# Physics Potential at Electron Proton Colliders

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*for the LHeC study group*


Early career meeting
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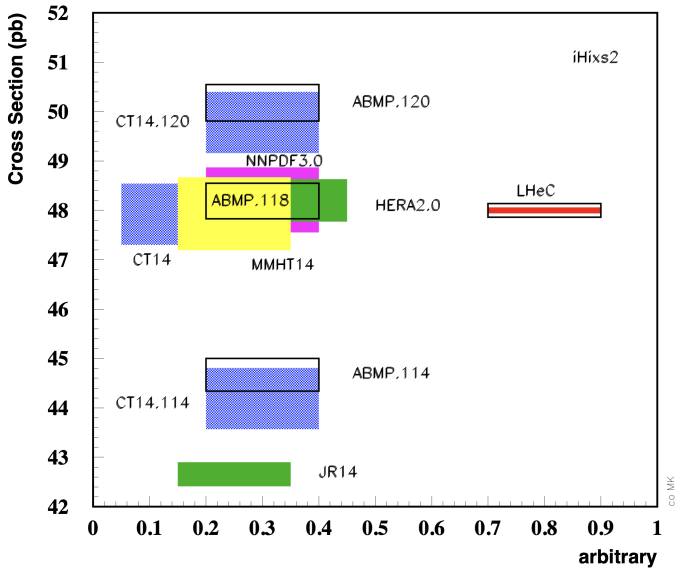
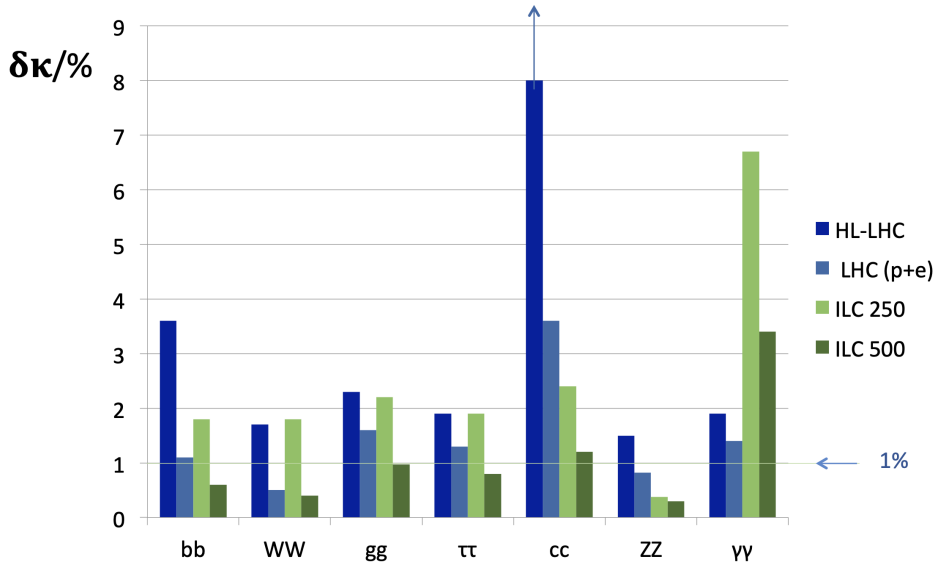
# Introduction (what it is)

- The **L**arge **H**adron **e**lectron **C**ollider:
  - official CERN project, http://lhec.web.cern.ch/
  - Conceptual design report LHeC study group; [arXiv:1206.2913 [physics.acc-ph]]
  - Very recent update LHeC study group; [arXiv:2007.14491 [hep-ex]]
  - Part of the **F**uture **C**ircular **C**ollider: FCC-he (hadron electron)
- Working groups: PDF, Higgs, Top, Electroweak, BSM, ...
- Well represented during the update of the European Strategy for Particle Physics.
- New technology, PERLE:
  - high **p**ower **E**nergy **R**ecovery **L**inac for **E**xperiments in Orsay.
  - Collaboration: CERN, JLAB, STFC ASTeC Daresbury, Liverpool University, IJC Lab Orsay, BINP Novosibirsk
  - Demonstrators and prototypes exist.

