Energy-frontier lepton-hadron collisions at CERN: the LHeC and the FCC-eh

Masahiro Kuze
Tokyo Institute of Technology

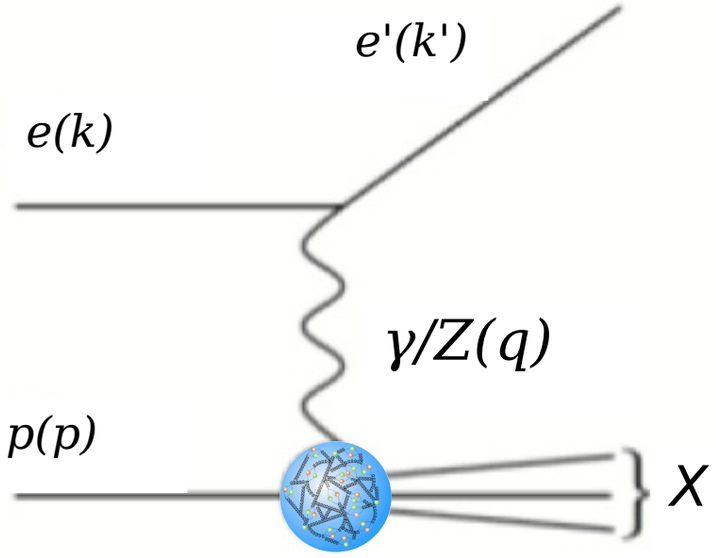
PANIC 2017
Beijing, 1 Sep. 2017

130th Anniversary in 2011

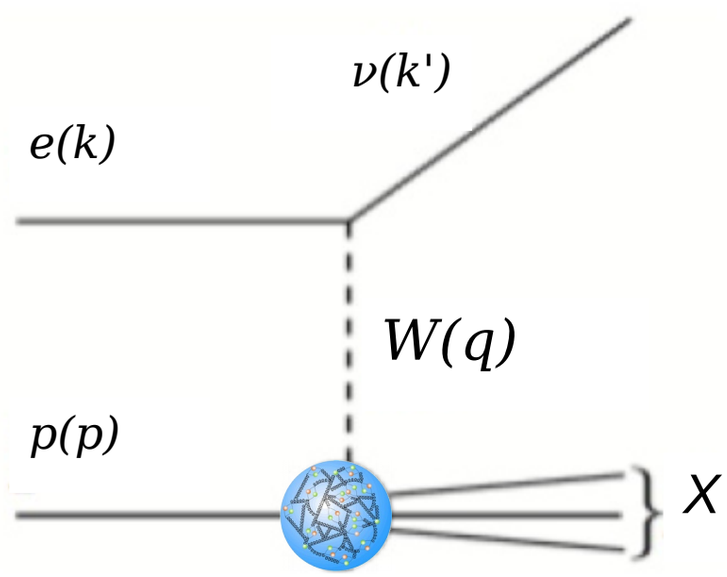
ep collisions: DIS

- Traditional and best way to probe the inner structure of nucleons and nuclei
- At high energy, electroweak bosons (Z/W) play roles in addition to γ

Neutral current scattering
$ep \rightarrow e'X$



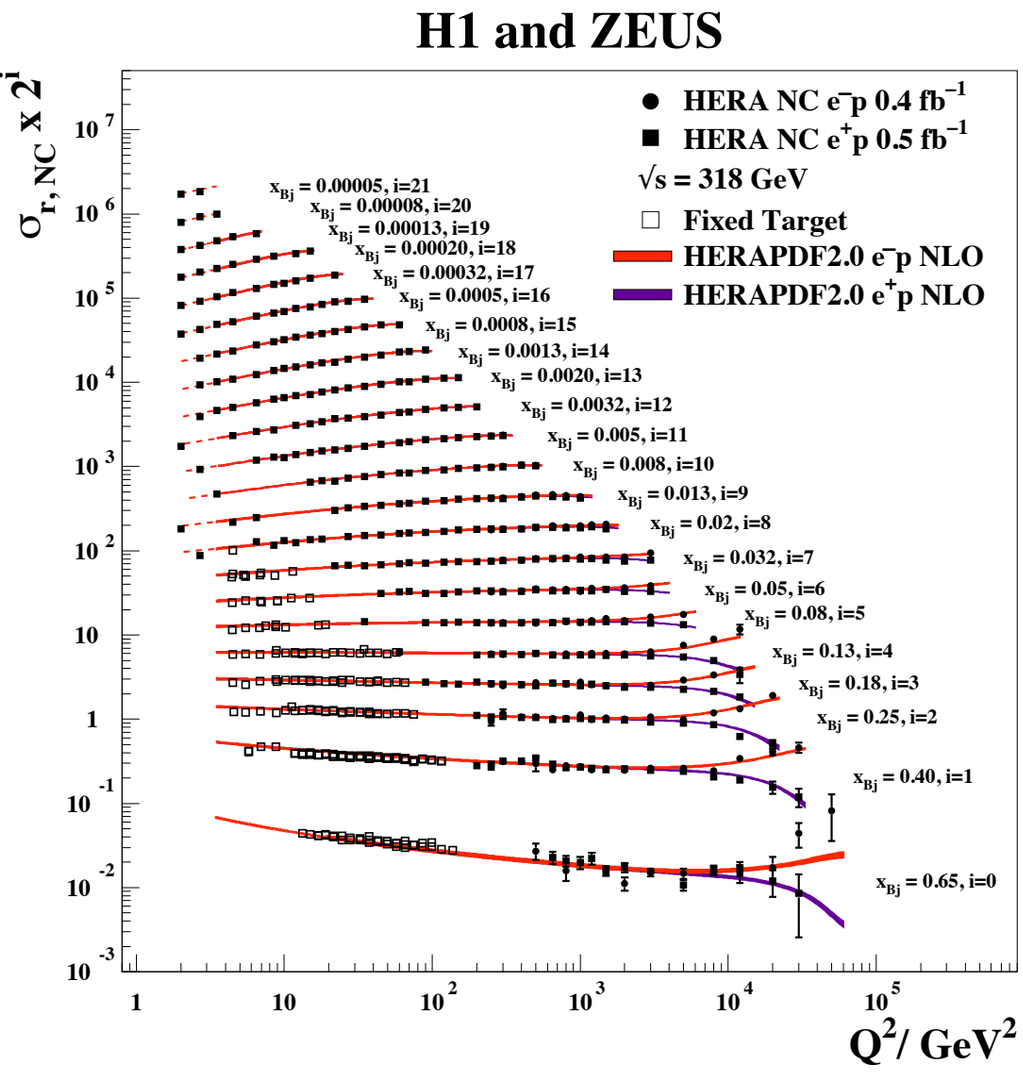
Charged current scattering
$ep \rightarrow \nu_e X$

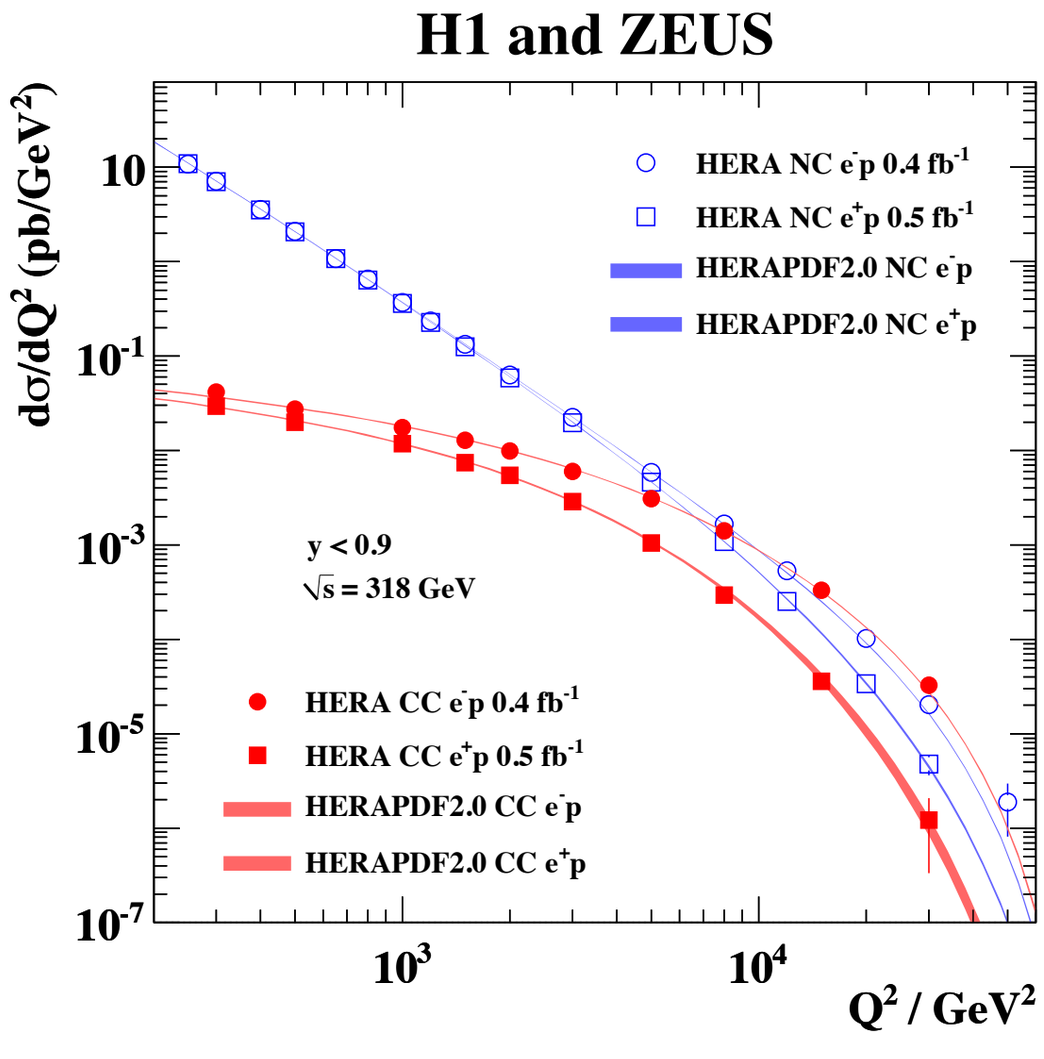


$Q^2 = -q^2 = -(k-k')^2$	Momentum transfer
$x = Q^2/2pq$	Bjorken x

HERA: the last ep collider

- E_e =27.6 GeV, E_p =920 GeV, $\sqrt{s}$ =318 GeV
- Most precise measurement of PDF (parton distribution functions) up to $Q^2 \sim 10^4$ GeV^2, down to $x \sim 10^{-5}$
- Indispensable inputs to energy-frontier hadron collider (LHC)



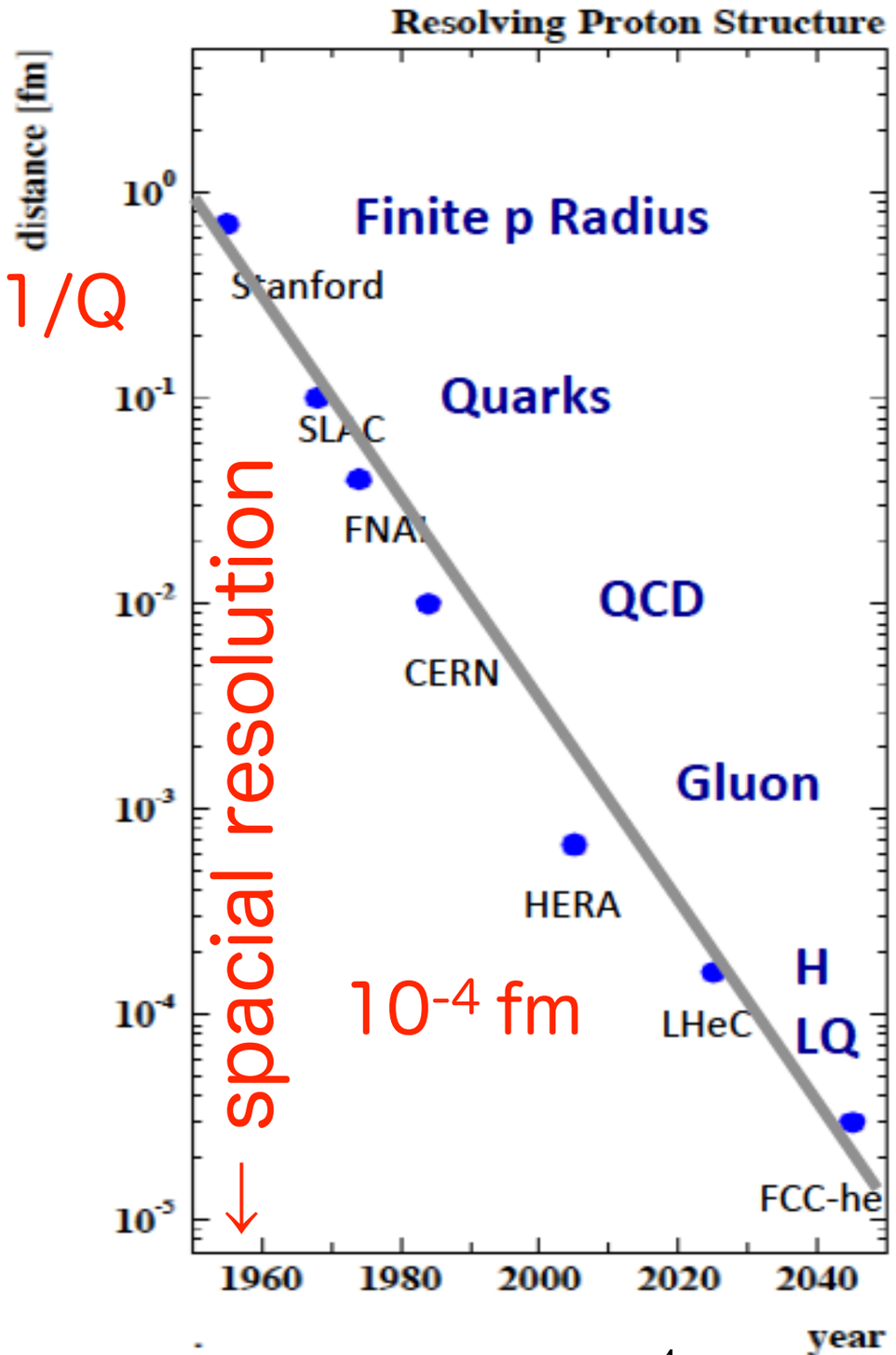


Future of DIS - ep(eA) collider

- Use a p(A) beam of the hadron collider, collide with a new (polarized) e-beam
- LHeC: 60 GeV e × 7 TeV p
  → $\sqrt{s}$ = 1.3 TeV
- FCC-eh: 60 GeV × 50 TeV p
  → $\sqrt{s}$ = 3.5 TeV

