LHeC and FCC-eh to Snowmass

Introduction
European Strategy
Energy Recovery
Bits of Physics
White Paper
Summary

Large Hadron electron Collider:
e:10-60 GeV, p: 1-7 TeV (LHC)
$s = 4 E_e E_p$

FCC-eh: Few TeV cms eh collider
e:10-60 GeV, p: 20 .. 50 TeV

Max Klein
University of Liverpool, ATLAS, H1
For the LHeC/FCC-eh and PERLE Collaborations

For **LHeC:** see Conceptual Design Report arXiv:1206.2913 (J.Phys.G) and Update and plethora of talks and papers, Web site http://lhec.web.cern.ch (needs update)

For **FCC-eh** see FCC books 1 (physics) and 3 (FCC-hh with eh integrated)
See also the CDR presentation in March 2019: https://indico.cern.ch/event/789349/
with talks on FCC-eh machine (OB), Higgs in eh (UK) and QCD (MK).

Brief Introduction to Conversation with Snowmass Energy Frontier Convenors, 9.6.2020

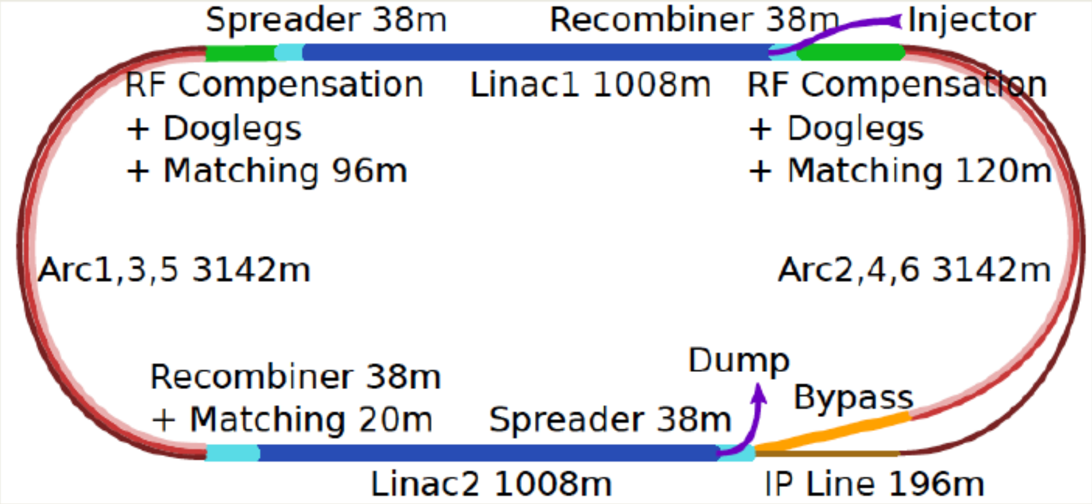
The Basic Concept

Energy $\sqrt{s} = \sqrt{(4 E_e E_p)}$ = 0.2-1.3 TeV

electrons: E_e=10-60 GeV, protons: E_p=1-7 TeV, ions Pb: E=2.75 TeV

LHeC: a next generation TeV energy electron-proton collider. Large coverage of kinematic DIS range, down to 10^{-6} in x owing to high energy and approaching x=1 due to high luminosity. Electron-ion collisions extend the kinematic range by 3-4 orders of magnitude since HERA missed its electron-ion collider phase.

Default layout of the ERL configuration for the LHeC



A recent review on the project and physics: MK, arXiv:1802.04317

An intense electron beam (20mA current) is accelerated in three passes through two 1km linacs in an energy recovery linac racetrack configuration, which is positioned tangentially to the LHC (at IP2, or L for FCC).

The electron-proton interaction does not disturb the proton beams in a noticeable manner. Thus the LHeC may operate synchronously with the LHC. The installation of the ERL is in a separate tunnel, while the detector installation requires a typical LHC shutdown length of two years. The whole project concept therefore is that of adding instrumentation and providing crucial new physics, i.e. of making the LHC physics richer and thus sustaining its HL phase.

Luminosity:

10^{34} cm^{-2} s^{-1} → O(1) ab^{-1} in 10 years

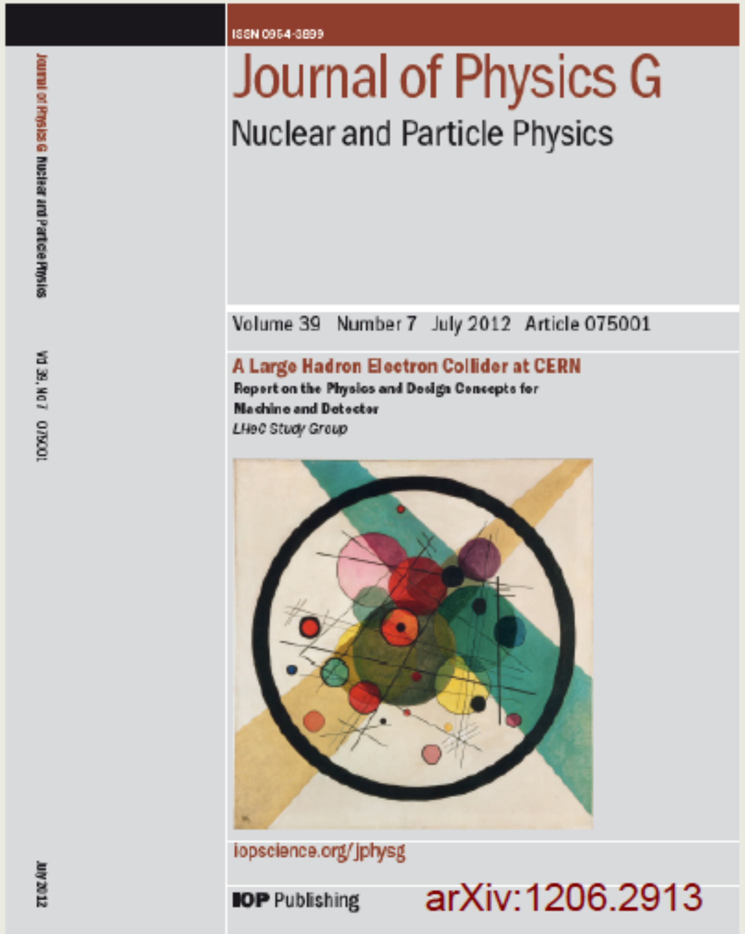
This is 1000 times higher than HERA, owing to the high beam brightness of the HL-LHC, the large electron current from the ERL and may be achieved through the interaction of matched e and p beams at a β* below 10cm.

New default electron energy for LHeC: 50 GeV instead of 60 GeV to economise ~400 M SF and effort.

Thoughts about higher electron energy for FCC-eh, especially if E_p is lowered.

Conceptual Design Report and beyond

Ring Ring Design
Kurt Huebner (CERN)
Alexander N. Skrinsky (INP Novosibirsk)
Ferdinand Willeke (BNL)
Linac Ring Design
Reinhard Brinkmann (DESY)
Andy Wolski (Cockcroft)
Kaoru Yokoya (KEK)
Energy Recovery
Georg Hoffstaetter (Cornell)
Ilan Ben Zvi (BNL)
Magnets
Neil Marks (Cockcroft)
Martin Wilson (CERN)
Interaction Region
Daniel Pitzl (DESY)
Mike Sullivan (SLAC)
Detector Design
Philippe Bloch (CERN)
Roland Horisberger (PSI)
Installation and Infrastructure
Sylvain Weisz (CERN)
New Physics at Large Scales
Cristinel Diaconu (IN2P3 Marseille)
Gian Giudice (CERN)
Michelangelo Mangano (CERN)
Precision QCD and Electroweak
Guido Altarelli (Roma)
Vladimir Chekelian (MPI Munich)
Alan Martin (Durham)
Physics at High Parton Densities
Alfred Mueller (Columbia)
Raju Venugopalan (BNL)
Michele Arneodo (INFN Torino)



In 2012, parallel to the discovery of the Higgs boson by the ATLAS and CMS experiments at the LHC, a 500 pages report was published on the design of the LHeC. It was the summary of the work of a very large international collaboration for about 4 years, following mandates by ECFA, CERN and in collaboration with NuPECC. The report, on the physics, accelerator and a complete detector, was discussed for a year with referees, listed on the left, which CERN had invited. The report was for 10^{33} cm^{-2} s^{-1} luminosity obtainable in concurrent electron-proton and proton-proton operation. It contained a ring-ring and a linac-ring collider concept.

The European strategy in 2013 opened the path to a much enlarged luminosity and prolonged lifetime for the LHC. The Higgs boson set a more ambitious luminosity goal also for ep, where ep → vHX has a 200 fb cross section. The CERN directorates thus mandated a second phase of the LHeC design, for higher luminosity, with only the ERL version, and adapted to the evolving LHC physics.

The CDR in 2012 was very detailed and extensively refereed. It is time for an update, deadline November - this year.

High Luminosity Electron-Hadron Physics at TeV energy

The LHeC represents a new laboratory for high energy physics.

Its programme comprises five major themes:

MICROSCOPE of substructure
By the nature of the high energy eh interaction, the LHeC is the cleanest high resolution microscope of matter, the Hubble telescope of substructure.

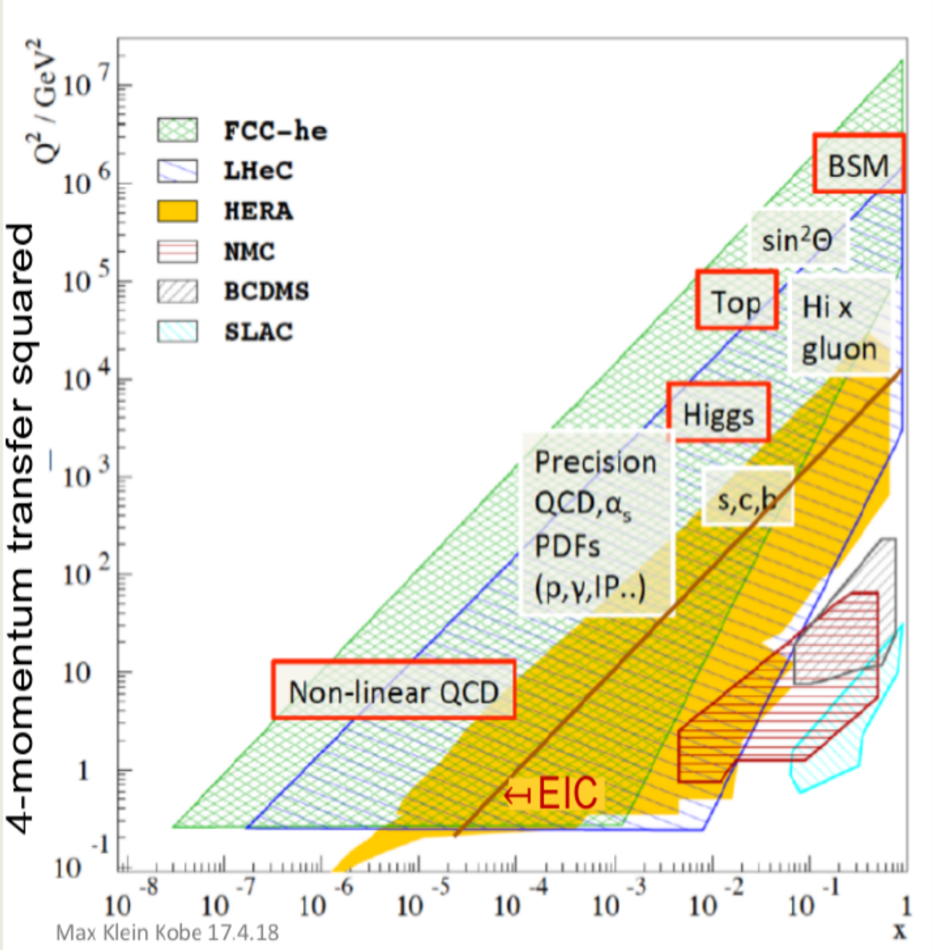
EMPOWERMENT of LHC physics
The LHC lacks crucial input on the proton structure and QCD dynamics. The clean, external input on partons will clarify the high mass predictions, and thus extend the reliablity and range for BSM searches, and provide input required for precision QCD, electroweak and Higgs physics. This way, it empowers the LHC physics and utilises the LHC infrastructure optimally. It is the near detector for the GPDs.

