From 2014 to 2015
Remarks on the LHeC Status

Max Klein
On Behalf of the Coordination Group

Chavannes-de-Bogis, 25.6.2015

Workshop at Chavannes, I/14

Coordination Group

Gianluigi Arduini
Nestor Armesto
Oliver Brüning
Stefano Forte
Andrea Gaddi
Erk Jensen
Max Klein
Peter Kostka
Bruce Mellado
Paul Newman
Daniel Schulte
Frank Zimmermann

Thanks

to the whole

LHeC

Collaboration

to the FCC

team

and

www.lhec.cern.ch

Physics Groups + Convenors

PDFs, QCD	Fred Olness, Voica Radescu
Higgs	Uta Klein, Masahiro Khuze
BSM	Georges Azuelos, Monica D'Onofrio
Top	Olaf Behnke, Christian Schwanenberger
Nuclei	Nestor Armesto
Small x	Paul Newman, Anna Stasto

The LHeC design has been a strong community effort

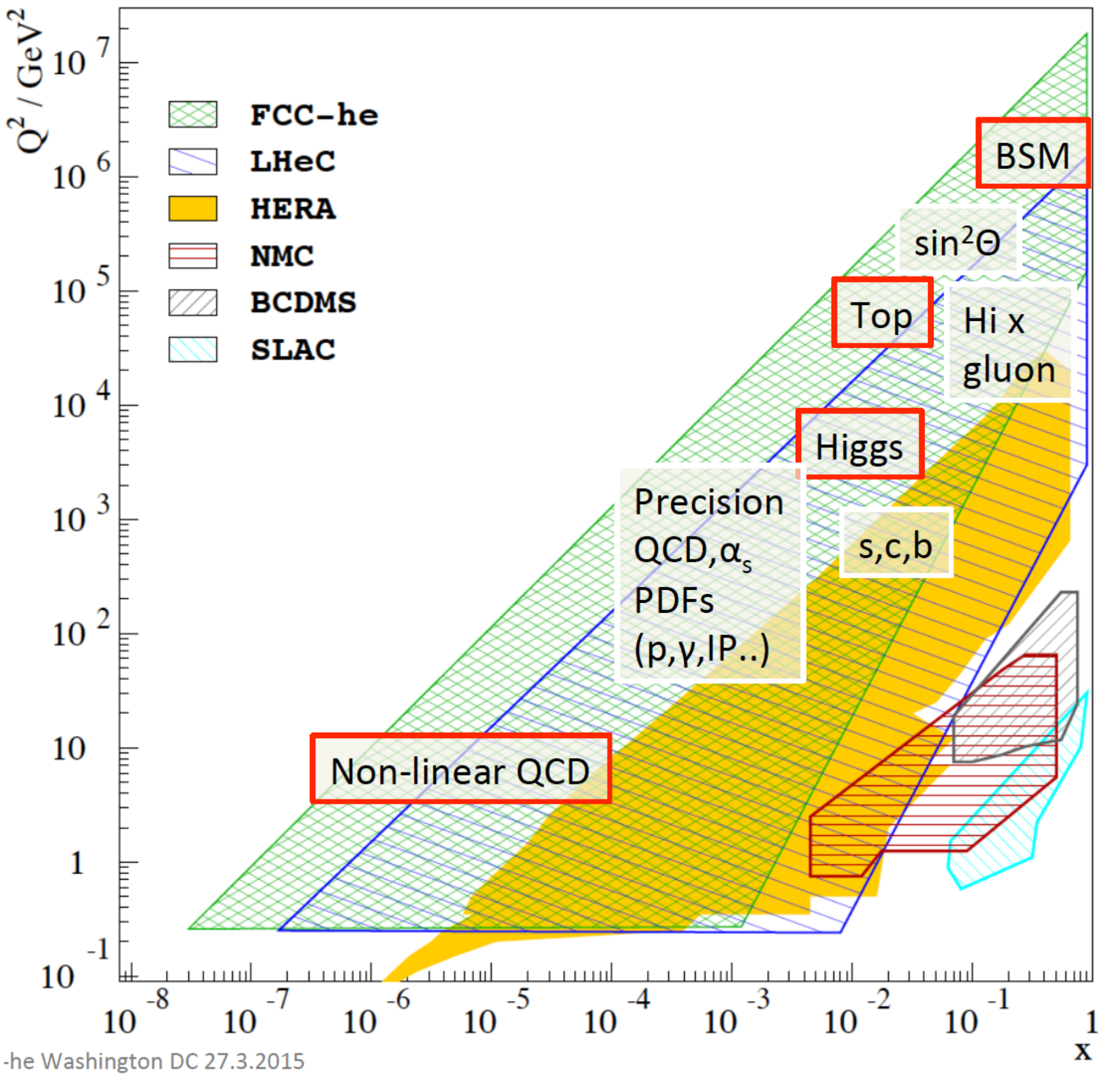
Referees for Design Report

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)

CDR: arXiv:1206.2913

LHC Electron Beam Upgrade

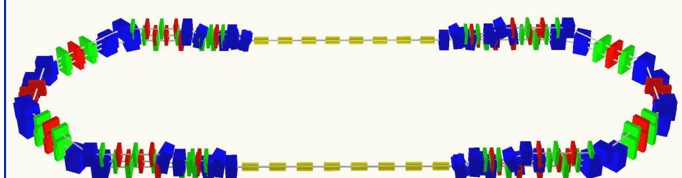
on 1 slide
at DIS15



Luminosity of order 10^{34}cm^{-2} s^{-1}
in concurrent ep-pp operation

LHeC

- -Finest microscope of the world
- -The next machine which sees H
- -Transforms LHC in precision lab.
- -PDFs gain O(.5)TeV search range
- -Revolution of nuclear structure



ERL Facility:
Two LINACS 150 MeV, 3 passes
with energy recovery → 900MeV

Design Concept 2015
AsTEC, BINP, CERN, Jlab +
scRF, ERL, Physics, Tests

International Advisory Committee + Mandate

Guido Altarelli (Rome)
Sergio Bertolucci (CERN)
Nichola Bianchi (Frascati)
Frederick Bordry (CERN)
Stan Brodsky (SLAC)
Hesheng Chen (IHEP Beijing)
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**
Jurgen Schukraft (CERN)
Achille Stocchi (LAL Orsay)
John Womersley (STFC)

IAC Composition June 2014, plus
Oliver Brüning   Max Klein ex officio

The IAC was invited in 12/13 by the DG with the following

Mandate 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.

Some news since 1/2014 – few items

HEP	LHeC	FCC-eh	NP
LHC restarted !! Lifetime projection until 2037	10^{34} probably possible	Washington 3/15. No RR at CERN, but perhaps in China	EIC on NSAC route (recall LHeC is on NuPECCs)
Higgs SM (?)	PERLE	LHeC(e)xFCC(p) IR and parameter set	pPb collective
No BSM – 1000 papers	Advanced physics studies	H-HH, CI, PDF, UHE ν	…
HERA “over” NC+CC	Detector refined IR, simulations, technology	Detector concept	

Decades ago..

Tuesday Afternoon: Accelerator Physics, R. F. Bacher presiding.

Hofstadter opened the discussion with a presentation of some of the extremely elegant electron-scattering work being done by a large group consisting of himself and J. Fregeau, B. Hahn, R. Helm, A. Knudsen, R. McAllister, and J. McIntyre.

