Prospects to measure xQ (Q=s,c,b,t) at the LHeC

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Light
Charm
Beauty
Top
Strange
LHeC

LHeC

http://lhec.web.cern.ch
CDR 2012, Update 2018
ep (and eA) at the LHC

For the LHeC Study Group

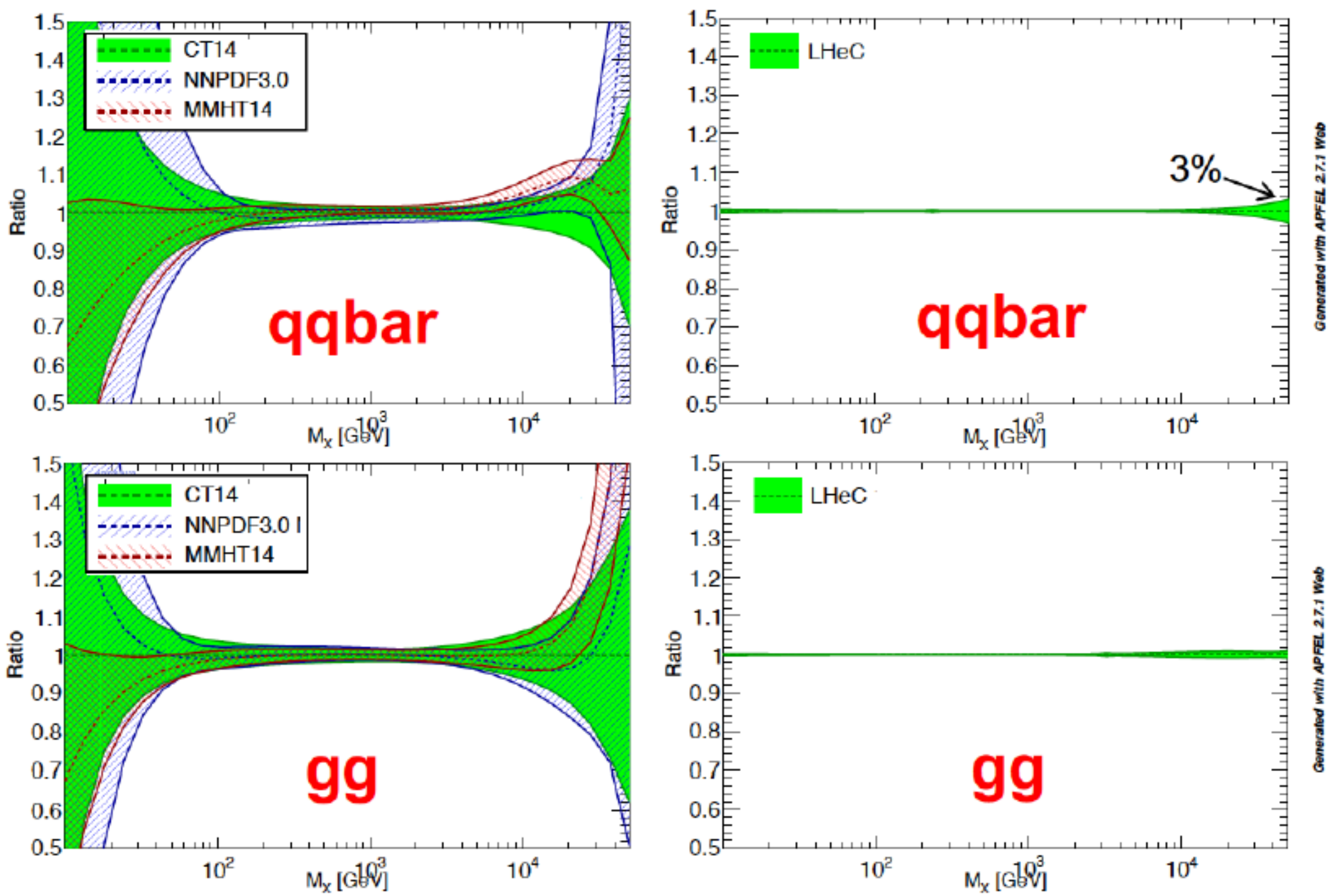
Presentation to the HL-HE LHC Workshop, CERN, 31.10.2017

The LHeC PDF Programme

Resolve parton structure of the proton completely: u_v,d_v,s_v?,u,d,s,c,b,t and xg
Unprecedented range, sub% precision, free of parameterisation assumptions,
Resolve p structure, solve non linear and saturation issues, test QCD, N^3LO…

Strong Coupling in inclusive DIS at LHeC to 0.1%

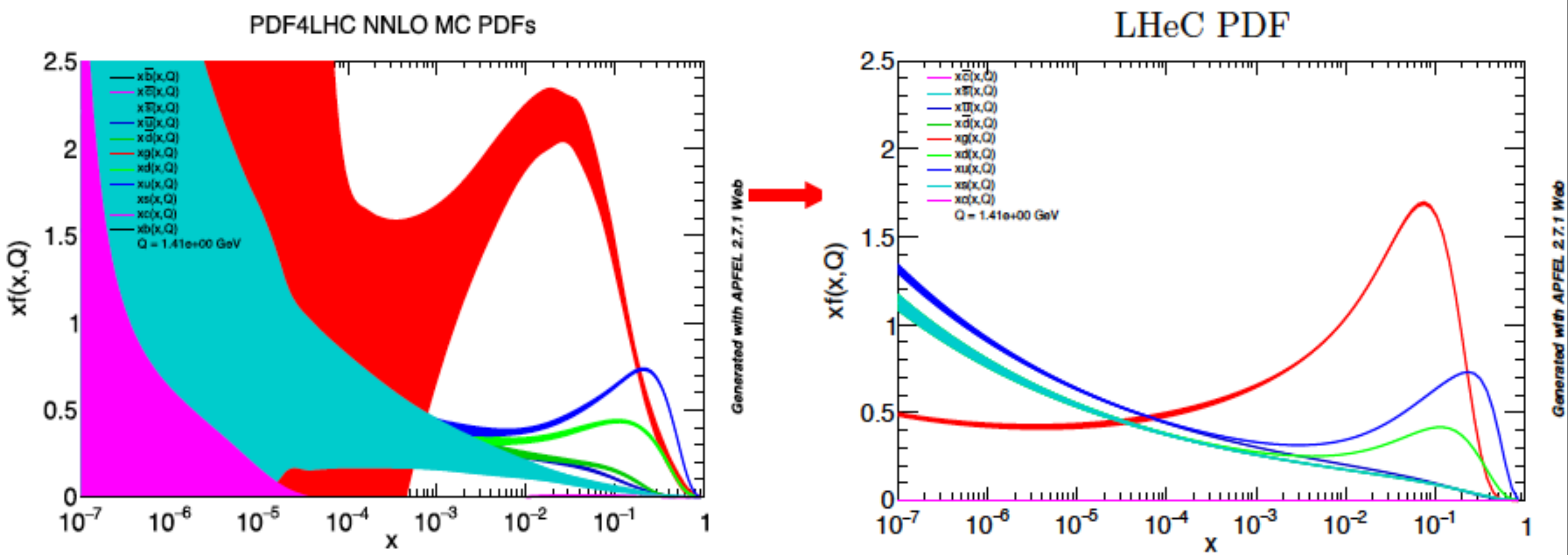
Lattice??
Jets??
BCDMS??
GUTs?
Higgs in pp



Note that LHC is about to reach its own limits on PDFs. pp is NOT DIS, cf ATLAS W,Z to 0.5%

M.Klein at DIS17

- Many other important QCD/EW measurements possible: **strong coupling** to 0.1% (exp), 0.5% (theor), **electroweak couplings**….
- Possibility for N^3LO PDF extraction (given splitting functions).



- **LHeC PDFs** available in **LHAPDF** format.
- Work **actively ongoing** on studies/projections. Expect updates next year for input to European Strategy.

For global PDF progress and ep discussion: see Lucian Harland-Lang, talk today in SM session

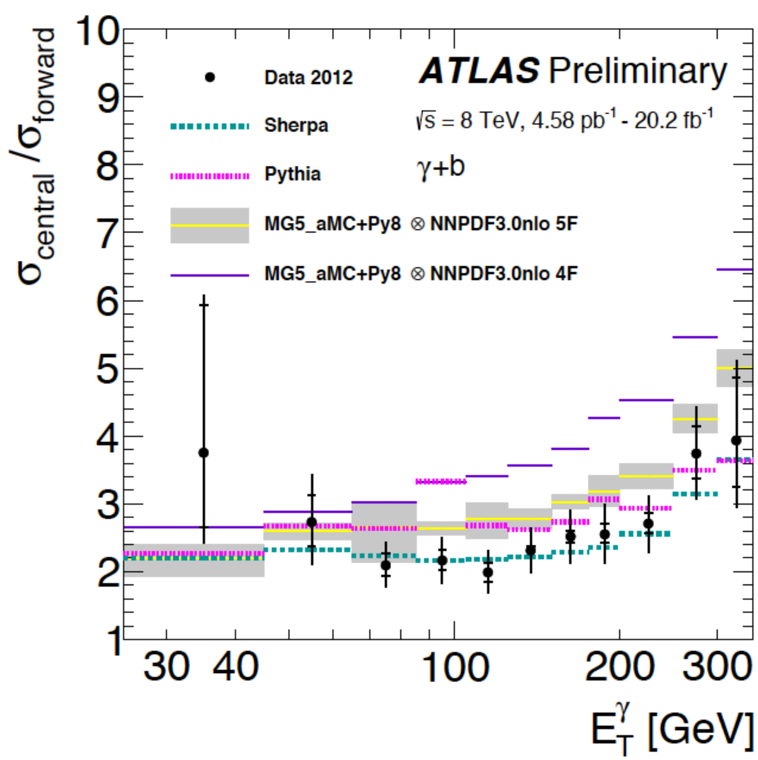
Charm

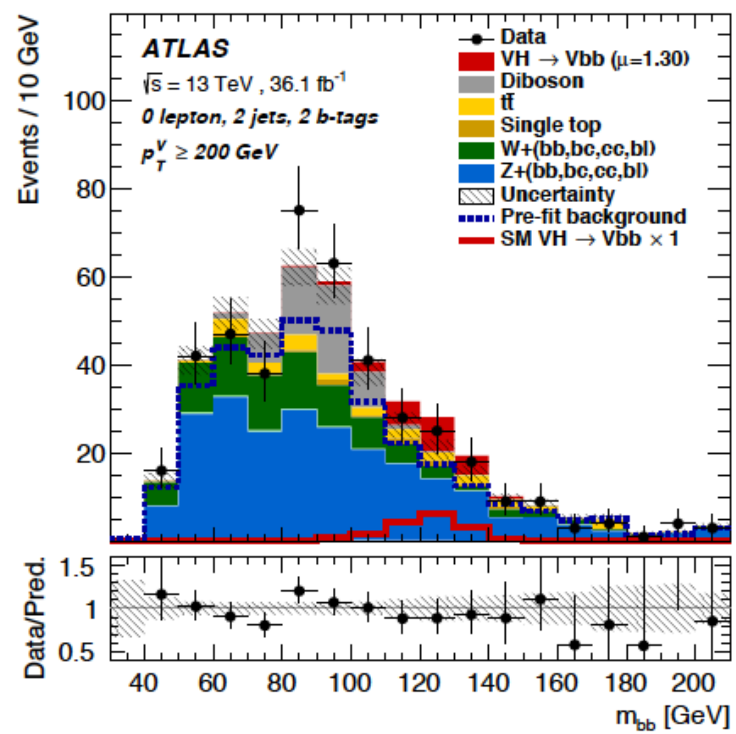
FFNS: massive charm, 3 active flavours, c from hard scattering, y/Z-g fusion to O(α_s)

VFNS: low Q^2 : FFNS, high $Q^2 >> m_c^2$ VFNS at zero mass

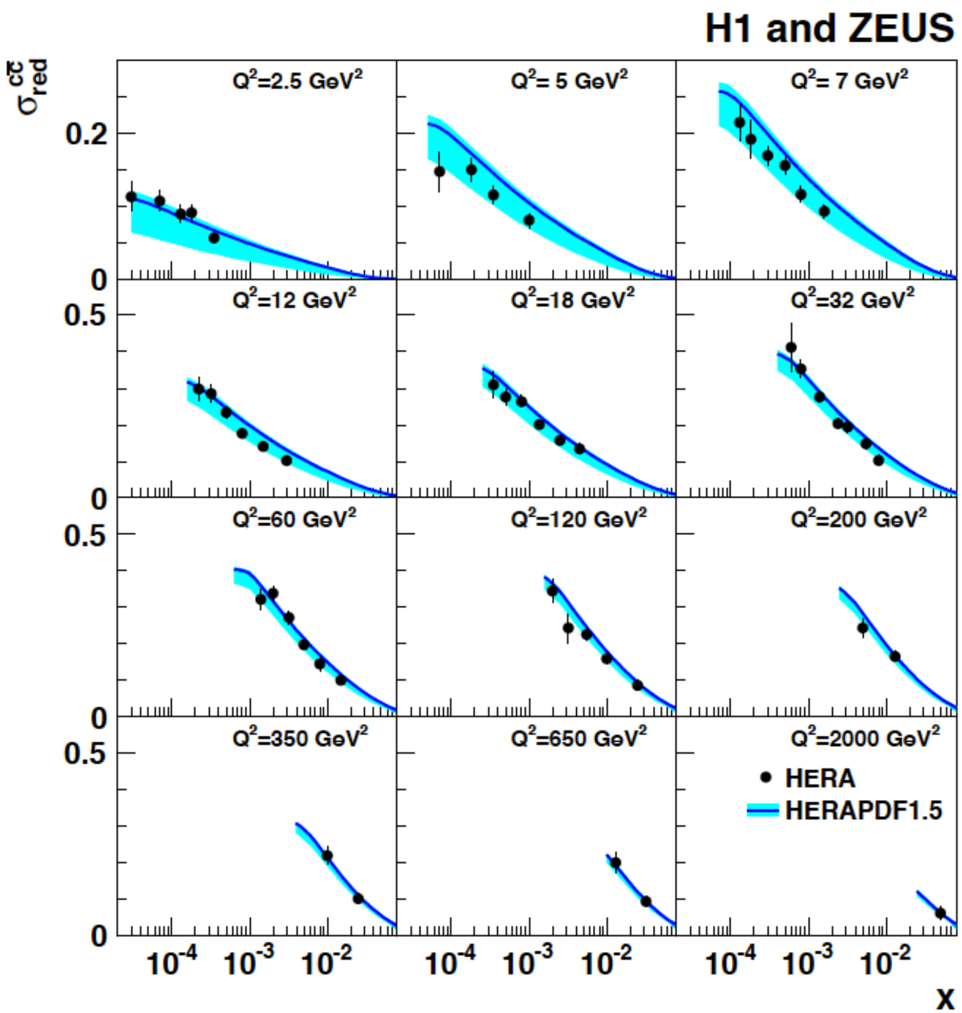
m_c ($\overline{MS}$) = m_c (pole) [1 –α_s/π-..) M_c in GM VFNS QCD analysis is 'effective parameter'

