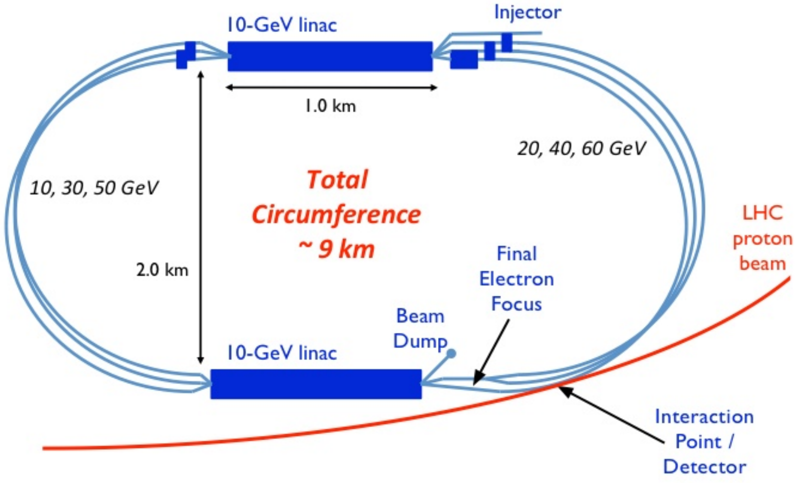
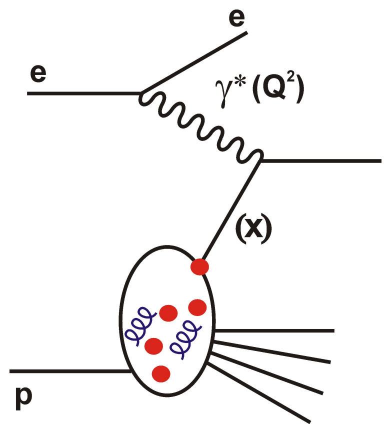
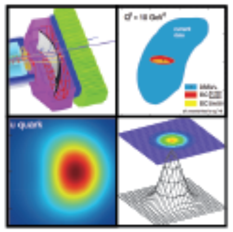
Overview of the LHeC Project



Paul Newman
Birmingham University

- *Lepton-hadron collider based on the high lumi LHC*
- *Can we add ep and eA collisions to the existing LHC pp, AA and pA programme?*



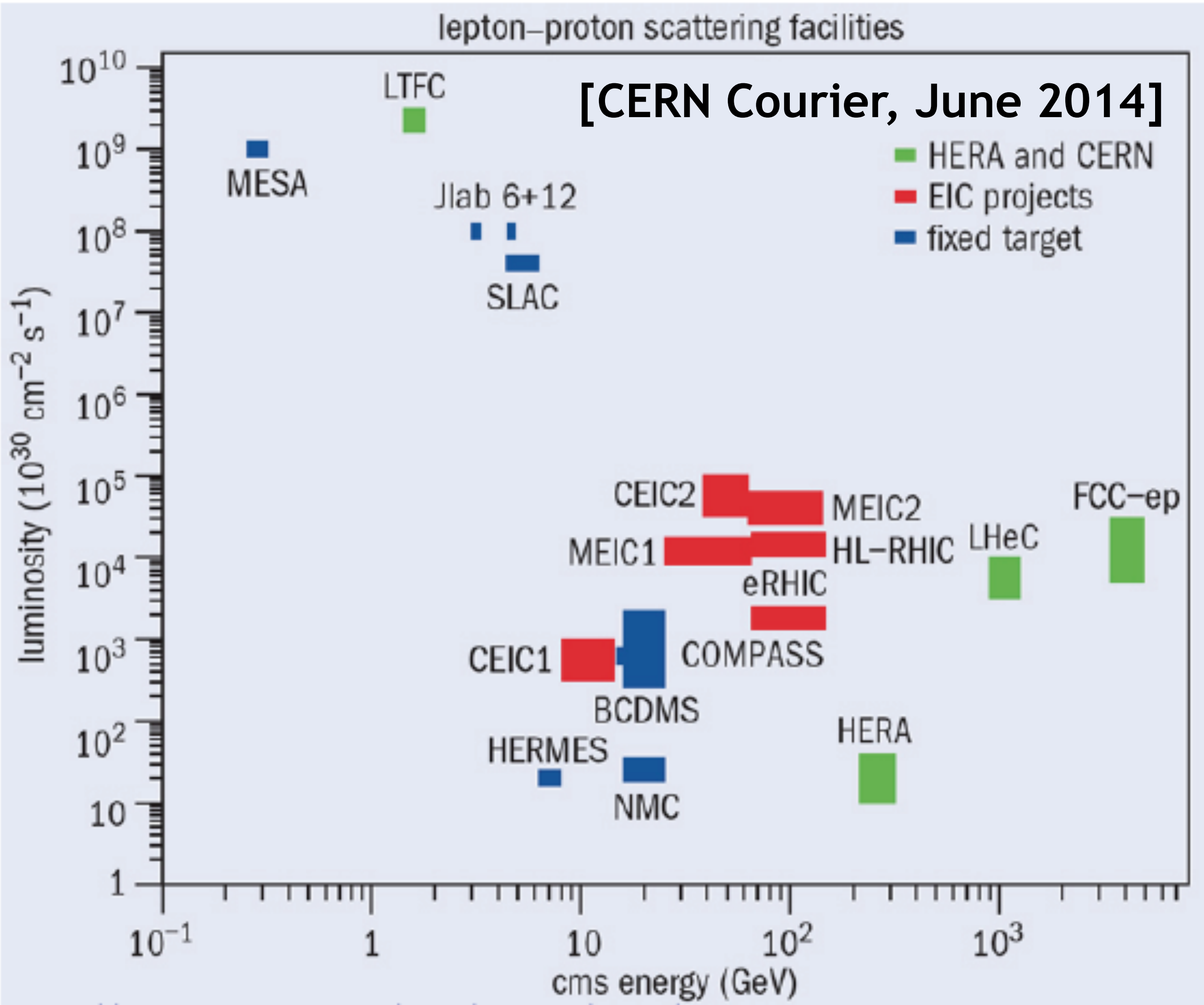


POETIC VI

September 7th-11th 2015
Palaiseau, France

6th International Conference on Physics Opportunities at an Electron-Ion Collider

LHeC / FCC-he Context



Lepton-hadron scattering at the TeV scale …

LHeC: 60 GeV electrons x LHC protons & ions
→ 10^{34} cm^{-2} s^{-1}
→ Simultaneous running with ATLAS / CMS sometime in HL-LHC period

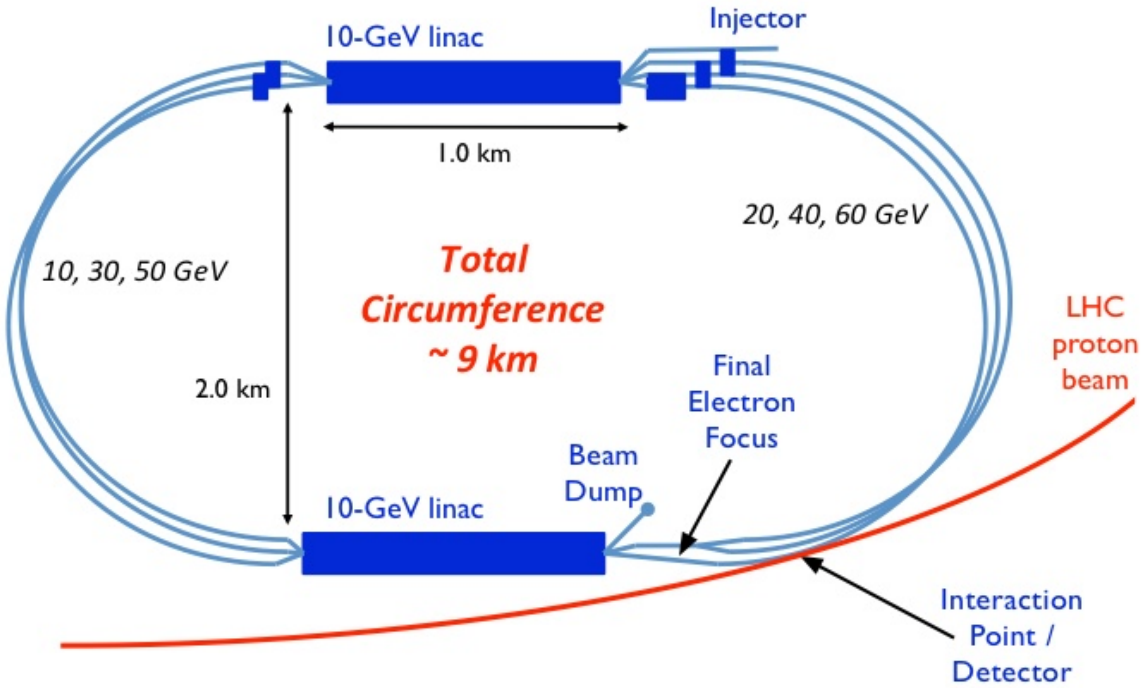
FCC-he: 60 GeV electrons x 50 TeV protons from FCC

Baseline# Design (Electron "Linac")

LHeC CDR, July 2012 [arXiv:1206.2913]

Design constraint: power consumption < 100 MW → E_e = 60 GeV

- Two 10 GeV linacs,
- 3 returns, 20 MV/m
- Energy recovery in same structures [CERN plans energy recovery prototype]



- ep lumi → 10^{34} cm^{-2} s^{-1}
→ ~100 fb^{-1} per year →~1 ab^{-1} total
- **eD and eA collisions have always been integral to programme**
- **e-nucleon Lumi estimates ~ 10^{31} (10^{32}) cm^{-2} s^{-1} for eD (ePb)**

Alternative designs based on electron ring and on higher energy, lower luminosity, linac also exist

Recent Developments

LHC programme runs to >2035. Longer term at CERN? → FCC?

... CERN-sponsored ongoing work to evaluate how LHeC fits in.