A NOVEL HIGGS PHYSICS FACILITY
The clean final state, the absence of pile-up, the large Higgs production cross section and novel detection and analysis techniques enable precision input in all large decay channels, including H→ cc, which combined with pp, lead to percent level LHC Higgs coupling results, comparable to ee prospects.

DISCOVERY of new physics
The LHeC is a TeV energy scale new configuration, it has large discovery potential in QCD (saturation), electroweak (Higgsinos, rh neutrinos), top and substructure physics.

REVOLUTION of nuclear particle physics
The partonic structure of nuclei is of an infant status like that of protons before HERA, it will be established in a huge range with stand-alone eA PDF one may then relate to those in ep. The understanding of the Quark-Gluon Plasma needs ep.

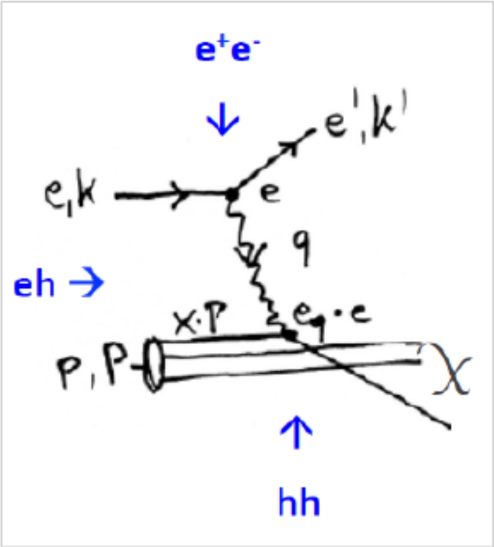
CERN-ACC-Note-2018-084, subm EU strategy, J.Phys.G to appear

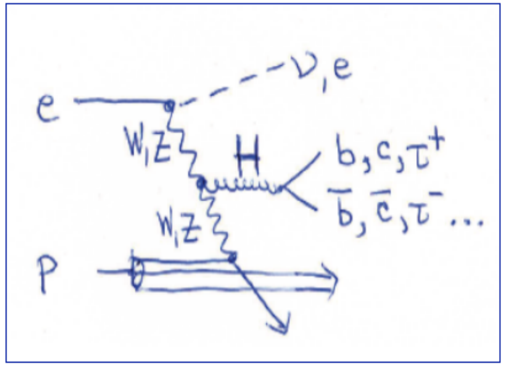


Following HERA, **deep inelastic scattering needs high energy** (and also luminosity) to reach Higgs, top, BSM physics, to use charged currents for unfolding parton structure, independently of nuclear and higher twist effects, to clarify the existence of BFKL dynamics at small x, and prepare for FCC.

With polarised protons, there is **a case for a lower (than HERA) energy eh collider**, which also studies proton structure at medium Bjorken x, the EIC.

DIS: the cleanest high resolution microscope and a laboratory for new particles and new dynamics.





Organisation

International Advisory Committee

Mandate by CERN (2014+17) to define
"..Direction for ep/A both at LHC+FCC"

Sergio Bertolucci (CERN/Bologna)
Nichola Bianchi (Frascati)
Frederick Bordry (CERN)
Stan Brodsky (SLAC)
Hesheng Chen (IHEP Beijing)
Eckhard Elsen (CERN)
Stefano Forte (Milano)
Andrew Hutton (Jefferson Lab)
Young-Kee Kim (Chicago)
Victor A Matveev (JINR Dubna)
Shin-Ichi Kurokawa (Tsukuba)
Leandro Nisati (Rome)
Leonid Rivkin (Lausanne)
Herwig Schopper (CERN) – Chair
Juergen Schukraft (CERN)
Achille Stocchi (LAL Orsay)
John Womersley (ESS)

We miss Guido Altarelli.

Coordination Group

Accelerator+Detector+Physics

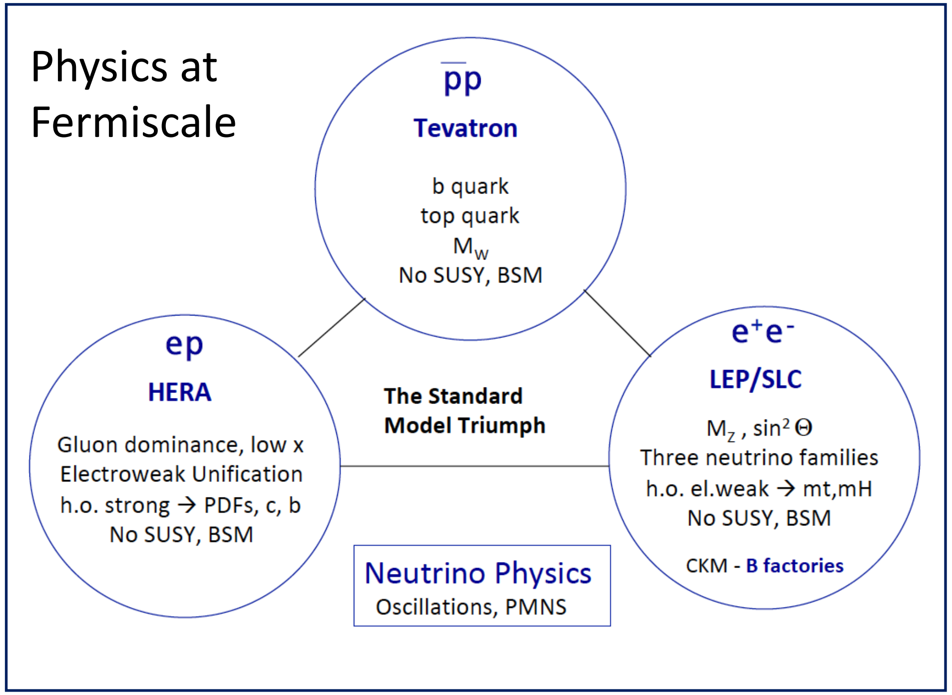
Gianluigi Arduini
Nestor Armesto
Oliver Brüning – Co-Chair
Andrea Gaddi
Erk Jensen
Walid Kaabi
Max Klein – Co-Chair
Peter Kostka
Bruce Mellado
Paul Newman
Daniel Schulte
Frank Zimmermann

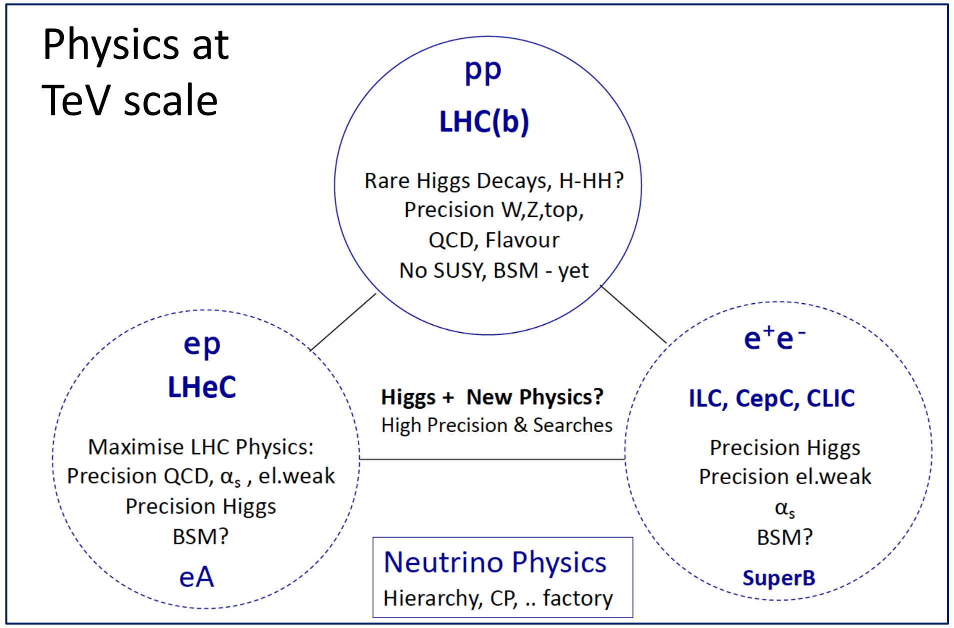
5(12) are members of the FCC coordination team

OB+MK: co-coordinate FCCeh

Working Groups

PDFs, QCD
Fred Olness,
Claire Gwenlan
Higgs
Uta Klein,
Masahiro Kuze
BSM
Georges Azuelos,
Monica D'Onofrio
Oliver Fischer
Top
Olaf Behnke,
Christian
Schwanenberger
eA Physics
Nestor Armesto
Small x
Paul Newman,
Anna Stasto
Detector
Alessandro Polini
Peter Kostka





Strategy and Expectations

Recognition of the complementarity of pp/AA, ep/A and ee, and the special role of DIS to supplement hh, LHC/FCC → Support for technical (IR..) and detector developments

Recognition of energy recovery as a revolutionary, novel technology for next generation colliders of high impact → Support the development of ERL technology and the international PERLE Coll.