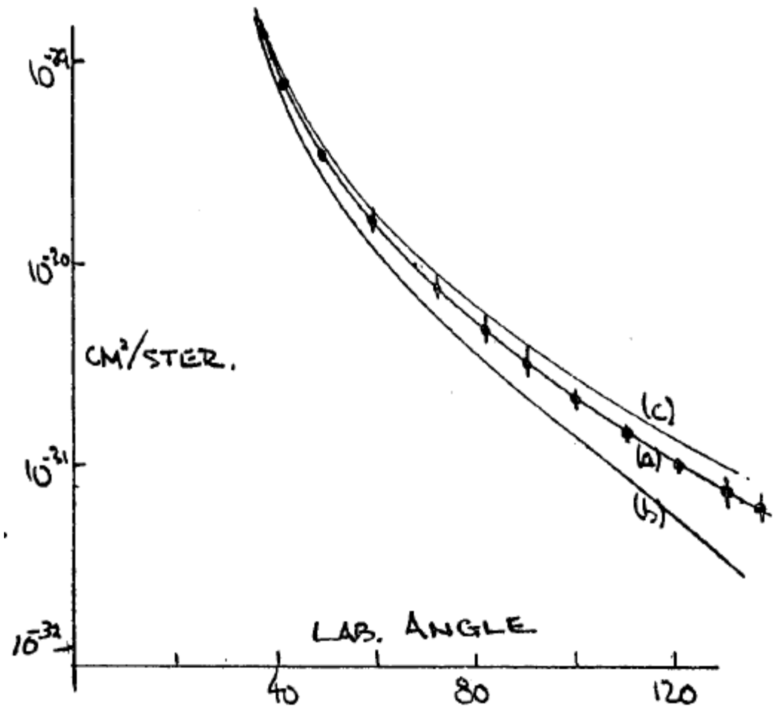


Fig. 2

Rochester Conference 1955

DEEP INELASTIC SCATTERING: THE EARLY YEARS

Nobel Lecture, December 8, 1990

RICHARD E. TAYLOR

With both CEA and DESY operating, the amount of elastic scattering data at high Q^2 (which essentially measures G_M) increased rapidly in both quantity and accuracy. The data continued to follow the so-called dipole model to a good approximation. By the Hamburg conference in 1965 there were no dissenters from the view that

$$G_{Ep} = \frac{G_{Mp}}{\mu_p} = \frac{G_{Mn}}{\mu_n},$$

$$G_{En} \cong 0 \text{ at large } Q^2,$$

and

$$G_{Ep}(Q^2) \cong \left(\frac{1}{1 + \frac{Q^2}{0.71\ \mathrm{GeV}^2}} \right)^2 \text{ up to } Q^2 \backsim 10\ \mathrm{GeV}^2$$

Madison 1980 Leon Lederman in the future HEP panel

"two problems: shortage of money and overconfidence of theorists"

Madison 1980 Leon Lederman in the future HEP panel

"two problems: shortage of money and overconfidence of theorists"

..I assume the resources will come (GA yesterday)

THEORY

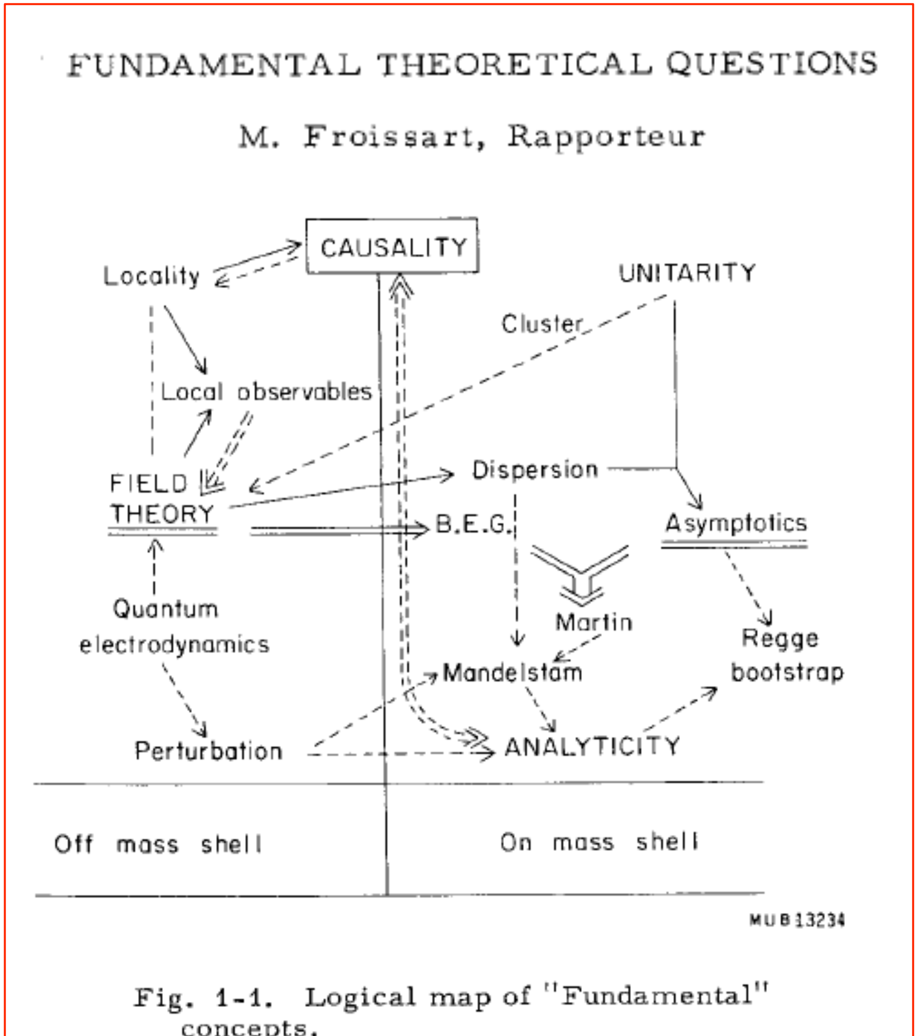
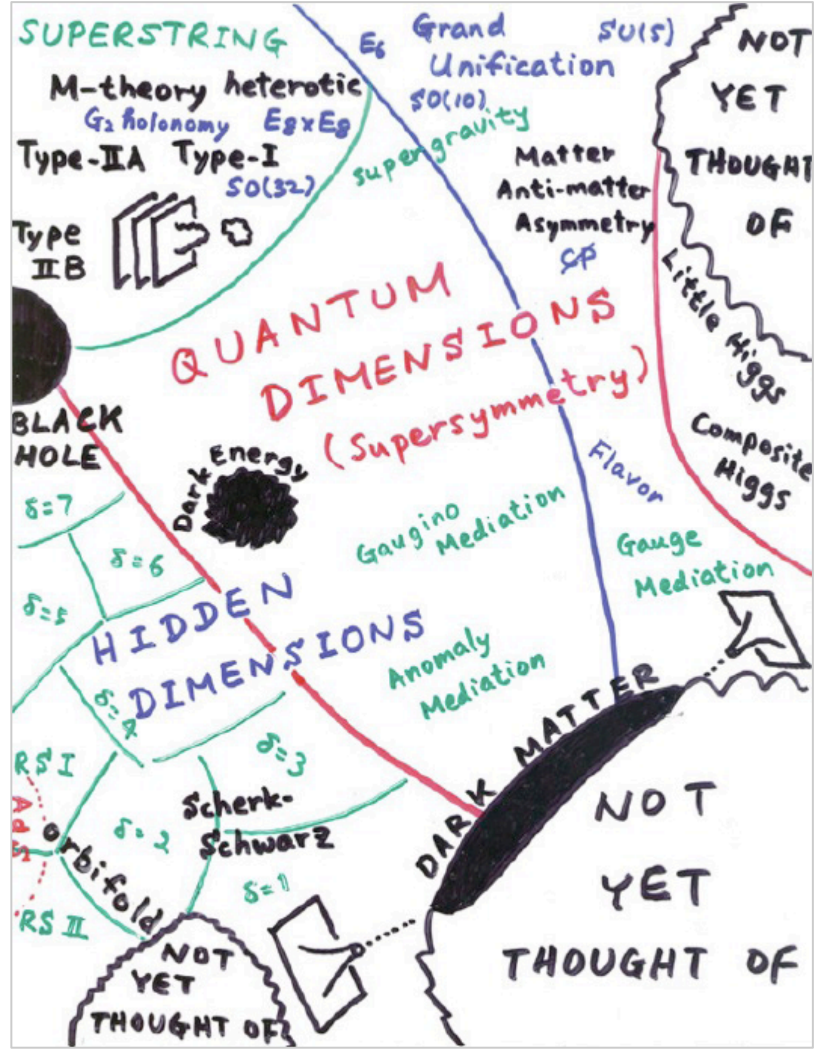


Fig. 1-1. Logical map of "Fundamental" concepts.

