Future Precision PDF Physics with ep/A

LHeC:
E_e=60 GeV
x E_p= 7 TeV

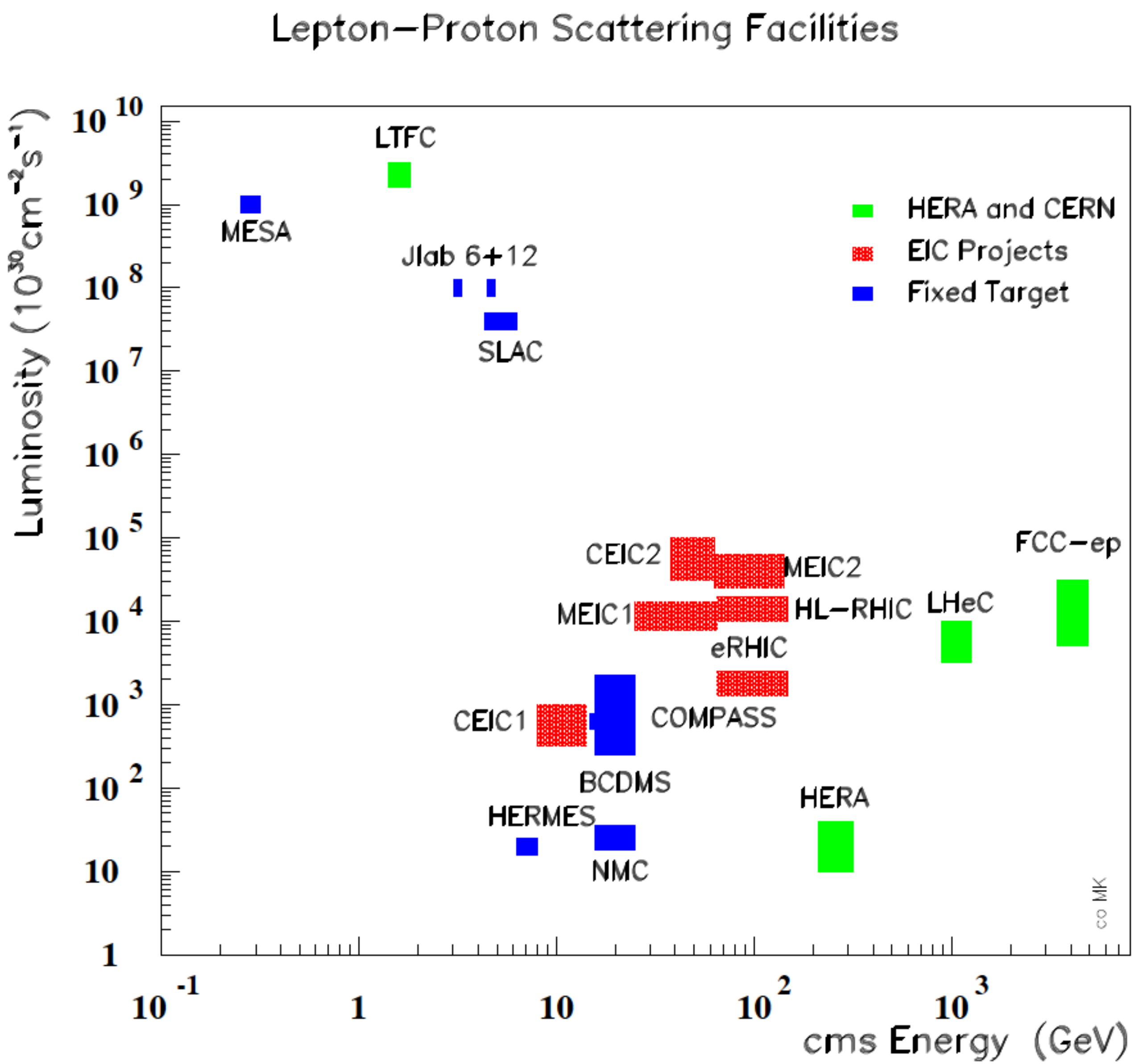
For references,
please consult
lhec.web.cern.ch
LHeC CDR
arXiv:1206.2913
J.Phys. G39 (2012) 075001

Max Klein
University of Liverpool
for the LHeC Study Group

FCC_eh:
E_e=60 GeV
x E_p =50 TeV

Precise Experiments for Precise Theory, Quy Nhon, Rencontre du Vietnam, 27th of September 2016

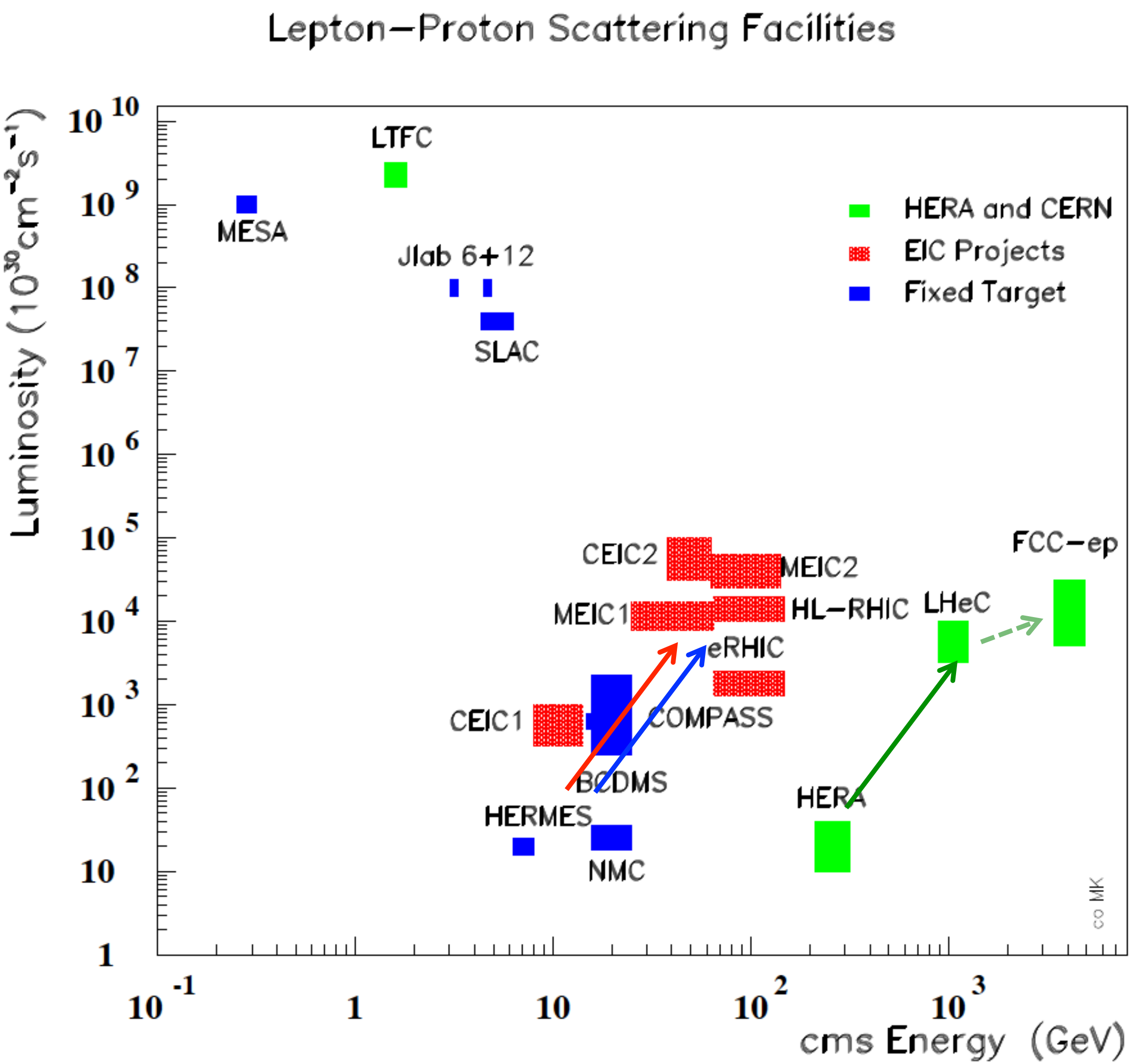
Intensity and Energy Frontier of Future DIS



From CERN Courier
MK, H.Schopper
June 2014

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

Intensity and Energy Frontier of Future DIS



From CERN Courier
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A.Hutton, R.Ent,
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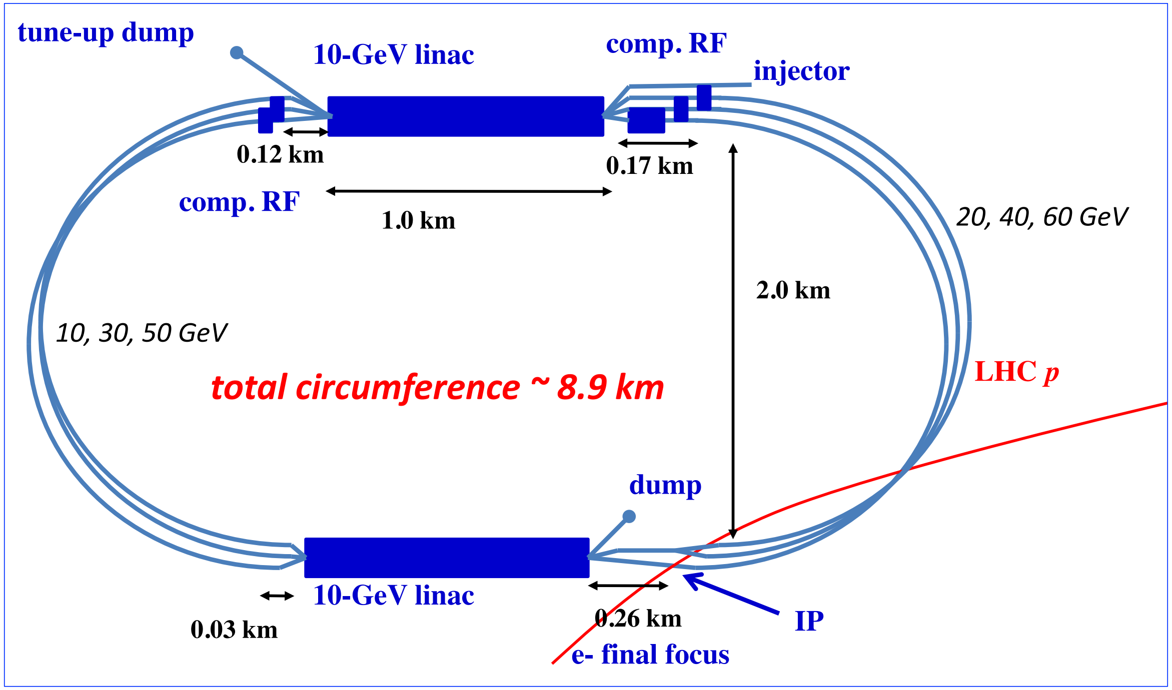
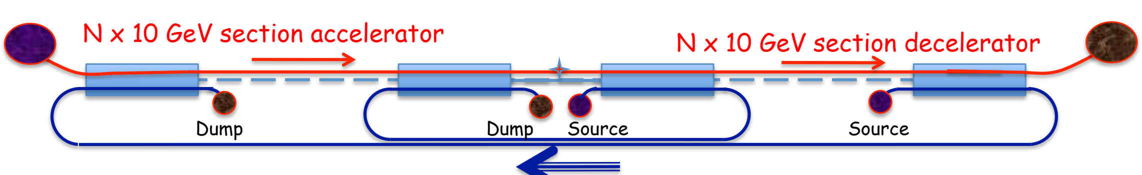
1. ep/A with the LHC

Conceptual Design Report: arXiv:1206.2913, published in JPhysG – 20 referees..



LHeC: 60 GeV off 7 TeV, L(ep) $=10^{34}$ cm^{-2} s^{-1} (1000 x HERA) in synchronous ep+pp operation

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



LHeC Accelerator Design: Participating Institutes

CERN

SLAC NATIONAL ACCELERATOR LABORATORY

NTNU Norwegian University of Science and Technology

ECFA

clic

The Cockcroft Institute of Accelerator Science and Technology

Jefferson Lab Thomas Jefferson National Accelerator Facility

ANKARA ÜNİVERSİTESİ 1946

NİĞDE ÜNİVERSİTESİ 1992

ULUDAĞ ÜNİVERSİTESİ 1975

TOBB ETU

INFN Istituto Nazionale di Fisica Nucleare

Laboratori Nazionali di Legnaro

DESY

LAL Physique des accélérateurs

EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

UNIVERSITY OF LIVERPOOL

KEK

BROOKHAVEN NATIONAL LABORATORY

СИБИРСКОЕ ОТДЕЛЕНИЕ РАН ИНСТИТУТ ЯДЕРНОЙ ФИЗИКИ им. Г.И.Будкера

630090 Новосибирск

Source	Power [MW]
Cryogenics (linac)	21
Linac grid power	24
SR compensation	23
Extra RF cryopower	2
Injector	6
Arc magnets	3
Total	**78**

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

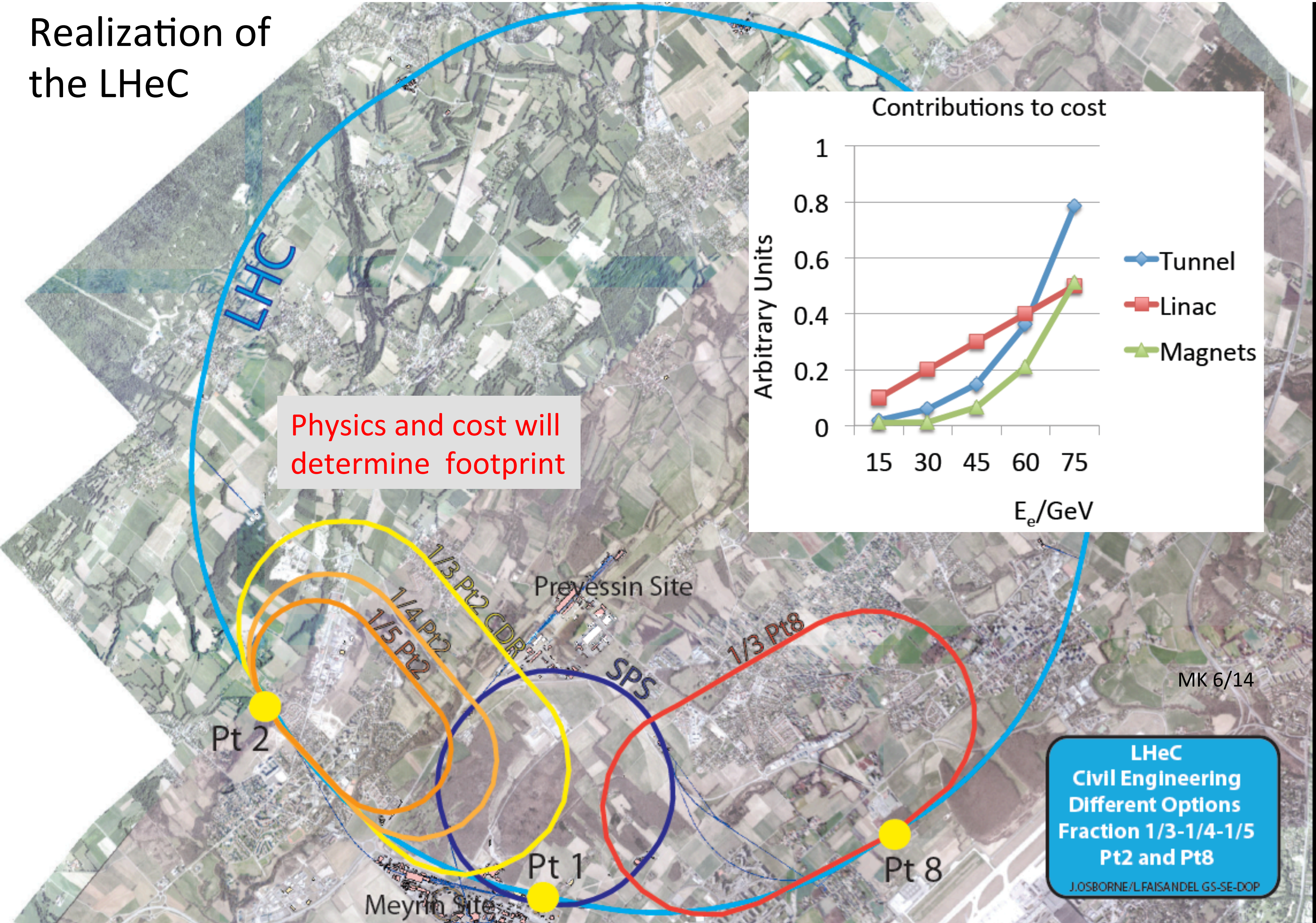
Table 1: Baseline parameters of future electron-proton collider configurations based on the ERL electron linac.

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

May count on 1ab^{-1} in 10 years of OP, 1000xHERA in ep with HL LHC, with HE-LHC and with FCC_eh

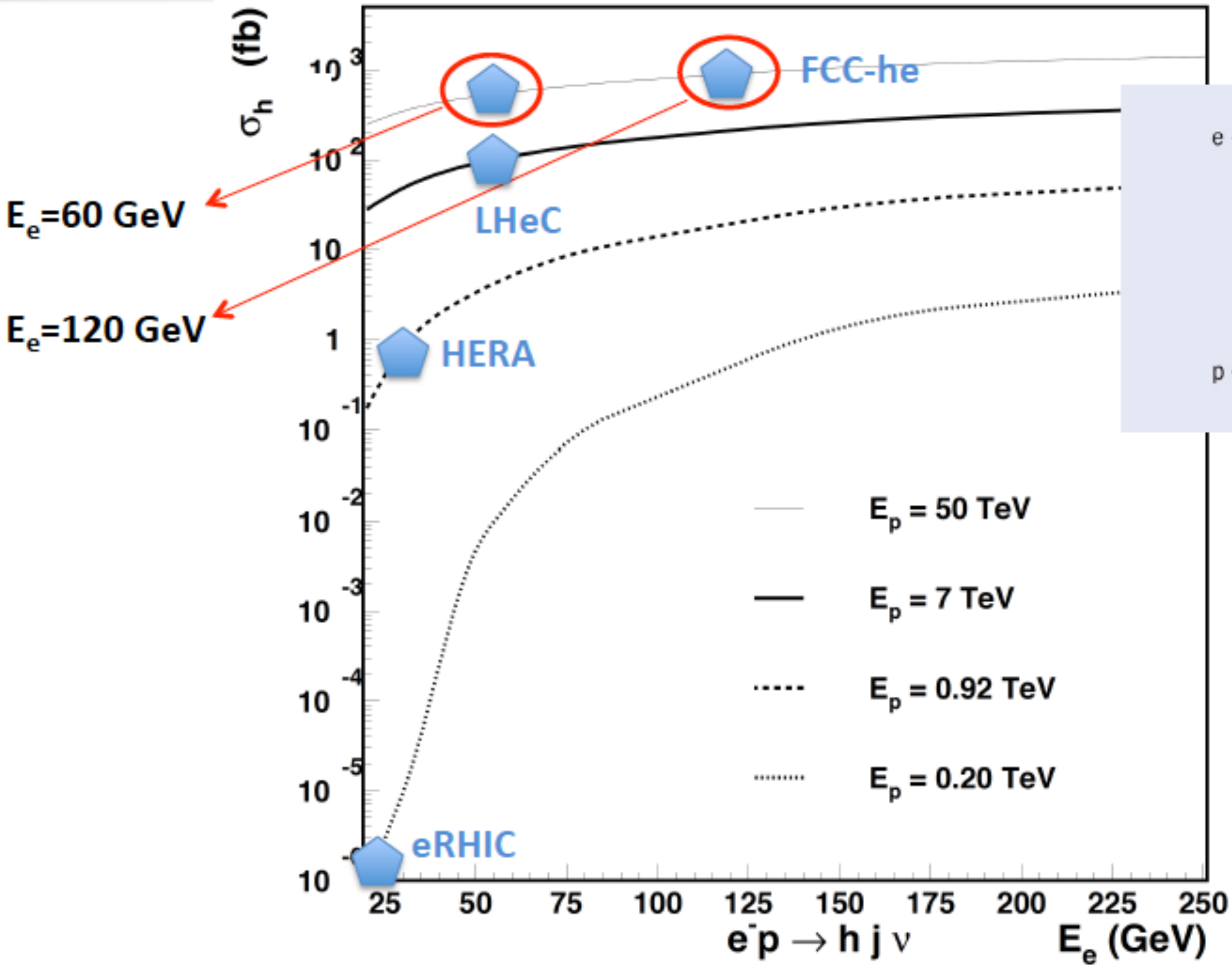
work in progress (also eA)