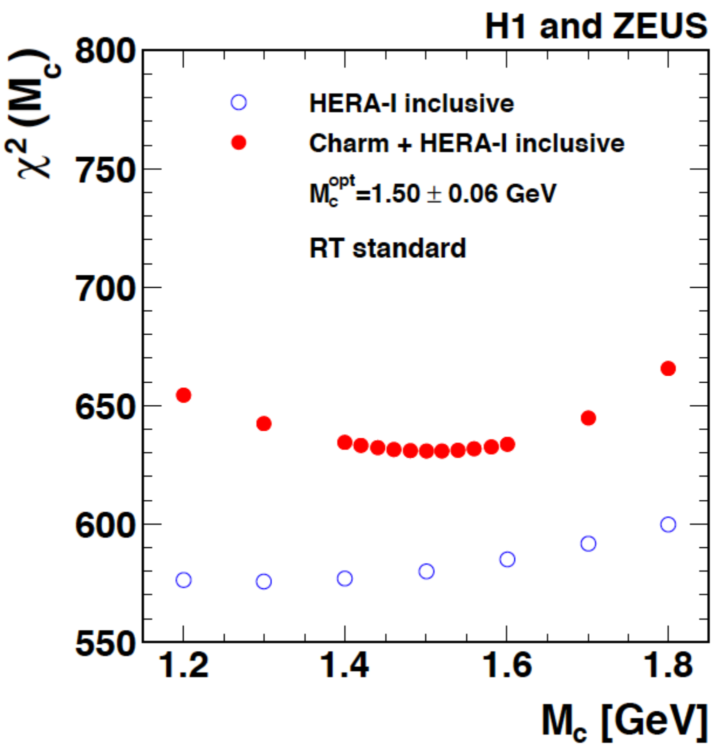
Treatment of heavy flavour and size of heavy quark densities are very important for QCD, electroweak and Higgs interpretations





HERA Charm



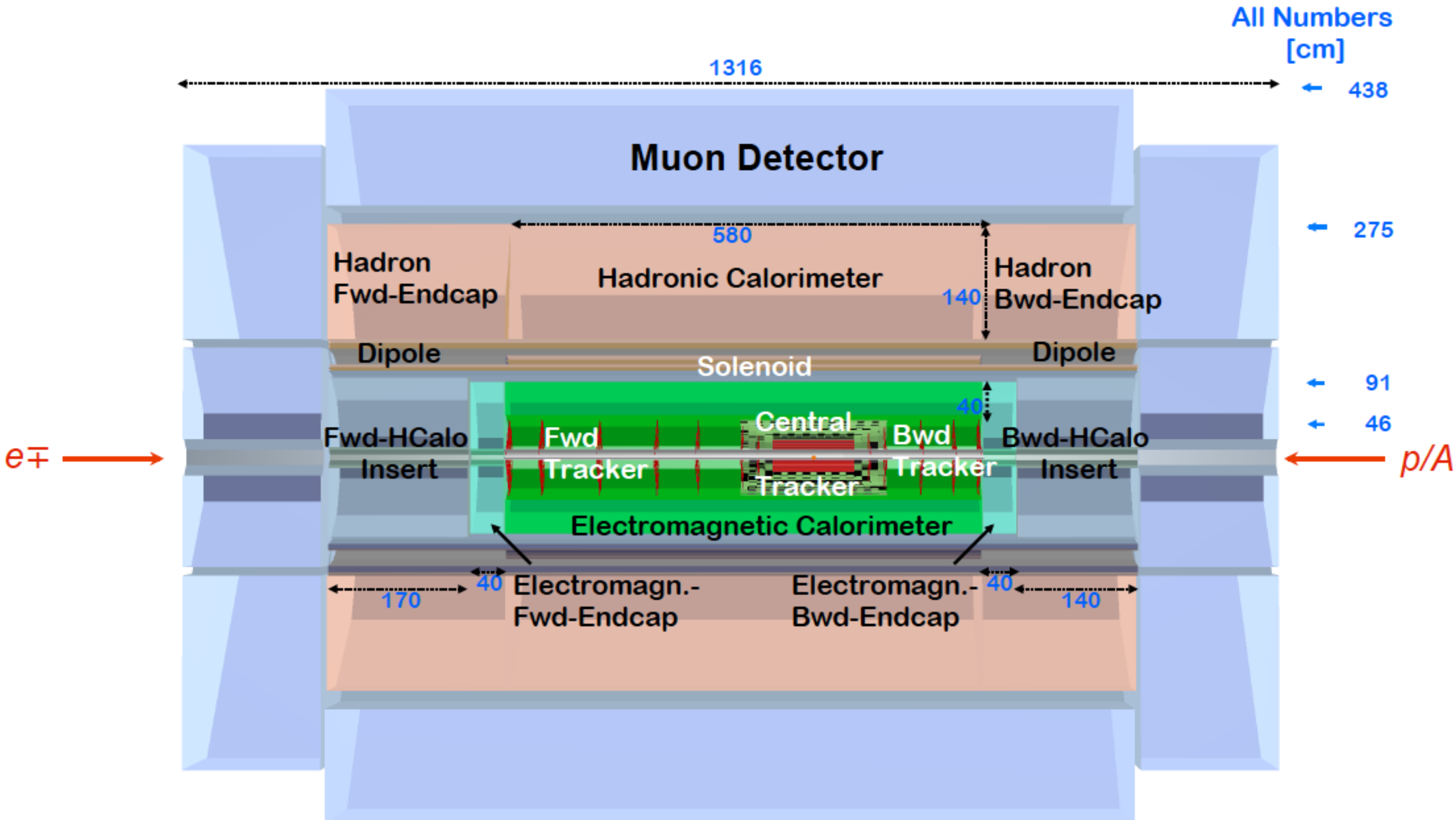


uncertainty on m_c O(50MeV)

Measurements of D* and impact parameters

Initial F_2^{cc} measurements by H1 and ZEUS
blue uncertainty largely from charm mass
(update imminent) DESY12-172

LHeC Detector 2016



P.Kostka: Status 11/16

Full acceptance collider detector, derived from HERA and LHC detectors, being updated
Three main challenges: interaction region, forward region and hadronic fs resolution

Silicon Tracker and EM Calorimeter

Transverse momentum $\Delta p_t/p^2_t \rightarrow 6\ 10^{-4}\ GeV^{-1}$
Resolution transverse impact parameter
→ O(10) µm

Status of CDR, 2012

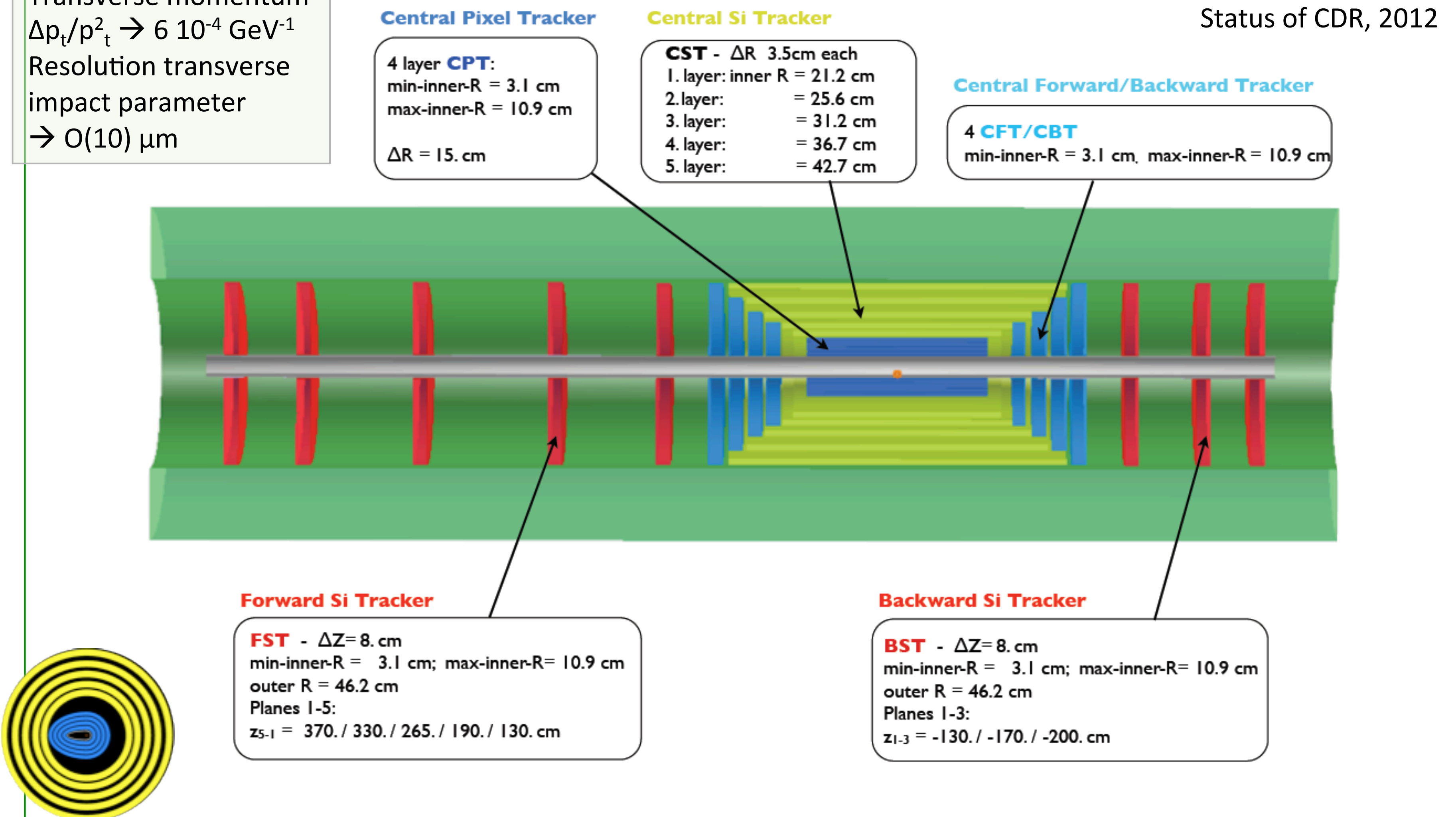
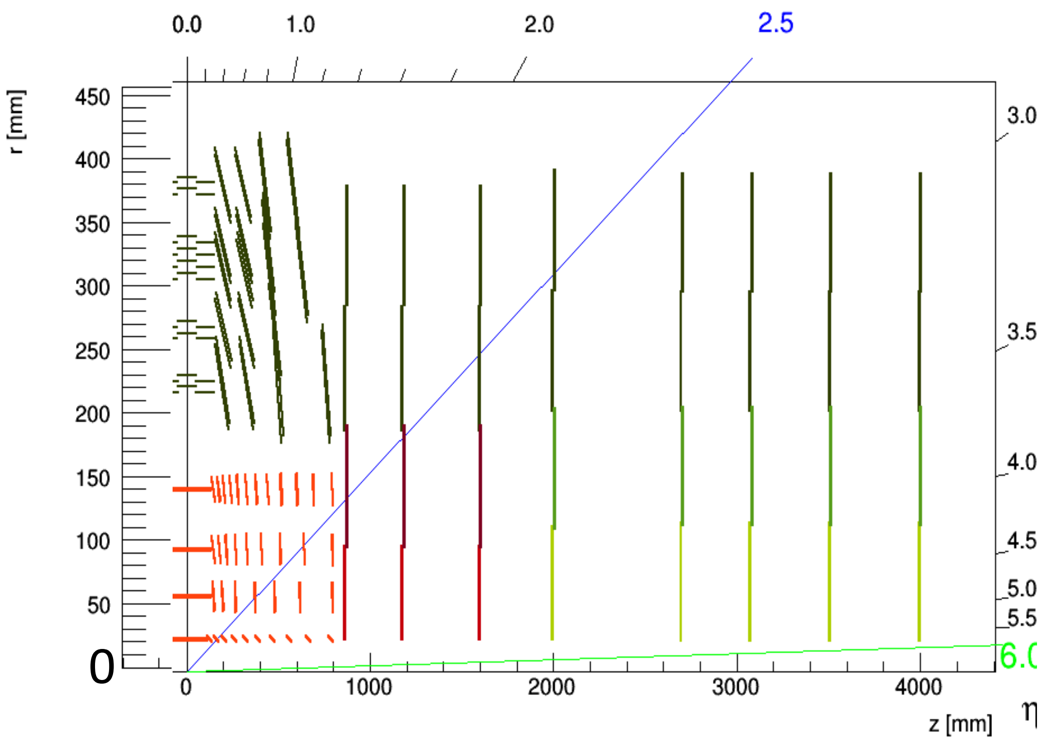
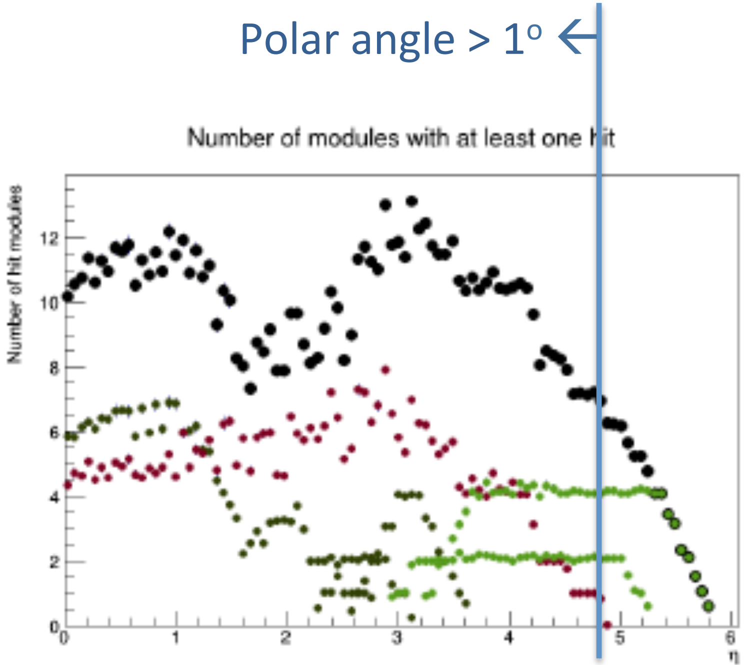


Figure 13.18: Tracker and barrel Electromagnetic-Calorimeter rz view of the baseline detector (Linac-Ring case).

