Opportunities and challenges for QCD physics in high-energy ep collisions at future facilities

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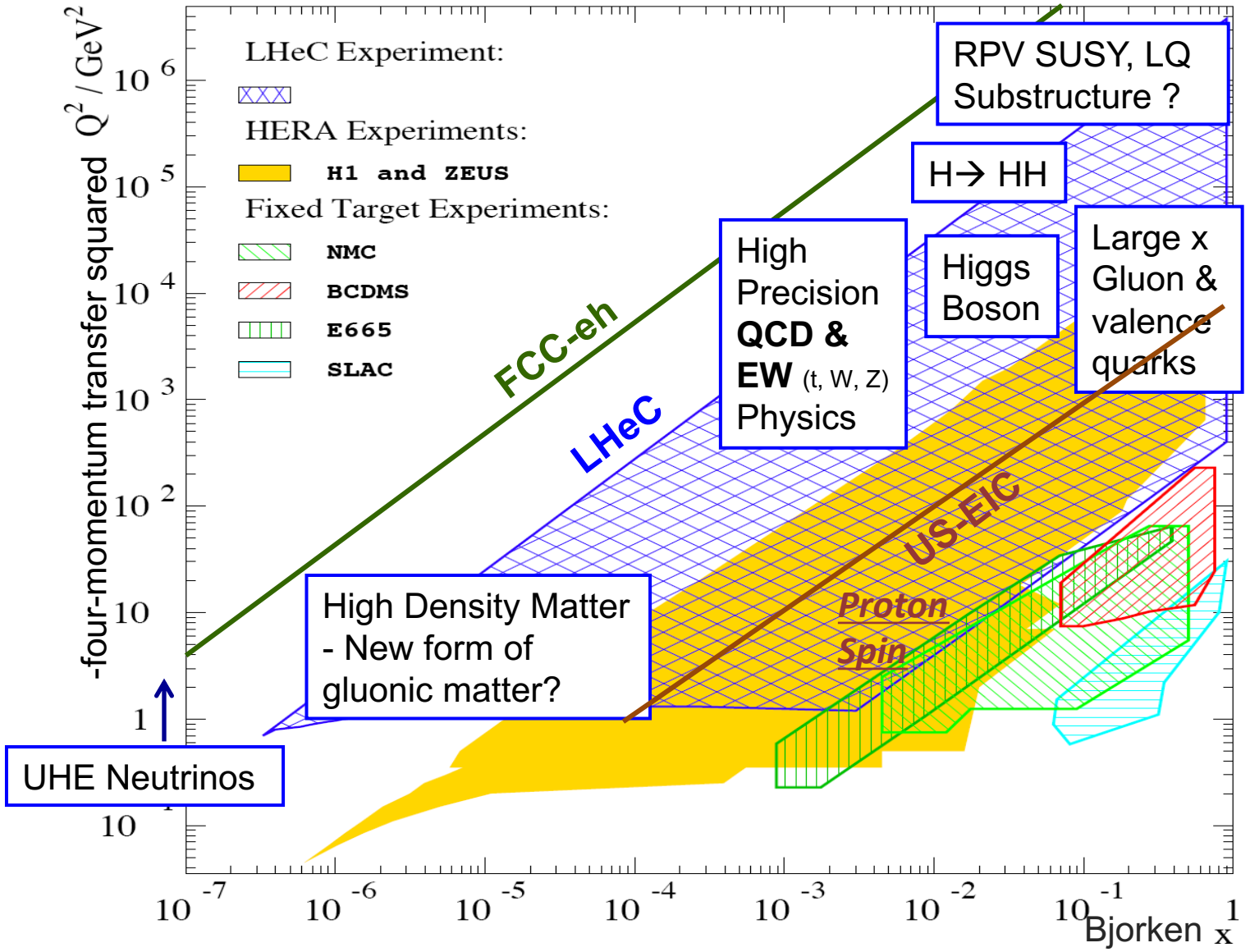
on behalf of

the LHeC/FCC-eh Study Group

Granada Preparation Meeting, April 15th, 2019

The ep Physics at the Energy Frontier

and unfold hadron sub-structure for LHC and FCC-hh unambiguously



New ep colliders beyond HERA

Extensions of both x and Q^2 ranges are crucial for pp experiments and HEP theory developments;

