

Looking Beyond the Standard Model at the EIC

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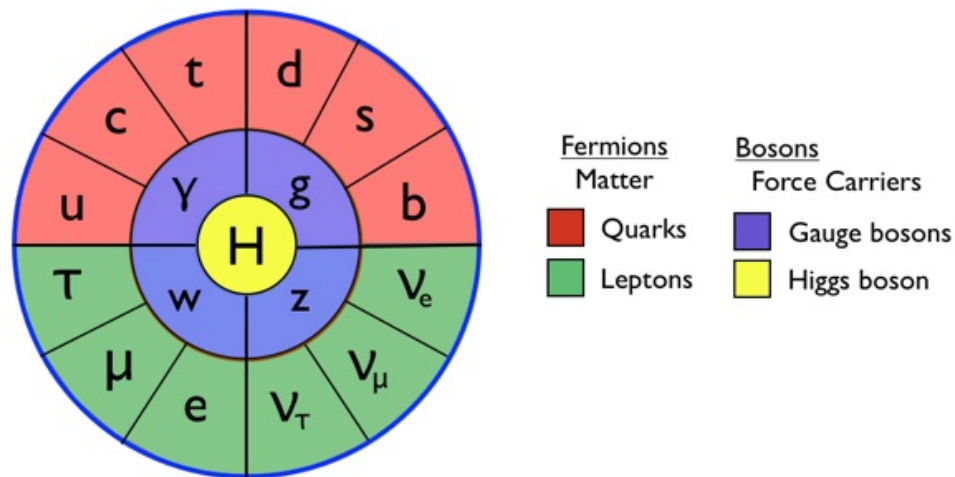
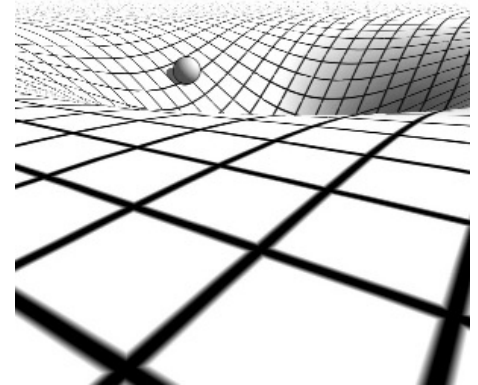


Electromagnetic Interactions with Nucleons and Nuclei (EINN 2025)

October 28-November 1, 2025, Paphos, Cyprus

State of the art:

- Gravity: still General Relativity (> 100 years!)
- Subatomic phenomena: Standard Model



Particles of the Standard Model

- There are some, often modest and transient, anomalies

SM and GR: consistent with all “settled” tests

However, we are not done!

The Case for New Physics

- Despite great success of SM+GR, new physics is needed
- There is strong experimental evidence for this inference:

★ Neutrino flavor oscillations $\rightarrow m_\nu \neq 0$

- Adding right-handed neutrinos (over a broad range of masses) can explain this
- Nature of m_ν unknown

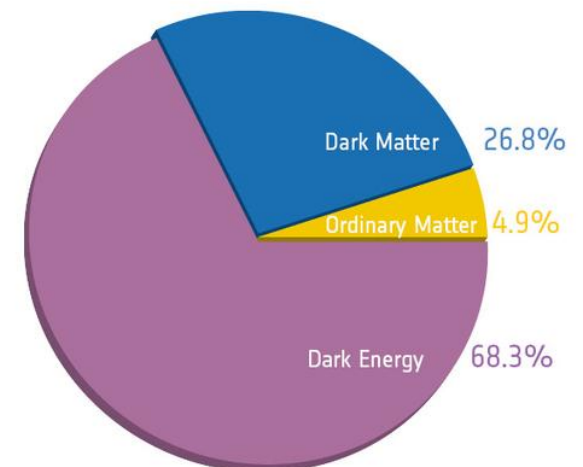
★ Cosmology

- What is accelerating cosmic expansion? (dark energy; may be vacuum energy)
- What is holding galaxies together? (dark matter; may have its own sector)
- What caused ordinary matter asymmetry? (requires more CP violation,...)

95% of the Universe is unknown to us!

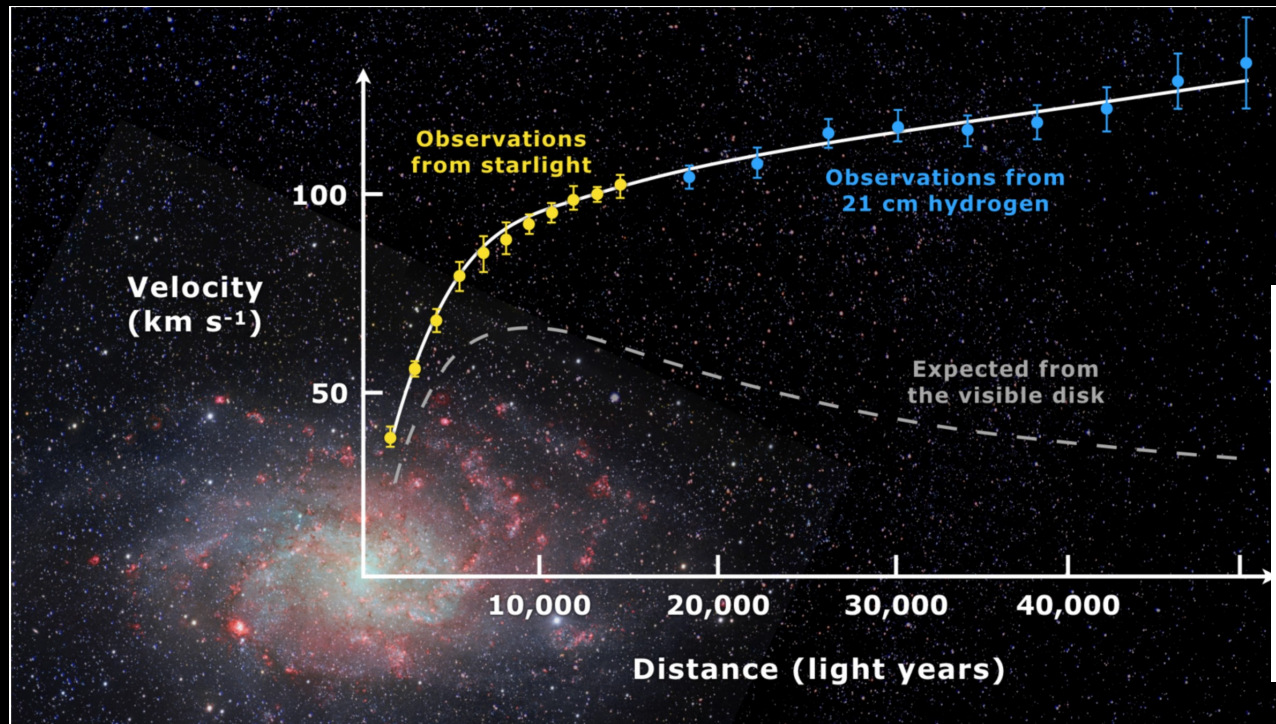
Planck

- There are also theoretical hints
- Why is gravity so weak?
- Why is CP violation so suppressed in QCD?
- ...

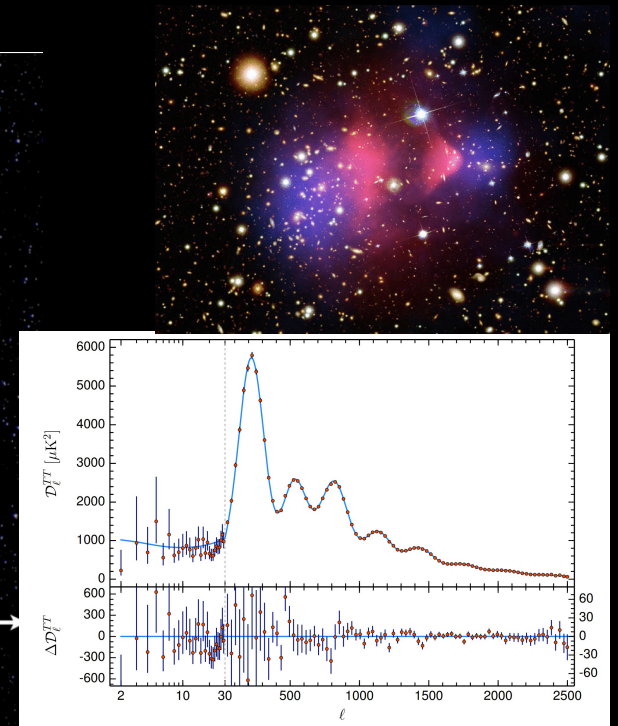


Dark matter (DM)

- Robust evidence from cosmology and astrophysics
 - Rotation curves of galaxies, CMB, Bullet Cluster, ...



Mario De Leo, CC BY-SA 4.0, via Wikimedia Commons

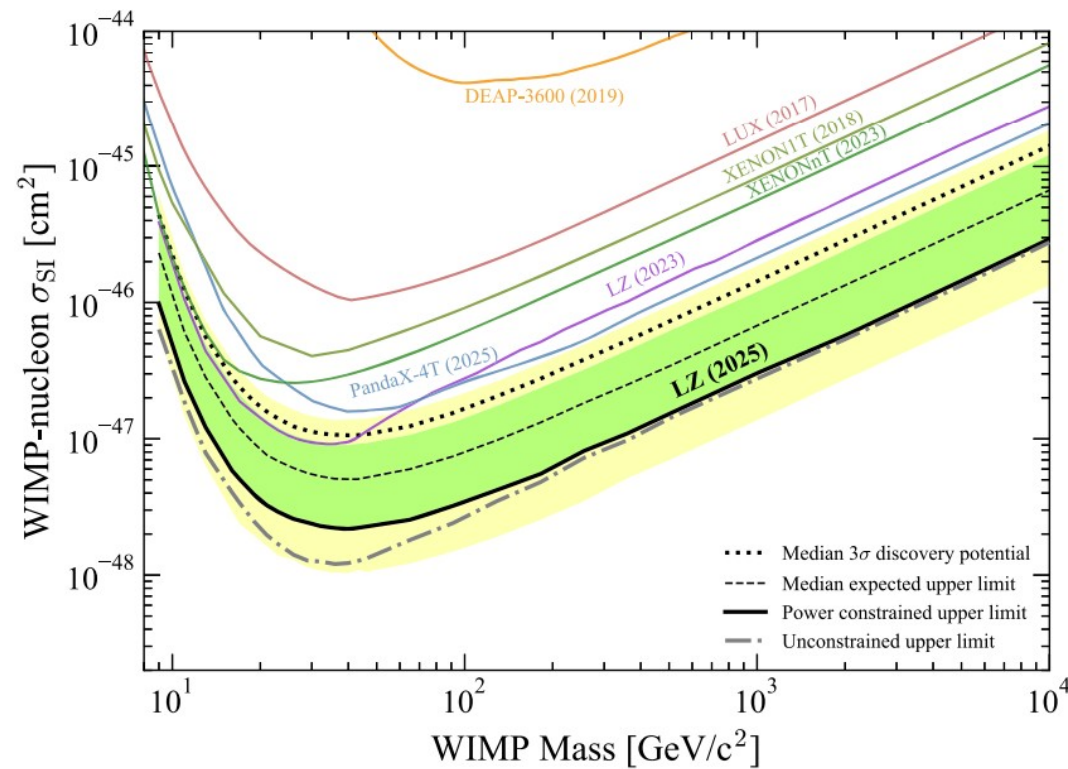


Planck Collaboration; 1807.06209

- $\sim 27\%$ of energy density
- Feeble interactions with atoms, photons
- Self-interactions not strong ($\sigma \lesssim 1$ barn)
- Not explained in SM

