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SMEFT probes in future precision DIS experiments

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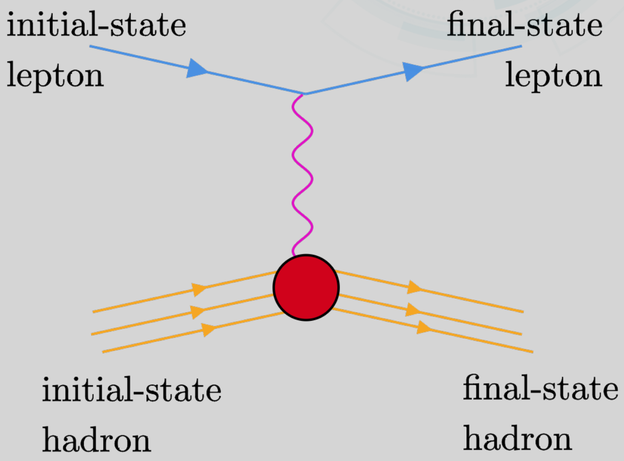
Prelude

FCC, LHeC, and EIC

Two hundred thousand dollars is a lot of money. We're gonna have to earn it. -Blondie

Next-gen e^--hadron colliders

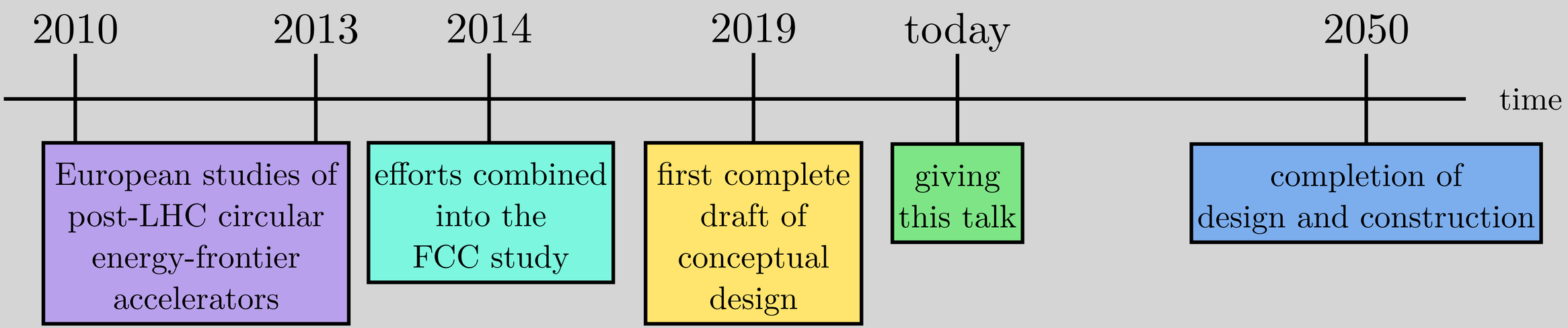


e^--hadron colliders: [Brüning *et al.* FPhy(2022)]

- Ultimate tool for high-precision QCD studies
- Ultimate *microscope* for probing internal structure of hadrons
- e^- is an ideal probe of proton structure due to unmatched precision of QED
  - ➡ Clean environment (no color interactions)
  - ➡ Kinematics uniquely determined by e^- beam, scattered lepton, or hadronic final state
- *Hadron-Elektron-Ringanlage* (HERA@DESY, Germany) was the only e^-H collider ever operated (1991-2007).
- It will take at least 30 years for design+construction of **F**uture **C**ircular **C**ollider (FCC@CERN, Switzerland).
- **L**arge **H**adron-**e**lectron **C**ollider (LHeC@CERN, Switzerland) is awaiting approval.
- Construction of **E**lectron-**I**on **C**ollider (EIC@BNL, NY) will start in 2024.