LHeC-LHC: no pile-up, less radiation, smaller momenta, apart from forward region

Forward Tracking at LHeC

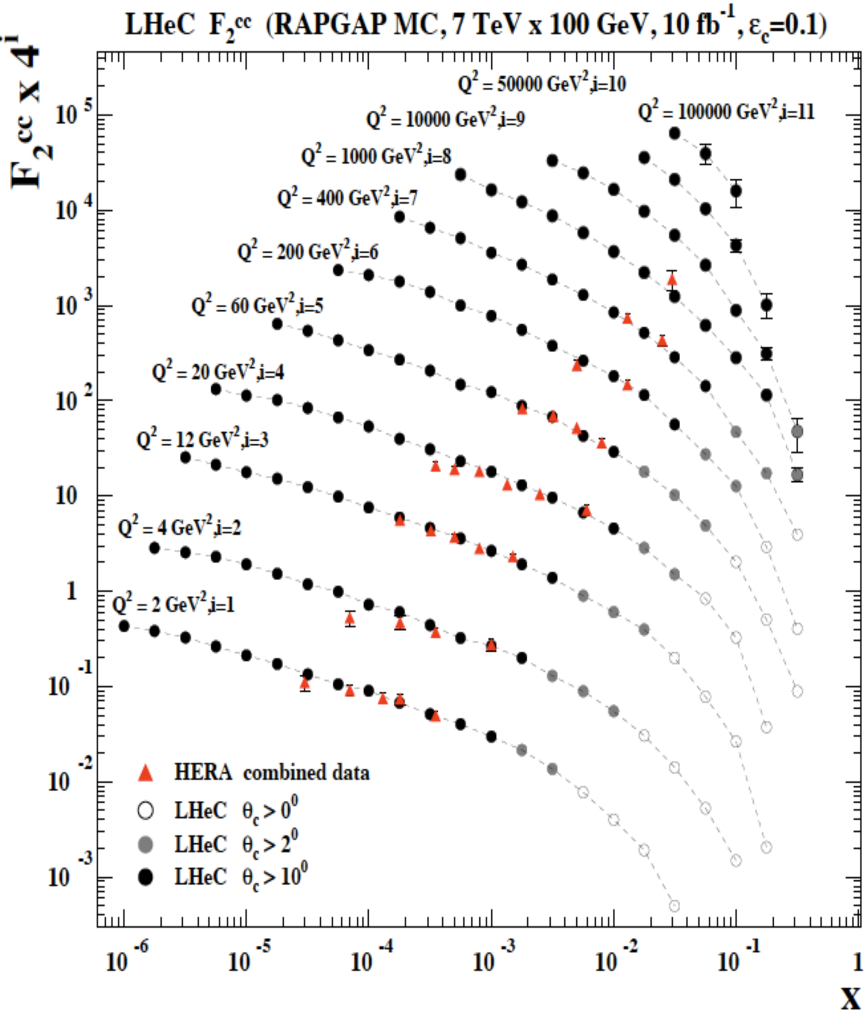




Work in progress, on tracker layout, with emphasis on forward acceptance, and technical issues as asymmetric beam pipe and material budget.
cf talks by A Pollini, P Kostka and A Gaddi
September LHeC workshop : https://indico.cern.ch/event/639067

Charm F_2^{cc} and Mass

LHeC CDR arXiv:1206.2913



HERA 0.0005/2.5 .. 0.05/2000 GeV²

LHeC 0.00001/1 .. 0.2/200000 GeV²

ε(c) assumed 10%, 1% light background, ~3% δ(syst)

Heavy Flavour with LHeC

Beam spot (in xy): 7μm

Impact parameter: better than 10μm

Modern Silicon detectors, no pile-up

Higher E, L, Acceptance, ε, than at HERA

→ Huge improvements predicted

	HERA	LHeC
$m_c(m_c)$/GeV	1.26	?
δ(exp)	0.05	0.003
δ(mod)	0.03	~0.002
δ(par)	0.02	~0.002
$\delta(\alpha_s)$	0.02	0.001

LHeC determines strong coupling to 0.1%

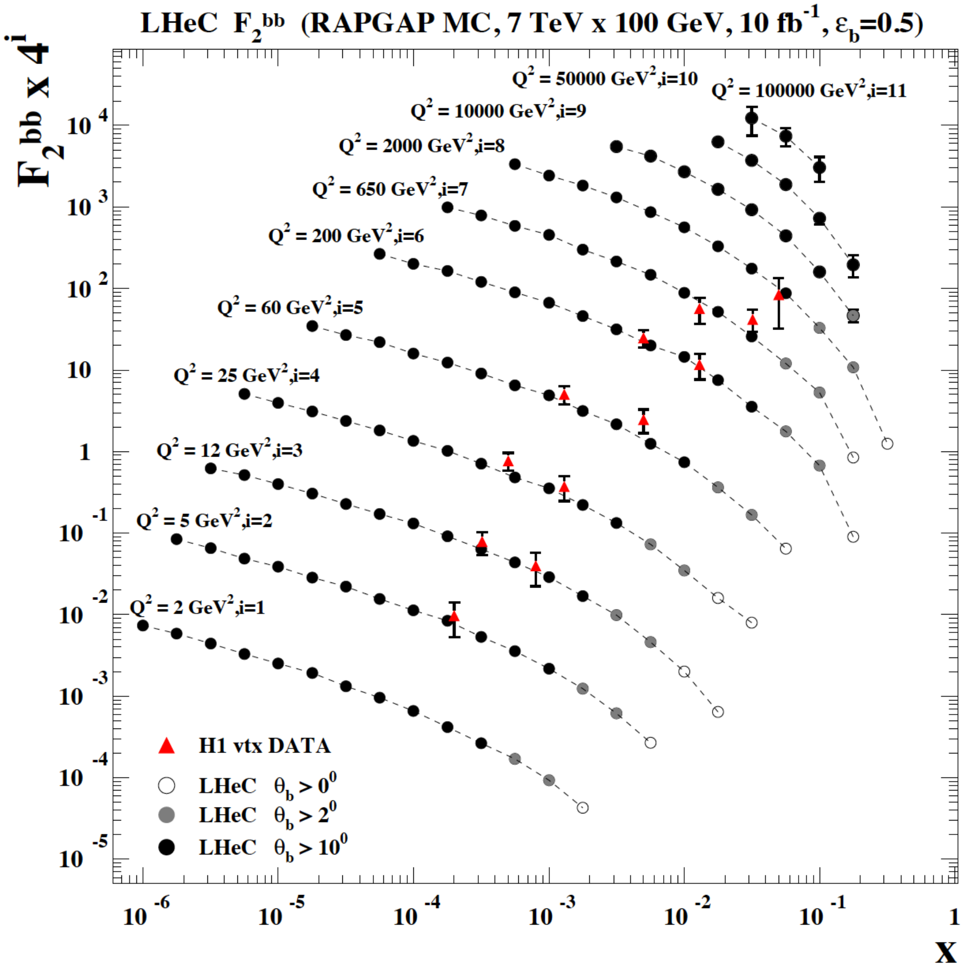
High precision PDF data will reduce the mod and par errors by a very large amount.

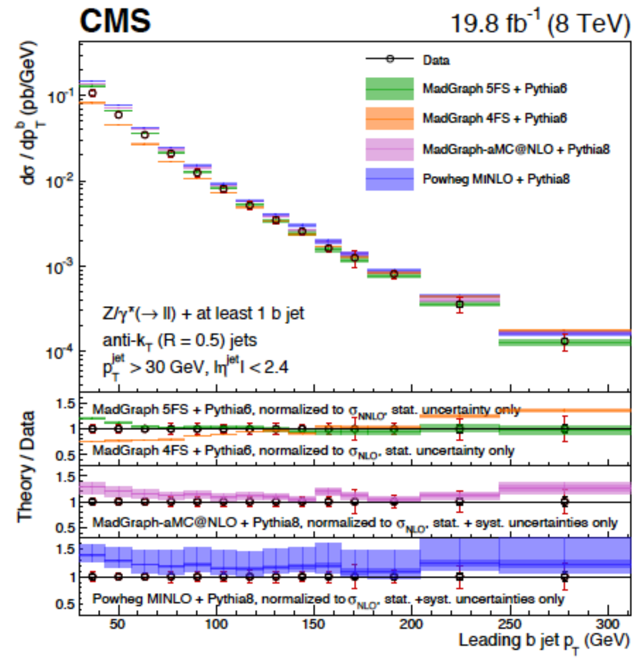
Determination of charm mass to 3 MeV: crucial for M_W in pp or H→ cc in ep

cf also NNPDF3.1 (arXiv:1706.00428) and refs

Bottom F_2^{bb} and Mass

LHeC CDR arXiv:1206.2913





Bottom density not well known

Scheme dependence affects LHC interpretations

In MSSM: Higgs from bb→ H not gg (we only miss the MSSM..)

Huge improvement vs HERA for the same reasons as for charm

$m_b(m_b)$ with LHeC to 10 MeV

Strange Strange

Strange quark suppression [dimuons in neutrino data] vs light flavour democracy [W,Z LHC]

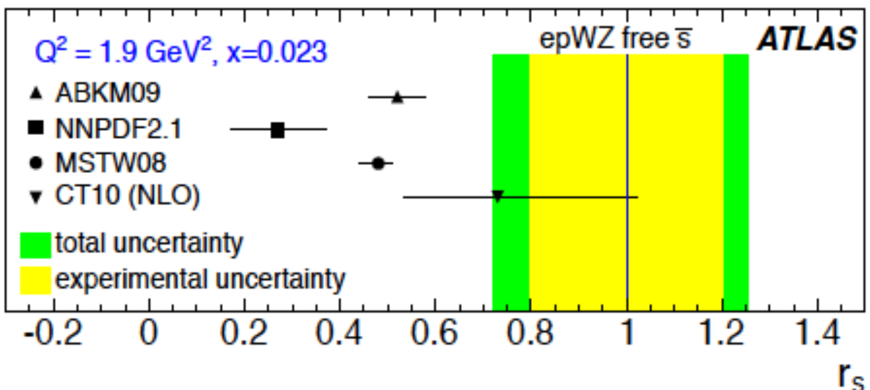


FIG. 2. Predictions for the ratio $r_s = 0.5(s + \bar{s})/\bar{d}$, at $Q^2 = 1.9\,\mathrm{GeV}^2$, $x = 0.023$. Points: global fit results using the PDF uncertainties as quoted; bands: this analysis; inner band, experimental uncertainty; outer band, total uncertainty.

ATLAS: 1203.4051, PRL

ATLAS discovered large strange fraction, at a mean Bjorken x ~ 0.01, in joint QCD analysis of HERA+ATLAS data (3/2012) still a surprise vs neutrino dimuon data.

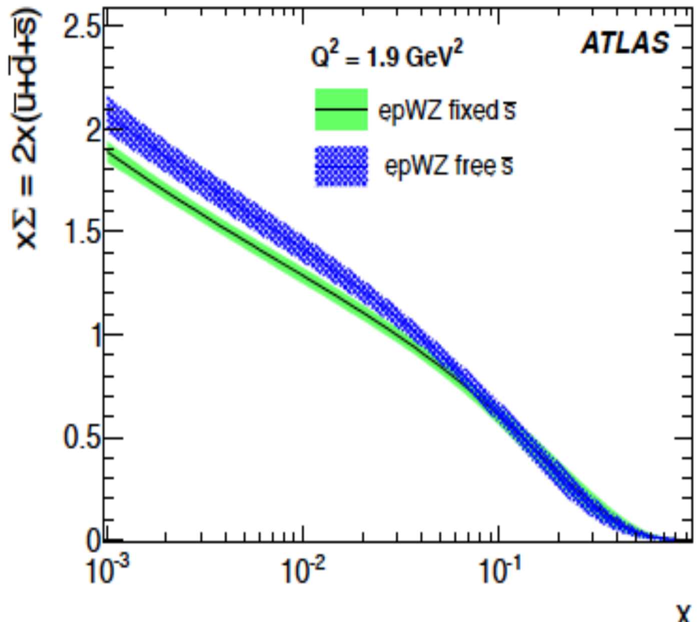
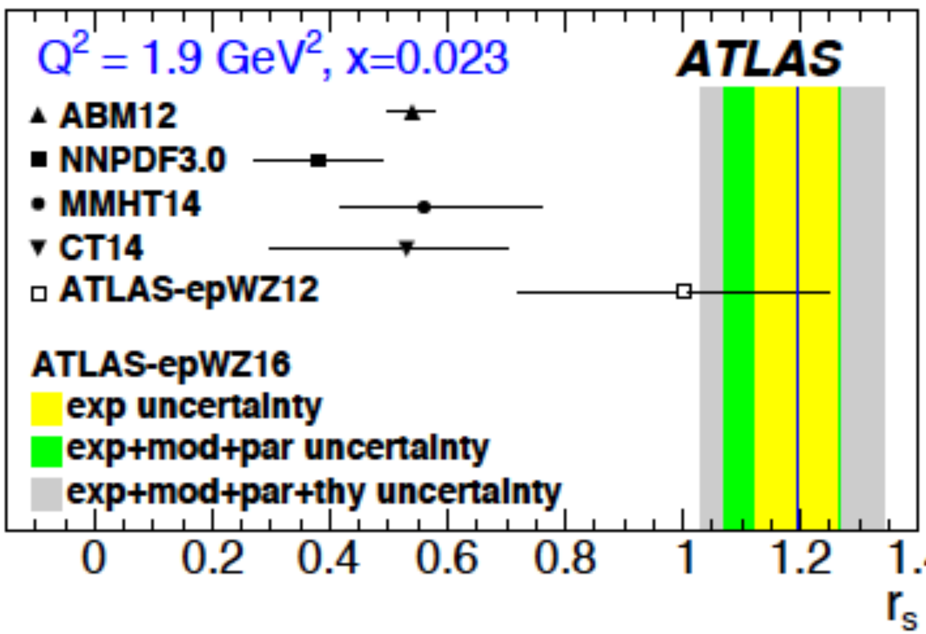


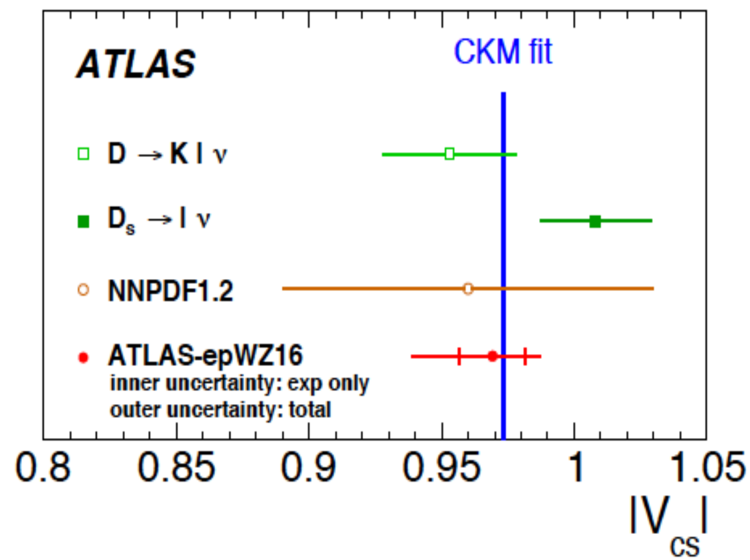
FIG. 3. Distribution of the light sea quarks, $x\Sigma = 2x(\bar{u} + \bar{d} + \bar{s})$, in the NNLO analysis of HERA and ATLAS data with a fixed fraction of strangeness (lower, green curve) and with a fitted fraction of about unity (upper blue curve). The bands represent the experimental uncertainties.