→ Further develop physics aims, accelerator & detector, both LHeC & FCC

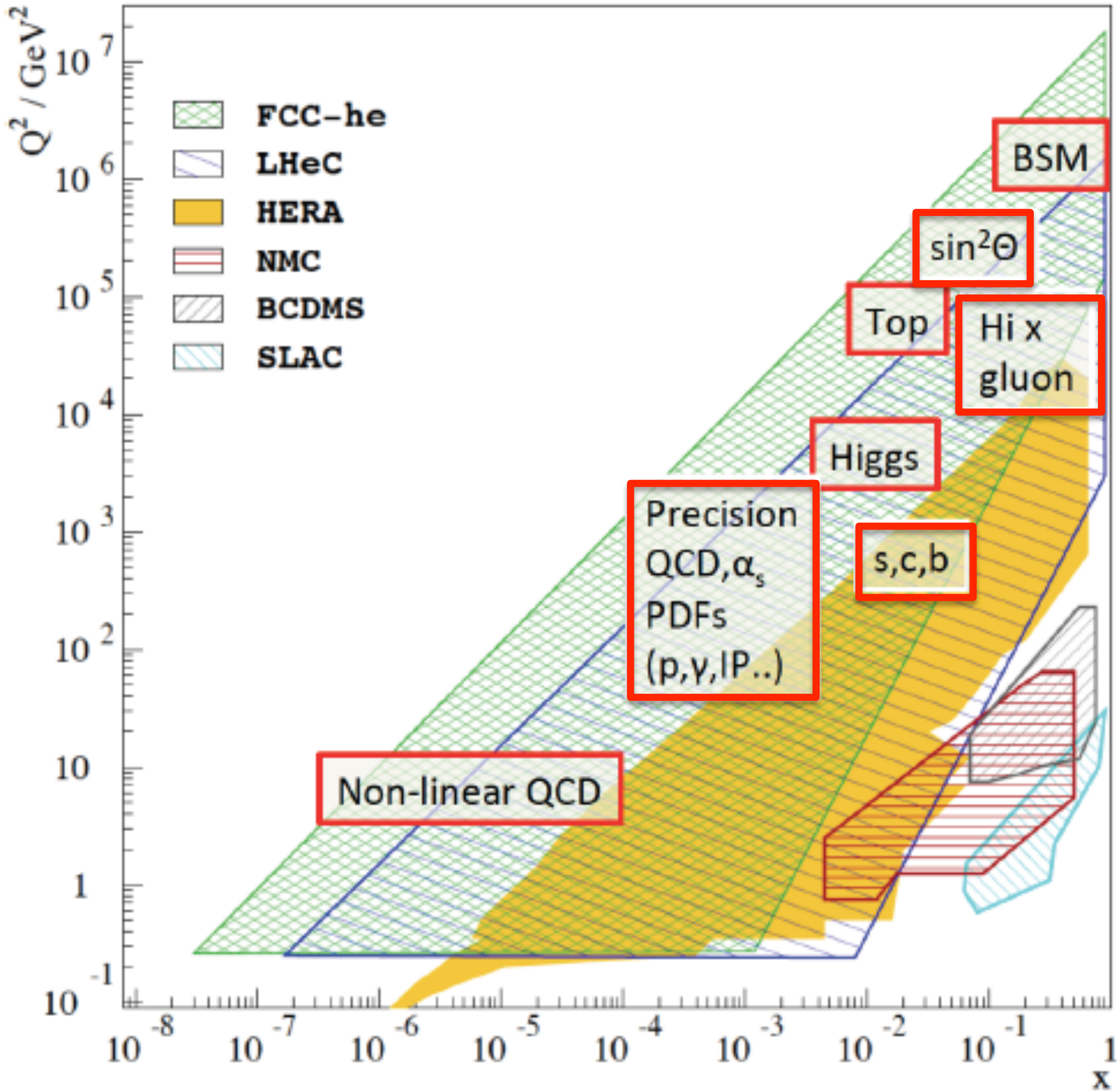
→ Continue building collaboration

→ Design ERL test facility @ CERN

ERL Test Facility:

- Test centre for accelerator development, LHeC prototype
- Most ambitious design (2 x 150 MeV linacs, 3 passes → 900 GeV) has significant physics potential of its own (10^{40} cm^{-2} s^{-1} fixed target) ... EW parameters, proton radius, photonuclear physics, dark photons ...
- Conceptual Design Report by end 2015

Physics Overview



- Next experimental facility to see Higgs?

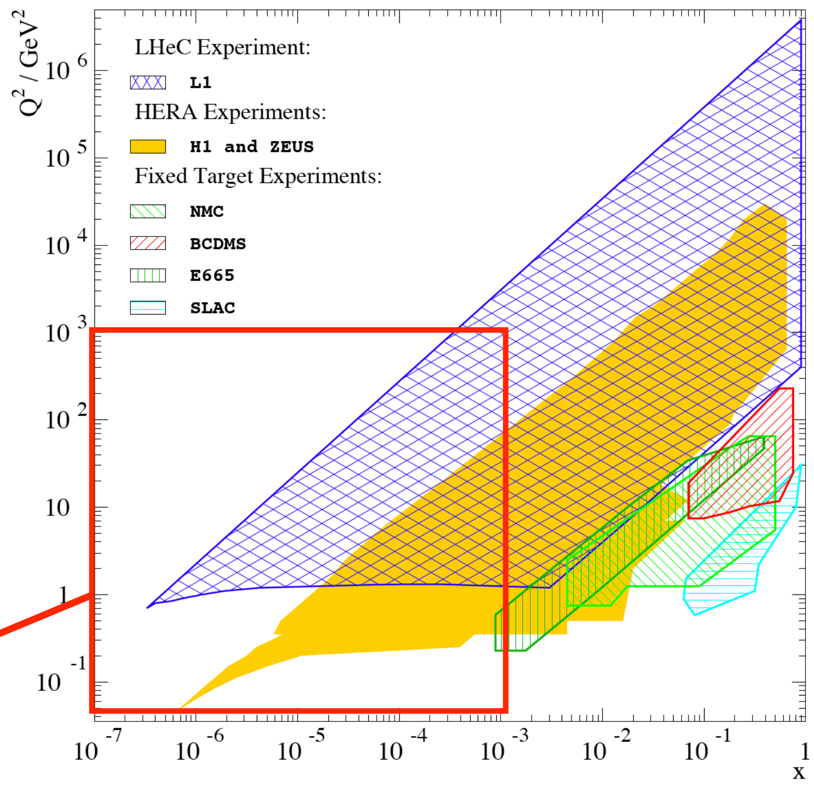
- Enhanced PDF precision enhances LHC new heavy particle sensitivity by ~0.5 TeV & transforms LHC precision at EW scale

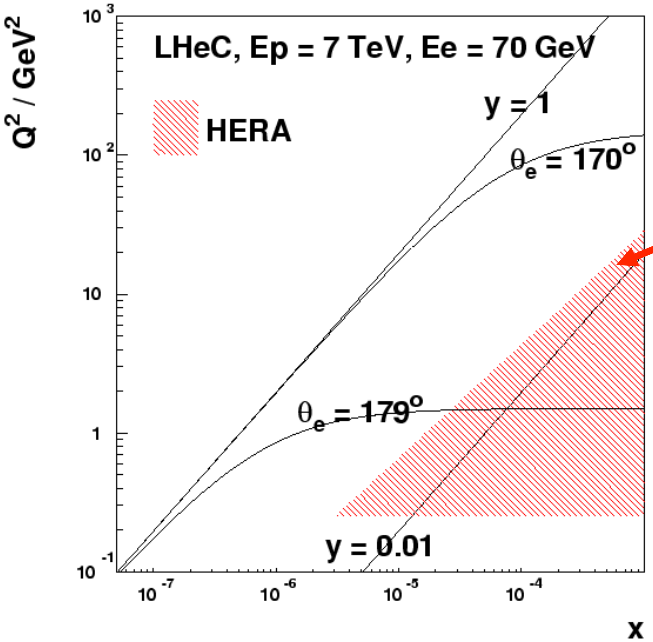
- Elucidates new low x dynamics in both ep and eA

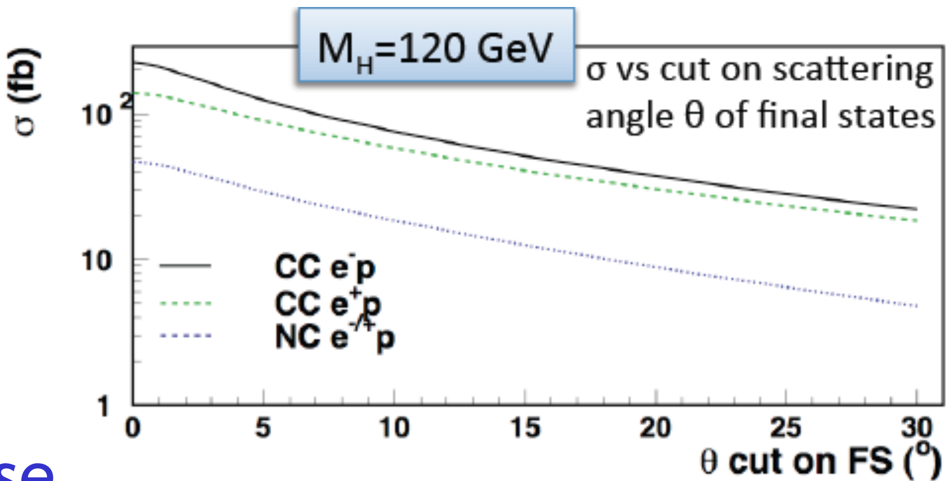
- Revolutionises knowledge of nuclear structure

LHeC Kinematic Detector Requirements

Access to Q^2=1 GeV^2 in ep mode for all x > 5 x 10^{-7} requires scattered electron acceptance to 179°

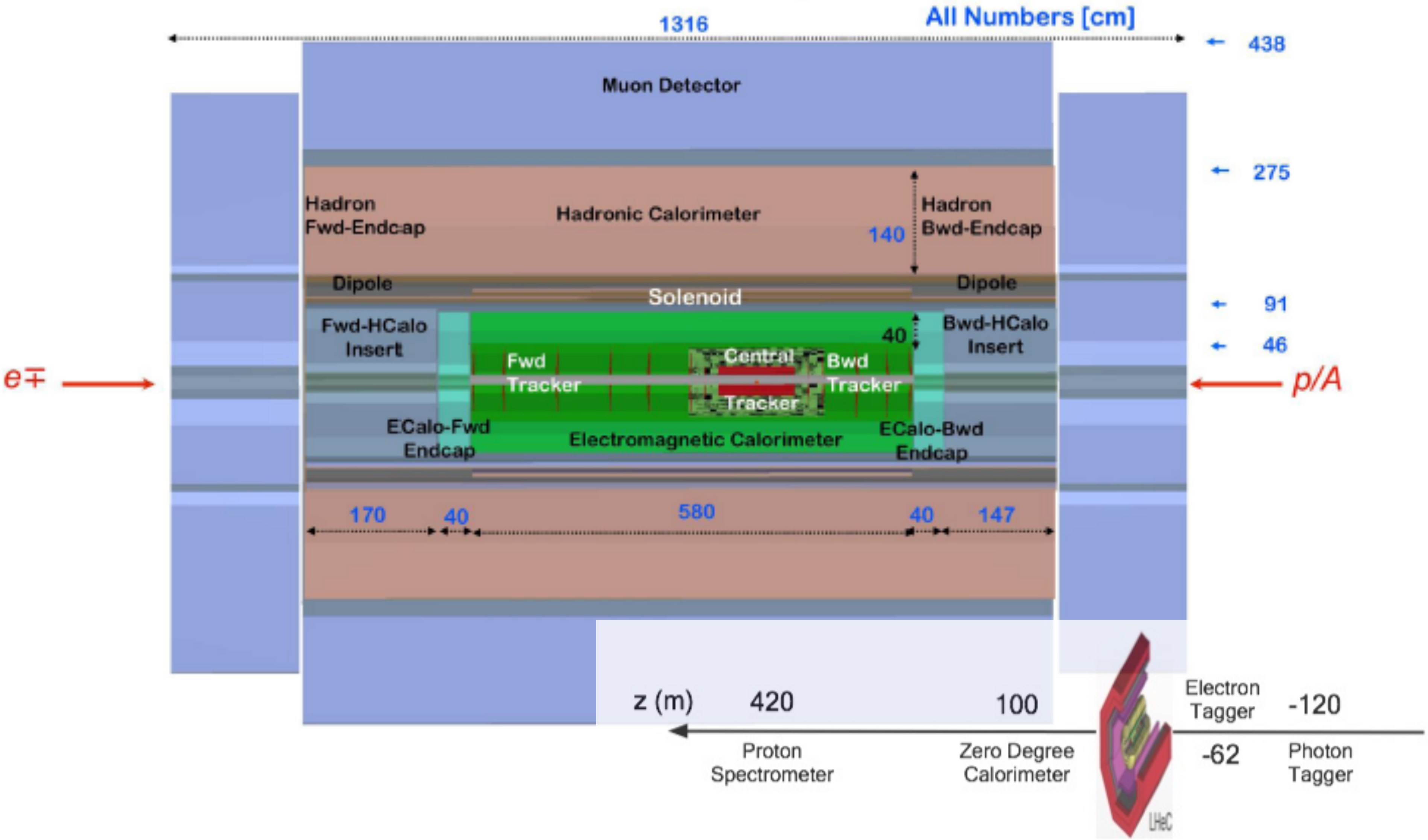






Also need 1° acceptance in proton direction to contain hadrons for kinematic reconstruction, maximise acceptance for H, new massive particles, Mueller-Navelet jets …

Detector Design Overview

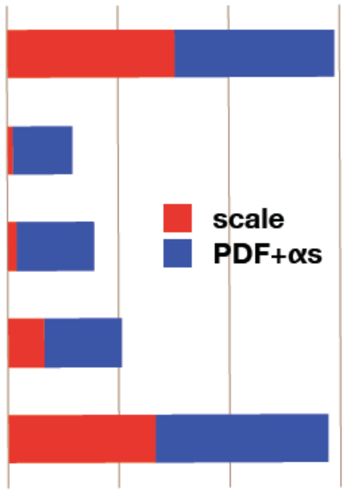


- Present size 13m x 9m (c.f. CMS 21m x 15m, ATLAS 45m x 25m)
- 1º tracking acceptance in both forward & backward directions
- Forward & backward beam-line instrumentation integrated

