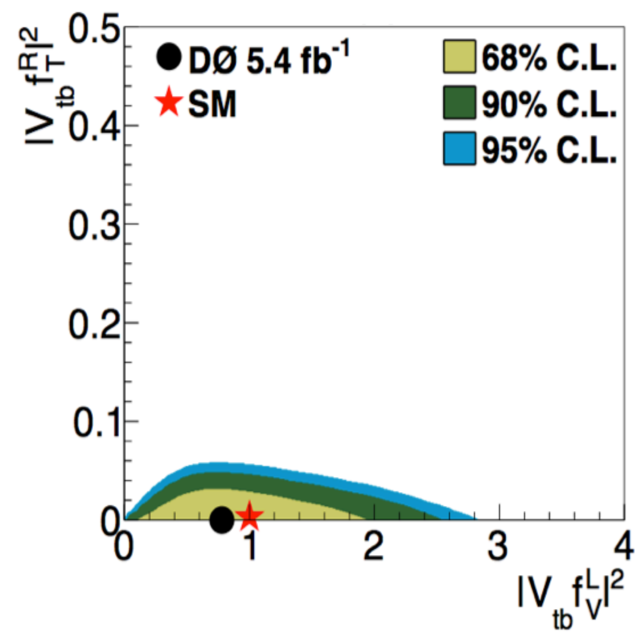
single top











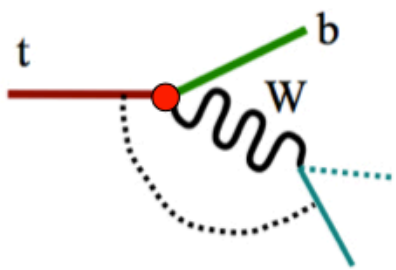
Search for Anomalous Wtb Couplings

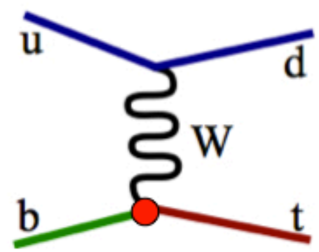
$$L = -\frac{g}{\sqrt{2}} \bar{b} \gamma^{\mu} V_{tb} \left(f_V^L P_L + f_V^R P_R \right) t W_{\mu}^{-} - \frac{g}{\sqrt{2}} \bar{b} \frac{i \sigma^{\mu\nu} q_{\nu}}{M_W} \left(f_T^L P_L + f_T^R P_R \right) t W_{\mu}^{-} + h.c.$$

= 1 in SM

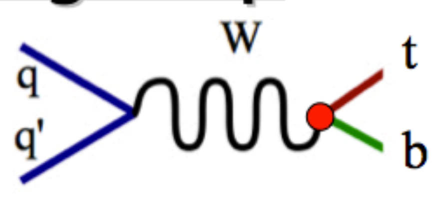
PLB 713, 165 (2012)