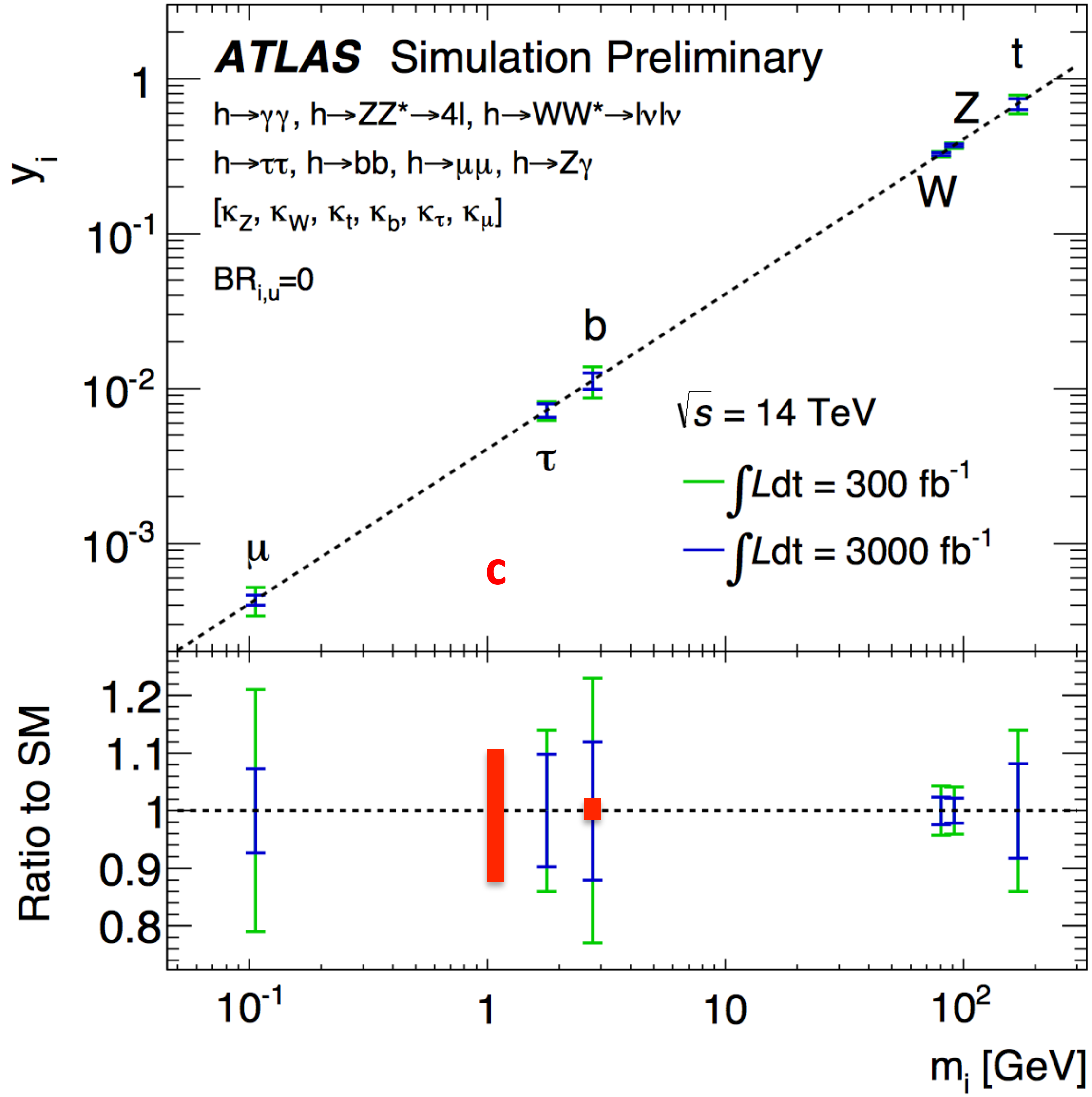


→ Quarks in 1969

→ ?in 2015+?

We like to see particle physics as driven by experiment … Burt Richter

Luminosity Upgrade - Higgs



LHeC, $1ab^{-1}$

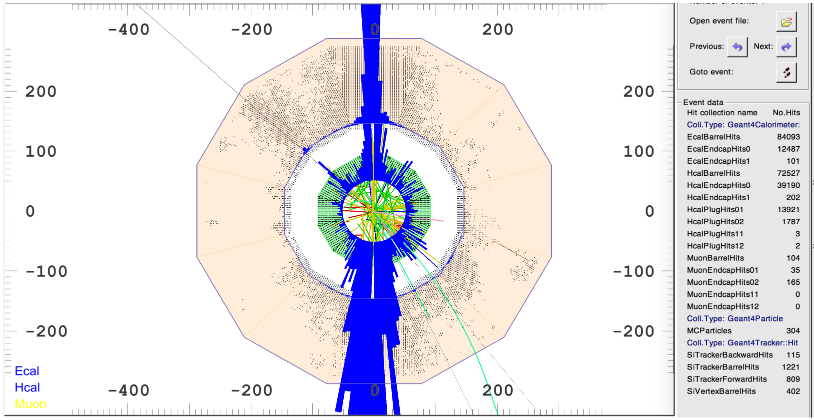
Work in progress

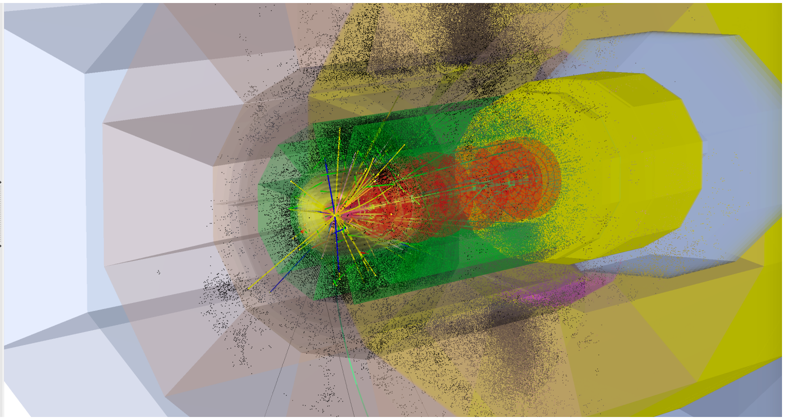
Br: b 59% c 3%

$$y_{V,i} = \sqrt{\kappa_{V,i}\frac{g_{V,i}}{2v}} = \sqrt{\kappa_{V,i}}\frac{m_{V,i}}{v} \qquad y_{F,i} = \kappa_{F,i}\frac{g_{F,i}}{\sqrt{2}} = \kappa_{F,i}\frac{m_{F,i}}{v}$$

ATL-PHYS-PUB-2014-016

The LHeC (+FCC-he) Detector and its Software.