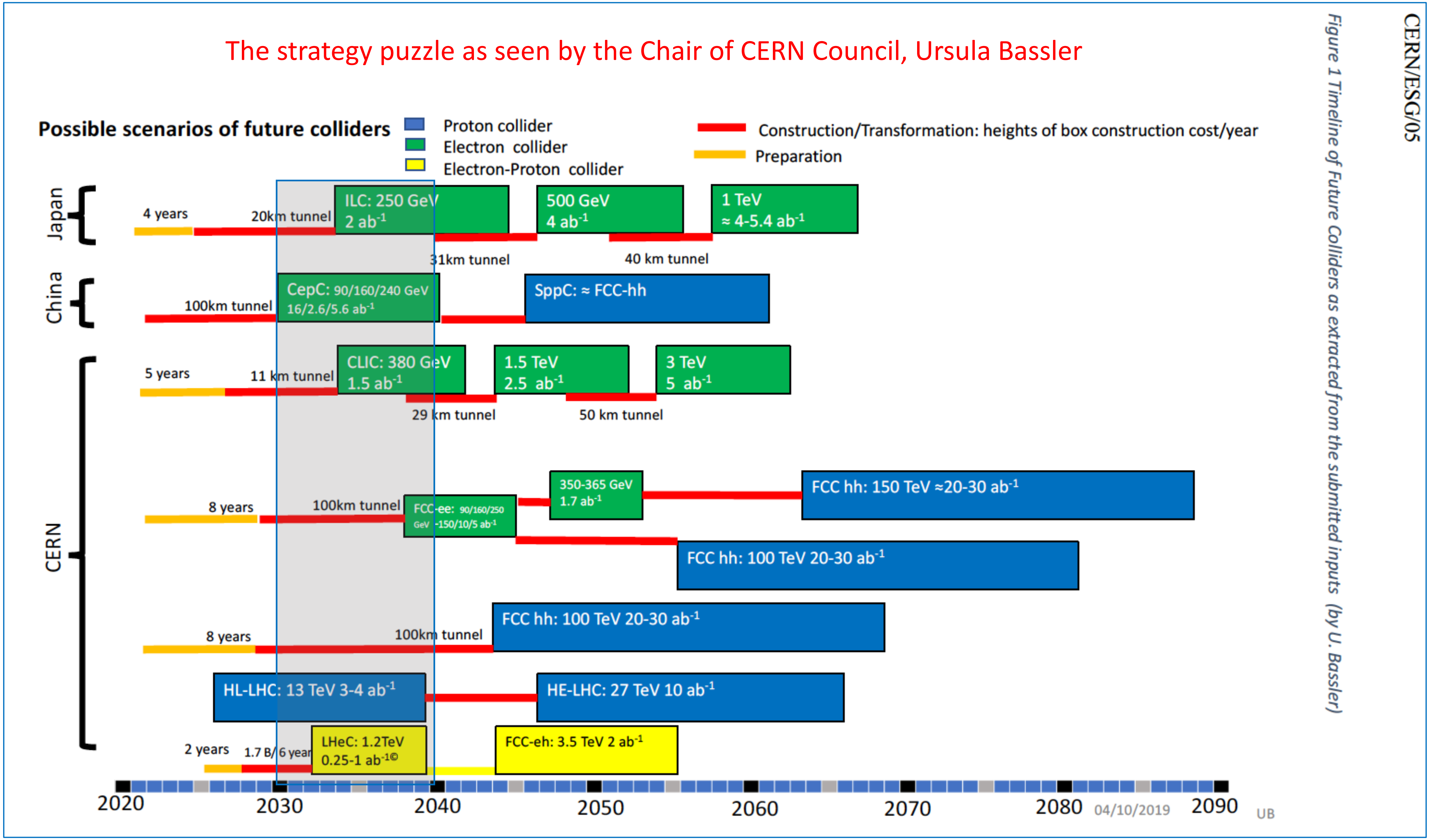
CERN/ESG/05
29 September 2019

	2020-2040	2040-2060 1st gen technology	2060-2080 2nd gen technology
CLIC-all	HL-LHC	**CLIC380-1500**	CLIC3000 / other tech
CLIC-FCC	HL-LHC	**CLIC380**	FCC-h/e/A (Adv HF magnets) / other tech
FCC-all	HL-LHC	**FCC-ee (90-365)**	FCC-h/e/A (Adv HF magnets) / other tech
LE-to-HE-FCC-h/e/A	HL-LHC	**LE-FCC-h/e/A (low-field magnets)**	FCC-h/e/A (Adv HF magnets) / other tech
LHeC-FCC-h/e/A	HL-LHC **+ LHeC**	**LHeC**	FCC-h/e/A (Adv HF magnets) / other tech

SUPPORTING NOTE FOR BRIEFING BOOK 2020

The future is under discussion (cf A Stocchi on Friday) and DIS has become part of it. The big question is on the next big machine.

The strategy puzzle as seen by the Chair of CERN Council, Ursula Bassler



High-energy DIS collider for QCD:

Hot & Dense QCD

A coherent and complementary "hot & dense QCD program" at the SPS brings valuable and unique contributions in the exploration of the QCD phase diagram.

An (HL-HE-)LHC/FCC based AA/pA/fixed-target program is unique and provides essential science at the frontline towards a profound understanding of particle physics.

Precision QCD

A globally concerted "precision QCD program" provides a unique avenue to find new physics that breaks the Standard Model.

A high-luminosity e^+e^- collider at the EW scale and a high-energy ep collider provide a unique environment for high-precision QCD, essential for most of our aspirations in particle physics.

Partonic Structure

A "hadronic structure program" exploring the complementarity of ep/pp/eA colliders provides vital ingredients for the high precision exploration in searches for new physics and as well steps into uniquely unknown territories of QCD.

Theory

It is vital to support coherently the QCD theory community to succeed in all these programs and to link QCD to the rest of the particle physics research program, especially for our HL-LHC exploration.

Organization

Strengthening the synergies in research and technology with adjacent fields will reinforce our efforts.

Global platforms, networks and institutes have the potential to enhance the research exchange among experts worldwide and to provide essential training opportunities.

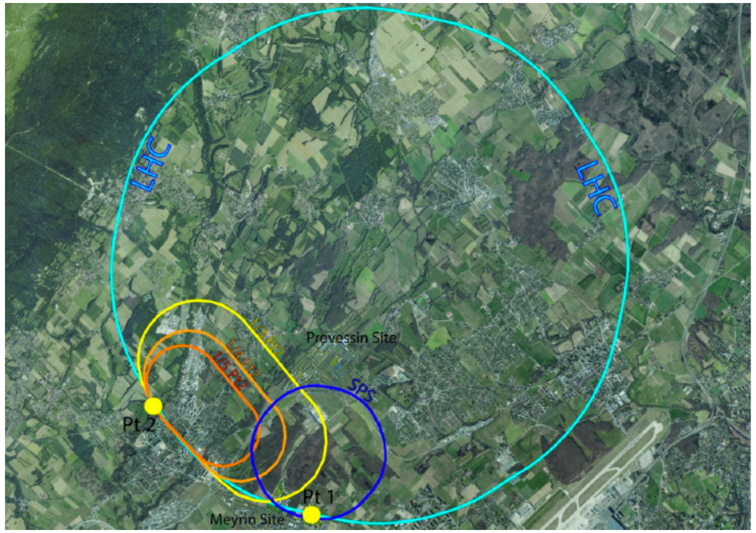
Summary on QCD of Jorgen D'Hondt and Krzysztof Redlich, Granada May 2019

ERL: Accelerator Energy Frontier

CERN-ACC-Note-2020-0002
Version v1.0
Geneva, June 2, 2020

LHeC

400 pages update of 2012 CDR - to appear

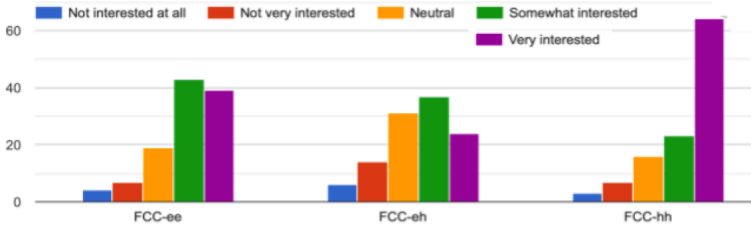


50 GeV to limit cost [1/4 or 1/5 of U(LHC)]
Three pass ERL, two ~800m long linacs
I_e=20mA for 10^{34} luminosity, f=801.58 MHz
(Erk at Daresbury 16, Frank M at Orsay 18)
Operation concurrent to LHC (+dedicated)

(when) will that happen.? We don't know
I met Abhay Deshpande in Snowmass 2001,
when he presented the EIC, not for the 1st time

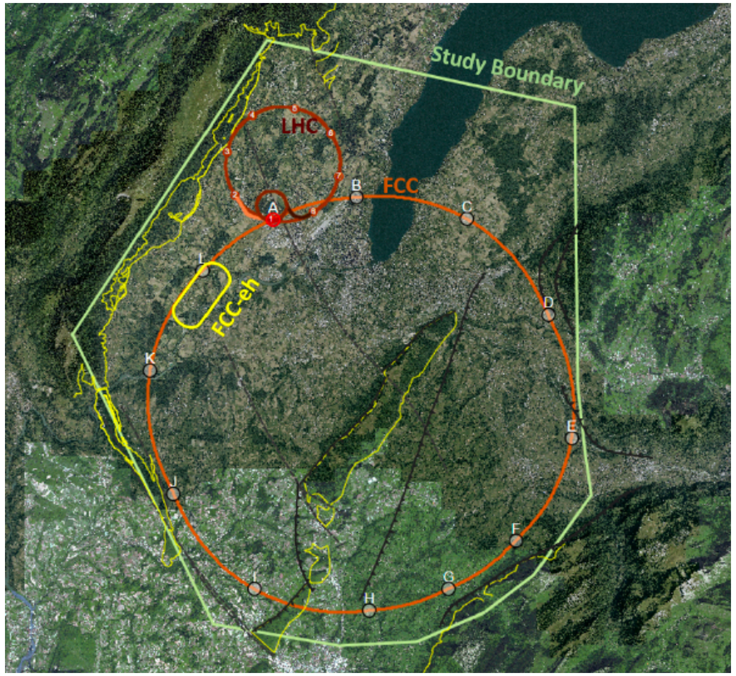
HL-LHC dominates all of PP,
Its programme will extend to 2040