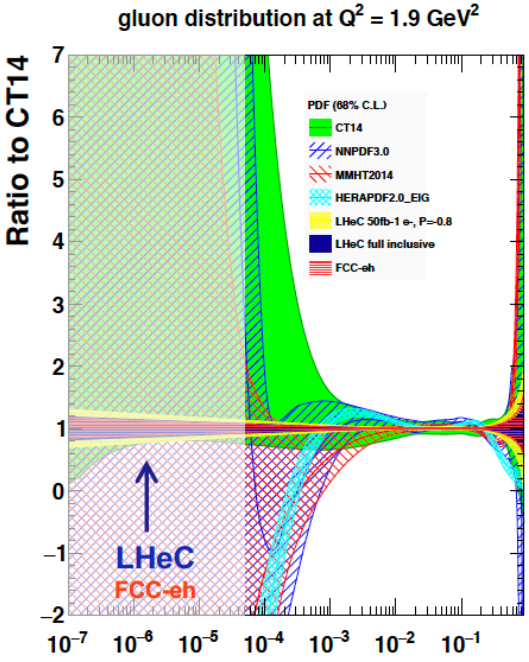
HERA established the validity of pQCD down to $x > 10^{-4}$ (DGLAP) due to a very high lever arm in Q^2:

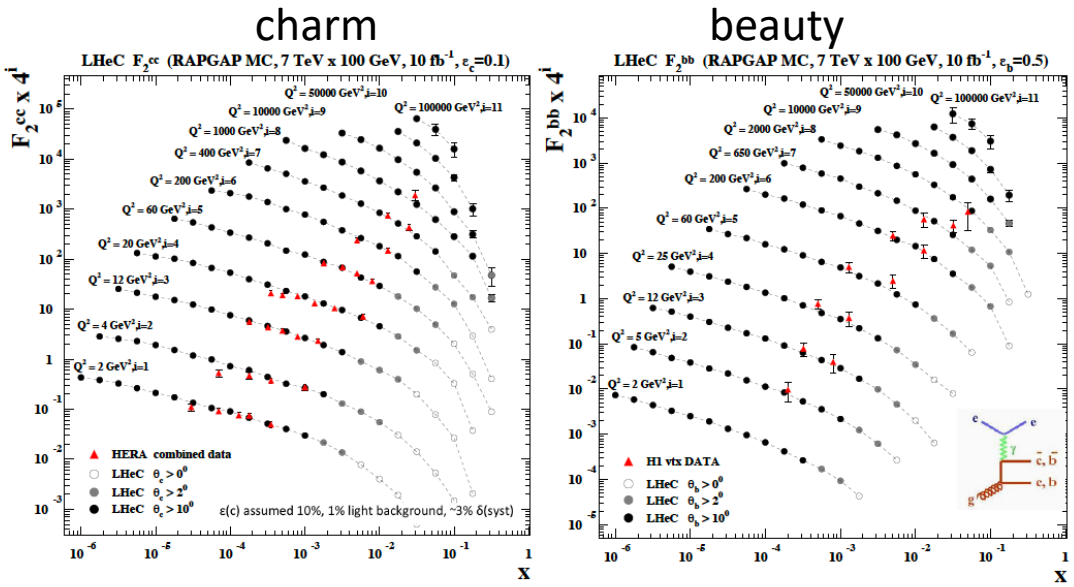
→ high luminosity colliders with high c.m.s. energy of 1.3 – 3.5 TeV

Five themes for discussion - 1

1) "DGLAP" proton (sub) structure

- Significant extension of HERA2.0 + jets : 1-year of LHeC means 10 times luminosity of 15-years-HERA
- N^{3}LO DIS theory framework
- New world of heavy quark PDFs; s, c, b, t → clarification of HFL schemes
- High precision strong coupling measurement to per mille





LHeC: enormously extended range and much improved precision c.f. HERA

- **δMc = 50 (HERA) to 3 MeV**: impacts on αs, regulates ratio of charm to light, crucial for precision t, H
- **δMb to 10 MeV**; MSSM: Higgs produced dominantly via $b\bar{b} \rightarrow A$