Why PDFs? → Uncertainties for LHC Higgs

Theory Cross Section Uncertainties
(125 GeV Higgs
J Campbell, ICHEP'12)

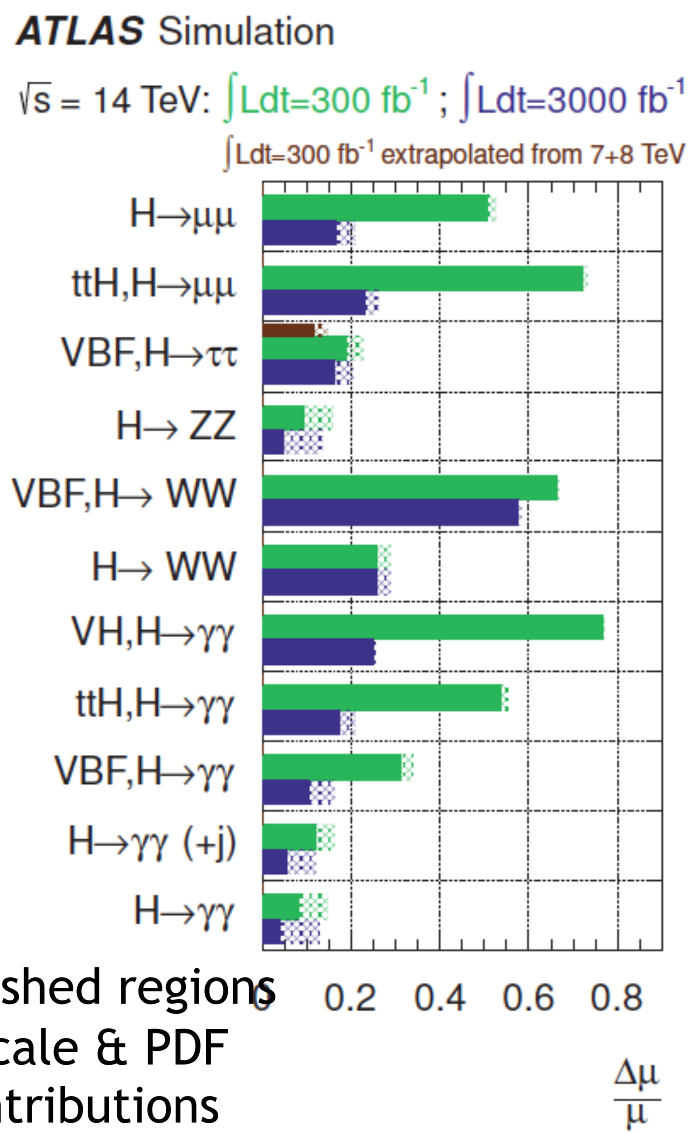
		σ (8 TeV)	uncertainty
NNLL QCD +NLO EW	gg→H	19.5 pb	14.7%
NNLO QCD +NLO EW	VBF	1.56 pb	2.9%
	WH	0.70 pb	3.9%
	ZH	0.39 pb	5.1%
NLO QCD	ttH	0.13 pb	14.4%



Similarly fermionic modes (bbbar, ccbar)

… tests of Standard Model in Higgs sector become limited by knowledge of PDFs in HL-LHC era

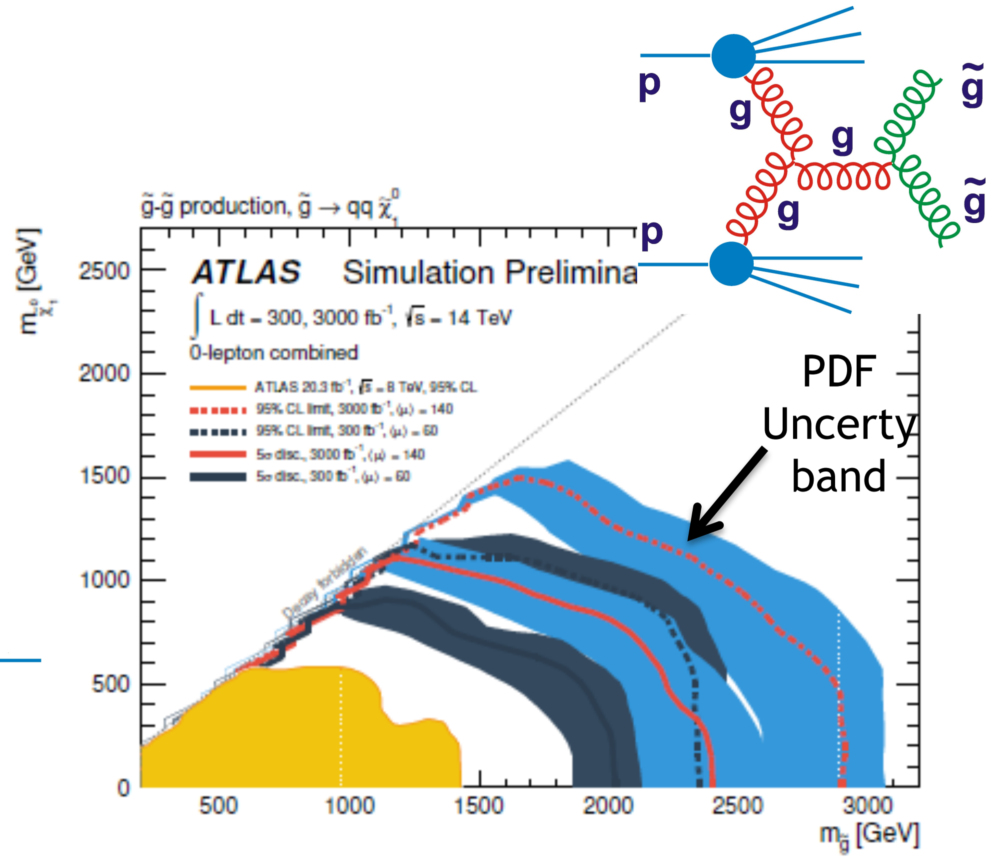
Projected Experimental Uncertainties

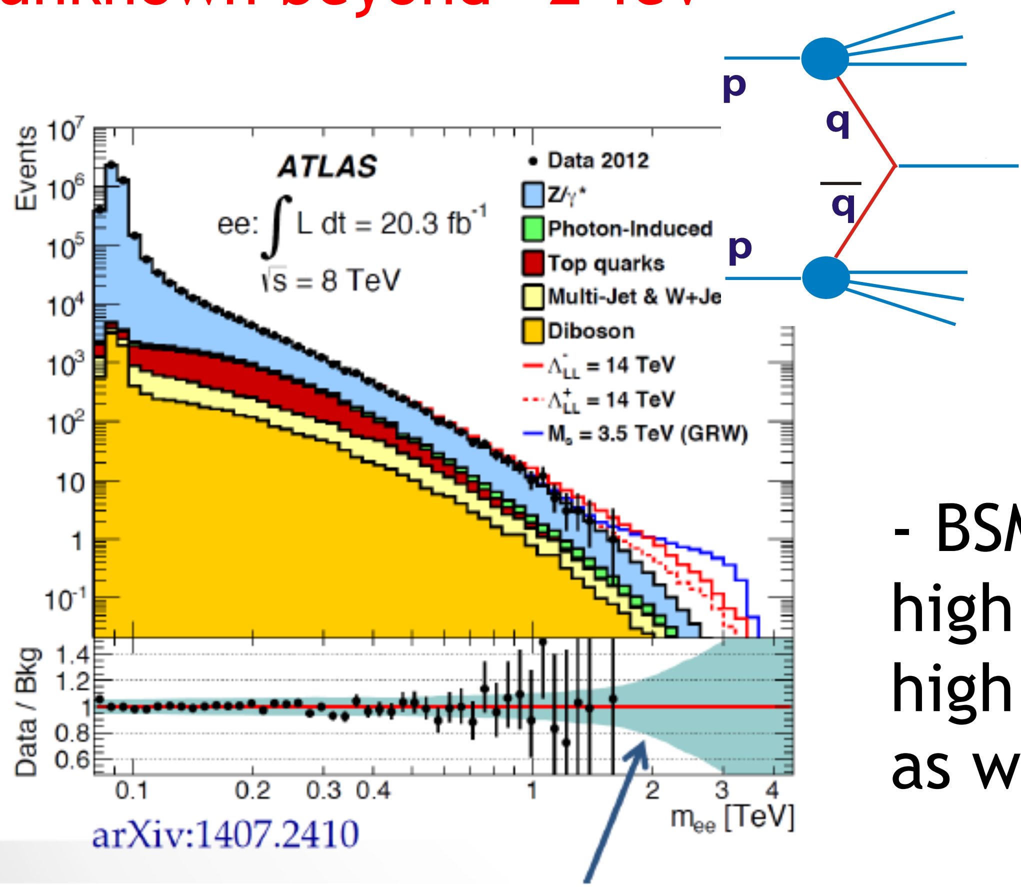


[Dashed regions = scale & PDF contributions

PDFs → New High Mass LHC Particles

- Gluino signature is excess @ large invariant mass
- Both signal & background uncertainties driven by error on gluon density … essentially unknown beyond ~2 TeV



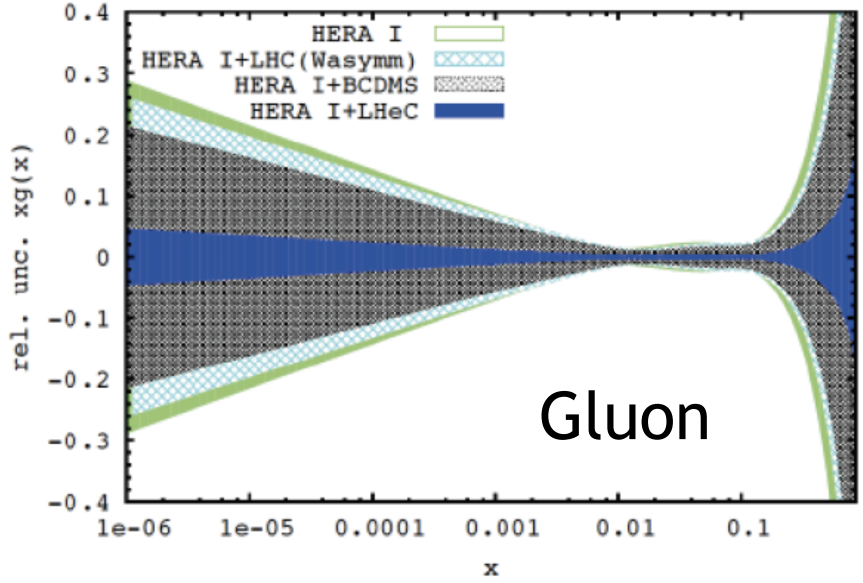


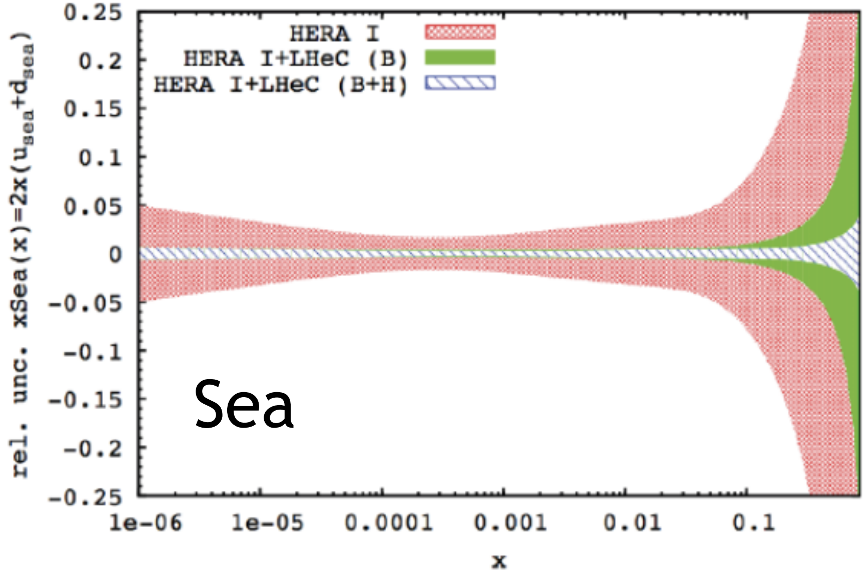
arXiv:1407.2410

- BSM sensitivity through excess in high mass Drell-Yan limited by high x antiquark uncertainties as well as valence