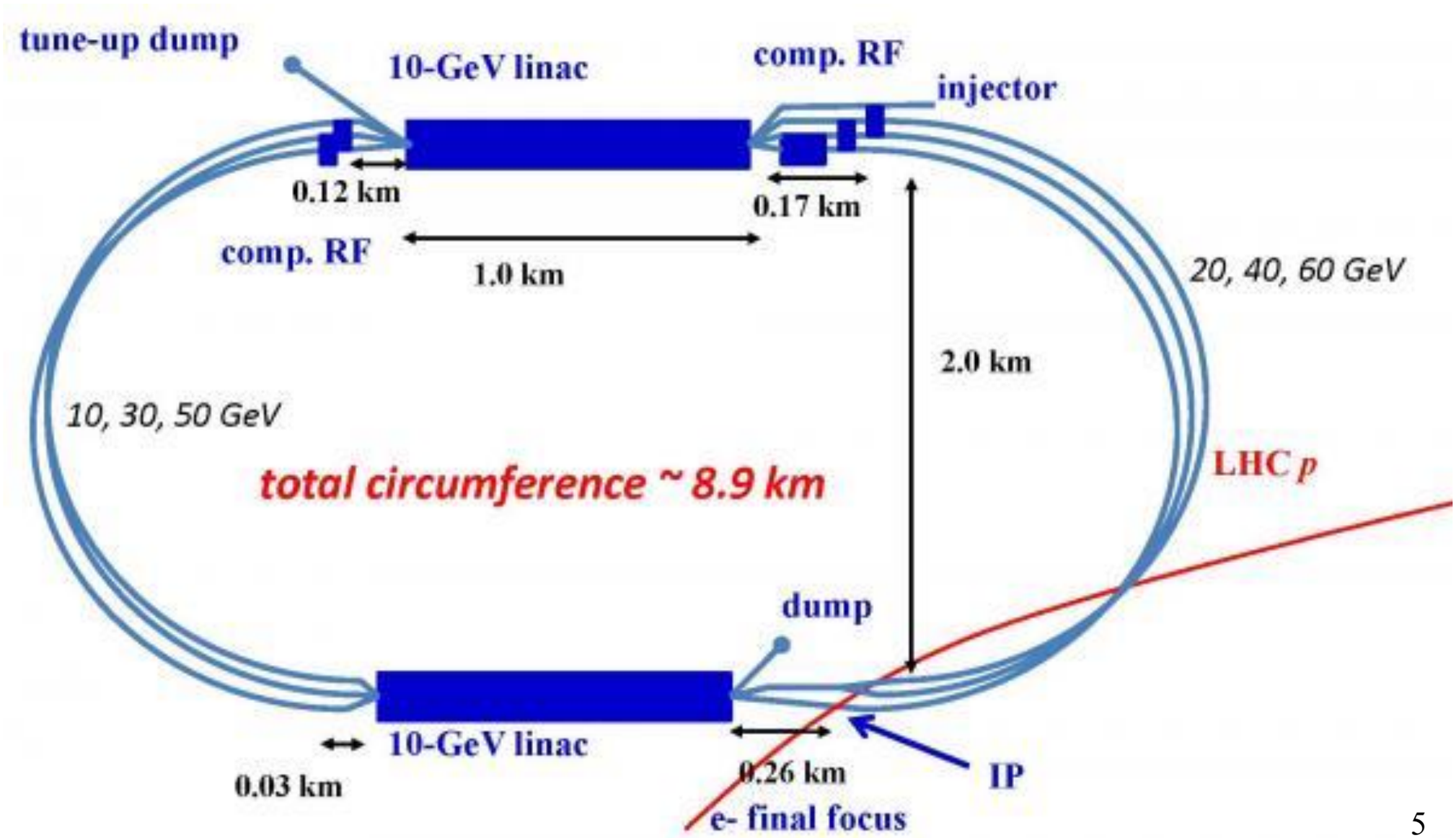
- No major additional investment in hadron beam facility: affordable cost!
- Can run concurrently with h-h collider
- Higher CMS energy than e^+e^-
- Much cleaner environment than h-h (Negligible pile-up)

M. Klein



New e-beam by ERL

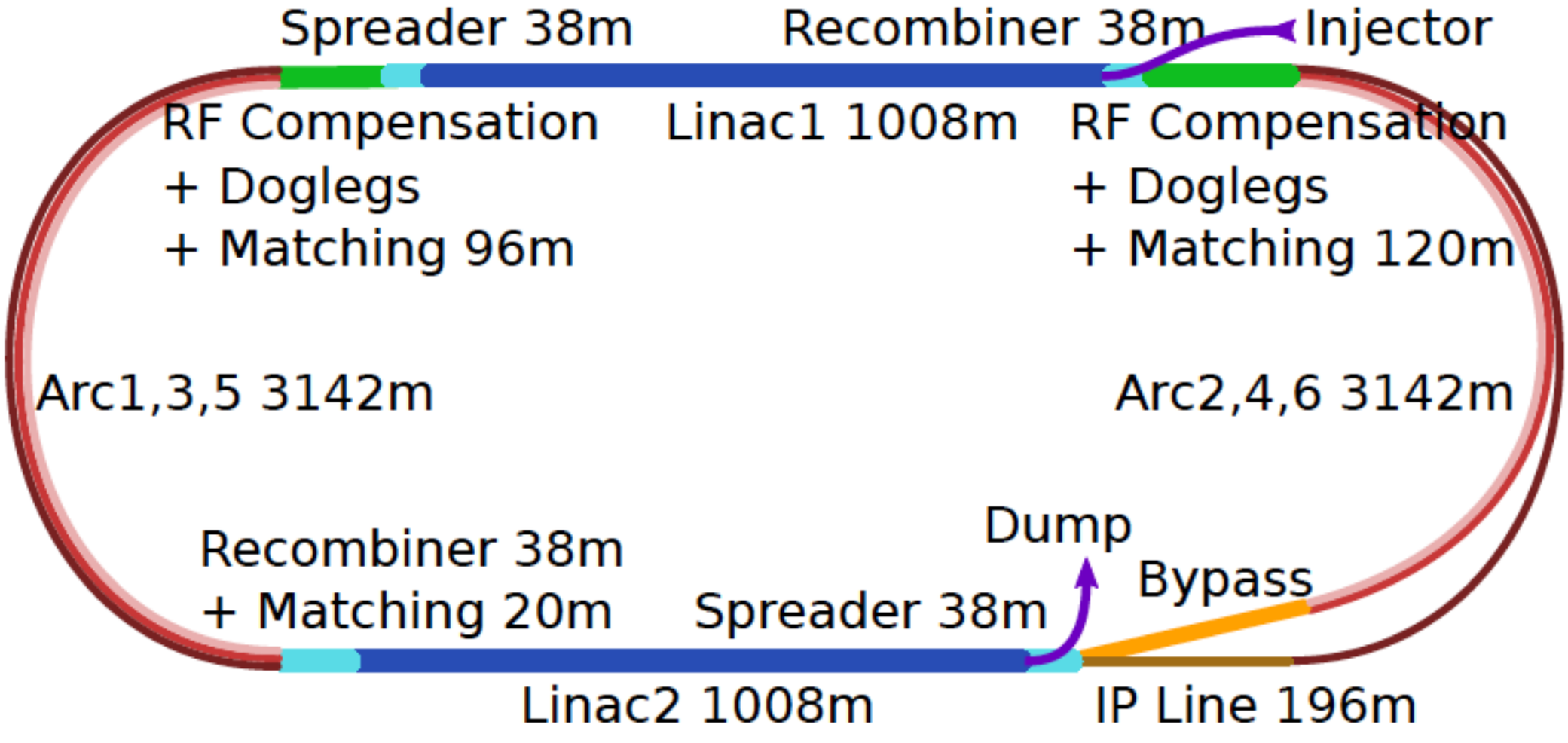
- Energy Recovery LINAC (3 turns of 2×10 GeV)
- Decelerate unconsumed beam, whose power is recycled (accel. and decel. beams in opposite RF phase)



ERL design

- 802Hz, 5-cell s.c. cavity, 18 MV/m
- Aiming at L~10^{34} ($100\ fb^{-1}$/year)

D. Pellegrini, DIS17

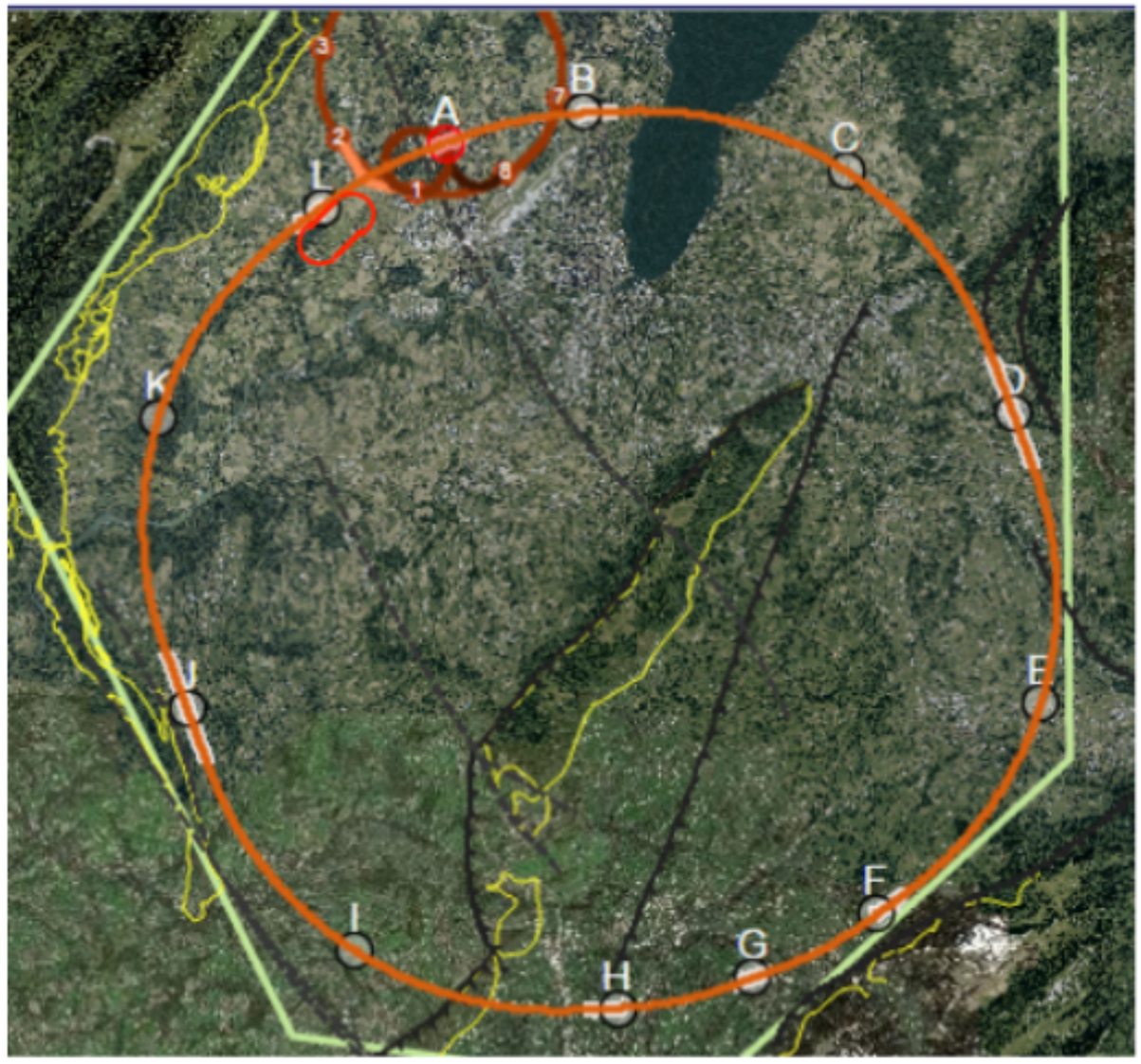


Location and footprint

M. Klein, DIS17

LHC

FCC



Energy – Cost – Physics – Footprint
are being reinvestigated

A 9km ERL is a small add-on for the FCC
Doubling the energy to 120 GeV hugely
Increases cost and effort.

