Precision electroweak measurements and SMEFT studies at the EIC

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Reference:
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Collaborators:
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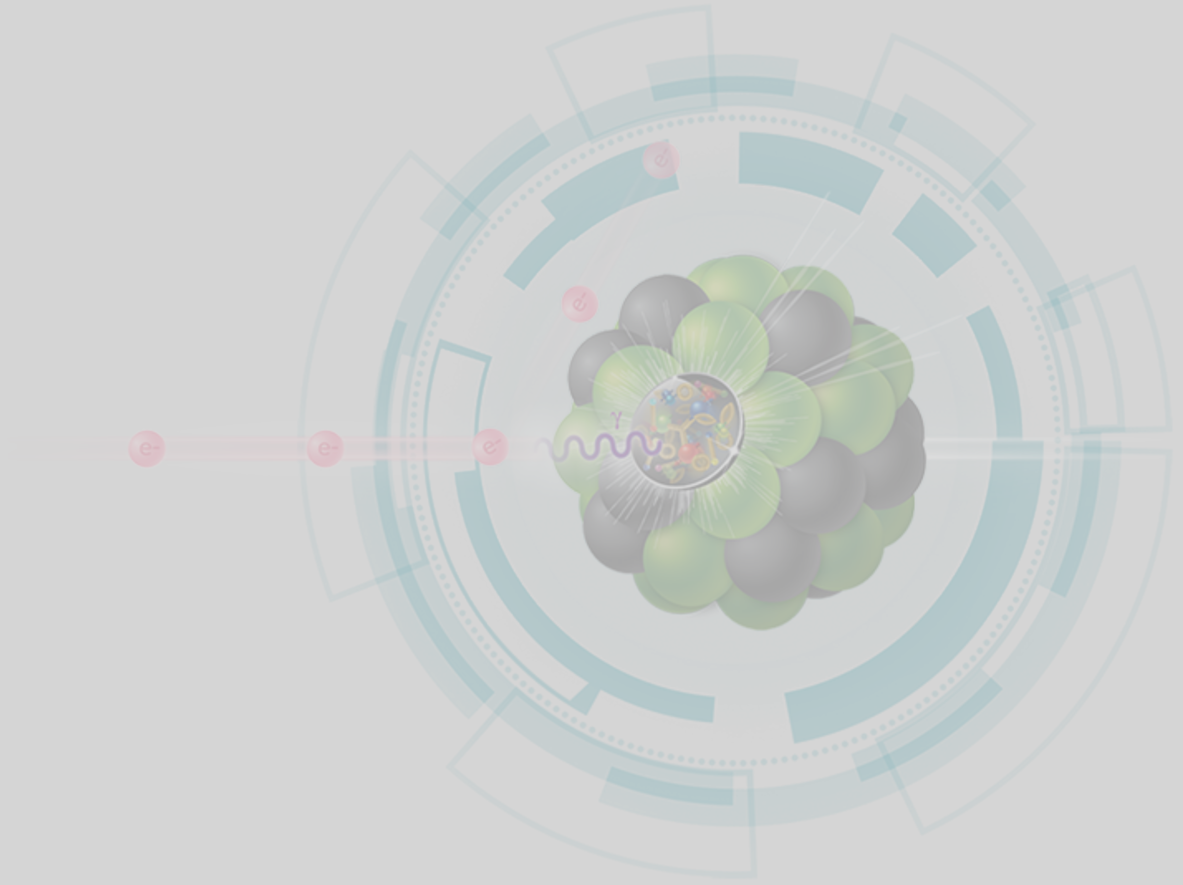
S. Mantry *et al.* (EIC Group)

