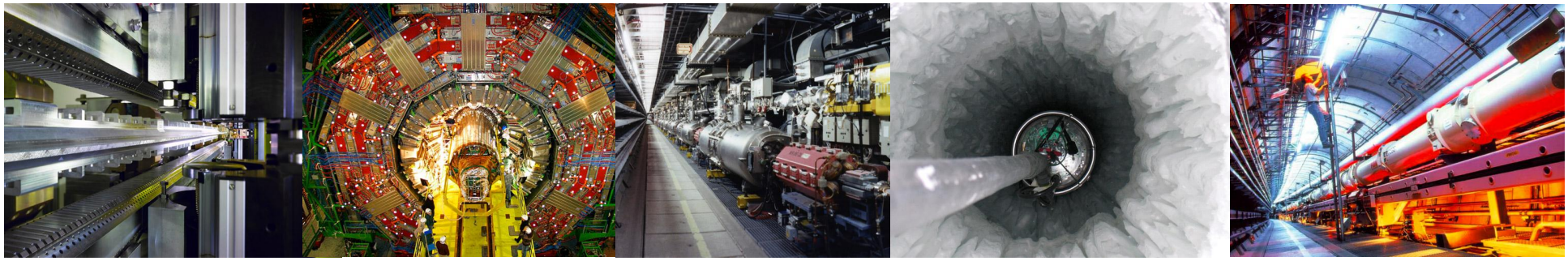
The LHeC Project

Machine, Detector, Physics

http://cern.ch/lhec



Thomas Schörner-Sadenius

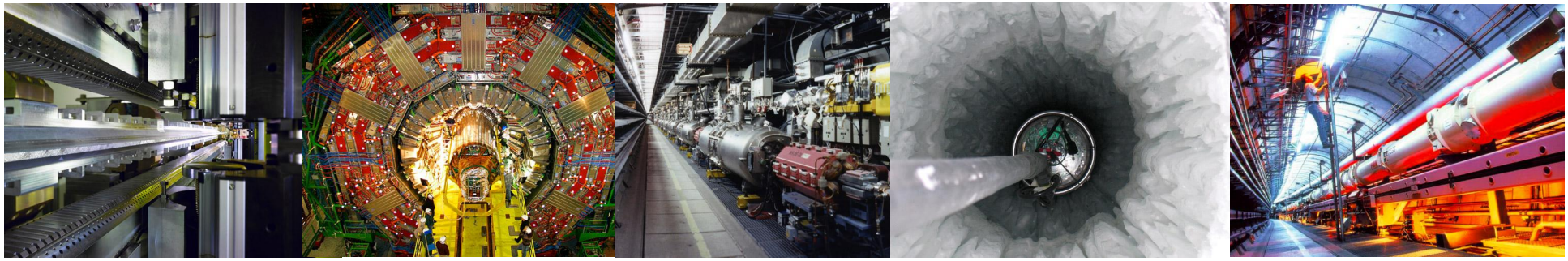
Photon 2011 Conference
Spa, 23-27 May 2011

Thanks to M. Klein, P. Newman, O. Behnke

The LHeC Project

Machine, Detector, Physics

- Motivation
- Machine concepts
- Detector overview
- Some physics cases
  (PDF, jets, HF, low x, eA, Higgs/BSM)



Thomas Schörner-Sadenius

Photon 2011 Conference
Spa, 23-27 May 2011

All preliminary –
wait for CDR !!!
See talks at DIS11 !!!

SETTING THE SCENE FOR ep

- Quarks, NC, asymptotic freedom …
- proton PDFs, precision QCD …
- high density, structure, eq spectroscopy …

ep
fixed target
HERA
LHeC

- Charm, $N_C=3$, gluons
- M_Z, $\sin^2\theta$, 3v, h.o.elweak
- Higgs, BSM spectroscopy

e^+e^-
…
PETRA
LEP
LC

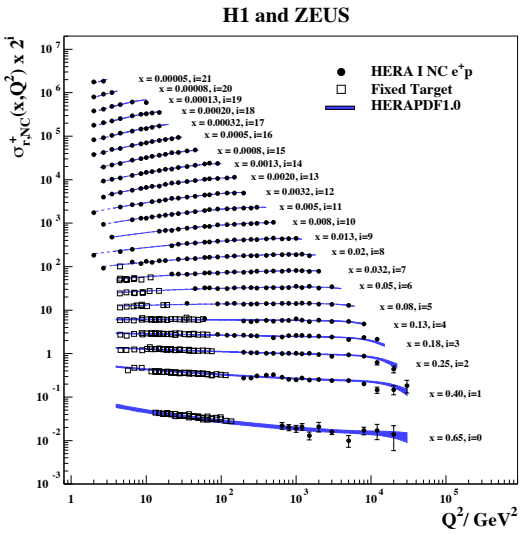
Important role of ep in
- Establishing SU(2)×U(1) and QCD
- Triumph of Standard Model
- Finding / understanding new physics?

pp
…
TEVATRON
LHC

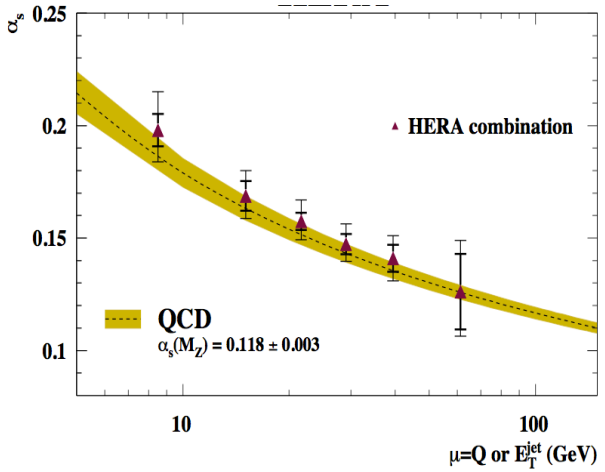
-Drell-Yan, Charm, W/Z, jets …
- b,t,m_W, (H?) …
- new particles/symmetries?

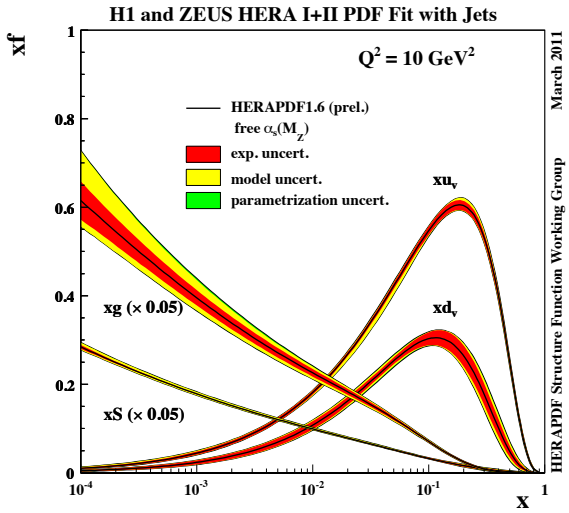
Adapted from R. Heuer, M. Klein

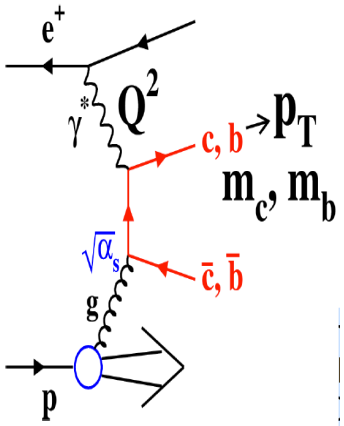
HERA LEGACY

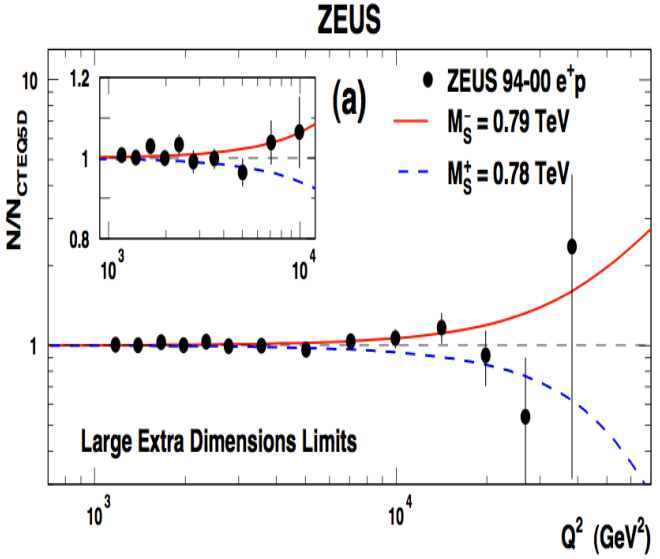


ep
fixed target
HERA
LHeC



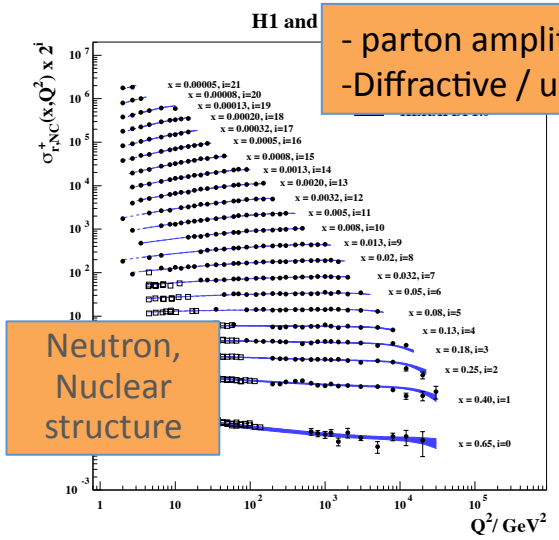






HERA LEGACY – OPEN QUESTIONS

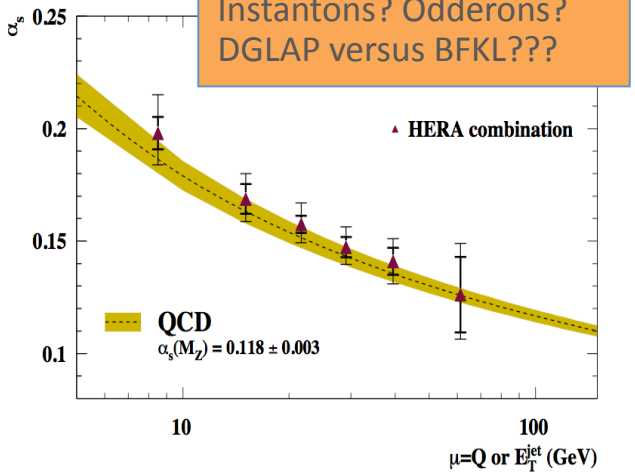
- parton amplitudes (GPDs)?
-Diffractive / unintegrated PDFs?



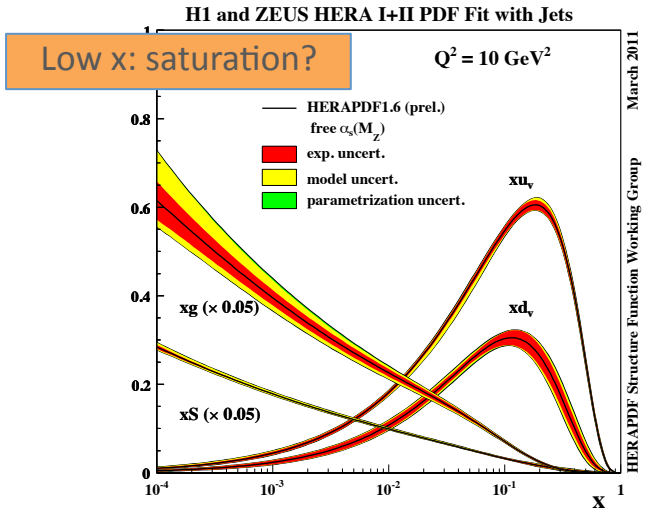
Neutron, Nuclear structure

ep
fixed target
HERA
LHeC

Higher orders? Precision? Instantons? Odderons? DGLAP versus BFKL???

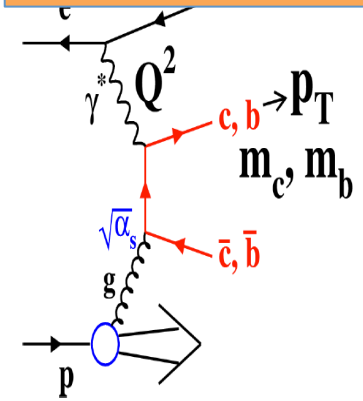


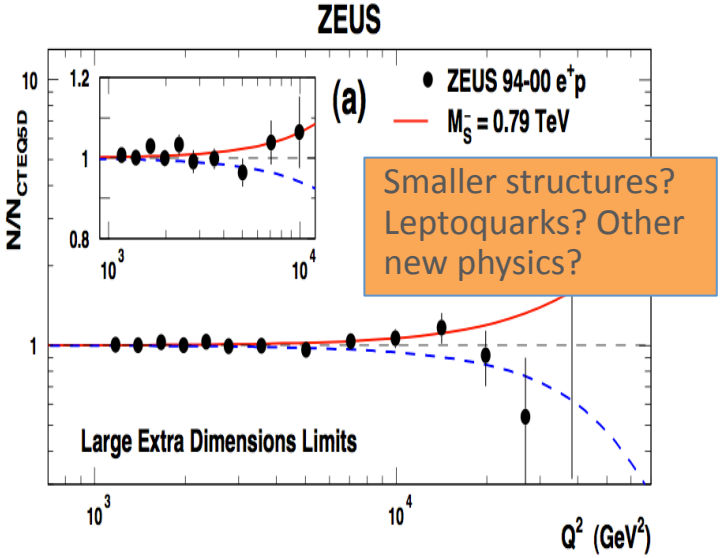
Low x: saturation?



High x: u/d? xg?

Treatment of HF mass?
Contribution to ep?





