Top and EWK Physics at the LHeC and FCC-eh

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DESY

for the LHeC/FCC-eh Study Group

EPS-HEP 2017

EPS Conference on High Energy Physics

Lido die Venezia

8 July 2017

Outline

Introduction
Electroweak Physics
Top Quark Physics
Conclusions

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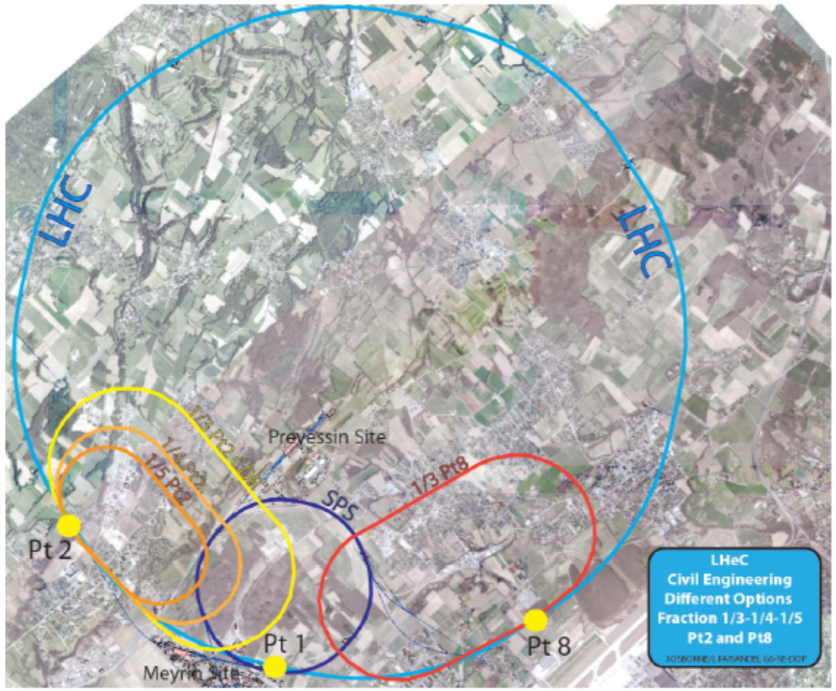
Top Quark Physics
Conclusions

Linac-Ring Collider, LHeC and FCC-eh



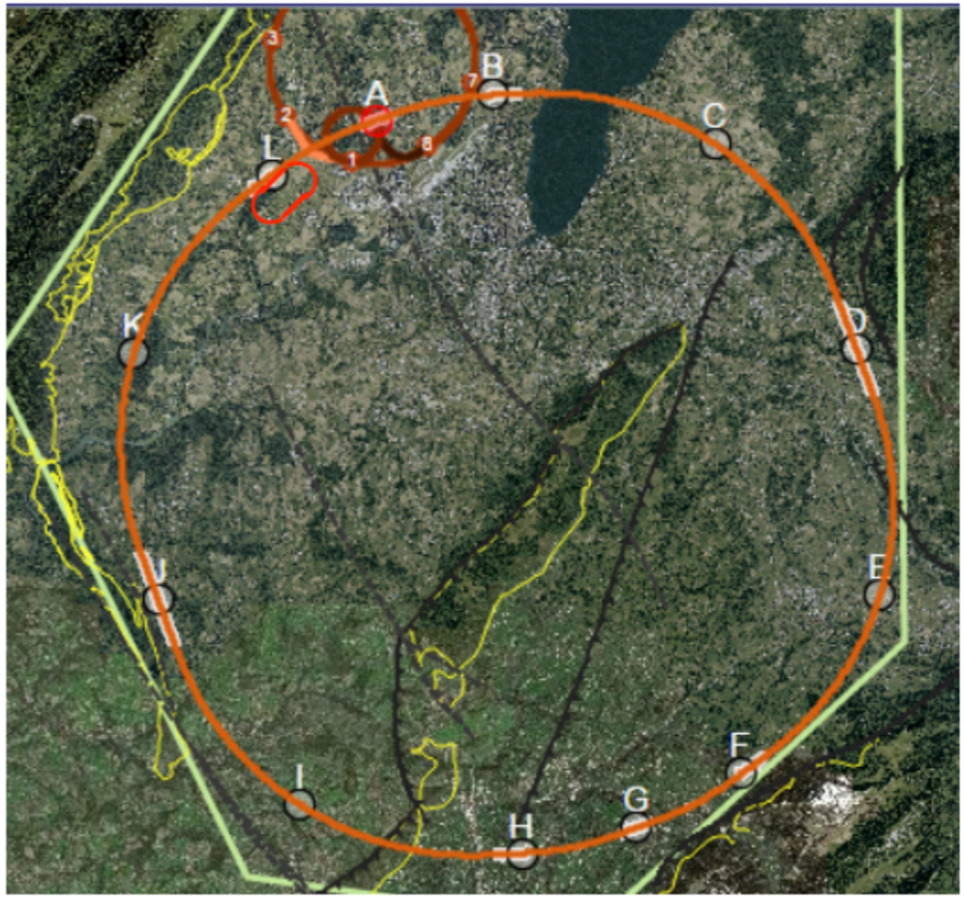
LHeC

Energy Recovering Linac

$e^{\pm}$ beam: 60 GeV

studied here:
L_{int} up to 1 ab^{-1}

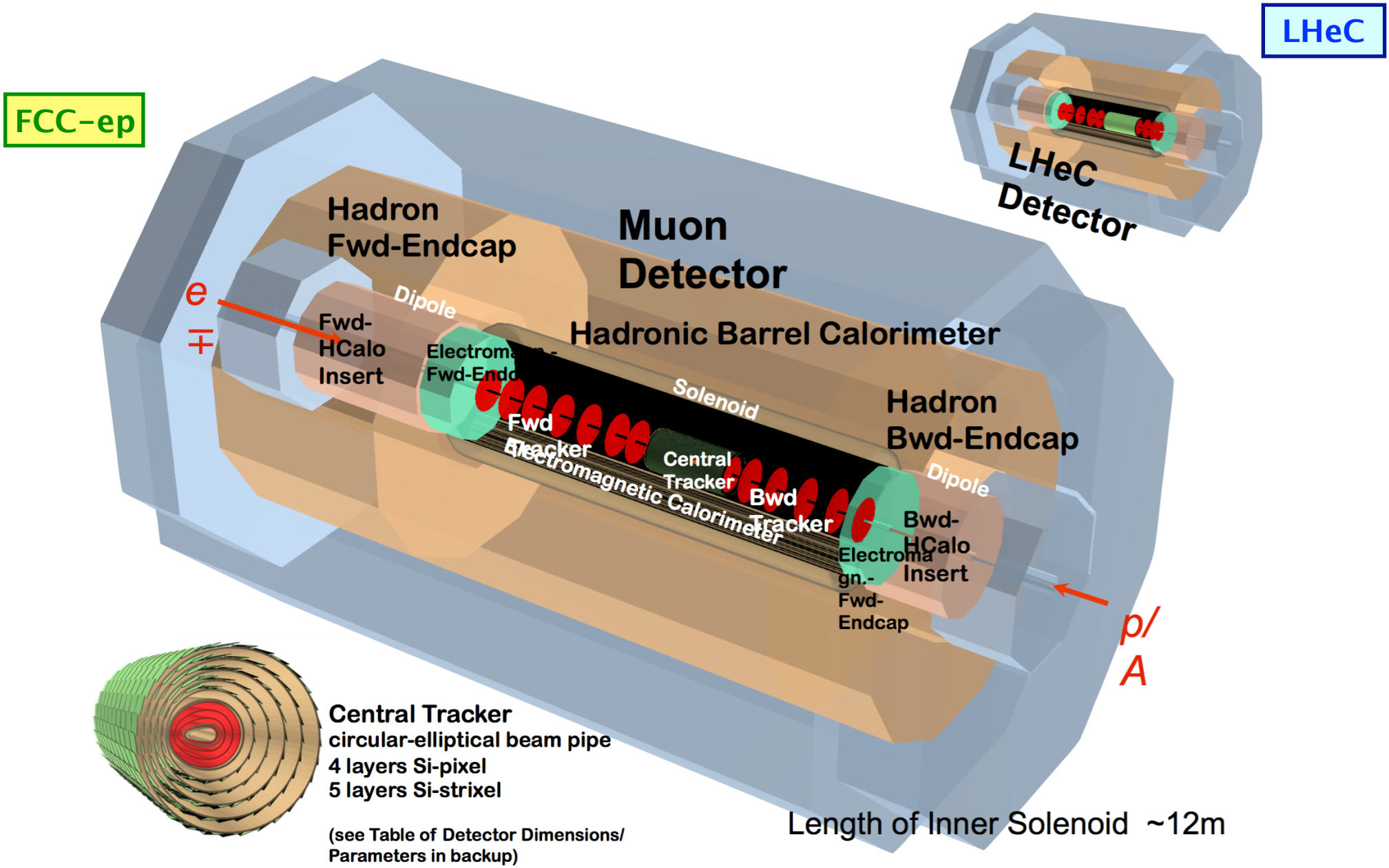
FCC-ep



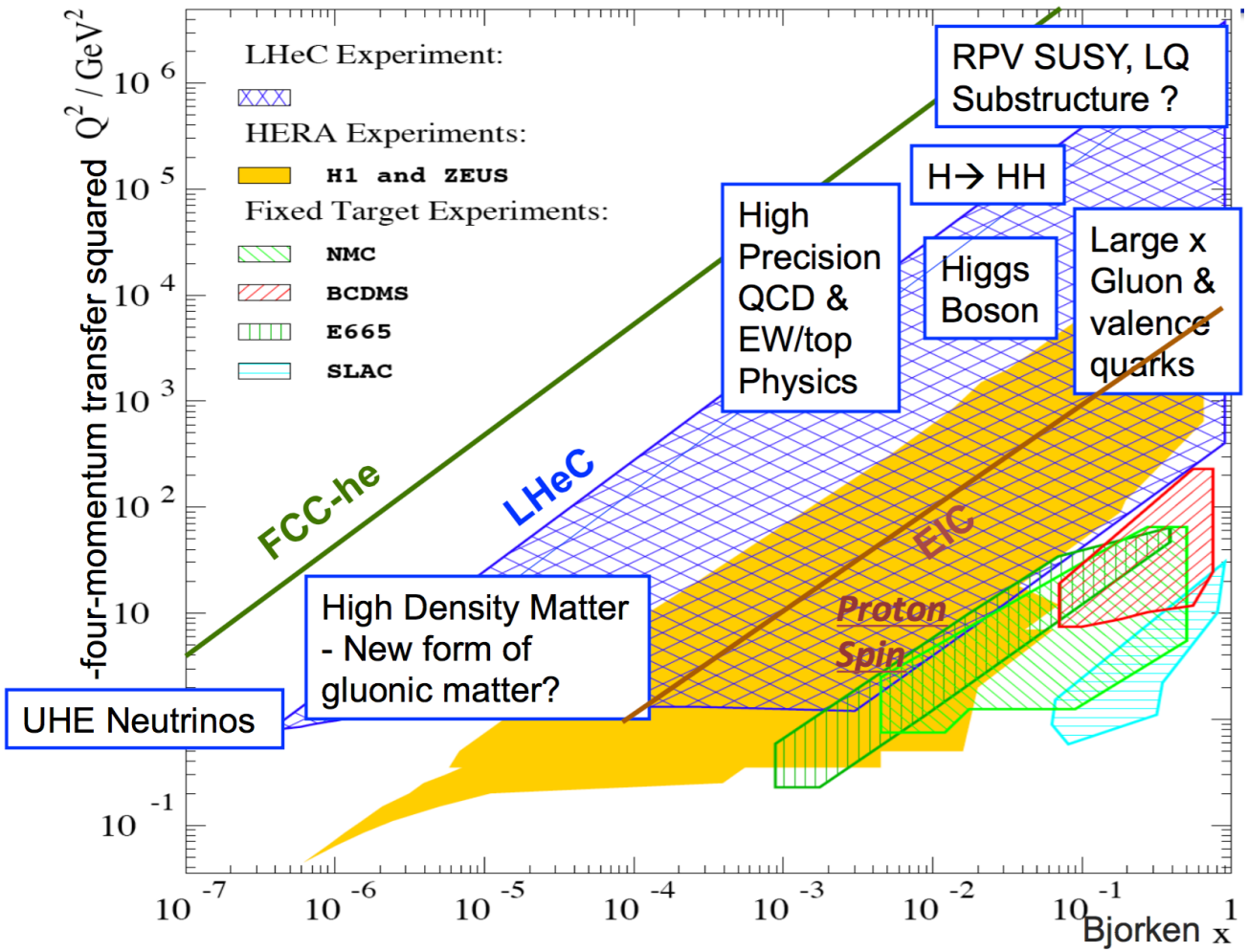
operated synchronously

- **with HL-LHC:**
  p beam: 7 TeV, $\sqrt{s}$=1.3 TeV
- **with HE-LHC:**
  p beam: 13.5 TeV, $\sqrt{s}$=1.8 TeV
- **or later with FCC-hh:**
  p beam: 50 TeV, $\sqrt{s}$=3.5 TeV

LHeC and FCC-eh Detector Layout



High energy frontier eh physics



EW symmetry breaking:

- **precision EW measurements**
- **top quark factory: study EW interactions with top quarks**
- **search for new physics**

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

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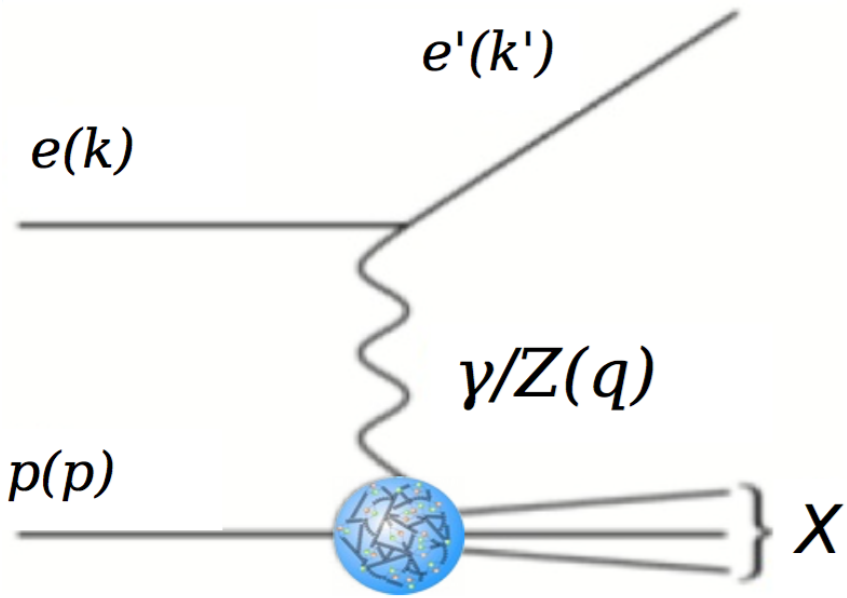
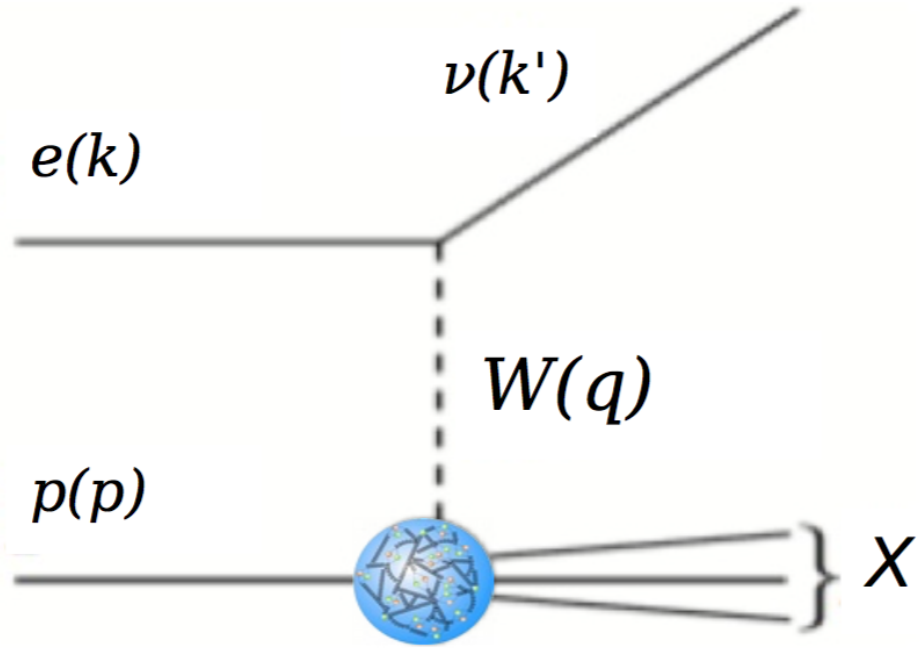
Deep Inelastic Scattering

Neutral Current (NC)



Charged Current (CC)

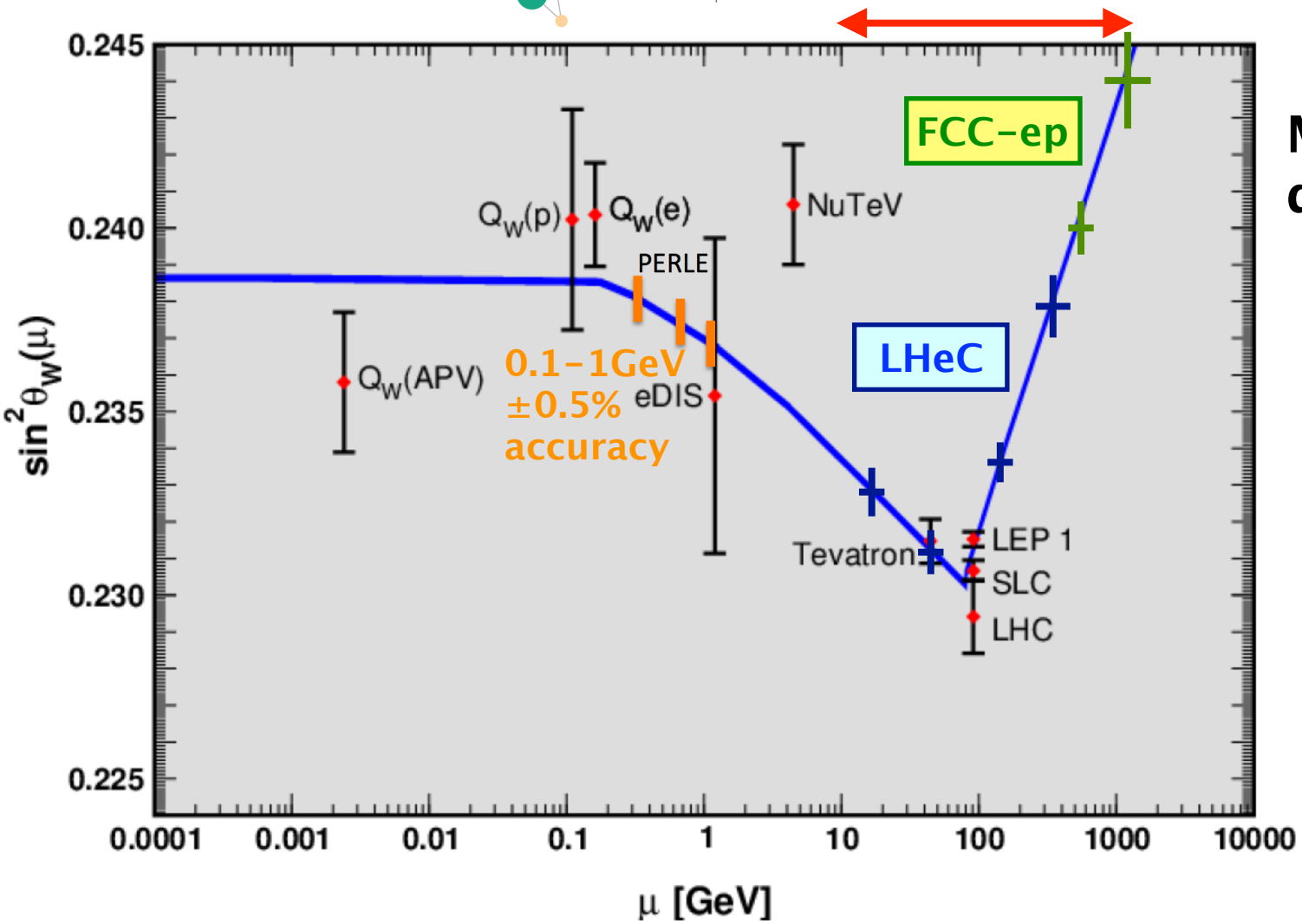


→ **LHeC/FCC-eh are unique facilities for testing EW theory: NC+CC, two e-beam charge and polarisation states, p or isoscalar targets**

Scale Dependence of $\sin^2\theta_W$

PERLE CDR, Arduini et al, to be published
ICFA BeamNewsletter 68 (January 2016)

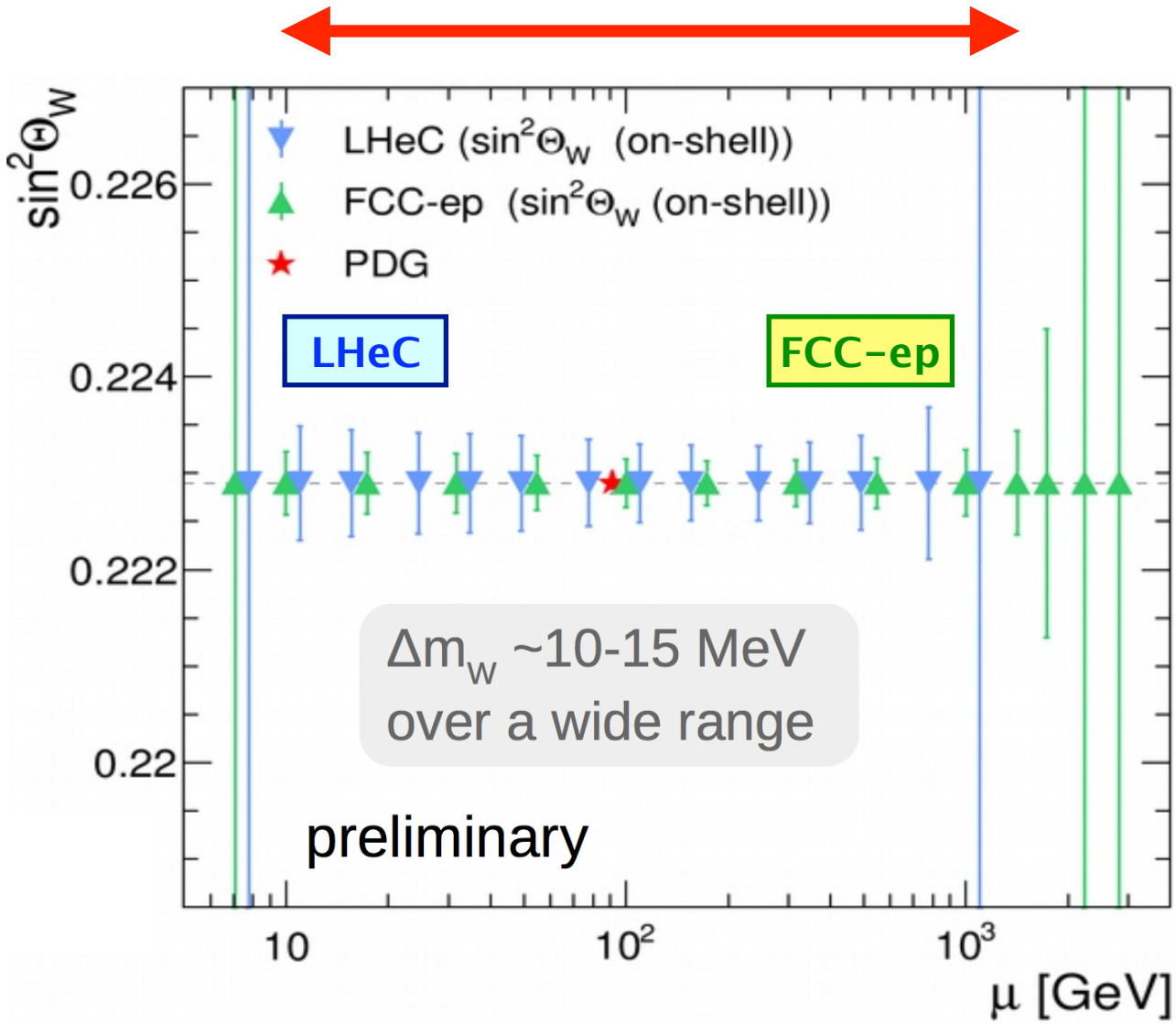
LHeC CDR,
J.Phys. G39,
075001 (2012)



MSbar definition

→ probe large range of scale dependence

Scale Dependence of $\sin^2\theta_W$



on-shell definition

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

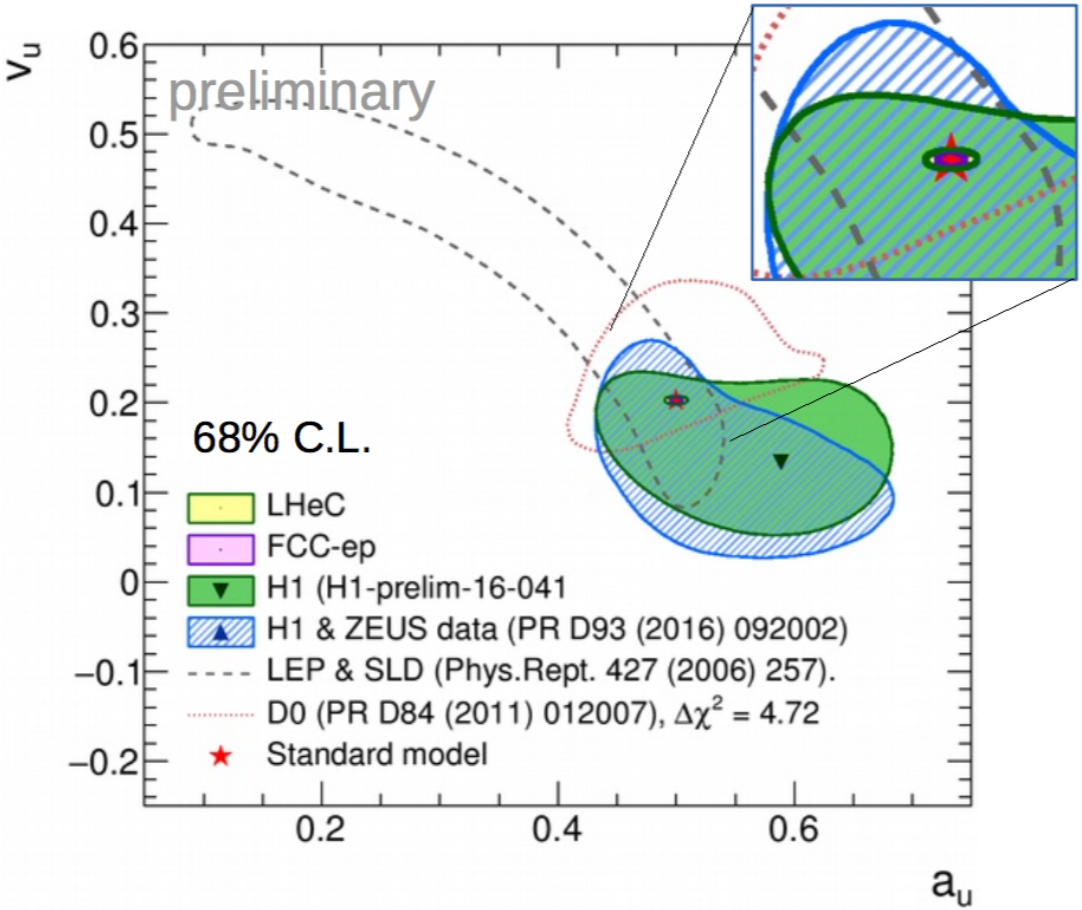
→ **probe large range of scale dependence**