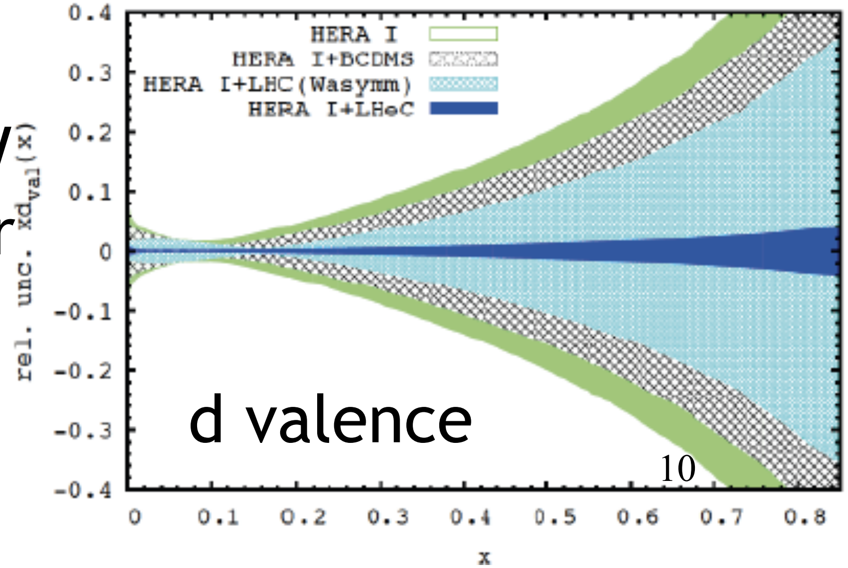
PDF Constraints at LHeC

Full simulation of inclusive NC and CC DIS data, including systematics → NLO DGLAP fit using HERA technology…

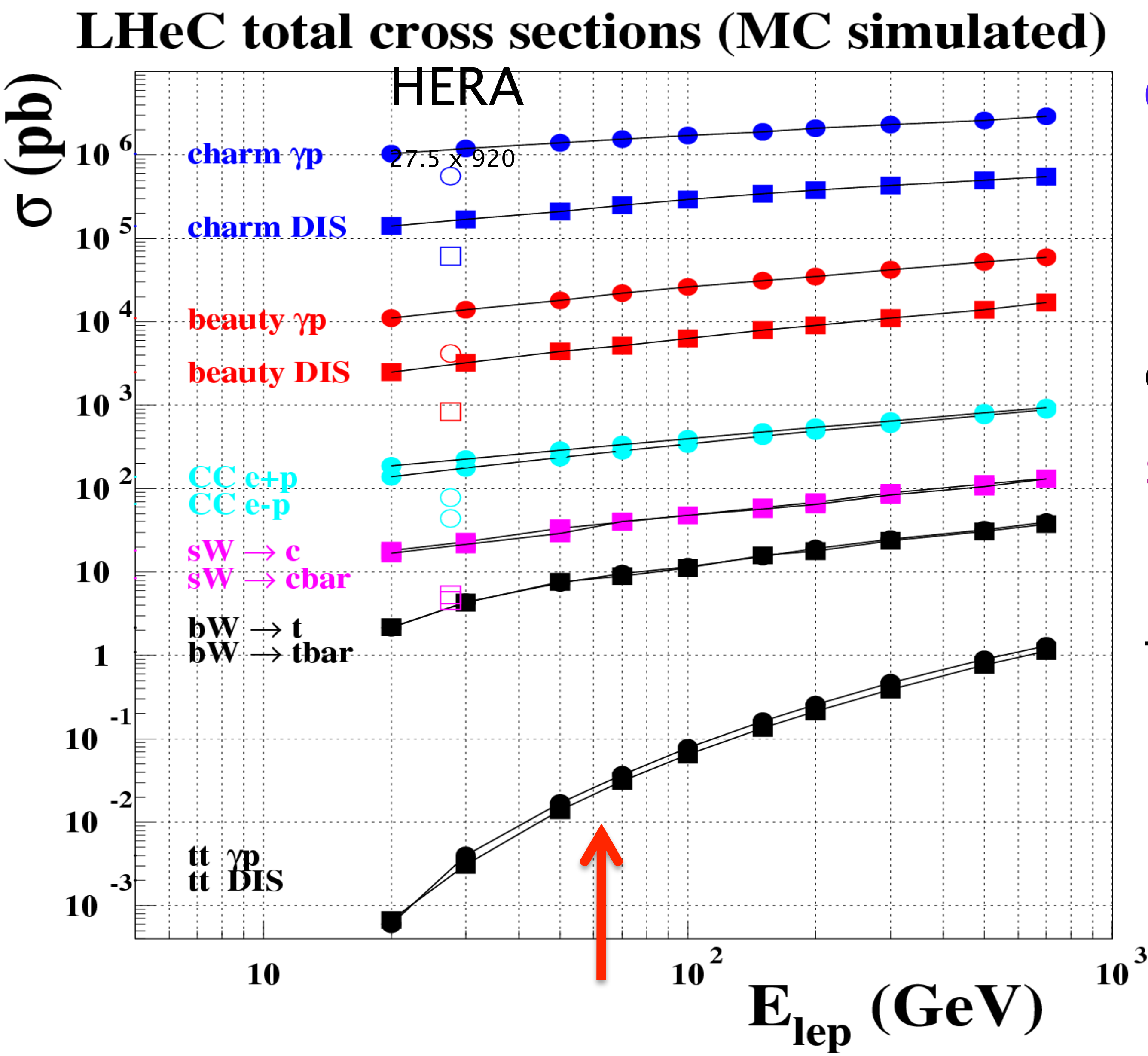




- Low x → novel QCD / unitarity
- Medium x → precision Higgs and EW
- High x → new particle mass frontier
- Per-mille experimental α_s precision
- Full Flavour decomposition



Cross Sections and Rates for Heavy Flavours



Charm [10^{10} / 10 fb^{-1}]

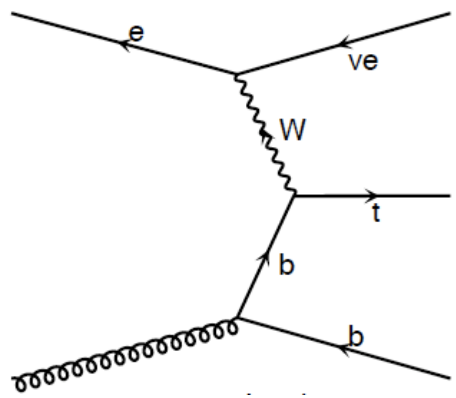
Beauty [10^8 / 10 fb^{-1}]

cc

sW → c [4.10^5 / 10 fb^{-1}]

bW → t [10^5 / 10 fb^{-1}]

ttbar [10^3 / 10 fb^{-1}]



c.f. luminosity of ~10-100 fb^{-1} per year

…

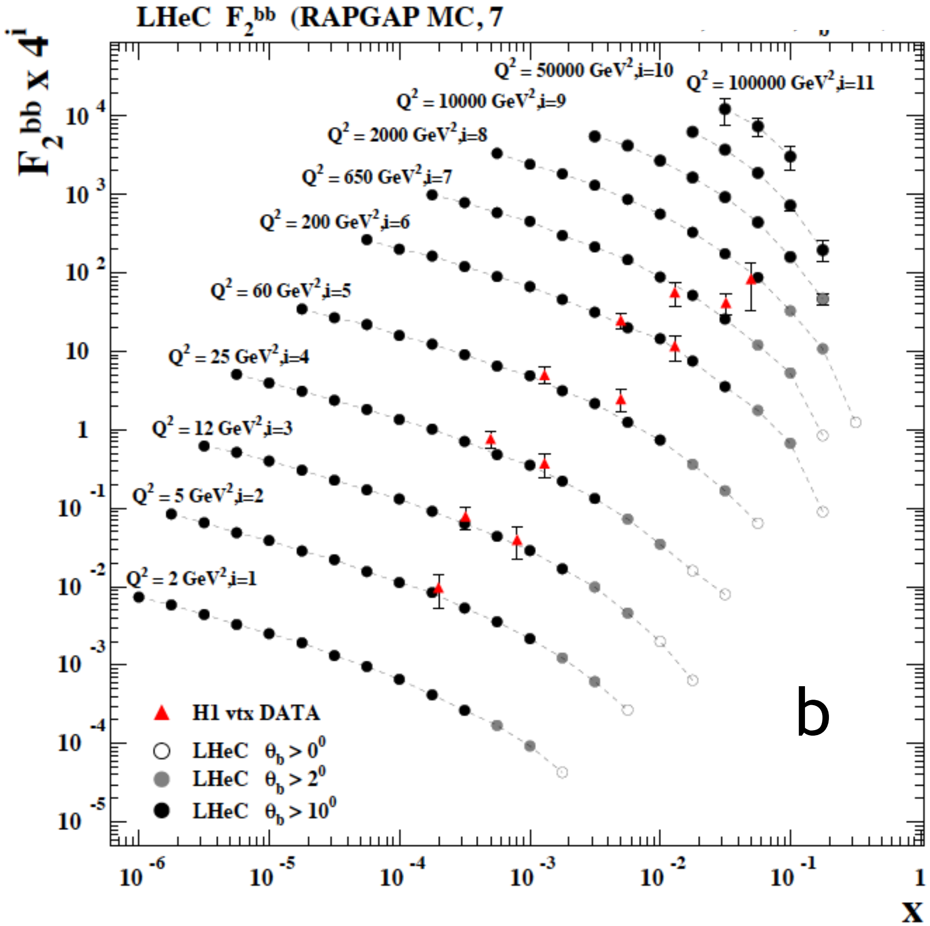
Flavour Decomposition

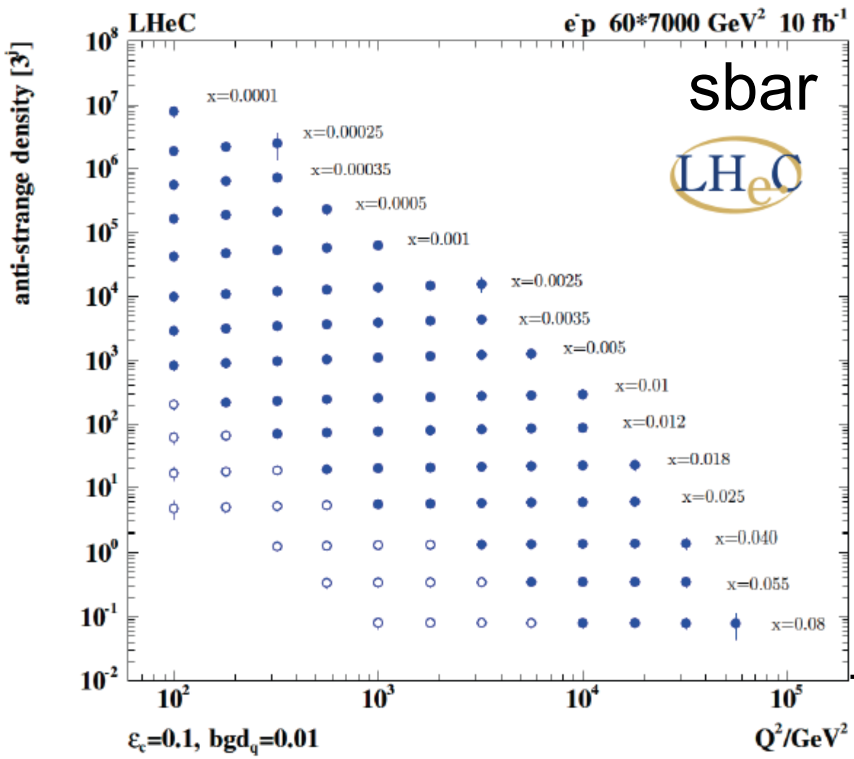
Precision c, b measurements (modern Si trackers, beam spot 15 * 35 μm^2 , increased HF rates at higher scales).

