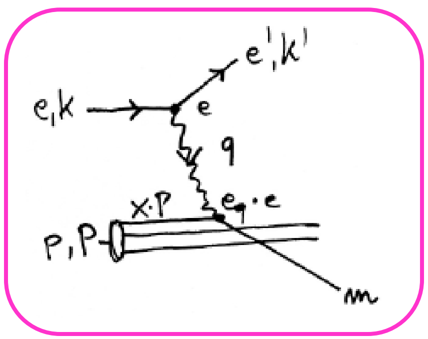
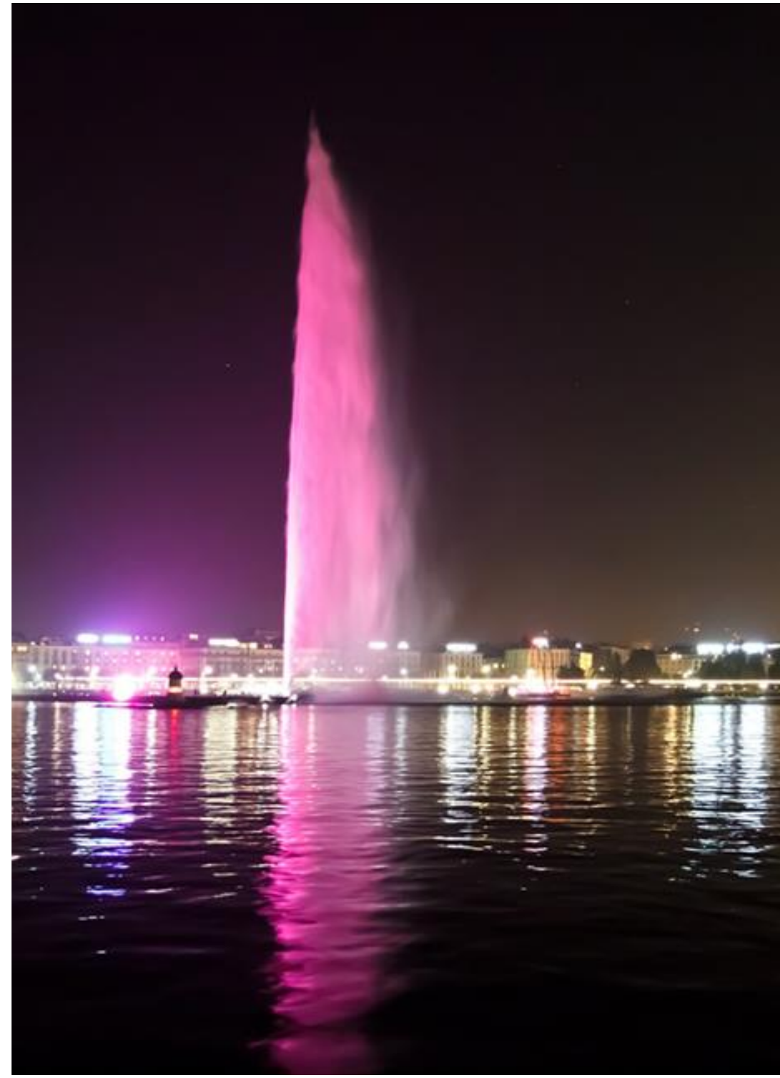
Lepton-Hadron collider:
Physics, Experiments and Detectors

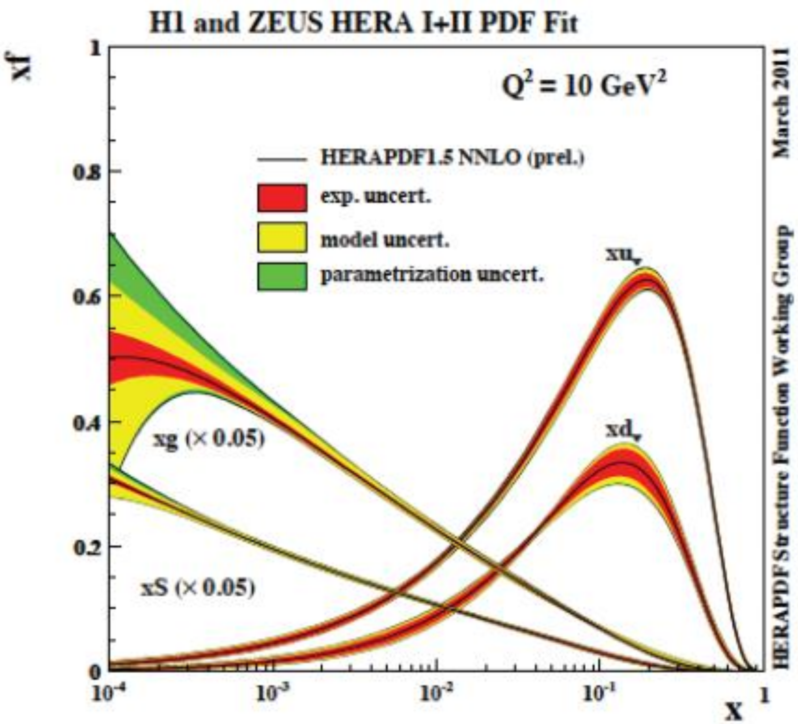
Monica D'Onofrio
University of Liverpool
(on behalf of many…)





Future Circular Colliders Study Kick-off meeting
Geneva, February 13th 2014

e-p at HERA .. and beyond



- At HERA, extensive tests of QCD, measurements of α_S and base for PDF fits in x range relevant for hadron colliders
- But also:
  - New limits for leptoquarks, excited electrons and neutrinos, quark substructure and compositness, RPV SUSY etc.

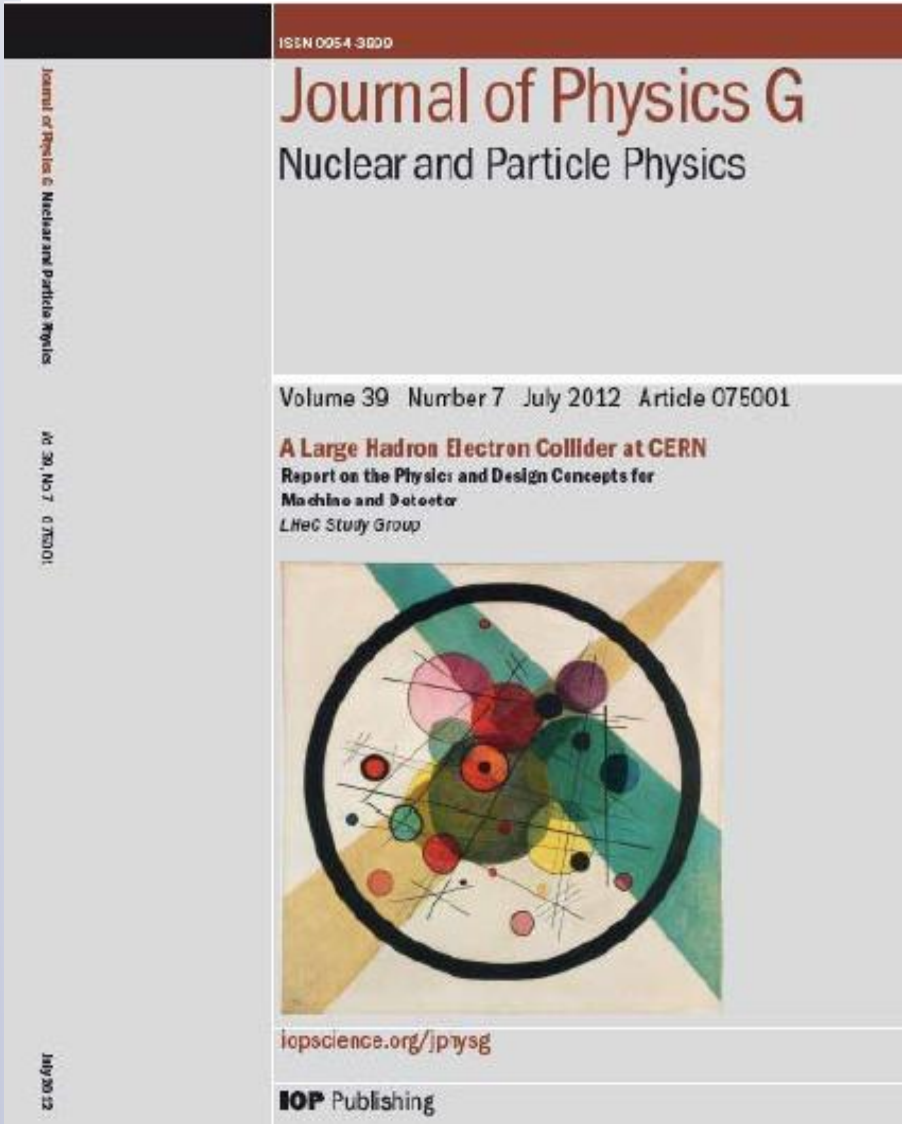
The idea of an e-p collider at CERN, the LHeC, proposed in 2005, has been developed in the last years: http://cern.ch/LHeC

Tevatron/HERA/LEP → HL-LHC/LHeC/(ILC?)

(fermiscale) (Terascale)

(or, the complimenatarity pattern)

LHeC: Conceptual Design Report (July 2012) and more

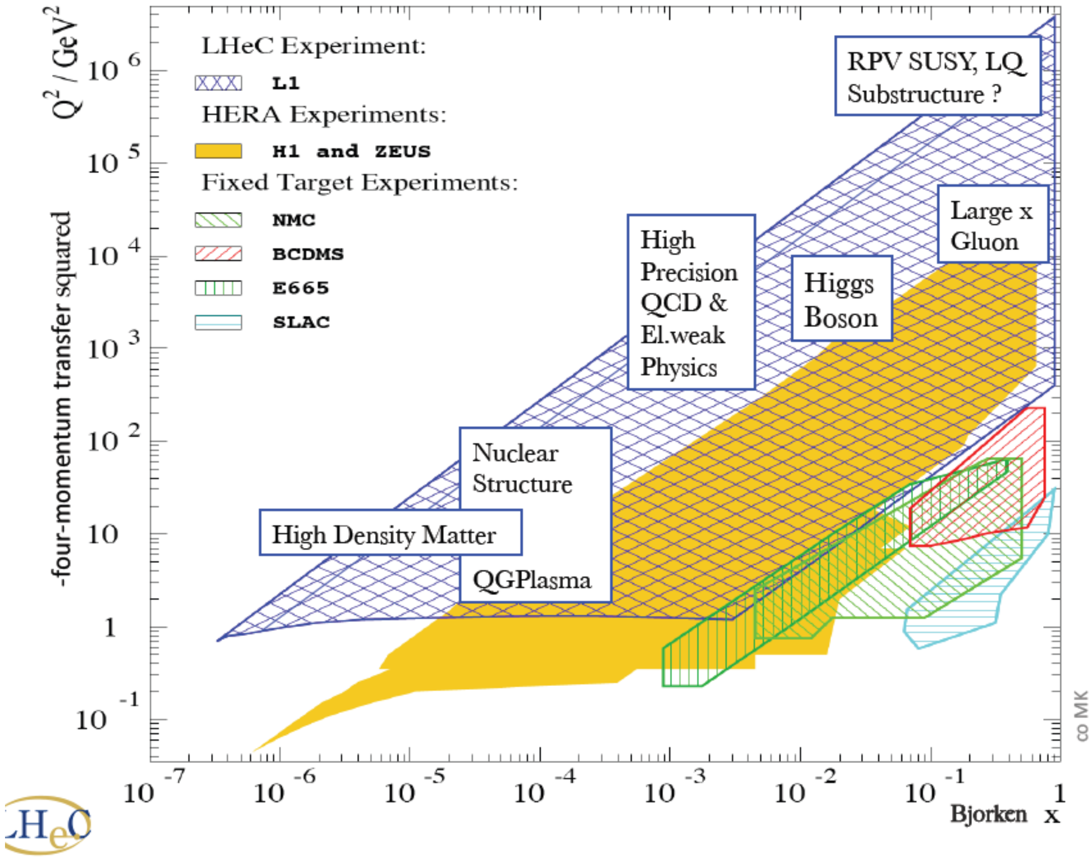


- 630 pages summarising 5 years of studies commissioned by CERN, ECFA and NuPECC
- About 200 participants, 69 institutes
- Further updates
  - *'A Large Hadron Electron Collider at CERN'* arXiV:1211.4831
  - *'On the relation of the LHeC and the LHC'* arXZiV:1211.5102
  - *'The Large Hadron Electron Collider'* arXiV:1305.2090
  - *'Dig Deeper'* Nature Physics 9 (2013) 448
- Regular workshops and presentations in Conferences

The LHeC

- Unique opportunity to take lepton-hadron physics to the TeV centre-of-mass scale at high luminosity

LHeC: E_e=60 GeV, $\sqrt{s}$ = 1.3 TeV



Designed to exploit intense **hadron beams** in high luminosity phase of LHC running from mid 2020s:

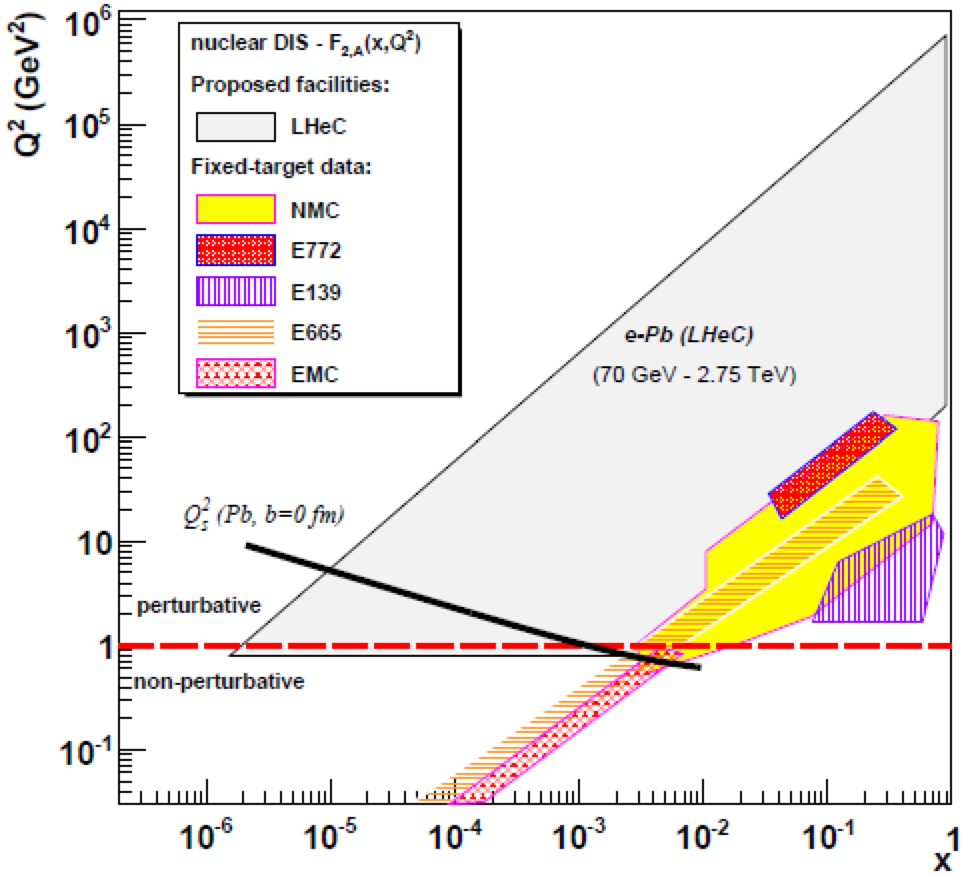
→ Use 7 TeV protons

→ Add an **electron beam** to the LHC

LHeC as electron-Ion Collider

- **Four orders of magnitude increase** in kinematic range over previous DIS experiments