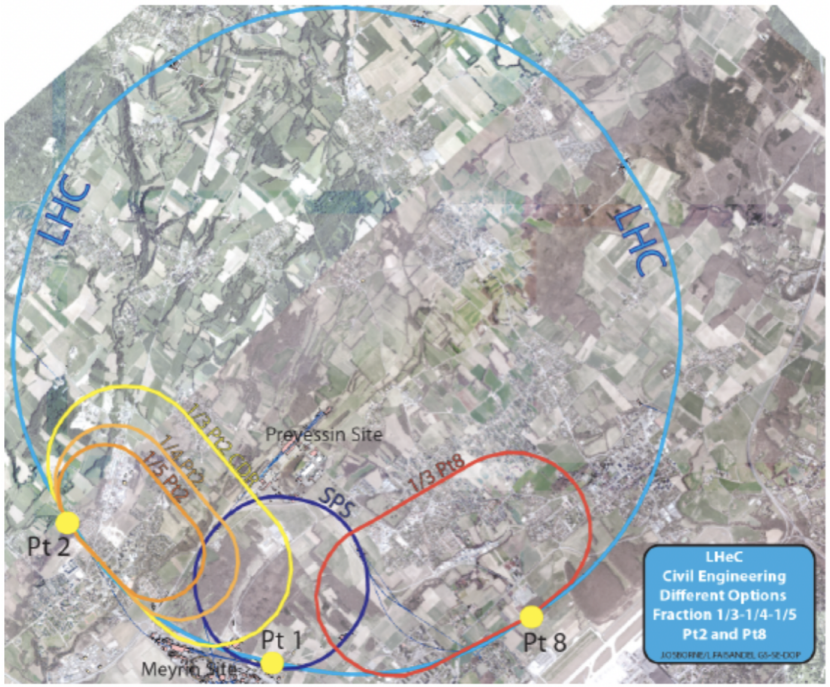
# Motivation (why we should care)



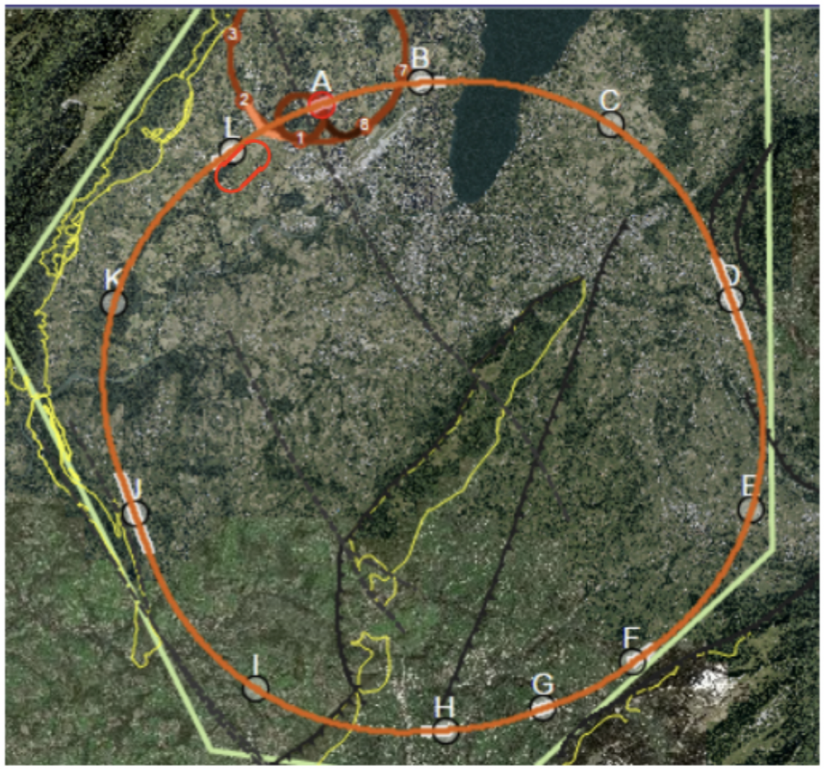




- High-resolution microscope: test QCD at smallest distances.
- PDF: improve precision of LHC results.
- **Higgs!**
- Precision from single top production.
- ...