FCC-eh LHeC

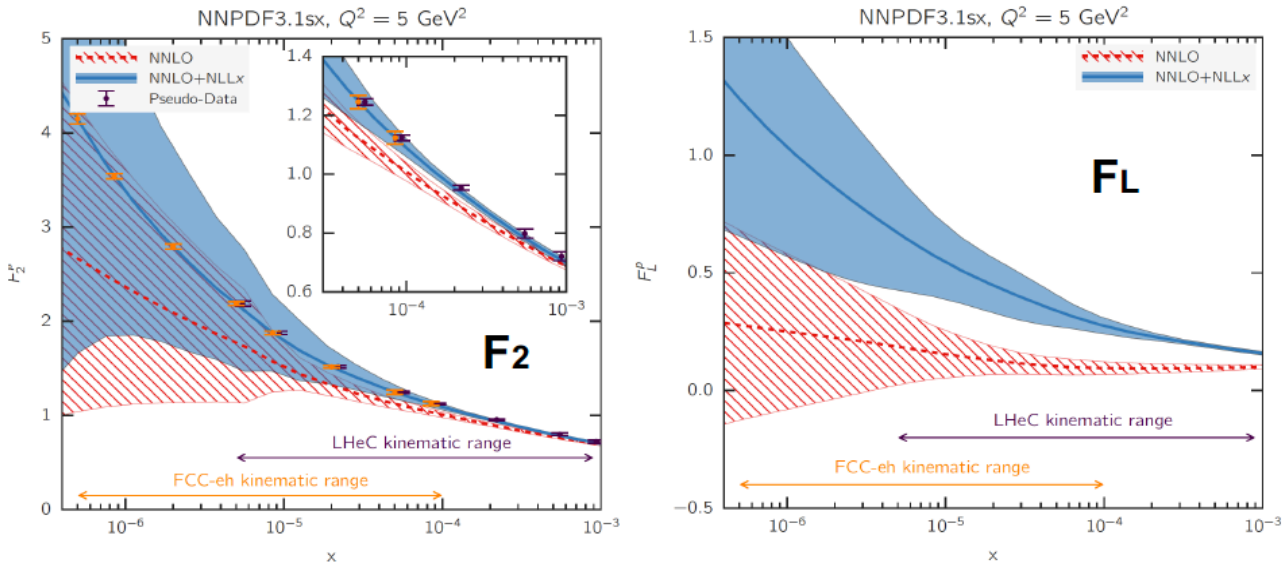
Five themes for discussion - 2

2) Parton dynamics

- Low x resummation, BFKL, gluon saturation unveiled via precision structure function measurements of F_2 and F_L
- Test of momentum sum rule via precision high and low x data

gluon at small x

arXiv:1710.0593



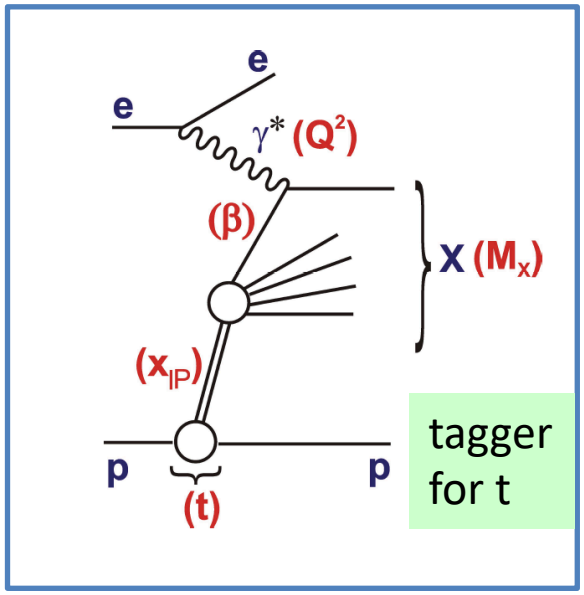
F2 and FL predictions for simulated kinematics of LHeC and FCC-eh