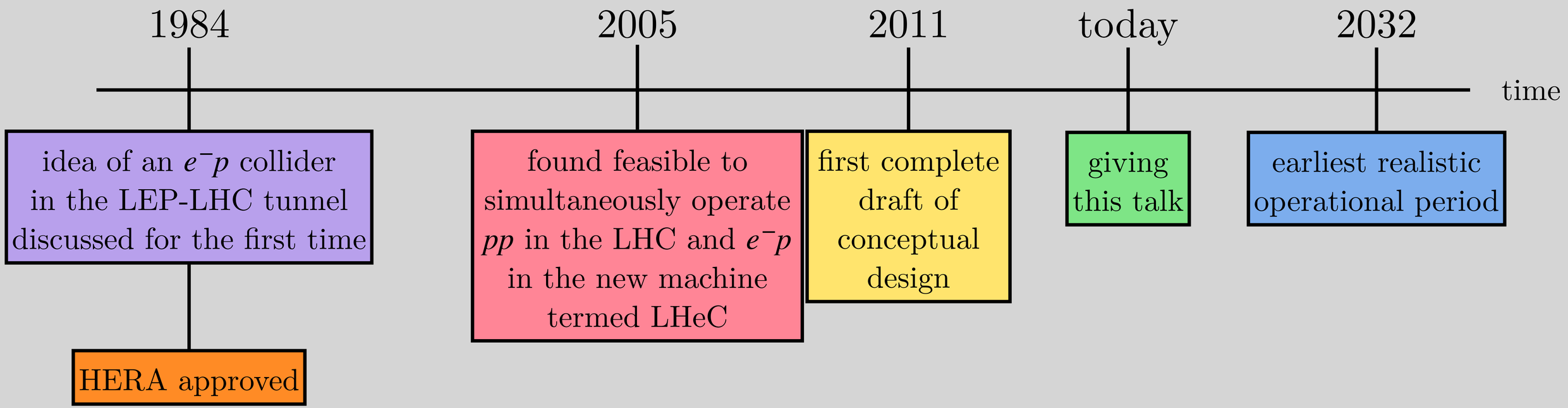
Future Circular Collider

A next-gen electron-hadron collider [Abada *et al.* EPJC**79**(2019)474]



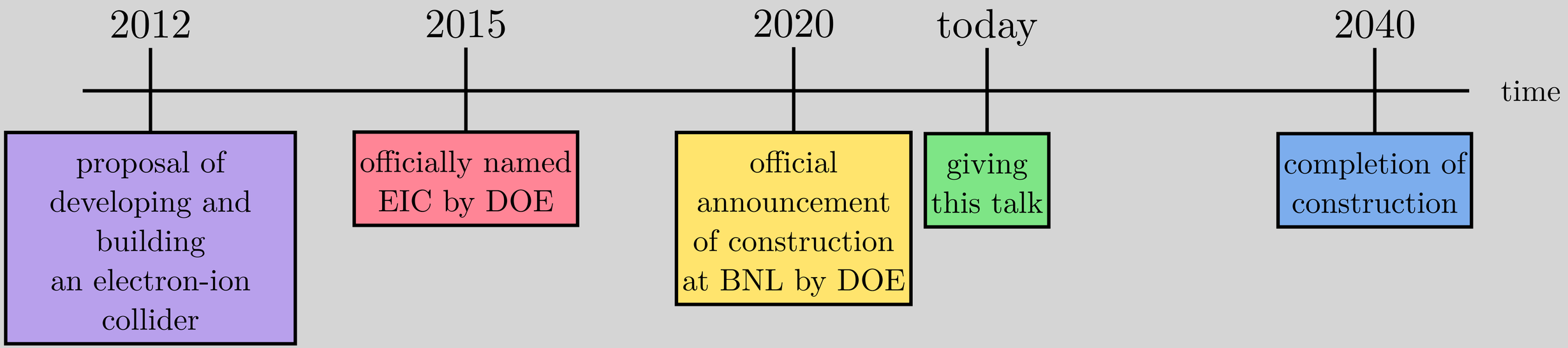
Large Hadron-electron Collider

A next-gen electron-hadron collider [Fernandez *et al.* 1206.2913]



Electron-Ion Collider

A next-gen electron-hadron collider [Accardi *et al.* 1212.1701]



Observables of interest

At the FCC-eh and LHeC:

$\sigma^{\pm}_{\mathrm{NC}}$: unpolarized NC $e^{-}H$ DIS cross section with only lepton beam polarized