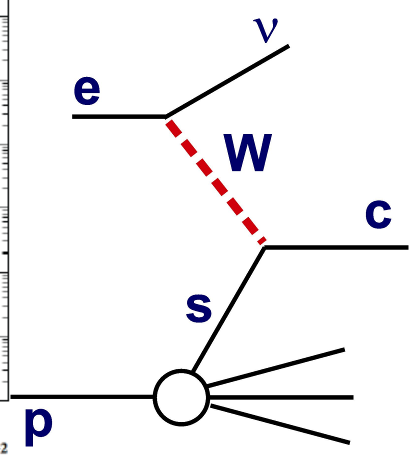
Systematics at 10% level

→beauty as a low x observable

→s, sbar from charged current

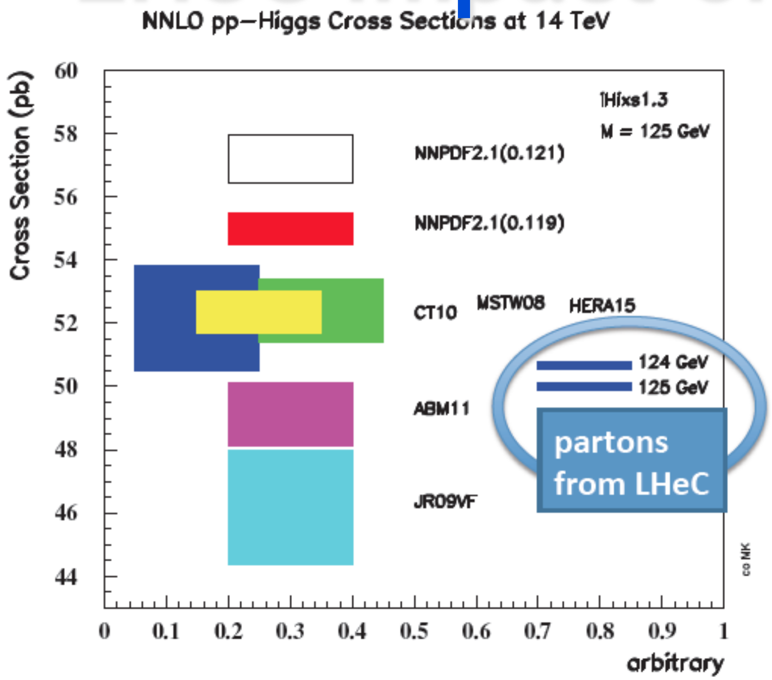






(Assumes 1 fb^{-1} and
- 50% beauty, 10% charm efficiency
- 1% uds → c mistag probability.
- 10% c → b mistag)

LHeC Impact on LHC Higgs PDF Unc'ty

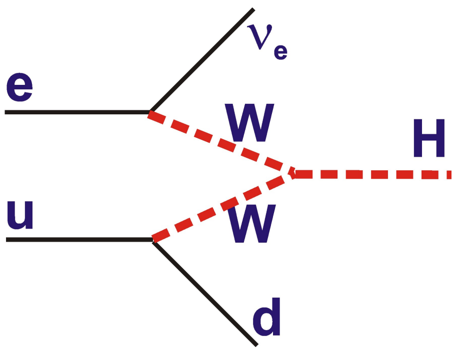


... needs N^3LO Higgs calculation

... needs improved α_s measurement (also @ LHeC)

c.f. experimental uncertainty ~0.25%

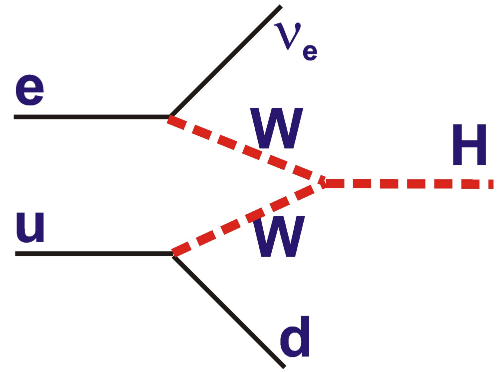
Higgs Production at LHeC & FCC-eh



Estimated integrated yields ...

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

A Direct Higgs Study

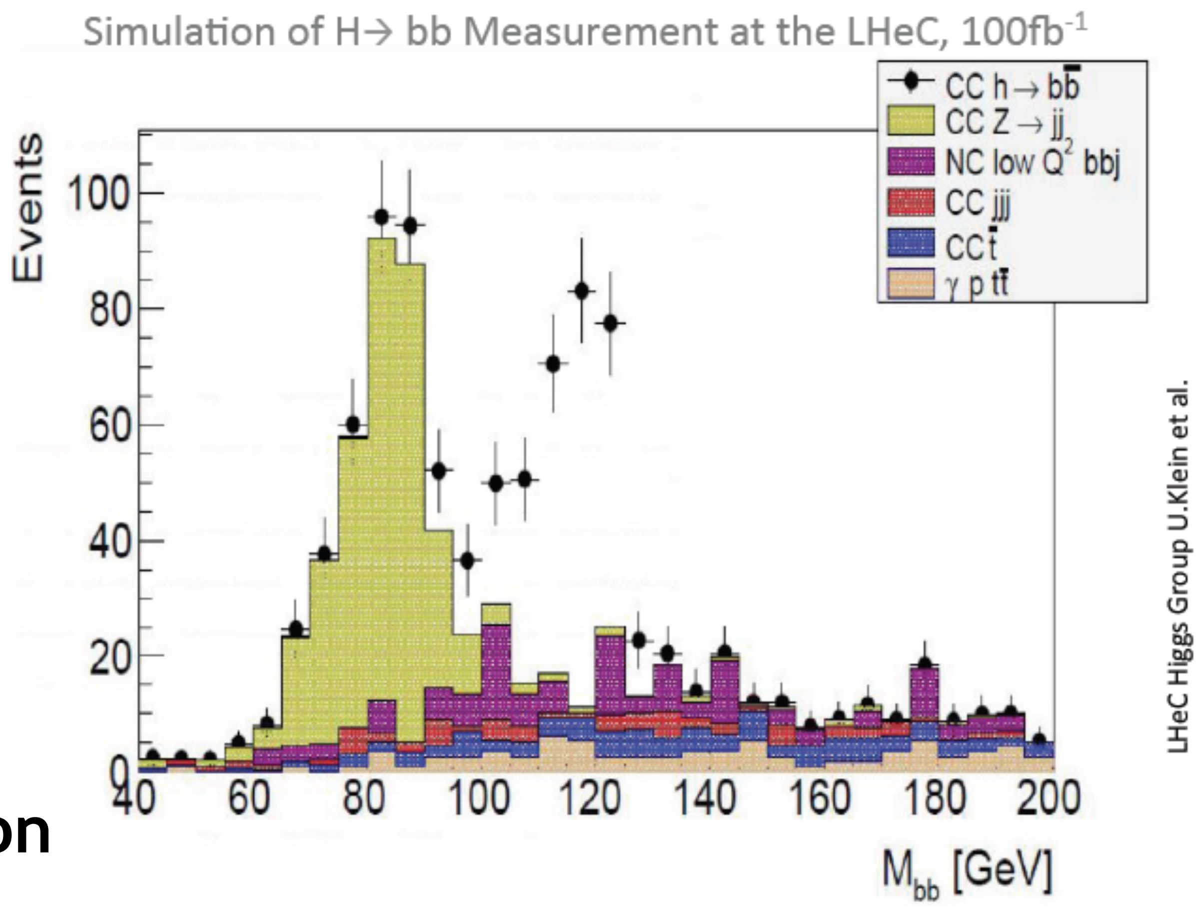


Study of H → bbbar in generic simulated LHC detector

- 80% lepton polarisation enhances signal by factor 1.7

- Signal/Background ~ 1-2

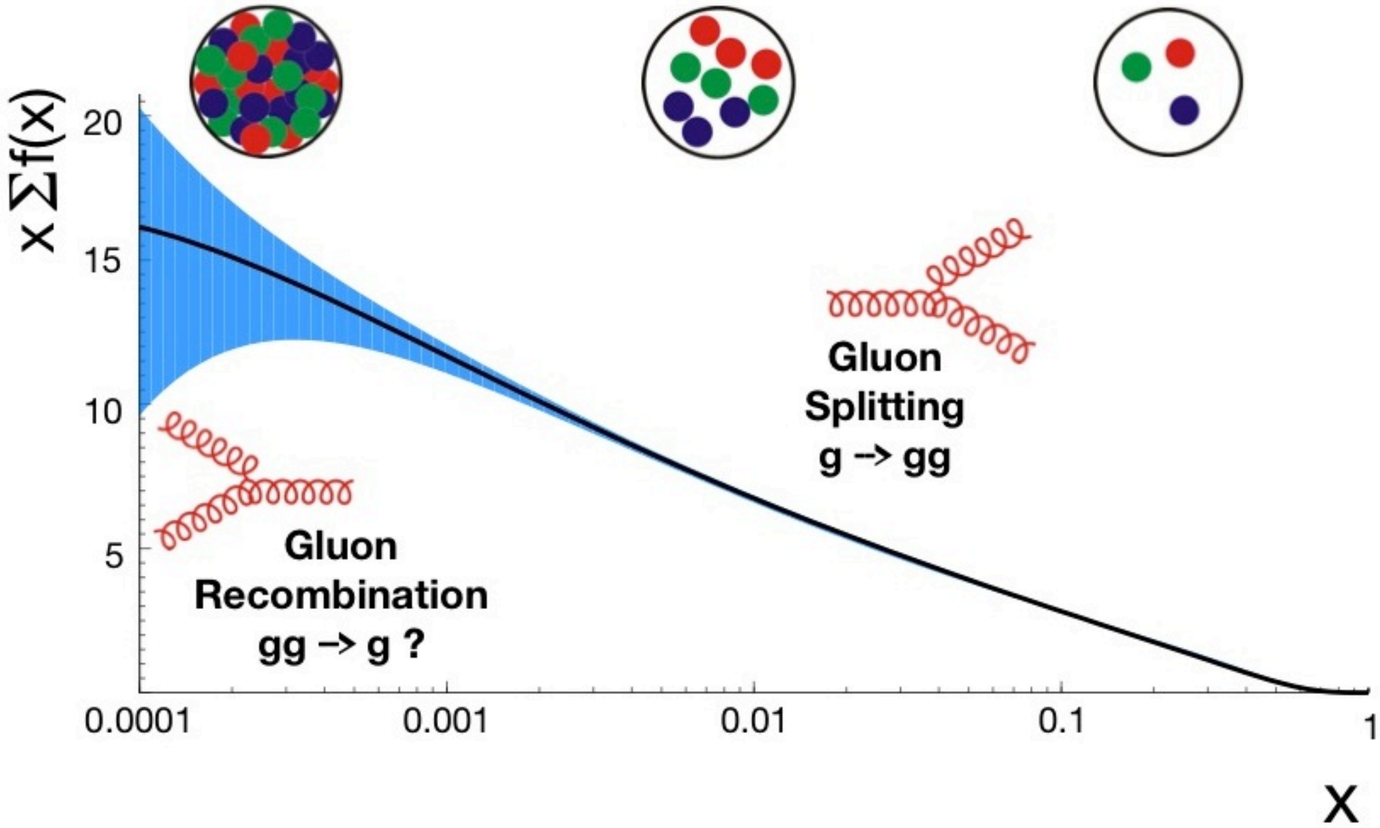
- With 10^{34} luminosity, x10 more data
  → ~1% H→bbbar coupling …
way beyond LHC precision