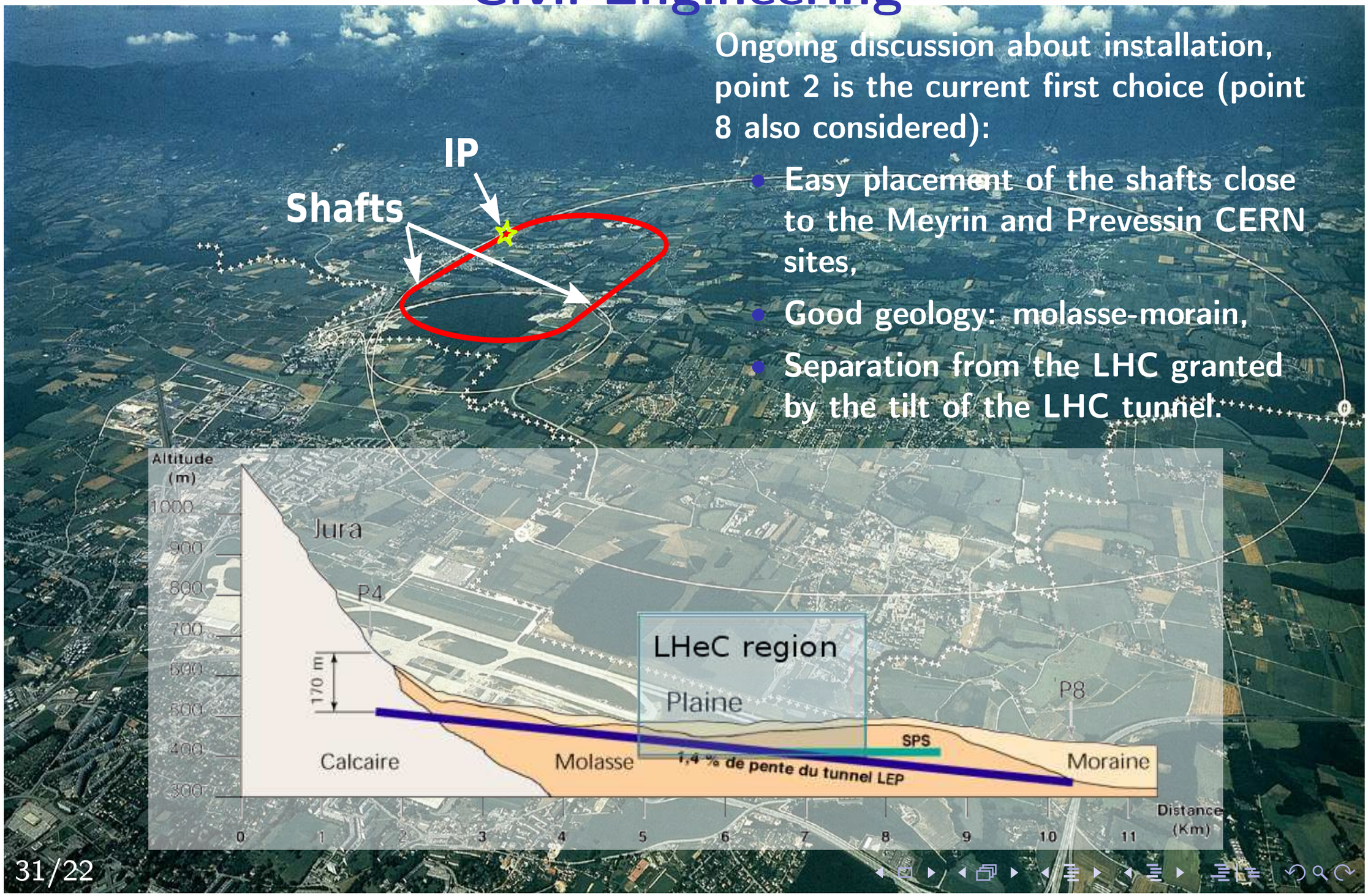
Civil Eng. consideration

Civil Engineering

D. Pellegrini, DIS17

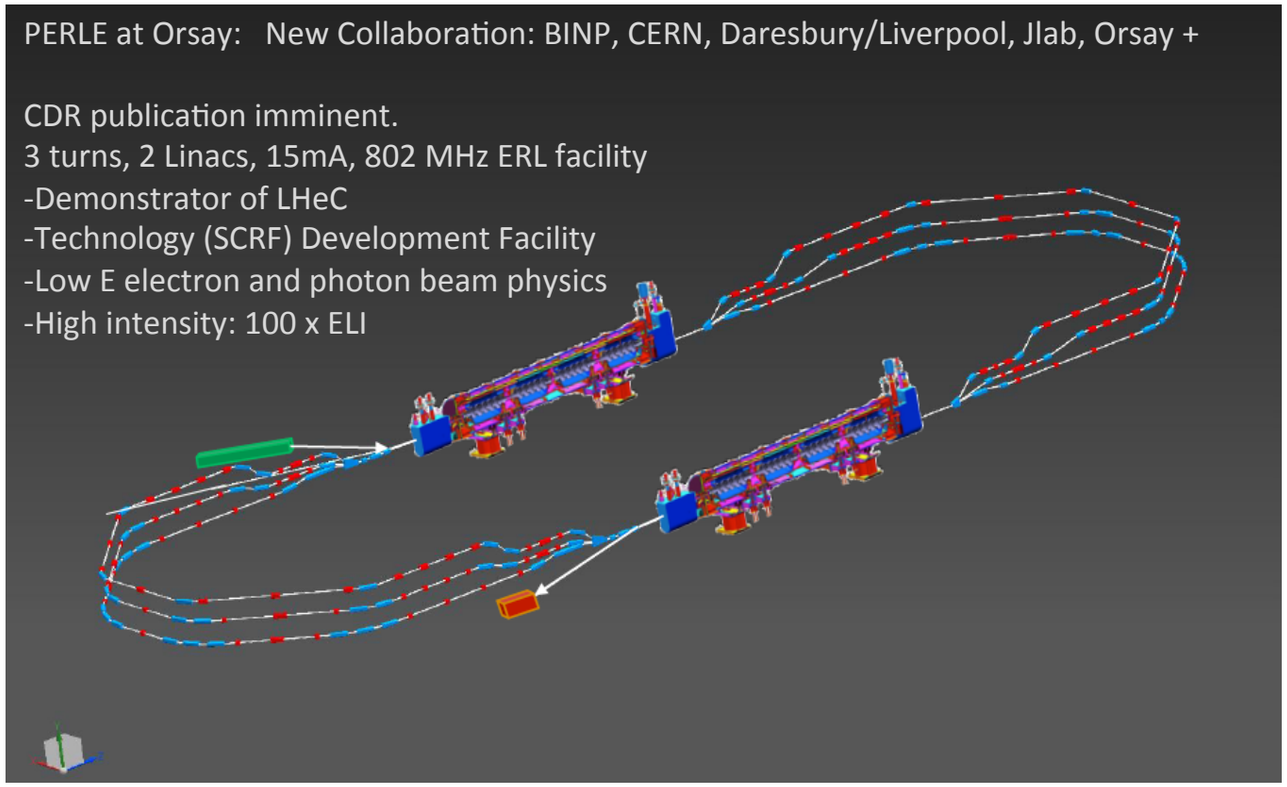
Ongoing discussion about installation, point 2 is the current first choice (point 8 also considered):

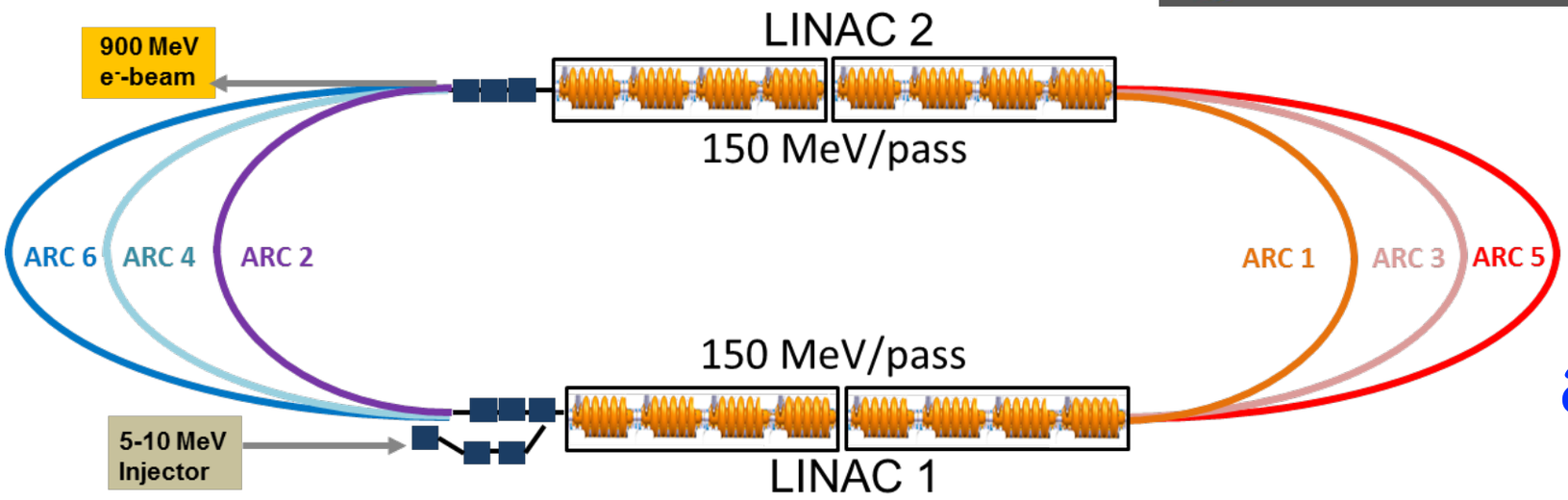
- Easy placement of the shafts close to the Meyrin and Prevessin CERN sites,
- Good geology: molasse-morain,
- Separation from the LHC granted by the tilt of the LHC tunnel.



Demonstrator: PERLE

- 8-cavity×2, 3 turns → 1 GeV e-beam, 10~20 mA
- Proposal at LAL (Orsay) with 1/2 RF (400 MeV)
- Probe ERL operation in multi-MW regime
- Can do low-energy, high-intensity ep/eA (γp/γA) beam physics