Plot from C Gwenlan, DIS2019

Five themes for discussion - 3

3) Beyond the collinear parton model: opening a new QCD lab

- Diffractive PDFs
- Generalized PDFs, unintegrated PDFs → 3D proton structure

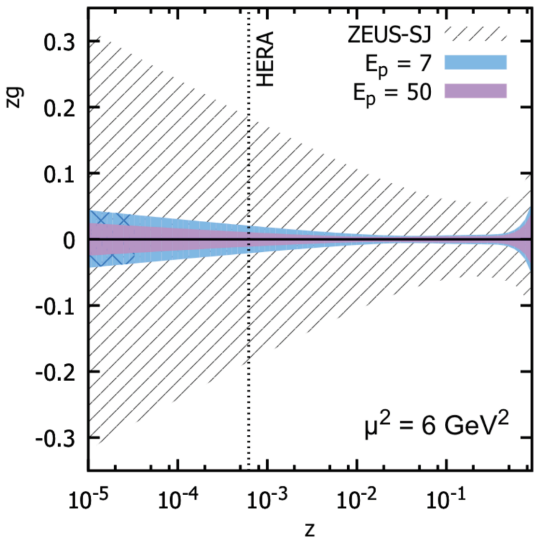


- Low x_{IP} → cleanly separate diffraction
- Low β → Novel low x effects
- High Q^2 → Lever-arm for gluon,flavour decompositi
- Large M_x → Jets, heavy flavours, W/Z …
- Large E_T → Precision QCD with jets …