Weak Scale and DM

- Weakly interacting massive particles (WIMPs)
- Longtime search targets
- Motivation: physics of the Higgs potential
- $M_{\text{new}} \gtrsim M_H \approx 125 \text{ GeV}$ (weak scale); natural thermal relics



J. Aalbers *et al.*, LUX-ZEPLIN (LZ) Collab., PRL 135 (2025) 1, 011802

• New physics not close to M_H (sample below, LHC Run 2)

ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits

Status: May 2020

ATLAS Preliminary

$$\int \mathcal{L} dt = (3.2 - 139) \text{ fb}^{-1}$$

$$\sqrt{s} = 8, 13 \text{ TeV}$$

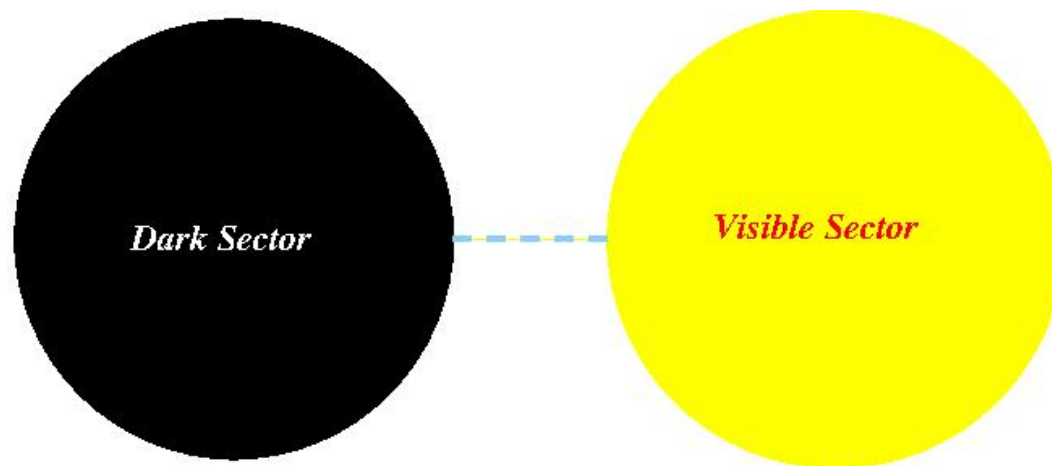
	Model	ℓ, γ	Jets [†]	$E_{\text{T}}^{\text{miss}}$	$\int \mathcal{L} dt [\text{fb}^{-1}]$	Limit	Reference	
Extra dimensions	ADD $G_{KK} + g/q$	$0 e, \mu$	$1-4 j$	Yes	36.1	M_0 7.7 TeV	$n = 2$ 1711.03301	
	ADD non-resonant $\gamma\gamma$	2γ	–	–	36.7	M_S 8.6 TeV	$n = 3$ HLZ NLO 1707.04147	
	ADD QBH	–	$2 j$	–	37.0	M_{th} 8.9 TeV	$n = 6$ 1703.09127	
	ADD BH high Σp_T	$\geq 1 e, \mu$	$\geq 2 j$	–	3.2	M_{th} 8.2 TeV	$n = 6, M_D = 3 \text{ TeV, rot BH}$ 1606.02265	
	ADD BH multijet	–	$\geq 3 j$	–	3.6	M_{th} 9.55 TeV	$n = 6, M_D = 3 \text{ TeV, rot BH}$ 1512.02586	
	RS1 $G_{KK} \rightarrow \gamma\gamma$	2γ	–	–	36.7	$G_{KK} \text{ mass}$ 4.1 TeV	$k/\overline{M}_{Pl} = 0.1$ 1707.04147	
	Bulk RS $G_{KK} \rightarrow WW/ZZ$	multi-channel	–	–	36.1	$G_{KK} \text{ mass}$ 2.3 TeV	$k/\overline{M}_{Pl} = 1.0$ 1808.02380	
	Bulk RS $G_{KK} \rightarrow WV \rightarrow \ell\nu qq$	$1 e, \mu$	$2 j / 1 J$	Yes	139	$G_{KK} \text{ mass}$ 2.0 TeV	$k/\overline{M}_{Pl} = 1.0$ 2004.14636	
	Bulk RS $g_{KK} \rightarrow tt$	$1 e, \mu$	$\geq 1 b, \geq 1J/2j$	Yes	36.1	$g_{KK} \text{ mass}$ 3.8 TeV	$\Gamma/m = 15\%$ 1804.10823	
	2UED / RPP	$1 e, \mu$	$\geq 2 b, \geq 3 j$	Yes	36.1	$KK \text{ mass}$ 1.8 TeV	Tier (1,1), $\mathcal{B}(A^{(1,1)} \rightarrow tt) = 1$ 1803.09678	
Gauge bosons	SSM $Z' \rightarrow \ell\ell$	$2 e, \mu$	–	–	139	$Z' \text{ mass}$ 5.1 TeV	$\Gamma/m = 1.2\%$ 1903.06248	
	SSM $Z' \rightarrow \tau\tau$	2τ	–	–	36.1	$Z' \text{ mass}$ 2.42 TeV	1709.07242	
	Leptophobic $Z' \rightarrow bb$	–	$2 b$	–	36.1	$Z' \text{ mass}$ 2.1 TeV	1805.09299	
	Leptophobic $Z' \rightarrow tt$	$0 e, \mu$	$\geq 1 b, \geq 2 J$	Yes	139	$Z' \text{ mass}$ 4.1 TeV	2005.05138	
	SSM $W' \rightarrow \ell\nu$	$1 e, \mu$	–	Yes	139	$W' \text{ mass}$ 6.0 TeV	1906.05609	
	SSM $W' \rightarrow \tau\nu$	1τ	–	Yes	36.1	$W' \text{ mass}$ 3.7 TeV	1801.06992	
	HVT $W' \rightarrow WZ \rightarrow \ell\nu qq$ model B	$1 e, \mu$	$2 j / 1 J$	Yes	139	$W' \text{ mass}$ 4.3 TeV	2004.14636	
	HVT $V' \rightarrow WV \rightarrow qq qq$ model B	$0 e, \mu$	$2 J$	–	139	$V' \text{ mass}$ 3.8 TeV	$g_V = 3$ 1906.08589	
	HVT $V' \rightarrow WH/ZH$ model B	multi-channel	–	–	36.1	$V' \text{ mass}$ 2.93 TeV	$g_V = 3$ 1712.06518	
	HVT $W' \rightarrow WH$ model B	$0 e, \mu$	$\geq 1 b, \geq 2 J$	–	139	$W' \text{ mass}$ 3.2 TeV	$g_V = 3$ CERN-EP-2020-073	
LRSB $W_R \rightarrow tb$	multi-channel	–	–	36.1	$W_R \text{ mass}$ 3.25 TeV	1807.10473		
LRSB $W_R \rightarrow \mu N_R$	2μ	$1 J$	–	80	$W_R \text{ mass}$ 5.0 TeV	1904.12679		
CI	CI $qqqq$	–	$2 j$	–	37.0	Λ 21.8 TeV	η_{LL} 1703.09127	
	CI $\ell\ell qq$	$2 e, \mu$	–	–	139	Λ 35.8 TeV	η_{LL} CERN-EP-2020-066	
	CI $tttt$	$\geq 1 e, \mu$	$\geq 1 b, \geq 1 j$	Yes	36.1	Λ 2.57 TeV	$ C_{4\ell} = 4\pi$ 1811.02305	
DM	Axial-vector mediator (Dirac DM)	$0 e, \mu$	$1-4 j$	Yes	36.1	m_{med} 1.55 TeV	$g_a=0.25, g_s=1.0, m(\chi) = 1 \text{ GeV}$ 1711.03301	
	Colored scalar mediator (Dirac DM)	$0 e, \mu$	$1-4 j$	Yes	36.1	m_{med} 1.67 TeV	$g=1.0, m(\chi) = 1 \text{ GeV}$ 1711.03301	
	$VV_{\chi\chi}$ EFT (Dirac DM)	$0 e, \mu$	$1 J, \leq 1 j$	Yes	3.2	M_s 700 GeV	$m(\chi) < 150 \text{ GeV}$ 1608.02372	
	Scalar reson. $\phi \rightarrow t\chi$ (Dirac DM)	$0-1 e, \mu$	$1 b, 0-1 J$	Yes	36.1	m_ϕ 3.4 TeV	$y = 0.4, \lambda = 0.2, m(\chi) = 10 \text{ GeV}$ 1812.09743	
LQ	Scalar LQ 1 st gen	$1, 2 e$	$\geq 2 j$	Yes	36.1	LQ mass 1.4 TeV	$\beta = 1$ 1902.00377	
	Scalar LQ 2 nd gen	$1, 2 \mu$	$\geq 2 j$	Yes	36.1	LQ mass 1.56 TeV	$\beta = 1$ 1902.00377	
	Scalar LQ 3 rd gen	2τ	$2 b$	–	36.1	$LQ_3^u \text{ mass}$ 1.03 TeV	$\mathcal{B}(LQ_3^u \rightarrow b\tau) = 1$ 1902.08103	
	Scalar LQ 3 rd gen	$0-1 e, \mu$	$2 b$	Yes	36.1	$LQ_3^d \text{ mass}$ 970 GeV	$\mathcal{B}(LQ_3^d \rightarrow \tau\tau) = 0$ 1902.08103	
Heavy quarks	VLQ $TT \rightarrow Ht/Zt/Wb + X$	multi-channel	–	–	36.1	T mass 1.37 TeV	SU(2) doublet 1808.02343	
	VLQ $BB \rightarrow Wt/Zb + X$	multi-channel	–	–	36.1	B mass 1.34 TeV	SU(2) doublet 1808.02343	
	VLQ $T_{5/3} T_{5/3} T_{5/3} \rightarrow Wt + X$	$2(SS)/\geq 3 e, \mu$	$\geq 1 b, \geq 1 j$	Yes	36.1	$T_{5/3} \text{ mass}$ 1.64 TeV	$\mathcal{B}(T_{5/3} \rightarrow Wt) = 1, c(T_{5/3} Wt) = 1$ 1807.11883	
	VLQ $Y \rightarrow Wb + X$	$1 e, \mu$	$\geq 1 b, \geq 1 j$	Yes	36.1	Y mass 1.85 TeV	$\mathcal{B}(Y \rightarrow Wb) = 1, c_Y(Wb) = 1$ 1812.07343	
	VLQ $B \rightarrow Hb + X$	$0 e, \mu, 2 \gamma$	$\geq 1 b, \geq 1 j$	Yes	79.8	B mass 1.21 TeV	$\kappa_B = 0.5$ ATLAS-CONF-2018-024	
	VLQ $QQ \rightarrow WqWq$	$1 e, \mu$	$\geq 4 j$	Yes	20.3	Q mass 690 GeV	1509.04261	
Excited fermions	Excited quark $q^* \rightarrow qg$	–	$2 j$	–	139	$q^* \text{ mass}$ 6.7 TeV	only u^* and d^* , $\Lambda = m(q^*)$ 1910.08447	
	Excited quark $q^* \rightarrow q\gamma$	1γ	$1 j$	–	36.7	$q^* \text{ mass}$ 5.3 TeV	only u^* and d^* , $\Lambda = m(q^*)$ 1709.10440	
	Excited quark $b^* \rightarrow bg$	–	$1 b, 1 j$	–	36.1	$b^* \text{ mass}$ 2.6 TeV	1805.09299	
	Excited lepton ℓ^*	$3 e, \mu$	–	–	20.3	$\ell^* \text{ mass}$ 3.0 TeV	$\Lambda = 3.0 \text{ TeV}$ 1411.2921	
	Excited lepton ν^*	$3 e, \mu, \tau$	–	–	20.3	$\nu^* \text{ mass}$ 1.6 TeV	$\Lambda = 1.6 \text{ TeV}$ 1411.2921	
Other	Type III Seesaw	$1 e, \mu$	$\geq 2 j$	Yes	79.8	$N^0 \text{ mass}$ 560 GeV	$m(W_R) = 4.1 \text{ TeV, } g_L = g_R$ ATLAS-CONF-2018-020	
	LRSB Majorana ν	2μ	$2 j$	–	36.1	$N_R \text{ mass}$ 3.2 TeV	1809.11105	
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\ell$	$2, 3, 4 e, \mu$ (SS)	–	–	36.1	$H^{\pm\pm} \text{ mass}$ 870 GeV	DY production 1710.09748	
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\tau$	$3 e, \mu, \tau$	–	–	20.3	$H^{\pm\pm} \text{ mass}$ 400 GeV	DY production, $\mathcal{B}(H^{\pm\pm} \rightarrow \ell\tau) = 1$ 1411.2921	
	Multi-charged particles	–	–	–	36.1	multi-charged particle mass 1.22 TeV	DY production, $ q = 5e$ 1812.03673	
	Magnetic monopoles	–	–	–	34.4	monopole mass 2.37 TeV	DY production, $ g = 1g_D, \text{ spin } 1/2$ 1905.10130	
	$\sqrt{s} = 8 \text{ TeV}$	$\sqrt{s} = 13 \text{ TeV}$ partial data	$\sqrt{s} = 13 \text{ TeV}$ full data					
					10^{-1}	1	10	Mass scale [TeV]