… ongoing studies of LHeC H→ccbar and FCC-eh possibilities

Low-x Physics and Parton Saturation

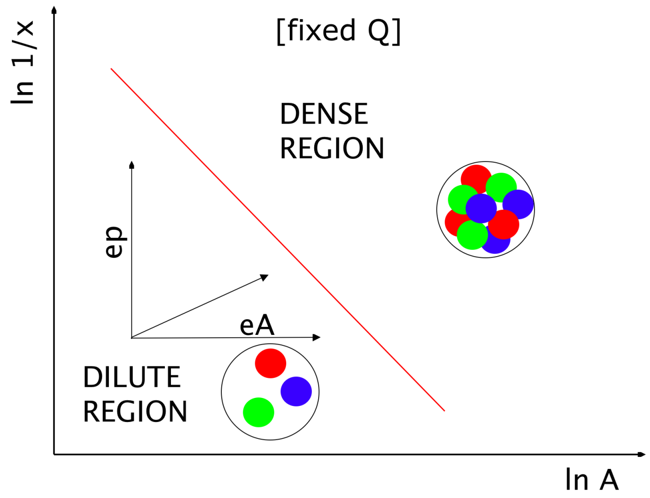
- Somewhere & somehow, the low x growth of cross sections must be tamed to satisfy unitarity … non-linear effects



→ new high density, small coupling parton regime of non-linear parton evolution dynamics (e.g. Colour Glass Condensate)? …
… gluon dynamics → confinement and hadronic mass generation

Some limited evidence from HERA, LHC picture (e.g pPb) unclear

LHeC: Accessing saturation region at large Q^2

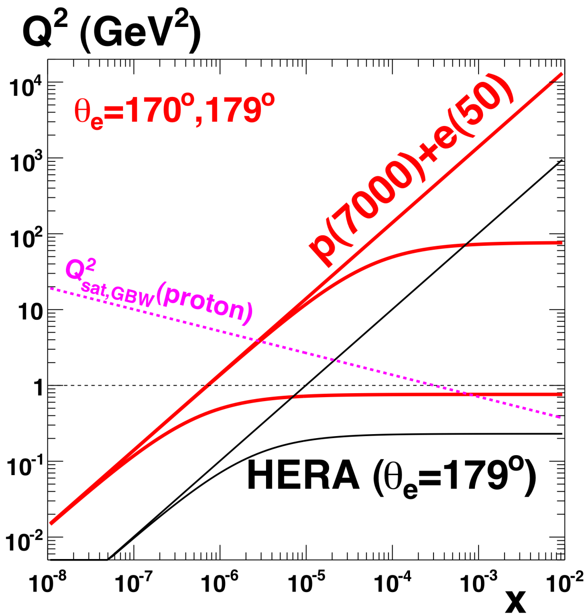


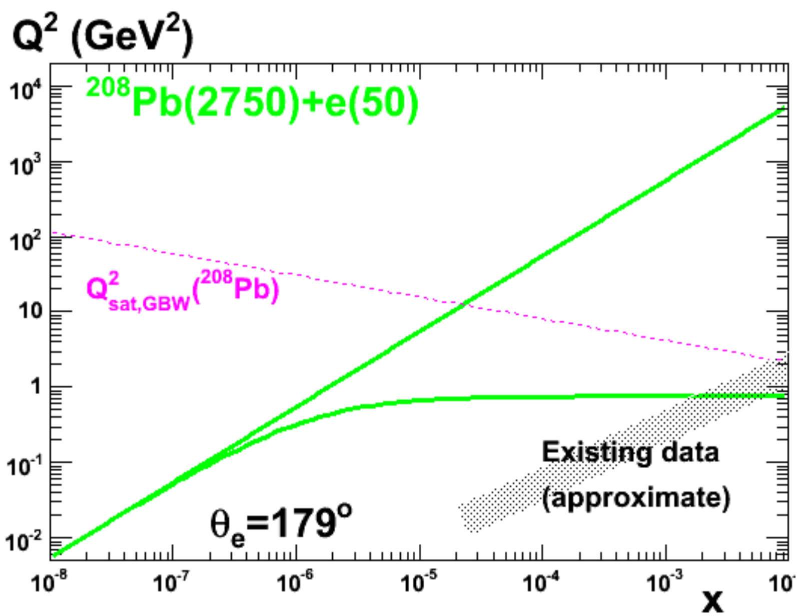
LHeC delivers a 2-pronged approach:

Enhance target `blackness' by:

1) Probing lower x at fixed Q^2 in ep
   [evolution of a single source]

2) Increasing target matter in eA
   [overlapping many sources at fixed kinematics …
   Density ~ $A^{1/3}$ ~ 6 for Pb … worth 2 orders of magnitude in x]

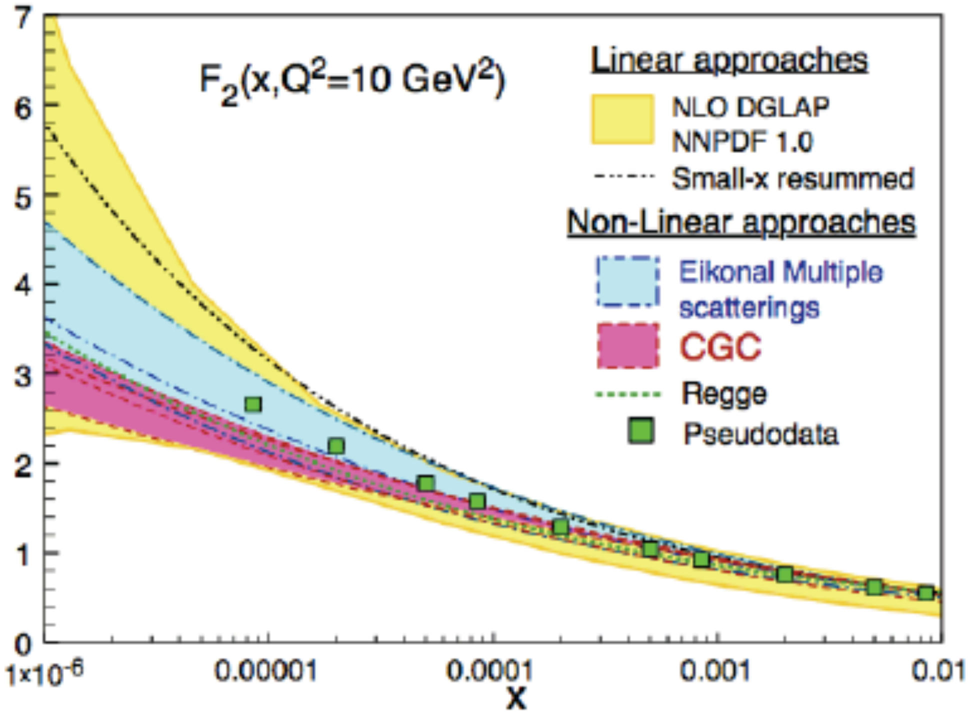


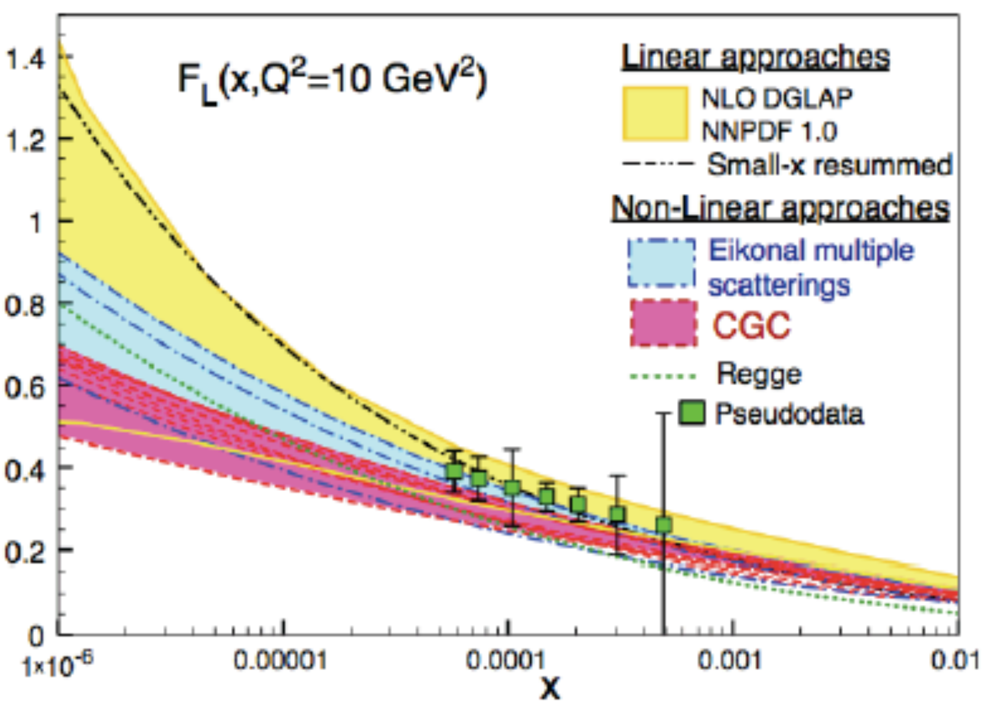


… Reaches saturated region in both ep & eA inclusive data according to models

Establishing and Characterising Saturation

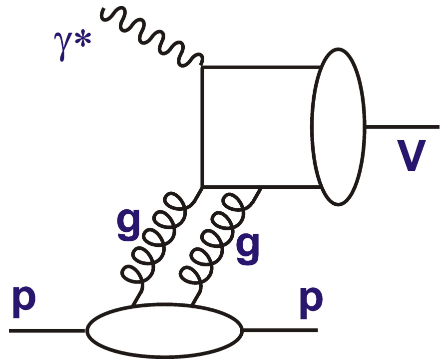
With 1 fb^{-1} (1 month at 10^{33} cm^{-2} s^{-1}), F_2 stat. < 0.1%, syst, 1-3%
F_L measurement to 8% with 1 year of varying E_e or E_p





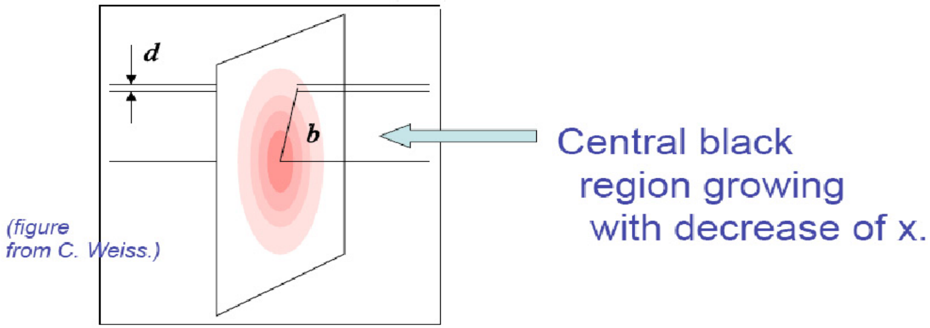
- LHeC can distinguish between different QCD-based models for the onset of non-linear dynamics
- Unambiguous observation of saturation will be based on tension between different observables e.g. F_2 v F_L in ep or F_2 in ep v eA

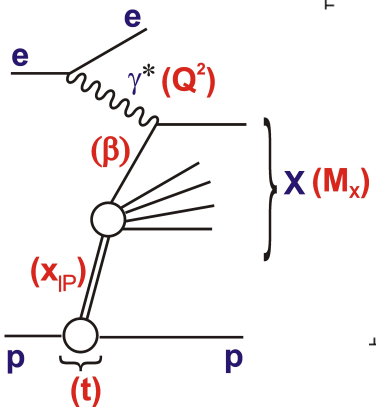
Exclusive / Diffractive Channels and Saturation