  → will change QCD view of the structure of nuclear matter



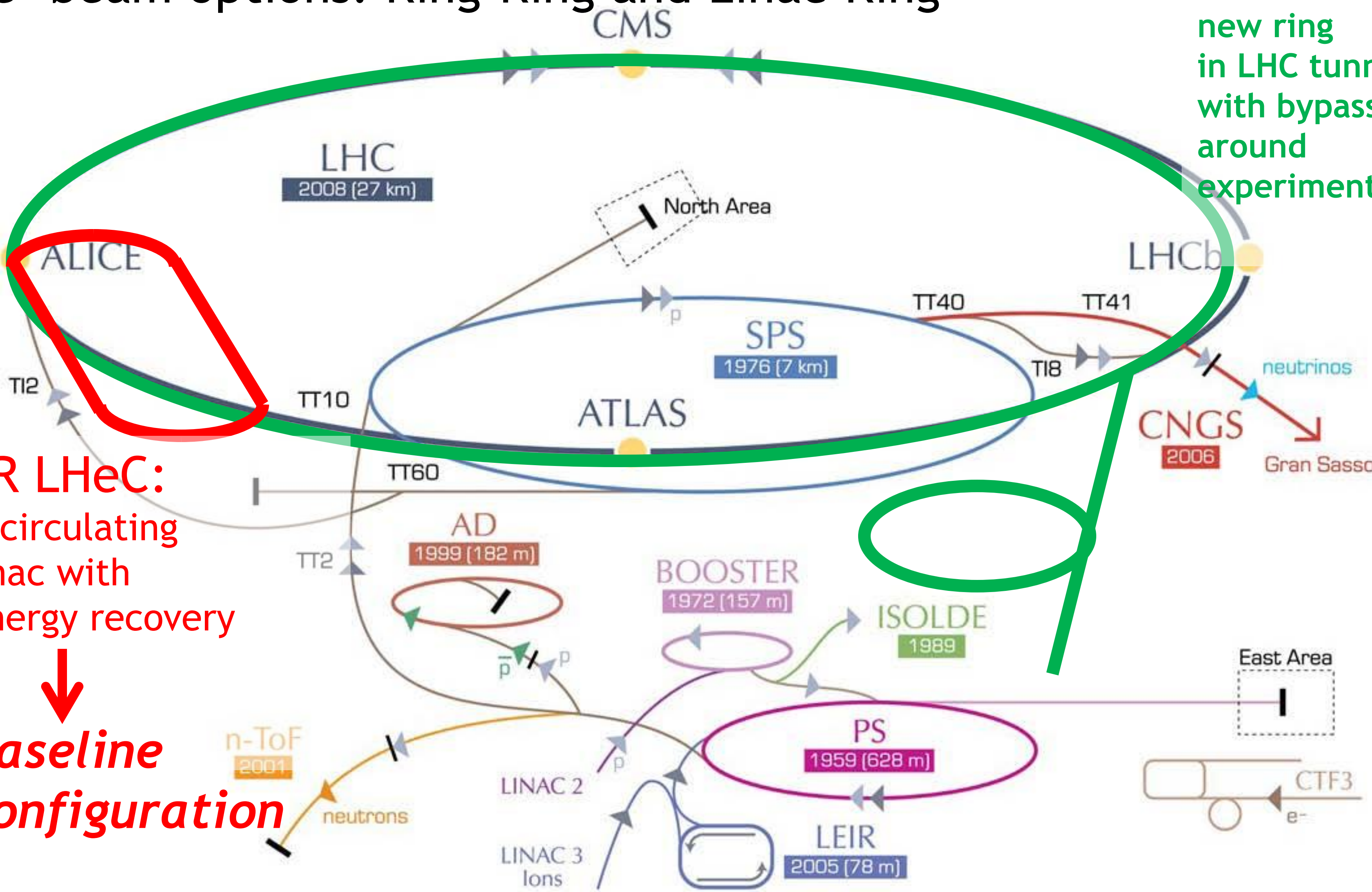
Study interactions of densely packed but weakly decoupled partons

Precision QCD study of parton dynamics in nuclei

May lead to genuine surprises:
- no saturation of $xg(x,Q^2)$,
- broken isospin invariance
- …

The LHeC ‘facility’

e± beam options: Ring-Ring and Linac-Ring

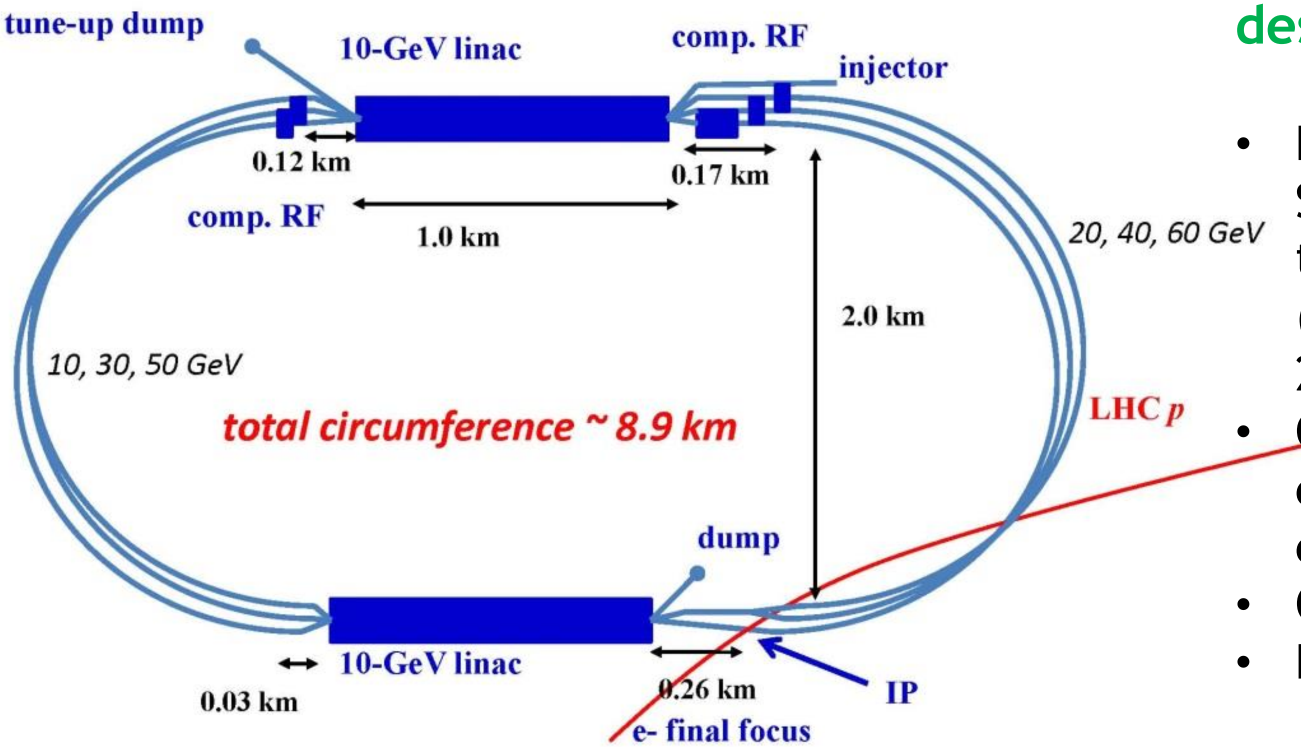


RR LHeC:
new ring in LHC tunnel, with bypasses around experiments

LR LHeC:
recirculating linac with energy recovery
↓
baseline configuration

Energy Recovery Linac

- Power consumption < 100 MW, **E(ele)=60 GeV** *(design constraints)*
- Two 10 GeV Linacs; 3 returns, 20 MV/m
- Energy recovery in same structures
- 60 GeV e-'s collide w. LHC protons/ions



Test Facility under design

- Development of SuperConducting RF technology at CERN (Approved November 2013)
- Operation and experience with S.C. energy recovery linac
- Quench tests of magnets
- Possible e/γ experiments

More in O. Brunig and F. Zimmerman talks on Friday

The LHeC baseline parameters

Luminosity [10^{33}cm^{-2}s^{-1}]	1-10**
Detector acceptance [deg]	1
Polarization [%]	90
IP beam sizes [μm]	7
Crossing angle [mrad]	0
e- L* [m]	30
Proton L* [m]	15
e- beta*$_{x,y}$ [m]	0.12
Proton beta*$_{x,y}$ [m]	0.1
Synchrotron power [kW]	10

***e^-p* and *e^+p* collisions (possibly with similar luminosity)**
→ 60 GeV (ele), 7 TeV proton

***e^-/e^+* polarization**

Operations simultaneous with HL-LHC *pp* physics

- ep Lumi: 10^{33} (10^{34})** cm^{-2} s^{-1} *(**: according to recent studies)*
- 10-100 fb-1 per year
- 100 fb^{-1} – 1 ab^{-1} total
- eD and eA collisions integral part of the programme
  - E-nucleon Lumi estimates → 10^{31} (10^{32}) cm^{-2} s^{-1} for eD (ePb)

LHeC Physics

- Rich physics program for e-q physics at TeV energies:
  - Precision QCD,EWK physics
  - Higgs measurements and searches for BSM
  - Complimentarities to LHC physics program and boosting its precision (eg PDF at high x)

arXiv:1211:4831+5102

QCD Discoveries Higgs Substructure New and BSM Physics Top Quark	$\alpha_s < 0.12$, $q_{sea} \neq \overline{q}$, instanton, odderon, low x: (n0) saturation, $\overline{u} \neq \overline{d}$ WW and ZZ production, $H \to b\overline{b}$, $H \to 4l$, CP eigenstate electromagnetic quark radius, e^*, ν^*, W?, Z?, top?, H? leptoquarks, RPV SUSY, Higgs CP, contact interactions, GUT through α_s top PDF, $xt = x\overline{t}$?, single top in DIS, anomalous top
Relations to LHC	SUSY, high x partons and high mass SUSY, Higgs, LQs, QCD, precision PDFs
Gluon Distribution Precision DIS	saturation, $x \approx 1$, J/ψ, Υ, Pomeron, local spots?, F_L, F_2^c $\delta\alpha_s \simeq 0.1\,\%$, $\delta M_c \simeq 3\,\mathrm{MeV}$, $v_{u,d}$, $a_{u,d}$ to $2-3\,\%$, $\sin^2\Theta(\mu)$, F_L, F_2^b
Parton Structure Quark Distributions QCD	Proton, Deuteron, Neutron, Ions, Photon valence $10^{-4} \lesssim x \lesssim 1$, light sea, d/u, $s = \overline{s}$?, charm, beauty, top N^3LO, factorisation, resummation, emission, AdS/CFT, BFKL evolution
Deuteron Heavy Ions Modified Partons	singlet evolution, light sea, hidden colour, neutron, diffraction-shadowing initial QGP, nPDFs, hadronisation inside media, black limit, saturation PDFs "independent" of fits, unintegrated, generalised, photonic, diffractive
HERA continuation	F_L, xF_3, $F_2^{\gamma Z}$, high x partons, α_s, nuclear structure, ..

Table 3: Schematic overview on key physics topics for investigation with the LHeC.

Coordination group for future DIS at CERN

- Toward a concrete planning: **International Advisory Committee**

Guido Altarelli (Rome) *)
Sergio Bertolucci (CERN)
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)

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.

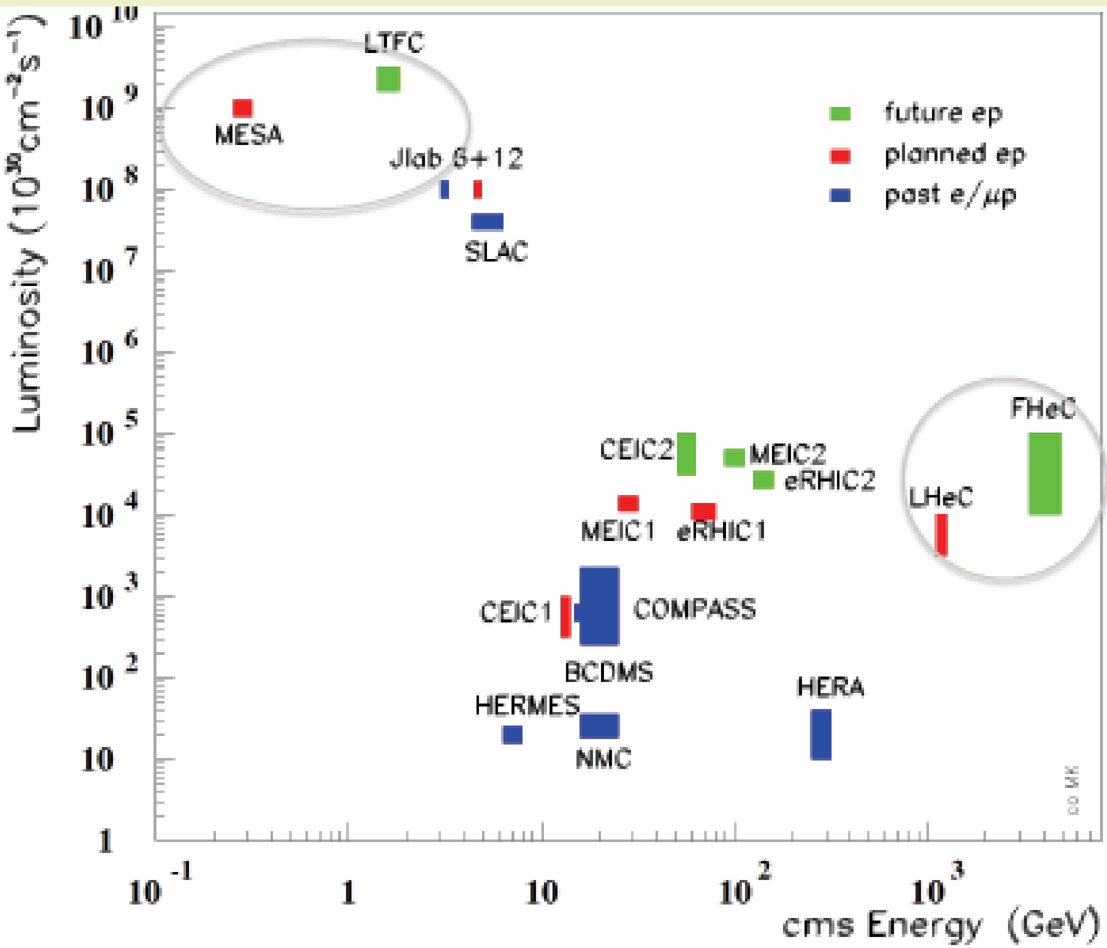
See also Panel discussion at the recent LHeC workshop (Chavannes, 20-21 Jan 2014) H. Schopper slides: https://indico.cern.ch/event/278903/contribution/55

*) IAC Composition End of January 2014 + Oliver Brüning Max Klein ex officio

From the LHeC to the FCC-he *(aka FHeC)*

Tevatron/HERA/LEP → HL-LHC/LHeC/(ILC?) → FLHC/FHeC/FLC

(fermiscale) (Terascale) (Multi-Terascale)



Lepton-Proton Scattering Facilities

Realistic opportunity for energy frontier DIS → 3 order of magnitude higher lumi wrt HERA; huge step in energy (Q^2,1/x)

FCC-he preliminary parameters

e$^-$ **energy = 60, 120 GeV up to 175 GeV**
(*e*$^+$ option open)

Energy recovery is 60 GeV
Ring-Ring might go up to 175 GeV

p **energy = 50 TeV**

CM energy [TeV] = 3.5 (60 GeV e), 4.9 (120 GeV e)

IP spot size determined by *p*

Towards the FCC-he

- Various aspects considered at this stage

Physics	Detector	Testfacility	Accelerator	Infrastructure
Higgs Top LHC-LHeC eA Low x Theory	Simulation Design Taggers Collaboration	Cavcryo module Magnets Source Optics Operation Coordination	Optimisation Optics IR Q1,2 Pipe+Vacuum Positrons Deuterons	Installation CE Resources Conferences Outreach Relations

- **In this talk:**
  - **Highlights of physics programme**
  - **Ideas for detector design**
  - **Parameters and FCC complex view**

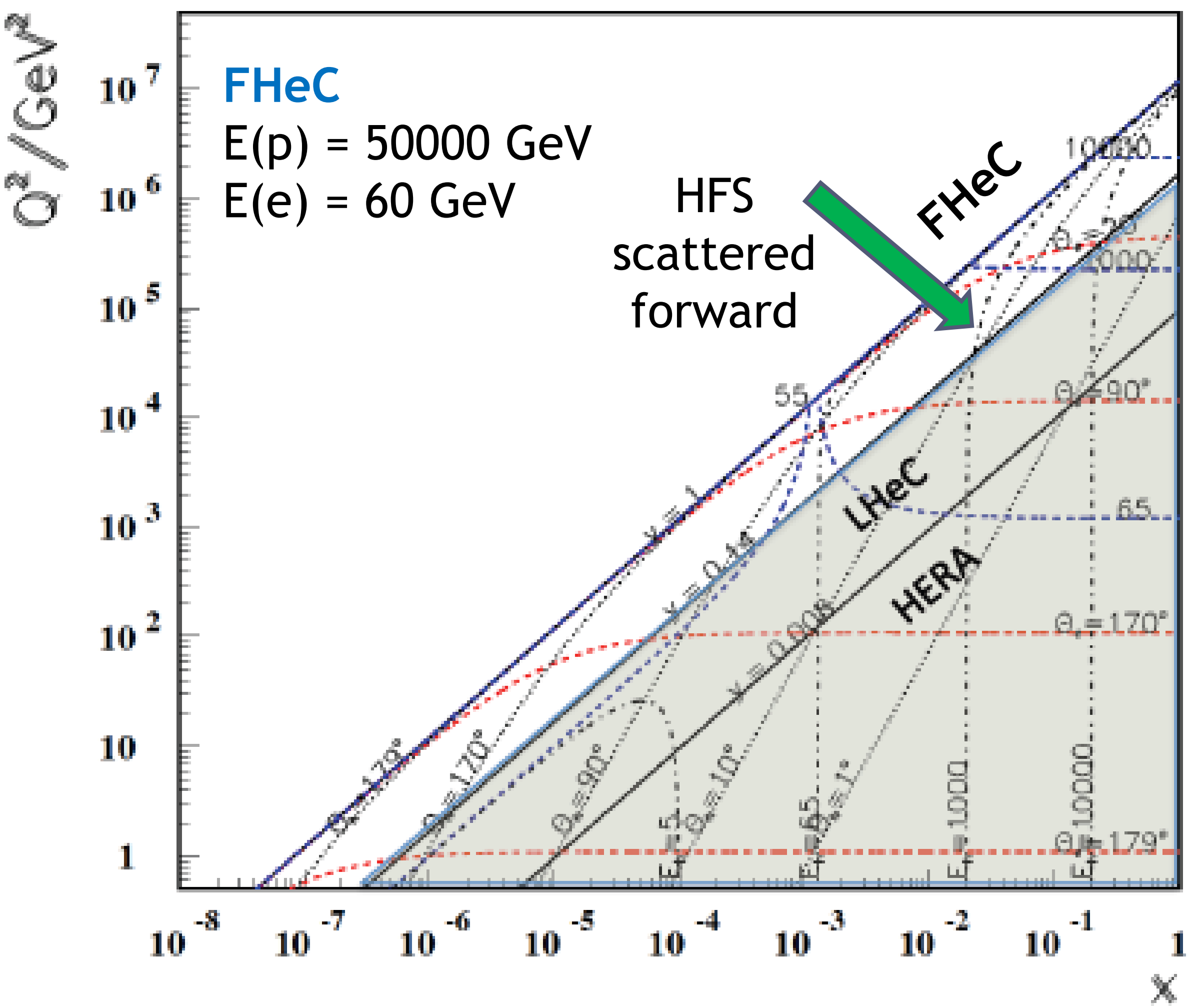
More detailed talks in the parallel session tomorrow at 2 pm

https://indico.cern.ch/event/282344/session/15/?slotId=0#20140214

Physics highlights

- PDF fits, measurements of α_S and impact on higgs/BSM
- Higgs measurements (H→bbbar or ccbar, HHH couplings)
- New Physics (CI, LQ, RPV SUSY)
- EWK measurements ($\sin^2\theta_W$)
- e-Ion highlights

