BSM searches at FCC-eh

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for the BSM ep team
[coord. MD, Oliver Fischer, Georges Azuelos]

FCC Week, Amsterdam, April 12th 2018
Introduction

- ep collider is ideal to study common features of electrons and quarks with
  - EW / VBF production, LQ, multi-jet final states, forward objects
- Broad BSM program at the FCC-eh in terms of
  - Exploration of new and/or challenging scenarios
  - Characterization of hints for new physics if some excess or deviations from the SM are found at pp colliders
- Differences and complementarities with pp colliders
  - Some promising aspects:
    - small background due to absence of QCD interaction between e and p
    - very low pileup
  - Some difficult aspects:
    - low production rate for NP processes due to small $s$
- Lately, great engagement from theory community working with experimentalists
A wide programme of searches on going...

number general

SUSY (general)
2 Han, C., Li, R., Pan, R.-O., & Wang, K., Searching for the light Higgsinos at the CERN LHC. http://arxiv.org/abs/1802.03879
3 S. Kuroda, Resonant Production of Btought via RPV Couplings at the LHeC. http://arxiv.org/abs/1304.2124

Long-lived particles - SUSY and beyond

heavy/sterile neutrinos
6 Duarte, L., Zapata, G., & Sempayo, O. A., Angular and polarization tests from effective interactions of Majorana neutrinos at the LHeC. http://arxiv.org/abs/1802.07920

anomalous couplings, Effective Lagrangian

BSM Higgs:

compositeness, contact interactions, excited/heavy fermions,GUT
14 see also new limits from HERA: Zeus Collaboration, 1604.01286 and Zernacki, 1511.03825

top quark FCNC and anomalous couplings (top group)

exotic and miscellaneous
27 Ren-You, Z., Hua, W., Liang, H., & Wen-Gan, M., Probing $H+\gamma$-violating coupling via bottom resonance production at the LHeC. http://arxiv.org/abs/1401.1298

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12 April 2018
I will give an overview on on-going studies focusing on a selected list of topics:

- **Direct searches for BSM**
  - BSM Higgs (new charged higgses)
  - SUSY:
    - RPC (EWK, Higgsinos prompt and long-lived)
    - RPV (3rd generation squarks)
  - Leptoquarks
  - Sterile neutrinos
  - anomalous couplings (VVV)
- [in back-up] Indirect impact on search potential for FCC-hh: improved PDF
- Outlook and summary

**Aim of this talk:**
- report on most recent studies and progress
- brief overview of previously finalized studies
- encourage future studies and synergies
BSM Higgs

- Higgs invisible decays
  - \( h \rightarrow \text{Chi0 Chi0} \rightarrow \text{invisible} \)

- Higgs exotic decays
  - \( h \rightarrow 2\phi \rightarrow bb \ (bb) \) [arXiv1608.08458 ]

- Charged Higgs
  - \( H^\pm \), in Vector Boson Scattering
    [Georges Azuelos, Hao Sun, and Kechen Wang, 1712.07505 ]
  - \( H^{\pm\pm} \), in Vector Boson Scattering [in back-up]
  - \( H^+ \), in 2HDM type III,
    \( p \ e \rightarrow vjH \rightarrow vj \ cb \)
    [J. Hernández-Sánchez, etc. 1612.06316]

(see also talk by K. Wang at 2\textsuperscript{nd} FCC Physics Week, Jan 2018)
**Georgi-Machacek Model:**
- No fundamental reason for a minimal Higgs sector $\Rightarrow$ extend scalar sector with higher isospin multiplets
- Might generate Majorana mass for neutrinos via type-II seesaw mechanism

$$5 \text{-plet} \ (H^+_5, H^0_5, H^-_5, H^-_5, H^0_5)$$

---

**Signal production cross section**

$p e^+ \rightarrow j e^- H^+_5, (H^+_5 \rightarrow Z W^\pm)$

Final state: $1 e^- + 1 j + 1 Z(\rightarrow l^+ l^-) + 1 W(\rightarrow j j); l = e, \mu$