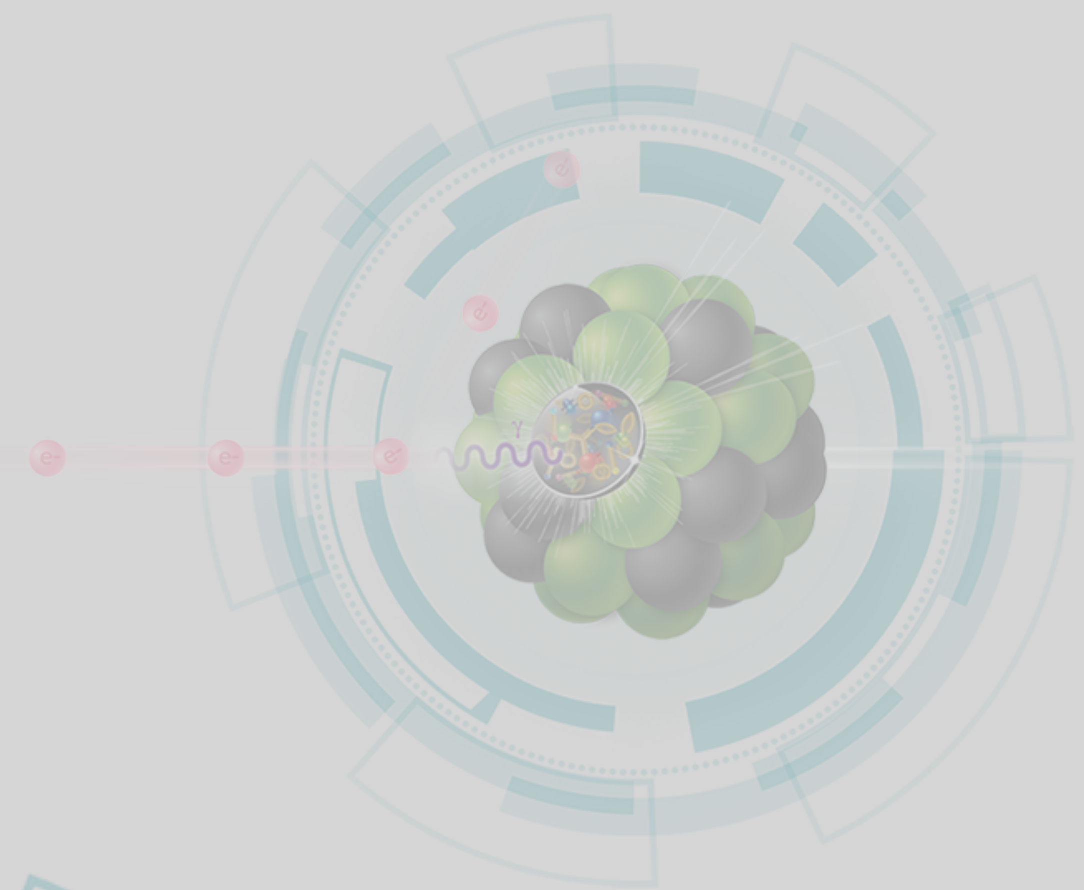


Prelude

Electron-Ion Collider

A next-gen electron-hadron collider

Accardi *et al.* 1212.1701

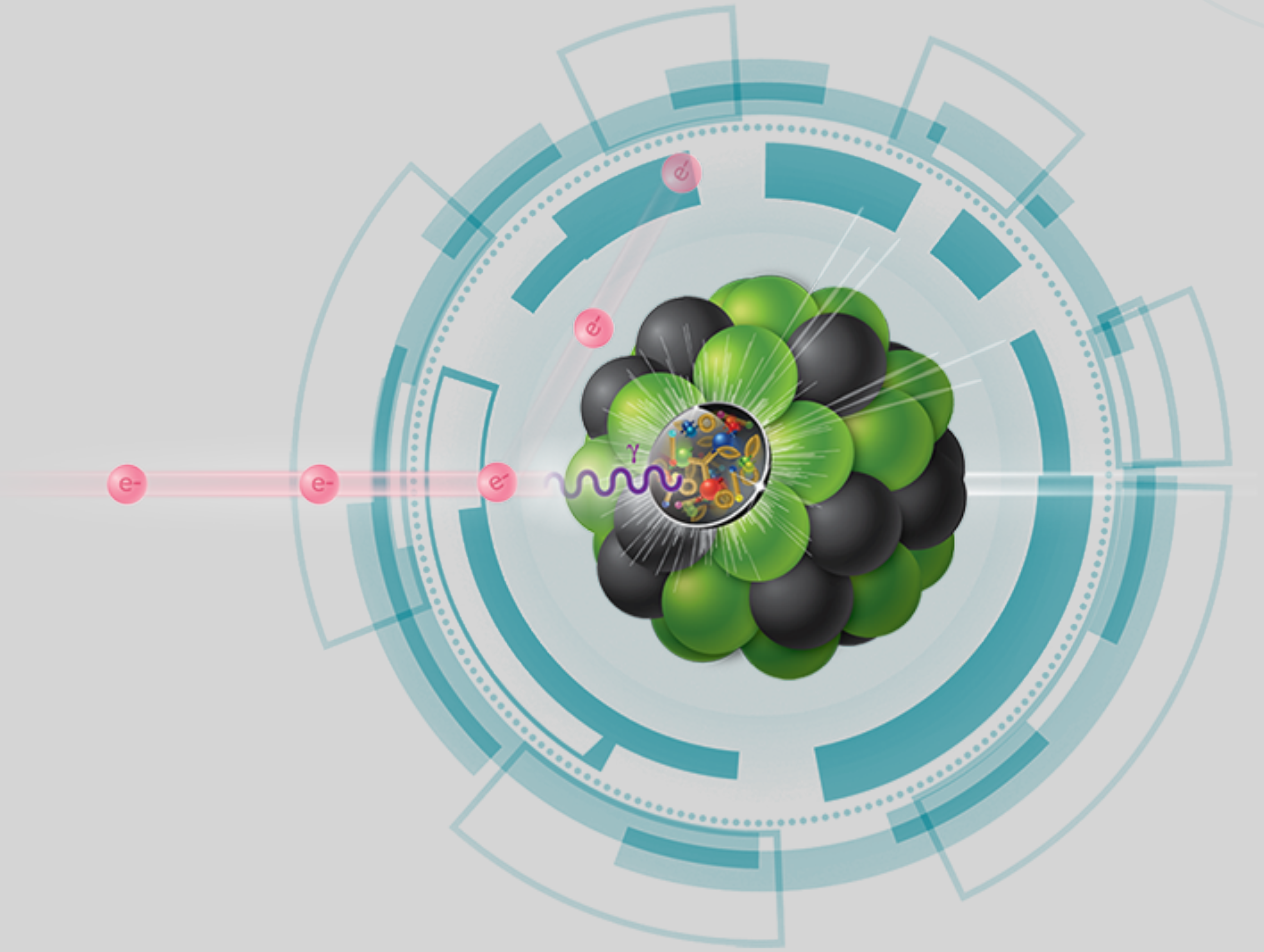


first lepton-ion collider to polarize both beams

$$\sqrt{s} = 70 \text{ to } 140 \text{ GeV}$$

luminosity $= 1000 \times$ HERA

5 to 18 GeV e^-



41 to 275 GeV polarized p

up to 137 GeV polarized ^{2}H

up to 166 GeV polarized ^{3}He

unpolarized heavy ion up to 110 GeV

Electron-Ion Collider

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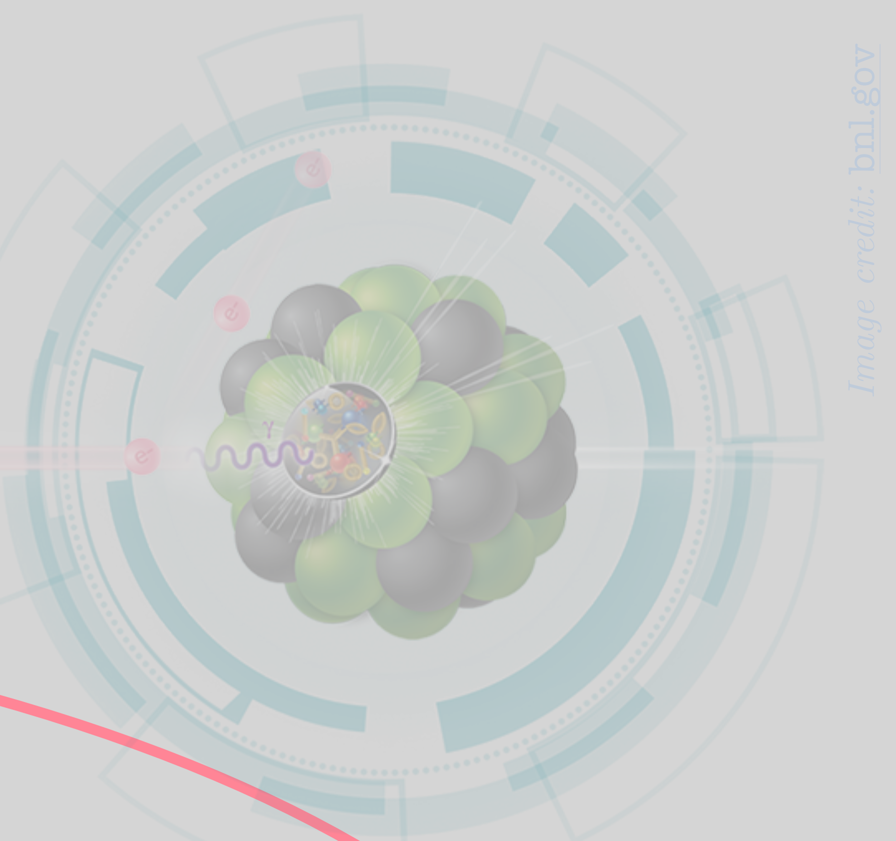


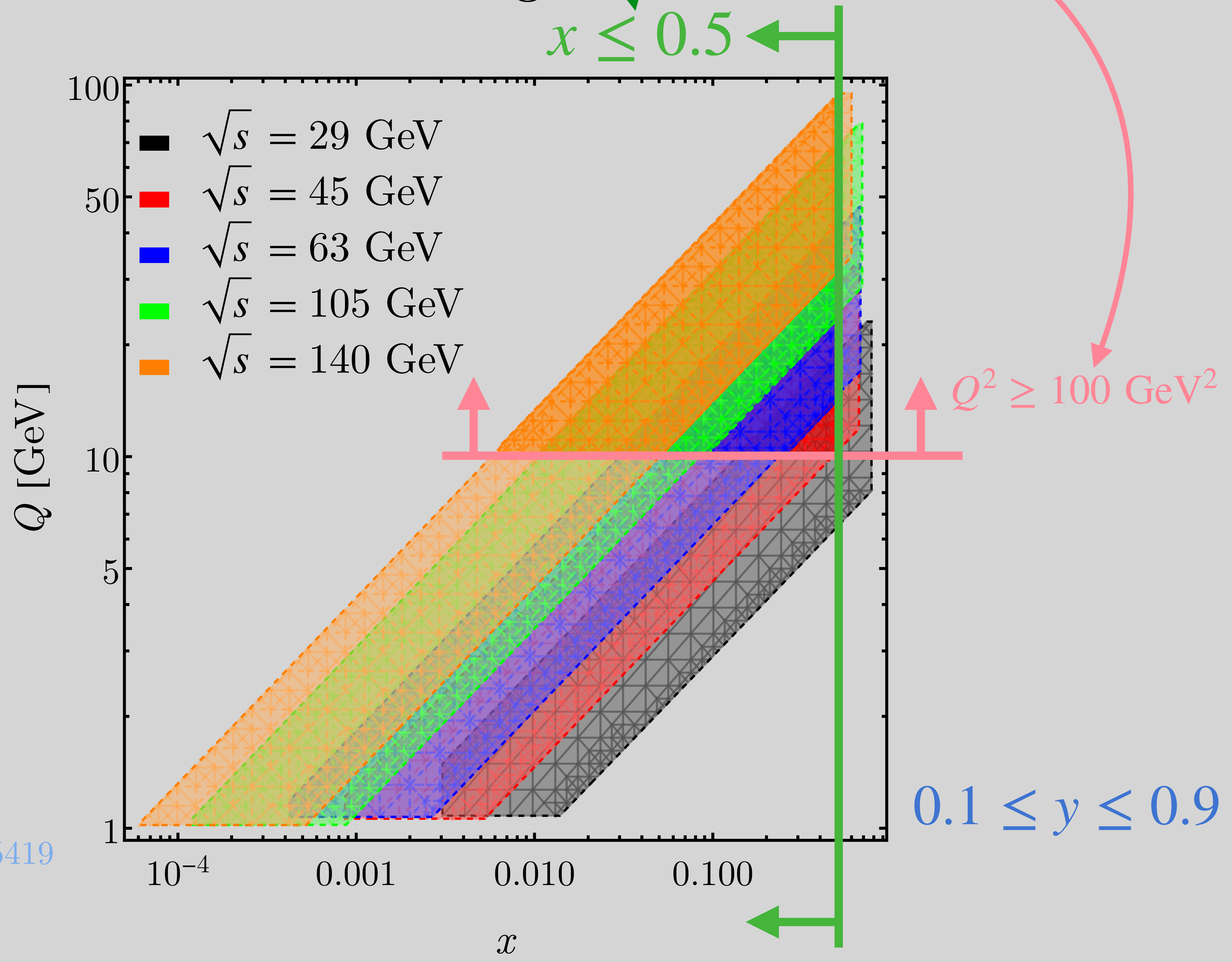
Data sets:

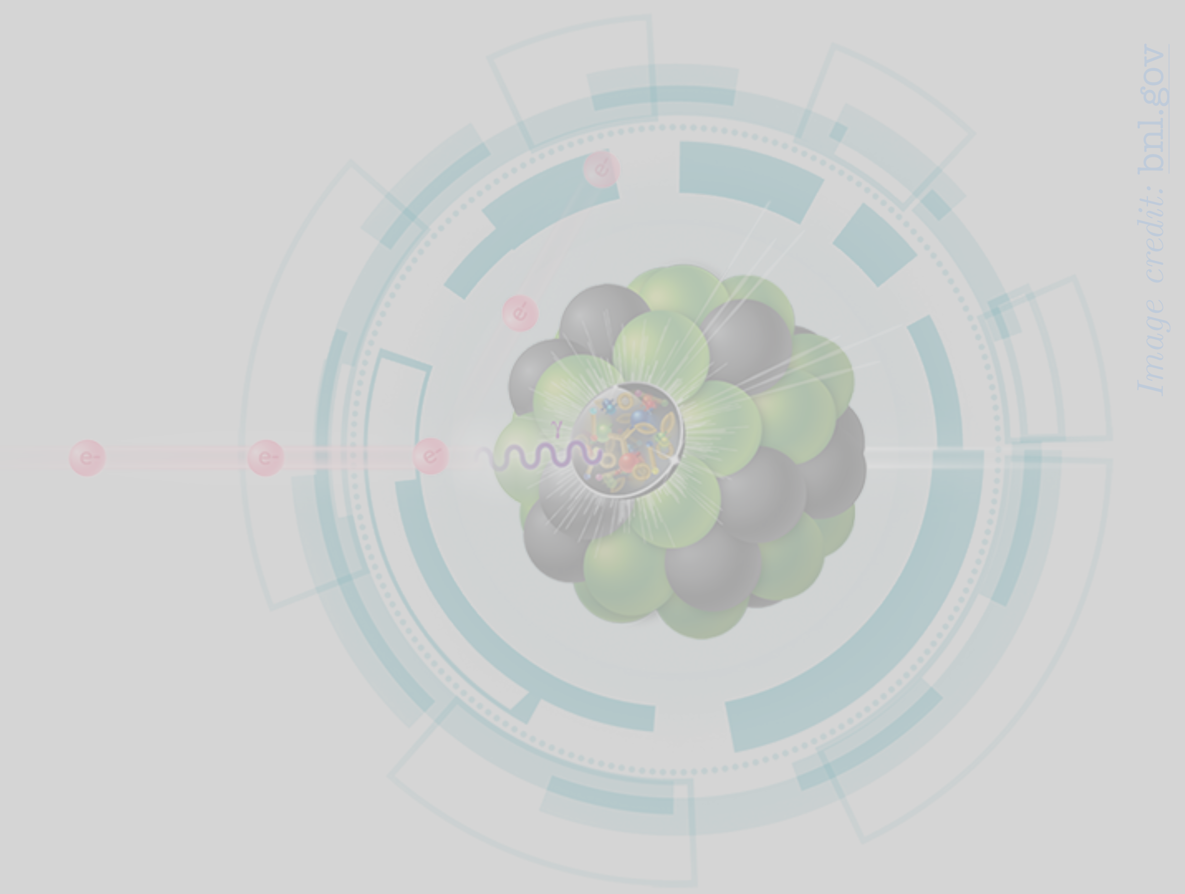
Label	E_e [GeV] $\times$ E_H [GeV]	$\mathcal{L}$ [fb^{-1}]
D1	5×41	4.4
D2	5×100	36.8
D3	10×100	44.8
D4	10×137	100
D5	18×137	15.4
P1	5×41	4.4
P2	5×100	36.8
P3	10×100	44.8
P4	10×275	100
P5	18×275	15.4
P6	18×275	100

