Future Deep Inelastic Scattering at High Energies

High Energies
Default Electron Accelerator Design
Demonstration of ERL
Realisations
Detectors
Key Physics Subjects
Prospects

Max Klein
University of Liverpool
for the LHeC Collaboration

For all references,
please consult
lhec.web.cern.ch

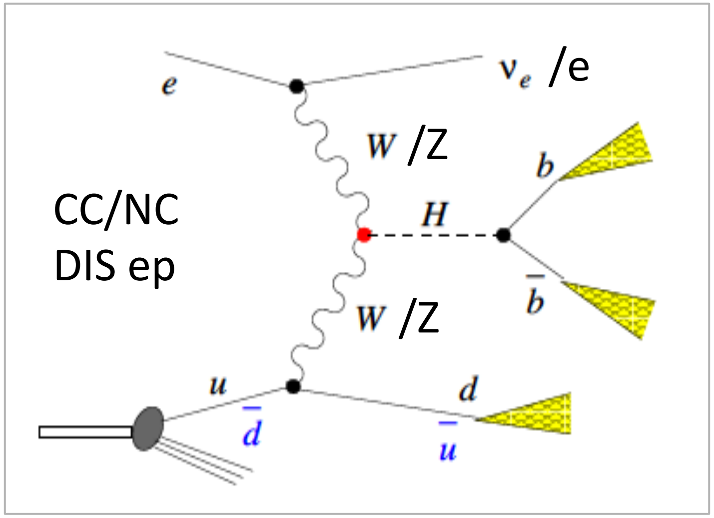
Dedicated to Isabelle Irene Poncette (11.7.1988-24.7.2016)

ICHEP Conference, Chicago, USA, 5th of August 2016

A Revival of electron-proton (ion) colliders following HERA

ep colliders 11.2014 Max Klein	CEPC	MEIC	eRHIC	HERA 92-07	CepC	LHeC	SepC	FCC-he
$\sqrt{s}$/GeV	**13**	**35**	**122**	**319**	**1000**	**1300**	**3375**	**3464**
L/10^{33} $cm^{-2}s^{-1}$	0.4	5.6	1.5	0.04	4.8	16	8.9	10
E_e /GeV	3	5	15.9	27.6	120	60	80	60
E_p /GeV	15	60	250	920	2100	7000	35600	50000
f /MHz	500	750	9.4	10.4	20	40	40	40
$N_{e/p}10^{10}$	3.7/0.54	2.5/0.42	3.3/3	3/7	1.3/16.7	0.4/22	3.3/5	0.5/10
$\varepsilon_{e/p}$ /µm	.03/.15	54/.35	32/.27	4.6/.09y	250/1	20/2.5	7.4/2.4	10/2
$\beta^*_{e/p}$/cm	10/2	10/2	5/5	28/18 y	4.2/10	10/5	9.3/75	9/40
comment	Lanzhou	full acc.	“Day1”	HERA II	Booster	ERL (H)	$E_e = M_W$	ERL (HH)
source	X.Chen July 14	McKoewn POETIC14	Litvinenko S.Brook 14	B.Holzer at CERN 2008	Y.Peng Oct. 2014	Frank Z. LHeC 2014	Y.Peng Oct. 2014	Frank Z. IPAC 2014

High Energy and Luminosity ep Scattering

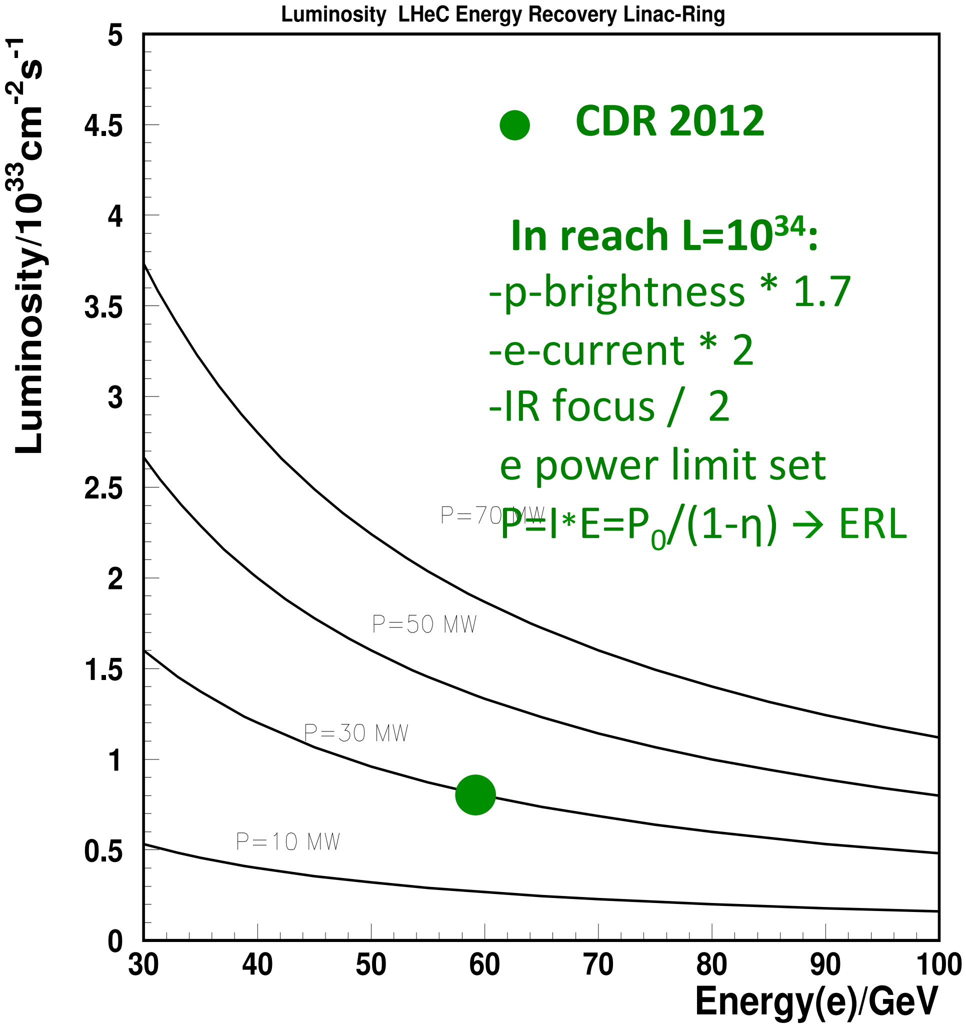


E_p=7 – 14 – 50 TeV (HL,HE LHC, FCC)
→ the energy frontier is at CERN
E_e= 60 GeV, lower: cost, higher: H,BSM

Current working point for LHeC
- 60 GeV: 200fb = σ(WW→ H) in e^-p
- 10^{34} → 1ab^{-1} [all of L(HERA) in days]

$s=4E_eE_p$ → $Q^2_{max} = s = 10^6$ GeV^2 (10^7 at FCC)
x_{Bj} ~ 1/s : down to $10^{-6\,(-7)}$ for Q^2 =1 GeV^2
High luminosity enables to access x → 1

$$\boxed{L = \frac{1}{4\pi} \cdot \frac{N_p}{\varepsilon_p} \cdot \frac{1}{\beta^*} \cdot \gamma \cdot \frac{I_e}{e}}$$

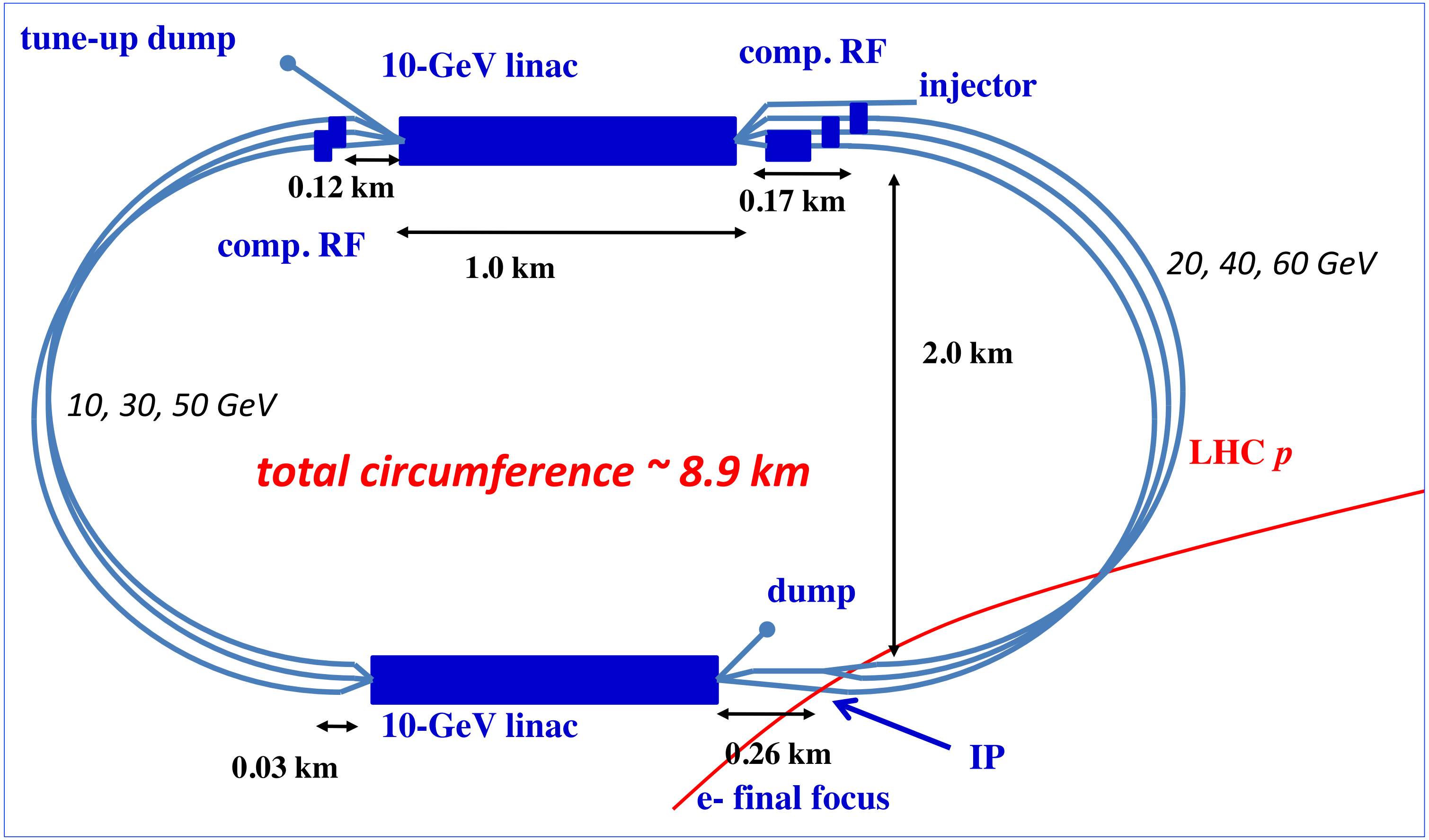


● **CDR 2012**

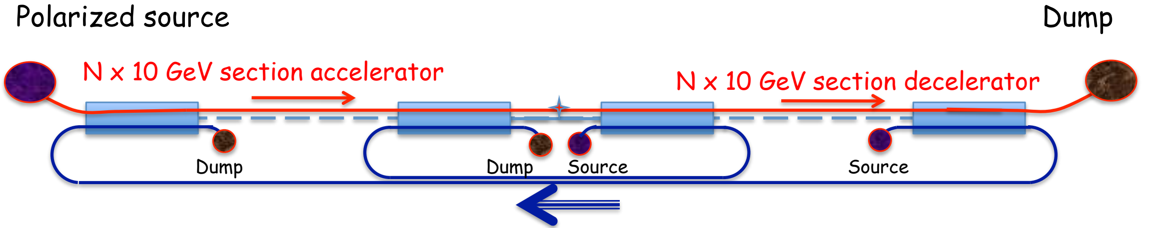
In reach L=10^{34}:
-p-brightness * 1.7
-e-current * 2
-IR focus / 2
e power limit set
P=I*E=P_0/(1-η) → ERL

Default Electron Accelerator Configuration

Conceptual Design Report arXiv:1206.2913



Non default: An expensive generalisation to achieve E_e= 500 GeV or more



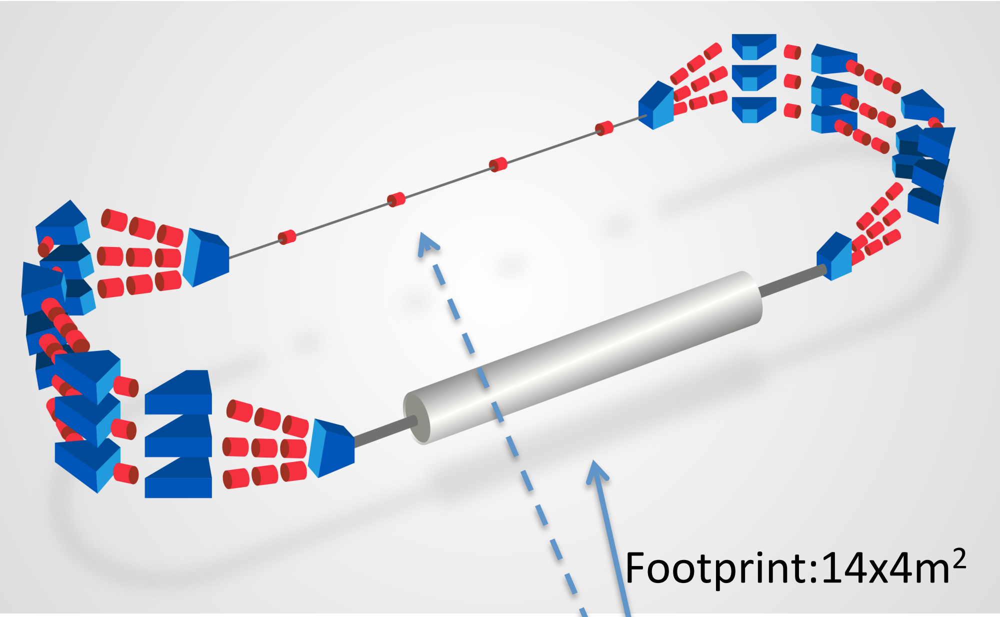
Energy flux is carried out by 10 GeV beams

LHeC Demonstrator

Demonstration of high current (10mA), multi(3)turn ERL

Test and development of 802MHz SCRF technology

E_e = 200 (400) MeV with 1(2) module



Parameter	Value
Dipoles per arc	3/4
Dipole length	50 cm
Max B Field	1.1 T
Quadrupoles per arc	5
Quadrupoles in straight lines	4
Dipoles in Spreader/Combiner	1-3
Quads in Spreader/Combiner	3
Dipoles for Injection-Extraction	6

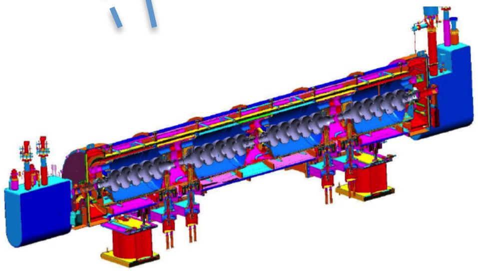


Figure 3.9: SNS high β module adapted to house β =1 5-cell cavities for LHeC.

BINP, CERN, Daresbury, Jlab, Liverpool, Orsay (LAL/INP),+

Collaboration being established
802 MHz cavity soon produced

PERLE CDR to be published, ICFA Beam Newsletter 68 (2016)

802 MHz Cavity Parameters

design to also test FCC-ee

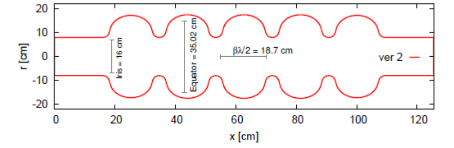
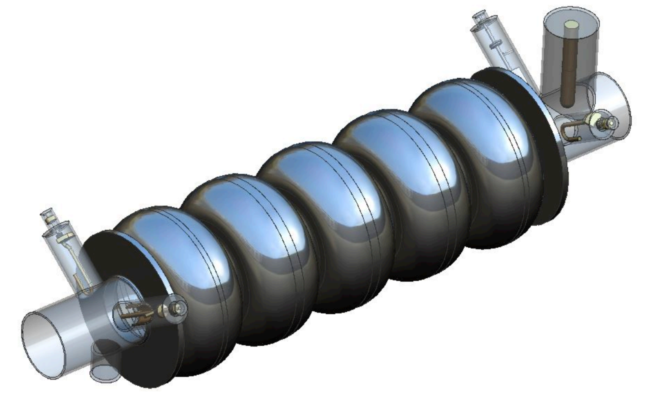


Fig. 6: Envelope of the second version of the five-cell ERL cavity at 802 MHz with 16 cm aperture.