---

2 free pars. $M(H_5), \sin \theta_H$

$\text{BR}(H^+_5 \rightarrow W^+ Z) \approx 100\%$

$\text{BR}(H^+_5 \rightarrow W^\pm W^\mp) \approx 100\%$

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[Georges Azuelos, Hao Sun, and Kechen Wang, 1712.07505 ]

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**$H^\pm$ in Vector Boson Scattering**

- **MVA BDT analysis @ detector-level**

Limits for $H^\pm$ assuming 10% systematic uncertainty on the background

Around 500-600 GeV, strong constraints in comparison to the existing (CMS) ones
CC production, various scenarios considered

\[ p e^- \rightarrow vjH^+ \rightarrow vj (c \bar{b}) \]

Parameters for a few optimistic benchmark points in the 2HDM-III as a 2HDM-I, -II and -Y configuration.

@ LHeC with 100/fb only

(Here, \( \varepsilon_b = 0.50, \varepsilon_c = 0.1 \) and \( \varepsilon_j = 0.01 \), where \( j = u, d, s, g \))

<table>
<thead>
<tr>
<th>2HDM</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>( m_{H^+}^{25} = 110 ) GeV</th>
<th>( \sigma . cb )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ia</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>0.99</td>
<td>97.36</td>
</tr>
<tr>
<td>Ib</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>0.99</td>
<td>99.80</td>
</tr>
<tr>
<td>IIa</td>
<td>32</td>
<td>0.5</td>
<td>32</td>
<td>0.99</td>
<td>92.00</td>
</tr>
<tr>
<td>Ya</td>
<td>32</td>
<td>0.5</td>
<td>0.5</td>
<td>0.99</td>
<td>75.12</td>
</tr>
</tbody>
</table>

Masses O(100 GeV) are very challenging at p-p due to large bkg from multi-jet bkg

Good discovery potential at FCC-eh [ work in progress ]
EWK SUSY sector: higgsinos and more

- SUSY EWK sector remains the most challenging for pp colliders in favored regions of the parameter space
  - Higgsino scenarios (~ mass degenerate, low cross sections)
  - Wino/bino compressed (sleptons heavier than charg/neut)
  - Promptly decaying or long-lived (exp. short lifetimes)
**Higgsino**

- C. Han, R. Li, R. Pan, K. Wang arXiv:1802.03679
- Clearly a difficult scenario to probe at the LHC (JHEP 1402 (2014) 049)

**Typical signal:** electron + jet + missing energy

- $E_T^{miss} > 70$ GeV
- $5$ GeV $< p_T^e < 25$ GeV, $1.0 < \eta^e < 5.0$
- $p_T^j > 20$ GeV, $-5.0 < \eta^j < -3.0$
- $m_{ej} > 400$ GeV
- $y = \frac{k_p \cdot (k_{in}^e - k_{out}^e)}{k_{in}^e \cdot k_p} > 0.2$

**Standard model main backgrounds**

**Preliminary result**

$E_e = 60$ GeV, $E_p = 50$ TeV

- $\mathcal{L} = 1ab^{-1}$
- $\mathcal{L} = 2ab^{-1}$
- $\mathcal{L} = 3ab^{-1}$
(long-lived) Higgsino

Production at e-p via vector boson fusion

**Signal:** single soft displaced pion

Beam remnant jet ⇒ primary vertex with O(10) µm precision

**FIG. 5.** Production rate of Higgsinos at LHeC.

**FIG. 8.** Regions in the LLP signature space for the FCC-eh with a 240 GeV electron beam.

~ 450 GeV higgsino (thermal relic DM) can be discovered with 1/ab
“light” sleptons \((m > \text{charg, neut})\)

- Sleptons might be a bit heavier than EWKinos
  - Motivated by g-2 anomalies
  - Would play no role in the decay of charginos and next-to-lightest neutralino - phenomenology unchanged at pp
  - At e-p, cross section is enhanced