YR reference
Khalek *et al.* 2103.05419

Kinematic coverage:

cuts to avoid nonperturbative QCD and nuclear dynamics





Electron-Ion Collider

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Observable of interest:

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

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

$$A_{\rm LC} = \frac{\sigma^{e^-}_{\rm NC} - \sigma^{e^+}_{\rm NC}}{\sigma^{e^-}_{\rm NC} + \sigma^{e^+}_{\rm NC}}$$ lepton-charge (LC) asymmetry

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

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

$\sigma^{e^\pm}_{\rm NC}$: unpolarized NC $e^\pm H$ DIS cross section with *no beams* polarized

Electron-Ion Collider

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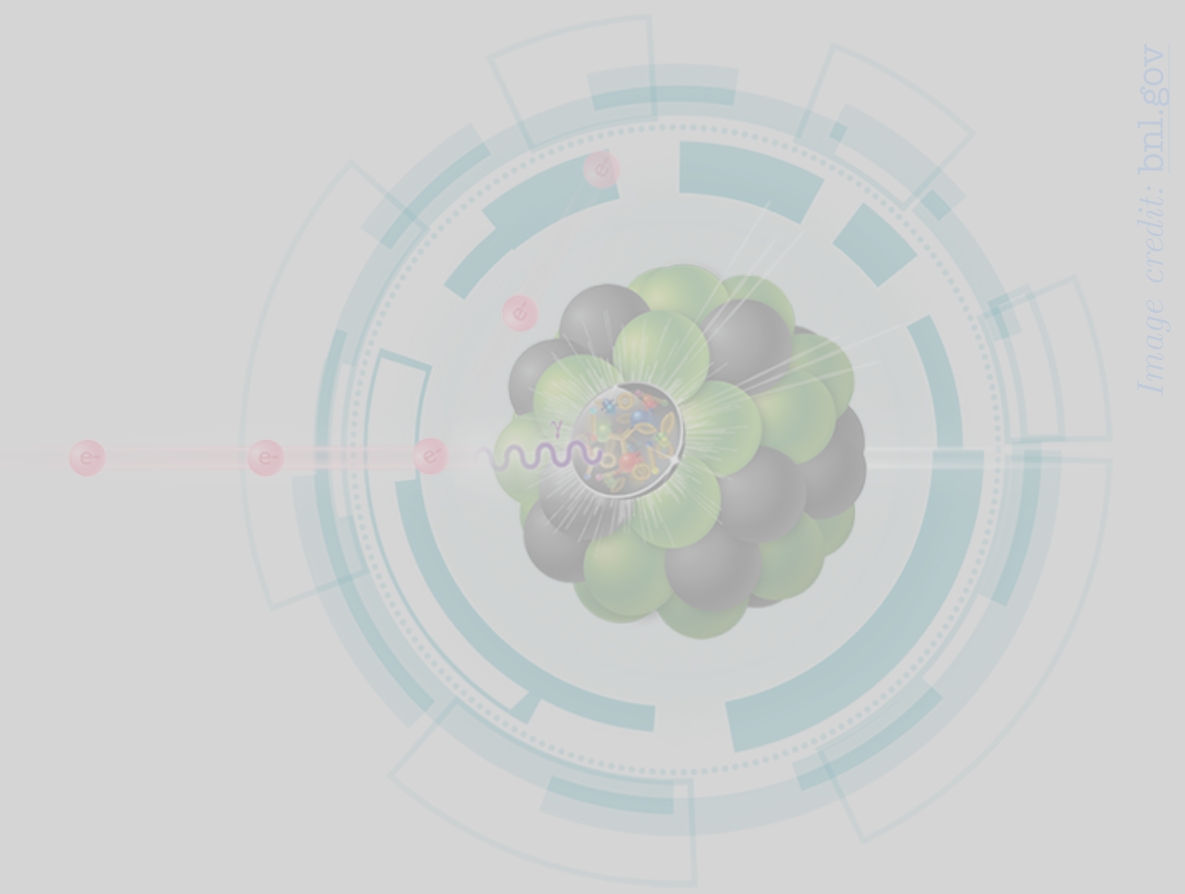

Uncertainty	A_{PV}	ΔA_{PV}	A_{LC}
Statistical (NL) Statistical (HL)	$\delta A_{PV,stat} = \frac{1}{P_\ell}\frac{1}{\sqrt{N}}$ $\frac{1}{\sqrt{10}}\ \delta A_{PV,stat}$	$\frac{P_\ell}{P_H}\ \delta A_{PV,stat}$ $\frac{1}{\sqrt{10}}\frac{P_\ell}{P_H}\ \delta A_{PV,stat}$	$\sqrt{10}P_\ell\ \delta A_{PV,stat}$ NO
Uncorrelated systematic	1% rel.	1% rel.	1% rel.
Fully correlated beam polarization	1% rel.	2% rel.	NO
Fully correlated luminosity	NO	NO	2% abs.
Uncorrelated NLO QED	NO	NO	$5\% \times (A_{LC}^{NLO\ QED} - A_{LC}^{Born})$
Fully correlated PDF	YES	YES	YES

PDF sets used:

- Precision EW:
  - ⋆ CT18NLO
  - ⋆ MMHT2014nlo_68cl
  - ⋆ NNPDF31 NLO
- BSM analysis:
  - ⋆ NNPDF3.1 NLO
  - ⋆ NNPDFPOL1.1