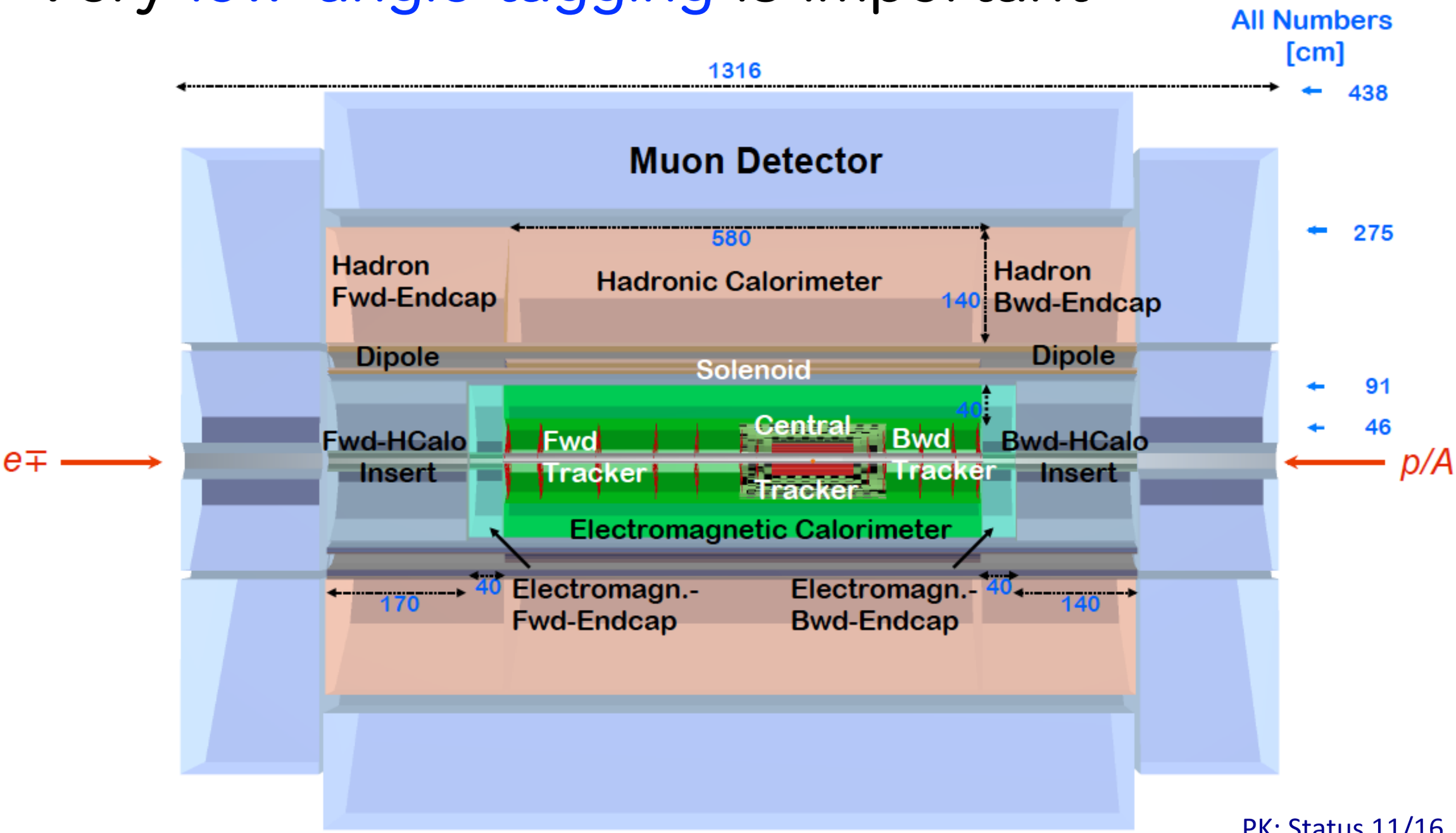




arXiv:1705.08783

Detector design

- Asymmetric energy → asymmetric detector
- Very low-angle tagging is important

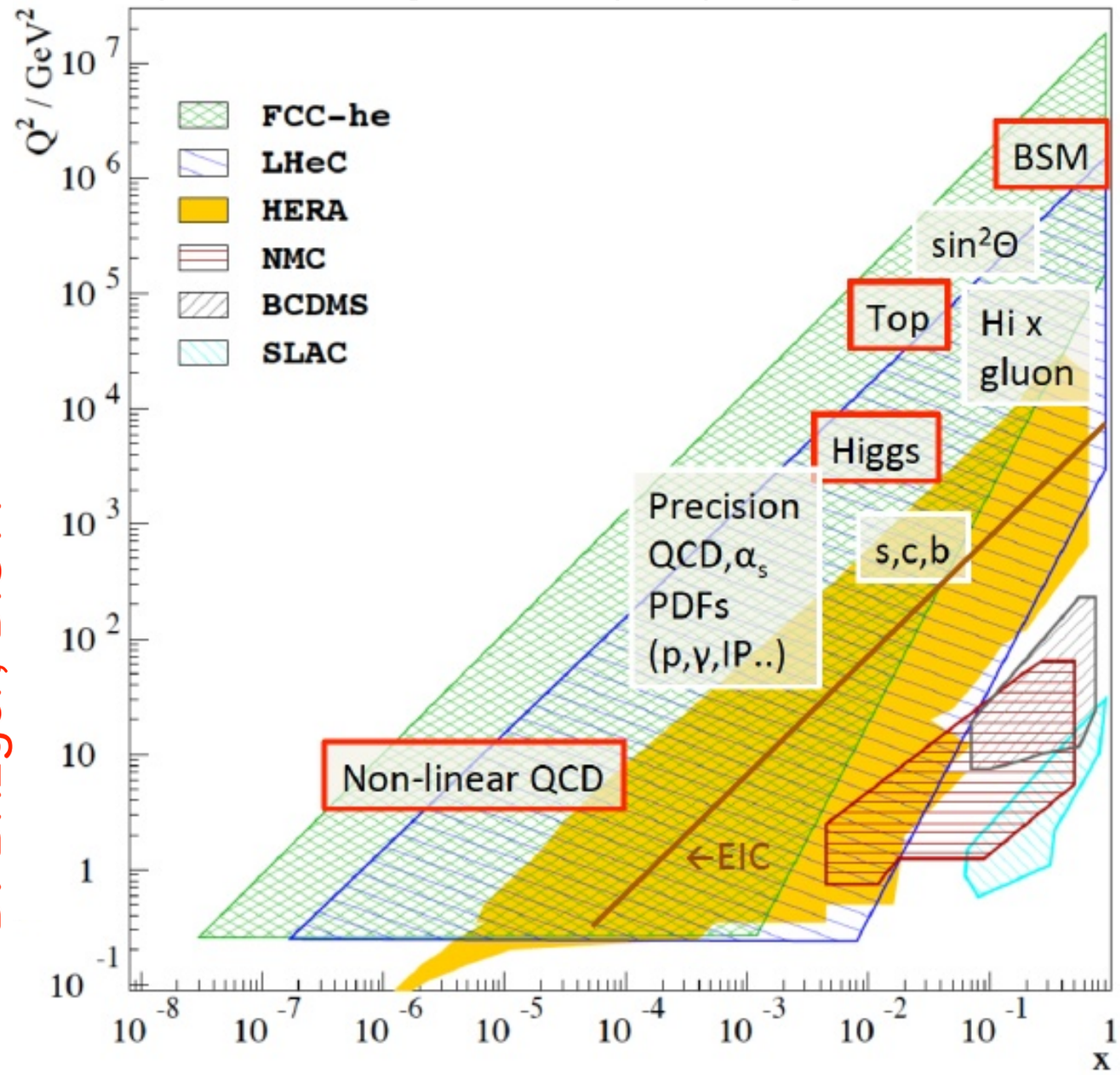


PK: Status 11/16

Physics at the LHeC/FCC-he

- Any interesting physics in energy-frontier ep(A)?
- Yes!

e.g.: P. Newman [NPPS 191 (2009) 307]

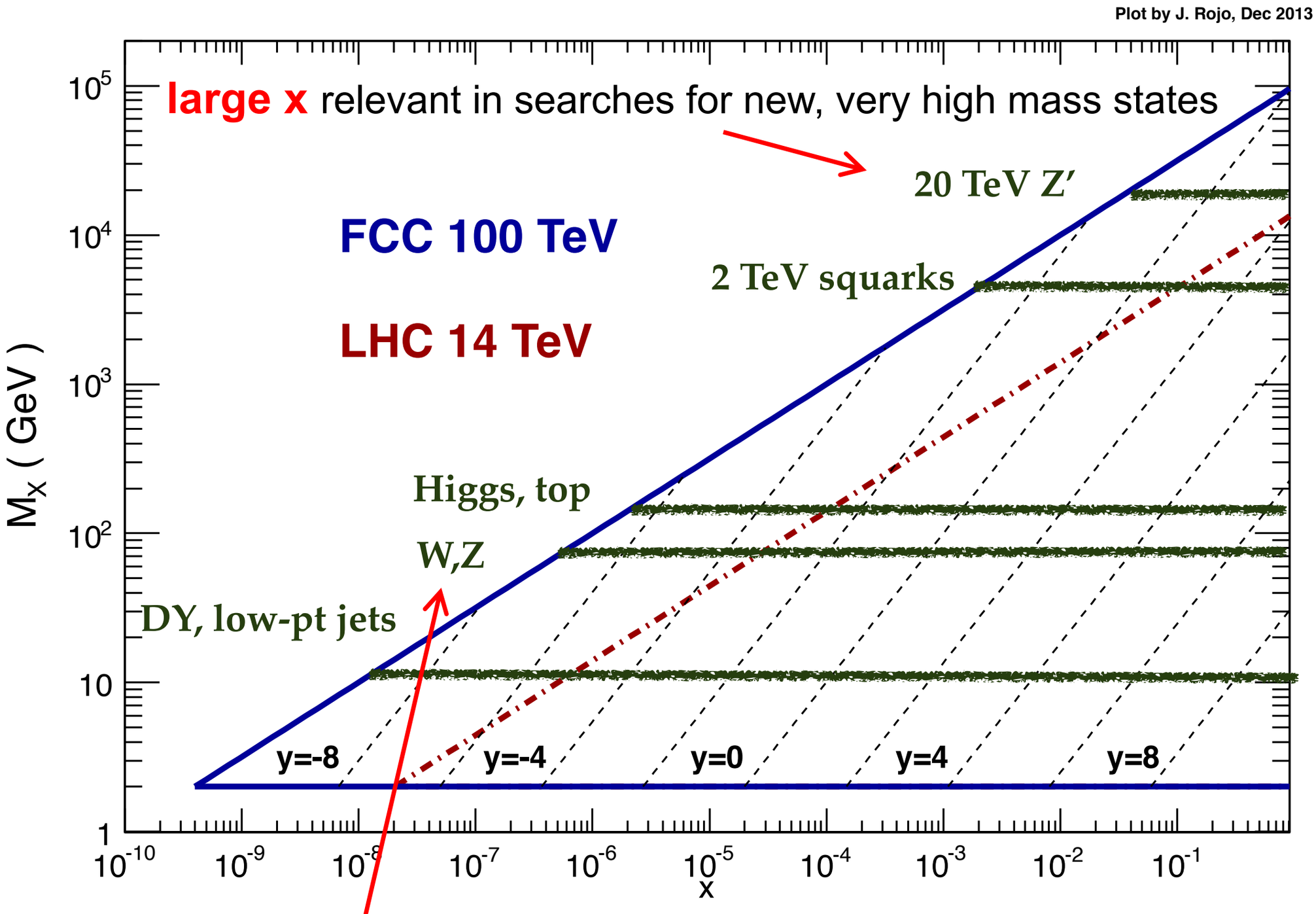


D. Brizger, DIS17

- Ultimate precision in PDF and α_s meas.
- Higgs/top factory
- EW physics
- BSM searches
- low-x/diffraction
- eA (nuclear PDF)