FCC hh ee he

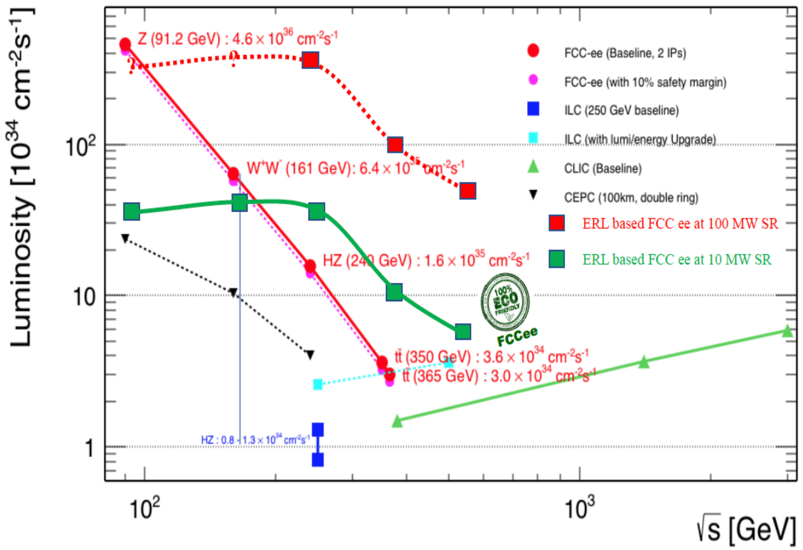


ECFA: Interest of young scientists 2002.02837

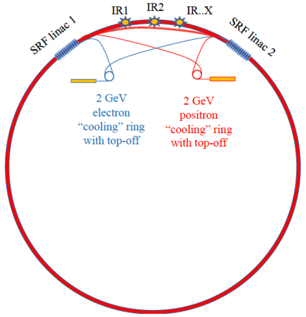
60 GeV ERL design applied to FCC-he



FCC-ee



Vladimir Litvinenko et al, 1909.04437



4-6 turns

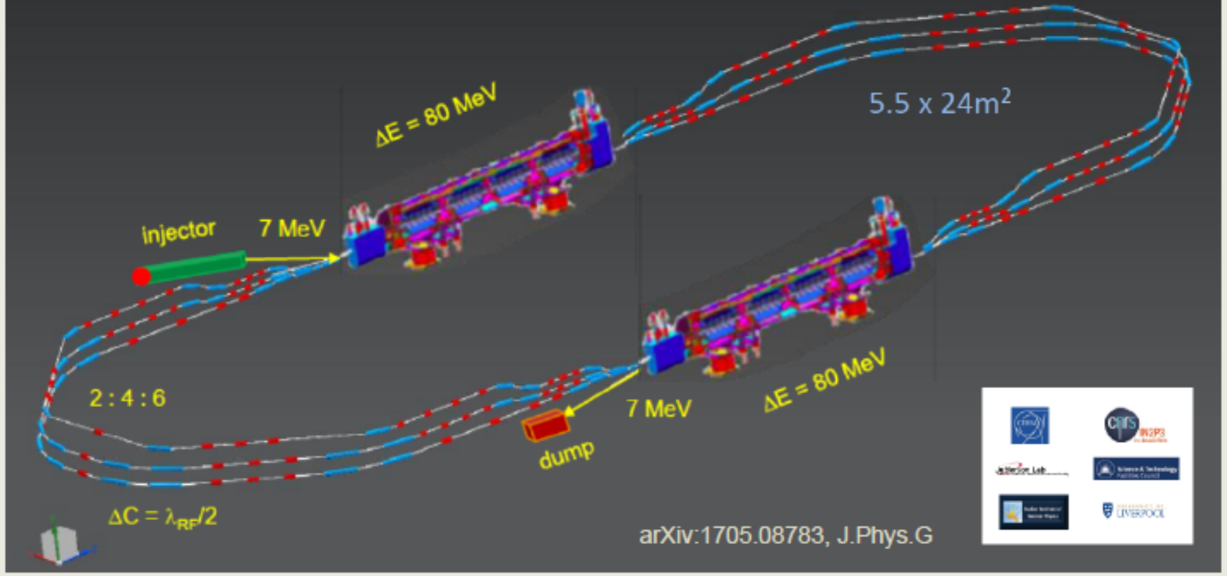
E/linac = $M_{Z,..HH}/(2 * N_{turn})$

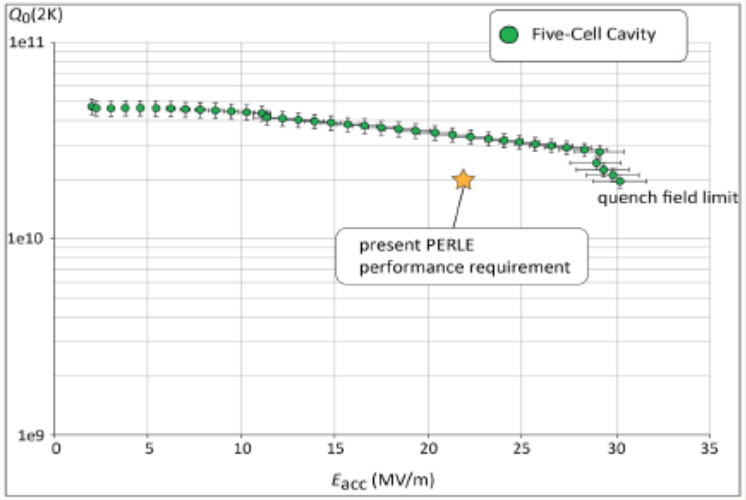
EIC: Polarised eh Collider at BNL
IBS: emittance growth: needs ERL 100mA (!)
CW e beam cooling of p/A beam (for CBETA)
cf e.g. F Willeke APS talk, April 2018

Coherent Electron Cooling
V.N. Litvinenko, Y.S. Derbenev, *PRL* **102**, 114801, 2009

PERLE powerful energy recovery linac for experiments

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





Test (Q_0 vs gradient) of 5-cell cavity built by:

Energy recovery is one of the few revolutionary concepts for accelerator design. A high energy collider application is for the LHeC (and possible successors with FCC). For stability, cost and CERN's RF, the frequency was chosen to be 802 MHz. A first 5-cell Niobium cavity, built at Jlab, reached a Q_0 of 3 10^{10} with a large gradient stability margin (see right). **The PERLE Collaboration was built to realise a 500 MeV energy facility at Orsay,** for the development of ERL with LHeC conditions: high current and 3 passes. In a second phase it provides unique opportunity for intense low energy physics and industrial use.

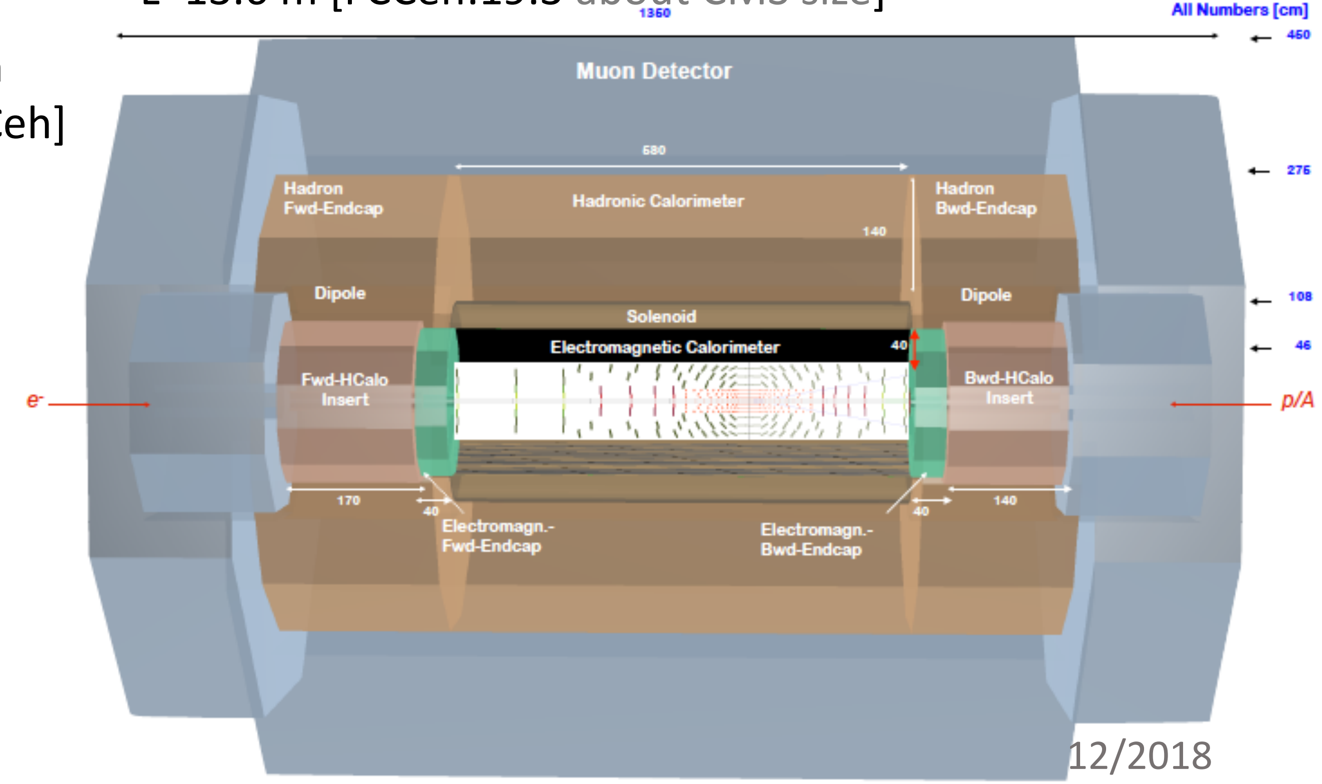
Thank you all

PERLE is progressing (source, injector, magnets, HOMs.. – radiation safety - in its recognition). International Collaboration

LHeC Detector

L=13.6 m [FCCeh:19.3 about CMS size]

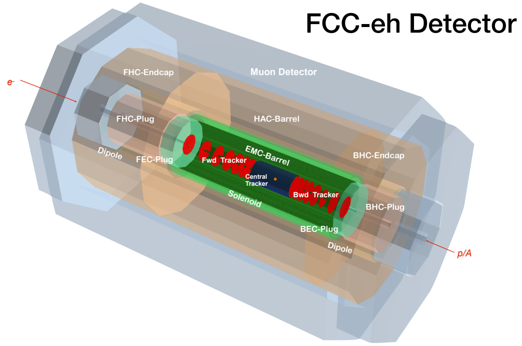
R=4.6 m
[6.2 FCCeh]



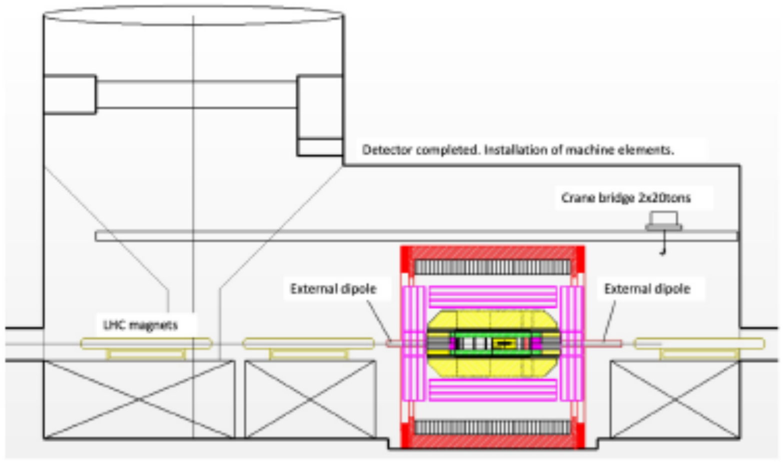
12/2018

Figure 2: Current status of the LHeC central detector design. The detector is complemented by photon and electron taggers in the electron beam direction and by proton and neutron tagging forward spectrometers as were presented in the CDR [1].