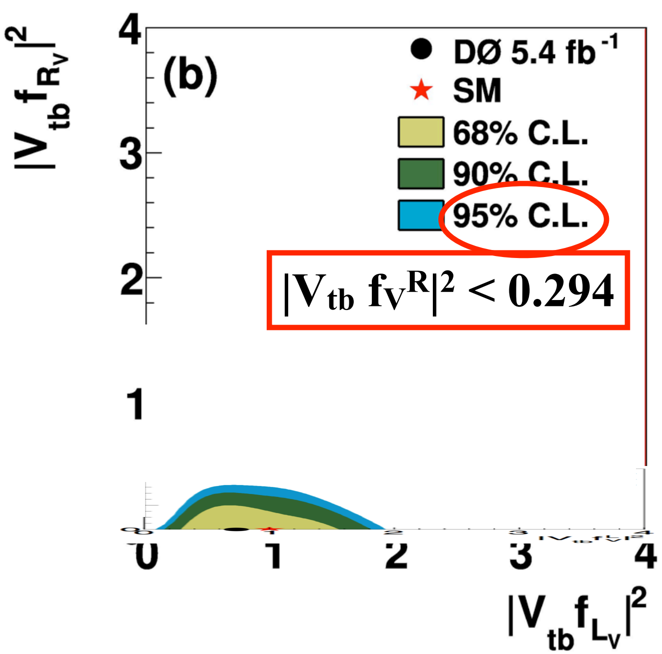
W helicity

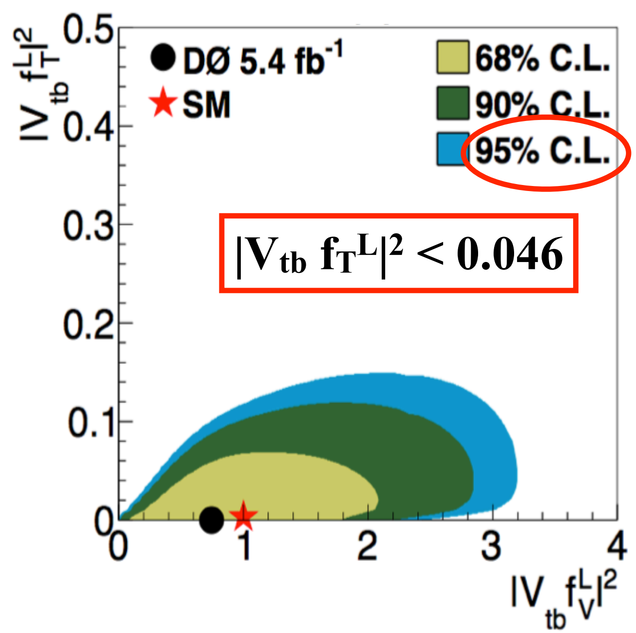


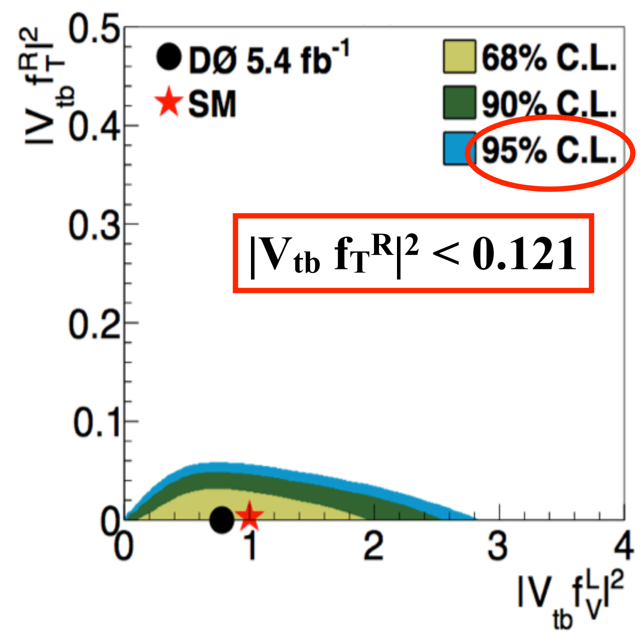


single top

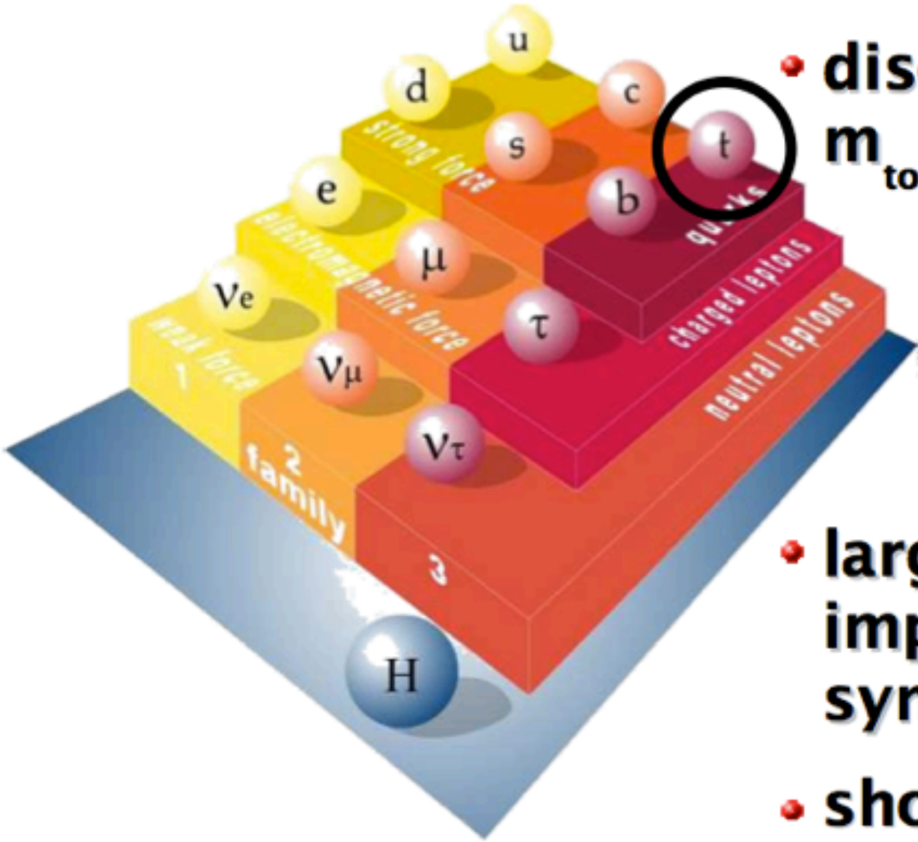








The Top Quark

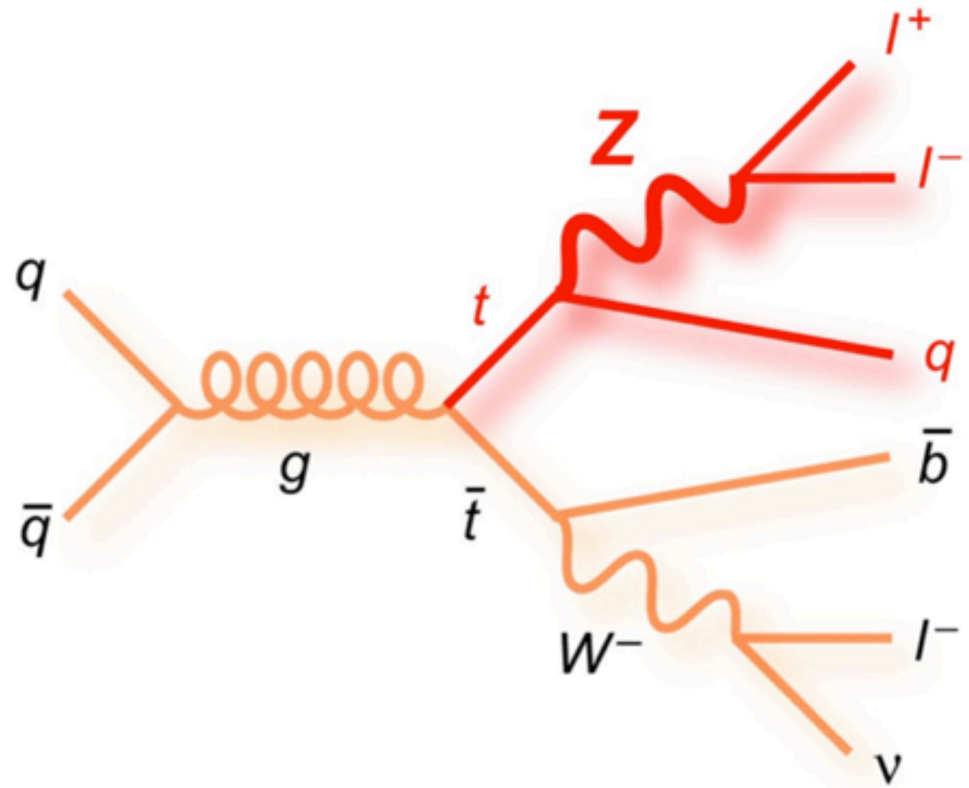


- needed as isospin partner of bottom quark
- discovered in 1995 by CDF and DØ: m_{top} ~ gold nucleus
- large coupling to Higgs boson ~ 1: important role in electroweak symmetry breaking?
- short lifetime: $\tau \sim 5 \cdot 10^{-25}\mathrm{s} \ll \Lambda^{-1}_{QCD}$: decays before fragmenting → observe "naked" quark

Is the top quark the particle as predicted by the SM?

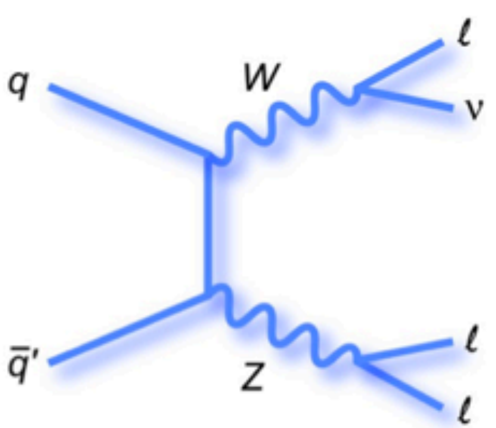
Search for FCNC in Top Quark Decays

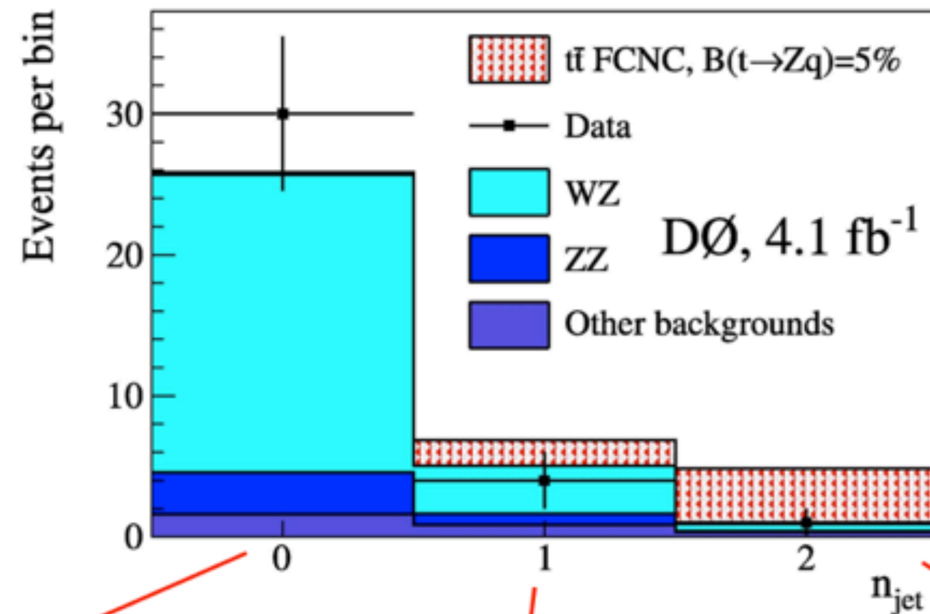
$$\mathcal{L}_{FCNC} = \frac{e}{2\sin\theta_W \cos\theta_W} \bar{t}\gamma_\mu(v_Z - a_Z\gamma_5)qZ^\mu + h.c.$$