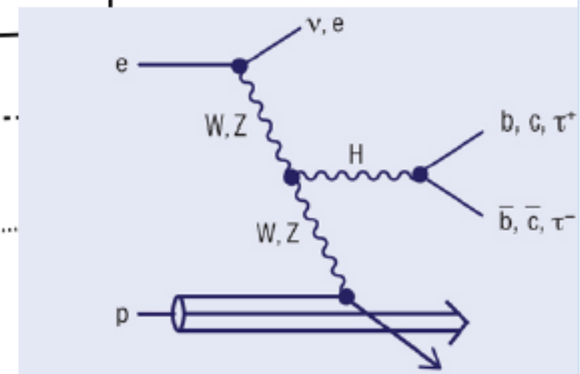
Realization of the LHeC



Physics and cost will determine footprint

2. SM Higgs in ep → ν/e H X



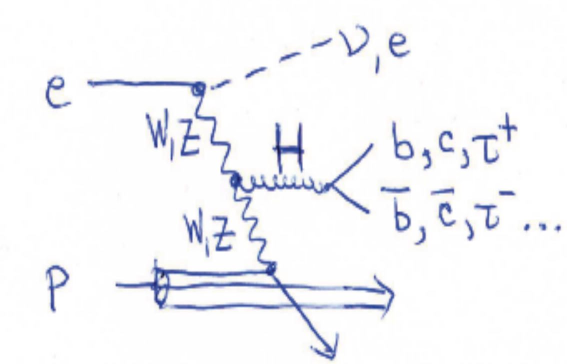


$\sigma(e^-p)$ = 200 fb^{-1}

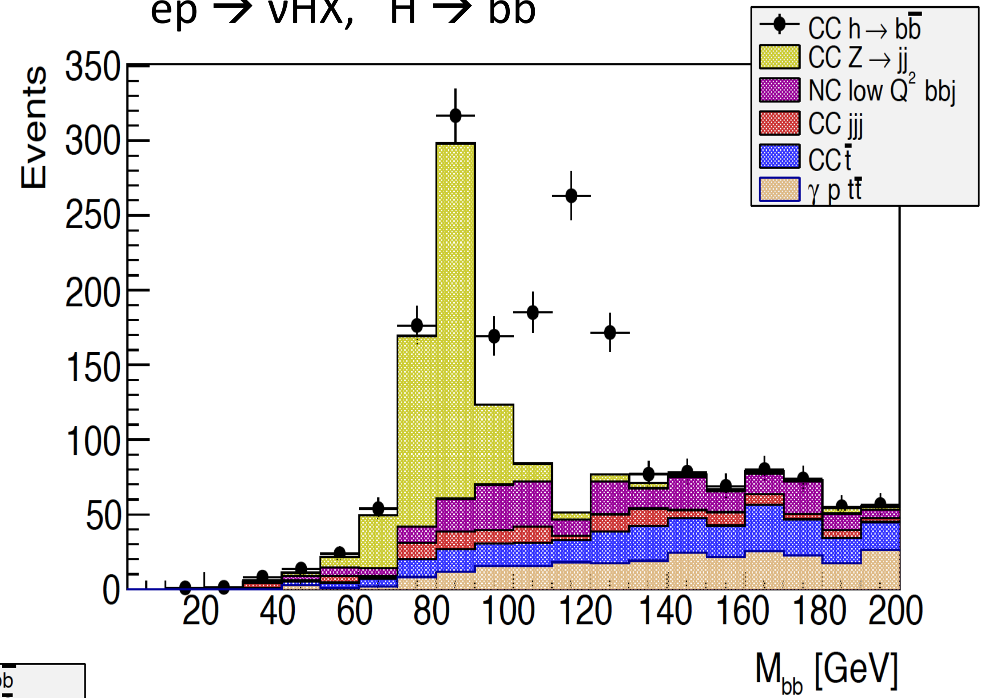
at LHeC, pol. CC

LHeC / FCC-he: Sizeable charged current DIS unpolarised **ep cross sections**

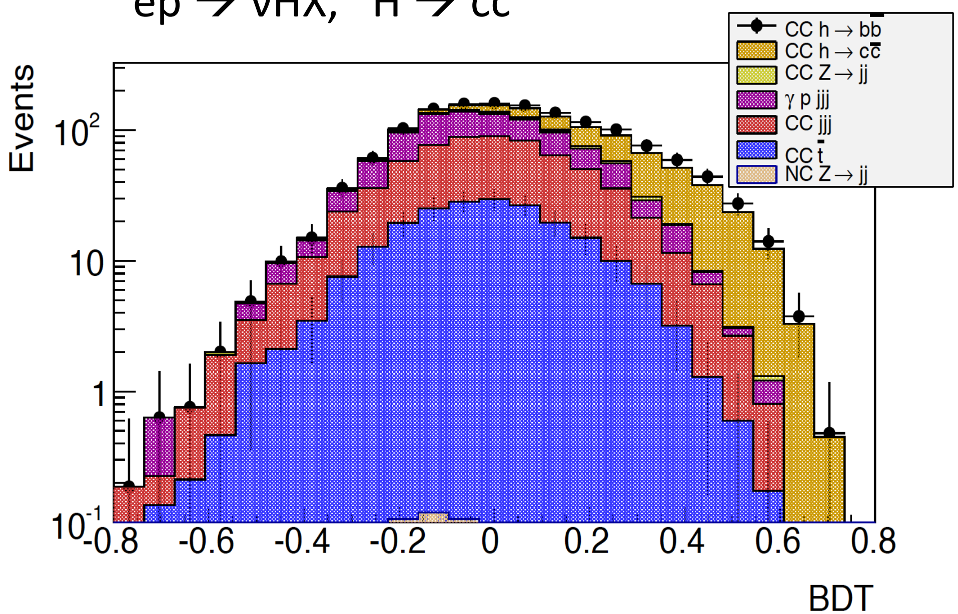
Higgs in ep



ep → νHX, H → bb



ep → νHX, H → cc



H → bb cut based: 1% coupling error

H → cc BDT based: 6% coupling error

To study: WW, ττ, Higgs width in NC..

ep complements Higgs in pp, also with N^3LO PDFs and strong coupling to 0.1%

From Uta Klein: Turning the LHC into a powerful Higgs facility (UCL seminar, 17.02.2016), cf LHeC H+t group

Further Recent Studies on Higgs in ep

BSM Higgs with LHeC

Invisible Higgs Decay at the LHeC

Yi-Lei Tang,[1,*] Chen Zhang,[2,†] and Shou-hua Zhu[1,2,3,‡]

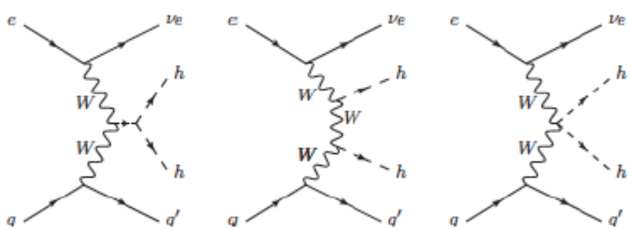
arXiv:1508.01095, 2015

Our study clearly justifies a luminosity upgrade to 1 ab^{-1} for the LHeC to become a Higgs boson factory [46] and demonstrates its huge potential on study of exotic Higgs decays. Besides the invisible Higgs decay, the LHeC is suited to the study of those exotic Higgs decays which suffer from large backgrounds, trigger or p_T threshold problem at the (HL-)LHC such as $h \to 4b$, $h \to 2b2\tau$, $h \to 4j$, $h \to b\bar{b} + \not{E}_T$ [73], $h \to \gamma + \not{E}_T$, $h \to Z + \not{E}_T$ [74]. Work on these directions is in progress [75]. The

H-HH with FCC-he (√s=3.5 TeV vs 0.3 at FCC-ee)

Probing anomalous couplings using di-Higgs production in electron-proton collisions

Mukesh Kumar,[1,*] Xifeng Ruan,[2,†] Rashidul Islam,[3,‡] Alan S. Cornell,[1,§] Max Klein,[4,¶] Uta Klein,[4,**] and Bruce Mellado[2,††]



(a) (b) (c)

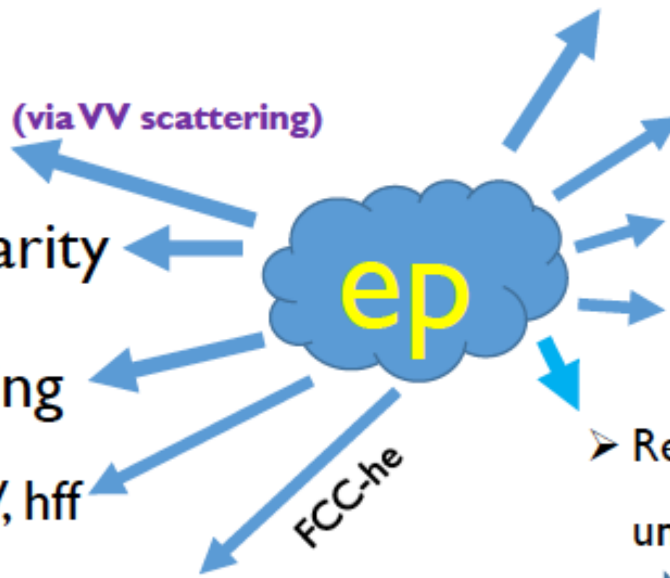
arXiv:1509.04016, 2015.

Higgs cross section at FCC-ep is O(1pb) [4x FCCee]→striking potential being studied

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 (talk at annual FCC week 2016, Rome)

In the absence of any explicit new states, or overwhelming theory prejudice, the goal is to systematically study the SM EFT for hints of NP, using all possible future facilities to maximize physics conclusions.

Michael Trott at LHeC Workshop I/2014

Specifics of the linear SM EFT.

Four fermion operators with leptons and quark fields:

$8:(\bar{L}L)(\bar{L}L)$	
Q_{ll}	$(\bar{l}_p\gamma_\mu l_r)(\bar{l}_s\gamma^\mu l_t)$
$Q_{qq}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{q}_s\gamma^\mu q_t)$
$Q_{qq}^{(3)}$	$(\bar{q}_p\gamma_\mu\tau^I q_r)(\bar{q}_s\gamma^\mu\tau^I q_t)$
$Q_{lq}^{(1)}$	$(\bar{l}_p\gamma_\mu l_r)(\bar{q}_s\gamma^\mu q_t)$
$Q_{lq}^{(3)}$	$(\bar{l}_p\gamma_\mu\tau^I l_r)(\bar{q}_s\gamma^\mu\tau^I q_t)$

$8:(\bar{R}R)(\bar{R}R)$	
Q_{ee}	$(\bar{e}_p\gamma_\mu e_r)(\bar{e}_s\gamma^\mu e_t)$
Q_{uu}	$(\bar{u}_p\gamma_\mu u_r)(\bar{u}_s\gamma^\mu u_t)$
Q_{dd}	$(\bar{d}_p\gamma_\mu d_r)(\bar{d}_s\gamma^\mu d_t)$
Q_{eu}	$(\bar{e}_p\gamma_\mu e_r)(\bar{u}_s\gamma^\mu u_t)$
Q_{ed}	$(\bar{e}_p\gamma_\mu e_r)(\bar{d}_s\gamma^\mu d_t)$
$Q_{ud}^{(1)}$	$(\bar{u}_p\gamma_\mu u_r)(\bar{d}_s\gamma^\mu d_t)$
$Q_{ud}^{(8)}$	$(\bar{u}_p\gamma_\mu T^A u_r)(\bar{d}_s\gamma^\mu T^A d_t)$

$8:(\bar{L}L)(\bar{R}R)$	
Q_{le}	$(\bar{l}_p\gamma_\mu l_r)(\bar{e}_s\gamma^\mu e_t)$
Q_{lu}	$(\bar{l}_p\gamma_\mu l_r)(\bar{u}_s\gamma^\mu u_t)$
Q_{ld}	$(\bar{l}_p\gamma_\mu l_r)(\bar{d}_s\gamma^\mu d_t)$
Q_{qe}	$(\bar{q}_p\gamma_\mu q_r)(\bar{e}_s\gamma^\mu e_t)$
$Q_{qu}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{u}_s\gamma^\mu u_t)$
$Q_{qu}^{(8)}$	$(\bar{q}_p\gamma_\mu T^A q_r)(\bar{u}_s\gamma^\mu T^A u_t)$
$Q_{qd}^{(1)}$	$(\bar{q}_p\gamma_\mu q_r)(\bar{d}_s\gamma^\mu d_t)$
$Q_{qd}^{(8)}$	$(\bar{q}_p\gamma_\mu T^A q_r)(\bar{d}_s\gamma^\mu T^A d_t)$

$8:(\bar{L}R)(\bar{R}L)+\mathrm{h.c.}$	
Q_{ledq}	$(\bar{l}_p^j e_r)(\bar{d}_s q_{tj})$

$8:(\bar{L}R)(\bar{L}R)+\mathrm{h.c.}$	
$Q_{quqd}^{(1)}$	$(\bar{q}_p^j u_r)\epsilon_{jk}(\bar{q}_s^k d_t)$
$Q_{quqd}^{(8)}$	$(\bar{q}_p^j T^A u_r)\epsilon_{jk}(\bar{q}_s^k T^A d_t)$
$Q_{lequ}^{(1)}$	$(\bar{l}_p^j e_r)\epsilon_{jk}(\bar{q}_s^k u_t)$
$Q_{lequ}^{(3)}$	$(\bar{l}_p^j \sigma_{\mu\nu} e_r)\epsilon_{jk}(\bar{q}_s^k \sigma^{\mu\nu} u_t)$

Number of 4 fermion parameters with lepton-quark: $13\,n_g^4$ *or* 1053 *of* 2499

3. PDFs in ep/n - beyond this presentation

Generalised Parton Distributions [DVCS] – "proton in 3D - tomography"

Unintegrated Parton Distributions [Final State] – DGLAP/BFKL?

Diffractive Parton Distributions [Diffraction] – pomeron, confinement??

Photon Parton Distribution [Photoproduction Dijets,QQ; $F_{2,L}$] - fashionable..

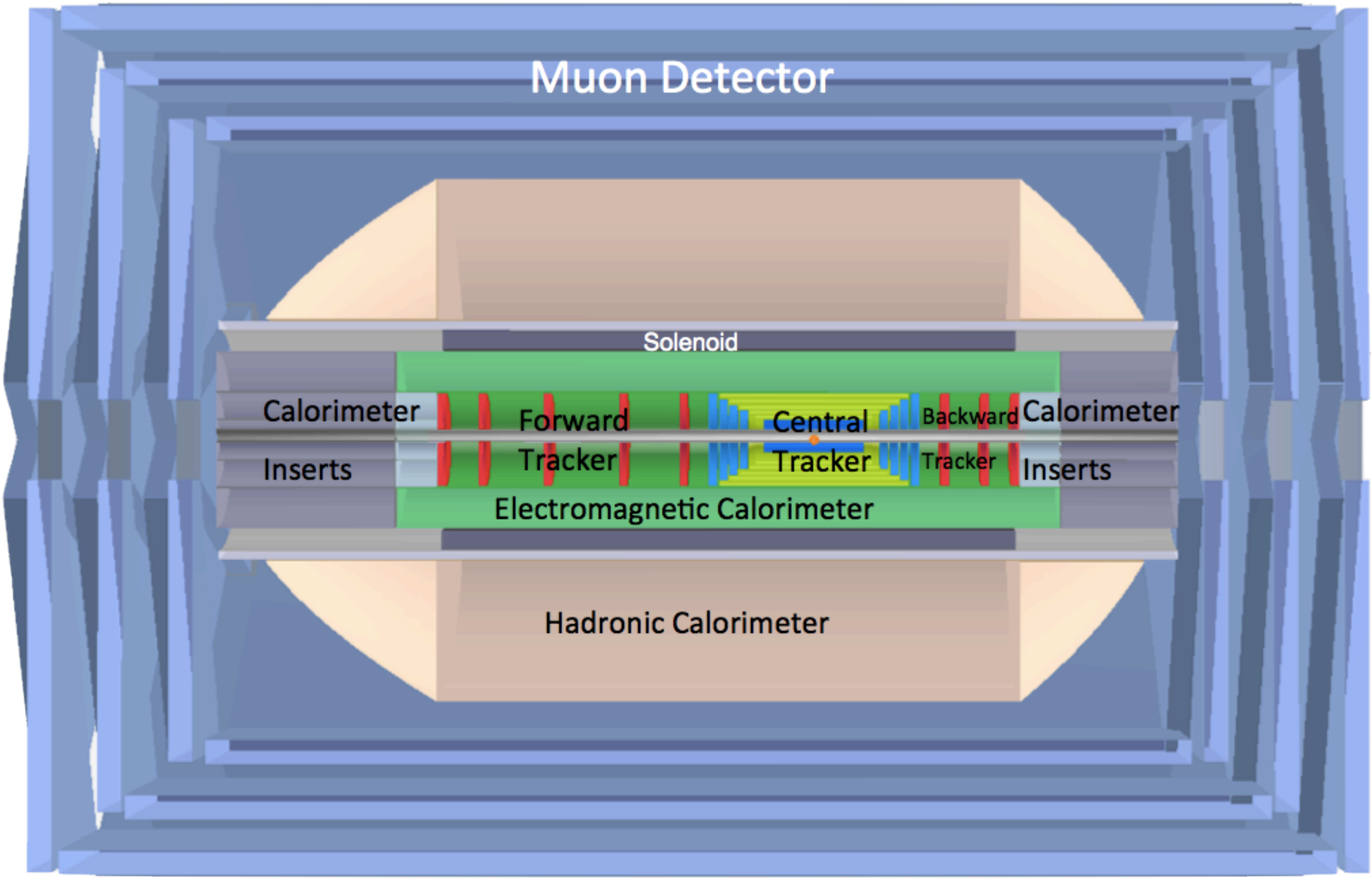
Neutron Parton Distributions [Tagged en (eD) Scattering] – ignored at HERA

+ Huge extension of kinematic range and precision through energy and luminosity gains
  cf CDR for initial studies [arXiv:1206.2913]

+ Note that ALL of these areas are at their infancy, just discovered/opened with HERA, also LHC

+ Complementarity here with EIC: lower energy, larger x, but more ions and proton polarisation
  [EIC White paper, published yesterday: A.Accardi et al, EPJA 52 9(2016) 268, arXiv:1212:1701]

4. A New Detector and its Simulation



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)

Simulation and LHeC PDF Set

Numerical program to simulate NC and CC cross sections

(based on J.Blümlein and MK, PHE 90-19, benchmarked with H1 Monte Carlo Simulation)

source of uncertainty	error on the source or cross section
scattered electron energy scale $\Delta E'_e/E'_e$	0.1 %
scattered electron polar angle	0.1 mrad
hadronic energy scale $\Delta E_h/E_h$	0.5 %
calorimeter noise (only $y < 0.01$)	1-3 %
radiative corrections	0.5%
photoproduction background (only $y > 0.5$)	1 %
global efficiency error	0.7 %

Full simulation of NC and CC inclusive cross section measurements including statistics, uncorrelated and correlated uncertainties – based on typical best values achieved by H1

- Statistical it ranges from 0.1% (low Q^2) to ~10% for x=0.7 in CC
- Uncorrelated systematic: 0.7 %
- Correlated systematic: typically 1-3% (for CC high x up to 9%)

50fb^{-1}

PDF set like HERAPDF available at LHAPDF

LHeC-Note-2013-002 PHY
Geneva, July 26, 2013

MK + Voica Radescu
PDF set update to come

5. Nine Quark Distributions (and xg)

u_v, d_v, $\bar{u}$, $\bar{d}$, s, $\bar{s}$, c, b, t

Various important features of the NC and CC and F_L and HQ Structure Function DIS Data:

- high precision (e-h redundancy, clean final state, no pile-up..)
- high statistics (1000 times HERA) – much increased precision at high x, recall: $xq_v \sim (1-x)^3$
- much extended kinematic range: at high $Q^2 < 1$ TeV^2: CC becomes precise, unlike at HERA
- charged current: hugely important for: Higgs, strange, top and flavour separation
- low x ~ 1/s : DGLAP may fail, long expected BFKL? xg damping "saturation"
- beam spot extension ~7µm in x and y. with modern Silicon trackers → precision HQdfs
- …

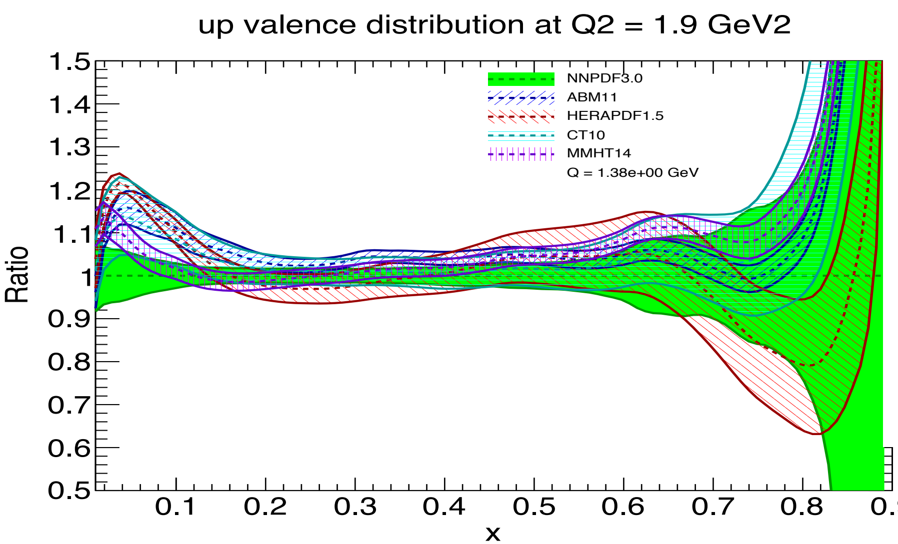
Theory: clean, light cone. In 10 years time: provide N^{3}LO PDFs - for precision Higgs at LHC
Phenomenology: no more symmetry assumptions, HQ known, no HT, no nuclear corrections,
parameterisation uncertainties 'gone', model errors also (mc, α_s, ...)