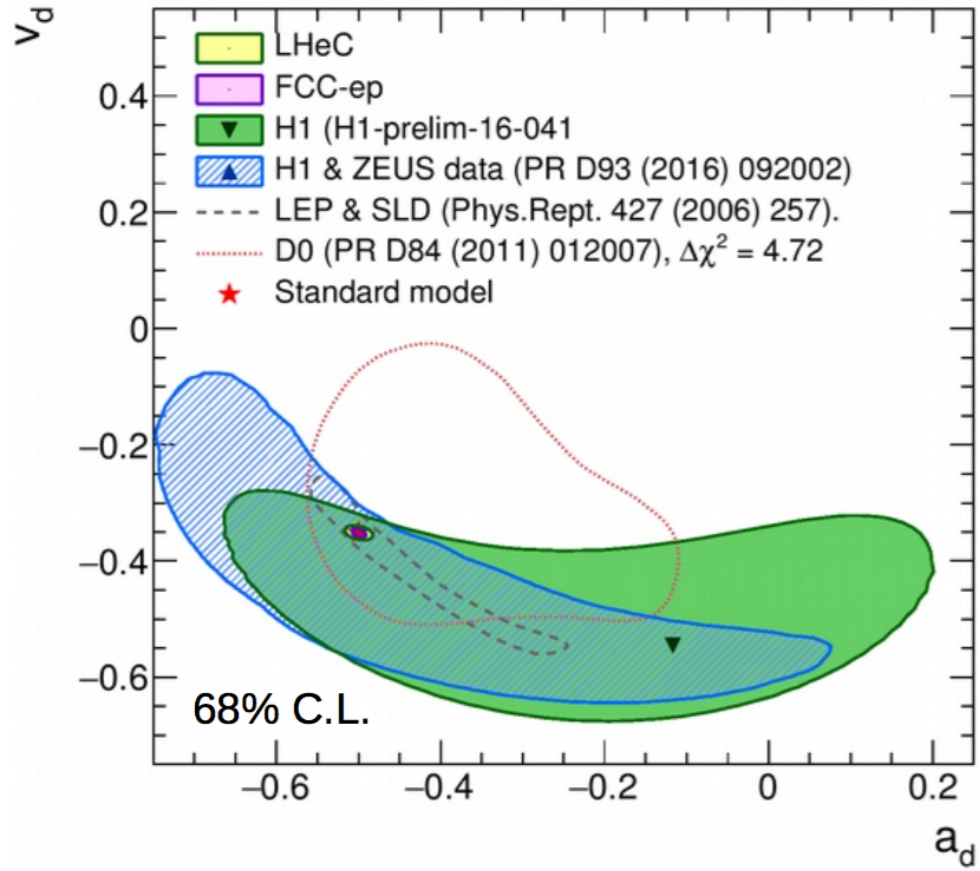
Vector and Axial Vector NC Couplings

LHeC

- simultaneous extraction with PDFs

FCC-ep





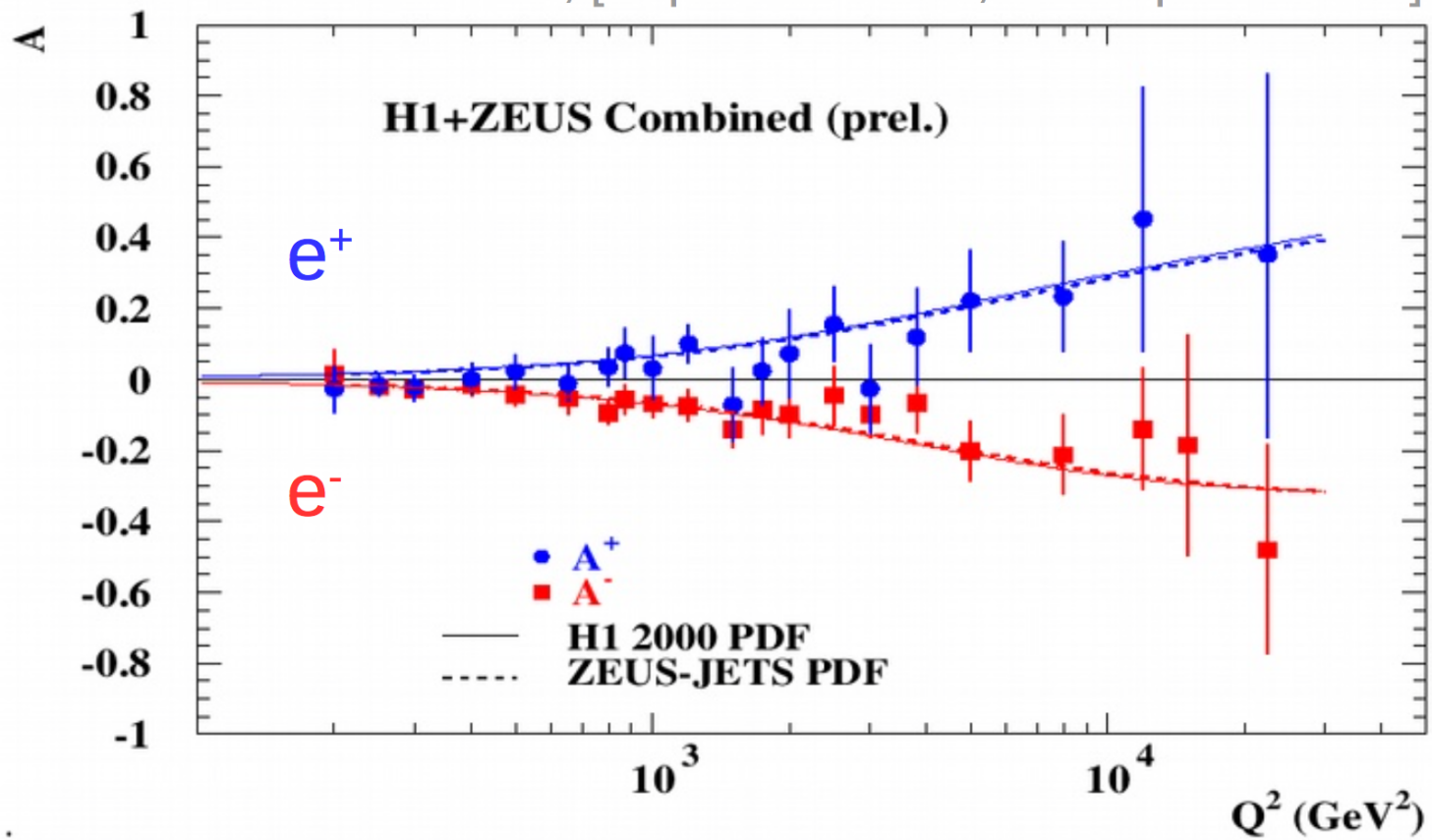
→ high precision measurement of light quark couplings
→ test new physics: Z' boson, R-parity violating SUSY, leptoquarks

Asymmetry Measurements

$$A^{\pm} = \frac{2}{P_L^{\pm} - P_R^{\pm}} \cdot \frac{\sigma^{\pm}(P_L^{\pm}) - \sigma^{\pm}(P_R^{\pm})}{\sigma^{\pm}(P_L^{\pm}) + \sigma^{\pm}(P_R^{\pm})}$$

- **study P-violation in NC-EW interactions**

H1+ZEUS, [H1prelim-06-142, ZEUS-prel-06-022]



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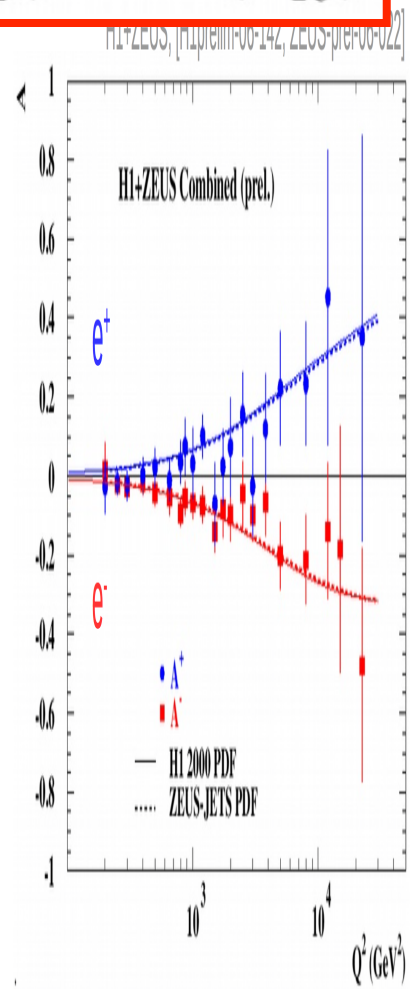
- study P-violation in NC EWK interactions



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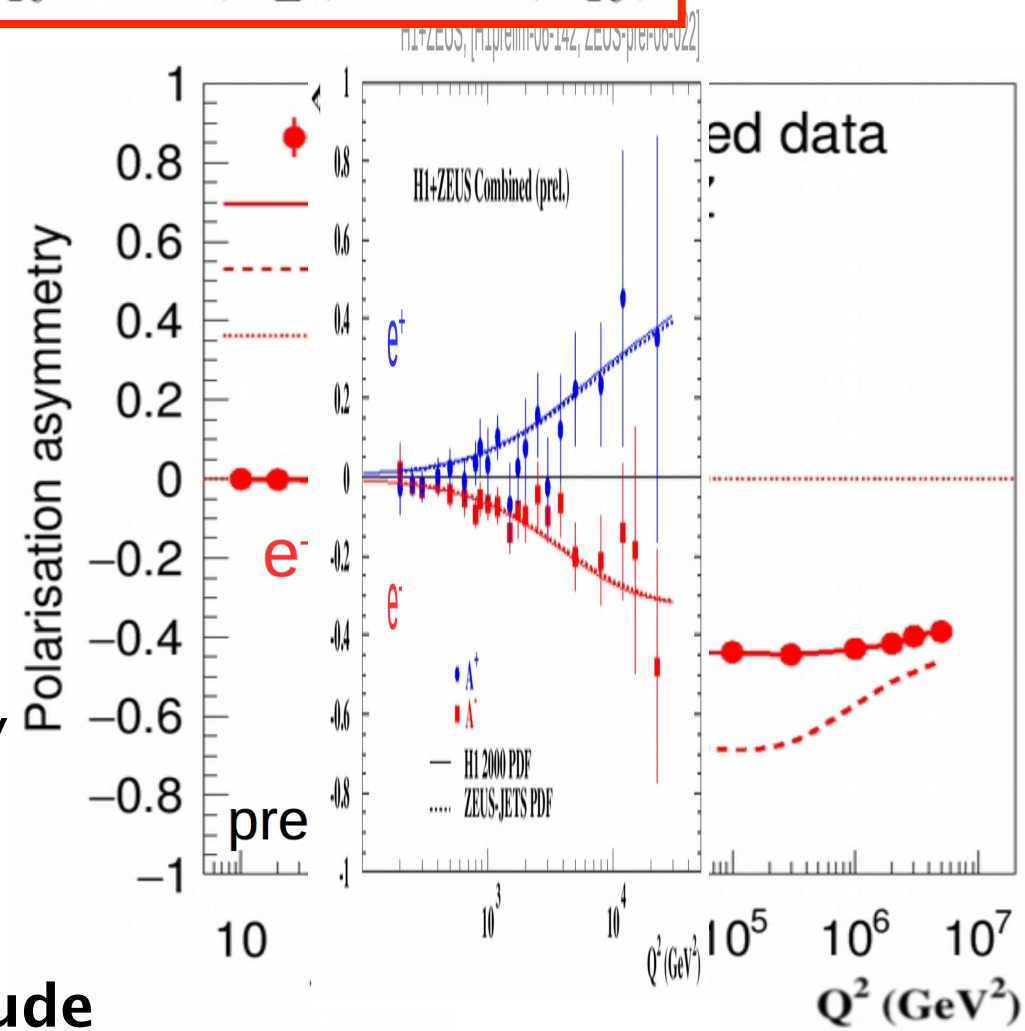

FCC-ep

- 11 times higher center-of-mass energy
- 100-1000 times higher luminosity
- 2-3 times higher polarisation

→ extend by 2-3 orders of magnitude

Asymmetry Measurements

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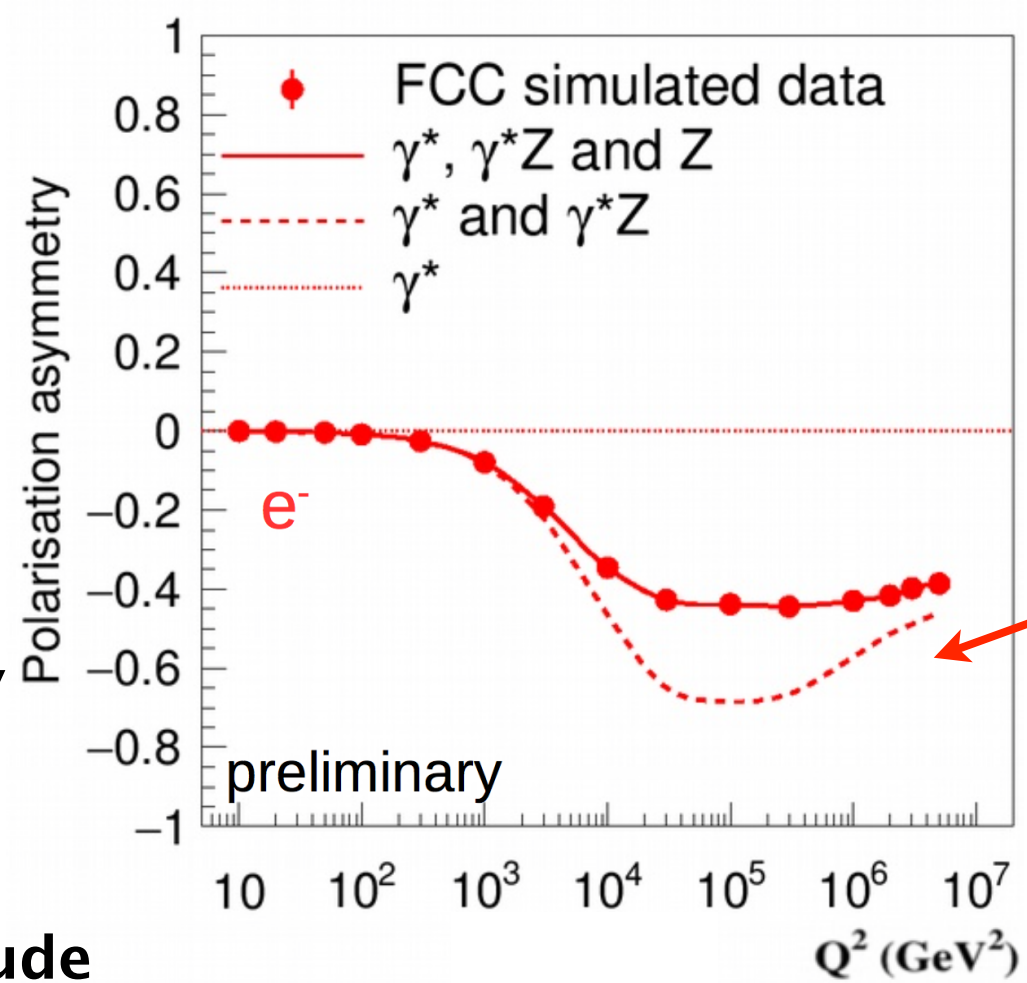
- study P-violation in NC EWK interactions

FCC-ep



pure Z exchange becomes important

- 11 times higher center-of-mass energy
- 100-1000 times higher luminosity
- 2-3 times higher polarisation

→ extend by 2-3 orders of magnitude

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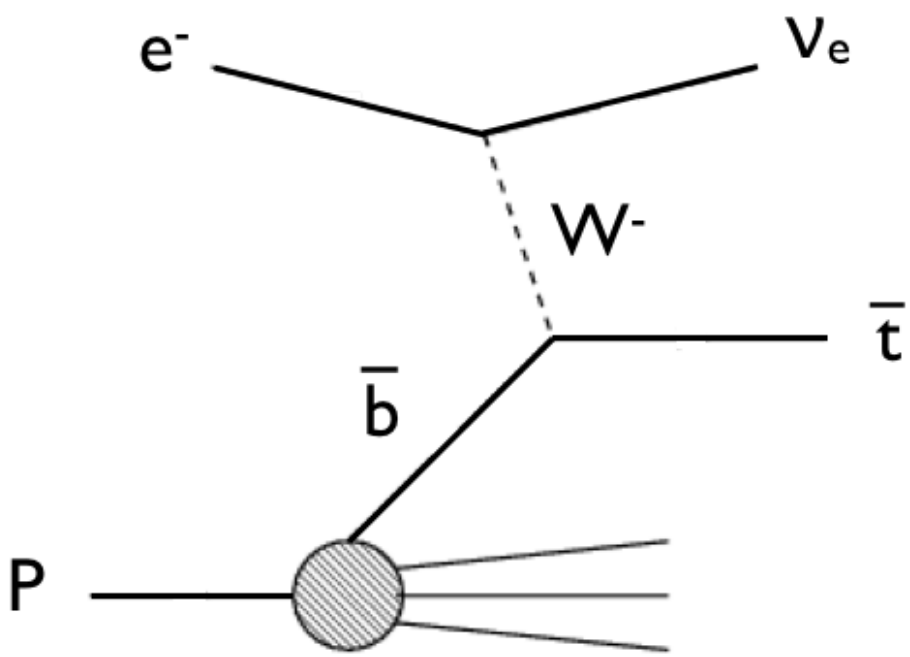
SM Top Quark Production

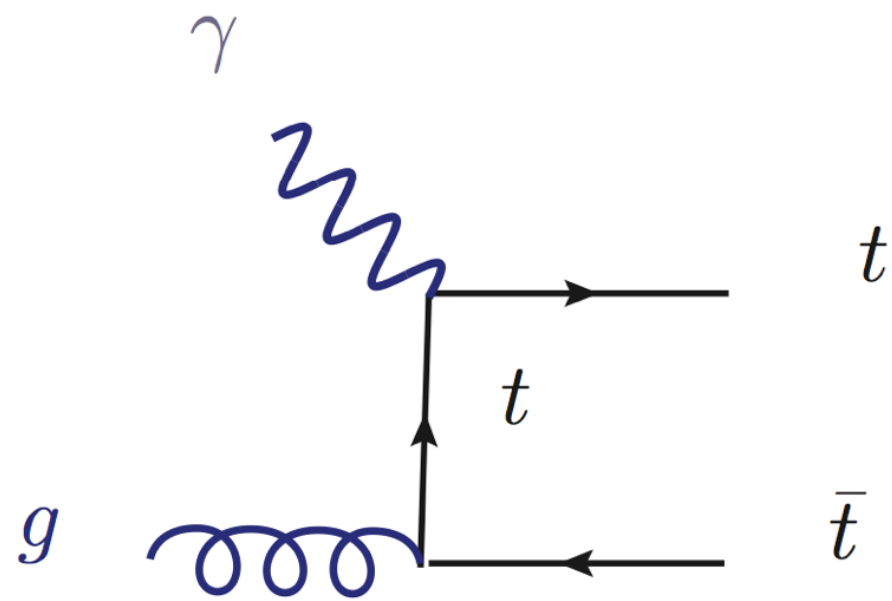
CC DIS top production



σ=1.73pb @ LHeC

σ=15.3pb @ FCC-ep

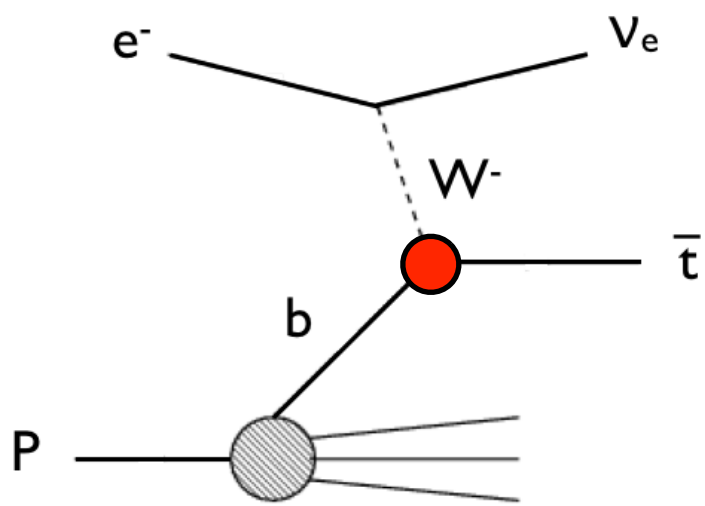
top photoproduction



σ=0.70pb @ LHeC

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

Direct Measurement of $|V_{tb}|$

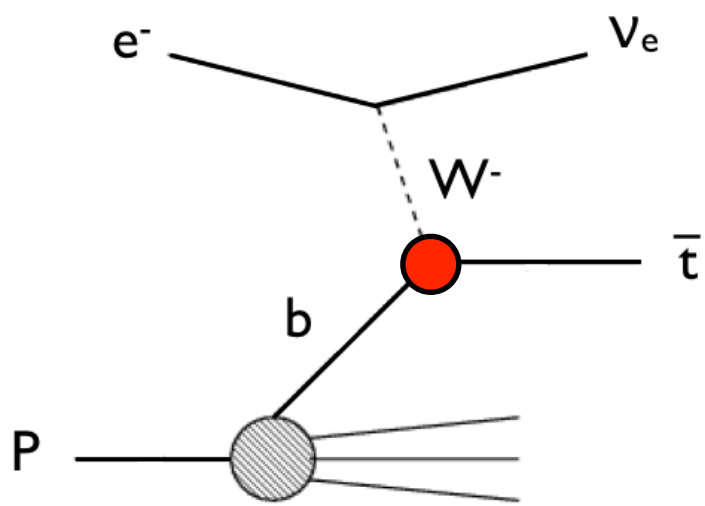


$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

Limits on Anomalous Wtb Couplings

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

= 1 in SM



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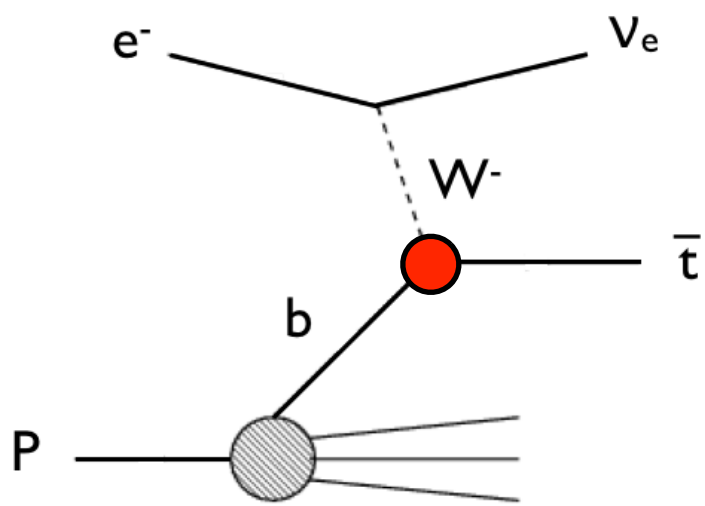

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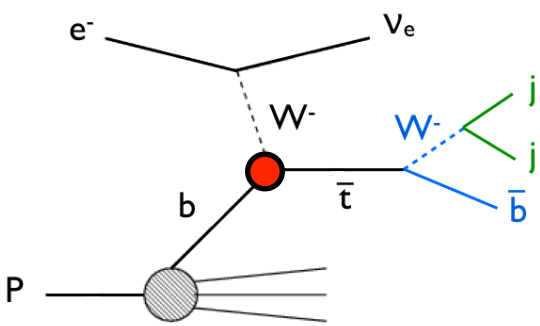
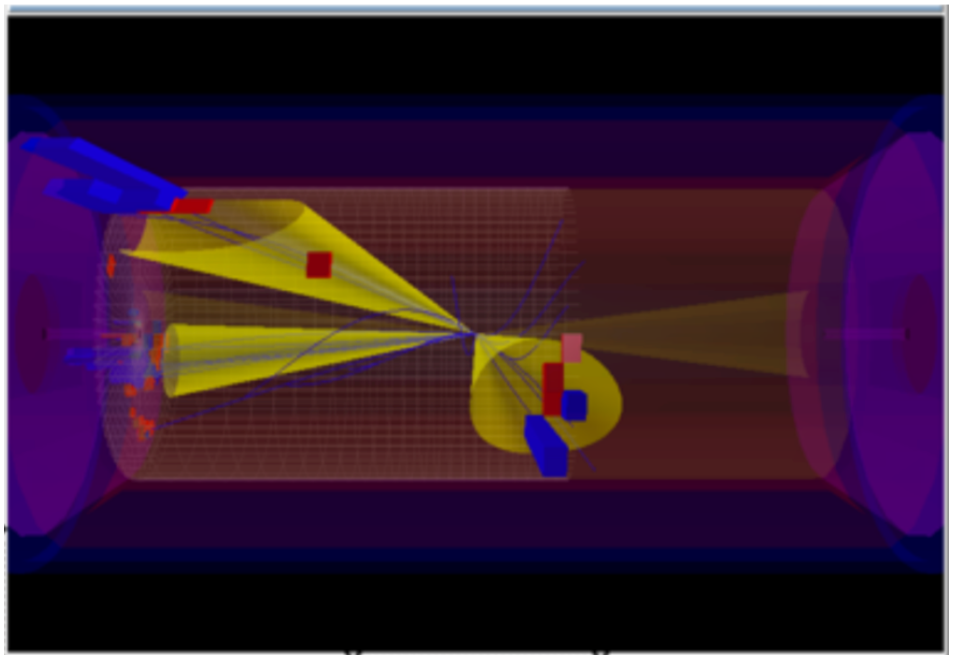
= 1 in SM

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

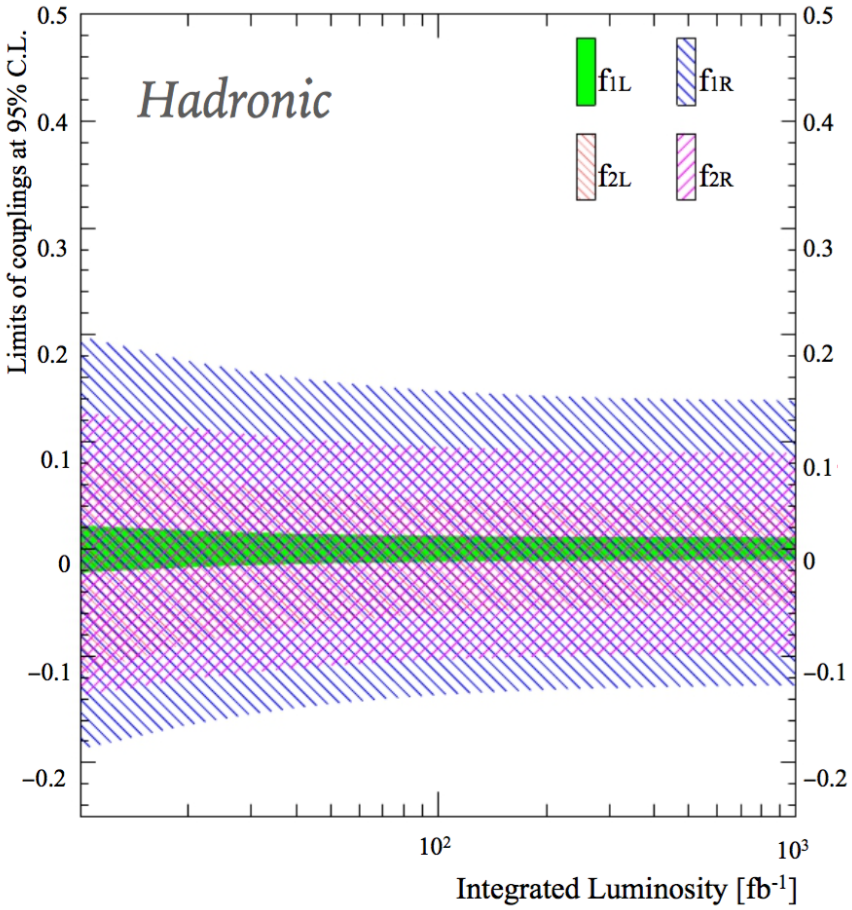
95% C.L.



DELPHES



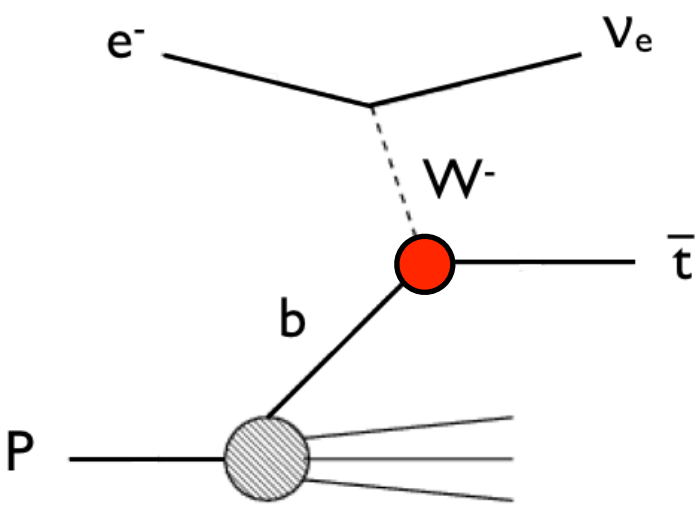
including detector simulation (Delphes)



<0.14
<0.09
<0.04
<0.01

Direct Measurement of $|V_{tb}|$

[1] including top-quark mass uncertainty
[2] σ_{theo}: NLO PDF4LHC11
NPPS205 (2010) 10, CPC191 (2015) 74
[3] including beam energy uncertainty



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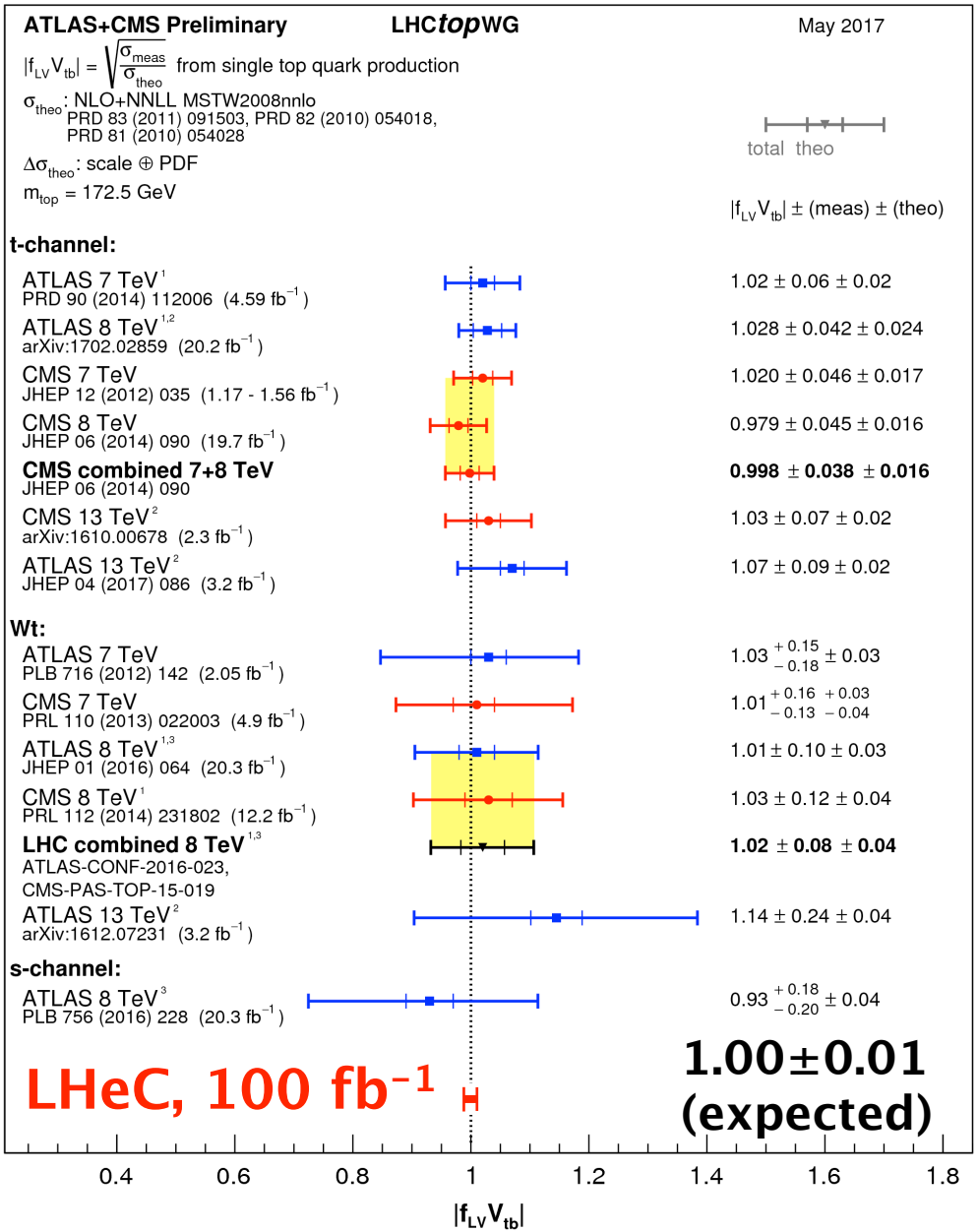
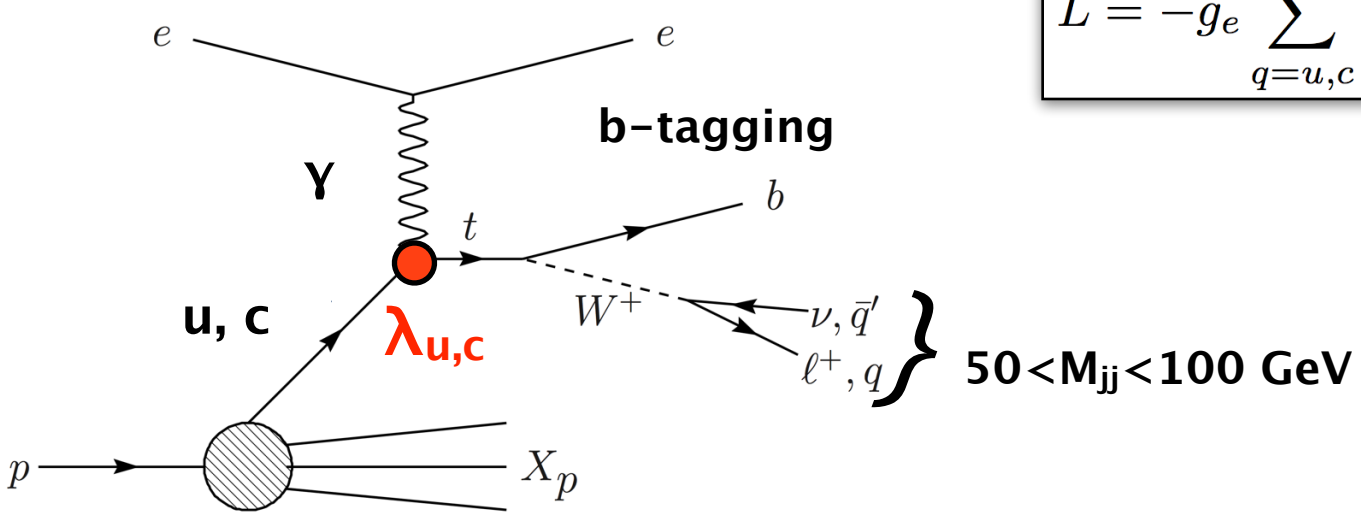