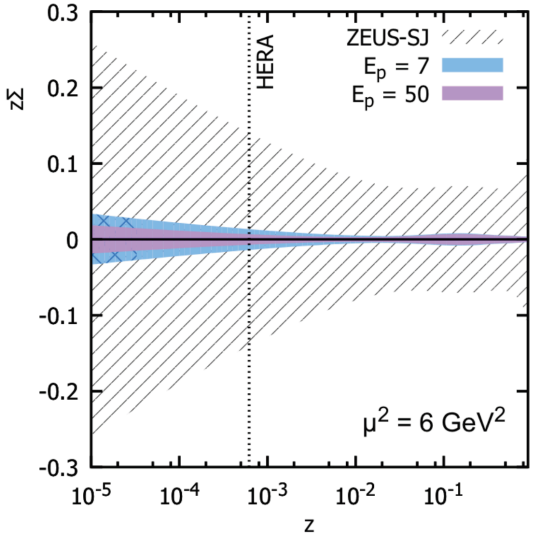
Diffractive PDFs

Study by W Slominski & arXiv:1901.09076

Gluons



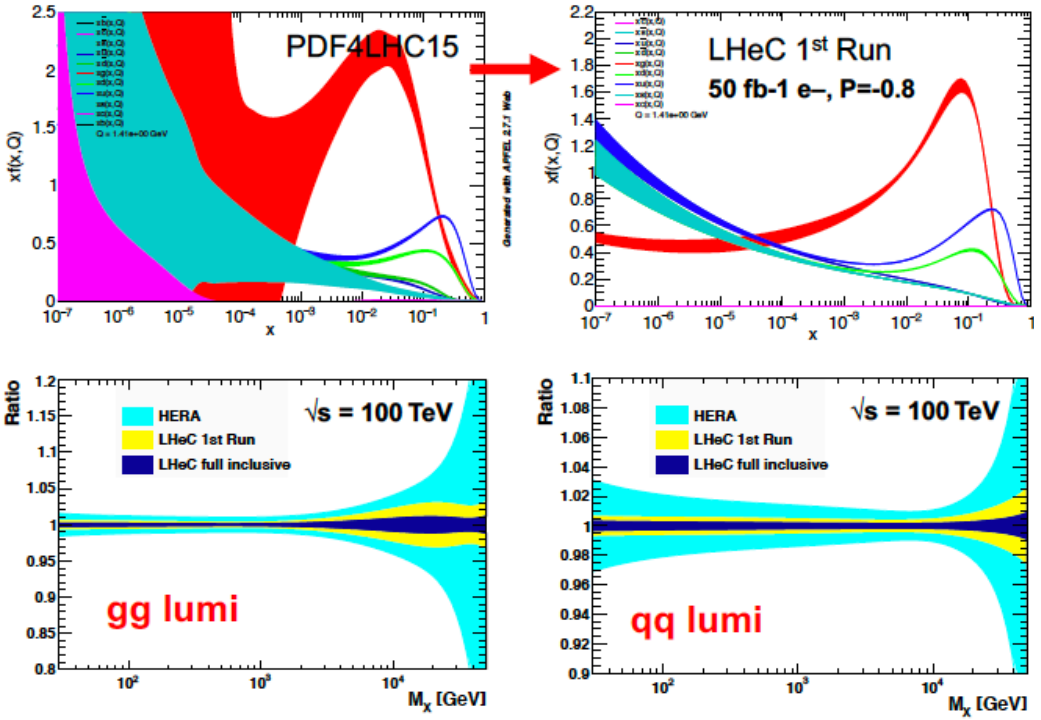
Quarks



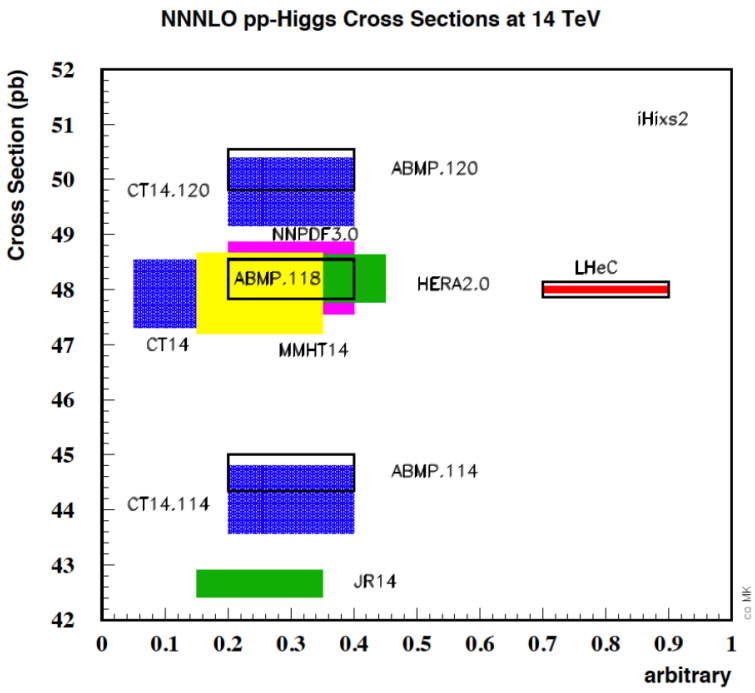
Five themes for discussion - 4

4) High precision QCD and synergies

- N3LO PDFs and precision α_s for σ_{Higgs} in pp (and for AA)
- Precision PDFs & α_s for pp discoveries, e.g. W', Z', SUSY, EFT interpretations
- Test of factorization in pp and AA
- Crucial external input for HL-LHC, HE-LHC, FCC-hh, e.g. precision Z predictions for pp luminometer, precision M_W and $\sin^2\theta$ pp+ep measurement