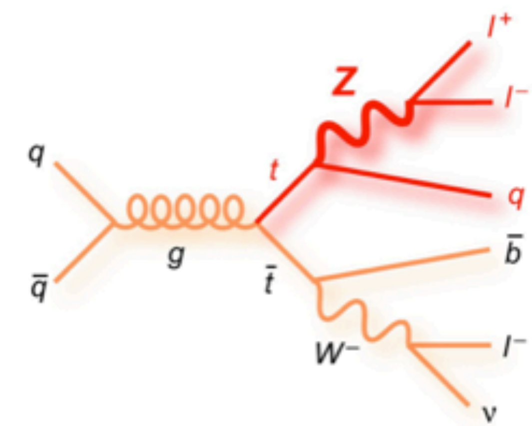


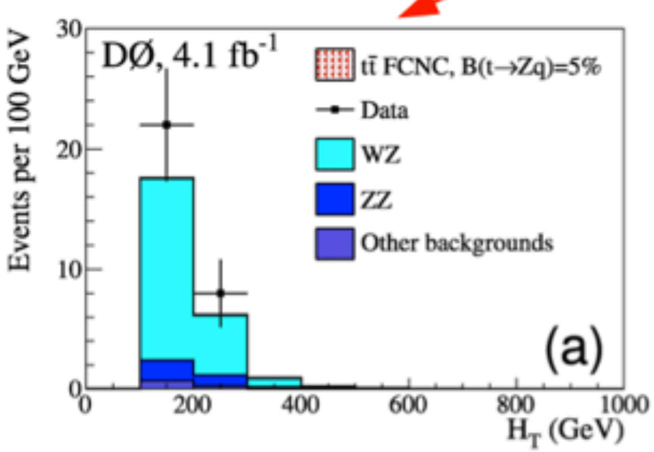
- **select 3 leptons, missing transverse momentum, 2 jets**

