Top Quark Physics in FCC-ep

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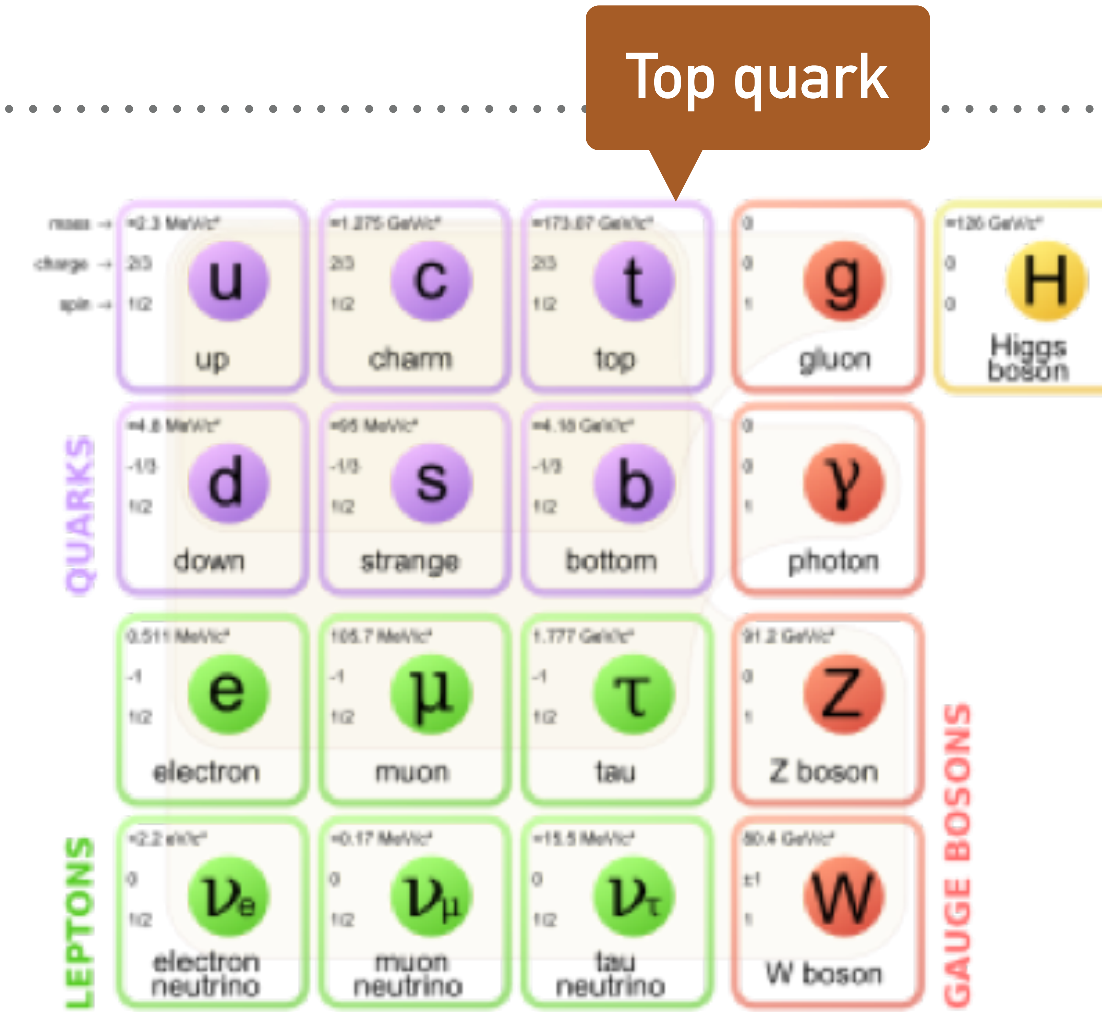
1st FCC Physics Workshop, 16-20 January 2017, CERN

OUTLINE

- Top Quark Weak Interactions
- Top Quark Anomalous Interactions
- Searches For Top Quark FCNC Interactions
- Conclusions

TOP QUARK PHYSICS

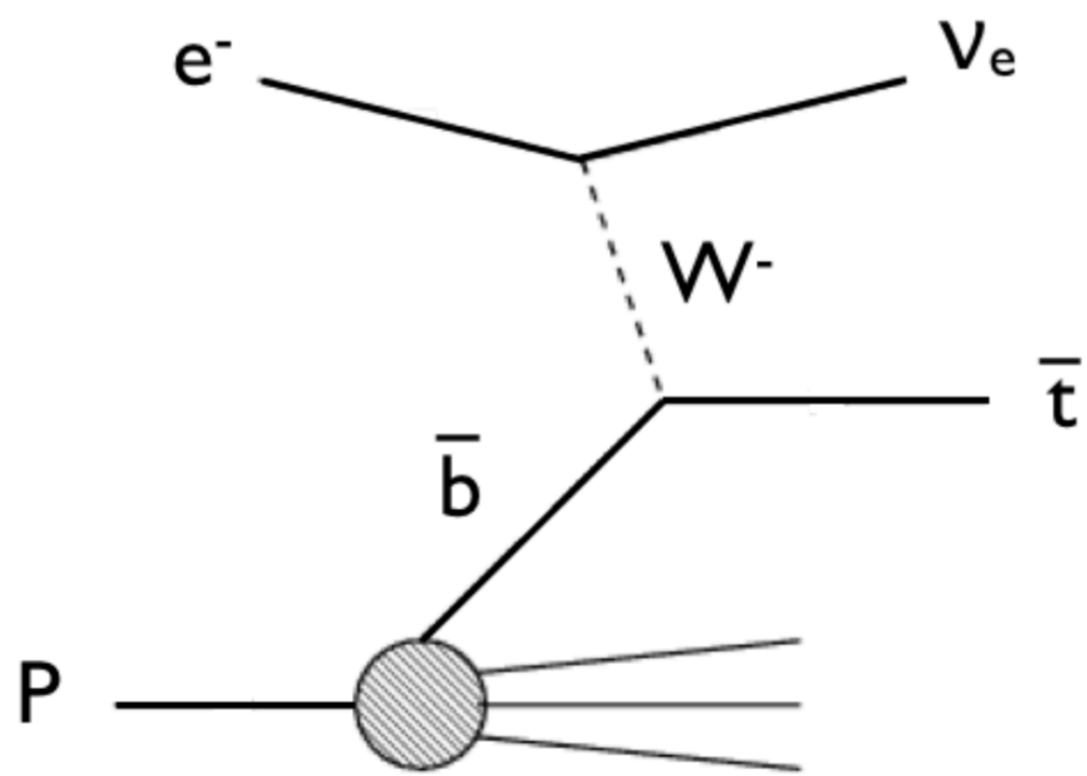


Precise measurements of couplings between SM gauge bosons and quarks and leptons are sensitive test of new physics (search for deviations), **top quark** is expected to be the most sensitive to BSM physics, due to its large mass.

The single top quark production is about three times less frequent in the LHC collisions, as the production mechanism involves the electroweak interaction, while top pairs can be readily produced by strong interaction processes.

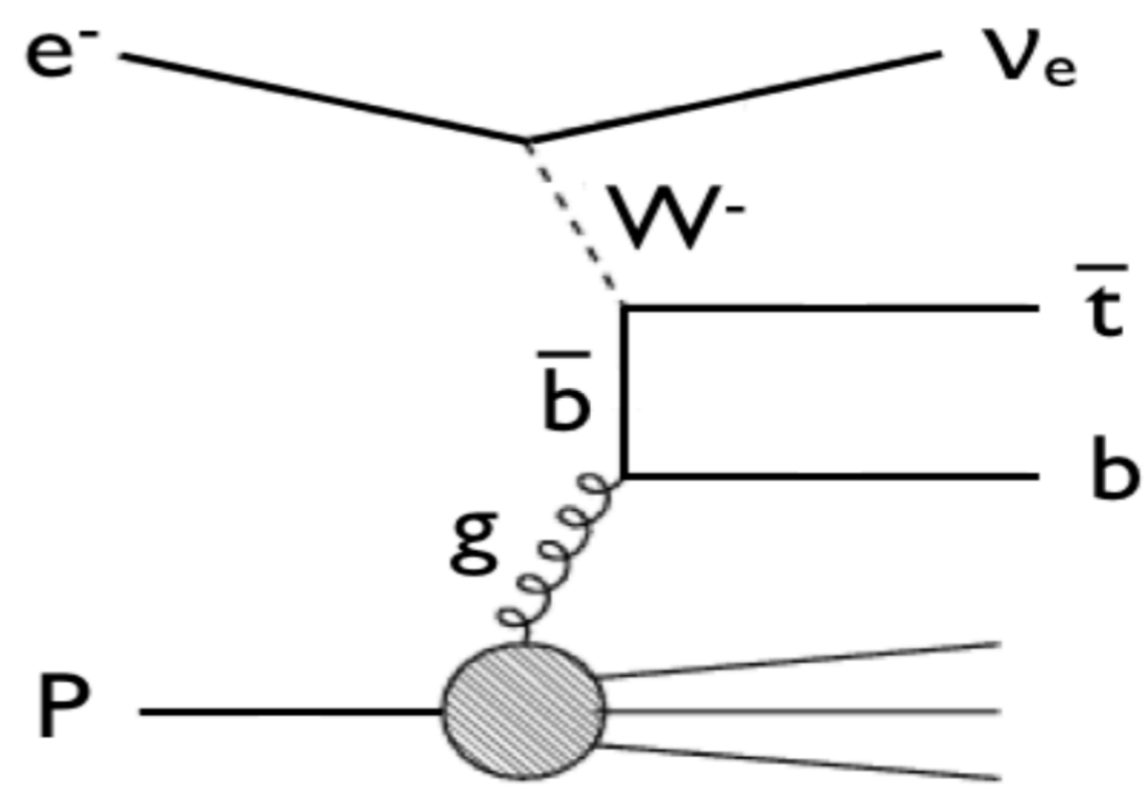
The future **ep** colliders offers excellent prospects for top physics.

TOP QUARK CC WEAK INTERACTIONS AT EP COLLIDERS



σ=*16.55 pb*

at FCC-ep



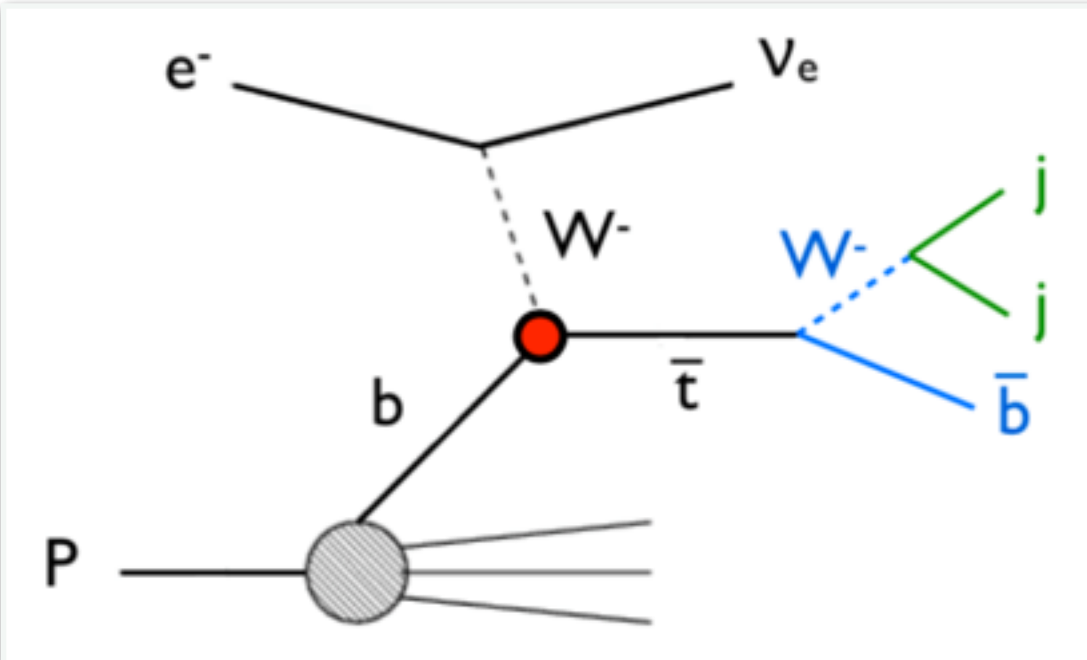
σ=*14.26 pb*

at FCC-ep

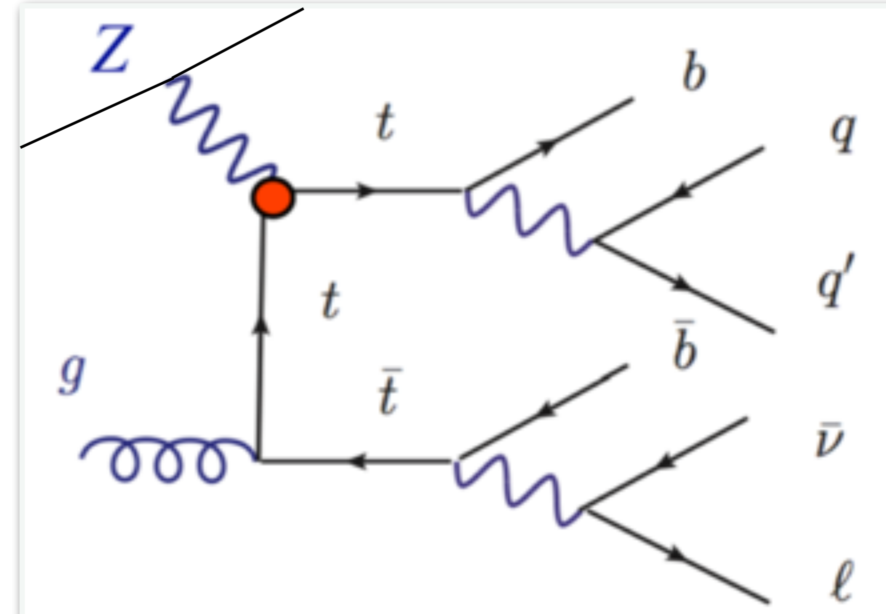
Future ep collider is ideal to study CC interactions of the top quark via single production.

TOP QUARK ANOMALOUS INTERACTIONS

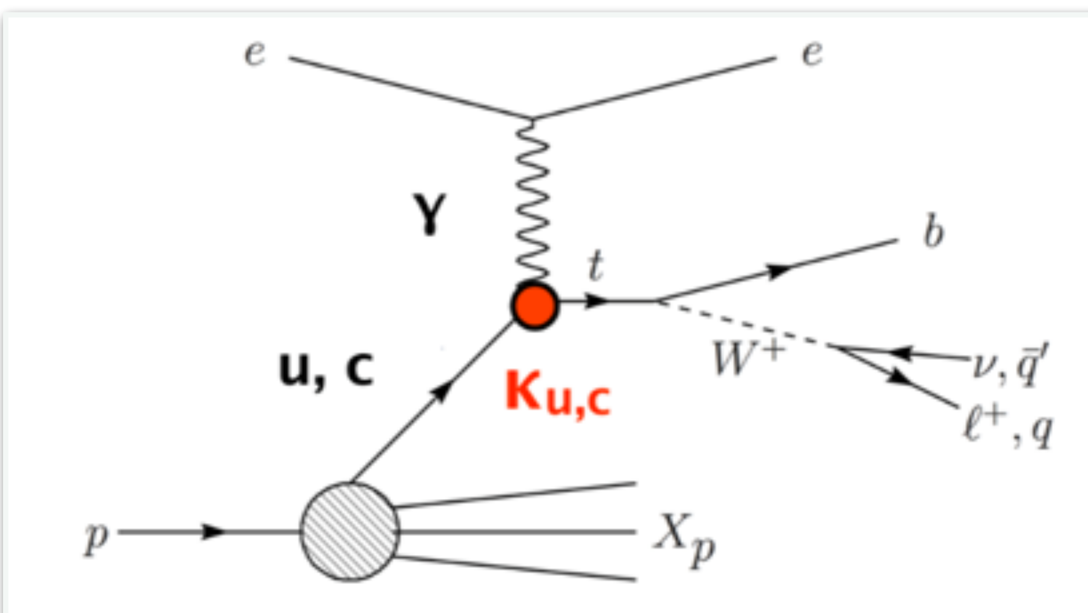
C. Schwanenberger
@DIS2015



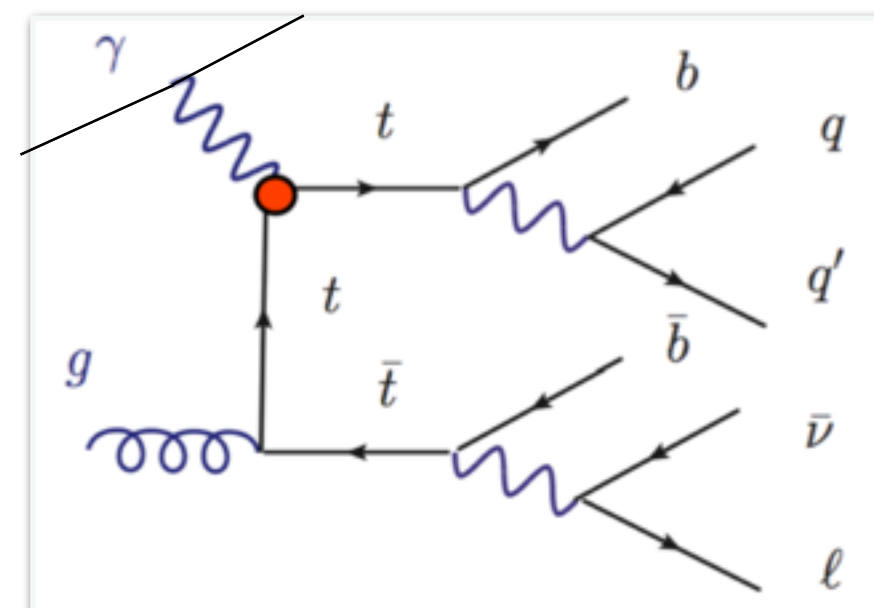
High precision measurements of V_{tb} and search for anomalous Wtb couplings