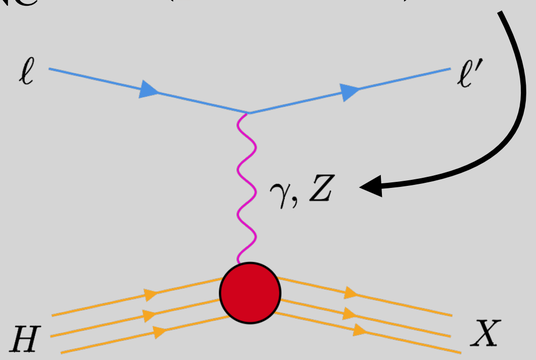
At the EIC:

$$A_{\mathrm{PV}} = \frac{\sigma^{+}_{\mathrm{NC}} - \sigma^{-}_{\mathrm{NC}}}{\sigma^{+}_{\mathrm{NC}} + \sigma^{-}_{\mathrm{NC}}}$$ unpolarized PV asymmetry

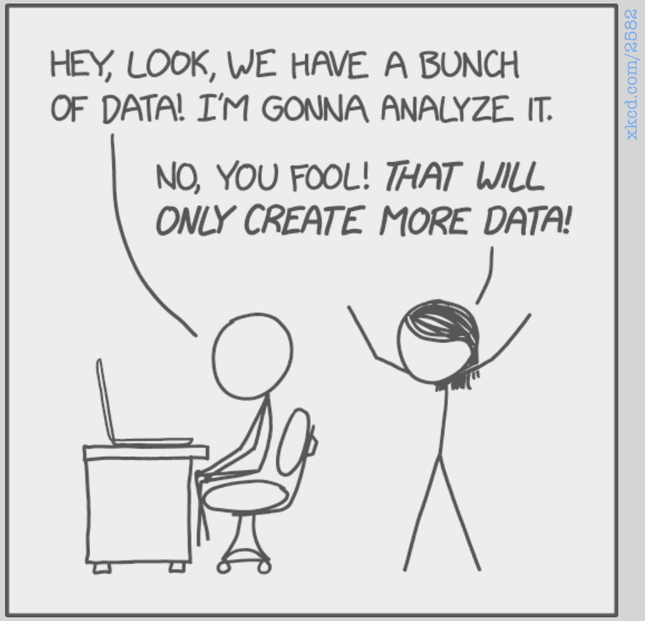
$$\Delta A_{\mathrm{PV}} = \frac{\Delta\sigma^{0}_{\mathrm{NC}}}{\sigma^{0}_{\mathrm{NC}}}$$ polarized PV asymmetry

$(\Delta)\sigma^{\pm}_{\mathrm{NC}}$: un(polarized) NC $e^{-}H$ DIS cross section with only one beam polarized