MVA-BDT analysis @ detector-level

Production cross sections

Limits on DM mass

Preliminary results from [Kechen Wang, Sho Iwamoto, Monica D’Onofrio, Georges Azuelos]
“light” sleptons ($m > \text{charg, neut}$), long-lived

- If charginos are long-lived
  - Cross section enhanced with “3-body production”

Simple efficiency analysis
- Requiring minimal detection length $l_{min}$
- Charginos (Wino) with selectron

1 ab$^{-1}$ @ FCC-eh:
- $c\tau > 100$ mm
- ~ 40 events for 600 GeV
- ~ 10 events for 750 GeV
excellent discovery potential

With no polarization;
\[ m_{\tilde{e}_L} = m_{\tilde{\chi}_1^0} + 9 \text{ GeV} \]

Preliminary results from [Kechen Wang, Sho Iwamoto, Monica D’Onofrio, Georges Azuelos]
R-parity violating SUSY

Most studied at e-p colliders

Various strong constrains from LHC on \( \lambda \) and \( \lambda'' \) (from multilepton and multijet searches). At e-p colliders, studies made on stop and sbottom:

stop

Couplings with third gen quarks
In e-p production rate depending on:
- e-d-t: \( \lambda'_{131} \) (constraint: < 0.03)

Probe RPV LQD terms:
In this case \( \lambda'_{131} \times \lambda''_{233} \)

FCC-eh potential being re-evaluated:
(Ren-You Zhang, Liang Han et al)

\[
W_{R\bar{p}} = \lambda_{ijk} \hat{L}_i \hat{L}_j \hat{E}_k^C + \lambda'_{ijk} \hat{L}_i \hat{Q}_j \hat{D}_k^C + \epsilon_i \hat{L}_i \hat{H}_u + \lambda''_{ijk} \hat{U}_i \hat{D}_j^C \hat{D}_k^C
\]

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single RPV sbottom production

Recent coupling limits
\[ \lambda'_{113} = \lambda'_{123} \leq 0.18, \quad \lambda'_{231} = \lambda'_{232} \leq 0.45 \]

Preliminary results (Sinan Kuday, in prep.)

- LHeC can extend the limits of LQD couplings up to $10^{-3}$ for just 1 fb$^{-1}$ integrated luminosity at the %95 C.L. with 60 GeV $e^-$ beam option.

@FCC-eh: expect to have
Sensitivity up to 2.5 TeV for $\lambda'_{113} < 0.02$
[work in progress for FCC CDR]
Lepto-quark production

- lately, LQs raised a lot of attention as possible motivation for LHCb anomalies (mostly involving 3rd generation LQ)
- Phenomenology pretty equivalent to SUSY RPV
- At the p-p, mostly pair production (from gg or qq)
  - if $\lambda$ not too strong (0.3 or lower) cross section independent on $\lambda$

- At the e-p: ideally suited to search for and study properties of new particles coupling to both leptons and quarks

- single, resonant production; sensitive to $\lambda$
LQ reach at FCC -eh

1st generation LQs $\rightarrow$ Current constraints almost there with 3.2/fb @ 13 TeV

<table>
<thead>
<tr>
<th>LQ</th>
<th>Scalar LQ 1st gen</th>
<th>Scalar LQ 2nd gen</th>
<th>Scalar LQ 3rd gen</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\lambda_{LQ}$</td>
<td>$\geq 2j$</td>
<td>$\geq 2j$</td>
<td>$\geq 1b, \geq 3j$</td>
</tr>
<tr>
<td>$M_{LQ}$</td>
<td>1.1 TeV</td>
<td>1.05 TeV</td>
<td>640 GeV</td>
</tr>
</tbody>
</table>

(CMS also excluded single production 1st gen LQ < 860 GeV)

e-p scenario: sensitive to $\lambda \ll e=\sqrt{4\pi\alpha}=0.03$

Sensitivity of HL-LHC could go to $\sim 2.8 - 2.9$ TeV
$\rightarrow$ Close to the reach for FCC-eh
$\rightarrow$ Dependence on $\lambda$

If deviations are found by the end of HL-LHC, FCC-hh will definitely see them, and FCC-eh can characterize those signals!