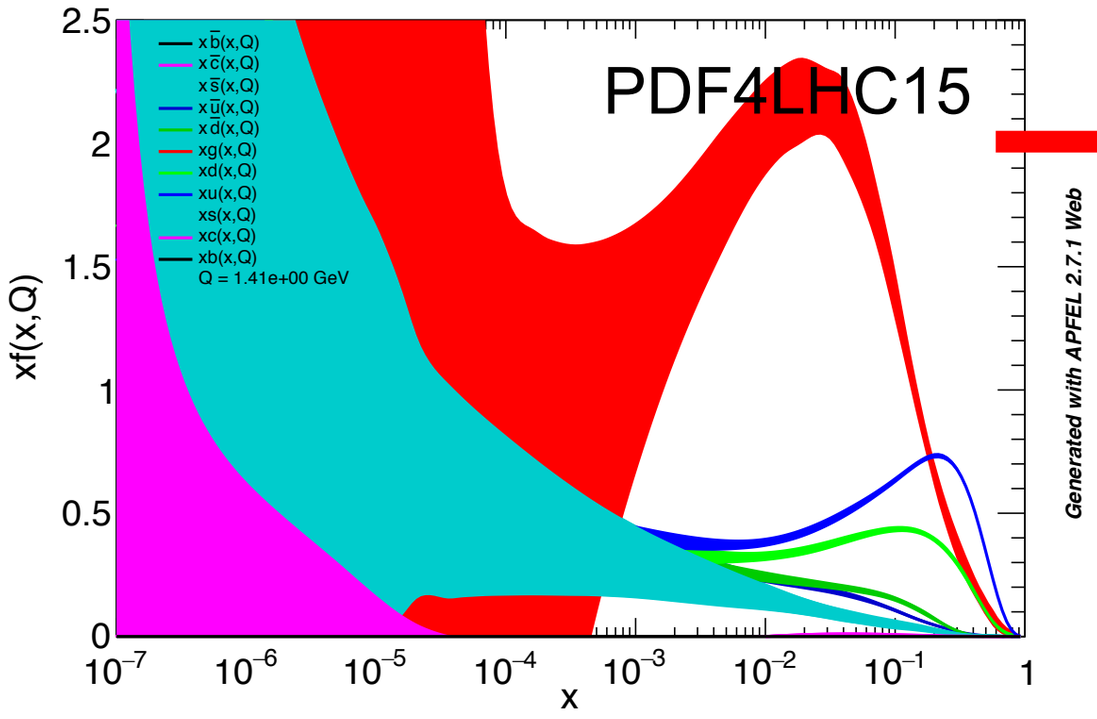
Physics example: PDF

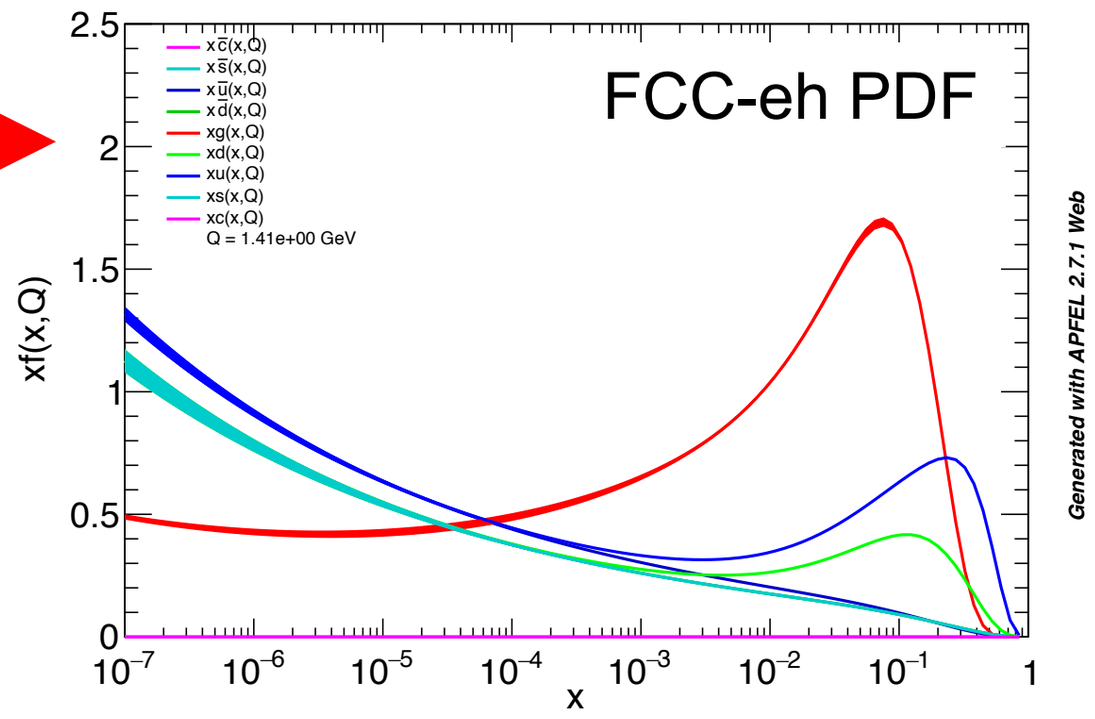
C. Gwenlan, DIS17



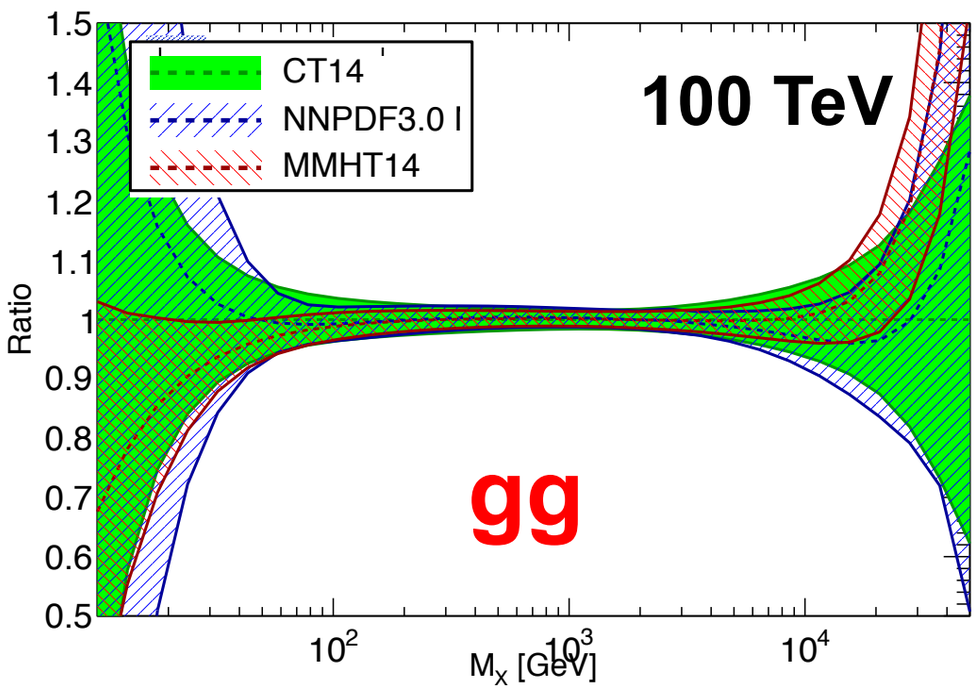
small x becomes relevant even for “common” physics (EG. W, Z, H, t)

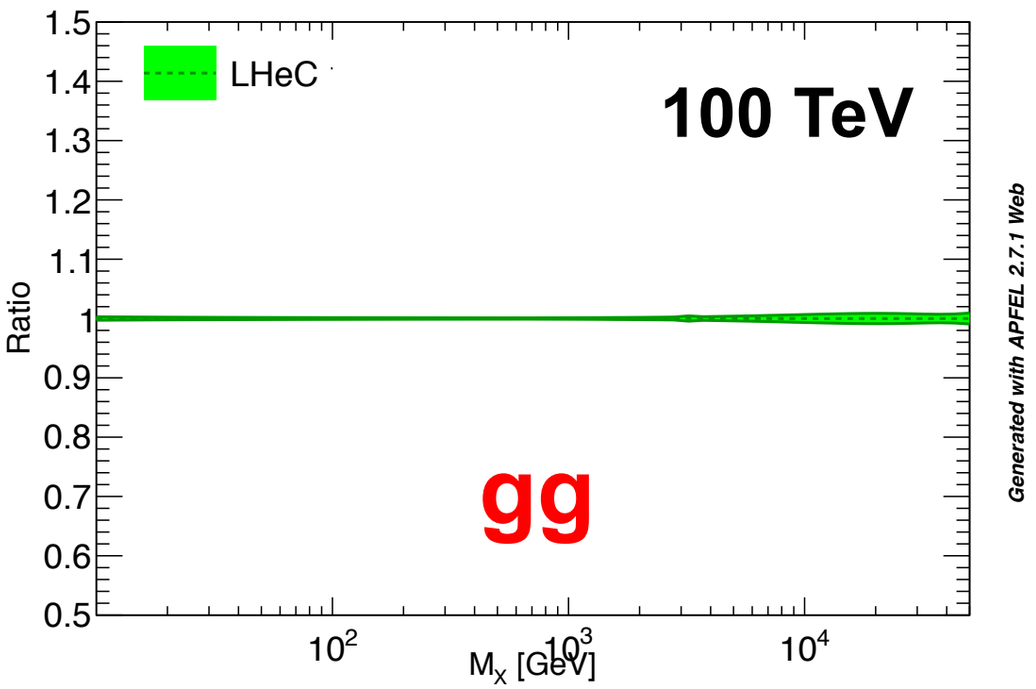
PDF for E-frontier physics





today FCC parton luminosities **… then,** if we have **LHeC:**

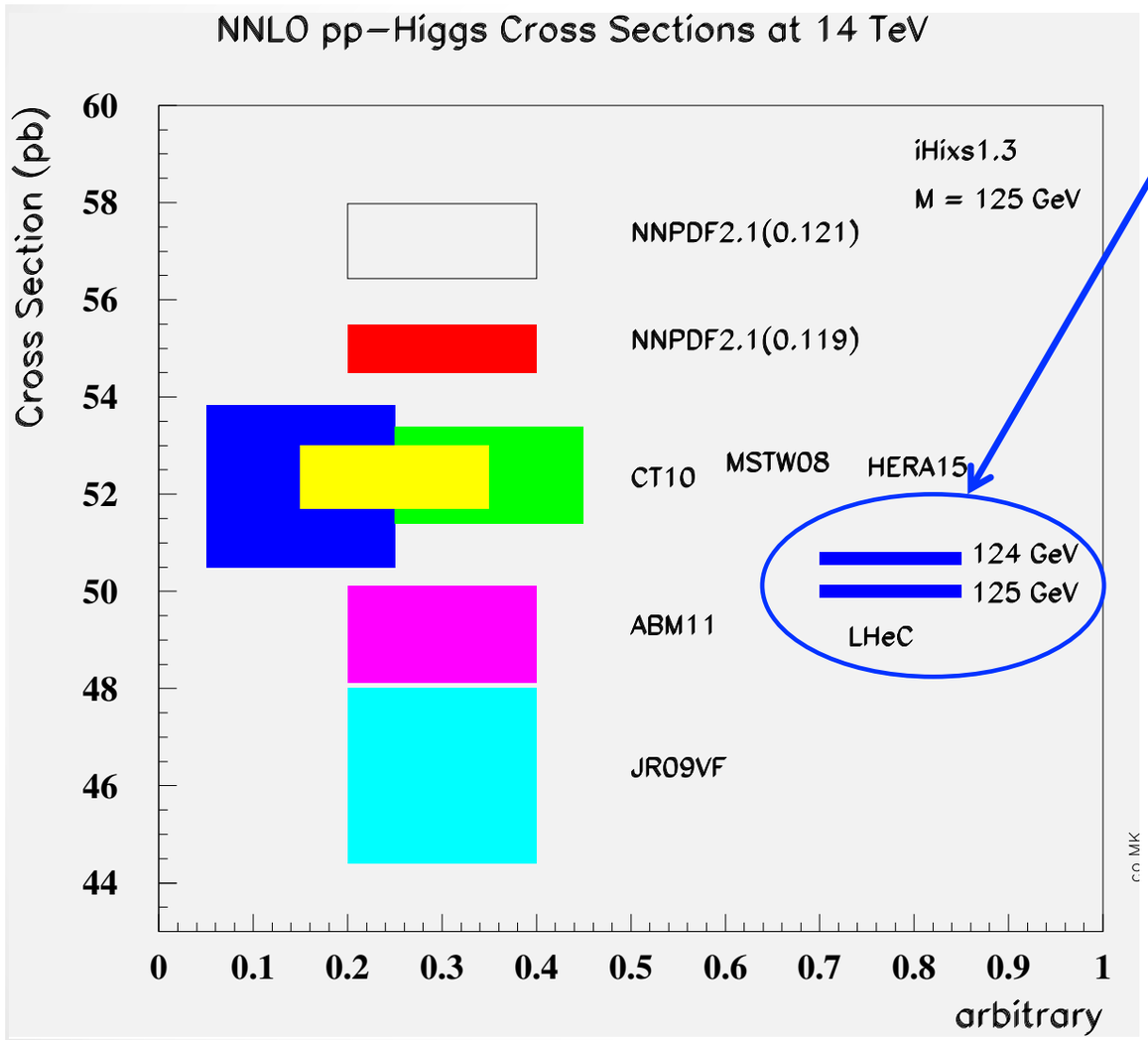




C. Gwenlan, DIS17

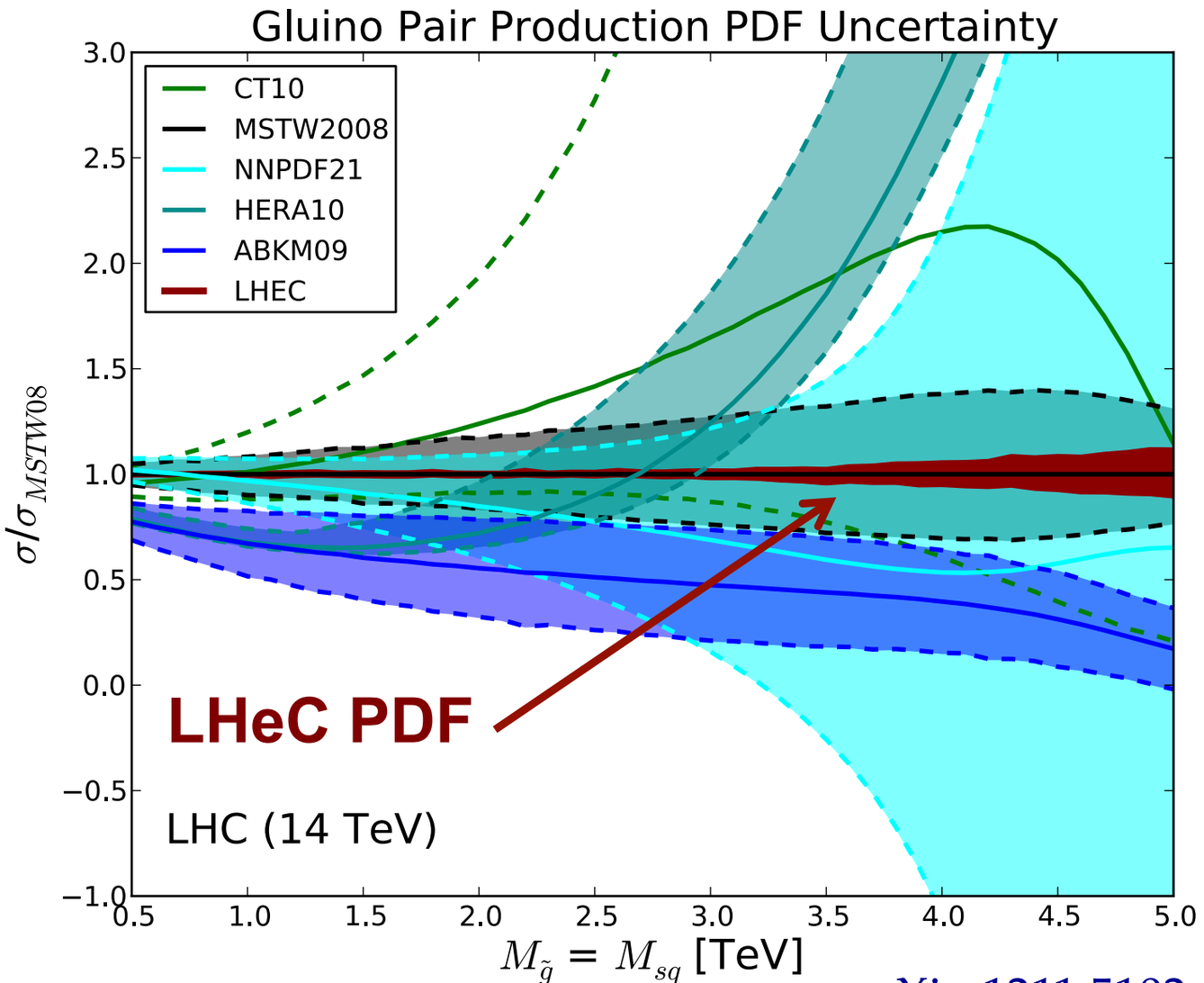
Mx [GeV] Mx [GeV]