Search for FCNC in Top Quark Decays

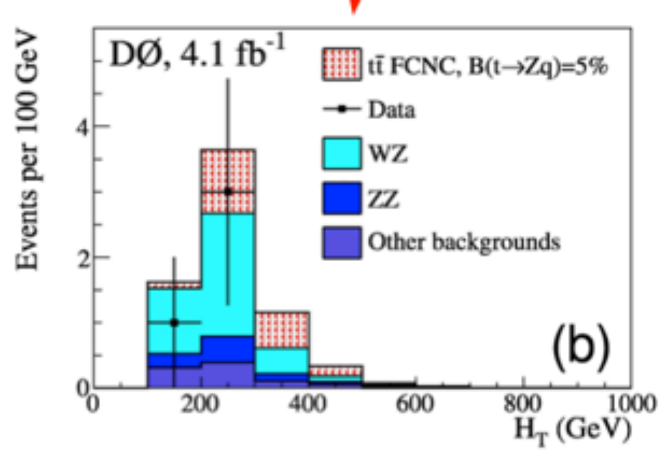




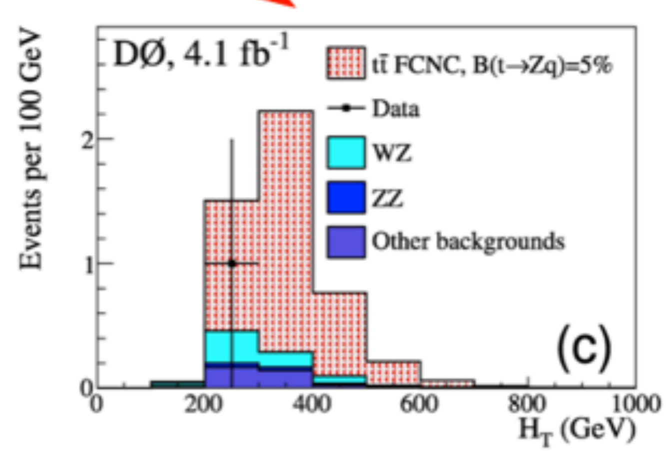




3 leptons + 0 jets

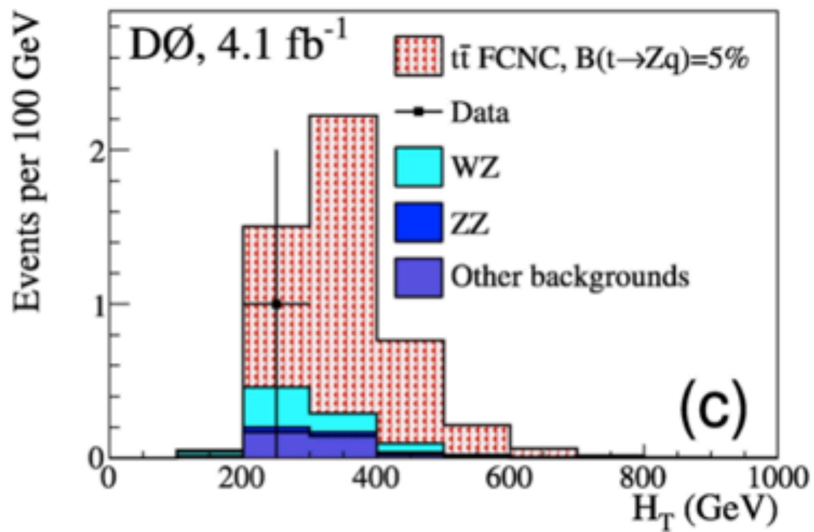


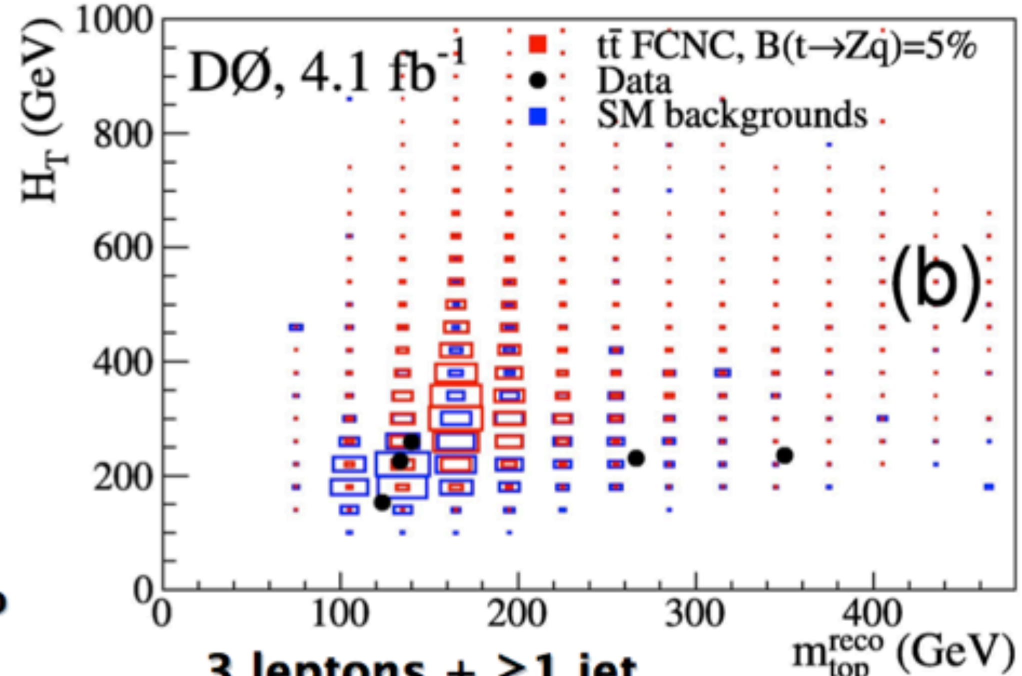
3 leptons + 1 jet

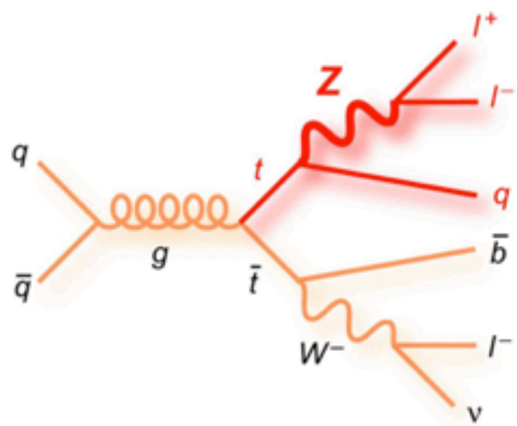


3 leptons + ≥2 jets

Search for FCNC in Top Quark Decays

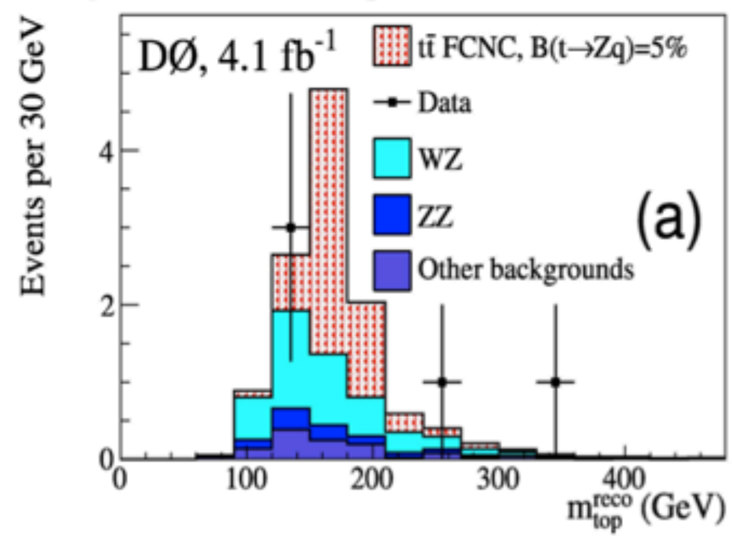






m_{top}^{reco}

3 leptons + ≥1 jet



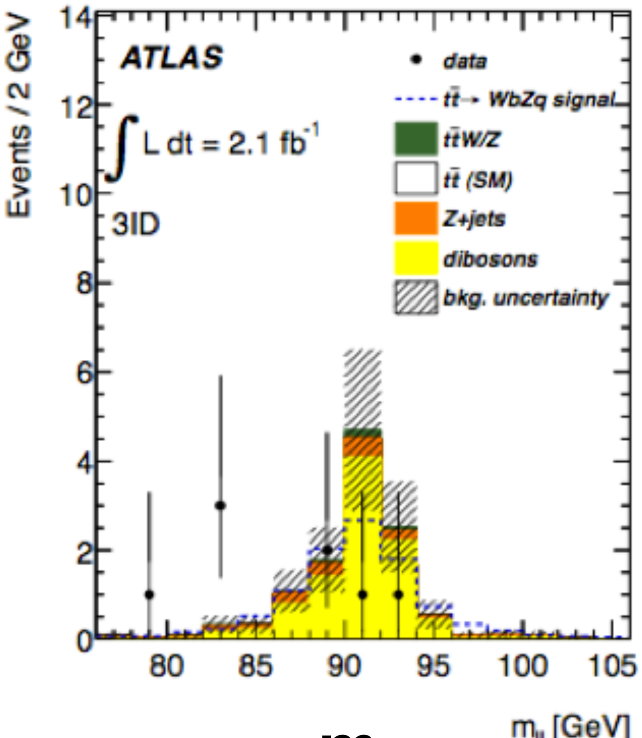
Phys. Lett. B701, 313 (2011)

95% C.L.

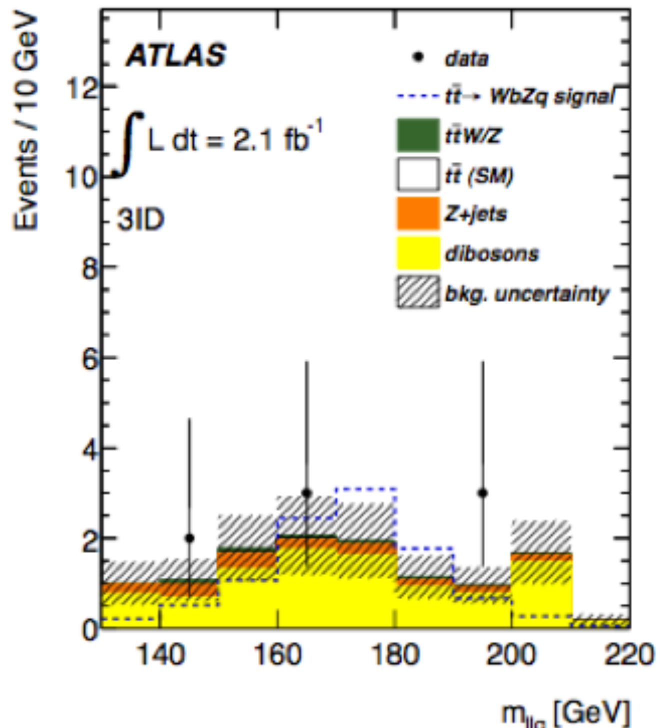
B(t→Zq) < 3.2% (3.8% expected)

Search for FCNC in Top Quark Decays

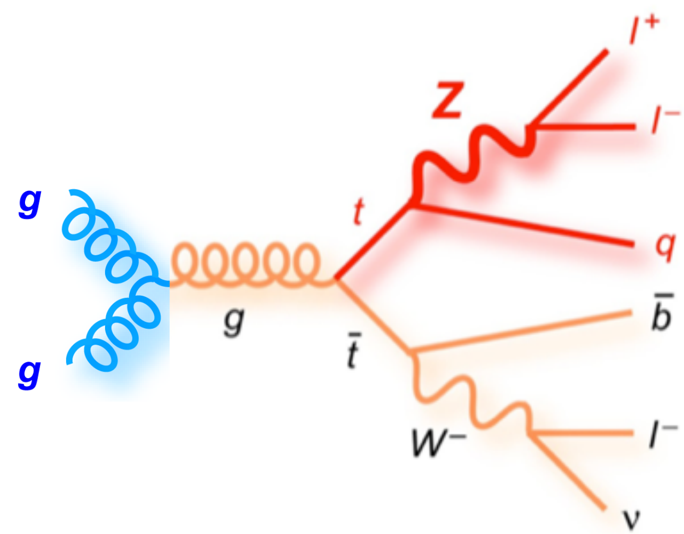
$$pp \rightarrow t\bar{t} \rightarrow Zq + Wb \rightarrow \ell\ell q + \ell\nu b \, (\ell = e, \mu)$$