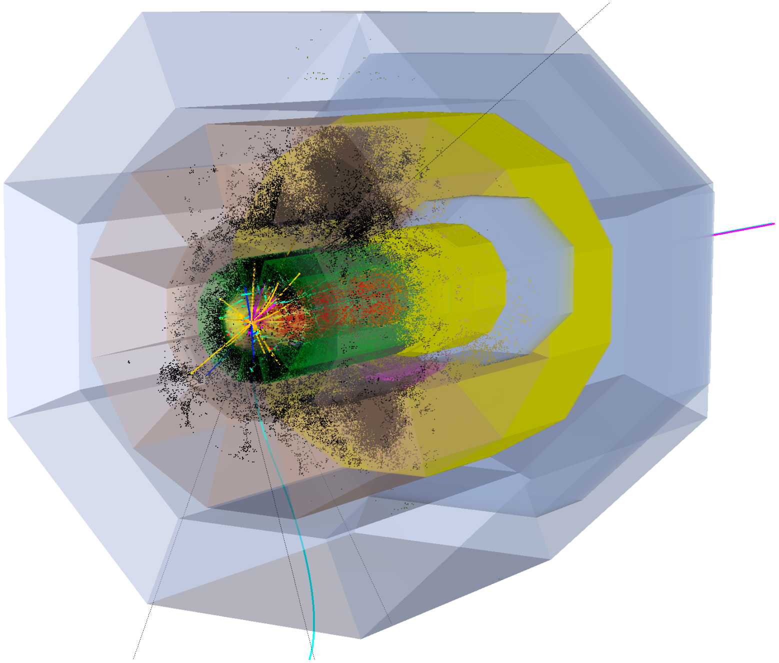




Simulation of Higgs->bb from LHeC e-p

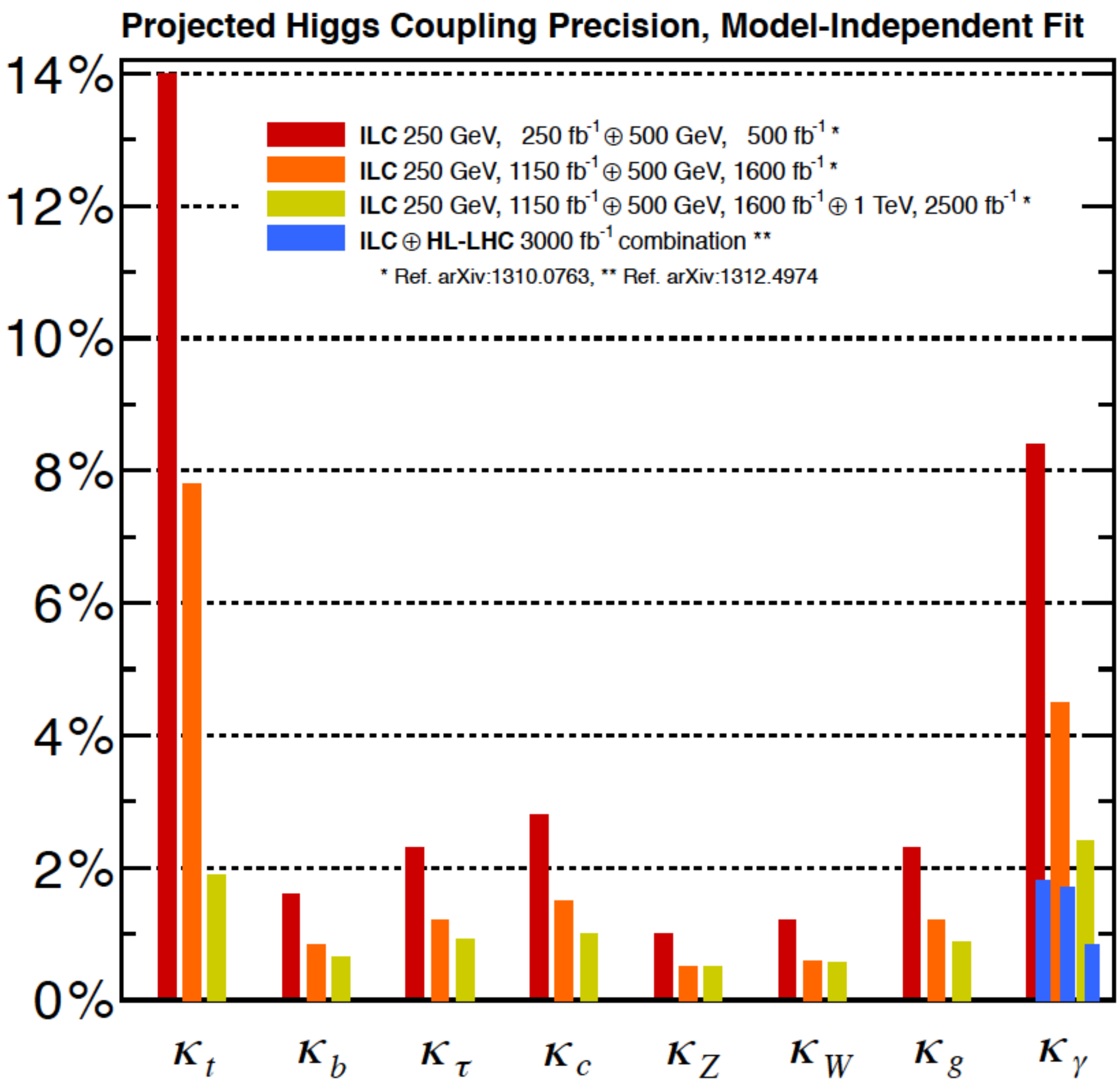
- **A compact DD4hep/DDG4 detector model mimic/simulate the response on physics, on reconstruction schemes, on analysis chains (ROOT/GEANT4 based)**

- **The DD4hep/DDG4 toolbox covers**
  - **full detector description:**
    geometry, materials, visualisation, readout, alignment, calibration …
  - **single source of detector information for simulation, reconstruction, analysis**
  - **support of all phases of the experiment life cycle:**
    detector concept development, detector optimization, construction, operation



Courtesy P. Kostka

Higgs in e^+e^-



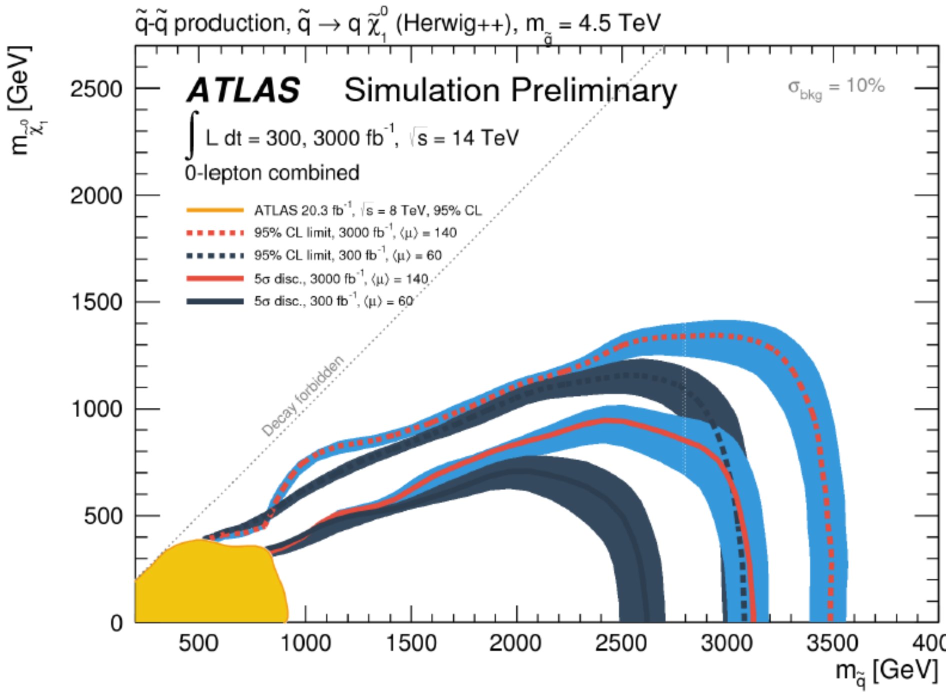
Note the huge Luminosities

Yellow
$1 ab^{-1}$ at 250 GeV
$1.6 ab^{-1}$ at 500
$2.5 ab^{-1}$ at 1 TeV

→ $5 ab^{-1}$ in three machine stages!

ILC as an example

Luminosity Upgrade – SUSY?