*Only a selection of the available mass limits on new states or phenomena is shown.

[†]Small-radius (large-radius) jets are denoted by the letter j (J).

Dark Sectors

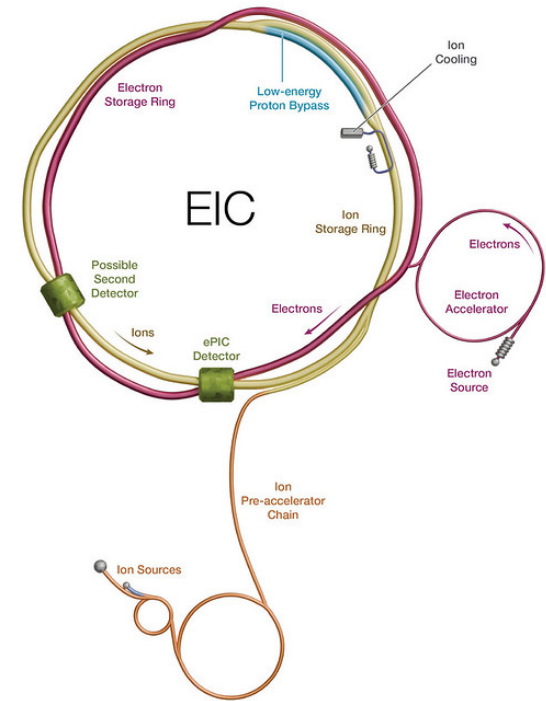
- With lack of evidence for new physics near weak scale (M_H), alternatives to WIMPs have been put forth in recent years
- DM could be light ($m \lesssim \text{GeV}$), not associated with EW symmetry breaking (EWSB)
- DM may reside in a separate *sector* with its own forces
- Analogy with SM, the “visible sector”
- Visible and dark sectors connected by feeble interactions
- Mediators could be light, accessible to low energy experiments ($\sqrt{s} \lesssim 100 \text{ GeV}$)



The Electron Ion Collider (EIC)

2103.05419, EIC Yellow Report

- EIC, to be built at BNL: next collider with relatively large $\sqrt{s}$, luminosity
 - Up to $E_e = 18$ GeV, 275 GeV proton beam
 - Large nuclei (high Z): e.g. gold, lead
 - 110 GeV per nucleon ion beam, e.g. Au
 - Fixed target equivalent of ~ 4 TeV e -beam
 - $\sim 100 \text{ fb}^{-1}/A$ possible
- New frontier in studying hadronic systems
 - E.g. spin composition and parton distribution in nucleons,....
- Unique capability: $\sim 70\%$ polarized e and p beams



What can we learn about new physics at the EIC?*

* This talk: only a sample of possibilities; unfortunately many interesting works not covered

EIC and New Physics

- We will consider two large classes of beyond SM (BSM) physics:
 - (I) Heavy physics, indirect signals
 - (II) Light physics, perhaps from dark/hidden sectors, direct signals
- Class (I) signals generally require precision
 - Could be formulated in the language of SM effective field theory (SMEFT)
 - Beam polarization can be leveraged
- Class (II) physics could lead to direct detection of new particles
 - A variety of models
 - Access to new states around the GeV scale
 - Large atomic number ions can provide Z^2 enhanced coherent cross sections

We will mostly focus on Class (II) in this talk.

Heavy New Physic and SMEFT

- Physics above weak scale, may be accessible to LHC, future colliders
- Integrate out heavy states: higher-dimension operators (point-like interactions)
- BSM encoded in SMEFT: $\Lambda > \langle H \rangle$ scale of new physics

$$\mathcal{L} = \mathcal{L}_{\text{SM}} + c_5^1 \frac{HLHL}{\Lambda} + \sum_i c_6^i \frac{O_i}{\Lambda^2} + \dots$$

- Wilson coefficients c_d^i ; operators O_i of dimension $d \geq 5$, made of SM fields

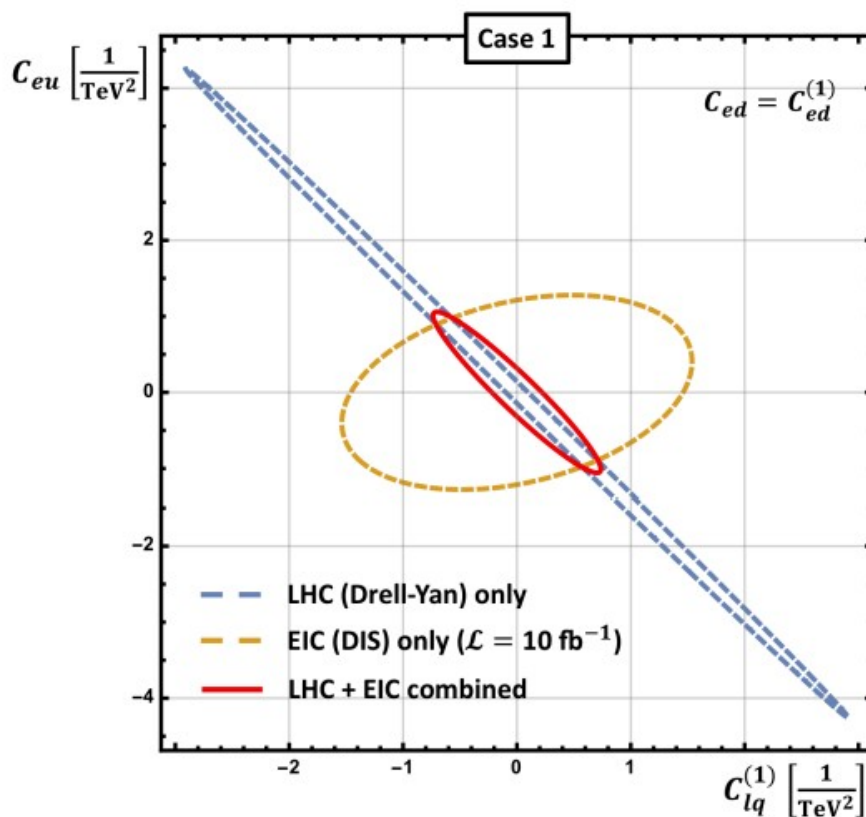
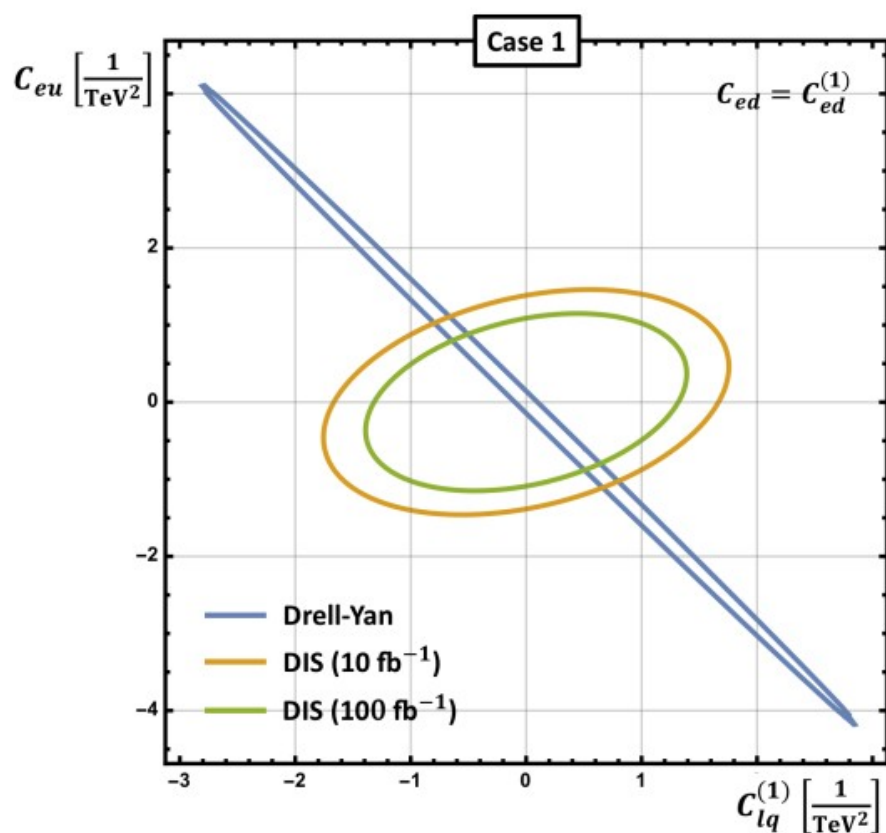
Example: SMEFT Constraints at LHC and EIC [Boughezal, Petriello, Wiegand, 2004.00748](#)