Single Top Quark Production: NC

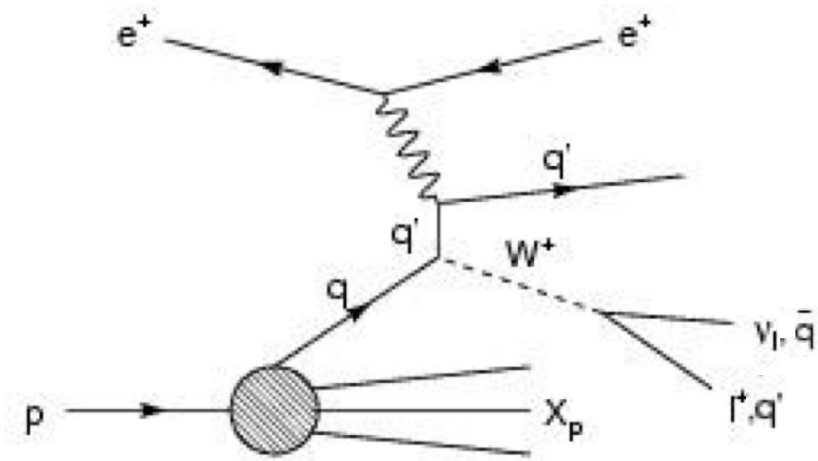
signal

arXiv:1705.05419 [hep-ph]

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



background



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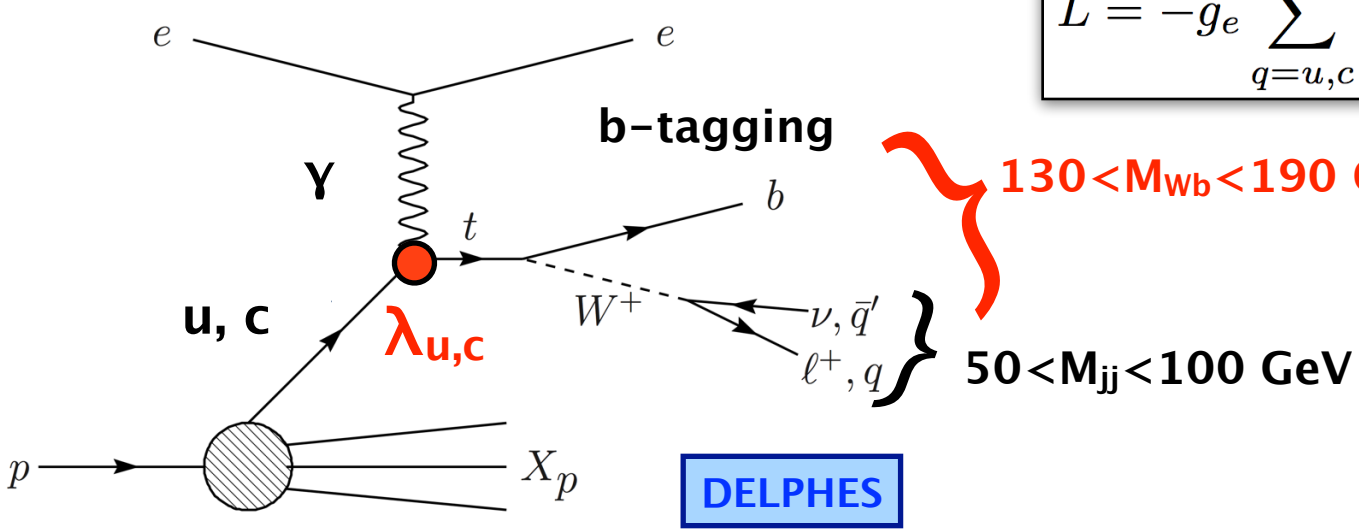

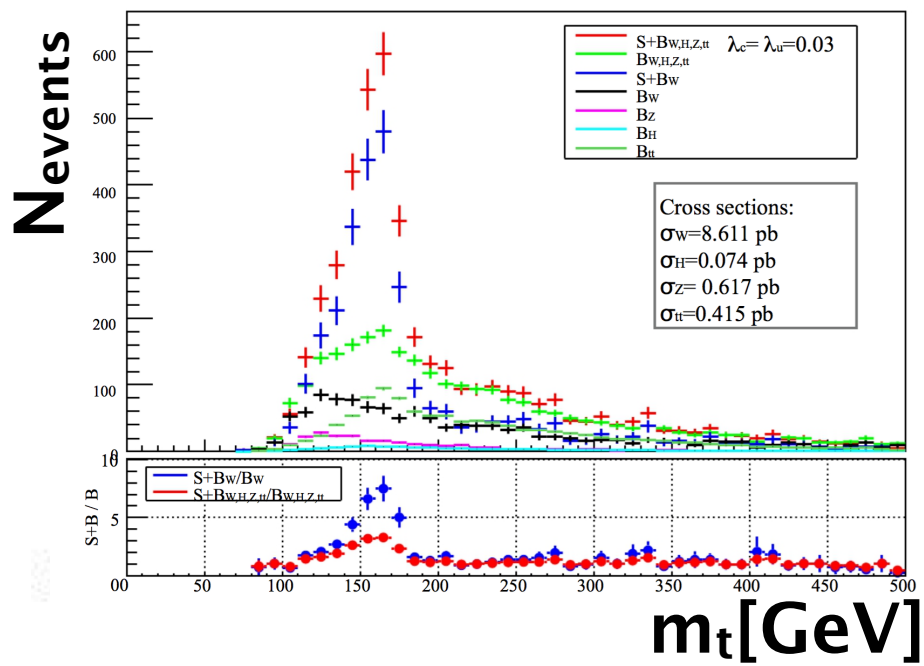

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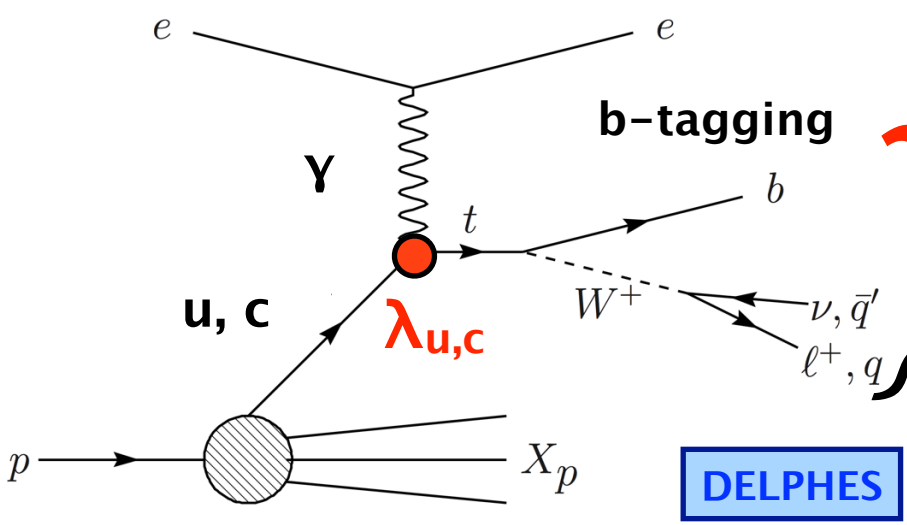


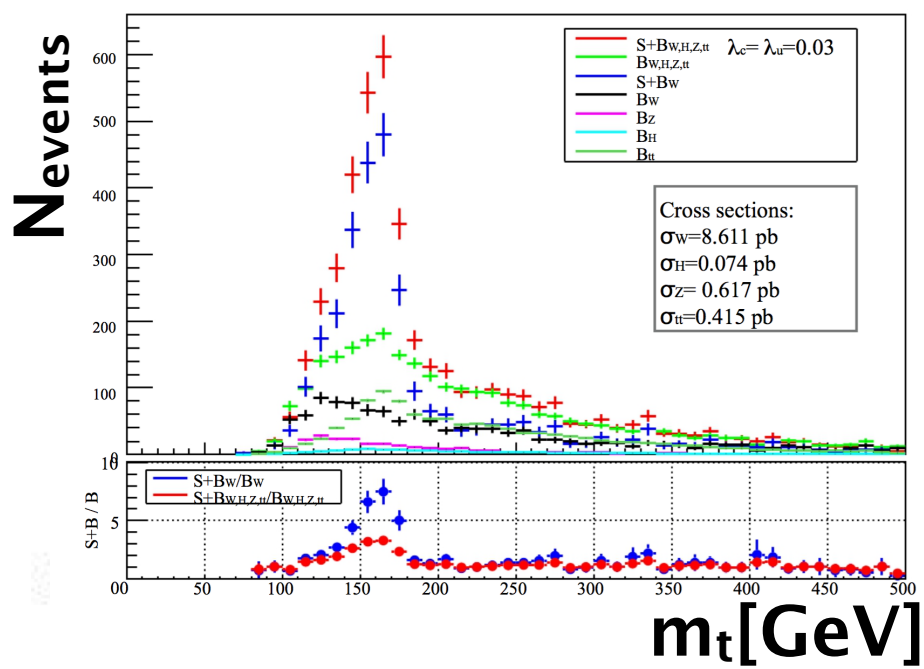
130<M_{Wb}<190 GeV

300 fb^{-1}, √s= 14 TeV: λ<0.022 @ 95% C.L.

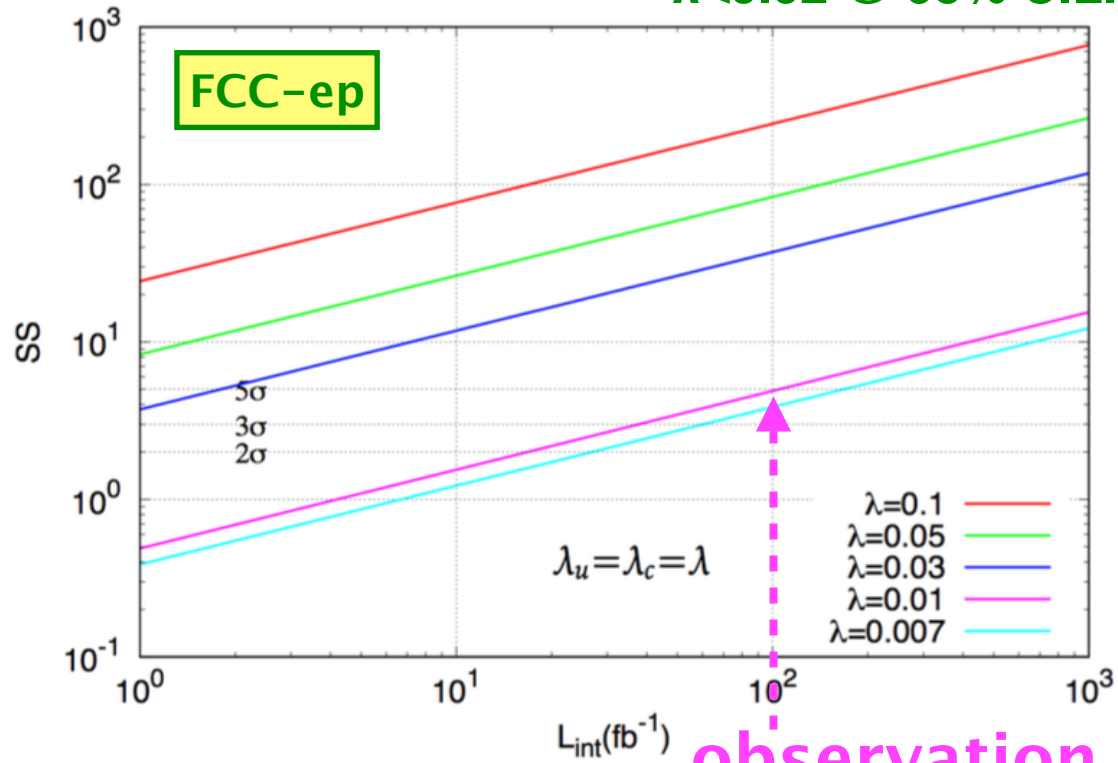
50<M_{jj}<100 GeV

500 fb^{-1} , √s= 250 GeV: λ<0.02 @ 95% C.L.

DELPHES



FCC-ep



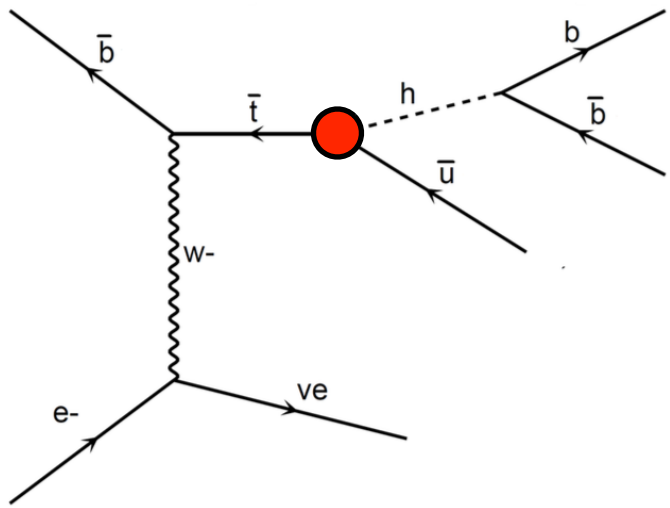
observation

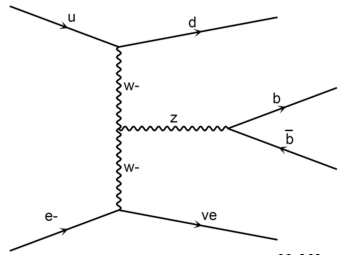
Search for Anomalous FCNC tHu Coupling

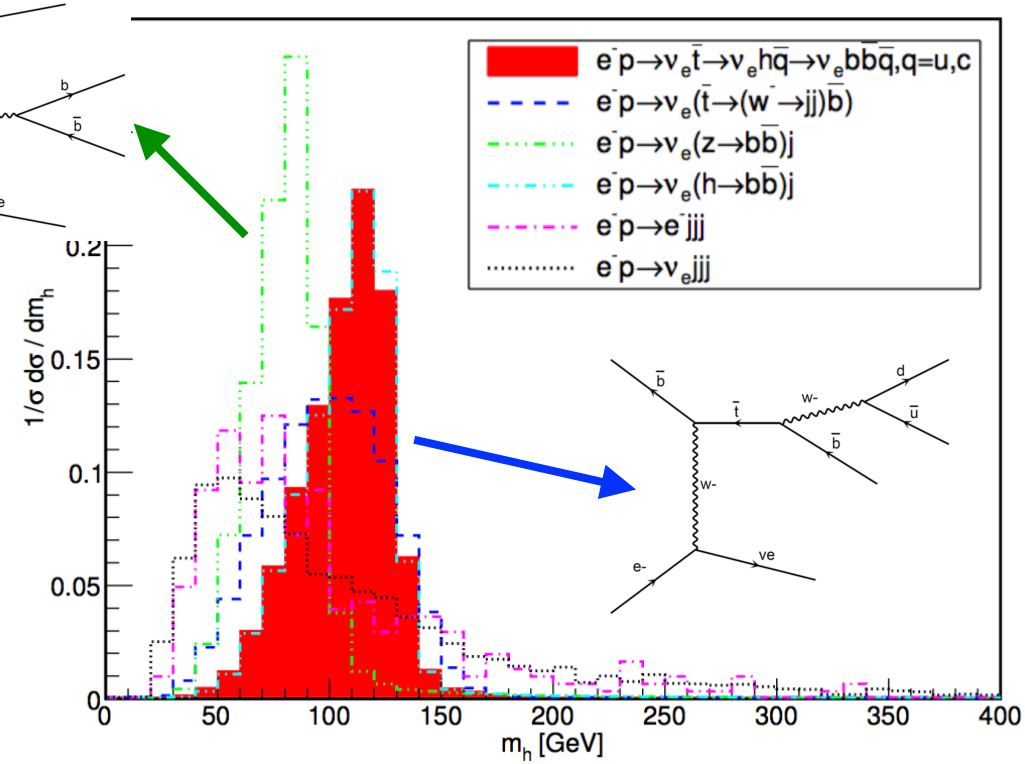
signal

arXiv:1602.04670 [hep-ph]

background







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

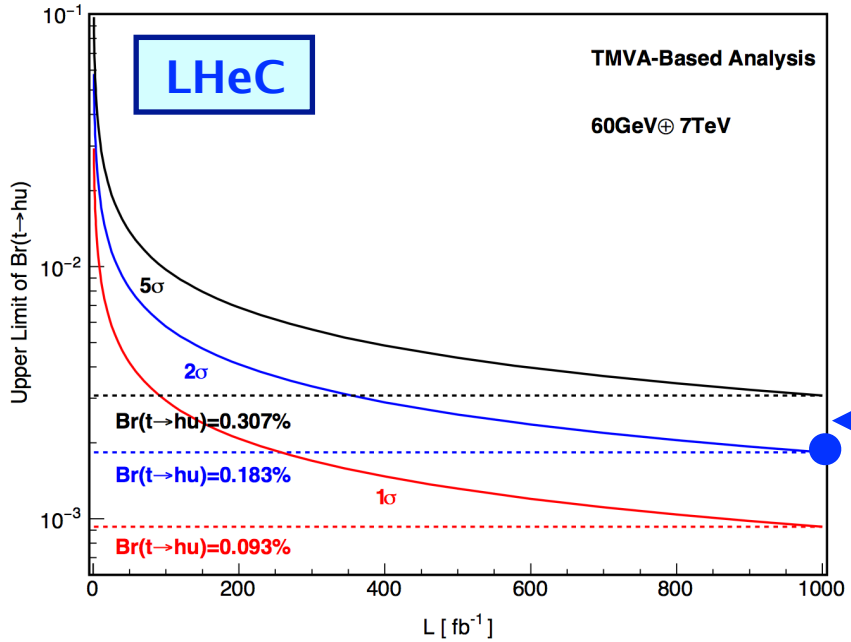
$$\mathcal{L} = \kappa_{tuh} \bar{t} u h + \kappa_{tch} \bar{t} c h + h.c.$$

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

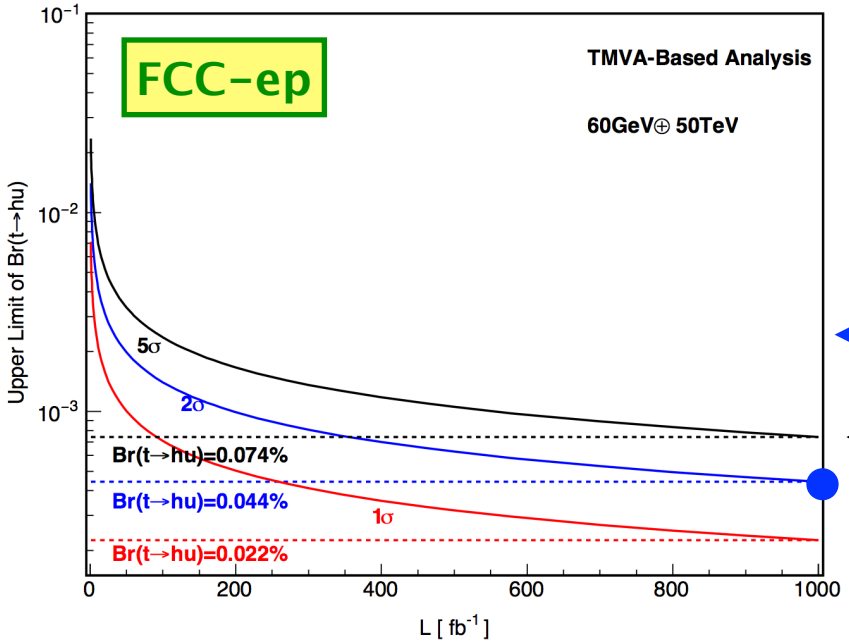
Upper Limit on Br(t→uH) in MVA analysis

arXiv:1602.04670 [hep-ph]

parametrisation



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



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

observation

→ **improves sensitivity of HL-LHC**

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Summary

- future ep collider has a rich analysis programme for electroweak interactions of light and heavy quarks
- high precision EW measurements: $\sin^2\theta_W$, light quark couplings to bosons (v_u, a_u, v_d, a_d), W mass and Z mass, …
- top quark couplings to bosons ($|V_{tb}|$, Wtb, $tt\gamma$, ttZ, tH, FCNC)
- analyse top quark properties: polarisation, charge, PDFs of tops, …
- many stringent searches for new physics:
  anomalous couplings, FCNC, CP violation in ttH, heavy top, SUSY stops…

→ further exciting studies to come for

Backup

FCC-eh: tracker, calorimeters and steps

Tracker	FST_{pix}	FST_{strix}	CFT_{pix}	CPT_{pix}	CST_{strix}	CBT_{pix}	BST_{strix}	BST_{pix}
#Wheels	7		2	–	–	2	5	
#Rings/Wheel	2_{inner}	3_{outer}	3/4	–	–	3/4	3_{outer}	2_{inner}
#Layers	–	–	–	4	5	–	–	–
$\theta_{min/max}$ [^{0}]	0.5	3.8	3.6	5.1	24/155	176.4	173.1	179.3
$\eta_{max/min}$	5.4	3.4	3.5	±3.1	±1.4	-3.5	-2.8	-5.2
$Si_{pix/strix}$ [m^2]	9.7	13.3	2.8	5.4	33.7	2.8	9.7	6.9
Sum-Si [m^2]	84.3 double layers taken into account							

Calo	FHC_{SiW}	FEC_{SiW}	$EMC_{SciPb/LAr}$	HAC_{SciFe}	BEC_{SiPb}	BHC_{SiFe}
$\theta_{min/max}$ [^{0}]	0.3	0.4	5.6/173.4	8.6/167	179.4	179.6
$\eta_{max/min}$	6.0	5.6	3.0/-2.7	2.5/-2.2	-5.3	-5.6
Volume [m^3]	13.2	3.1	28.8	407	1.98	7.0
Sum-Si [m^2]	461					

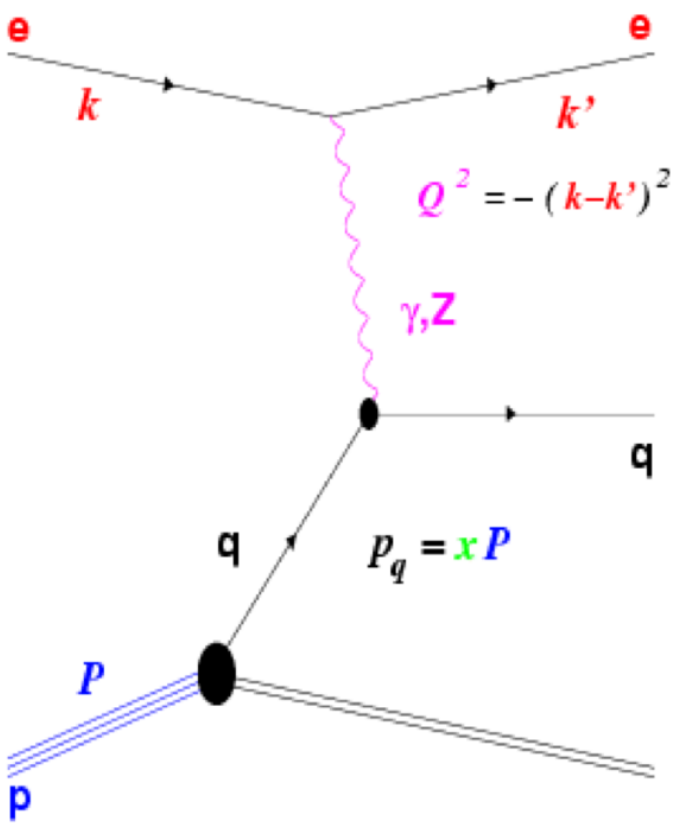
Input to detector design: HERA, ATLAS/CMS+their upgrades, CALICE, LHeC (CDR and update)

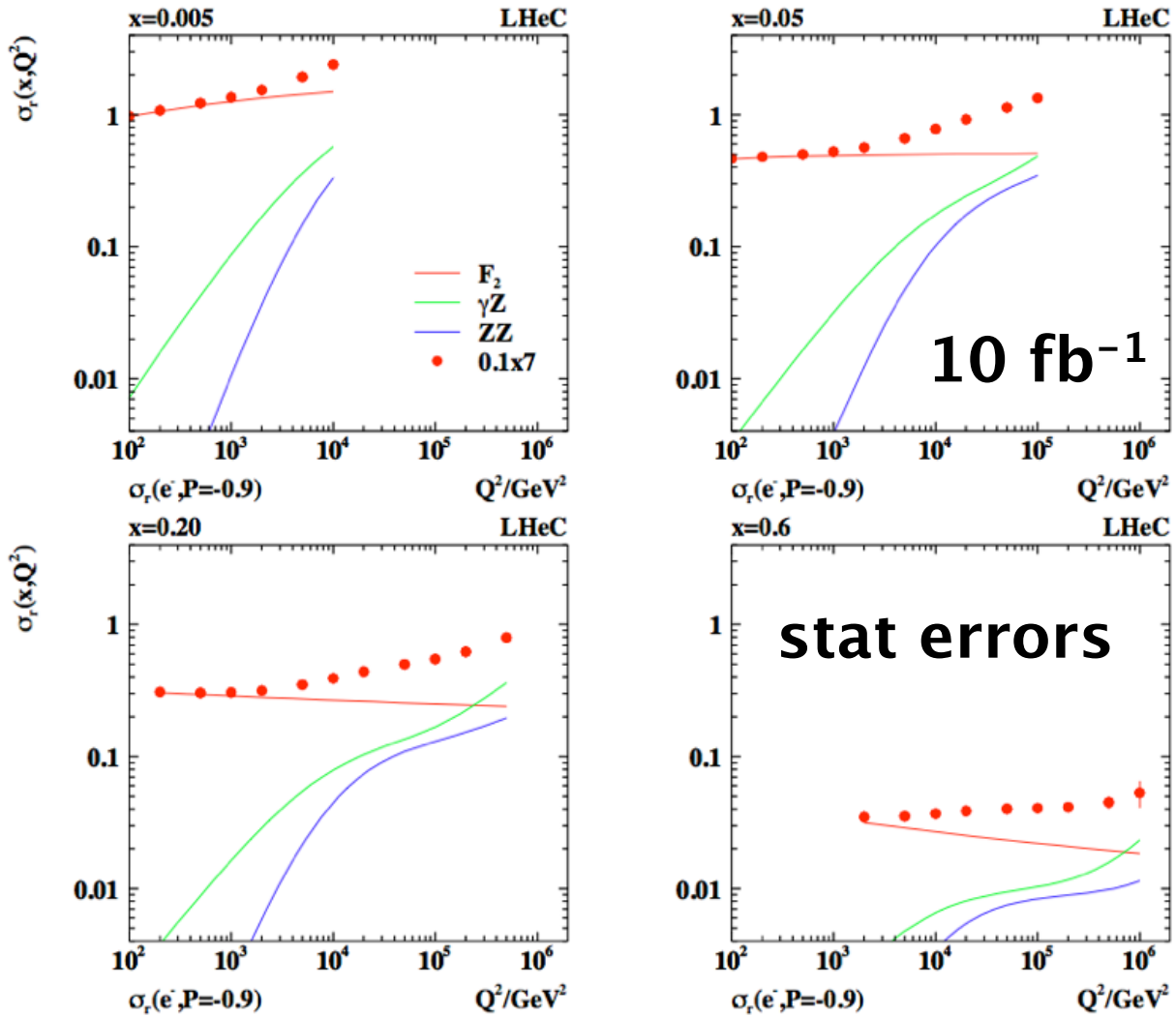
At FCC-eh unlike LHeC we think muon momentum measurement is vital (H-μμ)

Next steps: final choice of CDR technology, IR integration, joint eh-hh consideration, software

NC Cross Section Measurement

Neutral Current (NC)