5σ up to ~3TeV squarks

5σ up to ~1.2 TeV stops

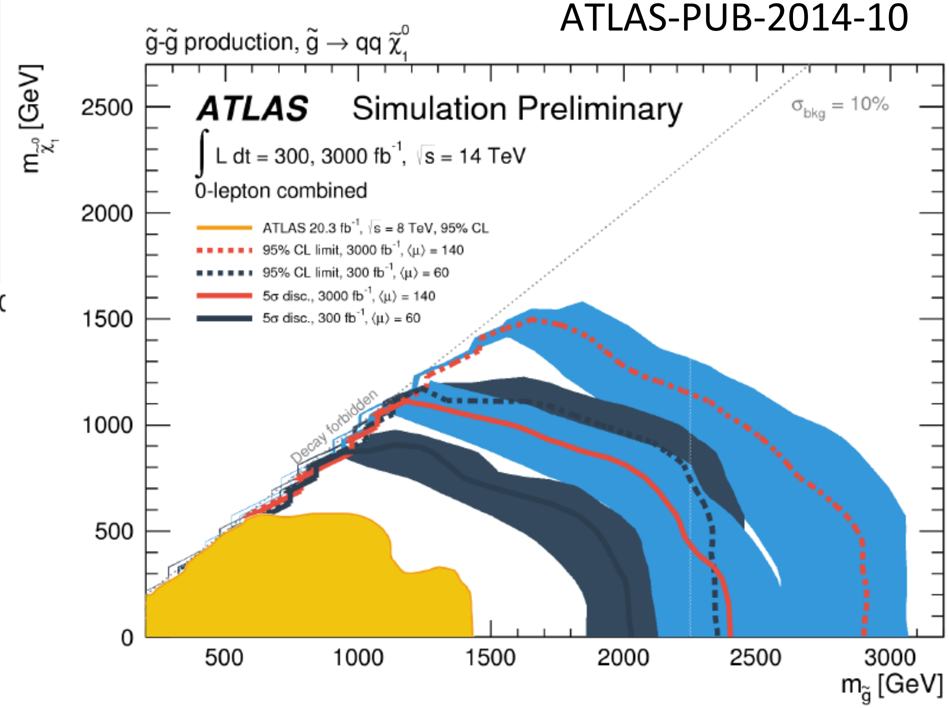
5σ up to ~1.3 TeV sbottoms

@ HL-LHC

5σ up to ~2.5TeV gluinos

@ HL-LHC

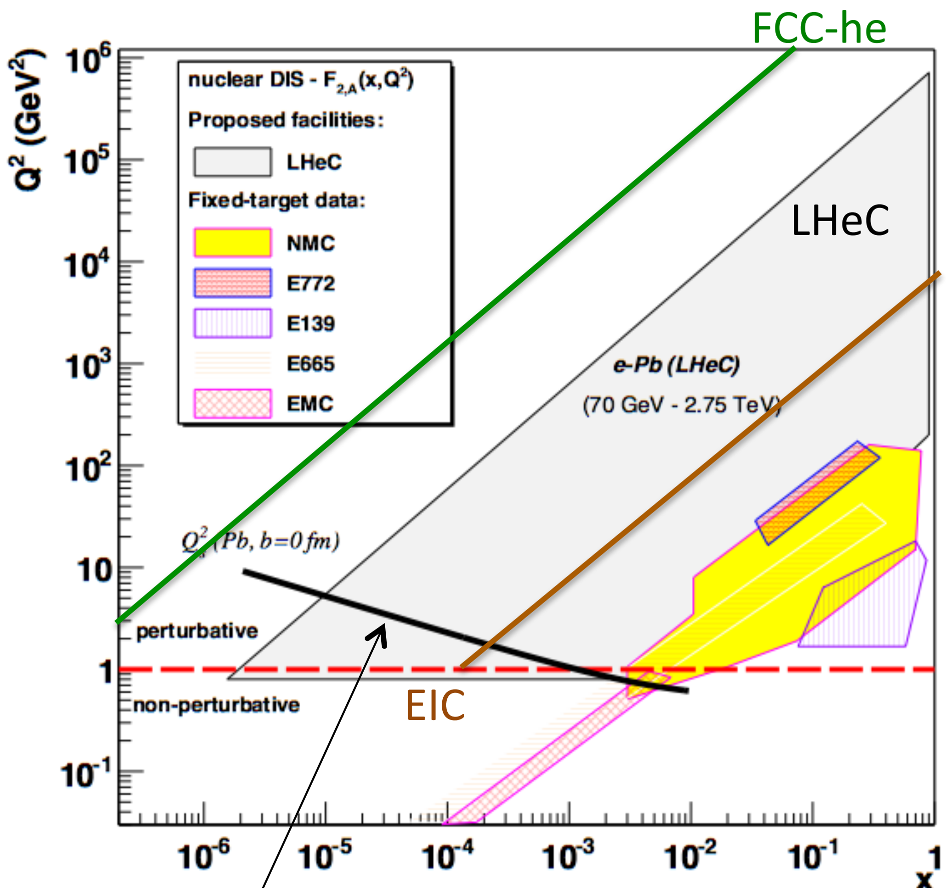
ATLAS-PUB-2014-10



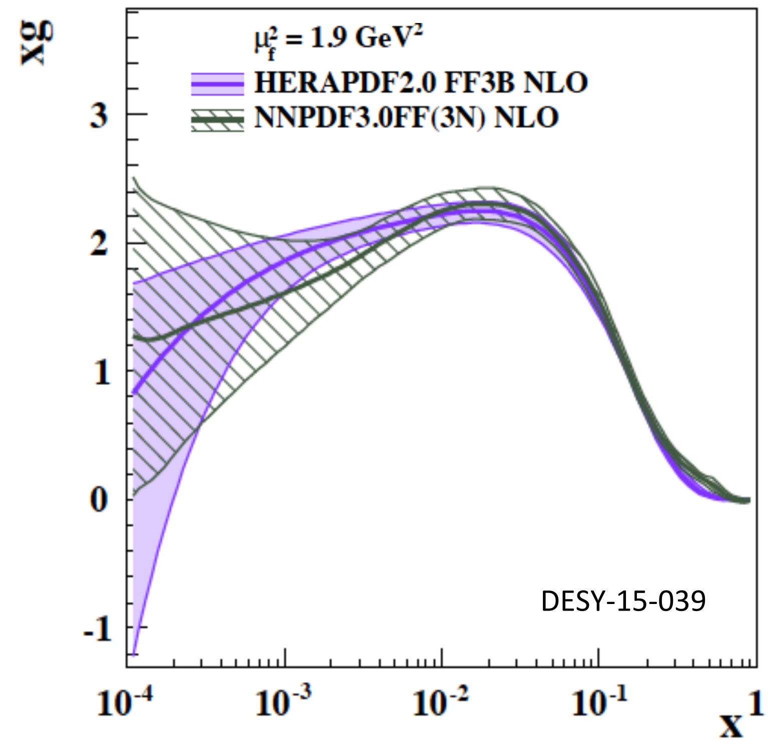
cf Flera Rizatdinova at this workshop

Note that RUN 2 is for 100 fb^{-1} until LS2. Searches need **energy**, clarity and luminosity

Two remarks on eA physics



Huge kinematic range,
NC,CC, c,b,s in nuclei. Neutron!
PDFs $f_A = Rf_p \rightarrow R = f_A/f_p$



Expect saturation of rise at

$$Q^2_s \approx xg\,\alpha_s \approx c\,x^{\lambda}A^{1/3}$$

The gluon at Q^2 near 1 GeV^2 is valence-like at low x, i.e. the power λ is positive, not negative. Any test of saturation requires a negative λ, a Q^2 range to measure xg and Q^2 high enough for the strong coupling to be small. Therefore, given HERAs results, saturation cannot be tested with low energy EICs.

Tentative parameters

PERLE | Powerful energy recovery linac experiments

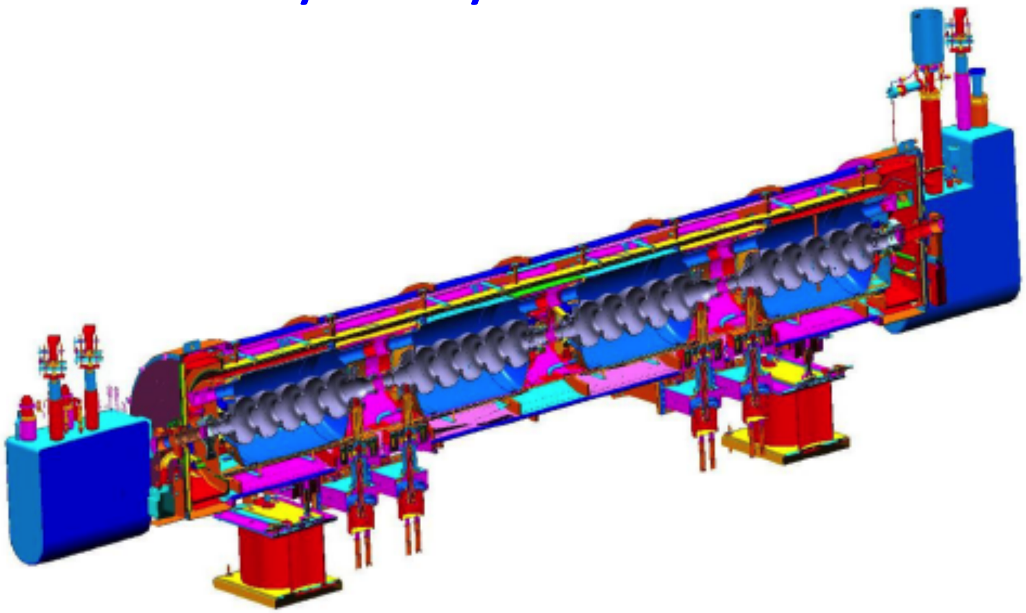
2 10^9 e/bunch, 25ns, 10cm hydrogen target → **L(ep) ~ 3 10^{40} cm^{-2} s^{-1}**

GAMMA BEAM PARAMETERS		
Energy	30 MeV	
Spectral density	$9*10^4$ γ/s/eV	← *or much higher!*
Bandwidth	< 5%	
Flux within FWHM bdw	$7*10^{10}$ ph/s	
ph/e^- within FWHM bdw	10^{-6}	
Peak Brilliance	$3*10^{21}$ ph/s*mm^2*$mrad^2$ 0.1% bdw	

→ **Huge physics potential – a new fixed target programme at CERN possibly**
G_E, G_M, r_p, $\sin^2\theta_W$, dark photons, photonuclear physics: today plenary 6.15pm

Courtesy by Alessandra Valloni, Name by Erk Jensen with the Support of OB+MK [+ you?]