FCC-eh Detector



Study of installation (sequence) of LHeC detector in IP2 cavern using L3 magnet support structure [commensurate with 2 year shutdown]
A. Ghaddi et al, LHeC Workshop 2015



Currently: increase radius of tracker, choose technology, summarise/simulate response: update this fall

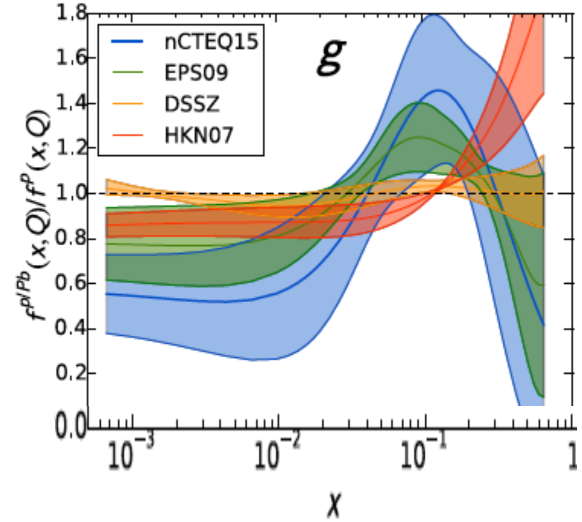
Nuclear PDFs at LHeC/FCCeh

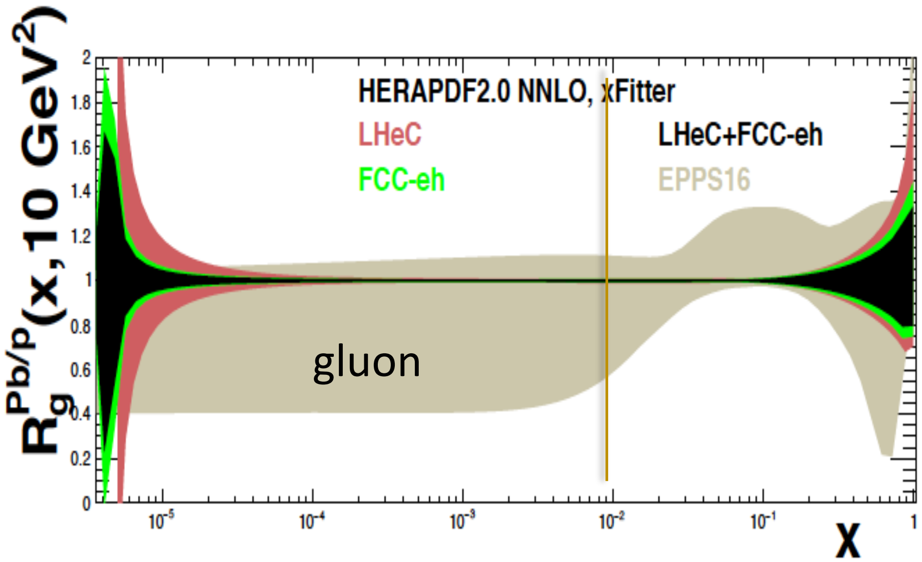
Unique nuclear/HI physics programme
Extension of fixed target range by 10 [3-4]
QCD of QGP, de-confinement, saturation..
nPDFs independent of p PDFs

High luminosity ~ 10 [33] enables high statistics in short eA runs
cf J Jowett et al

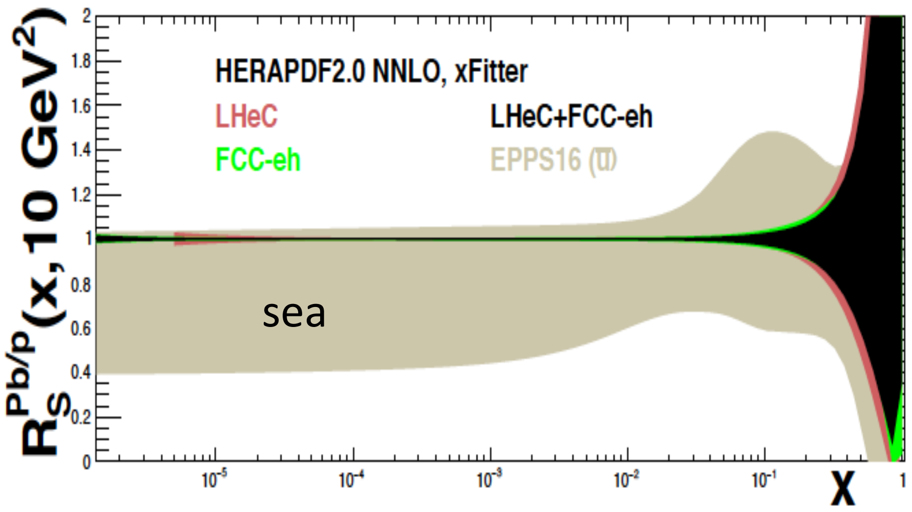
present status → on xg Pb/p

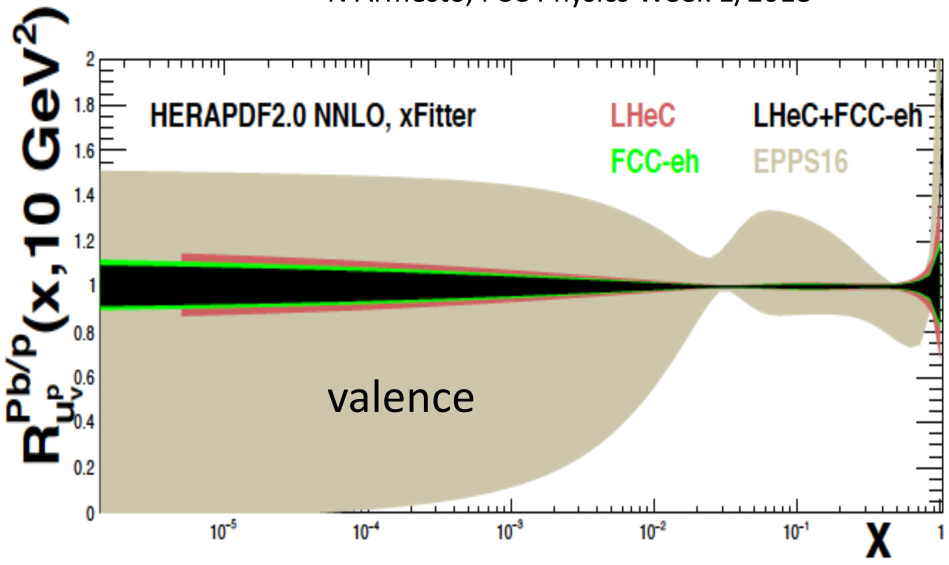
1509.00792





N Armesto, FCC Physics Week 1/2018

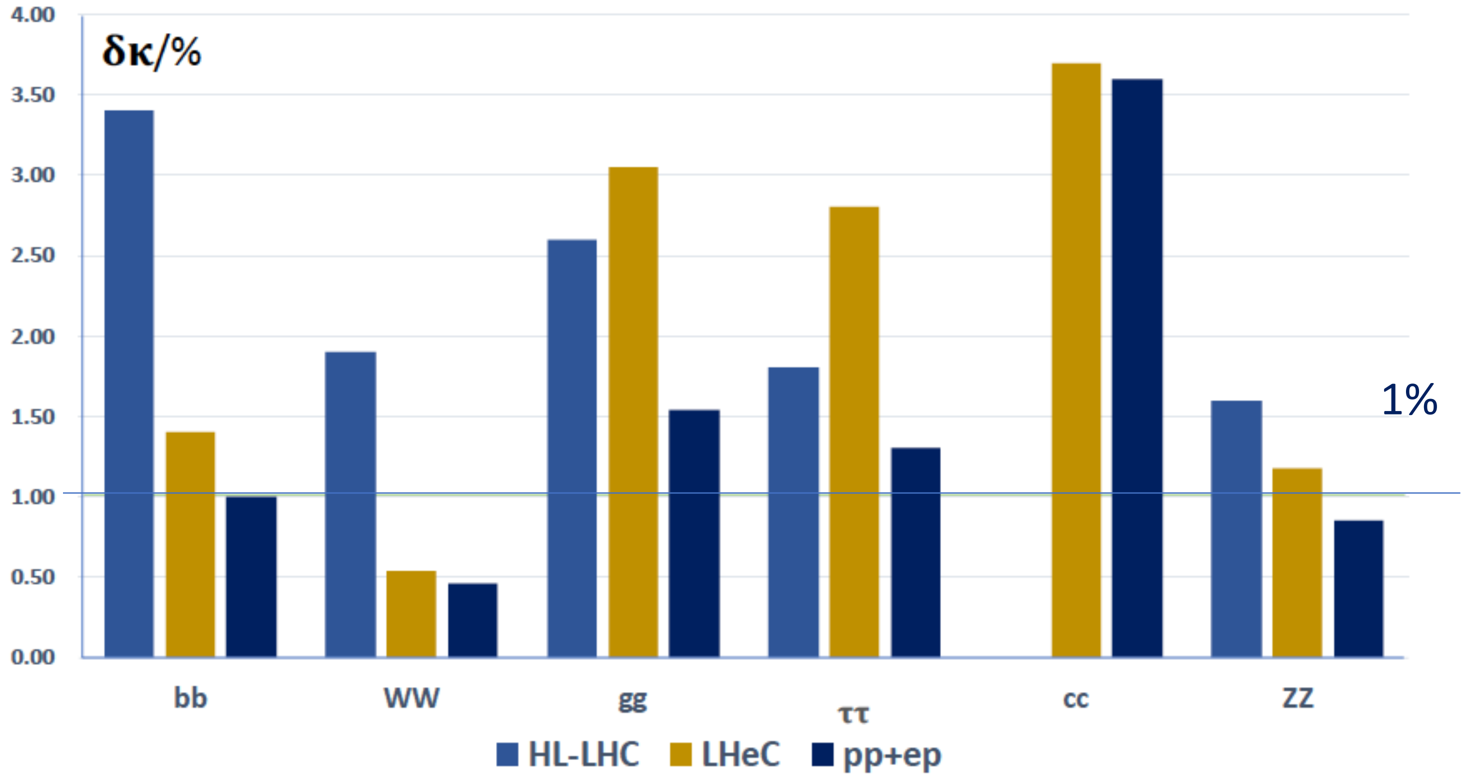




LHeC: Full error, $\Delta\chi^2=1$. EPPS $\Delta\chi^2=52$

Higgs in ep and pp [LHeC and HL-LHC]

Determination of SM Higgs couplings from pp + ep



The combined ep+pp at LHC reaches below 1% for dominant channels
ep adds charm. Analysis in EFT framework work in progress (aTGCs in ep..)