CERN-ACC-NOTE-2015-xxx
28-05-2015
Rama.Calaga@cern.ch

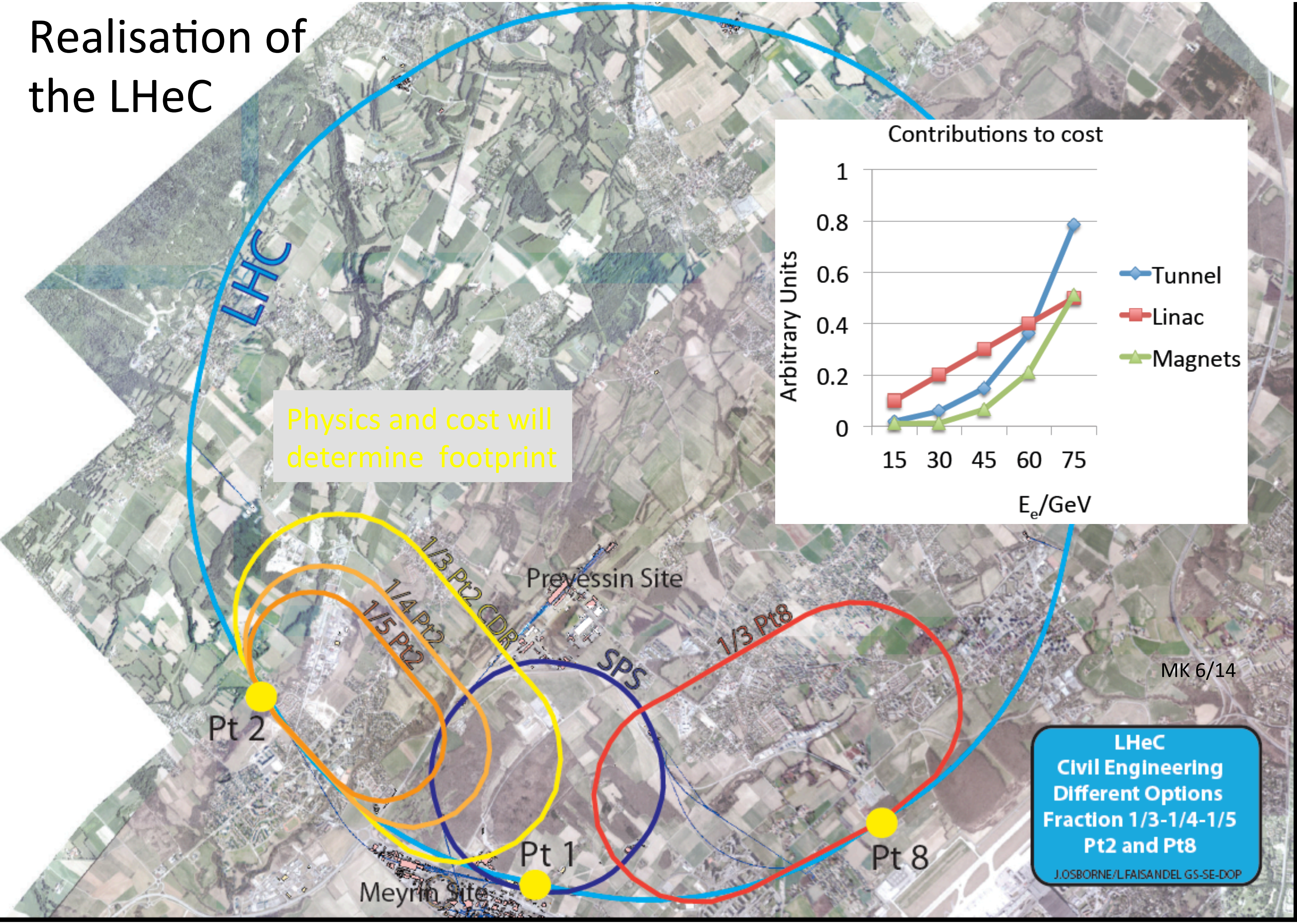
Parameter	Unit	Value	Value	Value		Value	
cavity type		**LHeC prototype (2016)**	LHeC study (2015)	LHeC study (2015)		LHeC Ver. 1	LHeC Ver. 2
frequency	MHz	**801.58**	802	802		801.58	801.58
number of cells		**5**	5	5		5	5
L_{active}	mm	**917.91**	922.31	922.14		935	935
R/Q = $V_{eff}^2/(\omega * W)$	Ω	**523.7**	580.1	5			3
R/Q/cell	Ω	**104.7**	116.0	1			6
G	Ω	**274.6**	273.2	2			3
R/Q·G/cell		**28765**	31702	3			44
Eq. Diameter	mm	**327.95**	323.12	32			.2
Iris Diameter	mm	**130**	115				0
Tube Diameter	mm	**130**	140				0
Eq./Iris ratio		**2.52**	2.81	2			9
Wall angle (mid-cell)	deg	**0**	0				5
E_{peak}/E_{acc} (mid-cell)		**2.26**	2.07	2			0
B_{peak}/E_{acc} (mid-cell)	mT/(MV/m)	**4.20**	4.00	4.00		4.77	4.92
k_{cc}	%	**3.22**	2.14	2.14		4.47	5.75
N^2/k_{cc}		**7.78**	11.71	11.71		5.59	4.35
cutoff TE_{11}	GHz	**1.35**	1.26	1.53		1.17	1.10
cutoff TM_{01}	GHz	**1.77**	1.64	2.00		1.53	1.43



Detail end group + flange locations → build

F.Marhauser, B.Rimmer, J.Henry (Jlab) + R.Calaga, E.Jensen, K. Schirm et al (CERN) [4.8.16]

Realisation of the LHeC

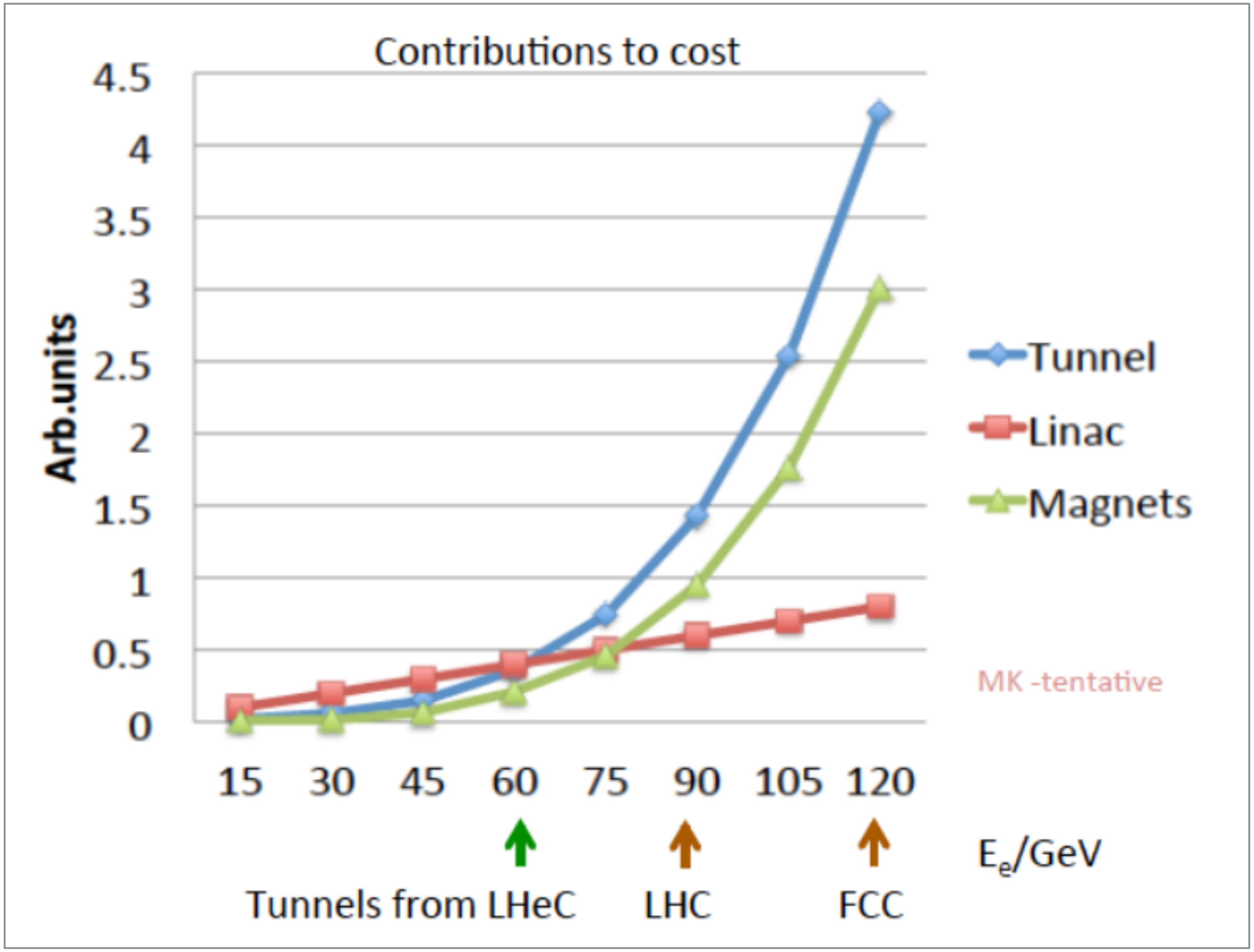


Physics and cost will determine footprint

LHeC
Civil Engineering
Different Options
Fraction 1/3-1/4-1/5
Pt2 and Pt8
J.OSBORNE/L.FAISANDEL GS-SE-DOP

MK 6/14

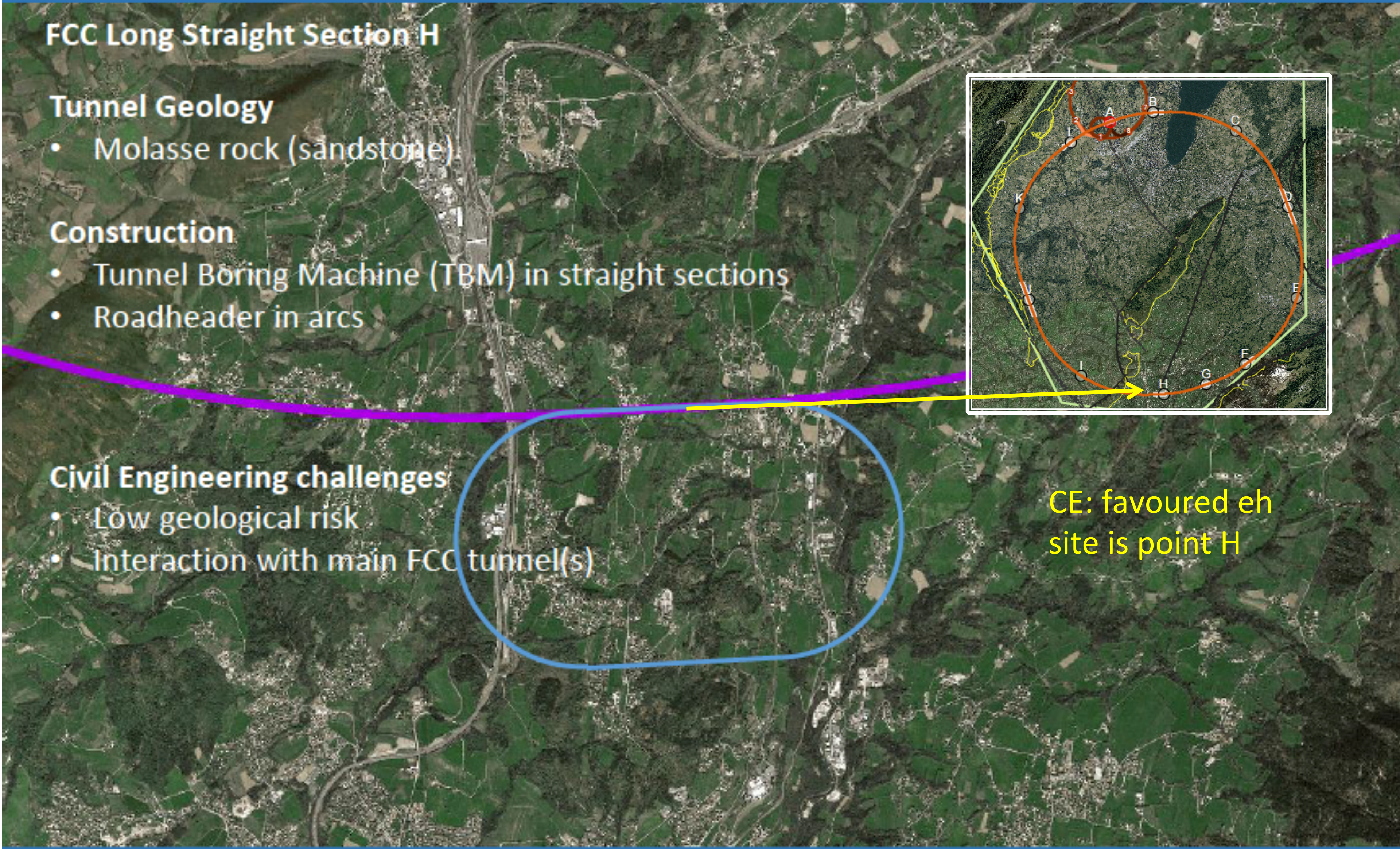
Choice of FCC_eh Baseline Configuration = f(cost,E_e,s)



→ Cost strongly rising with tunnel circumference. Presently stick to LHeC default.
→ Maximise independence of ring installation, design for synchronous ep and pp OP

FCC-he Civil Engineering

FCC-he Point H



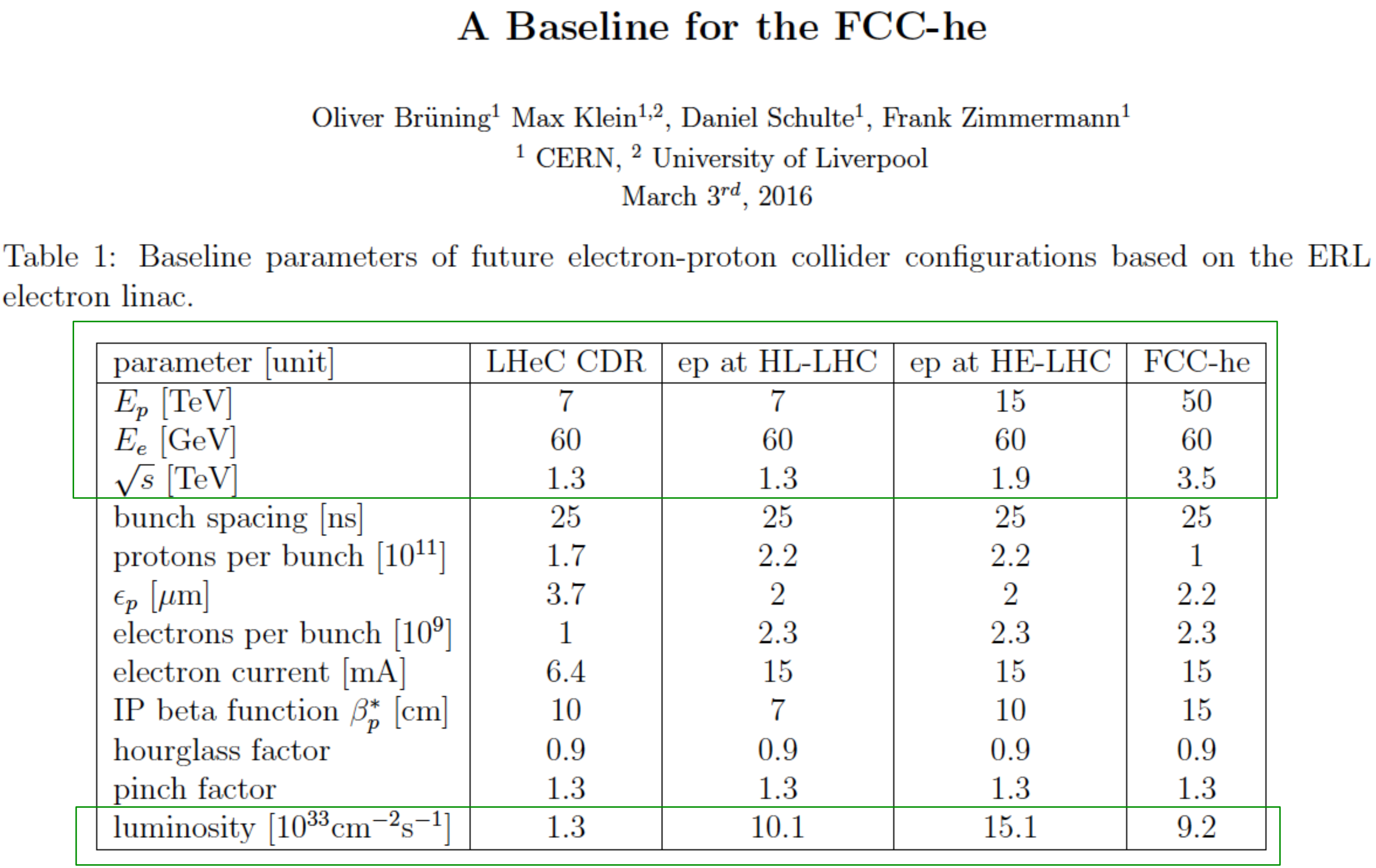
FCC Long Straight Section H

Tunnel Geology
- Molasse rock (sandstone)

Construction
- Tunnel Boring Machine (TBM) in straight sections
- Roadheader in arcs

Civil Engineering challenges
- Low geological risk
- Interaction with main FCC tunnel(s)

CE: favoured eh site is point H



A Baseline for the FCC-he

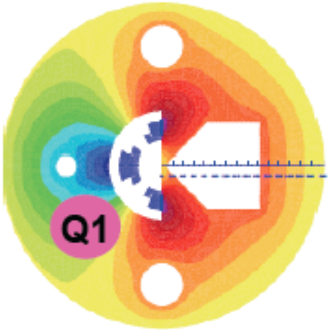
Oliver Brüning[1] Max Klein[1,2], Daniel Schulte[1], Frank Zimmermann[1]
[1] CERN, [2] University of Liverpool
March 3rd, 2016

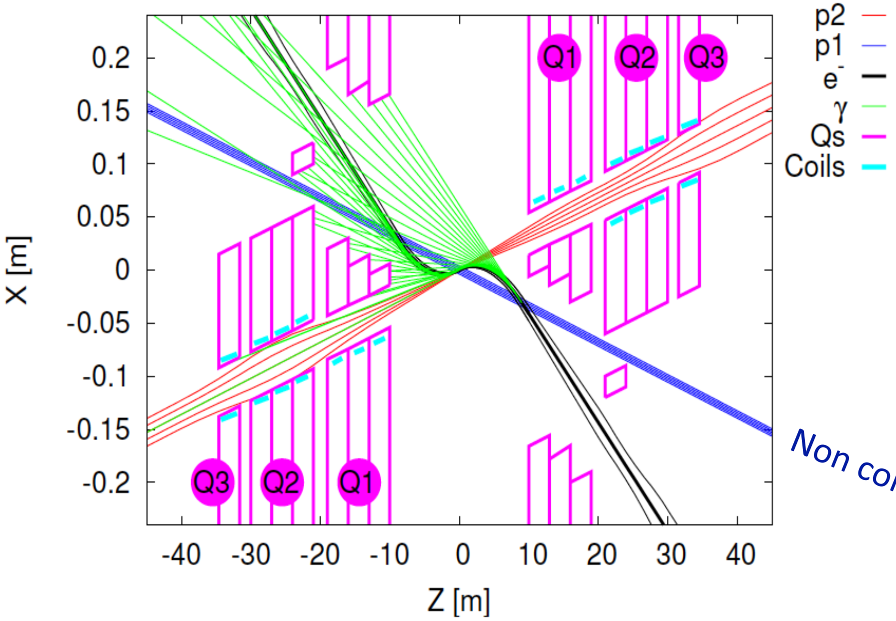
Table 1: Baseline parameters of future electron-proton collider configurations based on the ERL electron linac.

parameter [unit]	LHeC CDR	ep at HL-LHC	ep at HE-LHC	FCC-he
E_p [TeV]	7	7	15	50
E_e [GeV]	60	60	60	60
$\sqrt{s}$ [TeV]	1.3	1.3	1.9	3.5
bunch spacing [ns]	25	25	25	25
protons per bunch [10^{11}]	1.7	2.2	2.2	1
ϵ_p [μm]	3.7	2	2	2.2
electrons per bunch [10^9]	1	2.3	2.3	2.3
electron current [mA]	6.4	15	15	15
IP beta function β_p^* [cm]	10	7	10	15
hourglass factor	0.9	0.9	0.9	0.9
pinch factor	1.3	1.3	1.3	1.3
luminosity [10^{33}cm^{-2}s^{-1}]	1.3	10.1	15.1	9.2

work in progress (also eA)