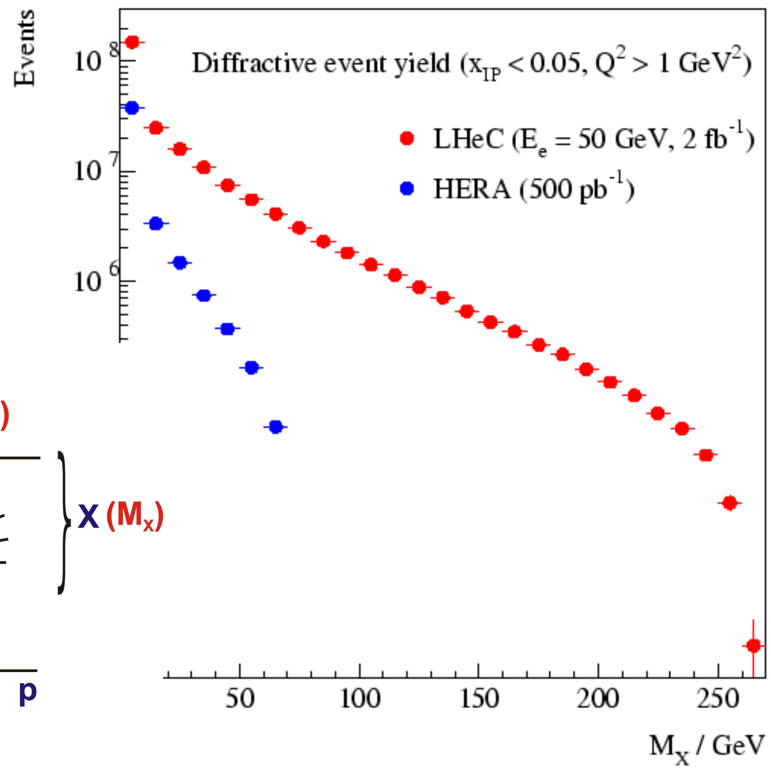


• [Low-Nusinov] interpretation as 2 gluon exchange → enhanced low x gluon sensitivity

• Additional variable t provides impact parameter (b) dependent amplitudes → Large t (small b) probes densest region of proton



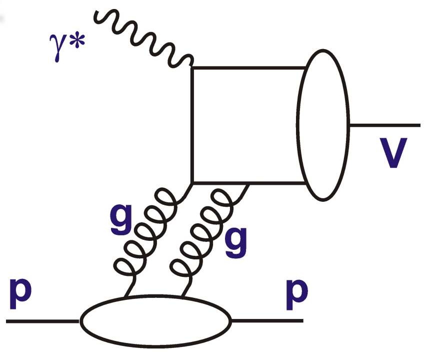




→ Investigations of exclusive VM production, DVCS, inclusive diffraction & diffractive dijets

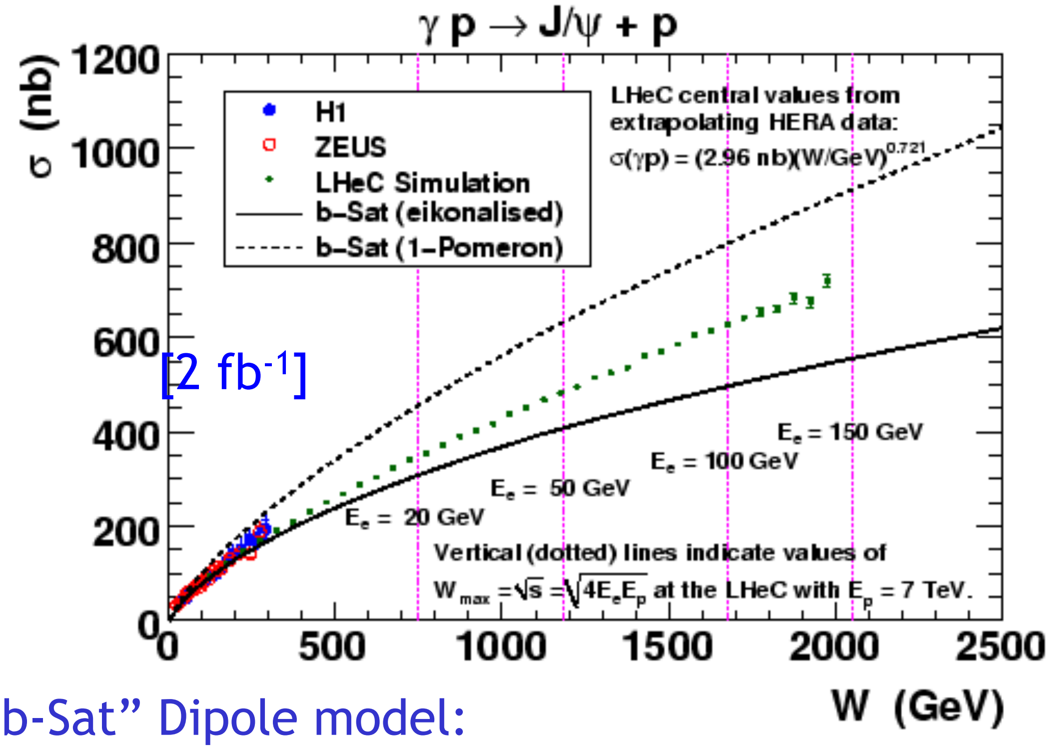
→ Any 1^- system with mass up to 250 GeV accessible

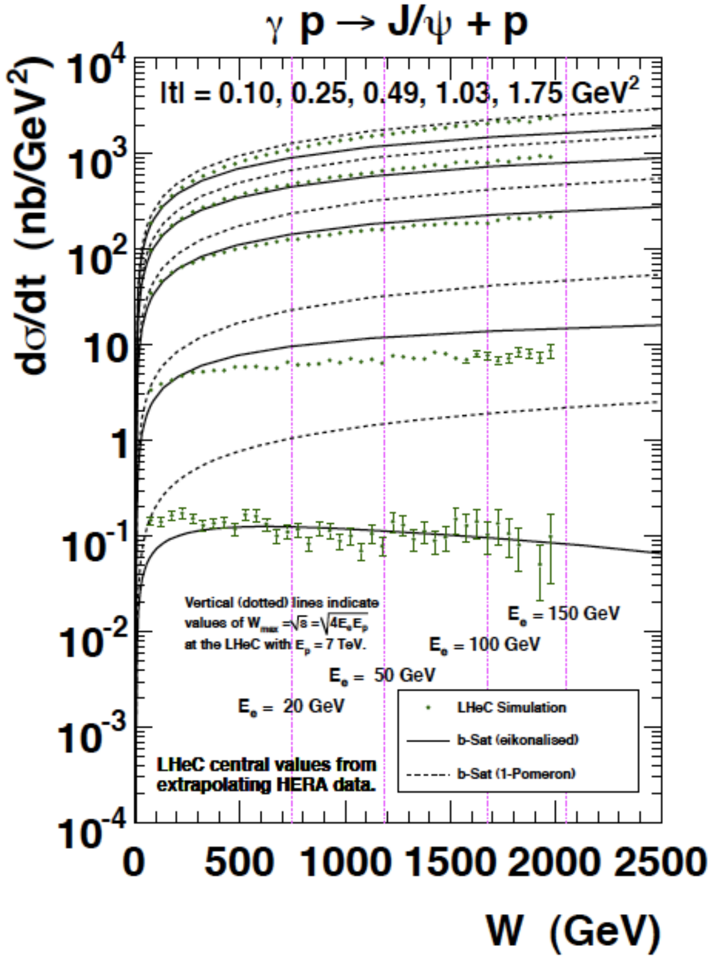
e.g. J/ψ Photoproduction v W, t & Q^2



Precise kinematic reconstruction from decay μ tracks over wide W and Q^2 range to |t| ~ 2 GeV^2

- Significant non-linear effects expected in LHeC kinematic range

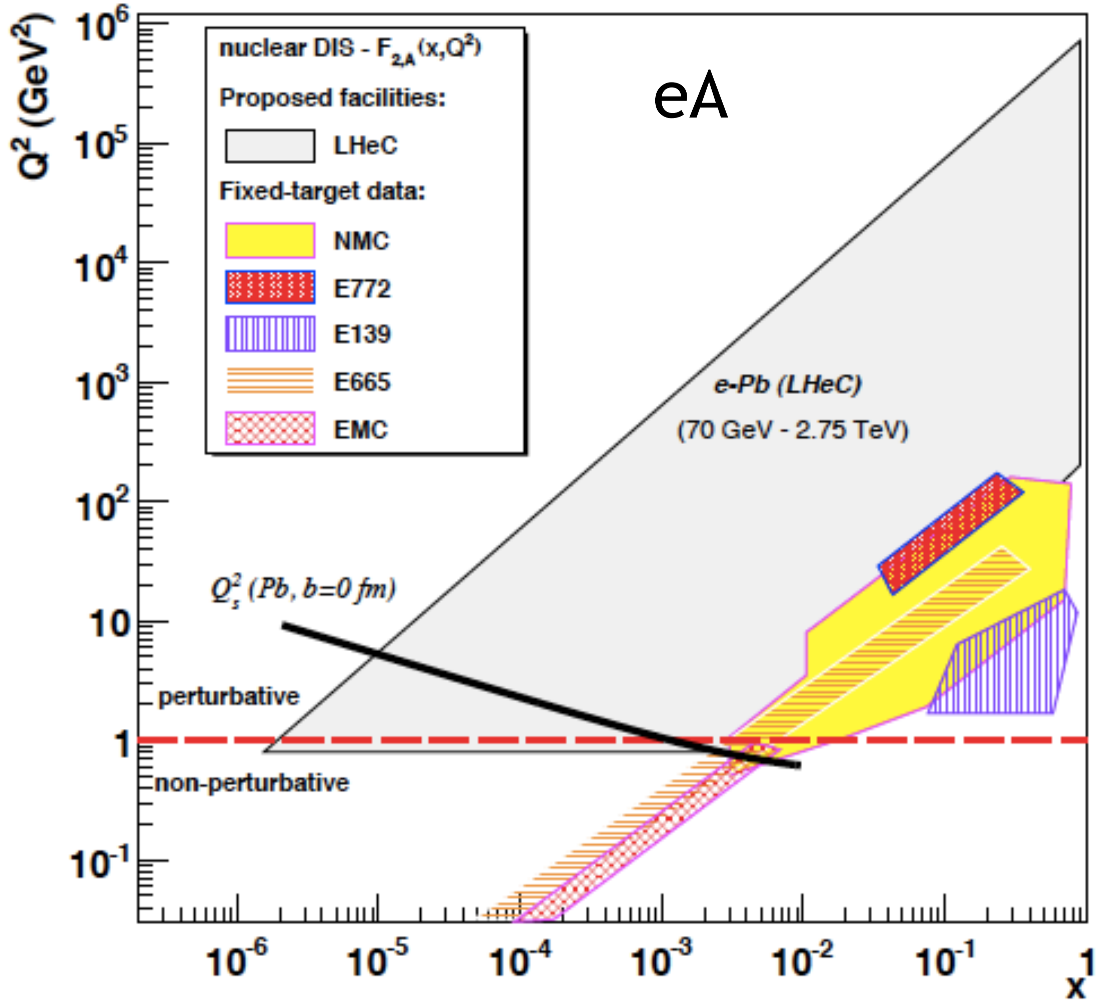




"b-Sat" Dipole model:
- "eikonalised" – with IP-dependent saturation
- "1 Pomeron": non-saturating

LHeC as an Electron-Ion Collider

Four orders of magnitude increase in kinematic range over previous DIS experiments → Wide ranging programme …