Smaller structures? Leptoquarks? Other new physics?

AGENDA FOR THE LHeC

ep
fixed target
HERA
LHeC

Complete **unfolding of the partonic structure** of the proton; mapping of gluon/ flavour structure

Complementing the LHC programme: LQ, eeqq CI, Higgs, e*, single top …

Novel QCD phenomena: instantons, odderons, hidden colour etc.

A **new phase of hadronic matter** – high density, small coupling, saturation!

Partons in nuclei nuclear parton distributions, ed/A physics, saturation, black body limit of F_2, colour transparency

Ultra-**high precision in DIS**: coupling unification, inclusive versus exclusive, N^kLO QCD, parton evolution …

Requires: – high-energy e,p,d,A
– high luminosity
– 4π acceptance
– high resolution (e/h)
– …

LHeC – SCENARIOS

Config	E(e) [GeV]	E(N) [GeV]	N	Int L(e^+)	Int L(e^-)	|Pol|	L/1032 [$fb^{-1}a^{-1}$]	P [MW]	Years	Type
A	20	7	p	1	1	---	1	10	1	SPL
B	50	7	p	50	50	0.4	25	30	2	RR hiQ2
C	50	7	p	1	1	0.4	1	30	1	RR lowx
D	100	7	p	5	10					
E	150	7	p	3	6					
F	50	3.5	D	1	1					
G	50	2.7	Pb	0.1	0.1					
H	50	1	p	---	1					

Current planning: 10 fb^{-1} per year, irrespective of detector option, with:

LHeC: $e^{\pm}p/A$

E_e=10…140 GeV

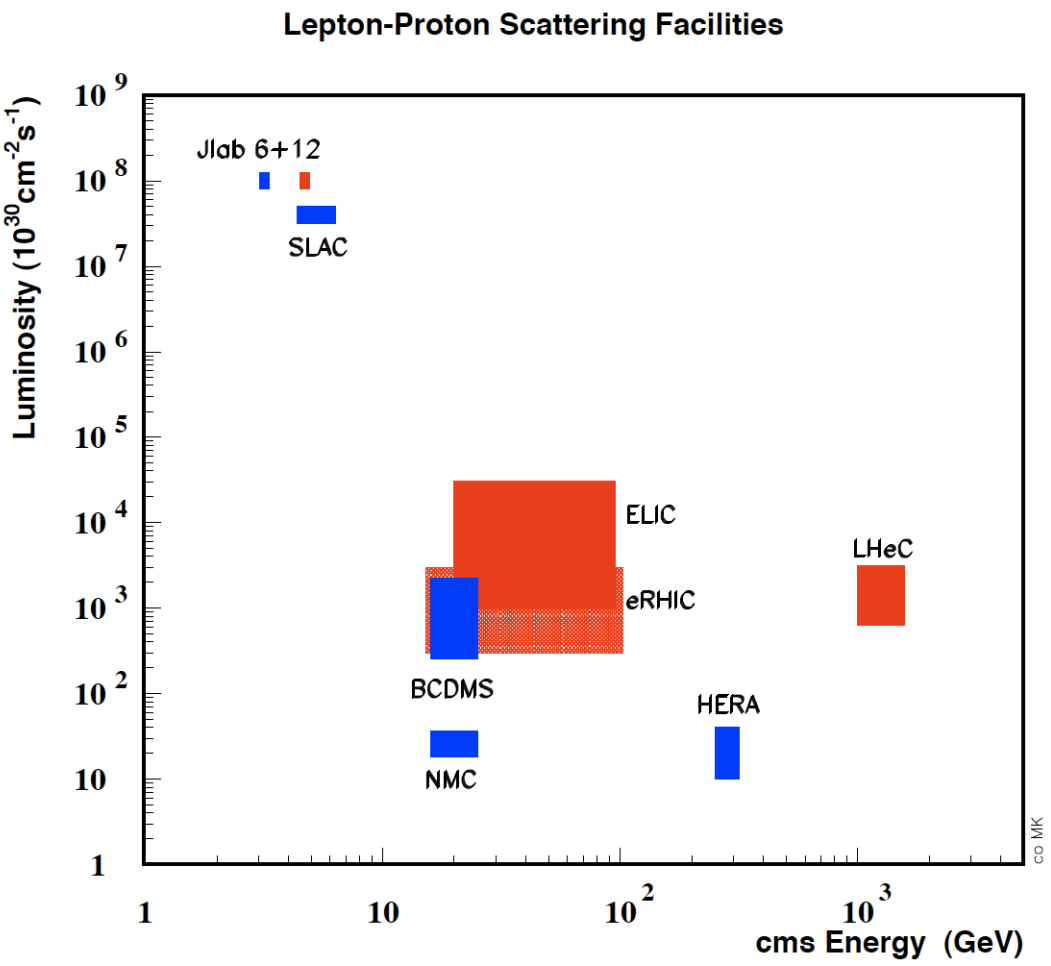
E_p=1..7 TeV

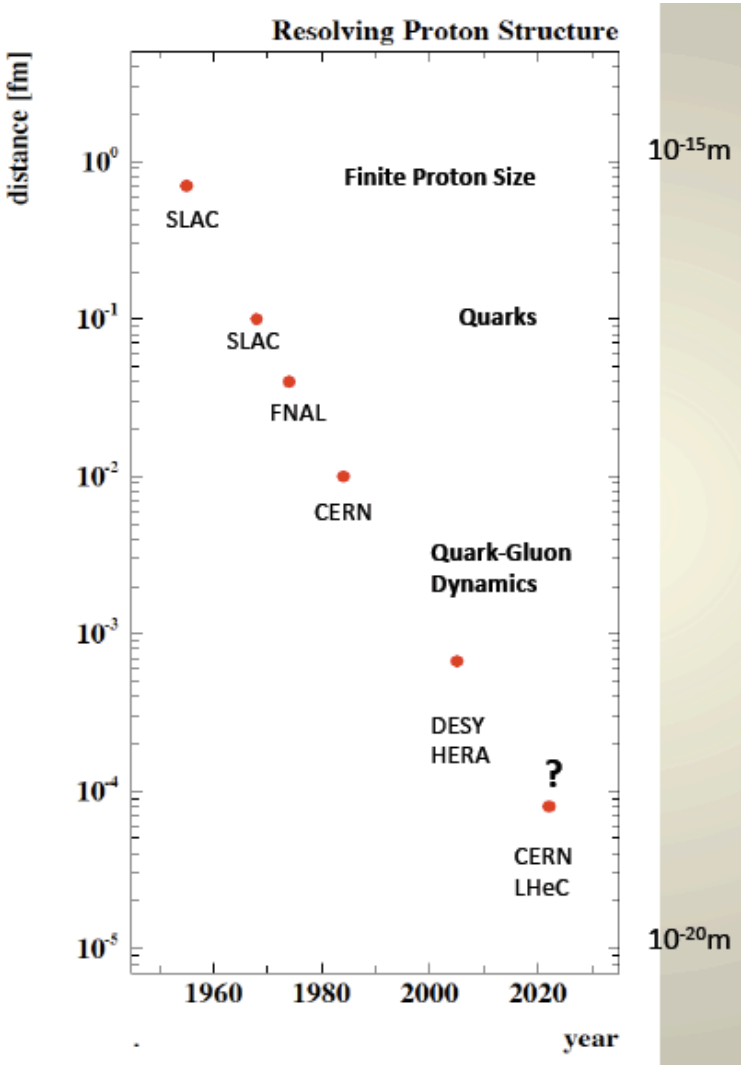
$E_A=E_p * Z/A$

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

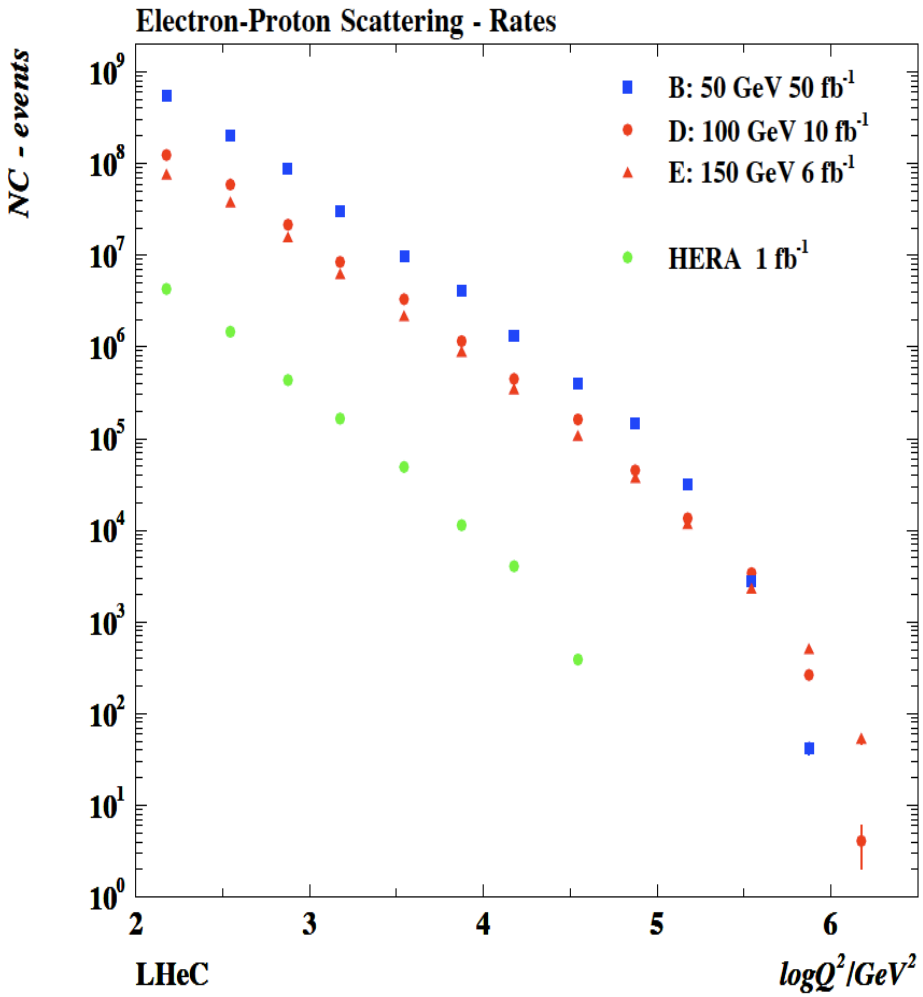
while LHC runs

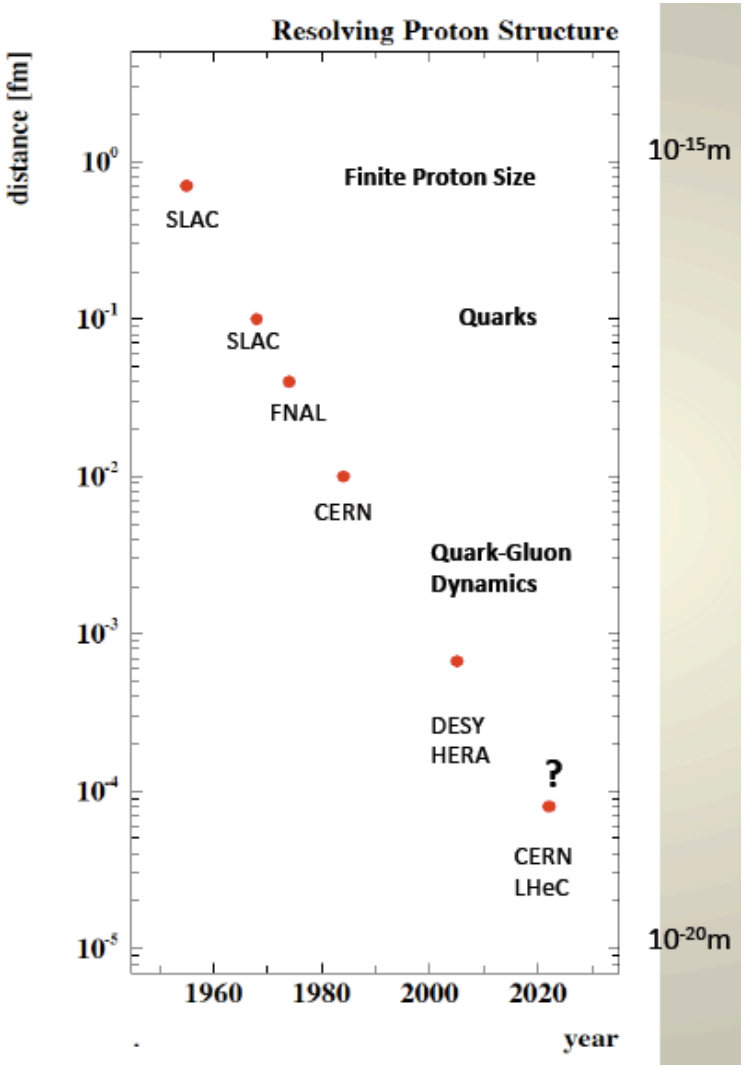
DIS HISTORY AND FUTURE





KINEMATIC REACH

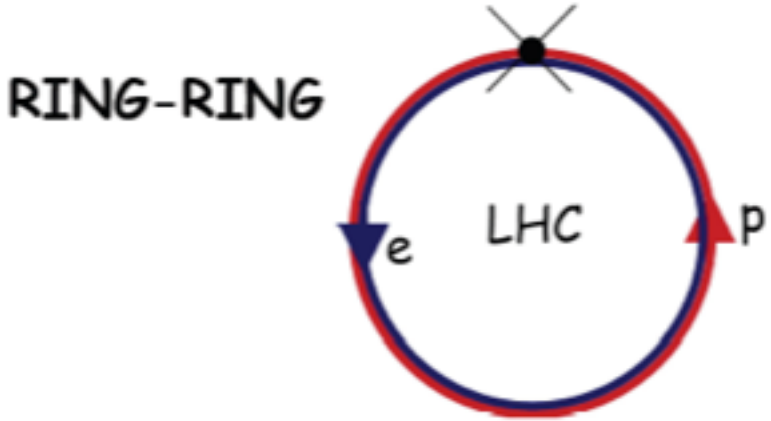


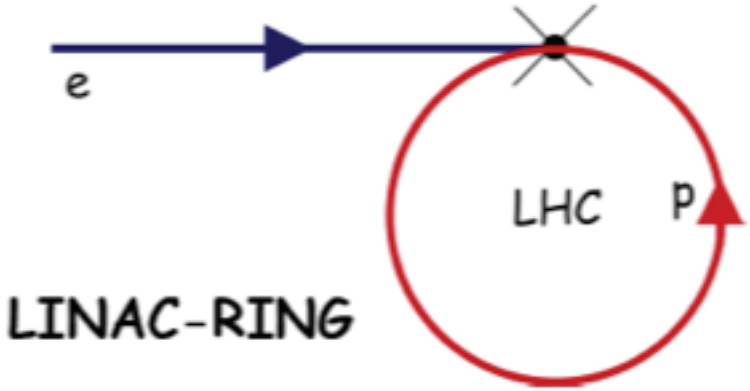


Massive increase in kinematic reach!