- 4-fermion operators: deep inelastic scattering (DIS) and Drell-Yan processes
- Drell-Yan: $pp \rightarrow l\bar{l}$ ($q\bar{q} \rightarrow l\bar{l}$), LHC ; DIS: $lp \rightarrow l'X$ ($lq \rightarrow l'q'$), EIC

$\mathcal{O}_{lq}^{(1)}$	$(\bar{l}\gamma^\mu l)(\bar{q}\gamma_\mu q)$	$\mathcal{O}_{lu}$	$(\bar{l}\gamma^\mu l)(\bar{u}\gamma_\mu u)$
$\mathcal{O}_{lq}^{(3)}$	$(\bar{l}\gamma^\mu \tau^I l)(\bar{q}\gamma_\mu \tau^I q)$	$\mathcal{O}_{ld}$	$(\bar{l}\gamma^\mu l)(\bar{d}\gamma_\mu d)$
$\mathcal{O}_{eu}$	$(\bar{e}\gamma^\mu e)(\bar{u}\gamma_\mu u)$	$\mathcal{O}_{qe}$	$(\bar{q}\gamma^\mu q)(\bar{e}\gamma_\mu e)$
$\mathcal{O}_{ed}$	$(\bar{e}\gamma^\mu e)(\bar{d}\gamma_\mu d)$		

From 2004.00748

- $\sim 20 \text{ fb}^{-1}$ of ATLAS data at $\sqrt{s} = 8 \text{ TeV}$ (1606.01736)
- EIC: $\sqrt{s} \approx 140 \text{ GeV}$, 70% e, p polarization
- EIC integrated luminosity: 10 and 100 fb^{-1}
- DIS cross section: taking advantage of both e and p polarizations



From 2004.00748 (Contours: 68% C.L.)

Charged Lepton Flavor Violation (LFV)

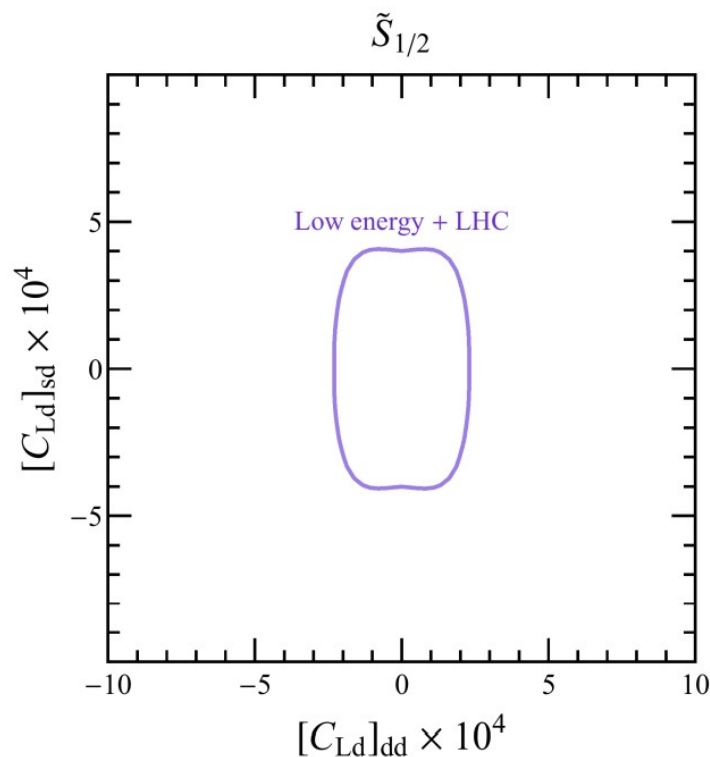
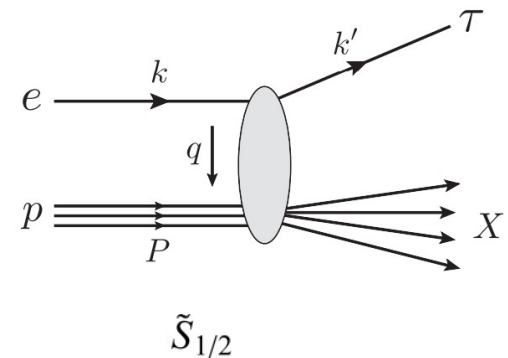
- Could be mediated by, e.g., t channel heavy (> 1 TeV) leptoquarks at EIC
Early work by: [Gonderinger, Ramsey-Musolf, 2010](#)

- Leptoquark: color charged; couples to quarks and leptons

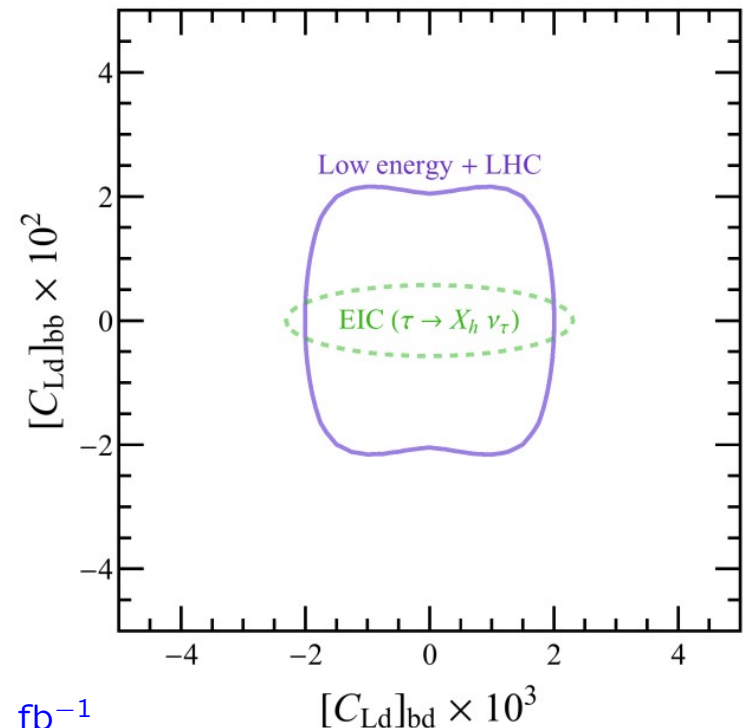
[Cirigliano, Fuyuto, Lee, Mereghetti, Yan, 2102.06176 \(figures\)](#)

- Bounds on the induced dim-6 4-fermion operators

- Bounds from LHC, low energy (τ , B , decays)
- Competitive EIC bounds, depending on operator



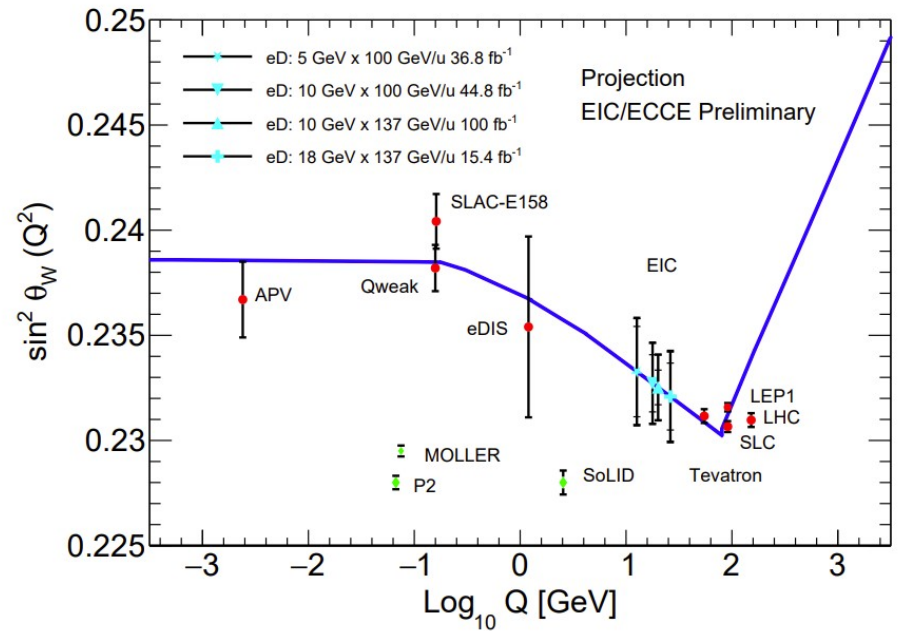
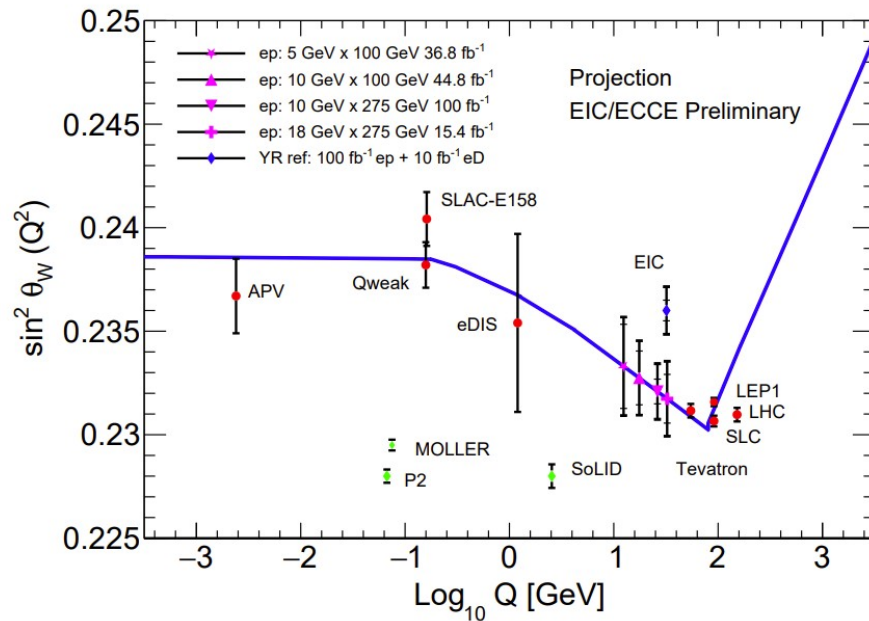
$\sqrt{s} = 141$ GeV, 100 fb^{-1}