Interaction Regions for ep with Synchronous pp Operation

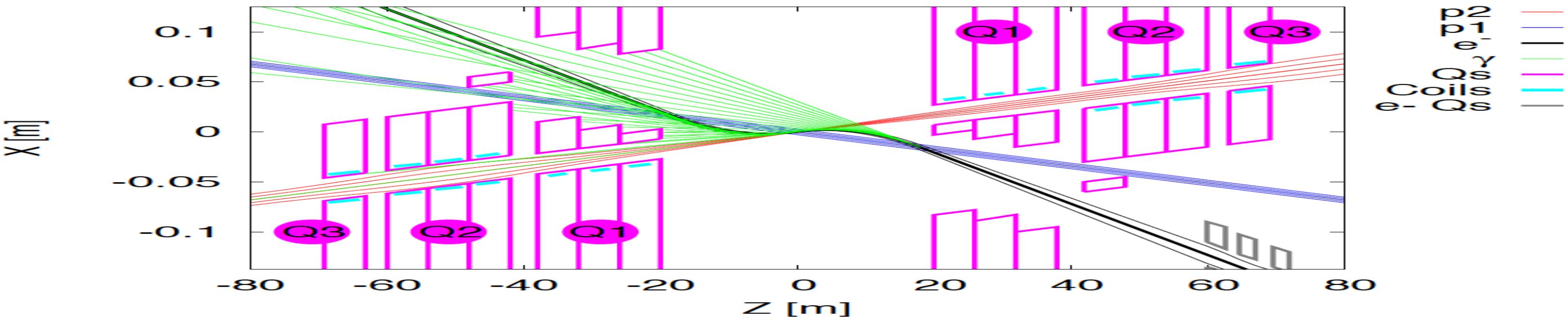




Non colliding p beam

LHeC (CDR)
60 GeV * 7 TeV

Still work in progress:
may not need half
quad if L*(e) < L*(p)

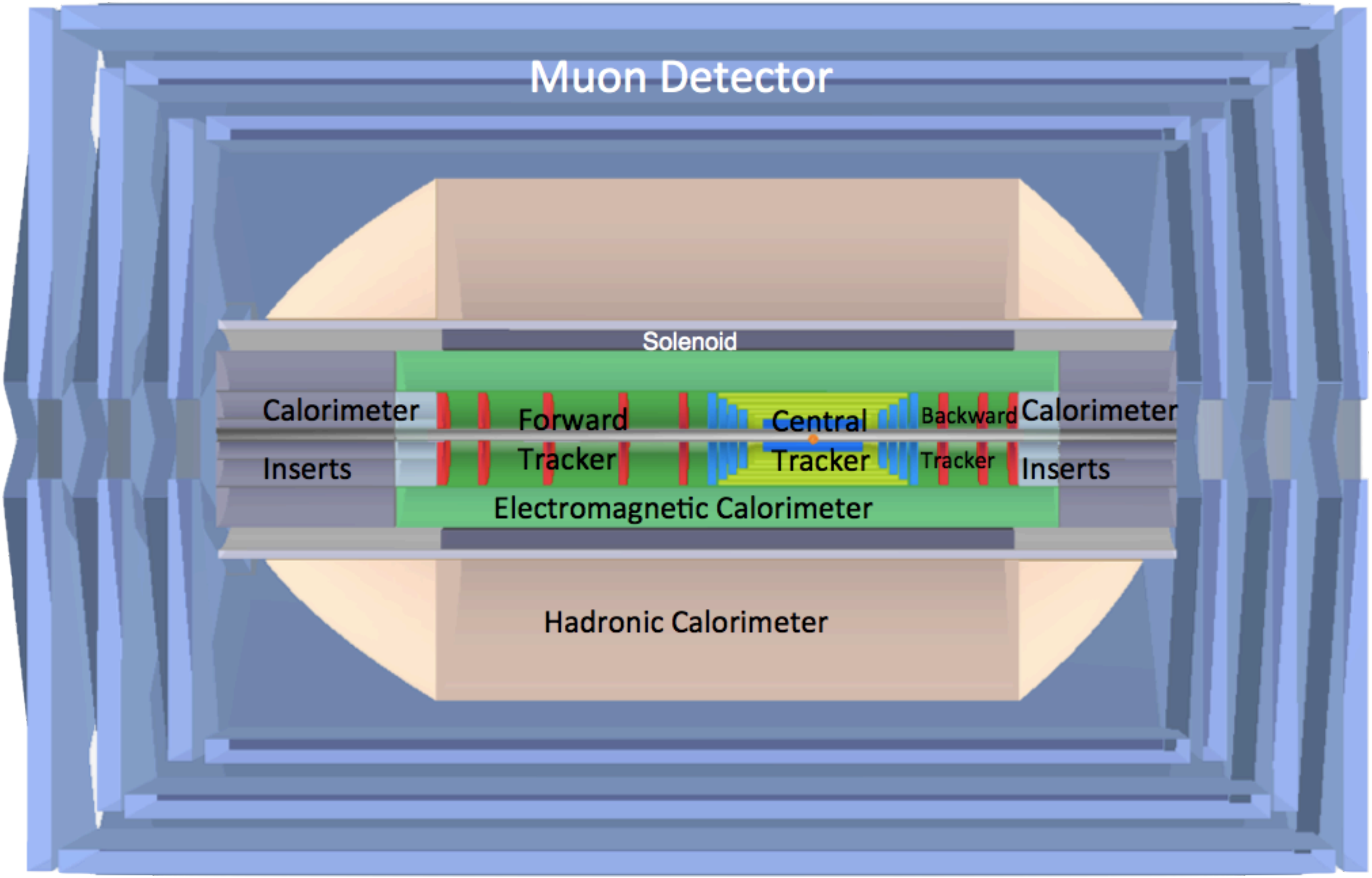


Tentative: ε_p=2μm, β^*=20cm → σ_p=3μm ≈σ_e matched! ε_e=5μm ..

FCC-he (ERL)
60 GeV * 50 TeV

Rogelio Tomas et al

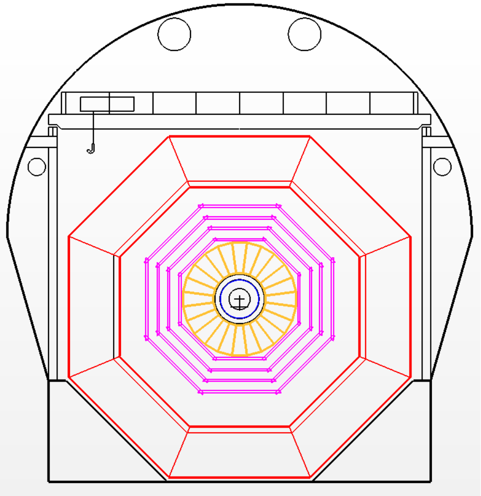
LHeC Detector Overview



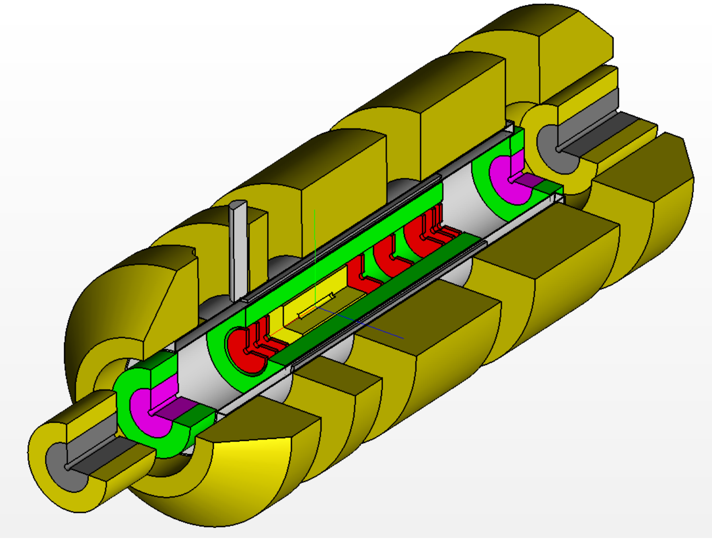
Detector option 1 for LR and full acceptance coverage

Forward/backward asymmetry in energy deposited and thus in geometry and technology
Present dimensions: LxD =14x9m^2 [CMS 21 x 15m^2, ATLAS 45 x 25 m^2]
Taggers at -62m (e), 100m (γ,LR), -22.4m (γ,RR), +100m (n), +420m (p)

Installation Study

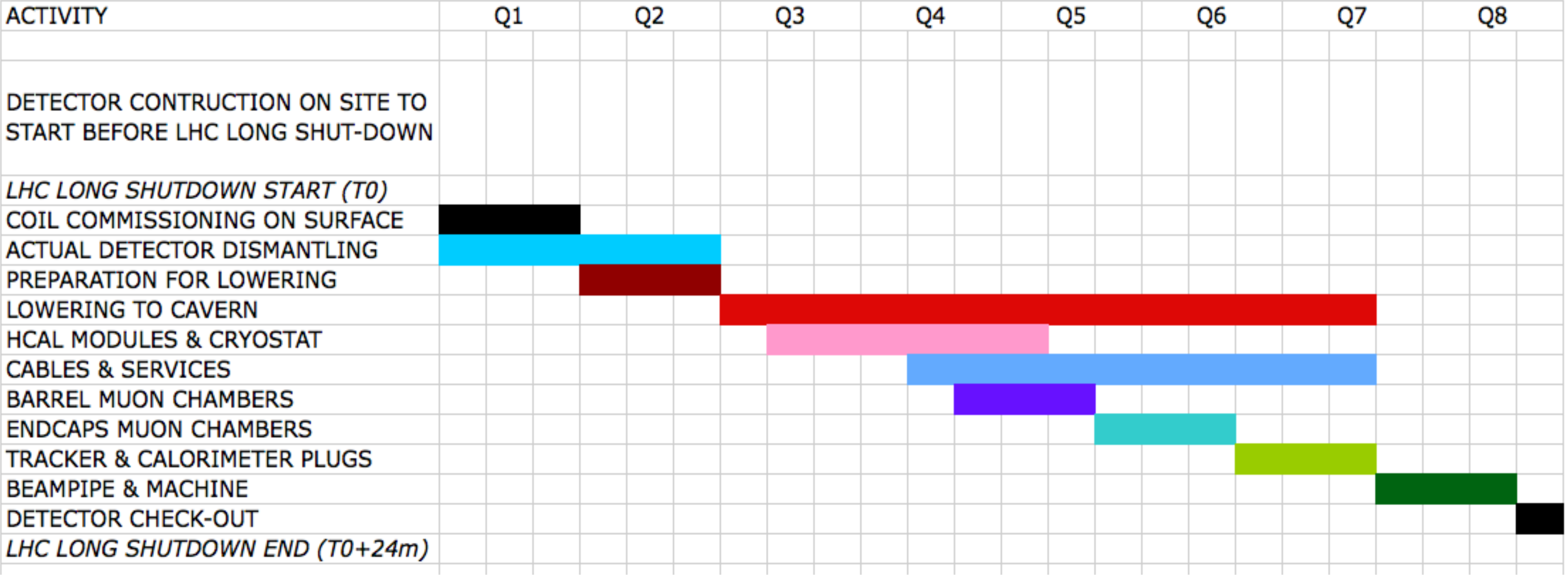


Detector fits in L3 magnet support



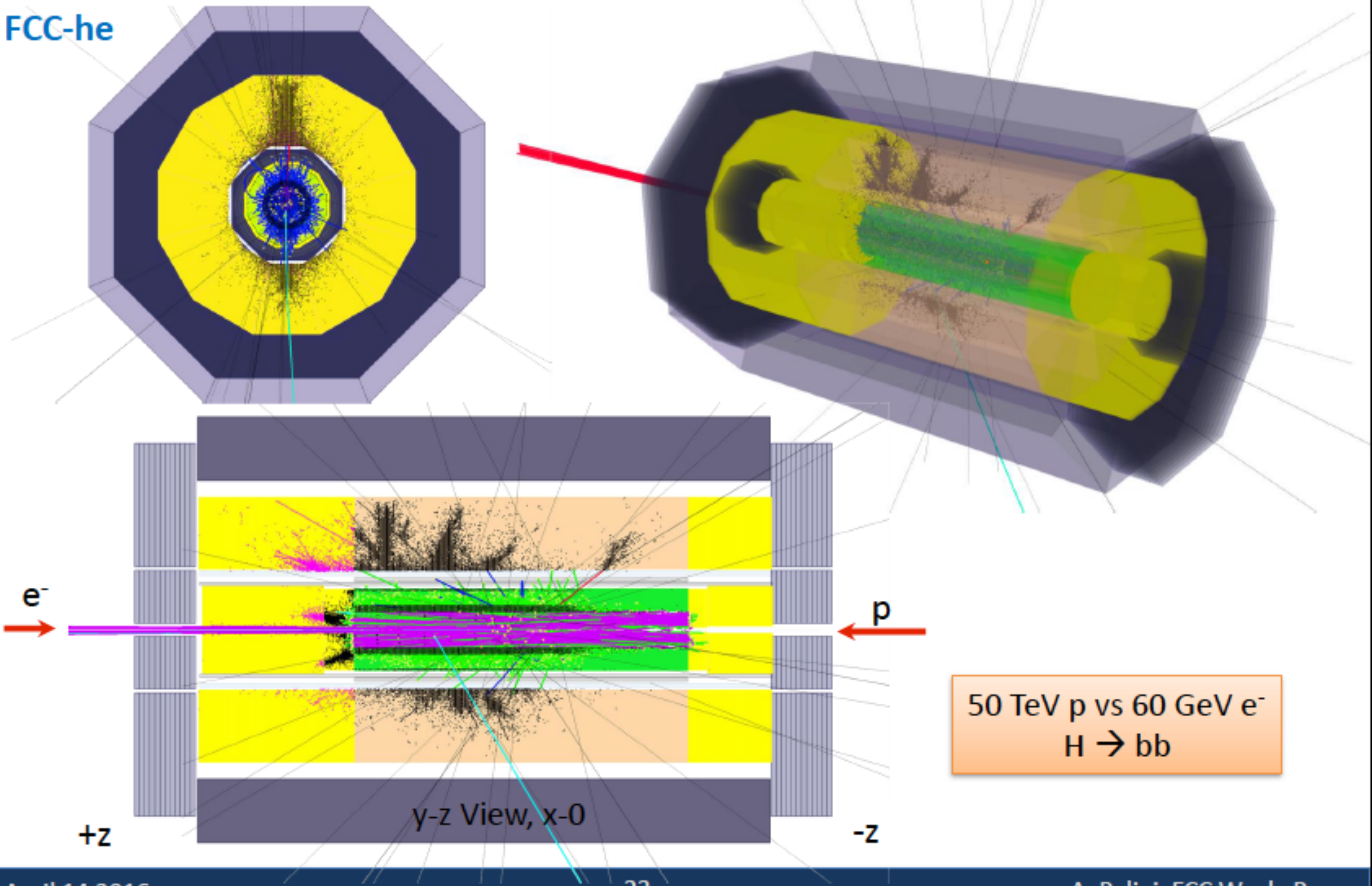
Modular structure

LHeC INSTALLATION SCHEDULE



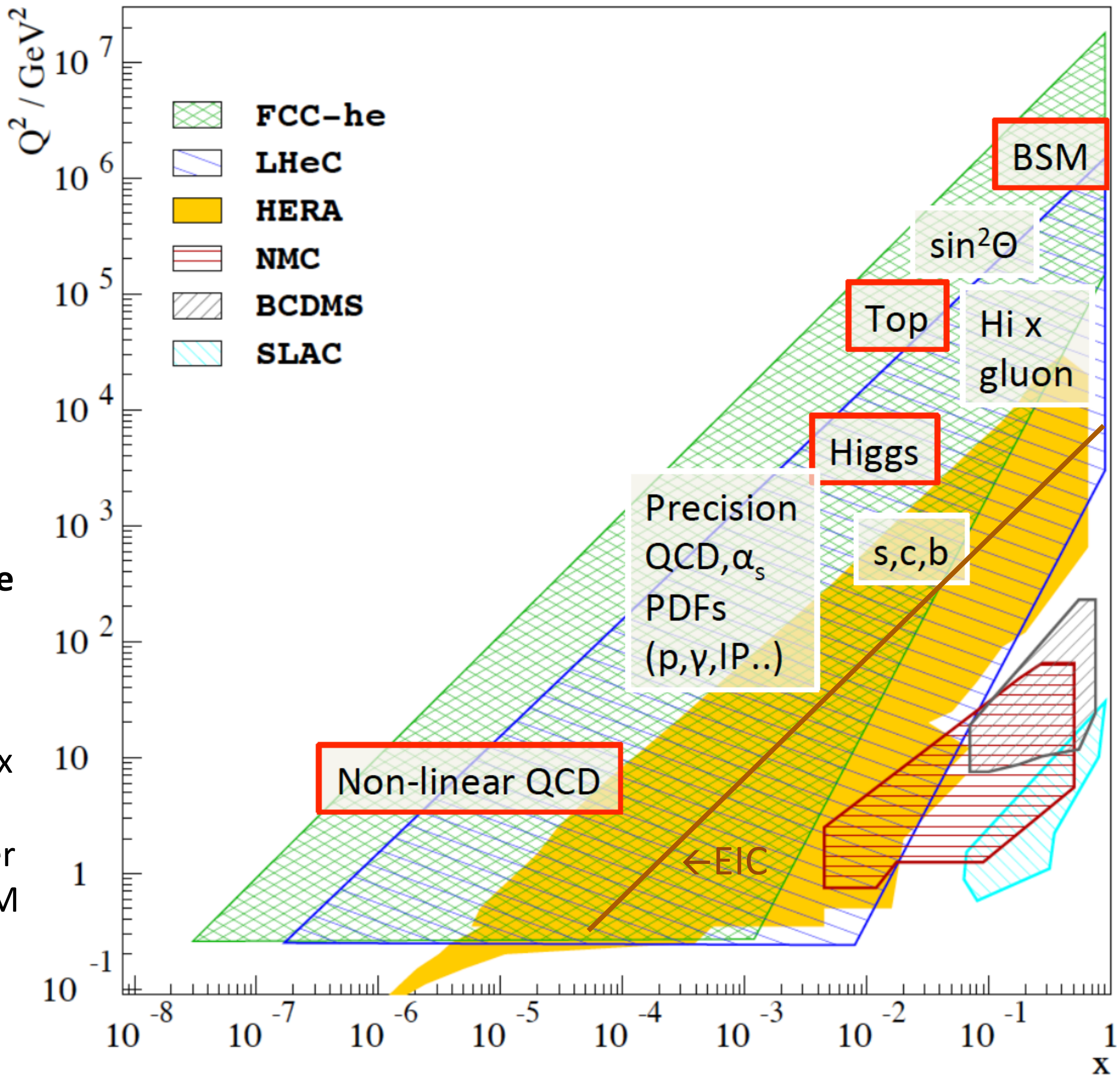
ACTIVITY	Q1			Q2			Q3			Q4			Q5			Q6			Q7			Q8		
DETECTOR CONTRUCTION ON SITE TO START BEFORE LHC LONG SHUT-DOWN																								
LHC LONG SHUTDOWN START (T0)																								
COIL COMMISSIONING ON SURFACE	■	■	■																					
ACTUAL DETECTOR DISMANTLING	■	■	■	■	■	■																		
PREPARATION FOR LOWERING				■	■	■																		
LOWERING TO CAVERN							■	■	■	■	■	■	■	■	■	■	■	■	■	■				
HCAL MODULES & CRYOSTAT								■	■	■	■	■	■											
CABLES & SERVICES											■	■	■	■	■	■	■	■	■	■				
BARREL MUON CHAMBERS												■	■	■										
ENDCAPS MUON CHAMBERS															■	■	■							
TRACKER & CALORIMETER PLUGS																		■	■	■				
BEAMPIPE & MACHINE																					■	■	■	
DETECTOR CHECK-OUT																								■
LHC LONG SHUTDOWN END (T0+24m)																								