CERN-Jlab Cavity + Cryomodule Collaboration



Magic Ms
..MoU..
..MTP..
Cavity 1
in 2016

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

The ERL test facility will need up to four cryomodules each containing four 802 MHz five cell cavities. A convenient concept for these can be developed by simply adapting the four-cavity SNS high beta cryomodule designed by JLab [39], to accommodate 5-cell β=1 cavities, as shown in Fig. 3.9. Since the cavities are almost the same length as the original 805 MHz $\beta = 0.81$ 6-cells no major changes to the module would be required. This

From PERLE CDR 24.6.2015

FCC-eh at Washington

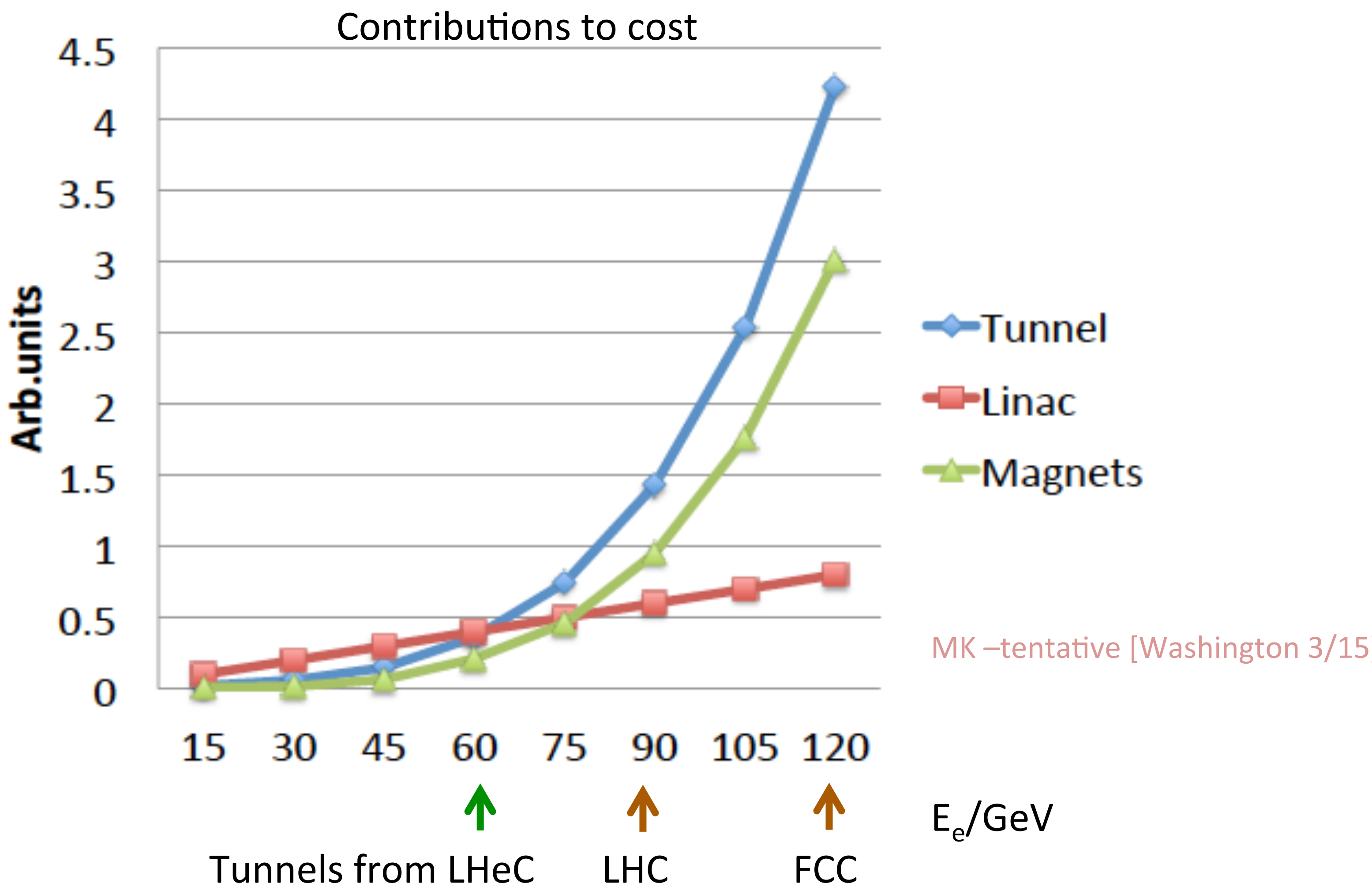
Parallel Session on Accelerator	
Introduction	Max Klein
ep Collider	Frank Zimmermann
Circular ERL	Alessandra Valloni
Beam-Beam	Ed Nissen
Linear ERL	Vladimir Litvinenko

Parallel Session Detector+Physics	
Detector	Peter Kostka
IR	Brett Parker
Higgs in ep	Max Klein
PDFs	Fred Olness
BSM	Georges Azuelos
eA	Mateusz Ploskon

Contribution to joint thy/exp hh-he-ee session: PDFs and α_s Voica Radescu
Also covered in other talks in that session (Markus Kluge, Higgs) → *synergy*

Thanks to all *he* speakers at Washington

Advancing the FCC-he Option ?



Default configuration is to assume that the LHeC ERL operates with a 50 TeV p beam

We will evaluate carefully the gain in physics and extra effort in going conceptually beyond 60 GeV.

"The future belongs to those who believe in the beauty of their dreams."

Anna Eleanor Roosevelt
(1884-1962)

Universal Declaration of Human Rights (1948)

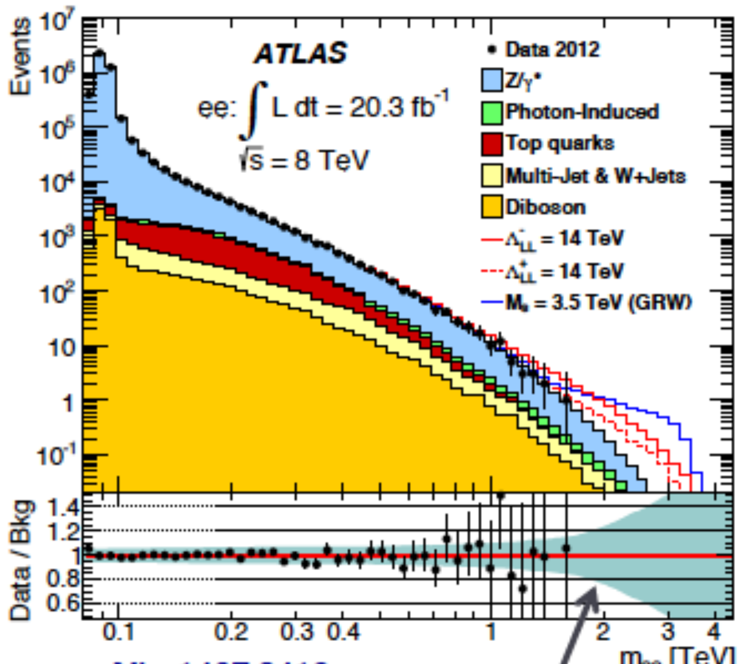
cited by Frank Zimmermann at the FCC Meeting at Washington DC, March 2015


Have a nice workshop
Dinner today at 19.30
Contact us for any problem
we may be able to solve.