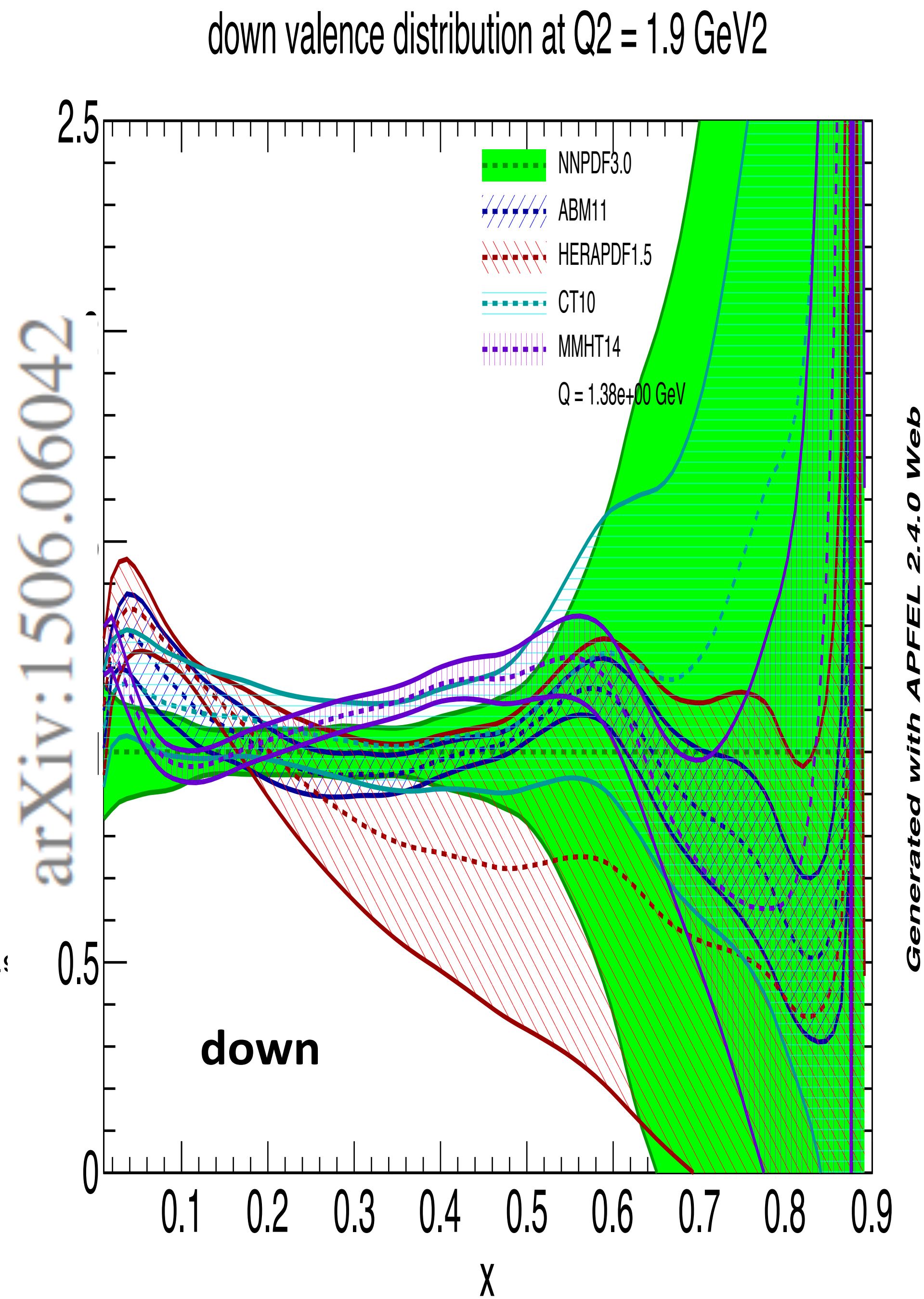
Here some illustrations. See talk by A. Cooper Sarkar at DIS16, further by C.Gwenlan, V.Radescu, MK

Valence quarks

High x crucial for HL LHC searches
Related to DrellYan , W mass etc
d/u → 1 a classic question, still there

up





Valence quarks

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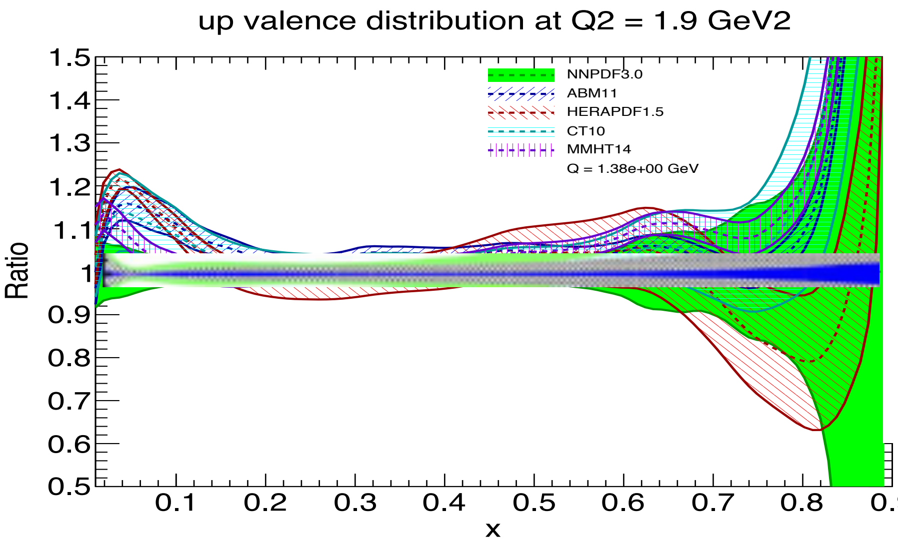
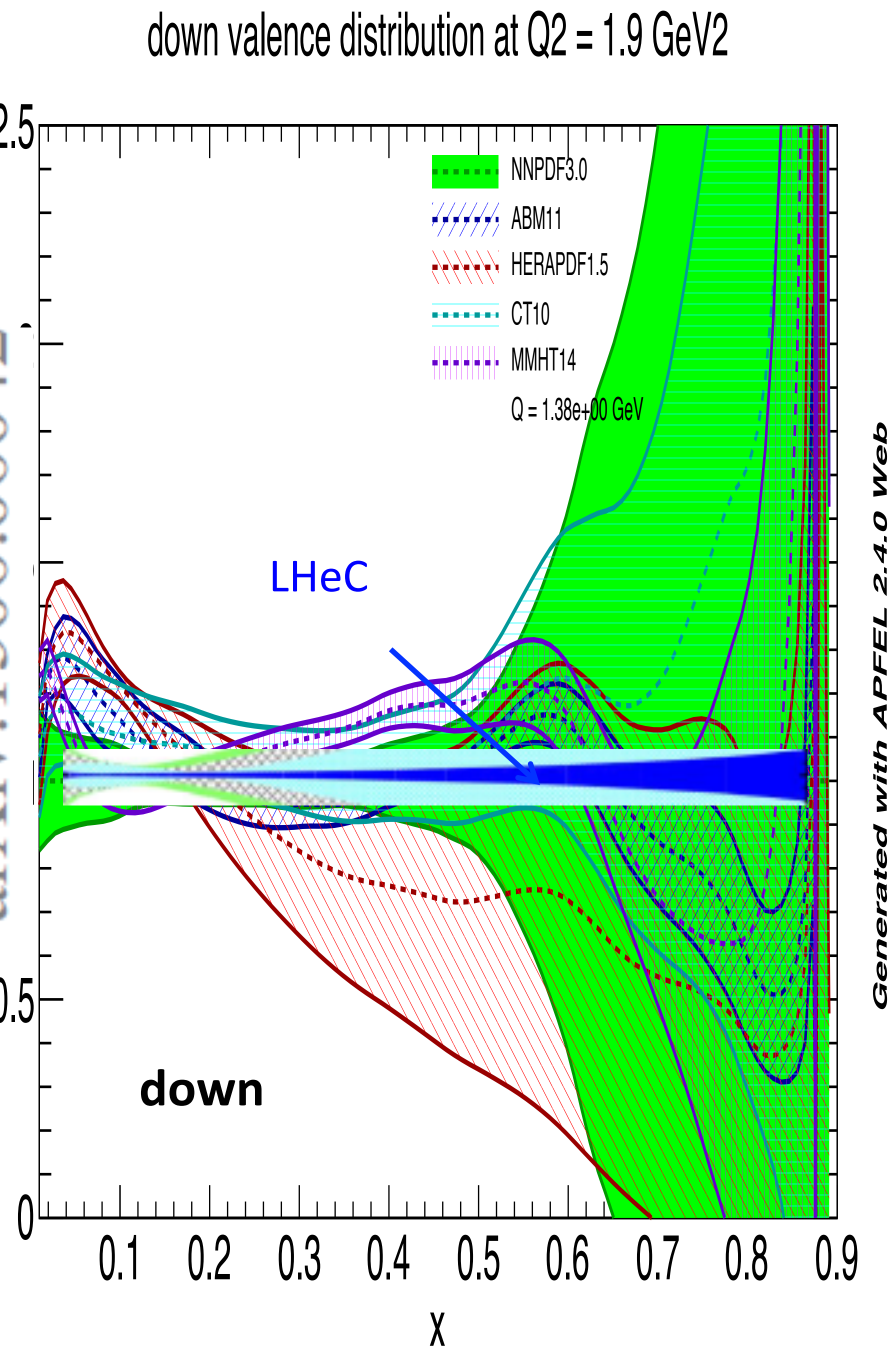
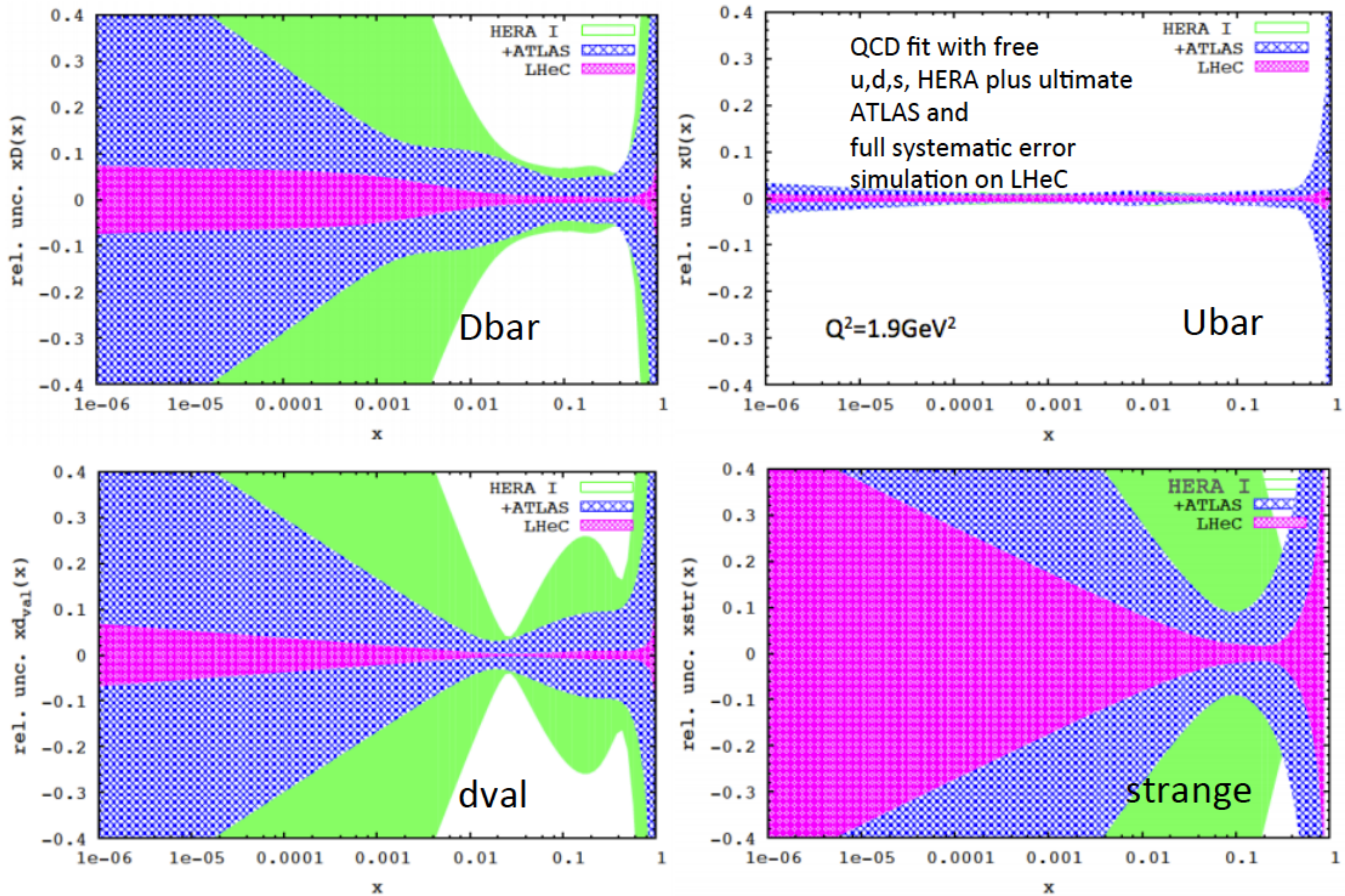




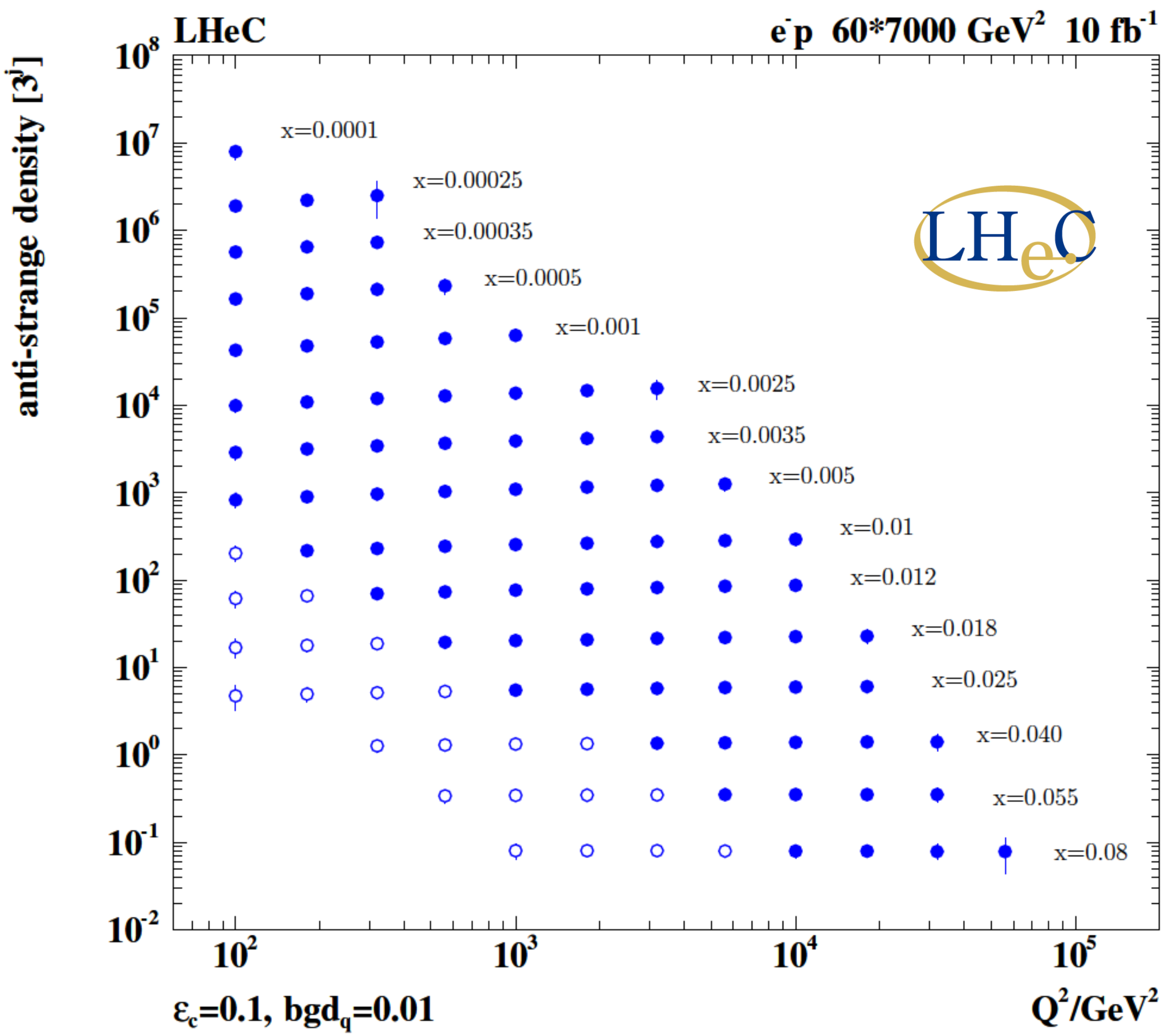
ep + pp and free fit to ū,d̄,s



HERA: assume ubar=dbar and no sensitivity to s. LHC (W,Z) helps. LHeC provides independent determination

MK, V.Radescu at 2014 LHeC Workshop, Chavannes, January 2014

Strange Quark Distribution from LHeC

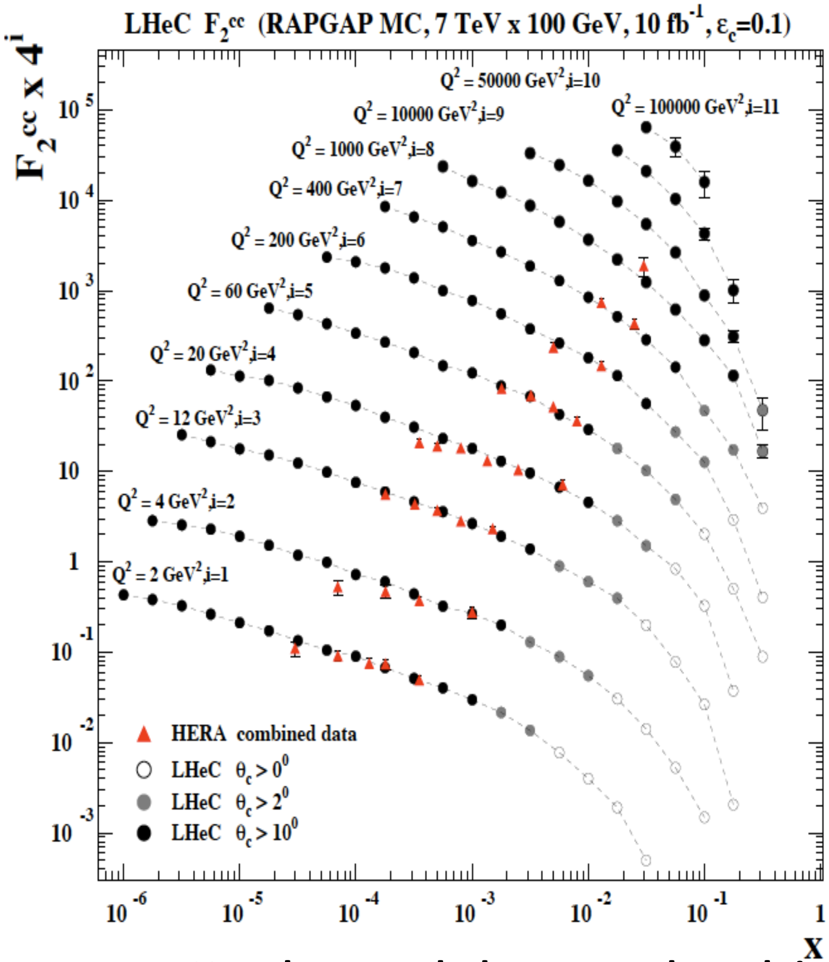


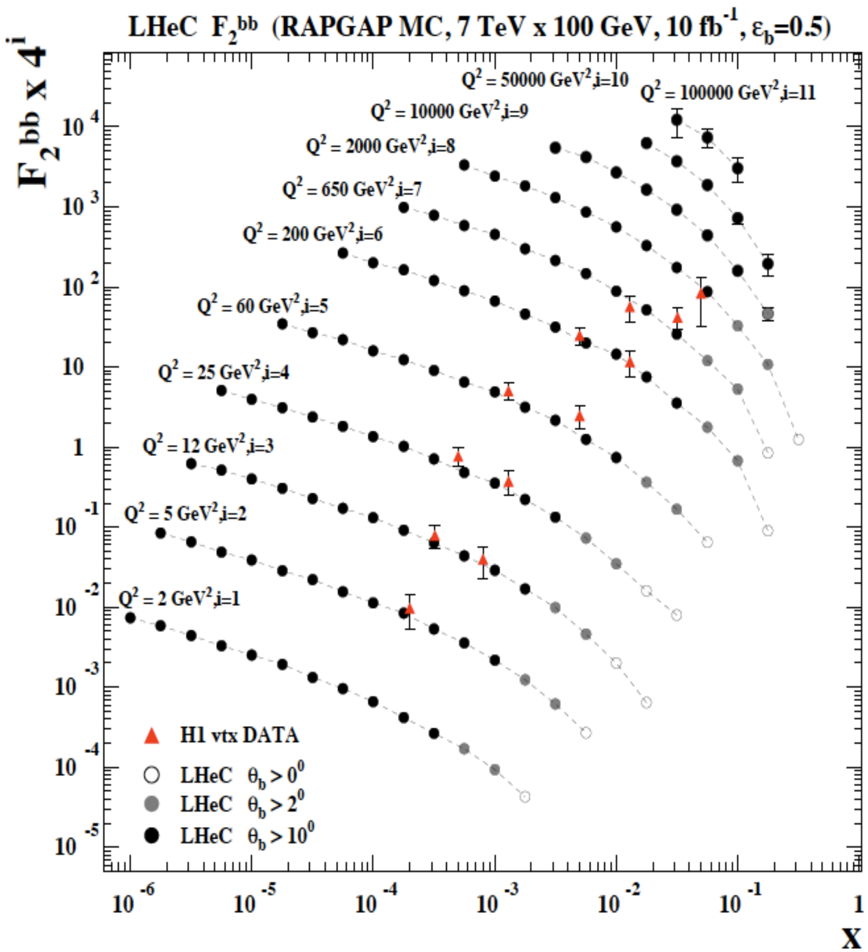
→ First (x,Q^2) measurement of the (anti-)strange density, HQ valence?