First FCC-eh Simulations



50 TeV p vs 60 GeV e^-
H → bb

Summary of ep Physics



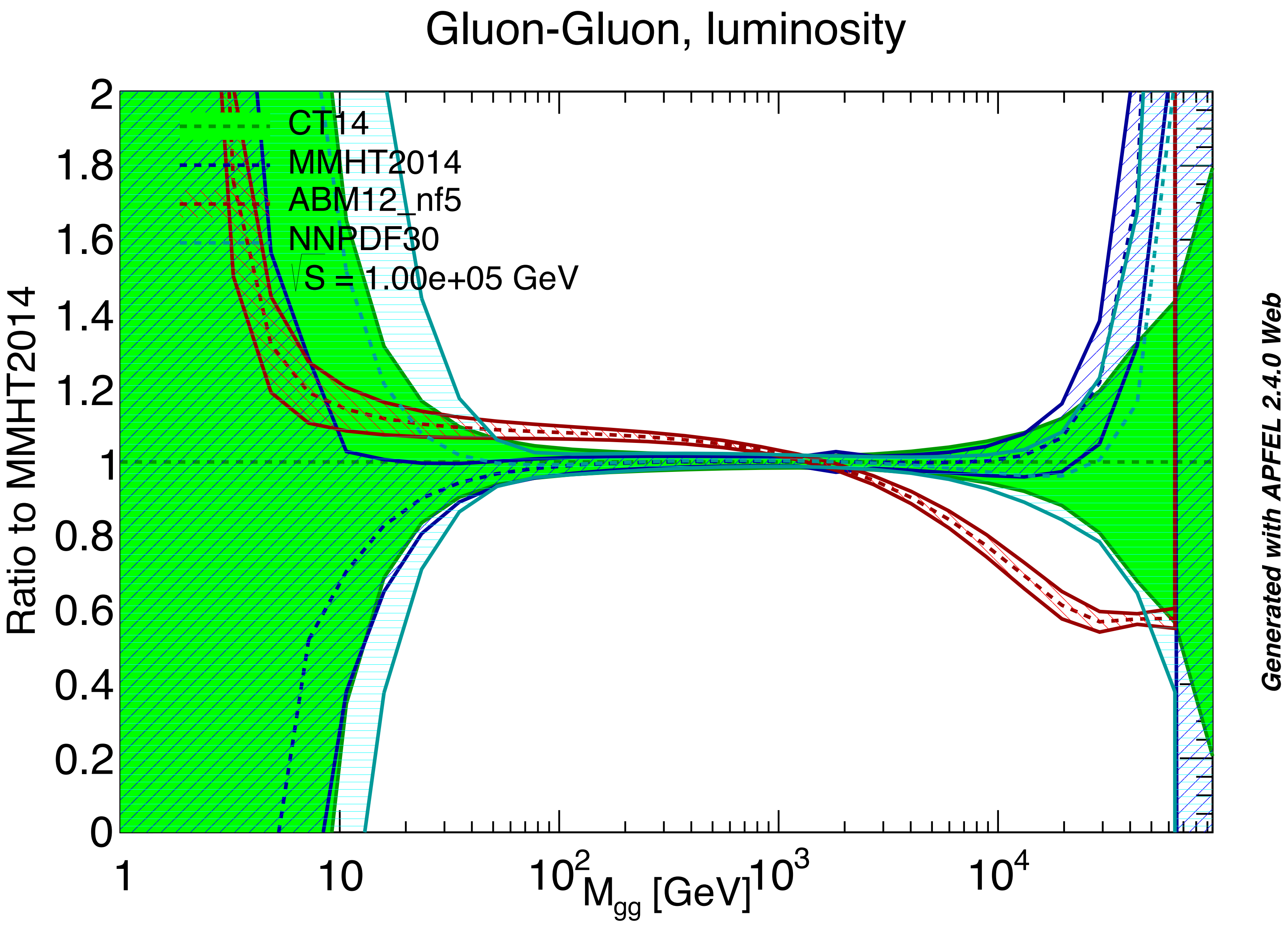
At this conference

B Mellado: Higgs

A Stasto: eA+low x

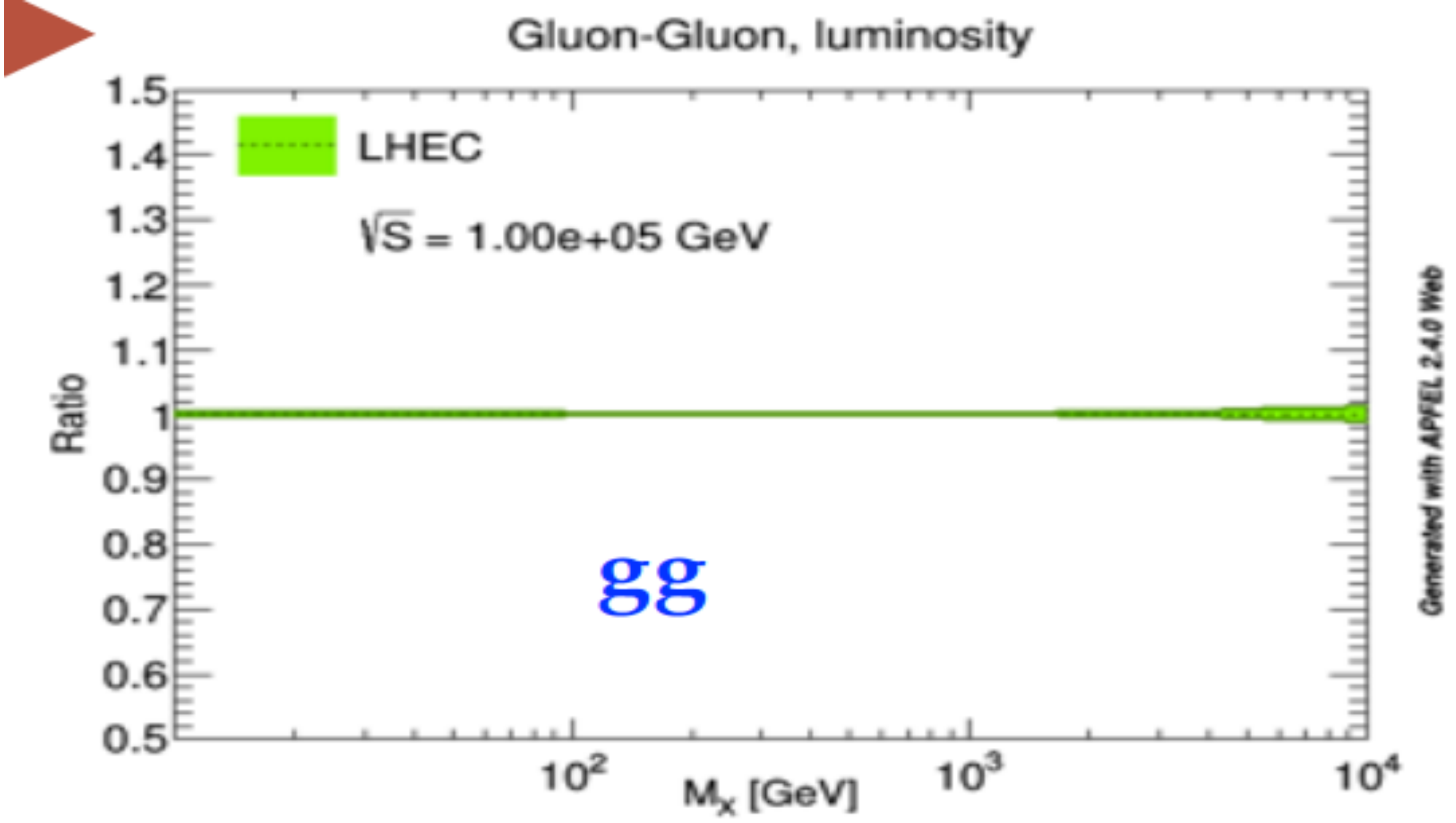
C Schwanenberger
Top, elweak + BSM

Poster on QCD



Current status of gluon-gluon sub-cross section uncertainty at FCC (hh) vs mass produced

The unique value of PDFs from ep DIS: Complete set of quark and gluons: Unprecedented precision, independence of symmetry assumptions, N^3LO
→ clean prediction for substructure, QCD, Higgs and searches in pp

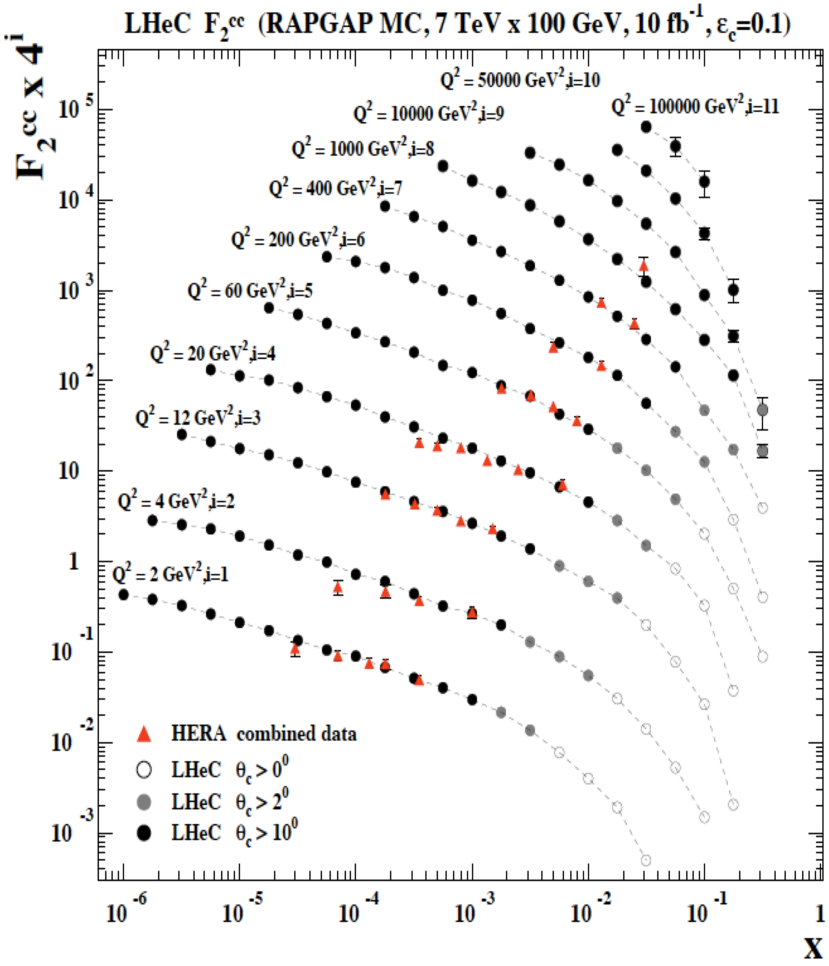


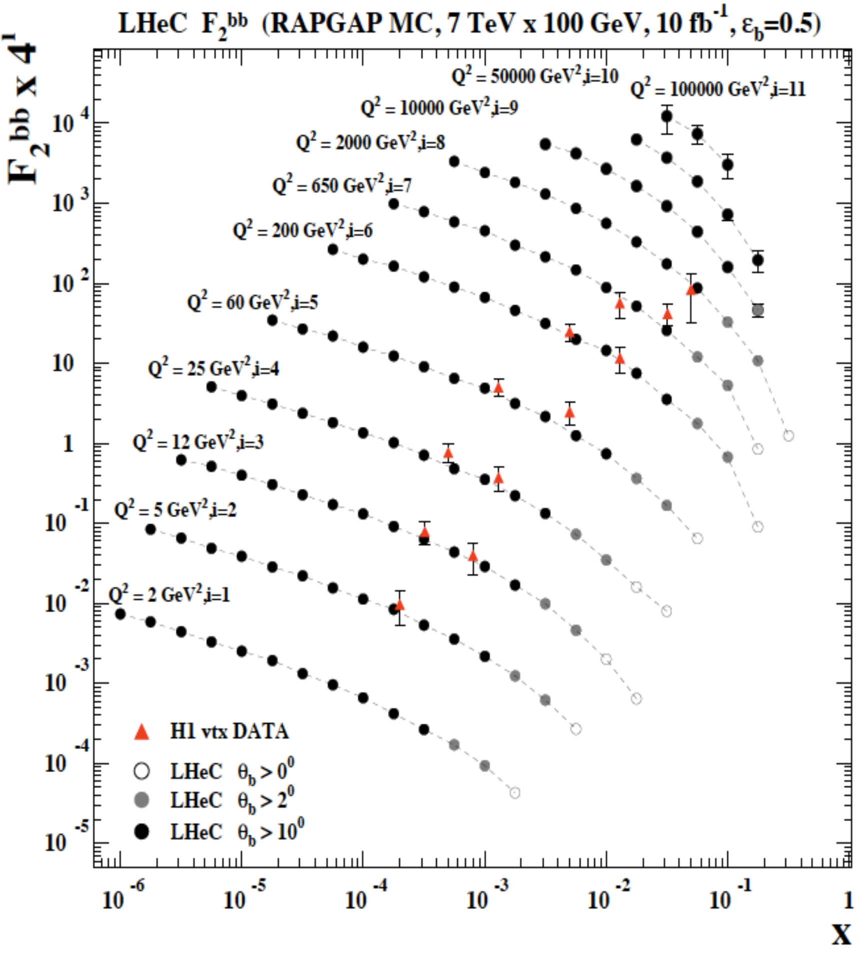
Needs extension of grid beyond $Q^2=10^8$ GeV^2 ..

V.Radescu

Expected gluon-gluon sub-cross section uncertainty at FCC (eh) vs mass produced

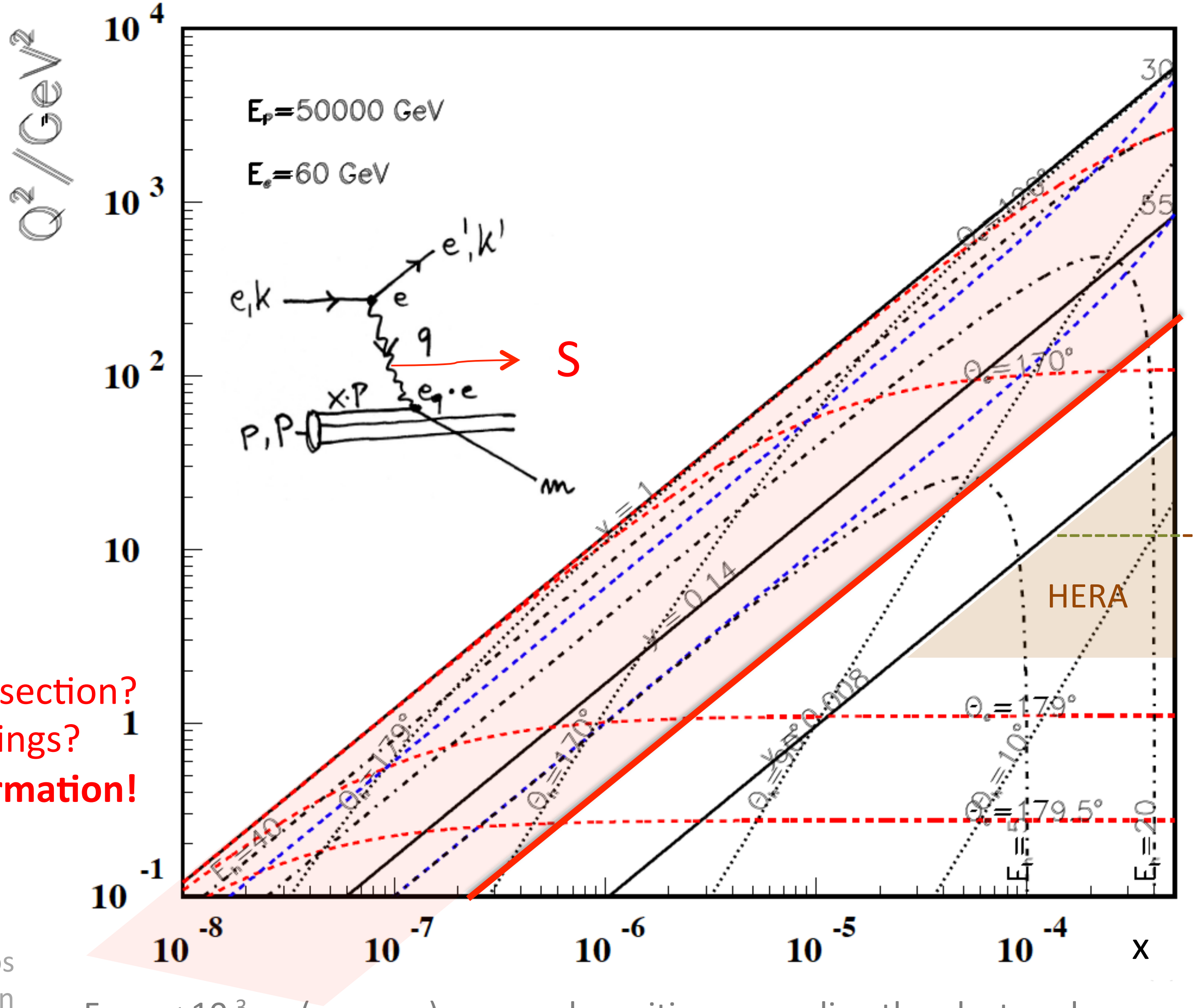
F_2^{charm} and F_2^{beauty} from LHeC





Hugely extended range and much improved precision (δM_c=60 HERA → 3 MeV)
will pin down heavy quark behaviour at and far away from thresholds, crucial for precision t,H..
In MSSM, Higgs is produced dominantly via bb → H (Pumplin et al) , but where is the MSSM..