Plot from C Gwenlan, DIS2019

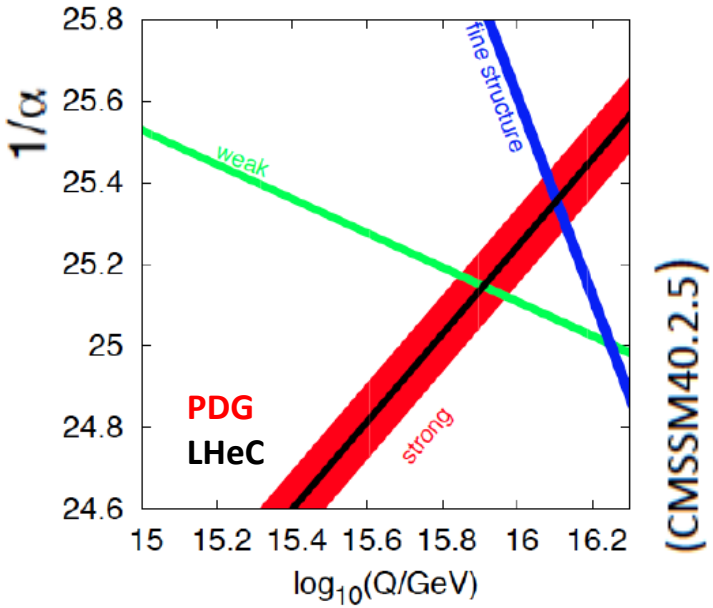


Plot from M Klein, DIS2019

Five themes for discussion - 5

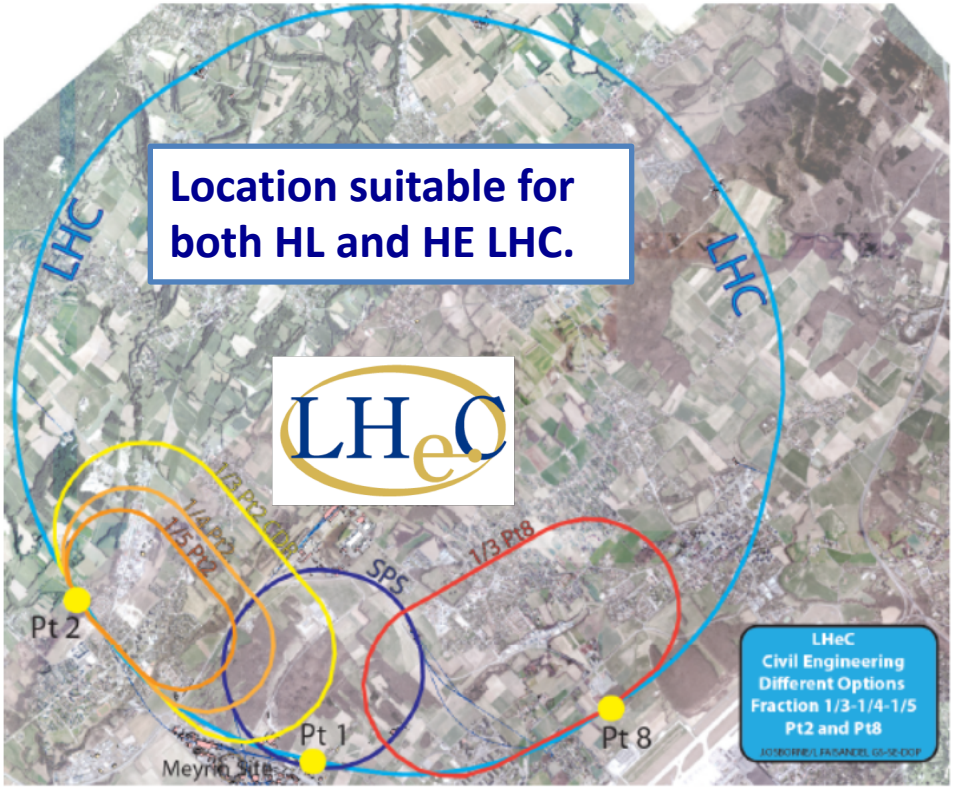
5) Surprises and QCD discoveries

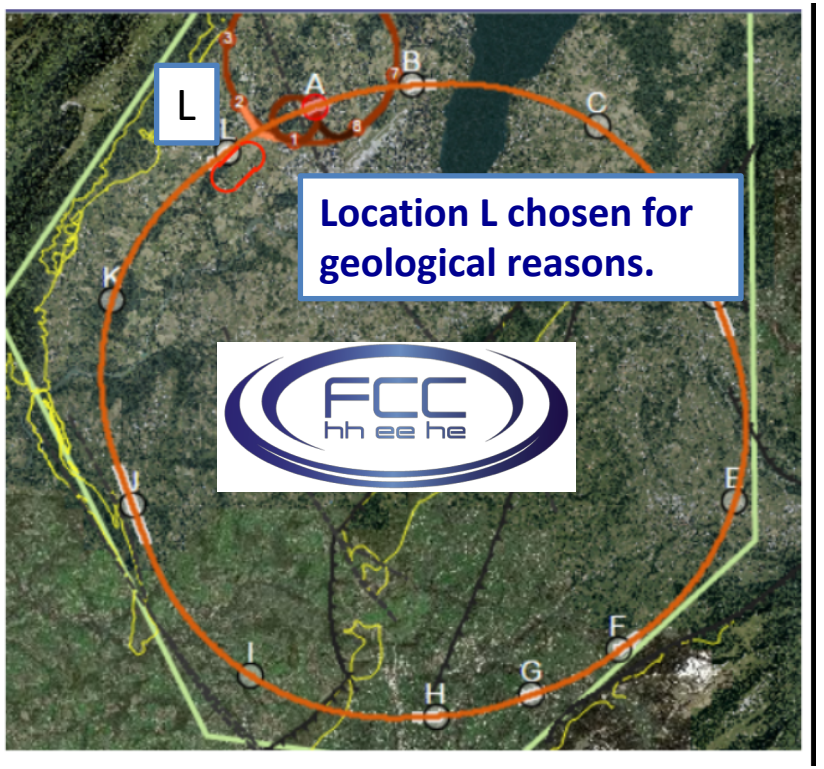
- Leptoquarks may be discovered in pp → needs ep for spectroscopy
- α_s may be LOW and not in agreement with lattice calculations → GUT?
- … SM has 61 elementary particles… Quarks may have a sub-structure → test via contact interactions to 100 TeV at FCC-eh
- Free broken charge particles? Free colour? The gluon may NOT saturate [decisive test only with F_2 and F_L possible]



ep: Opportunities and Challenges

ERL-electron beam external to pp rings.