Electron-Ion Collider

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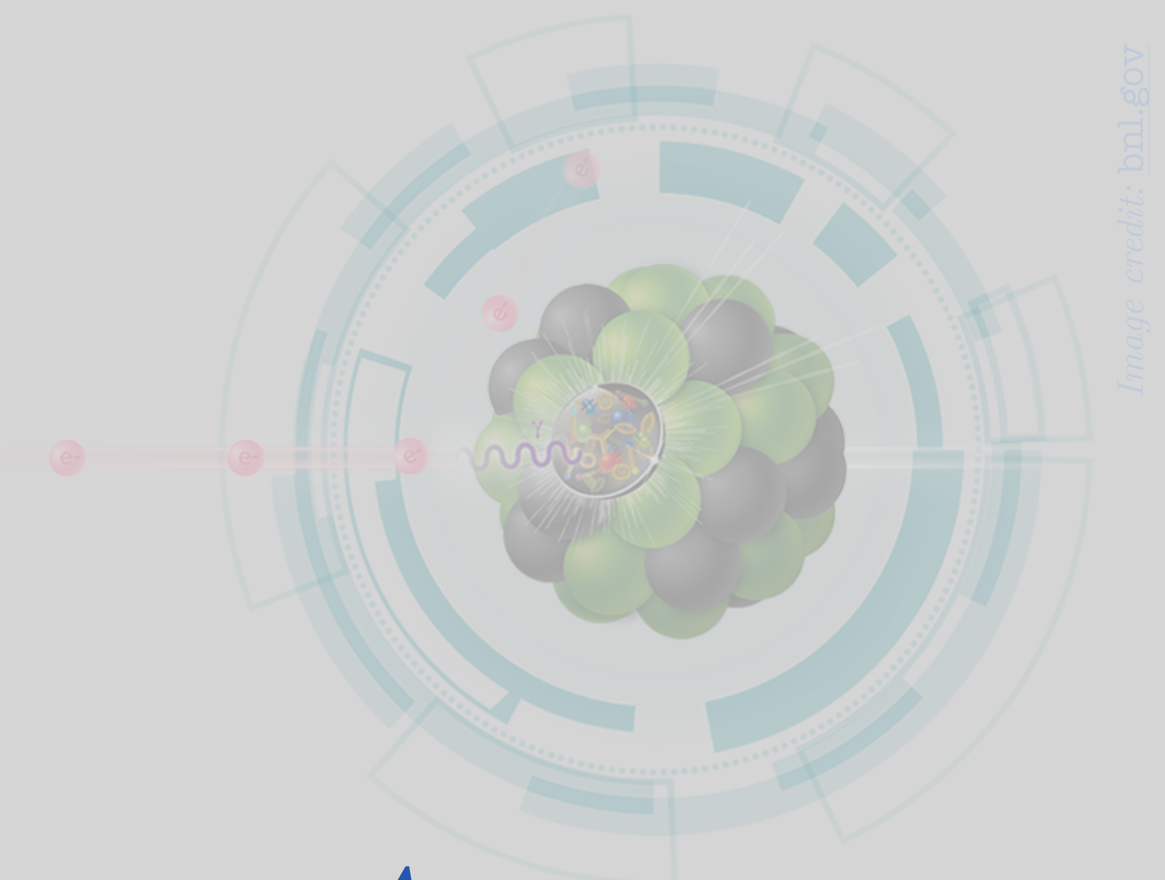
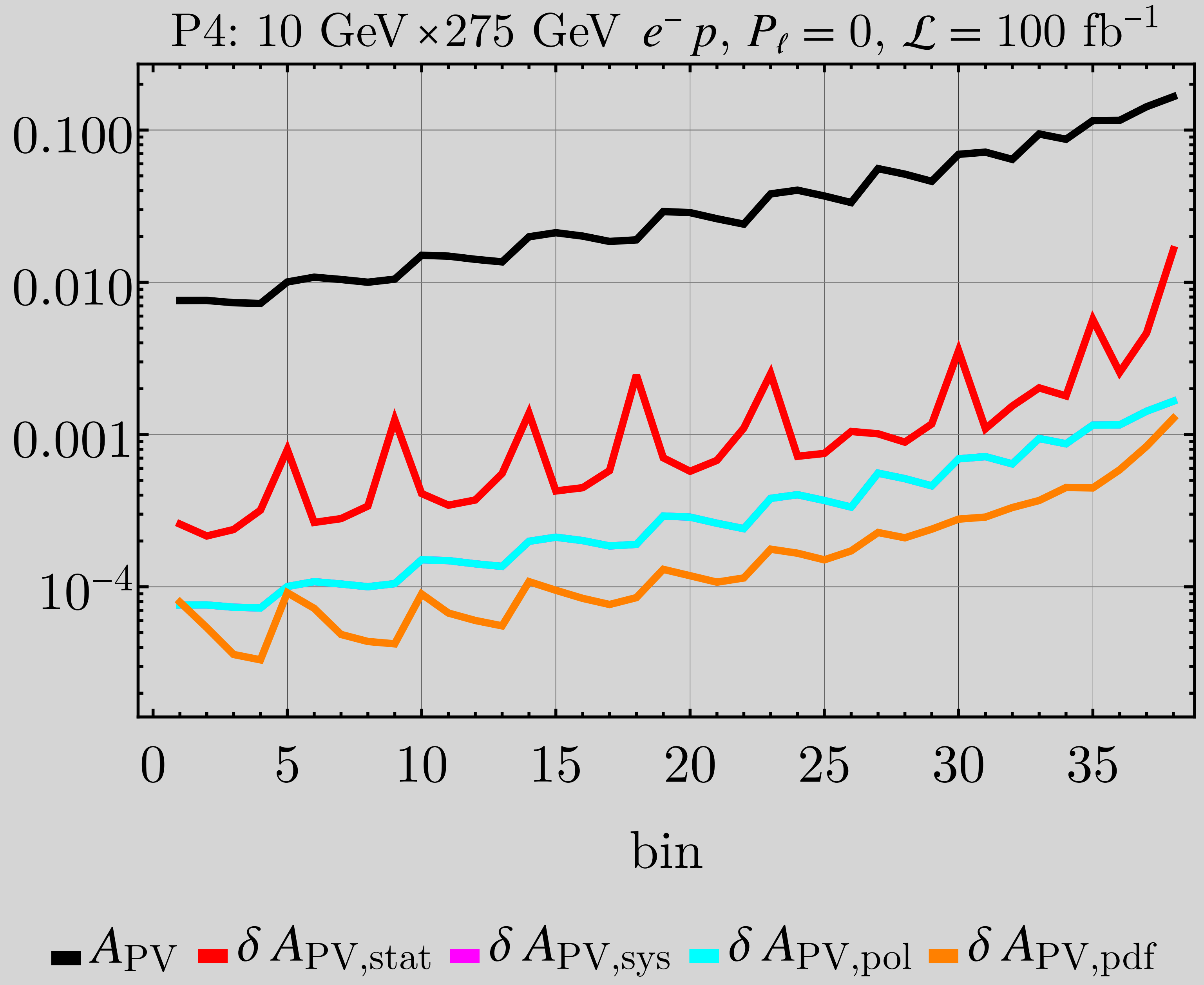
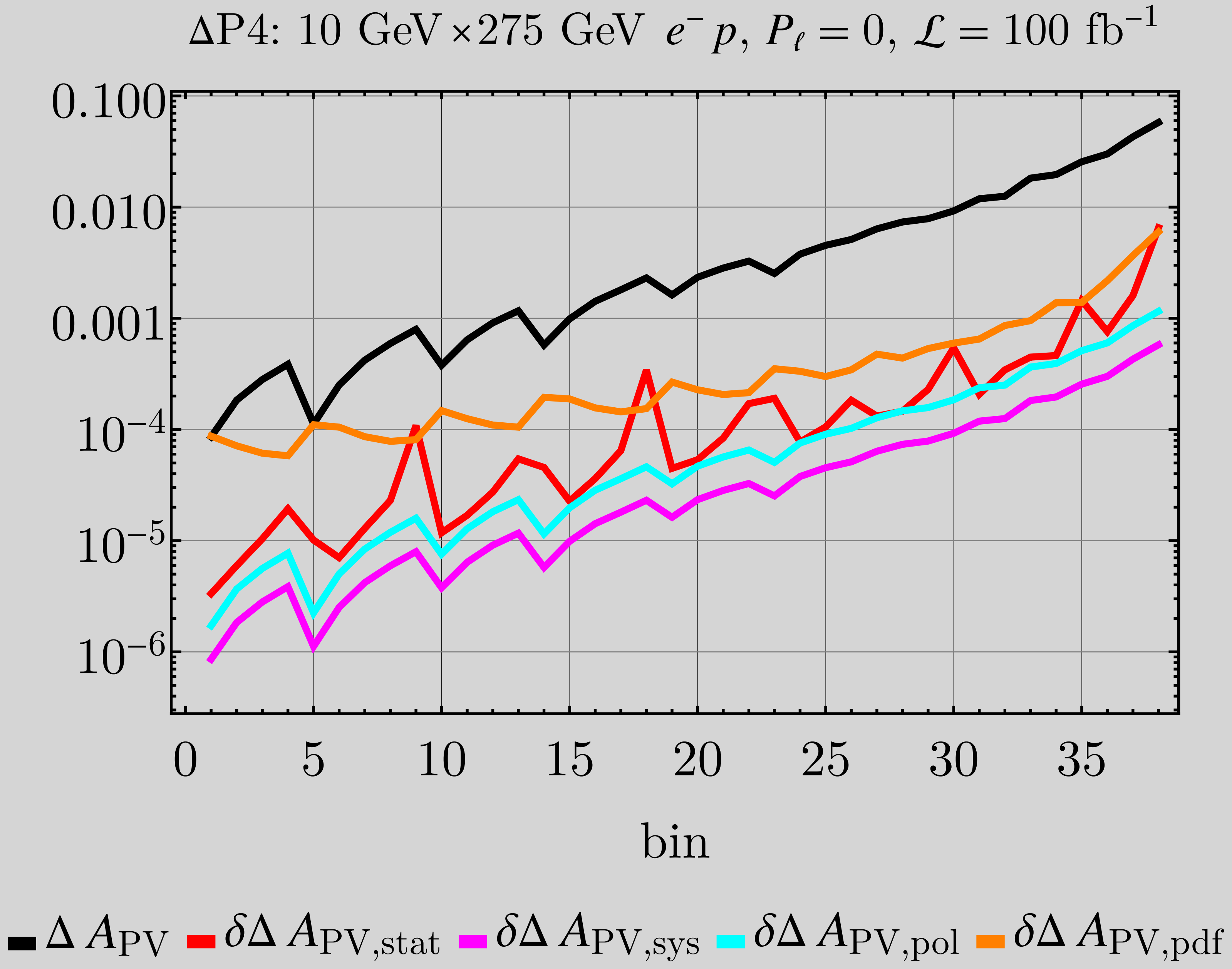