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LQ reach at FCC -eh

1st generation LQs → Current constraints almost there with 3.2/fb @ 13 TeV

(CMS also excluded single production 1st gen LQ < 860 GeV)

E-p scenario:
sensitive to $\lambda \ll e=\sqrt{4\pi\alpha}=0.03$

Results being revisited, see for example
Mod.Phys.Lett. A33 (2018) no.06, 1850039

More ideas being explored about
mixed generation LQ. E.g.:

e.g. reach equivalent to RPV SUSY
Sterile neutrinos

- Neutrino oscillations are evidence for non-zero \( m_\nu \).
- Low scale type I seesaw with sterile neutrinos → heavy neutrino mass eigenstates with \( M \sim \nu_{EW} \)
- Neutrino mixing \( |\theta_\alpha|, \alpha = e, \mu, \tau \Rightarrow \) Weak current production.
- Present constraints: \( |\theta_e| \leq 10^{-3} \Rightarrow \) sizable cross sections at ep.


\[
\begin{align*}
e^- & \rightarrow W^- \\
q & \rightarrow j \text{ (production channel: } W_t^{(q)}) \\
e^- & \rightarrow W^- \\
\gamma & \rightarrow W^- \text{ (production channel: } W_t^{(\gamma)})
\end{align*}
\]

\( \sigma \) divided by the square of the active-sterile mixing parameter \( |\theta_e|^2 \)
Sterile neutrinos (II)

### Leading order signatures

| Name          | Final State | Channel [production,decay] | $|\theta_\alpha|$ dependency | LNV/LFV |
|---------------|-------------|----------------------------|-----------------------------|---------|
| lepton-trijet | $jjj\ell_\alpha$ | $[W_t^{(q)}, W]$ | $\frac{|\theta_\alpha^2|}{\theta^2}$ | ✓/✓     |
| jet-dilepton  | $j\ell_\alpha^\pm \ell_\beta^\mp \nu$ | $[W_t^{(q)}, \{W, Z(h)\}]$ | $\left\{\frac{|\theta_\alpha^2|}{\theta^2}, |\theta_\epsilon^2|\right\}$ | ×/✓     |
| trijet        | $jjj\nu$   | $[W_t^{(q)}, Z(h)]$ | $|\theta_\epsilon|^2$ | ×       |
| monojet       | $j\nu\nu\nu$ | $[W_t^{(q)}, Z]$ | $|\theta_\epsilon|^2$ | ×       |

| lepton-quadrijet | $jjjj\ell_\alpha$ | $[W_t^{(\gamma)}, W]$ | $\frac{|\theta_\alpha^2|}{\theta^2}$ | ✓/✓     |
| dilepton-dijet  | $\ell_\alpha \ell_\beta \nu jj$ | $[W_t^{(\gamma)}, \{W, Z(h)\}]$ | $\left\{\frac{|\theta_\alpha^2|}{\theta^2}, |\theta_\epsilon^2|\right\}$ | ×/✓     |
| trilepton      | $\ell_\alpha^- \ell_\beta^- \ell_\gamma^+ \nu \nu$ | $[W_t^{(\gamma)}, \{W, Z(h)\}]$ | $\left\{\frac{|\theta_\alpha^2|}{\theta^2}, |\theta_\epsilon^2|\right\}$ | ×/✓     |
| quadrijet      | $jjjj\nu$    | $[W_t^{(\gamma)}, Z(h)]$ | $|\theta_\epsilon|^2$ | ×       |
| lepton-dijet   | $\ell_\alpha^- jj\nu\nu$ | $[W_t^{(\gamma)}, Z(h)]$ | $|\theta_\epsilon|^2$ | ×       |
| dijet          | $jj\nu\nu\nu$ | $[W_t^{(\gamma)}, Z]$ | $|\theta_\epsilon|^2$ | ×       |
| monoletop      | $\ell_\alpha^- \nu\nu\nu\nu$ | $[W_t^{(\gamma)}, Z]$ | $|\theta_\epsilon|^2$ | ×       |