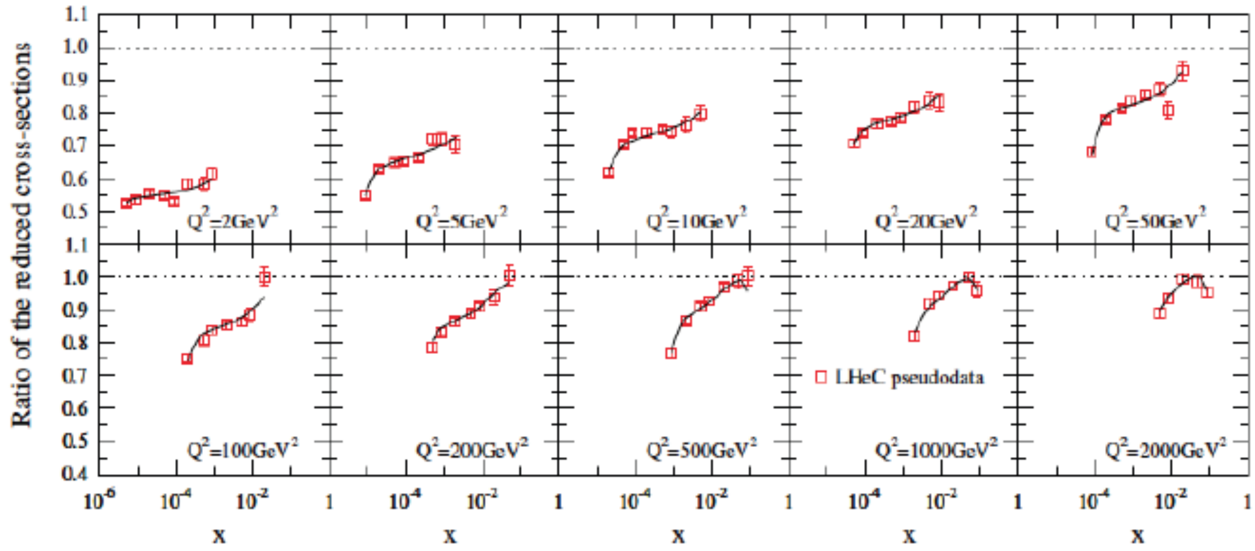


→ Revolutionises knowledge of nuclear partonic structure

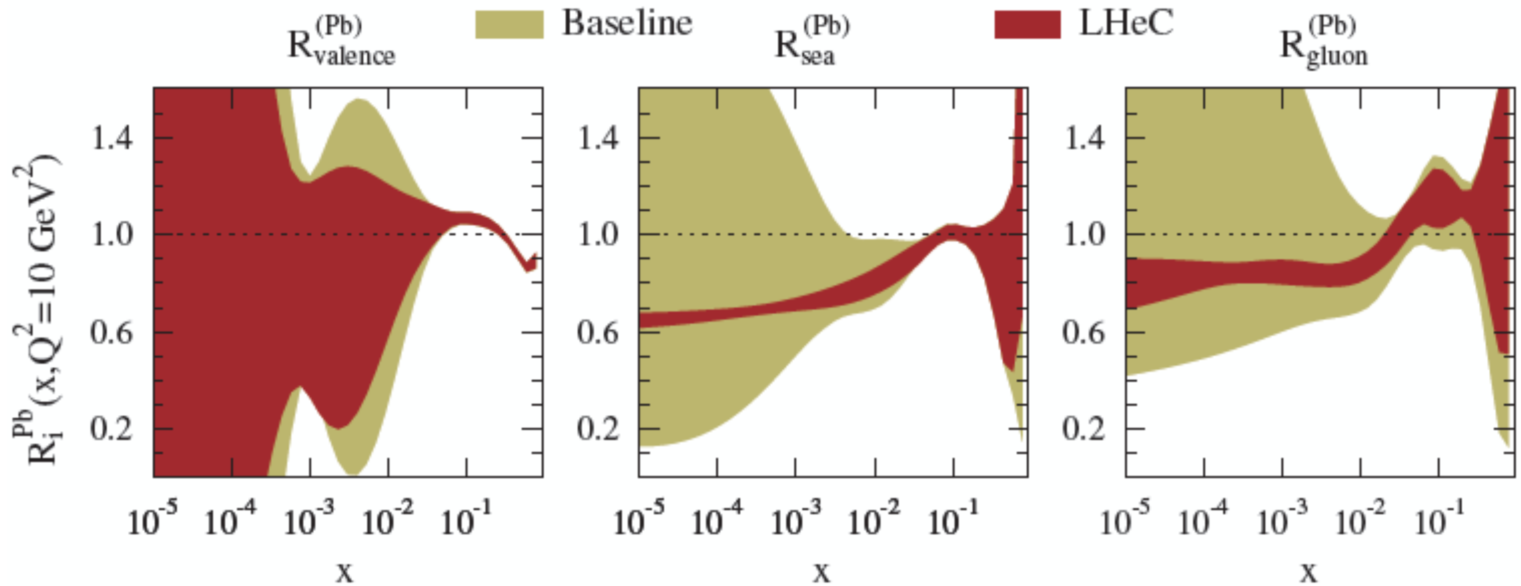
→ Low x / diffactive eA programme gives additional lens on densely packed, weakly coupled, partons

→Ultra-clean probe of passage of `struck' partons through cold nuclear matter

Impact of Simulated ePb LHeC F_2 & F_L data

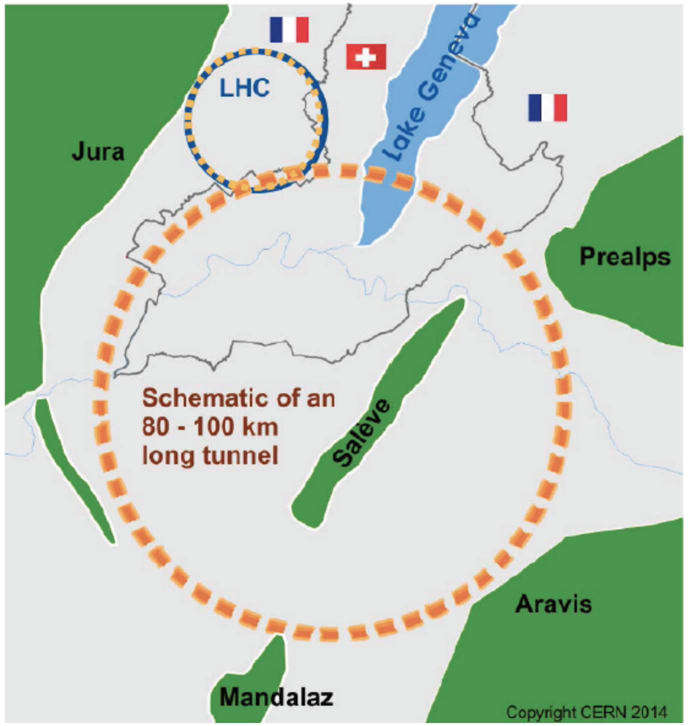


- Studies in context of EPS'09 nPDF set, with more flexible low x parameterisation at starting scale …
- LHeC data have huge impact on low x gluon & sea uncertainties



R_i = Nuclear PDF i / (A * proton PDF i)

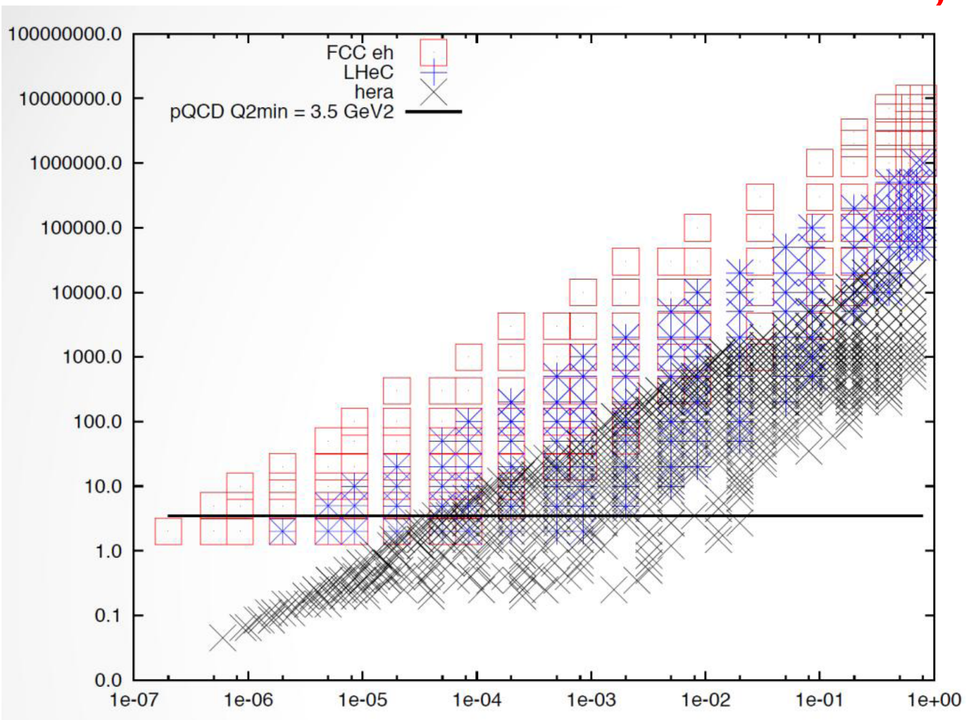
First Thoughts on FCC-he



Ongoing work based on similar electron ERL to LHeC, with 50 TeV protons

Detector is scaled-up version of LHeC [shower depths x ln(50/7)~2]

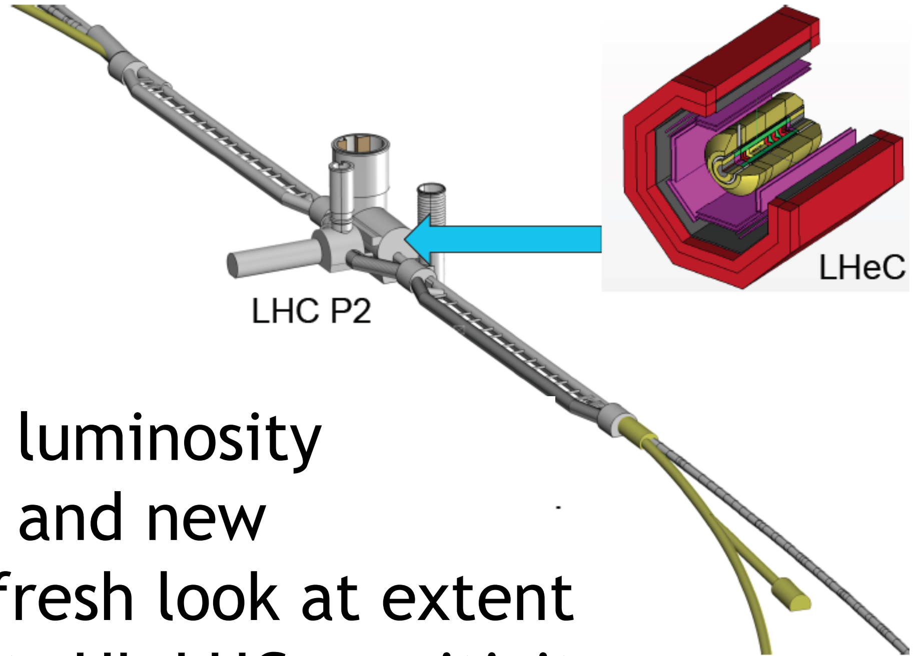
-Total FCC-he H x-sec ~ 1 pb, lumi ~ 10^{34} $cm^{-2}s^{-1}$, H→HH x-sec ~0.5 fb in range?...



- Sensitive to quark density down to x~10^{-7} for Q^2>1 GeV^2,
- Gluons to ~10^{-6},
- Hadronic final state to W → 4 TeV

... Studies just beginning

Summary



- LHeC CDR 2012 + ongoing work

- Renewed interest following
  1) Possibility of 10^{34} cm^{-2} s^{-1} luminosity
  2) Higgs discovery, searches and new measurements at LHC→ fresh look at extent to which PDFs / QCD limits HL-LHC sensitivity.
  3) Associated technical developments (High gradient cavities, Energy recovery linacs)
  4) Longer term perspective of LHC and possibility of FCC

- For more on recent updates, see also:
  - POETIC'15: (Nestor Armesto, Claire Gwenlan, Max Klein)
  - Slides from recent LHeC Chavannes Workshop (June 2015)
  - LHeC web: http://lhec.web.cern.ch