SM Electroweak Parameters; $\sin^2 \theta_W$

- Running $\sin^2 \theta_W(Q^2)$: fundamental parameter of SM electroweak sector
- Has been measured in atomic, fixed target, and Z -pole measurements
- EIC offers access to intermediate Q^2 regime

From Bougezal et al., 2204.07557



Electron beam polarization: 80% with 1% uncertainty

Direct Detection of New GeV Scale Physics

- Dark vector bosons
 - Simplest case: dark $U(1)_d$, analogue of visible electromagnetism
 - Dark photon (kinetic mixing) and dark Z (mass mixing)
 - Coupled to SM via a small mixing parameter
 - Gauge bosons with tiny gauge couplings: *e.g.* $L_e - L_\tau, \dots$ (anomaly free)
- Dark scalars
 - Axion-like particles (ALPs), analogues of QCD pions (pseudo-scalars)
 - Like pions, manifestations of spontaneously broken approximate global symmetries
 - QCD pions: broken chiral symmetry (approximate due to small quark masses)
 - ALPs can arise in a variety of models, naturally “light” (massless for exact symmetries)
 - Could be a regular scalar, a “dark Higgs”

Charged LFV via ALPs at the EIC

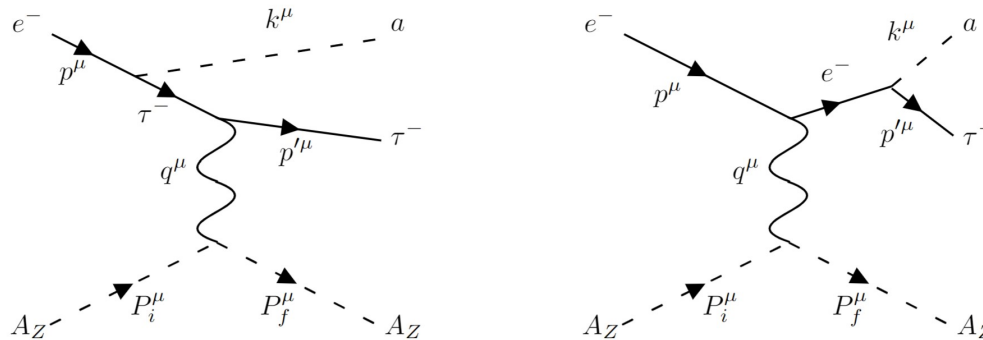
H.D., Marcarelli, Neil, 2112.04513

- EFT for ALP interactions

$$\mathcal{L}_\ell = \frac{C_{\ell\ell'}}{\Lambda} a \sum_{\ell\ell'} \bar{\ell} (m^- \sin \theta_{\ell\ell'} - m^+ \cos \theta_{\ell\ell'} \gamma_5) \ell' + \text{H.C.} \quad ; \quad m^\pm \equiv m_\ell \pm m_{\ell'}$$

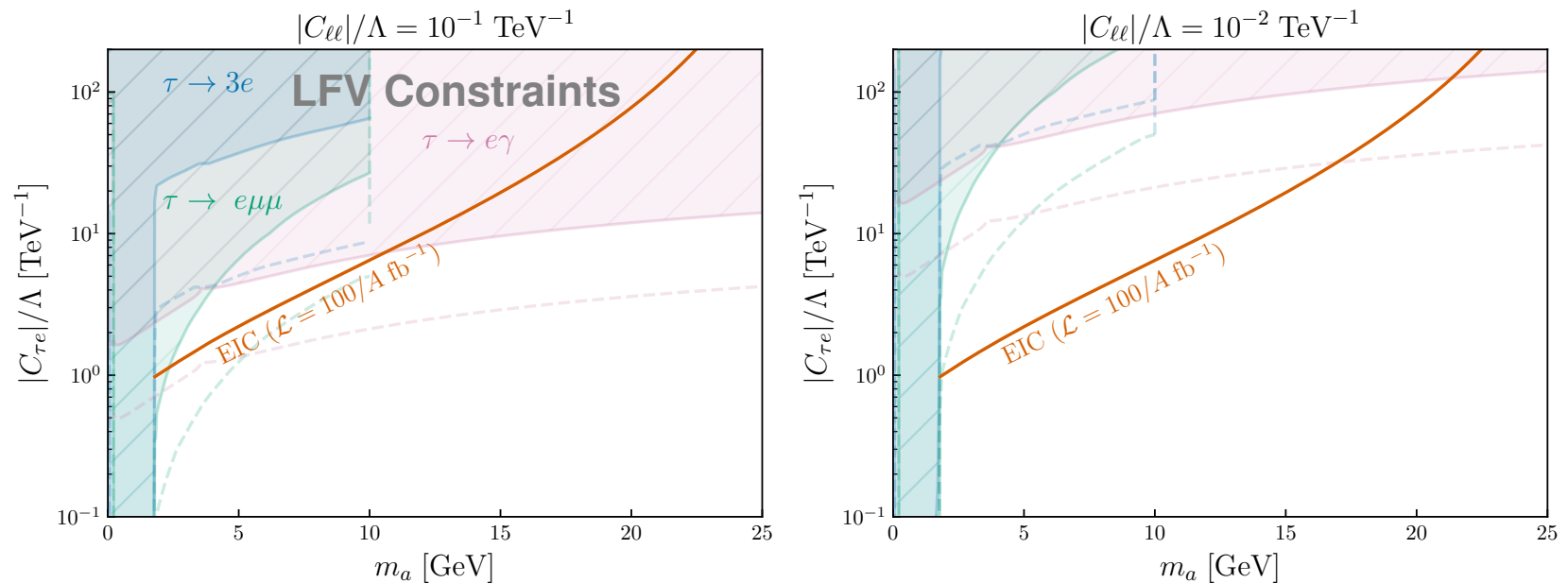
See, e.g., Bauer, Neubert, Renner, Schnubel, Thamm, 2019; Cornella, Paradisi, Sumensari, 2019

- $\theta_{\ell\ell'} = 0$: P even; maximal PV for $\theta_{\ell\ell'} = \pi/4, 3\pi/4$ (only L, R coupling)
 - Probed via polarized e -beams
- Search for $e - \tau$ LFV in coherent $eA_Z \rightarrow \tau A_Z a$; $A_Z = \text{Au}; Z = 79$



- Main decay channels: (i) $a \rightarrow \tau^- \tau^+$, (ii) $a \rightarrow \tau^- e^+$, (iii) $a \rightarrow \tau^+ e^-$
- Consider $a(\rightarrow e^+ \tau^-) \tau^-$ final state; veto on e^-
- Three-pronged τ decays; efficiency $\epsilon_\tau \approx 1\%$ from Zhang *et al.*, 2207.10261
 - Other decay modes and veto of ion break-up can enhance the search

- Main background from τ pairs through Bethe-Heitler process
 - Estimated from τ pair production in rock by cosmic ray muons [Bulmahn, Reno, 2008](#)
- Good EIC prospects for probing charged LFV ALPs, especially with diagonal couplings suppressed
 - Weakened τ decay constraints
- Adding μ detection may improve the search (τ identification)



Solid line BABAR, dashed line Belle II with 50 ab⁻¹; tree-level $a\gamma\gamma$ ignored

From H.D., Marcarelli, Neil, 2112.04513

Heavy Neutral Leptons at the EIC Batell, Ghosh, Han, Xie, 2210.09287

- HNLs arise in a variety of models; good example type I seesaw for $m_\nu \neq 0$
- Coupling to SM: $yHLN$

H Higgs doublet L lepton doublet in SM; N HNL

- After EWSB: N mixes with SM neutrinos

$\rightarrow \ell W N, \nu_\ell Z N$ couplings ($\ell = e, \mu, \tau$)

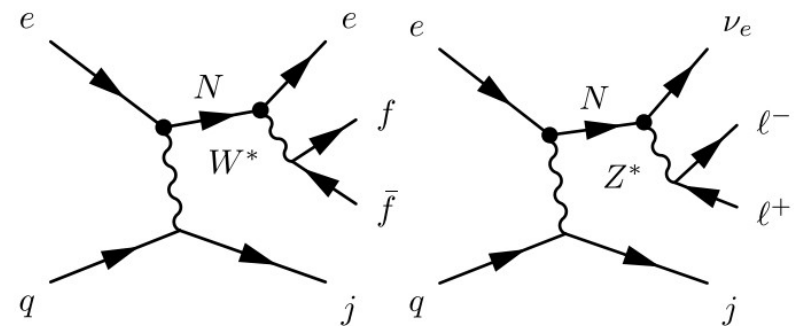
- Production in $e + p/A \rightarrow N + X$:

- Through charged current
- Depends on e -flavor mixing parameter U_e
- Simplified setup: one HNL and only $U_e \neq 0$

- Phenomenological approach: mass m_N and mixing U_e free parameters

- Both Dirac and Majorana N considered

- N decays: Prompt and displaced, as well as invisible (dark sector)



From 2210.09287

- $\sqrt{s} = 141 \text{ GeV}$, $\mathcal{L} = 100 \text{ fb}^{-1}$, $P_e = 70\%$