- **LNV/LFV** indicates that an unambiguous signal (with no neutrinos in the final states) for LNV and/or LFV is possible.
- **Signatures can be prompt or long-lived (displaced vertex)**
Sterile neutrinos (III)

- **Displaced vertices:**
  - Heavy neutrino-antineutrino oscillations
  - Oscillation from $\Delta m^2_\nu$ \cite{Antusch:2017yhn}

- **Lepton flavor violation:**
  - Unambiguous: $\mu+$jets, $\tau+$jets, $\mu\tau+$jets
  - highest sensitivity to $|\theta_e \theta_\alpha|^2$, $\alpha = \mu, \tau$

\[\text{complementarities } ee-pp-ep\]
More: “Effective” majorana neutrinos

(Duarte, Zapata, Sampayo)

* Model BSM Majorana neutrino $N_R$ interactions with effective Lagrangian for $e^- p \rightarrow l^+ + 3\text{jets}$

* Goal: distinguish scalar and vectorial interactions.

FCC-eh POLARIZED BEAM:

* The number of events produced by scalar and vectorial interactions depends on initial electron polarization $P_e$.

* arXiv: 1802.07620, 1412.1433

FCC-eh can give a hint on the kind of new physics behind Lepton Number Violation and $N$ interactions!!


### Anomalous gauge coupling

- **Triple gauge boson vertices** $WWV, \, V=\gamma, Z$
  - Precisely defined in SM
  - Parametrise possible new physics contributions to this vertex $(\Delta \kappa_\gamma, \lambda_\gamma)$
  - Current constraints (best from LEP) use various assumptions

[A. Senol, O. Cakir, I. Turk Cakir]

$ep \rightarrow \nu e q ZX$ for $Z \rightarrow ll \ (l = e, \mu)$

Sensitivities to anomalous couplings $\lambda_Z \sim 10^{-3}$

**Figure 1:**

1. $10 \text{ fb}^{-1}$
2. $100 \text{ fb}^{-1}$

FCC-eh

$P(e^-) = -0.8$

https://cds.cern.ch/record/2209389/?ln=en
Anomalous gauge coupling (II)

- Triple gauge boson vertices WWV, V=γ,Z

[ R. Li, X. Shen, K. Wang, T. Xu, L. Zhang and G. Zhu, 1711.05607 ]

Process $p \, e^- \rightarrow j \, e^- \, \mu^+ \nu$

Limits via shape analysis by constructing $\chi^2$ from all bins

Sensitivity ~ 10^{-3} @ LHeC with 2-3 ab^{-1} → Better @ FCC-eh! Work in progress

$\Delta \phi_{ej}$: azimuthal angle between scattered beam electron and jet

$\theta_{\mu W}$: angle between decay product $\mu$+ in the $W$+ rest frame and the $W$+ direction in the collision rest frame

95% C.L.
FCC-eh offers a variety of opportunities for BSM searches in a lot of expected and maybe unexpected scenarios

- LQ and RPV SUSY but also
- EWK SUSY and DM
- BSM Higgs
- Sterile neutrinos

Prompt and non-prompt signatures are being explored

- Potential for LLP is huge thanks to the low expectation of bkg

Ideal to study properties of new particles with couplings to electron-quark

Ideal to improve precision of measurements and searches thanks to PDF improvements (see other talks this conference and in back-up)

Great opportunity for new ideas - all being documented in the CDR!
Back-up
$H^{±±}$ in Vector Boson Scattering