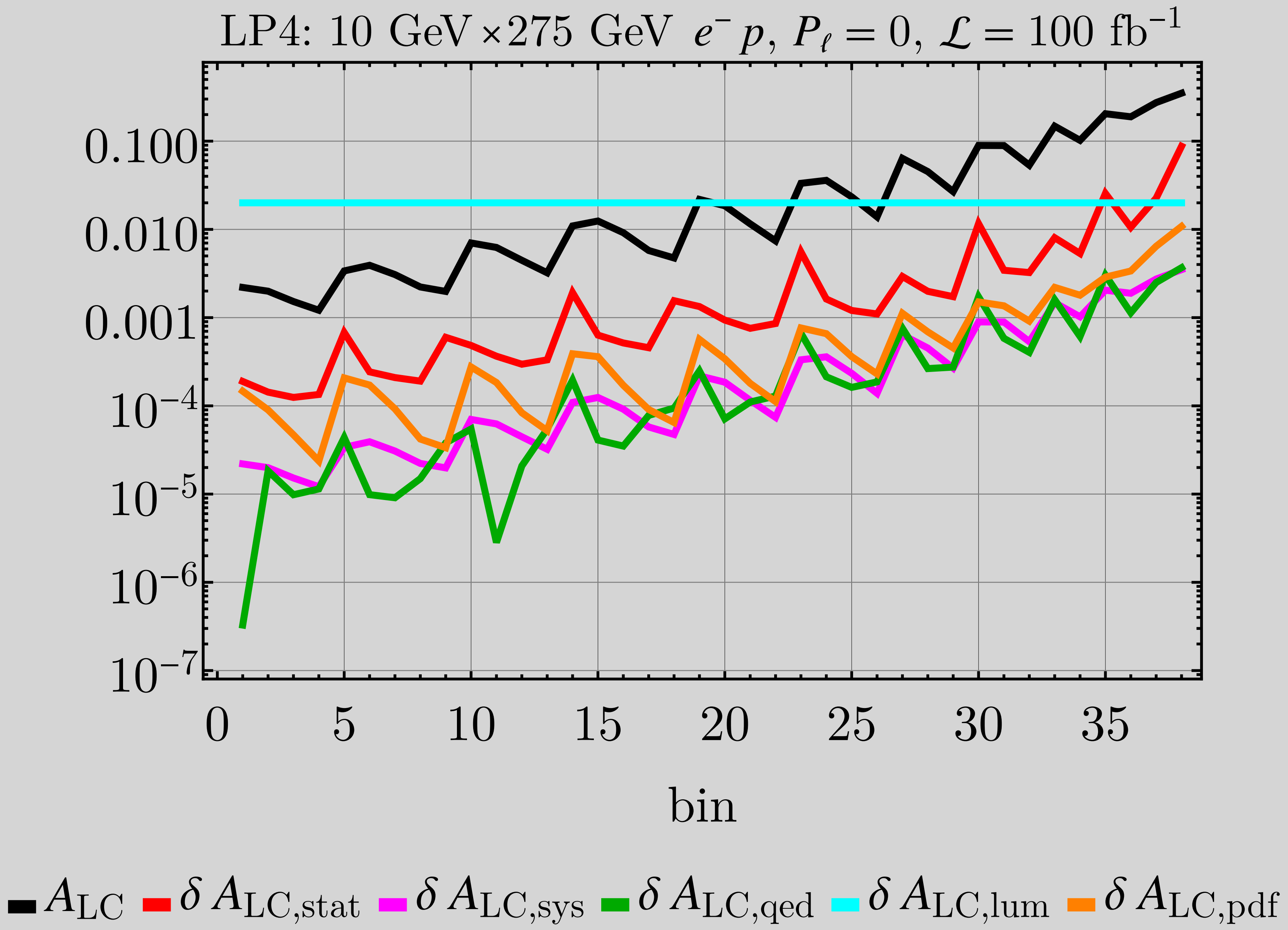
A_{PV}



ΔA_{PV}

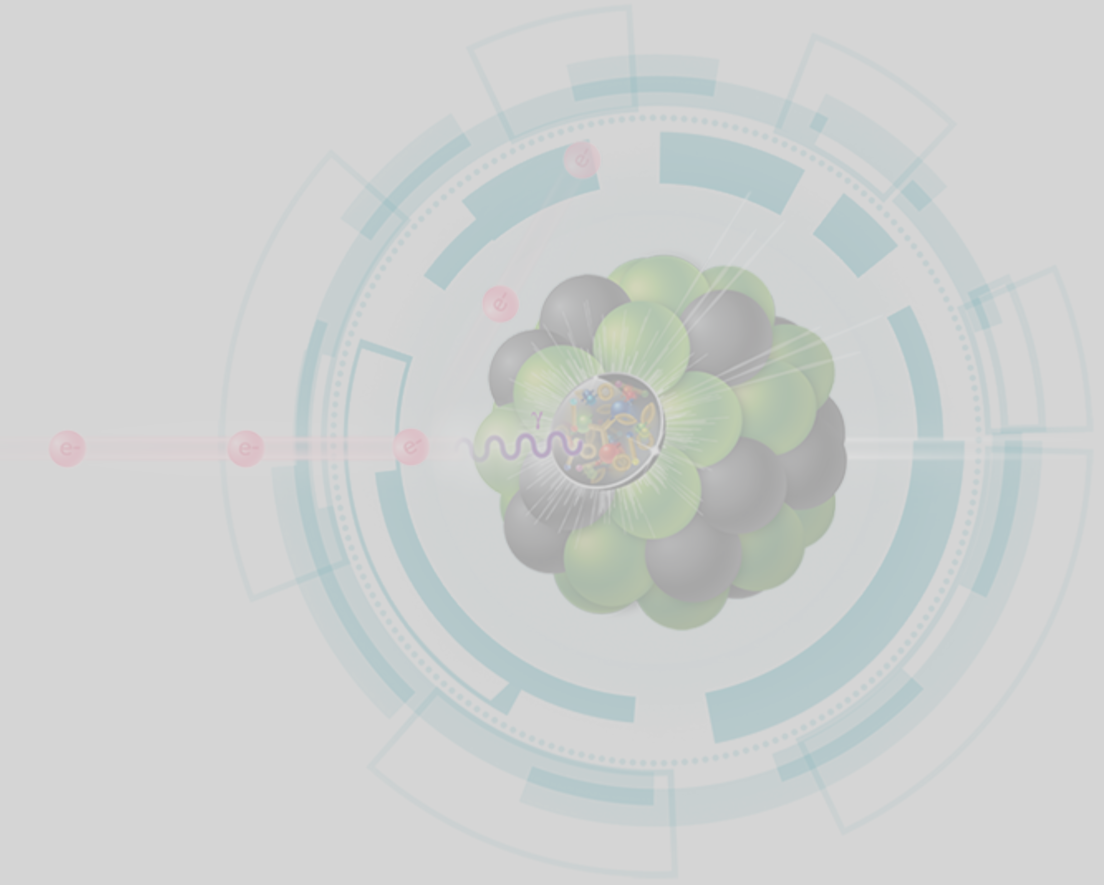


A_{LC}



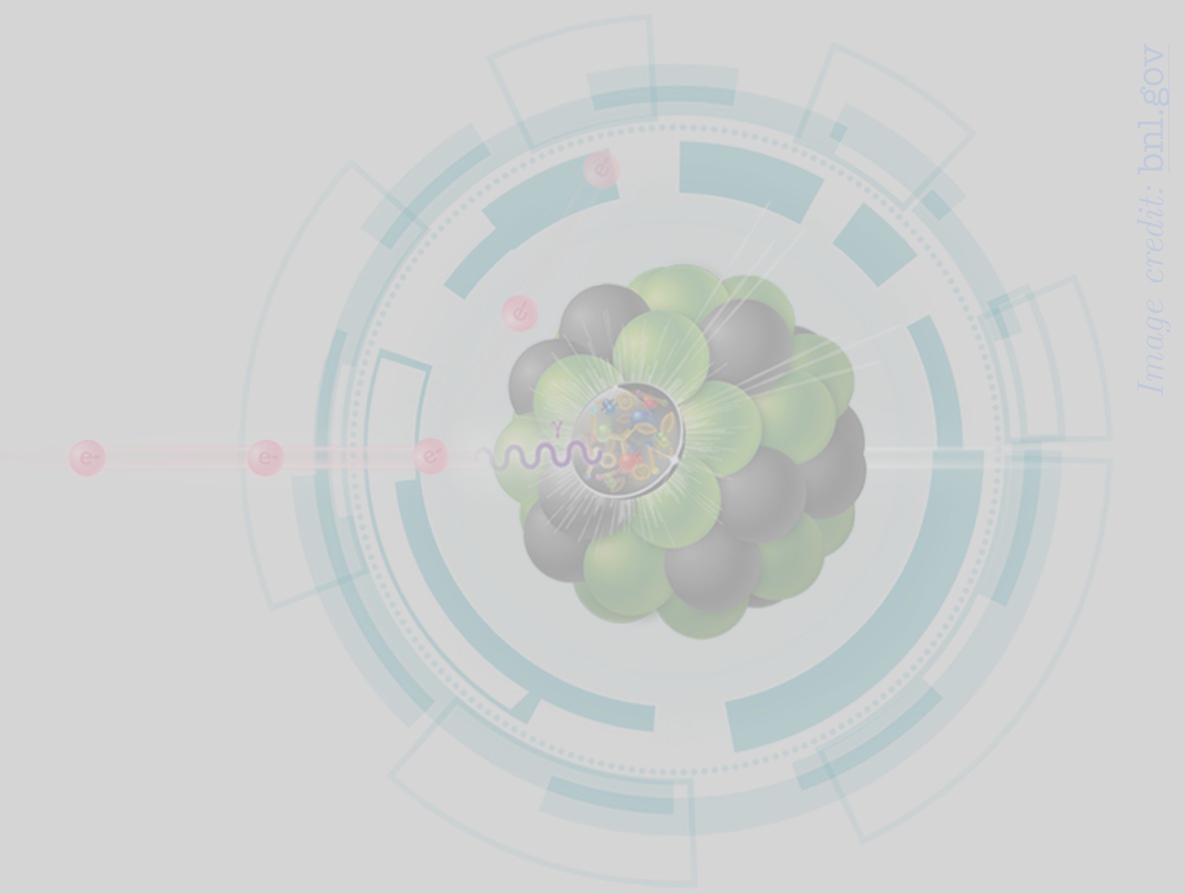
Dominant uncertainties:

A_{PV} : statistical $\quad$ ΔA_{PV} : PDF $\quad$ A_{LC} : luminosity



Phenomenology

Precision EW measurements



Extraction of $\sin(\theta_W)^2$

Boughezal *et al.* 2204.07557

Observable: unpolarized PV asymmetry including target-mass correction terms in the structure-function language

$$A_{\rm PV} = \frac{P_e \eta_{\gamma Z}\left[g_A^e 2yF_1^{\gamma Z} + g_A^e\left(\frac{2}{xy} - \frac{2}{x} - \frac{2M^2xy}{Q^2}\right)F_2^{\gamma Z} + g_V^e(2-y)F_3^{\gamma Z}\right]}{2yF_1^{\gamma} + \left(\frac{2}{xy} - \frac{2}{x} - \frac{2M^2xy}{Q^2}\right)F_2^{\gamma} - \eta_{\gamma Z}\left[g_V^e F_1^{\gamma Z} + g_V^e\left(\frac{2}{xy} - \frac{2}{x} - \frac{2M^2xy}{Q^2}\right)F_2^{\gamma Z} + g_A^e(2-y)F_3^{\gamma Z}\right]}$$

$\sin(\theta_W)^2$ enters through $g^e_{V,A}$ and $g^q_{V,A}$. One-loop RGE of $\sin(\theta_W)^2$ in the $\overline{\rm MS}$ scheme and particle thresholds arising between $\mu = m_Z$ and $\mu = \sqrt{Q^2}$ are included.

Fitting procedure:

$$\chi^2 = (A^{\rm theory} - A^{\rm pseudodata})^\top H (A^{\rm theory} - A^{\rm pseudodata})$$

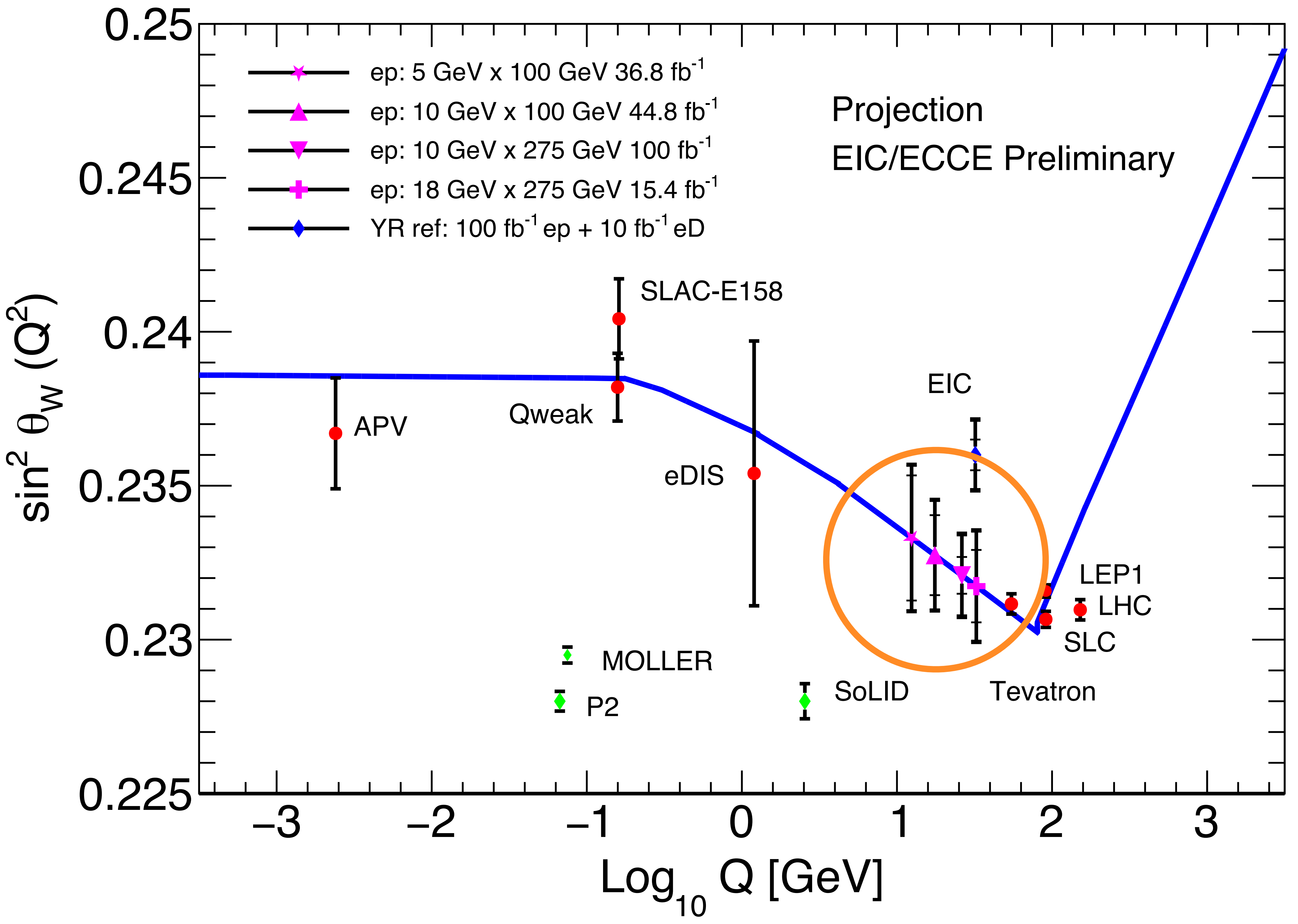
where pseudodata is generated by smearing uncertainties around the SM predictions with a gaussian profile.