Measurement of top isospin and anomalous ttZ (EDM, MDM)



Sensitive search for FCNC couplings will constrain BSM models

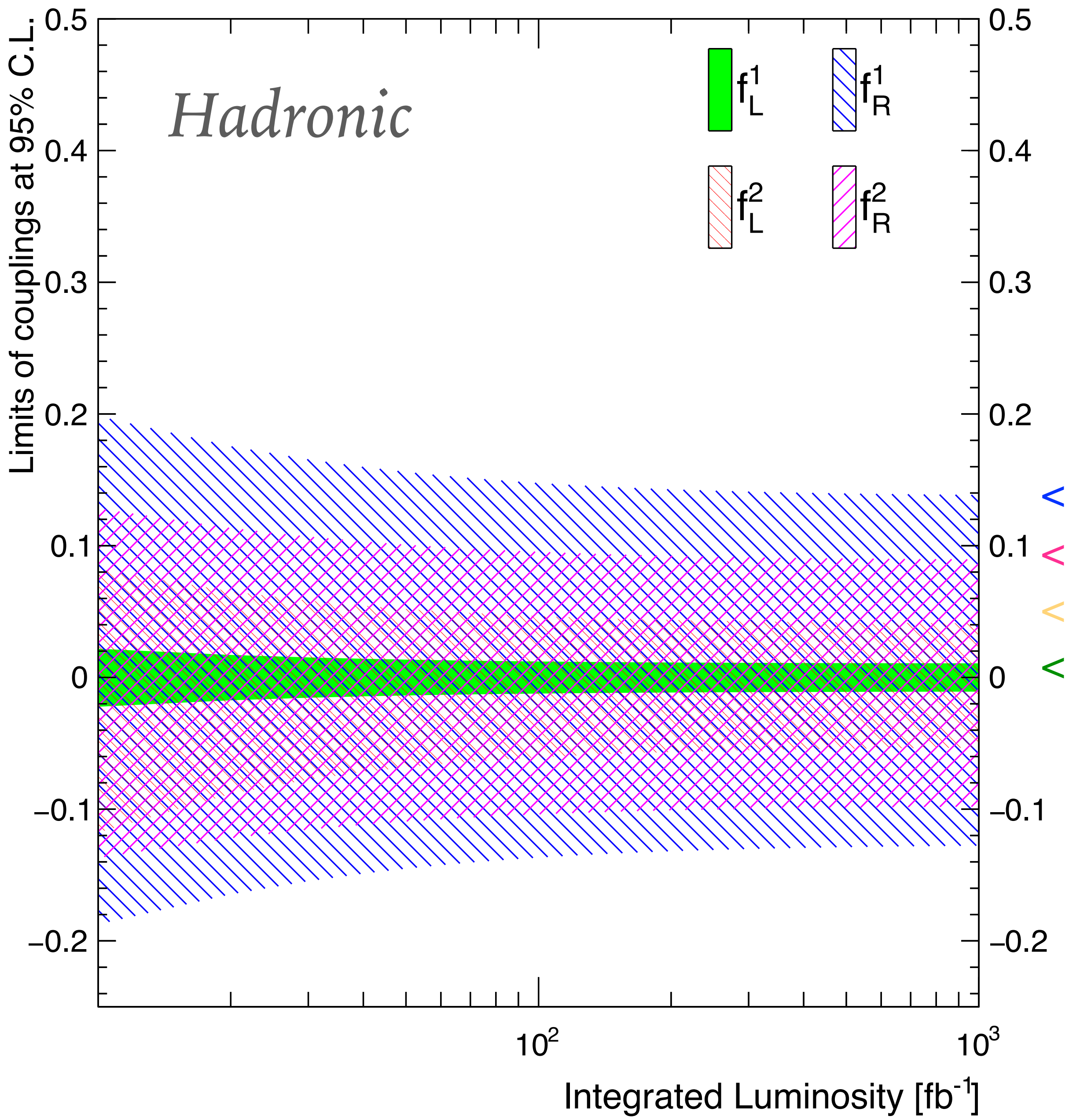


Measurement of top charge and anomalous ttγ (EDM, MDM)

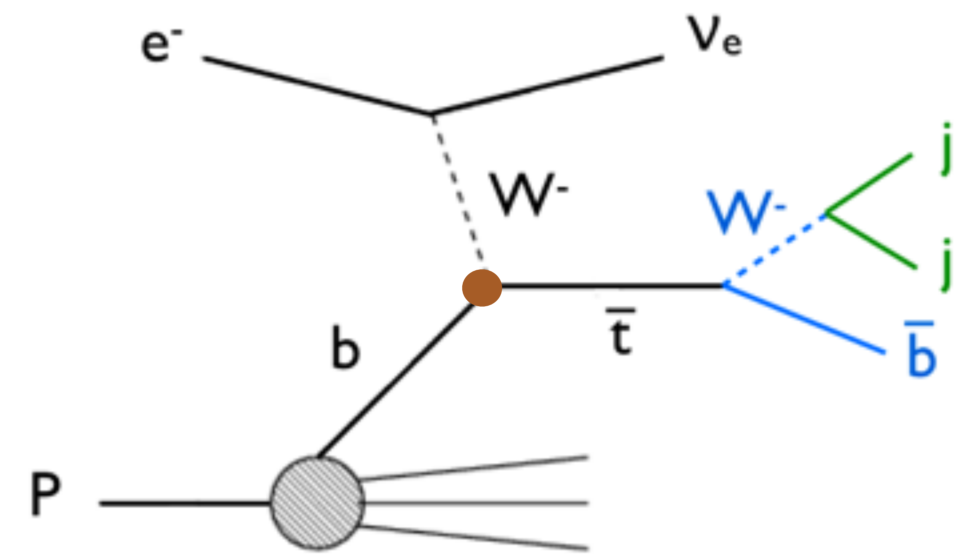
TOP QUARK ANOMALOUS INTERACTIONS

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

The updated plots for FCC-eh (a conservative estimate). The errors are systematically limited (assumed to be similar for LHeC and FCC-eh). A better sensitivity to the hadronic channel.



< 0.14
< 0.09
< 0.04
< 0.01



vector/right coupling = 0 in SM

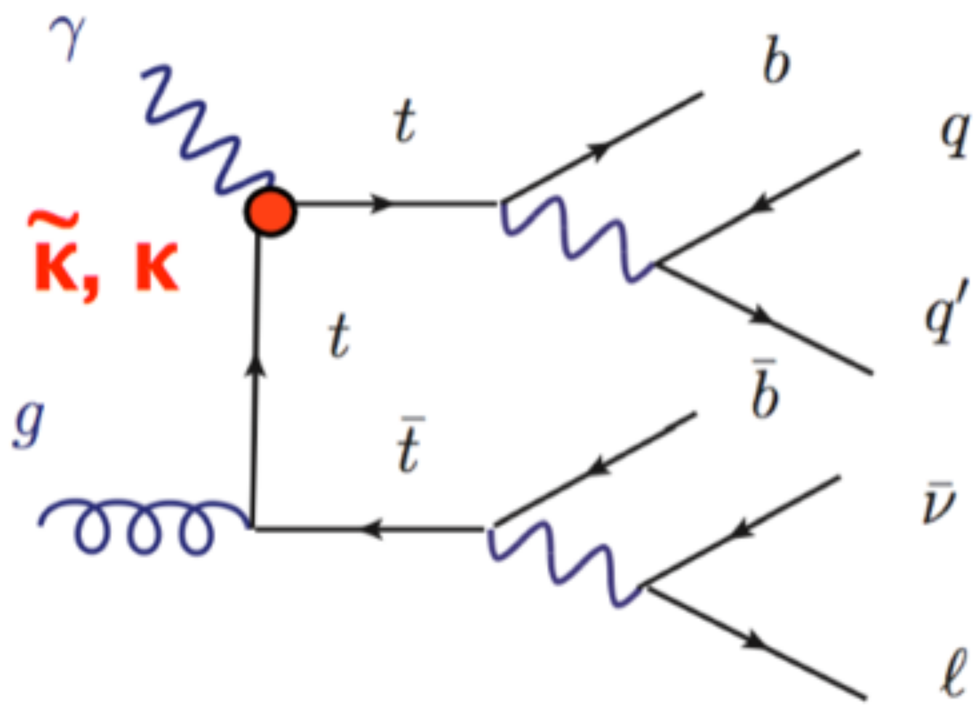
$$\mathcal{L}_{Wtb} = \frac{g}{\sqrt{2}}\left[W_\mu \bar{t}\gamma^\mu (V_{tb} f_1^L P_L + f_1^R P_R) b - \frac{1}{2\, m_W} W_{\mu\nu}\bar{t}\sigma^{\mu\nu}(f_2^L P_L + f_2^R P_R) b\right] + h.c.$$

vector/left coupling = 1 in SM

Tensor/left/right couplings

TOP EDM AND MDM

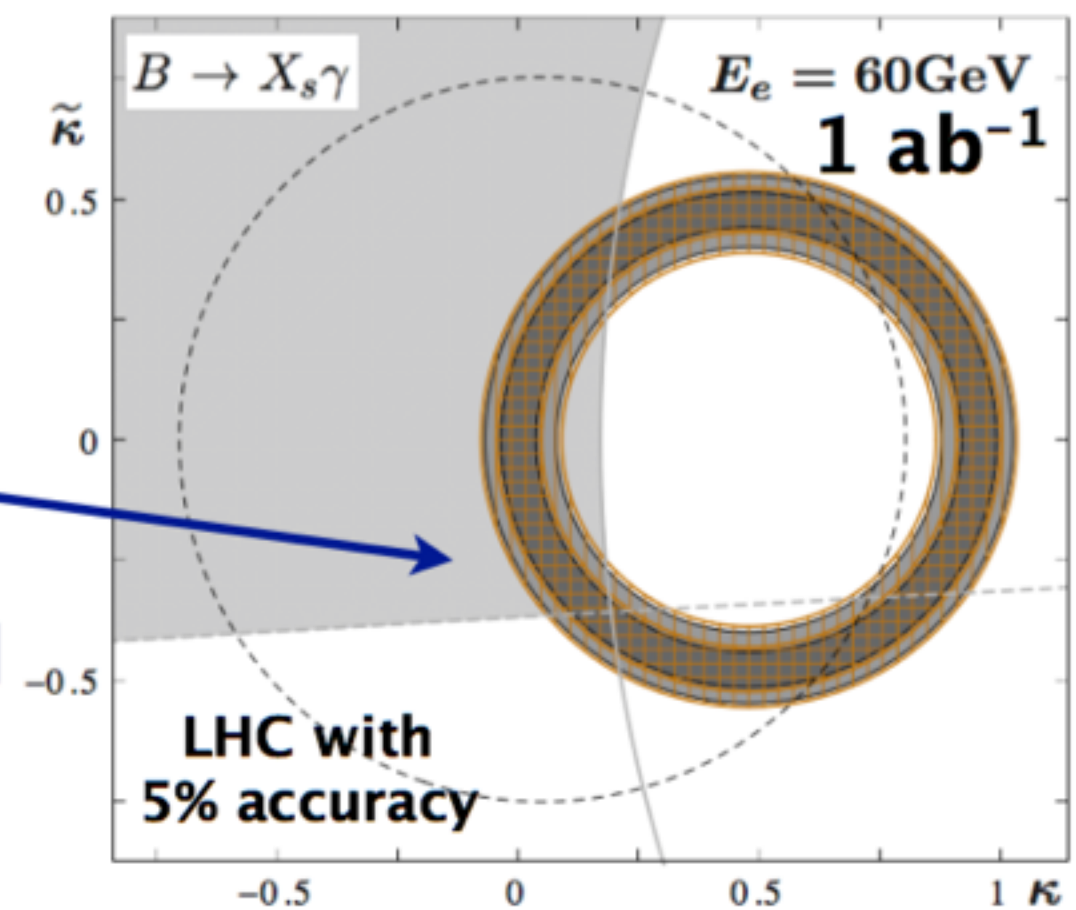
- the results can also be applied conservatively to the FCC-ep.



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

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

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

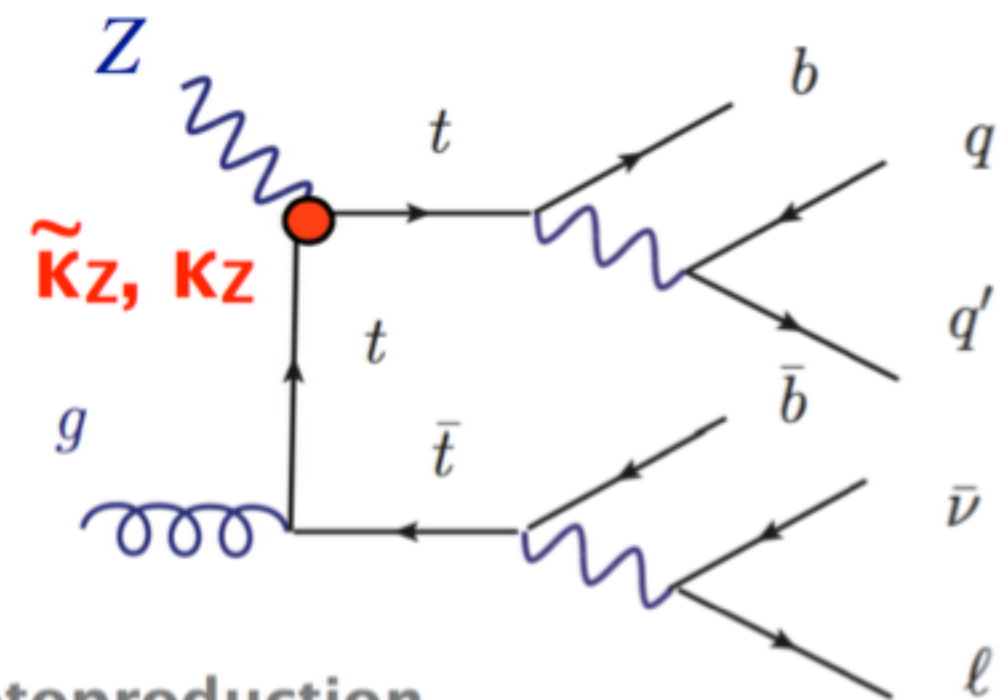


magnetic dipole moment: κ

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

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

TOP EDM AND MDM

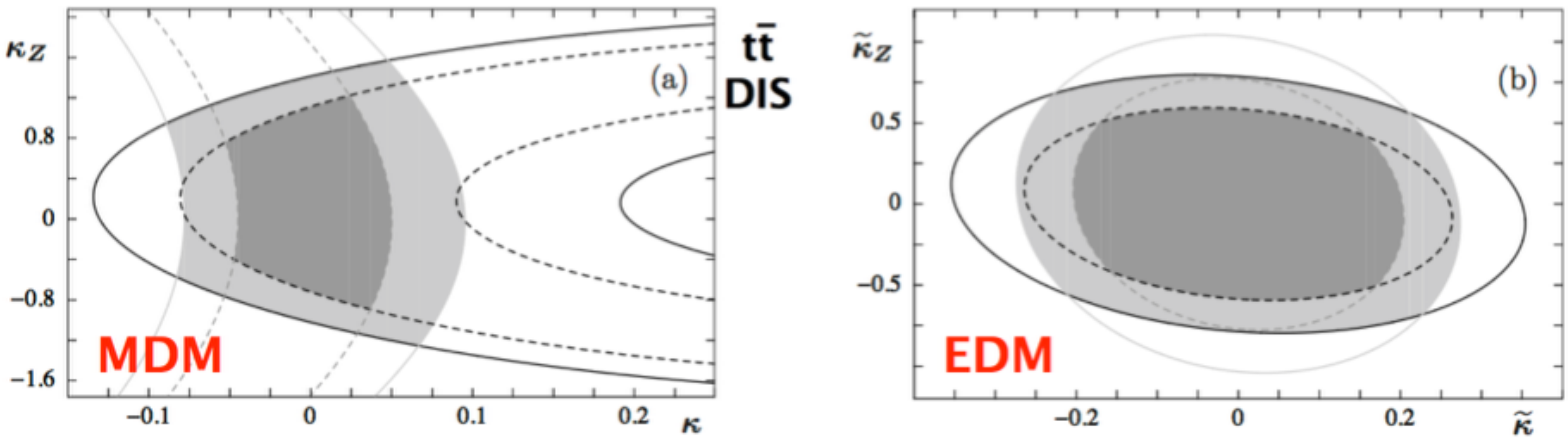


Bouzas, Larios,
Physical Review D 88, 094007 (2013)