**Signal via WW-fusion**


Final state: $\geq 1$ j + 2 $\mu^-$ + MET

Cut-and-count analysis @ detector-level

- $E_T^j \geq 10$GeV
- $p_T^{j,l} \geq 10$GeV
- $|\eta^j| \leq 5$, $|\eta^l| \leq 2.5$
- $\Delta R_{jj} \geq 0.4$, $\Delta R_{jl} \geq 0.4$, $\Delta R_{ll} \geq 0.4$
- $\Delta \phi^{\mu\mu} \in (-\pi,-1.28)$ or $(1.36,\pi)$
- $\Delta R^{\mu\mu}$
- $M_{inv}^{\mu\mu} > 75$GeV
- $M_T^{\mu\mu} > 40$GeV

PLD 90, 115025 (2014)

FCC-eh, unpol.

FCC-eh, pol.
Measuring the LQ quantum numbers in e-p

- Quantum numbers and couplings:
  - Fermion number:
    - can be obtained from asymmetry in single LQ production, since \( q \) have higher \( x \) than \( \bar{q} \)
    - At pp: very poor asymmetry precision achievable in single LQ production

\[
A = \frac{\sigma_{e^-} - \sigma_{e^+}}{\sigma_{e^-} + \sigma_{e^+}} \begin{cases} > 0 & \text{for } F=2 \\ < 0 & \text{for } F=0 \end{cases}
\]

- spin
  - At p-p, pair production of LQ-LQ leads to angular distributions which depend on the g-LQ-LQ coupling
    → may need to look for spin correlations
  - At e-p, \( \cos \theta^* \) distribution is sensitive to the spin
  - vector leptoquarks can have anomalous couplings

- couple chirally (i.e. to L or R but not both)?
  - could be probed by measuring sensitivity of cross sections to polarization of the electron beam

- generation mixing?
  - does LQ decay to 2\(^{\text{nd}}\) generation?
    \[
e_L^{-} u_L \rightarrow S_3 \rightarrow \nu_e d_L
\]
  - BR to neutrino, good S/B in \( \nu_j \) channel
Contact interactions

- if new physics enters at higher scales: $\Lambda >> \sqrt{s}$
- such indirect signatures can be seen as effective 4-fermion interaction

$$\mathcal{L} = \frac{4\pi}{2\Lambda^2} j^{(e)}_{\mu} j^{(\mu)}_{(q)}; \quad j^{(f=e,q)}_{\mu} = \eta_L \bar{f}_L \gamma_{\mu} f_L + \eta_R \bar{f}_R \gamma_{\mu} f_R + h.c.$$ 

$\Rightarrow$ all combinations of couplings $\eta_{ij} = \eta^{(e)}_i \eta^{(q)}_j; \quad q = u, d$

- may be applied very generally to new phenomena

$\Lambda$

- LQ mass $>> \sqrt{s}$
- Planck scale ($M_s$) of extra dimensional models
- compositeness scale
- ...

Sensitivity to fermion radius recalculated with current expectations at the FCC-eh

$R \rightarrow 3(1.5) \times 10^{-20}m$

pessimistic (optimistic) calculations

Form factor: $f(Q^2) = 1 - \frac{1}{6} \left< r^2 \right> Q^2$

$$\frac{d\sigma}{dQ^2} = \frac{d\sigma^{SM}}{dQ^2} f_e^2(Q^2) f_q^2(Q^2)$$
Contact interactions (eeqq)

- New currents or heavy bosons may produce indirect effect via new particle exchange interfering with $\gamma/Z$ fields.
- Reach for $\Lambda$ (Cl eeqq): VV: $\sim 290$ TeV; LL: $\sim 160$ TeV

$\sim$ equivalent sensitivity at the FCC-hh at least for some of the couplings (same as HL-LHC vs LHeC) but need more calculations!
E-p “specific” searches: Instantons

- New physics as non-perturbative QCD effect at high energies
  - Instantons → non-perturbative fluctuations of the gluon field
- Photon-gluon fusion process
- HERA recent results start probing interesting theoretical scenarios
- Feasibility could / should be considered for the future