Acceptance of a 750 GeV Ghost S



FCC-he
60 GeV

LHeC

← y >0.047
(=0.33 LHeC)

← 179°
@ 180 GeV
.. very low x requires not the maximum of E_e

3 C's

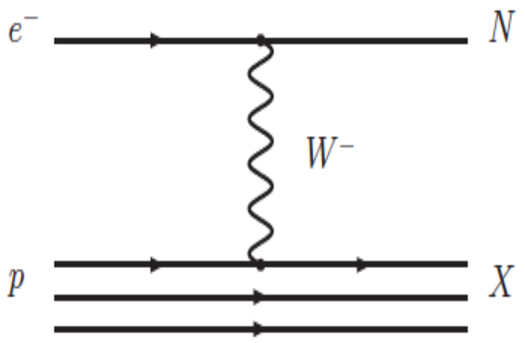
Cross section?
Couplings?
Confirmation!

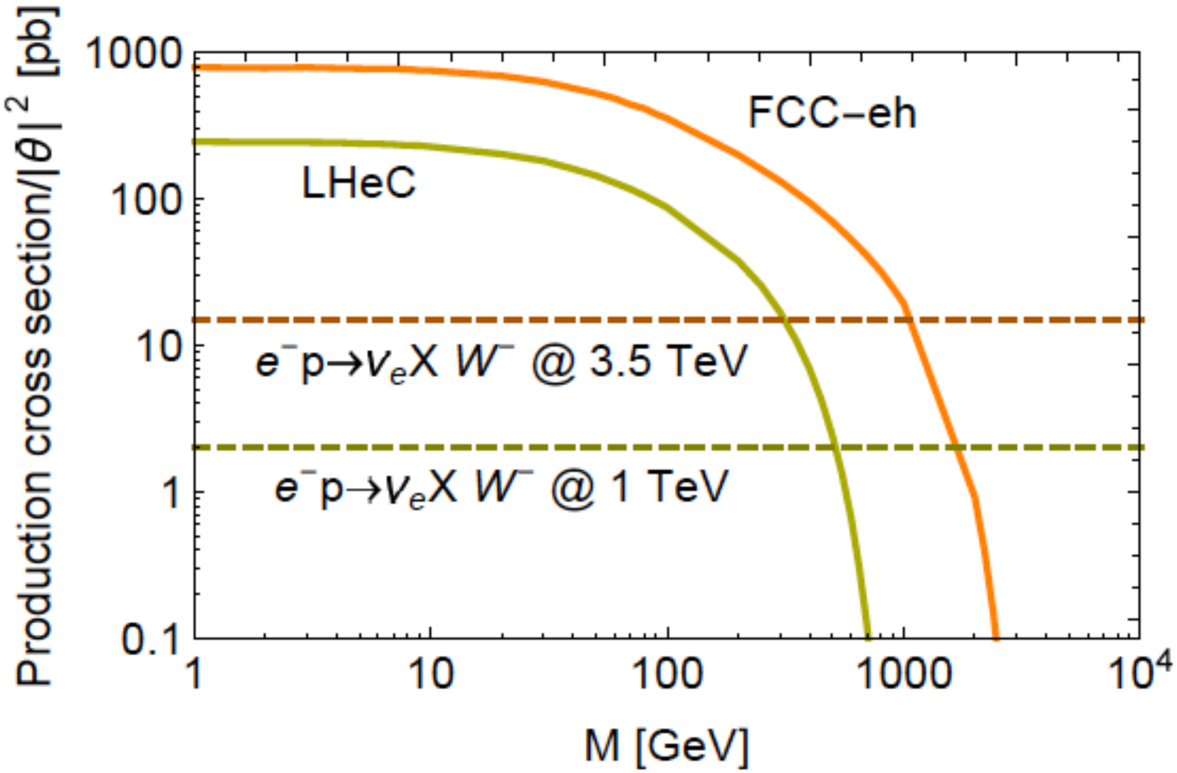
G Azuelos
U,M.Klein

For x < 10^{-3} no (average) energy deposition exceeding the electron beam energy

Heavy Neutrino Search at FCC (ee,hh,eh)

Oliver Fischer
Rome Talk
Sterile Neutrinos



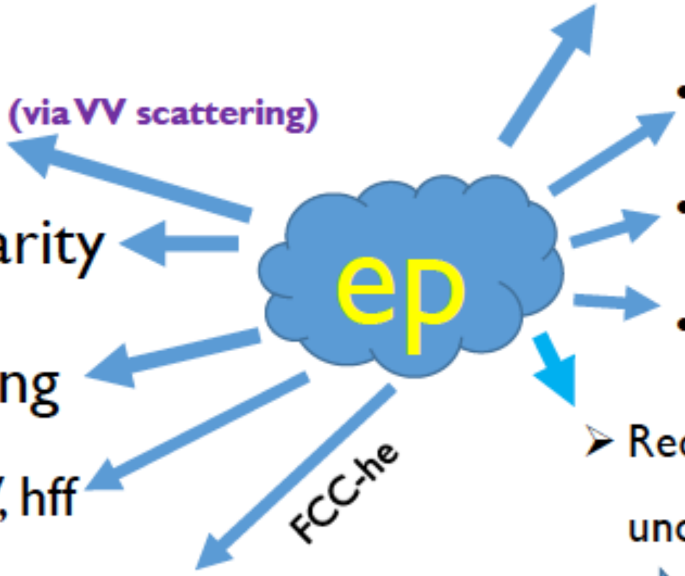


⇒ The FCCs provide great prospects for discovering the origin of neutrino masses.

- Future electron-proton colliders provide significant gain in mass reach and fairly "stable" production cross sections.

The Phenomenological Higgs Landscape (Revisited)

Future ep colliders could make important contribution to Higgs physics!



- Mass
- Width (via VV scattering)
- Spin-Parity
- Coupling
  - hVV, hff
  - 3h,4h, hhVV
  - FCNC coupling

- Exotic Higgs Decay
  - h to invisible
  - h to 4b
  - …

➢ Reducing PDF & Alpha_s uncertainties in Higgs measurements

➡ See talk given by Voica Radescu

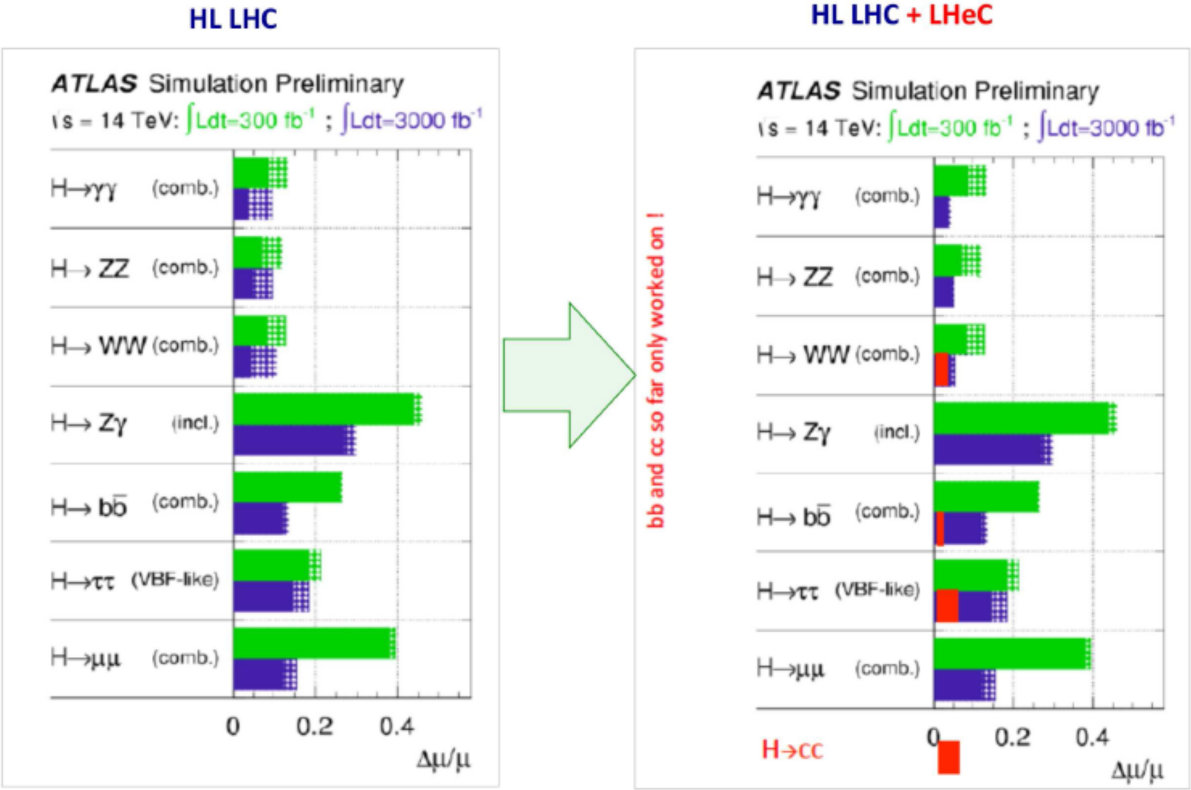
Philosophy could be traced back to
Phys. Rev. D82 (2010) 016009 by T. Han and B. Mellado.

See also:
M. Kumar et al., 1509.04016
S. S. Biswal et al., Phys. Rev. Lett. 109 (2012) 261801
U. Klein, talk given at LHeC Workshop 2015

Chen Zhan 12.4.16

HIGGS PHYSICS AT THE LHeC

SUMMARY



- GLUON FUSION AND W FUSION ⇒ PDF+α_s UNCERTAINTY REMOVED (hatched bands)
- $H\bar{b}b$ MEASURED TO PERCENTAGE PRECISION;
- $\tau\tau$ AND $\bar{c}c$ ALSO MEASURABLE

S.Forte ECFA 11/15

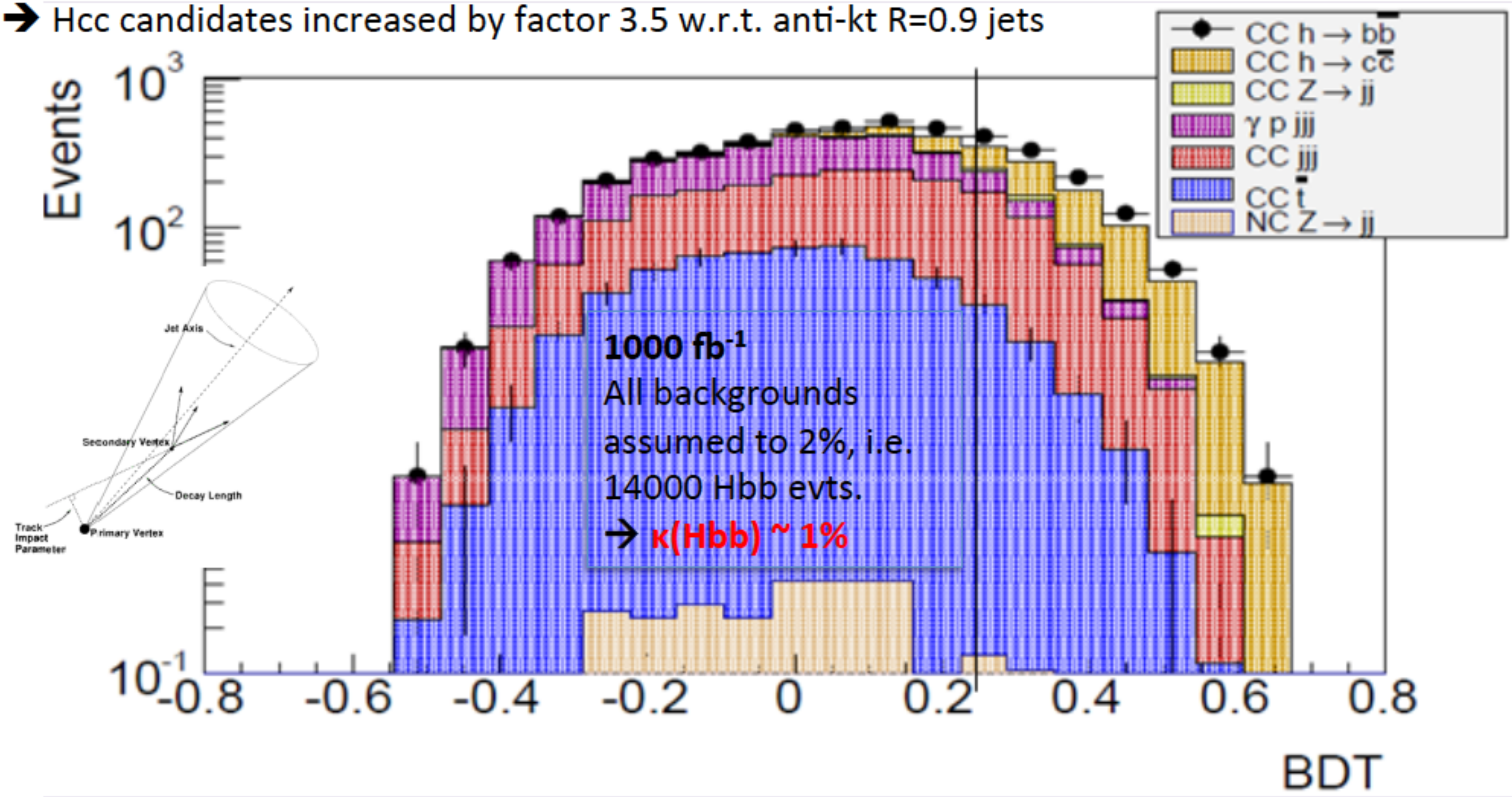
BDT Results Higgs→ cc

U Klein and D Hampson.
May 2016

For analysis and variables, c.f. U Klein LHeC Workshop

NEW : Using R = 0.5 anti-kt jets and ATLAS IBL vertex resolution (5 μm)

→ Hcc candidates increased by factor 3.5 w.r.t. anti-kt R=0.9 jets

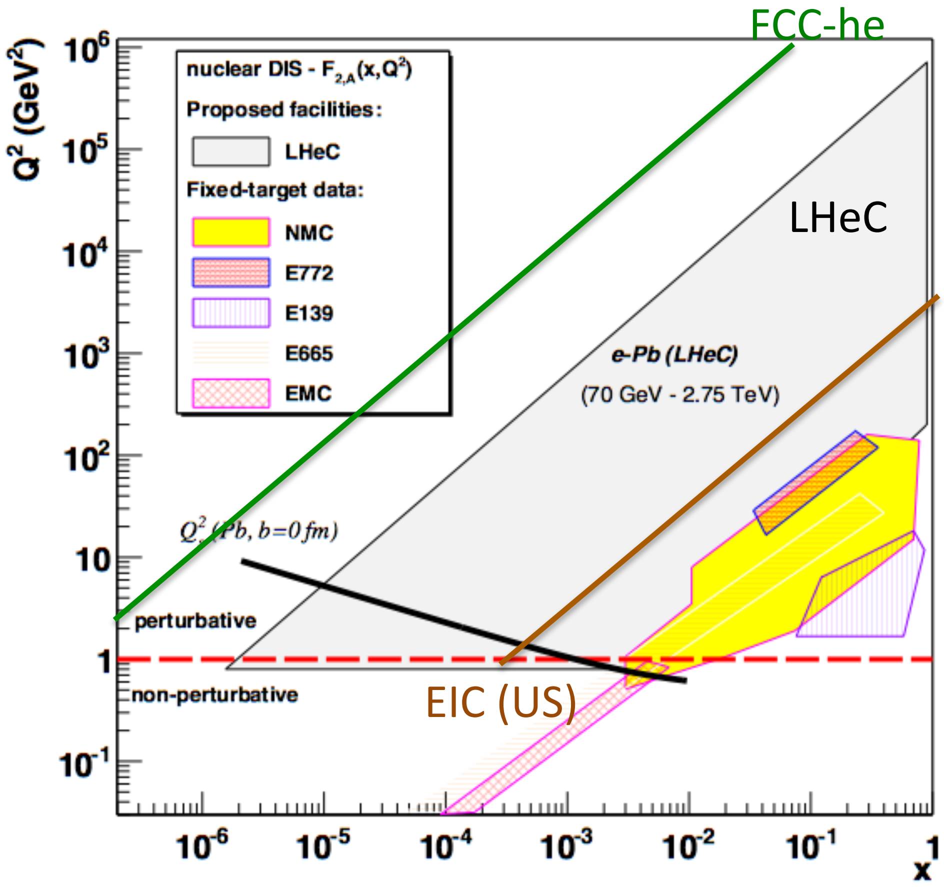


$1000\ fb^{-1}$
All backgrounds assumed to 2%, i.e. 14000 Hbb evts.
→ κ(Hbb) ~ 1%

BDT cut >0.2: Hcc Signal events : 474
S/√S+B=12.8 → **κ(Hcc) = 5% for 1000 fb^{-1}**

Clear potential to access the Higgs to charm decay channel at the LHeC.

LHeC-FCC-he as Electron Ion Collider(s)



LHeC is part of NuPECCs
long range plan since 2010
$L_{eN} \sim 10^{32}$ cm^{-2} s^{-1}

Extension of kinematic range in lA by 4-5 orders of magnitude will change QCD view on nuclear structure and parton dynamics

May lead to genuine surprises…

- No saturation of xg (x,Q^2) ?
- Small fraction of diffraction ?
- Broken isospin invariance ?
- Flavour dependent shadowing ?

Some expect g-saturation at
$Q^2_s \approx xg\, \alpha_s \approx c\, x^{-\lambda} A^{1/3}$
Note that the gluon is valence like at low Q^2

Precision QCD study of parton dynamics in nuclei
Investigation of high density matter and QGP
Gluon saturation at low x, in DIS region.

Remarks on the Project Status

LHeC: CDR in 2012 (300 authors, 600 pages). 2014+16: CERN Mandate to continue the study:

> Mandate to the International Advisory Committee 2014-2017
>
> Advice to the LHeC Coordination Group and the CERN directorate by following the development of options of an ep/eA collider at the LHC and at FCC, especially with:
>
> Provision of scientific and technical direction for the physics potential of the ep/eA collider, both at LHC and at FCC, as a function of the machine parameters and of a realistic detector design, as well as for the design and possible approval of an ERL test facility at CERN.
>
> Assistance in building the international case for the accelerator and detector developments as well as guidance to the resource, infrastructure and science policy aspects of the ep/eA collider.
>
> Chair: Herwig Schopper

Two major next goals:

-Design and build an LHeC ERL demonstrator (10mA, 3 turn, 802 MHz)

-Update of the CDR by 2018: LHC physics, 10^{34} lumi, detector and accelerator updates

FCC-eh: Utilize the LHeC design study to describe baseline ep/A option.
Emphasis: 3 TeV physics, IR and Detector: synchronous ep-pp operation.
Open to other configurations and new physics developments (750..)

Organisation*)

International Advisory Committee

"..Direction for ep/A both at LHC+FCC"

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Achille Stocchi (LAL Orsay)
John Womersley (STFC)

IAC being renewed by new DG

We lost Guido Altarelli.