$x = 10^{-4} .. 0.05$
$Q^2 = 100 – 10^5\ GeV^2$

Initial study (CDR): Charm tagging efficiency of 10% and 1% light quark background in impact parameter

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





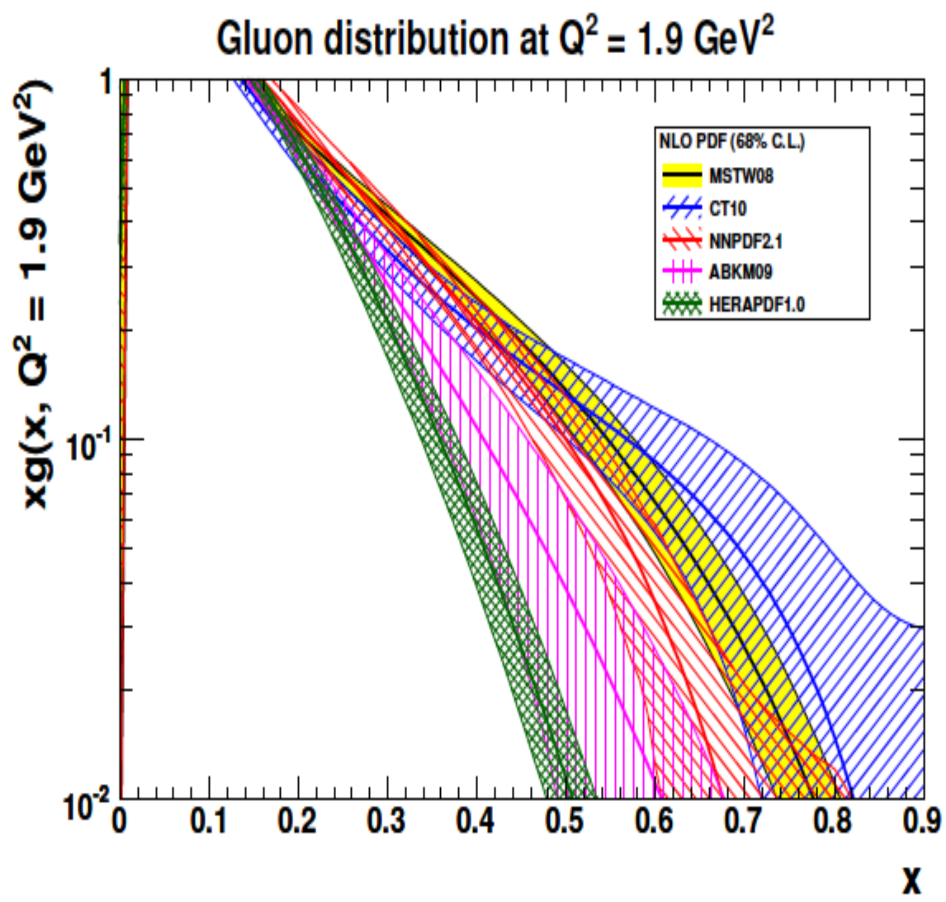
Hugely extended range and much improved precision **(δM_c=50 HERA → 3 MeV)**

will pin down heavy quark behaviour at and far away from thresholds, crucial for precision t,H..

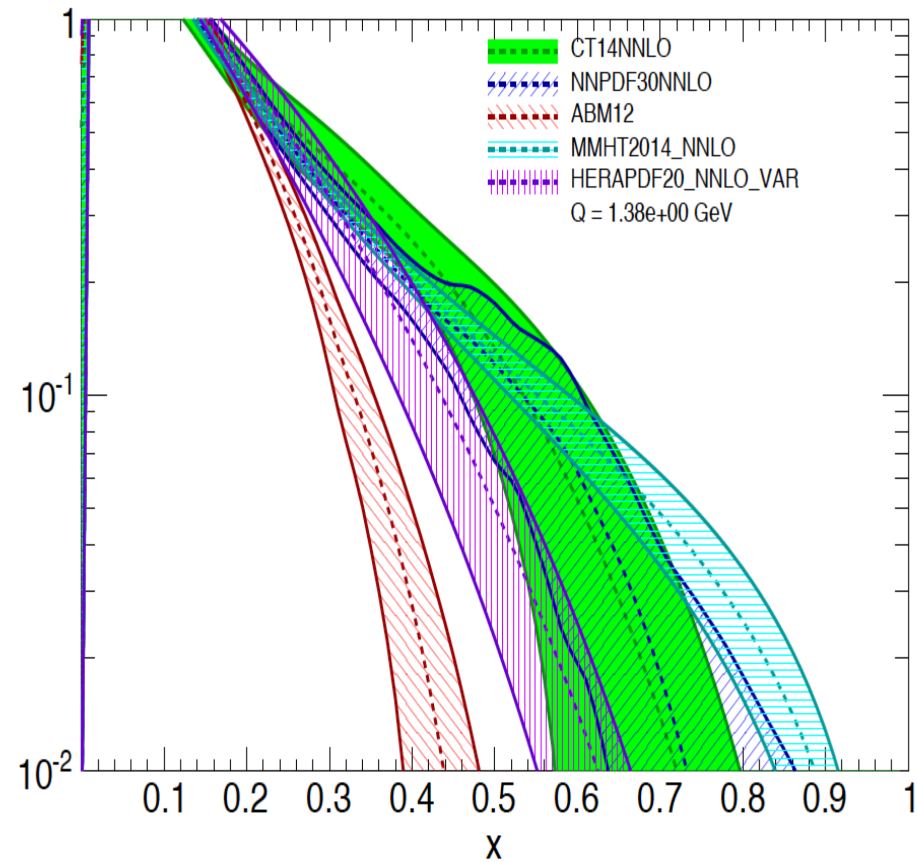
In MSSM, Higgs is produced dominantly via bb → H (Pumplin et al) , but where is the MSSM..

6. Gluon Density

High x



Gluon prior to LHC data (2011)



Gluon with (first) LHC data (2015)

used by CT14,NNPDF,MMHT

cf talks by Ringaile Plakacyte, Pavel Nadolsky, Sasha Glazov at this conference

Gluon from the LHeC

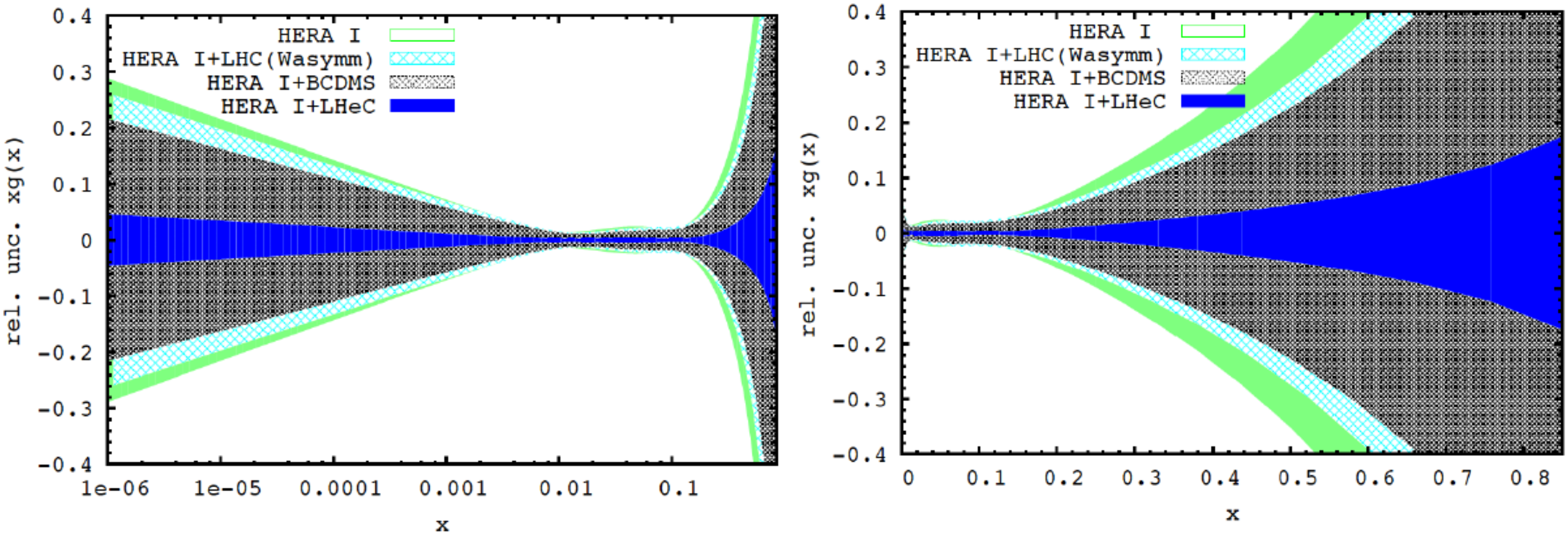
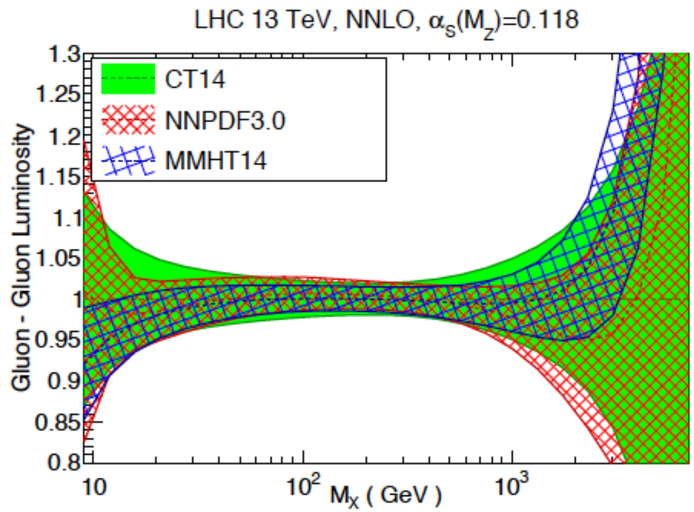


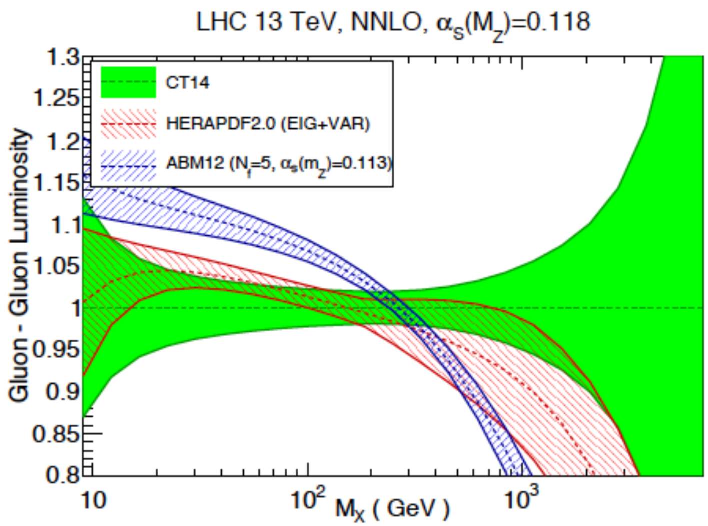
Figure 3.19: Relative uncertainty of the gluon distribution at $Q^2 = 1.9\,\mathrm{GeV}^2$, as resulting from an NLO QCD fit to HERA (I) alone (green, outer), HERA and BCDMS (crossed), HERA and LHC (light blue, crossed) and the LHeC added (blue, dark). Left: logarithmic x, right: linear x.

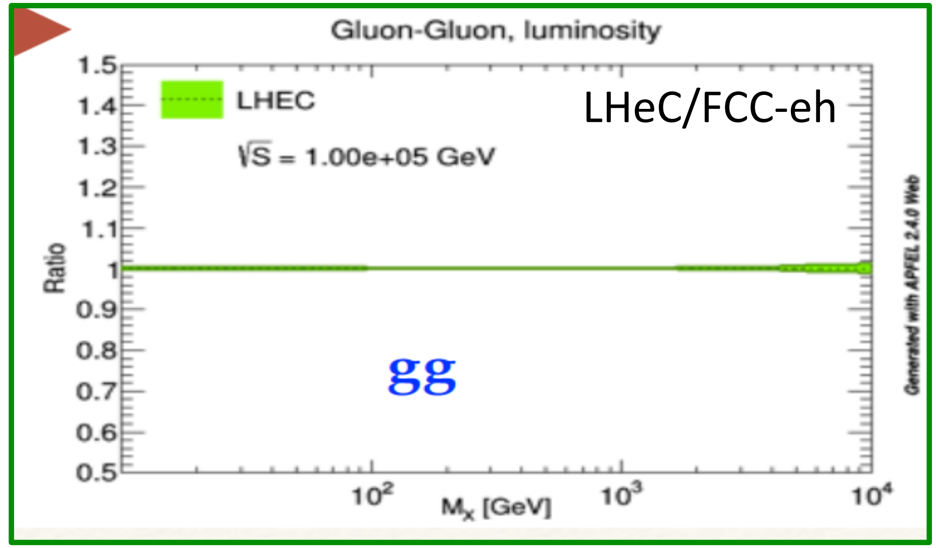
From the LHeC Conceptual Design Report

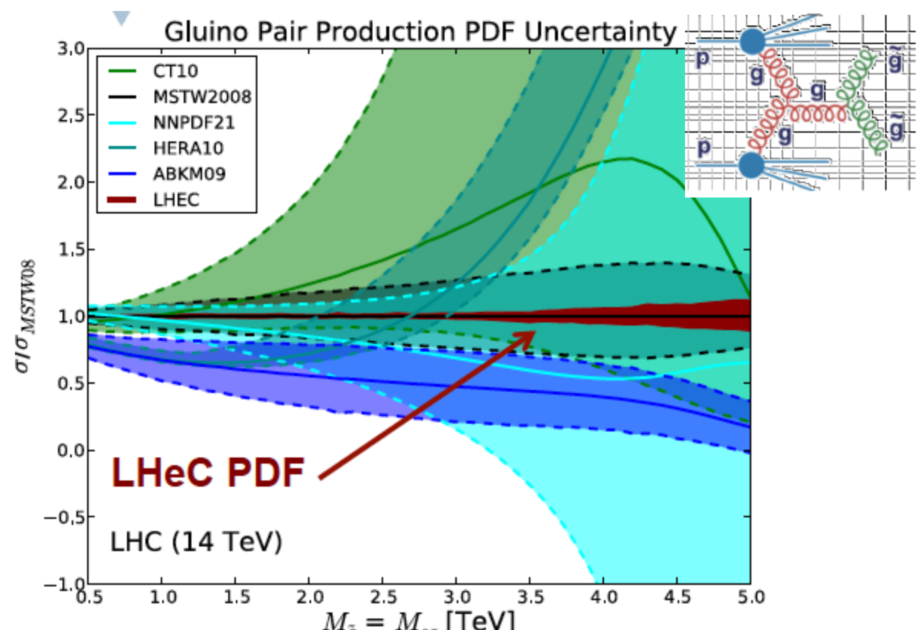
Gluon (gg) Luminosity

Present status









arXiv:1211.5102

Crucial for SUSY searches/limits
Similarly: Drell-Yan qq luminosity
Cf Jan Kretzschmar and Sasha Glazov

Low x

xg for x < 10^{-4} not known, it is not unknown above.

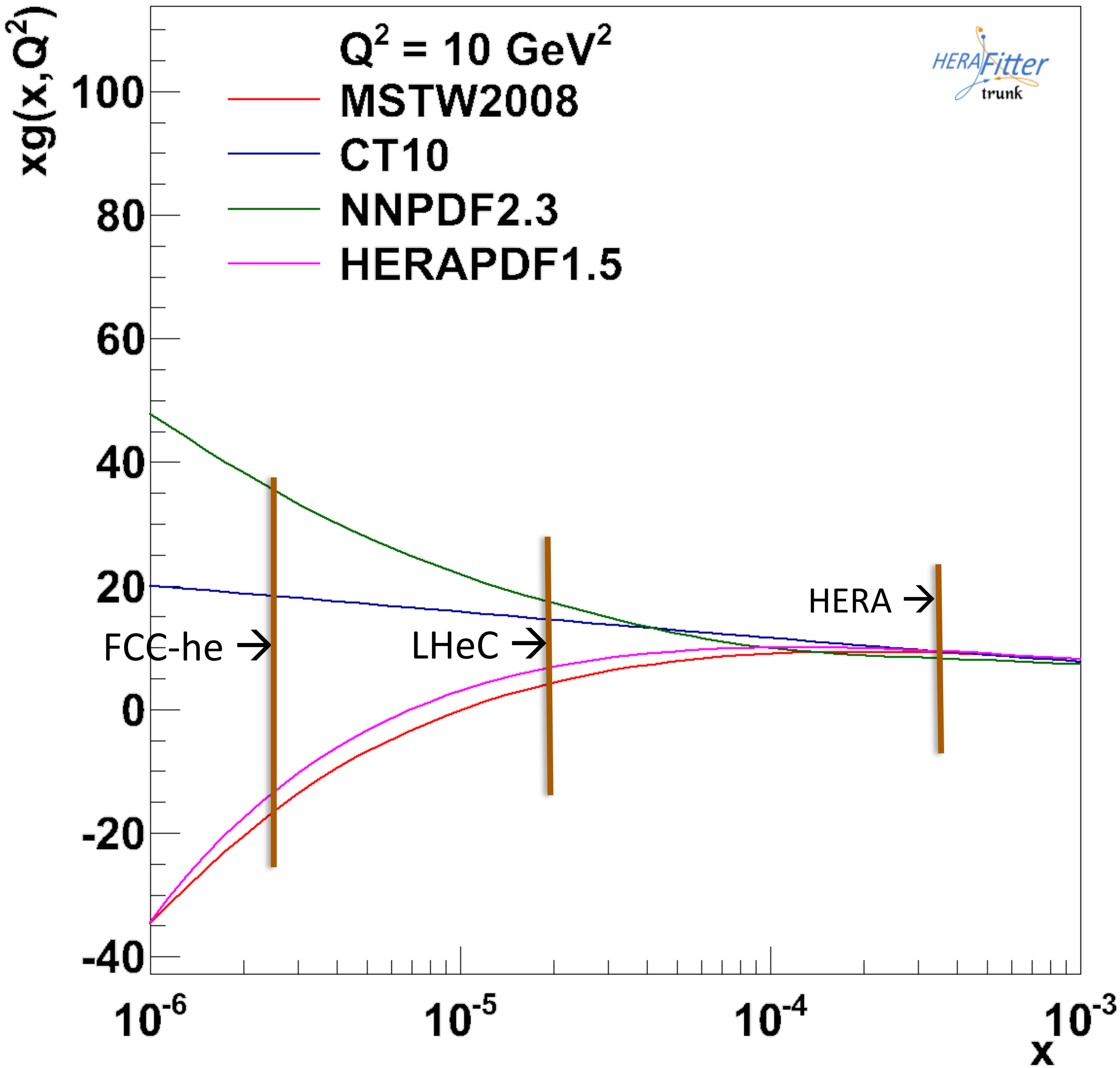
Low x evolution law unlikely linear DGLAP

HERA: where is BFKL?