Results for FCC-eh at
20 TeV E_p x 60 GeV E_e

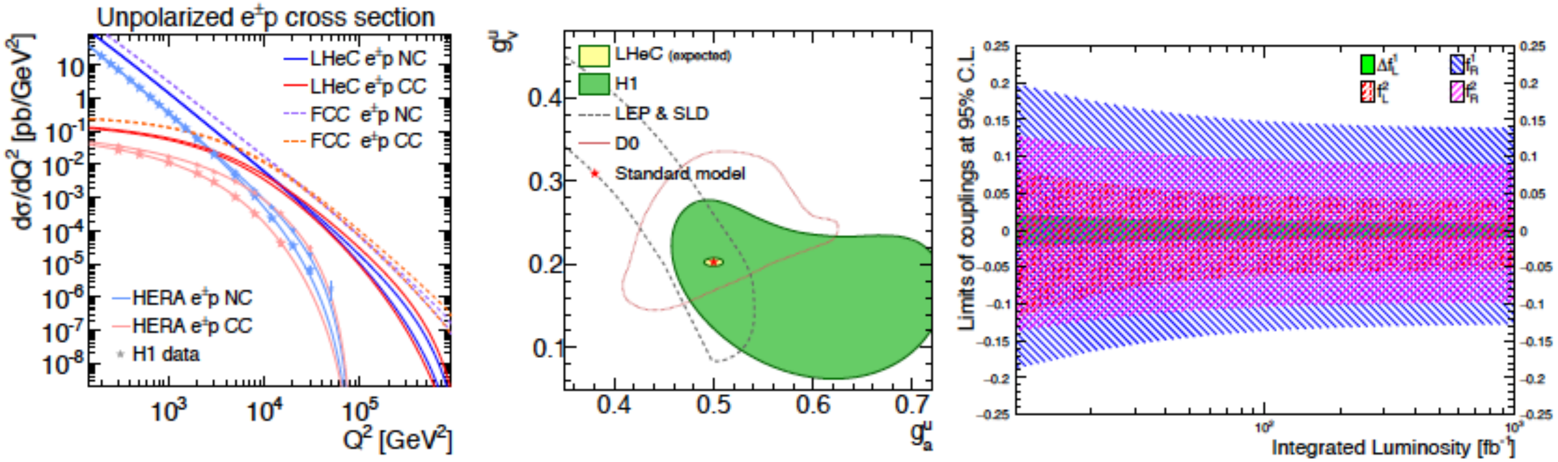
Uncertainties on kappa

Decay	FCCep	HL-LHC
bb	0.9	2.7
WW	0.3	1.2
gg	1.7	2.2
tau	1.5	1.6
cc	1.9	--
ZZ	0.5	1.0
yy	3.3	1.7

in percent. SM width.

Precision Electroweak Physics

Anomalous Wtb couplings



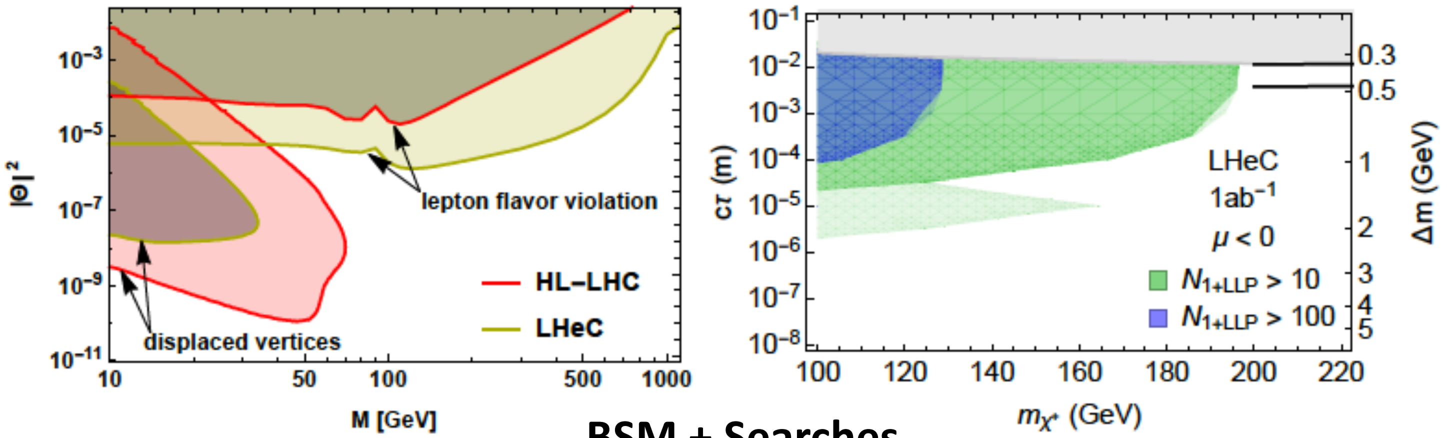
Electroweak+Top Physics

Figure 1: Left: Unpolarised inclusive NC and CC DIS cross sections as a function of Q^2 at the LHeC, in comparison to HERA (H1 [17]) and FCC-eh expectations; Middle: Determination of the up-quark weak neutral current vector and axial-vector couplings with LHeC (yellow) compared with current determinations; Right: Expected sensitivities as a function of the integrated luminosity on the SM and anomalous W_{tb} couplings [18].

cf EPS talks by
D Britzger and
C Schwanenberger

Heavy Neutrinos

Higgsinos



BSM + Searches

Figure 4: Left: Prospects for direct right-handed neutrino searches at the LHeC, first estimates for HL-LHC prospects for comparison, based on [34]. Right: Reach for long-lived Higgsinos in the mass (m_χ) - lifetime ($c\tau$) plane, compared to disappearing tracks at the HL-LHC [35], shown by the black lines. Light shading indicates the uncertainty in the predicted number of events due to different hadronization and LLP reconstruction assumptions. For details, see [36].

From LHeC strategy paper CERN-ACC-NOTE-2018-0084

MK at EPS 2019

CERN-ACC-Note-2020-0002
Version v2.0
Geneva, June 8, 2020

The Large Hadron-Electron Collider at the HL-LHC

Statement of the IAC (reproduced in CDR Update)

Members of the Committee

Sergio Bertolucci (Bologna)
Nichola Bianchi (INFN, now Singapore)
Frederick Bordy (CERN)
Stan Brodsky (SLAC)
Oliver Brüning (CERN, coordinator)
Hesheng Chen (Beijing)
Eckhard Elsen (CERN)
Stefano Forte (Milano)
Andrew Hutton (Jefferson Lab)
Young-Kee Kim (Chicago)
Max Klein (Liverpool, coordinator)
Shin-Ichi Kurokawa (KEK)
Victor Matveev (JINR Dubna)
Aleandro Nisati (Rome I)
Leonid Rivkin (PSI Villigen)
Herwig Schopper (CERN, em.DG, Chair)
Jürgen Schukraft (CERN)
Achille Stocchi (Orsay)
John Womersley (ESS Lund)

In conclusion it may be stated

- The installation and operation of the LHeC has been demonstrated to be commensurate with the currently projected HL-LHC program, while the FCC-eh has been integrated into the FCC vision;
- The feasibility of the project as far as accelerator issues and detectors are concerned has been shown. It can only be realised at CERN and would fully exploit the massive LHC and HL-LHC investments;
- The sensitivity for discoveries of new physics is comparable, and in some cases superior, to the other projects envisaged;
- The addition of an ep/A experiment to the LHC substantially reinforces the physics program of the facility, especially in the areas of QCD, precision Higgs and electroweak as well as heavy ion physics;
- The operation of LHeC and FCC-eh is compatible with simultaneous pp operation; for LHeC the interaction point 2 would be the appropriate choice, which is currently used by ALICE;
- The development of the ERL technology needs to be intensified in Europe, in national laboratories but with the collaboration of CERN;
- A preparatory phase is still necessary to work out some time-sensitive key elements, especially the high power ERL technology (PERLE) and the prototyping of Intersection Region magnets.

Recommendations

i) It is recommended to further develop the ERL based ep/A scattering plans, both at LHC and FCC, as attractive options for the mid and long term programme of CERN, resp. Before a decision on such a project can be taken, further development work is necessary, and should be supported, possibly within existing CERN frameworks (e.g. development of SC cavities and high field IR magnets).

ii) The development of the promising high-power beam-recovery technology ERL should be intensified in Europe. This could be done mainly in national laboratories, in particular with the PERLE project at Orsay. To facilitate such a collaboration, CERN should express its interest and continue to take part.

iii) It is recommended to keep the LHeC option open until further decisions have been taken. An investigation should be started on the compatibility between the LHeC and a new heavy ion experiment in Interaction Point 2, which is currently under discussion.

After the final results of the European Strategy Process will be made known, the IAC considers its task to be completed. A new decision will then have to be taken for how to continue these activities.

Herwig Schopper, Chair of the Committee, Geneva, November 4, 2019

Beyond the LHC/LHeC: FCC

The far future is least defined
There big questions will remain
and new ones shall be posed
Crucial:
LHC and 1 TeV exploration
Developments of
Accelerator Technology
Experiments
Theoretical Physics
Peace for world collaboration

pp

FCC - hh

Higgs Potential
Rare H Decays
SUSY
GUT
??

ep

FCC - eh

High Precision Higgs
BSM in multi TeV range
DIS of top, g saturation
Leptoquarks and GUT

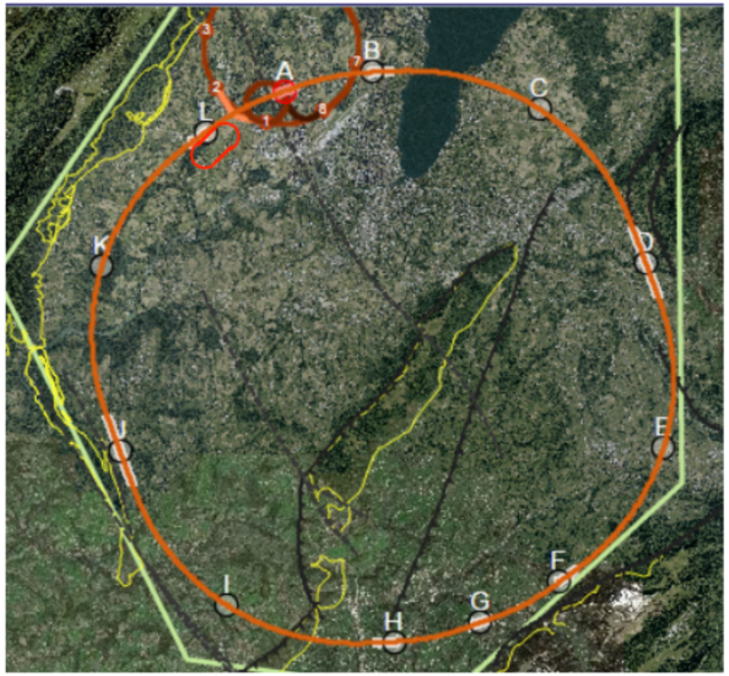
l^+l^-

CLIC, FCC - ee

High Precision Higgs
Top and BSM
Rh Neutrinos

Muon Collider ?