*)August 2016

Coordination Group

Accelerator+Detector+Physics

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

5(11) are members of the FCC coordination team

OB+MK: FCC-eh responsibles
MDO: physics co-convenor

Working Groups

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

Electron-Hadron Scattering at the Energy Frontier – A Higgs Physics Facility Resolving the Substructure of Matter

Draft Table of Contents (9. June 2016)

1. Introduction: The LHC, Modern Particle Physics and the Rôle of ep/eA
2. Physics: QCD/PDFs, Higgs, top, BSM, small x, eA at the LHeC; key items at 1.9/3.4 TeV
3. ERL electron beam: Design, Components, Injector, Dump, Civil Engineering ..
4. LHeC Performance: Collider Parameters, Luminosity, Joint Operation, Infrastructure..
5. Detector: Machine Interface (IR), Design and Performance, Components, Software
6. Installation of the Machine and Detector
7. Summary

Appendix:

- Status of the LHeC Demonstrator and ERL Developments
- Cost-Energy Relation and Cost Estimate for LHeC
- Detector Cost Estimate
- Extensions into the HE LHC Phase
- Electron-Hadron Scattering with the FCC (link to FCC CDR)

LHeC CDR update because:

- Lumi * 10
- LHC results
- Technology progress

Open for any **participation**

Update of the LHeC CDR[*)] and input to EU Particle and Nuclear Physics Strategy

*) arXiv:1206.2913

Summary

The CERN hadron beams (LHC and later HE LHC and/or FCC) enable (few) TeV cms energy collider experiments - at 1000 times the HERA luminosity.

The current default e beam is a 60 GeV, 3 turn ERL racetrack of 1/3 of U(LHC).
A demonstrator is under evaluation to study 802 MHz, 3 turn, 10mA ERL, i.e. the basic LHeC technology, in synergy with FCC and with low energy e/y physics community.

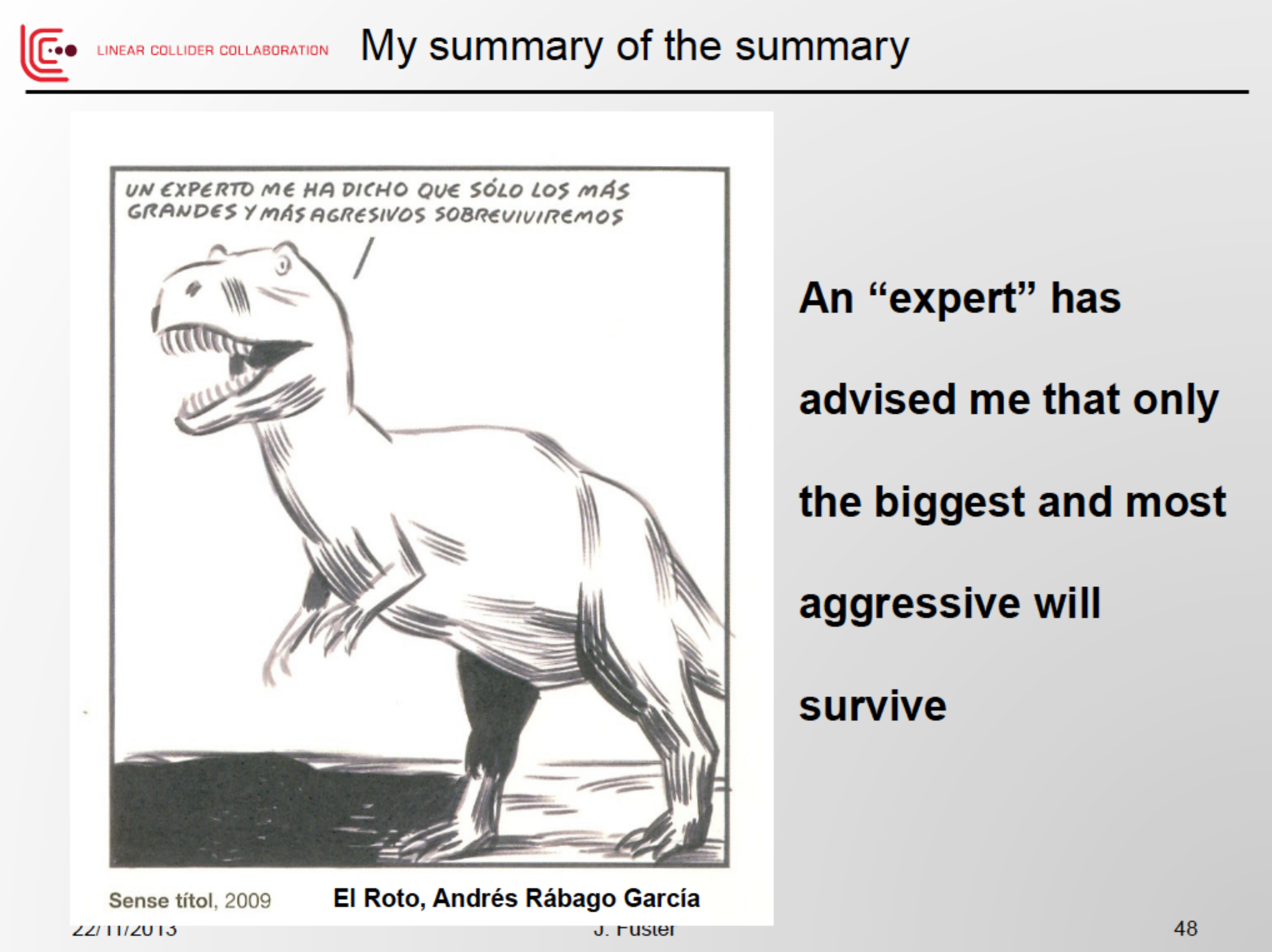
This electron-hadron machine has a unique QCD, eweak, Higgs, BSM programme. In short, CERN has the realistic option of building the world's cleanest microscope with which the LHC facility can be turned into a precision Higgs factory, operating with HL LHC.

The electron-ion physics potential is huge as the energy and luminosity are so high.

A new GPD detector, smaller than CMS, larger than H1, may be built to enable that physics.
An initial installation study demonstrates it could be installed in times commensurate with LSi

The next two important goals, approached with the support of the CERN directorate(s), are to develop the base technology and to update the 2012 CDR for the new luminosity goal, set by the Higgs discovery, the LHC results of Run 2 and technology progress.

2017: FCC physics week (Jan), LHeC Workshop (Feb), FCC Week (May), ERL Workshop (Jun)
at CERN Orsay Berlin CERN



My summary of the summary

An "expert" has advised me that only the biggest and most aggressive will survive

Sense títol, 2009 **El Roto, Andrés Rábago García**

22/11/2013 J. Fuster 48

Plenary ECFA talk by Juan Fuster, November 2013 at CERN, on the Linear Collider

I hope DT has not seen Juan’s picture and that the less aggressive ones are given a future too.

The electron beam upgrade has a place in between the recently endorsed luminosity and the not unlikely energy upgrade of the LHC. It builds on the biggest investment particle physics ever enjoyed and helps sustaining its future with a seminal physics programme.

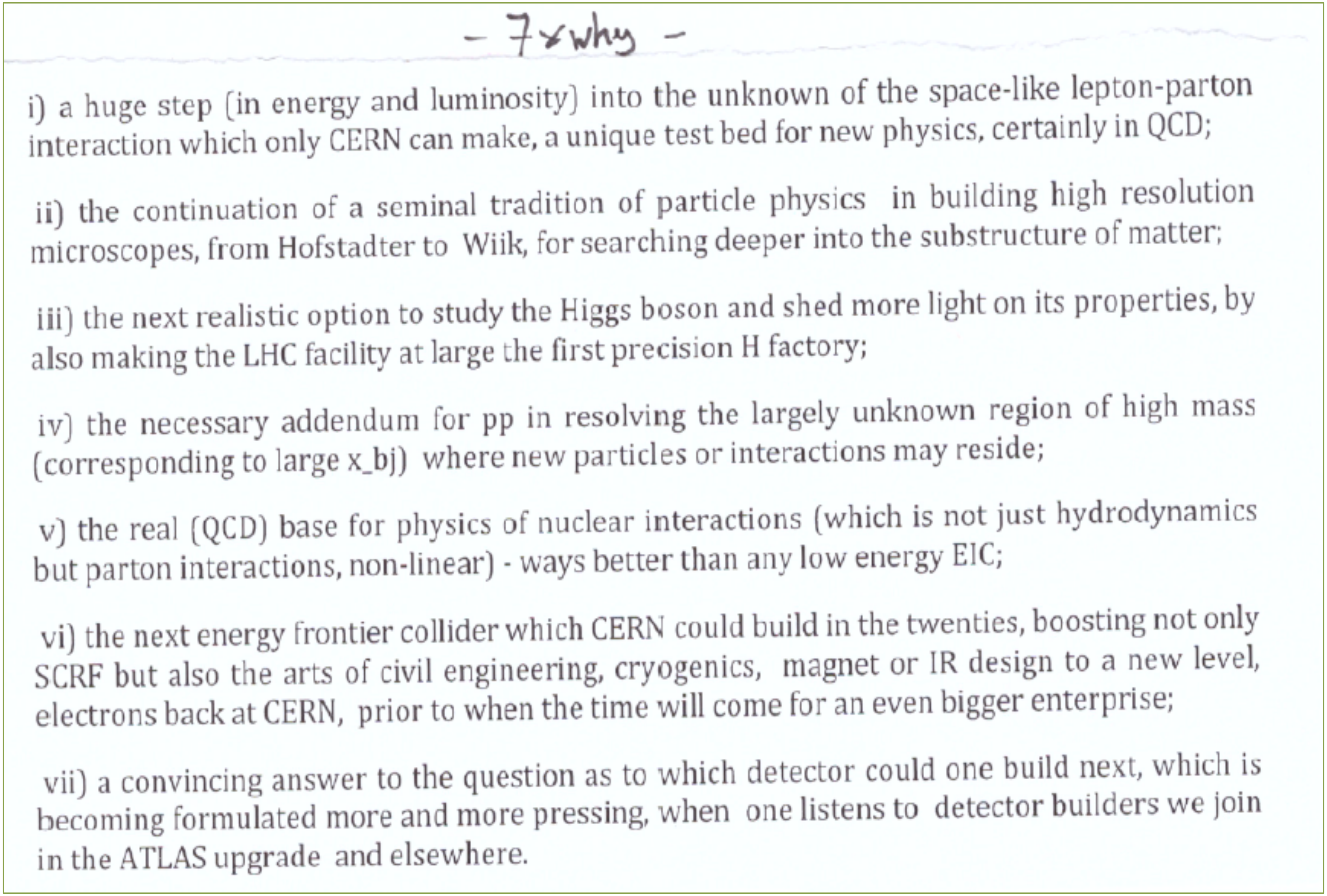
It provides a new, independent energy and intensity frontier collider configuration which fits to the needs of HEP - physics and community.

That may be realised, with the required courage and realism, bridging well to future, expensive ee and pp machines which it complements too.

Thank you.

Many thanks to CERN's directors, the IAC, the FCC team and the ep/h community engaged

backup



- 7×why -

i) a huge step (in energy and luminosity) into the unknown of the space-like lepton-parton interaction which only CERN can make, a unique test bed for new physics, certainly in QCD;

ii) the continuation of a seminal tradition of particle physics in building high resolution microscopes, from Hofstadter to Wiik, for searching deeper into the substructure of matter;

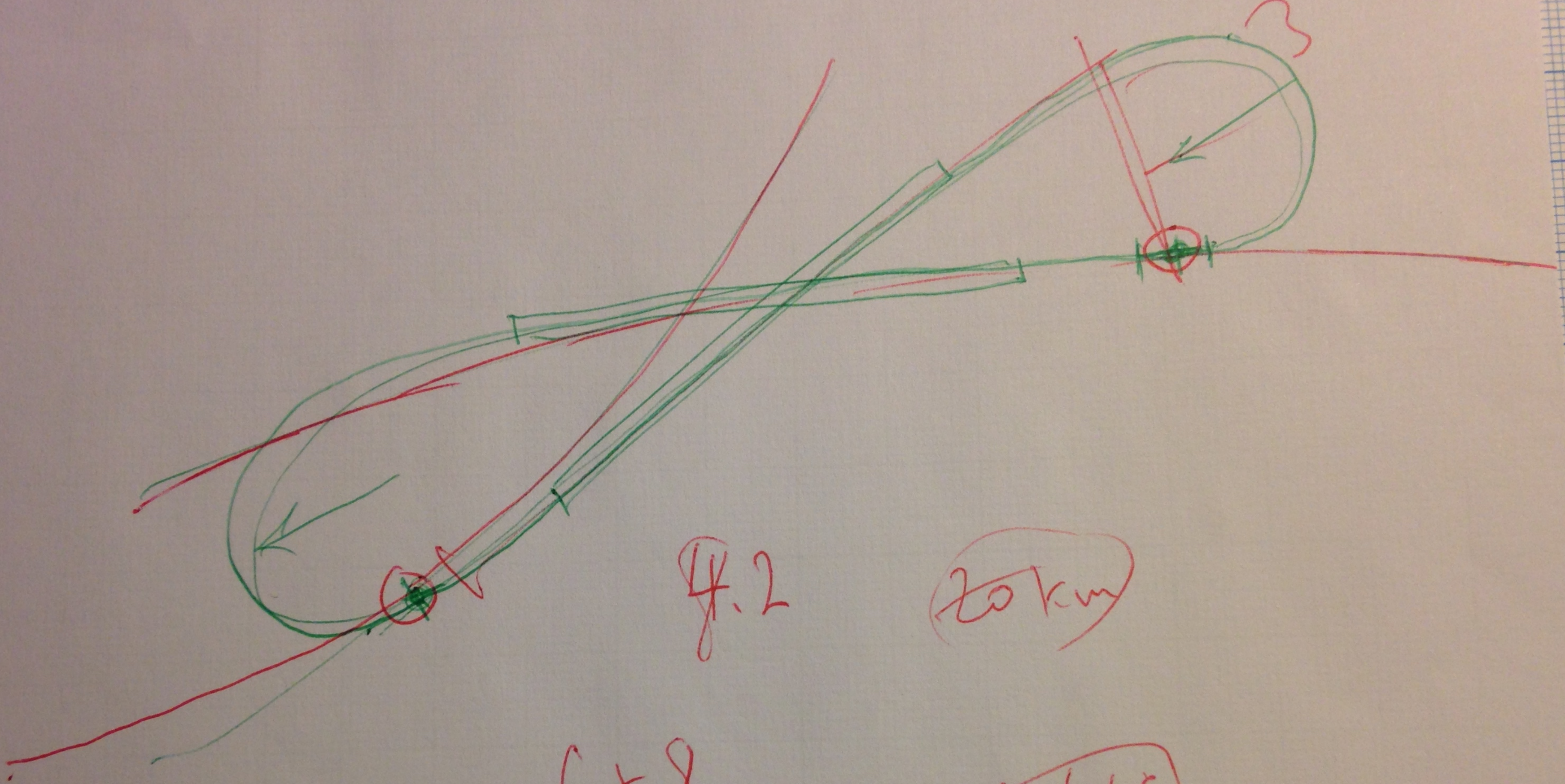
iii) the next realistic option to study the Higgs boson and shed more light on its properties, by also making the LHC facility at large the first precision H factory;

iv) the necessary addendum for pp in resolving the largely unknown region of high mass (corresponding to large x_bj) where new particles or interactions may reside;

v) the real (QCD) base for physics of nuclear interactions (which is not just hydrodynamics but parton interactions, non-linear) - ways better than any low energy EIC;

vi) the next energy frontier collider which CERN could build in the twenties, boosting not only SCRF but also the arts of civil engineering, cryogenics, magnet or IR design to a new level, electrons back at CERN, prior to when the time will come for an even bigger enterprise;

vii) a convincing answer to the question as to which detector could one build next, which is becoming formulated more and more pressing, when one listens to detector builders we join in the ATLAS upgrade and elsewhere.



4.2

20 km

6 + 8

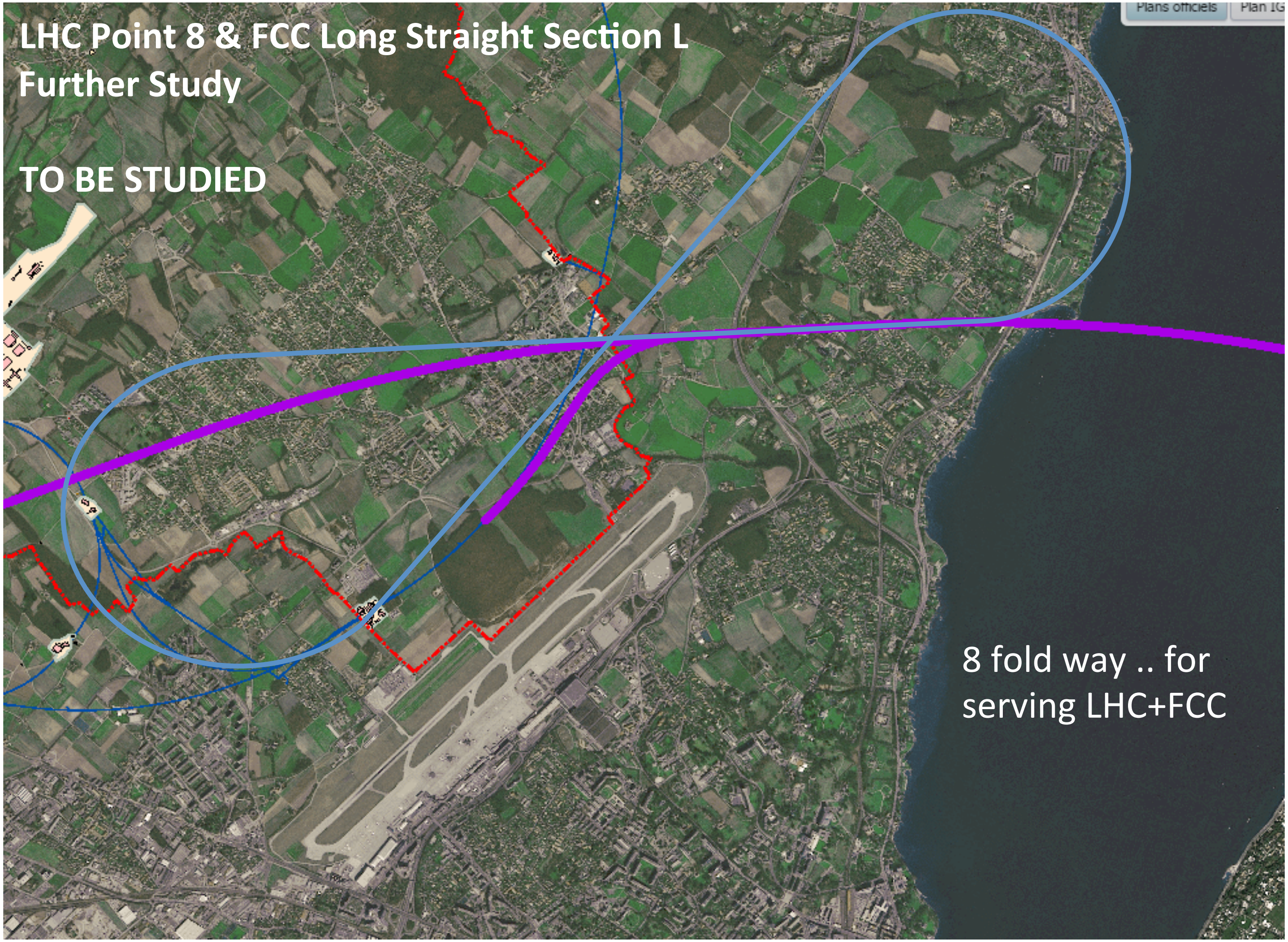
14

½ LHC

Max 7.4.16

An attempt to serve LHC and the FCC without relocation.