# Possible Layouts (where to build them)



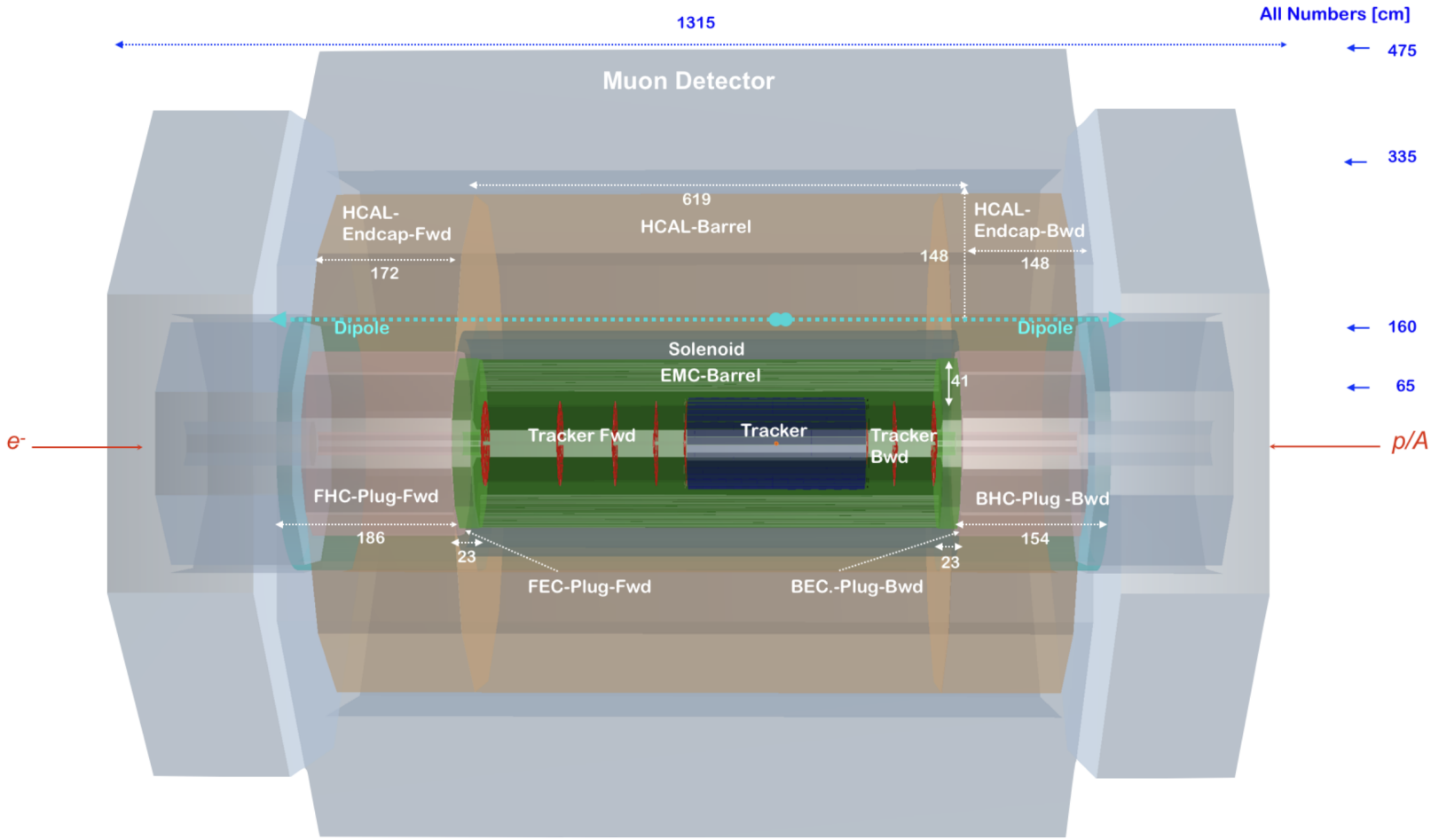

LHeC




FCC-he

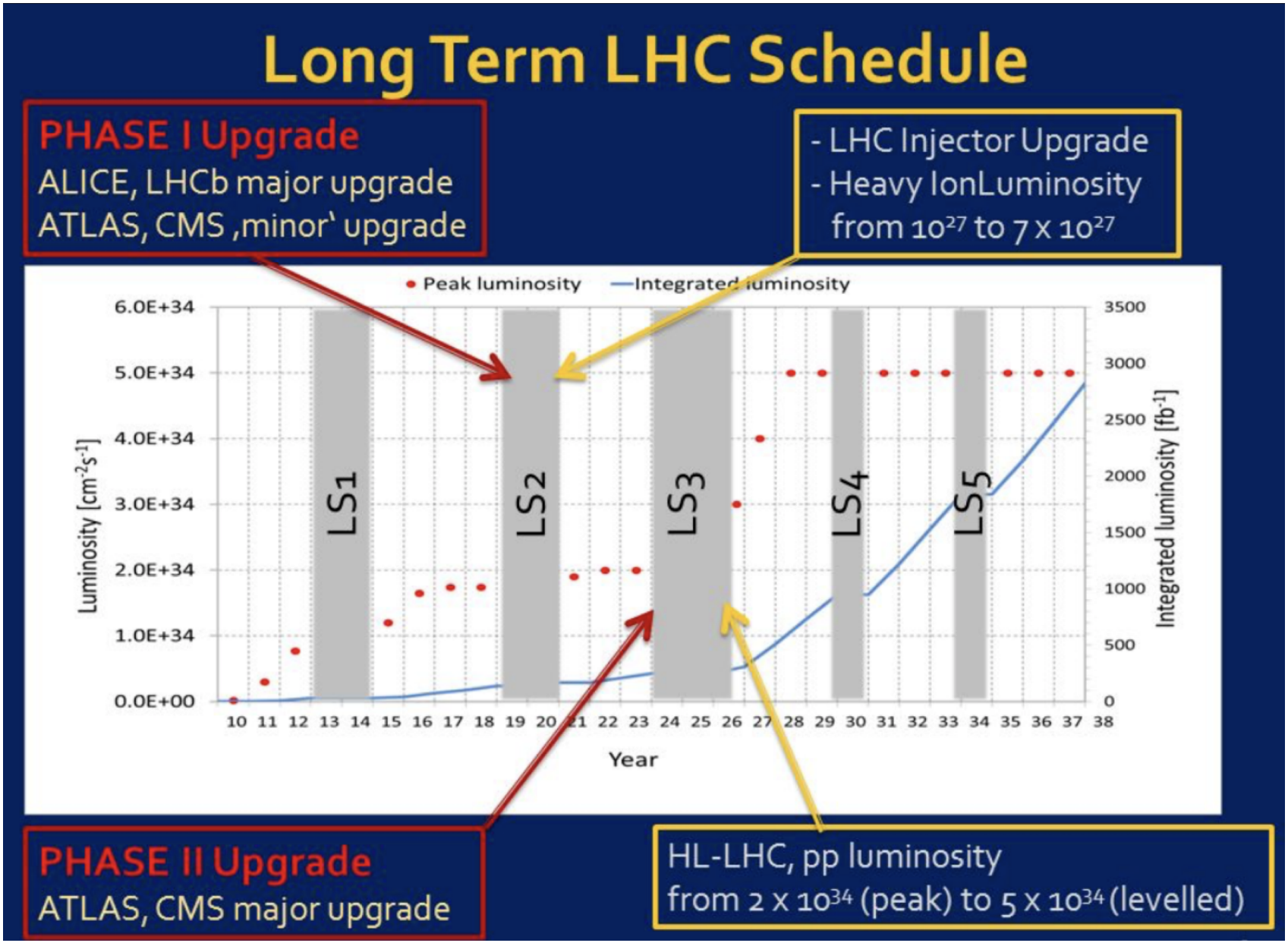
- Energy Recovering Linac ($e^-$ beam: 60 GeV).
- Operation of LHeC (FCC-he) concurrent with LHC (FCC-hh).
- ERL can be compatible with FCC ring design.

# The detector




- Asymmetric design, "standard" HEP detector technology.
- Delphes card for LHeC and FCC-he exist.