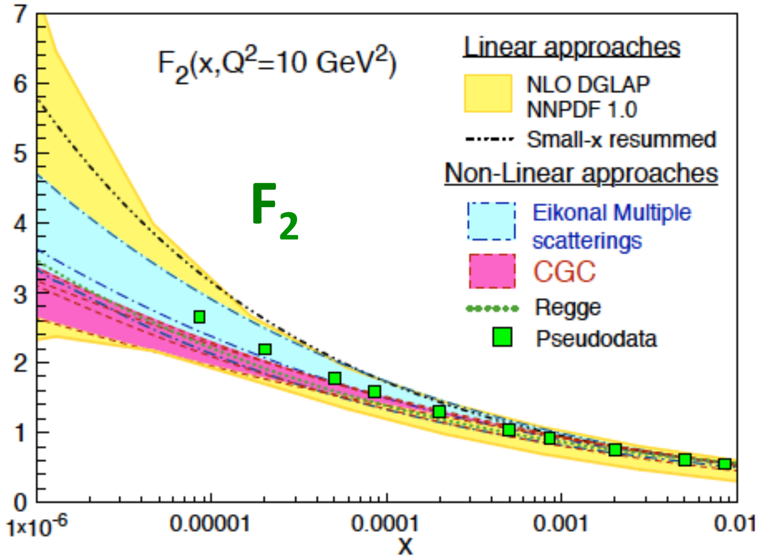
Needs precision F_2 and F_L in extended x range

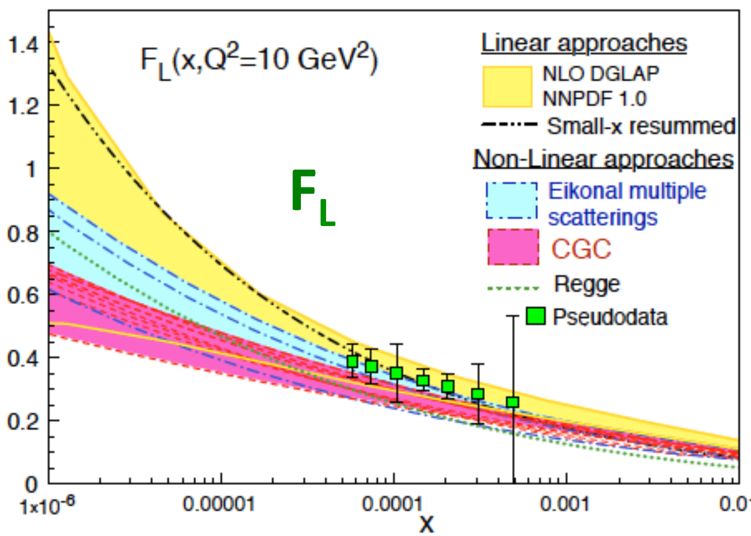
Search for Saturation requires xg to be large and α_s to be small → Q^2 ought to be > 10 GeV^2

Affects pp rates because $x=M/\surd(s) \exp(+-y)$

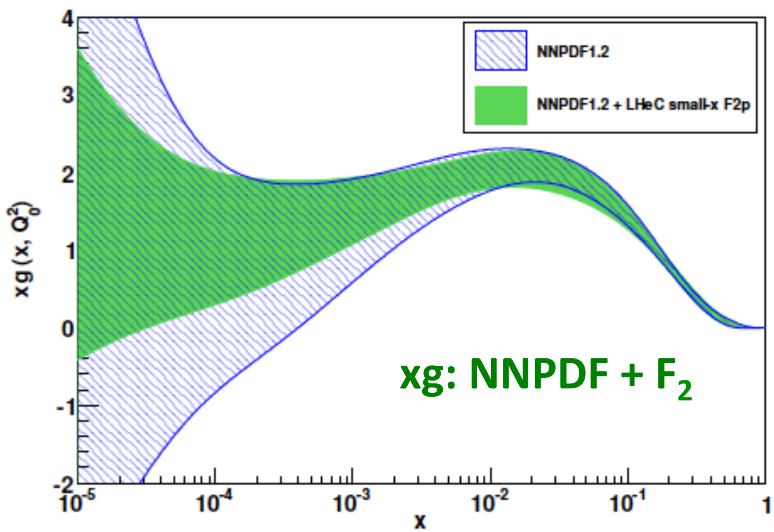


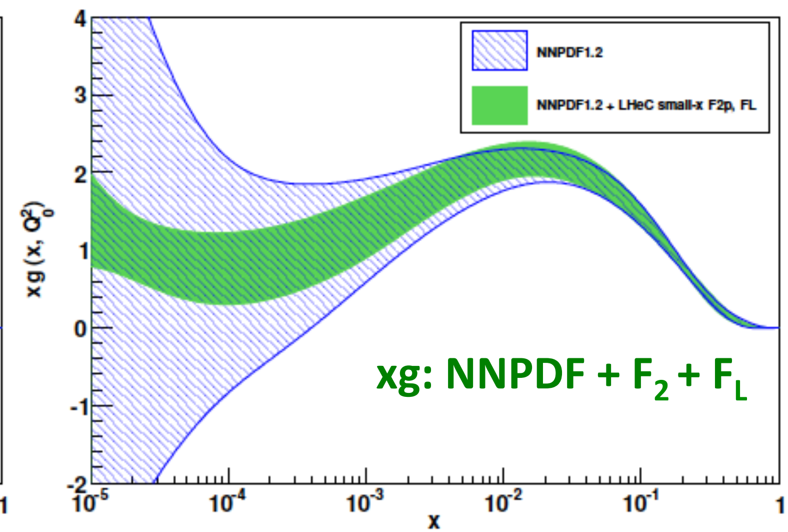
Low x Gluon





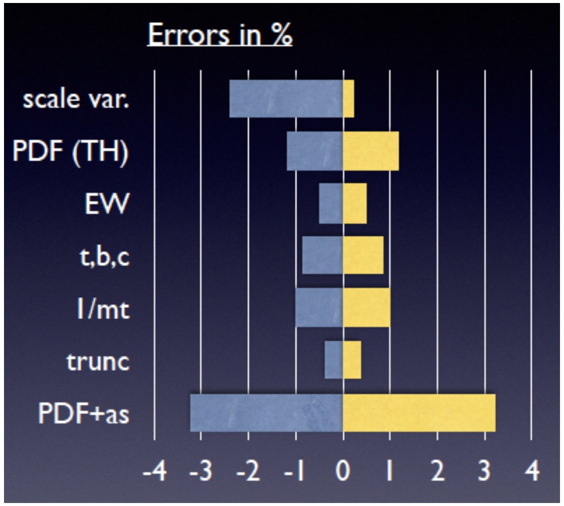
Fix the gluon at low x by the derivative of F_2 and precision F_L data → deviations from DGLAP?



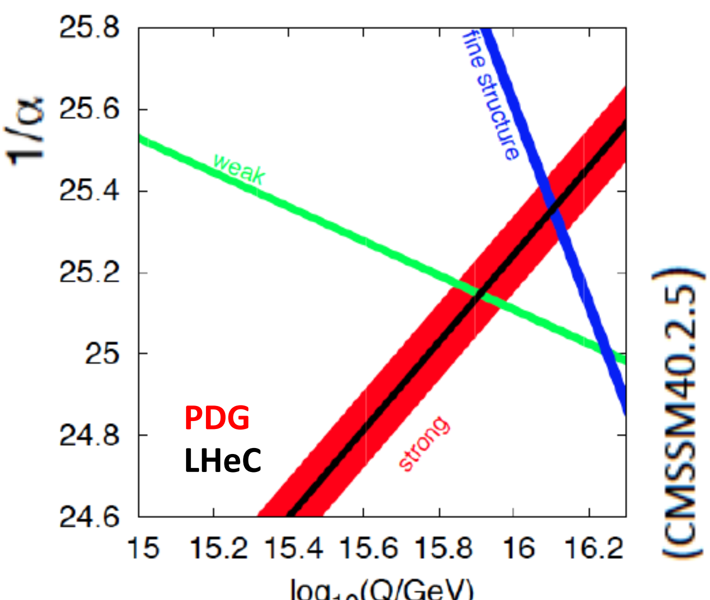


cf CDR

7. Strong Coupling Constant



Uncertainty on Higgs cross section
Giulia Zanderighi, this conference,
from C.Anastasiou et al, 1602.00695
who also discuss the ABM alpha_s..



- **α_s least known of coupling constants**
Grand Unification predictions need smaller $\delta\alpha_s$

- **Is α_s(DIS) lower than world average (?)**

- **LHeC: per mille - independent of BCDMS!**

- **High precision from inclusive data – α_s(jets)??**

- **Challenge lattice QCD** [cf L Del Debbio, this conf]

LHeC simulation, NC+CC inclusive, total exp error

case	cut [Q^2 in GeV^2]	relative precision in %
HERA only (14p)	$Q^2 > 3.5$	1.94
HERA+jets (14p)	$Q^2 > 3.5$	0.82
LHeC only (14p)	$Q^2 > 3.5$	0.15
LHeC only (10p)	$Q^2 > 3.5$	0.17
LHeC only (14p)	$Q^2 > 20.$	0.25
LHeC+HERA (10p)	$Q^2 > 3.5$	0.11
LHeC+HERA (10p)	$Q^2 > 7.0$	0.20
LHeC+HERA (10p)	$Q^2 > 10.$	0.26

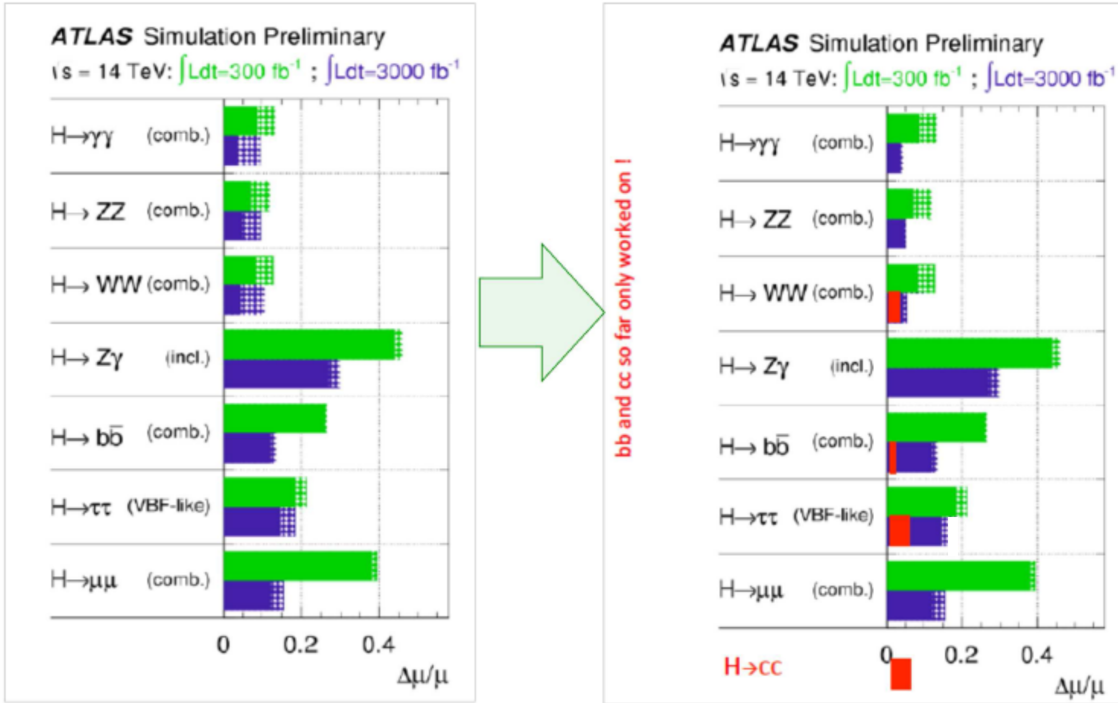
Two independent QCD analyses using LHeC+HERA/BCDMS

HIGGS PHYSICS AT THE LHeC

SUMMARY

HL LHC

HL LHC + LHeC

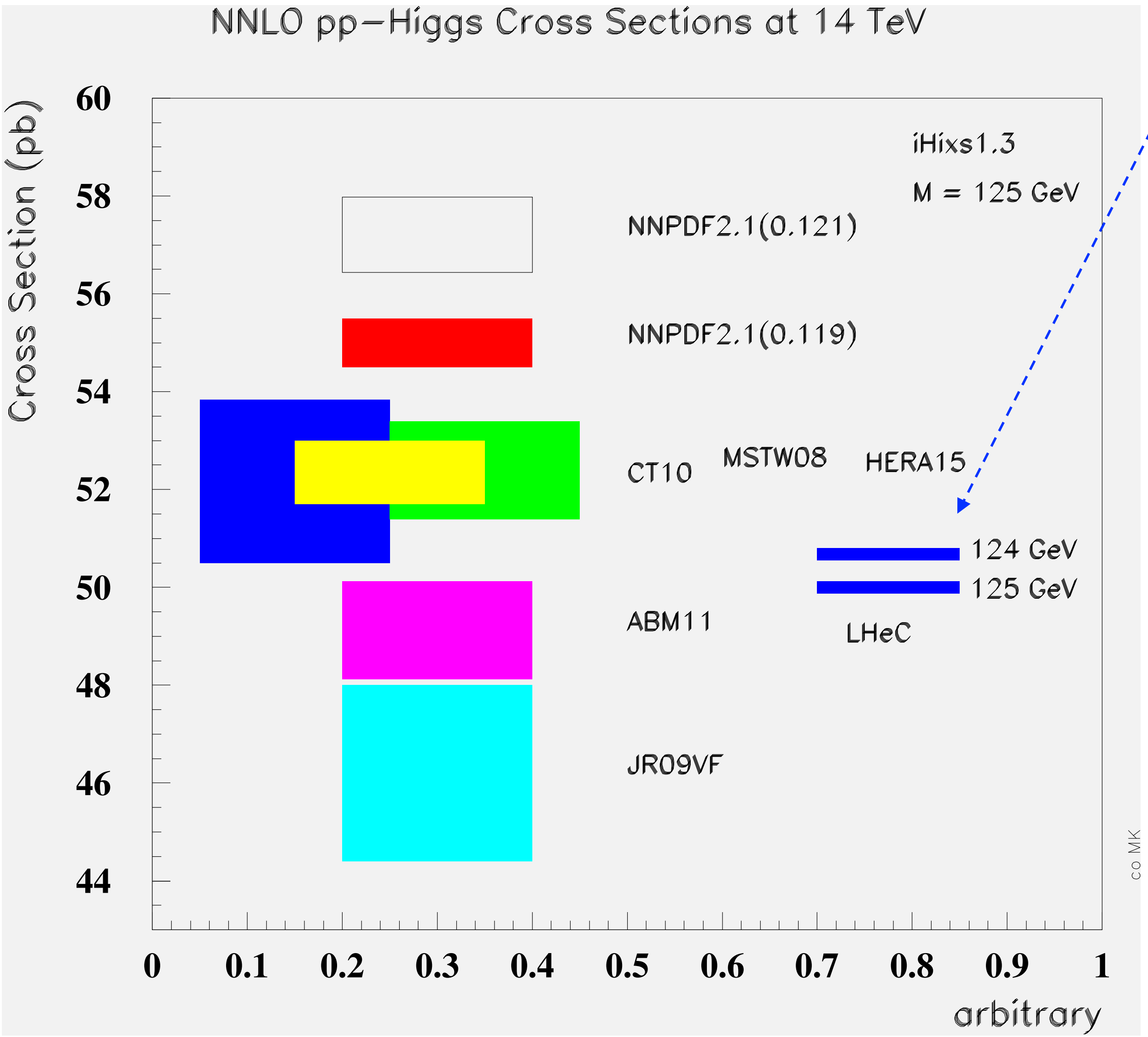


- GLUON FUSION AND W FUSION $\Rightarrow$ PDF+α_s UNCERTAINTY REMOVED (hatched bands)
- $H\bar{b}b$ MEASURED TO PERCENTAGE PRECISION;
- $\tau\tau$ AND $\bar{c}c$ ALSO MEASURABLE

S.Forte ECFA 11/15

The exp. error on the Higgs cross section calculated with LHeC PDF is 0.3% → sensitive to mass

Precision PDFs for Higgs at the LHC



LHeC:

Exp uncertainty of predicted H cross section is 0.25% (sys+sta), using LHeC only.

Leads to H mass sensitivity.

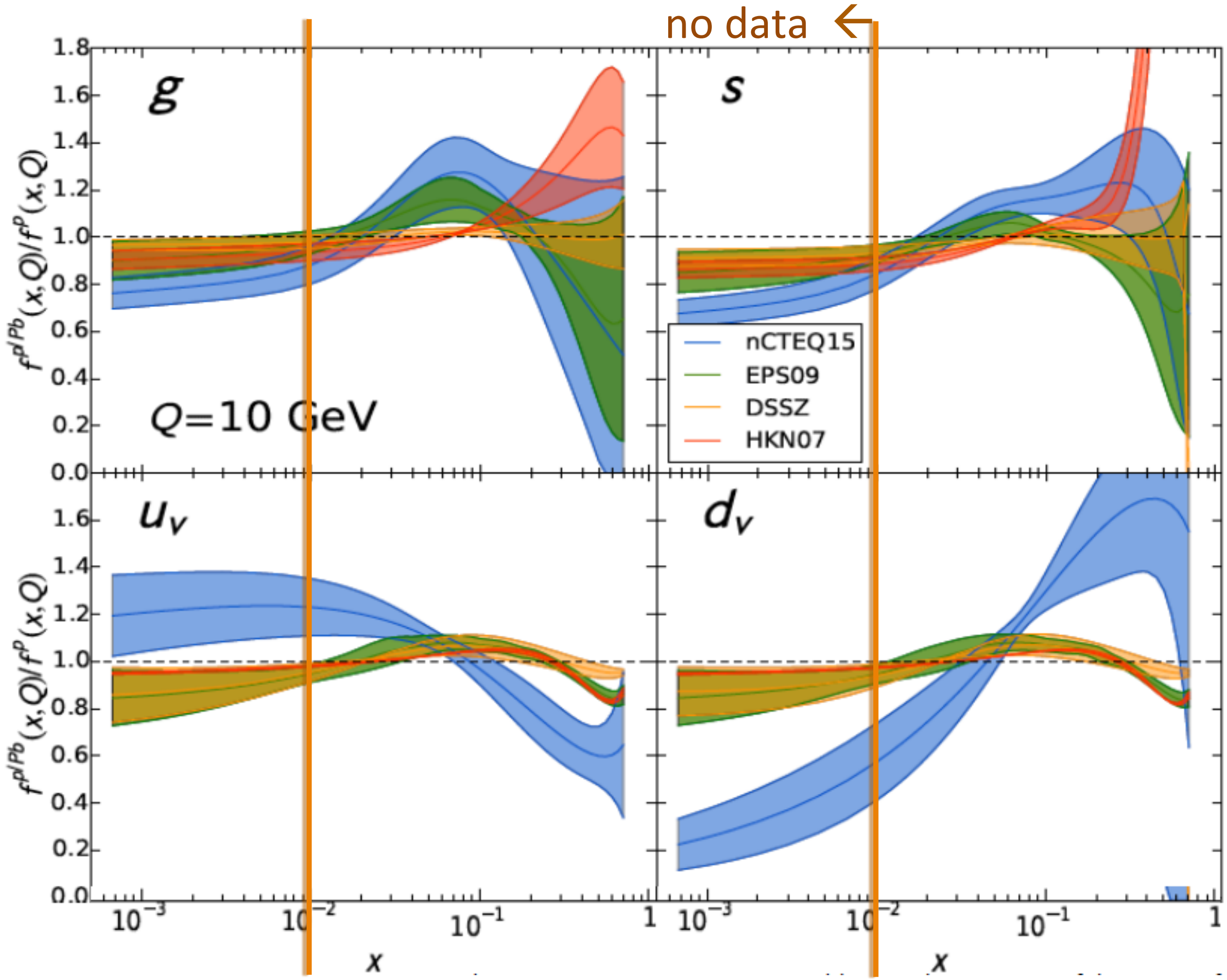
Strong coupling underlying parameter (0.005 → 10%). LHeC: 0.0002 !