LHeC/FCC-he Civil Engineering

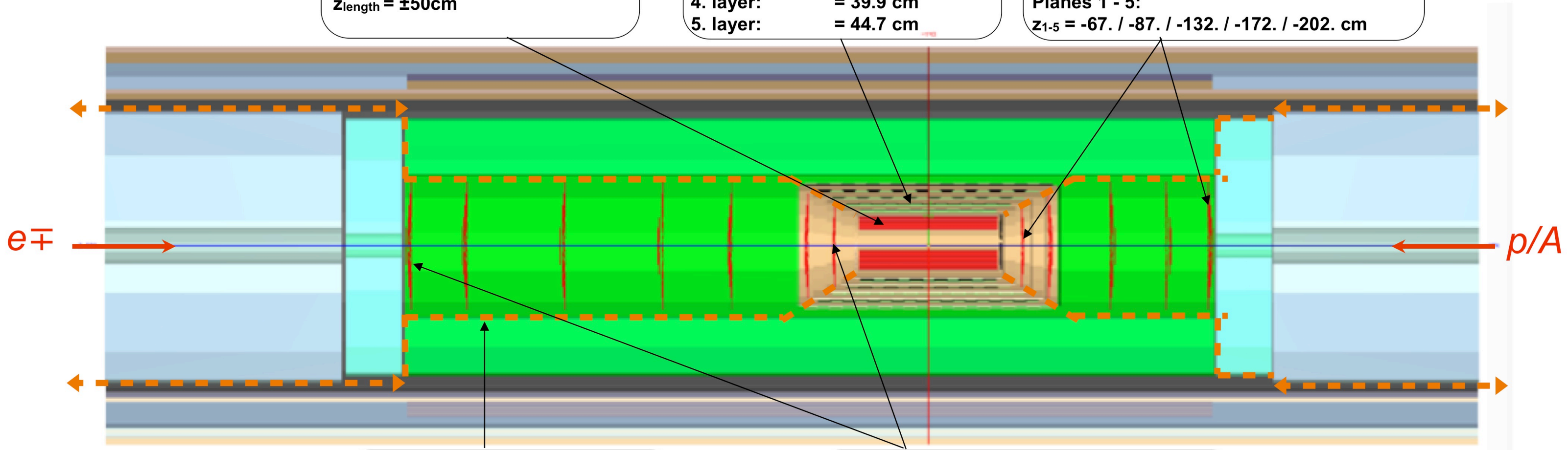


LHC Point 8 & FCC Long Straight Section L Further Study

TO BE STUDIED

8 fold way .. for serving LHC+FCC

Detector design: Inner Silicon Tracker (status 3/16)



Central Pixel Tracker - CPT
4 double-layers
min-inner-R = 4.51 cm
max-inner-R = 17.13 cm
z_{length} = ±50cm

Central Silicon Tracker – CST
5x(double-layers)
1. layer: inner R = 25.1 cm
2. layer: = 30.0 cm
3. layer: = 34.9 cm
4. layer: = 39.9 cm
5. layer: = 44.7 cm

Backward Silicon Tracker – BST
5x(double layers pix / strix)
min-inner-R = 4.3 cm;
max-inner-R= 16.2 cm
max-outer R = 45.1 cm
Planes 1 - 5:
$z_{1\text{-}5}$ = -67. / -87. / -132. / -172. / -202. cm

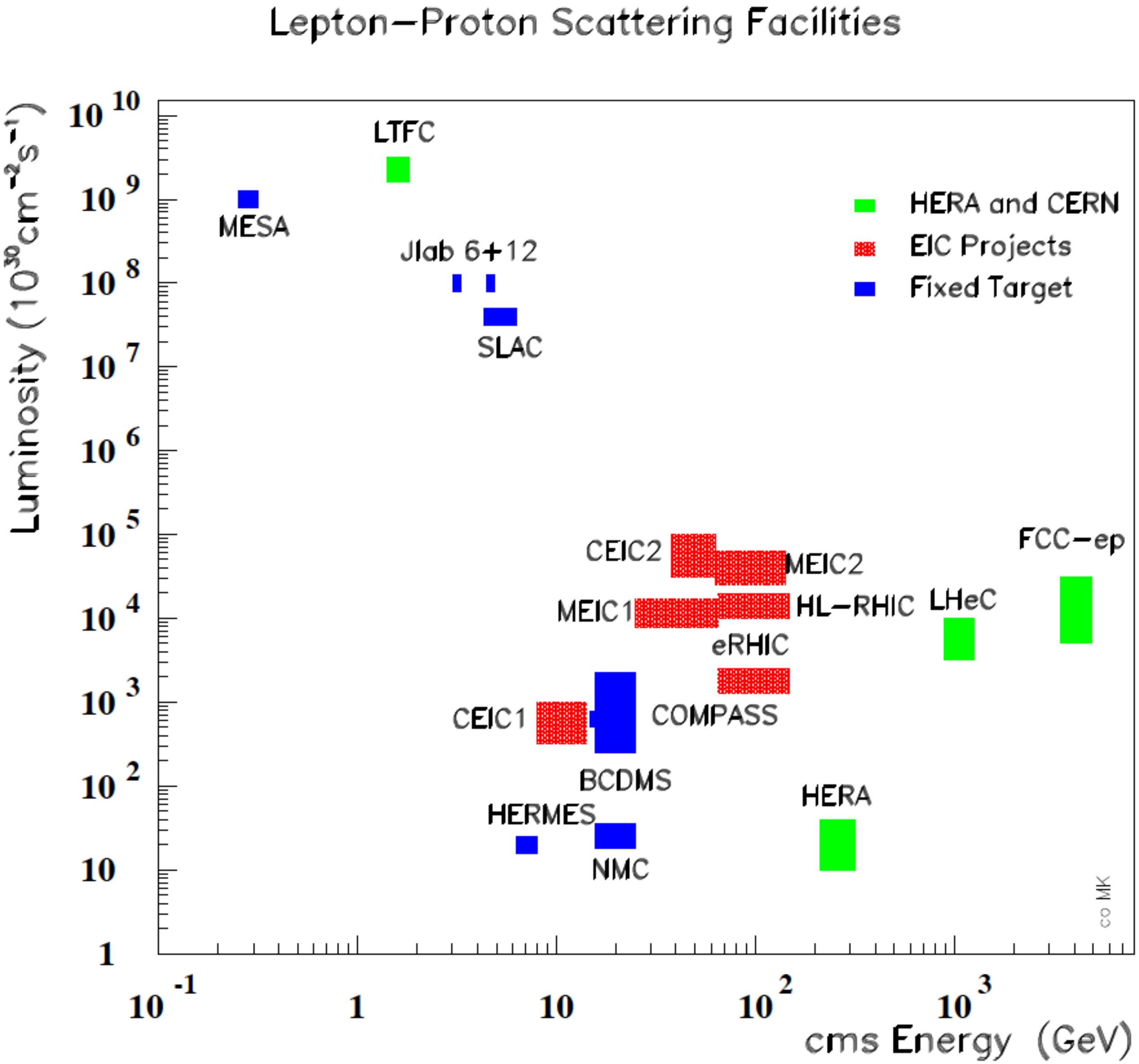
Path of services for all tracking. The detector services (shown in dark orange) shall be integrated into support structures whenever possible. Optimum of costs and detector acceptance. Design of services and infrastructure crucial for material budget.

Forward Silicon Tracker - FST
7x(double layer pix/ strix)
min-inner-R = 4.3 cm;
max-inner-R= 16.2 cm
max-outer R = 45.1 cm
Planes 1 - 7:
$z_{1\text{-}7}$ = 67. / 87. / 142. / 230. / 292. / 332. / 372. cm

More detailed designs for other components too. DD4HEP software developments..

An opportunity for R+D and building a novel, challenging 4π detector in the twenties.

Intensity and Energy Frontier of Future DIS



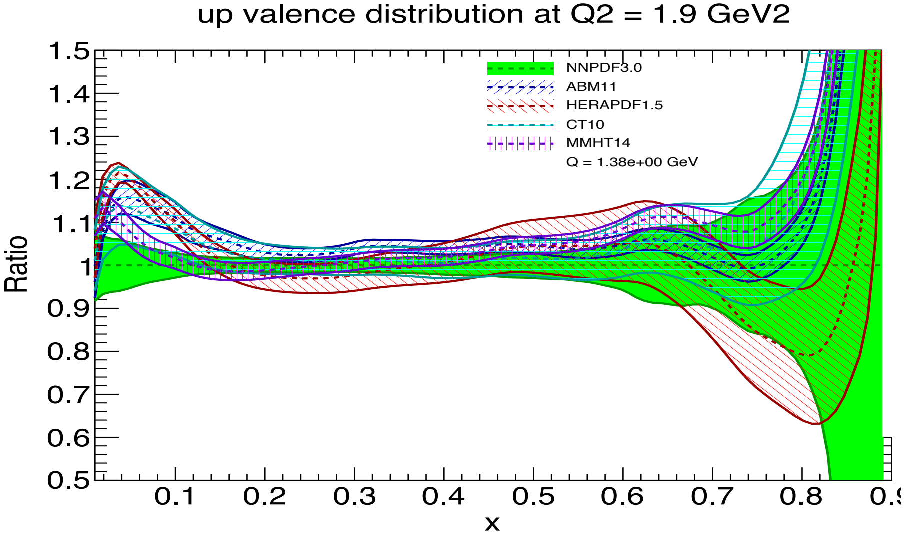
From CERN Courier
MK, H.Schopper
June 2014

With input from
A.Hutton, R.Ent,
F.Maas, T.Rosner

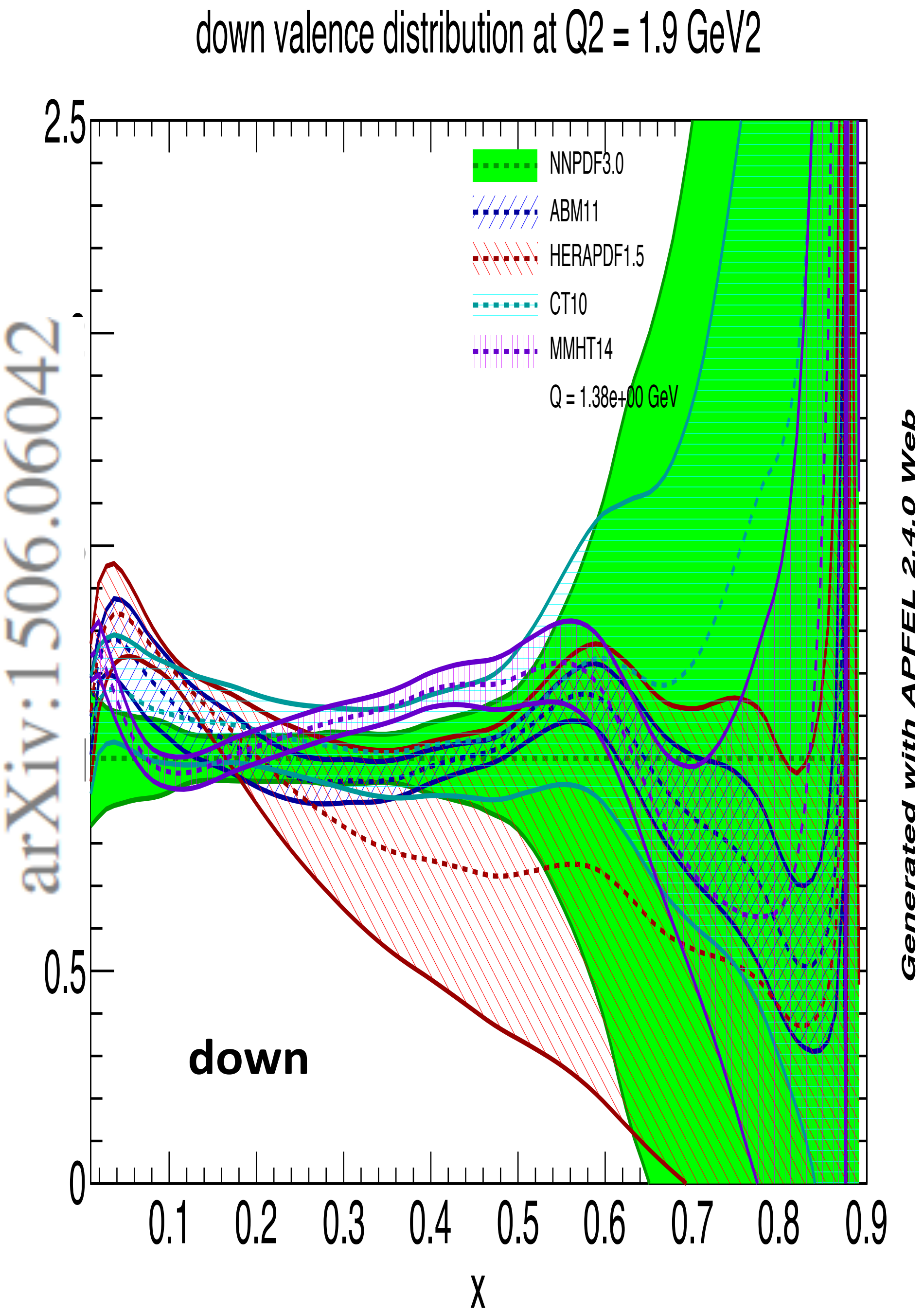
It will be crucial for the LHC to resolve the high x and Q^2 uncertainties, for its sustainable future. This requires hi L+s!

Valence quarks

up



Related to DY , W mass etc
Recall $xq_v \sim (1-x)^3$
d/u → 1 a classic question



October 2012

Luminosity

The CDR Luminosity

$$L = \frac{N_e N_p f \gamma_p}{4\pi\varepsilon_p \beta^*}$$

$$N_e = 10^9$$

$$N_p = 1.7 \cdot 10^{11}$$

$$\varepsilon_p = 3.7\mu m$$

$$f = \frac{1}{\Delta} = 40MHz$$

$$\beta^* = 0.1m$$

$$\Rightarrow L = 10^{33} cm^{-2} s^{-1}$$

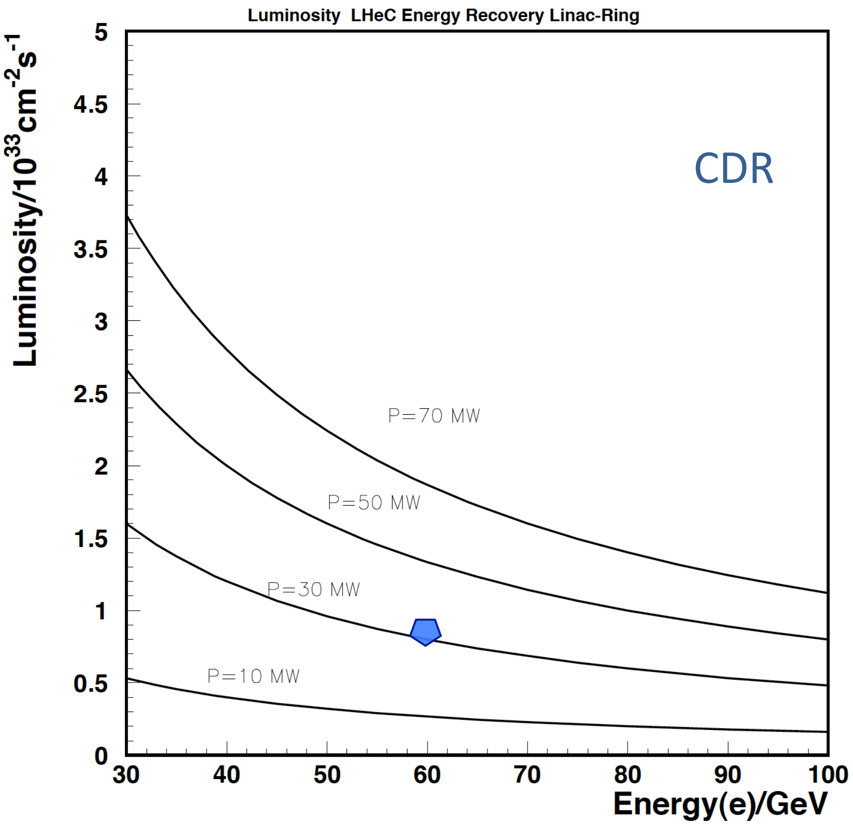
$$I_e = eN_e f = 6.4mA$$

$$I_e = \frac{P}{E_e}$$

$$P = \frac{P_0}{(1-\eta)}, \eta = 0.94$$

$$P_0 = 24MW$$

H*pinch(e^-)*gap-loss ~ 1



Higgs in ep sets scale for luminosity!

… so do searches, high x and special conditions such as positron, deuteron, eA or low energy..