DIS: from HERA to FHeC



Low x:
Q^2min ~ E_e^2 → keep 60 GeV electrons

Large x:
need very fwd tracking (@ 1 degree)

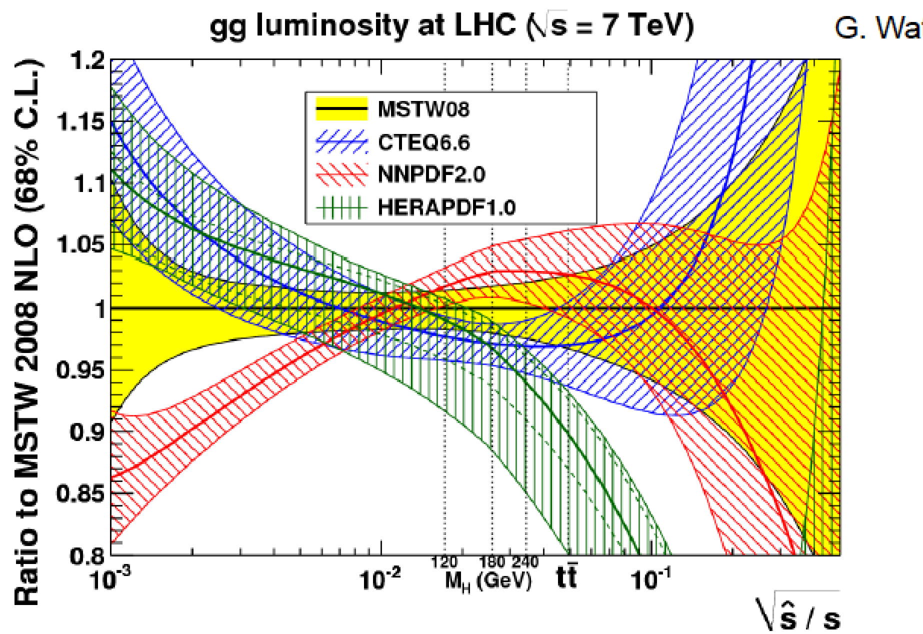
Scattered electron: need broad angle acceptance for accessing **low Q^2** and **high y region**

PDF fits

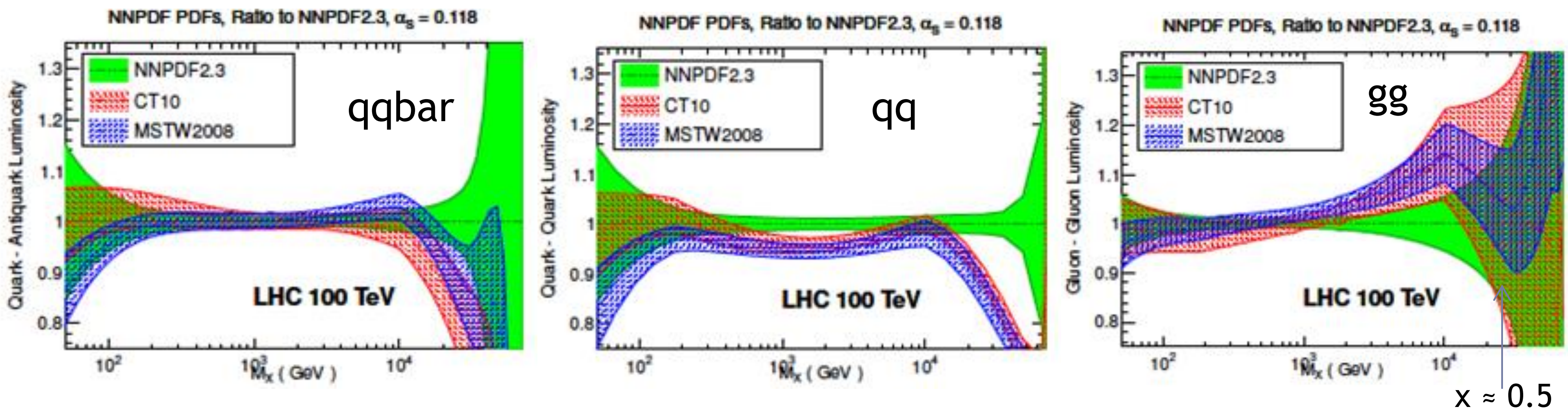
- Current status →

Need to know the PDFs much better than now at low and high x

- E.g.: for QCD development, q-g dynamics, Higgs measurements and searches



The LHC will provide further constraints, but a new level of precision in determination of PDFs can only be achieved with the e-p



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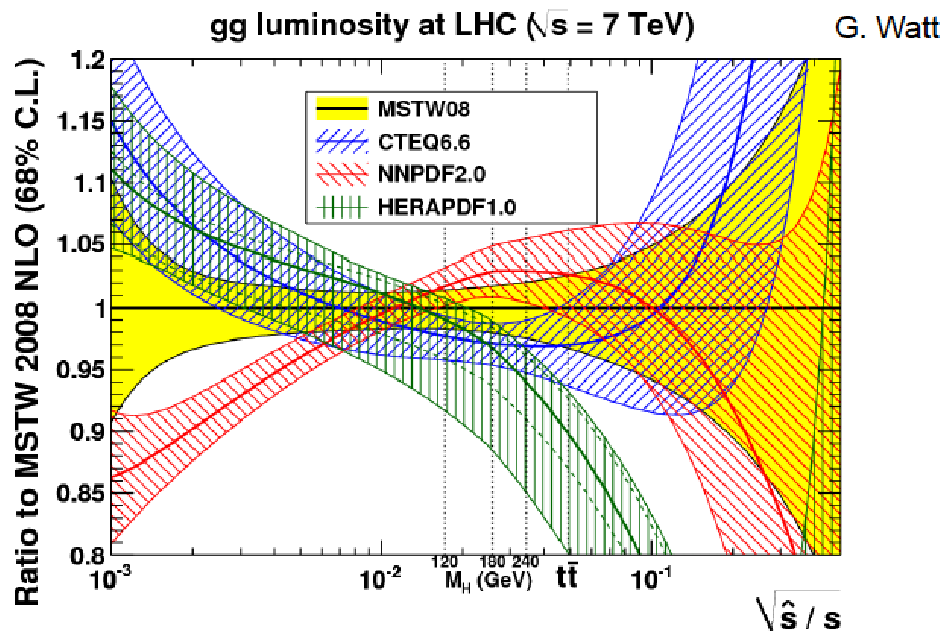
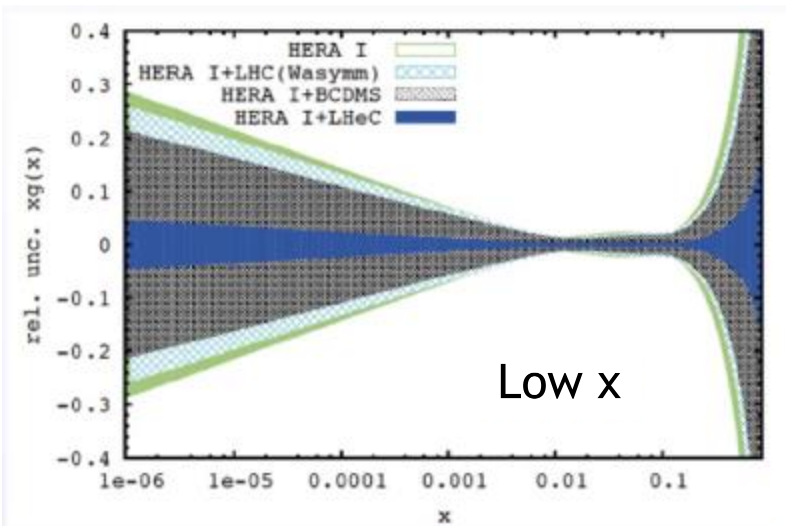
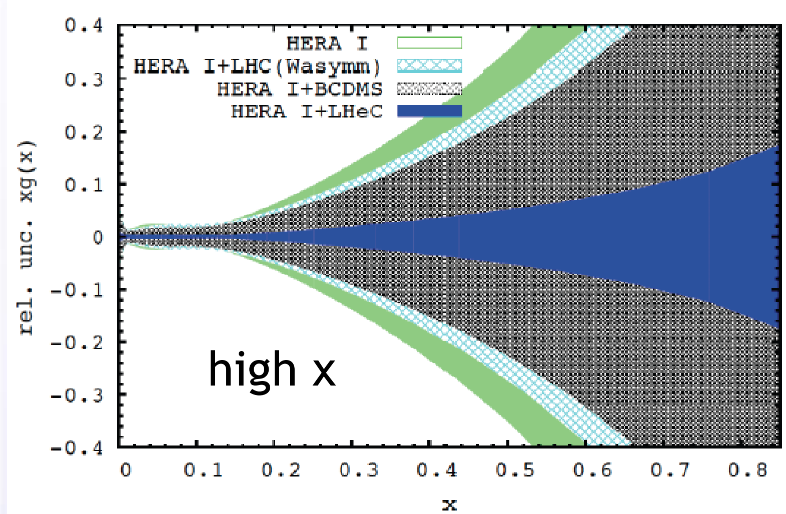


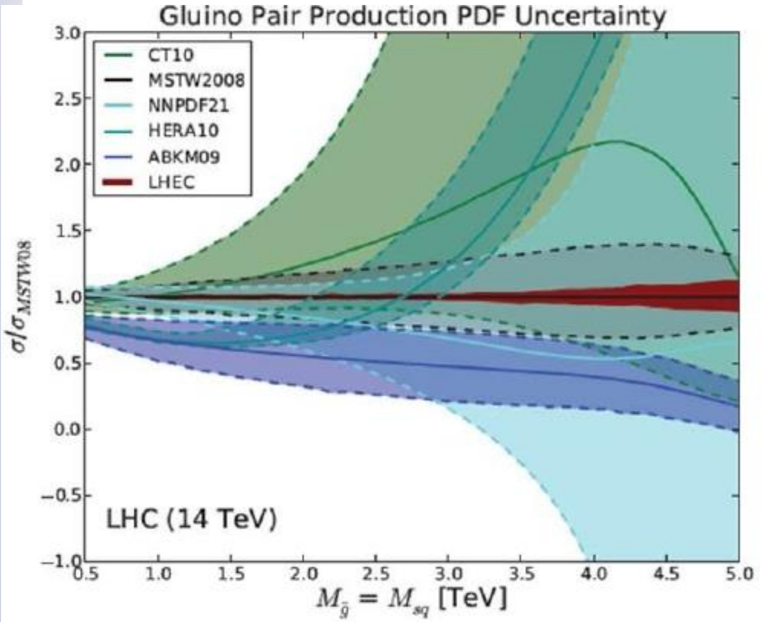
Example gluon PDF at the LHeC (blue band): < 5% at x=10^{-6} and x=0.5

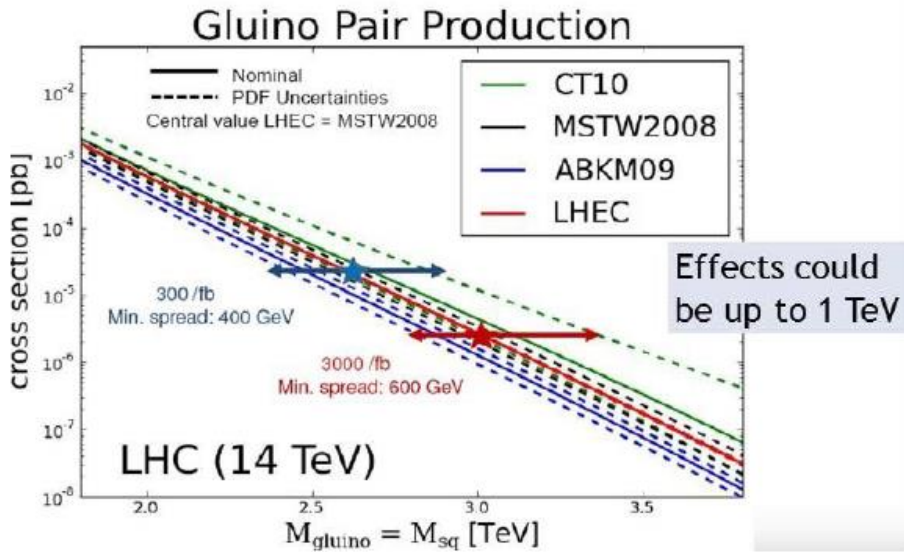




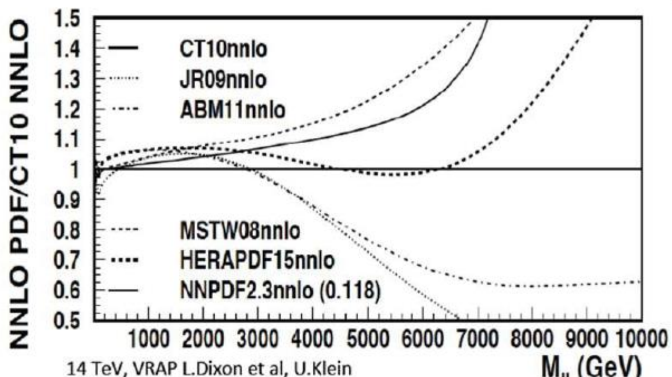
Impact of high-x PDF on HL-LHC/FCC-hh

- Searches near HL-LHC / FCC-hh kinematic boundary may ultimately be limited by knowledge of PDFs (especially gluon at x → 1)
  - Example: gluino production at HL LHC → Dependency on discovery potential and exclusion limits at 300 and 3000 /fb for 14 TeV c.o.m.