- C(ERL) = 1/n C(LHC): 60 GeV: 1/3 (9km)
→BSM, top, Higgs, Low x all want maximum E_e

C(ERL) = 1/11 C(FCC)
→ New physics may require E_e>60 GeV

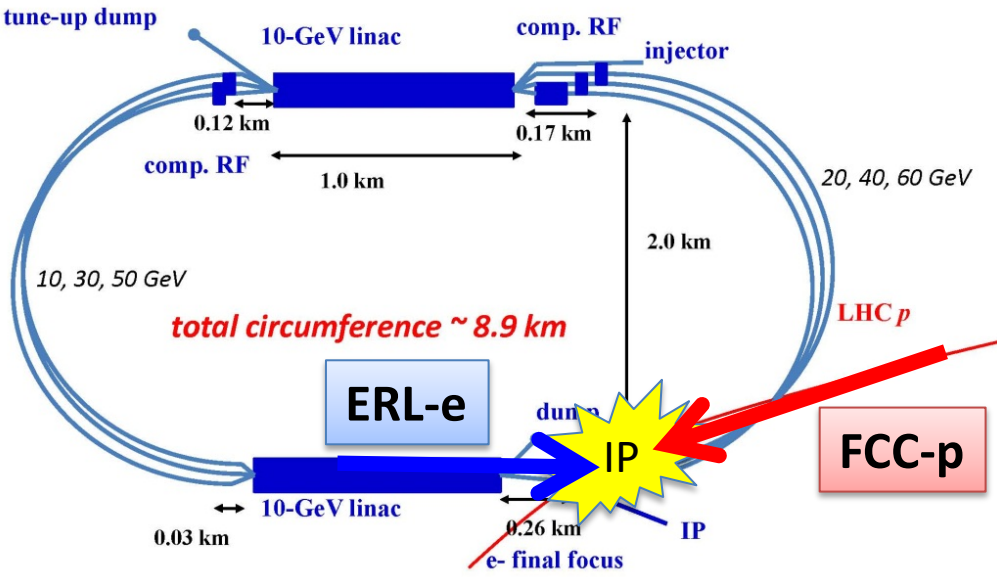
Nominal 60 GeV ERL: O(1) BCHF ; 1000 cavities; 3504 dipoles; 1440 quads

Energy – Cost – Physics – Footprint scenarios being worked out further

electrons for hh : ERL + FCC

- **Two 802 MHz Electron LINACs + 2x3 return arcs: using energy recovery in same structure: *sustainable* technology with power consumption < 100 MW** *instead of 1 GW for a conventional LINAC.*
- **Beam dump: no radioactive waste!**
- **high electron polarisation of 80-90%**

→ see talk by O. Bruening, 4.3.19



Concurrent eh and FCC-hh operation!
Same *Twin Collider* idea holds for HE-LHC and HL-LHC