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

$t\bar{t}$ photoproduction

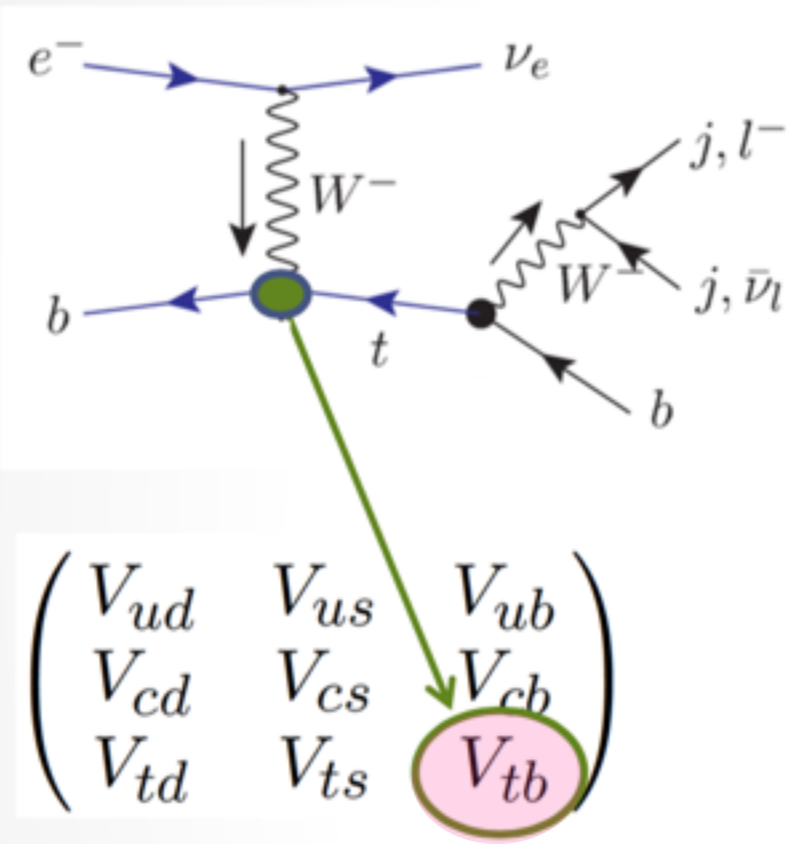
LHeC:
10% and 18% accuracy

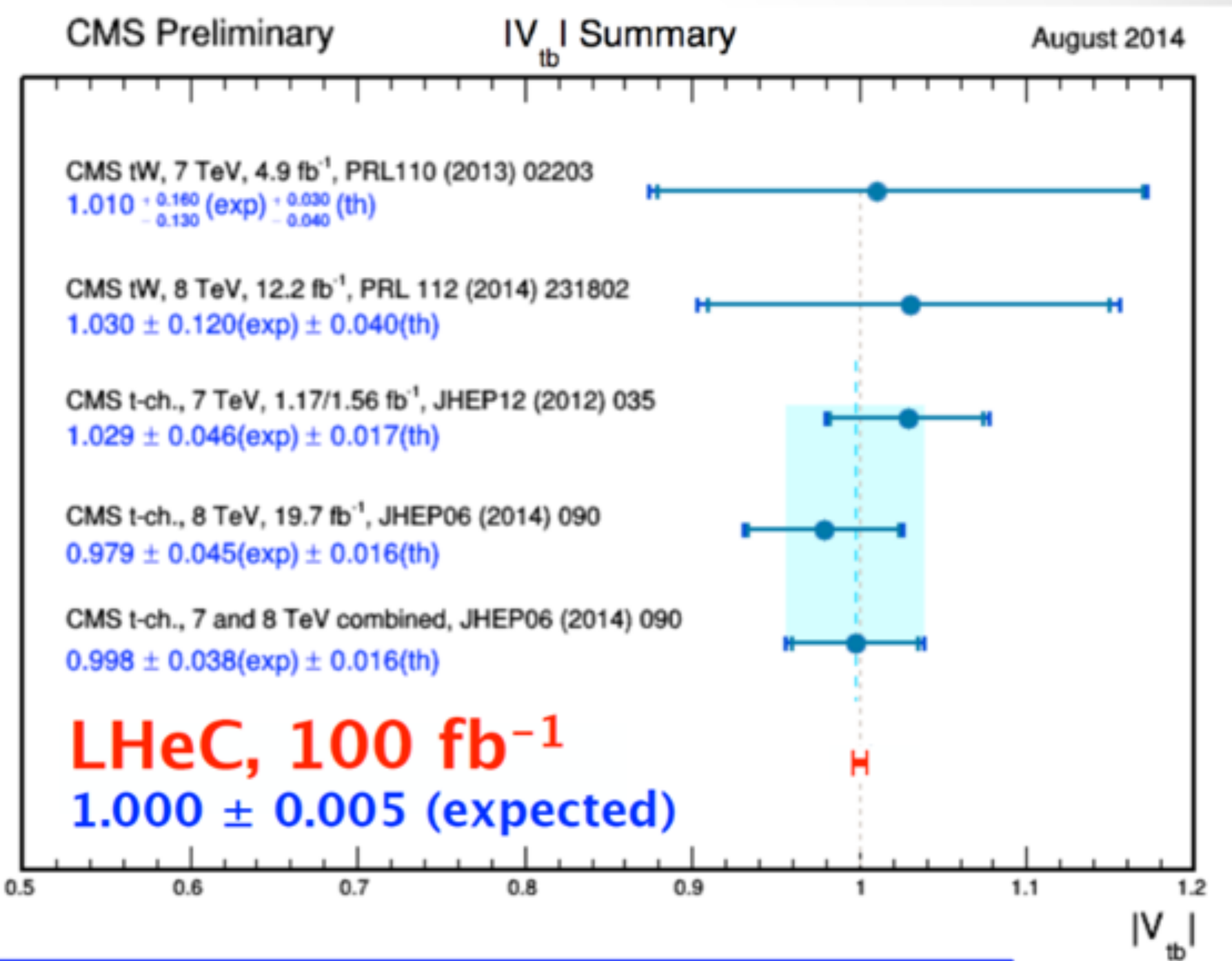


MEASUREMENT OF Vtb

➤ the results can also be applied conservatively to the FCC-ep.

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





e beam: 60 GeV

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

HAD: N_t = 22000, S/B=1.2

LEP: N_t = 11000, S/B=11

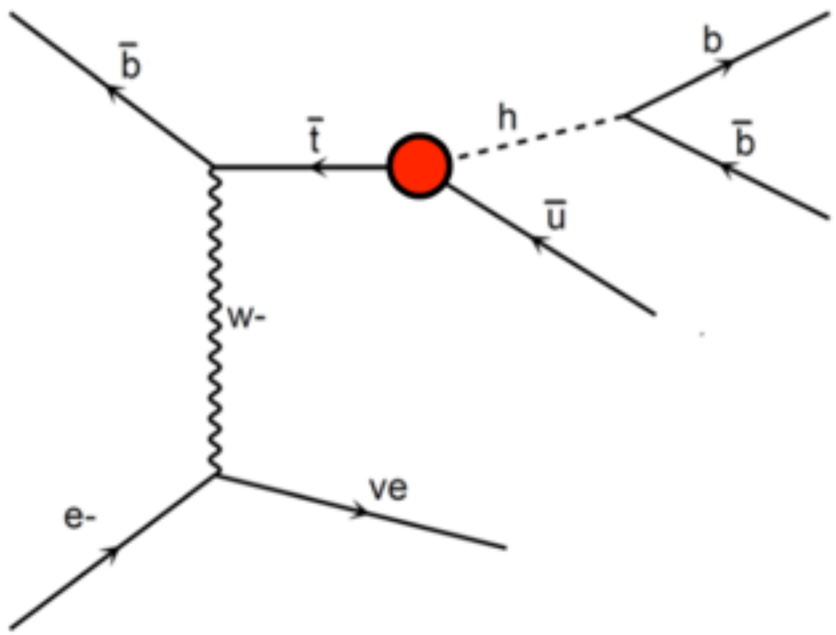
LHeC: very high precision measurement

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

ANOMALOUS FCNC TOP-HIGGS COUPLINGS

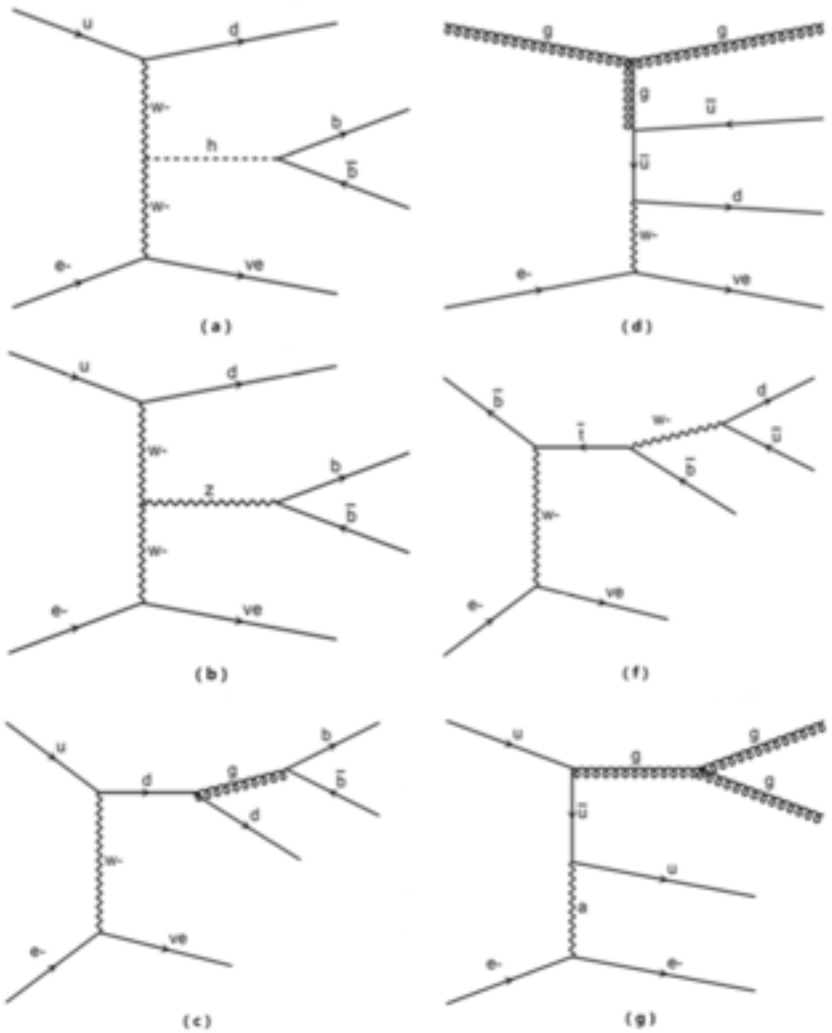
C. Schwanenberger
@ICHEP2016

signal



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

background



irreducible backgrounds:

$$e^- p \to \nu_e (h \to b\bar{b}) j$$
$$e^- p \to \nu_e (z \to b\bar{b}) j$$
$$e^- p \to \nu_e (g \to b\bar{b}) j$$

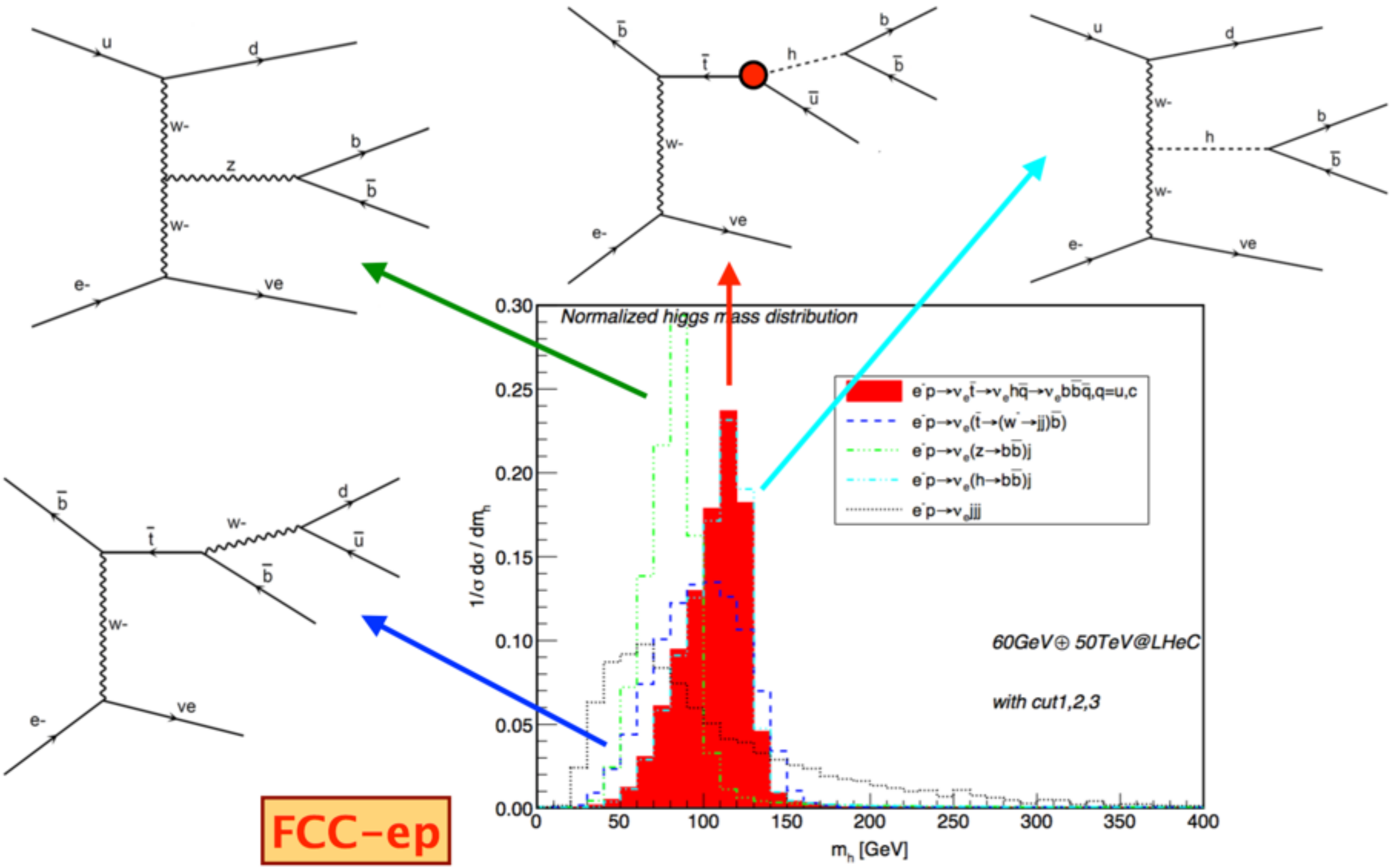
reducible backgrounds:

$$e^- p \to \nu_e jjj$$
$$e^- p \to \nu_e jjb/\bar{b}$$
$$e^- p \to \nu_e \bar{t}$$
$$e^- p \to e^- jjj$$
$$e^- p \to e^- jjb/\bar{b}$$
$$e^- p \to e^- (g \to b\bar{b}) j$$

- parametrised assumed resolutions for elecrons/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