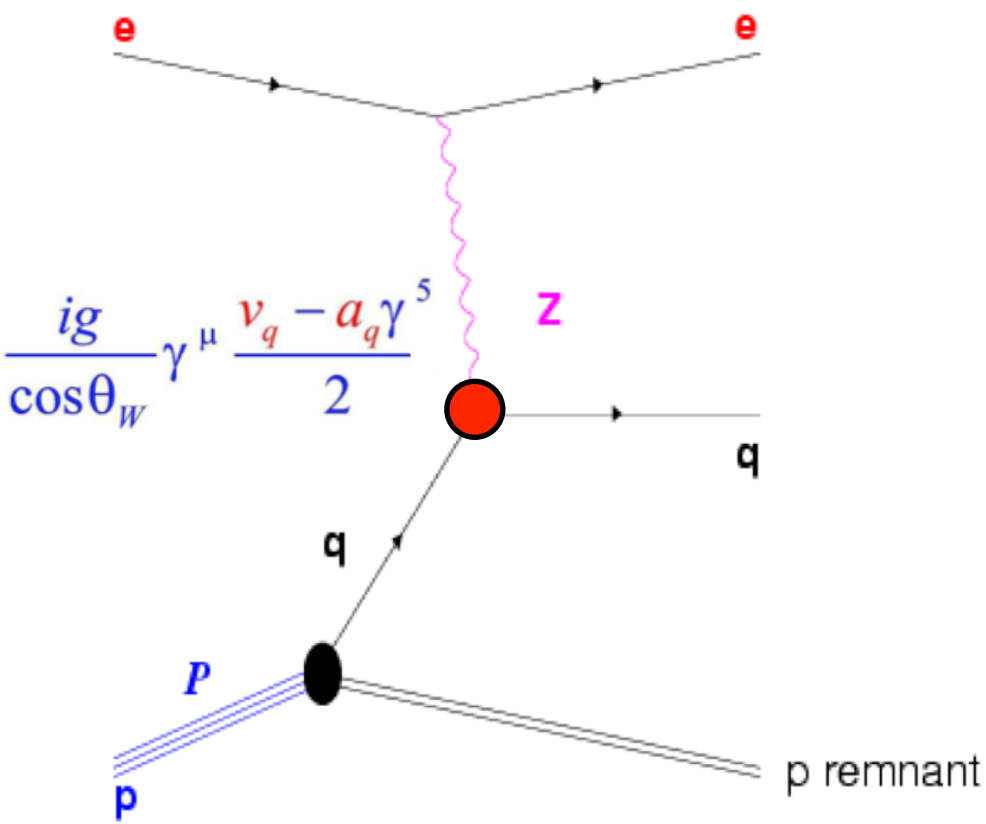


→ **high precision in large range of Bjørken x and Q^2**

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

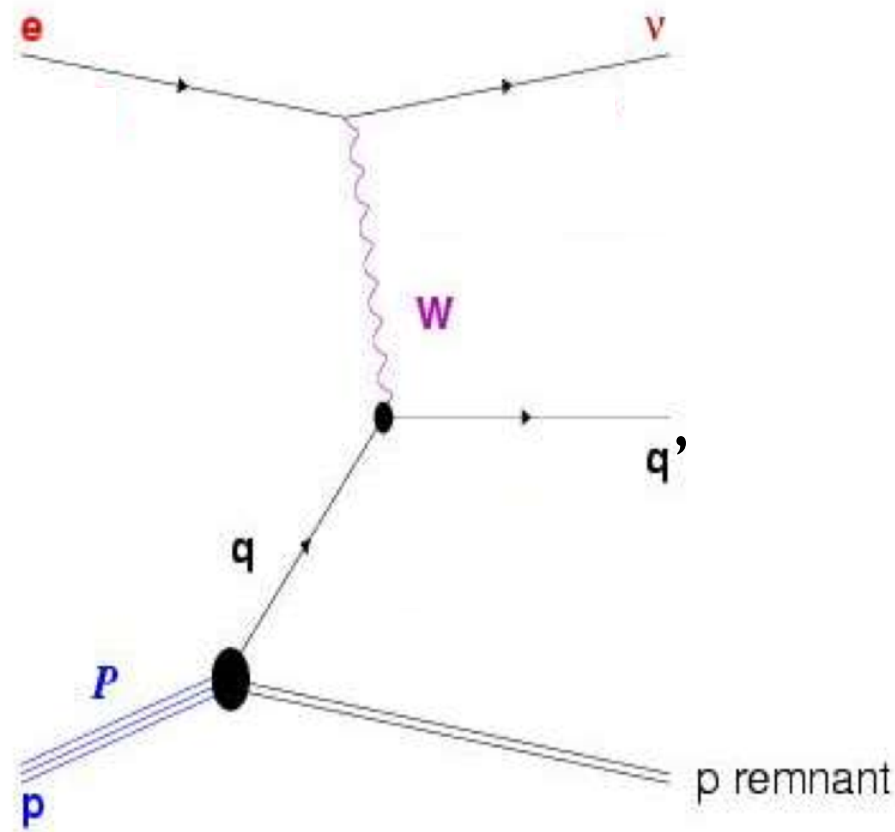
Quark Couplings to the Z boson

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, I^3=+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

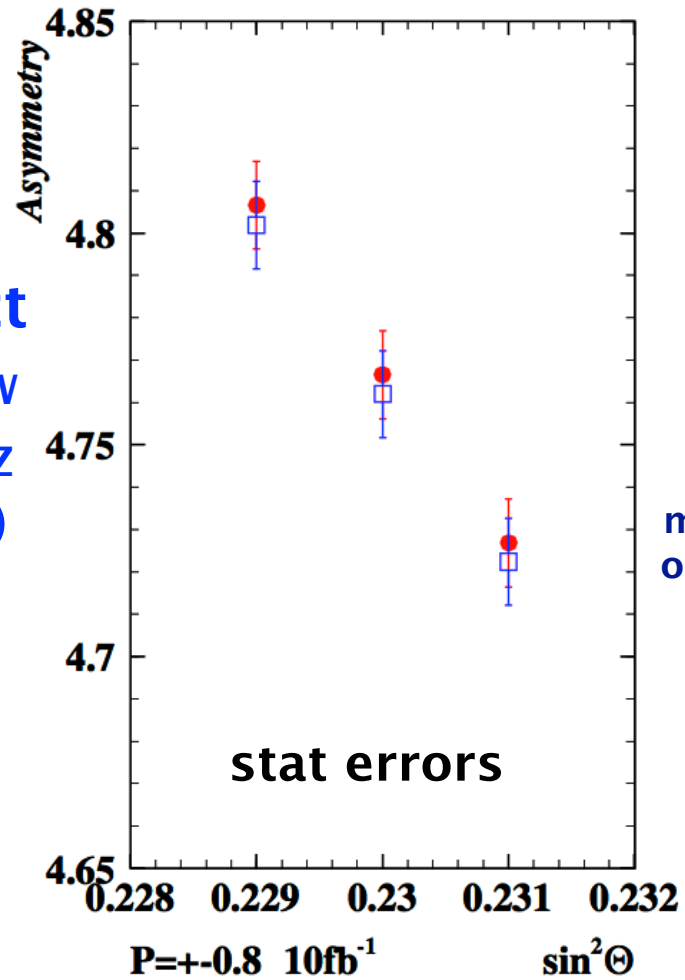
Asymmetry Measurements

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

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

A^-

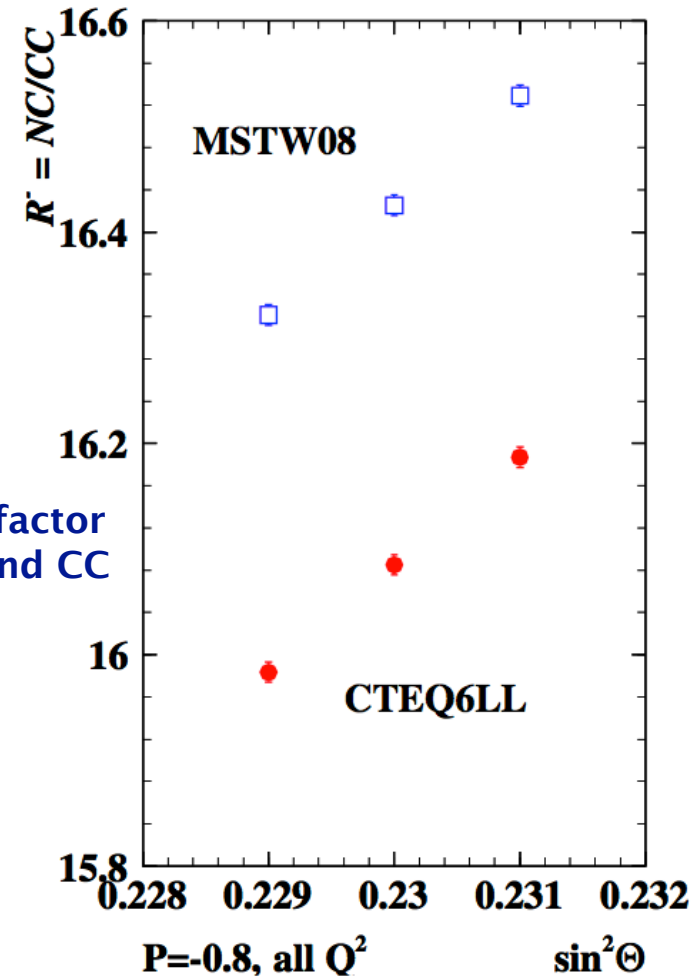
extract $\sin^2\theta_W$ (α, m_Z fixed)



10 fb^{-1}

e beam: 60 GeV

mean x differs by factor of 6 between NC and CC



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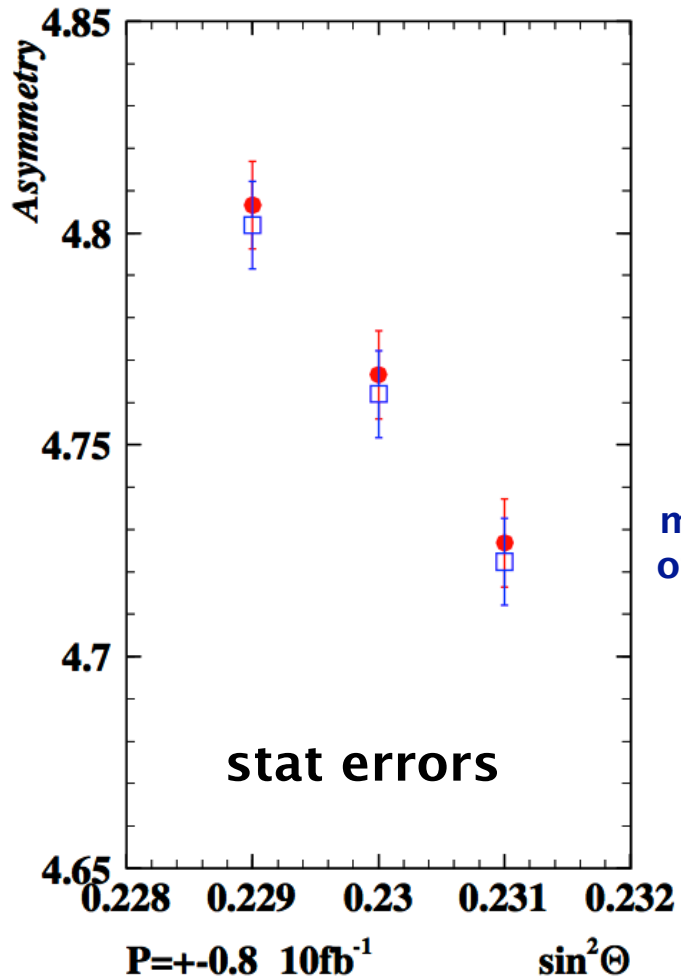
$$A^{\pm} = \frac{\sigma^{\pm}_{NC}(P_R) - \sigma^{\pm}_{NC}(P_L)}{\sigma^{\pm}_{NC}(P_R) + \sigma^{\pm}_{NC}(P_L)}$$

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

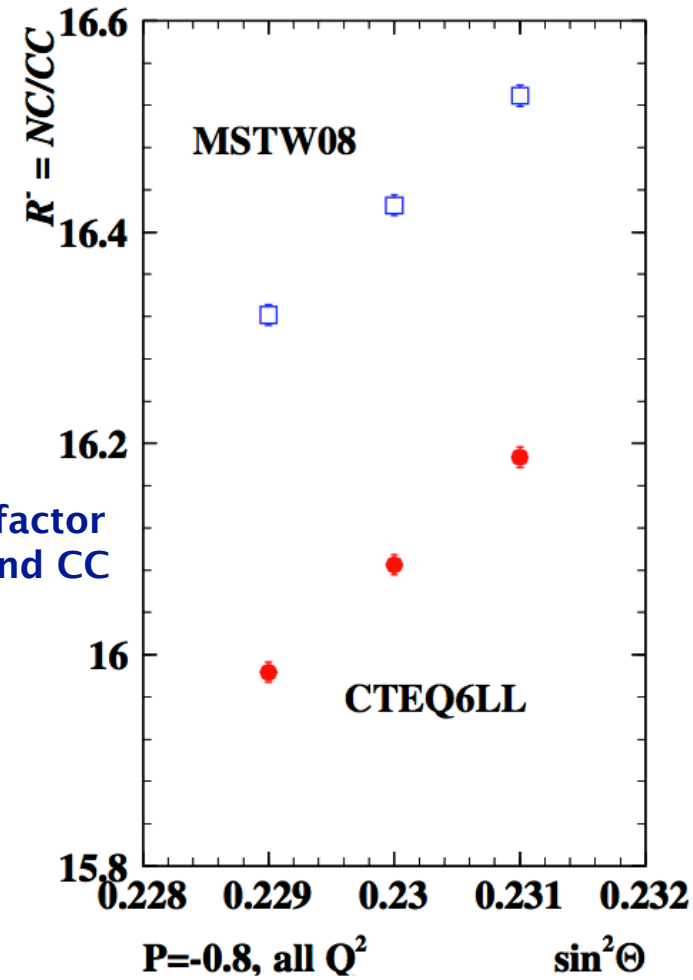
A^-



10 fb^{-1}

e beam: 60 GeV

mean x differs by factor of 6 between NC and CC



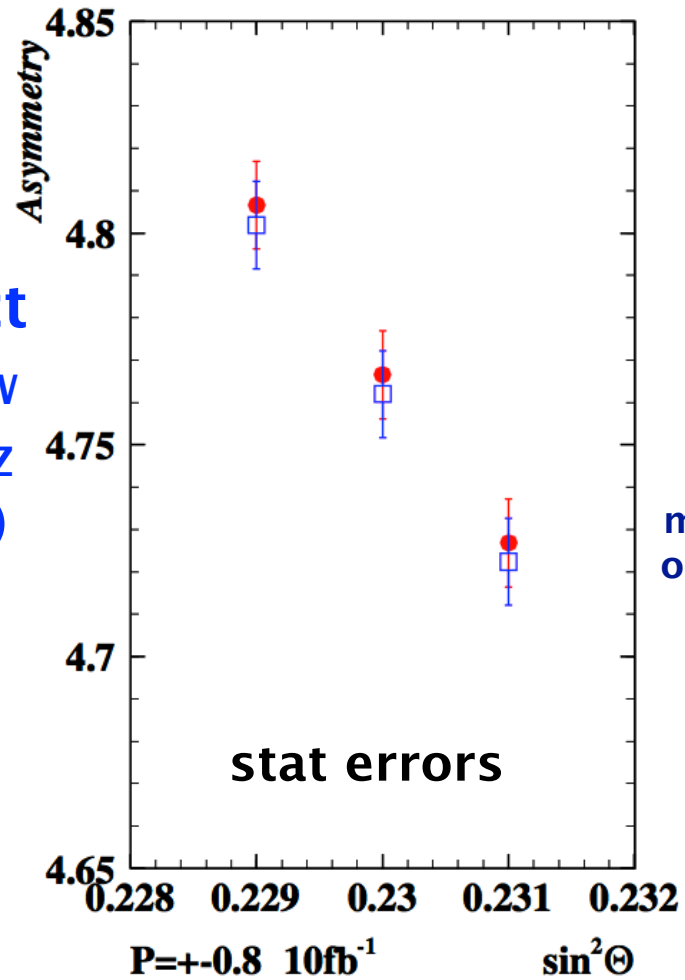
Asymmetry Measurements

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

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

A^-

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



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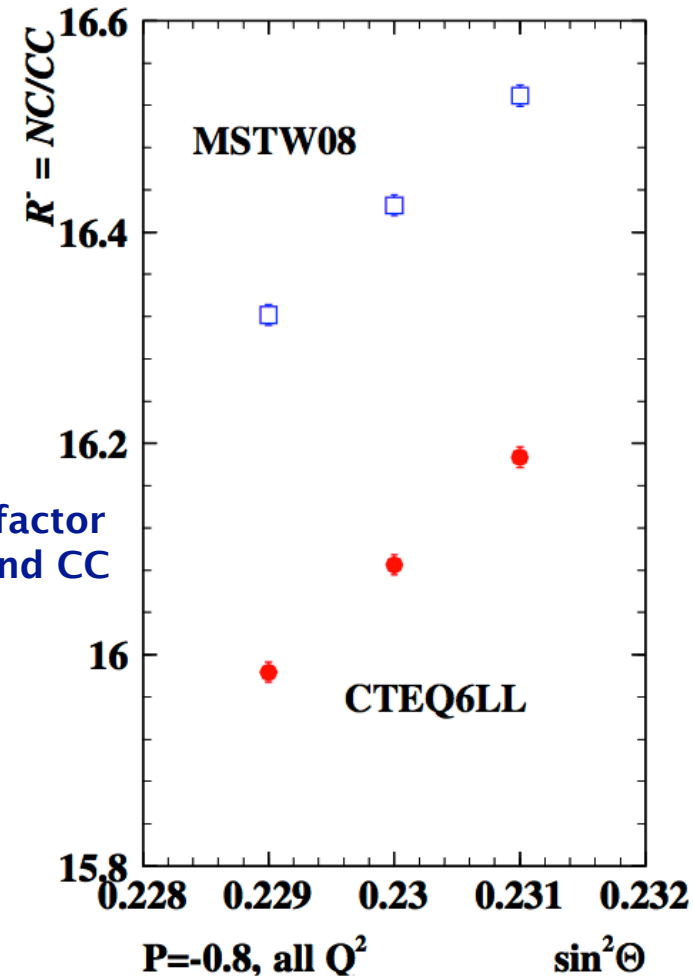


Signal and Backgrounds

signal

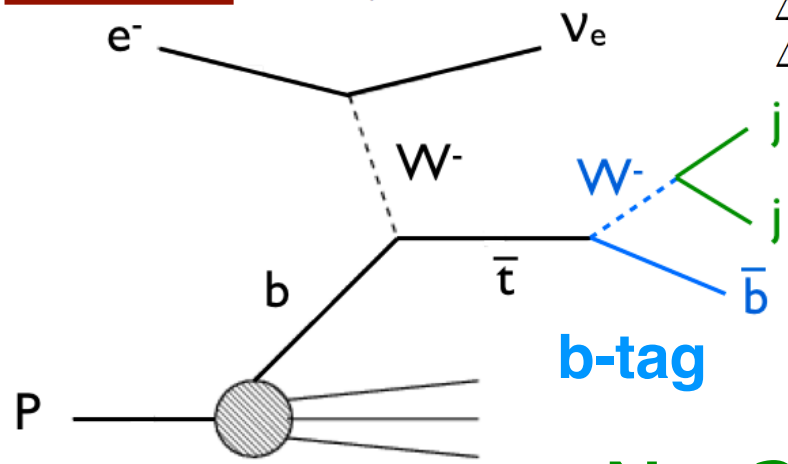
Dutta, Goyal, Kumar, Mellado, arXiv:1307.1688 [hep-ph]

background

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

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

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

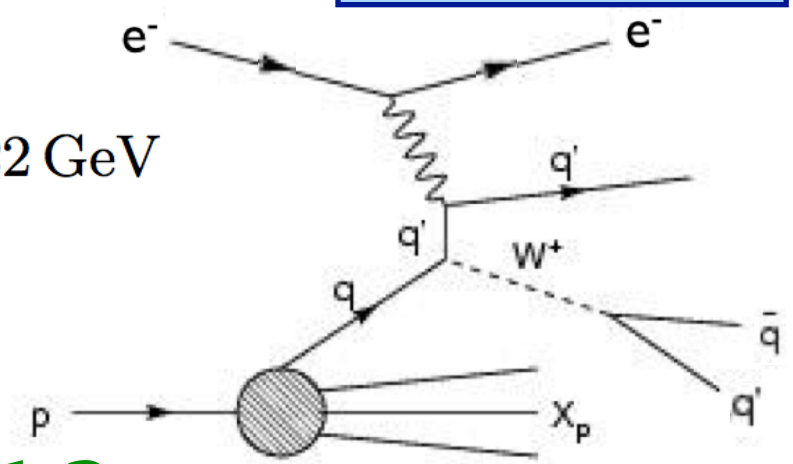


$|m_{j_1 j_2} - m_W| \leq 22\,\mathrm{GeV}$

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

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

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



N_t=22000, s/b=1.2

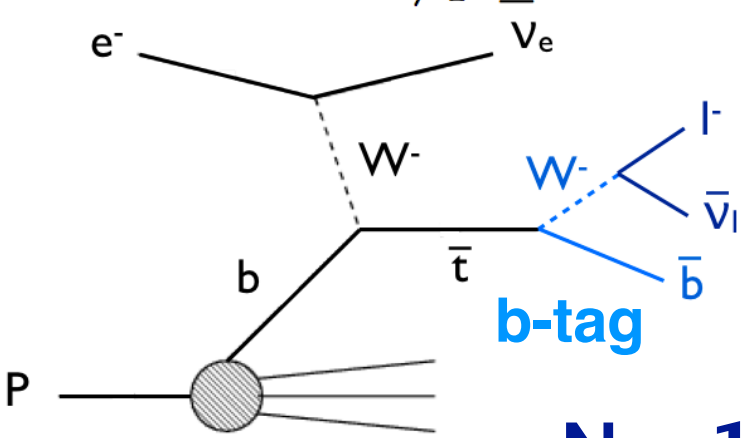
e beam: 60 GeV
100 fb^{-1}

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

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

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

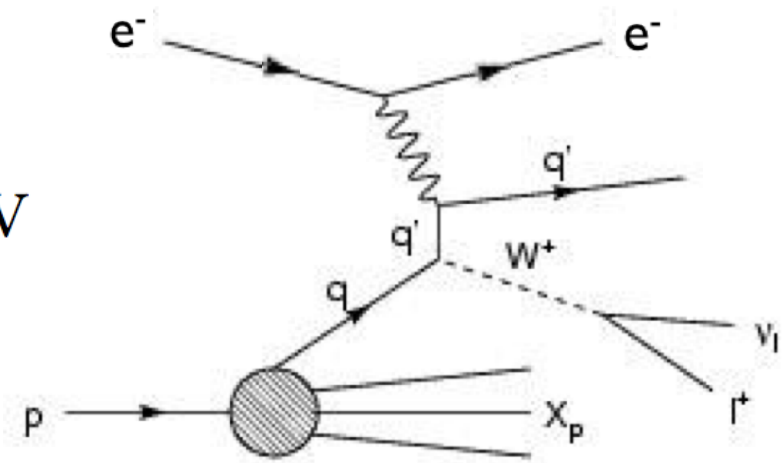
$\Delta\Phi_{\not{E},l} \geq 0.4$



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

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

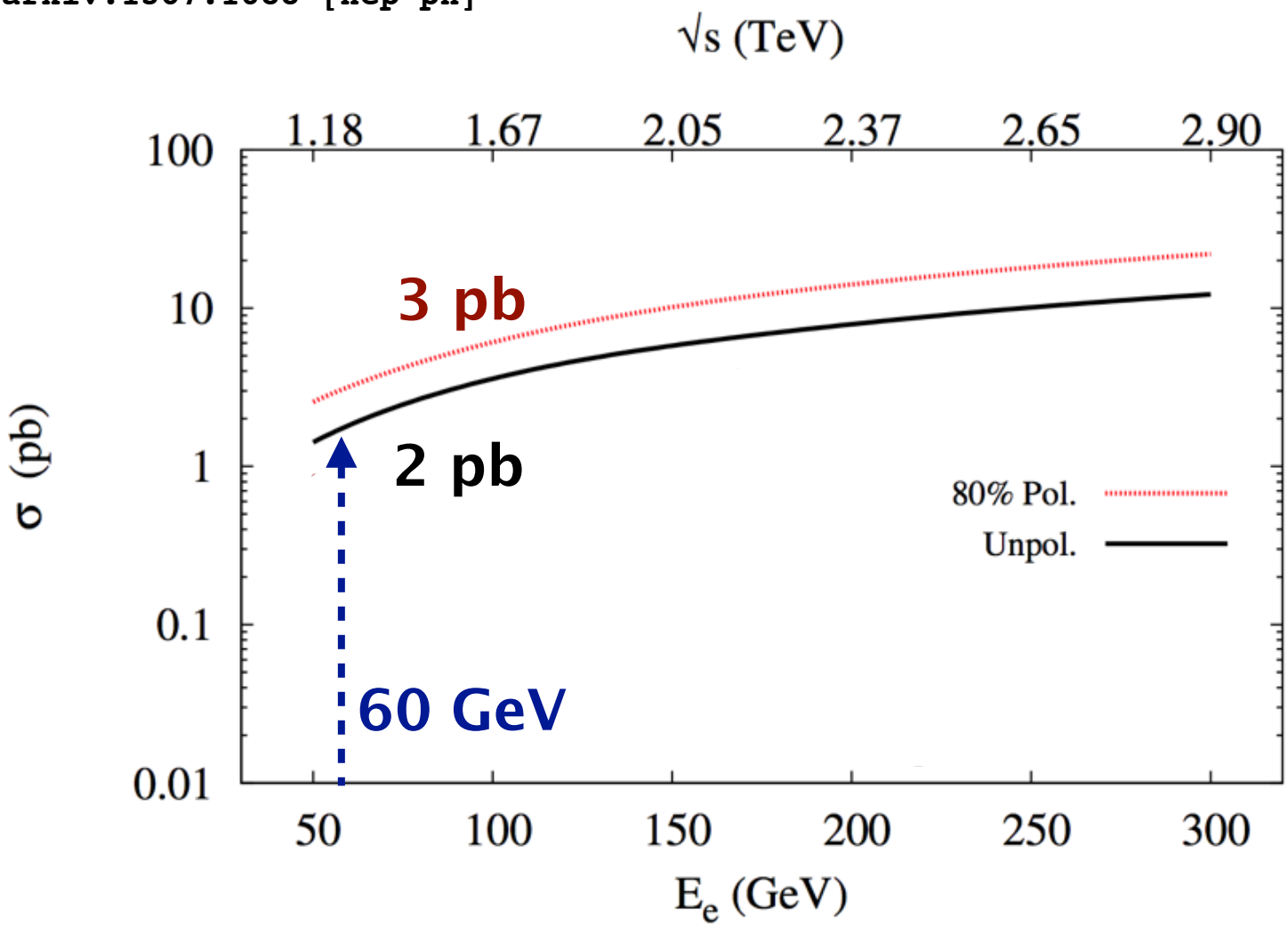
$\Delta R_{j,b/j} \geq 0.4$



N_t=11000, s/b=11

CC Single Top Quark Cross Section

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



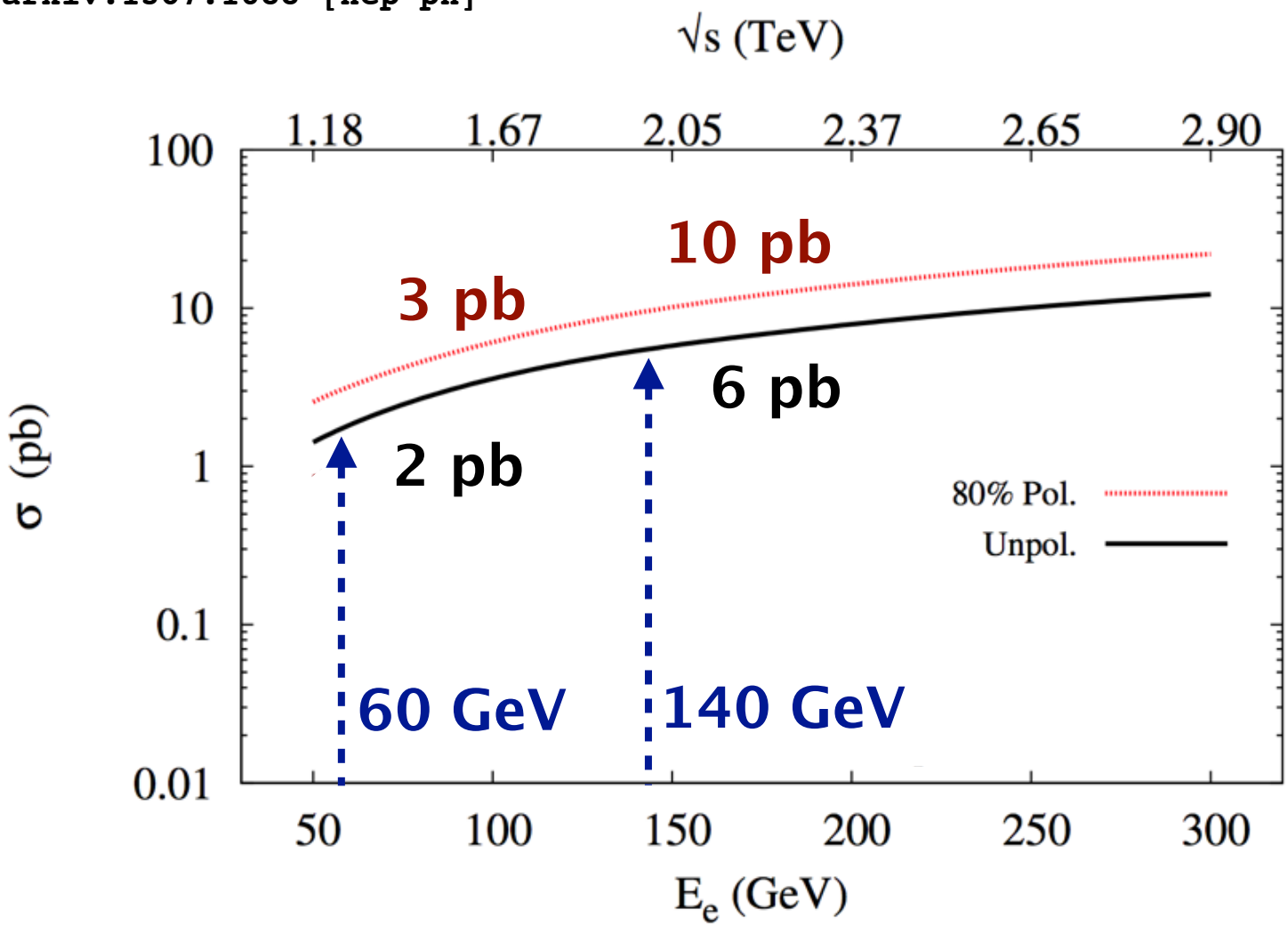
100 fb^{-1}:
$2 \cdot 10^5$ events
$3 \cdot 10^5$ events

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

CC Single Top Quark Cross Section

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

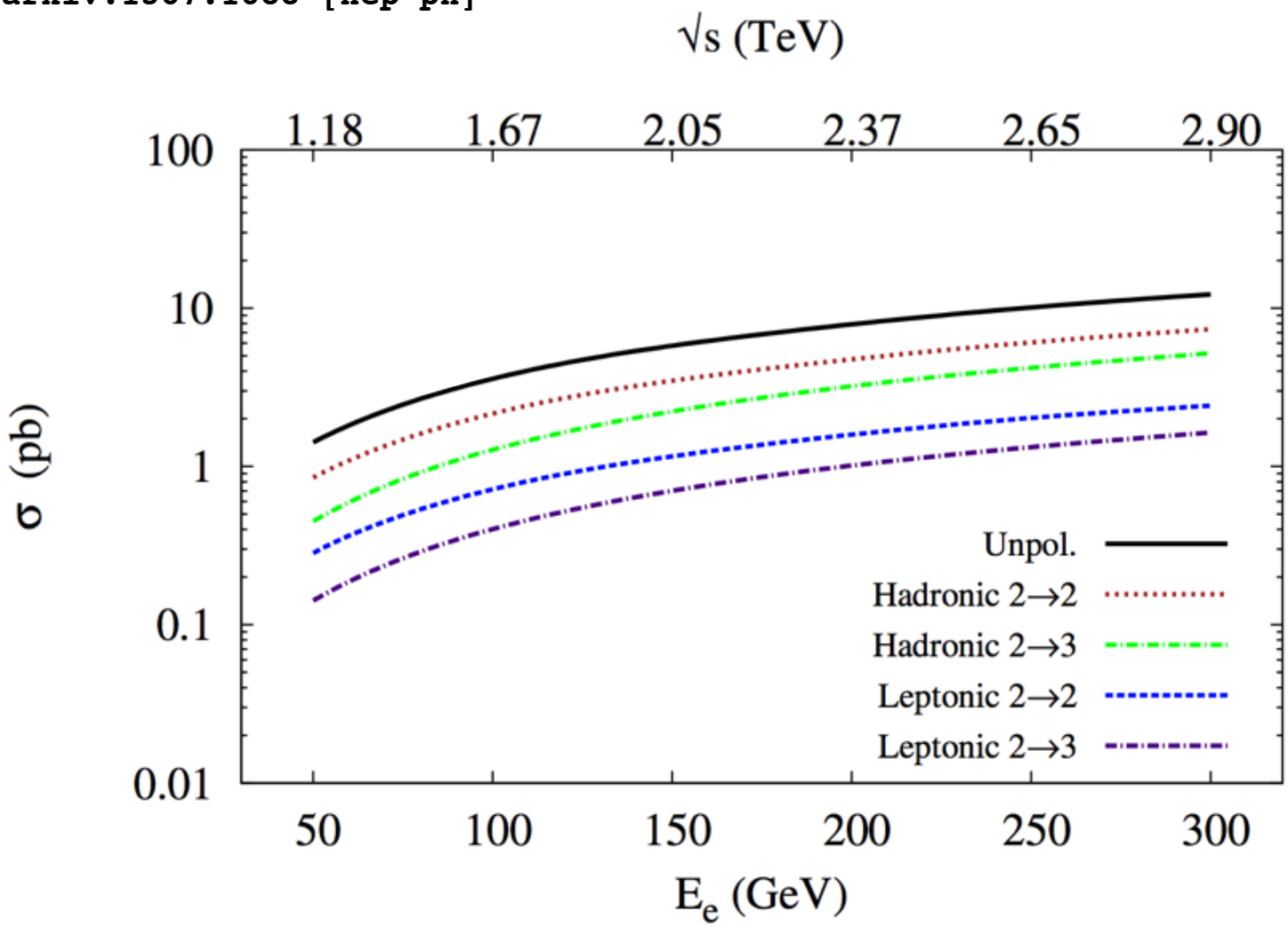
100 fb^{-1}:
2–6 · 10^5 events
3–10 · 10^5 events