Needs N^{3}LO

HQ treatment important …

O.Brüning and M.K. arXiv:1305.2090, MPLA 2013

8. Nuclear Parton Distributions



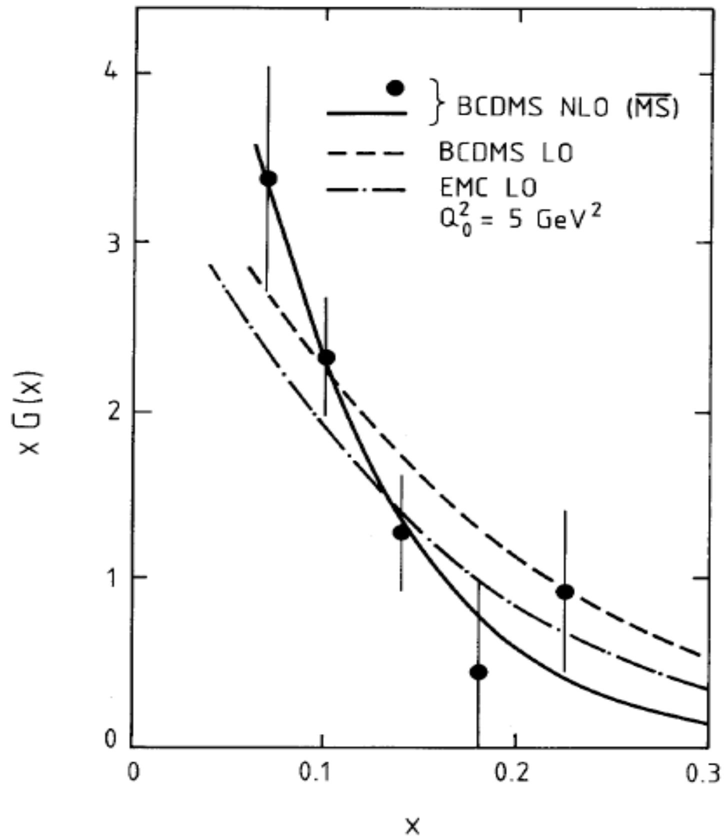
Nuclear Parton Distributions with the LHeC
MK, POETIC 2015, **EPJ Web Conf. 112 (2016) 03002**
Collaboration with H.Paukkuunen, N.Armesto, V.Radescu

nPDFs are in infant state, resembles →

Proton PDFs before HERA

BCDMS muon-proton, also -carbon

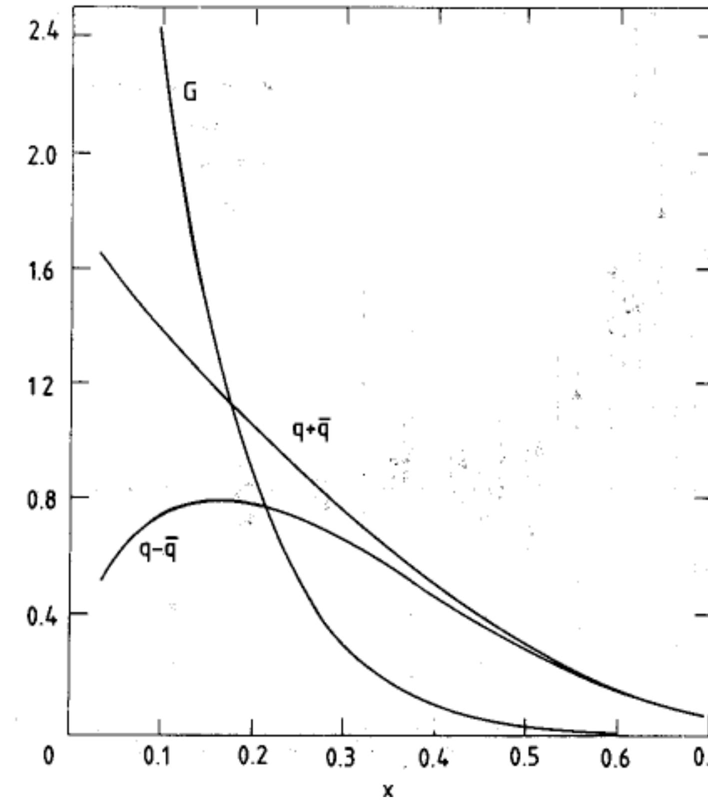
Gluon density in 1989



CERN-EP/89-07
January 17th, 1989

CDHS neutrino-iron scattering

Sea, valence and xg in 1989

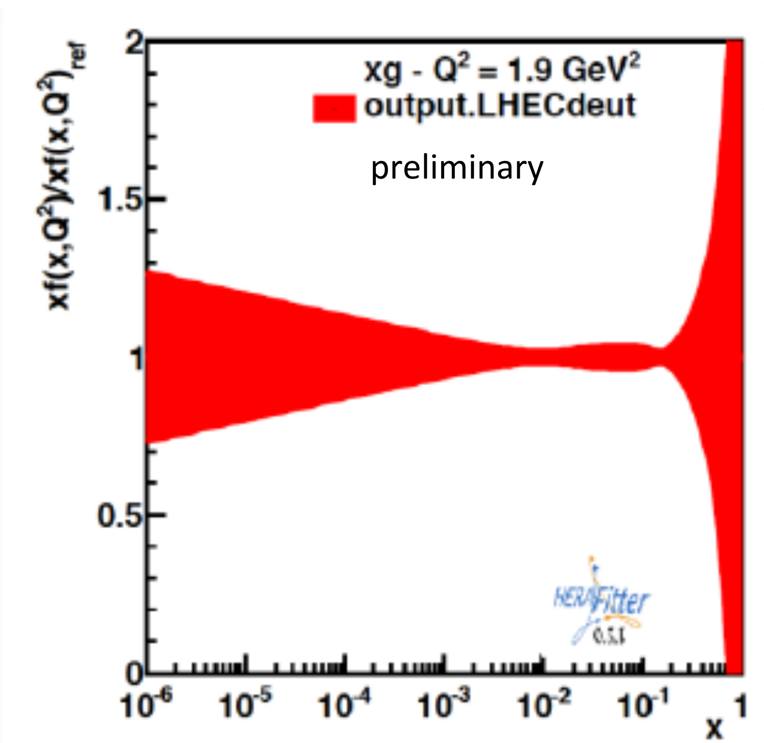


CERN-EP/89-103
15 August 1989

Future Nuclear PDFs

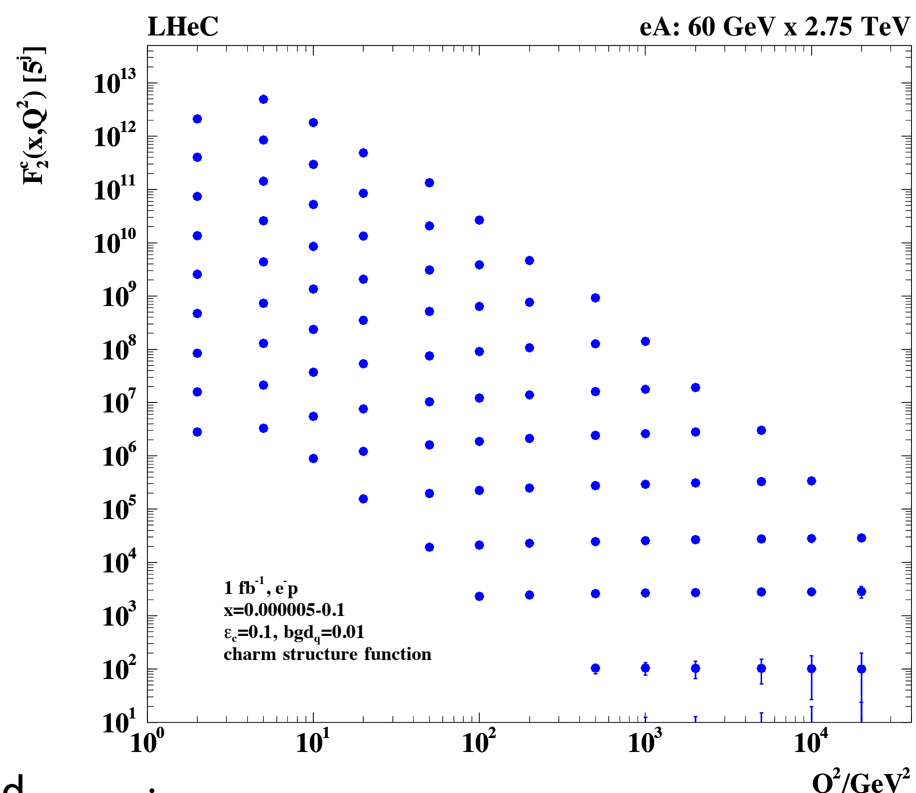
From an eA collider one can determine nuclear PDFs in a novel, the classic way.
Currently: use some proton PDF base and fit a parameterised shadowing term R.
Then: use the NC and CC eA cross sections directions and get R as p/N PDFs.

Gluon density uncertainty in eA



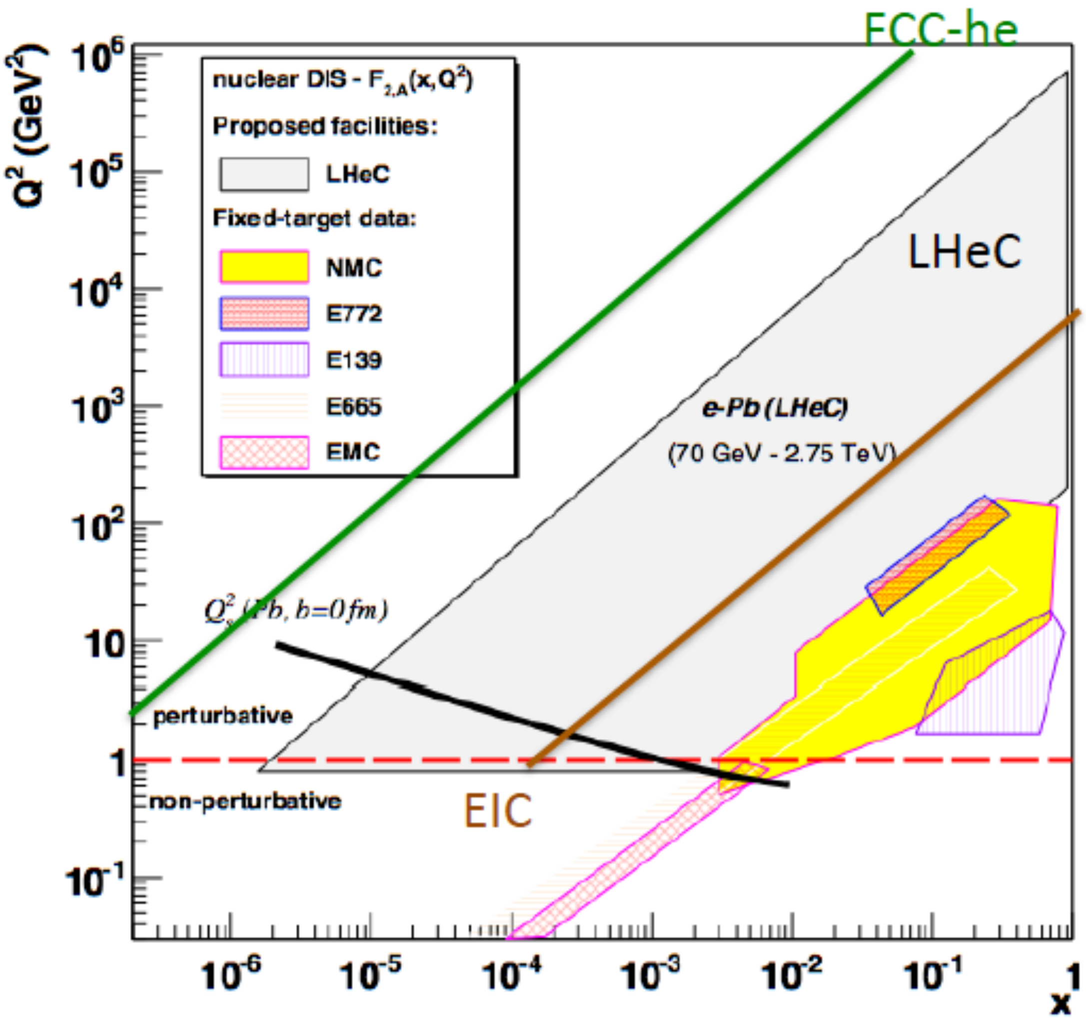
1fb^{-1} of sole eA isoscalar data fitted

Charm density in nuclei



Impact parameter measurement in eA

FCC-he, LHeC, EIC eA Colliders



Extension of kinematic range in lA by many 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 ?

Relates to LHC Heavy Ion Physics

- Quark Gluon Plasma
- Collectivity of small nuclei (p)?
- ..

Max Klein nPDFs with LHeC 10.9.2015 POETIC a PARIS

9. Remarks on the LHeC Project Status

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

DG: Mandate to the International Advisory Committee 2015-2018

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"

Sergio Bertolucci (CERN/Bologna)
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 being renewed by new DG
We lost Guido Altarelli.

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

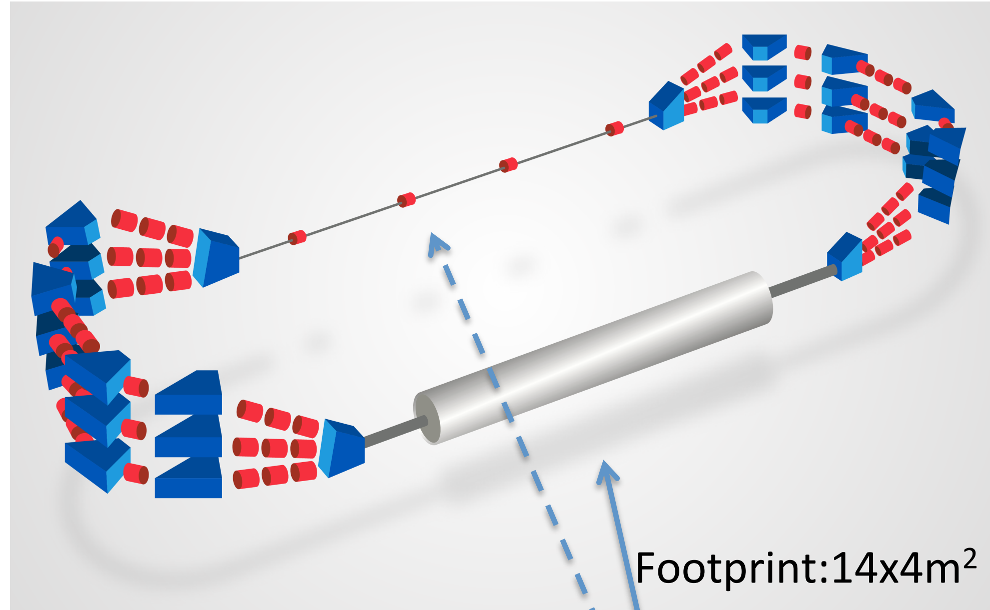
*)August 2016

ERL Testfacility

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 which houses four 5-cell cavities



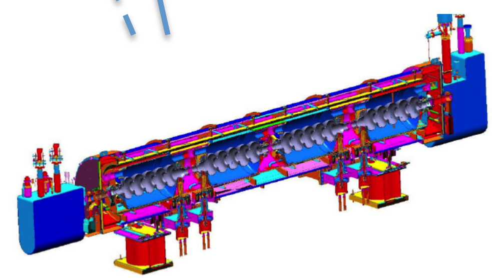


Figure 3.9: SNS high β module adapted to house β =1 5-cell cavities for LHeC.

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

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

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

Technical Design as next goal
802 MHz cavity soon produced

802 MHz Cavity Parameters

design to also test FCC-ee

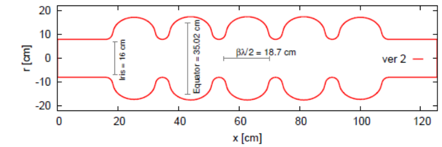
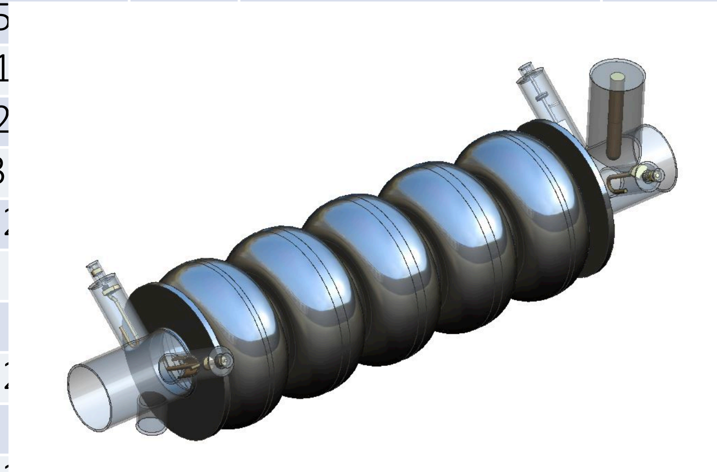


Fig. 6: Envelope of the second version of the five-cell ERL cavity at 802 MHz with 16 cm aperture.

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

Parameter	Unit	Value	Value	Value		Value	[illegible]
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	[illegible]	[illegible]	[illegible]	[illegible]
R/Q/cell	Ω	**104.7**	116.0	[illegible]	[illegible]	[illegible]	[illegible]
G	Ω	**274.6**	273.2	[illegible]	[illegible]	[illegible]	[illegible]
R/Q·G/cell		**28765**	31702	[illegible]	[illegible]	[illegible]	[illegible]
Eq. Diameter	mm	**327.95**	323.12	[illegible]	[illegible]	[illegible]	[illegible]
Iris Diameter	mm	**130**	115	[illegible]	[illegible]	[illegible]	[illegible]
Tube Diameter	mm	**130**	140	[illegible]	[illegible]	[illegible]	[illegible]
Eq./Iris ratio		**2.52**	2.81	[illegible]	[illegible]	[illegible]	[illegible]
Wall angle (mid-cell)	deg	**0**	0	[illegible]	[illegible]	[illegible]	[illegible]
E_{peak}/E_{acc} (mid-cell)		**2.26**	2.07	[illegible]	[illegible]	[illegible]	[illegible]
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]

FCC-he Point H

FCC Long Straight Section H

Tunnel Geology

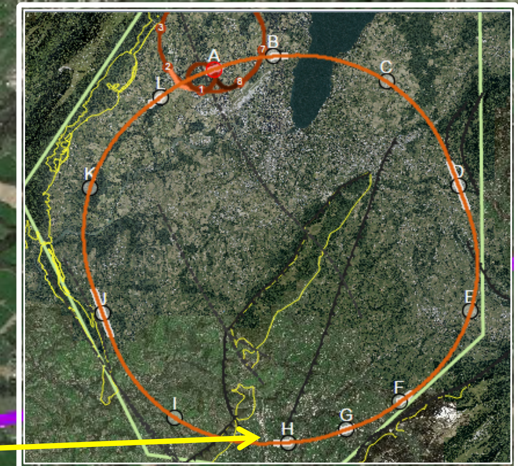
- Molasse rock (sandstone)

Construction

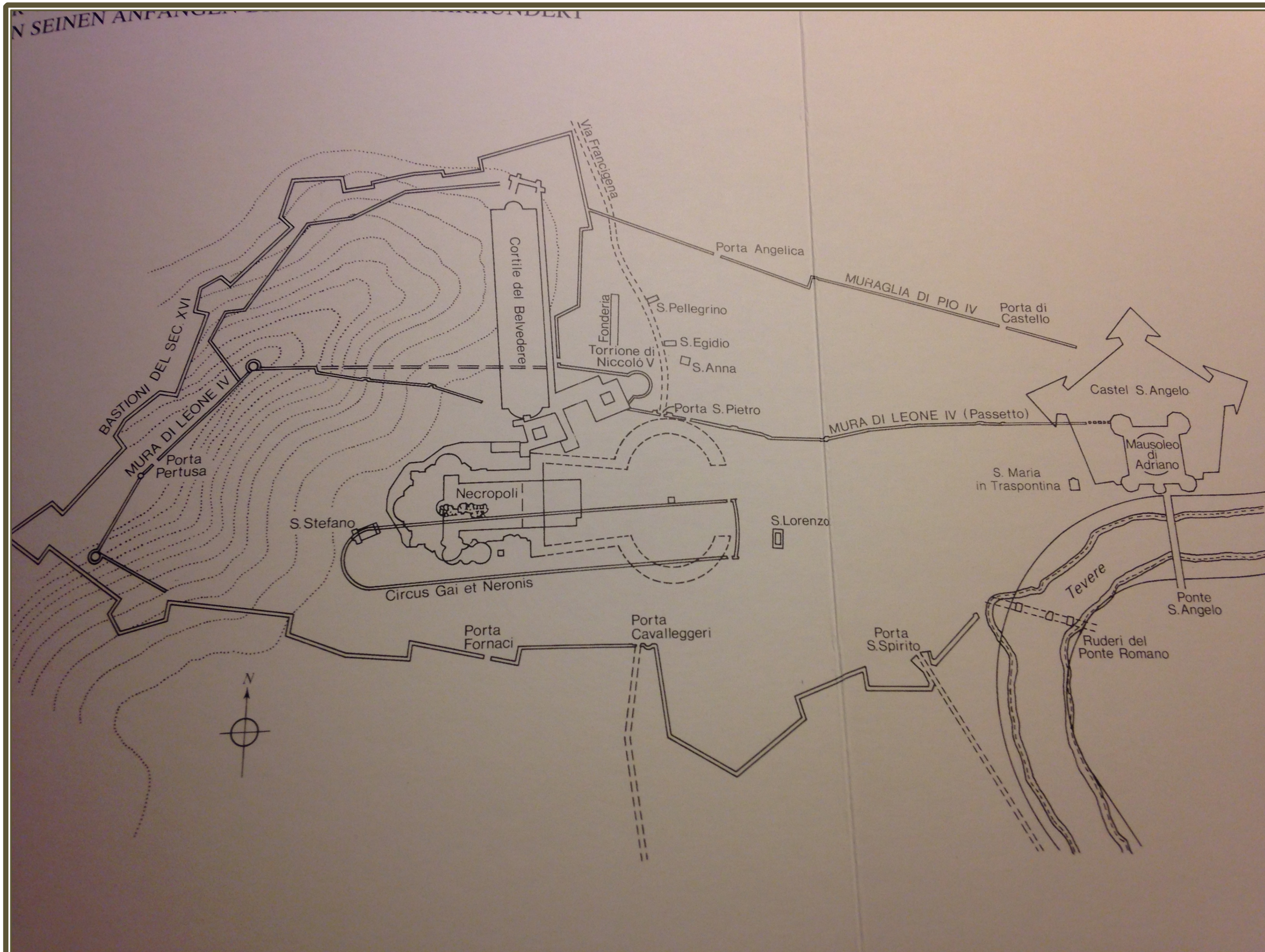
- Tunnel Boring Machine (TBM) in straight sections
- Roadheader in arcs