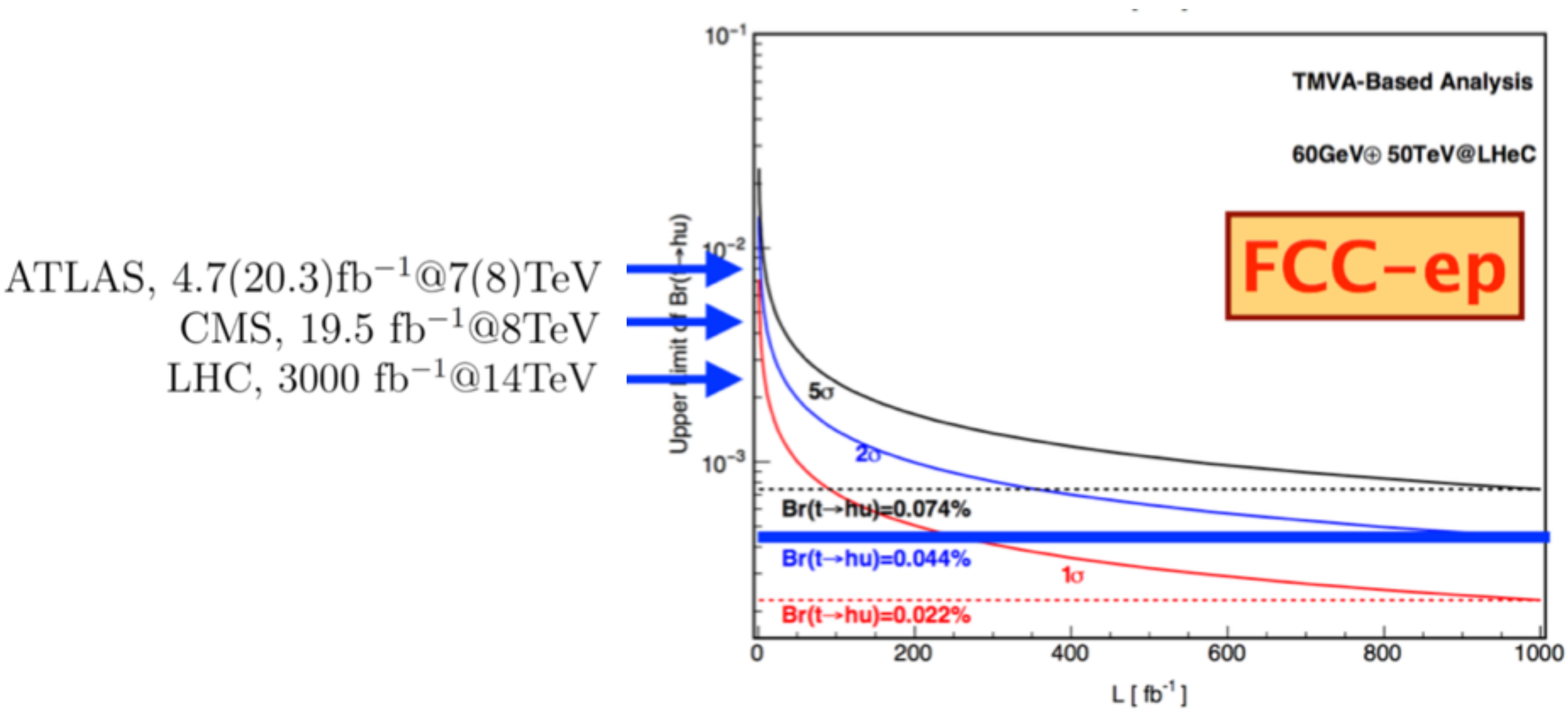
ANOMALOUS FCNC TOP-HIGGS COUPLINGS

C. Schwanenberger
@ICHEP2016



UPPER LIMITS ON BRANCHINGS

C. Schwanenberger @ICHEP2016



→ **improves sensitivity of HL−LHC**

TOP QUARK FCNC INTERACTIONS

O.Cakir (AU), H.Denizli (AIBU), A.Senol (AIBU),
A.Yilmaz (GU), I.Turk Cakir (GU), H.Karadeniz (GU),
1st FCC Physics Workshop, 16-20 Jan 2017, CERN

- The top quark FCNC interactions would be a good test of new physics at present and future colliders. These interactions can be described by the effective Lagrangian

$$\mathcal{L}_{FCNC} = \sum_{q=u,c} \frac{g_s}{2m_t}\bar{q}\lambda^a\sigma^{\mu\nu}(\zeta^L_{qt}P^L + \zeta^R_{qt}P^R)tG^a_{\mu\nu} - \frac{1}{\sqrt{2}}\bar{q}(\eta^L_{qt}P^L + \eta^R_{qt}P^R)tH -$$
$$-\frac{g_W}{2c_W}\bar{q}\gamma^\mu(X^L_{qt}P_L + X^R_{qt}P_R)tZ_\mu + \frac{g_W}{4c_W m_Z}\bar{q}\sigma^{\mu\nu}(K^L_{qt}P_L + K^R_{qt}P_R)tZ_{\mu\nu} +$$
$$+ \frac{e}{2m_t}\bar{q}\sigma^{\mu\nu}(\lambda^L_{qt}P_L + \lambda^R_{qt}P_R)tA_{\mu\nu} + H.c.$$

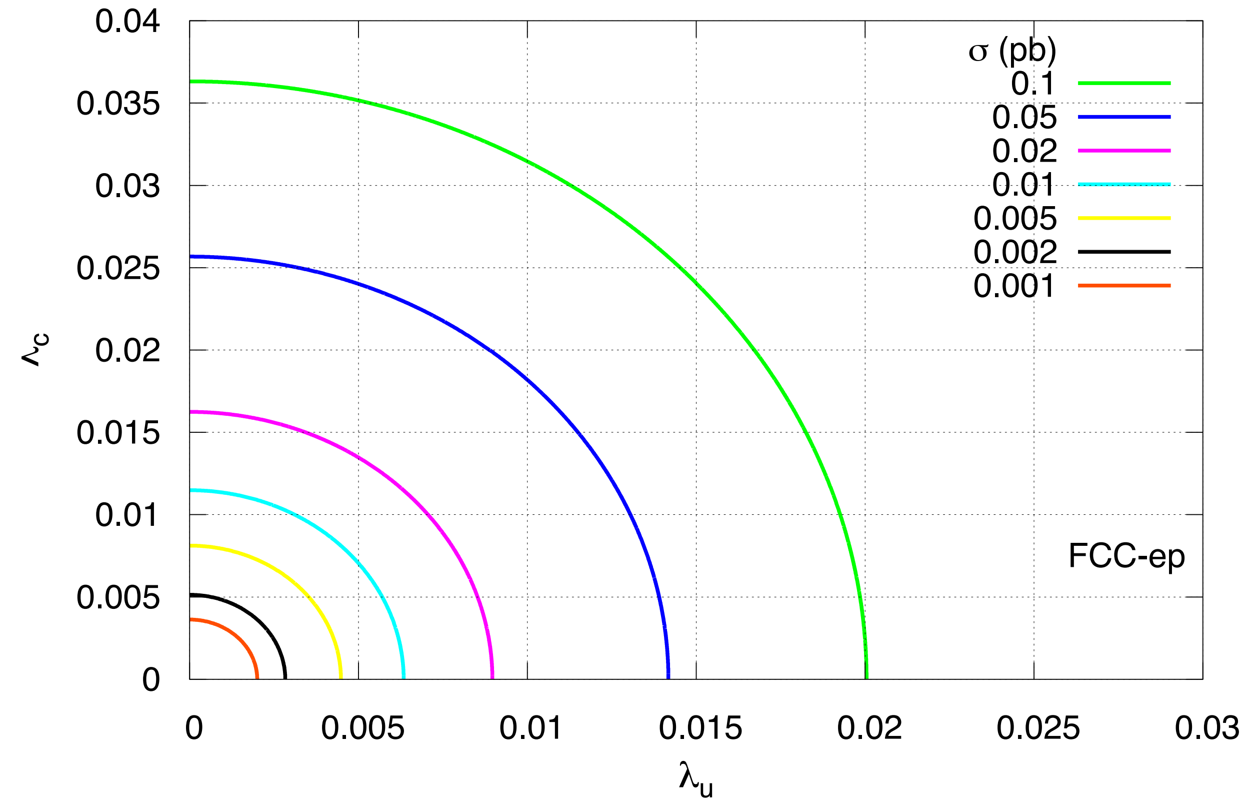
scaled to top mass

- *J.A.A-S, NPB812(2009)181*

Madgraph: model topFCNC_UFO from FeynRules

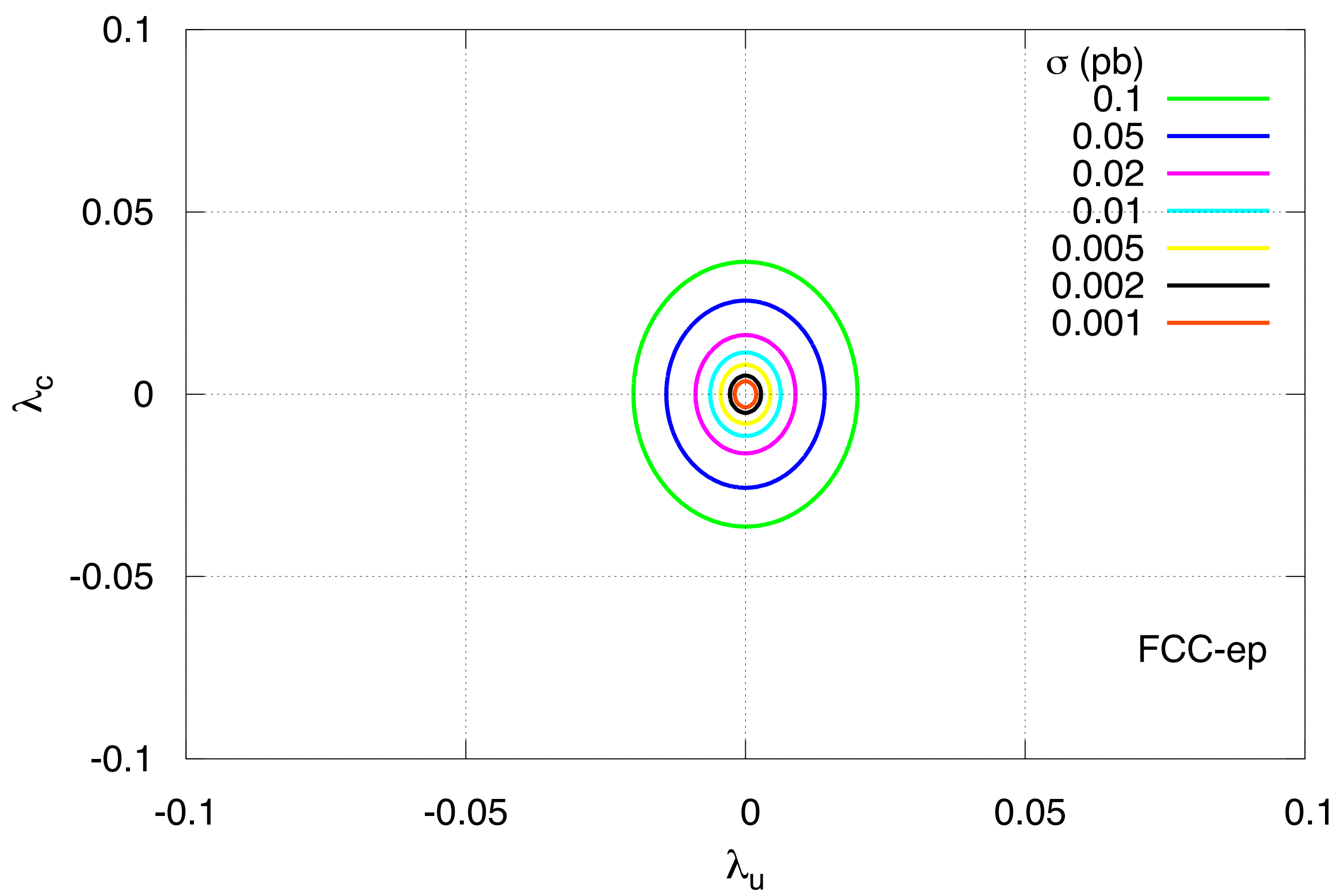
FCC-EP : SIGNAL CROSS SECTION AND PLANE OF COUPLINGS

Process e-p -> (e^-t + $e^-\tilde{t}$). Signal cross sections at FCC-ep collider depending on FCNC tqγ couplings λ_u and λ_c within the range [-0.1 : 0.1].



FCC-ep: Ee=60 GeV, Ep=50 TeV

PDF: NNPDF2.3

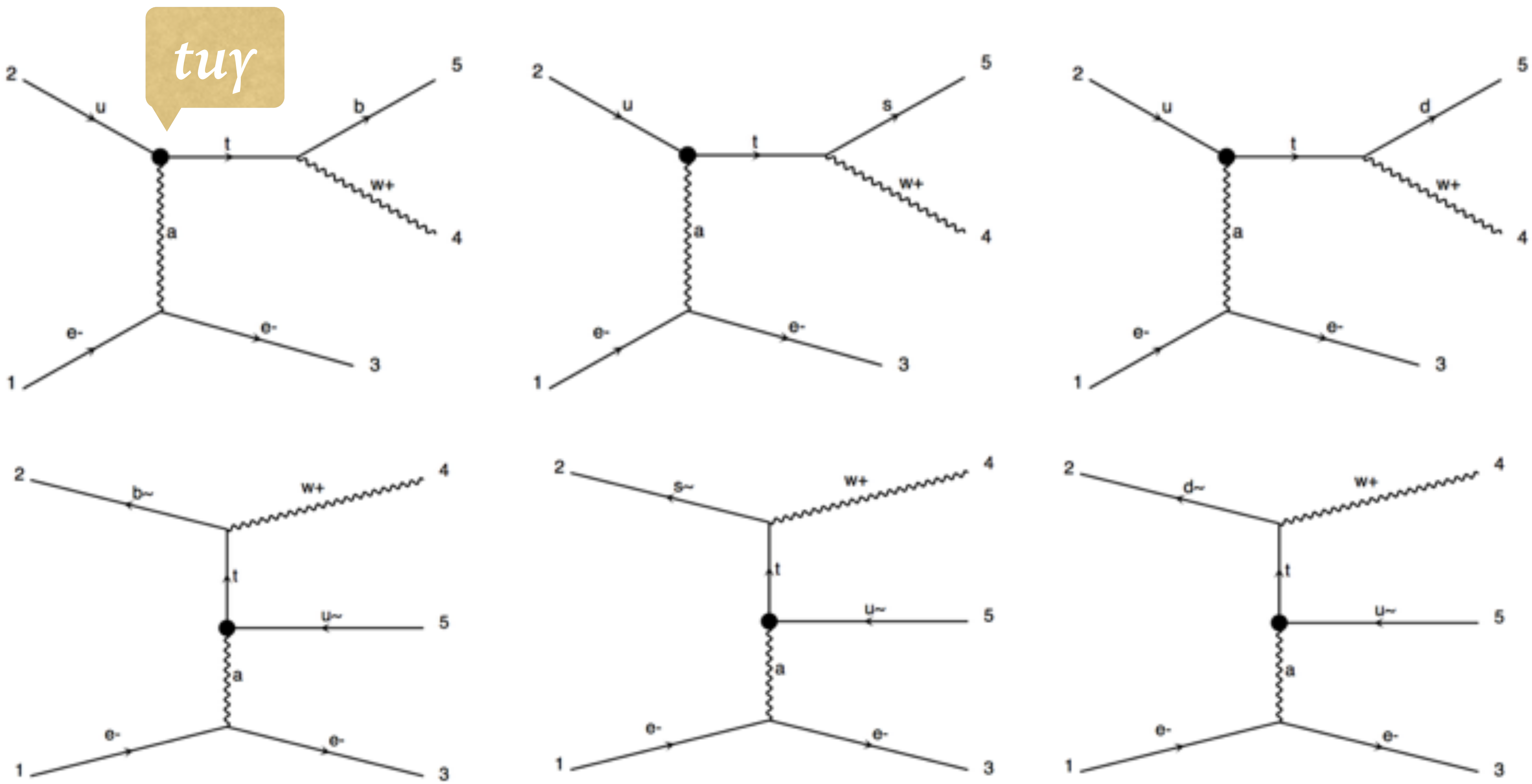


- *FCC-ep: cross section σ_u/σ_c=3.27 at λ_q=0.1*
- *Sensitivity λ_u/λ_c~1.8*

The cross section depends on λ_u and λ_c with different strength due to proton pdf, one obtain more sensitivity to λ_c at FCC-ep than LHeC.

For an estimation with overall acceptance of A=0.01 for the final state, contour lines can cover at least 10 signal events at 1 ab^{-1}.

DIAGRAMS FOR SIGNAL $(e^-p \longrightarrow e^-W^+q+X)$



+ similar diagrams for tcγ

- *further diagrams for process* $\boldsymbol{e^-p \to e^-W^-q+X}$ *with the interchange q<—>q~*

FCC-EP : CROSS SECTIONS (S+B)

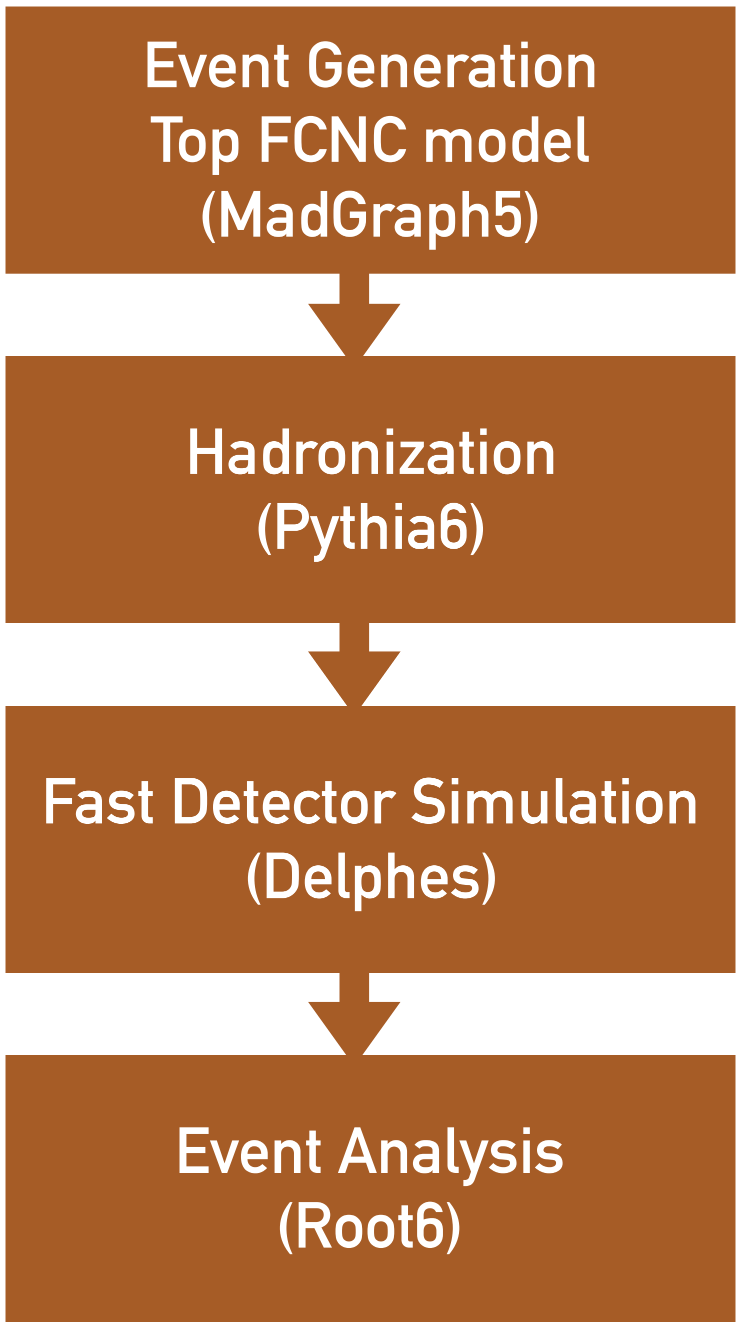
FCC-ep: Ee=60 GeV, Ep=50 TeV

PDF: NNPDF2.3

Cross sections (pb) for process $e^- p \to e^- ww q$ (where $ww=W^+$ or W^- and q contains all quarks other than top quark) at FCC-ep. The last row presents the results for the case of $\lambda_c=\lambda_u=\lambda$.