m_Z



m_{top}

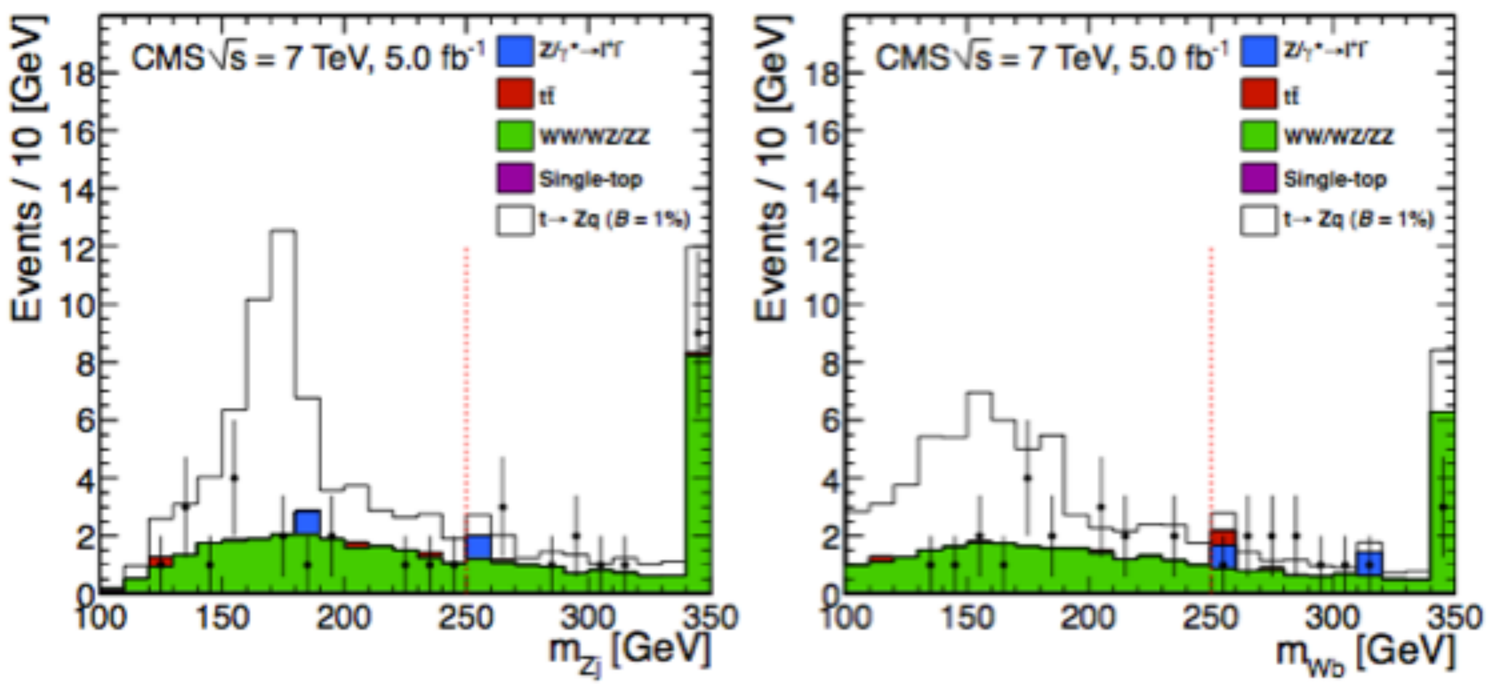


counting experiment:

B(t→Zq)<0.73%
(0.93% expected)

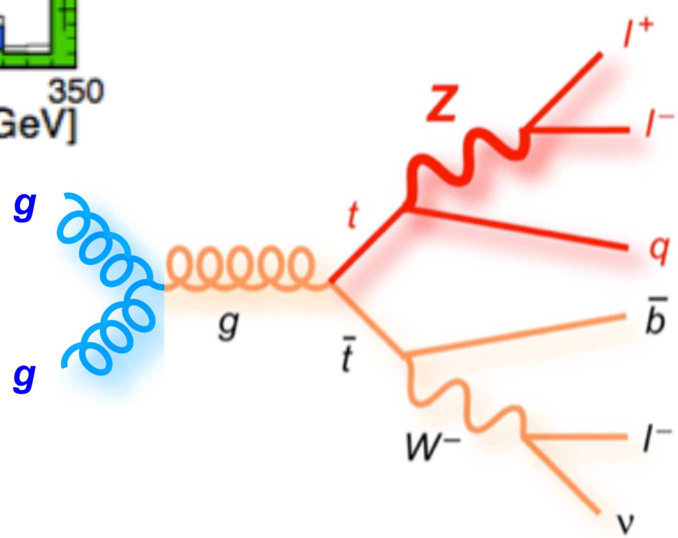
Search for FCNC in Top Quark Decays

$$pp \rightarrow t\bar{t} \rightarrow Zq + Wb \rightarrow \ell\ell q + \ell\nu b \, (\ell = e, \mu)$$



m_{top} m_{top}

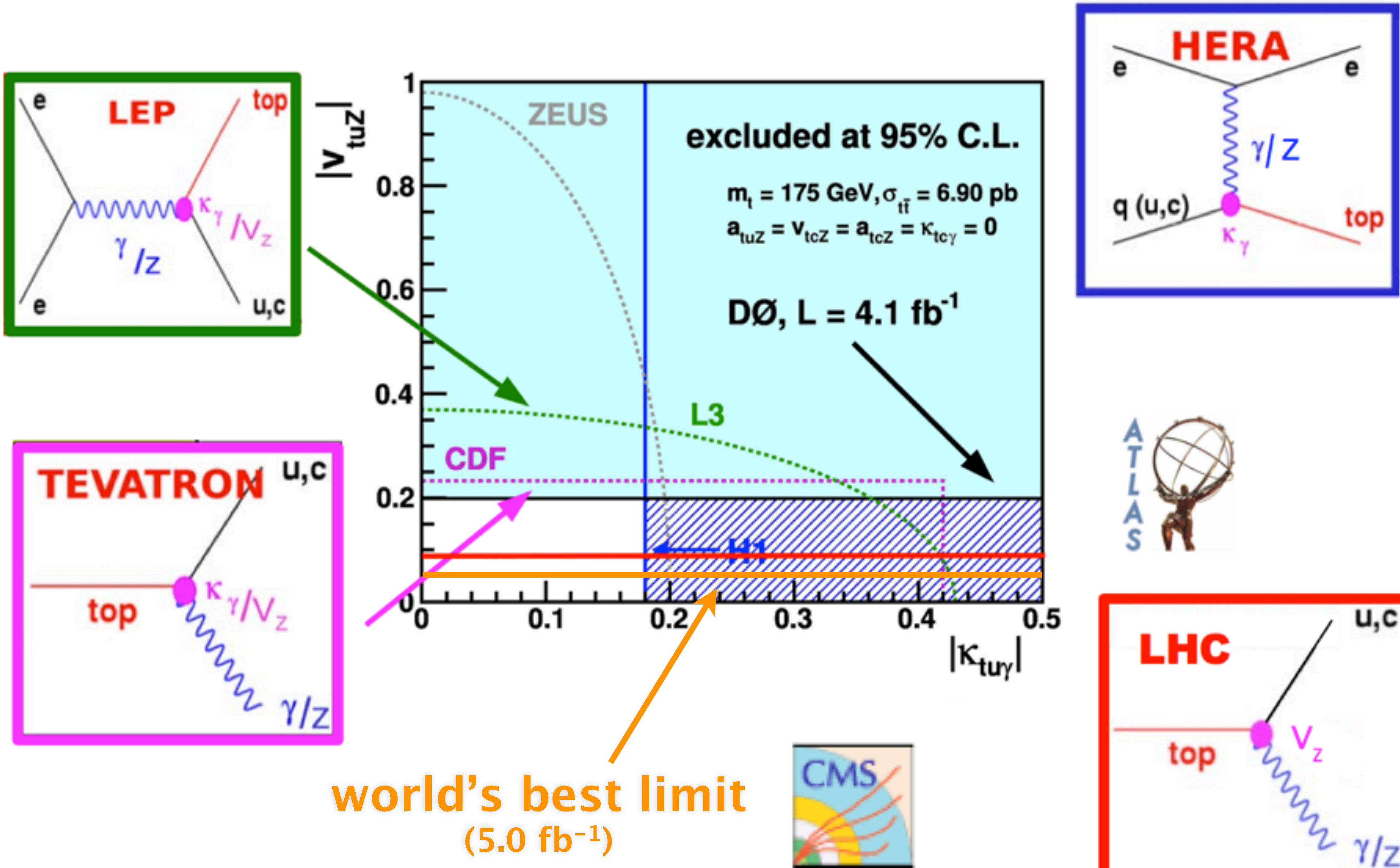
high H_T selection



counting experiment:

$\boxed{B(t \rightarrow Zq) < 0.24\%}$

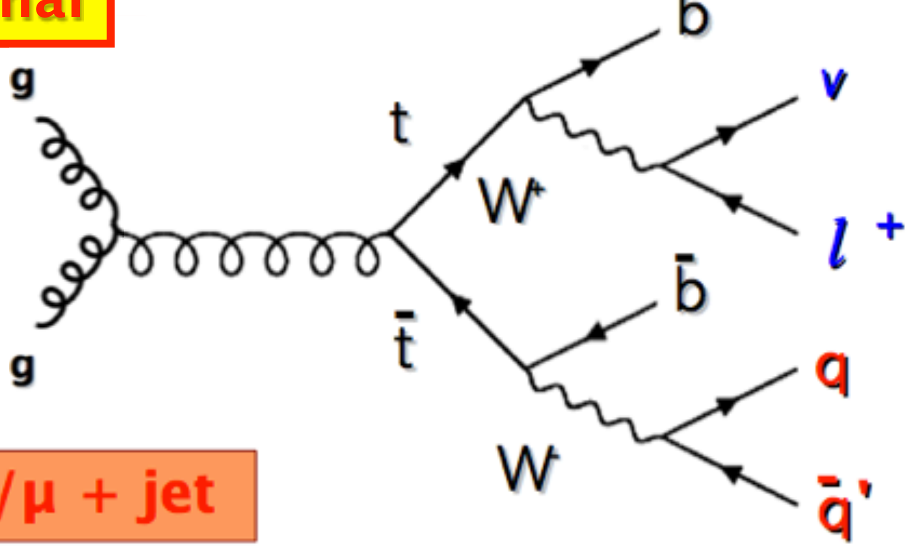
Search for FCNC in Top Quark Decays



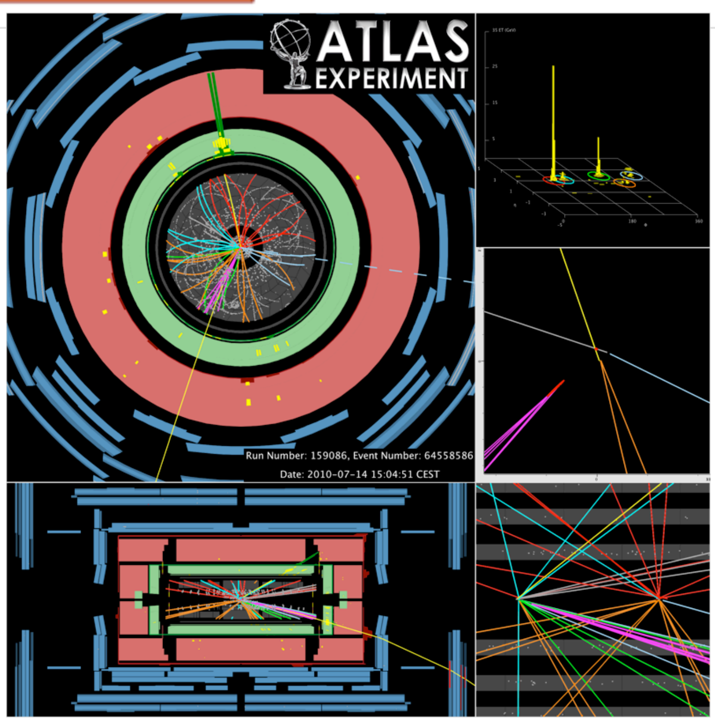
arXiv:1208.0957 [hep-ex]