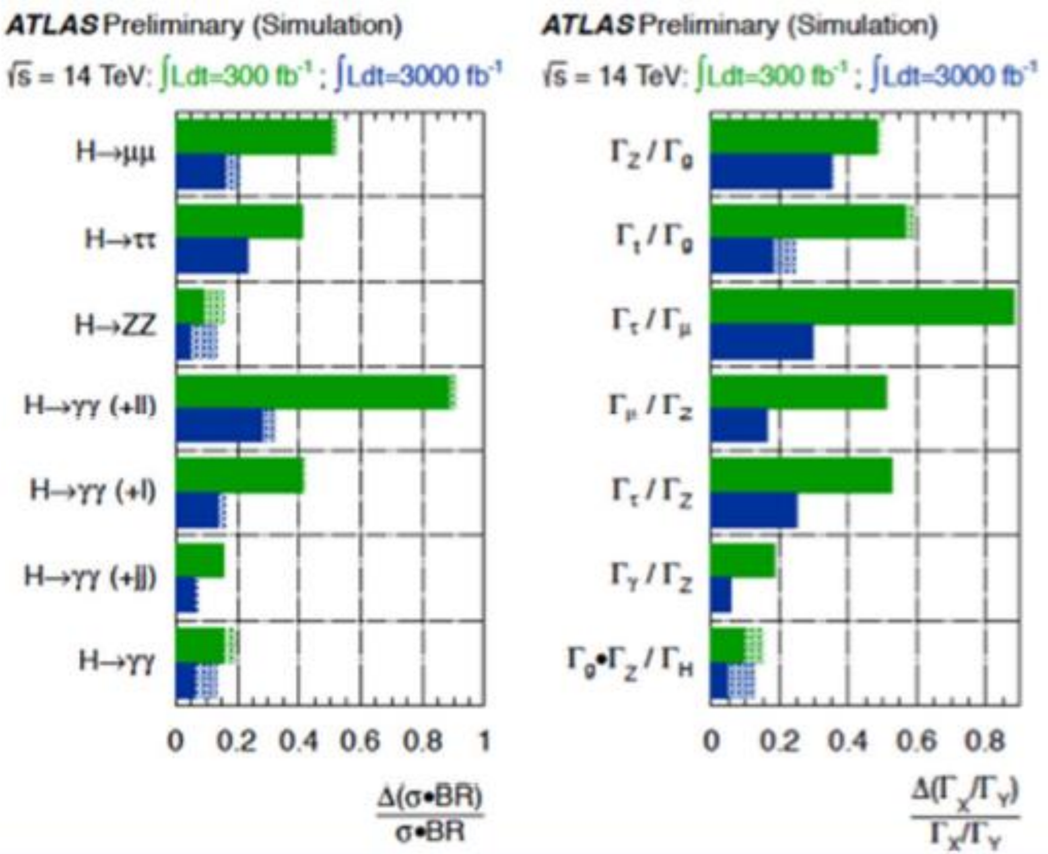


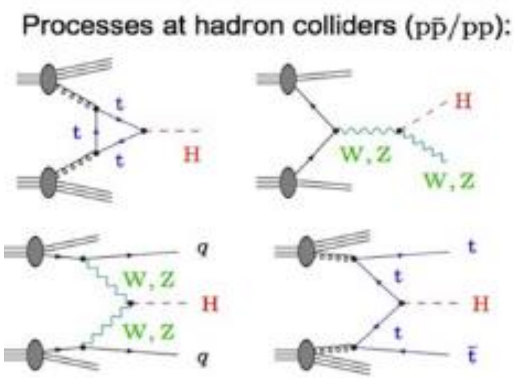
Similar conclusions for other non-resonant BSM signals involving high x partons (e.g. contact interactions signal in Drell Yan)



PDF uncertainties and Higgs in *pp*

- With LHeC: huge improvements in PDFs and precision in α_S → full exploitation of LHC data for Higgs physics
  - PDF uncertainties as limiting factor for several channels at the HL-LHC
- **Similar conclusion and relations expected for FHeC→FHC**





Dashed regions: scale & PDF contributions

PDF uncertainties and Higgs in *pp*

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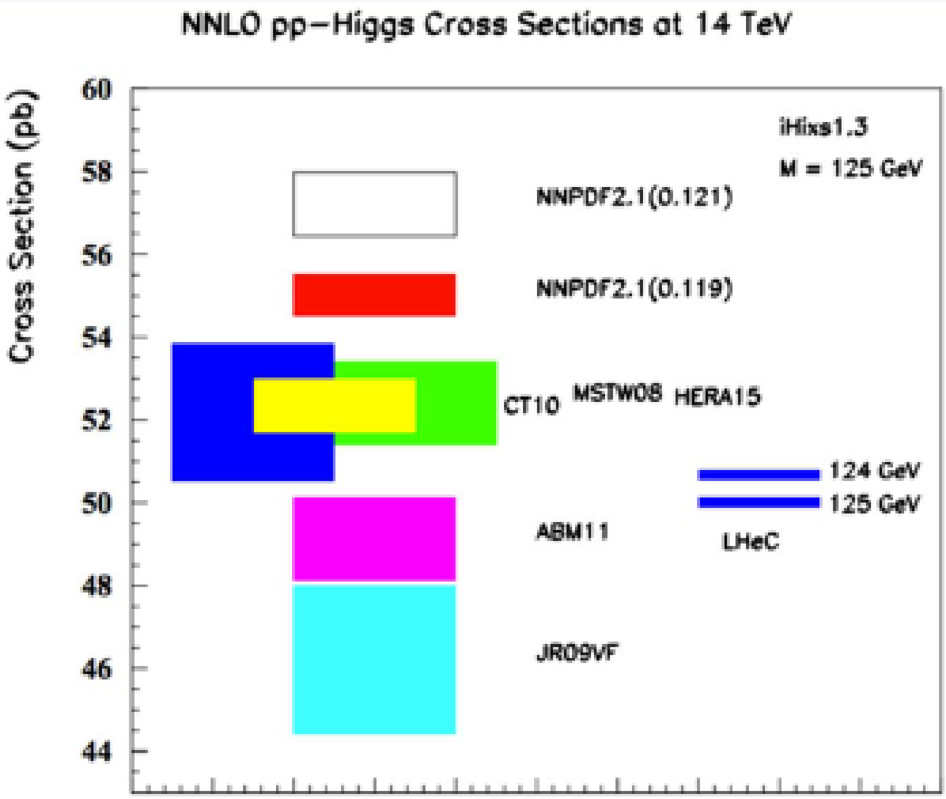
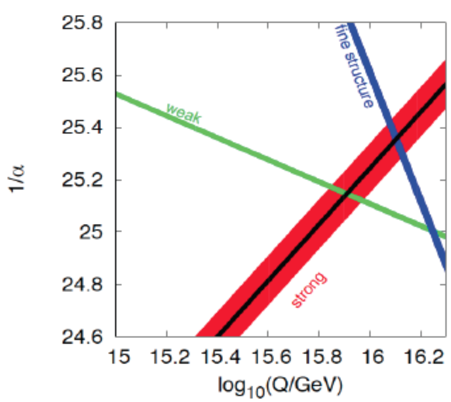


α_S = underlying parameter relevant for unc. (0.005 → 10%)
@ LHeC: measure to permille accuracy (0.0002)

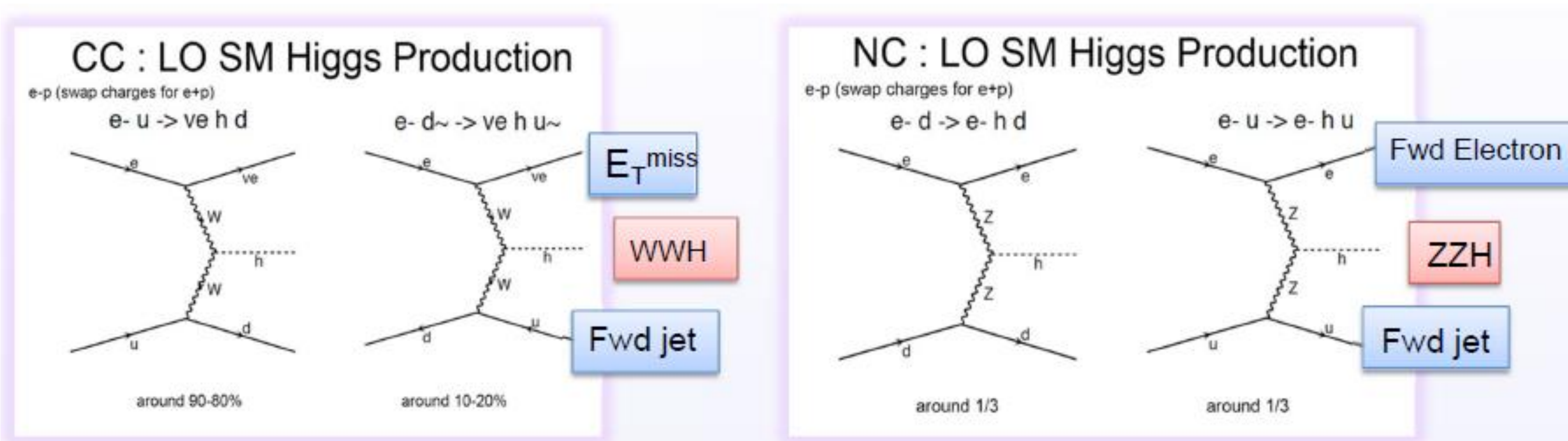
→ precision from LHeC can add a very significant constraint on the Higgs mass ***but also:***



Study unification of couplings

Direct Higgs measurements

- In **e-p**: Higgs radiated from W or Z → unique production mode, with low theoretical uncertainties: clean and well distinct signatures



→ In ep, direction of quark (FS) is well defined

LHeC: E_e=60 GeV, $\sqrt{s}$ = 1.3 TeV

High production cross sections

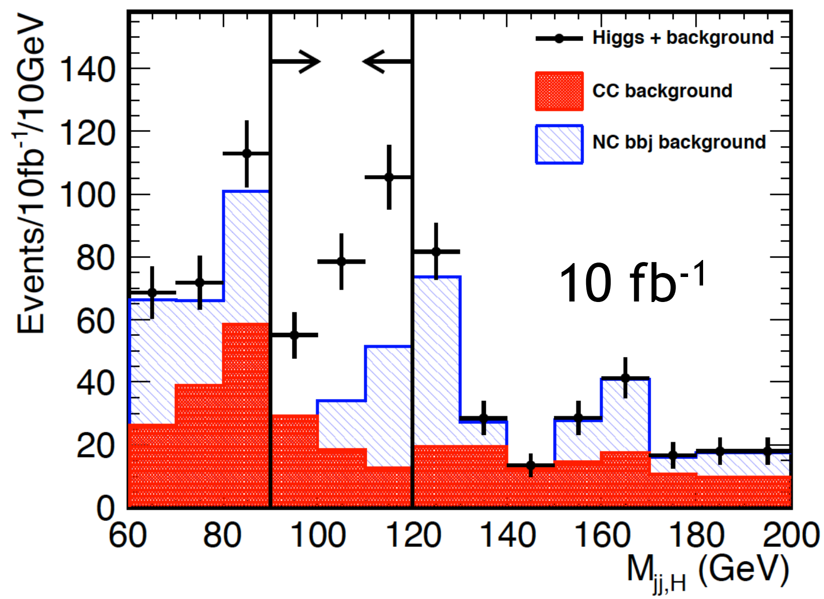
mH = 125 GeV	CC e^-p	CC e^+p	NC e^-p
cross section [fb]	109	58	20
polarised cross section [fb] Pol. = 80%	196	N.A.	25

H→ $b\bar{b}$ @ LHeC

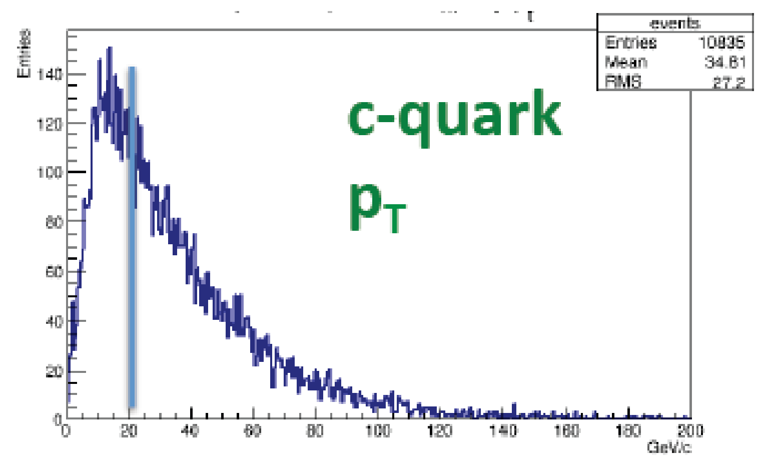
LHeC: E(e) = 60 GeV

- Clear signal obtained already with just cut based analysis

	E_e = 150 GeV ($10\ fb^{-1}$)	E_e = 60 GeV ($100\ fb^{-1}$)
H → bb signal	84.6	248
S/N	1.79	1.05
S/√N	12.3	16.1

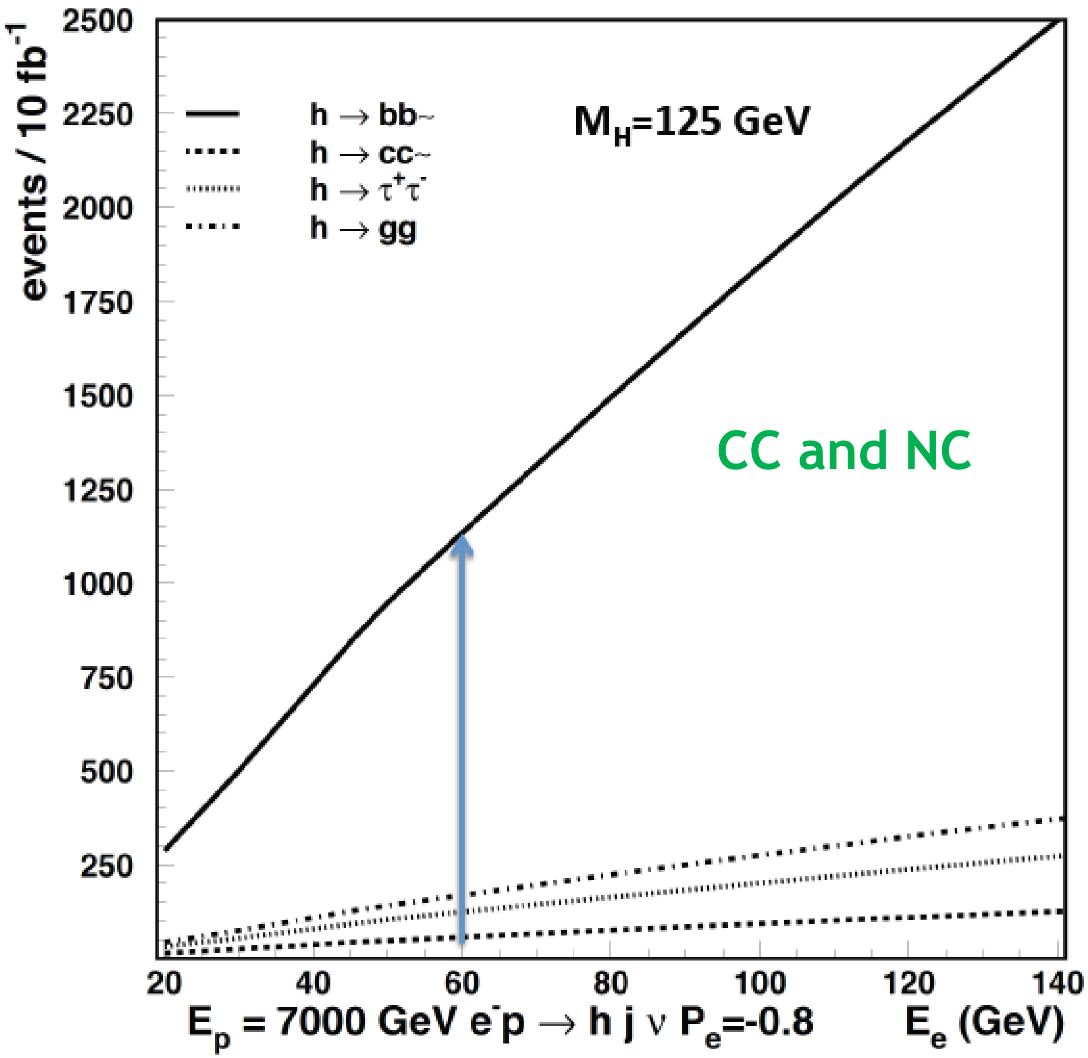


- Linac with high e polarization of about 90% → around 10K Higgs!
  - Allow Hbb coupling measurements with 1% statistical precision ($1\ ab^{-1}$)
  - **H→ccbar** channel also under study
    - Low but still 'taggable' charm-jets
    - Clean environment wrt *pp*