# Possible installation (LS3, data starting 2026)

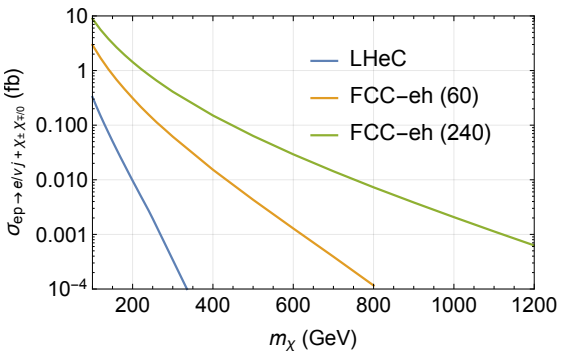


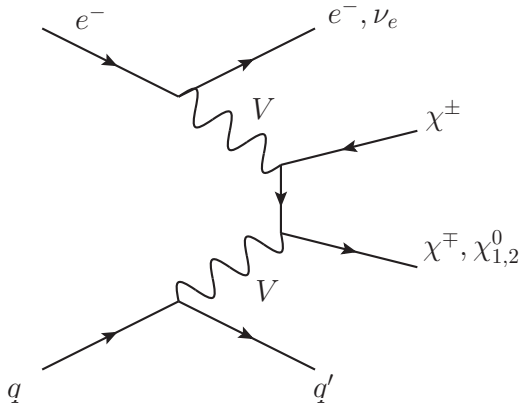
# Beyond the Standard Model studies

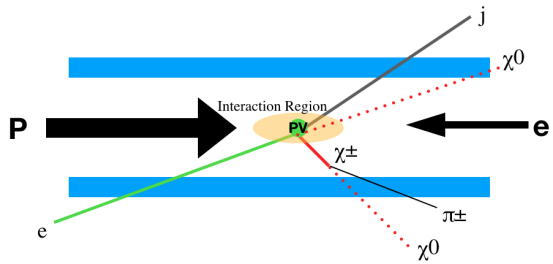
- Ideal to study common features of electrons and quarks.
- **Advantages:**
  - No towering (QCD) backgrounds.
  - No pileup at LHeC (very low at FCC-he).
  - Effectively triggerless.
  - Almost $4\pi$ angular acceptance.
- **Challenges:**
  - Production rates.
  - Centre-of-mass energy.
- **Good prospects** for new physics with ...
  - ... production from vector boson fusion
  - ... multi-jet final states
  - ... forward kinematics
- Does **your** model fit this description?
  There are **good chances** it has not been studied yet.

I will now present a few selected BSM@ep studies.

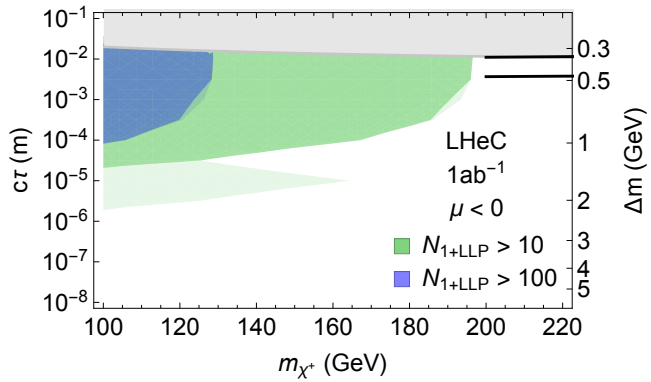
# Long-lived Higgsino searches

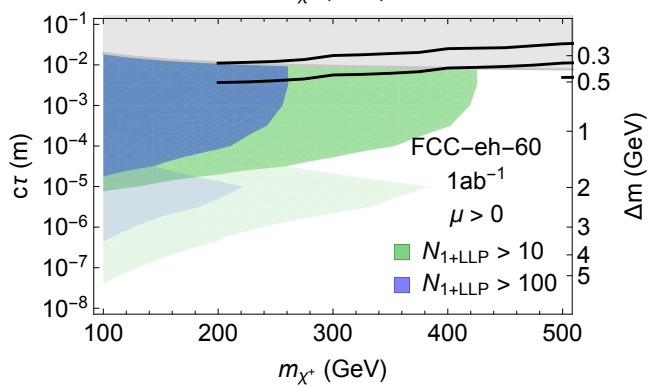



- Production via vector boson fusion
- Charginos can have very short lifetime $c\tau \sim \mu$m.
- Decay products $P_T = \mathcal{O}(100)$ MeV
- Beam remnant jet $\Rightarrow$ primary vertex with $\mathcal{O}(10)\,\mu$m precision
- Signal: single soft displaced pion.
- Looks like hadronic noise, but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