Civil Engineering challenges

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



CE: favoured eh site is point H



Vatican XV Century - a racetrack must be embedded in something bigger to make sense

10. Concluding Remarks

QCD - Developments and Discoveries

AdS/CFT

Instantons

Odderons

Non pQCD

QGP

N^kLO

Resummation

Saturation and BFKL

Non-conventional PDFs …

Breaking of Factorisation

Free Quarks

Unconfined Color

New kind of coloured matter

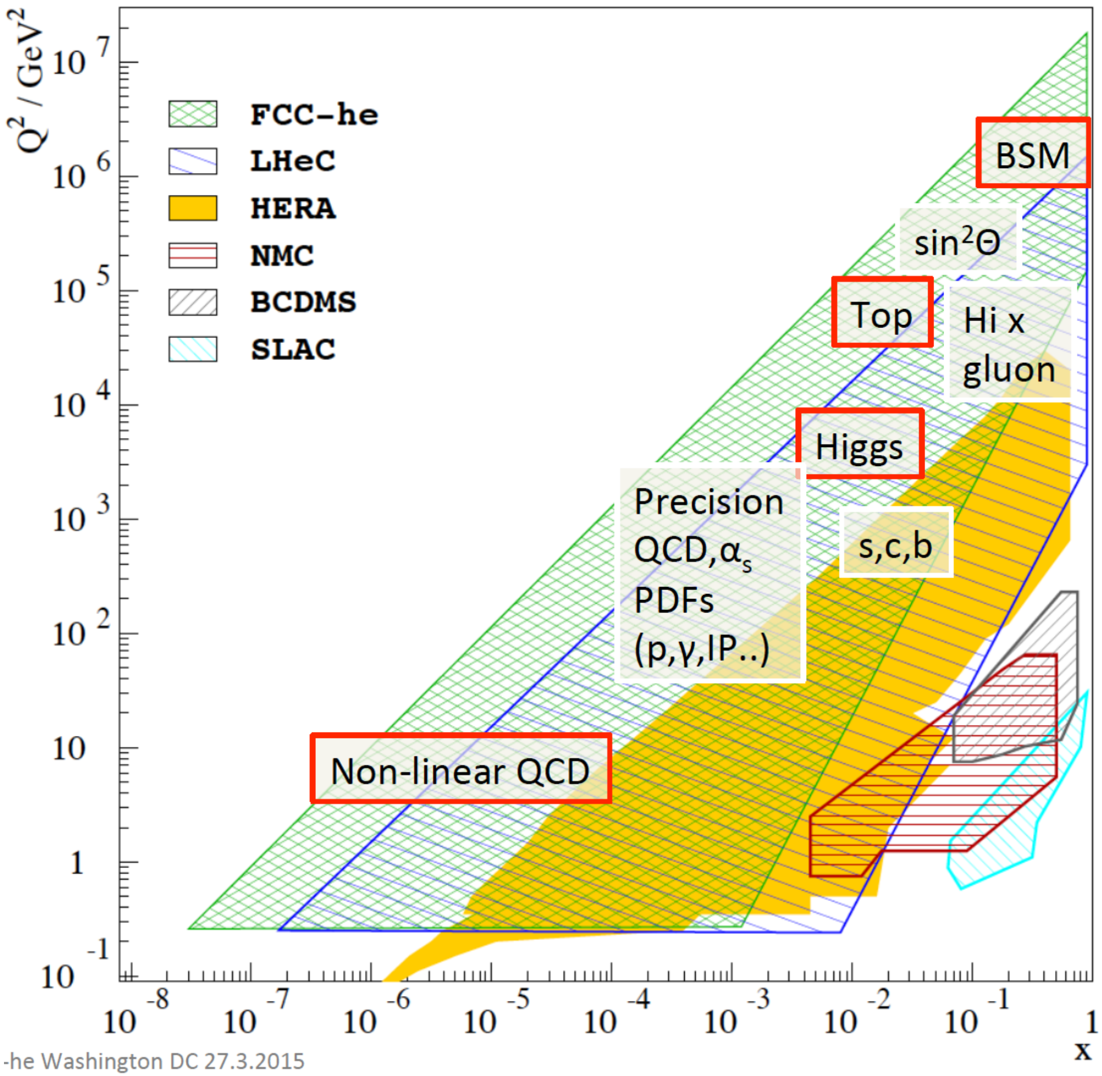
Quark substructure

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, on its own and as background. The contribution of the LHeC to that can not be overestimated.

Summary



MK: DIS at the energy frontier DOI: [10.1002/andp.201500252](https://doi.org/10.1002/andp.201500252)

High precision in pp matters.

It may be achieved with an electron beam upgrade of the LHC, following the luminosity upgrade.

That "delivers" PDFs to N^3LO, an order of magnitude more precise than so far and free of most of the current complications.

This provides the world with the cleanest microscope it can build, and it further exploits the LHC, transforming it to a precision Higgs facility and leading to BSM.

The novel electron ERL will be an ideal complement also of the HE LHC and later the FCC.

DIS needs to be kept to be an integral part of HEP at TeV scales. There is a way forward.

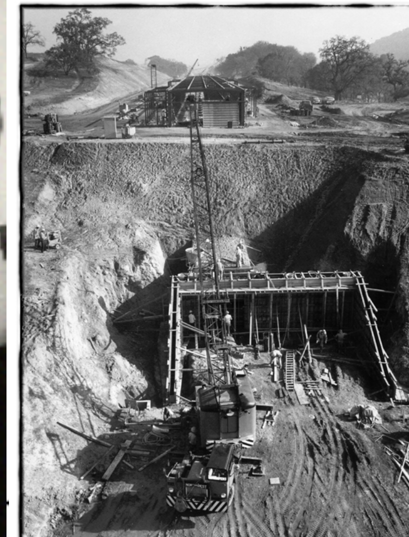
"The future belongs to those who believe in the beauty of their dreams."

Anna Eleanor Roosevelt
(1884-1962)

Universal Declaration of Human Rights (1948)

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

can one build a 2 km long linac?

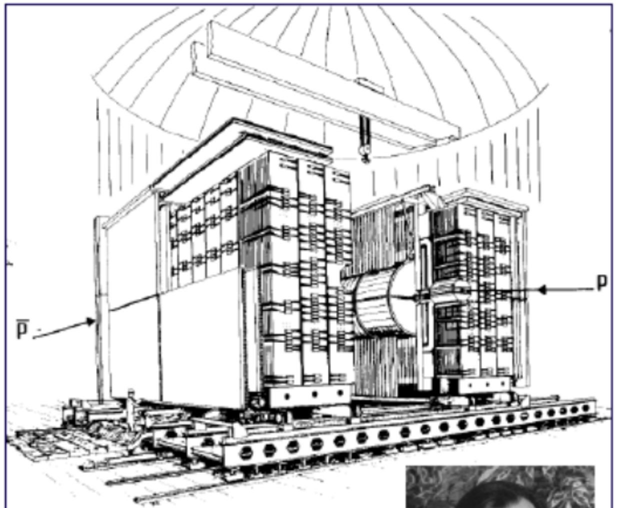


it has been done before

Courtesy F.Zimmermann

Can CERN host pp and DIS at once?

.. in the 80ies it successfully did



UA1

“ We have two tasks: kill Weinberg Salam, kill QCD”
Carlo Rubbia: 1978 BCDMS meeting at Dubna.
The failure to fulfill his task made Carlo famous…

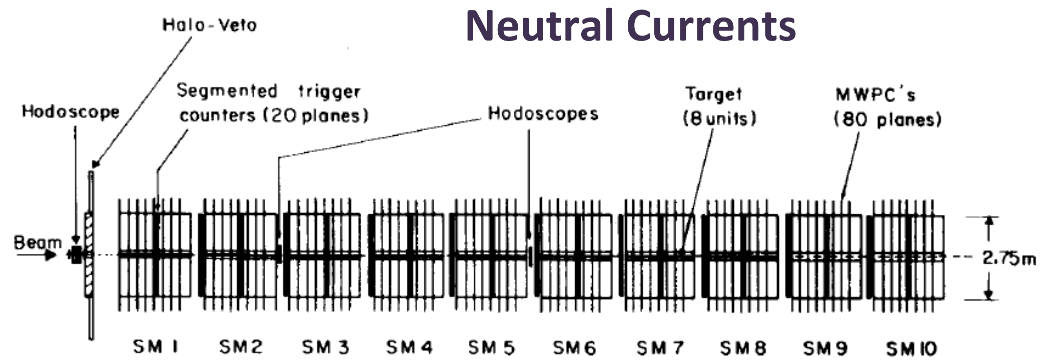
UA2

Pierre Darriulat
now in Vietnam

Charged Currents

BEBC, **CDHS(W)**, CHARM, CHORUS

Neutral Currents



BCDMS, EMC, SMC, COMPASS

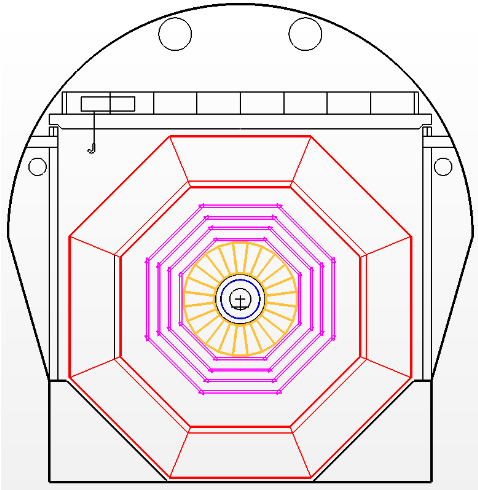
Logo of the CDR

W.Kandinsky: "Circles in a cirle" (1923) Philadelphia (USA) Museum of Art
First shown in LHeC context in a talk by A.S.Vera Workshop 2008

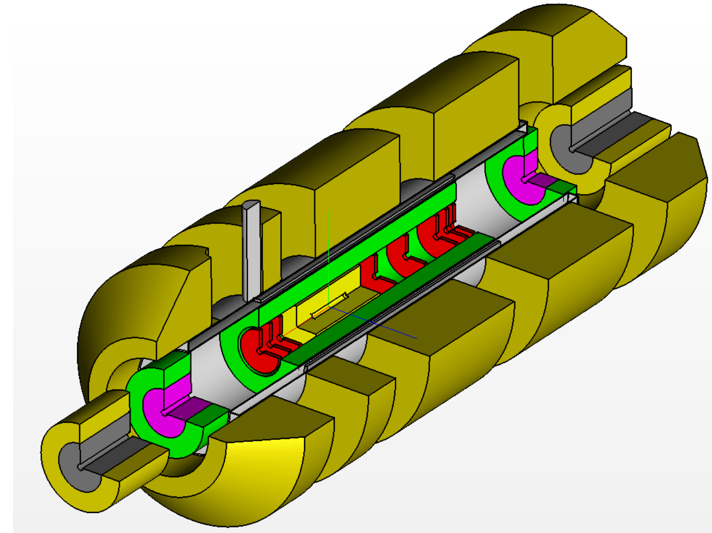
Many thanks to the LHeC/FCC-eh collaborators, the IAC, to CERN and our labs

backup

Installation Study

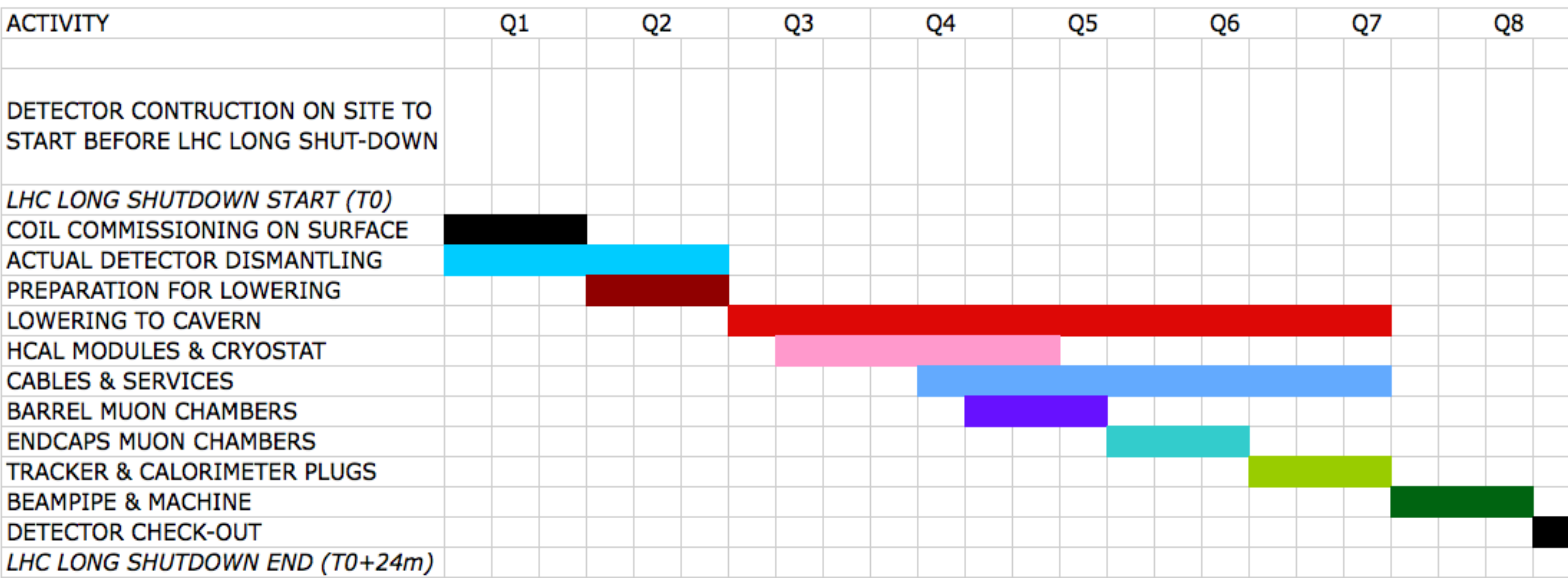


Detector fits in L3 magnet support

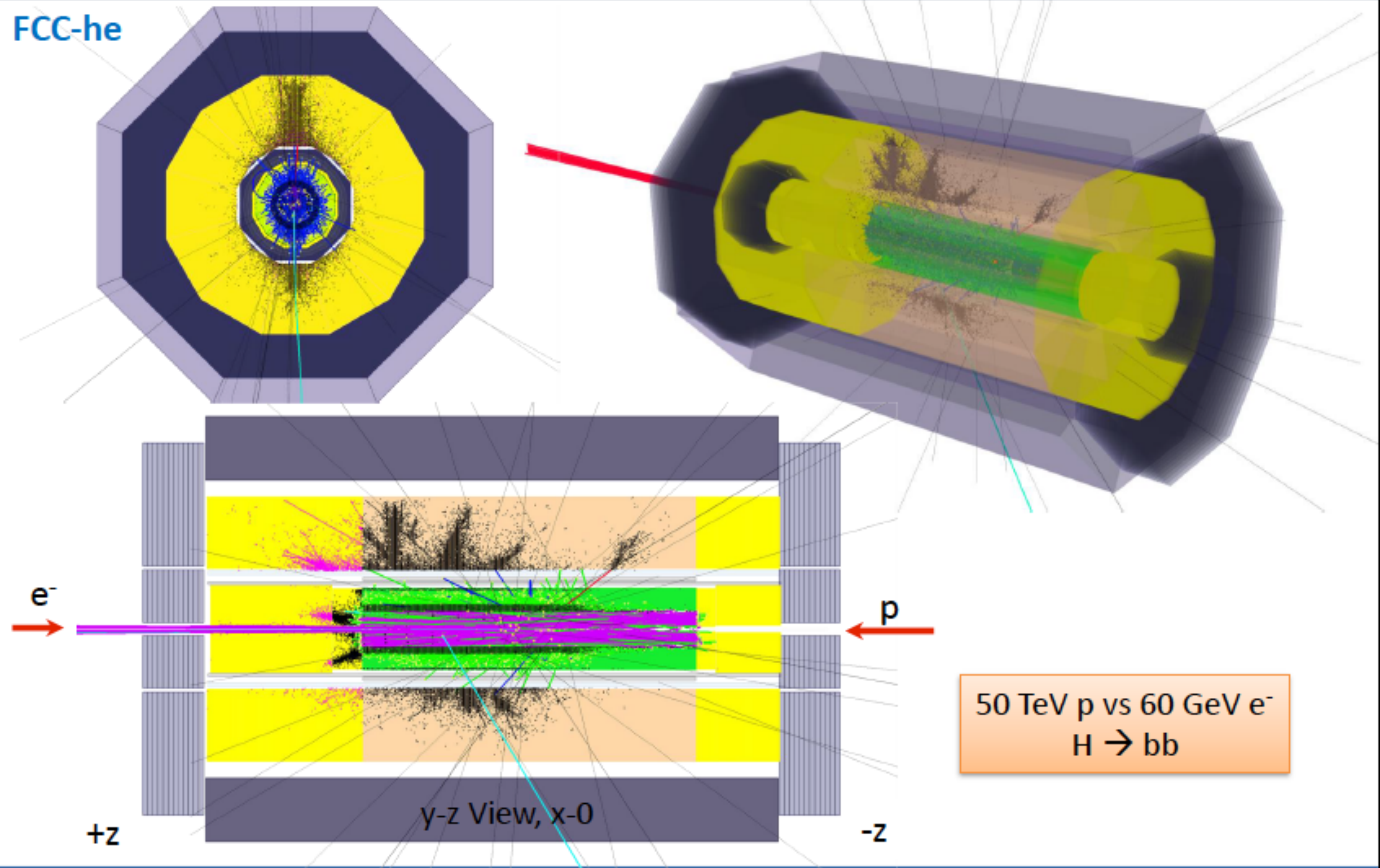


Modular structure

LHeC INSTALLATION SCHEDULE



First FCC-eh Simulations



50 TeV p vs 60 GeV e-
H → bb

item	HKN07	EPS09	DSSZ	nCTEQ	LHeC
Reference	Phys. Rev. C76 (2007) 065207	JHEP 0904 (2009) 065	Phys.Rev. D85 (2012) 074028	arXiv: 1509.00792	Workshops + this talk PRD(2030+)
Order pQCD	LO & NLO	LO & NLO	NLO	NLO	NNLO
NC e+A / e+d DIS	√	√	√	√	NC
Drell-Yan ll in p+A / p+d	√	√	√	√	--
RHIC pions in d+Au / p+p		√	√	√	--
Neutrino-nucleus DIS			√		CC
$\sqrt{Q^2}$ cut in DIS	1 GeV	1.3 GeV	1 GeV	2 GeV	free
# of data points	1241	929	1579	740	many
Free parameters	12	15	25	17	O(20)
Error sets available		√	√	√	(y)
Error tolerance $\Delta\chi^2$	13.7	50	30	35	1
Baseline	MRST98	CTEQ6.1	MSTW08	CTEQ6M?	None – or ep+eD+eA
Heavy quark treatment	ZM_VFNS	ZM_VFNS	GM_VFNS	GM_VFNS	s,c,b data

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

Draft Table of Contents (9. June 2016)

LHeC CDR update because:

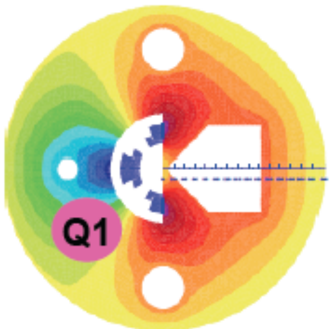
- Lumi * 10
- LHC results
- Technology progress