More details in U.Klein's talk tomorrow

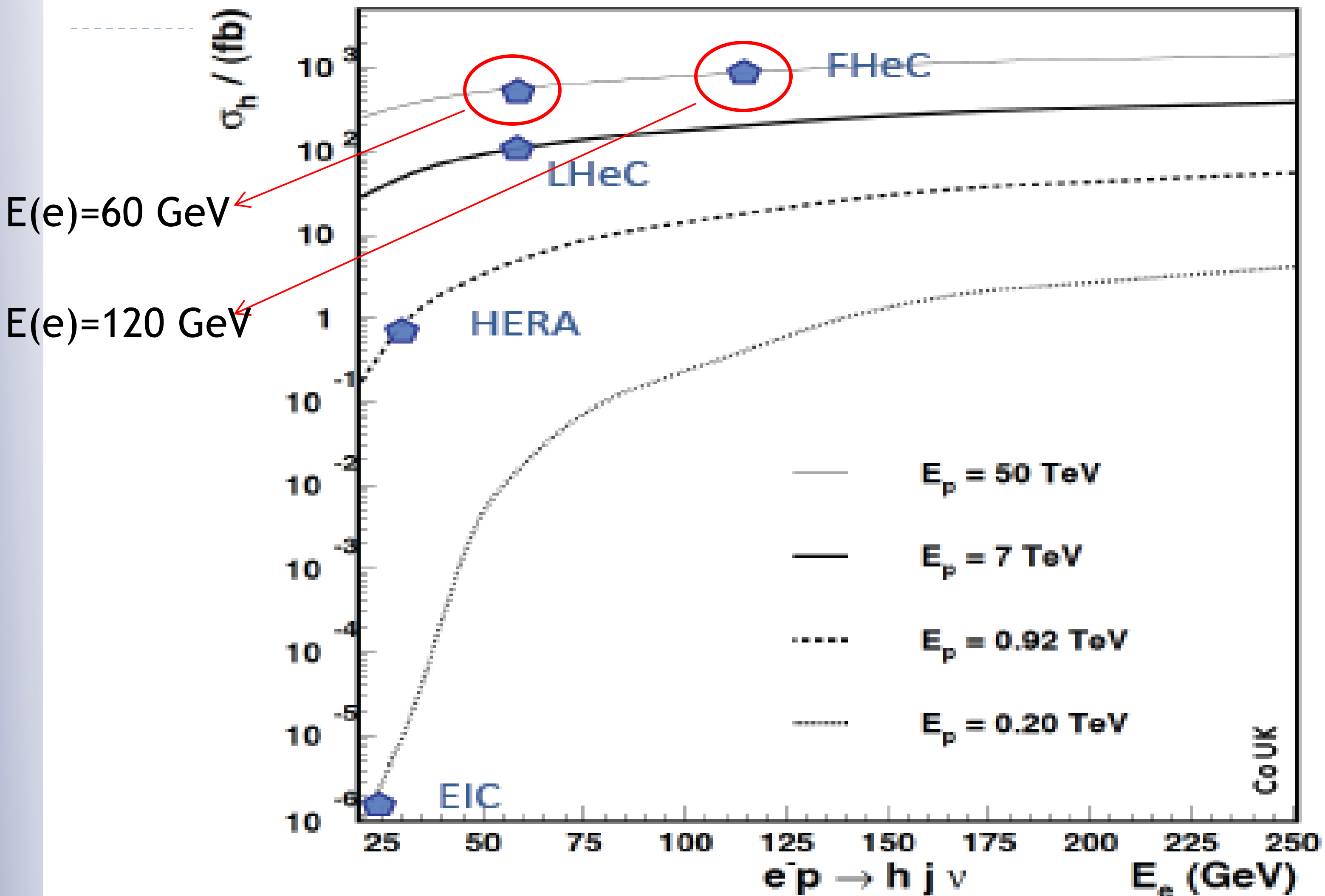
Dependence on electron energy and rates



Total event rate for 10 fb-1 = 1 month of high luminosity running using 60 GeV LINAC

1100 events H → bb
140 events H →ττ
60 events H → cc

Higgs production rate: LHeC → FHeC



- Charged current ep: cross section larger than e+e-

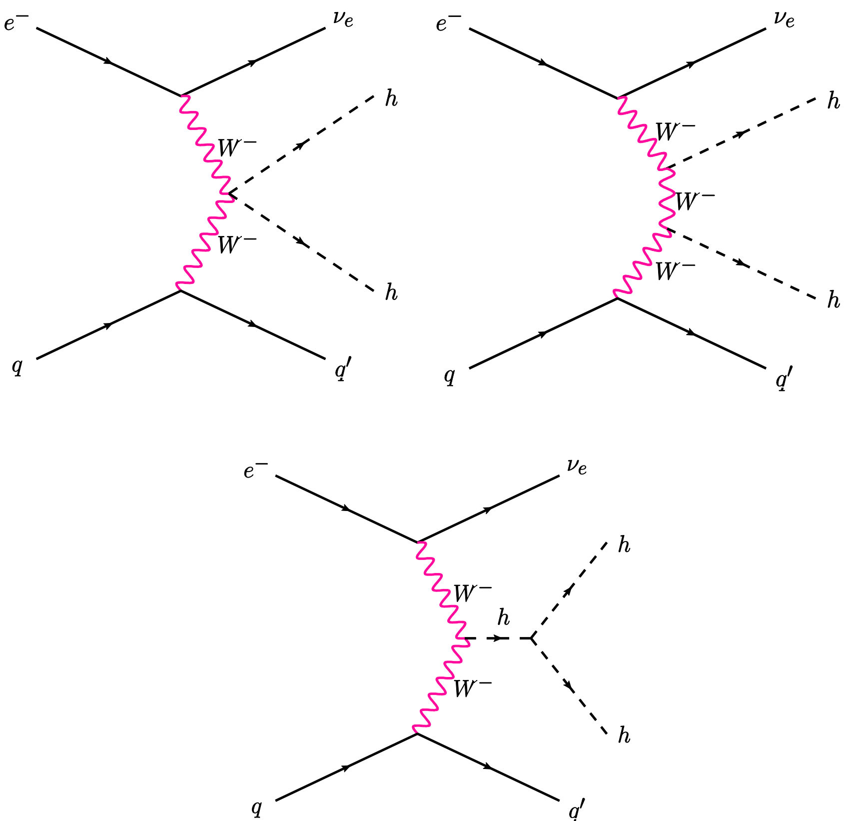
Higgs production rate: LHeC → FHeC (II)

Higgs in $e^- p$		CC - LHeC	NC - LHeC	CC - FHeC
Polarisation		-0.8	-0.8	-0.8
Luminosity [ab^{-1}]		1	1	5
Cross Section [fb]		196	25	850
Decay	BrFraction	N^H_{CC}	N^H_{NC}	N^H_{CC}
$H \to b\bar{b}$	0.577	113 100	13 900	2 450 000
$H \to c\bar{c}$	0.029	5 700	700	123 000
$H \to \tau^+\tau^-$	0.063	12 350	1 600	270 000
$H \to \mu\mu$	0.00022	50	5	1 000
$H \to 4l$	0.00013	30	3	550
$H \to 2l2\nu$	0.0106	2 080	250	45 000
$H \to gg$	0.086	16 850	2 050	365 000
$H \to WW$	0.215	42 100	5 150	915 000
$H \to ZZ$	0.0264	5 200	600	110 000
$H \to \gamma\gamma$	0.00228	450	60	10 000
$H \to Z\gamma$	0.00154	300	40	6 500

Can also explore H → HH

Double higgs production @ 50 TeV

- Electron-proton collisions offer the advantage of reduced QCD backgrounds and negligible pile-up with the possibility of using the 4b final state ($\sigma\times BR(HH\rightarrow 4b)$=0.08 fb).



Processes	E_e (GeV)	σ(fb)	σ_{eff}(fb)
$e^-p \rightarrow \nu_e hhj, h \rightarrow b\bar{b}$	60	0.04	0.01
	120	0.10	0.024
	150	0.14	0.034

$$p_{T_{j,b}} > 20\ GeV,$$
$$\not{E}_T > 25\ GeV,$$
$$|\eta_j| < 5,\ \Delta R = 0.4.$$

Cross-sections for CC HH->4b (branching ratios included) for unpolarized electron beam

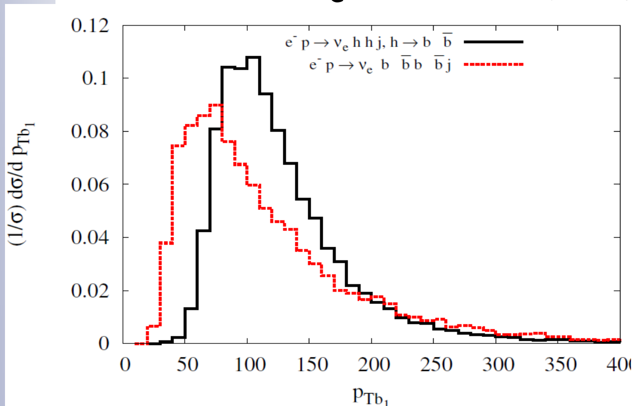
First feasibility studies

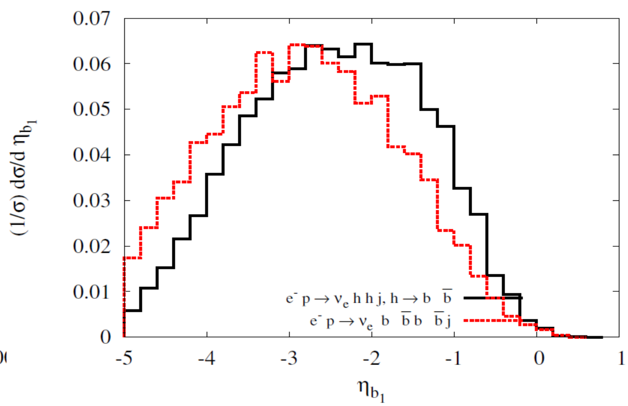
- Cross-sections for CC backgrounds in fb for E_e=60, 120,150 GeV

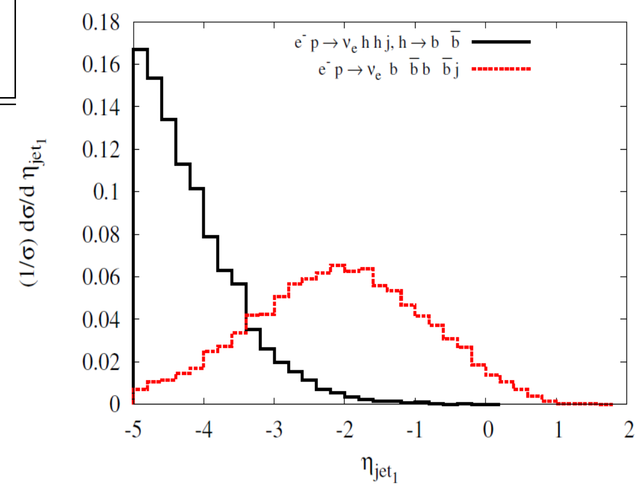
Processes	$E_e = 60$ GeV		$E_e = 120$ GeV		$E_e = 150$ GeV	
	σ(fb)	σ_{eff}(fb)	σ(fb)	σ_{eff}(fb)	σ(fb)	σ_{eff}(fb)
$e^- p \to \nu_e b\bar{b}b\bar{b}j$	0.086	0.022	0.14	0.036	0.15	0.038
$e^- p \to \nu_e b\bar{b}c\bar{c}j$	0.12	1.7×10^{-5}	0.36	1.8×10^{-3}	0.44	2.2×10^{-3}
$e^- p \to \nu_e c\bar{c}c\bar{c}j$	0.20	1.0×10^{-6}	0.24	3.4×10^{-5}	0.31	4.3×10^{-5}
$e^- p \to \nu_e b\bar{b}jjj$	26.1	3.9×10^{-3}	54.2	0.008	67.5	0.01
$e^- p \to \nu_e c\bar{c}jjj$	29.6	9.5×10^{-5}	66.9	2.0×10^{-4}	85.4	2.7×10^{-4}
$e^- p \to \nu_e jjjjj$	823.6	4.1×10^{-5}	1986	9.9×10^{-5}	2586	1.3×10^{-4}

Results assume 70% b-tagging efficiency, 0.1 (0.01) fake rates for c (light) jets

Plots for E_e=60 GeV (very similar for 120,150 GeV)







Despite large beam energy imbalance, b-jets are relatively central

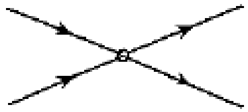
Scattered quark is more forward in signal → good discriminant!

NP in inclusive DIS at high Q^2

- At these small scales new phenomena not directly detectable may become observable as deviations from the SM predictions.
- A convenient tool: effective four-fermion contact interaction

$$\text{4-fermion interaction} \Rightarrow M_{eq\to eq} \sim \Lambda^{-2}$$

Observed as modification of the Q^2 dependence → all information in $d\sigma/dQ^2$
Also parametrized as form factors

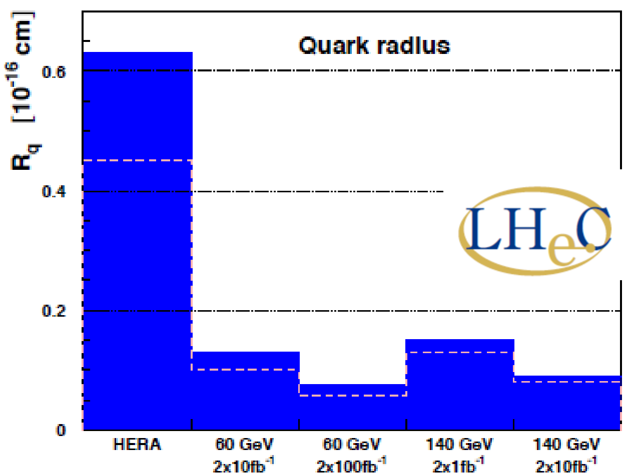


Λ : Compositeness scale

- **Radius** for composite fermions:
  - Proportional to scale

$$f(Q^2) = 1 - \frac{1}{6}\langle r^2\rangle Q^2 ,$$

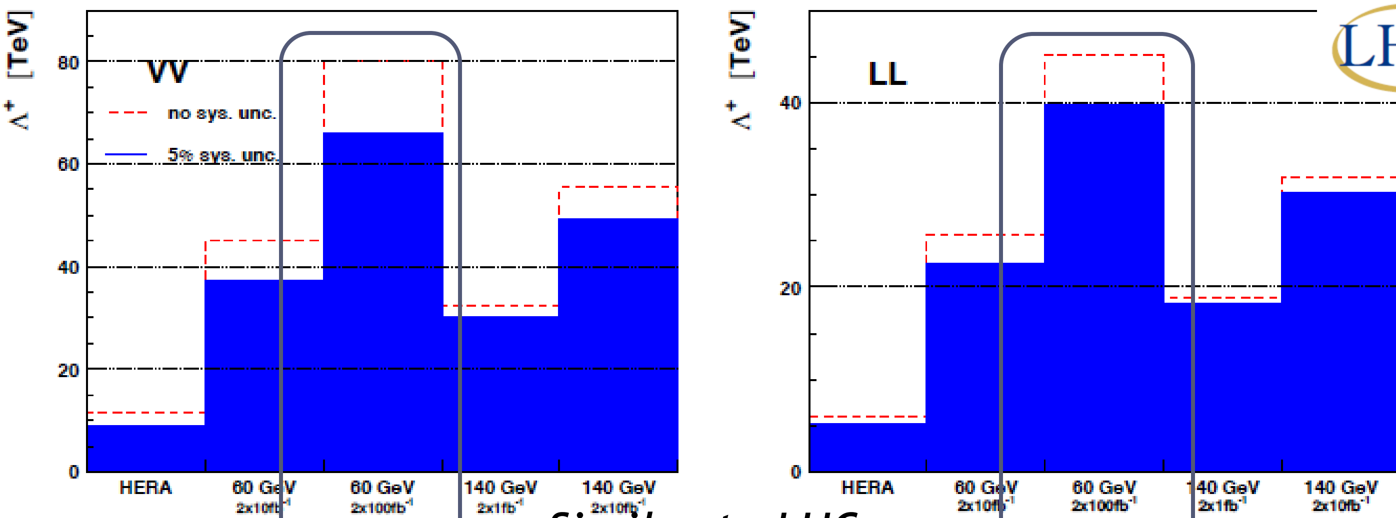
$$\frac{d\sigma}{dQ^2} = \frac{d\sigma^{SM}}{dQ^2} f_e^2(Q^2)\, f_q^2(Q^2)$$



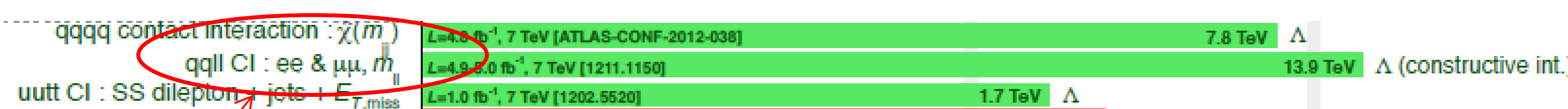
- reach **well below 10-^{19}(10-^{20}) m** (LHeC/FHeC)
- Complimentary to LHC/FHC (not directly probing EWK Radius)

Contact interactions (eeqq)

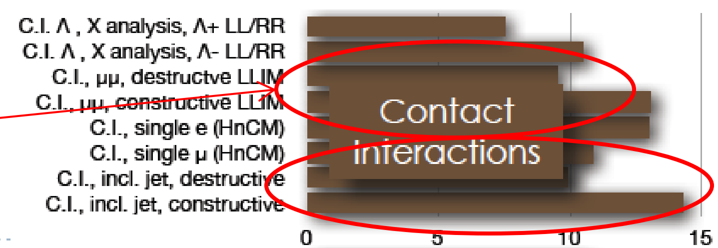
- New currents or heavy bosons may produce indirect effect via new particle exchange interfering with γ/Z fields.
- Reach for Λ (CI eeqq): 40-65 TeV with 100 fb^{-1} of data depending on the model