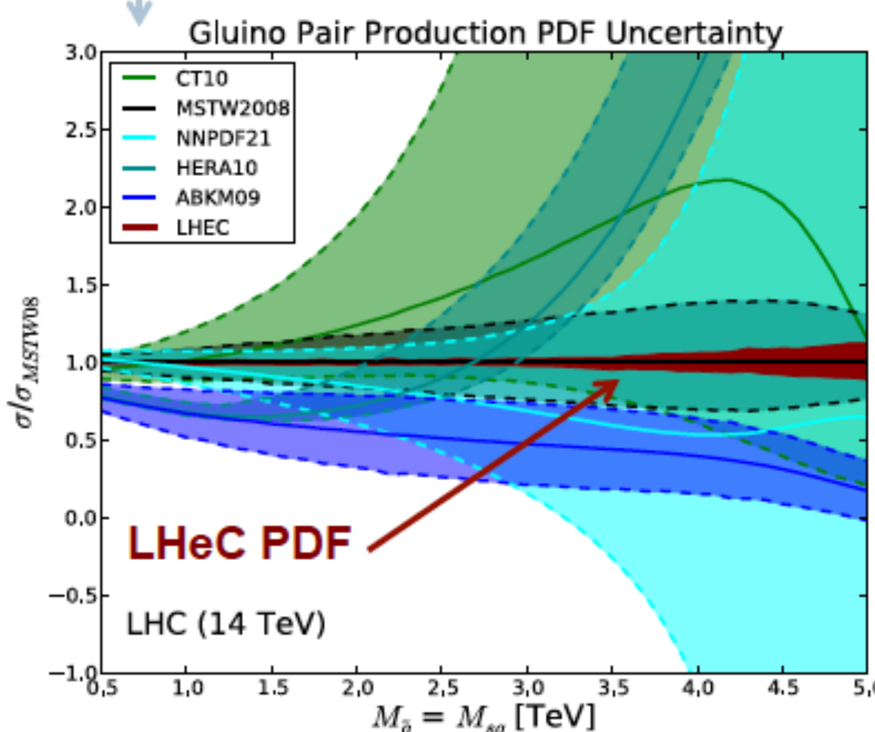
High x PDFs: link to LHC

- 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



arXiv:1407.2410



current BSM search in dilepton final state;
uncertainties on high-x (anti)quarks dominate

arXiv:1211.5102

"The future belongs to those who believe in the beauty of their dreams."

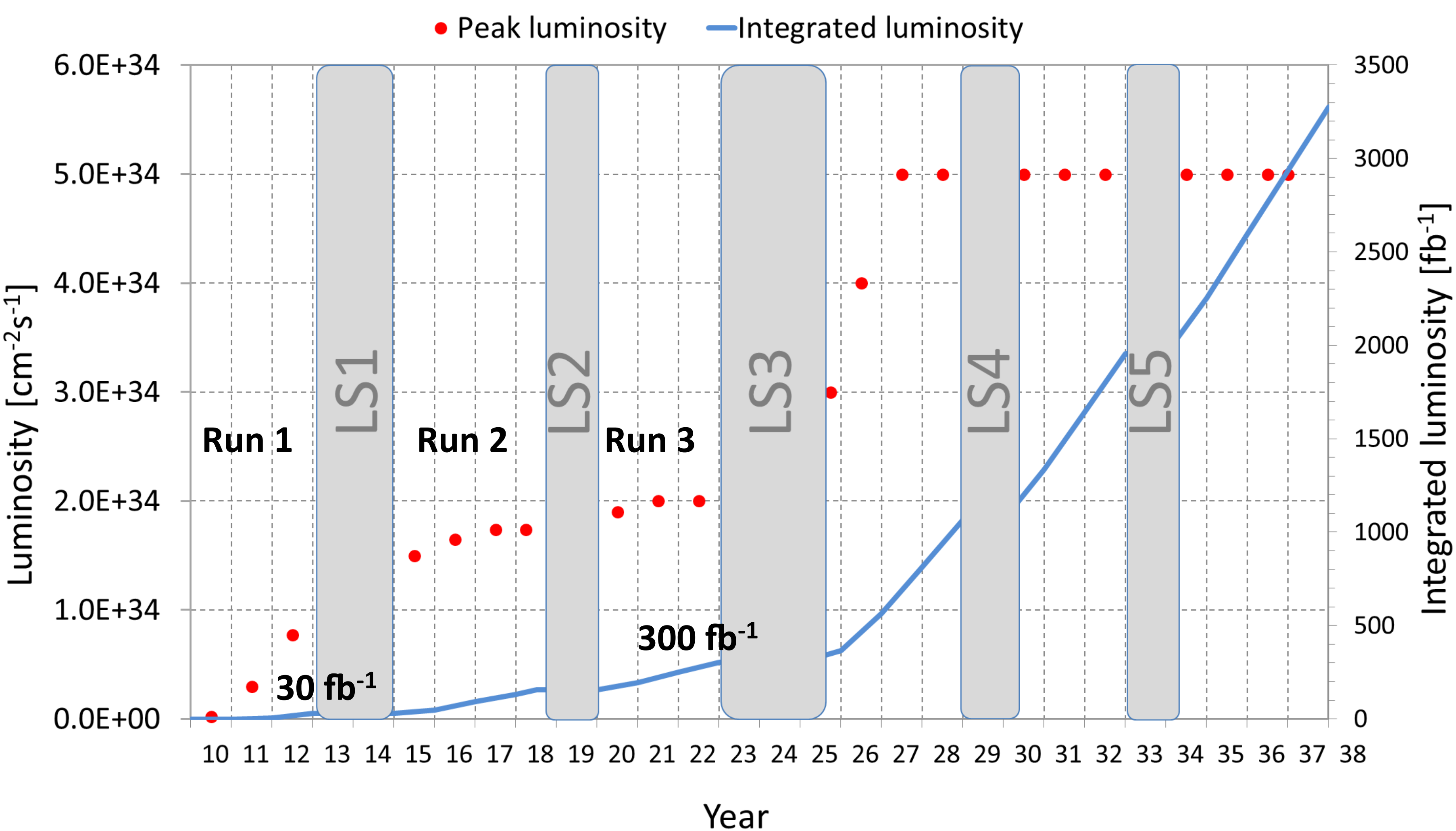
and are supported by those with whom they work – thank you!

Anna Eleanor Roosevelt
(1884-1962)

Universal Declaration of Human Rights (1948)

cited by Frank Zimmermann at the FCC Meeting at Washington DC, March 2015

Current Long Term Planning of the LHC Operation



F. Bordry at the FCC Workshop at Washington DC March 2015

Chris Quigg, IAS-HKUST
Jan. 19, 2015

Issues for the Future *(Starting now!)*

1. What is the agent of EWSB? *There is a Higgs* Might there be several?
2. Is the Higgs boson elementary or composite does it interact with itself? What triggers EWSI
3. Does the Higgs boson give mass to fermions only to the weak bosons? What sets the masse mixings of the quarks and leptons? *(How) is ferm mass related to the electroweak scale?*
4. Are there new flavor symmetries that give in into fermion masses and mixings?
5. What stabilizes the Higgs-boson mass below

6. Do the different CC behaviors of LH, RH fermions reflect a fundamental asymmetry in nature's laws?
7. What will be the next symmetry we recognize? Are there additional heavy gauge bosons? Is nature supersymmetric? Is EW theory contained in a GUT?
8. Are all flavor-changing interactions governed by the standard-model Yukawa couplings? Does "minimal flavor violation" hold? If so, why?
9. Are there additional sequential quark & lepton generations? Or new exotic (vector-like) fermions?
10. What resolves the strong CP problem?

11. What are the dark matters? Any flavor str
12. Is EWSB an emergent phenomenon conn with strong dynamics? How would that alter conception of unified theories of the strong, and electromagnetic interactions?
13. Is EWSB related to gravity through extra spacetime dimensions?
14. What resolves the vacuum energy proble
15. (When we understand the origin of EWS lessons does EWSB hold for unified theories inflation? … for dark energy?

16. What explains the baryon asymmetry of the universe? Are there new (CC) CP-violating phases?
17. Are there new flavor-preserving phases? What would observation, or more stringent limits, on electric-dipole moments imply for BSM theories?
18. (How) are quark-flavor dynamics and lepton-flavor dynamics related (beyond the gauge interactions)?
19. At what scale are the neutrino masses set? Do they speak to the TeV scale, unification scale, Planck scale, …?