FCC-ep (60x50000)	$\lambda=10^{-1}$	$\lambda=10^{-2}$	$\lambda=10^{-3}$
coupling ($tu\gamma$)	1.072×10^{1}	8.565×10^{0}	8.589×10^{0}
coupling ($tc\gamma$)	9.243×10^{0}	8.539×10^{0}	8.534×10^{0}
coupling ($tu\gamma$, $tc\gamma$)	1.151×10^{1}	8.641×10^{0}	8.613×10^{0}

ANALYSIS FRAMEWORK



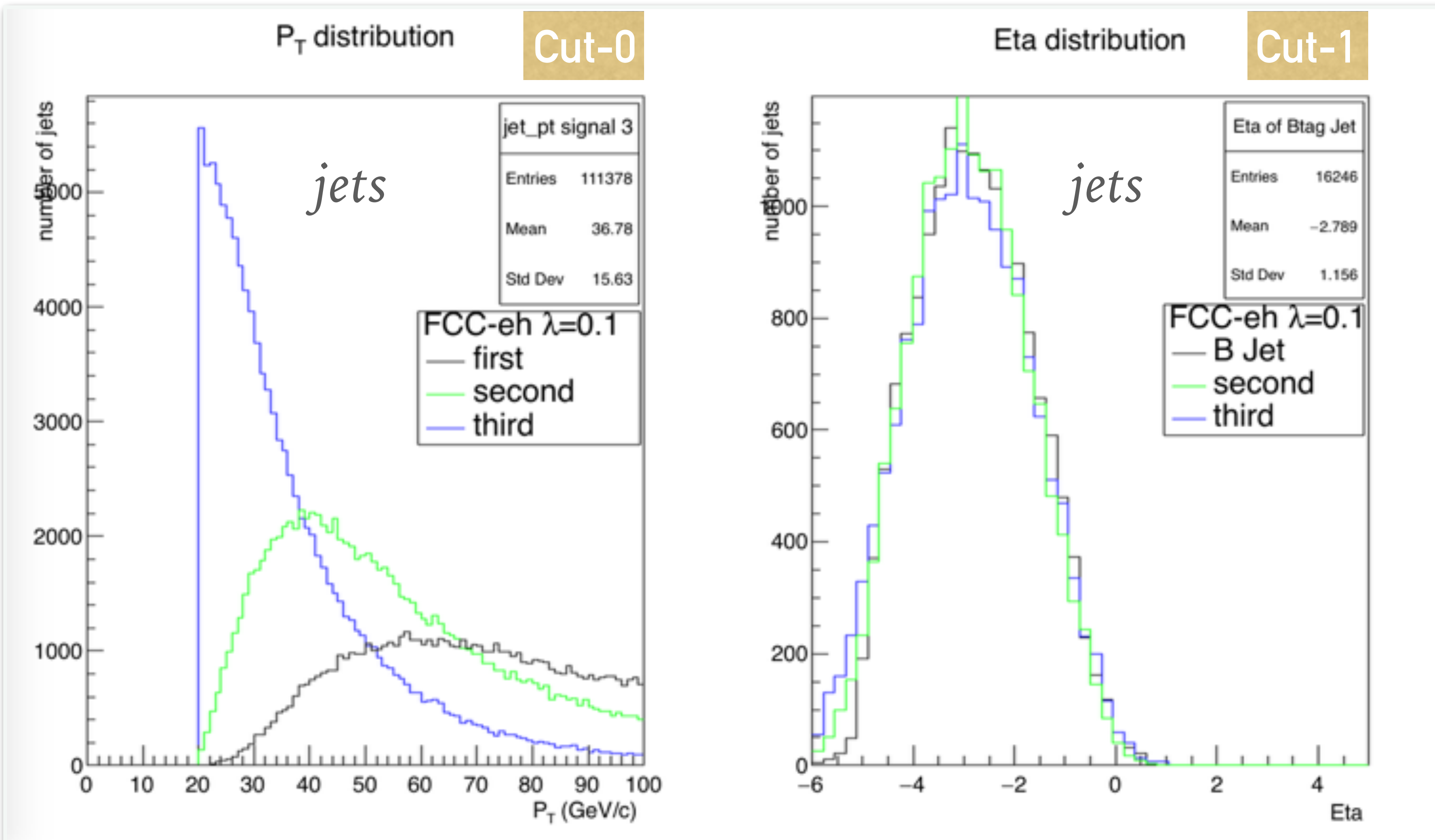
We study signal and background

- calculate cross sections with MadGraph5 importing topFCNC_UFO model including CKM matrix elements
- set Pythia6
- use delphes_card_FCC file and test new delphes_card_FCCep_PK_V2_1 file
- analyse events with Root6
- evaluate signal significance for FCNC couplings

FCC-EP : APPLIED CUTS FOR ANALYSIS

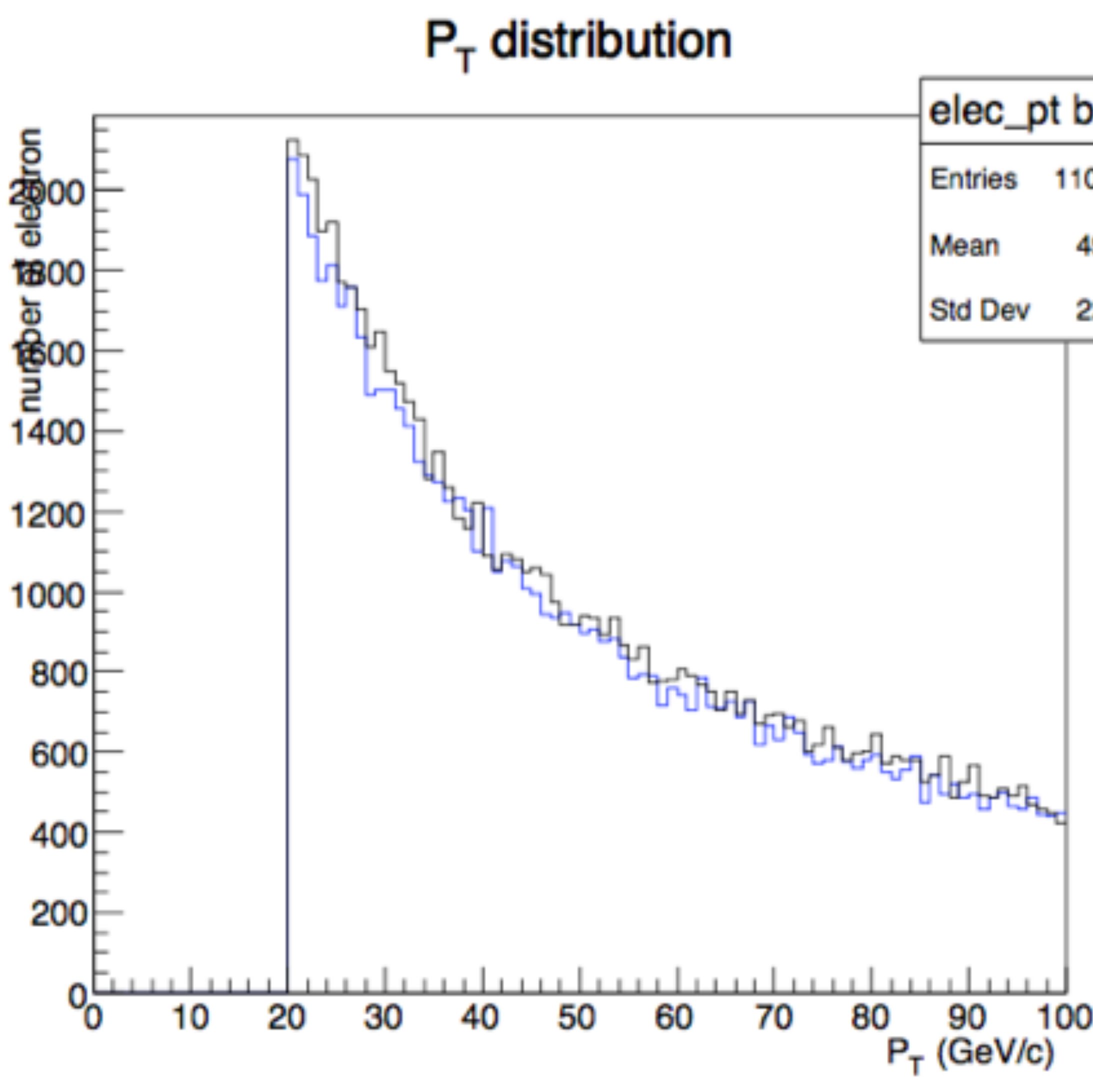
- For the analysis, after pre-selection cuts, we use the analysis cuts for further background suppression
  - **Cut-0 :** at least one electron and three jets (pre-selection with default MG5 cuts)
  - **Cut-1 :** require one of three jets as being b-tag
  - **Cut-2 :** b-tagged jet has transverse momentum p_T>35 GeV and other jets have p_T>25 GeV, and electron has p_T>20 GeV
  - **Cut-3 :** all jets have pseudo-rapidity $-5.0<\eta<0$; and electron has $-2.5<\eta<2.5$
  - **Cut-4 :** invariant mass of two jets within $50<m_{jj}<90$ GeV (for W-boson)
  - **Cut-5 :** invariant mass of three jets (for top) between $130<m_{bjj}<200$ GeV

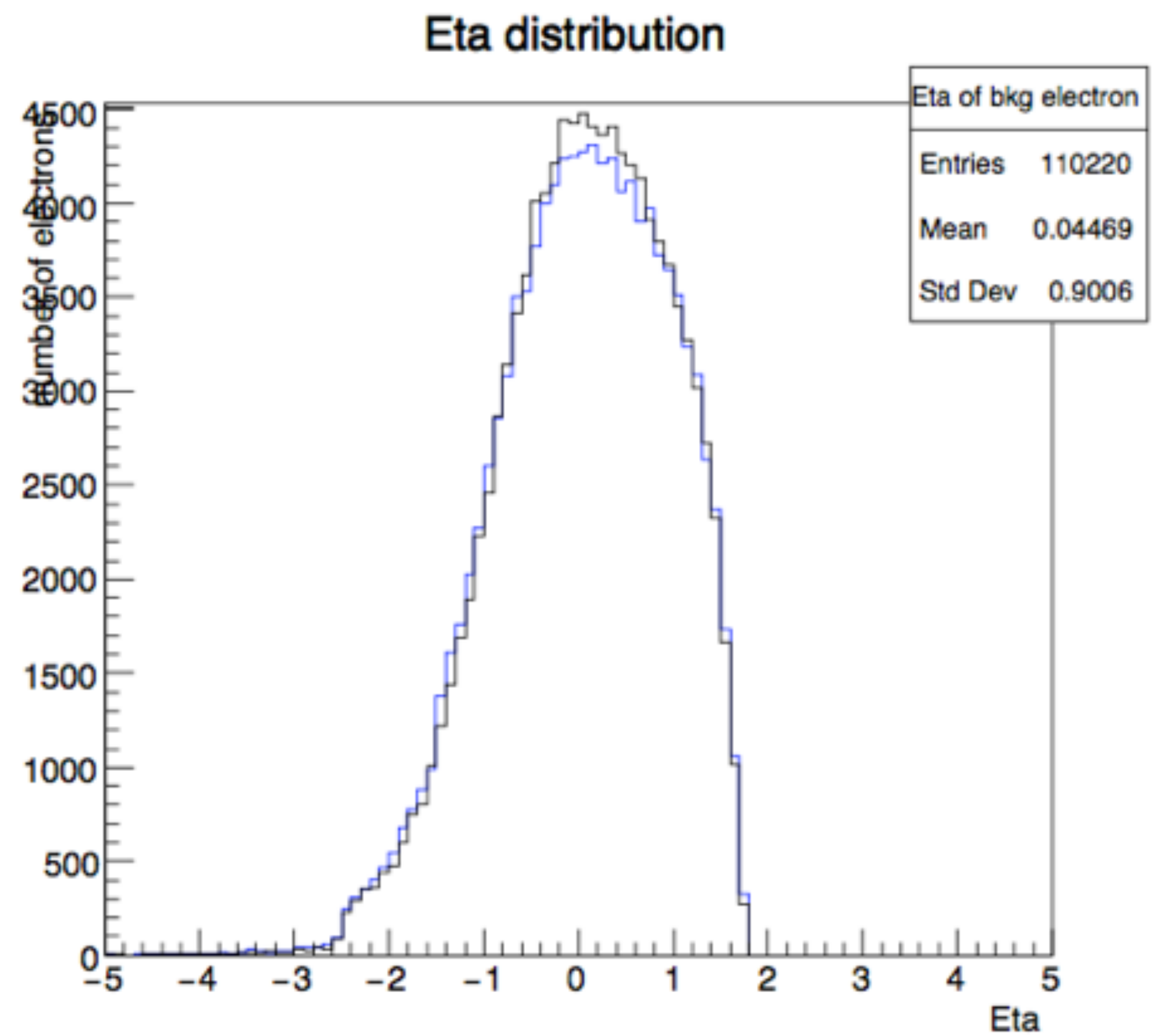
FCC-EP : DISTRIBUTIONS



- The p_T and eta distributions of three jets events for signal +background.