REALISATION

- Two different approaches towards simultaneous ep/pp running:





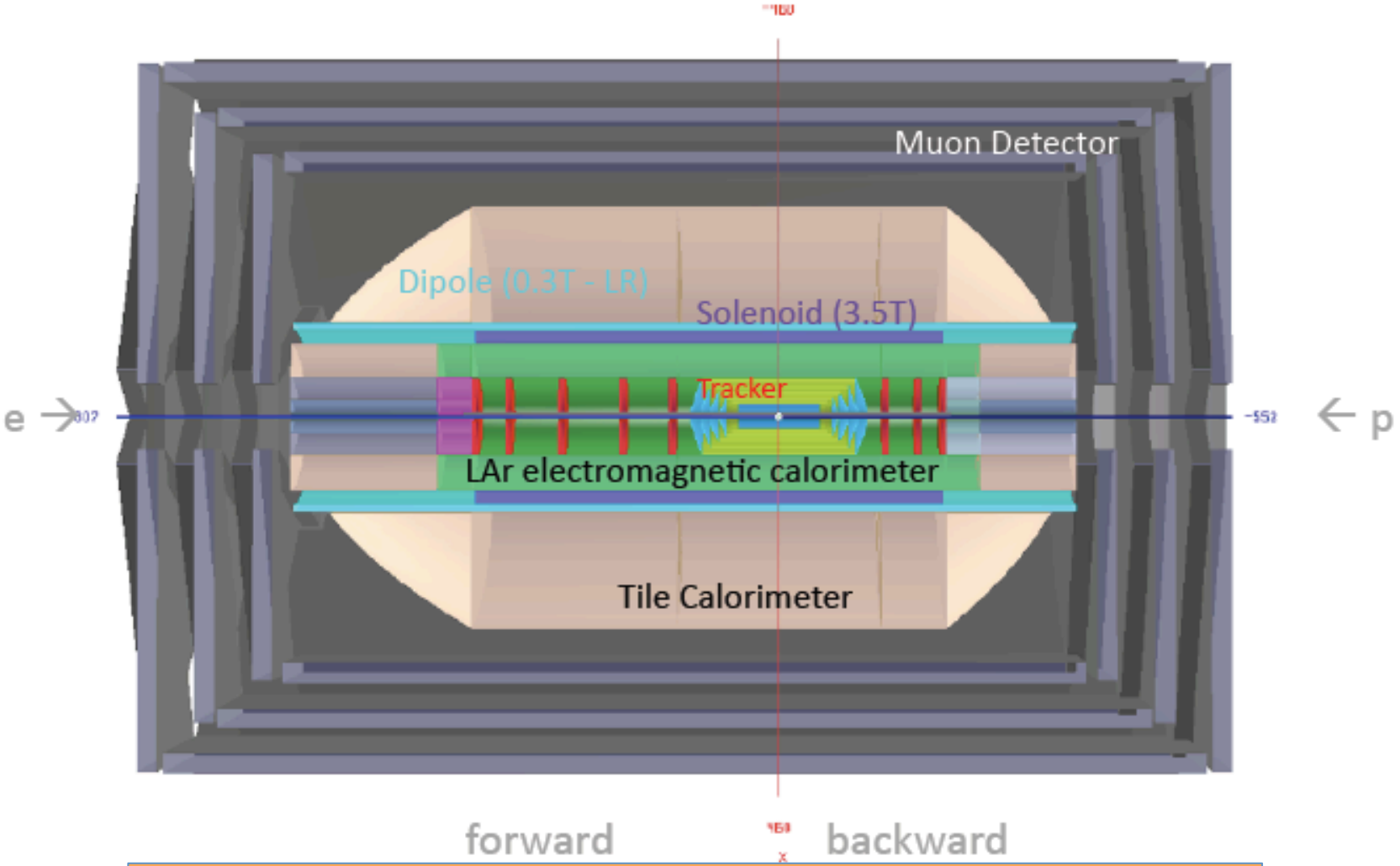
- Ring-ring (RR) option:
  - First considered 1984: LEP*LHC
  - Higher peak lumi: $3*10^{33}$ $cm^{-2}s^{-1}$
  - Difficulties: building e ring into LHC tunnel, synchrotron radiation and limitations of energy and lifetime
- Linac-ring (LR):
  - c.f. THERA, “QCD explorer”
  - low interference with LHC, high electron energy, LC relation
  - lower lumi at reasonable power, no previous experience

LHeC – DETECTOR LAYOUT

- Target precision: per-mille α_S (versus 1-2% now)
- Requirements:
  - HERA lumi * 100
  - high precision (resolution, calibration, tagging) – twice HERA precision!
  - Modular for fast installation
  - State-of-the-art for ~no R&D
  - 1-179^o acceptance for low Q^2, high x physics

	LHeC	HERA
Lumi [$cm^{-2}s^{-1}$]	10^{33}	$1\text{-}5*10^{31}$
Acceptance [^{o}]	1-179	7-177
Tracking to	0.1 mrad	0.2-1 mrad
EM calorimetry to	0.1%	0.2-0.5%
Hadronic calorimetry	0.5%	1-2%
Luminosity	0.5%	1%

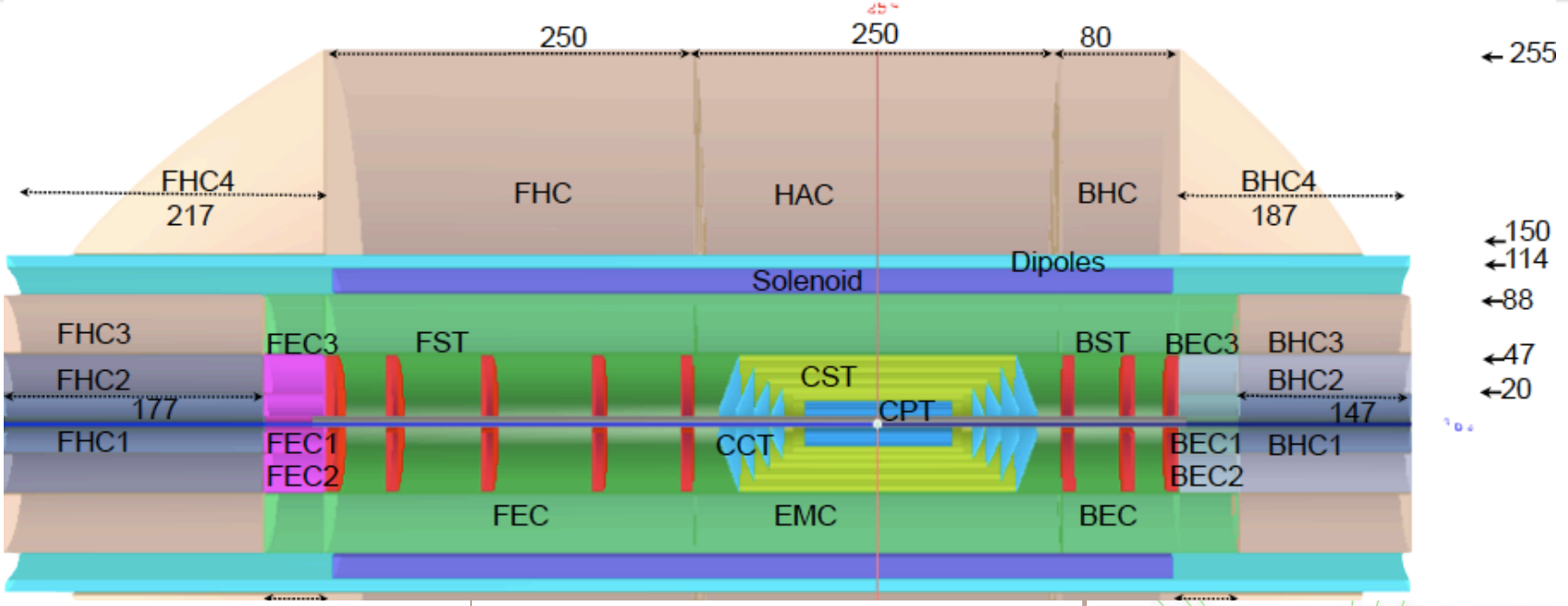
LHeC – DETECTOR LAYOUT



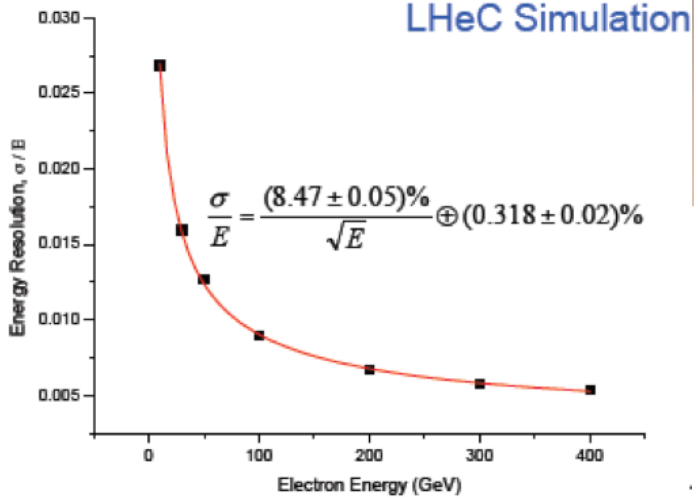
- **Present dimensions: LxD =14x9m^2 [CMS 21x15m^2 , ATLAS 45x25 m^2]**
- **Taggers at -62m (e),100m (γ,LR), -22.4m (γ,RR), +100m (n), +420m (p)**
- **General point: Lumi versus acceptance!**