Figures from 2210.09287

- Unpolarized PDFs, proton beam

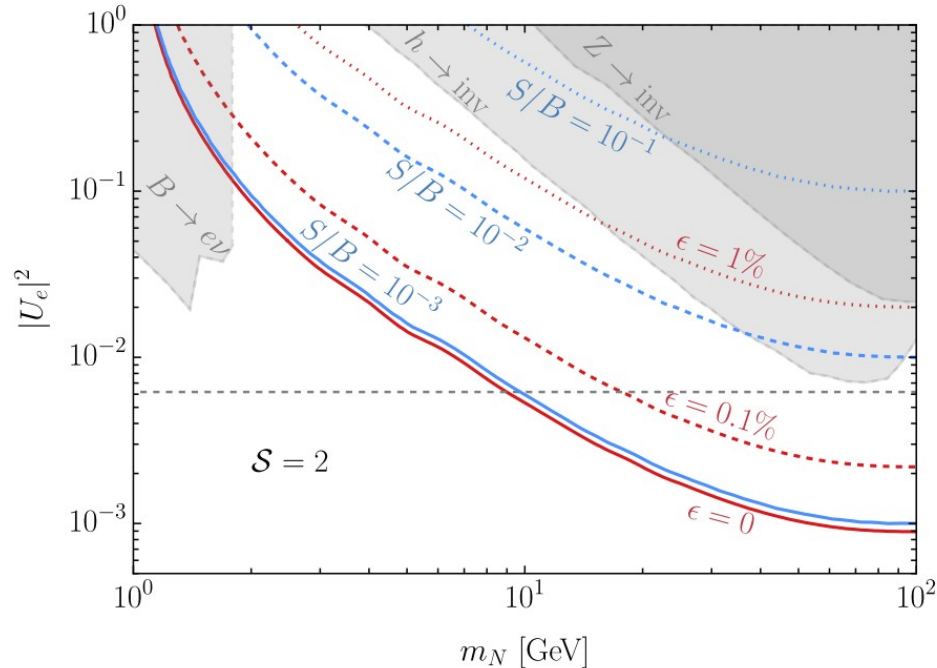
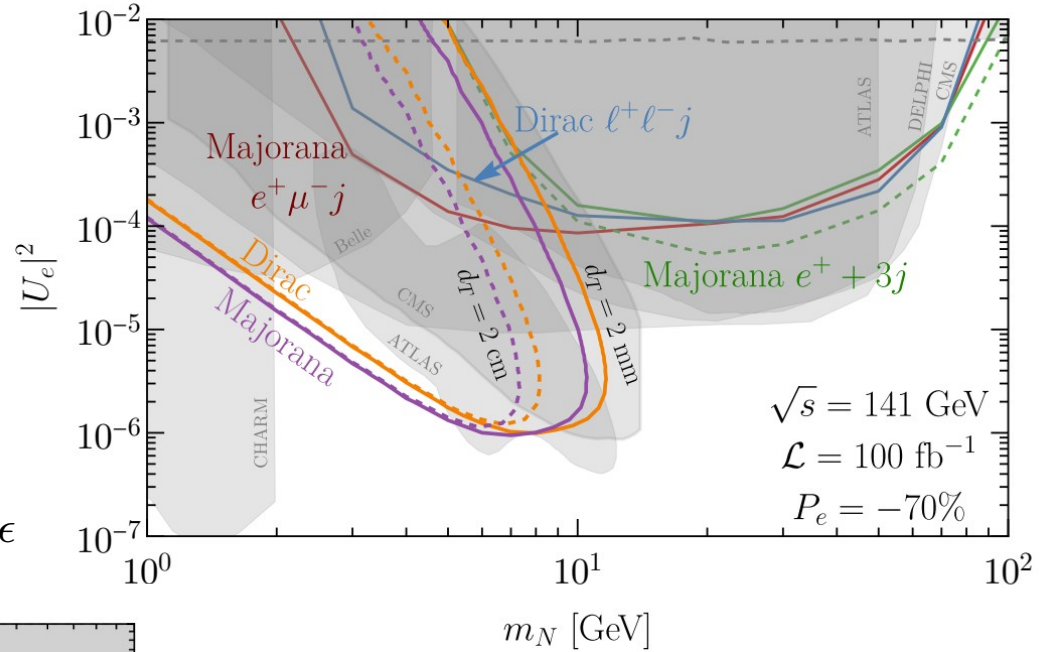
- Visible decays:

- prompt (95% CL)
- displaced (5 events)

- Invisible decays: mono-jet

- $\mathcal{S} = S/\sqrt{B + (\epsilon B)^2}$

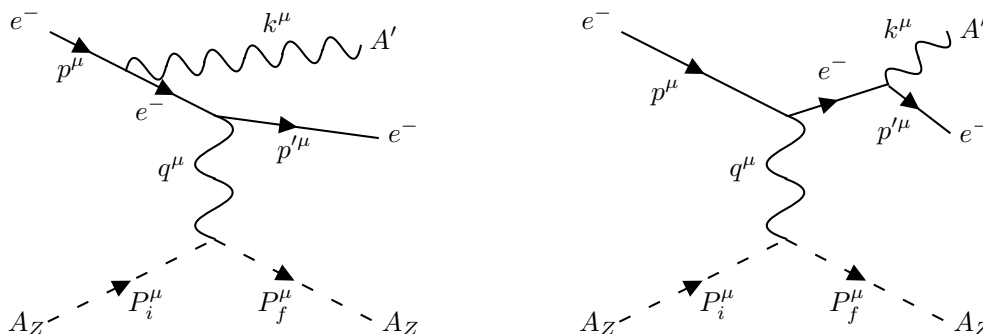
- fractional systematic uncertainty ϵ



Displaced Hidden Vectors at the EIC

H.D., Marcarelli, Neil, 2307.00102

- Coherent production from gold ion, $Z = 79$: $eA_Z \rightarrow eA_Z A'$ ($Z_d \leftrightarrow A'$)
- $q^2 \lesssim \mathcal{O}(100 \text{ MeV})$
- Large Z^2 enhancement of electromagnetic scattering



- Probability of detection of displaced decay: $P_{\text{disp}} = e^{-d_{\text{min}}/(\gamma_k v_k \tau)} - e^{-d_{\text{max}}/(\gamma_k v_k \tau)}$
- d_{min} from detector resolution, d_{max} from geometry γ_k boost, v_k velocity, τ lifetime
- Kinematic variables: laboratory frame
- Signal cross section: $\sigma_{\text{sig}}(g_{A'}) = \int P_{\text{disp}} \frac{d\sigma}{d\gamma_k d\eta_k} d\gamma_k d\eta_k \mathcal{B}(A' \rightarrow e^+ e^-)$
- We take $E_e = 18 \text{ GeV}$ and $E_A = 110 \text{ GeV/nucleon}$

Signal Selection:

- Assumed EIC Comprehensive Chromodynamics Experiment (ECCE) detector [arXiv:2209.02580 \[physics.ins-det\]](#)
- Now the **ePIC** (Electron-Proton/Ion Collider) detector, similar capabilities
- Signal requires both e^+ and e^- from vector decay

$\mu^+\mu^-$ also available for much of the parameter space

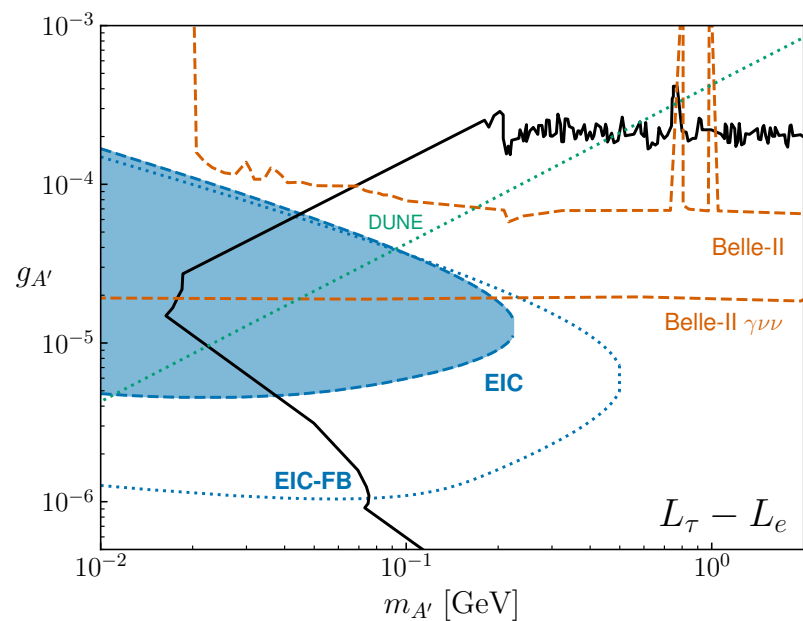
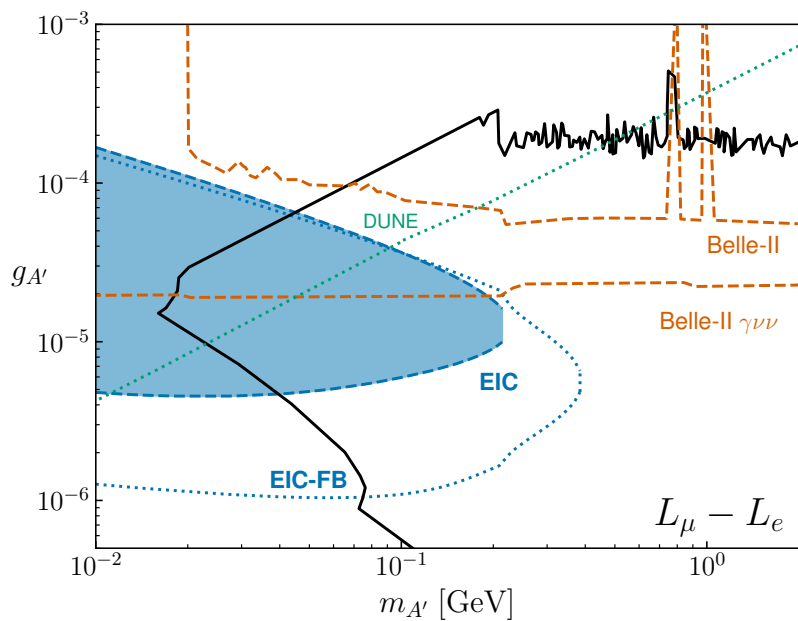
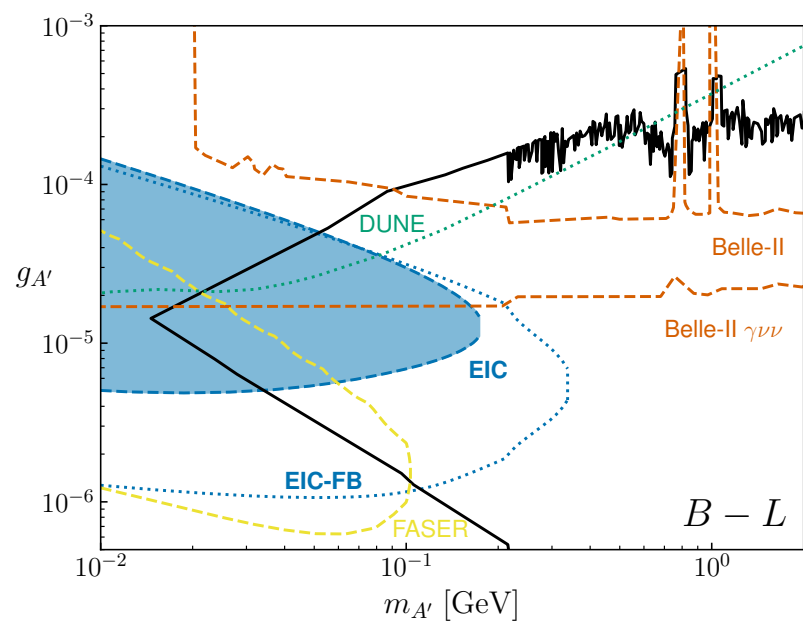
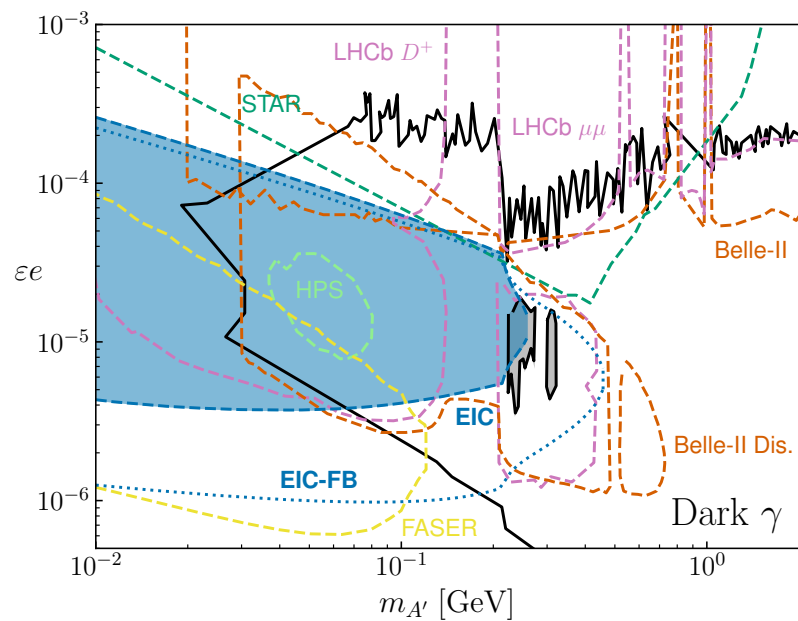
- We estimated: $d_{\min} \approx \gamma_k (\text{DCA}_{2\text{D}}^{\min}) / (v_k \cos \theta_k^{\text{lab}})$
- For pions: $\text{DCA}_{2\text{D}}^{\min} < 100 \mu\text{m}$
- $\Rightarrow d_{\min} \gg 0.1 \text{ mm}, d_{\max} = 1 \text{ m}$