Light quark sea is strongly fixed by F_2/x = 4 U + D.
→ if you change s, then u+d must follow, +8%

Strange Strange

Strange quark suppression [dimuons in neutrino data] vs light flavour democracy [W,Z LHC]





Confirmed with much higher precision

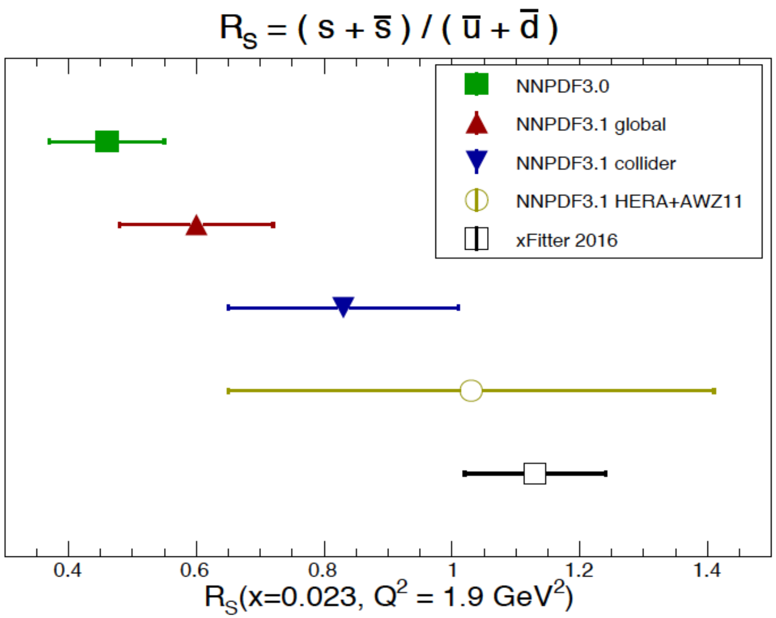
HERA+ATLAS → V_{cs}

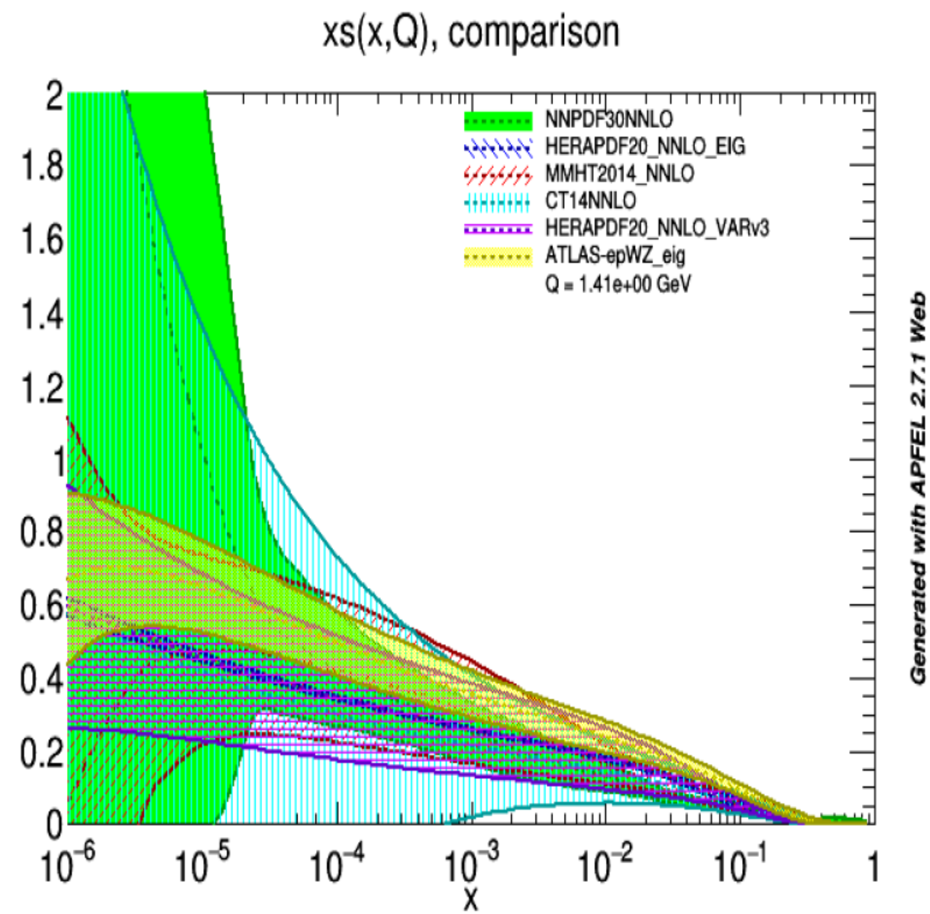
ATLAS: 1612.0301, PRD

Expect LHeC+HL LHC to be 10 x better from +2-3% to surely 0.5% or below

Strange Strange

Strange quark suppression [dimuons in neutrino data] vs light flavour democracy [W,Z LHC]



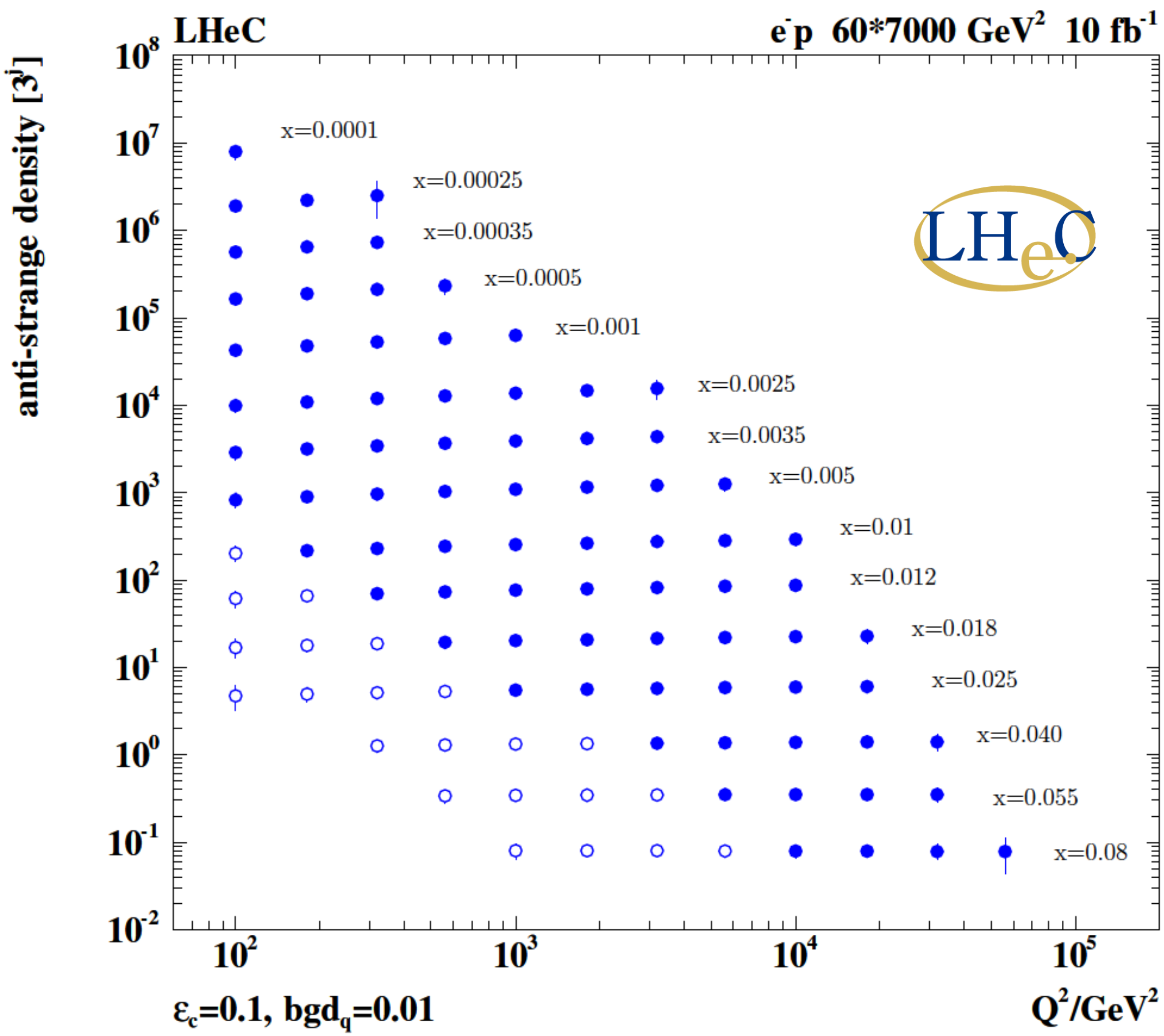


NNPDF3.1 arXiv:1706.00428, note:
"xFITTER16" = ATLAS: 1612.0301
Also look at MMHT and other results

A Cooper-Sarkar, DIS17

The strange quark density, after 60 years of DIS, has remained unknown. Is there a valence s?

Strange Quark Distribution from LHeC



High luminosity

High Q^2

Small beam spot

Modern Silicon

NO pile-up..

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

$x = 10^{-4}$ .. 0.1

$Q^2 = 100 – 10^5\ GeV^2$

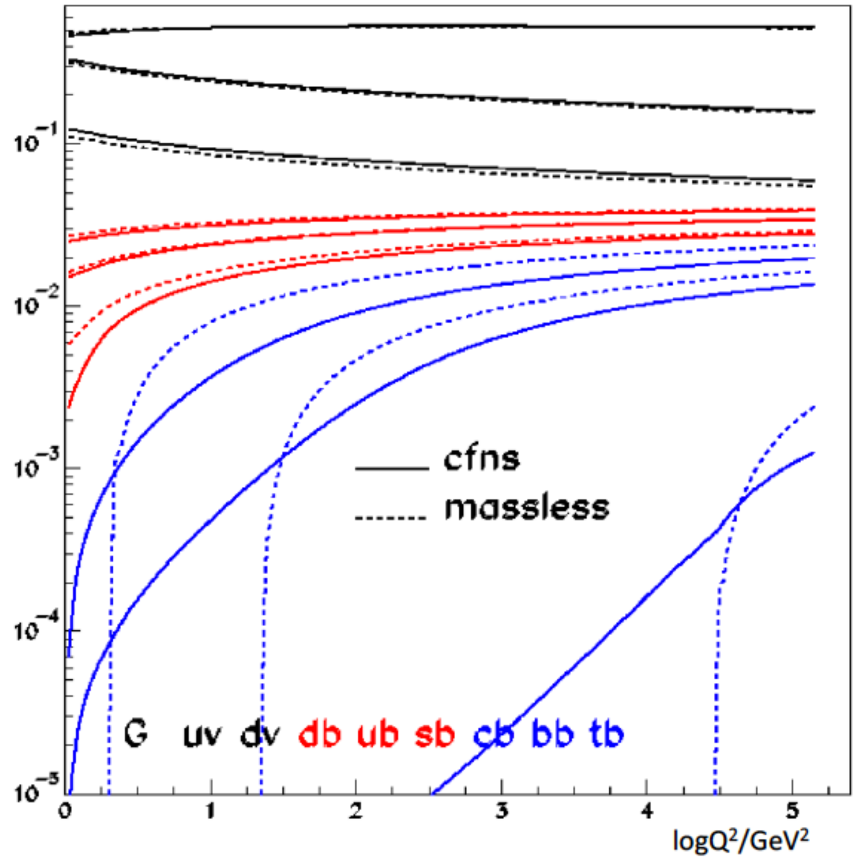
Initial study (CDR): Charm tagging efficiency of 10% and 1% light quark background in impact parameter

Top

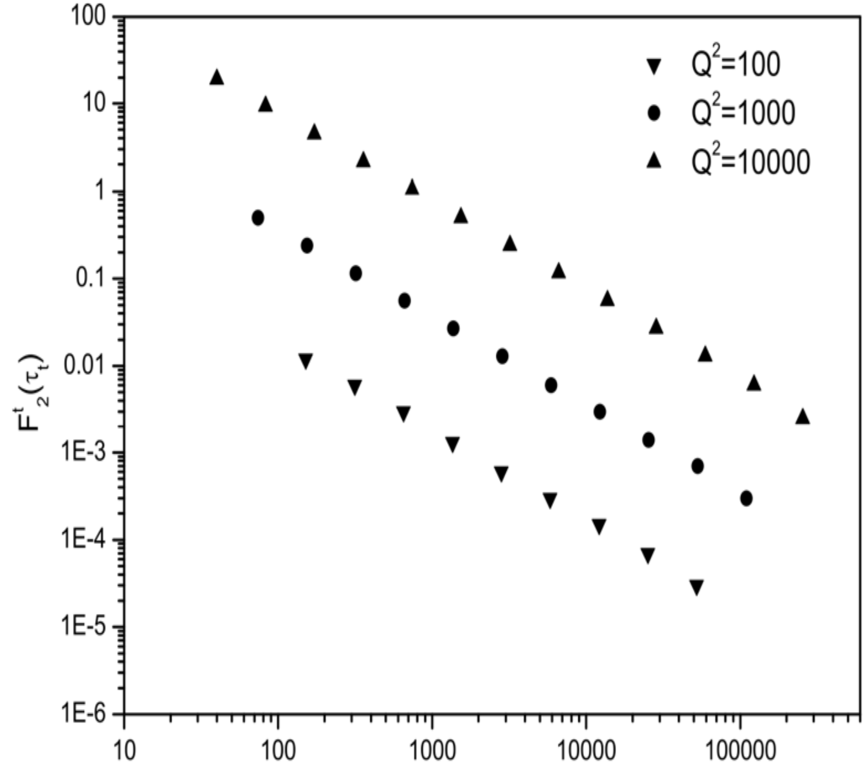
Cross sections and kinematic range base of unique SM and BSM top physics program in ep

See for example talk by U Klein today and by H Sun at DIS2017 at Birmingham. Here a note on the “top PDF”

LHeC CDR arXiv:1206.2913



At high $Q^2 \sim m_t^2$ top demands a fraction of proton’s momentum – need to understand what a “top PDF” is. Scheme dependence