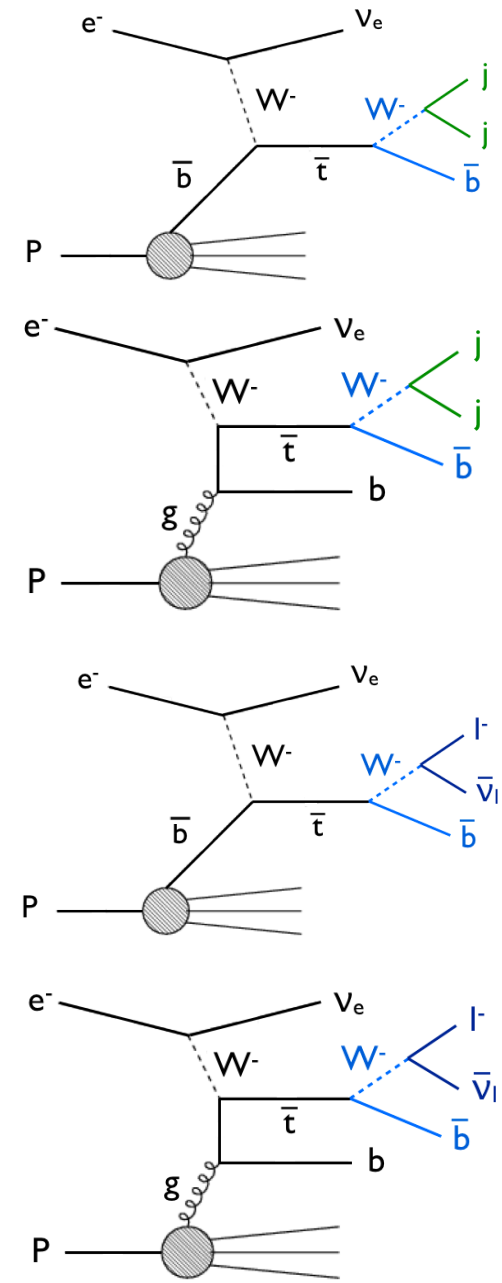


→ **LHeC offers excellent prospects for top quark physics**

CC Single Top Quark Cross Section

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





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	$e^- p \to \nu_e cjj$ & $e^- p \to \nu_e \bar{c} jj$	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}

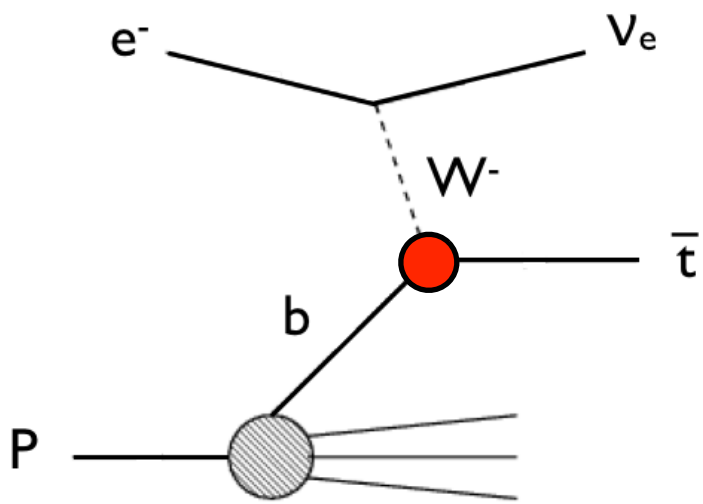
Event Selection	$p_{T\,j,b} \geq 20$ GeV $\lvert\eta_j\rvert \leq 5, \lvert\eta_b\rvert \leq 2.5$ $\Delta R_{j,b/j} \geq 0.4$ $\not{E}_T \geq 25$	$\Delta\Phi_{\not{E},j} \geq 0.4$ $\Delta\Phi_{\not{E},b} \geq 0.4$	$\lvert m_{j_1 j_2} - m_W\rvert \leq 22$ GeV	Fiducial Efficiency	$S/\sqrt{S+B}$
SM	3.2×10^4	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

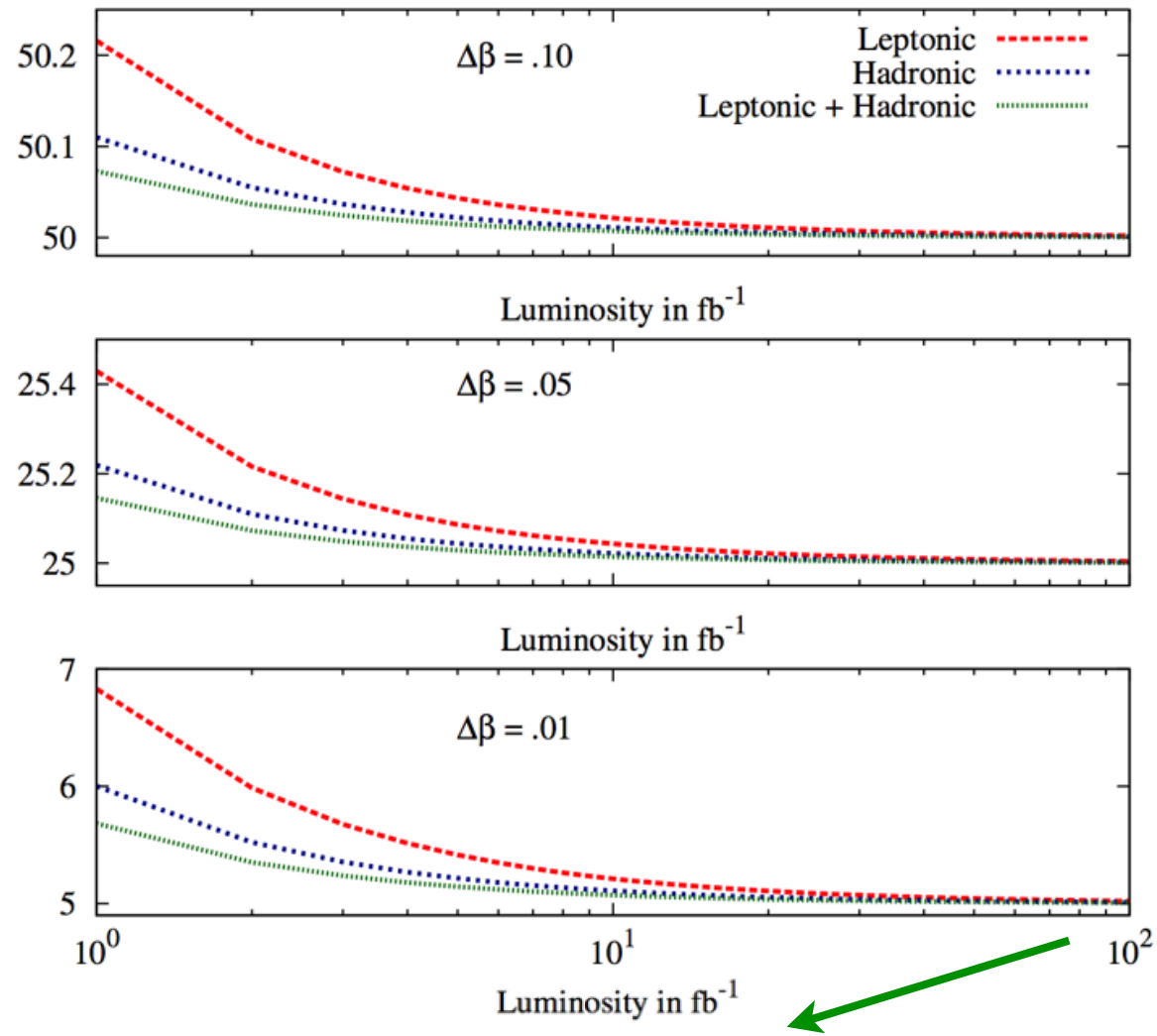
Direct Measurement of $|V_{tb}|$



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

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

$\Delta\beta$: luminosity uncertainty



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

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

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

Search for Anomalous Wtb Couplings

$$L = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}V_{tb}\left(f_V^L P_L + f_V^R P_R\right)tW_{\mu}^{-}$$
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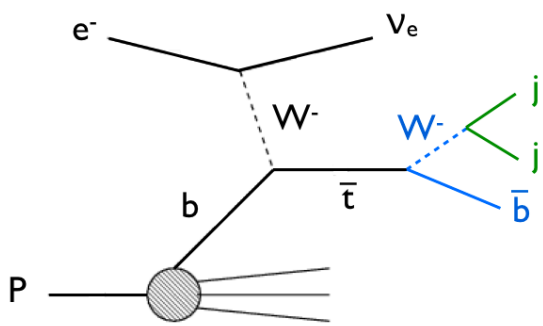
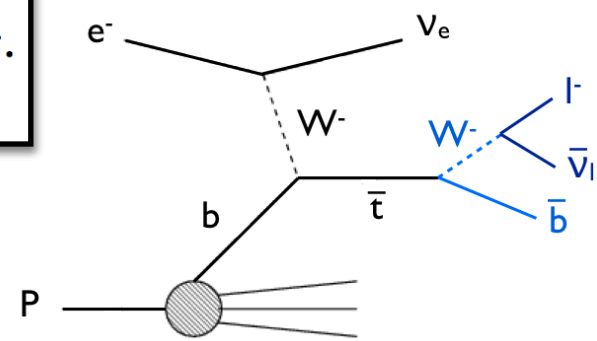
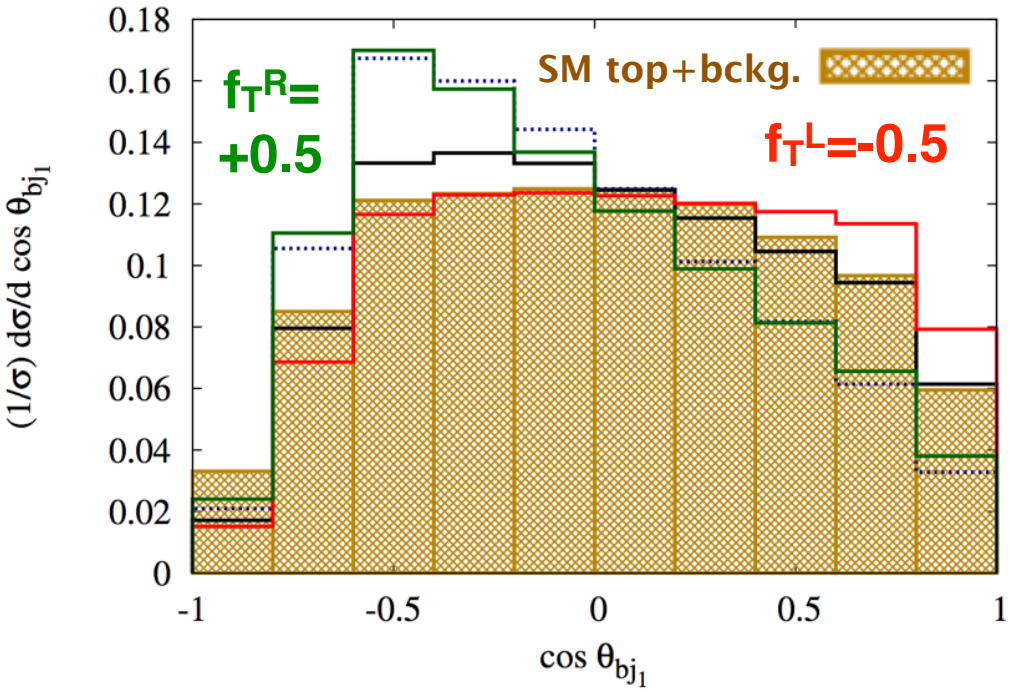
= 1 in SM

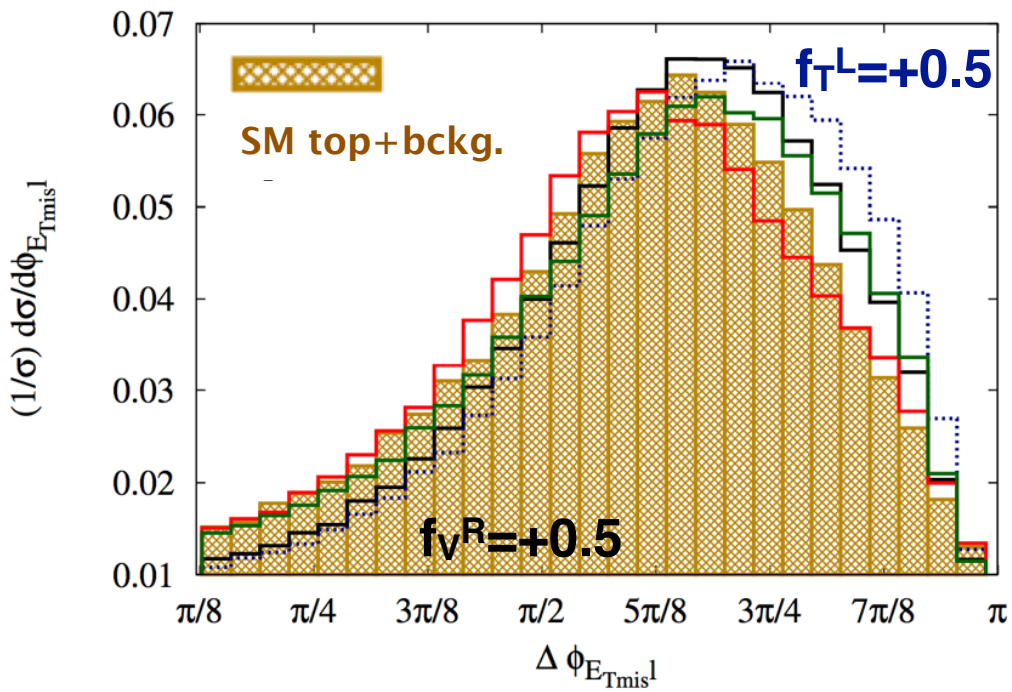
Dutta, Goyal, Kumar, Mellado, arXiv:1307.1688



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







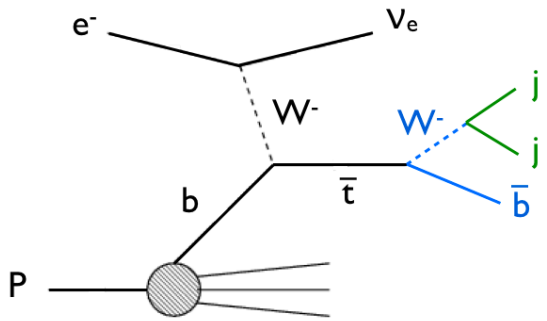
+ other variables sensitive on W helicity

Search for Anomalous Wtb Couplings

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

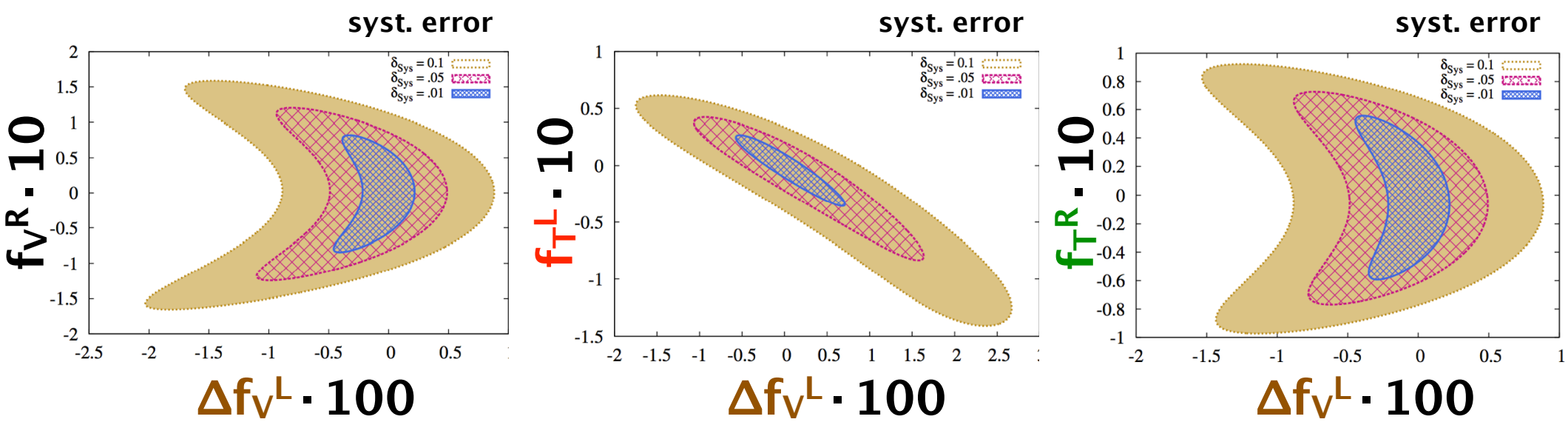
= 1 in SM

Dutta, Goyal, Kumar, Mellado, arXiv:1307.1688



68% C.L.

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

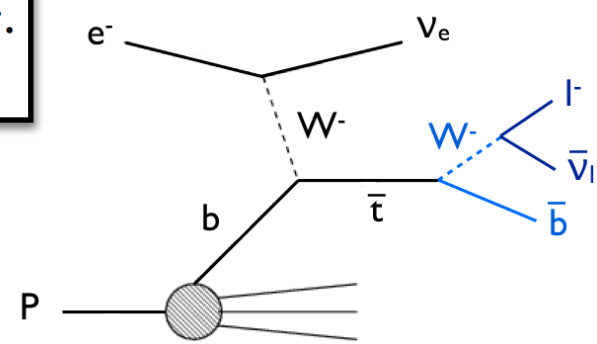


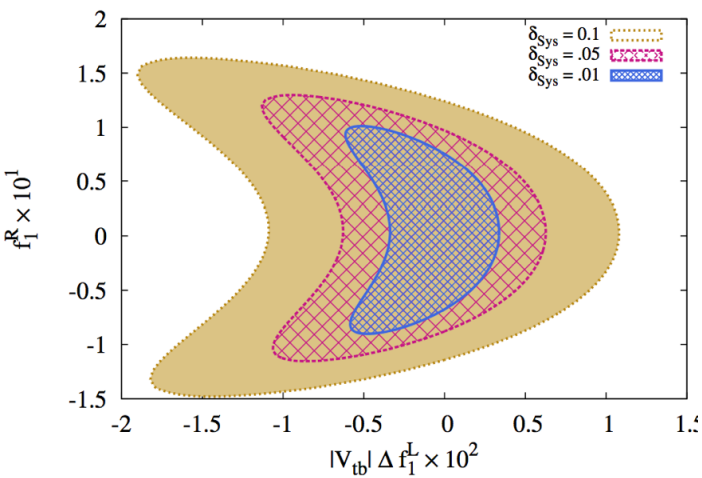
Search for Anomalous Wtb Couplings

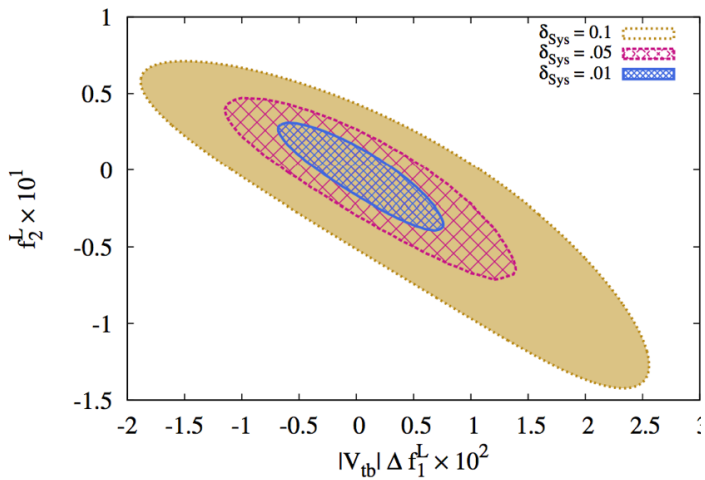
$$L = -\frac{g}{\sqrt{2}}\bar{b}\gamma^{\mu}V_{tb}\left(f_V^L P_L + f_V^R P_R\right)tW_{\mu}^{-}$$
$$-\frac{g}{\sqrt{2}}\bar{b}\frac{i\sigma^{\mu\nu}q_{\nu}}{M_W}\left(f_T^L P_L + f_T^R P_R\right)tW_{\mu}^{-} + h.c.$$

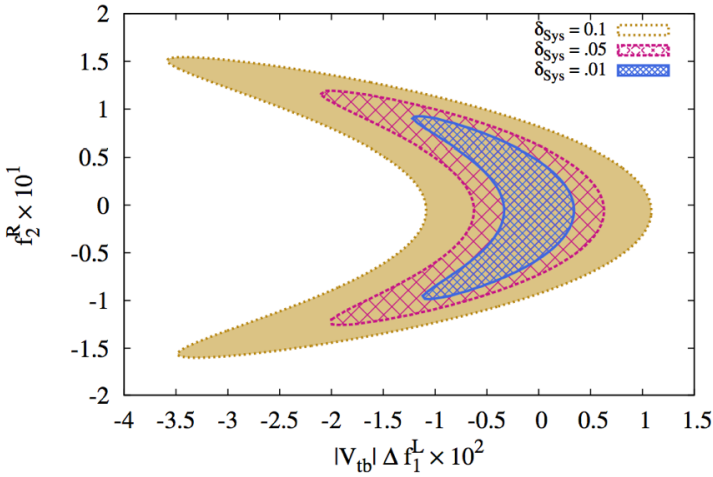
= 1 in SM

68% C.L.