DCA: distance of closest approach

- ECCE tracking: $|\eta| < 3.5$
- We also considered a detector at $z = -5 \text{ m}$

Further details of the current detector design may push this farther back; also a possibility for second detector

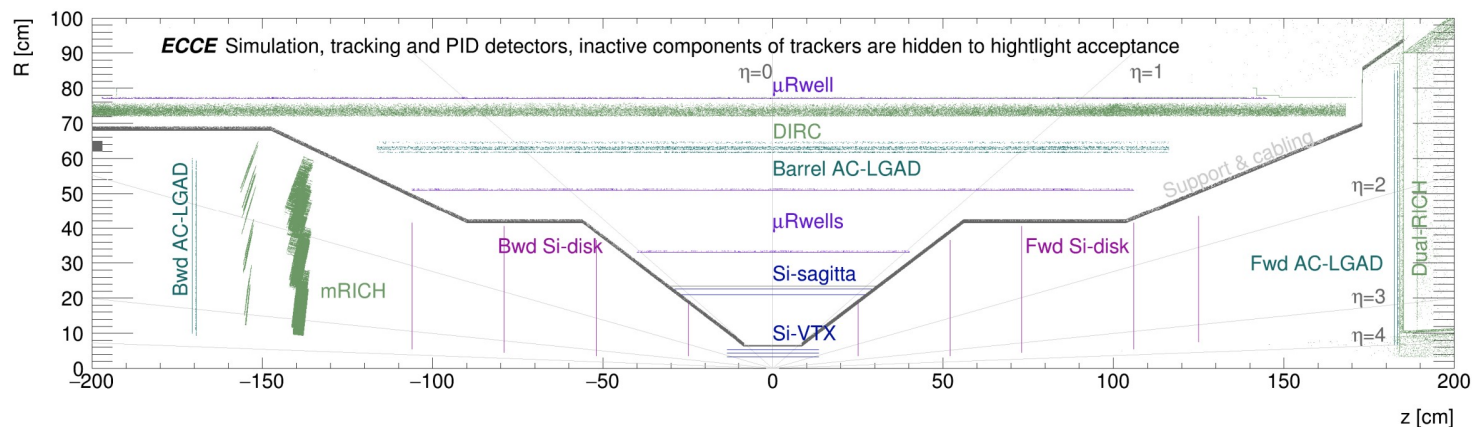
- Assumed: $\text{DCA}_{2\text{D}}^{\min} = 200 \mu\text{m}, d_{\max} = 5 \text{ m}$
- Covering far backwards (FB): $-6 < \eta < -4$



From H.D., Marcarelli, Neil, 2307.00102

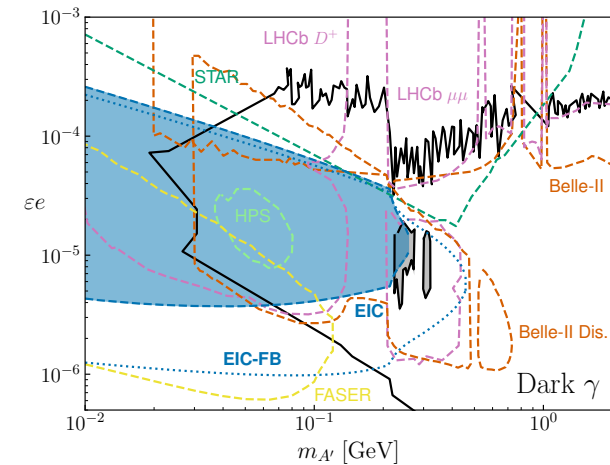
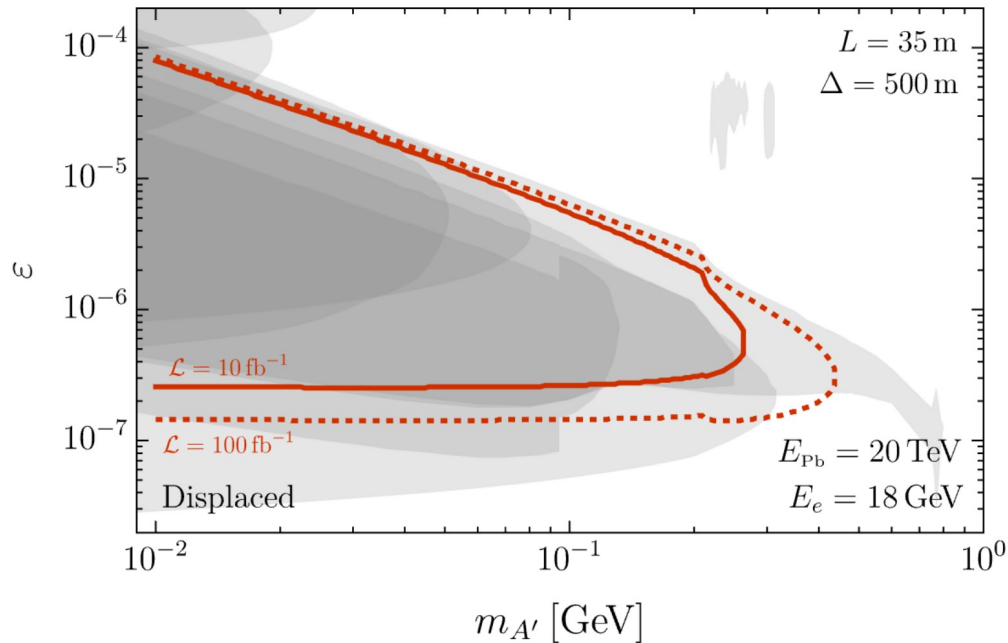
Background considerations

- We assumed zero background
- Photon conversion: sparse backwards detector systems [Adkins et al., 2209.02580](#)
- Si disks separated by ~ 25 cm: cut out thin regions from signal



- Misidentified pions as electrons: electron end cap fake rate $\sim 10^{-4}$
- Requiring both e^+ and e^-
- Additional signals if muon detectors added
- Losing signal events down the beam pipe: our estimate $\sim (20-30) \%$, manageable
- These are (theorist) projections, using rough approximations
- Detailed and more realistic simulations required for definitive results

Also [Balkin et al., 2310.08827, JHEP 02 \(2024\) 123](#)



- $eN \rightarrow eNA'$, coherent scattering from Pb
- Dark photon decay $A' \rightarrow \mu^+\mu^-$ (to reduce background)
- Decay volume $\Delta = 500$ m long (shielded) at $L = 35$ m from interaction point
- Does not exceed current bounds
 - Our work assumed much smaller ($\gtrsim$ mm) displacement
 - Worthwhile to determine efficiency of our suggested background suppression

[2307.00102](#)

- Work on ALP-photon coupling using coherent scattering at the EIC
 - Z^2 enhanced From Balkin *et al.*, 2310.08827

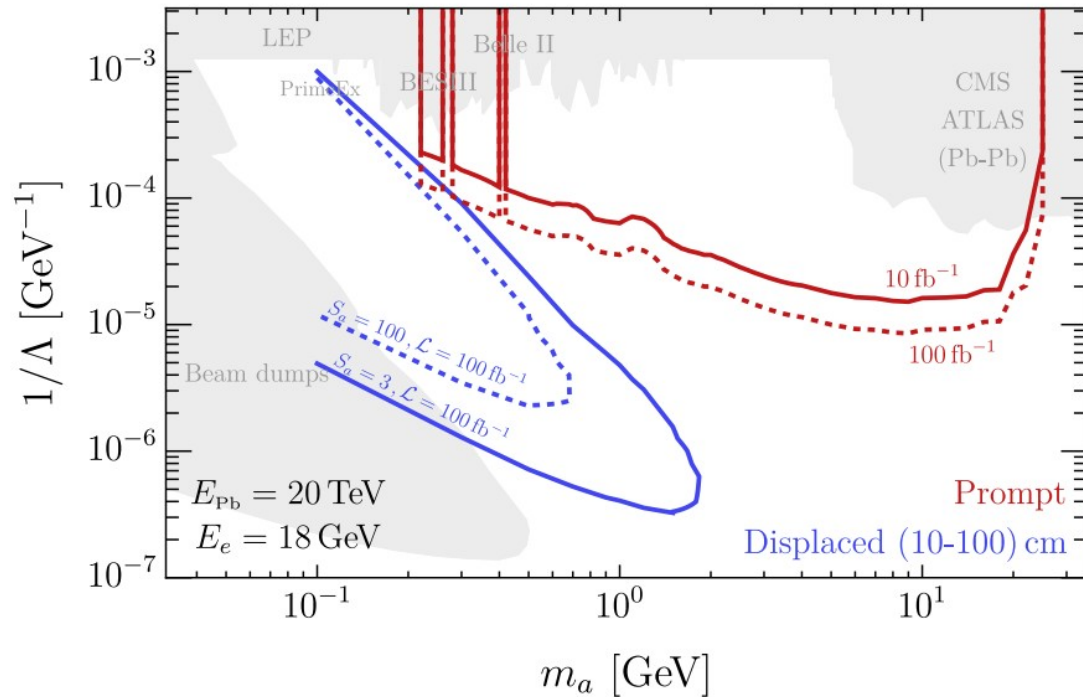
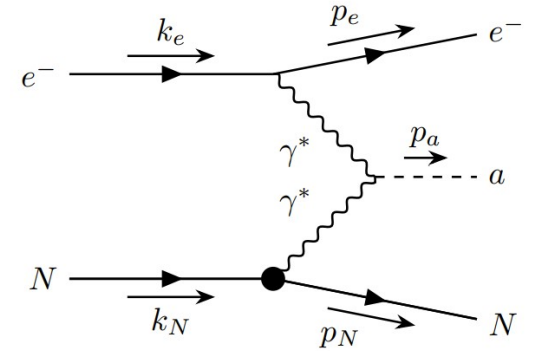


Figure 7: The EIC projections from the ALP searches with $E_e = 18$ GeV and $E_{Pb} = 20$ TeV. The solid (dashed) red lines show the prompt search results with 10 (100) fb^{-1} integrated luminosity. The solid (dashed) blue lines show the displaced search results with $S_a = 3$ ($S_a = 100$) with 100 fb^{-1} integrated luminosity, assuming the diphoton spatial resolution $L_R = 10$ cm and the distance between the interaction point and the EM calorimeter $L_{EM} = 100$ cm.