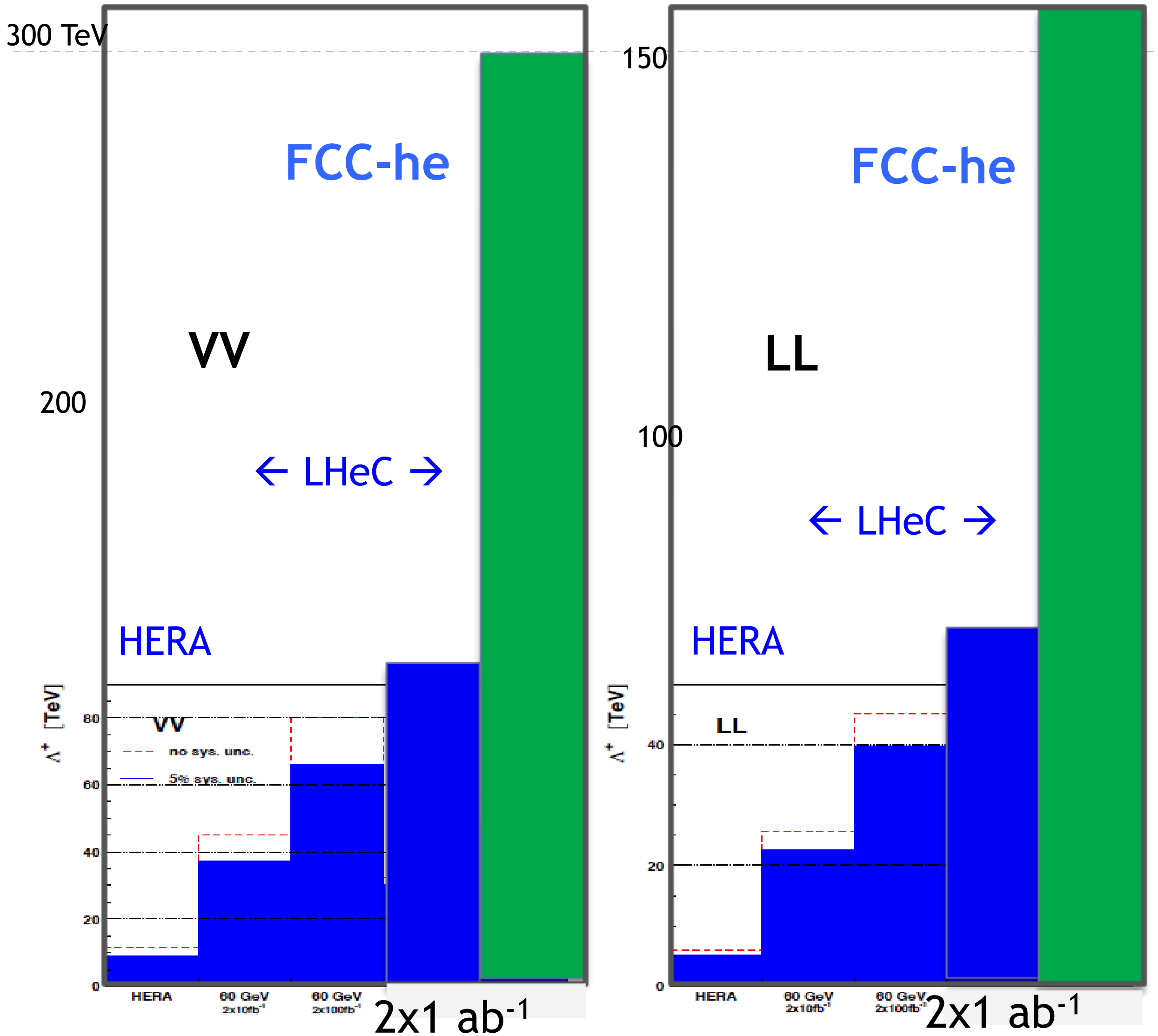
Similar to LHC



ATLAS and CMS constraints on eeqq CI (expected up to 30-40 TeV at c.o.m. 14 TeV LHC)



Reach for CI (eeqq) at FHeC



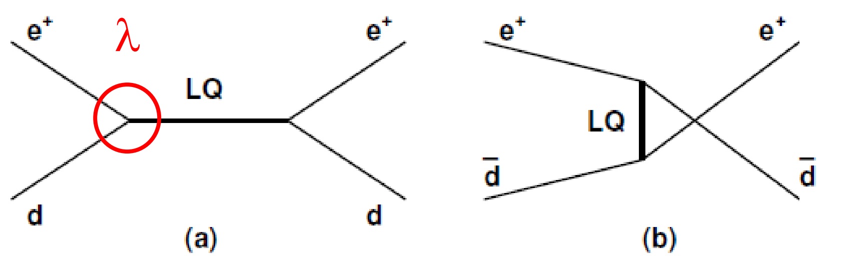
- Very preliminary scaling
- Reach about O(100) TeV, expected to be competitive with FHC

Lepto-Quark

- High Q^2 e-p collider competitive with p-p collider for NP models where initial state lepton is an advantage
  - By providing both B and L in the initial state, ideal to study the properties of new particles with couplings to an e-q pair
  - Probe single particle prod.

First gen. LQ

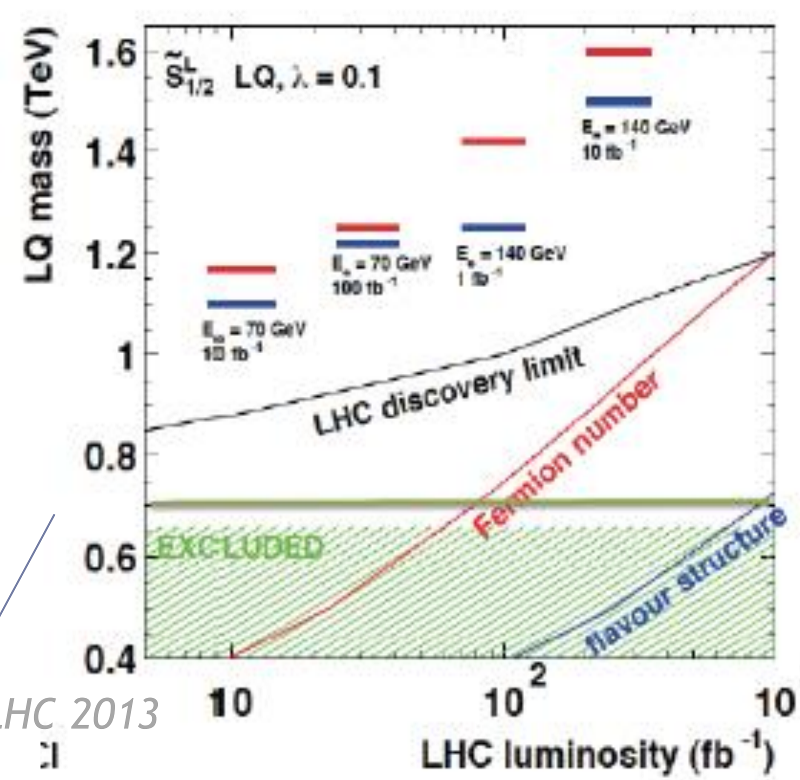
$$\sigma \approx \lambda^2 q(x)$$



- Can probe up to **4 TeV LQ** at FHeC
- If LQ are observed in p-p →

in e-p can measure fermion number (red) and flavor structure (blue)

Average LHC 2013 exclusion



From CDR 6/12

R-parity violating SUSY

Squarks in RPV models could be an example of 'Leptoquarks'

- R-parity = $(-1)^{3(B-L)+2s}$ (R = 1 for SM particles, -1 for MSSM partners)

If not conserved (RPV) → different terms, couplings constraint by proton decay

L-number violating terms

$$W_{\not R p} = \lambda_{ijk} \hat{L}_i \hat{L}_j \hat{E}_k^C + \lambda'_{ijk} \hat{L}_i \hat{Q}_j \hat{D}_k^C + \epsilon_i \hat{L}_i \hat{H}_u + \lambda''_{ijk} \hat{U}_i^C \hat{D}_j^C \hat{D}_k^C$$

bilinear terms

B-number violating terms

$\Delta L = 1$, 9 λ couplings, 27 λ' couplings

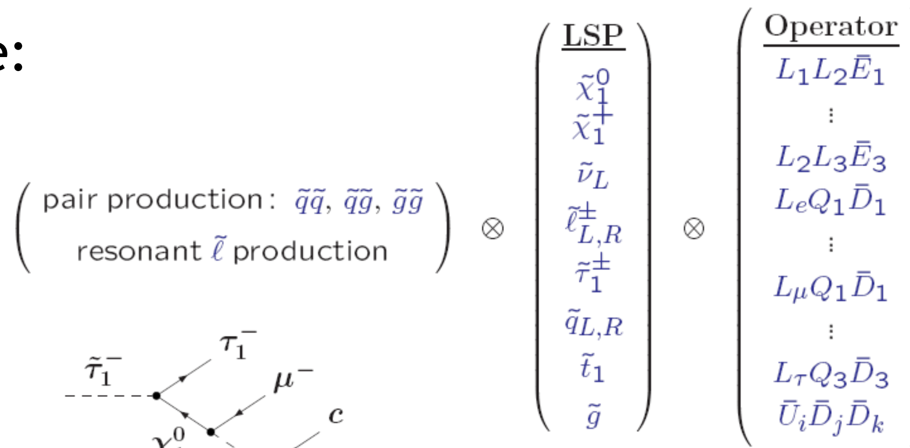
Plethora of new couplings, only partially constraints (m/100 GeV)

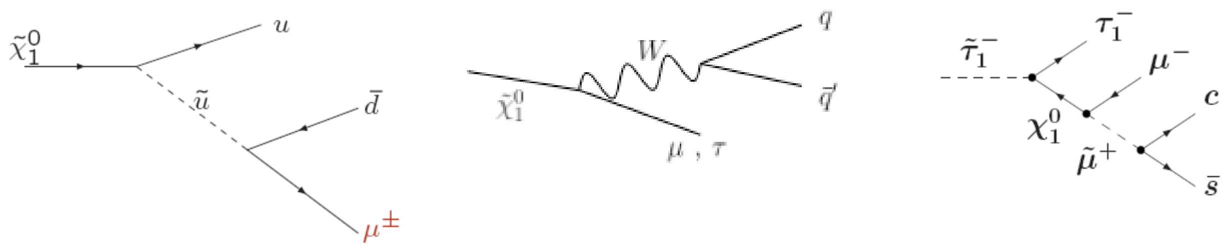
	$\lambda_{ijk} L_i L_j \bar{E}_k$	$\lambda'_{1jk} L_1 Q_j \bar{D}_k$	$\lambda'_{2jk} L_2 Q_j \bar{D}_k$	$\lambda'_{3jk} L_3 Q_j \bar{D}_k$
weakest	0.07	0.28	0.56	0.52
strongest	0.05	$5. \cdot 10^{-4}$	0.06	0.11

Various strong constraints from LHC on Lambda and Lambda'' (from multilepton and multijet searches)

SUSY and RPV scenarios

- Still, several final states to explore:
  - LSP no longer stable
  - > 700 possibilities + bilinear couplings! Examples:

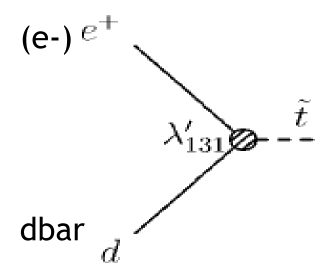




Relevant for e-p: squark production (e.g. stop): → λ_{131}' couplings relevant in e-p production, several can be explored for decays

Example for LHeC: [1107.4461.pdf]

Assume decay via μ+b $\lambda'_{131} \leq 0.03, \quad \lambda'_{233} \leq 0.45$



Sensitivity for high stop mass with 50-100 fb^{-1}

M (GeV)	$\sigma(e^+p)$ (pb)	exclusion $\mathcal{L}(e^+p)$ (pb^{-1})	$\sigma(e^-p)$ (pb)	exclusion $\mathcal{L}(e^-p)$ (pb^{-1})
600	0.14	50.03	2.73×10^{-2}	330.43
700	6.94×10^{-2}	109.36	8.52×10^{-3}	1.69×10^{3}
800	3.10×10^{-2}	282.27	2.22×10^{-3}	1.61×10^{4}

Many more decay modes (RPV or RPC) hard at LHC/FHC can be explored
(sbottom investigated as well)

Electroweak Physics in ep [$\sin^2\theta_W$]

- EWK precision measurements relevant for NP

Present situation

- $\sin^2\hat{\theta}_W(m_Z) = 0.23070 \pm 0.00026$ from A_{LR}, SLD
- $\sin^2\hat{\theta}_W(m_Z) = 0.23193 \pm 0.00029$ from $A_{FB}^{b\bar{b}}$, LEP1

  ➜ 3σ difference !
- $\sin^2\hat{\theta}_W(m_Z) = 0.23125 \pm 0.00016$ world average
- $\sin^2\hat{\theta}_W(m_Z) = 0.23104 \pm 0.00015$ from α, G_μ, m_Z and m_W

Very different implications for new physics:
look at S, T, U parameters, e.g.,

- from A_{LR} ➜ $S = -0.18 \pm 0.15$ ➜ Susy?
- from $A_{FB}^{b\bar{b}}$ ➜ $S = +0.46 \pm 0.17$ ➜ heavy Higgs? KK at 1 - 2 TeV?
- from average ➜ $S = +0.11 \pm 0.11$ ➜ new heavy doublets? KK above 3 TeV?

H. Spiesberger (Mainz) LHeC, 20. 1. 2014

Electroweak Physics in ep (II)

In Deep Inelastic Scattering:

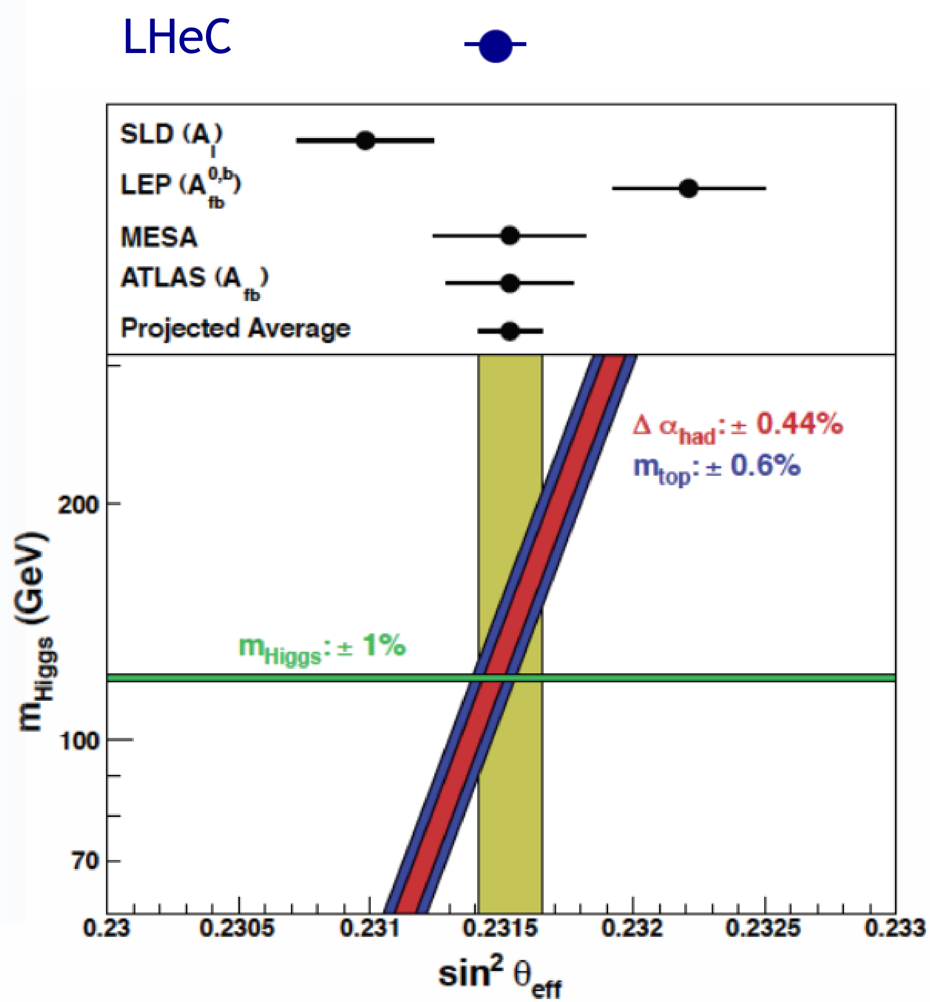
Polarisation Asymmetry $A^-(Q)$

NC-to-CC Ratio R- for P=±0.8

Measure weak mixing angle redundantly with very high precision of about 0.0001 as a function of the scale.