Neutrino Physics
Factory, Proton Decay



Higher energy than 60 GeV ?

Particle Physics has a long term future,
many of its quests are unresolved,
Nr of families, GUT, substructure, DM..

Beyond Europe: eh in China ? and the EIC

CEPC e-p and e-A Options

Y.H. Zhang

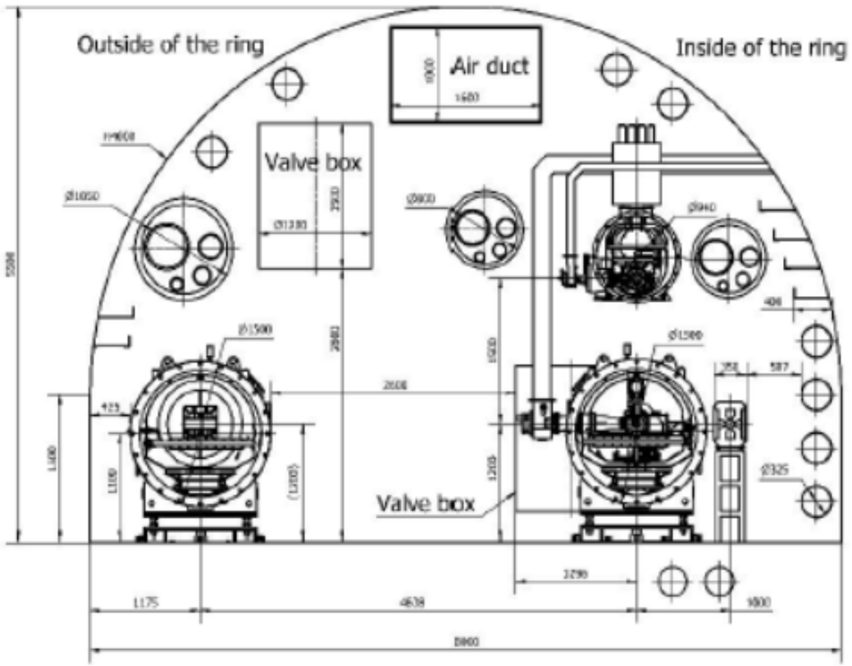
CEPC-SPPC *e-p* and *e-A* Design Parameters

Particle		Proton	Electron	Lead ($^{208}Pb^{82+}$)	Electron
Beam energy	TeV	37.5	0.12	14.8	0.12
CM energy	TeV	4.2		2.7	
Beam current	mA	730	34.8	730	34.8
Particles per bunch	10^{10}	15	0.72	0.18	0.72
Number of bunch		10080		10080	
Bunch filling factor		0.756		0.756	
Bunch spacing	ns	25	25	25	25
Bunch repetition rate	MHz	40	40	40	40
Norm. emittance, (x/y)	μm rad	2.35	282	0.22	282
Bunch length, RMS	Cm	7	0.5	7	0.5
Beta-star (x/y)	Cm	75	3.7	75	0.88
Beam spot size at IP (c/y)	Mm	6.6	6.6	3.25	3.25
Beam-beam per IP(x/y)		0.0004	0.12	0.0016	0.12
Crossing angle	mrad	~0.95		~0.95	
Hour-glass (HG) reduction		0.77		0.34	
Luminosity/nuclei per IP, with HG reduction	10^{33}/cm²/s			1.0	
Luminosity/nucleon per IP, with HG reduction	10^{33}/cm²/s	4.5		23.6	

Jie Gao, HKUST Conference, 22.1.18

Tunnel cross section at RF-section
Width: 8,000 mm. Height: 5,500 mm.

The Chinese 100km tunnel housing p and e



EICs in US and China: spin, eh complementary
US: expect support in CDi and site selection
→ CERN is the unique place for high energy eh

Remarks

LHeC and FCCeh are the only and unique possibilities to keep DIS as part of HEP in this century. A high responsibility of CERN.

The luminosity is 100-1000 times that of HERA and the kinematic range extends to $x=10^{-6}$ (LHeC) → 10^{-7} (FCC-eh)

With their BSM, PDF, small x, top, Higgs, HI .. programme they are different to EIC (like H1/ZEUS and HERMES/COMPASS) which is hosted by the NP community

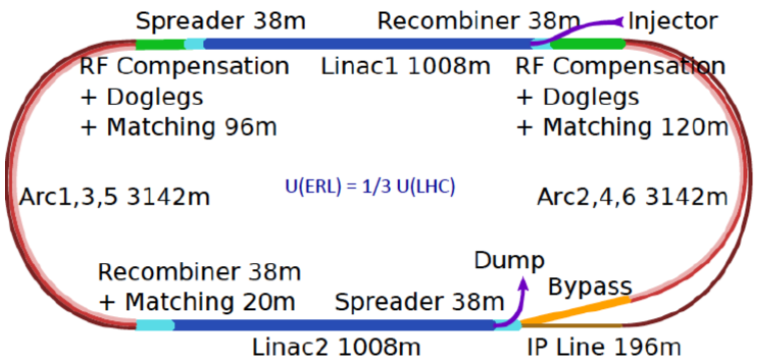
Organisation: contacts Nestor Armesto and Oliver Fischer

Talk on LHeC Machine: Oliver Bruening on 24.6. (today invited by V Shiltsev)

Many of us are interested to join

For these DIS projects to happen it will be crucial they are scrutinised and and eventually supported by the US HEP community
European Strategy paper expected to be released in June.

backup



Sustainability and Cost

LHC:
- see: SM, Higgs and no BSM
- use: Investment of O(5) BSF
- run: HL LHC until ~2040

LHeC [1206.2913]
- 1.2 TeV ep/A for O(1)BSF

→ Establish novel ep+pp Twin Collider Facility at CERN:
sustains HL LHC and bridges to CERN's long term future
For installation during LS4 (2030+) and long term use (HE LHC, FCCeh)

Three Raisons d'etre of the LHeC

Physics

- **Microscope**: World's Cleanest High Resolution
- **Empowerment** of the LHC Physics Programme
- **Creation** of a high precision, novel Higgs facility
- **Discovery** Beyond the Standard Model
- **Revolution** of Nuclear Particle Physics

Technology

Accelerator: Novel SRF ERL, green power facility
Detector: Novel high tech (CMOS..) apparatus

→ Keep accelerator and detector base uptodate while preparing for colliders that cost O(10)BSF

With many thanks to

all collaborators
from exp, acc + thy

CERN Directors

Advisory Committee
and its Chair,
H Schopper, em DG

Our home institutions and colleagues for supporting this engagement for the future

The LHeC/FCC coordinating groups and convenors

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Summary Papers submitted to the European Strategy 12/2018

CERN-ACC-NOTE-2018-0084
December 18, 2018

LHeC

Exploring the Energy Frontier with Deep Inelastic Scattering at the LHC

A Contribution to the Update of the European Strategy on Particle Physics

LHeC and PERLE Collaboration

LHeC also described in the ES paper by A.Caldwell, A.Levy, R.Ent, P.Newman and F.Olness

CERN-ACC-NOTE-2018-0086 December 18, 2018

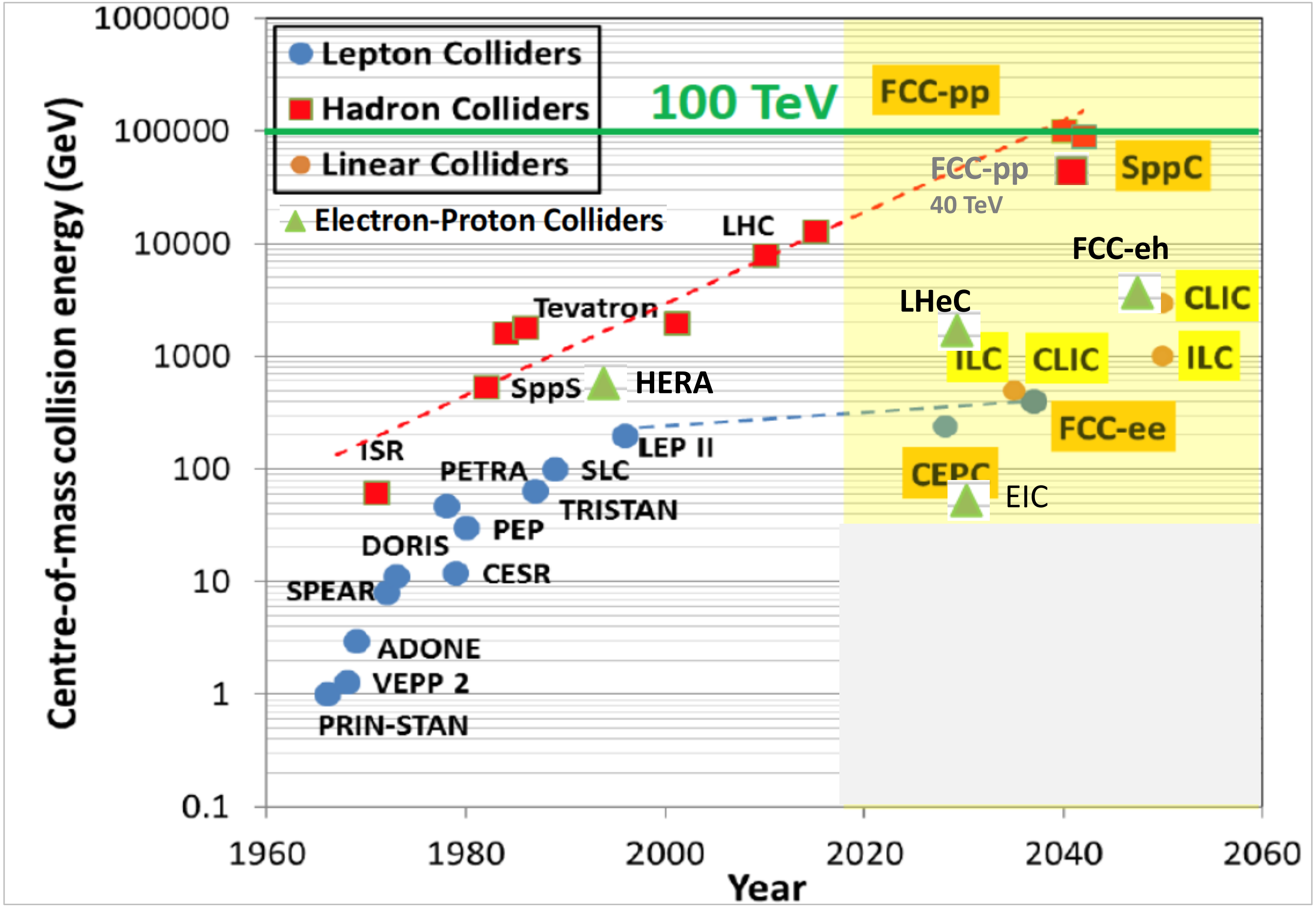
PERLE

PERLE : A High Power Energy Recovery Facility for Europe

A Contribution to the Update of the European Strategy on Particle Physics

Cockcroft Institute, AsTEC Daresbury, TU Darmstadt, BINP Novosibirsk, CERN, Liverpool University, IPN and LAL Orsay, Jefferson Laboratory, CEA Saclay