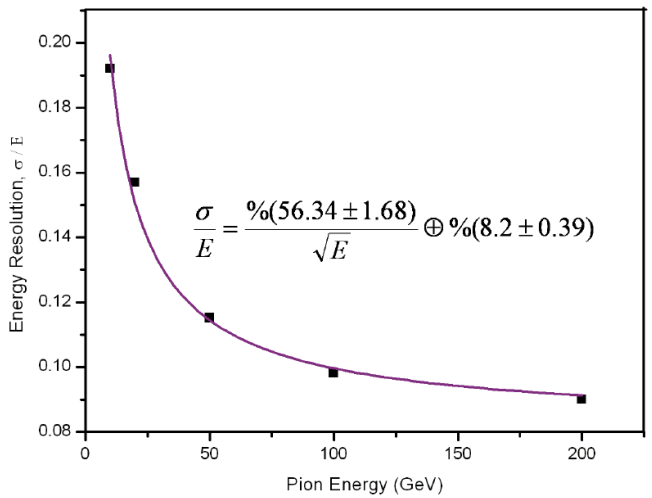
LHeC – CALORIMETER LAYOUT

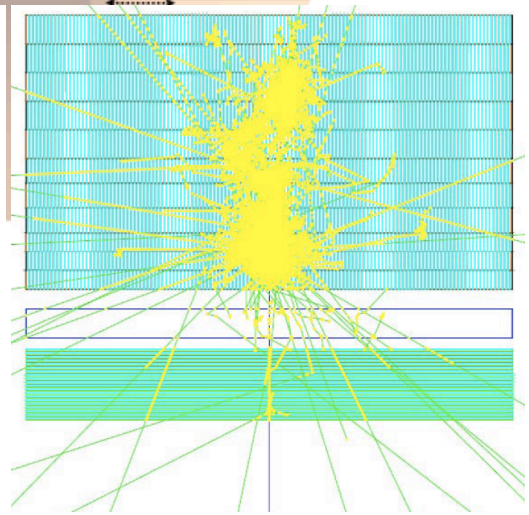
From P. Kostka, DIS11



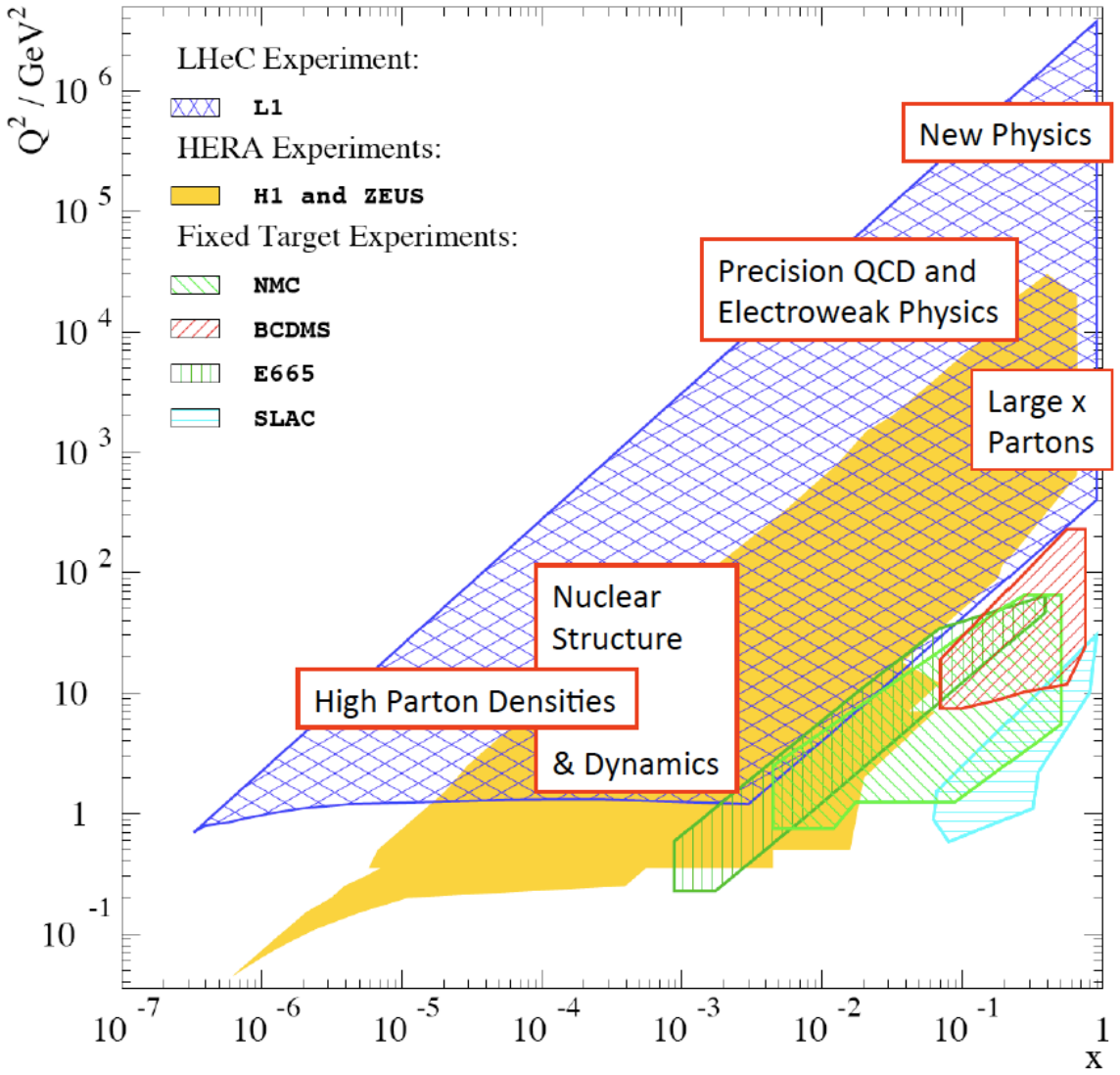
LHeC Simulation







DEEP-INELASTIC SCATTERING



Scenario B: lumi $e^{\pm}p$ = 50 fb^{-1}

- E_p = 7 TeV, E_e = 50 GeV
- $2 < Q^2 < 500{,}000$ GeV^2
- $0.000002 < x < 0.8$

Scenario H: lumi $e^{-}p$ = 1 fb^{-1}

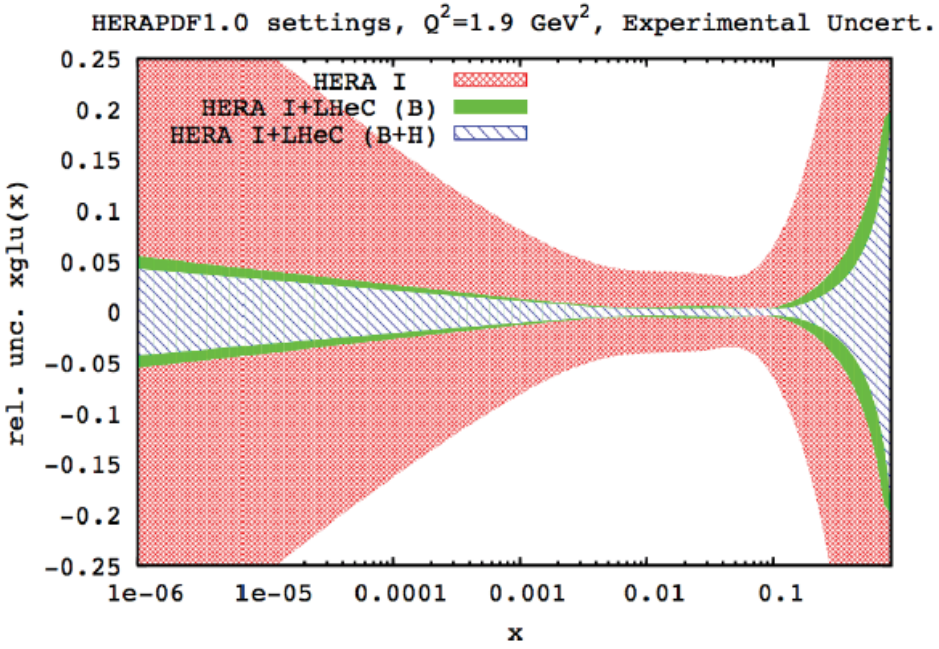
- E_p = 1 TeV, E_e = 50 GeV
- $2 < Q^2 < 100{,}000$ GeV^2
- $0.000002 < x < 0.8$

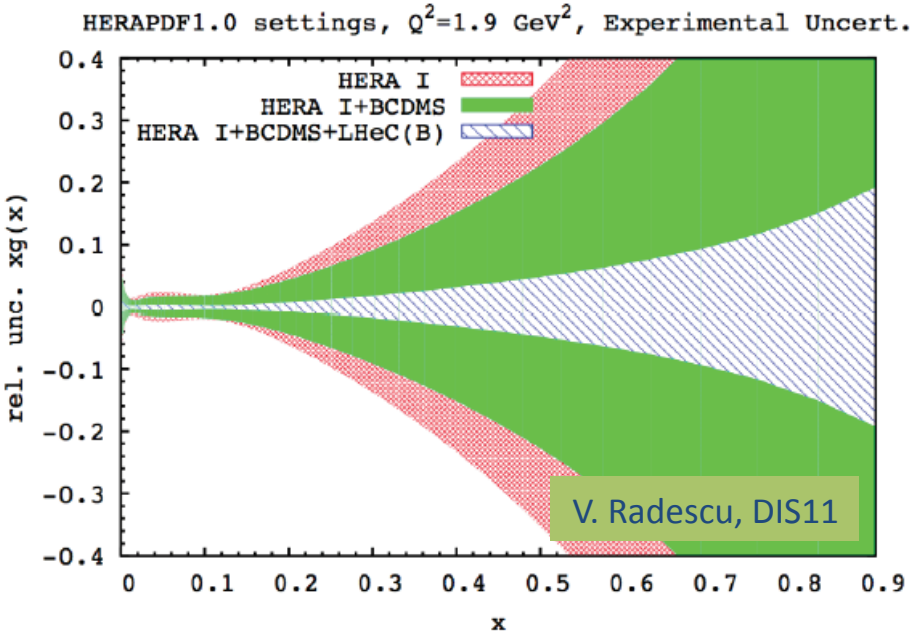
Uncertainties:

- Statistics < 1%
- uncorr. syst: 0.7%
- correlated syst: 1-3%

IMPACT ON GLUON DENSITY

- Assuming different scenarios and data sets …
  - HERA I, BCDMS, LHeC scenarios B and/or H …

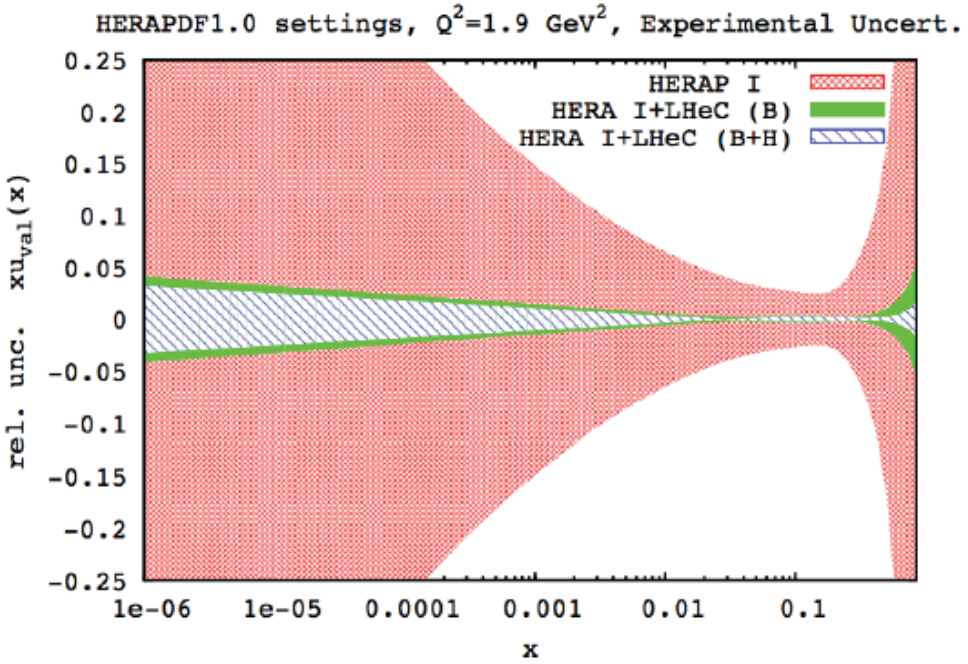


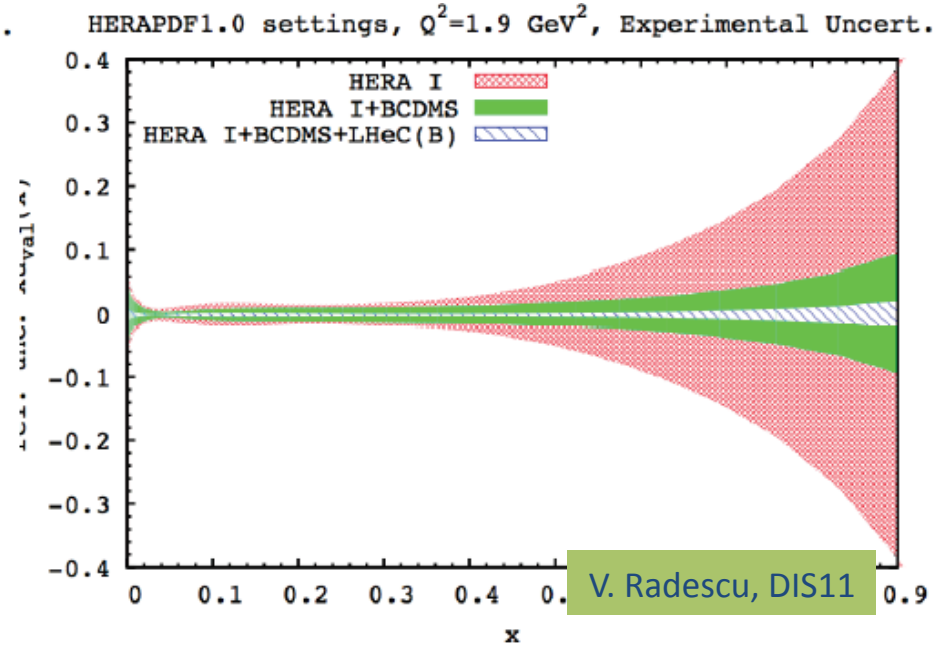


- Impressive potential for constraining the gluon density
  - at both low AND high x!!!
  - Consequences for pp physics at the LHC!

IMPACT ON U VALENCE

- Assuming different scenarios and data sets …
  - HERA I, BCDMS, LHeC scenarios B and/or H …





V. Radescu, DIS11

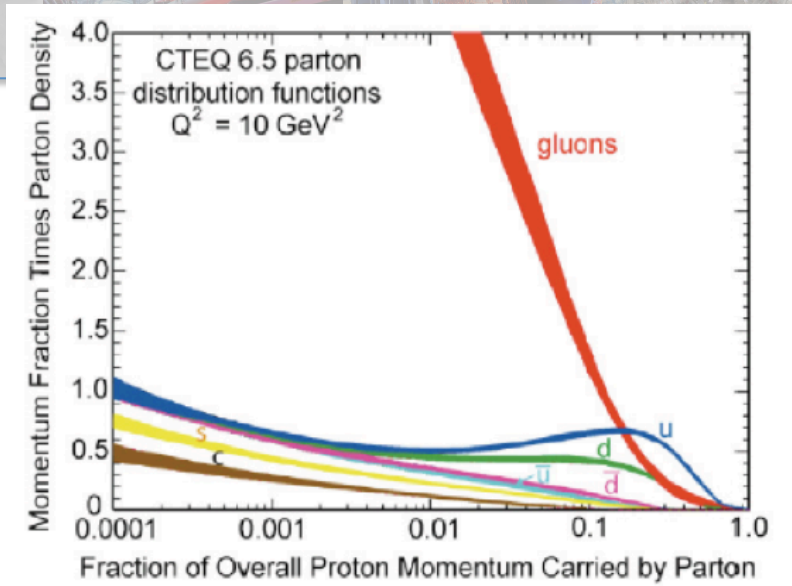
- Impressive potential for constraining u valence
  - at both low AND high x!!!
  - Full unfolding of parton structure WITHOUT assumptions like u=d @ low x!
  - Also question s = anti-s!