See also Liu, Yan, 2112.02477, Chin.Phys.C 47 (2023) 4, 043113 (e, p initial states)

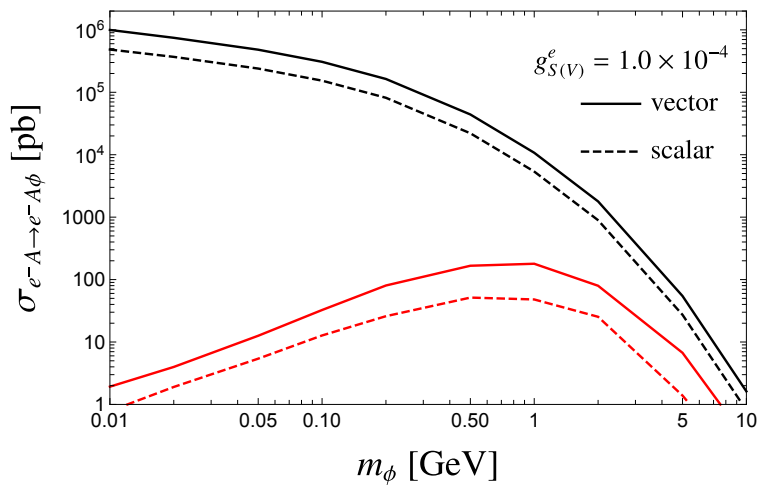
Discovering Invisible Dark Bosons at the EIC

H.D., Liu, 2505.08871

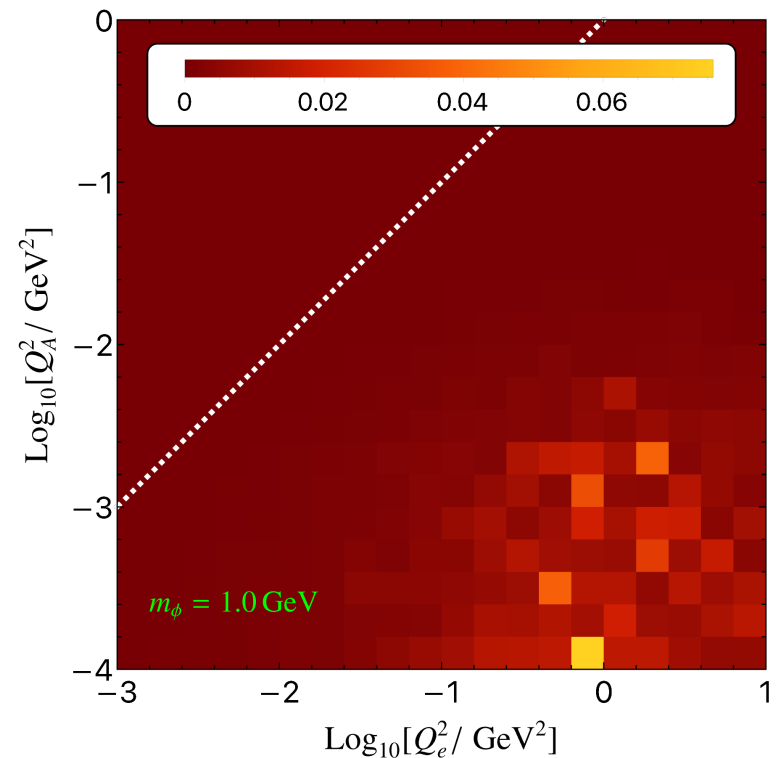
- Consider dark bosons in ~ 10 MeV-10 GeV mass regime
- Weakly coupled to electrons, $\mathcal{O}(1)$ invisible branching fraction:
 - $B - L$, $L_e - L_i$ with $i = \mu, \tau$, dark Z , ...
 - Significant invisible branching fraction from ν or “dark sector” final states
- Basic models
$$\mathcal{L}_S = g_S^e \phi \bar{e}e + g_S^\chi \phi \bar{\chi}\chi$$
$$\mathcal{L}_V = g_V^e \phi_\mu \bar{e}\gamma^\mu e + g_V^\chi \phi_\mu \bar{\chi}\gamma^\mu \chi$$
 - ϕ (ϕ_μ) a scalar (vector)
 - χ : ν or dark fermion; $\phi \rightarrow \bar{\chi}\chi$ allowed on-shell
- We consider coherent e -Au scattering
- $E_e = 18$ GeV, $E_A = 100$ GeV per nucleon

Kinematics

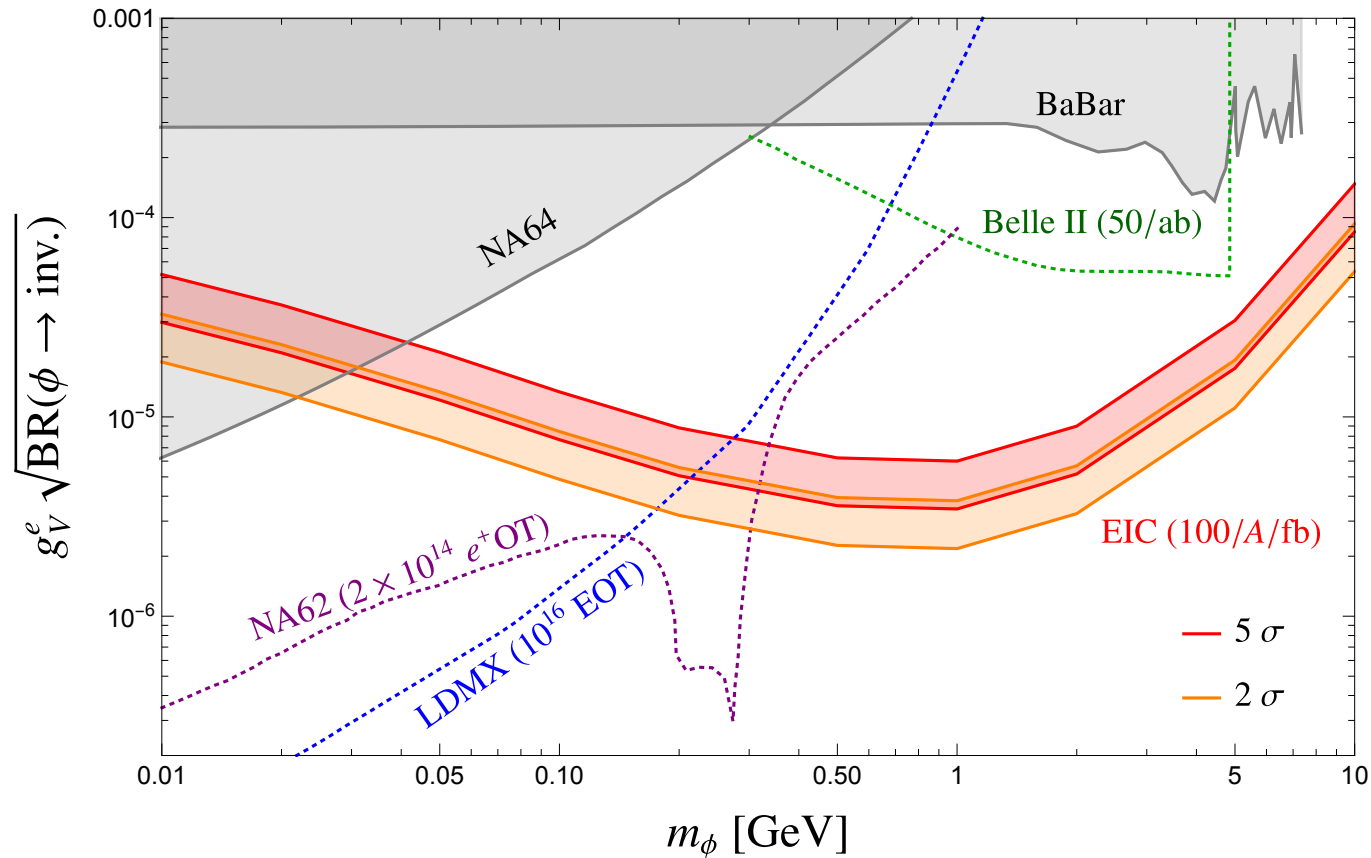
- Emitted ϕ takes most of the electron beam energy
- Momentum transfer Q^2 mostly on the electron side
- SM background marked by soft and similar Q^2 from either beam



- Similar cross sections for scalars and vectors
- Red curves: after cuts
- We focus on the vector case
- A main background: coherent $e^- A \rightarrow e^- A \gamma$, with γ missed
- Cuts: $|\eta_e| < 3.5$, $p_T^e > 1.2$ GeV, $E_e < 10$ GeV, $Q_e^2 > 4$ GeV²



- E_e cut $\rightarrow$ background E_γ mostly > 5 GeV, Inefficiency $10^{-6} \leq \epsilon \leq 10^{-4}$
 - for $|\eta_\gamma| < 3.5$ (assumed missed otherwise) [Maeda et al., 1412.6880](#); [Fry et al., 2501.14827](#)
 - Background: $70 \times \epsilon / 10^{-4}$ pb
- Taking similar ϵ for hard jets, DIS background $e^- A \rightarrow e^- X j$ also suppressed
 - Jet central ($|\eta_j| < 3.5$), $E_j > 8$ GeV
 - Background $\lesssim Z \times 0.2 \times \epsilon / 10^{-4}$ pb (smaller than bremsstrahlung, but not negligible)
 - Additional leverage from Zero Degree Calorimeter to veto incoherent scattering



Concluding Remarks

- Open fundamental questions strongly imply the need for new physics
- There are currently no solid hints about the nature and scale of new particles
- Longstanding theory arguments challenged, no new consensus has emerged
 - Motivates looking at a wide range of testable ideas
 - Any new facility that can help along should be leveraged
- The EIC can be a tool to probe new phenomena
 - Imprints of high scale phenomena may leave a trace (encoded via EFTs)
 - Low mass dark sectors
- We only sampled some ideas for BSM at EIC; good to have more
- Further studies are warranted and can provide
 - Optimized scientific impact for the EIC
 - Science case for extensions, *e.g.* a second detector
 - A nexus of collaboration for the high energy and nuclear physics communities