Hundred Years of HEP Colliders



ep/A Parameters:

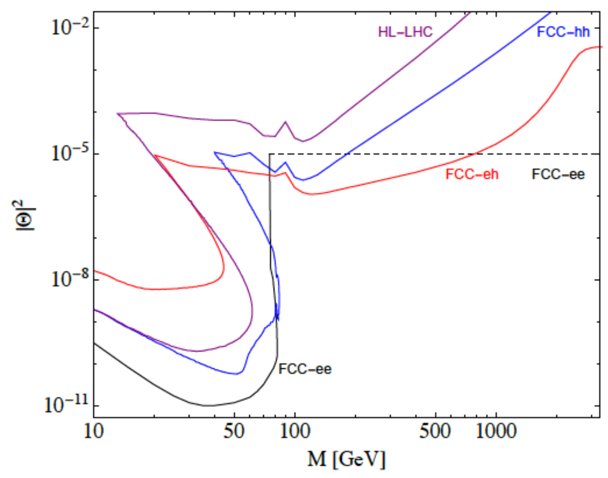
Oliver Brüning[1], John Jowett[1], Max Klein[2], Dario Pellegrini[1], Daniel Schulte[1], Frank Zimmermann[1]

EDMS 17979910 | FCC-ACC-RPT-0012

FCC-eh in the CDR [V1 Physics and V3 hh]

Volume 1 had been the collaborative effort to present **the entity of FCC physics, in ee, pp and ep, including AA and eA**
Volume 3 on FCC hh contains a short summary of **the main characteristics of FCC-eh and the detector concept**

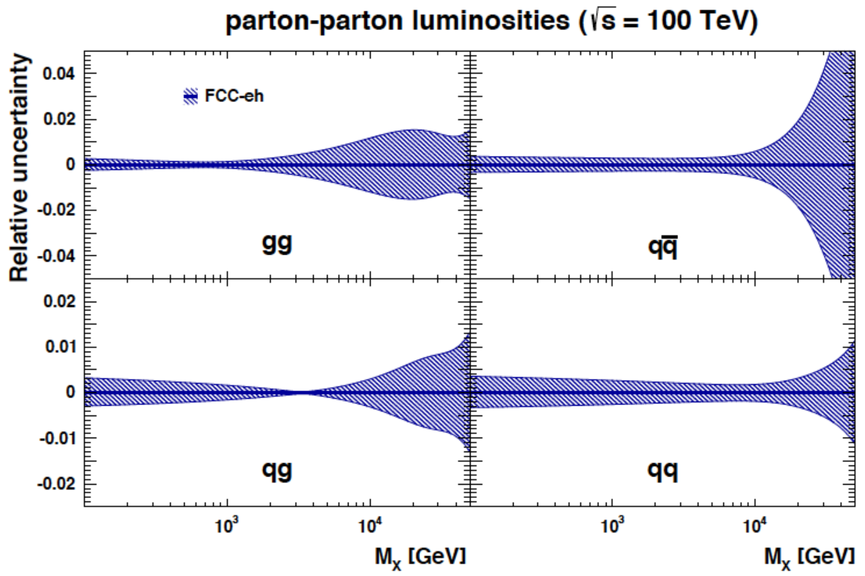
Some striking physics eh prospects are on searches and the high precision measurements on Higgs and proton structure:



Complementary prospects to **discover rh massive neutrinos** in ee, ep and pp
[mixing angle vs mass]

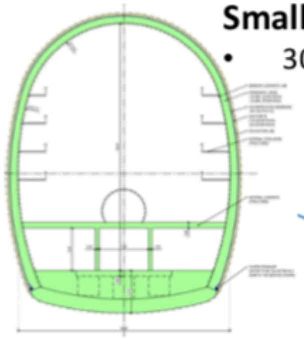
Collider	FCC-ee	FCC-eh
Luminosity (ab^{-1})	+1.5 @ 365 GeV	2
Years	3+4	20
$\delta\Gamma_H/\Gamma_H$ (%)	**1.3**	SM
$\delta g_{HZZ}/g_{HZZ}$ (%)	**0.17**	0.43
$\delta g_{HWW}/g_{HWW}$ (%)	**0.43**	0.26
$\delta g_{Hbb}/g_{Hbb}$ (%)	**0.61**	0.74
$\delta g_{Hcc}/g_{Hcc}$ (%)	**1.21**	1.35
$\delta g_{Hgg}/g_{Hgg}$ (%)	**1.01**	1.17
$\delta g_{H\tau\tau}/g_{H\tau\tau}$ (%)	**0.74**	1.10
$\delta g_{H\mu\mu}/g_{H\mu\mu}$ (%)	**9.0**	n.a.
$\delta g_{H\gamma\gamma}/g_{H\gamma\gamma}$ (%)	**3.9**	2.3
$\delta g_{Htt}/g_{Htt}$ (%)	–	1.7
BR_{EXO} (%)	< 1.0	n.a.

Prospects for high precision measurements of **Higgs couplings at FCC ee and ep**. Note ee gets the width with Z recoil. ee is mainly ZHZ, while ep is mainly WWH: complementary also to pp

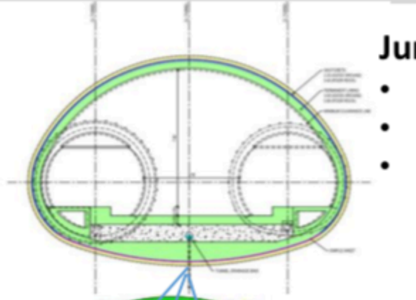


Unique resolution of partonic contents of and dynamics inside the proton, providing precise and independent parton luminosities for interpretation and searches on FCC-hh

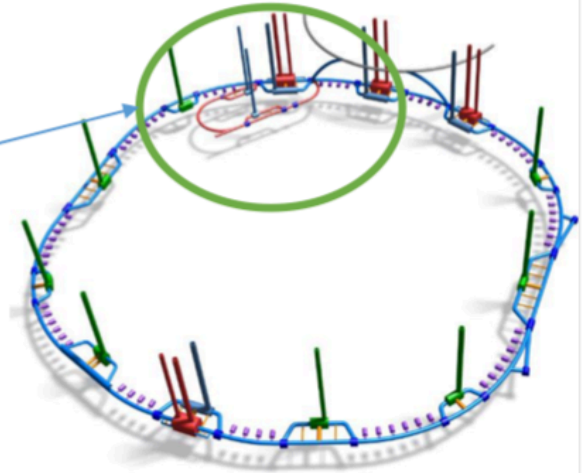
Scope of FCC-eh Structures

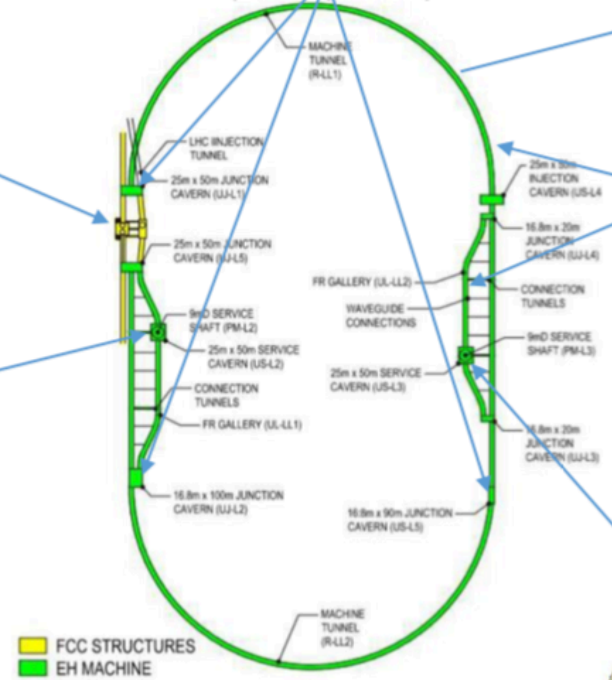


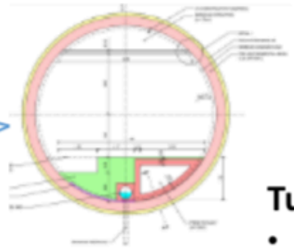
Small Experimental Caverns
- 30 m x 35 m x 66m



Junction Caverns
- 16.8 m x 15 m x 100 m
- 25 m x 15 m x 50 m
- 16.8 m x 15 m x 90 m

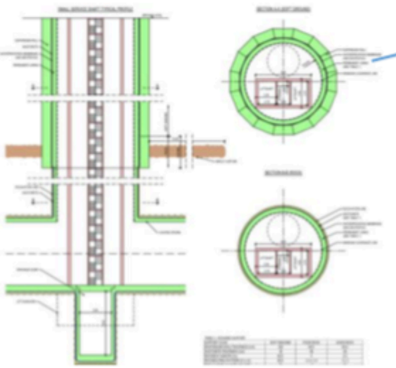


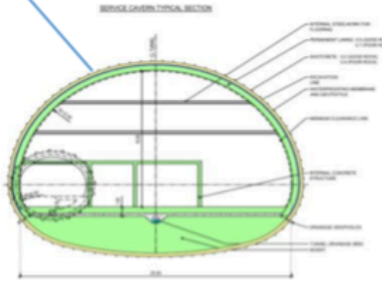




Tunnels:
- 9.091 km of 5.5m dia. machine tunnel.
- 2 x 1.04 km of 5.5m dia RF tunnel.

Shafts:
2 x Service shafts:
9 m dia. x 175 m depth





Service Caverns
- 25 m x 15 m x 50 m

title