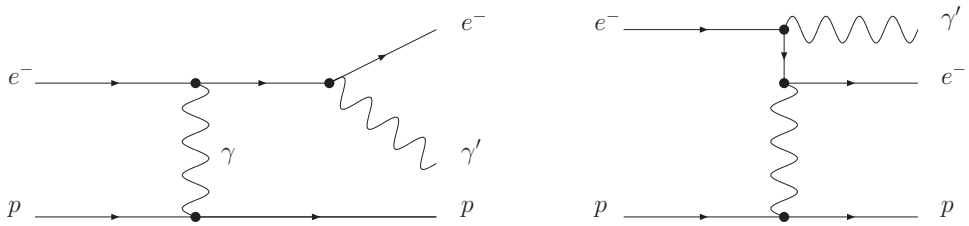


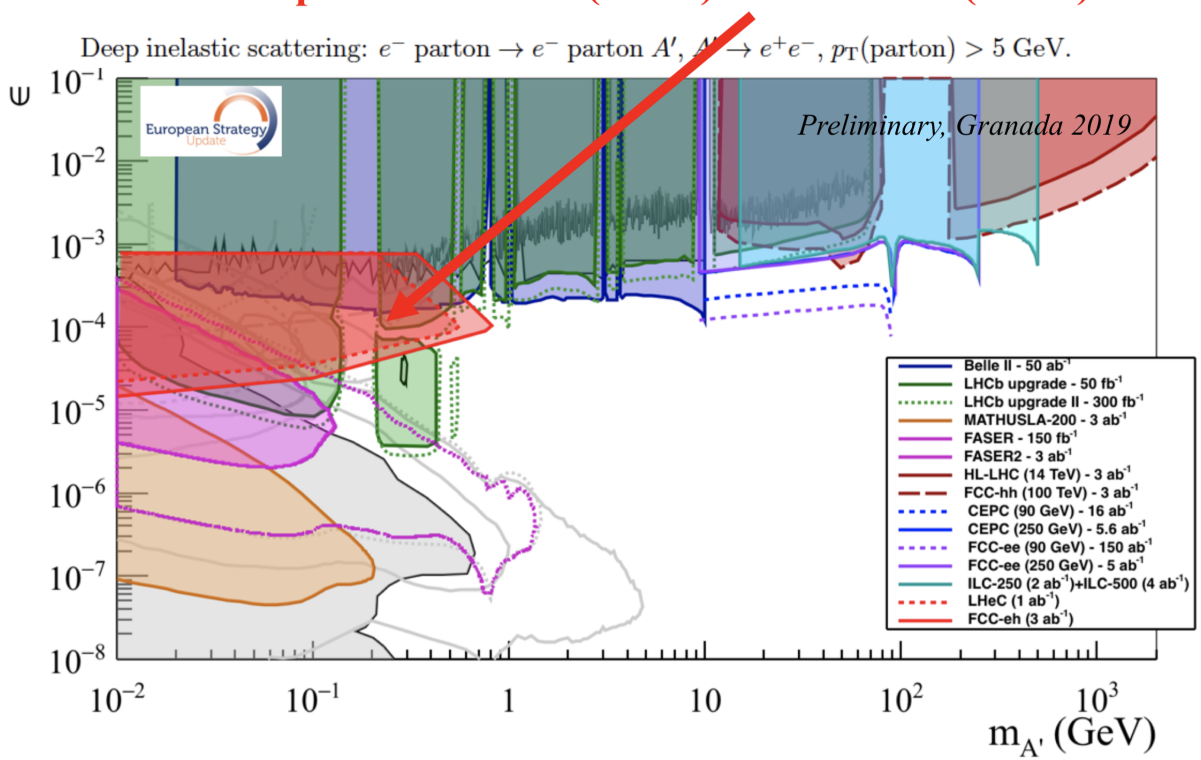

Curtin, Deshpande, OF, Zurita; [arXiv:1712.07135]