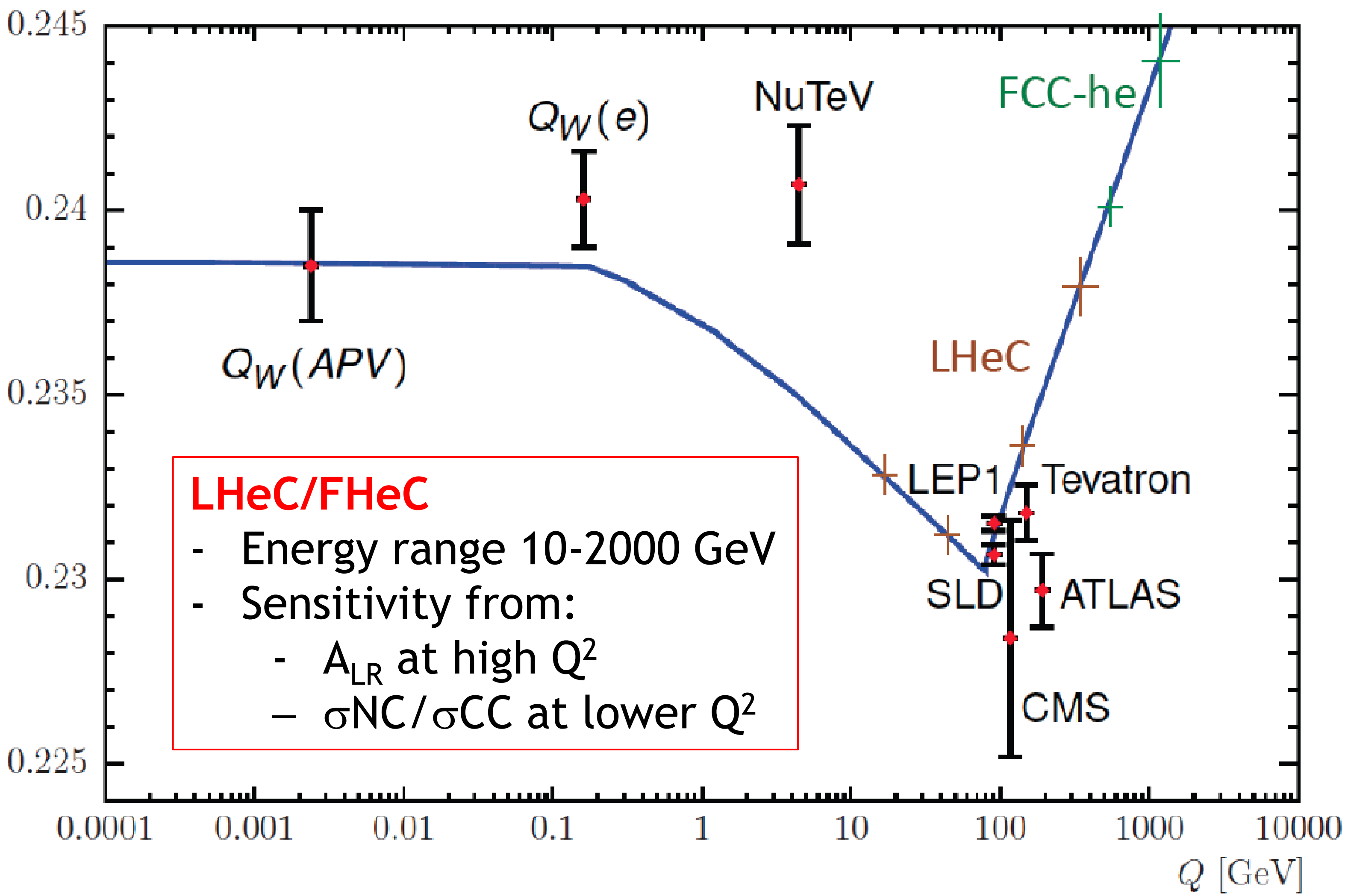
1% δM_{top} is about δ = 0.0001

PDF uncertainty comes in at second order and ep provides very precise PDFs



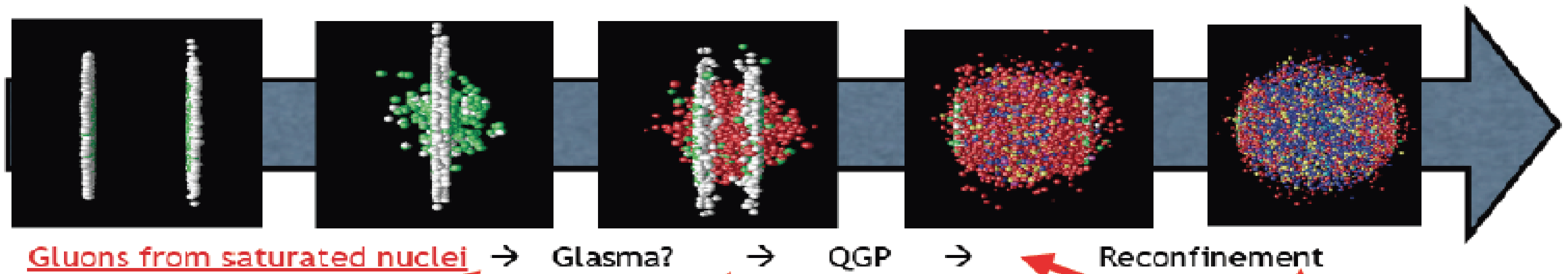
Scale dependence of $\sin^2\theta_W$

- Preliminary sketch



e-Ion physics

- Rich program, e.g. for Nuclear Parton density determination
  - More in B.Cole talk on tomorrow



- Nuclear wave function at small x: nuclear structure functions.

- Particle production at the very beginning: which factorisation in eA?

- How does the system behave as ~ isotropised so fast?: initial conditions for plasma formation to be studied in eA.

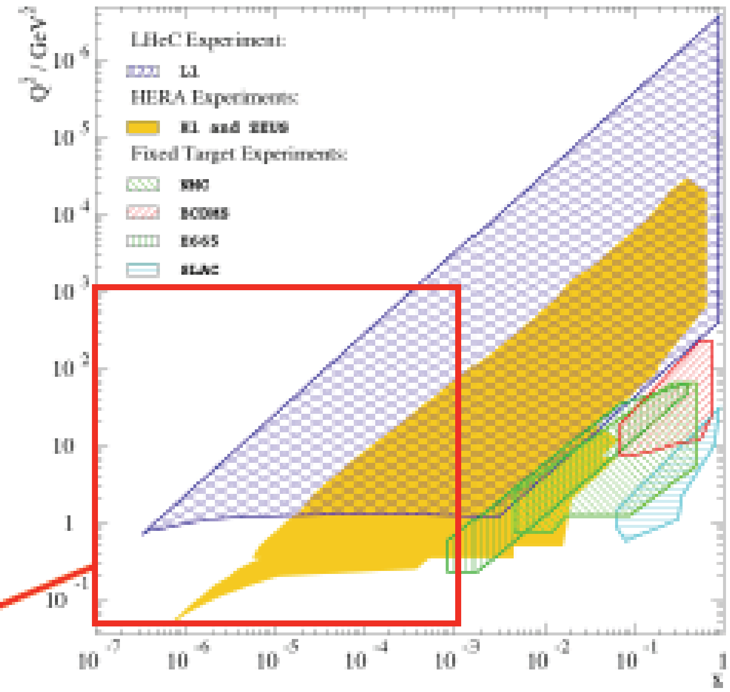
- Probing the medium through energetic particles (jet quenching etc.): modification of QCD radiation and hadronization in the nuclear medium.

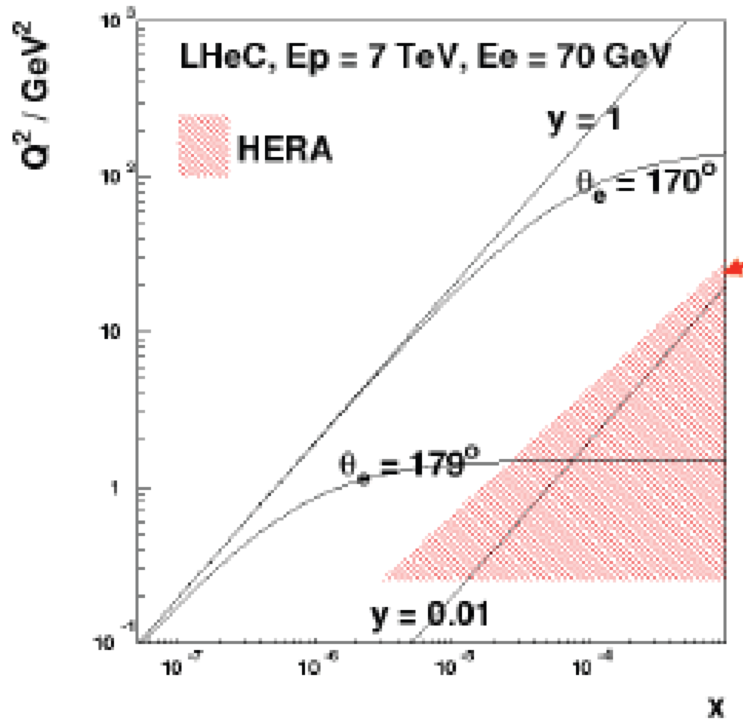
24

Detectors design and FHeC key parameters

Detector acceptance requirement: LHeC

- Access to $Q^2 = 1\ GeV^2$ in e-p mode for all x above 5×10^{-7} requires scattered electron acceptance to 179°



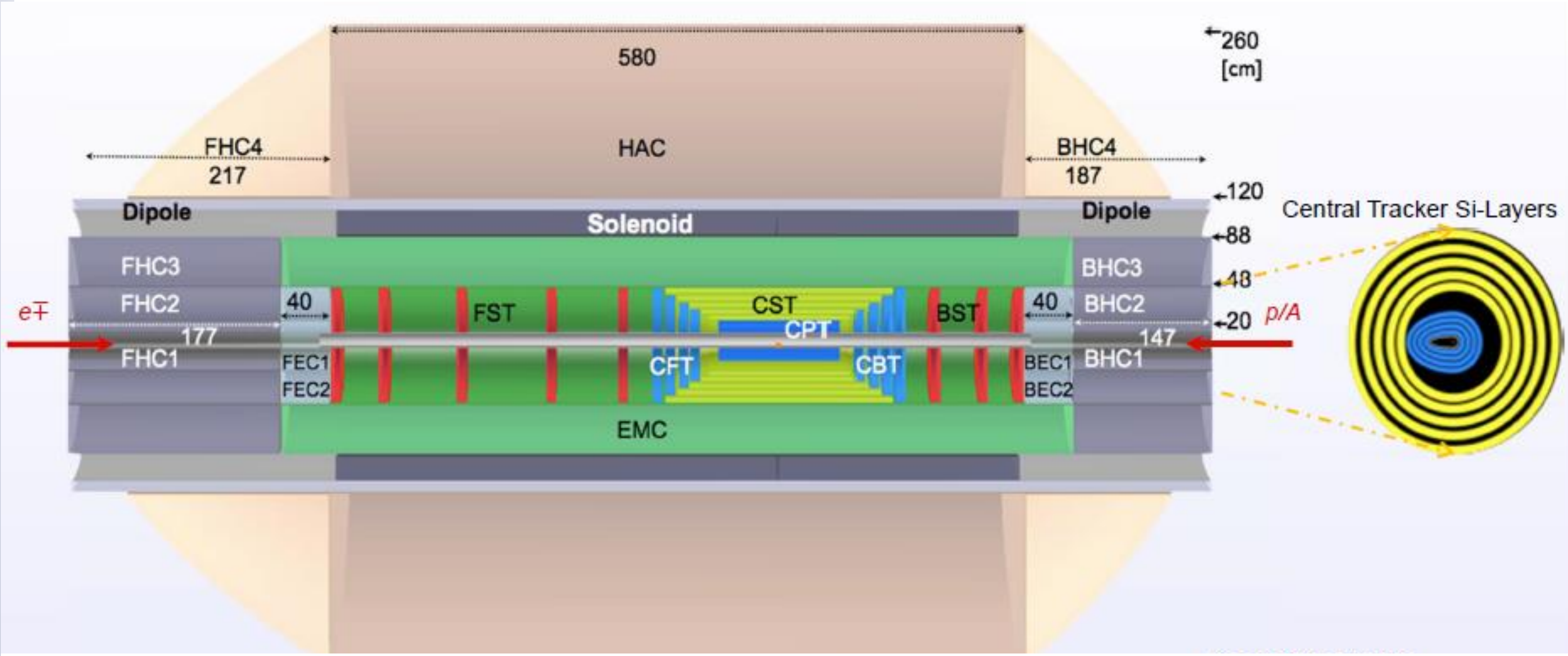


- Similarly, need 1° acceptance in outgoing proton direction to contain hadrons at high x

LHeC detector layout

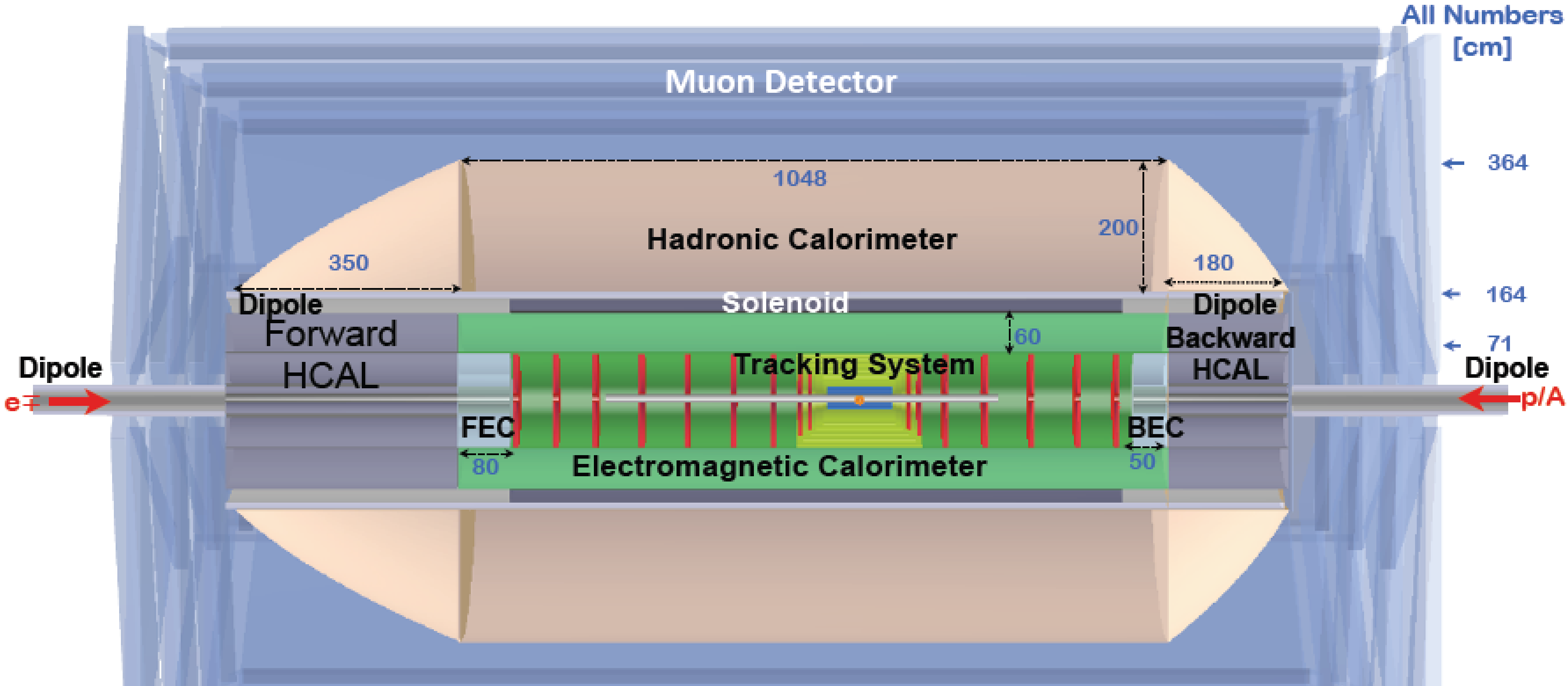
- **LHeC requirements:**
  - High acceptance silicon tracking system
  - Liquid Argon Electromagnetic Calorimeter
  - Iron-Scintillator Hadronic Calorimeter
  - Forward-Backward asymmetry in energy deposited hence in calorimeters geometry and technology: Si/W, Si/Cu
- **Detectors design:**
  - 14m x 9m (e.g.: CMS 21m x 15m; ATLAS 45m x 25m)
  - e/γ taggers ZDC, proton spectrometer integral to design from outset system providing tagging
    - At -62 m(e), 100m(γ,LR), -22.4m(γ,RR),+100m(n),+420m(p)
- **Magnets:**
  - Solenoid (3.5 T) + dual dipole 0.3 T
  - Might be embedded into EMC Lar Cryogenic System
    - Performance and impact of dead material in EMC-HAC sections under studies

LHeC detector layout



FHeC detector layout

- Longer in p direction (x 2 for calorimeters to contain showers)
- Same or slightly longer in electron direction (about 1.3 for 120 GeV)



Tracker	FST_{strip}	CFT_{pix}	CPT_{pix}	CST_{strip}	CBT_{pix}	BST_{strip}
#Layers / Wheels	7	2	4	5	2	5
Min. Polar Angle $\theta[^0]$	0.4	2.2	3.2	32.5	2.2	179.5
Max. / Min. $\|\eta\|$	5.7	3.9	3.5	1. 0	-3.9	-5.2
Project Area $[m^2]$	11.0	0. 8	1.4	12.8	0.8	7.9

Calorimeter	$FHC_{W/Si}$	$FEC_{W/Si}$	$EMC_{Pb/Sc}$	$HAC_{Fe/Sc}$	$BEC_{Pb/Si}$	$BHC_{Fe/Si}$
Min. / Max. Polar $\theta[^0]$	0.4	0.4	6.8 / 171.1	15.1 / 160.7	179.4	179.5
Max. / Min. $\|\eta\|$	5.7	5.6	2.8 / -2.5	2.0 / -1.7	-5.3	-5.5
Volume $[m^3]$	18.9	1.5	41.7	443.4	-5.3	-5.5