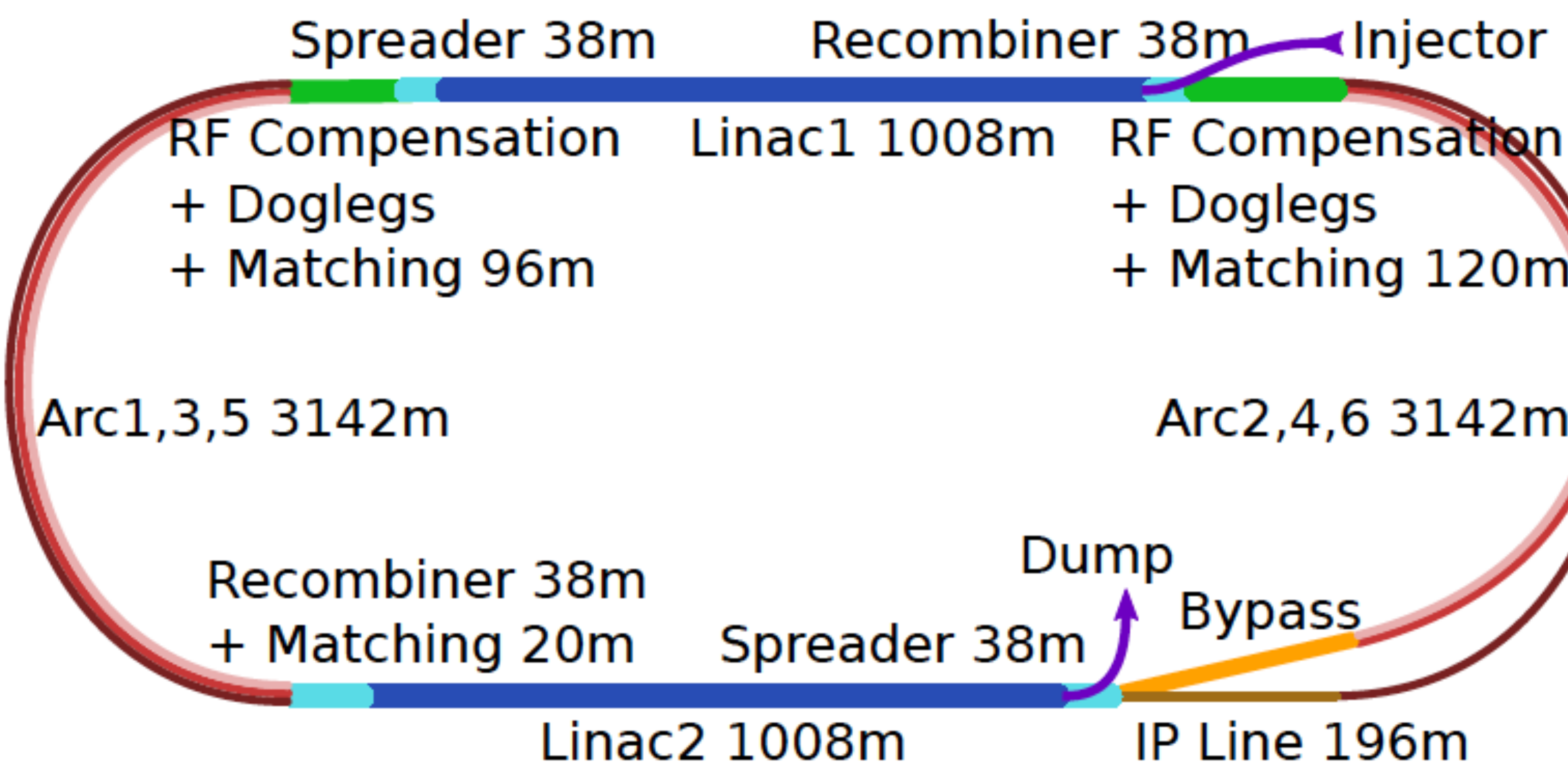


Boroun, Phys. Lett. B744, 142 (2015)

$$\tau_t = (1 + \frac{4m_t^2}{Q^2})^{1+\lambda} \frac{Q^2}{Q_0^2} (\frac{x_B}{x_0})^\lambda$$

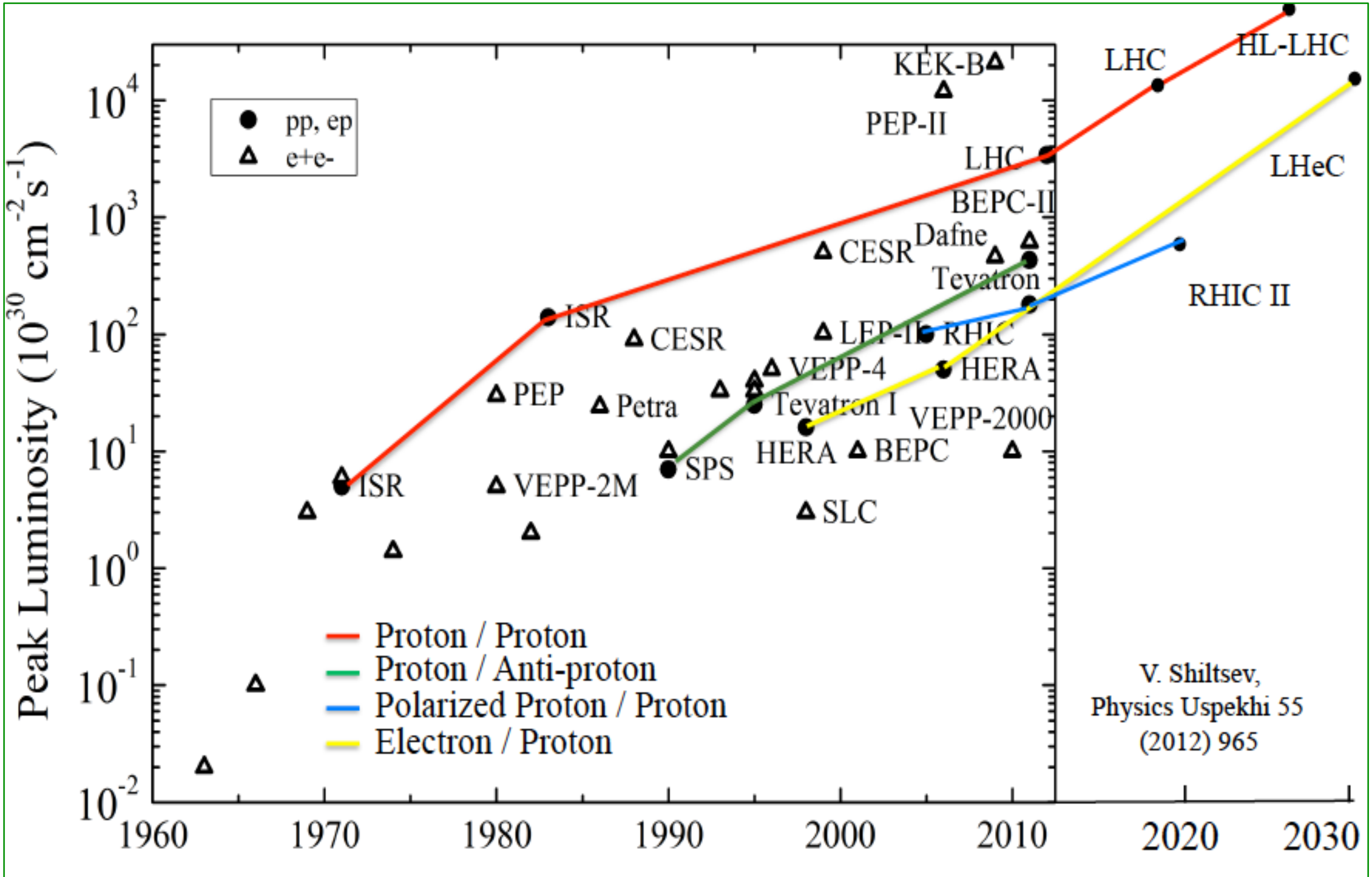
LHeC: Add an Electron Beam (ERL) to LHC (HL+HE)

Conceptual Design Report (2012), Update for next European Strategy



Concurrent operation to pp, LHC/FCC become 3 beam facilities. P(e) < 100 MW
10^{34} luminosity and factor of 15/30 (HL/HE) extension of Q^2, 1/x reach vs HERA

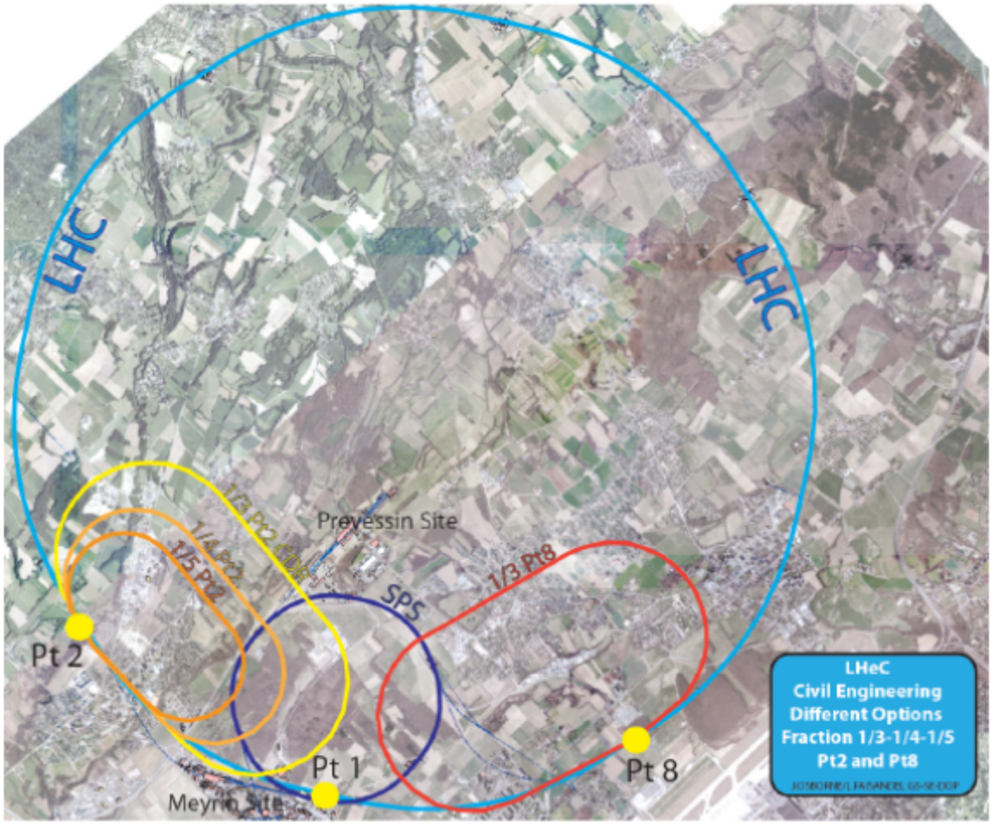
Collider Luminosities vs Year (pp and ep)



O. Bruening 2/17

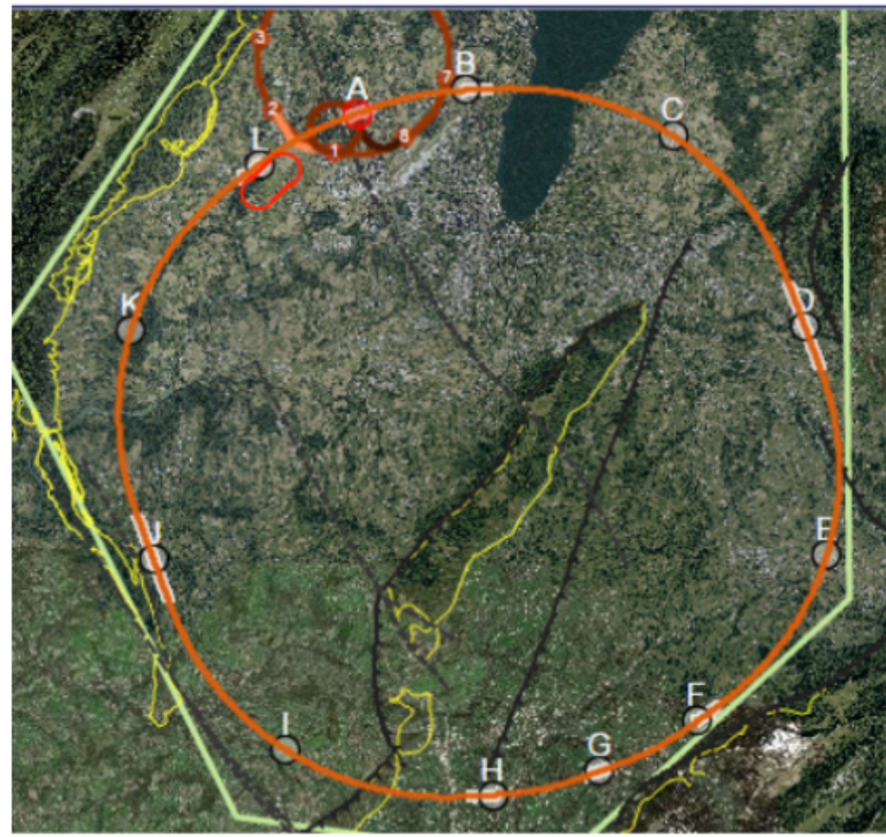
Location + Footprint of the electron ERL

LHC (HL and HE)



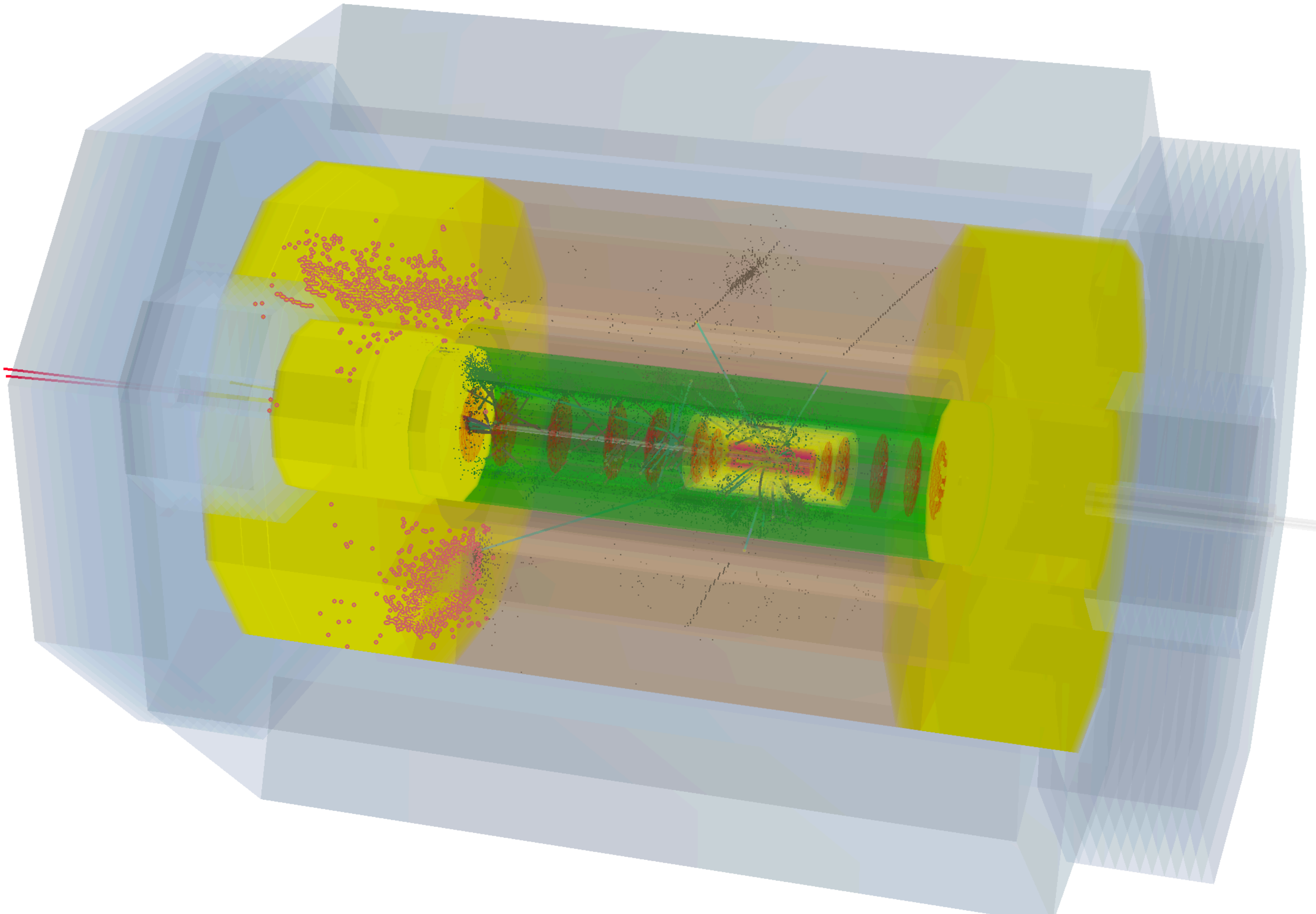
Energy – Cost – Physics – Footprint
are being reinvestigated

FCC

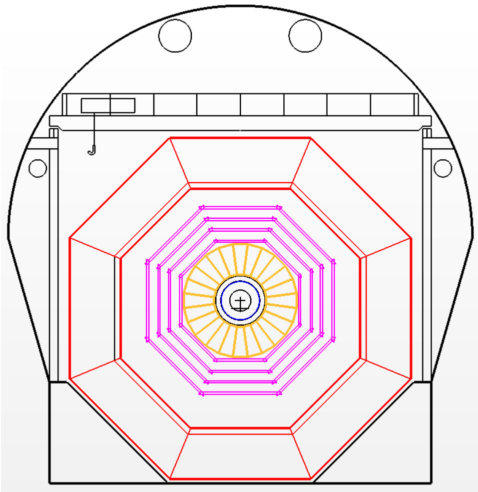


A 9km ERL is a small add-on for the FCC
Doubling the energy to 120 GeV hugely increases cost and effort.