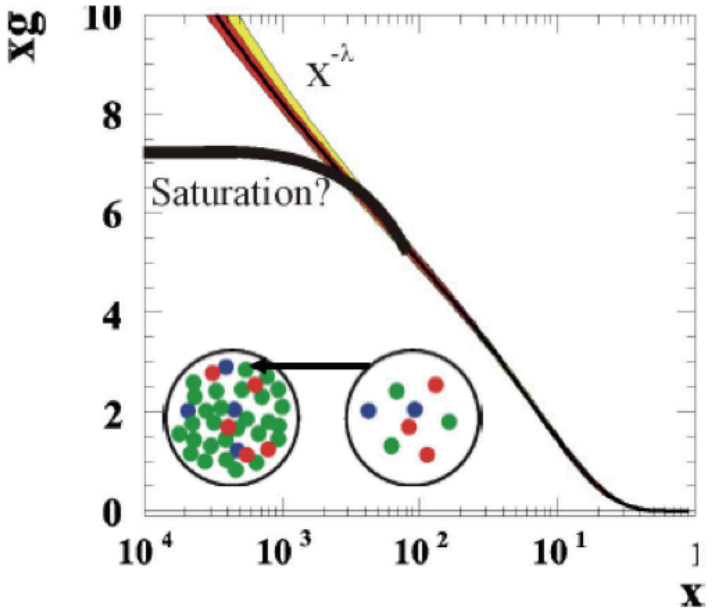
PDFs AND LOW-x …

Growth of Xsections towards low x must be tamed to satisfy unitarity.

- This requires non-linear effects.
- Aim of low x physics is to understand the underlying dynamics (gg recomb.)

$$Q_S^2 \sim xg(x)\alpha_S \sim cx^{-\lambda}A^{1/3}$$





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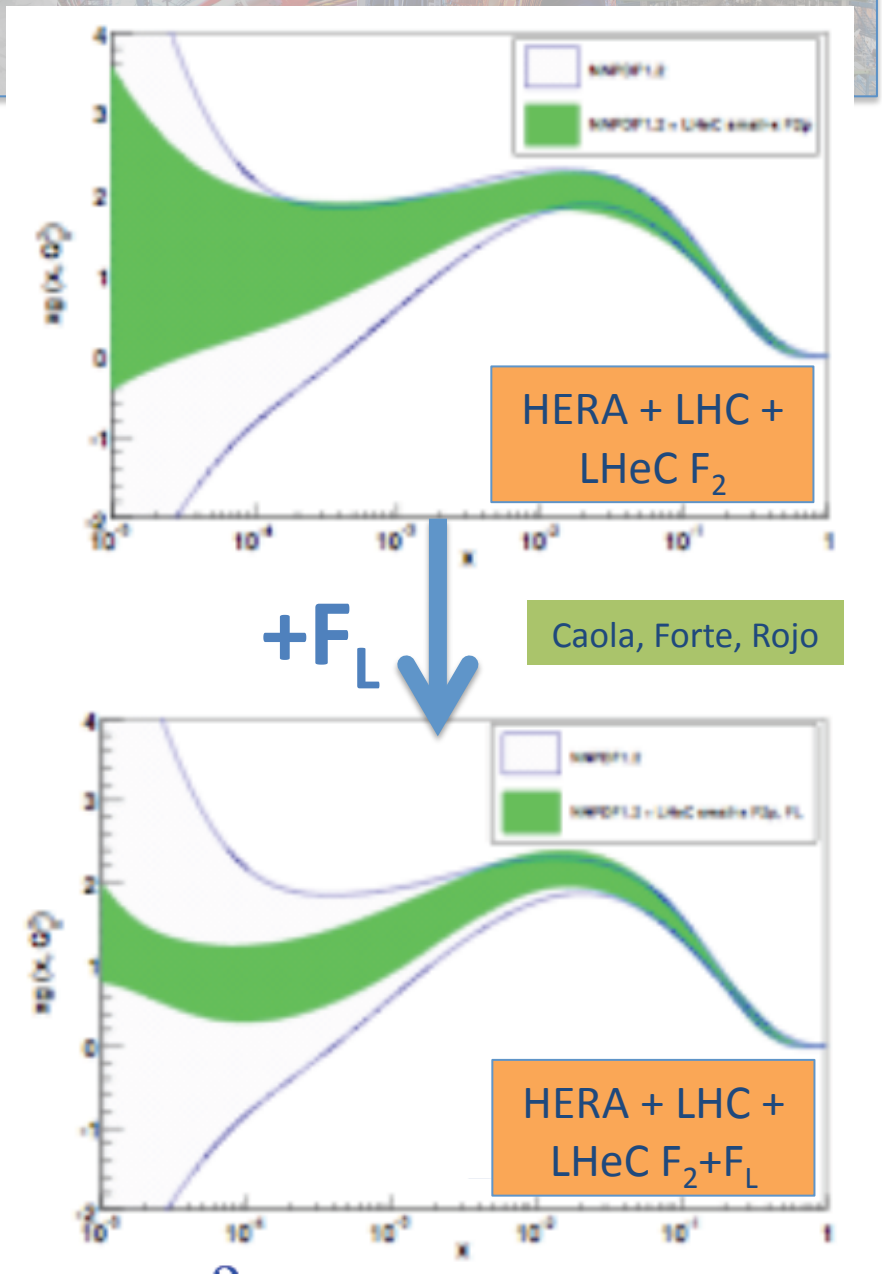
Inclusive / exclusive measurements

- For example measurement of F_L
  → constrain xg(x) at low x



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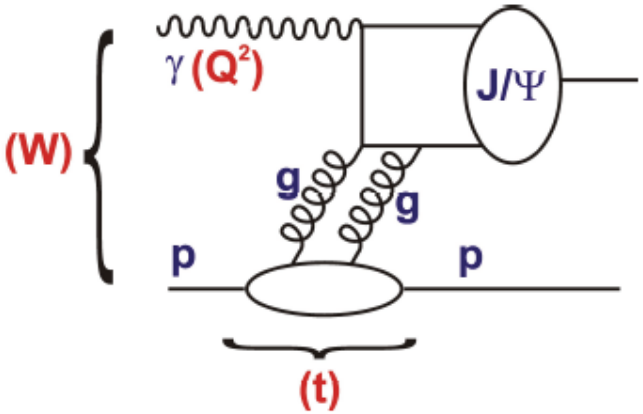
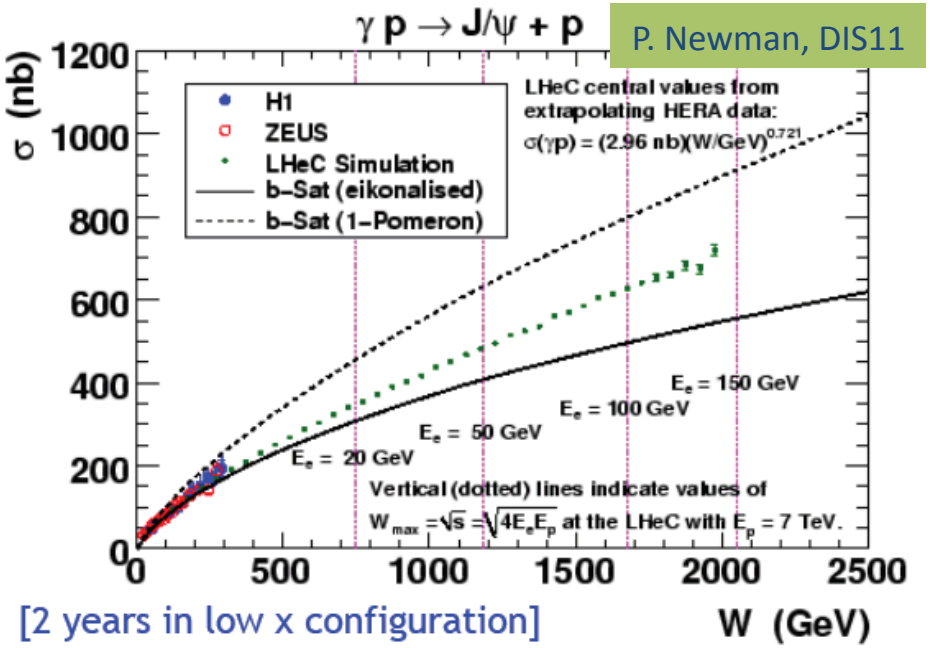


Inclusive / exclusive measurements

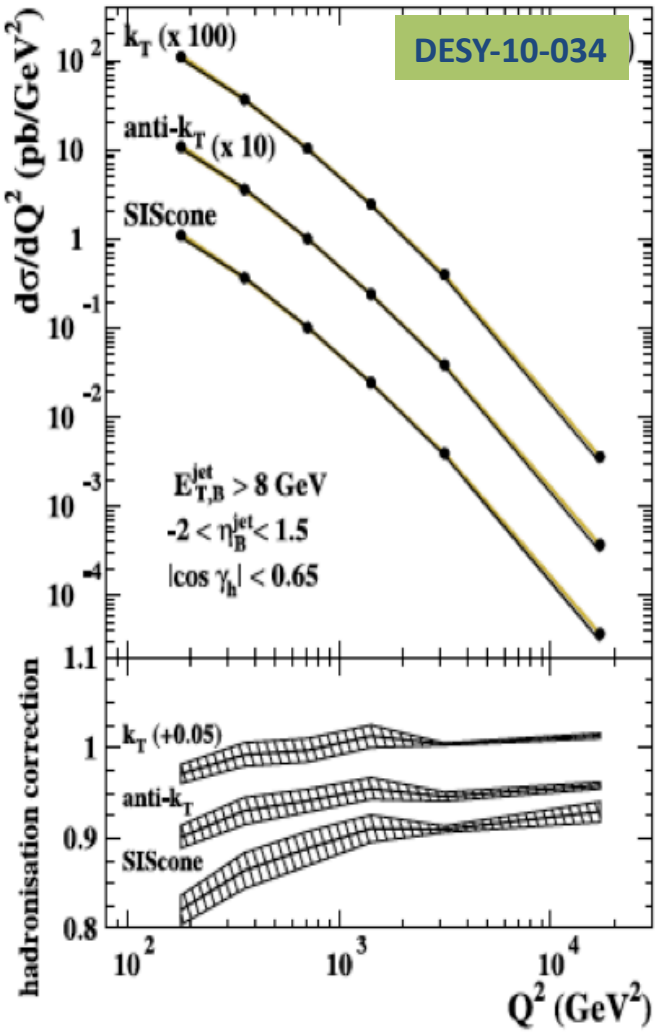
- For example measurement of F_L → constrain xg(x) at low x
- For example diffraction like J/Psi
  - interpretation of diffraction as 2g exchange!
  - b dependence → select densest area in proton!
- … but also other exclusive channels!

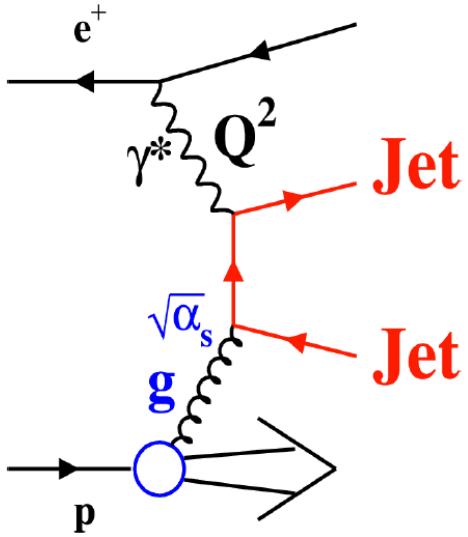


[2 years in low x configuration]

JETS@HERA – LESSONS LEARNED

- Many HERA measurements at HERA in DIS and photoproduction

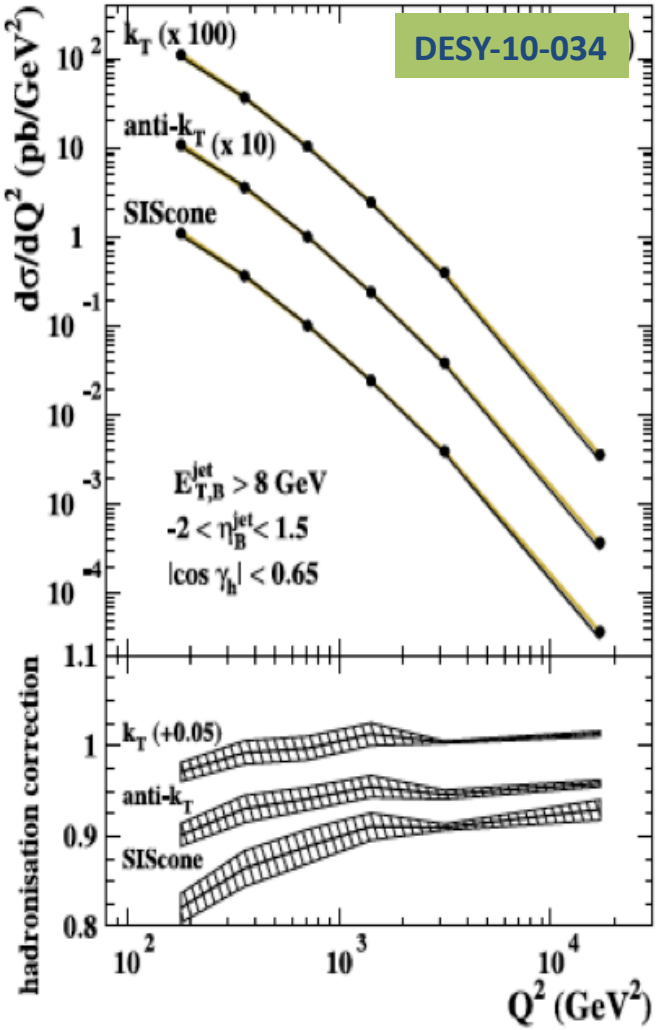


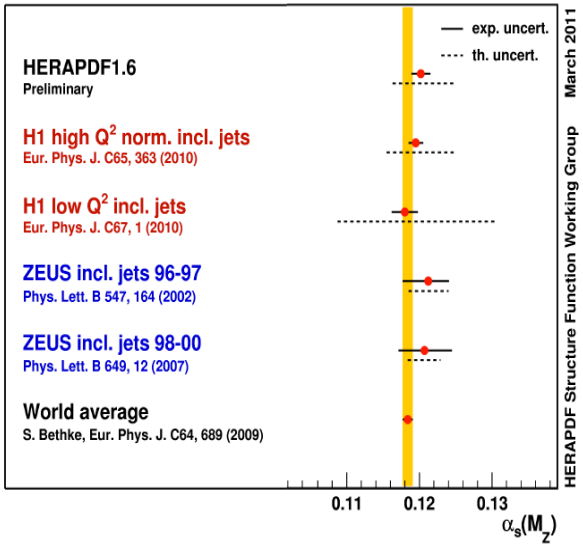


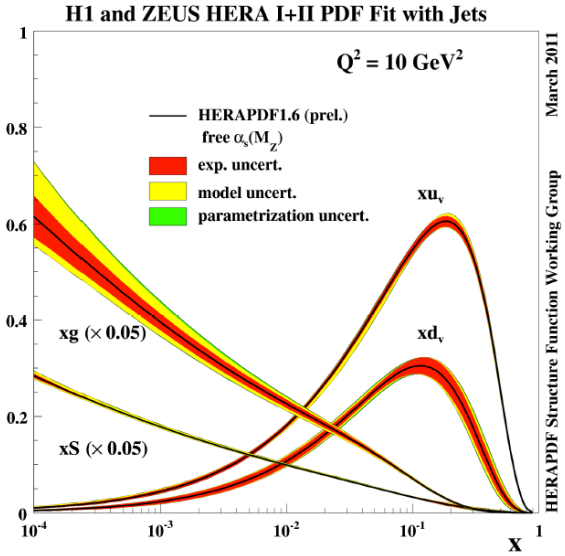
$$\sigma = \sum_n \alpha_S^n \sum_{i,q,\bar{q},g} f_{i/p} \times \hat{\sigma}_{i,n}$$