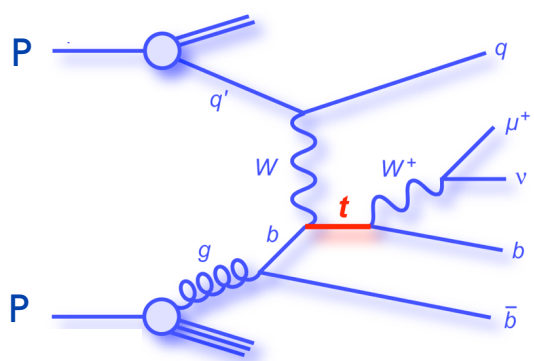


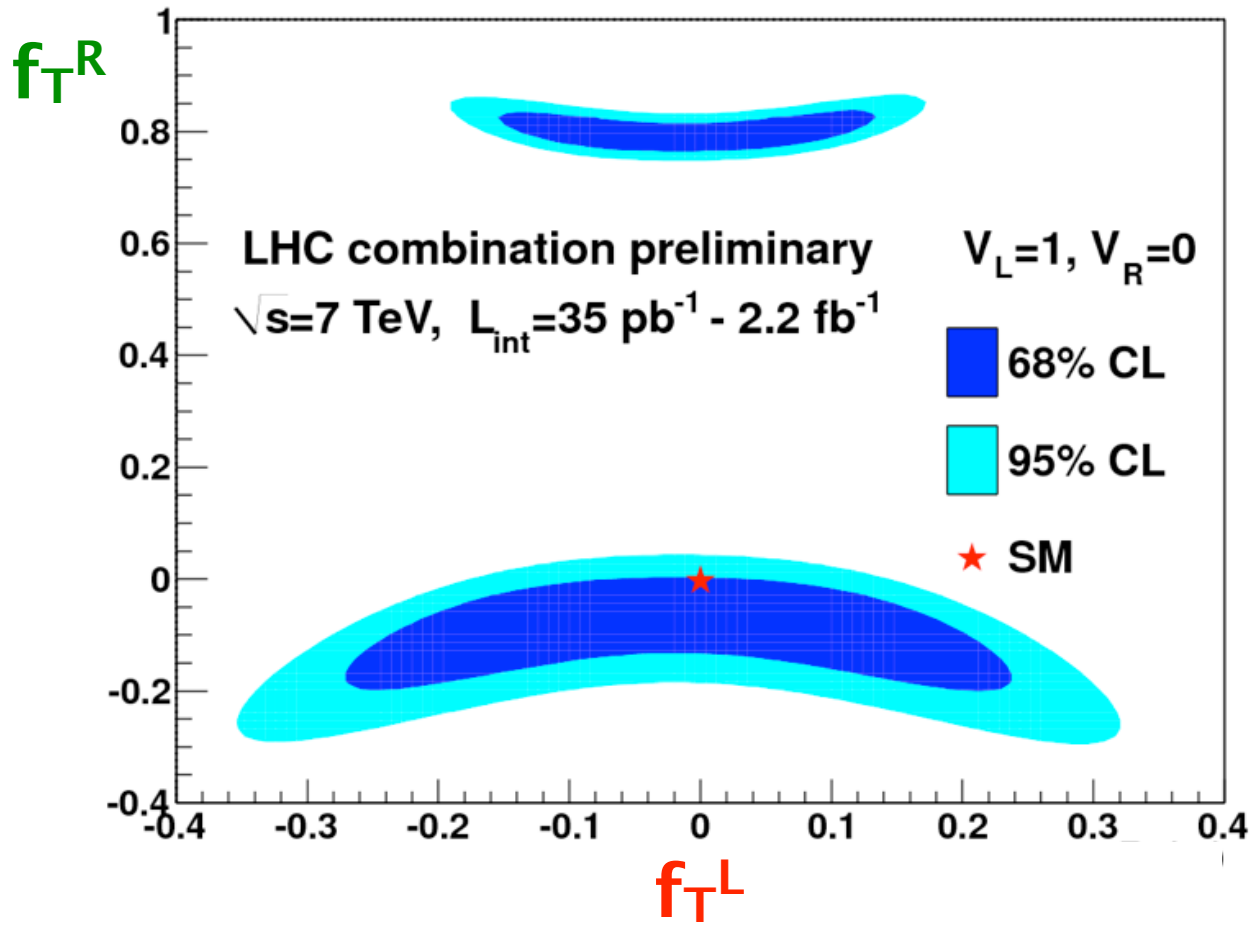


Search for Anomalous Wtb Couplings

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

= 1 in SM

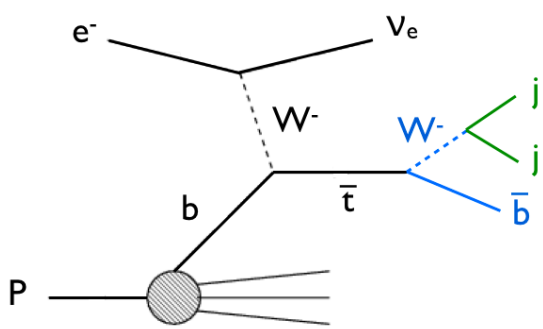


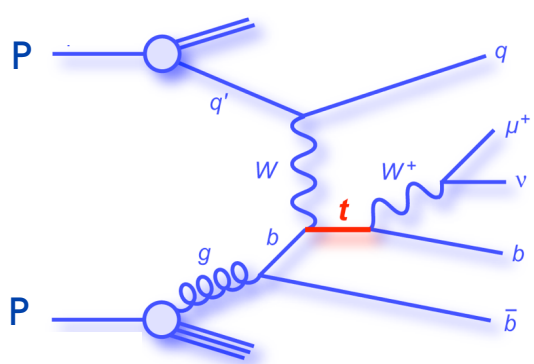


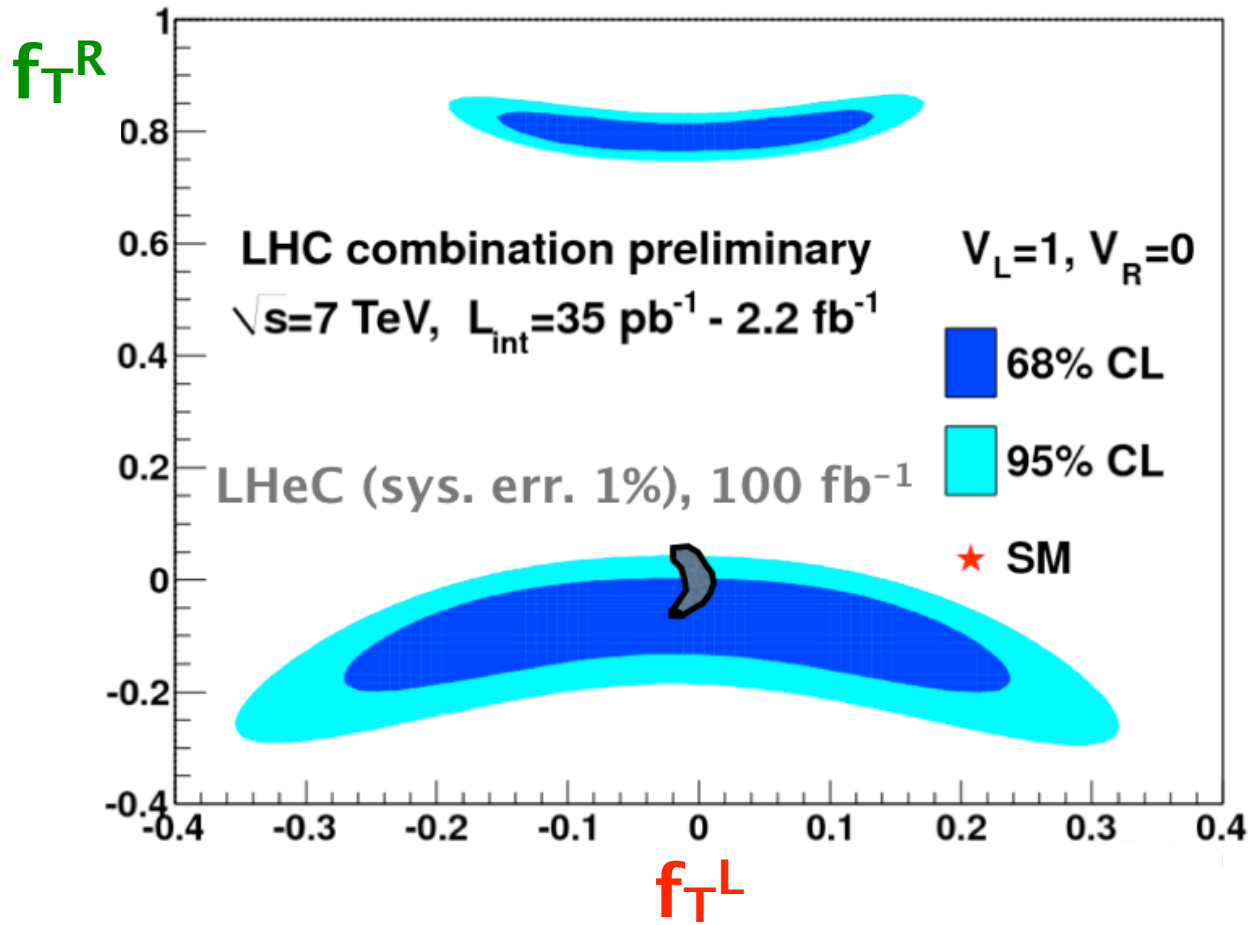
Search for Anomalous Wtb Couplings

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

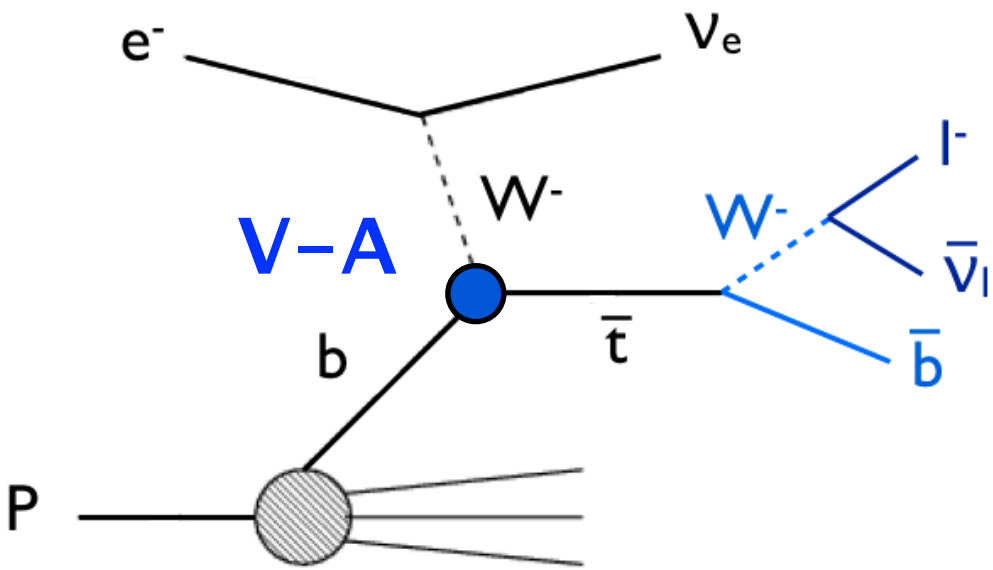
= 1 in SM







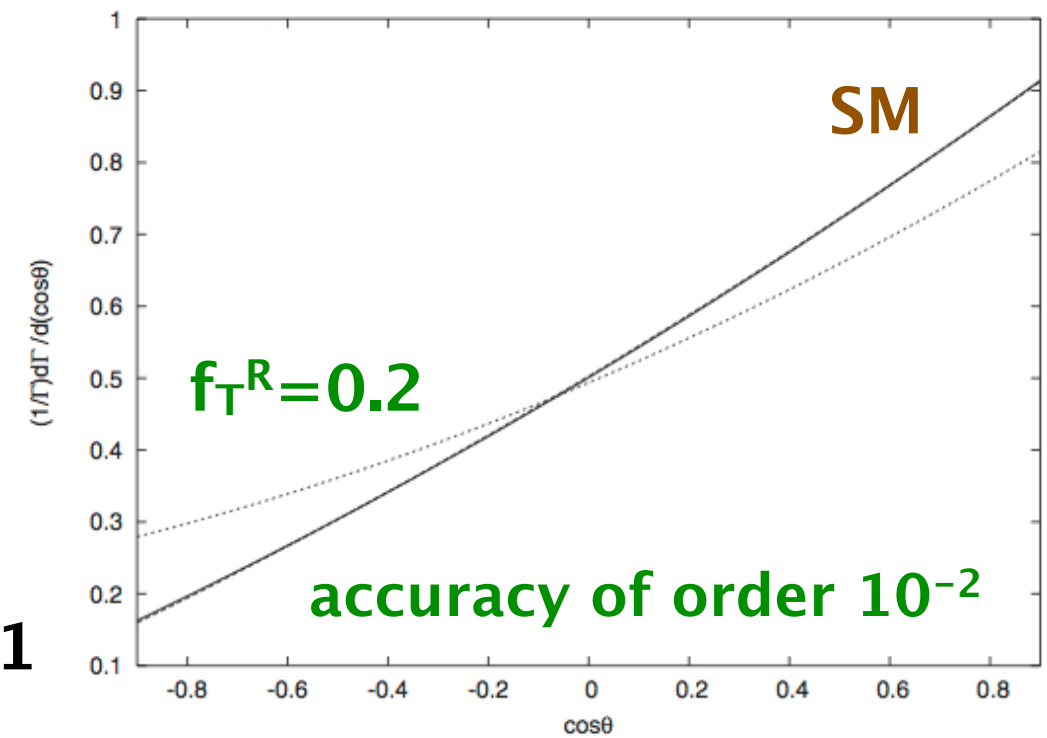
Top Quark Polarisation



Atag, Sahin,
PRD 73, 074001 (2006)

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

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



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

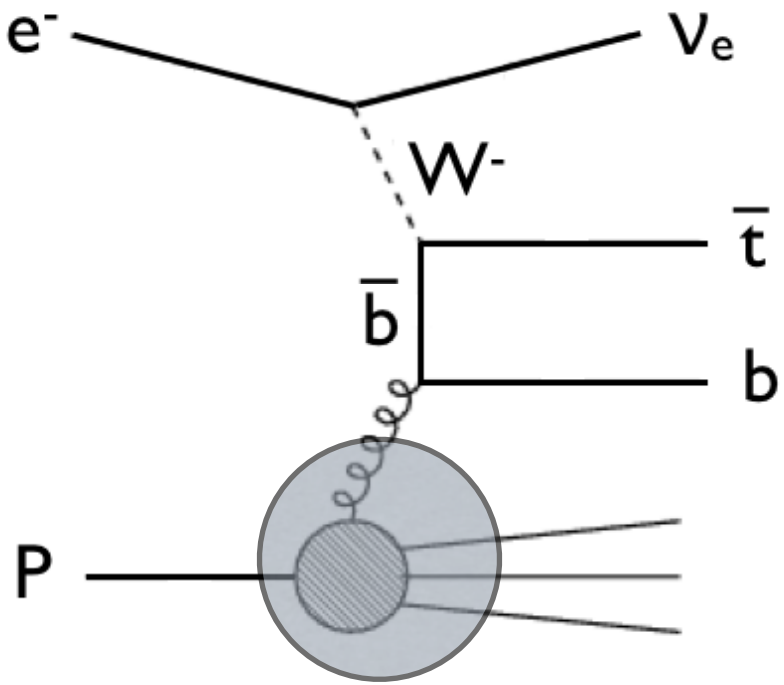
TESLA+HERAp:

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

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

JHEP 04 (2016) 073

Gluon Parton Density Function



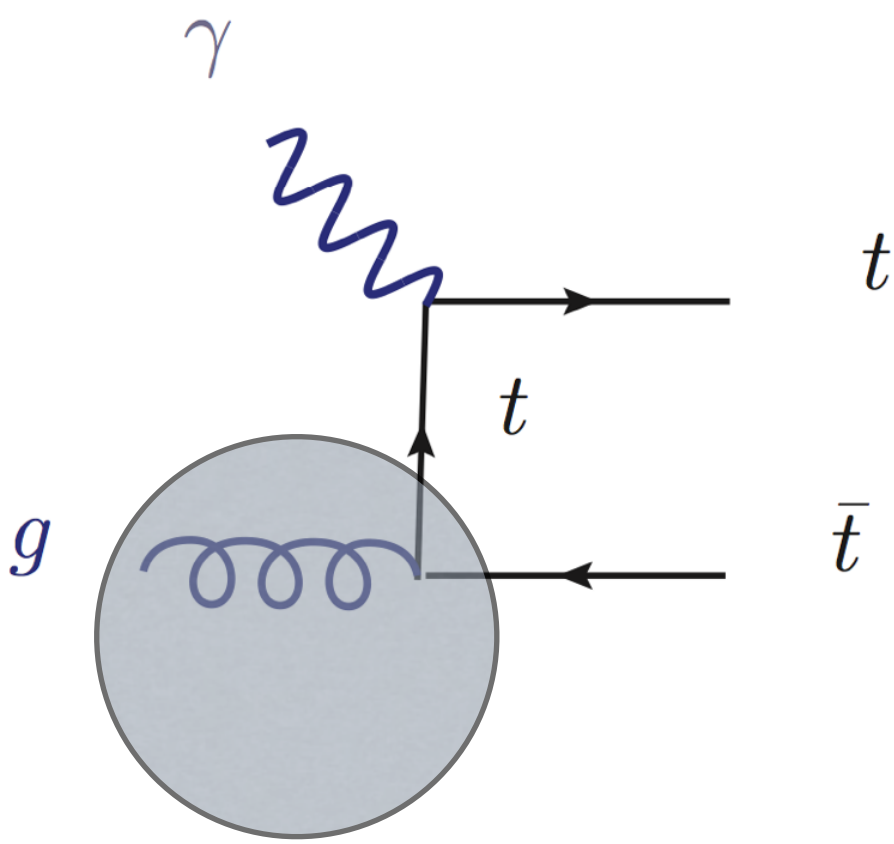
→ **measure gluon density at high x**

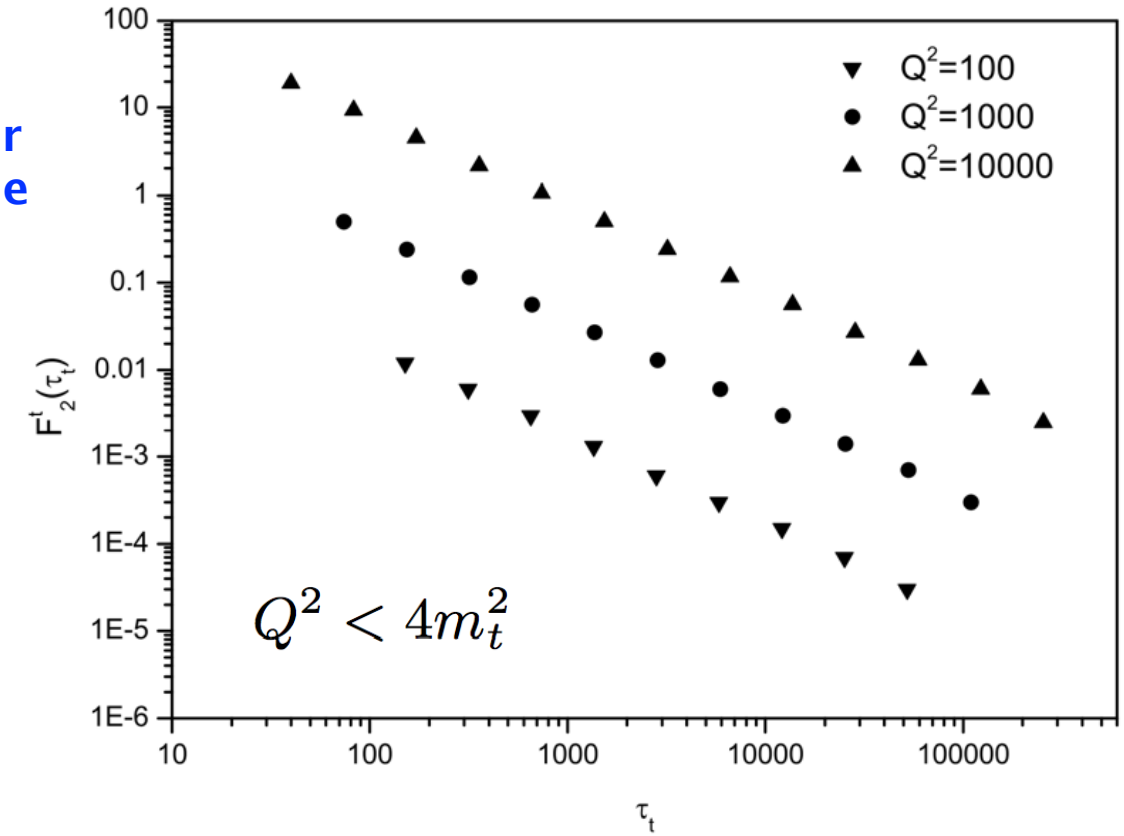
Top Quark Structure Function

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

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

variable flavour number scheme for top quark





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

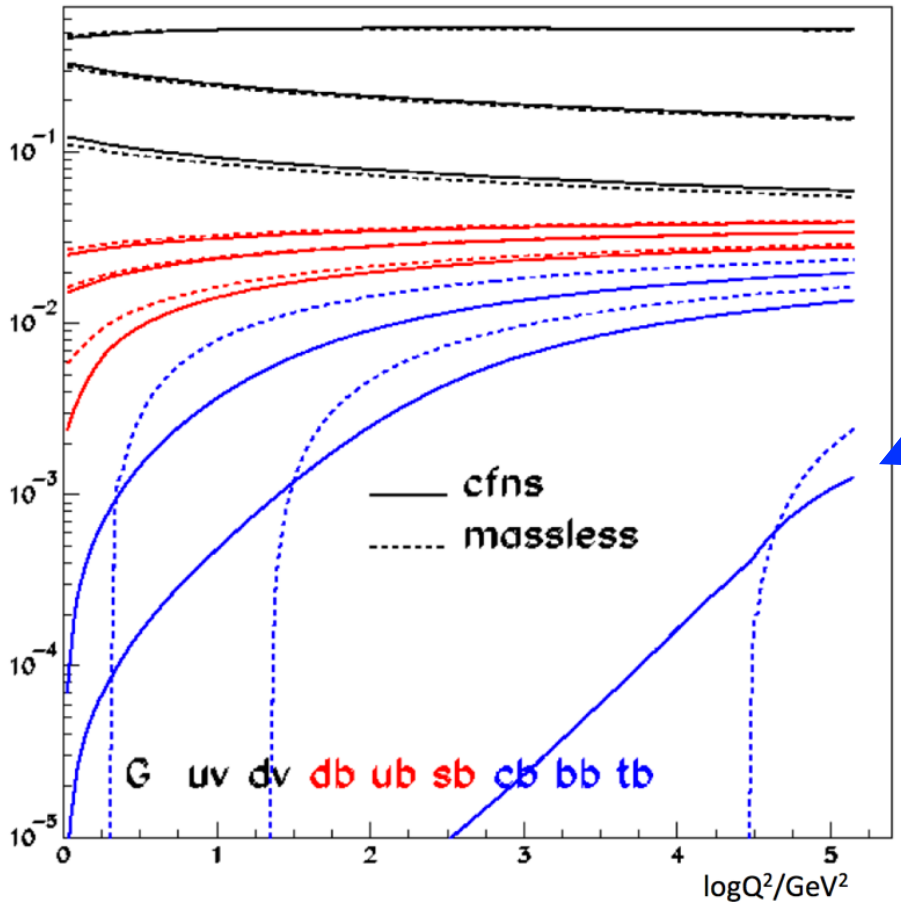
$$x = x_B (1 + \frac{4m_t^2}{Q^2})$$

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

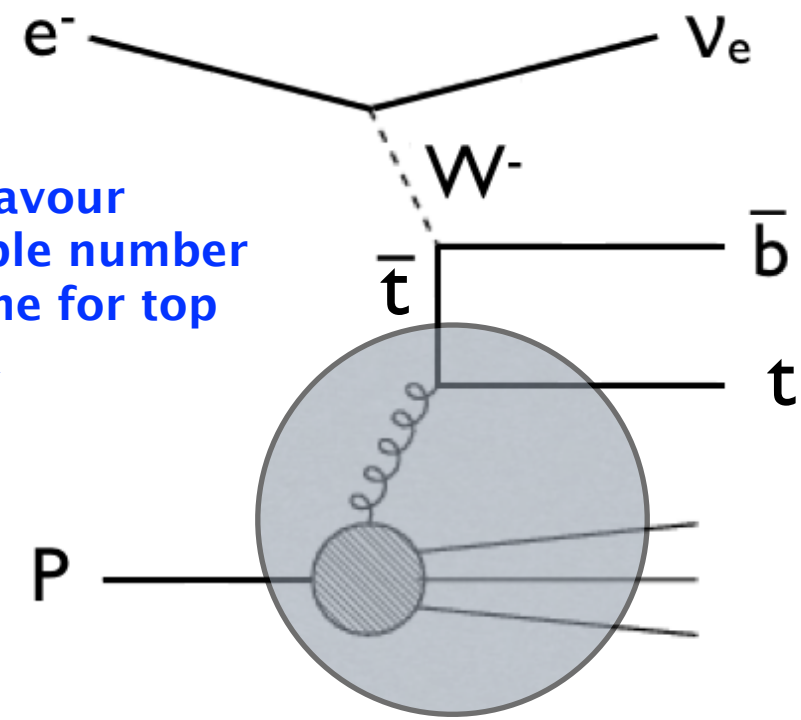
Top Quark Parton Density Function

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

parton momentum fraction



six-flavour variable number scheme for top quark



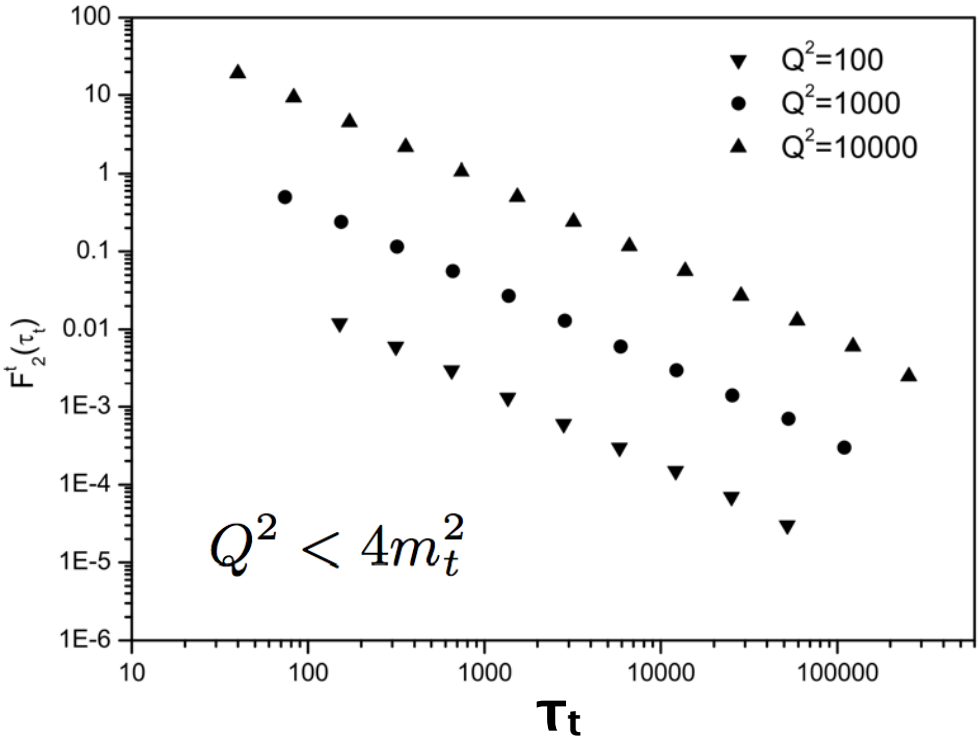
→ LHeC offers new field of research for top quark PDF

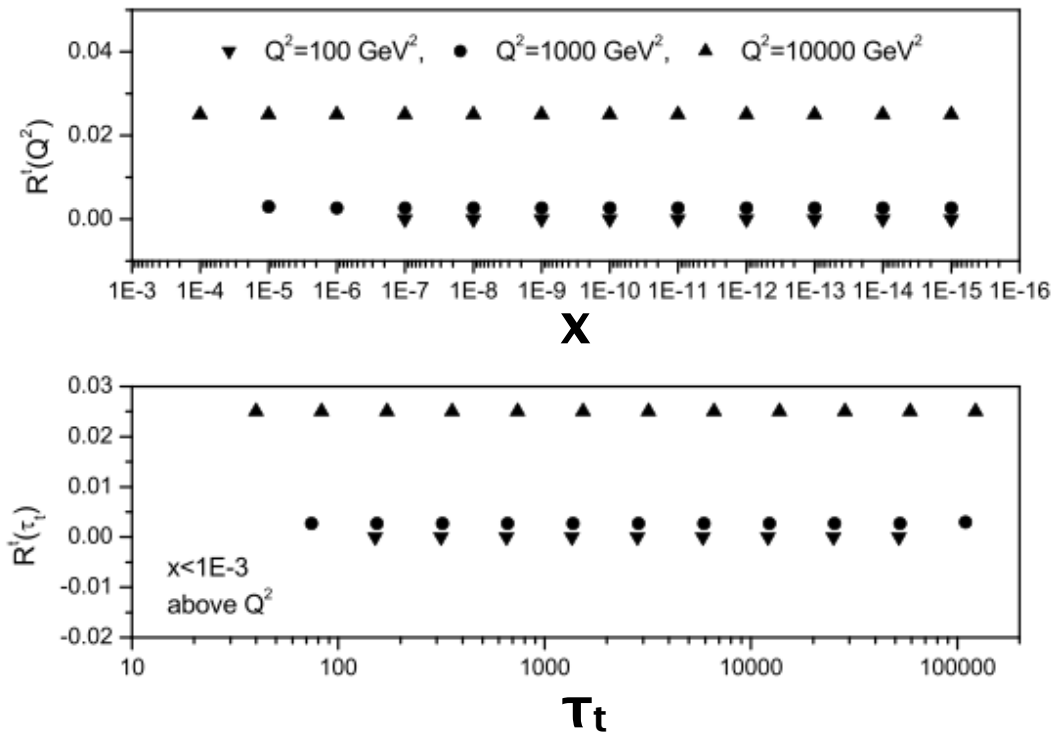
Top Quark Structure Function

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

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

variable flavour number scheme for top quark





→ approximately: $1/\tau_t$

→ independent of x and τ_t

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

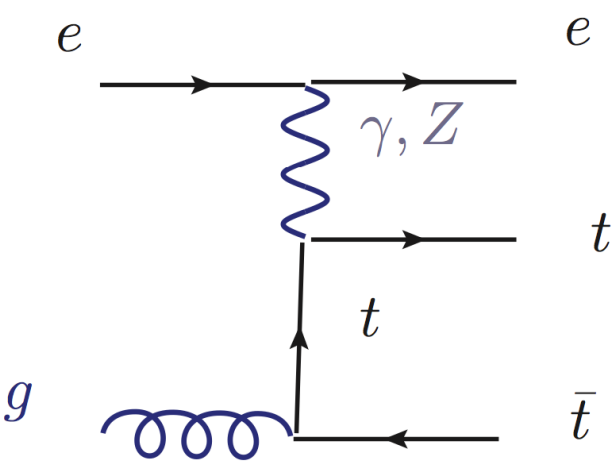
NC Top Quark Production

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

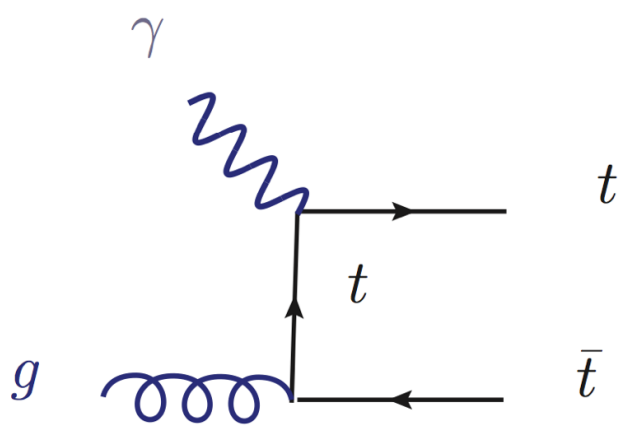
top pair production

single top production

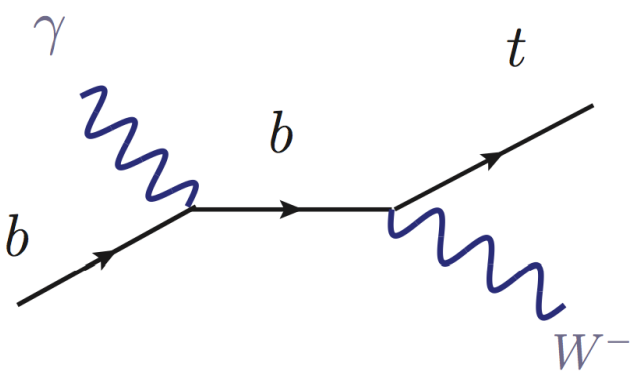
DIS



photoproduction



photoproduction

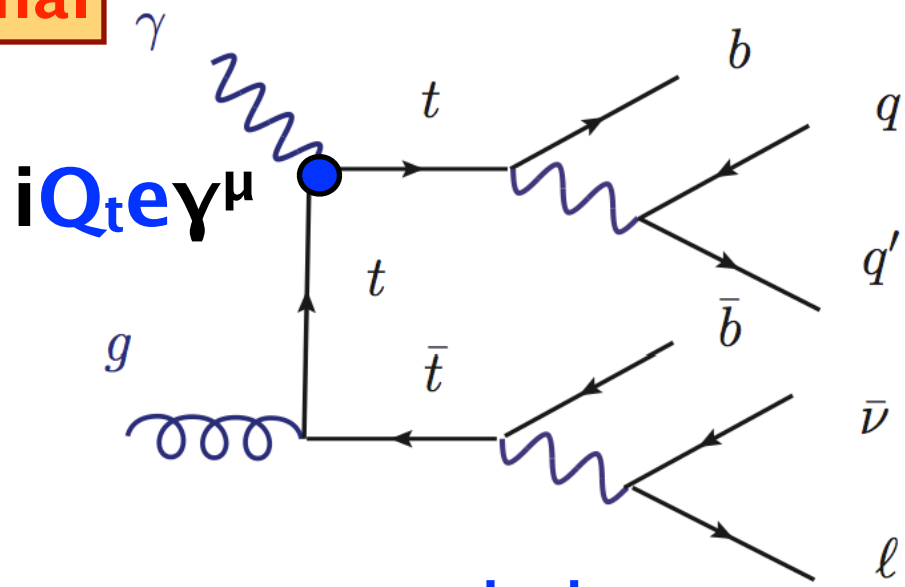


e-beam 60 GeV, 100 fb^{-1}:

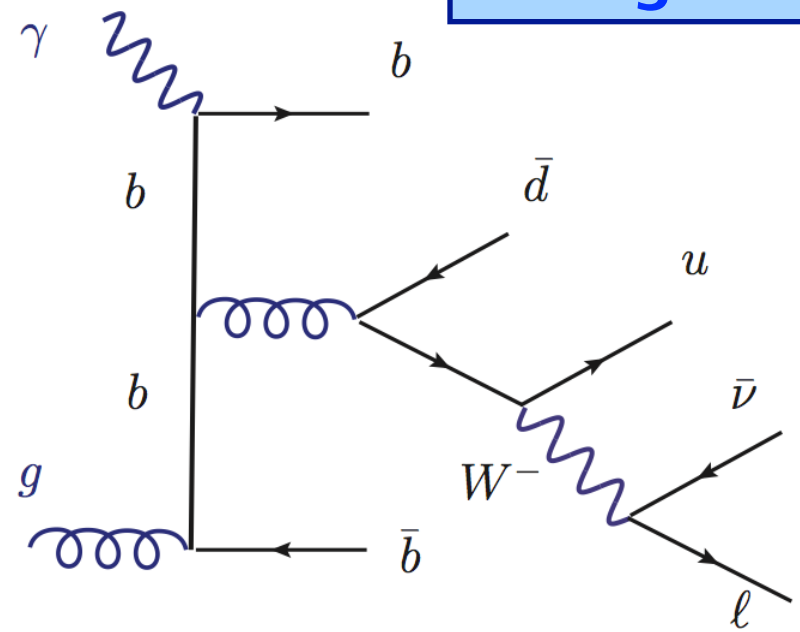
DIS	photoproduction	photoproduction
0.023 pb	0.70 pb	0.031 pb
$N_{t\bar{t}}$=2,300	$N_{t\bar{t}}$=70,000	N_t=3,100

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

signal

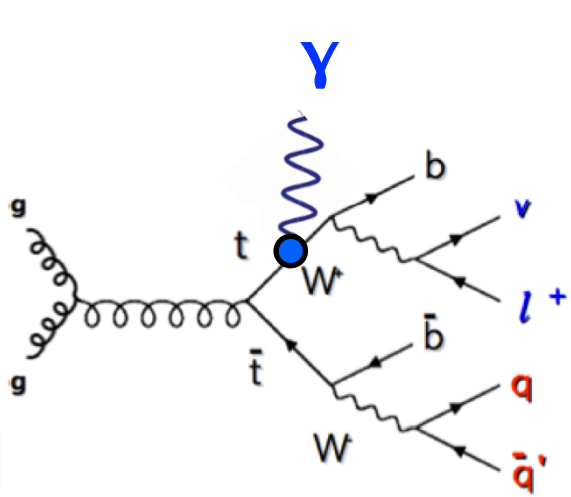


background

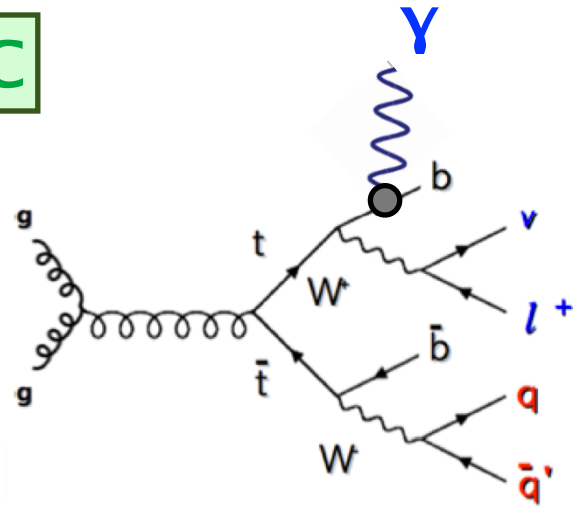


→ measure top quark charge

LHC



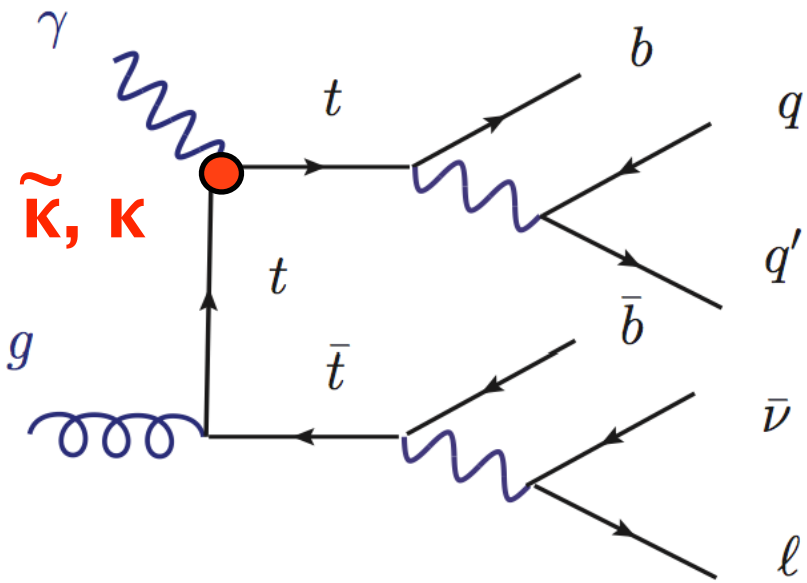
OR



?