**Figure 7:** Observed CLs

**Figure 6:** Distribution of the bin weights

**Figure 8:** Instanton production exclusion limits as a function of the discriminator $D$.
Vector Boson Scattering

2 TeV resonance

$e^- q \rightarrow e^- (q) WZ, \ (\nu q) WZ$

Typical cross sections for 2 TeV resonance ($c_F=0, c_H=1, g_V=3, 60 \text{ GeV} \times 50 \text{ TeV}$)

- highly dependent on acceptance and performance of detector
- FCC-eh (2 TeV resonance): $S = 0.01 \text{ fb}, \ B_{EW} = 100 \text{ fb}$
  (for comparison, LHC14: $S = 0.12 \text{ fb} \ B_{QCD} = 4.2 \text{ pb} \ B_{EW} = 300 \text{ fb}$)

low cross section, but kinematics of signal distinct from background
(invariant mass, rapidity of the objects, can use W/Z boosted hadronic decays)

→ Need very good detector performance
Improving PDFs with the LHeC

- **low-x**: no current data to constrain $x \leq 10^{-4}$; better but not much after HL-LHC; rely purely on extrapolation non-linear equations, gluon saturation?

- **mid-x**: need higher precision for Higgs

- **high-x**: very poorly constrained - limits searches for new, heavy particles

**FCC-eh**: access to much smaller $x$, larger $Q^2$

**Impact on PDF**: also depends on whether LHeC is realized or not
Potential of FCCeh on PDFs

See Stefano and Voica’s presentation

PDF4LHC set vs FCCeh (+HERA) at starting scale

FCCeh brings substantial impact at low x important for the FCCpp as it will probe much lower x regions for standard processes
Impact of PDF: High mass Drell-Yan

- Non resonant searches for ED (interference) sensitive to tails of DY distributions thus to PDF. Predominantly q-qbar

Uta Klein
VRAP 0.9 for NNLO QCD

“Troubles” at low and high x

FCCeh (and before, LHeC) can improve low and high M(ll) and M(lv) precision for standard candle measurements and searches for new physics
Impact of PDF @ High x

- large uncertainties in high x PDFs limit searches for new physics at high scales
  - many interesting processes at LHC are gluon-gluon initiated: top, Higgs, ... and BSM processes, such as gluino pair production
- For HL-LHC → studied in detail impact of LHeC

Studies updated with modern PDF sets!
- \( M(\text{squark}) = M(\text{gluino}) = \mu_R = \mu_F \)
- LHeC PDF uncertainties unchanged
- Normalized to MMHT14

NNPDF30nlo become negative at high masses despite positive constraints applied to the fitting procedure

\( < x > \sim 0.4 \)
Impact of PDF @ High x

- Large uncertainties in high x PDFs limit searches for new physics at high scales. Many interesting processes at LHC are gluon-gluon initiated: top, Higgs, ... and BSM processes, such as gluino pair production.
- For HL-LHC → studied in detail impact of LHeC

Studies updated with modern PDF sets!
- \( M(\text{squark})=M(\text{gluino})=\mu_R=\mu_F \)
- LHeC PDF uncertainties unchanged
- Normalized to MMHT14

Use prescription from J. Rojo to avoid negative x-section at at high masses for NNPDF30nlo → x-section calculation unstable

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arXiv:1211.5102

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12 April 2018
Impact of PDF @ High x: FCC

- FCC-hh reach up to 13(16) TeV for gluino pair production, 17(20) TeV for non-decoupled squark/gluino for 3(30)/ab⁻¹

- Similar x range for the sensitive region (<x> ~ 0.4) → ~40-50% uncertainties on the prediction of gluon-gluon initiated processes
  - *Might be an issue also for central values*

Other aspects might play a non-negligible role:

Top PDF: at the very high Q², top becomes small and will have to be included as 6F PDFs

No doubts that having an e-p machine running in parallel with p-p will be very important