Relevance of ultra-precise PDF



arXiv:1305.2090

- PDF-uncertainty of Higgs cross section squeezes to be sensitive to m_H

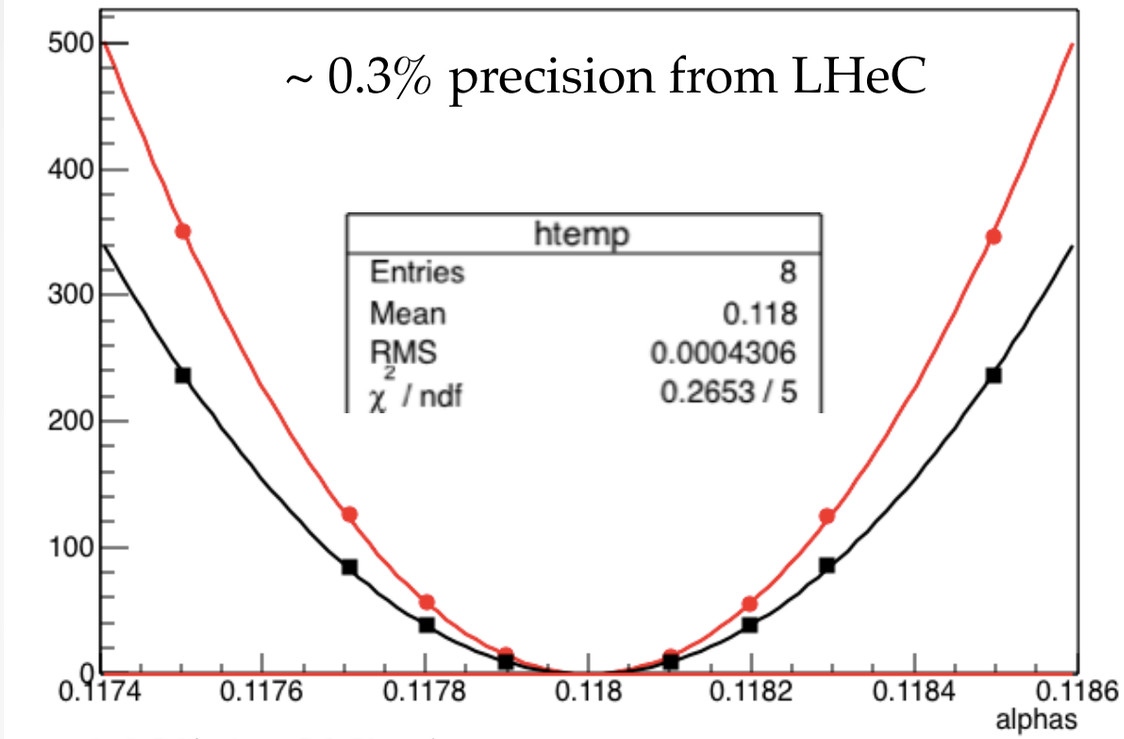


arXiv:1211.5102

- High-mass gluino xsec uncertainty >> 100%
  → squeezes to < 10%

Strong coupling constant

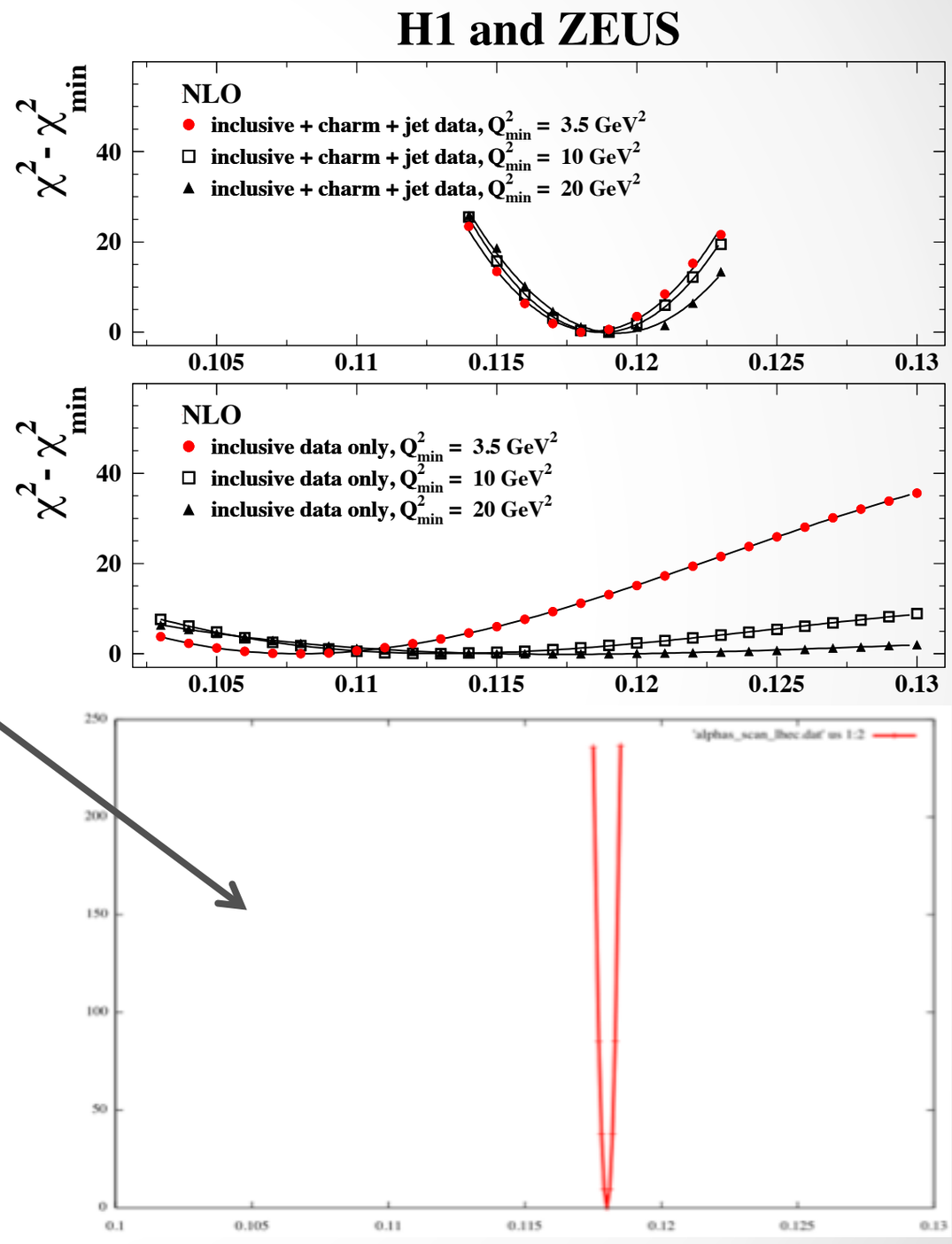
combined fit to PDFs+αs using LHeC data



M Klein, V Radescu

NC,CC

NC,CC+F2c



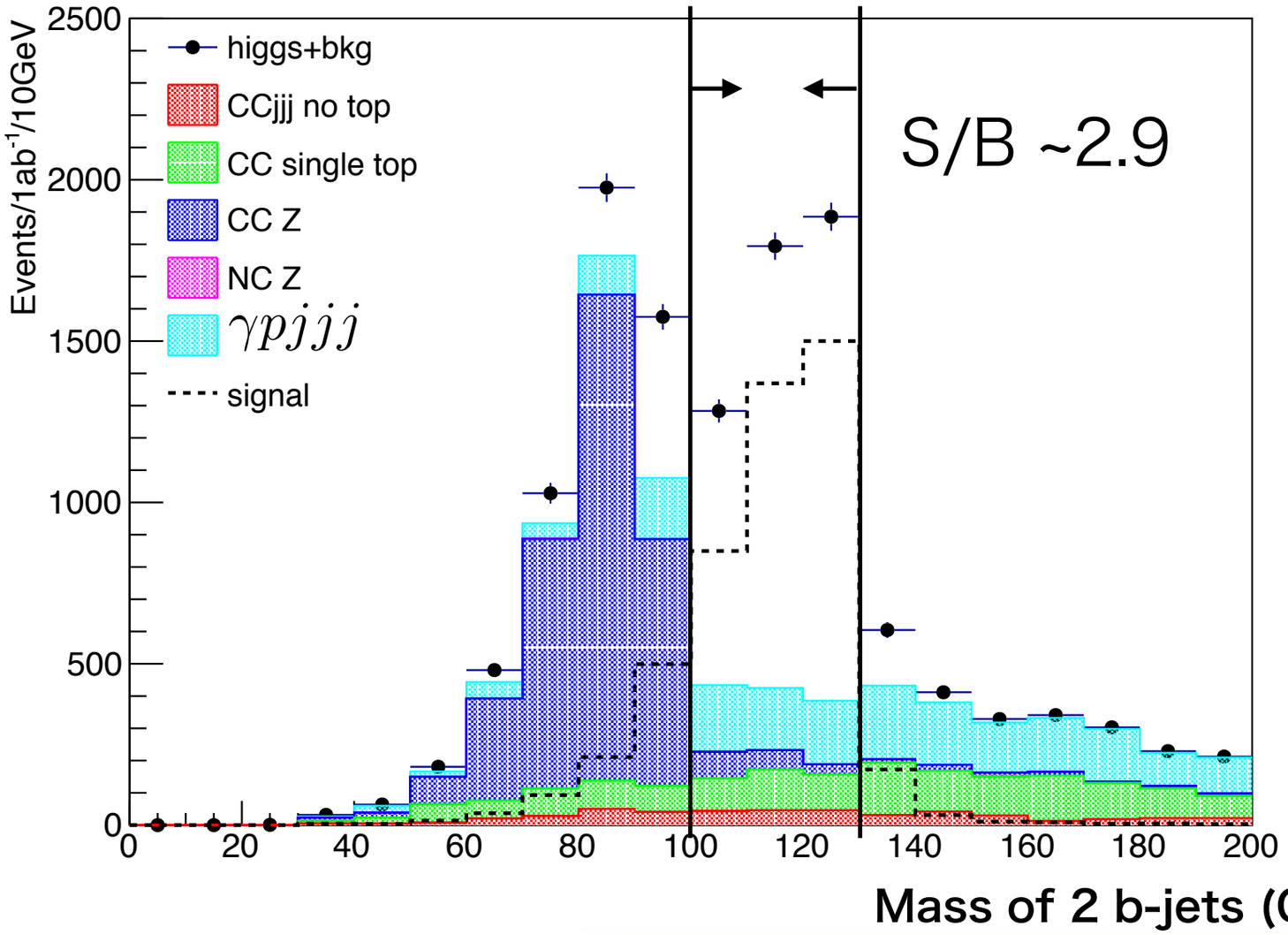
LHeC could resolve a > 30-year old puzzle:

αs consistent in inclusive DIS, versus jets?

expected 0.1% precision when combined with HERA

ep collider as Higgs factory

- Assumed 1000 fb^{-1} of statistics. (~10 years running for LHeC.)
- Veto efficiency of 90% for photo-production background is assumed, using forward electron tagging.



