BSM physics at the LHeC and the FCC-eh

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on behalf of the BSM@ep group
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Possible Layouts for the LHeC and FCC-he

- Energy Recovering Linac (e beam: 60 GeV).
- Operation of LHeC (FCC-he) concurrent with LHC (FCChh).
- ERL can be compatible with FCC ring design.
Motivation for Beyond the Standard Model studies

Electron-proton collider: ideal laboratory to study common features of electrons and quarks with EW / VBF production, LQ,multi-jet final states, forward objects

Promising aspects:
- Small background (no QCD interaction between e and p)
- Very low pileup

Here I give a short overview over a few selected topics.
Recent motivation from LHCb anomalies (theory explanations typically involve 3rd generation).

Phenomenology equivalent to R-parity violating SUSY.

ATLAS limits 1.5 TeV for 1,2 generations [1902.00377]

CMS limits 1 TeV [1901.03570]

In ep collisions singly produced as s channel resonance.

Very sensitive to 1st generation.

Can measure: Spin, quantum numbers, flavor structure.
Wino and Higgsino Dark Matter

- WIMPs are still a viable solution for Thermal DM (e.g. in many SUSY extensions/regions)
- Being broadly probed by Direct and Indirect detection as well as Colliders
- At e-p colliders, wino and higgsino DM can be searched for using disappearing track analyses
Long-lived Higgsino searches

- Production via vector boson fusion
- Charginos can have very short lifetime $c\tau \sim \mu$m.
- Decay products $P_T = \mathcal{O}(100)$ MeV
- Beam remnant jet $\Rightarrow$ primary vertex with $\mathcal{O}(10)$ $\mu$m precision
- Signal: single soft displaced pion.
- Looks like hadronic noise, but can be detected at ep colliders!

Curtin, Deshpande, Fischer, Zurita; [arXiv:1712.07135]
Dark Sectors

- Portal models to test generic dark sectors as benchmarks as discussed at the ESPP.
- New results from e-p presented in Granada and being documented.
- Vector portal:
  - Vector mediator (dark photon) for light thermal Dark Matter
  - New mass scale in the MeV-GeV range, feebly-coupled to SM

- Scalar portals:
  - Higgs decays into a pair of long-lived fermionic particles X.
  - Recastable into renormalizable models.

- Pseudo-scalar portals:
  - Search for axions/ALPs in the MeV-tens of GeV range.
  - Signature (e.g. diphoton) can allow determination of its mass.
Dark Photons at the LHeC and the FCC-he

Electron-proton colliders can close a mass gap around 1 GeV via searches for displaced decays.

Mixing between dark photon and SM photon

Prospects for LHeC (1 ab$^{-1}$) and FCC-eh (3 ab$^{-1}$)

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BSM searches at electron-proton colliders overview
Higgs decays into a pair of long-lived scalar particles $S$.

 Scalars decay into the heaviest SM fermion: $S \rightarrow f \bar{f}$.

 Assumption: $P_T(f) > 400$ MeV, displacement $> 50 \mu$m with 100% detection efficiency.
Pseudoscalar portal at the LHeC and the FCC-he

Prospects for LHeC with 1/ab and FCC-he with 3/ab

- Alp production from electron-photon scattering.
- Signature: diphoton with invariant mass $\sim m_{\text{Alp}}$.
- Gray: present exclusion limits.

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Pseudoscalar portal at the LHeC and the FCC-he

Prospects for LHeC with 1/ab and FCC-he with 3/ab

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- Signature: diphoton with invariant mass $\sim m_{\text{Alp}}$.
- Gray: present exclusion limits.
Lowscale seesaw models allow large production cross-sections at colliders.

- Parameters: mass $M_N$ and the active-sterile mixing angles $\theta_\alpha$
- Present constraints: $|\theta_e| \leq 10^{-5}$

Promising at ep:
- Lepton-flavor violating final states: $\mu + \text{jets}$, $\tau + \text{jets}$
- Displaced vertices for $M_N < m_W$. 
Many other studies

- Light Sleptons and EWkinos
  K. Wang, S. Iwamoto, M. D’Onofrio, G. Azuelos

- Prompt EWkinos
  Han, Li, Pan, Wang, [arXiv:1802.03679]

- Charged scalar bosons
  Azuelos, Sun, Wang; [arXiv:1712.07505]

- Effective Majorana Neutrino Interactions and Polarization
  Duarte, Zapata, Sampayo; [arXiv:1802.07620]

- Georgi-Machacek model
  Azuelos, Sun, Wang; [arXiv:1712.07505]

- Extended Higgs sectors
  Liu, Tang, Zhang, Zhu; [arXiv:1608.08458]
  Sun, Luo, Wei, Liu; [arXiv:1710.06284]
  Hernández-Sánchez, Flores-Sánchez, Honorato, Moretti, Rosado; [arXiv:1612.06316]

- Leptoquarks and Heavy Neutrinos at the LHeC
  S. Mandal, M. Mitra and N. Sinha; Phys. Rev. D 98 (2018) no.9, 095004

- RPV SUSY.

- Exotic/rare top decays.

- …
Conclusions

- ep collider are complementary to pp and ee colliders. (Essential to fully exploit pp measurements due to PDF.)
- They offer a variety of opportunities for BSM searches.
- Ideal to study properties of new particles with couplings to electron-quark
- New opportunities for displaced signatures from LLPs:
  - Great reach for short lifetimes
  - Well suited to find signal that looks like hadronic noise.