JETS@HERA – LESSONS LEARNED

- Many HERA measurements at HERA in DIS and photoproduction

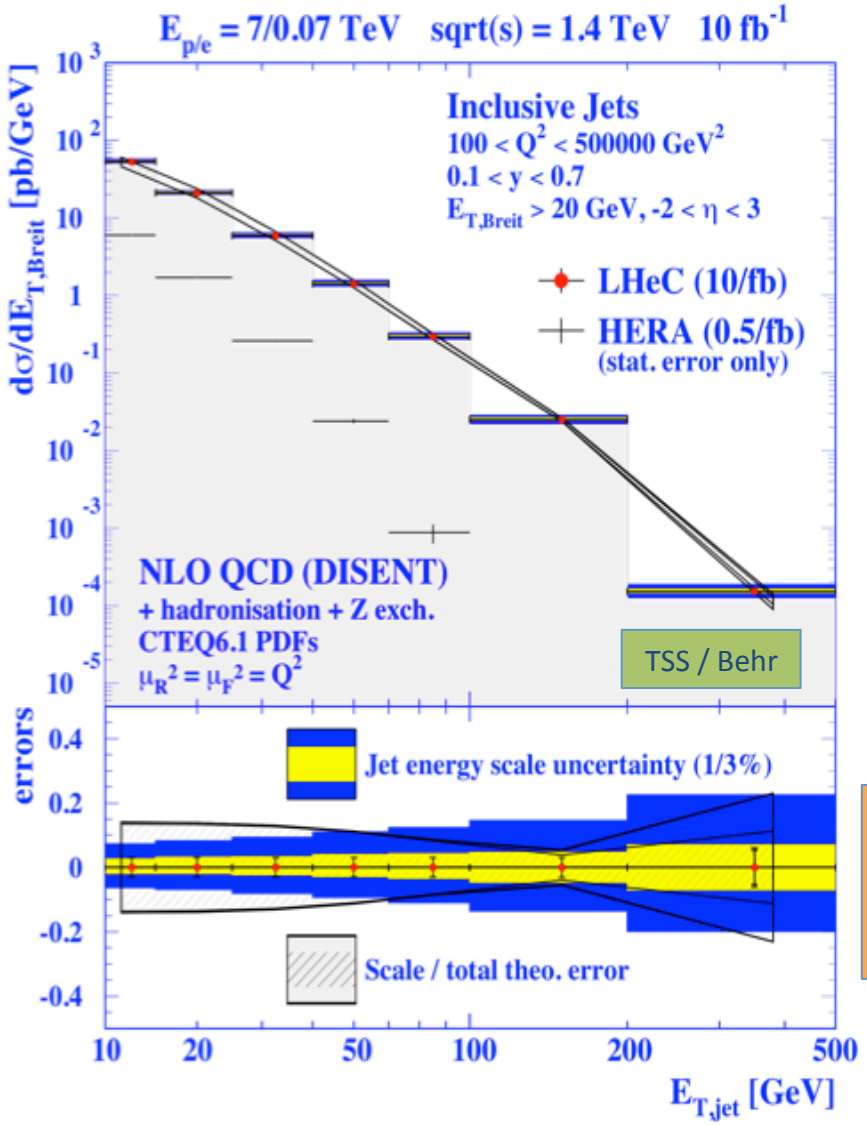


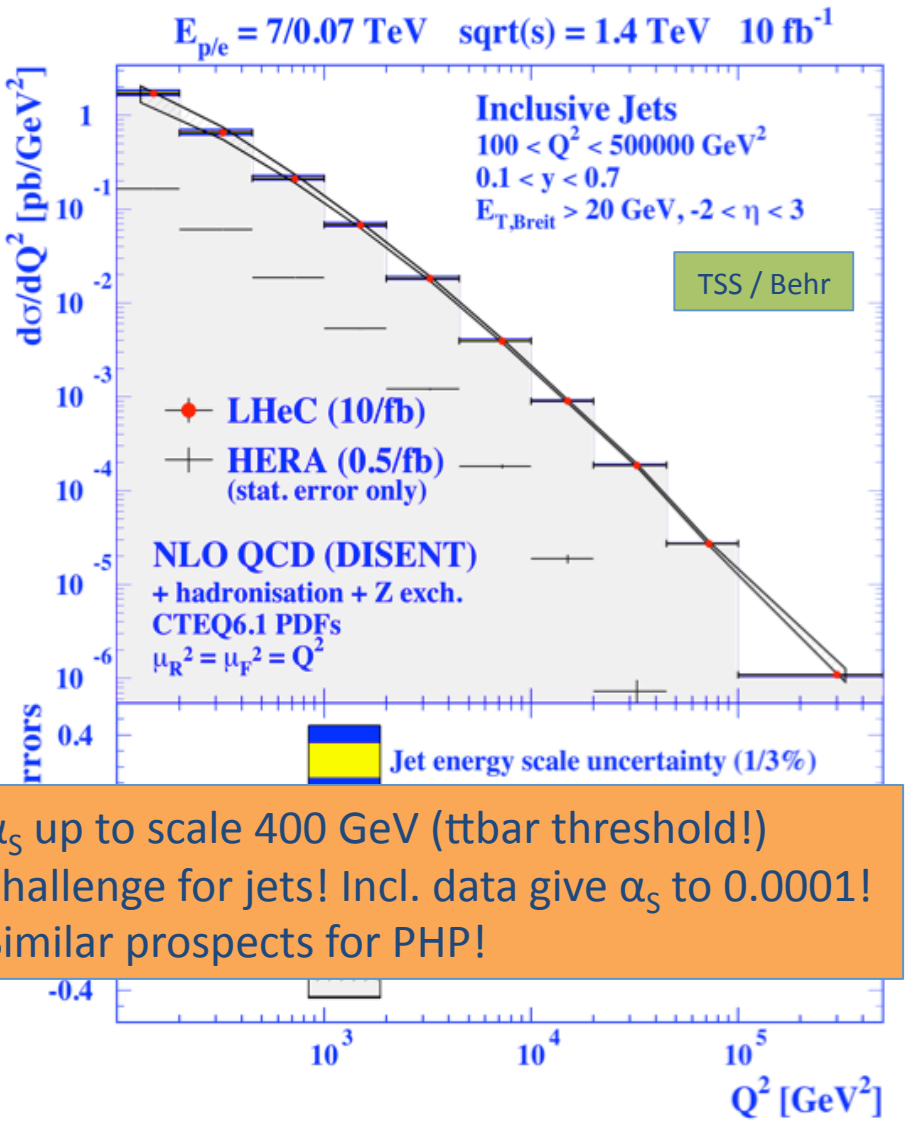




- Detailed pQCD studies (PDF universality, factorisation, series expansion …)
- Competitive α_S determinations
- Important input to PDFs
- Clues on colour factors, parton dynamics, photon PDF …

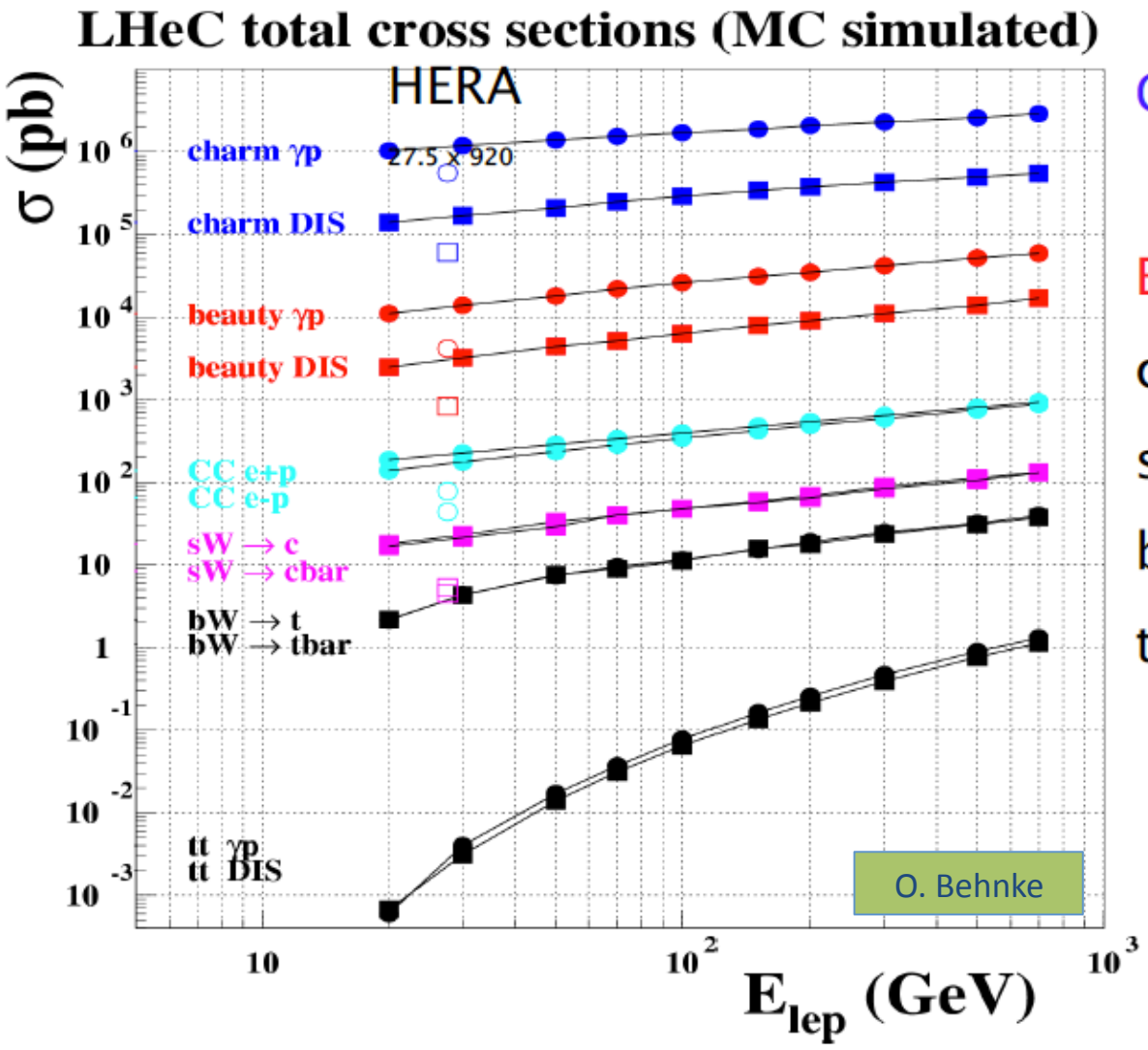
JETS@LHeC – DIS





- α_S up to scale 400 GeV (ttbar threshold!)
- challenge for jets! Incl. data give α_S to 0.0001!
- Similar prospects for PHP!