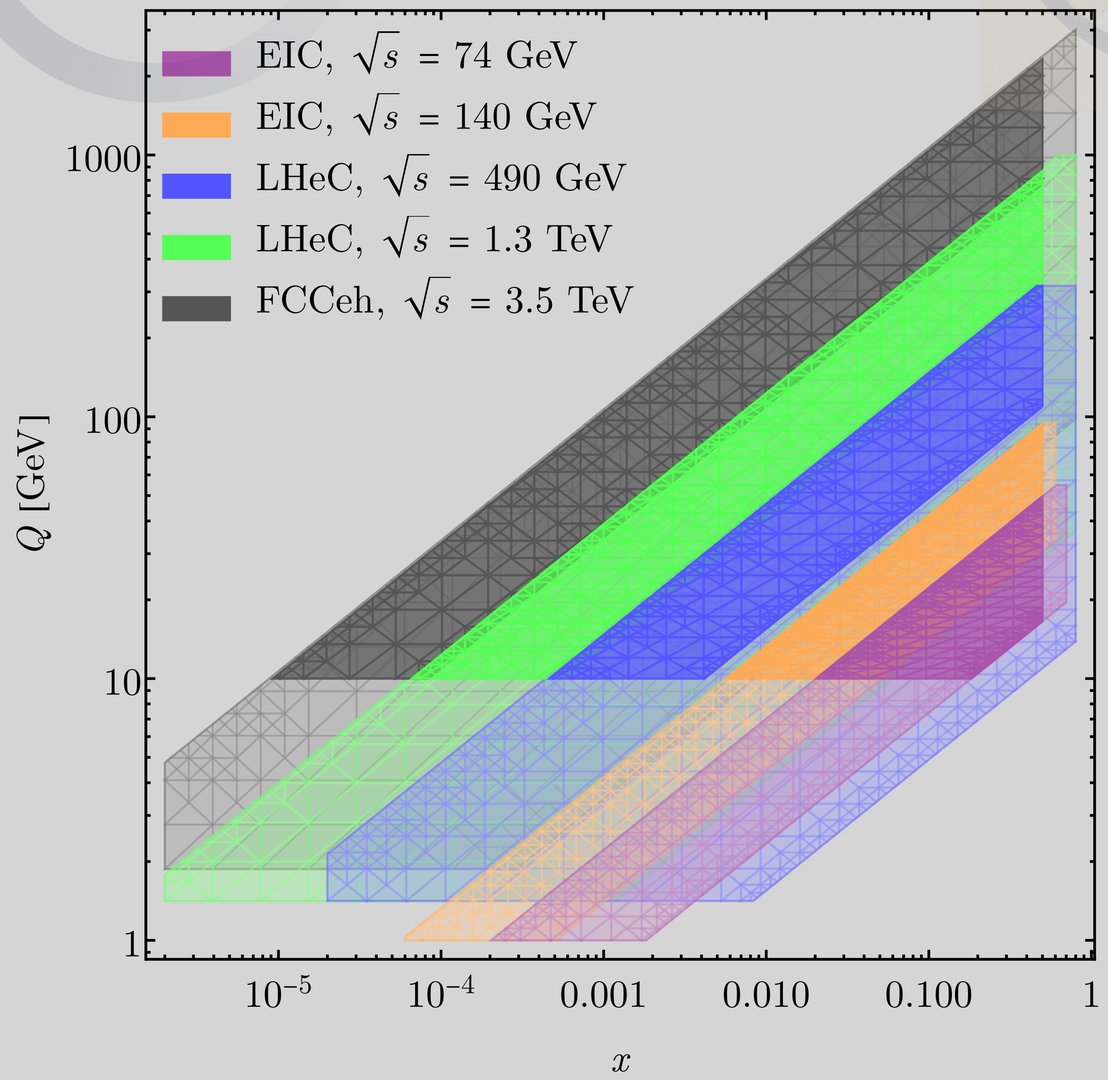
$(\Delta)\sigma^{0}_{\mathrm{NC}}$: un(polarized) NC $e^{-}H$ DIS cross section with no beams polarized



Data analysis



Kinematic coverage



Cuts:

$x \leq 0.5$

$Q > 10$ GeV

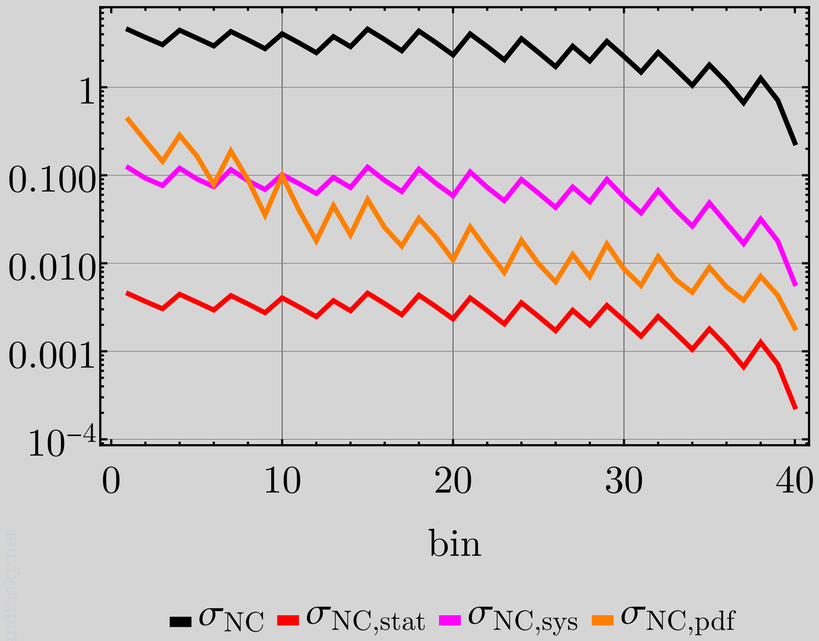
$0.1 \leq y \leq 0.9$

$\Rightarrow$ *good* bins

to avoid uncertainties from
nonperturbative QCD
and nuclear dynamics

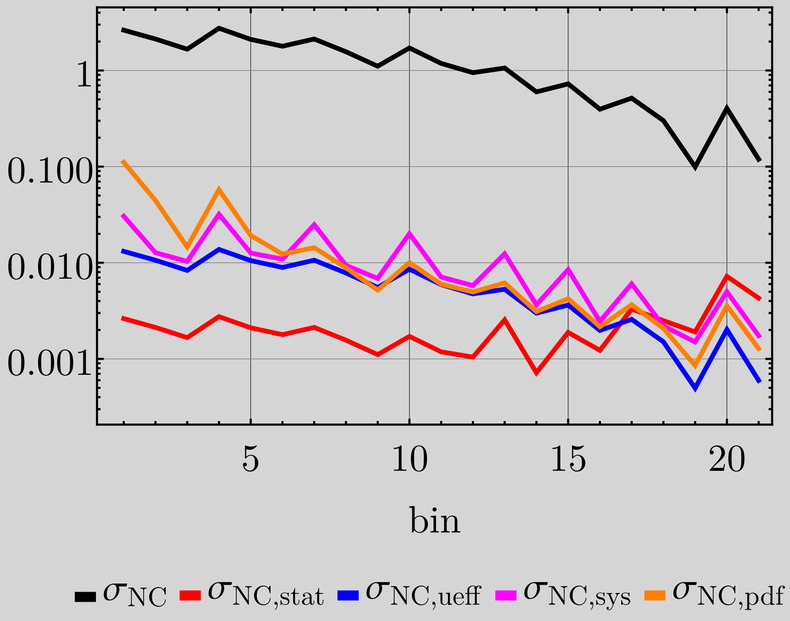
Error budget

FCC-eh



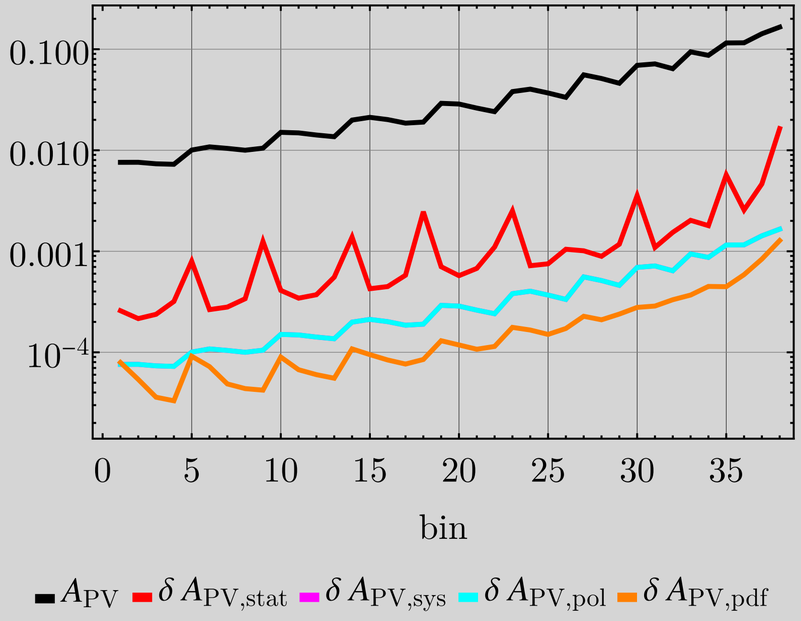
Systematics dominate.

LHeC



Systematics dominate.

EIC



Statistical uncertainties dominate.

BSM framework: **S**tandard **M**odel **E**ffective **F**ield **T**heory

What is SMEFT?

Model-independent extension of the SM Lagrangian with higher-dimensional operators, $O_k^{(n)}$, built up of SM fields at an energy scale Λ that is heaver than all SM fields and accessible collider energy, introducing Wilson coefficients, $C_k^{(n)}$, as effective couplings:

$$\mathcal{L} = \mathcal{L}_{\text{SM}} + \sum_{n>4} \frac{1}{\Lambda^{n-4}} \sum_k C_k^{(n)} O_k^{(n)}$$

Why SMEFT?