Lepton+jets Signatures

signal

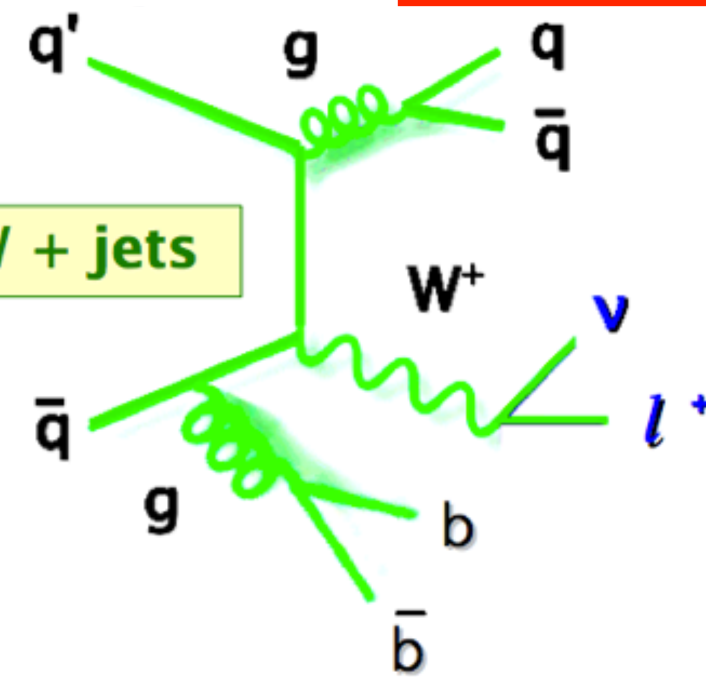


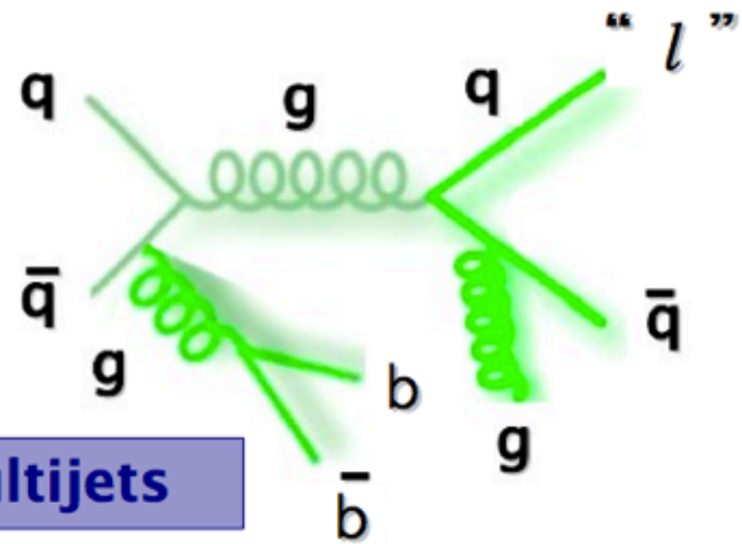
e/μ + jet



background

W + jets



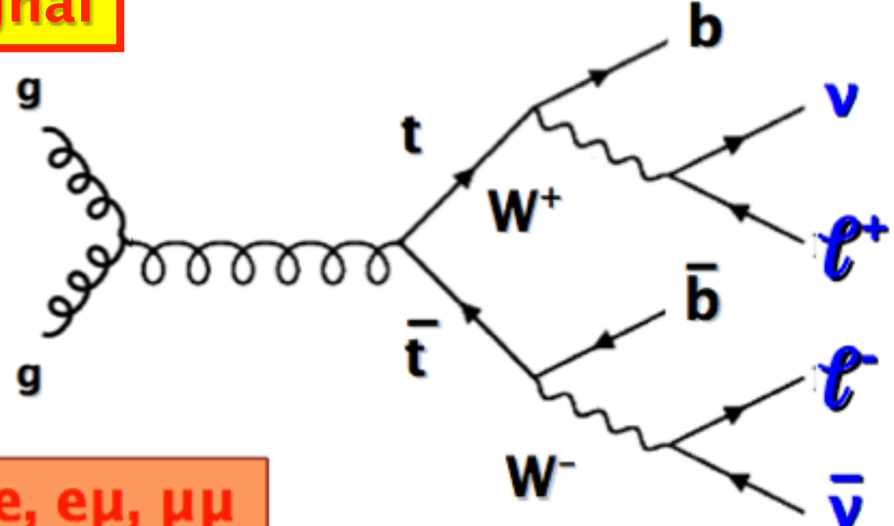


multijets

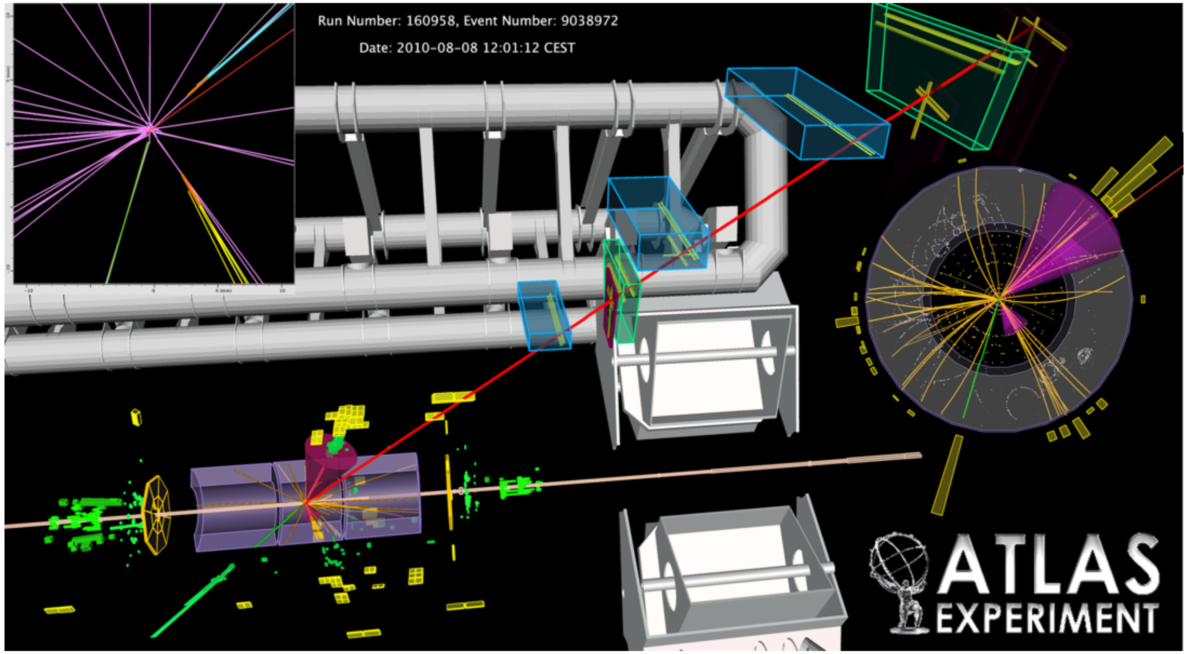
Dilepton Signatures

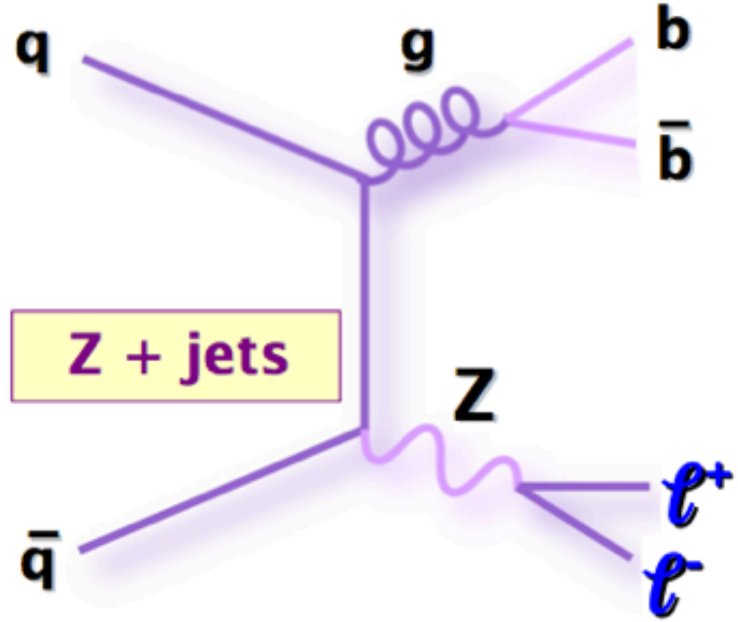
signal

background



ee, eμ, μμ

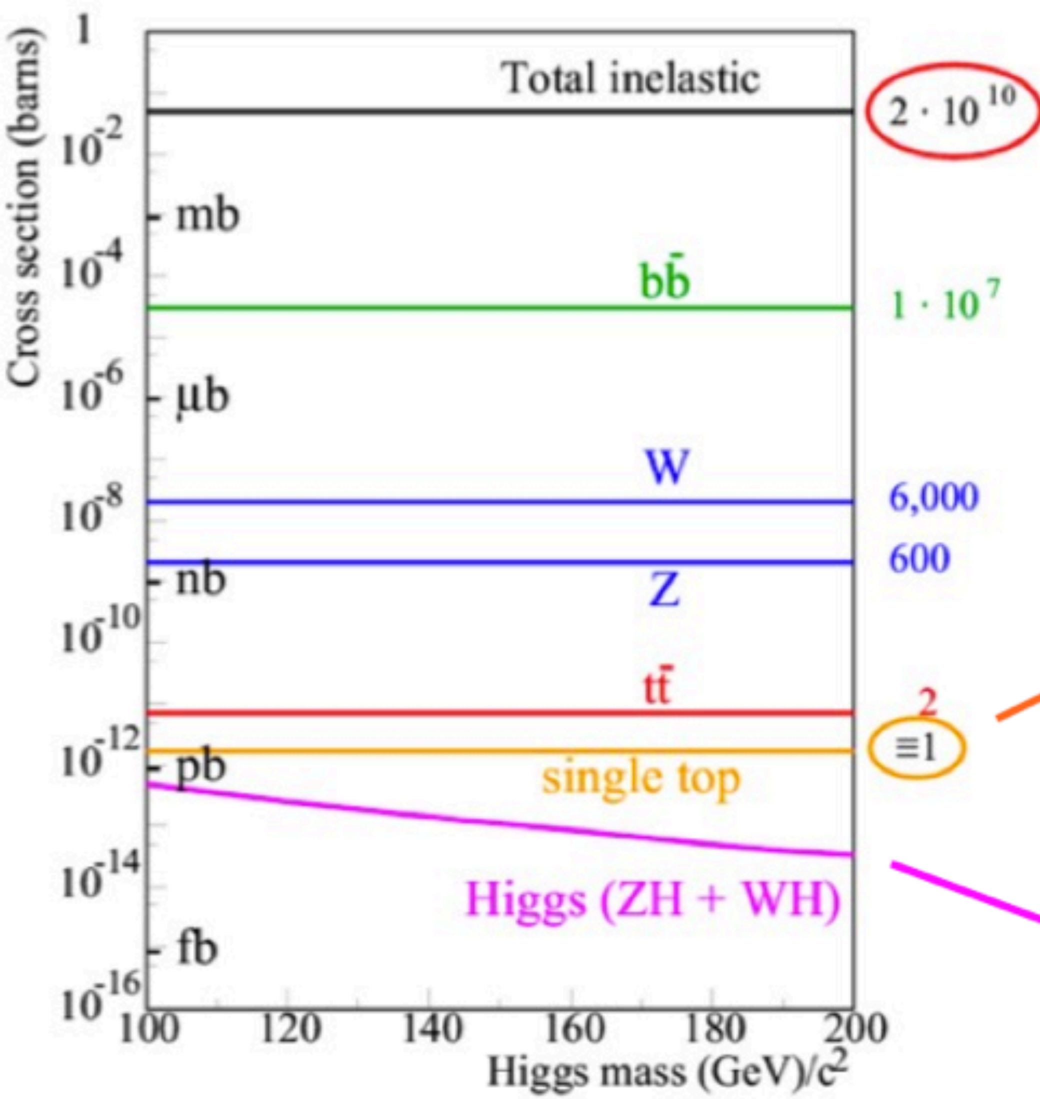


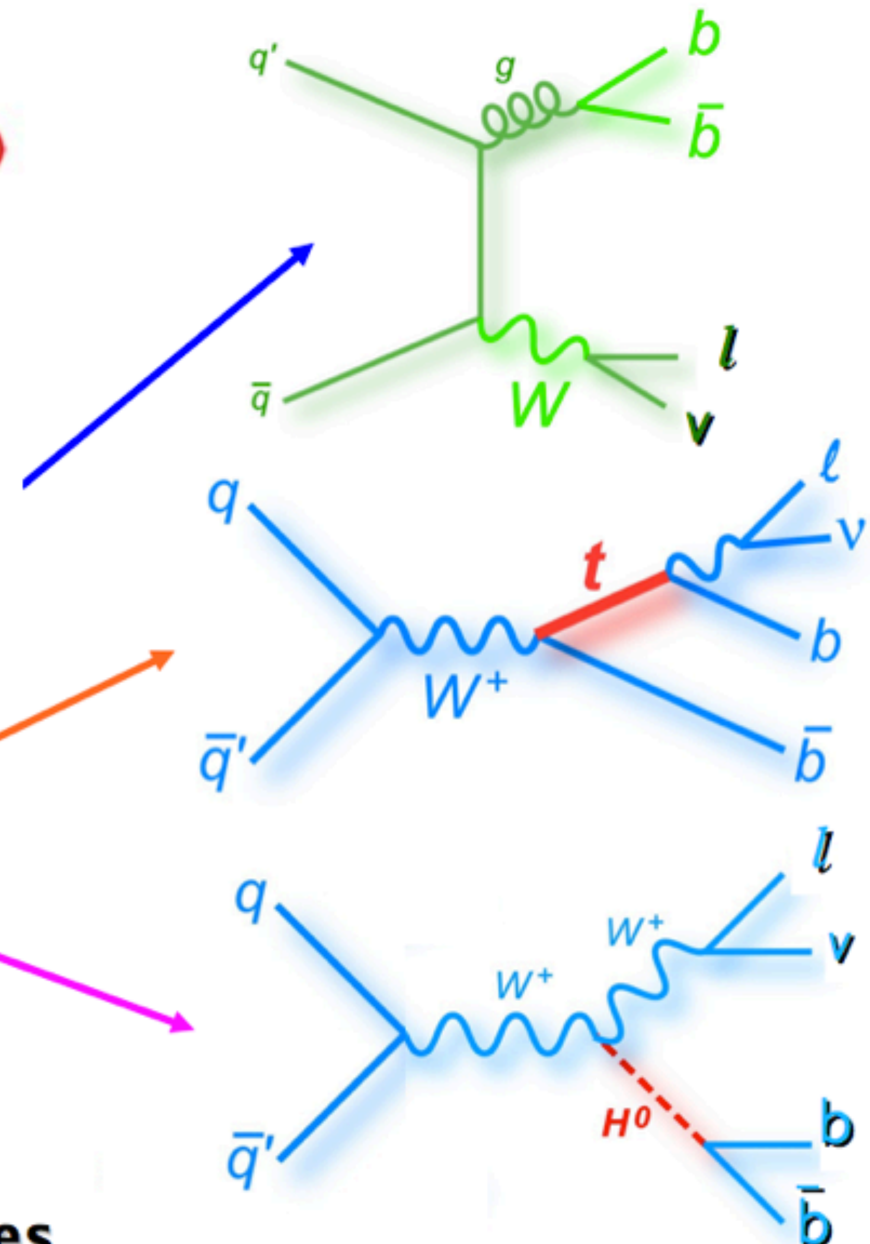


Z + jets

- less statistics
- less background

It has been challenging for years...