CHARM, BOTTOM, TOP AT LHeC



Charm

Beauty

cc

sW-> c

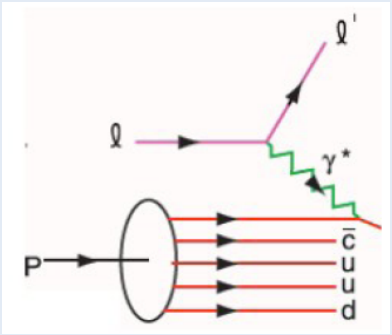
bW->top

ttbar

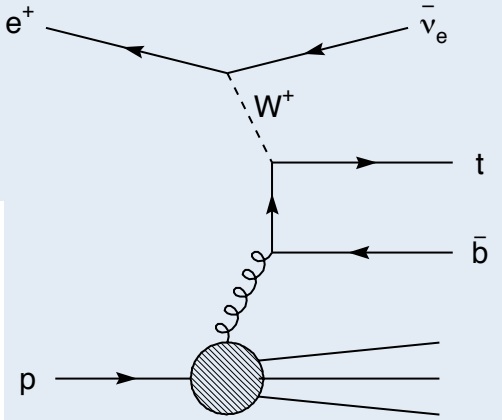
Flavour factory!!! Per 10 fb^{-1}:
10^{10} c events
10^{8} beauty events
10^{5} single top events,

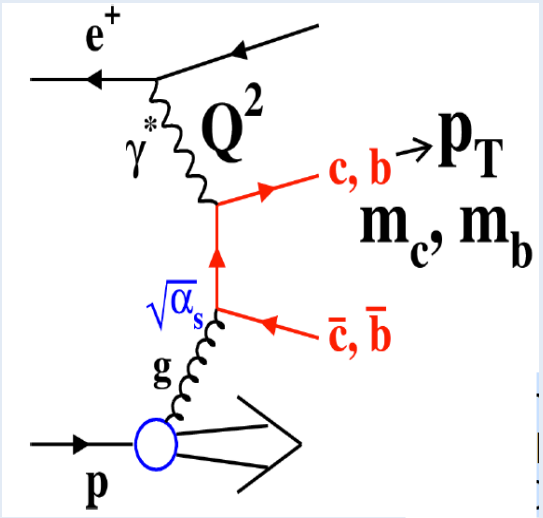
CHARM, BOTTOM, TOP AT LHeC

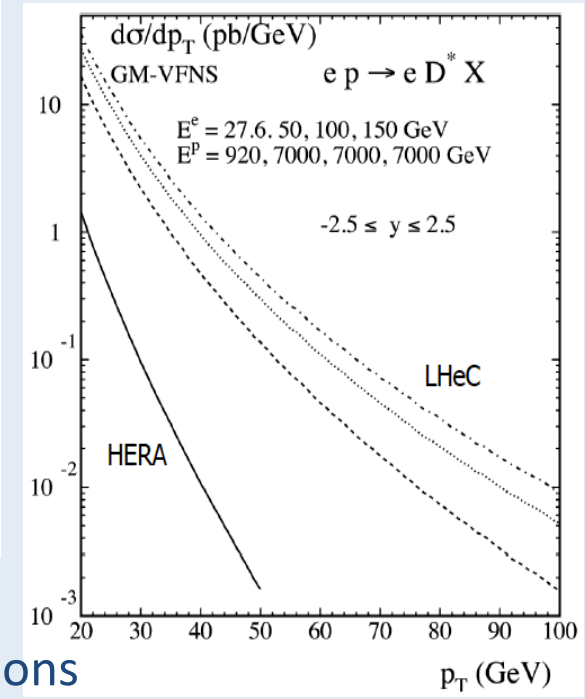
- Multi-scale QCD problem!
- Large contribution to σ(ep)
  → tagging important
- Access to gluon
- Intrinsic charm?



- First time top production in ep, mostly single top.







Many questions to be studied !

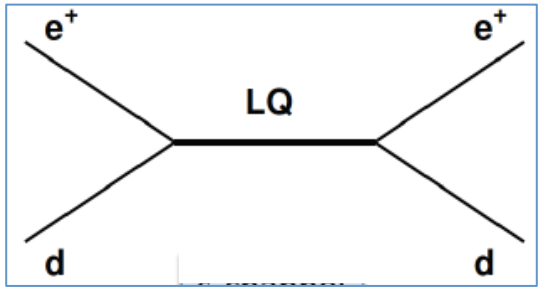
- Increased Xsections and scales – massive vs massless calculations

NEW PHYSICS @ LHeC

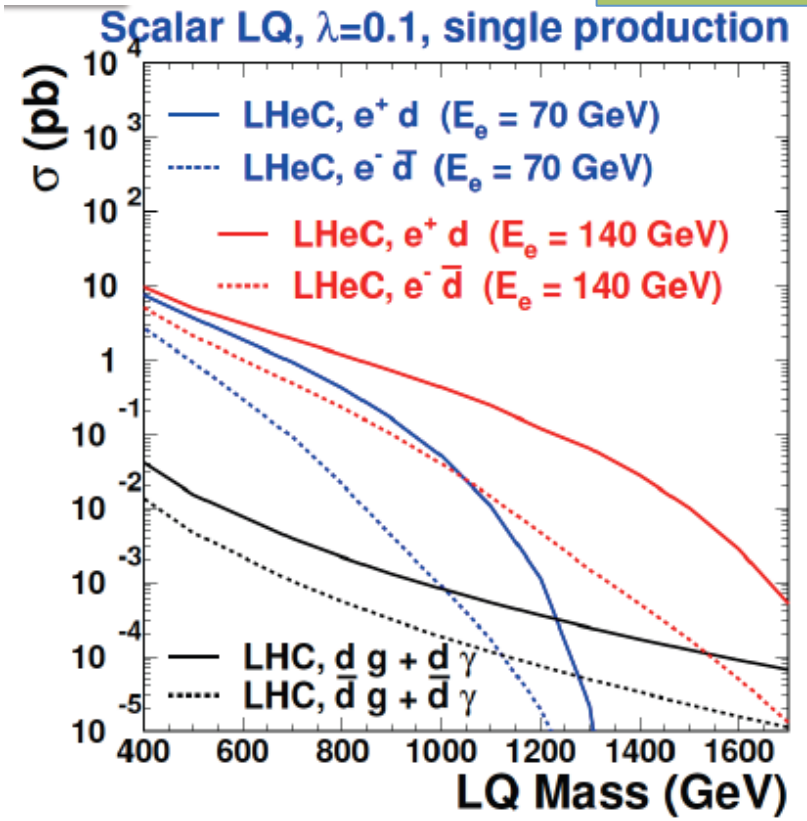
- LHC built to discover new physics – but LHeC could
  - deliver more precision
  - assist interpretation: l-q interactions (LQ, CI, compositeness, f*)
  - give insights into chiralities, CP properties, spectroscopy etc. …

- In some regions LHeC unique
  - small couplings in excited leptons

- Example leptoquarks:
  - Xsection: ~$\lambda^2 q(x)$
  - Signature: mass peak in final state inv. mass, Jakobian peak in lepton p_T at $M_Q/2$



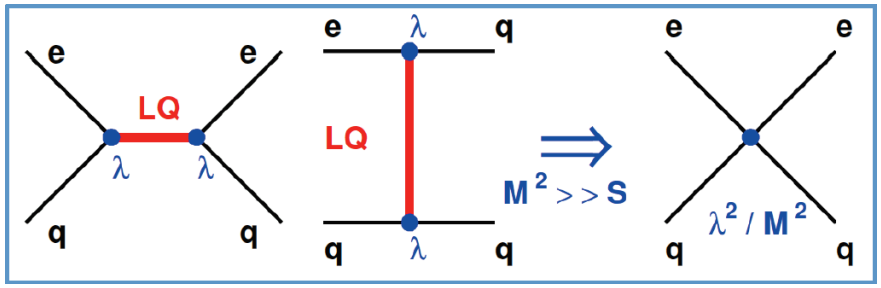
U. Klein, DIS11



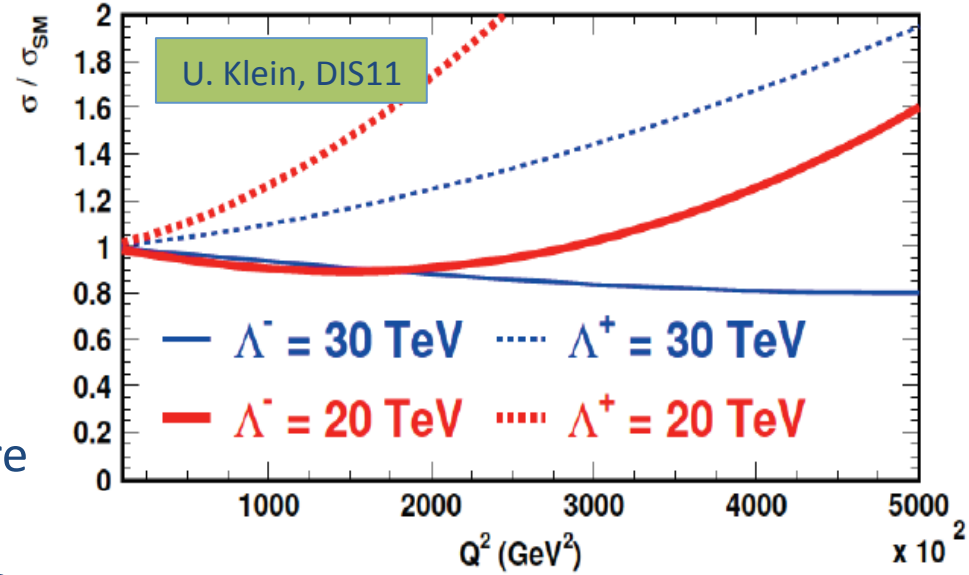
For same couplings and mass ranges, single LQ would be more abundantly produced in ep!

NEW PHYSICS: CONTACT INTERACT.

- Effective 4-fermion interaction
  - Study substructure beyond s
  - Study KK gravitons; ED for different quark flavours …



- Tool: compare ep cross section to SM + CI(Λ).
  - LHeC could reach sensitivity up to mass scales of 20-45 TeV!



- Polarised beams …
  - … help to establish chiral structure of new interaction
  - Likely need to combine ep and pp data for full understanding!

NEW PHYSICS: CONTACT INTERACT.

- Effective 4-fermion interaction
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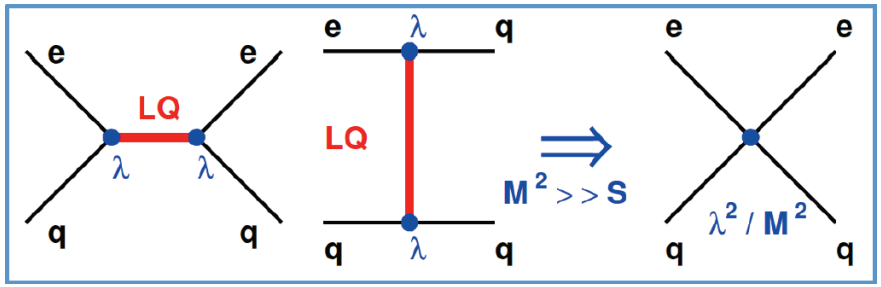
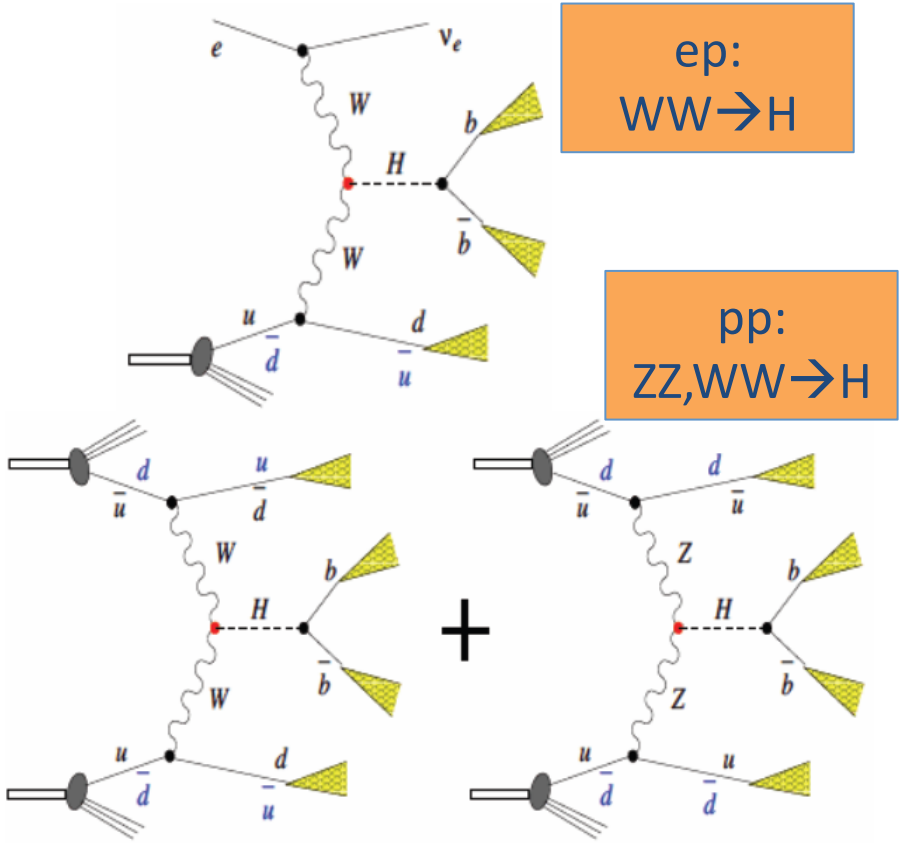
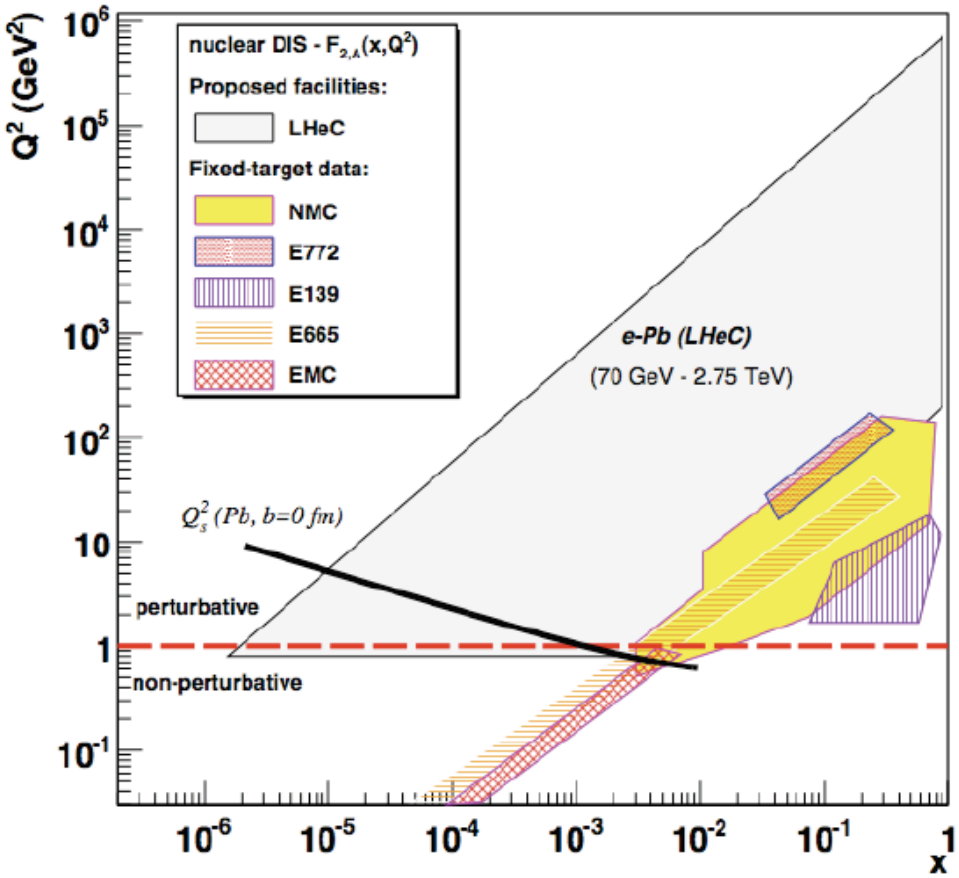
- Tool: compare ep cross section to SM + CI(Λ).
  - LHeC could reach sensitivity up to mass scales of 20-45 TeV!
- Polarised beams …
  - chiral structure of new interaction
  - Likely need to combine ep and pp data for full understanding!
- Other physics case: HWW vertex
  - Uniquely addressed by ep!





eA COLLISIONS

- Nucleus-nucleus initial state!
- Nuclear PDFs!
- QCD at high density!