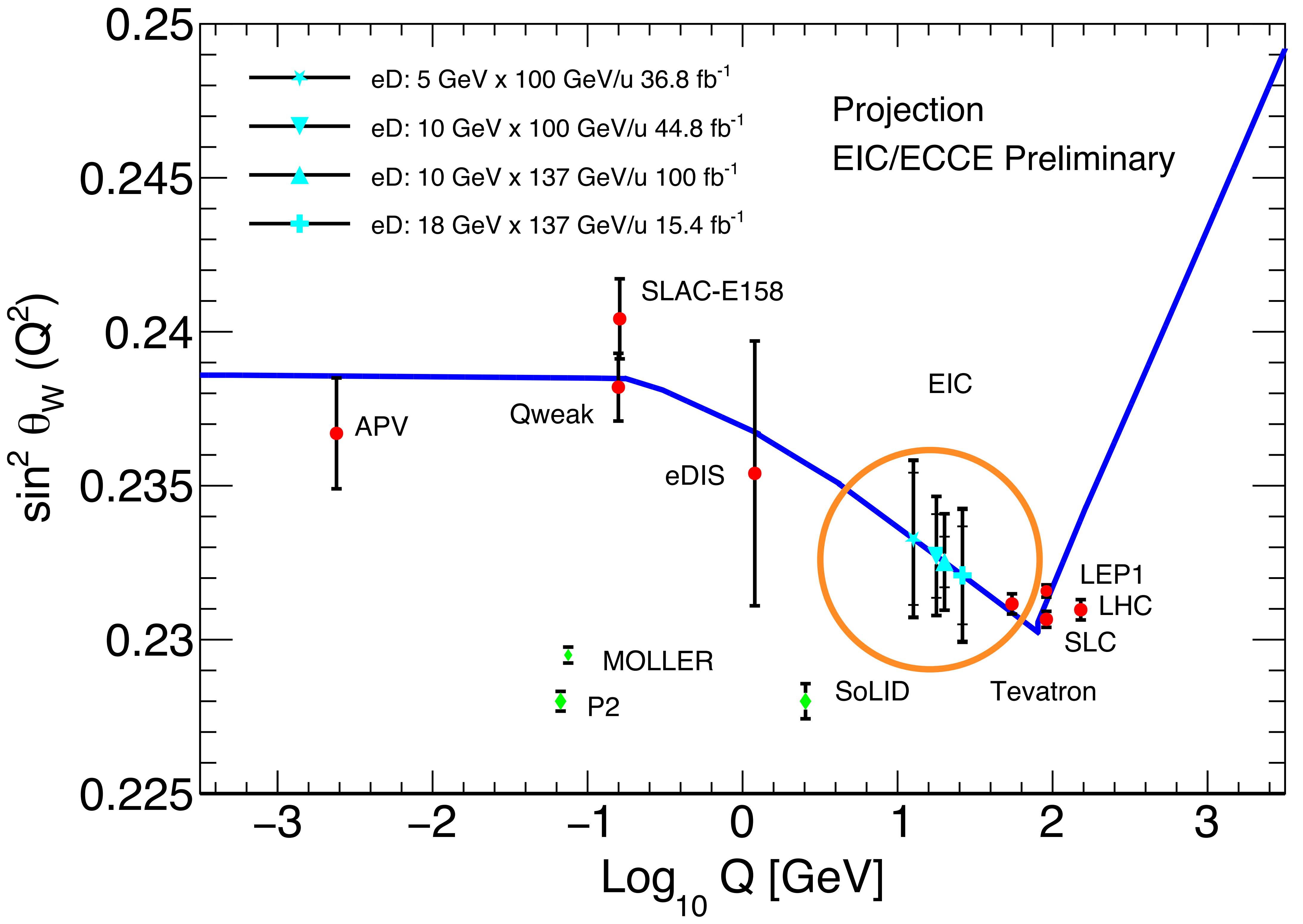
Precision EW measurements

Extraction of $\sin(\theta_W)^2$

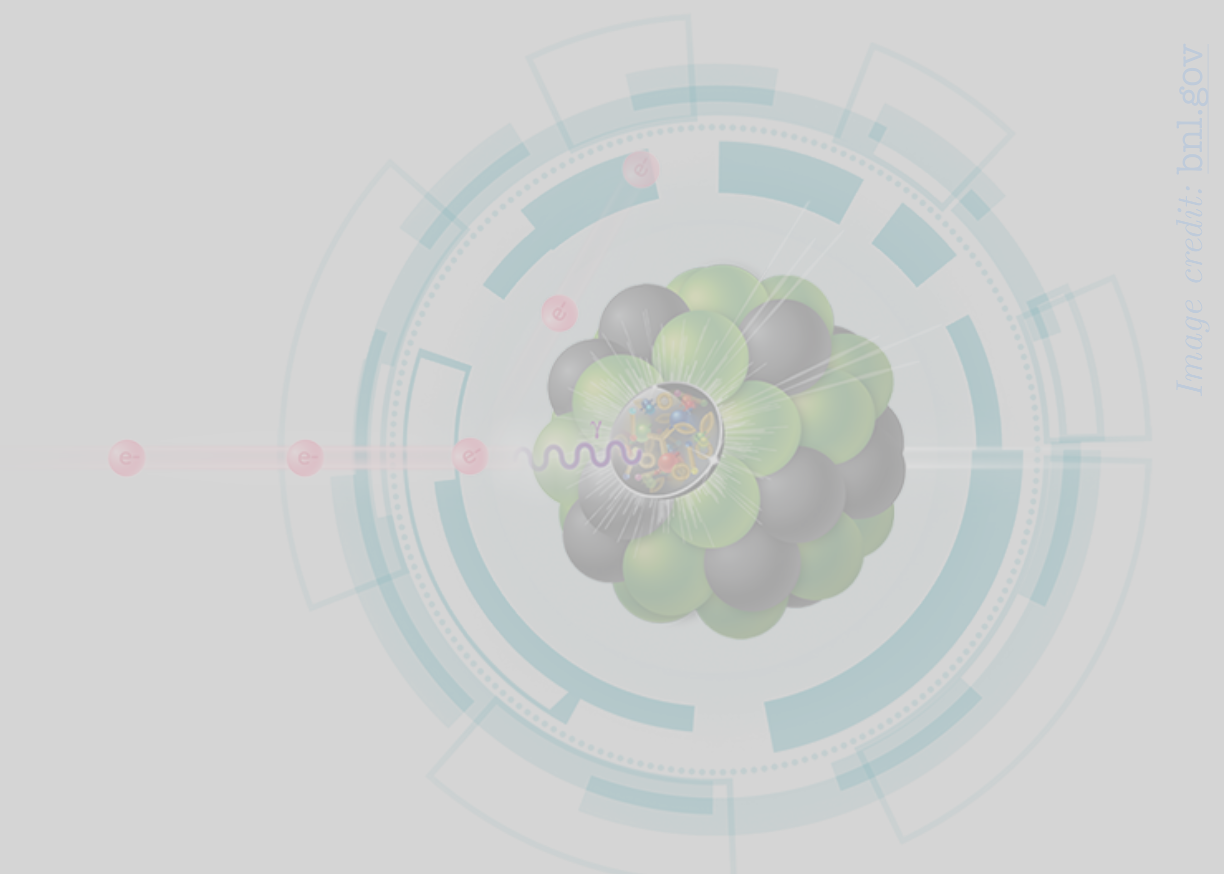
Boughezal *et al.* 2204.07557

bridge between high-energy colliders
and low- to medium-energy SM tests





BSM searches



Constraints on SMEFT parameters

Boughezal *et al.* 2204.07557

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

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

SM couplings are shifted in a gauge-invariant manner, e.g.

$$g^f_{V,A} \to g^f_{V,A}[1 + c^f_{V,A}(M_Z, G_F, \alpha; C_k, \Lambda)]$$

We focus on the case $n = 6$ and semi-leptonic four-fermion operators that induce the contact interaction of leptons with quarks.