M. Tanaka, DIS17
(cut-based analysis)

Precision of coupling constant
(Statistics error only)

$$\kappa = \frac{\sqrt{N_s + N_b}}{2N_s}$$

Signal: 3600

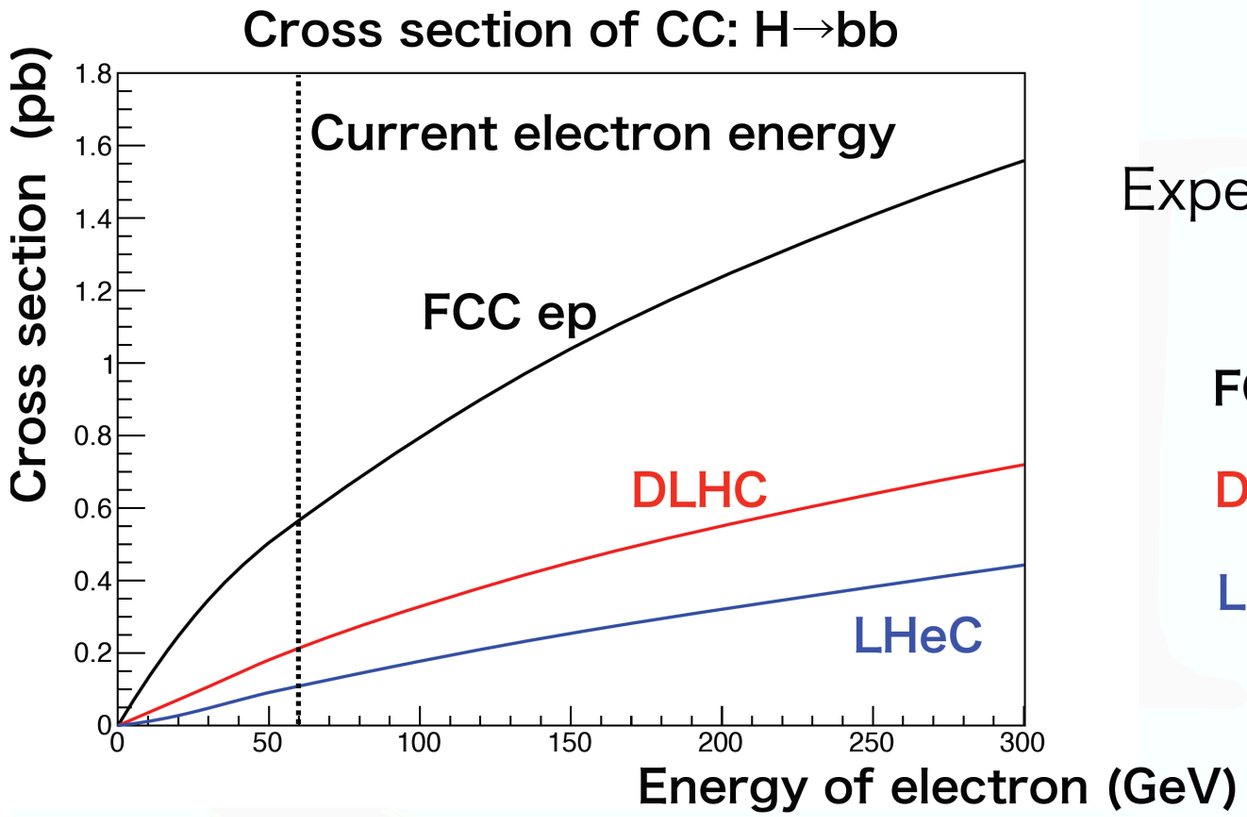
Bkg: 1250

κ(Hbb) ~ 0.97%

Applying BDT analysis further increases statistics (next page) →

Huge statistics Higgs physics

- Assume a 60 GeV polarized electron beam and 1000 fb^{-1} (~10 years running)
- Expected number of signal events and error of coupling constant from BDT results.
- Background assumed to be known to ~2%



U Klein (Liverpool)

Expected number of signal events
(E_e = 60 GeV)

FCC ep (~85,000 H→bb events)

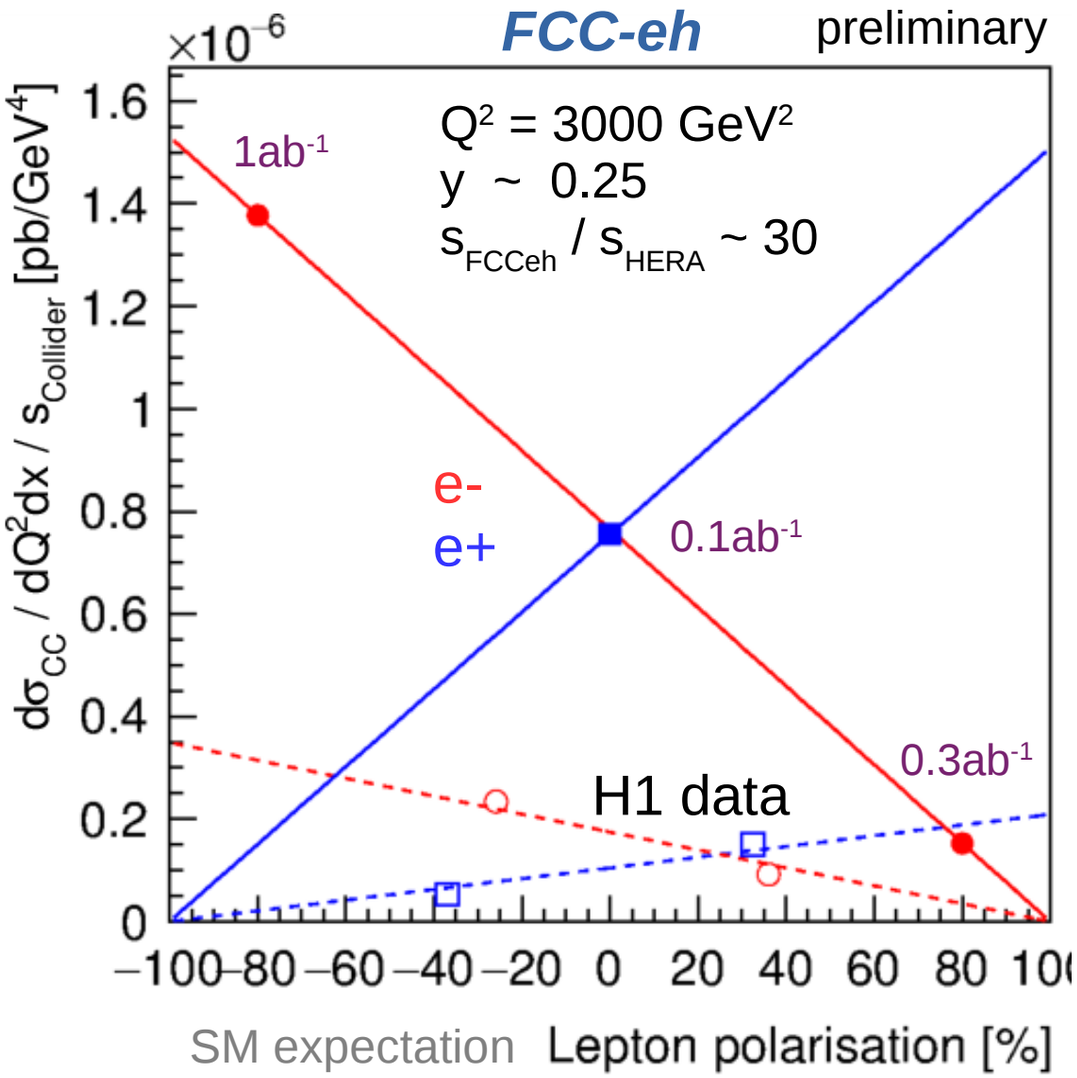
DLHC (~35,000 H→bb events)

LHeC (~15,000 H→bb events)

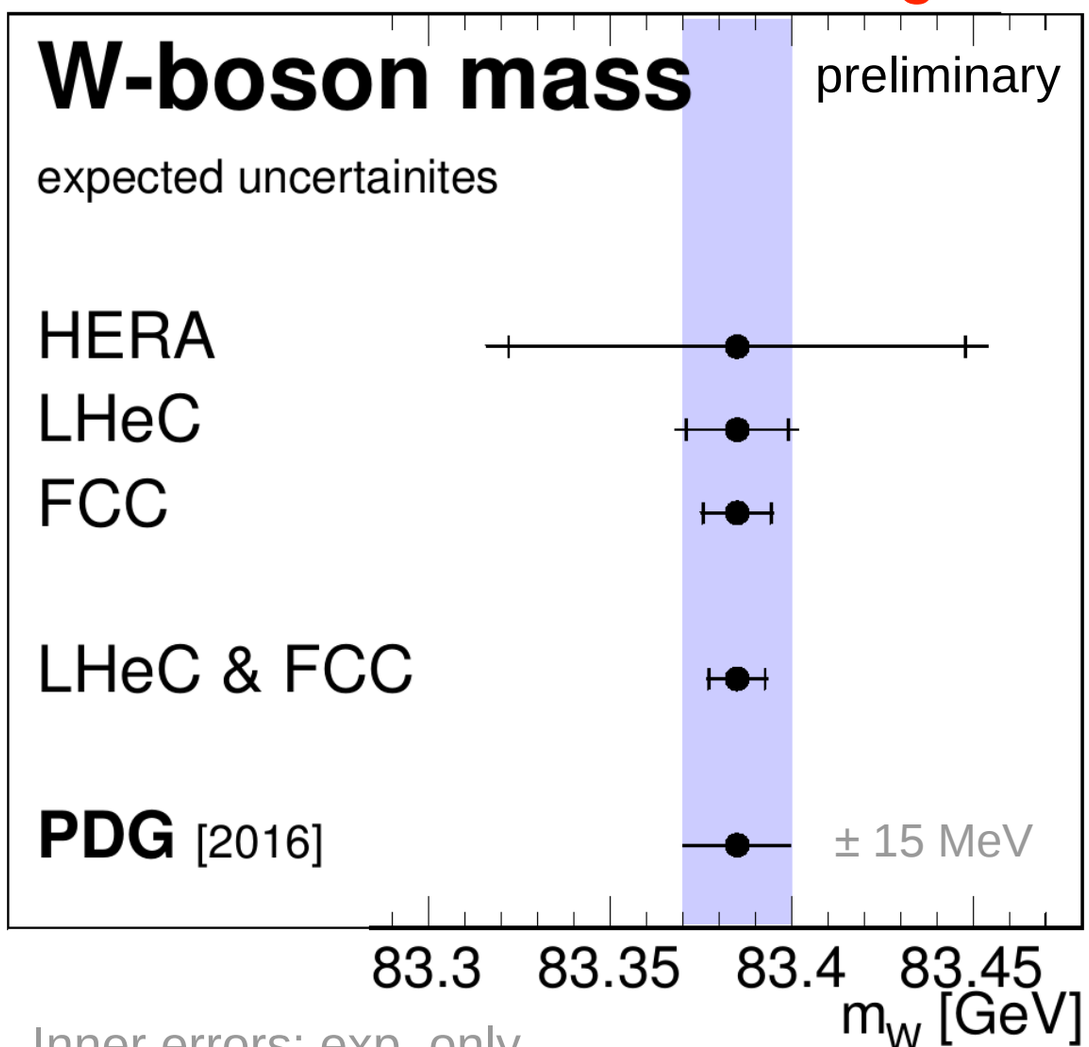
	LHeC (E_p = 7 TeV $\sqrt{s}$ ~1.3 TeV)	**DLHC** (E_p = 14 TeV $\sqrt{s}$ ~1.8 TeV)	**FCC ep** (E_p = 50 TeV $\sqrt{s}$ ~ 3.5 TeV)
κ (Hbb)	0.5%	0.3%	0.2%
κ (Hcc)	4%	2.8%	1.8%

Electroweak physics

- Polarization of e-beam possible (80%)
- Inclusive NC and CC events → EW & PDF fits
- E.g. W mass from CC → very competitive