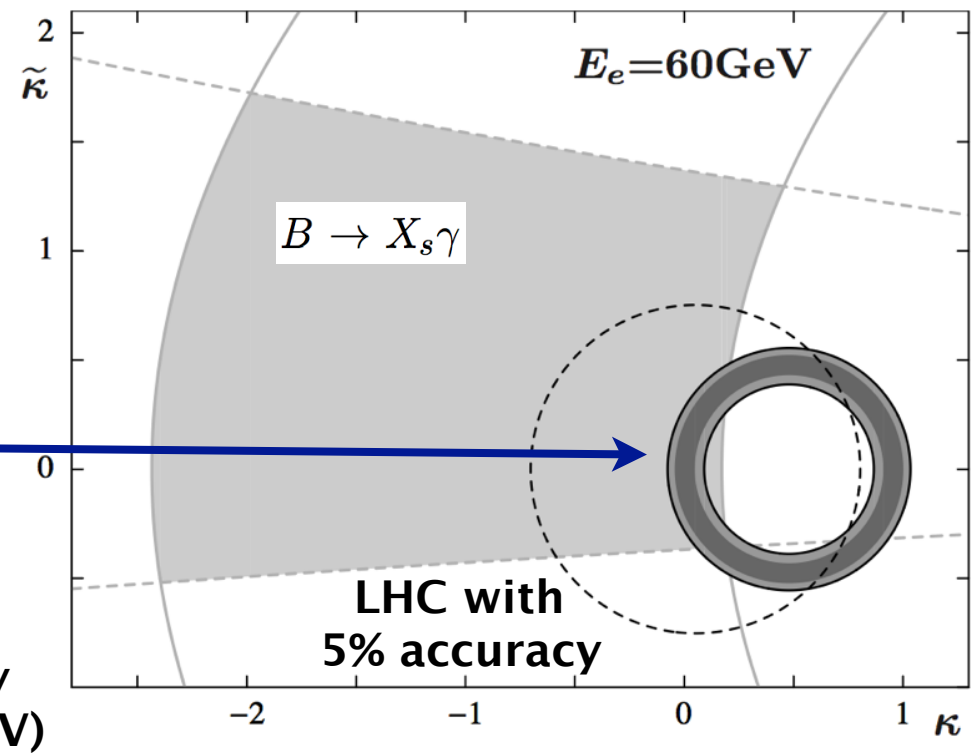
→ difficult at the LHC

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



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

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



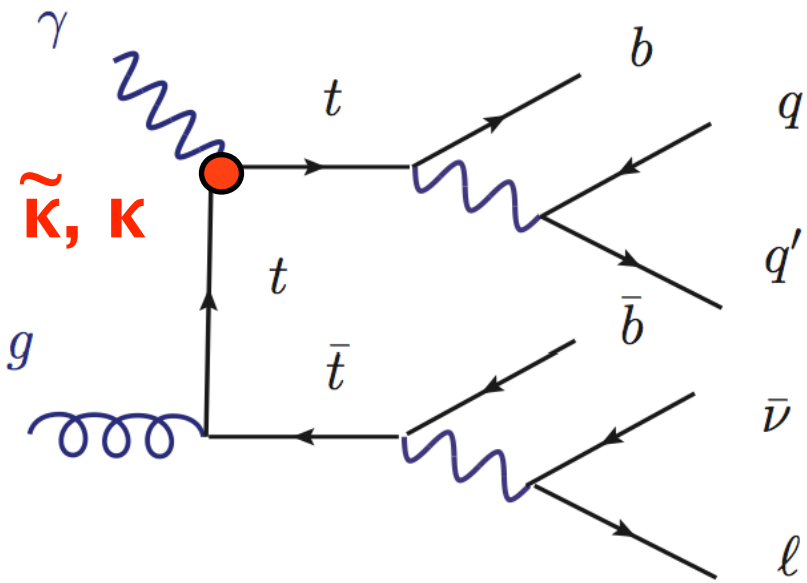
LHeC:
10% and 18% accuracy

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

magnetic dipole moment: κ

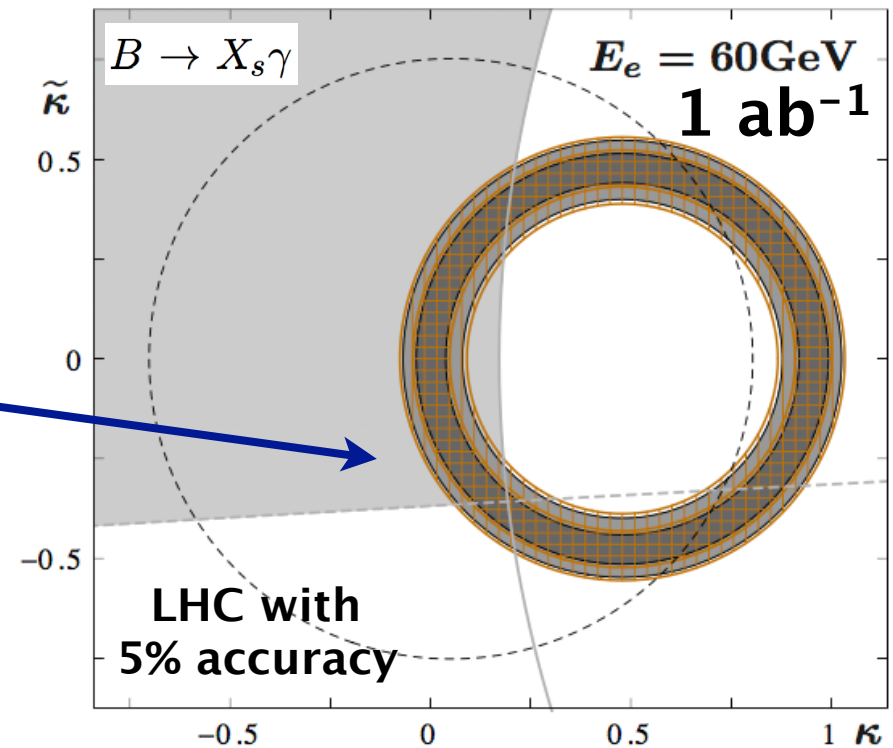
Bouzas, Larios,
Physical Review D 88, 094007 (2013)

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



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

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



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

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

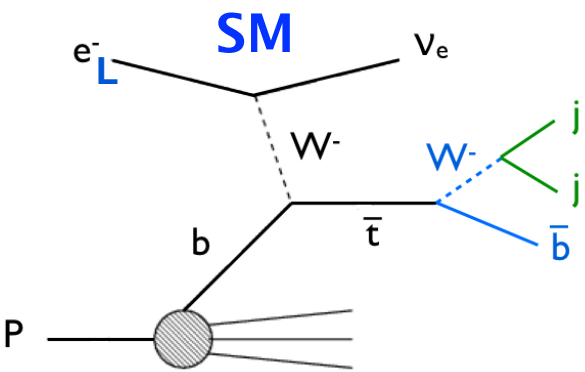
magnetic dipole moment: κ

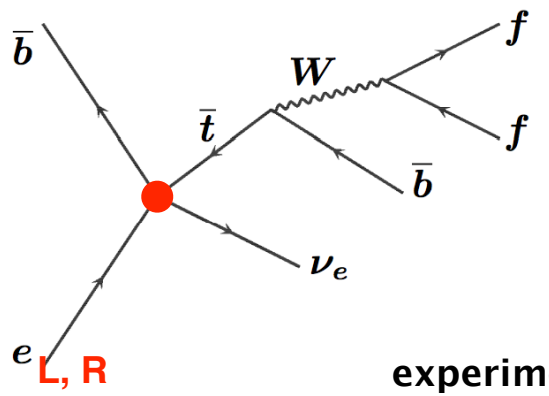
Bouzas, Larios,
Physical Review D 88, 094007 (2013)

Top Quark Dimension 6 Operators

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

Λ=1TeV





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

Sarmiento-Alvarado, Bouzas, Larios, arXiv:1412.6679

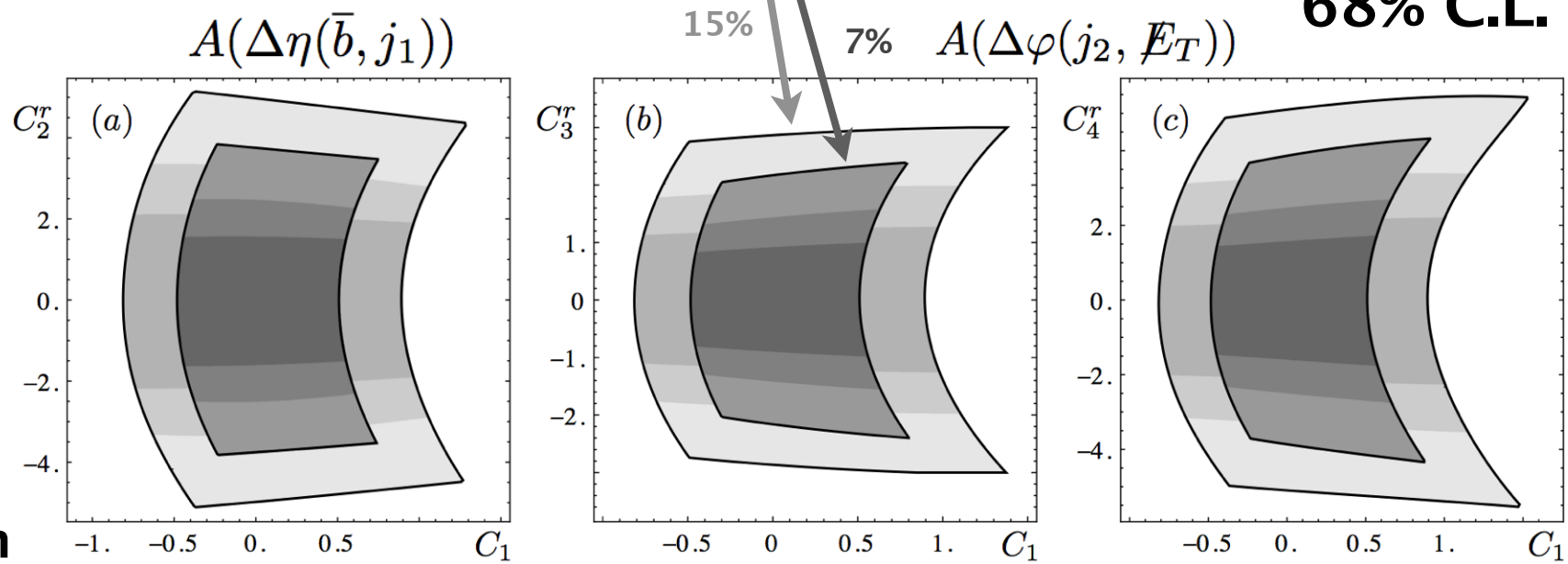
experimental error

68% C.L.

$\mathcal{P}_e = 0$

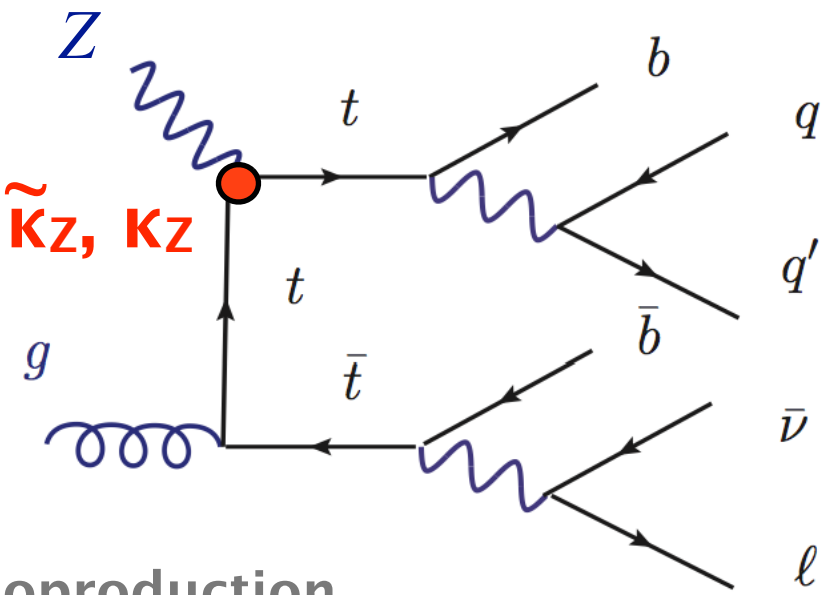
$\mathcal{P}_e = 0.4$

$\mathcal{P}_e = 0.7$



cross section

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

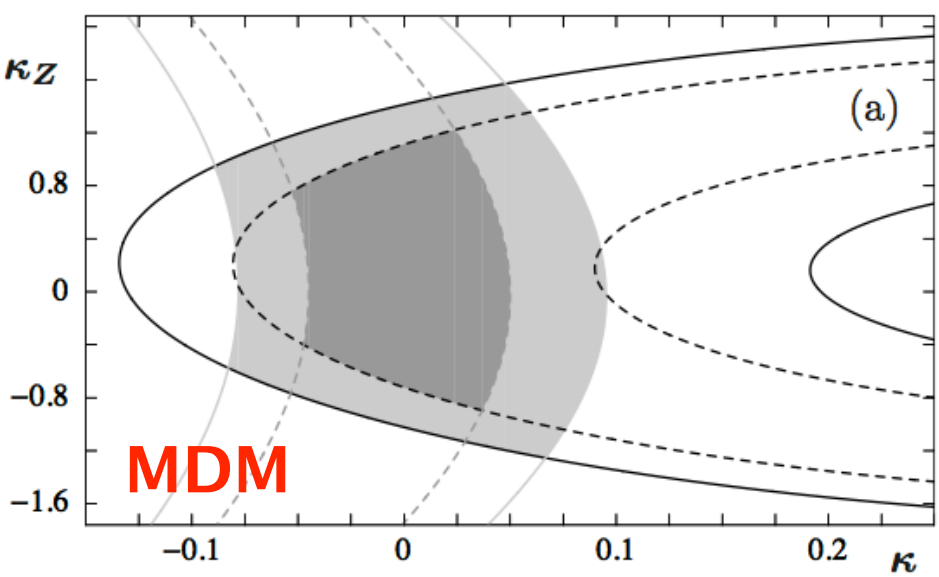


$t\bar{t}$ photoproduction

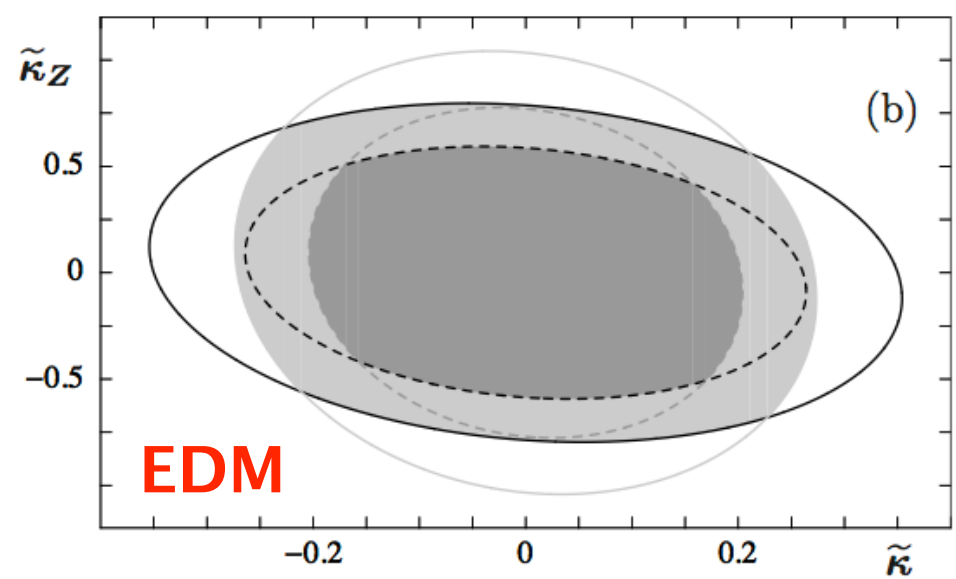
Bouzas, Larios,
Physical Review D 88, 094007 (2013)

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

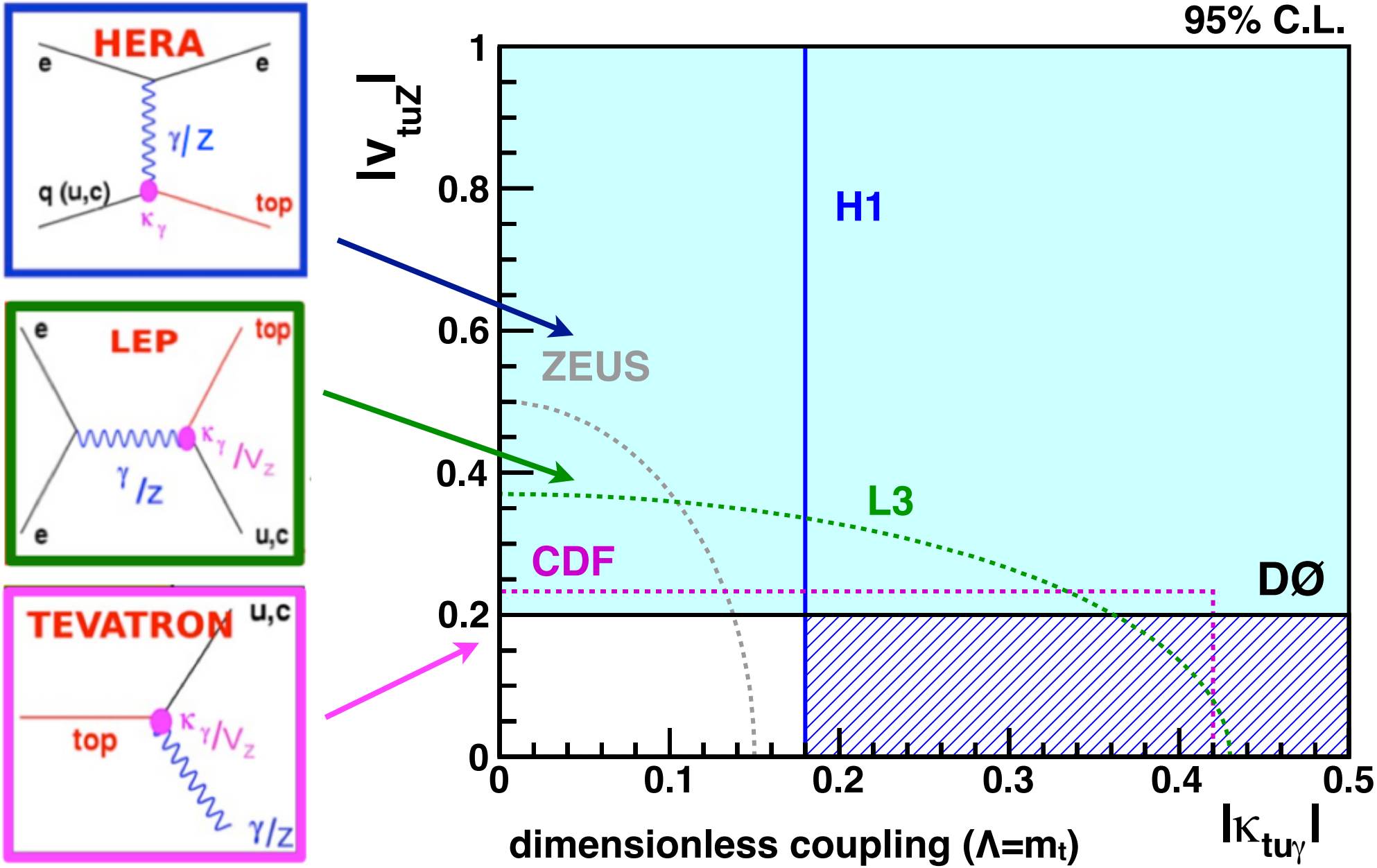
LHeC:
10% and 18% accuracy



$t\bar{t}$
DIS

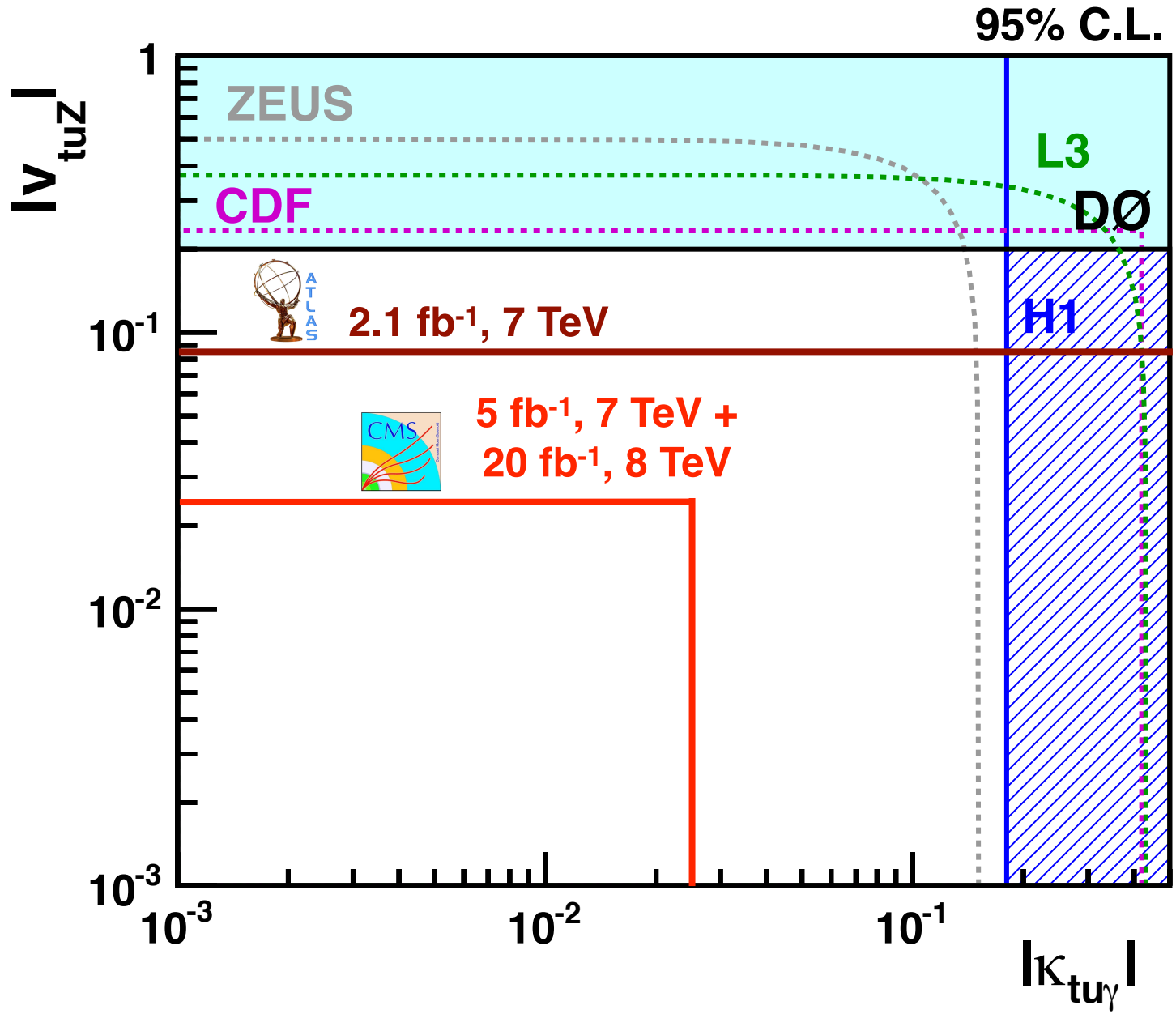


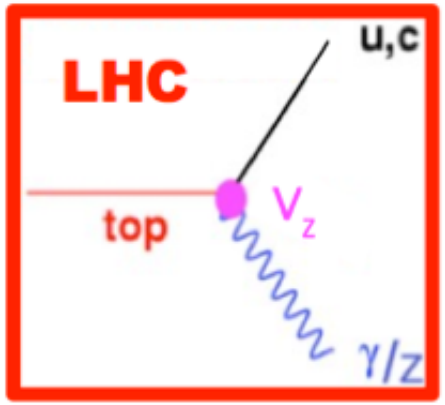
FCNC Top Couplings at Colliders



FCNC Top Couplings at Colliders

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





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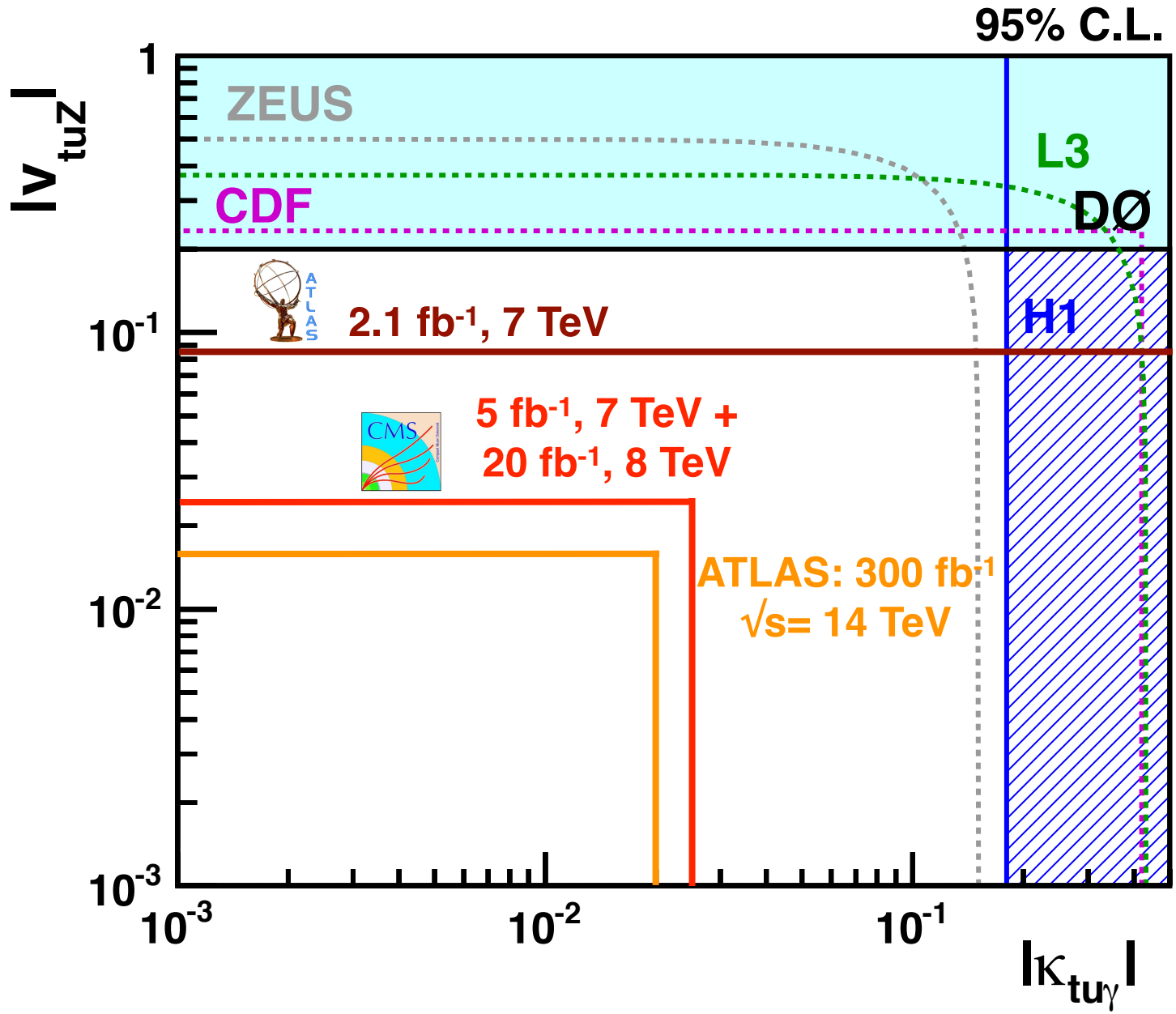
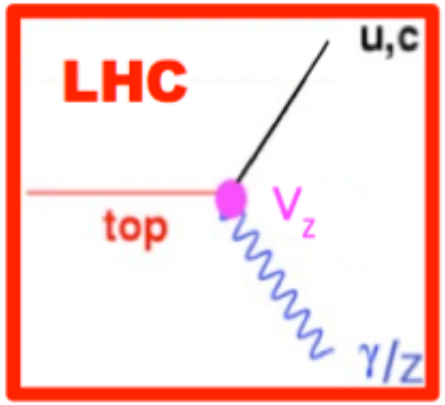
Top Quark Working Group Collaboration, arXiv:1311.2028 [hep-ph]