⇒ **multivariate analysis techniques**

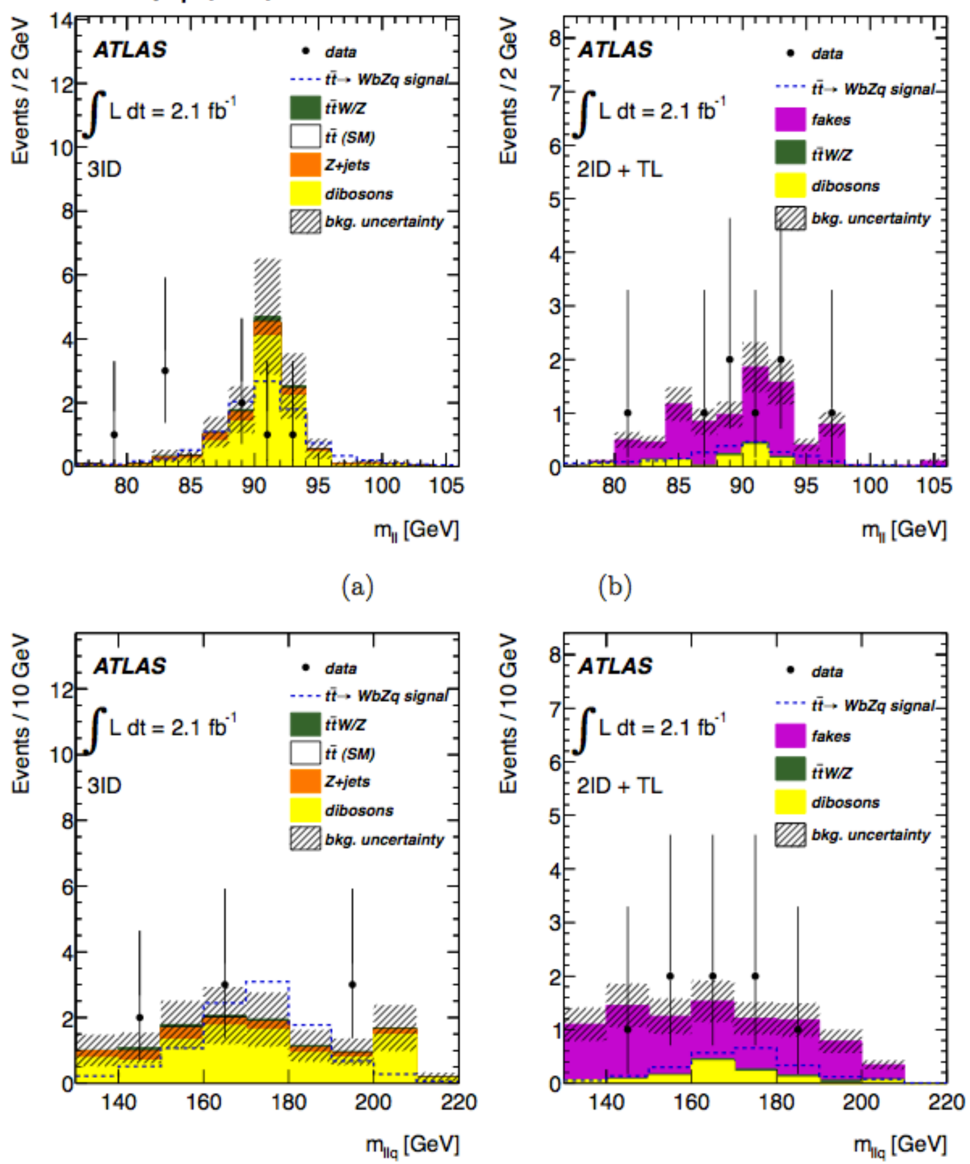
Search for FCNC in Top Quark Decays

3 ID selection

- p_T (1[st])>25 GeV

2ID+TL selection

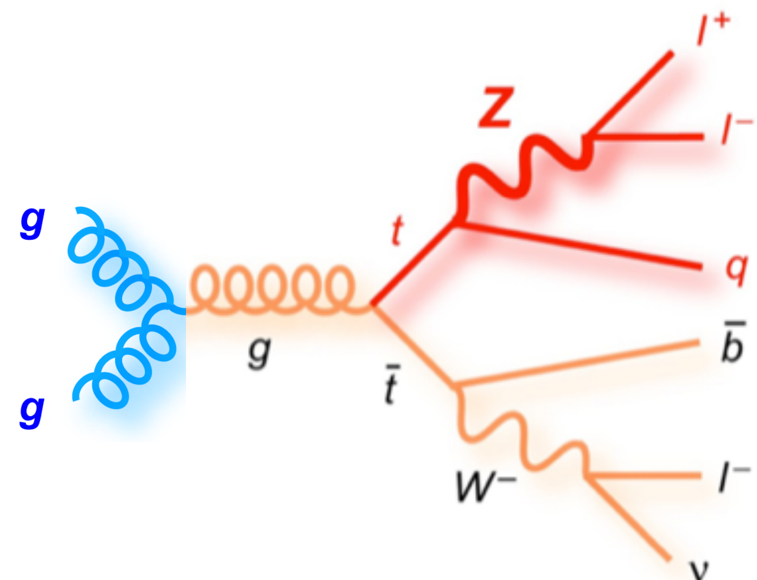
- 2ID + 'track lepton', p_T (TL)>25GeV



(a) (b)

$t\bar{t} \to qZ\ bW \to qll\ bl\nu$

- 3 leptons (p_T > 20 GeV)
- 2 same flavour $|m(l^+l^-) - m(Z)| < 15$ GeV
- E_T^{miss} > 20 GeV, >= 2 jets (p_T>25 GeV)



counting experiment:

$$\boxed{\begin{array}{c} B(t\to Zq) < 0.73\% \\ (0.93\%\ \text{expected}) \end{array}}$$