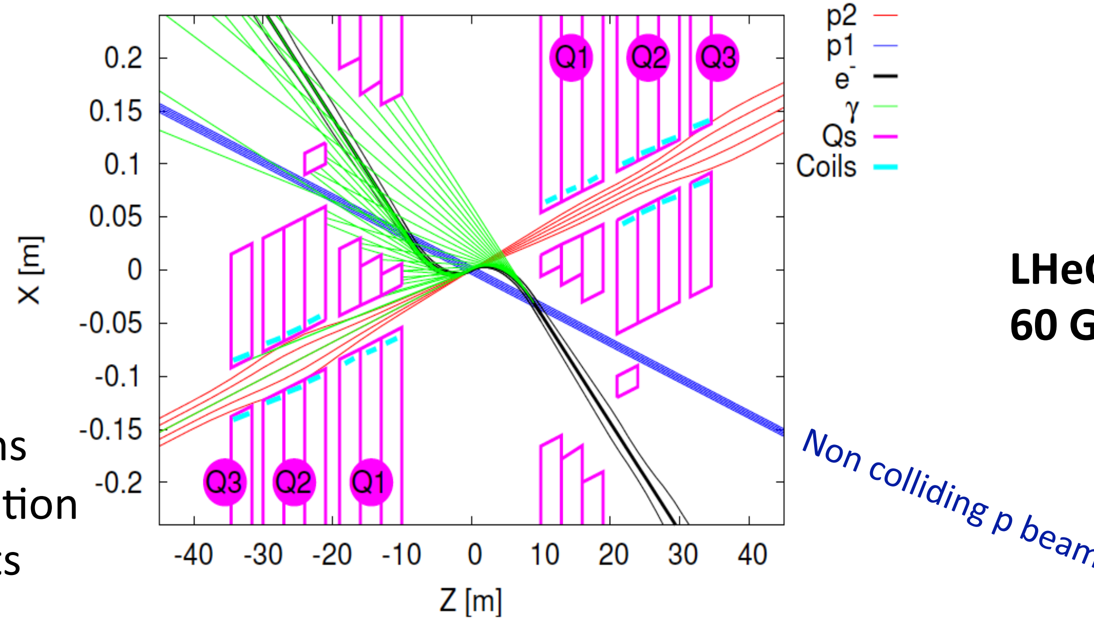
Open for any participation

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

*) arXiv:1206.2913

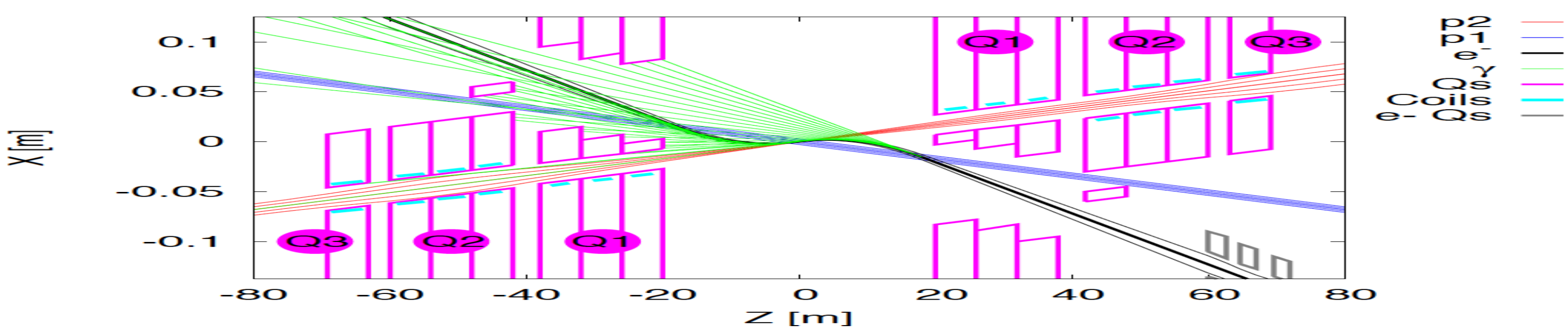
Interaction Regions for ep with Synchronous pp Operation





LHeC (CDR)
60 GeV * 7 TeV

Likely one IR.
Matching e and p beams
Limit synchrotron radiation
Design of inner magnets
Beam-beam effects ….

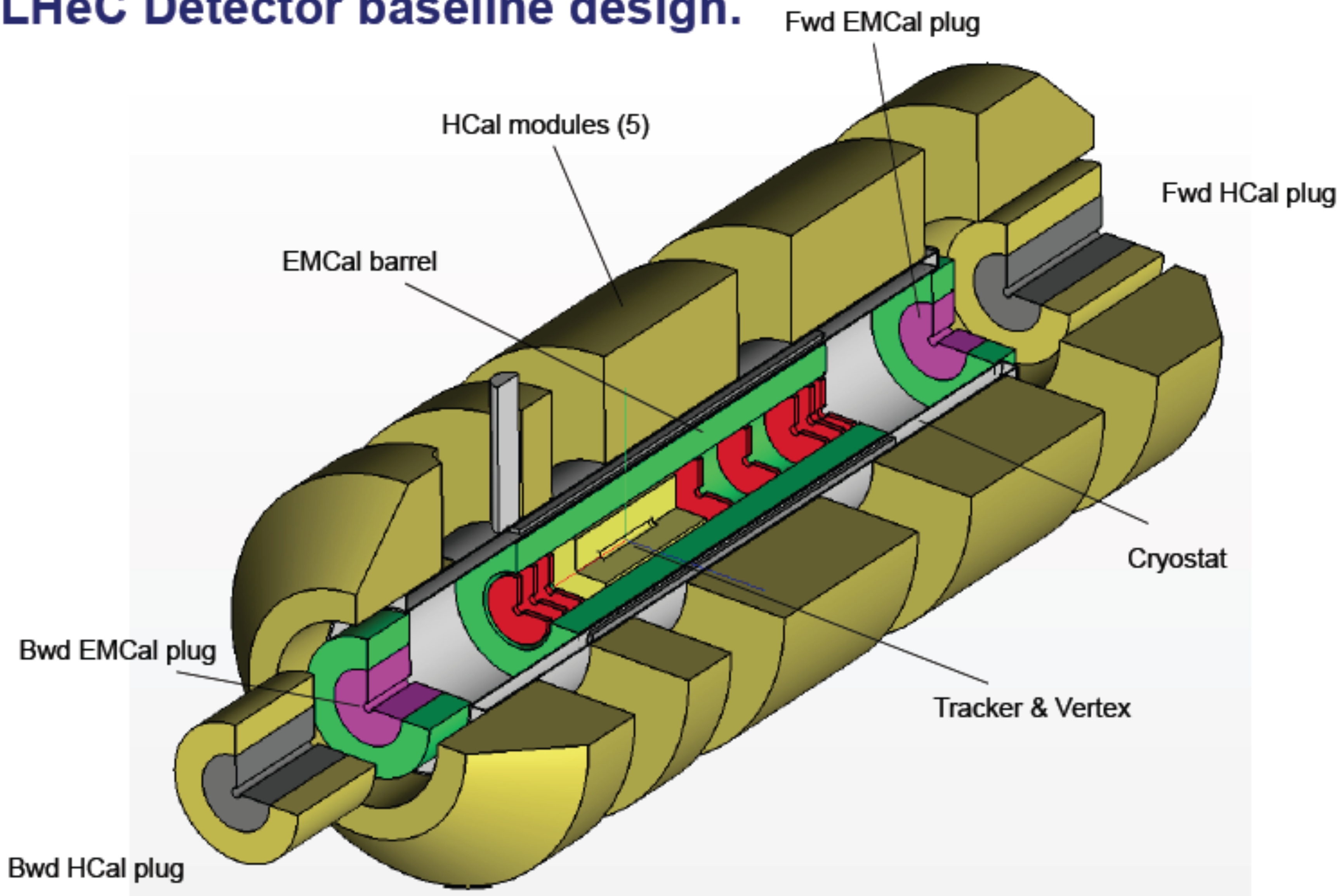


Tentative: ε_p=2µm, β^*=20cm → σ_p=3µm ≈σ_e matched! ε_e=5µm ..

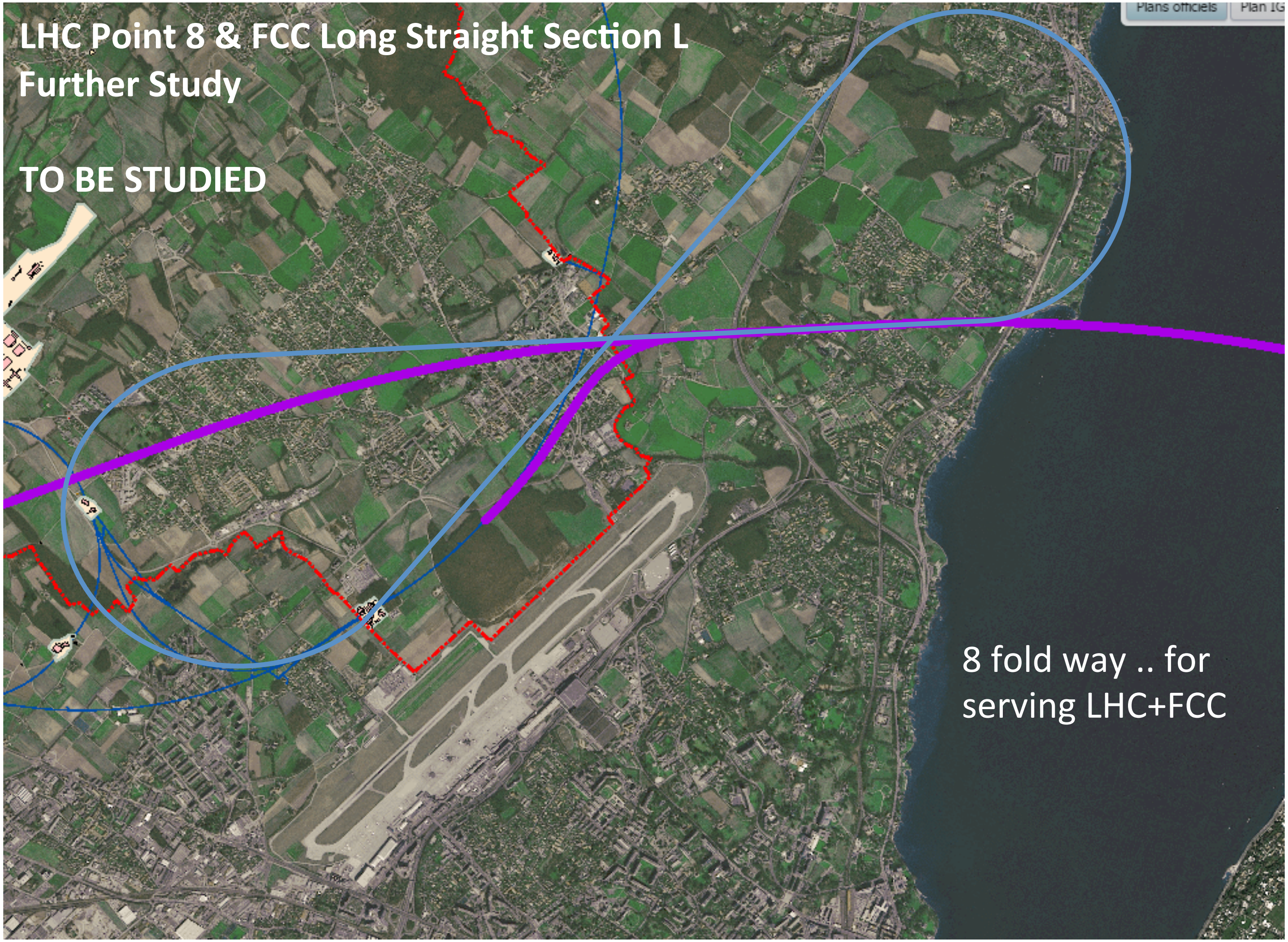
FCC-he (ERL)
60 GeV * 50 TeV

Rogelio Tomas, Max Klein, ICHEP14

LHeC Detector baseline design.

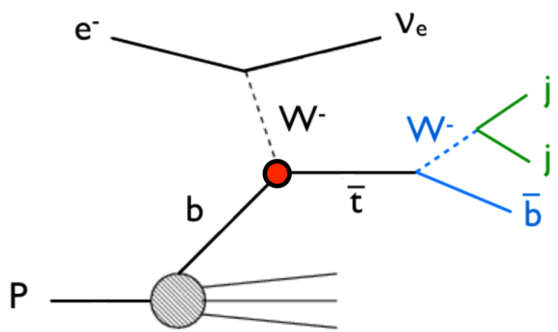


LHeC/FCC-he Civil Engineering

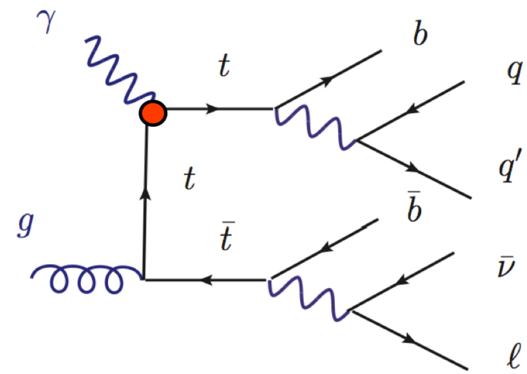


top quark electroweak interactions

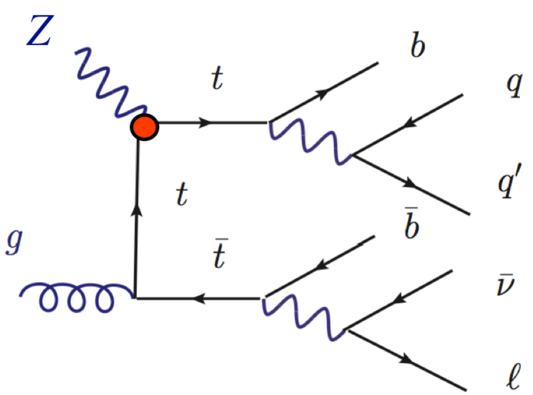
precise measurement of couplings between SM bosons and fermions sensitive test of new physics (search for deviations) : **top quark expected to be most sensitive to BSM physics, due to large mass**



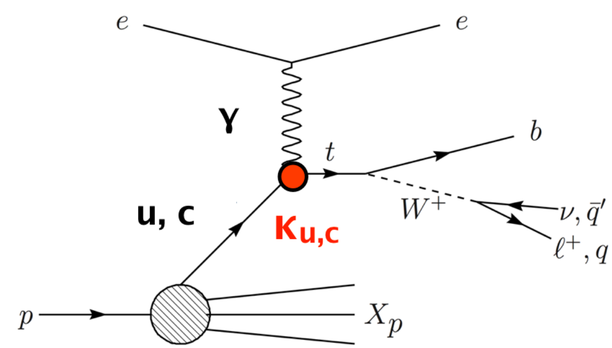
- high precision measurements of Vtb and search for anomalous Wtb couplings



- direct measurement of top quark charge and search for anomalous ttbarγ couplings (eg. EDM, MDM)



- measurement of top isospin and search for anomalous ttbarZ couplings (eg. EDM, MDM)



- sensitive search for FCNC couplings will constrain BSM models that predict FCNC (eg. SUSY, little Higgs, technicolour)

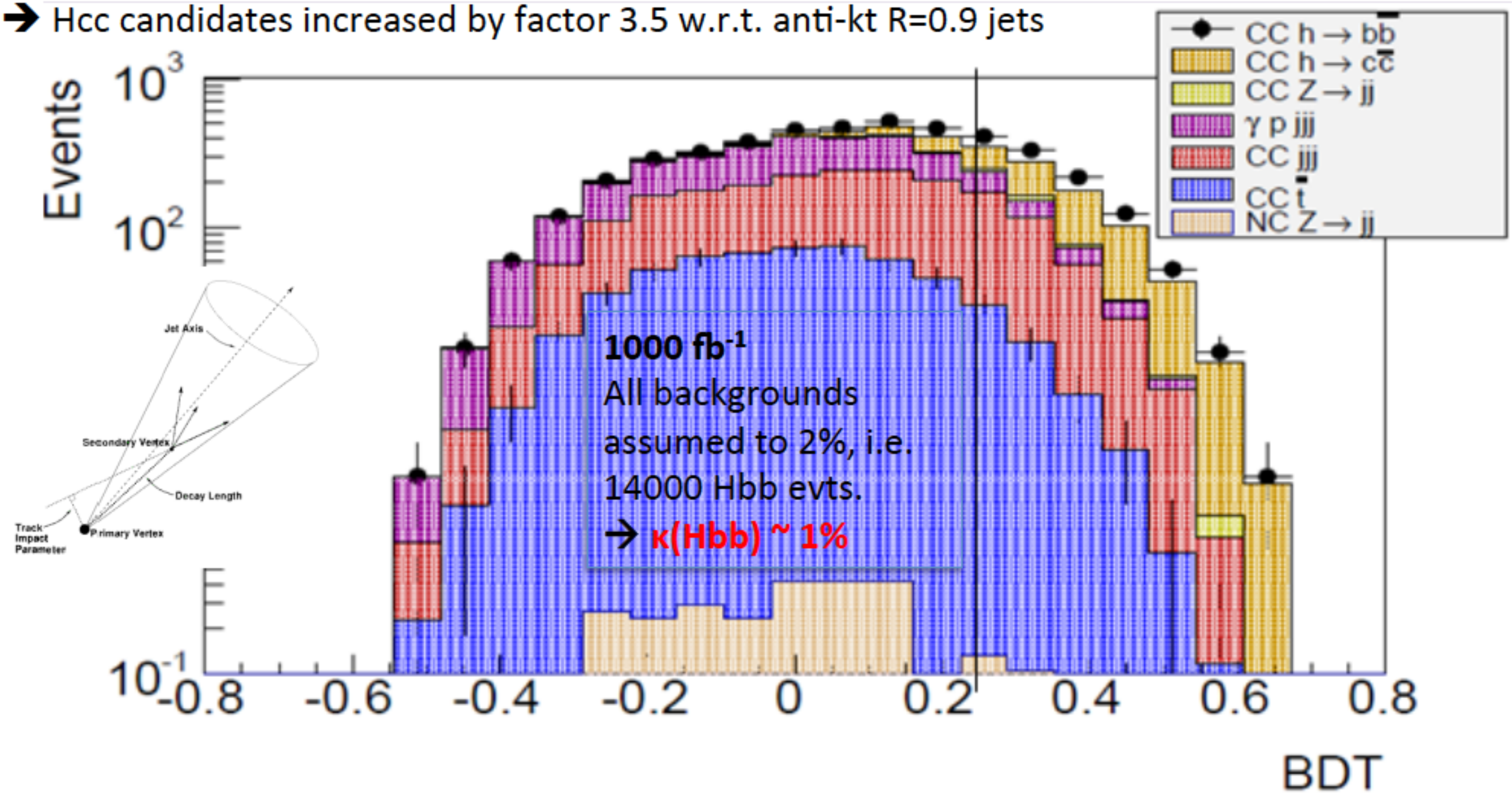
BDT Results Higgs→ cc

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

U Klein and D Hampson.
May 2016

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



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.

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 [SM+BSM].

It provides a new, independent energy and intensity frontier collider configuration which fits to the needs of both particles and nuclear physics and its collaborating communities.

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

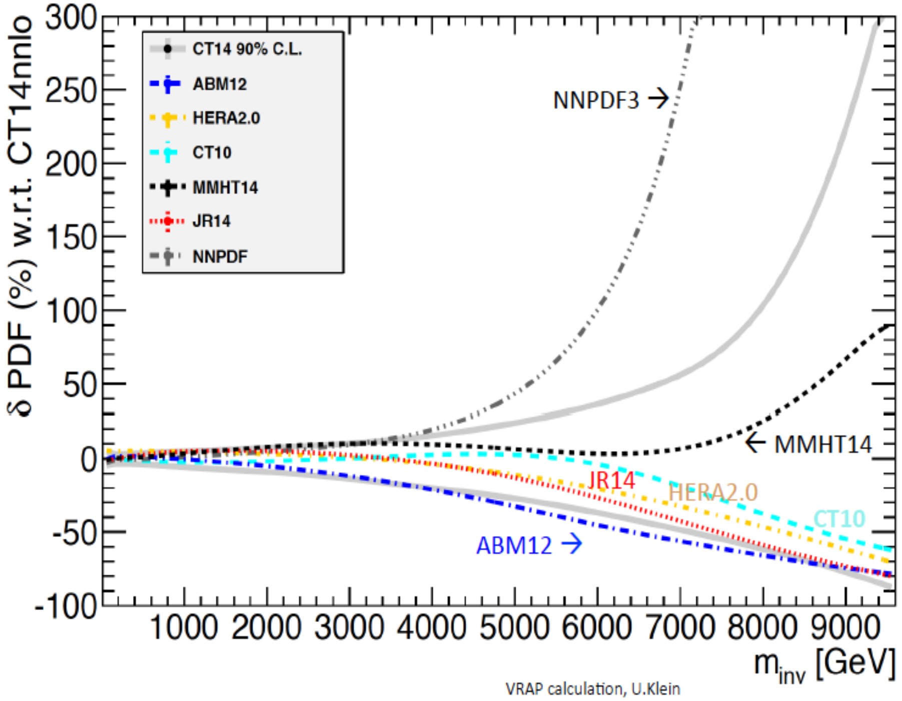
The DIS environment of the LHeC is extremely precise which gives theory a variety of fundamental new tasks and the experimentalists a novel GPD.

Thank you.

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

PDF precision matters at the LHC

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



Cf also talks by Jan Kretzschmar and Sasha Glazov and others