FCC-EP : DISTRIBUTIONS

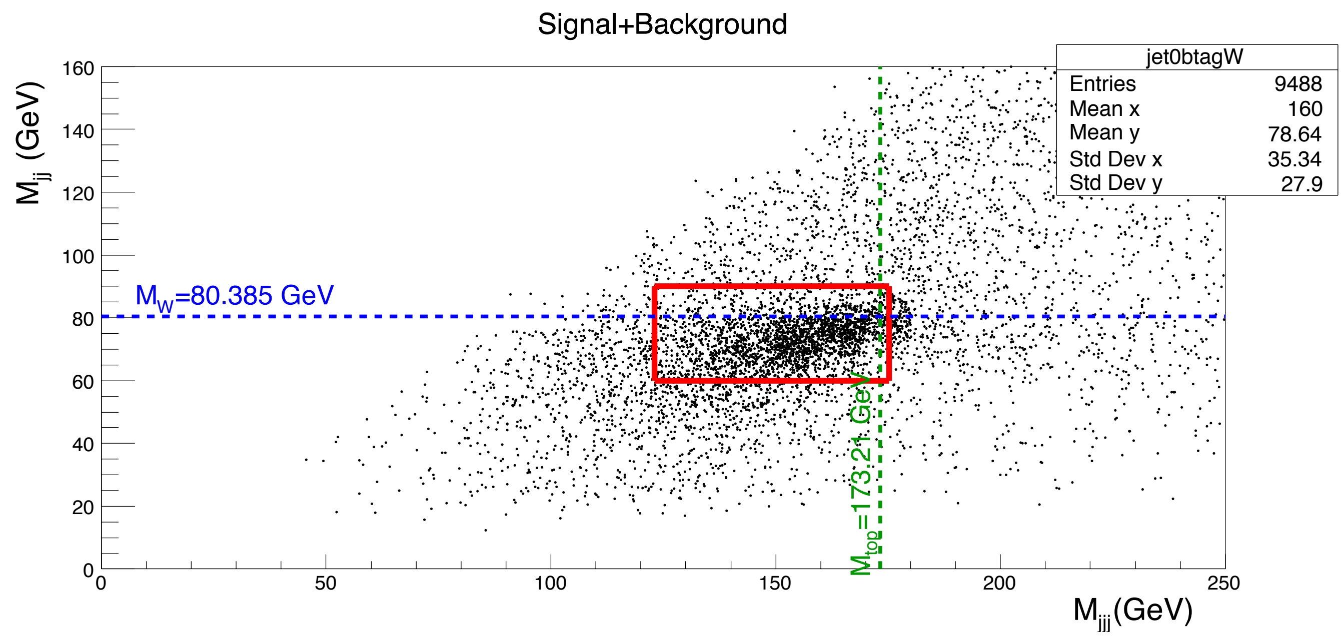


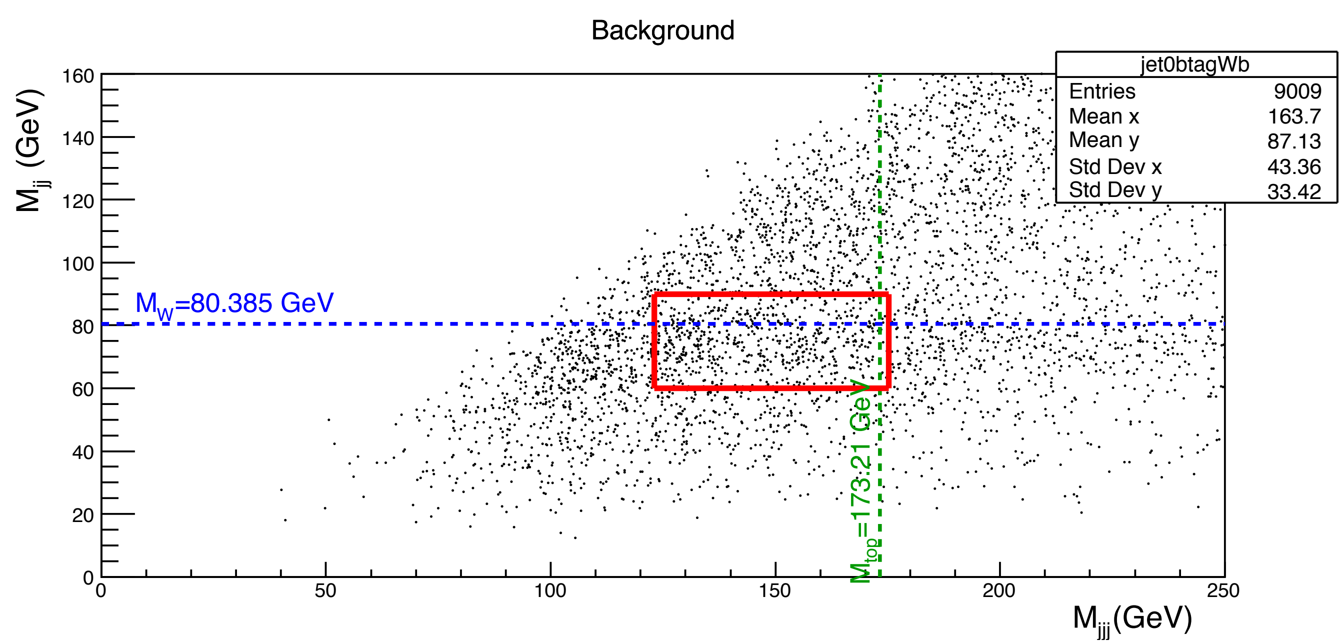


➤ Electron p_T and eta distributions

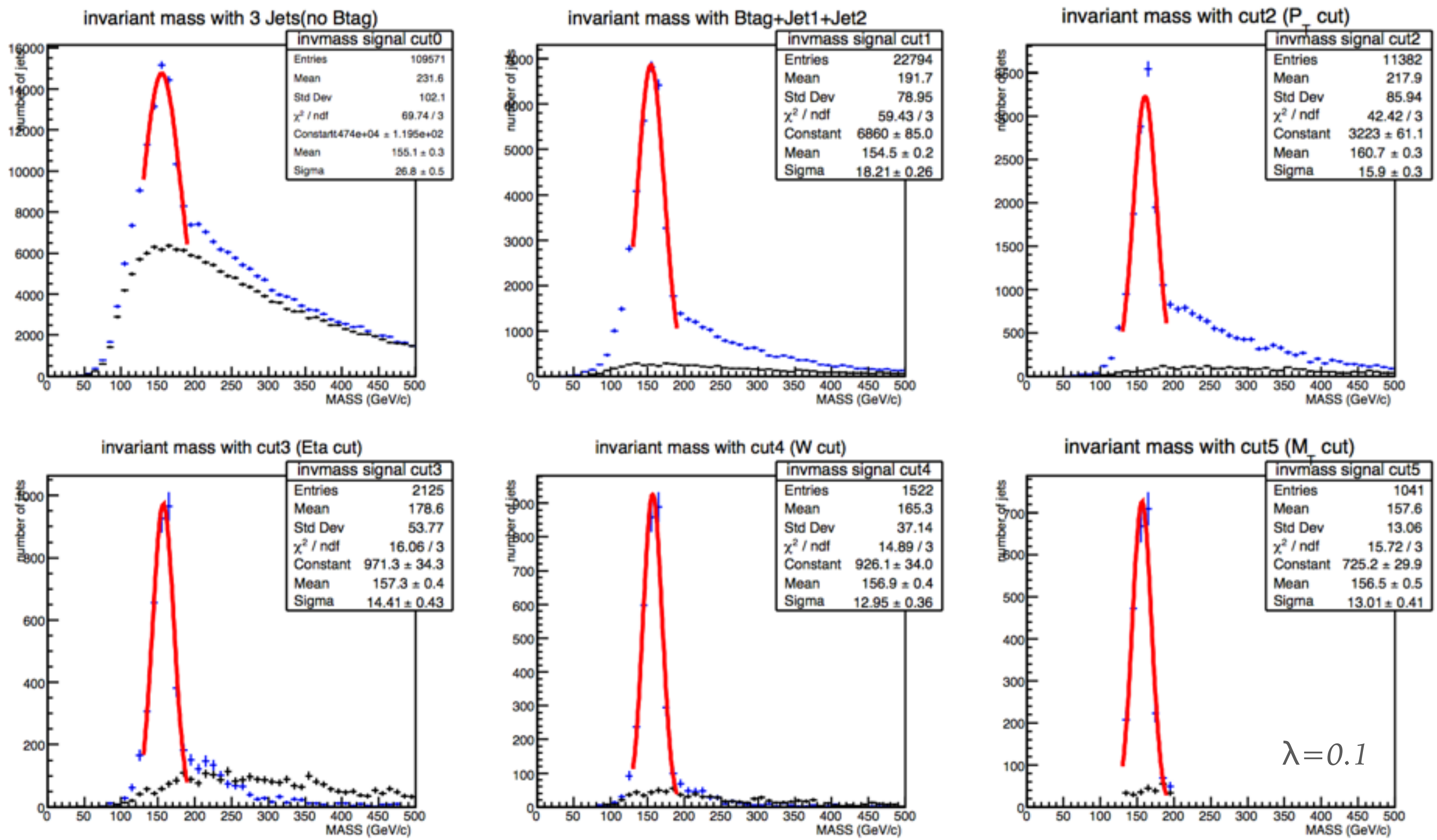
FCC-EP : FRAME OF CUTS

- Frame of cuts and comparison of signal and background invariant mass distributions



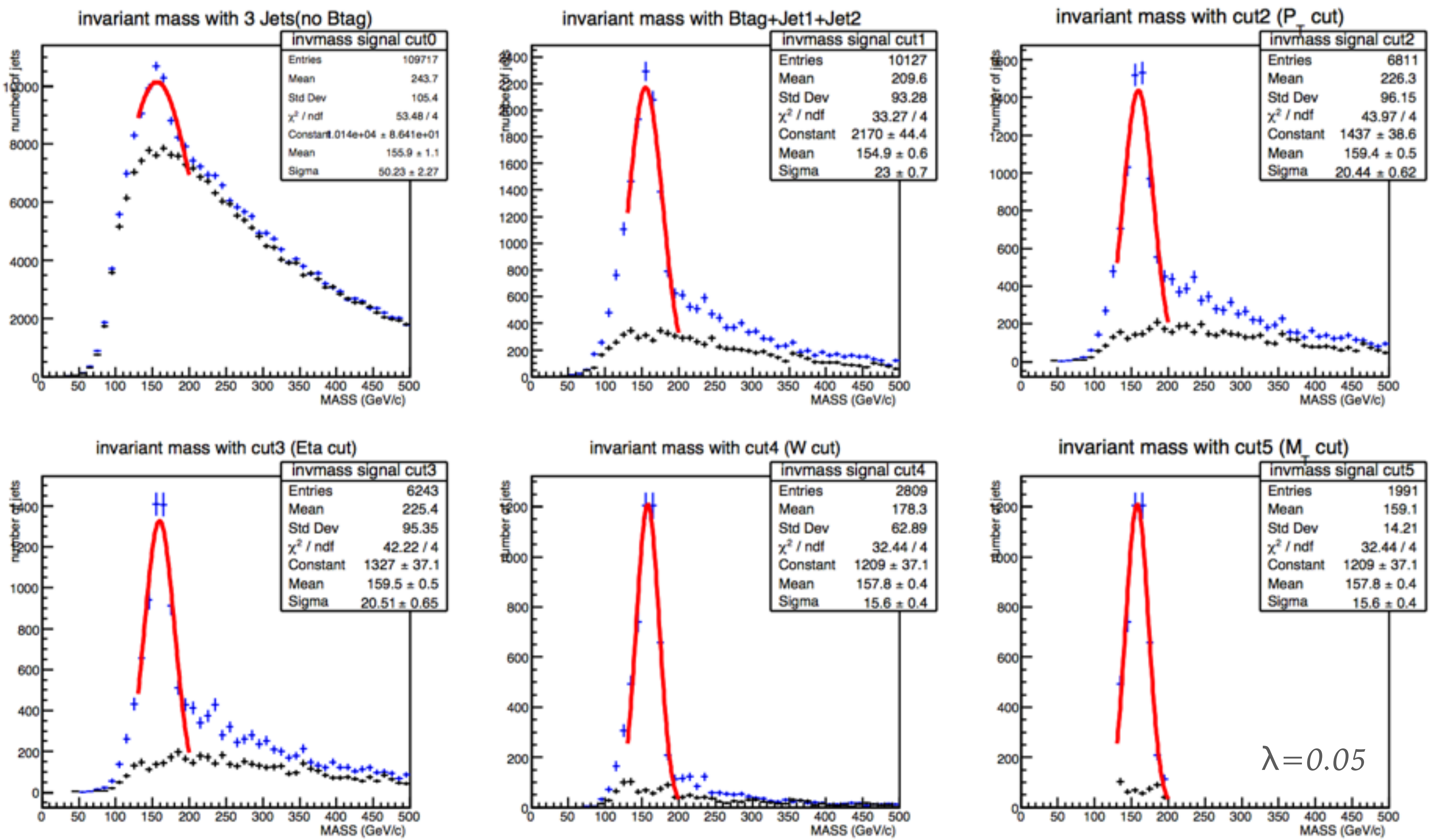


FCC-EP : INVARIANT MASS PLOT



- Top mass reconstruction after each cut applied.

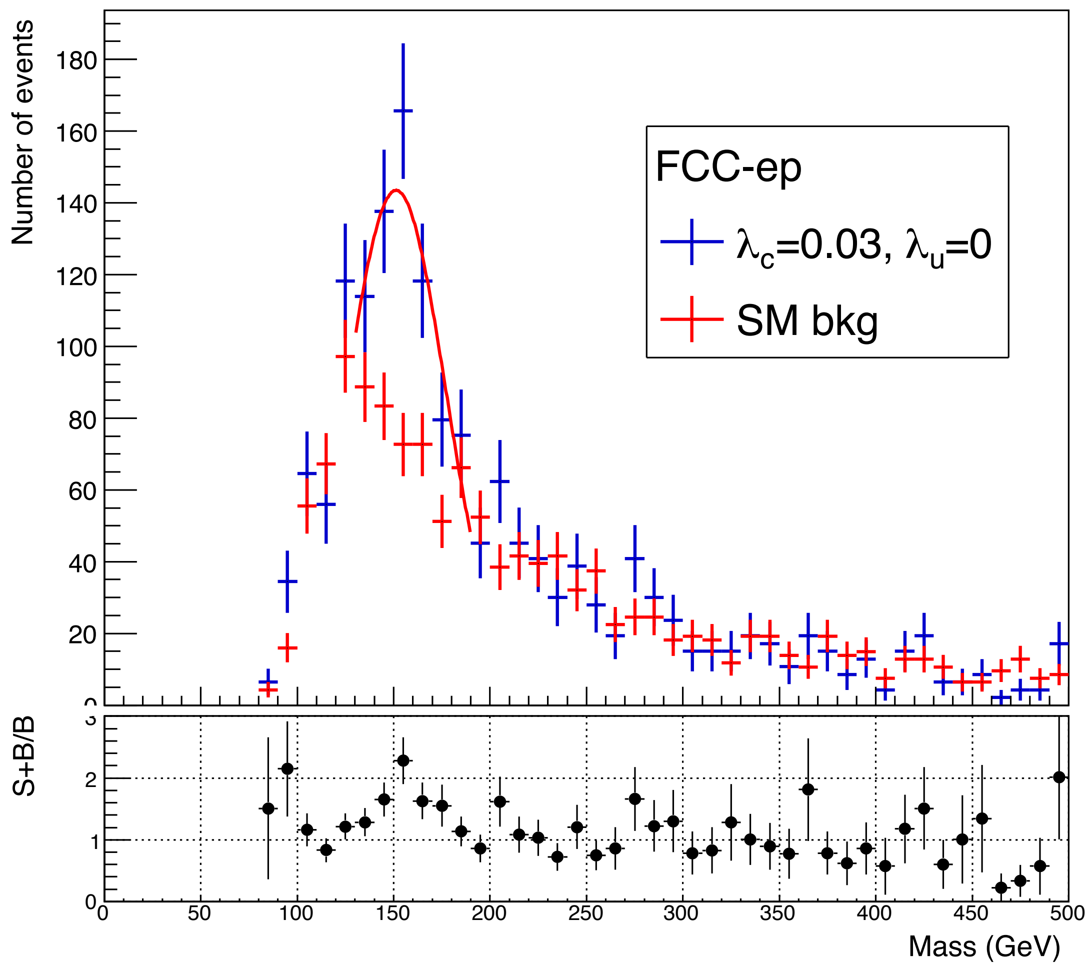
FCC-EP : INVARIANT MASS PLOT

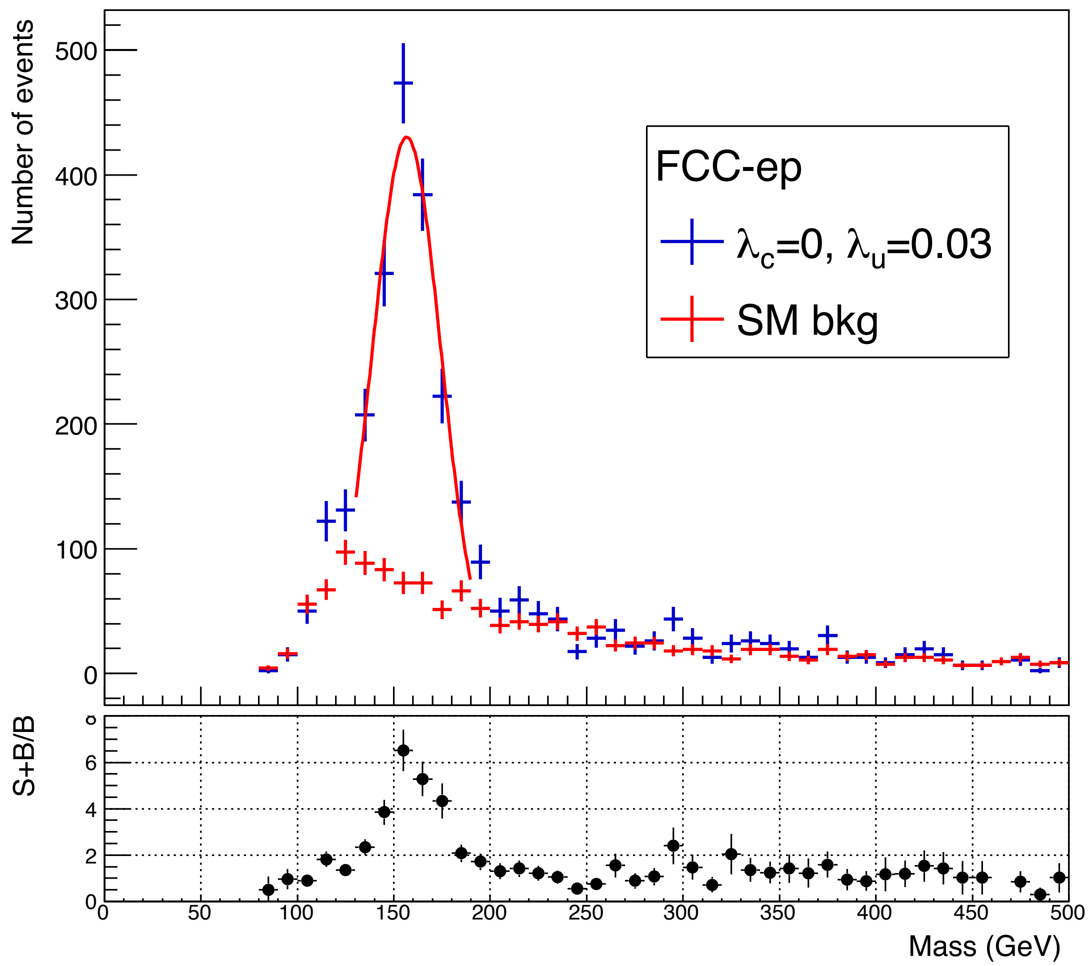


- Top mass reconstruction after each cut applied.