$\sqrt{s}$=3.5 TeV
E_e = 60 GeV
E_p = 50 TeV
Site: L

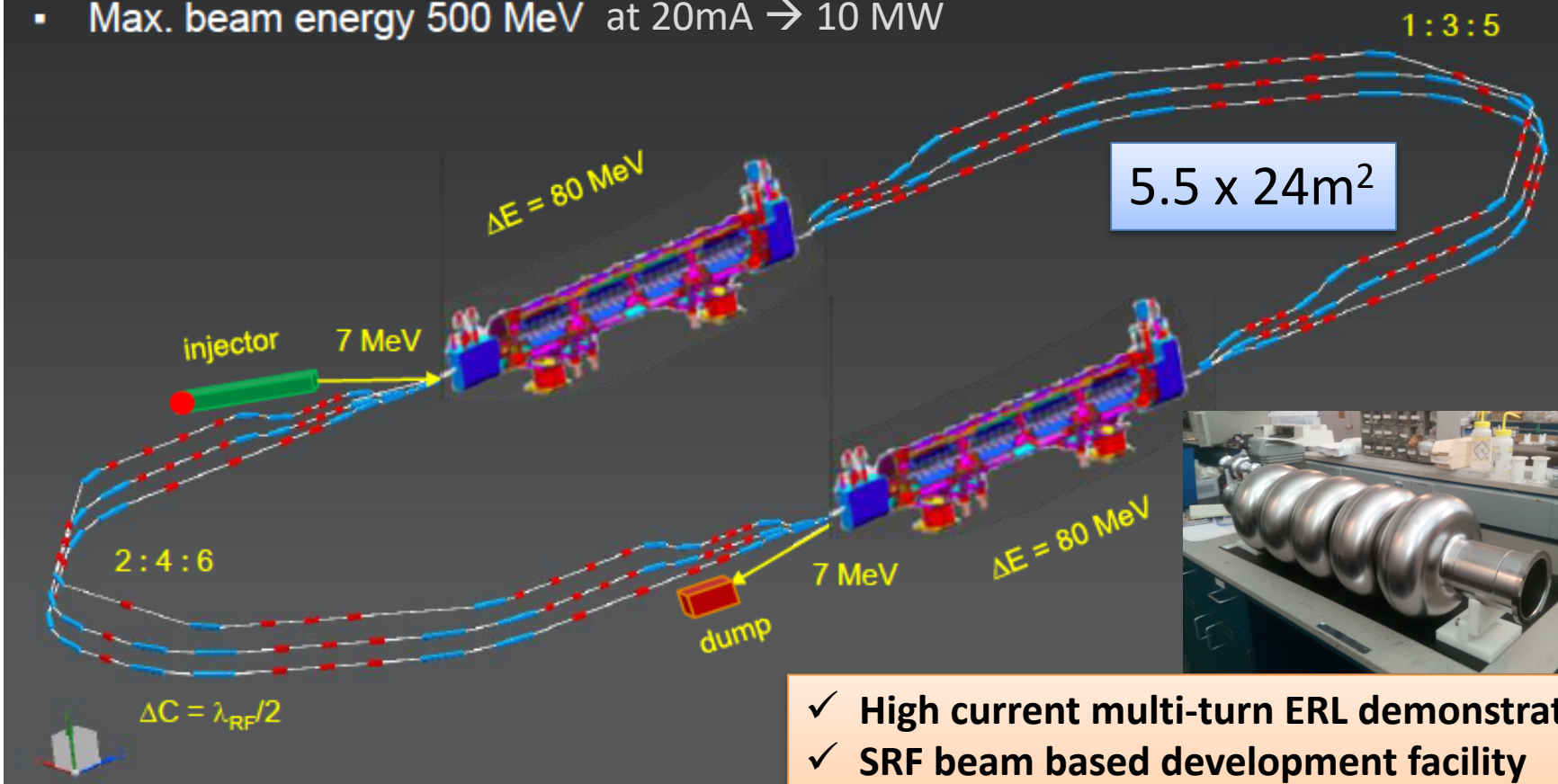
- ep peak lumi 10^{34} cm s^{-2} s^{-1} (based on existing HL-LHC design)
- **Operation scenario: F. Bodry et al.** CERN-ACC-2018-0037 [arXiv:1810.13022]
- **L= 2000 fb^{-1} total collected in 20 years**

ERL design detailed in **LHeC CDR: arXiv:1206.2913** and updates at LHeC/FCC-eh WS@CERN, 9/17 and Orsay, 6/18.

For ERL: PERLE @ Orsay

CERN, JLAB, Daresbury, Liverpool, Novosibirsk, LAL and IPN, +

- 2 Linacs (Four 5-Cell 801.58 MHz SC cavities)
- 3 turns (160 MeV/turn)
- Max. beam energy 500 MeV at 20mA → 10 MW



- ✓ **High current multi-turn ERL demonstrator**
- ✓ **SRF beam based development facility**
- ✓ **Low E electron and photon beam physics**
- ✓ **High intensity: O(100) x ELI**

cf Walid Kaabi, FCC Week 2018; Orsay WS 2018

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