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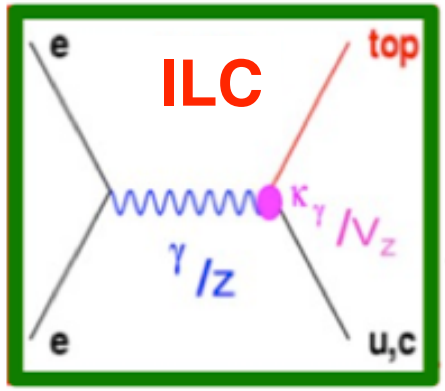
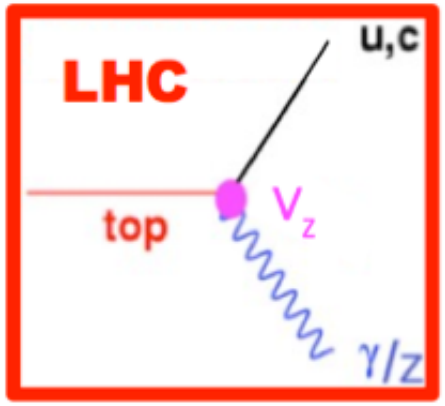
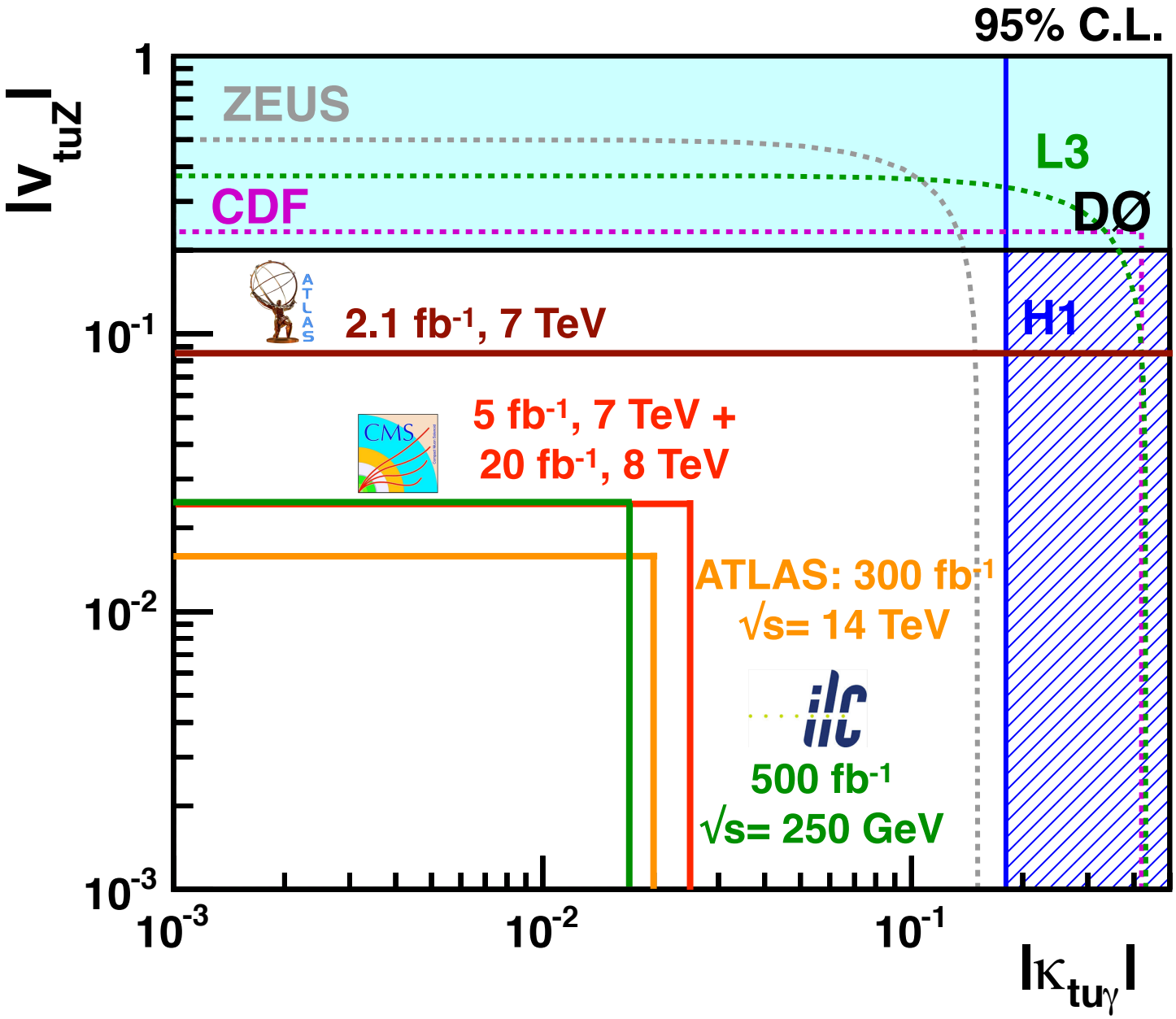
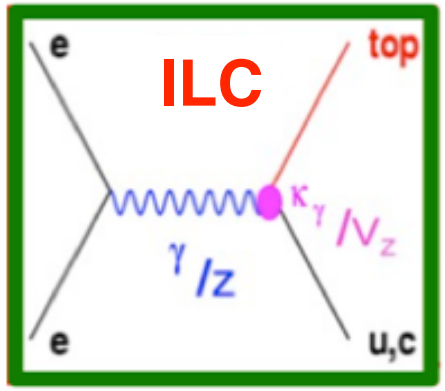
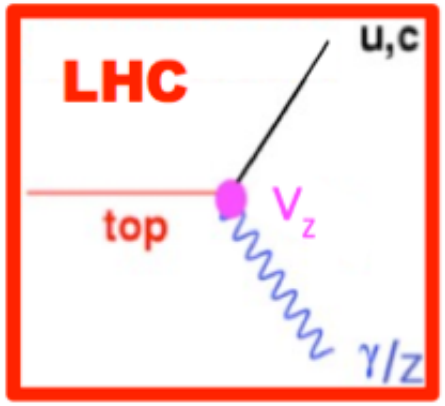


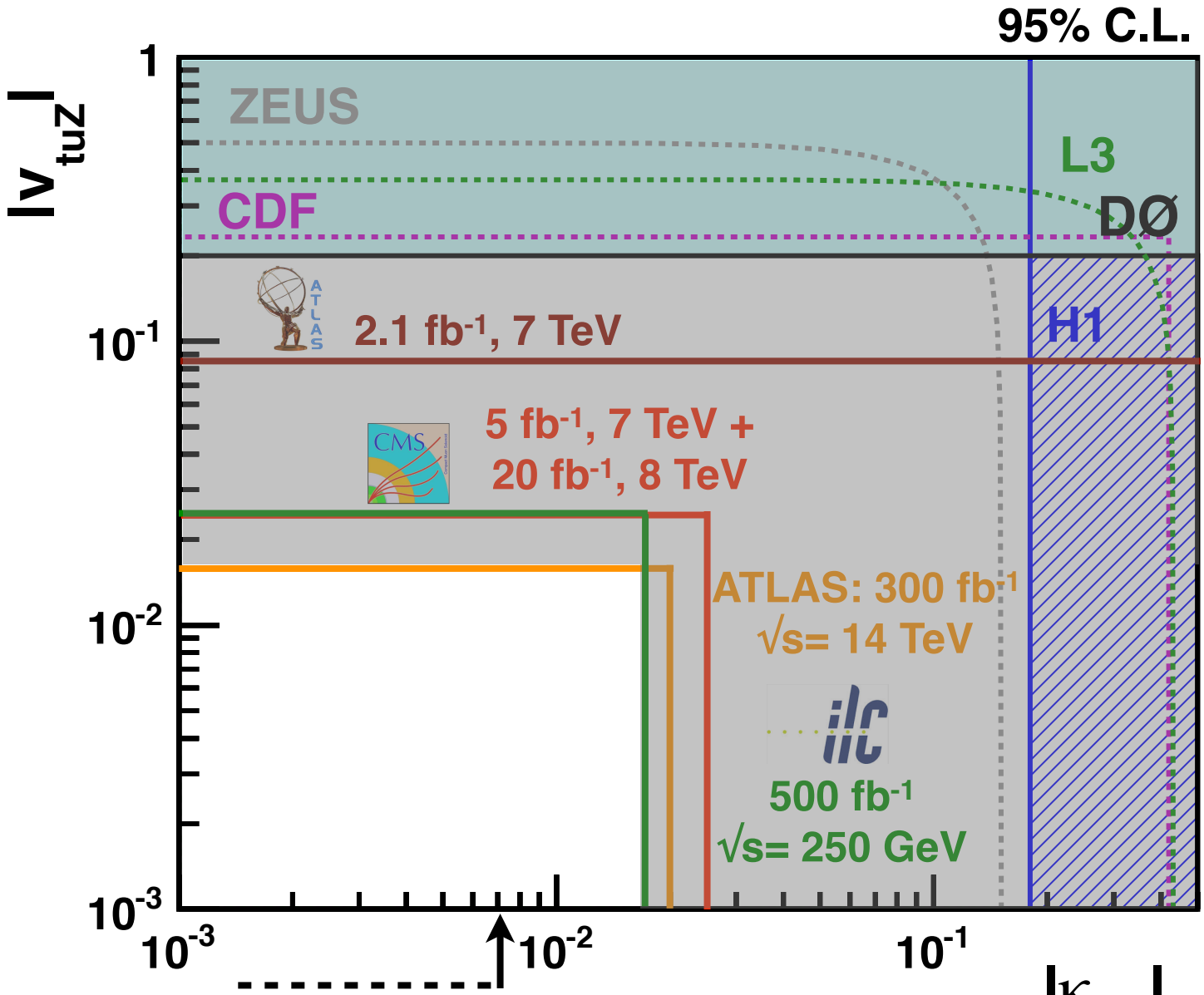




FCNC Top Couplings at Colliders

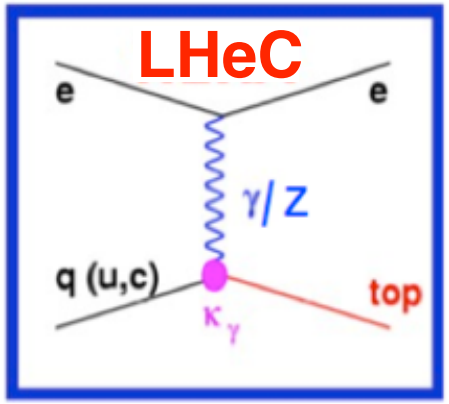


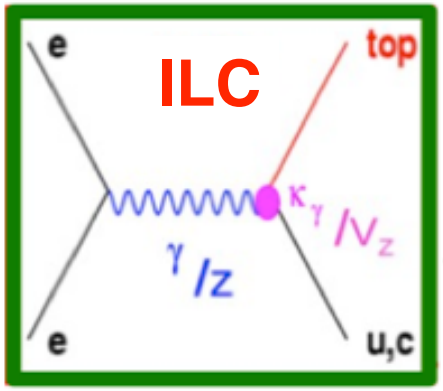


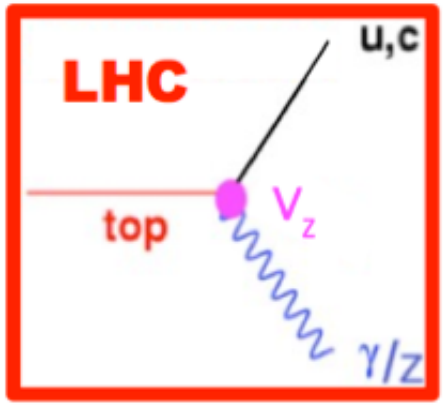


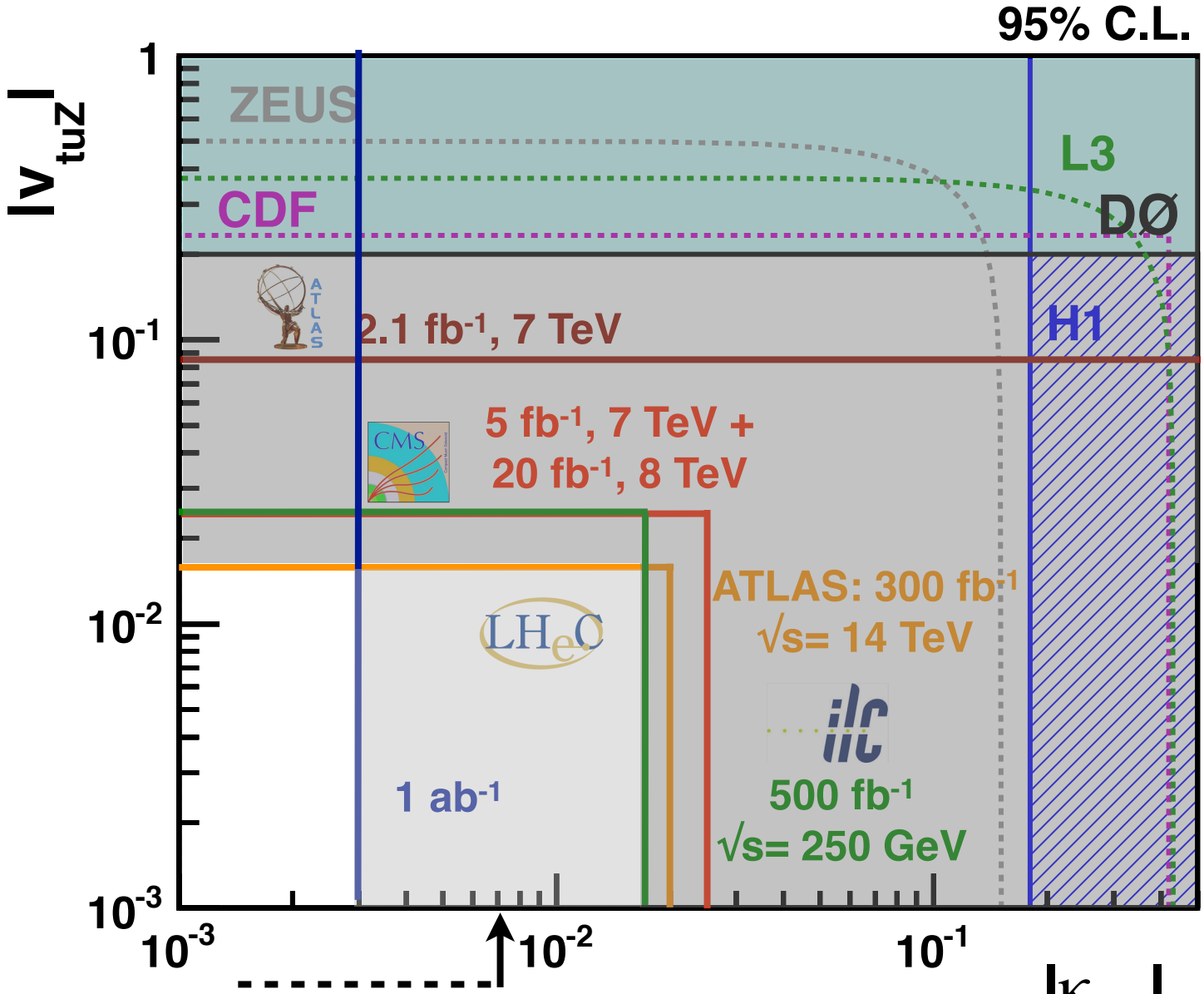
→ test SUSY, little Higgs, technicolor...

FCNC Top Couplings at Colliders



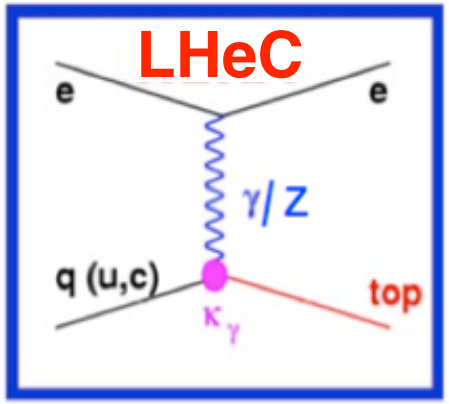


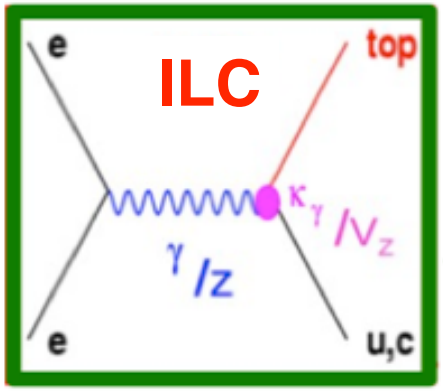


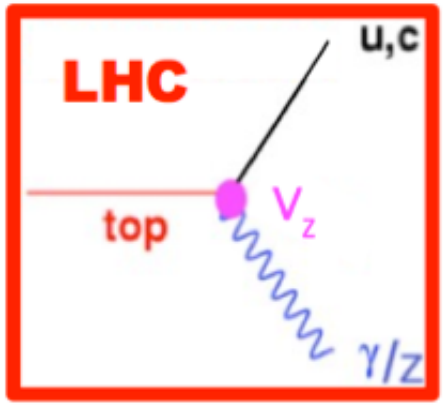


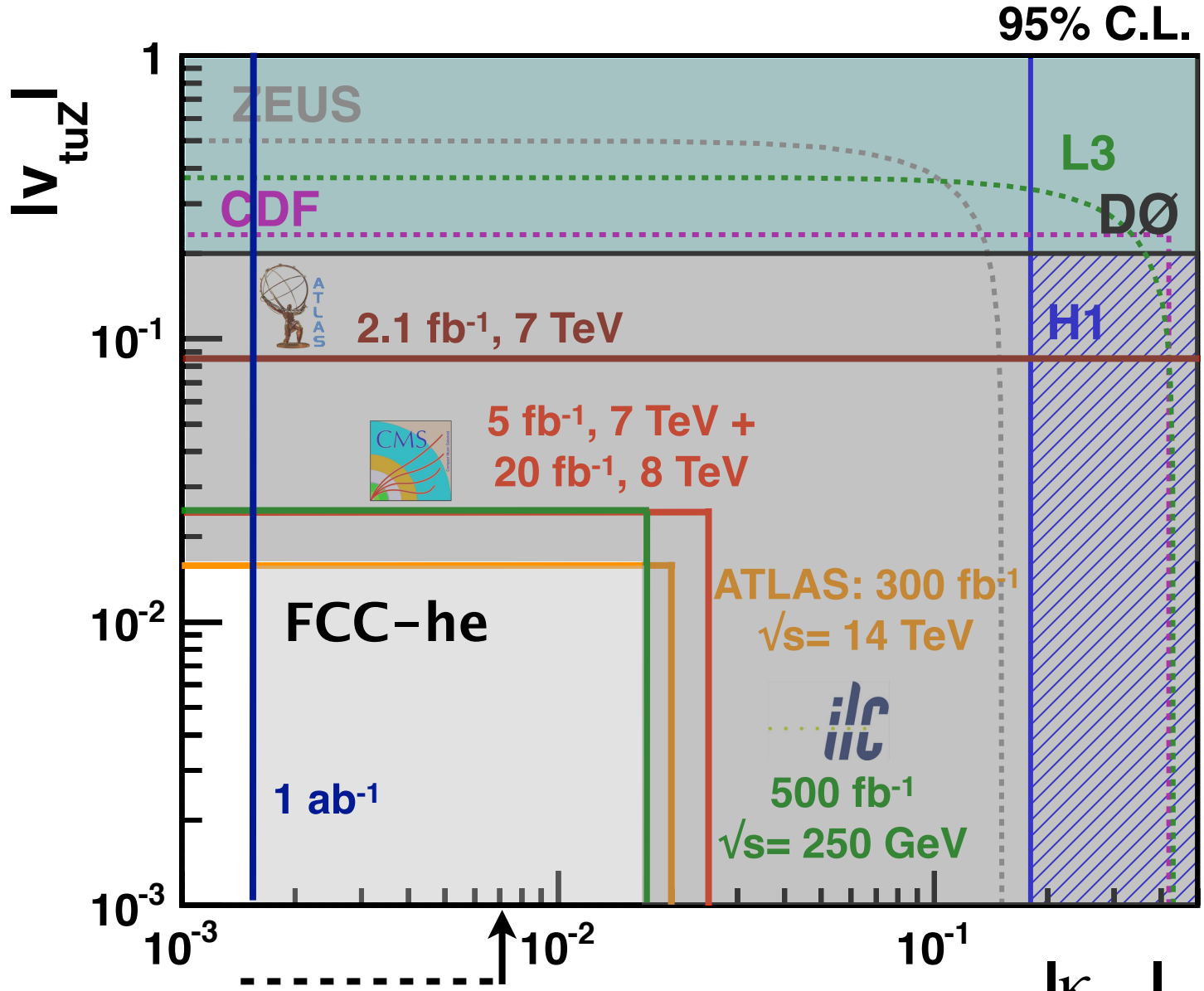
→ test SUSY, little Higgs, technicolor...

FCNC Top Couplings at Colliders



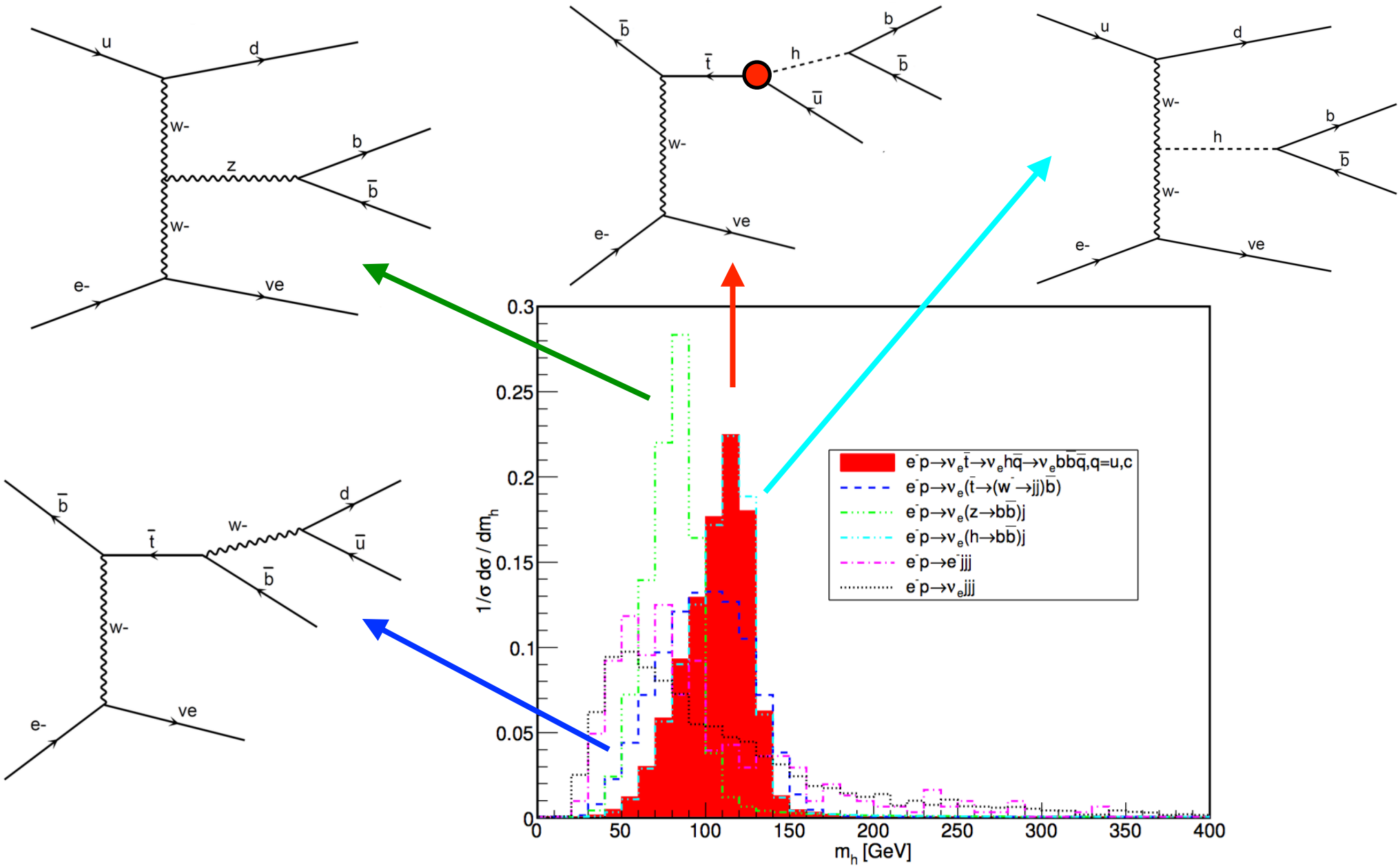




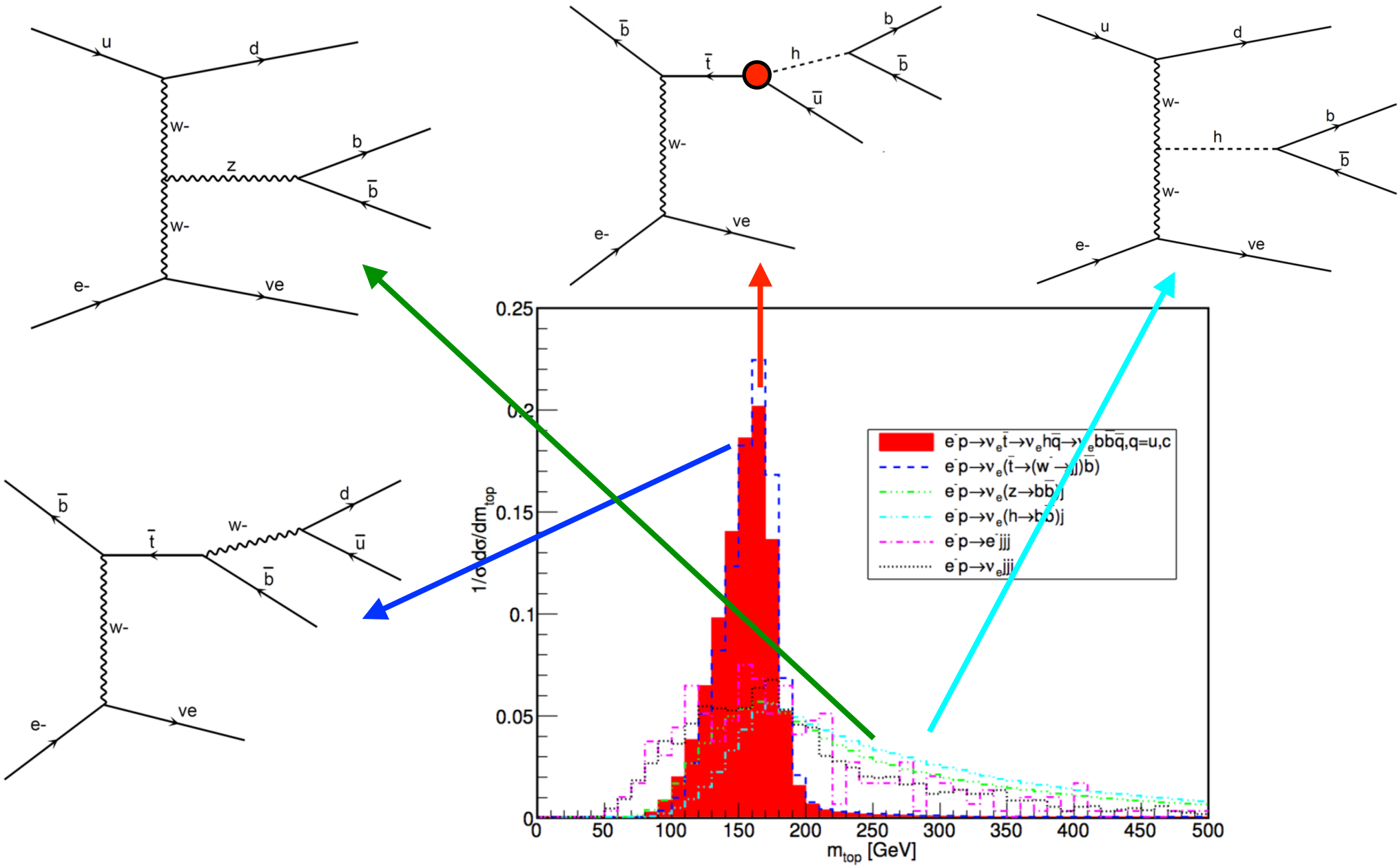


→ test SUSY, little Higgs, technicolor...

Reconstructed Higgs mass



Reconstructed top quark mass



Searches for RPV SUSY and stops

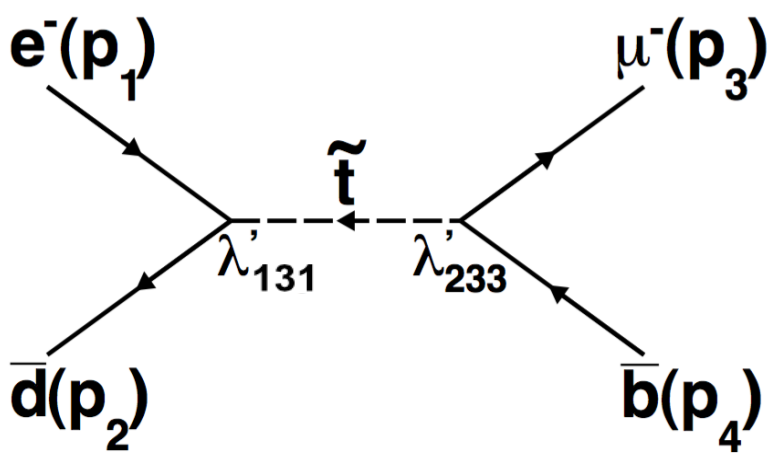
L-number violating terms

$$W_{\not{R}p} = \lambda_{ijk}\hat{L}_i\hat{L}_j\hat{E}^C_k + \lambda'_{ijk}\hat{L}_i\hat{Q}_j\hat{D}^C_k + \epsilon_i\hat{L}_i\hat{H}_u + \lambda''_{ijk}\hat{U}^C_i\hat{D}^C_j\hat{D}^C_k$$

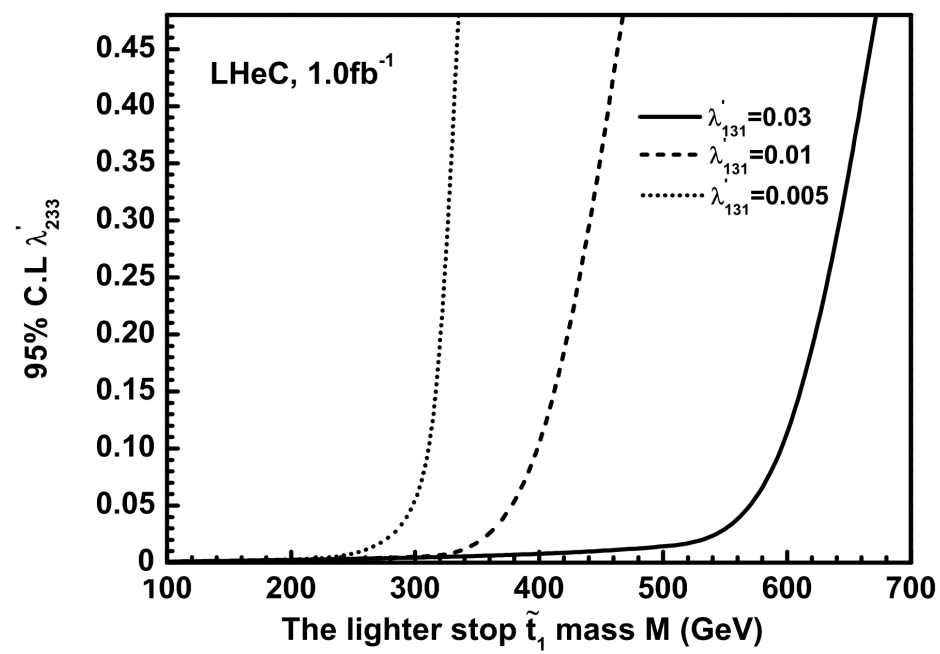
bilinear terms

B-number violating terms

ΔL =1, 9 λ couplings, 27 λ' couplings



similar to leptoquark searches with generation mixing



→ very promising with high luminosity

→ **RPV can be probed at unprecedented levels**