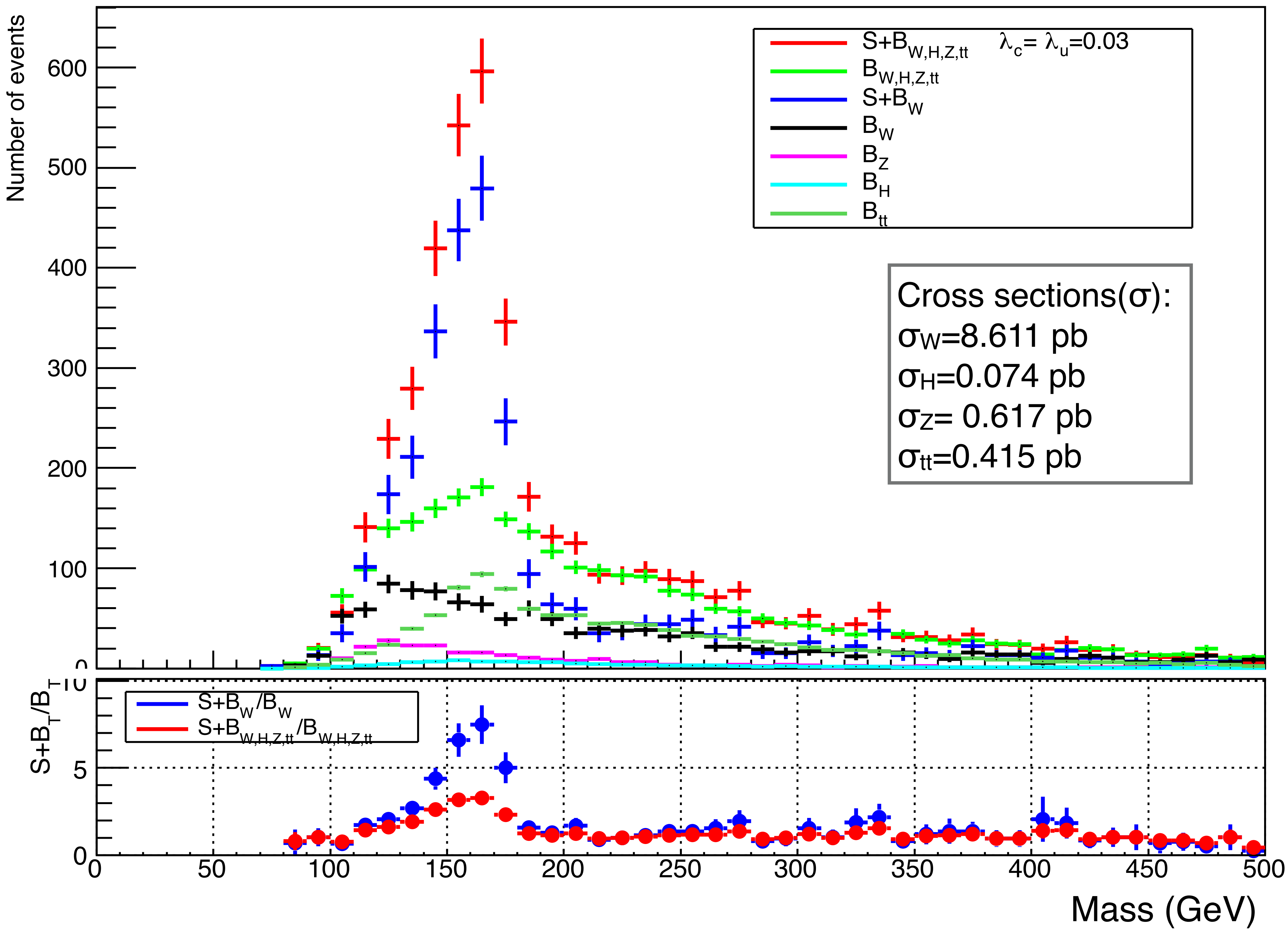
FCC-EP : (S+B)/B RATIO PLOT

Top mass reconstruction from S+B and B events and the ratio plot of (S+B)/B. It is clear from the left and right panel of the figure that there is different sensitivity to FCNC coupling in the vertices $tu\gamma$ and $tc\gamma$.





FCC-EP : (S+B)/B AND SUM OF RELEVANT BACKGROUNDS



$S: ep \to eWj$

$B_W: ep \to eWj$

$B_Z: ep \to eZj$

$B_H: ep \to eHj$

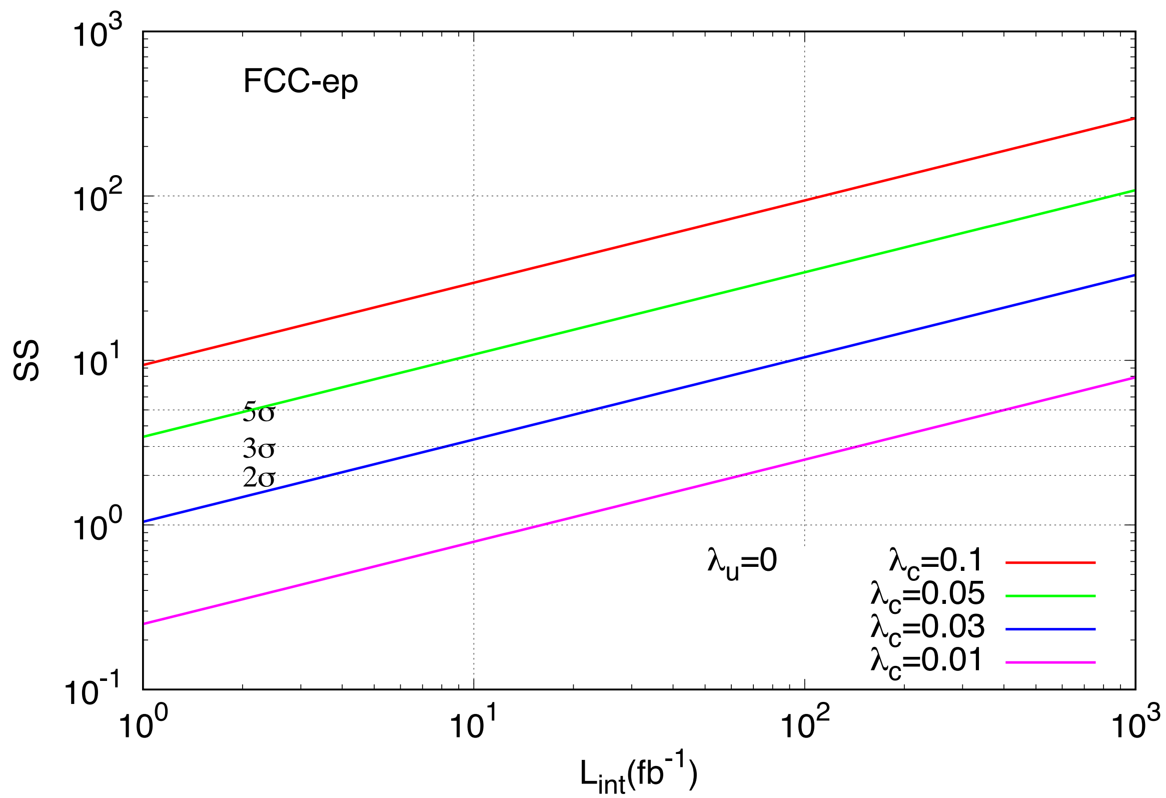
$B_{tt}: ep \to et\bar{t}$

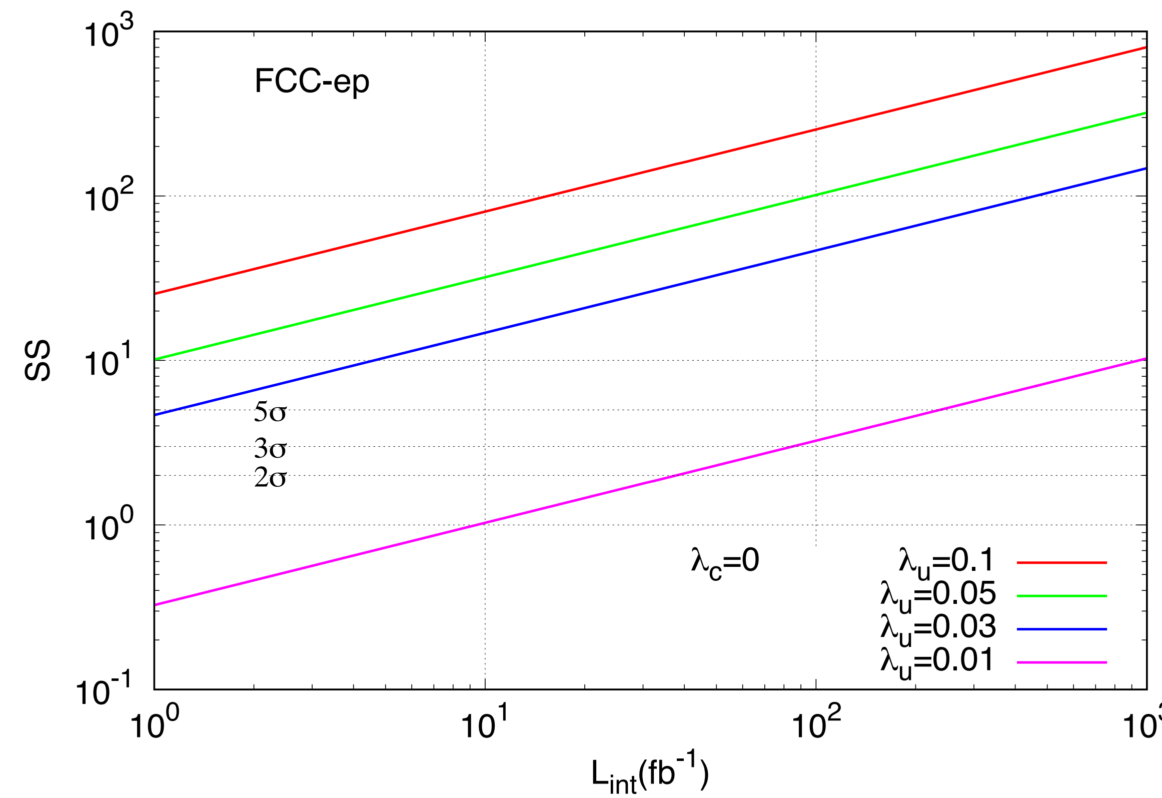
- *with the relevant backgrounds, the ratio (S+B)/B decreases a factor of 3/7 at top mass*

FCC-EP : SENSITIVITY TO COUPLINGS

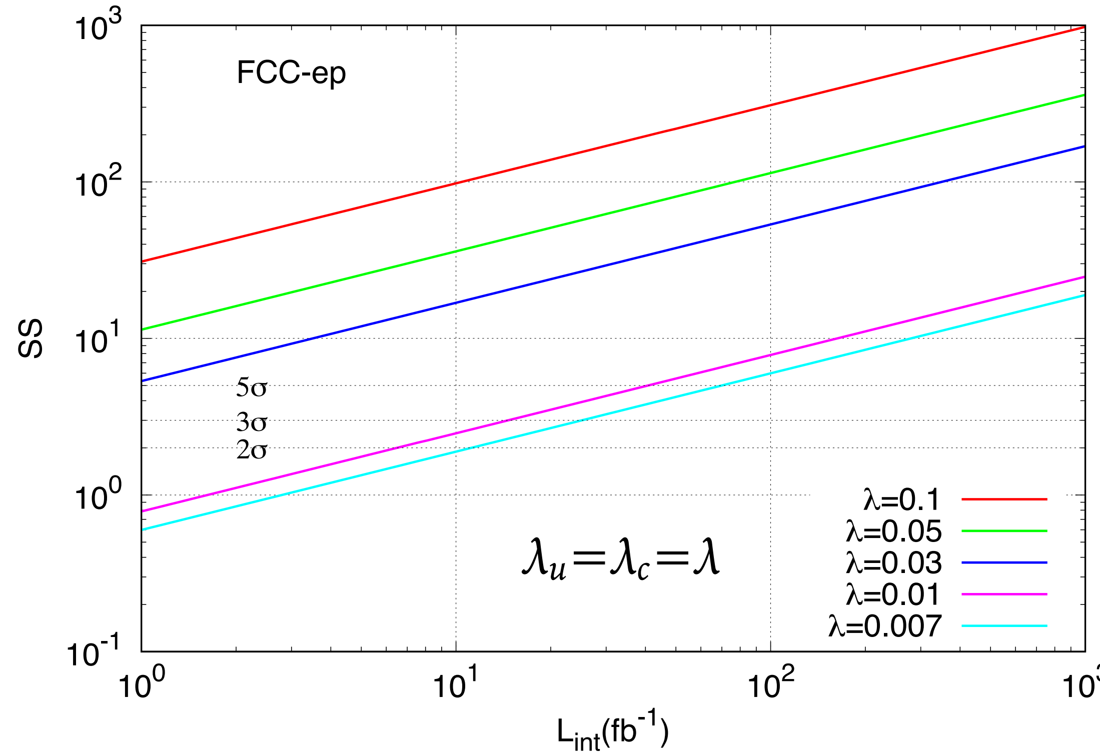
$(S+B_W)$

- Sensitivity to different couplings depending on integrated luminosity





- Sensitivity to equal couplings depending on integrated luminosity



<u>2σ significance:</u>

λ_u=0.01 for L_{int}=40/fb.

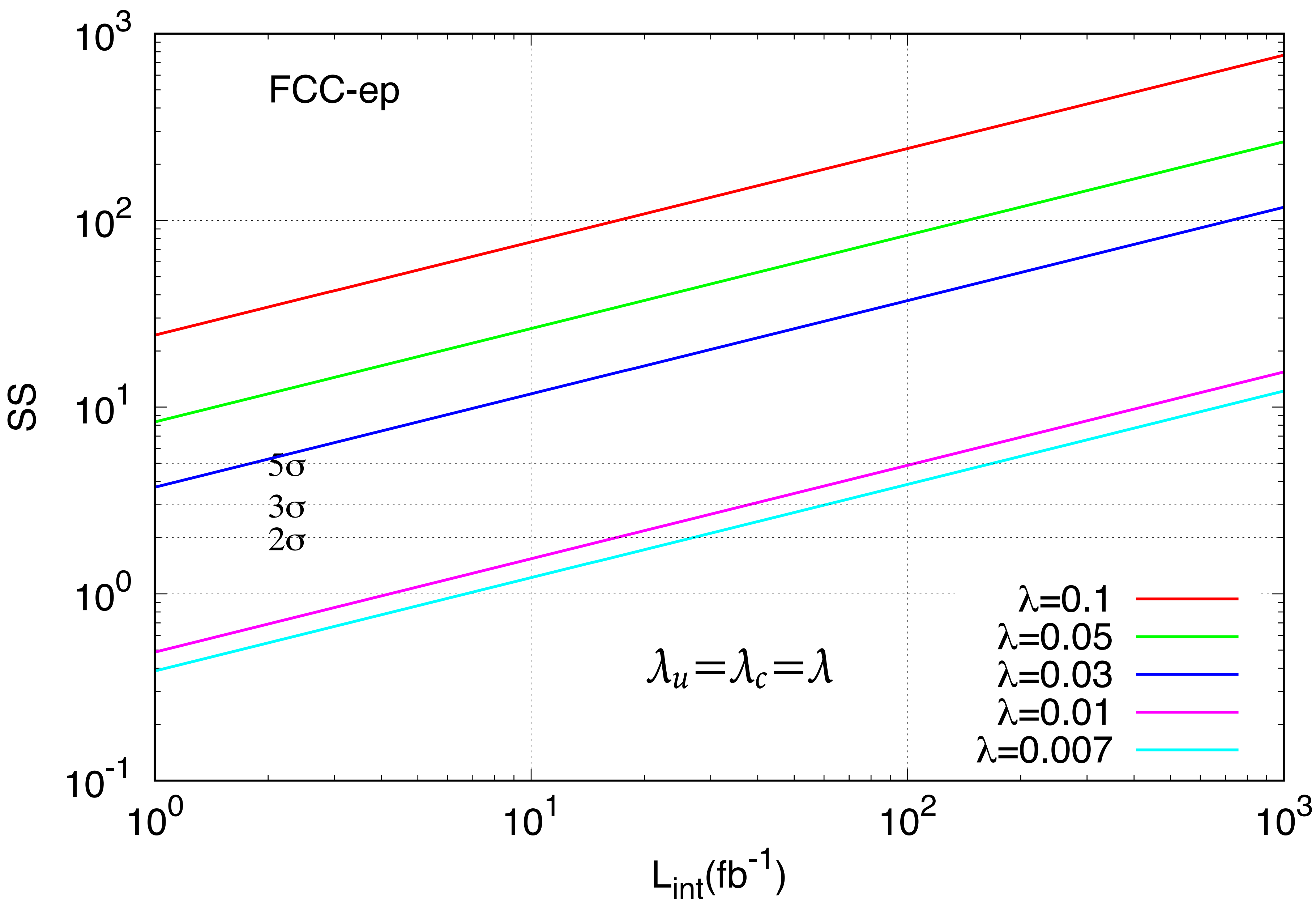
λ_c=0.01 for L_{int}=60/fb.