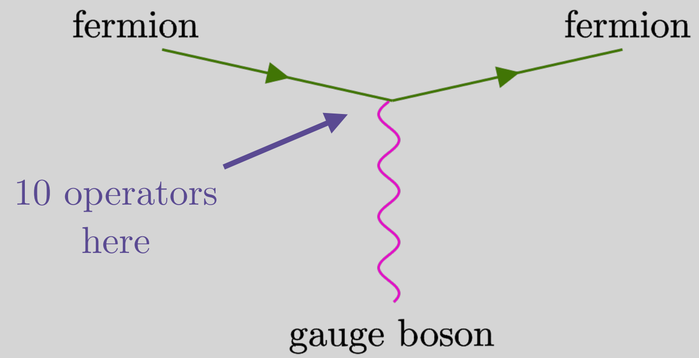
There has been no conclusive evidence for particles beyond the SM.

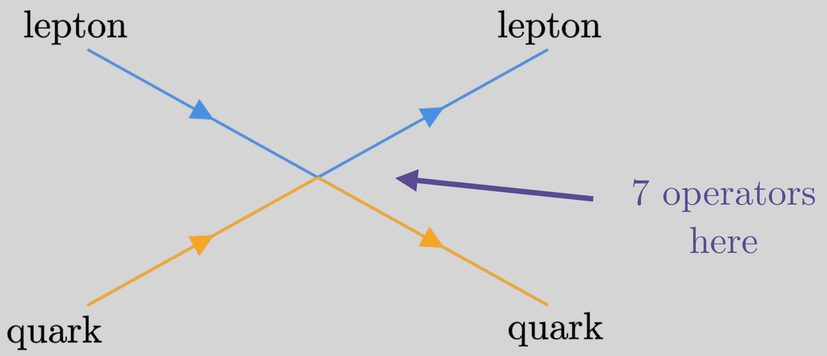
BSM framework: **S**tandard **M**odel **E**ffective **F**ield **T**heory

Case of dimension 6 relevant to our study:

$$\mathcal{L} = \mathcal{L}_{\mathrm{SM}} + \frac{1}{\Lambda^2} \sum_{k=1}^{17} C_k O_k$$

SMEFT Lagrangian obeys the symmetries of the SM Lagrangian, i.e. SM couplings are shifted in a gauge invariant manner.





$$V^{\mu}_{ffV} = V^{\mu(\mathrm{SM})}_{ffV}[1 + \mathscr{O}(C_k)]$$

$$V_{\ell\ell qq} = \mathscr{O}(C_k)$$

Fitting procedure

Observables, unpolarized cross section and un(polarized) PV asymmetries, are linearized w.r.t. C_k:

$$\mathcal{Q} = \mathcal{Q}_{\rm SM} + \sum_k C_k \; \delta\mathcal{Q}_k \qquad\qquad \mathcal{Q} = \sigma_{\rm NC}, (\Delta) A_{\rm PV}$$