BSM searches

Constraints on SMEFT parameters
Boughezal *et al.* 2204.07557

Observable: un(polarized) PV and lepton-charge asymmetries linearized w.r.t. C_k

$$A = A_{\text{SM}} + \sum_k C_k \; \delta A_k$$

Fitting procedure:

$$\chi^2 = (A^{\text{theory}} - A^{\text{pseudodata}})^\top H (A^{\text{theory}} - A^{\text{pseudodata}})$$

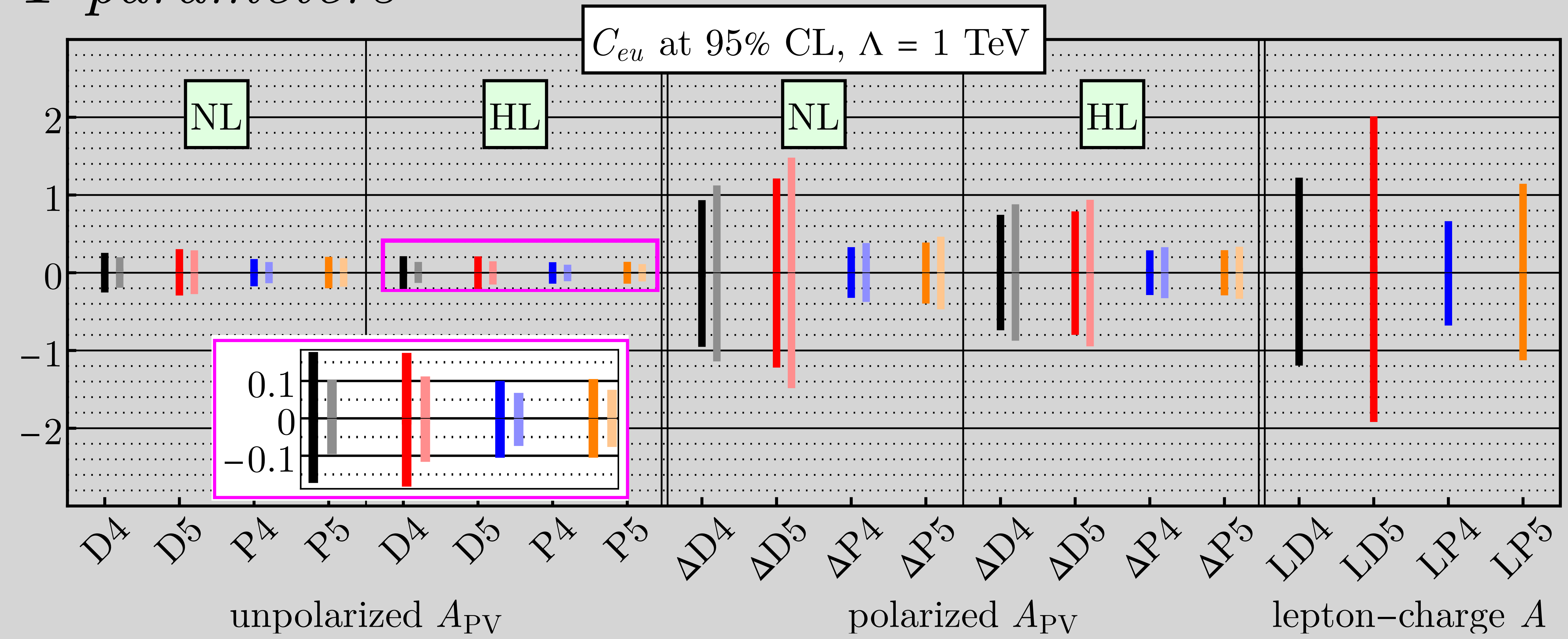
where pseudodata is generated by smearing uncertainties around the SM predictions with a gaussian profile.

BSM searches

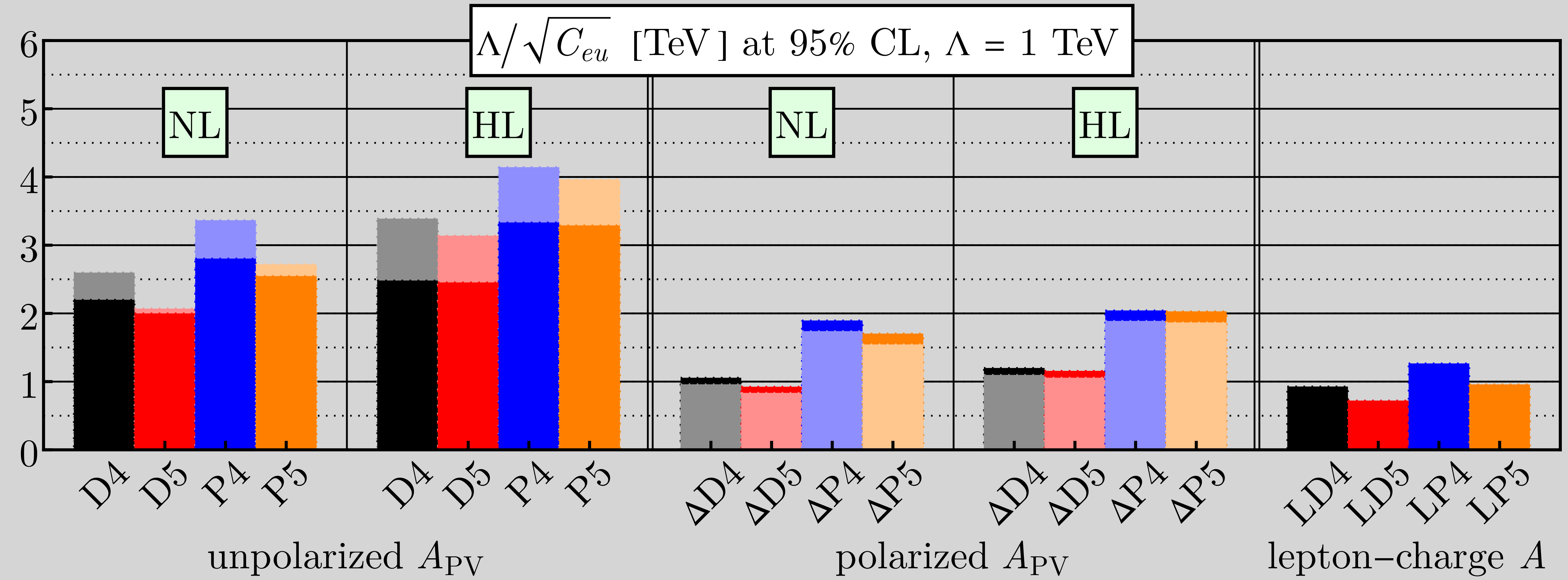
Constraints on SMEFT parameters

Boughezal *et al.* 2204.07557

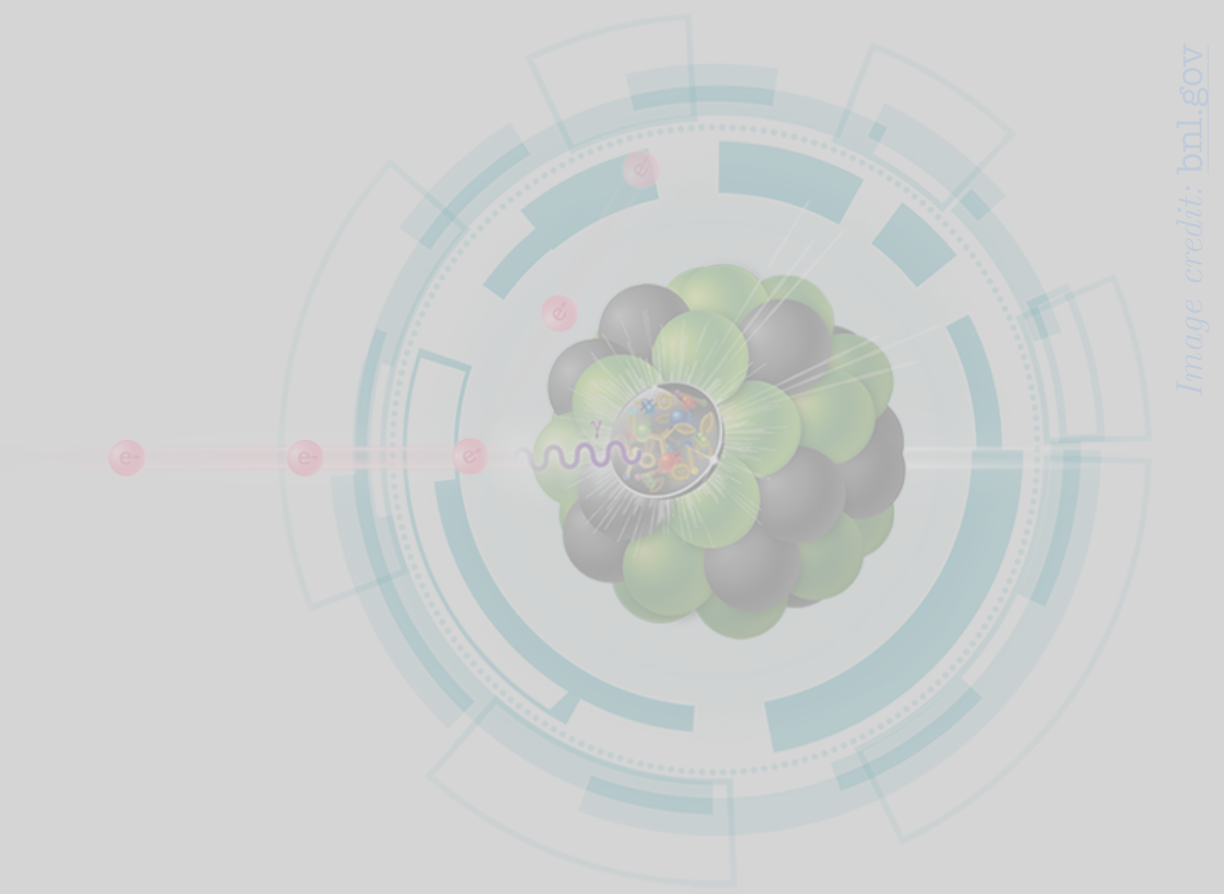
95% CL nonmarginalized bounds at $\Lambda = 1$ TeV in single-parameter fits