λ_q=0.01 for L_{int}=7/fb.

FCC-EP : SS PLOT

$(S+B_T)$

Statistical significance $SS=\sqrt{2[(S+B_T)\ln(1+S/B_T)-S]}$ for $e^-p \to e^- + j_{btag} + 2j$ with $tq\gamma$ FCNC interactions. Here, we assume equal coupling scenario $\lambda_u=\lambda_c=\lambda$.



all relevant backgrounds (B_T) are included

<u>3σ significance</u>

at λ_q=0.01

for L_{int}=40/fb.

- **compare with LHeC when λ_q=0.01 for L_{int}=80/fb.**

FCC-EP : COMMENT ON BRANCHING VS COUPLING

- Using top quark FCNC decay widths and total decay width we can calculate the branchings BR(t—>qγ) vs coupling λ. With all the relevant backgrounds, we find 3σ signal significance results to reach an upper limit λ=0.01, with an integrated luminosity of 40 fb^{-1} at FCC-ep and 80 fb^{-1} at LHeC. This limit on coupling can also be translated to the branching ratio BR(t—>qγ)=2x10^{-5}.

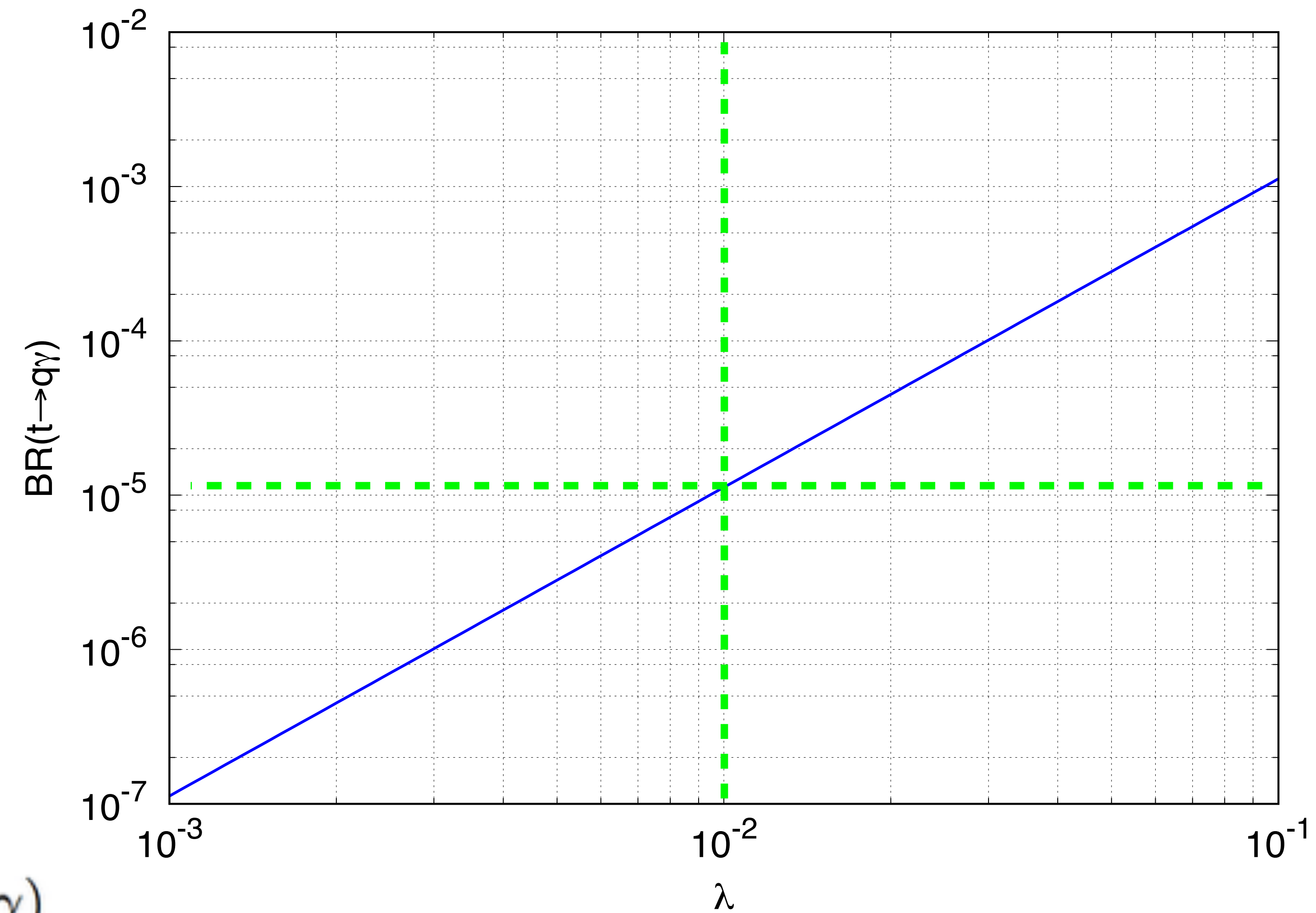
Decay widths :

$$\Gamma(t \to q\gamma) = \frac{\alpha}{8}\lambda_q^2 m_t$$

$$\Gamma(t \to bW) = \frac{\alpha}{16\sin^2\theta_w}|V_{tb}|^2\frac{m_t^3}{m_W^2} \times \left[1 - 3\frac{m_W^4}{m_t^4} + 2\frac{m_W^6}{m_t^6}\right]$$

Branching :

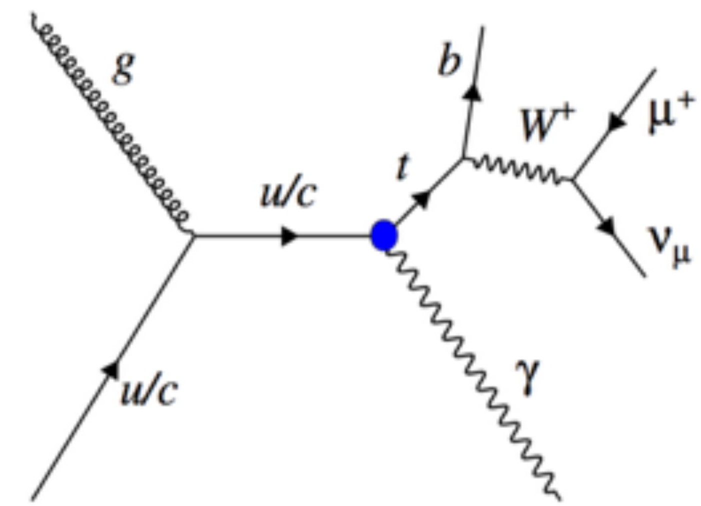
$$BR(t \to q\gamma) = \frac{\Gamma(t \to q\gamma)}{\Gamma(t \to bW) + \Gamma(t \to u\gamma) + \Gamma(t \to c\gamma)}$$

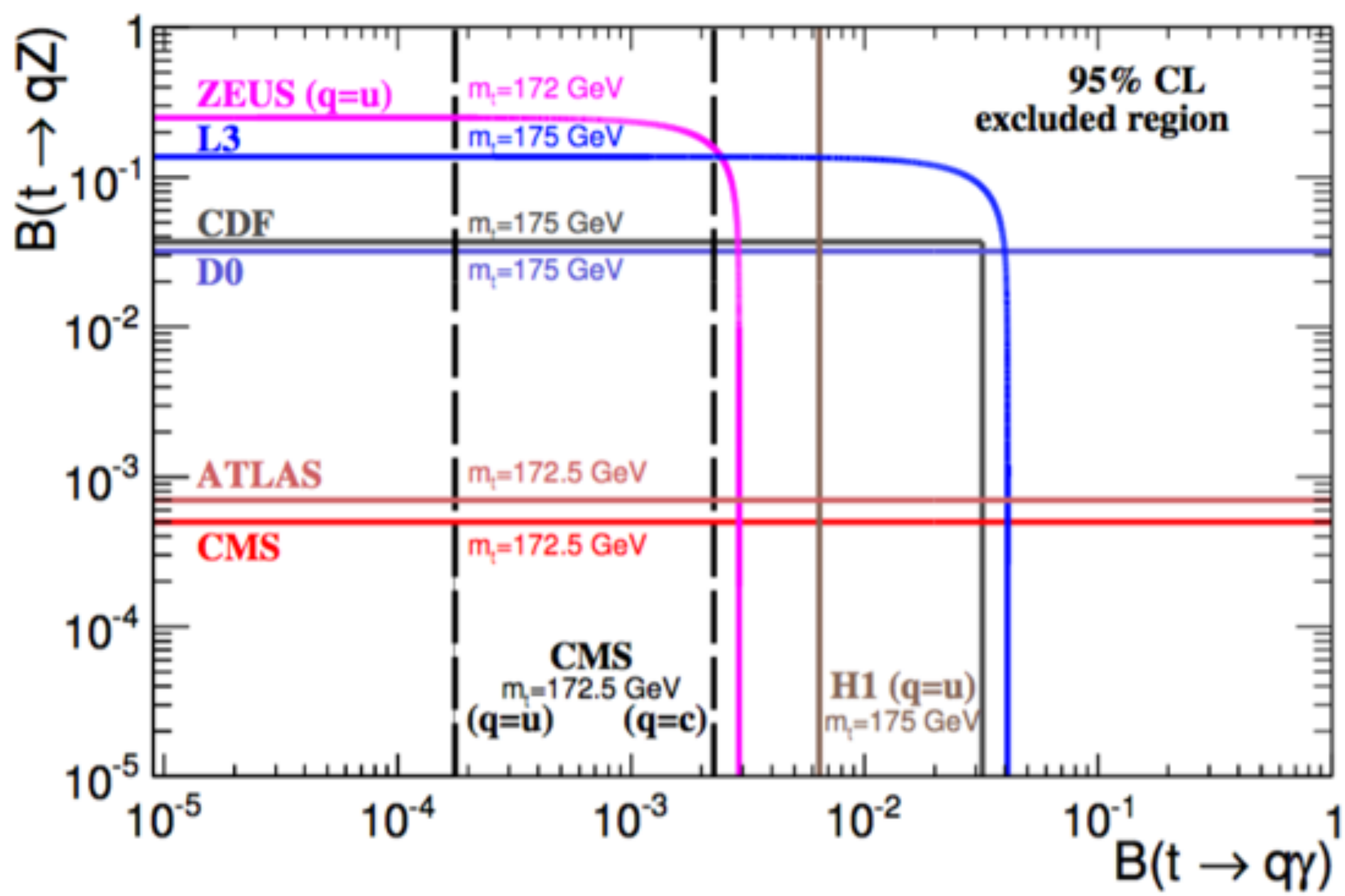


COMPARISON : TOP FCNC AT LHC

Based on proton-proton collisions at 8 TeV within the CMS detector at the LHC at an integrated luminosity of 19.8 fb^{-1}, the limits (95% CL) on the top quark FCNC couplings

$$\mathcal{L}_{\rm eff} = -eQ_{\rm t} \sum_{\rm q=u,c} \bar{\rm q} \frac{i\sigma^{\mu\nu} q_\nu}{\Lambda} (\kappa^{\rm L}_{\rm tq\gamma} P_{\rm L} + \kappa^{\rm R}_{\rm tq\gamma} P_{\rm R}) {\rm t} A_\mu + {\rm h.c.},$$





BR(t→uγ)=1.7x10^{-4}

BR(t→cγ)=2.2x10^{-3}

CMS Collab.JHEP04(2016)035

CONCLUSION

- Future ep collider has a rich physics programme for electroweak interactions of top quarks
- Top anomalous couplings can be measured down to 10^{-2} at the FCC-ep
- We study S+B and B for process e- p > e- ww q NP=1 (where ww=W+ or W-)
- For detector simulation we use Delphes card **delphes_card_FCC**, we have some tests for the new **delphes_card_FCCeh_V2_1** card
- For analysis, we use cut based method, top mass reconstruction and W mass reconstruction
- (S+B)/B ratio plot for different couplings (λ_u , λ_c)
- Study on different backgrounds (eWq , eZq , eHq, ett)
- SS vs integrated luminosity plot for different coupling parameters
- Branching vs coupling plot and conversion, comments on the limits.

+

Future ep colliders

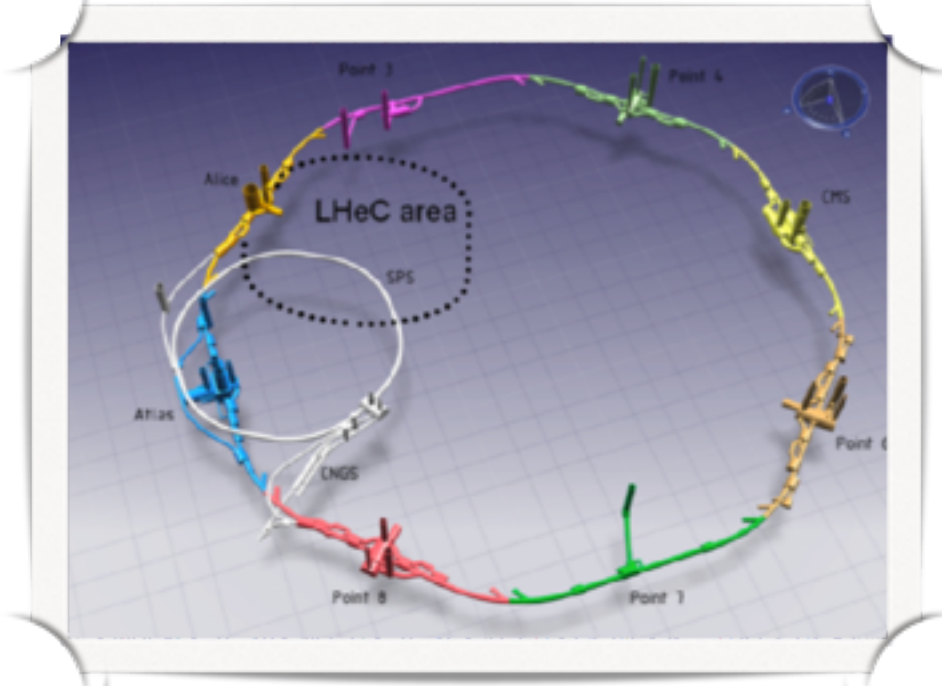
LHeC

7 TeV proton of LHC

and 60 GeV electron

($\sqrt{s} \sim 1.3$ TeV)

LHeC Layout



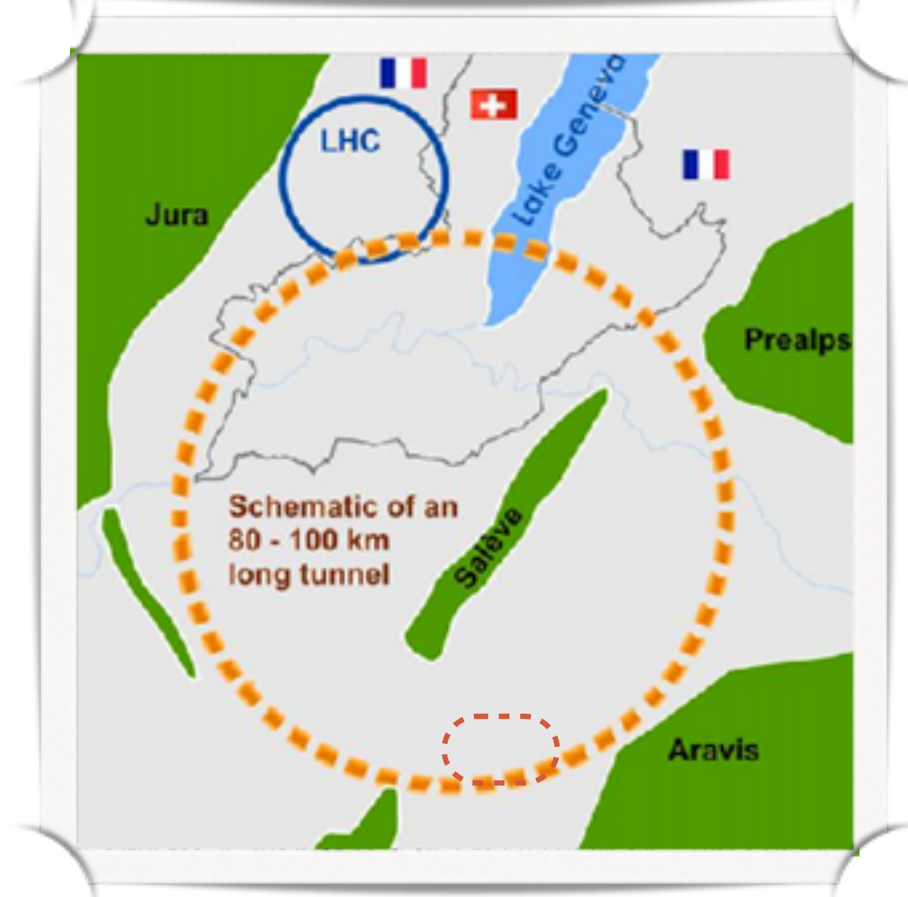
FCC-eh

50 TeV proton of FCC

and 60 GeV electron

($\sqrt{s} \sim 3.5$ TeV)

FCC-eh Layout



Both plan to create new electron facility