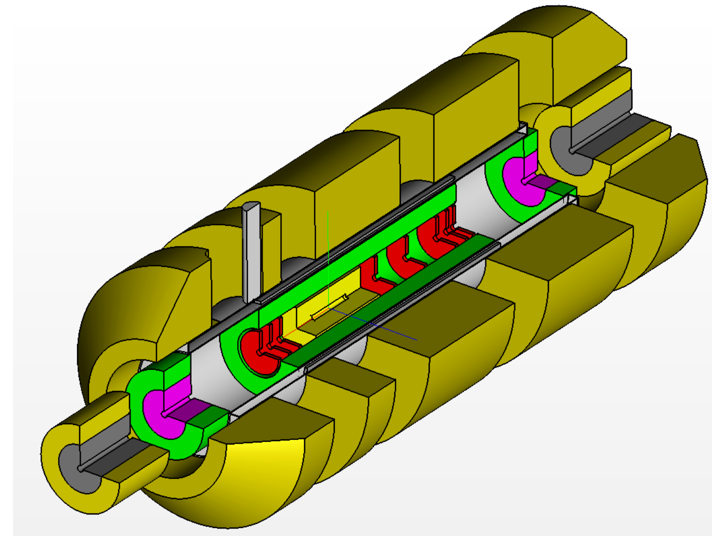
H→ bb in LHeC Detector



Installation Study

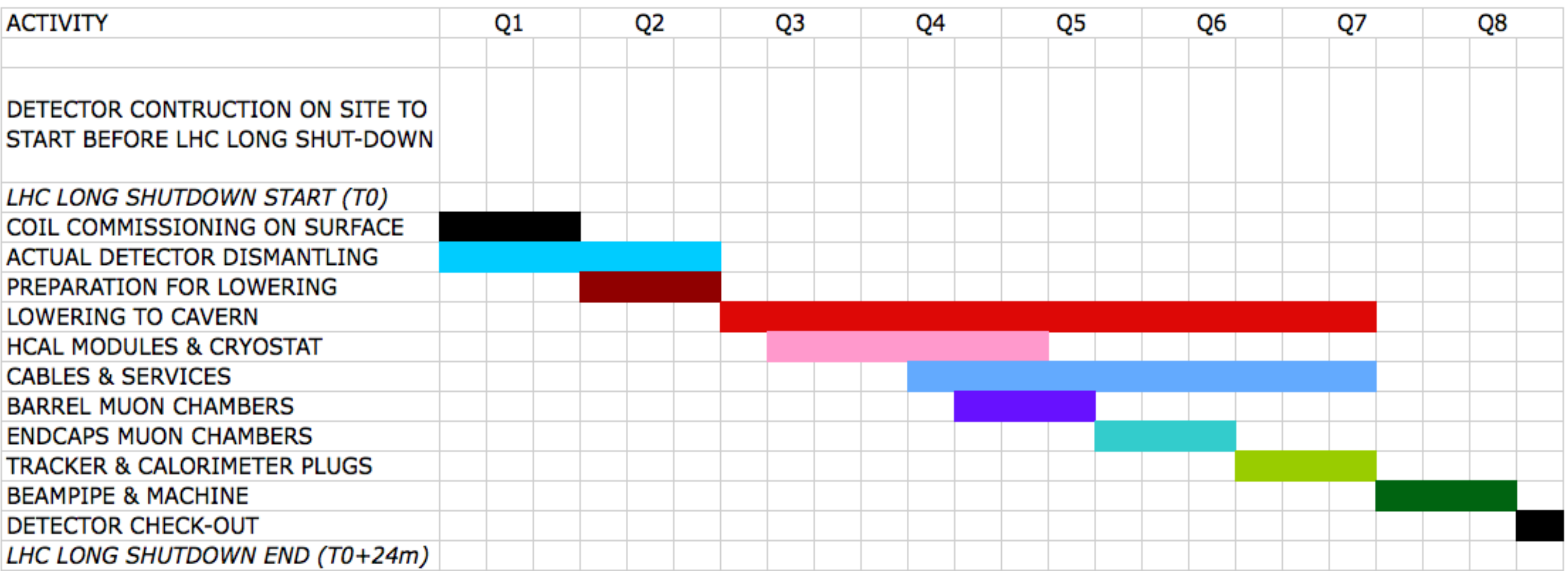


Detector fits in L3 magnet support



Modular structure

LHeC INSTALLATION SCHEDULE

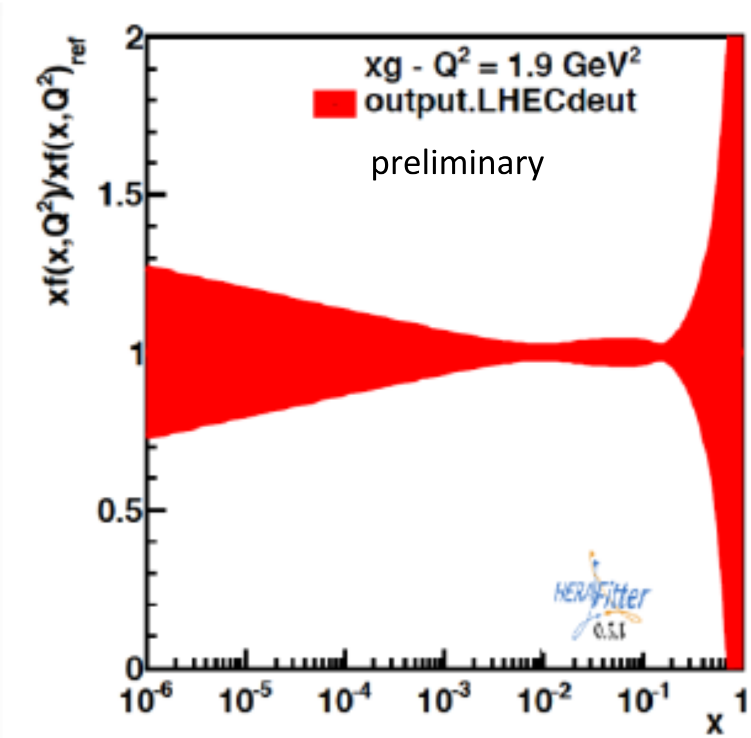


Future Nuclear PDFs with LHeC

cf talk by Nestor Armesto at this workshop

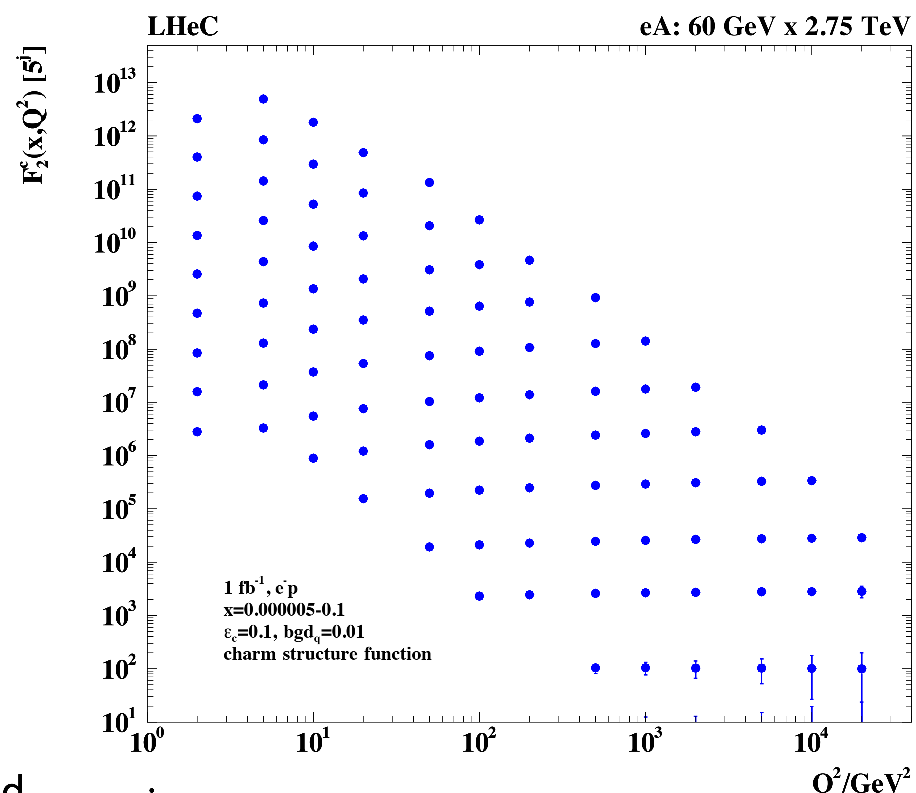
From an eA collider one can determine nuclear PDFs in a novel, the classic way.
Currently: use some proton PDF base and fit a parameterised shadowing term R.
Then: use the NC and CC eA cross sections directly and get $R(x,Q^2;p)$ as p/N PDFs.

Gluon density uncertainty in eA



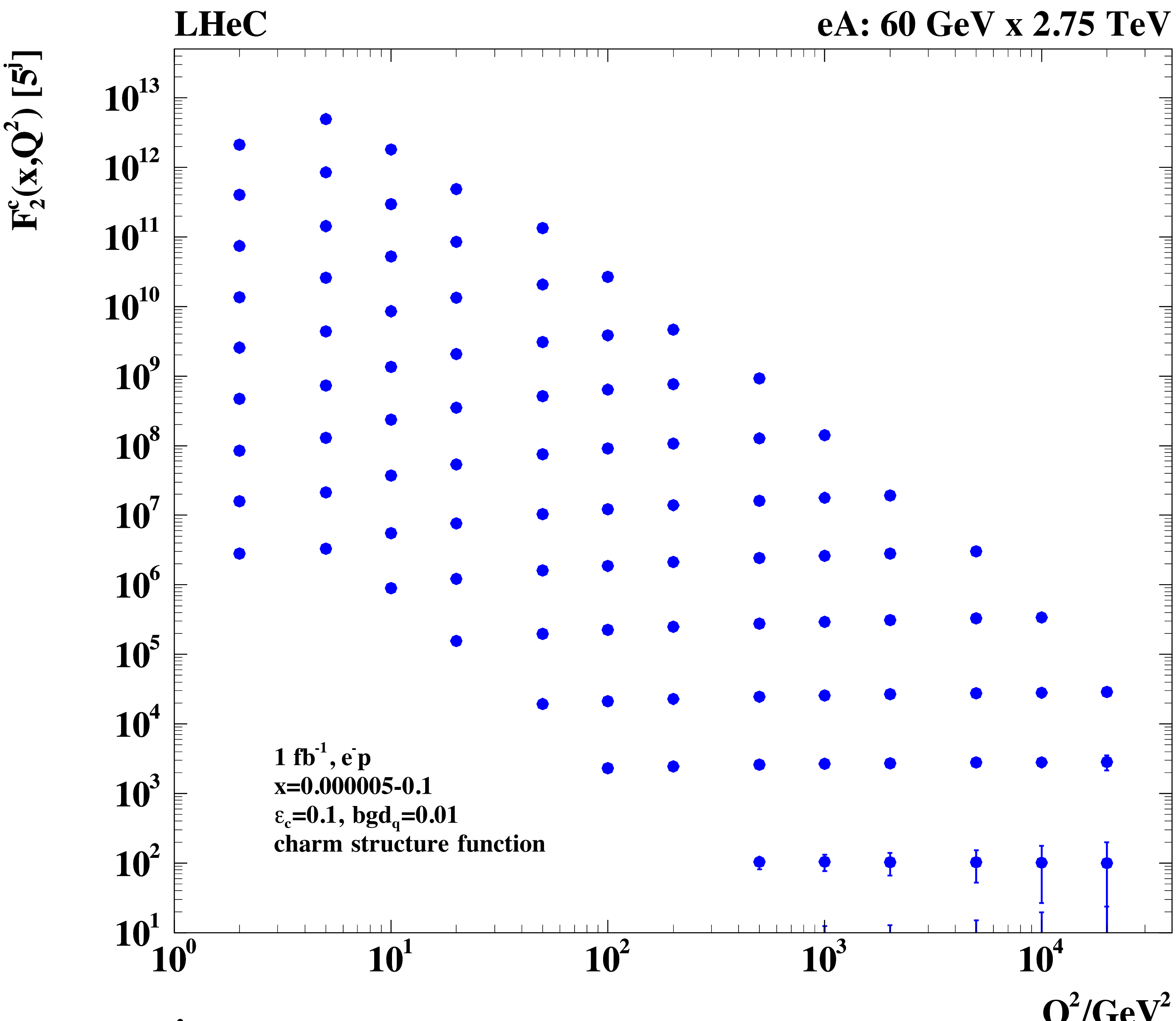
1fb^{-1} of sole eA isoscalar data fitted