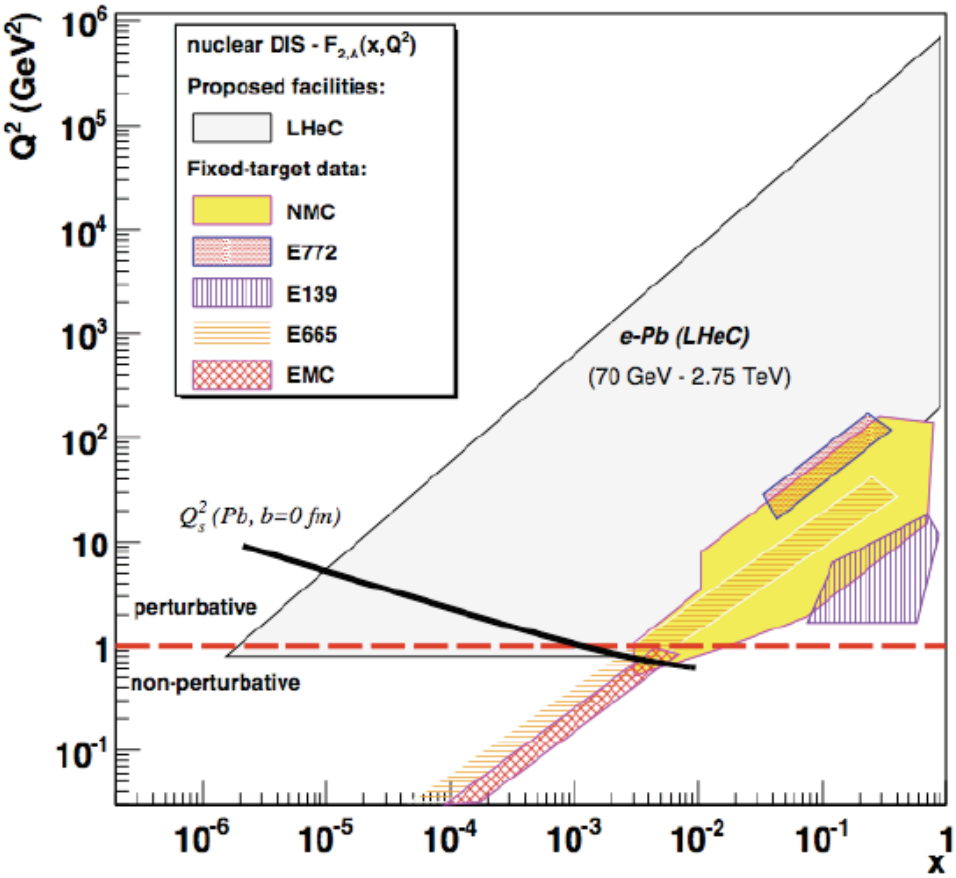
LHeC will dramatically increase x-Q^2 coverage of nuclear DIS !

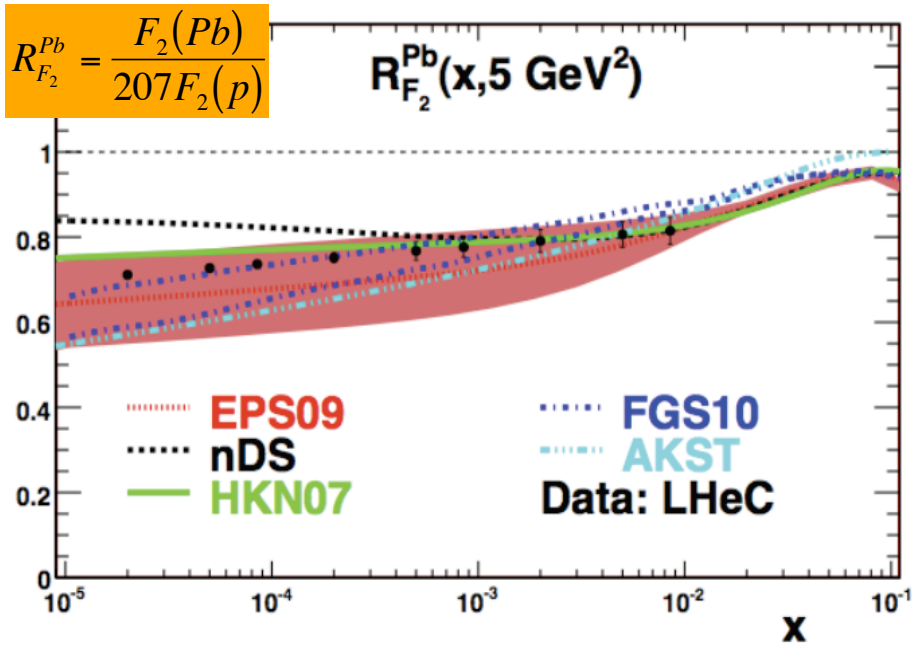
eA COLLISIONS

- Nucleus-nucleus initial state!
- Nuclear PDFs!
- QCD at high density!

Comparison of LHeC pseudo-data to current fits / parametrisations

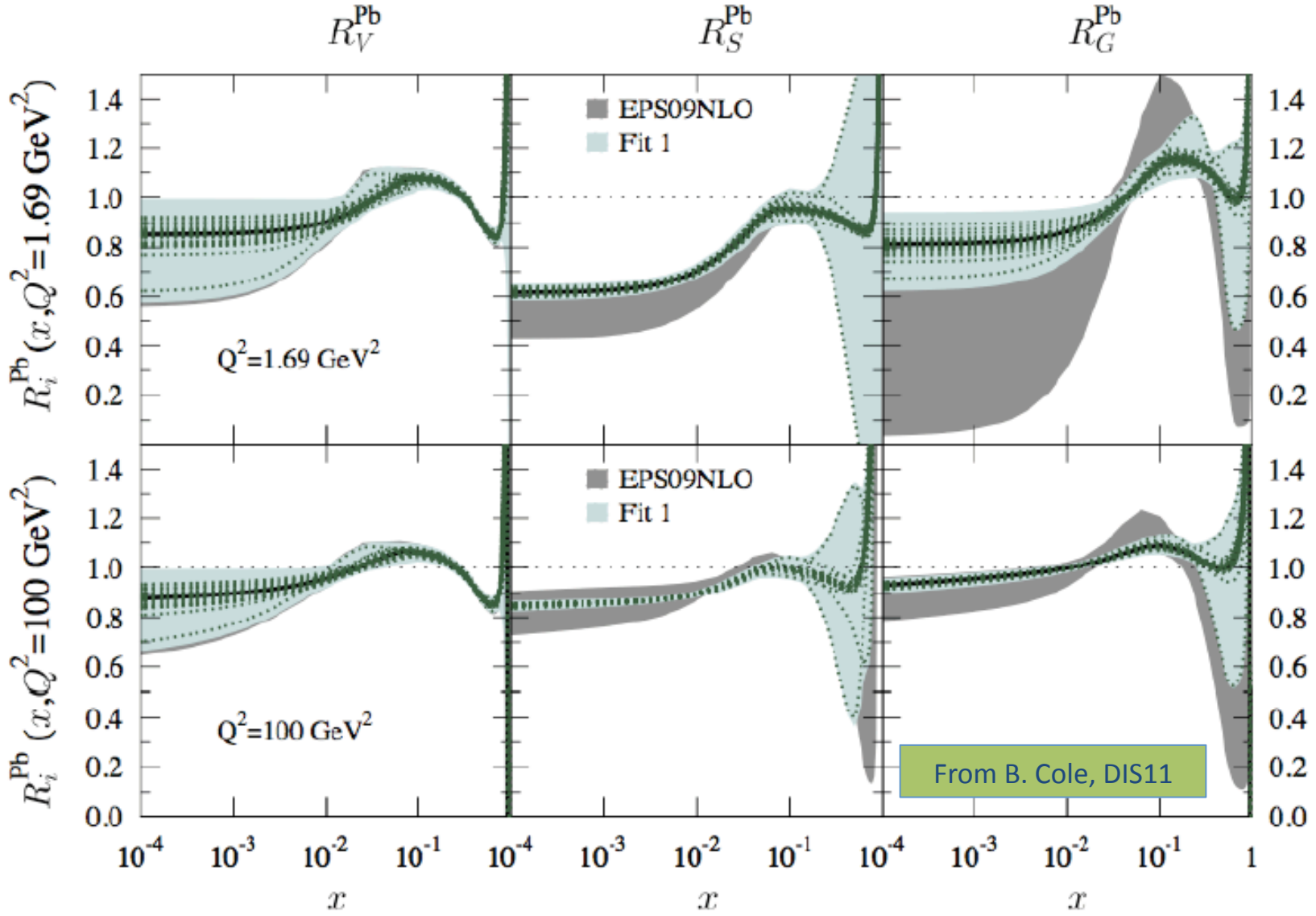
➔ huge potential!





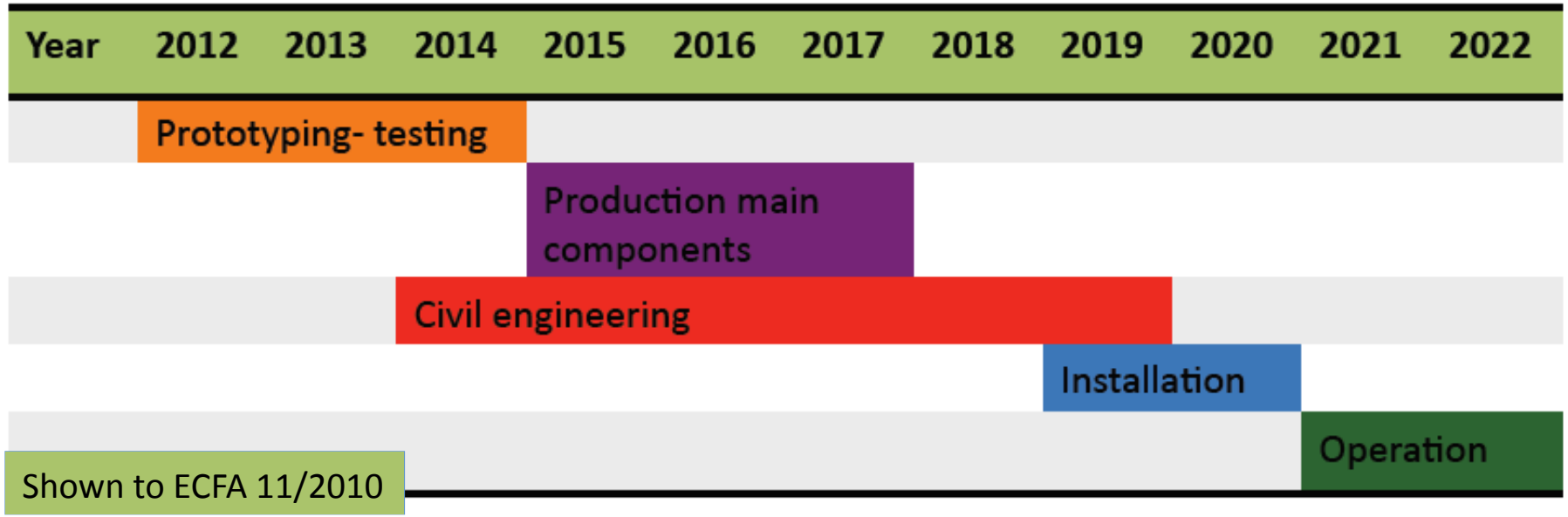
B. Cole, DIS11

eA COLLISIONS – NUCLEAR PDFs



PROJECT DRAFT TIMELINE

- Taking into account LHC schedule, series production, civil engineering …



- Variations possible, some steps may overlap
- Subject to LHC project changes
- Start in 2020 requires begin of prototyping in 2012.

NEXT STEPS, SUMMARY

2011

- Complete CDR document
- Workshop on positron intensity (20.5.11 at CERN)
- Referee process (5-9/2011)
- Update, print and hand in to ECFA/NuPECC/CERN
- Workshop on linac versus ring (fall 2011)
  main features, R+D, design …

2011/12

- Participation in European Strategy Process (EPS Grenoble)
- Update physics programme according to LHC findings
- Form international accelerator development group based at CERN
- Build an LHeC Collaboration for preparation of LoI on the Detector

The LHeC is the only way for the foreseeable future to realize DIS at the TeV energy scale, leading to new insight and continuing the path from 1911 to now. It will substantially enrich and extend the physics provided by the LHC, and it represents a new opportunity for challenging accelerator and detector developments

CONCLUSION

P. Newman

LHC is the future of the high energy frontier!

Can its unprecedented energy and intensity be exploited for DIS?

"… the LHeC is already half built" [J Engelen]

"… it would be a waste not to exploit the 7TeV beams for ep and eA physics at some stage during the LHC time" [G. Altarelli]