# Dark Photons at the LHeC and the FCC-he

D'Onofrio, OF, Wang; [arXiv:1909.02312 [hep-ph]]



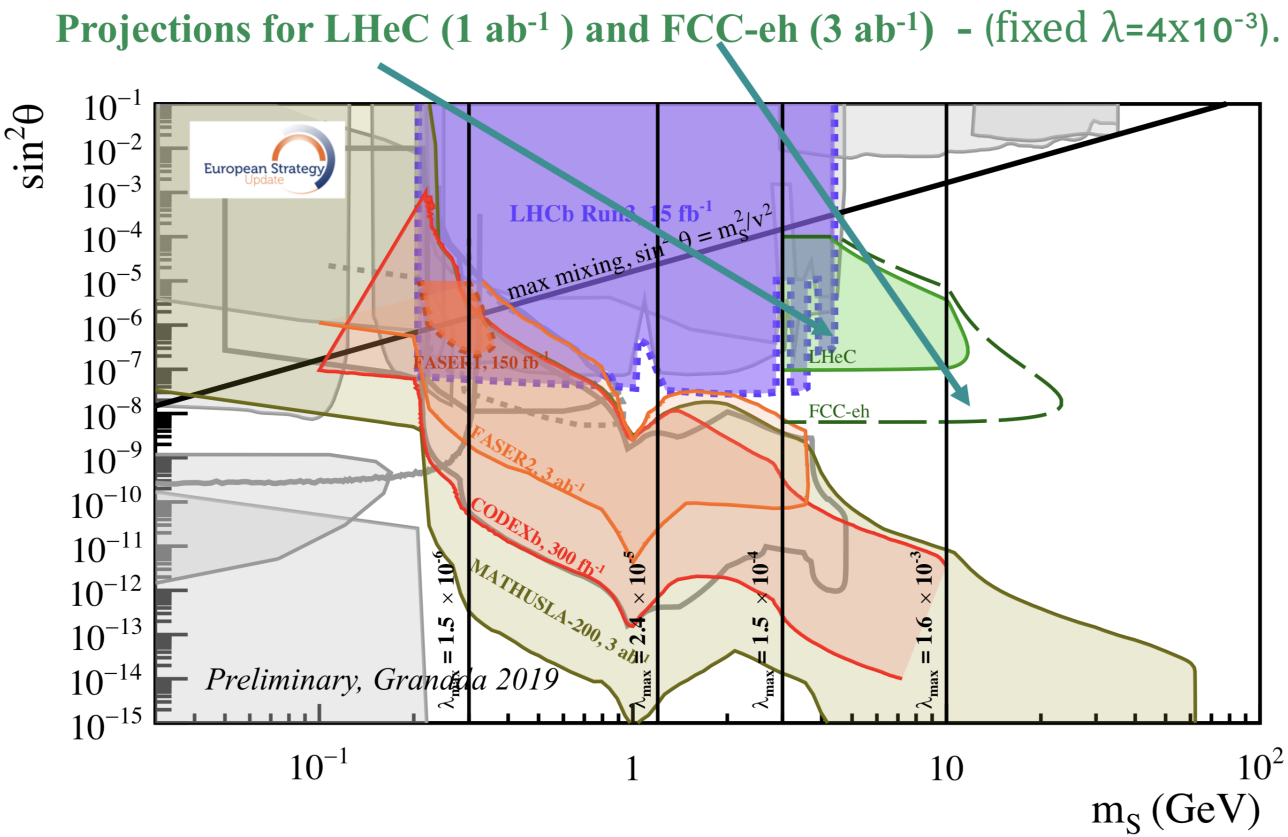

**Prospects for LHeC (1 ab$^{-1}$) and FCC-eh (3 ab$^{-1}$)**




from G. Lanfranchi, Granada

**ep colliders: test a gap around 1 GeV.**

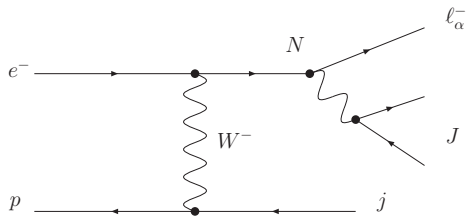
# Scalar portal at the LHeC and the FCC-he