Charm density in nuclei



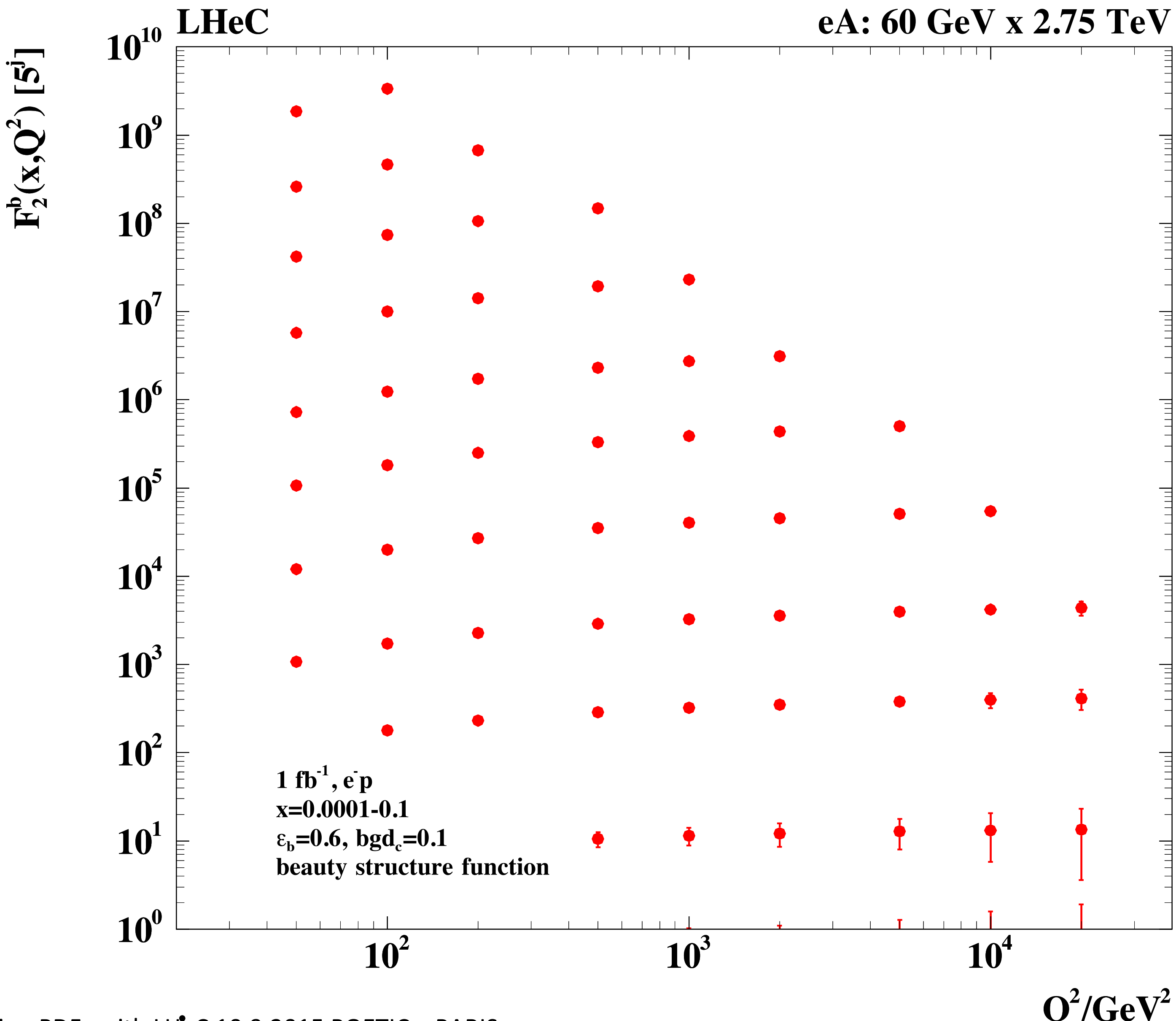
Impact parameter measurement in eA

Heavy Flavour – Charm in eA - from NC



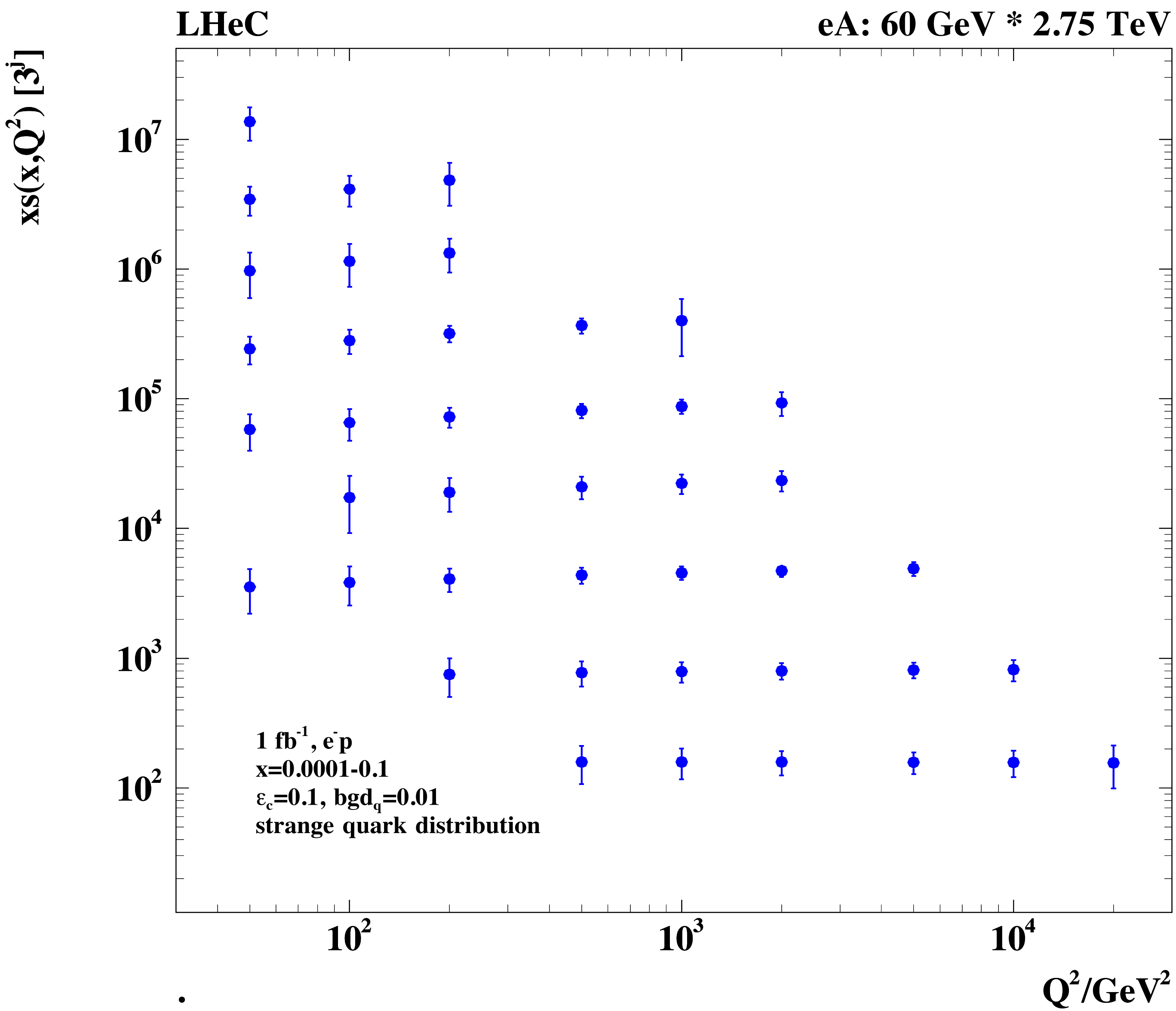
3-5%

Heavy Flavour – Beauty in ePb - from NC



3-5%

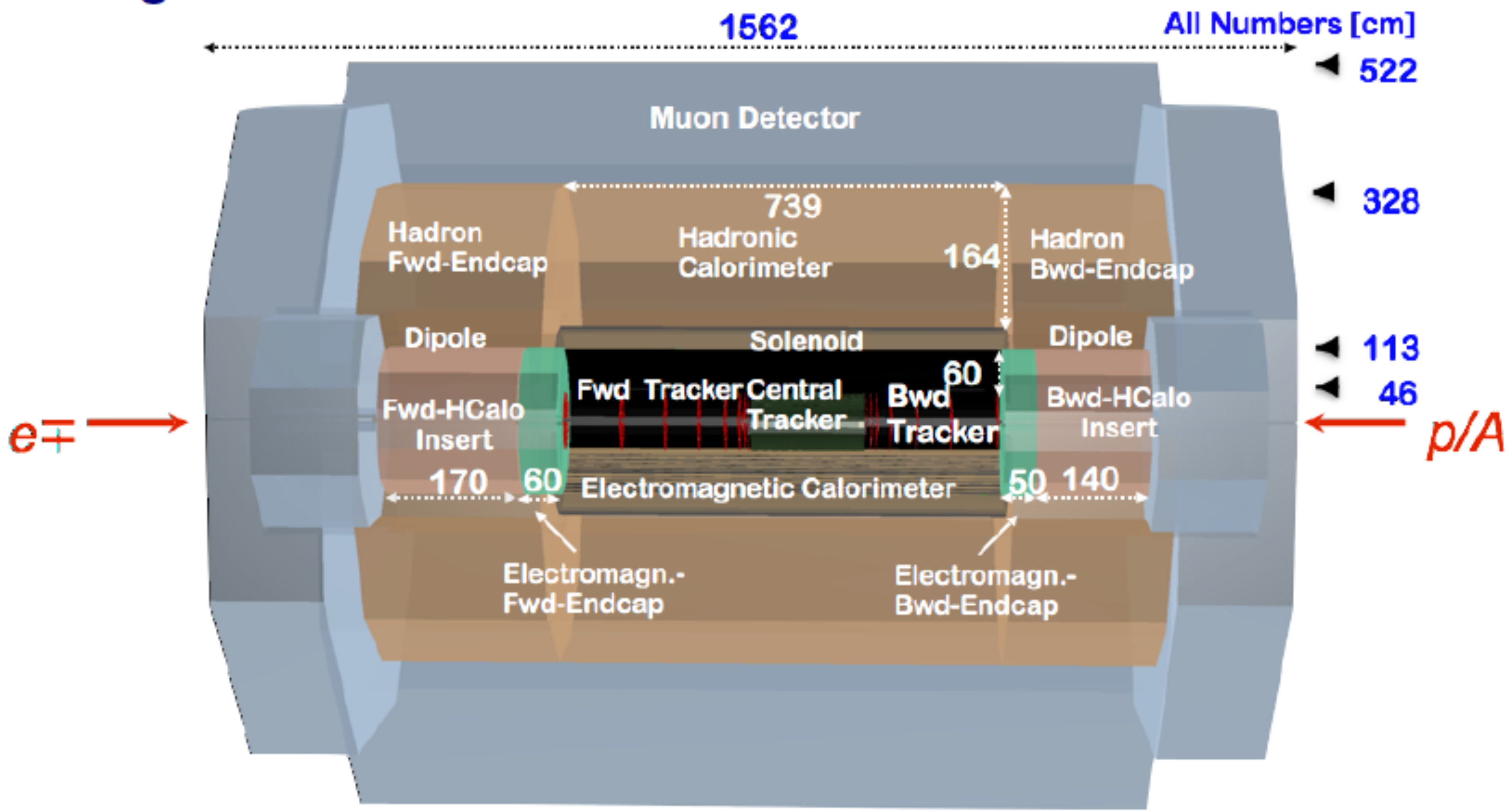
Heavy Flavour – Strange in ePb - from CC



10-20%

•

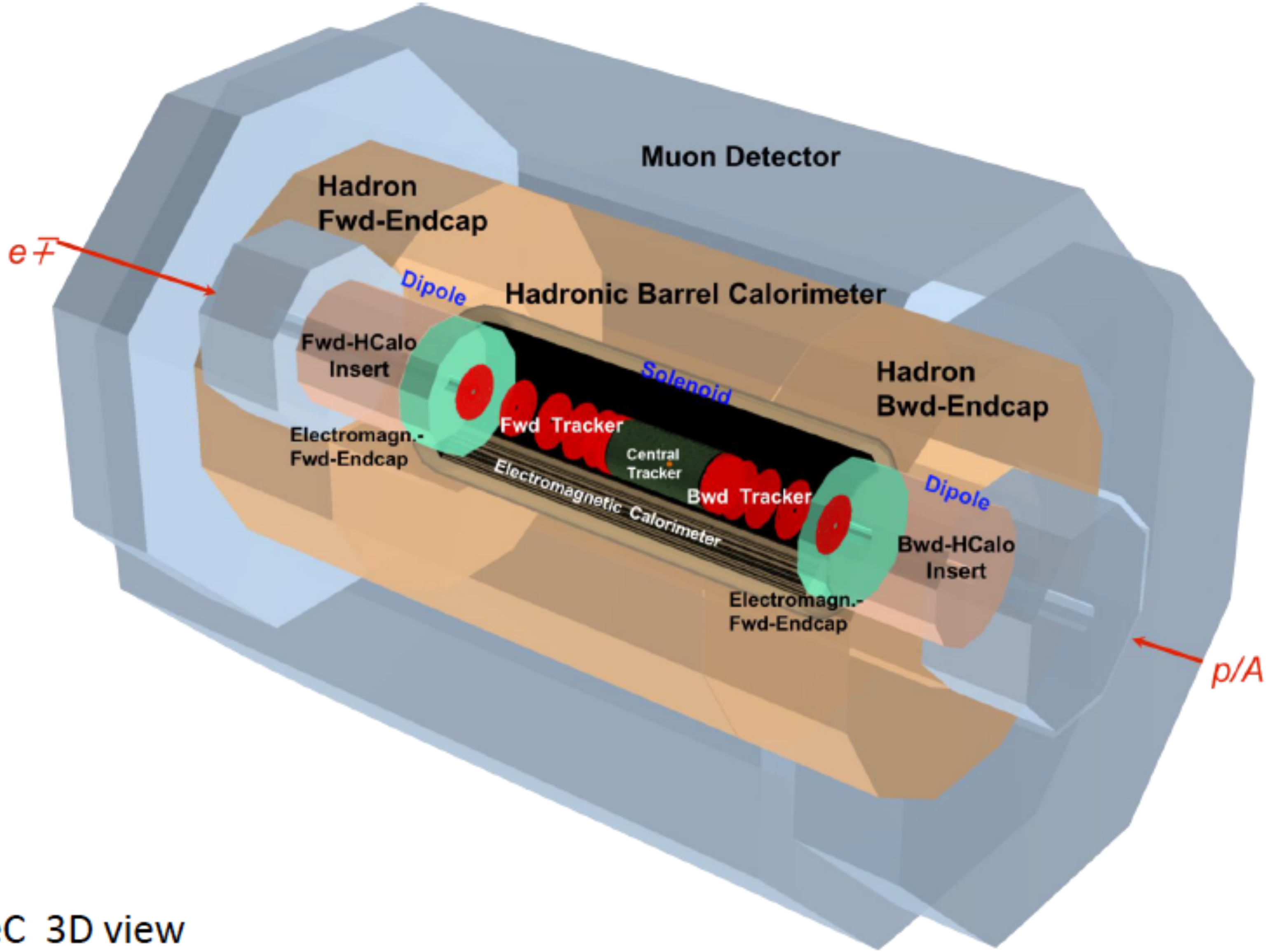
Changes from HL-LHC to HE-LHC.