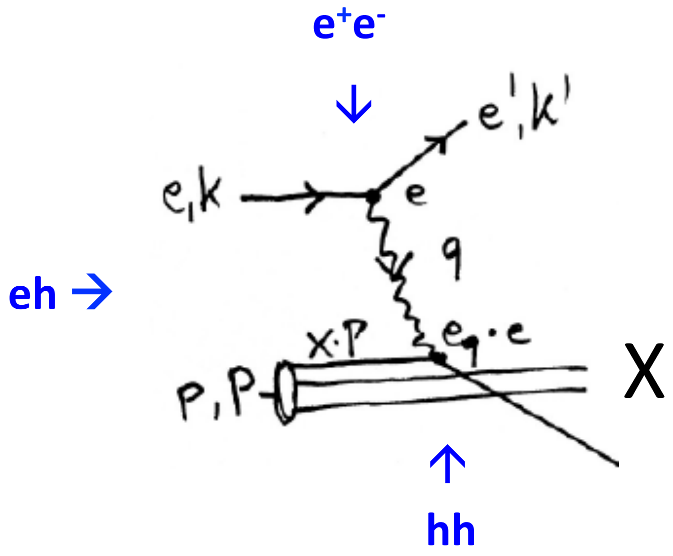
after the Higgs arXiv:1211.5102

2.5 * brightness, 2 * I_e , 0.5 * β*

LHeC Luminosity → 10^{34} cm^{-2} s^{-1}

L(E,P) subject of current study: beam-beam, ion gap stability…

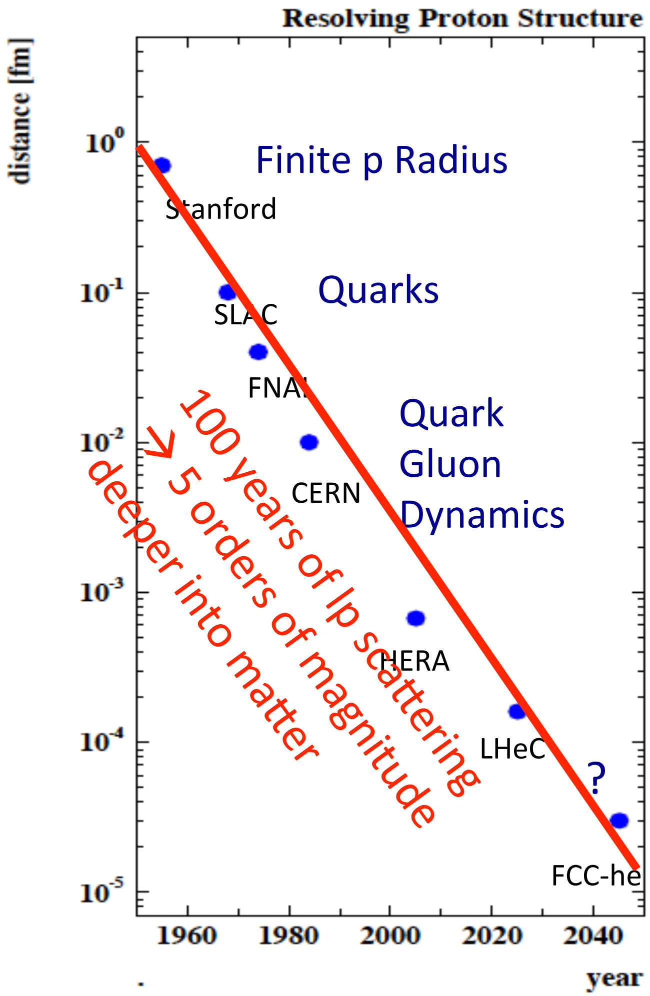
The high energy DIS future is here+near



-Parton momentum fixed by electron kinematics
-Incl. NC (γ,Z) and CC ($W^{\pm}$) independent of hadronisation
-Rigorous theory: Operator expansion (lightcone)
-Collider- as at HERA: $y_h=y_e$: Redundant kinematics

→ DIS is an ideal laboratory for the development of particle physics into the multi TeV energy scale era.

The CERN hadron beams are the unique base for building the world's cleanest microscopes exploring the inner structure and pursue novel measurements leading to discovery. In this quest, hh, eh and ee are an entity.



Cavity Parameters

Parameter	Unit	Value	Value	Value	Value	Value	Value
cavity type		LHeC study	LHeC study	CEBAF HC	LCLS-II (TESLA)	CEBAF OC	CEBAF LL
frequency	MHz	802	802	748.5	1300	1497	1497
number of cells		5	5	5	9	5	7
L_{active}	mm	922.31	922.14	1000	1036.02	500	700
$R/Q = V_{eff}^2/(\omega * W)$	Ω	580.1	583.4	518.8	1036.0	482.5	868.9
R/Q/cell	Ω	116.0	116.7	103.8	115.1	96.5	124.1
G	Ω	273.2	273.2	278.3	270.0	274.0	280.3
R/Q·G/cell		31702	31877	28876	31080	26441	34793
Eq. Diameter	mm	323.12	323.12	352.73	206.60	187.03	173.99
Iris Diameter	mm	115	115	140	70	70	53
Tube Diameter	mm	140	115	140	78	70	70
Eq./Iris ratio		2.81	2.81	2.52	2.95	2.67	3.28
Wall angle (mid-cell)	deg	0	0	0	13.31		8.10
E_{peak}/E_{acc} (mid-cell)		2.07	2.07	2.44	1.98	2.56	2.17
B_{peak}/E_{acc} (mid-cell)	mT/(MV/m)	4.00	4.00	4.24	4.17	4.56	3.74
k_{cc}	%	2.14	2.14	3.12	1.89	3.15	1.49
N^2/k_{cc}		11.71	11.71	8.01	42.97	7.94	32.89
cutoff TE_{11}	GHz	1.26	1.53	1.25	2.25	2.51	2.51
cutoff TM_{01}	GHz	1.64	2.00	1.64	2.94	3.28	3.28

Ranking	1	2	3	4	5

802 MHz Cavity Parameters

design to also test FCC-ee

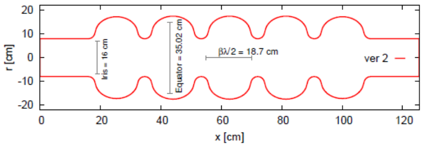


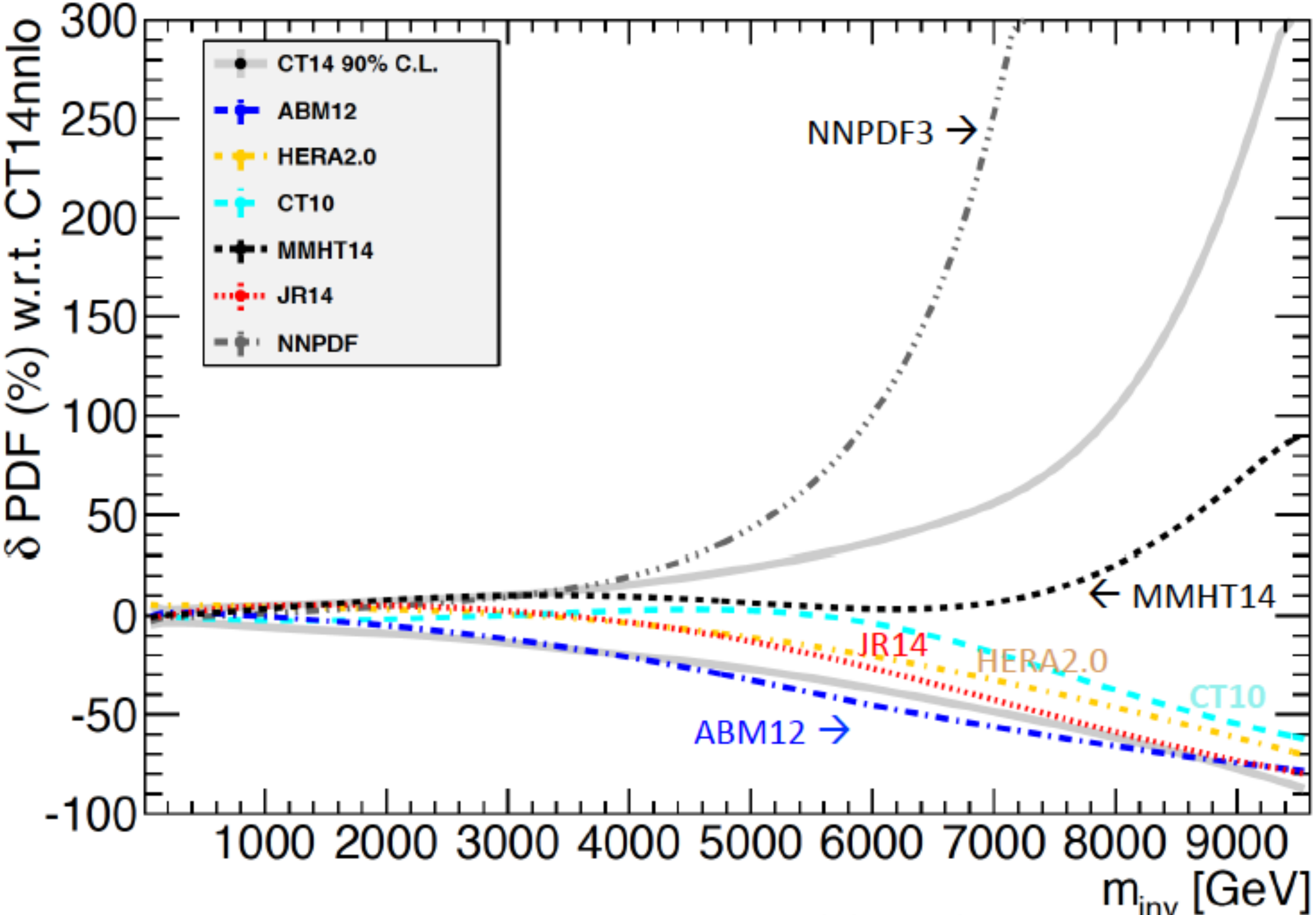
Fig. 6: Envelope of the second version of the five-cell ERL cavity at 802 MHz with 16 cm aperture.

CERN-ACC-NOTE-2015-xxx
28-05-2015
Rama.Calaga@cern.ch

Parameter	Unit	Value	Value	Value		Value	
cavity type		**LHeC prototype (2016)**	LHeC study (2015)	LHeC study (2015)		LHeC Ver. 1	LHeC Ver. 2
frequency	MHz	**801.58**	802	802		801.58	801.58
number of cells		**5**	5	5		5	5
L_{active}	mm	**917.91**	922.31	922.14		935	935
$R/Q = V_{eff}^2/(\omega * W)$	Ω	**523.7**	580.1	583.4		430	393
R/Q/cell	Ω	**104.7**	116.0	116.7		86.0	78.6
G	Ω	**274.6**	273.2	273.2		276	283
R/Q·G/cell		**28765**	31702	31877		23736	22244
Eq. Diameter	mm	**327.95**	323.12	323.12		350.2	350.2
Iris Diameter	mm	130	115	115		150	160
Tube Diameter	mm	**130**	140	115		150	160
Eq./Iris ratio		**2.52**	2.81	2.81		2.19	2.19
Wall angle (mid-cell)	deg	**0**	0	0		12.5	12.5
E_{peak}/E_{acc} (mid-cell)		**2.26**	2.07	2.07		2.26	2.40
B_{peak}/E_{acc} (mid-cell)	mT/(MV/m)	**4.20**	4.00	4.00		4.77	4.92
k_{cc}	%	**3.22**	2.14	2.14		4.47	5.75
N^2/k_{cc}		**7.78**	11.71	11.71		5.59	4.35
cutoff TE_{11}	GHz	**1.35**	1.26	1.53		1.17	1.10
cutoff TM_{01}	GHz	**1.77**	1.64	2.00		1.53	1.43

F.Marhauser, B.Rimmer, J.Henry (Jlab) + R.Calaga, E.Jensen, K. Schirm et al (CERN) [4.8.16]

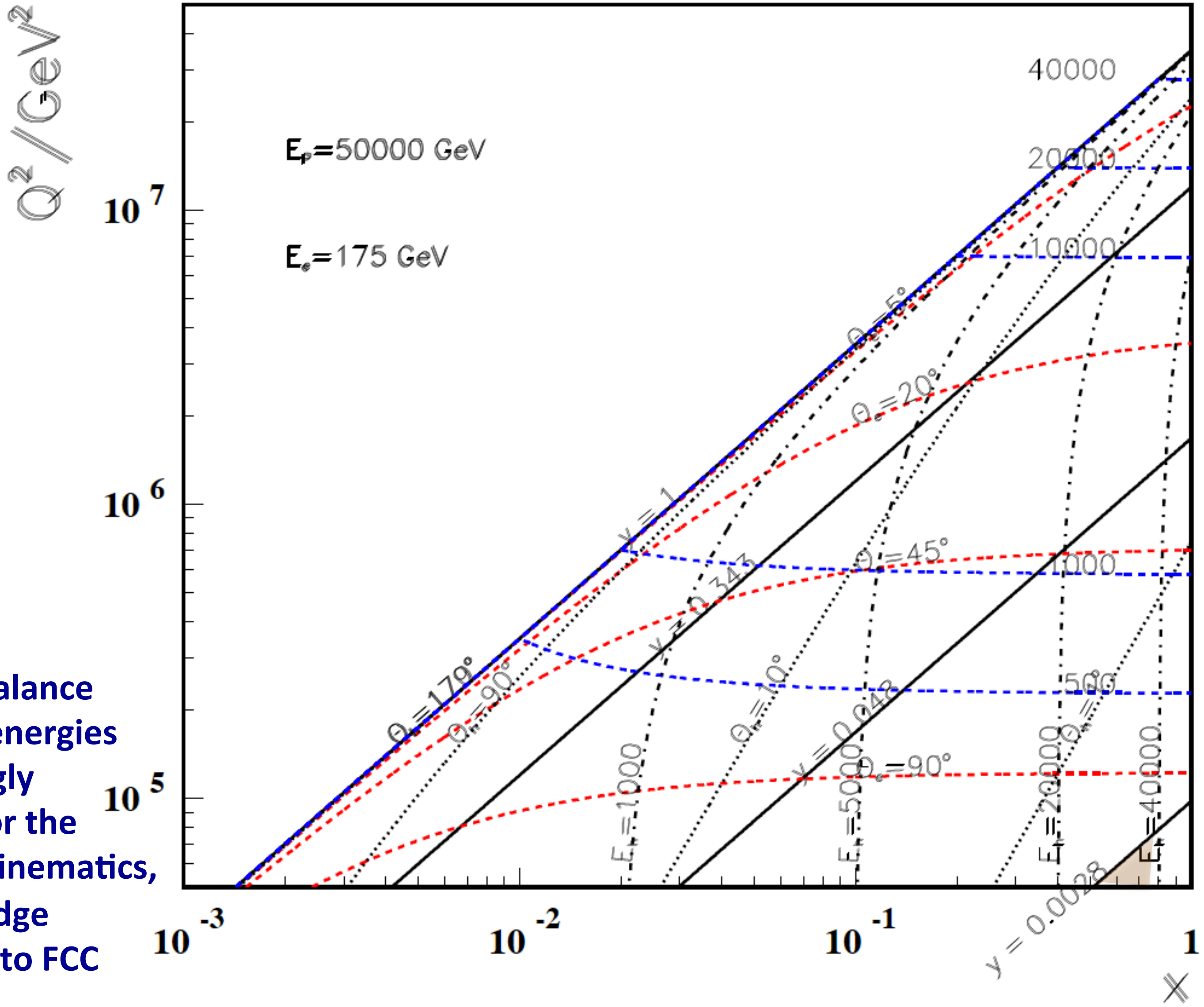
Very High Mass Dell Yan 13 TeV - σ(PDF)/σ(CT14)



VRAP calculation, U.Klein

High Q^2

Rutherford backscattering
of dozens of TeV e- energy



FCC-he
175 GeV
60 GeV

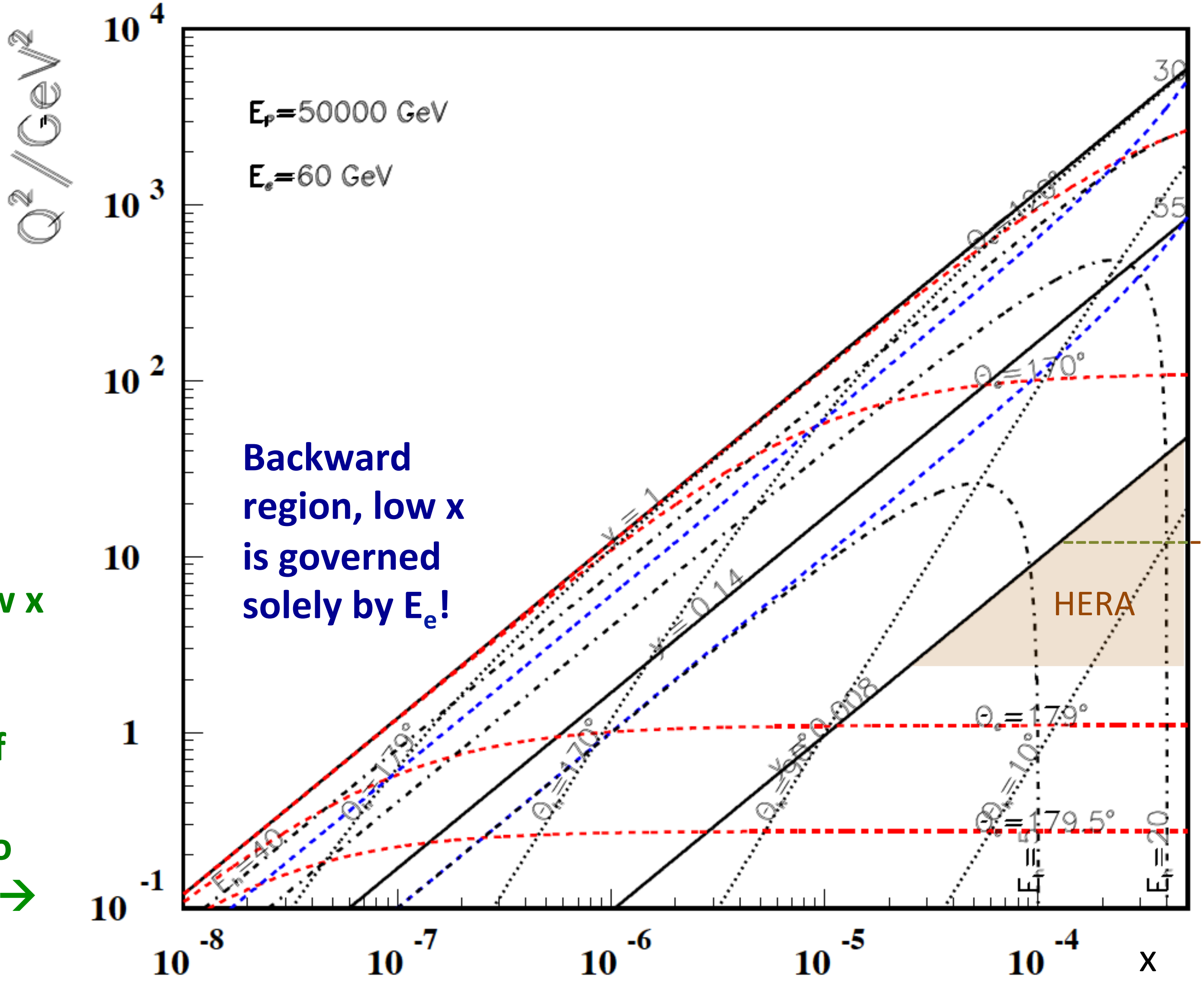
LHeC

← ϑ_h=1°

← HERA

Large imabalance of e and p energies is surprisingly tolerable for the high Q^2, x kinematics, LHeC to bridge from HERA to FCC

Low x



FCC-he
60 GeV

LHeC

Backward region, low x is governed solely by E_e!

← 179°
@ 180 GeV
.. very low x requires not the maximum of E_e

Very low x reaches direct range of UHE neutrino physics →

For x < 10^{-3} no (average) energy deposition exceeding the electron beam energy