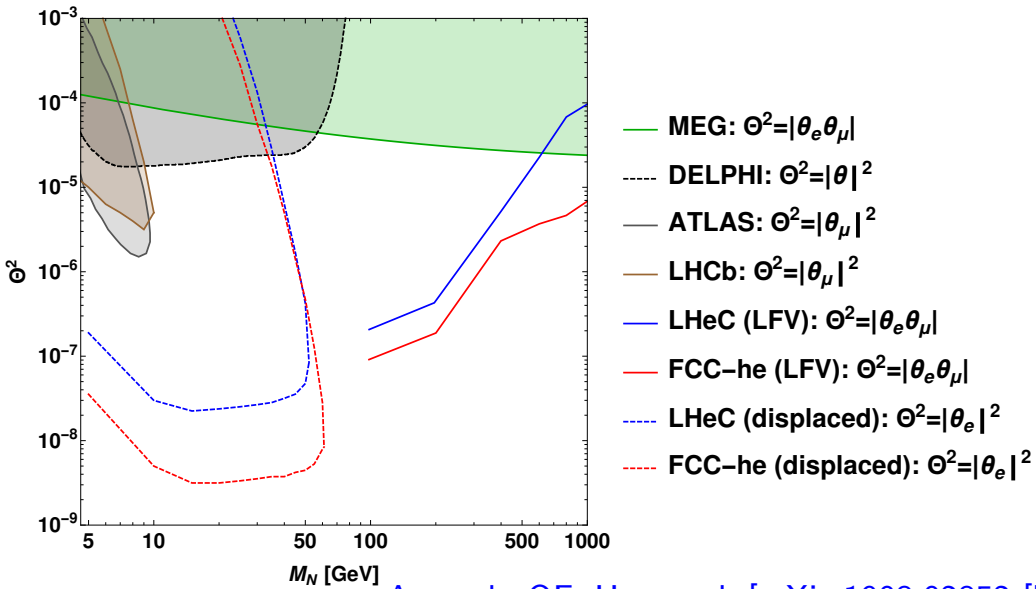



from G. Lanfranchi, Granada

- Higgs decays into a pair of long-lived scalar particles $S$.
- Scalars decay into the heaviest SM fermion: $S \to f\bar{f}$.
- Recent detailed study: Cheung, OF, Wang, Zurita; [arXiv:2008.09614 [hep-ph]]

# Sterile neutrinos at future electron-proton colliders




Antusch, OF, Hammad; [arXiv:1908.02852 [hep-ph]]

- Lowscale seesaw models allow large production xsections at colliders.
- Parameters: mass $M_N$ and the active-sterile mixing angles $\theta_\alpha$
- Comprehensive comparison of prospects at different collider types

Antusch, OF, Cazzato; [arXiv:1612.02728 [hep-ph]]

# 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]
- Leptoquarks and Heavy Neutrinos

  Mandal, Mitra and Sinha; Phys. Rev. D **98** (2018) no.9, 095004
- Charged scalar bosons — Azuelos, Sun, Wang; [arXiv:1712.07505]
- Effective Majorana Neutrino Interactions and Polarization

  Duarte, Zapata, Sampayo; [arXiv:1802.07620]
- Georgi-Machacheck 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]
- RPV SUSY.
- Exotic/rare top decays.
- ...

# Summary

- A lot of complementary to other colliders.
- Electron-proton collisions provide important information:
  - Study of QCD, Top, Electroweak physics.
  - Essential to fully exploit **pp** measurements due to PDF.
  - Higgs factory that can (almost) compete with **ee**.

  Europe's affordable track to precision Higgs measurements and the full exploitation of the LHC
- A variety of opportunities for BSM searches:
  - VBF produced particles with compressed spectra;
  - Long lived particles;
  - Signal that looks like hadronic noise.
  - Anything that connects to electron or light quark flavors.
- Plenty of room for **your** ideas!

Join us on Friday for the tutorial.