D. Britzger, DIS17

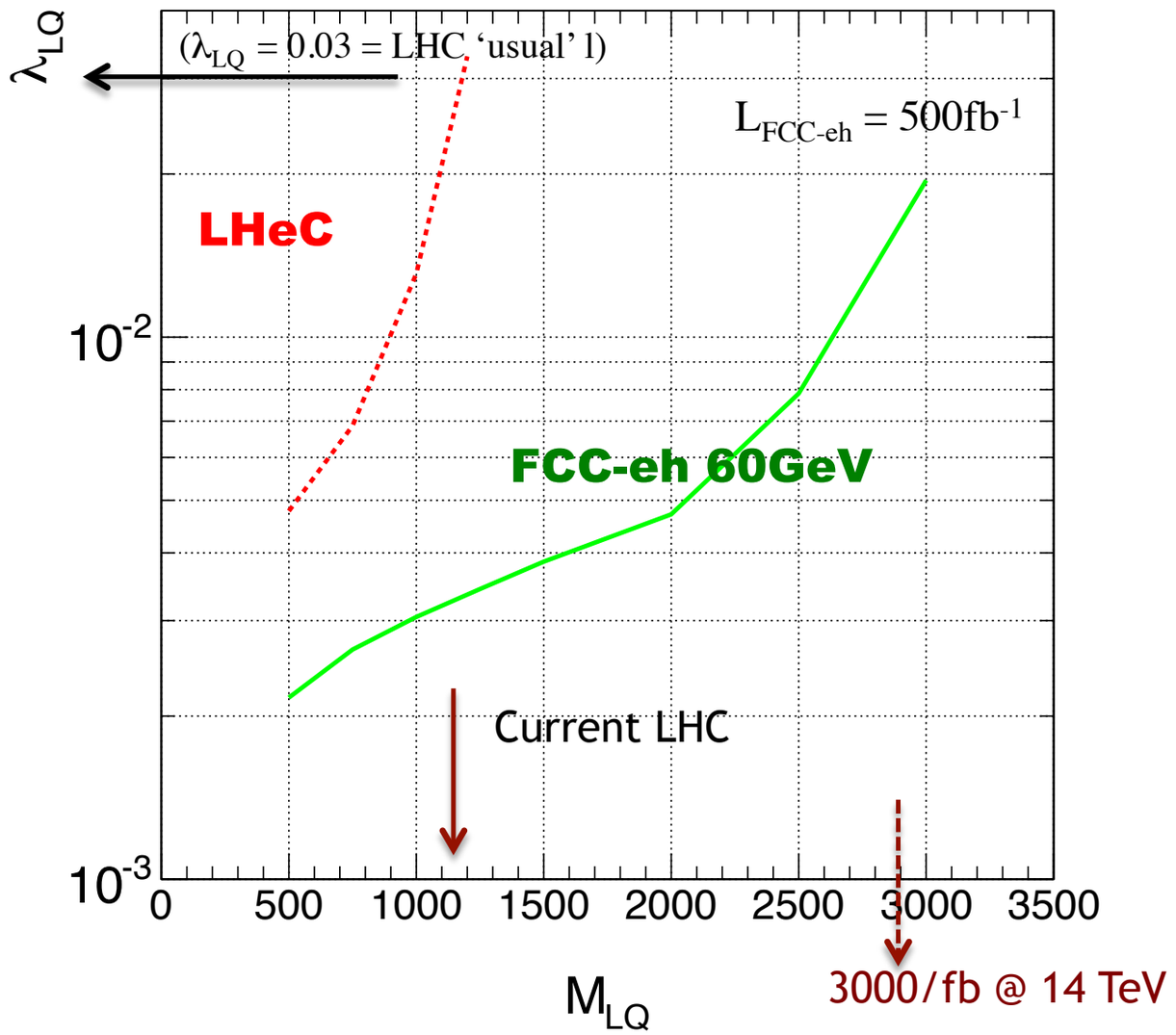


Inner errors: exp. only
Outer errors: exp. + PDF

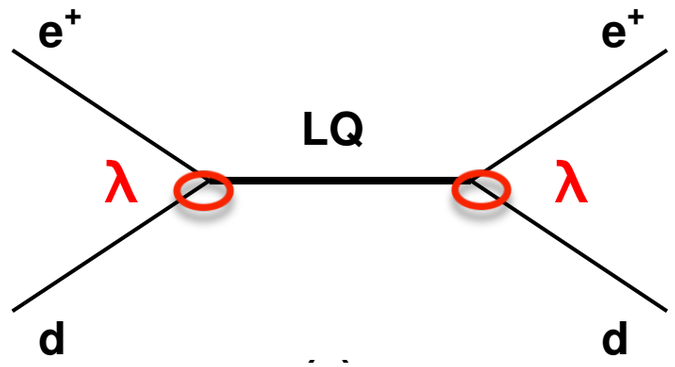
Beyond SM searches

- Example: Leptoquarks
- Production depends on e-q-LQ coupling λ
- For usual couplings, LQ found in (HL-)LHC would be found also in ep
- ep collider has handles to determine LQ quantum #'s
  - e^+/e^- beam, polarization
  - spin and generation
- Also interesting opportunities on top physics (FCNC, ...) and BSM Higgses (not shown today)

G. Azuelos



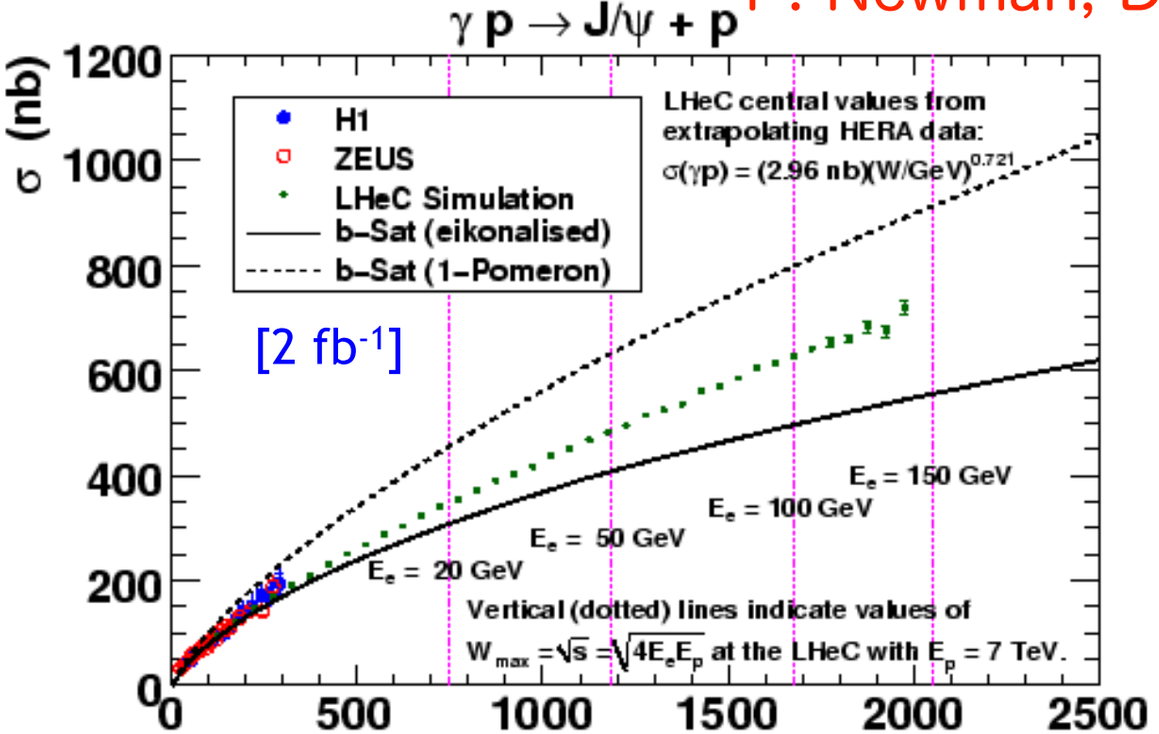
M. D'Onofrio, FCC physics week

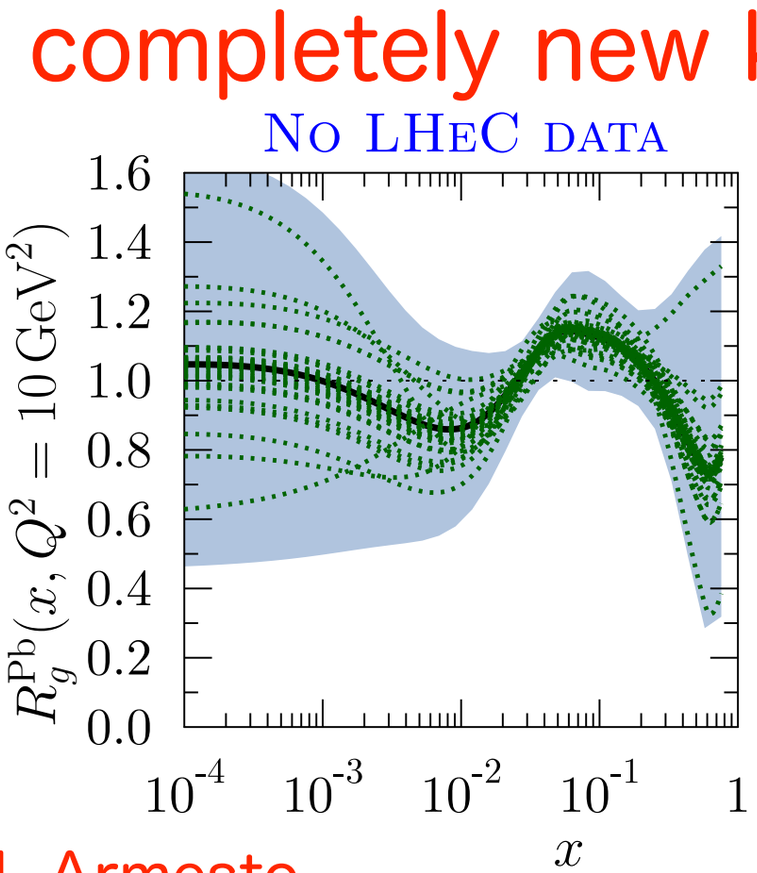


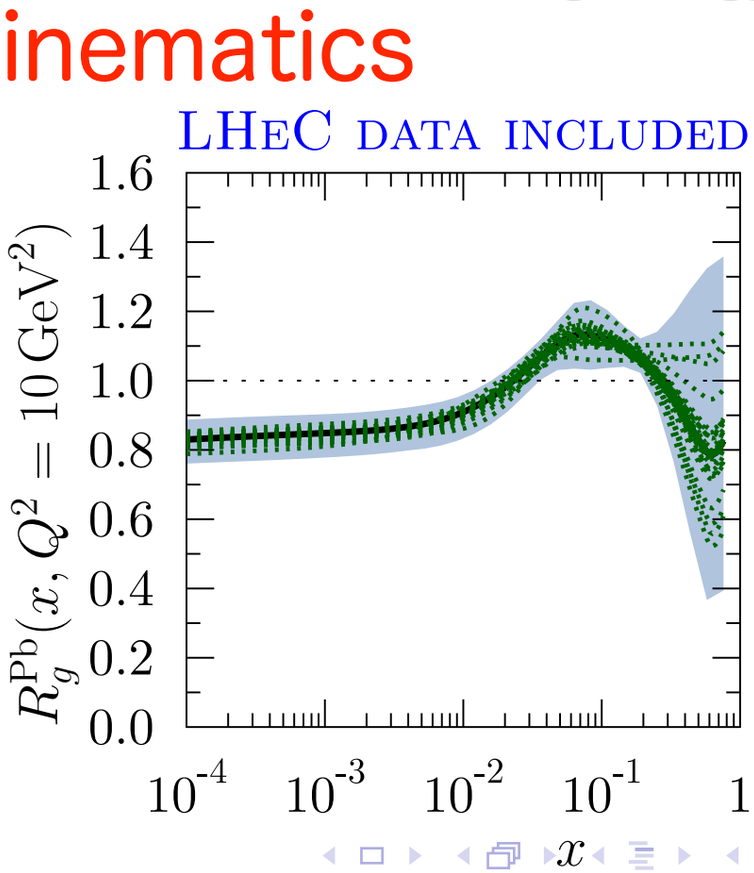
Diffraction / Nuclear PDF

- Diffractive physics with large rapidity gap and/or Roman-pot spectrometer
- e+p, e+Pb (and more?) for nuclear effects in completely new kinematics

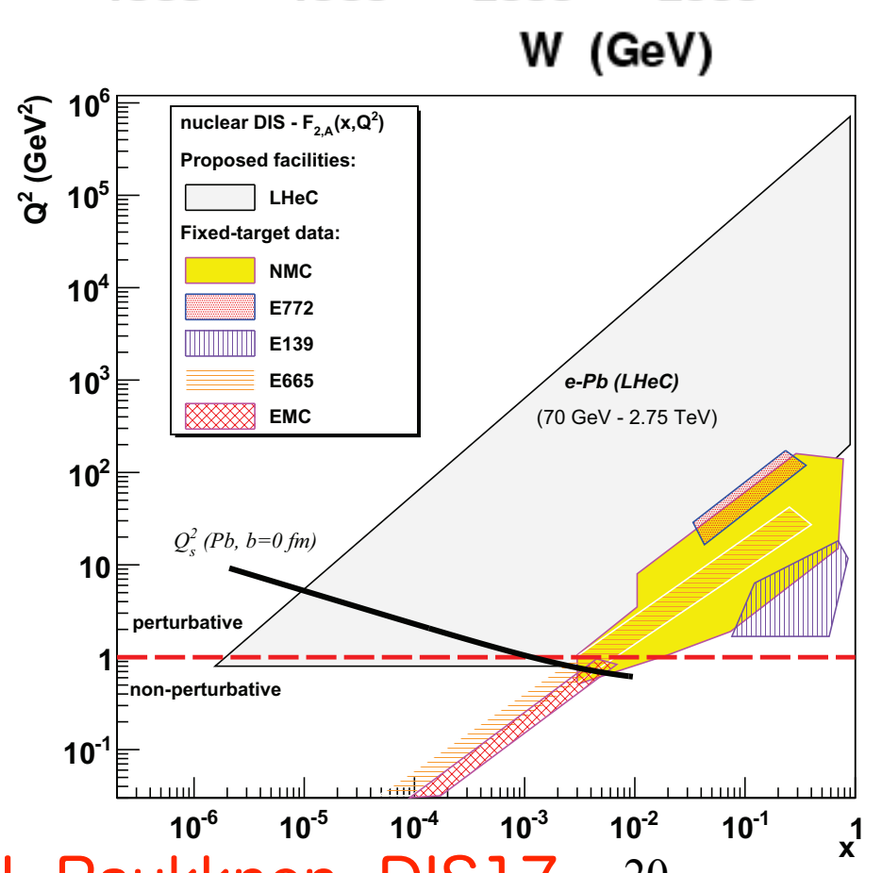
P. Newman, DIS17







N. Armesto



H. Paukkunen, DIS17

Conclusions

- A new electron-hadron collider, using a hadron beam of existing/planned hadron colliders, is a cost-effective and attractive future program.
- An ERL with 60 GeV is extensively designed by experts and a demonstrator PERLE is proposed.
- ep (eA) energy frontier machine with 100× Q^2 reach and 1000× luminosity of HERA → rich physics program complementary to HL-LHC and FCC-hh
- Different objective from low-energy machine EIC in US, which focuses on spin and medium-x structure of nucleons/nuclei.
- A dedicated workshop happens 11-13/Sep:

  https://indico.cern.ch/event/639067
- Also visit http://cern.ch/lhec/