Corresponding effective UV scales



~ 4 TeV with high-lum EIC

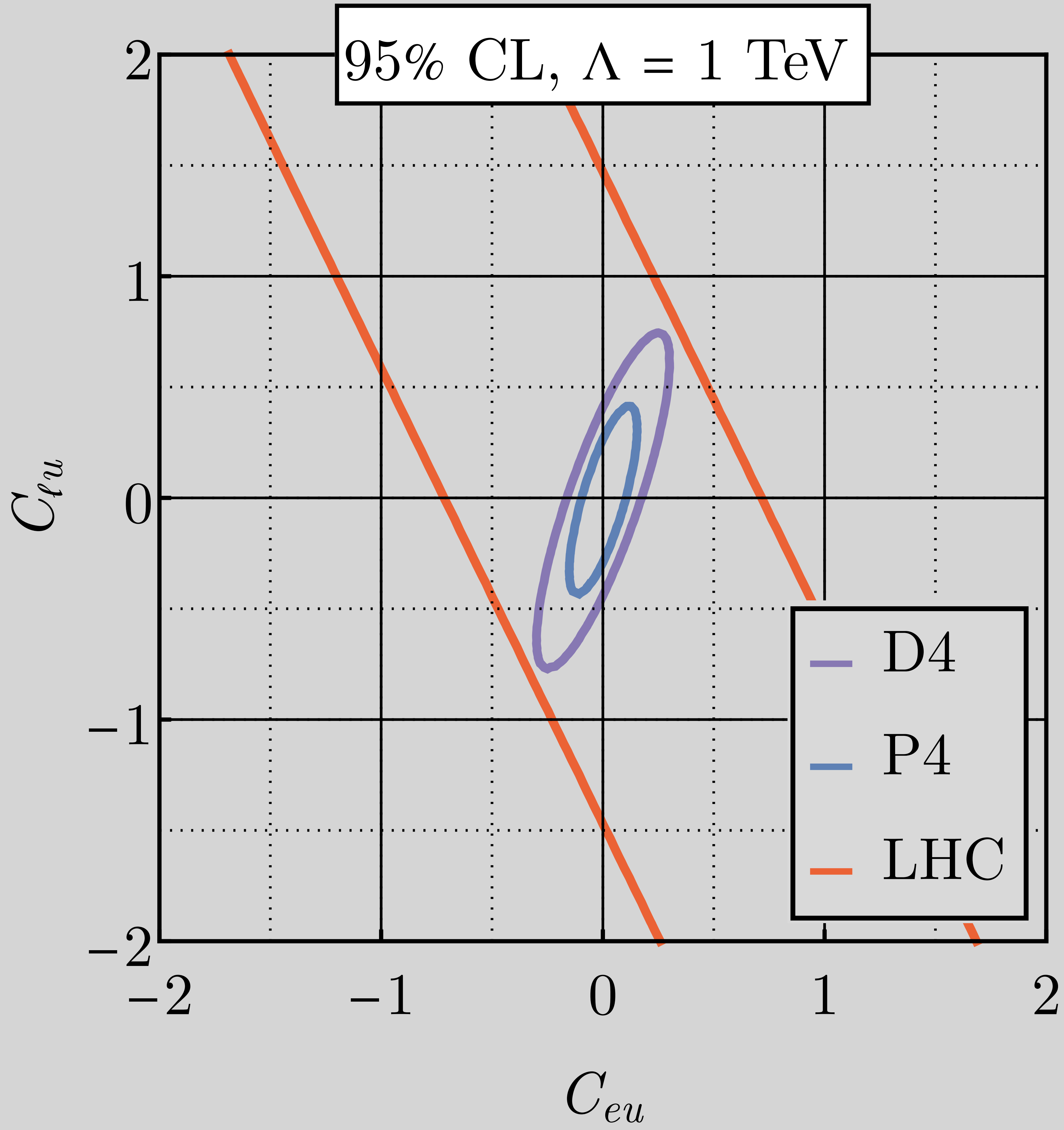


BSM searches

Constraints on SMEFT parameters

Boughezal *et al.* 2204.07557

95% confidence ellipse at $\Lambda = 1$ TeV in two-parameter fits



LHC NC Drell-Yan
8 TeV 20 fb^{-1}
not 13 TeV high lum

Boughezal *et al.* 2104.03979

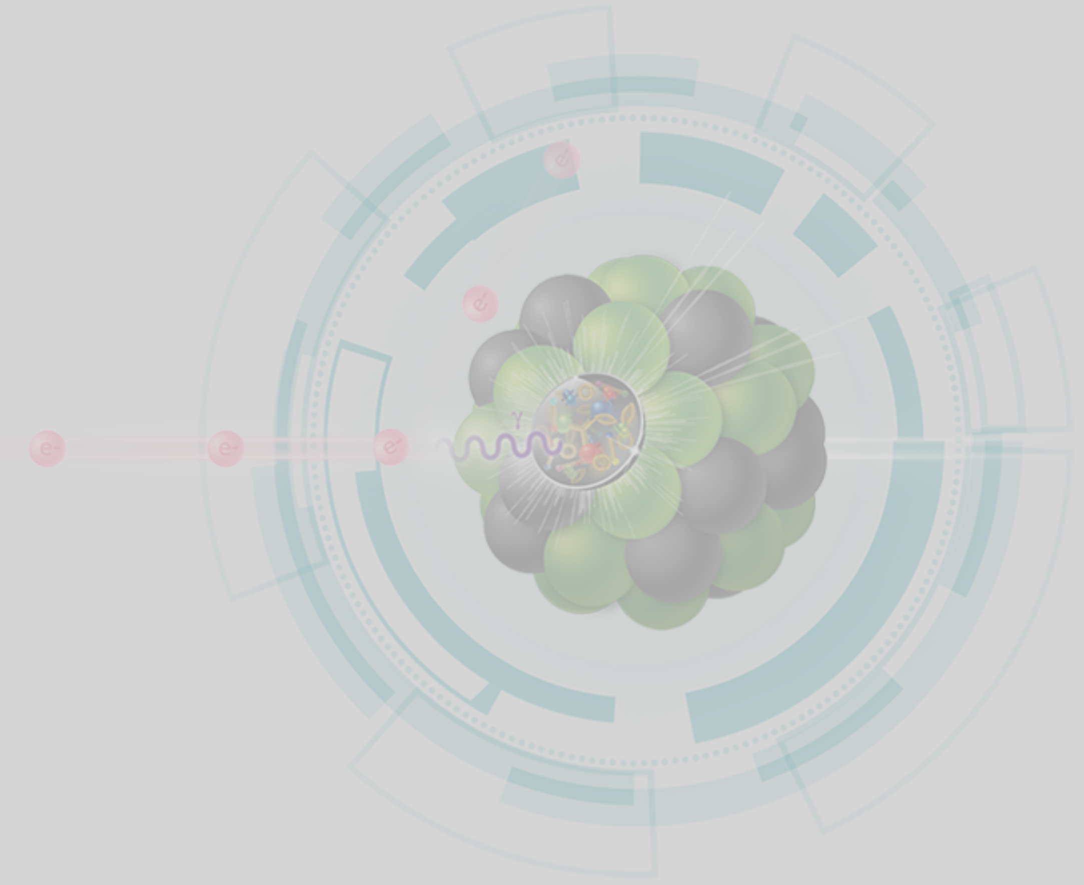
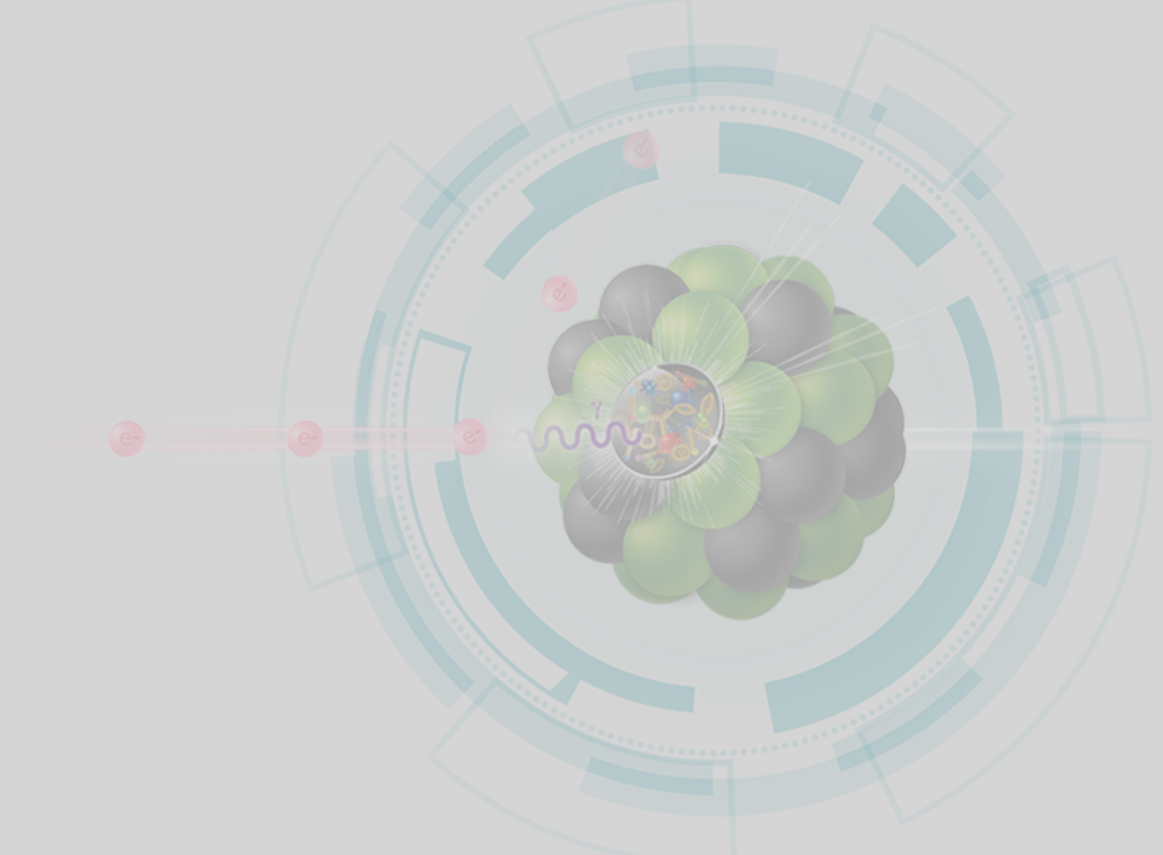


Image credit: bnl.gov

Coda

Conclusion



- The EIC will provide a determination of $\sin(\theta_W)^2$ at an energy scale that bridges higher-energy colliders with low- to medium-energy SM tests.
- It will offer distinct correlations compared to LHC Drell-Yan (also EWPO and LHeC; see the previous talk) fits of SMEFT parameters, showing complementarity, and resolve blind spots, demonstrating superiority of the EIC.

The EIC is designed as a QCD machine but seems promising as a useful probe of precision EW measurements, as well as BSM physics. Therefore, the taxpayers' money is wisely spent.