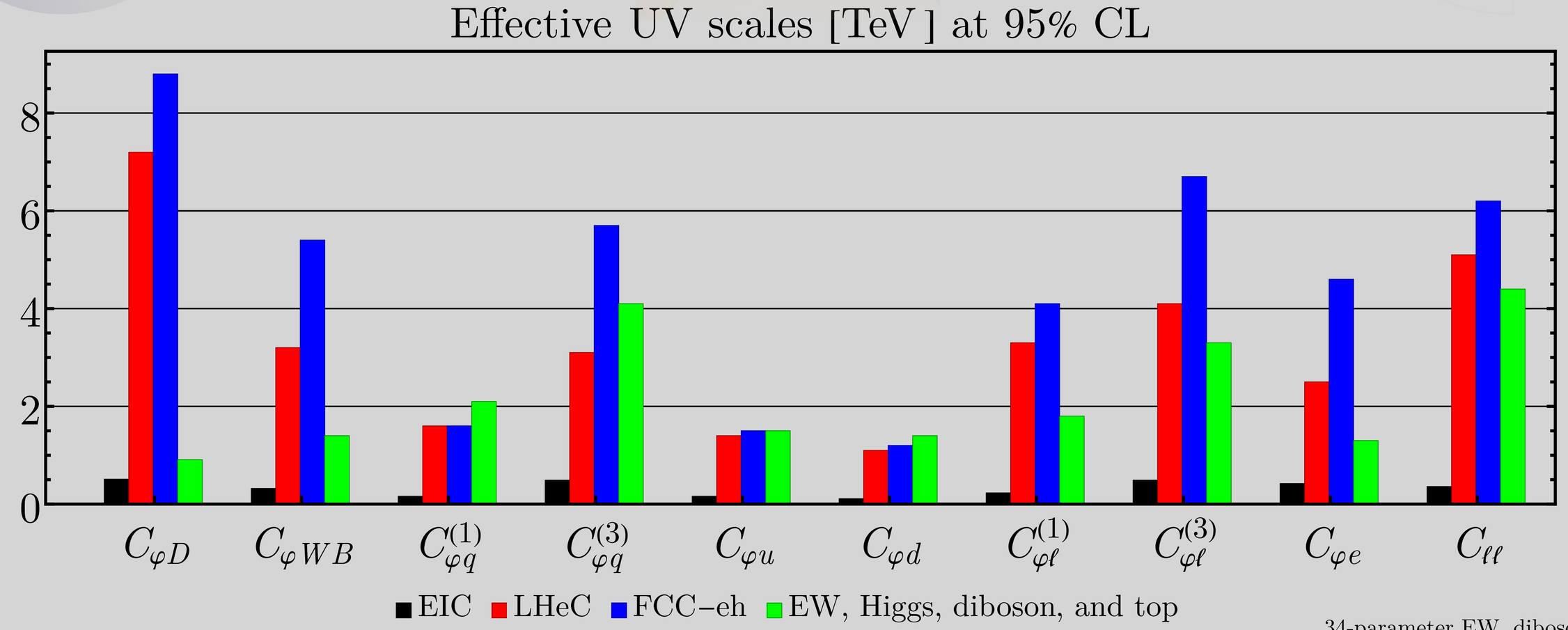
Fitting procedure:

$$\chi^2 = (\mathcal{Q} - \mathcal{Q}_{\rm pseudodata})^\top H (\mathcal{Q} - \mathcal{Q}_{\rm pseudodata})$$

where pseudodata is generated by smearing uncertainties around the SM predictions with a Gaussian profile.

Fit results

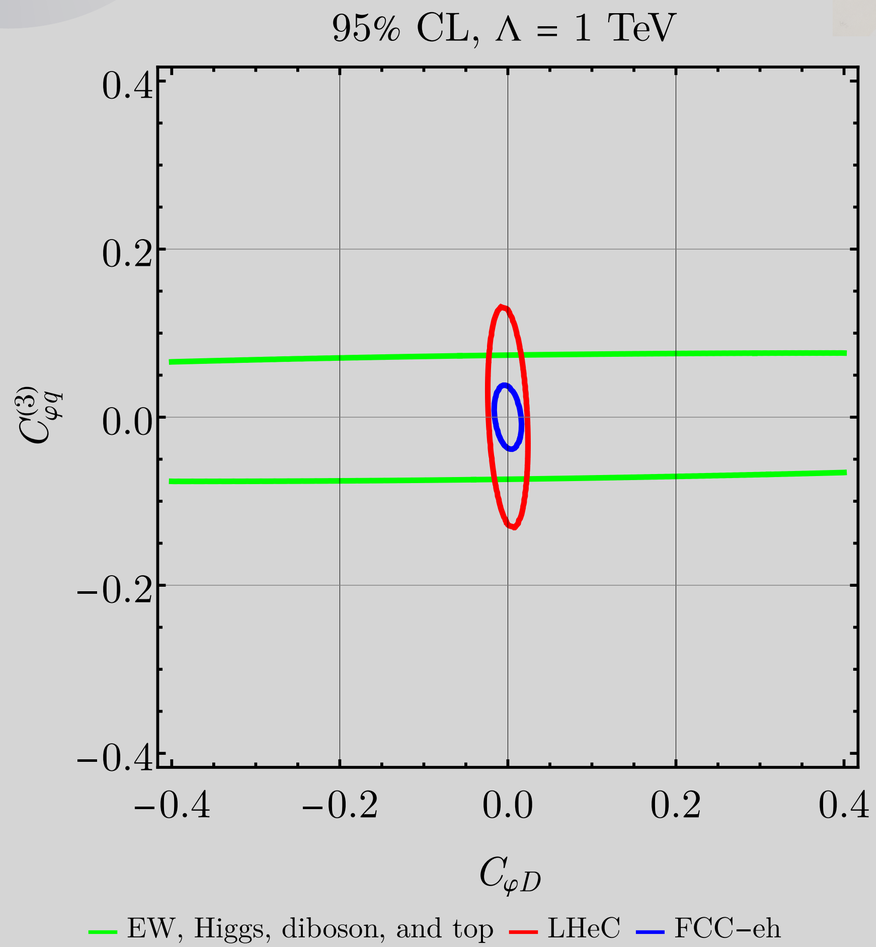
Marginalized effective UV scales that can be probed for BSM searches:

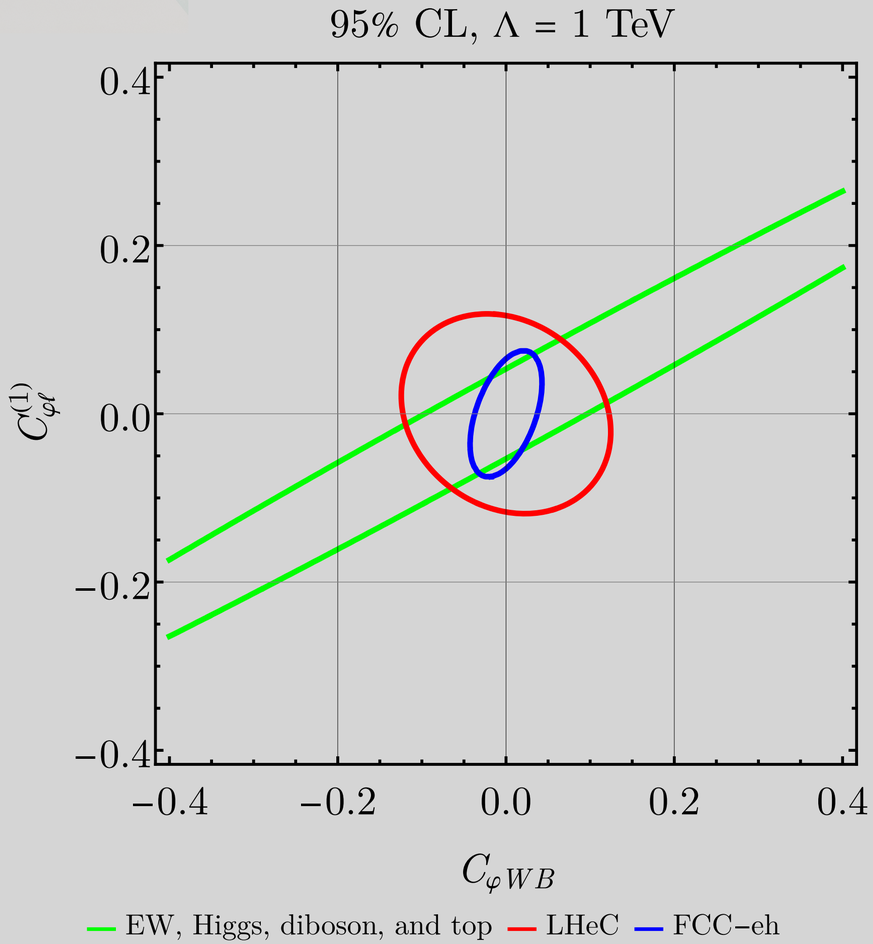


34-parameter EW, diboson, Higgs, and top data fit is adapted from [Ellis *et al.* 2012.02779].

Fit results

Marginalized confidence ellipses:





34-parameter EW, diboson, Higgs, and top data fit is adapted from [Ellis *et al.* 2012.02779].

Coda

Conclusion

- FCC-eh, LHeC, and EIC will offer distinct correlations, showing complementarity.
- FCC-eh will be superior to LHeC and EIC in constraining BSM parameters, therefore in probing deeper energy levels, thanks to higher energy reach.
- All promise to resolve blind spots in more extensive fits with electroweak pole measurements, diboson, Higgs, and top quark data.

All three are designed as EW and QCD machines but seem promising as useful probes of new physics. Therefore, the taxpayers' money is wisely spent.