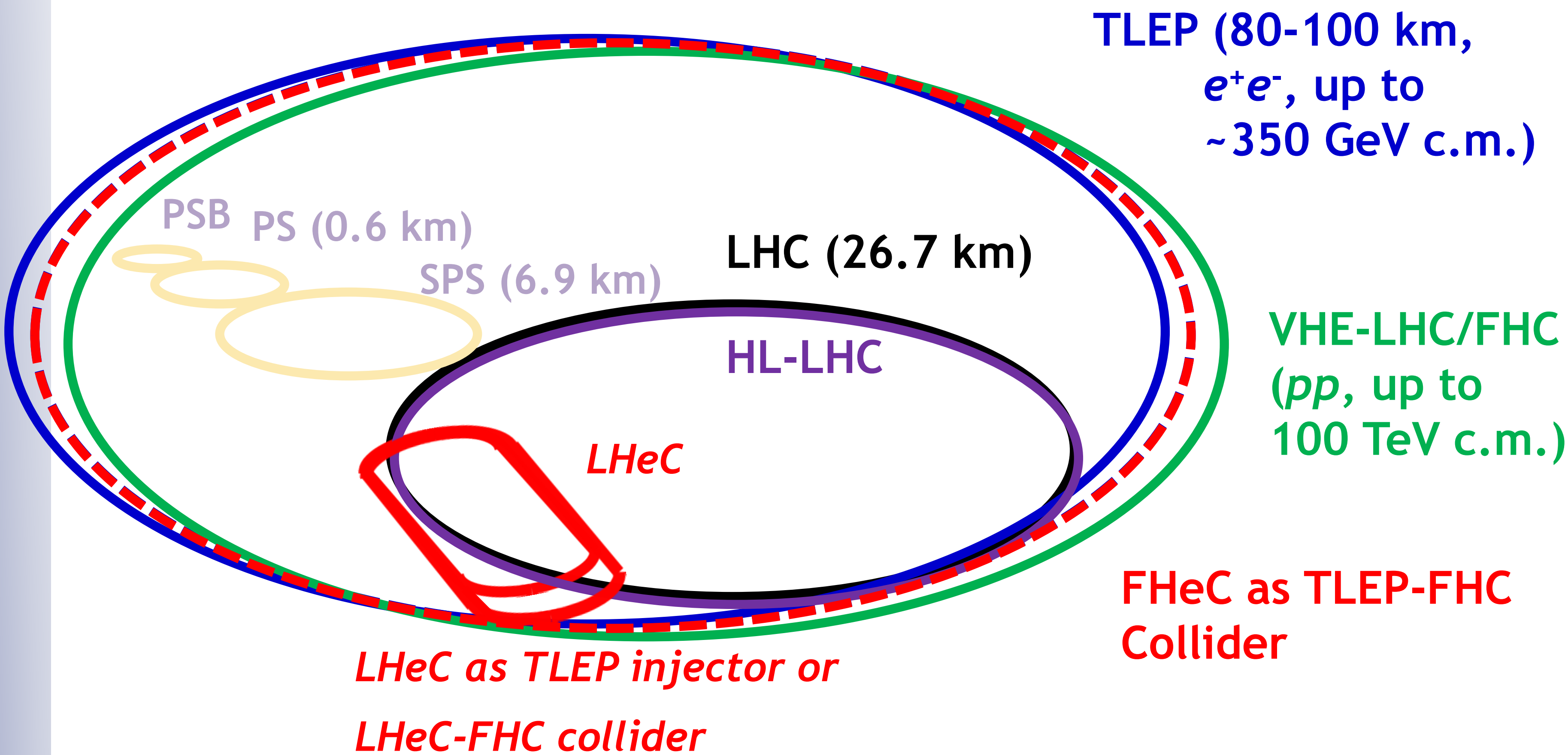
More details in P.Kostka's talk tomorrow

Key parameters of the FHeC

collider parameters	$e^{\pm}$ scenarios			protons
species	$e^{\pm}$	$e^{\pm}$	$e^{\pm}$	p
beam energy [GeV]	**60**	**120**	**250**	**50000**
bunch spacing [μs]	0.125	2	33	**0.125 to 33**
bunch intensity [10^{11}]	3.8	3.7	3.3	**3.0**
beam current [mA]	477	29.8	1.6	384 (max)
rms bunch length [cm]	0.25	0.21	0.18	**2**
rms emittance [nm]	6.0, 3.0	7.5, 3.75	4, 2	0.06, 0.03
$\beta_{x,y}$*[mm]	5.0, 2.5	4.0, 2.0	9.3, 4.5	500, 250
$\sigma_{x,y}$* [μm]	5.5, 2.7			
beam-b. parameter ξ	**0.13**	0.050	0.056	0.017
hourglass reduction	**0.42**	**0.36**	0.68	
CM energy [TeV]	3.5	4.9	7.1	
luminosity[10^{34}cm^{-2}s^{-1}]	**21**	**1.2**	**0.07**	

Possible view of FCC complex

F. Zimmerman (Chavannes, Jan.2014)



LHeC/FHeC: $e^{\pm}$ (60-250 GeV) – *p* (7 and/or 50 TeV) collisions

≥50 years e^+e^-, *pp*, $e^{\pm}p/A$ physics at highest energies!

Summary

- LHeC design matured over past 6 years; CDR published in 2012 and more publications followed up
- Great physics potential, complementary to HL-LHC

" The LHC is the primary machine to search for physics beyond the SM at the TeV scale. The role of the LHeC is to complement and possibly resolve the observation of new phenomena…" (LHeC CDR)

- LHeC compatible with long-term strategy (FCC)
- FCC-he : 60...175 GeV E_e x 50 TeV
- Rich physics program under development (in parallel with consolidation studies for LHeC)
  - E.g. On higgs direct production (in bb, cc), double higgs production
- Detector requirements and first layout presented

→ The FCC-he is a great opportunity for precision DIS, BMS and Higgs and novel heavy ion physics genuinely complementary also to FCC-hh and FCC-ee

Back-up

Details on parallel session (Fri 14/2 @ 2pm)

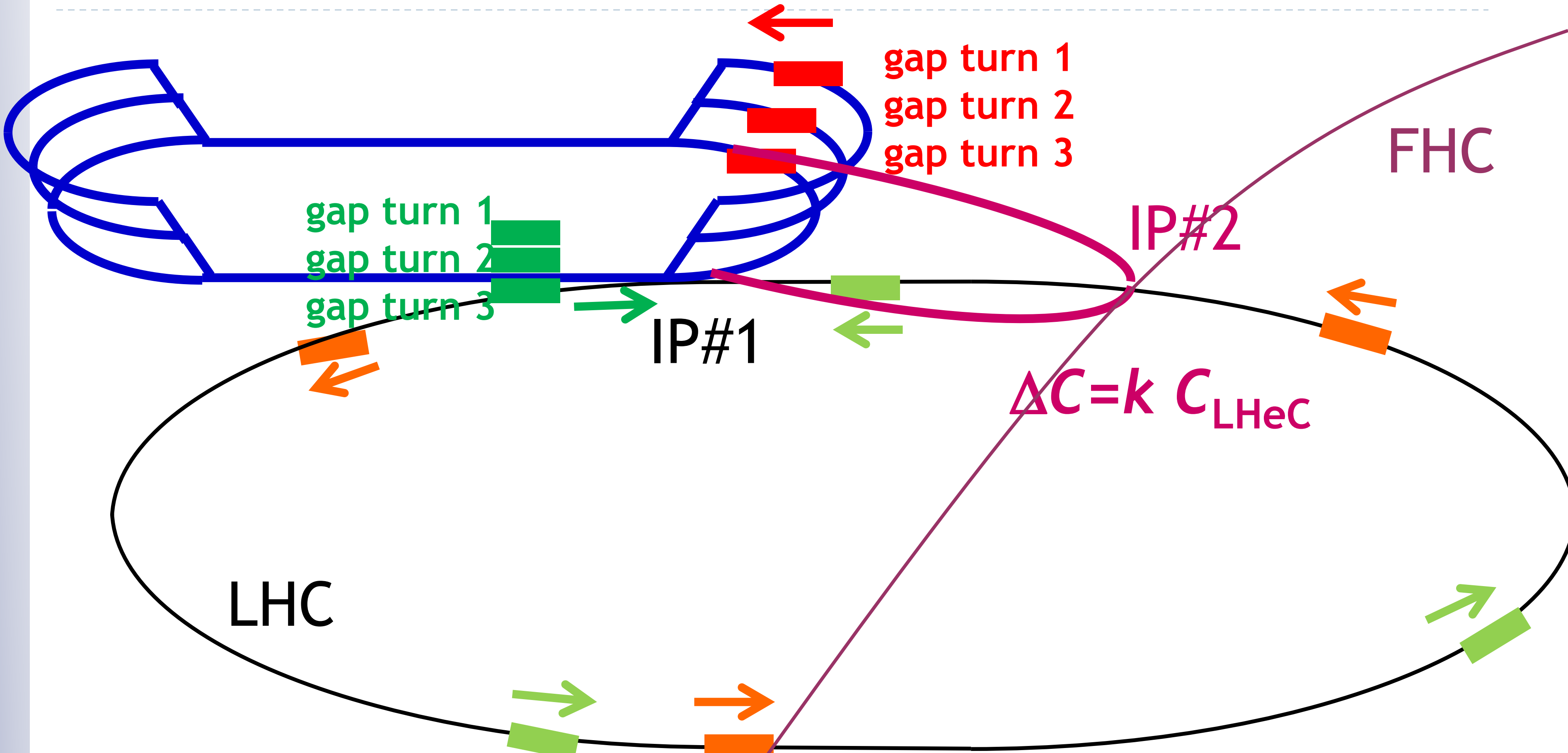
Talk	Speaker	Location	Time
Introduction	*Max KLEIN*	*Basement - MS 030, University of Geneva - UNI MAIL*	14:00 - 14:10
LHeC development	*Oliver BRUNING*	*Basement - MS 030, University of Geneva - UNI MAIL*	14:10 - 14:30
ERL Test Facility	*Alessandra VALLONI*	*Basement - MS 030, University of Geneva - UNI MAIL*	14:30 - 14:50
Machine parameters	*Frank ZIMMERMANN*	*Basement - MS 030, University of Geneva - UNI MAIL*	14:50 - 15:10
Interaction region	*Rogelio TOMAS GARCIA*	*Basement - MS 030, University of Geneva - UNI MAIL*	15:10 - 15:30
Detector considerations	*Peter KOSTKA*	*Basement - MS 030, University of Geneva - UNI MAIL*	15:30 - 15:50
Precision DIS measurements	*Max KLEIN*	*Basement - MS 030, University of Geneva - UNI MAIL*	
Heavy ion physics with eA	*Brian COLE*	*Basement - MS 030, University of Geneva - UNI MAIL*	
Higgs in ep	*Uta KLEIN*	*Basement - MS 030, University of Geneva - UNI MAIL*	17:00 - 17:20
BSM in ep and relation to pp	*Monica D'ONOFRIO*	*Basement - MS 030, University of Geneva - UNI MAIL*	17:20 - 17:40

Merged in 1 talk to be presented in the pheno session

LHeC Higgs factory (LHeC-HF) parameters

parameter [unit]		
species	*e-*	*p*
beam energy (/nucleon) [GeV]	60	7000
bunch spacing [ns]	25	25
bunch intensity (nucleon) [10^{10}]	**0.1 → 0.4**	**17→ 22**
beam current [mA]	**6.4 → 25.6**	**860 → 1110**
normalized rms emittance [μm]	50 → **20**	**3.75 → 2.5**
geometric rms emittance [nm]	**0.43 → 0.17**	**0.50 → 0.34**
IP beta function $\beta_{x,y}$* [m]	**0.12 → 0.10**	**0.10 → 0.05**
IP rms spot size [μm]	7.2 → **4.1**	7.2 → **4.1**
lepton *D* & hadron ξ	**6 → 23**	**0.0001→ 0.0004**
hourglass reduction factor H_{hg}	0.91→ **0.70**	
pinch enhancement factor H_D	1.35	
luminosity / nucleon [10^{33} cm^{-1}s^{-1}]	**1.3 → 16**	

ion gaps & circumference



$C_{LHeC} = C_{LHC} / n$

future: $C_{LHeC+} = C_{FHC} / m$

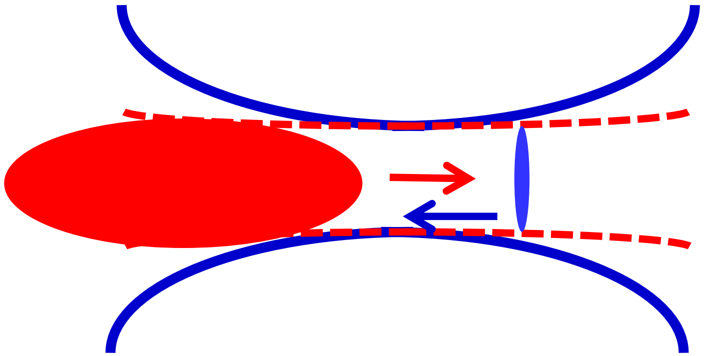
m, *n* (=3), *k*: integer

F. Zimmerman (20 Jan 2014)

Electron possibilities

ring-ring

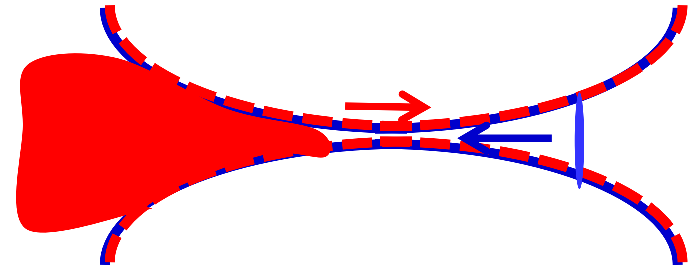
$\varepsilon_e >> \varepsilon_p, \ \beta_e^* << \beta_p^*$



minimum e^- beta function
and **beam sizes**
limited by hourglass effect;
small crossing angle acceptable;
little disruption

ring-linac

$\varepsilon_e \approx \varepsilon_p, \ \beta_e^* \approx \beta_p^*$



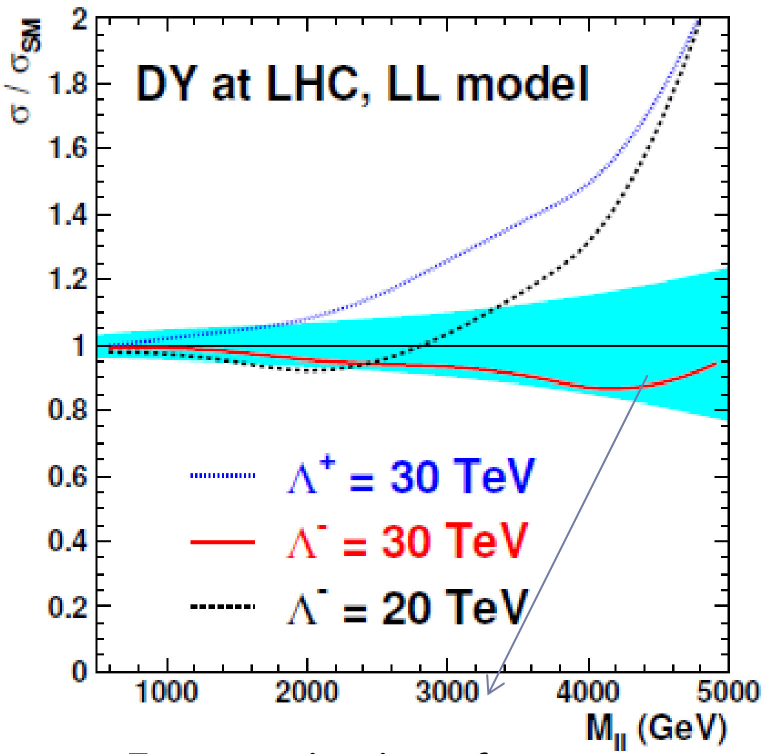
much smaller e^- **emittance**
smaller beta function
and **beam sizes** possible;
head-on collision required;
significant disruption

hourglass reduction factor

$$H_{hg} = \frac{\sqrt{\pi} z e^{z^2} \mathrm{erfc}(z)}{S} \ ; \ z \equiv 2\frac{(\beta_e^*/\sigma_{z;p})(\varepsilon_e/\varepsilon_p)}{\sqrt{1+(\varepsilon_e/\varepsilon_p)^2}} S \ ; \ S \equiv \sqrt{1+\frac{\sigma_{z,p}^2 \theta_c^2}{8\sigma^{*2}}}$$

CI at LHC and LHeC

- LHC: Variation of DY cross section for CI model
  - Cannot determine simultaneously Λ and sign of interference of the new amplitudes wrt SM (ε)



Ex: negative interference too small to be disentagled

LHeC: sign ε from asymmetry of σ/σ_{sm} in e+p and e-p data