20. How are we prisoners of conventional thinking?

ep colliders 11.2014 Max Klein	CEPC	MEIC	eRHIC	HERA 92-07	CepC	LHeC	SepC	FCC-he
√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

Madison 1980 Leon Lederman in the future HEP panel

"two problems: shortage of money and overconfidence of theorists"

Don't confuse majority with truth (Jean Cocteau)

Possible QCD Developments and Discoveries

AdS/CFT

Instantons

Odderons

Non pQCD

QGP and Nuclei

N^kLO

Resummation

Saturation and BFKL

Non-conventional PDFs …

Breaking of Factorisation

Free Quarks

Unconfined Color

New kind of coloured matter

Quark substructure

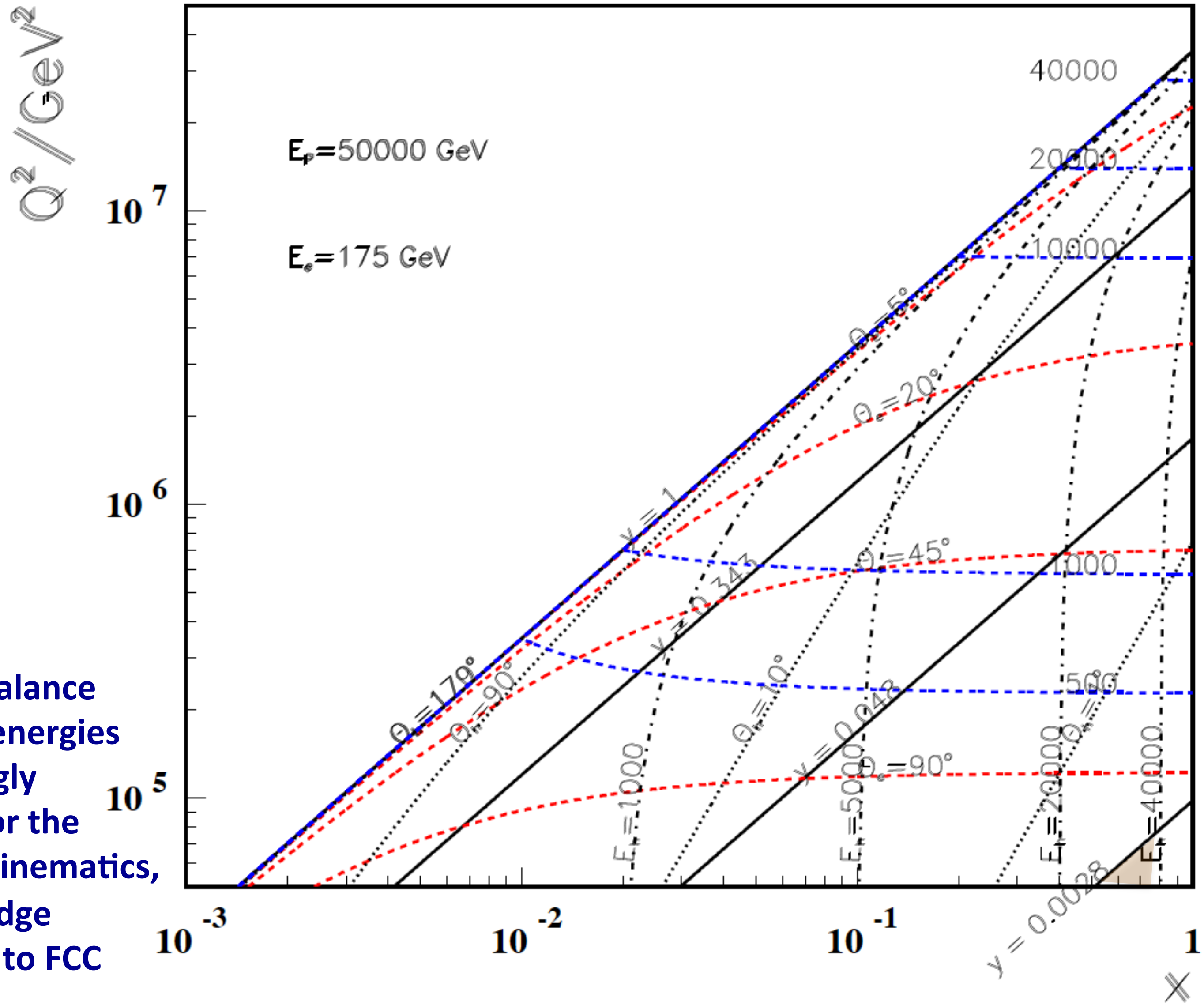
New symmetry embedding QCD

QCD may break .. (Quigg DIS13)

QCD is the richest part of the Standard Model Gauge Field Theory and will (have to) be developed much further, for its own and as background

High Q^2

Rutherford backscattering
of dozens of TeV e- energy



FCC-he
175 GeV
60 GeV

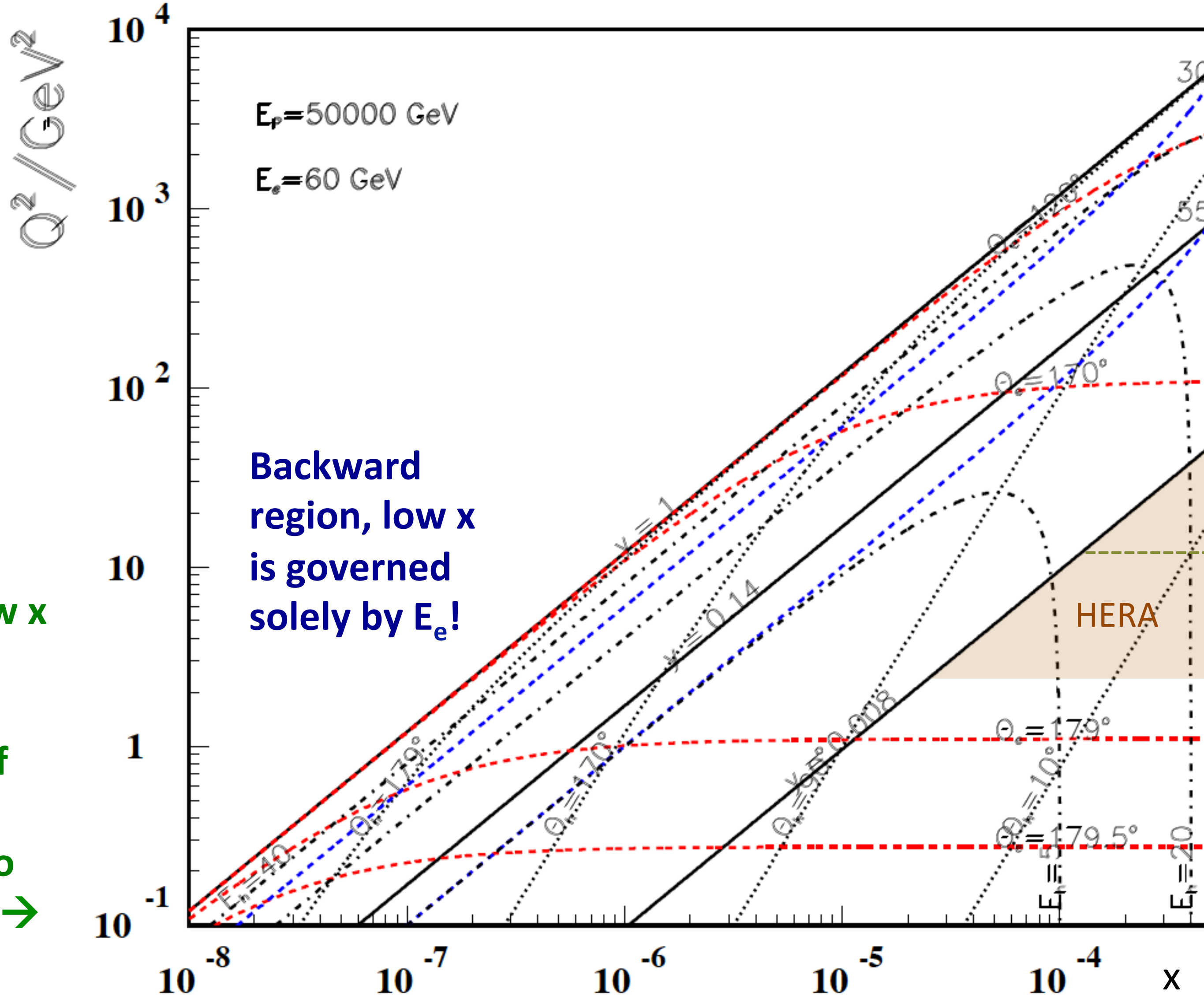
LHeC

← 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

← 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