Overall Detector length +2.5m

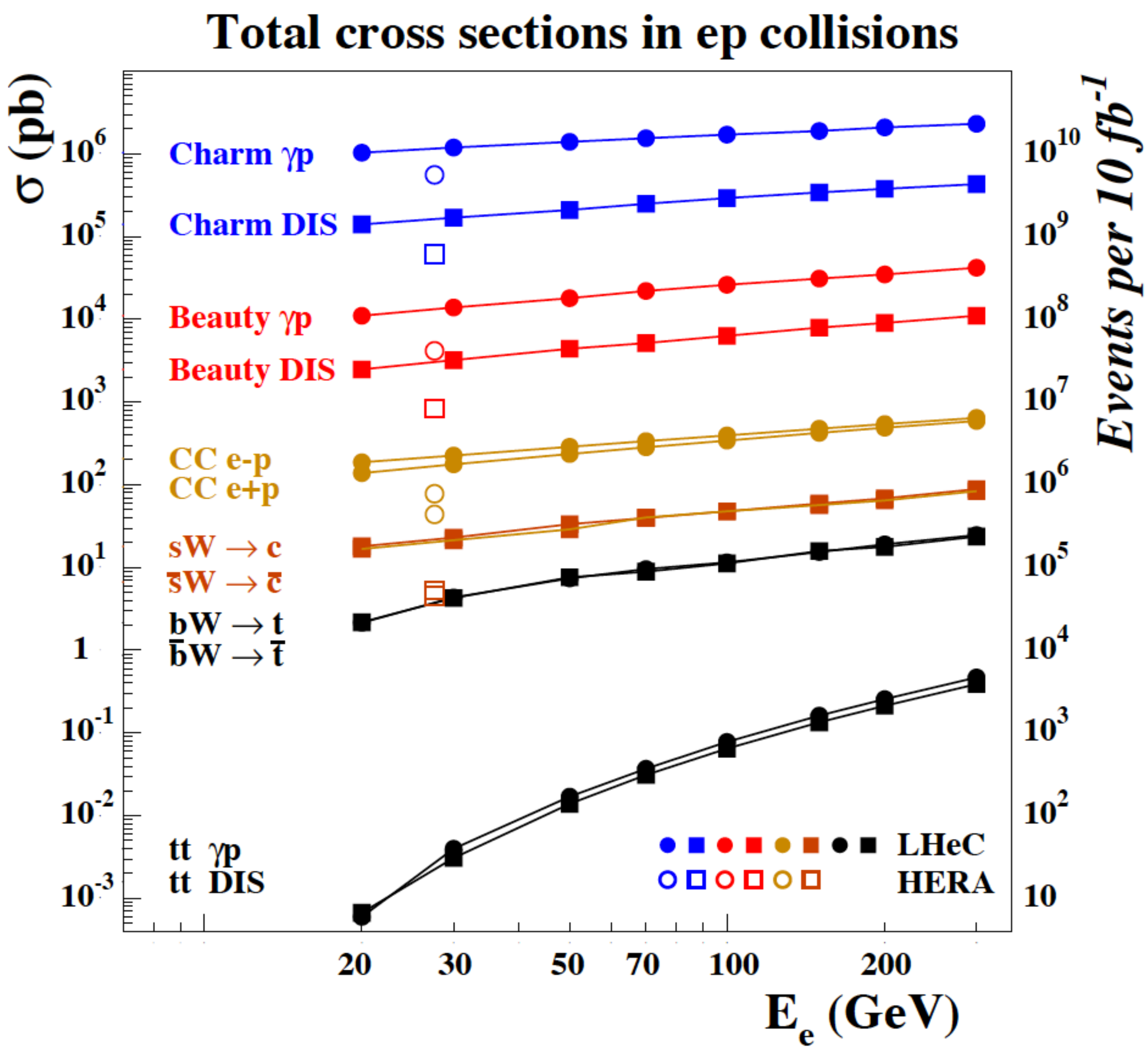
Detector diameter +2m

HE-LHeC detector



HE-LHeC 3D view

LHeC CDR arXiv:1206.2913



LHeC: The first ep+eA collider with which ALL s,c,b,t flavours can be measured. Note L=O(1000) HERA
Huge, unique physics return for LHC facility, the development of the SM and searches beyond

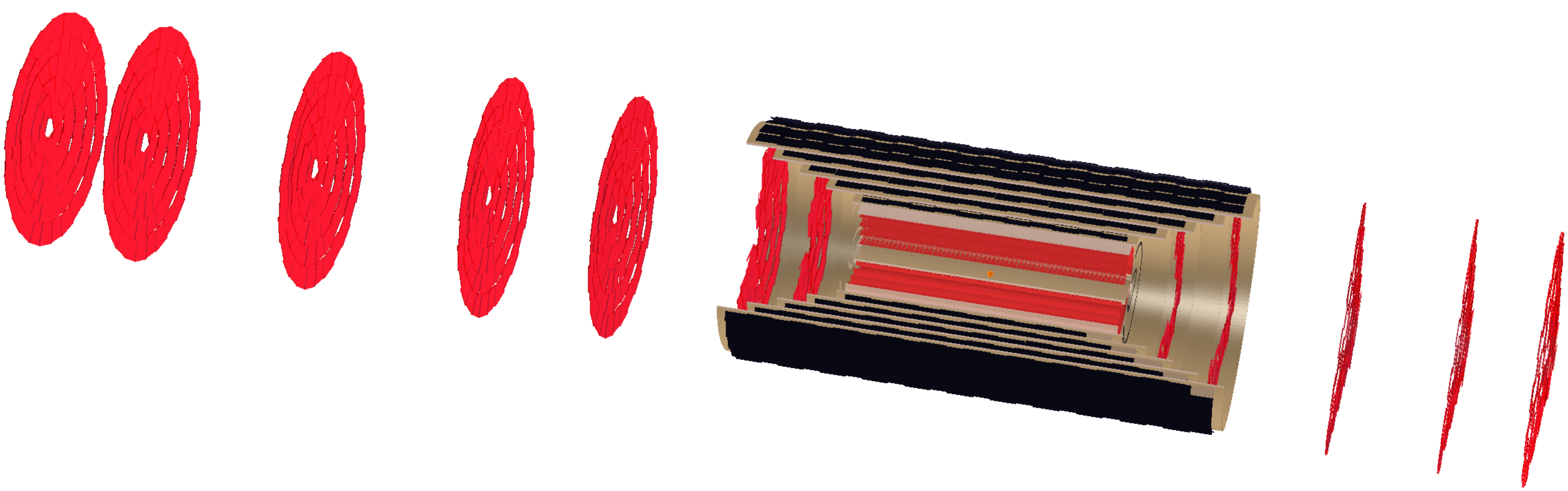
title

Dimensions and Multitudes - LHeC

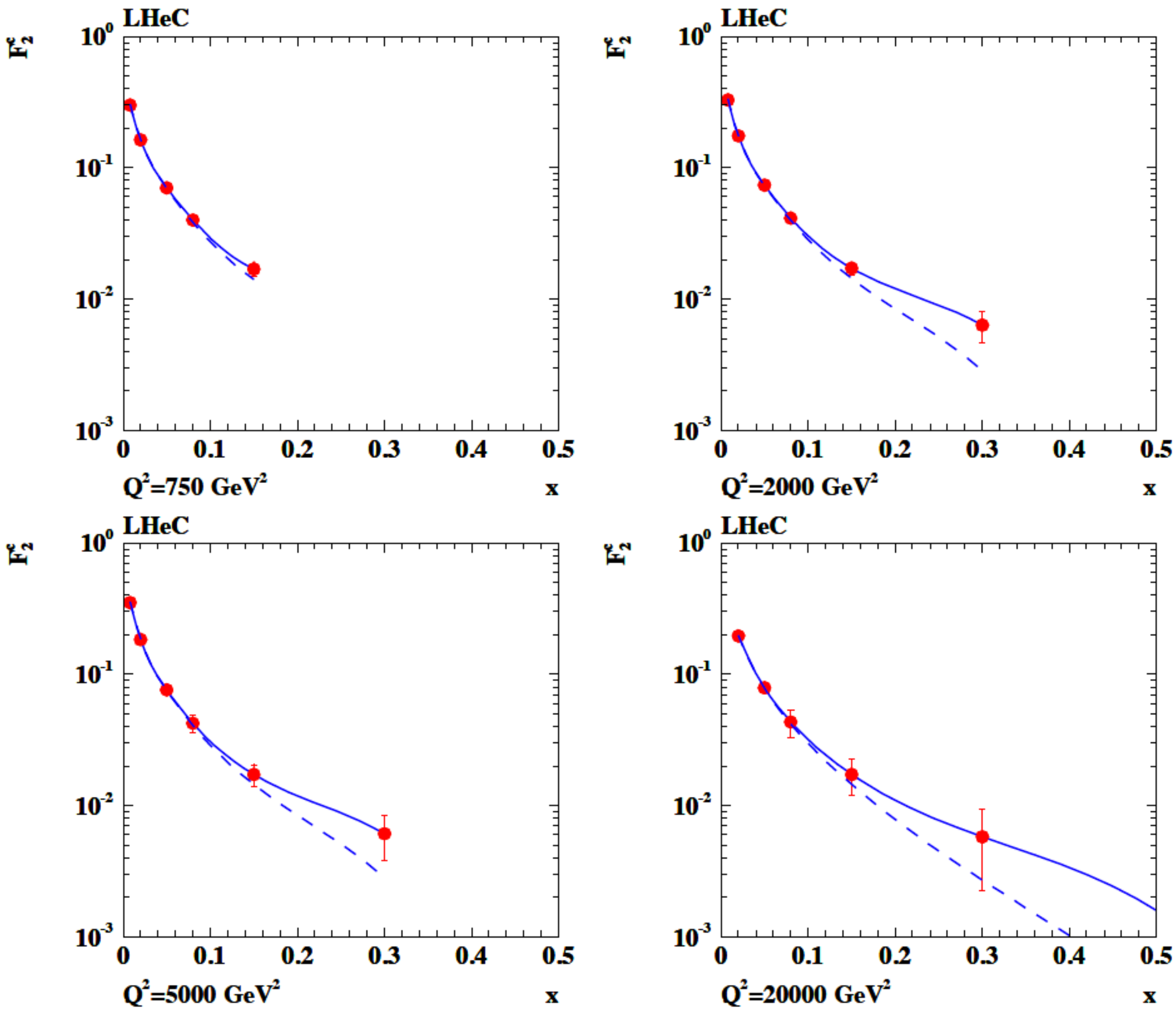
Tracker	FST_{pix}	FST_{strix}	CFT_{pix}	CPT_{pix}	CST_{strix}	CBT_{pix}	BST_{strix}	BST_{pix}
#Wheels	5		2	–	–	2	3	
#Rings/Wheel	2_{inner}	3_{outer}	3/4	–	–	3/4	3_{outer}	2_{inner}
#Layers	–	–	–	4	5	–	–	–
$\theta_{min/max}$ $[^0]$	0.7	3.8	3.0	5.1	24/155	177.8	173.1	178.7
$\eta_{max/min}$	5.1	3.4	3.6	±3.1	±1.4	-3.6	-2.8	-4.5
$Si_{pix/strix}$ $[m^2]$	6.9	9.5	2.8	5.4	33.7	2.8	5.7	4.1
Sum-Si $[m^2]$	70.9 double layers taken into account							

Calo	FHC_{SiW}	FEC_{SiW}	$EMC_{SciPb/LAr}$	HAC_{SciFe}	BEC_{SiPb}	BHC_{SiFe}
$\theta_{min/max}$ $[^0]$	0.61	0.68	8/166	14.2/160	178.7	178.9
$\eta_{max/min}$	5.2	5.1	2.7/-2.1	2.1/-1.7	-4.5	-4.7
Volume $[m^3]$	6.7	1.6	15.1	165	1.6	5.8
Sum-Si $[m^2]$	197.4					

The LHeC Silicon Tracker



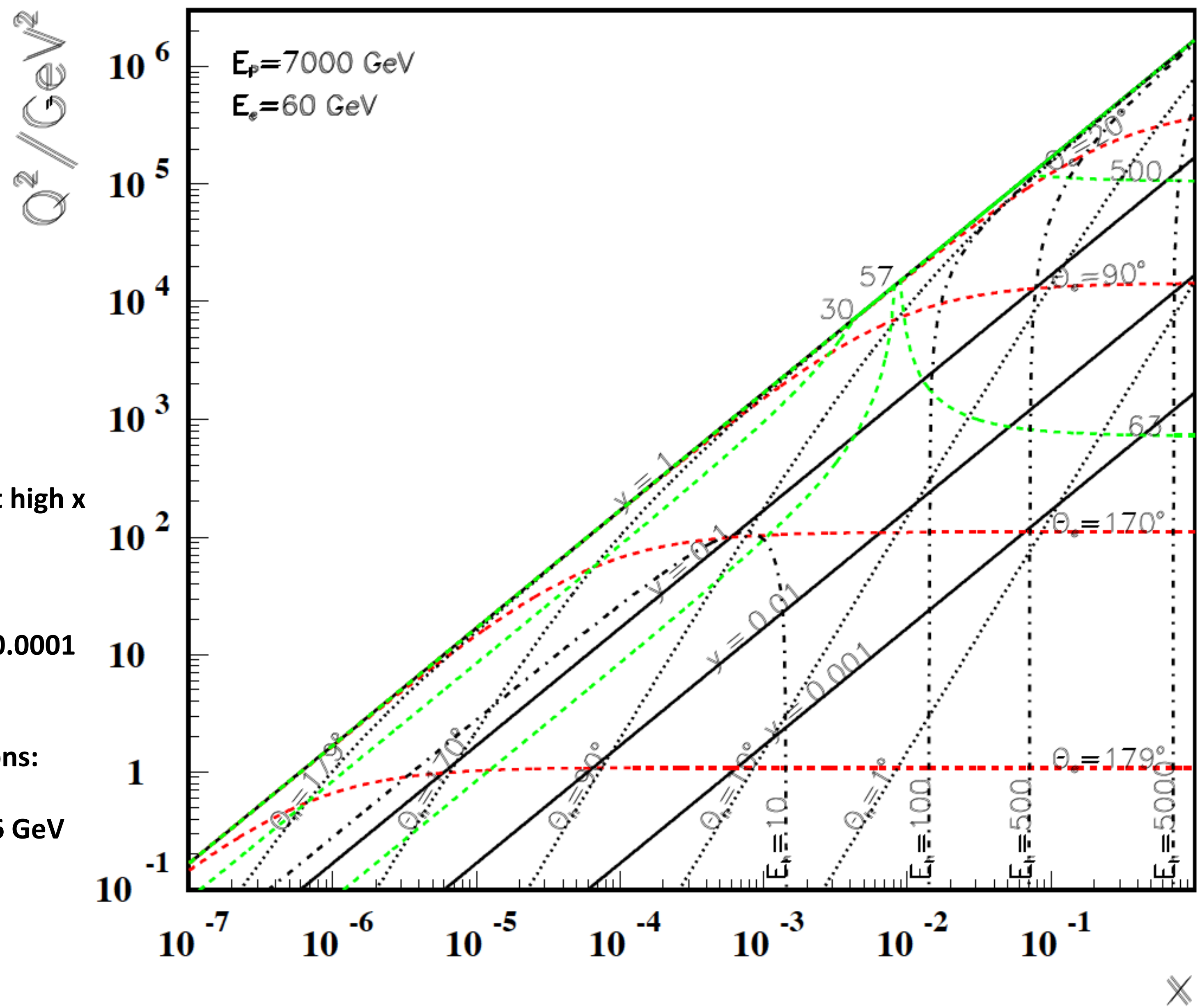
LHeC CDR arXiv:1206.2913



Search for intrinsic charm: solid: CTEQ66c, dashed: CTEQ6m; 60 GeV x 1 TeV, 1 fb^{-1}

Kinematics at LHeC

default energies



Observations

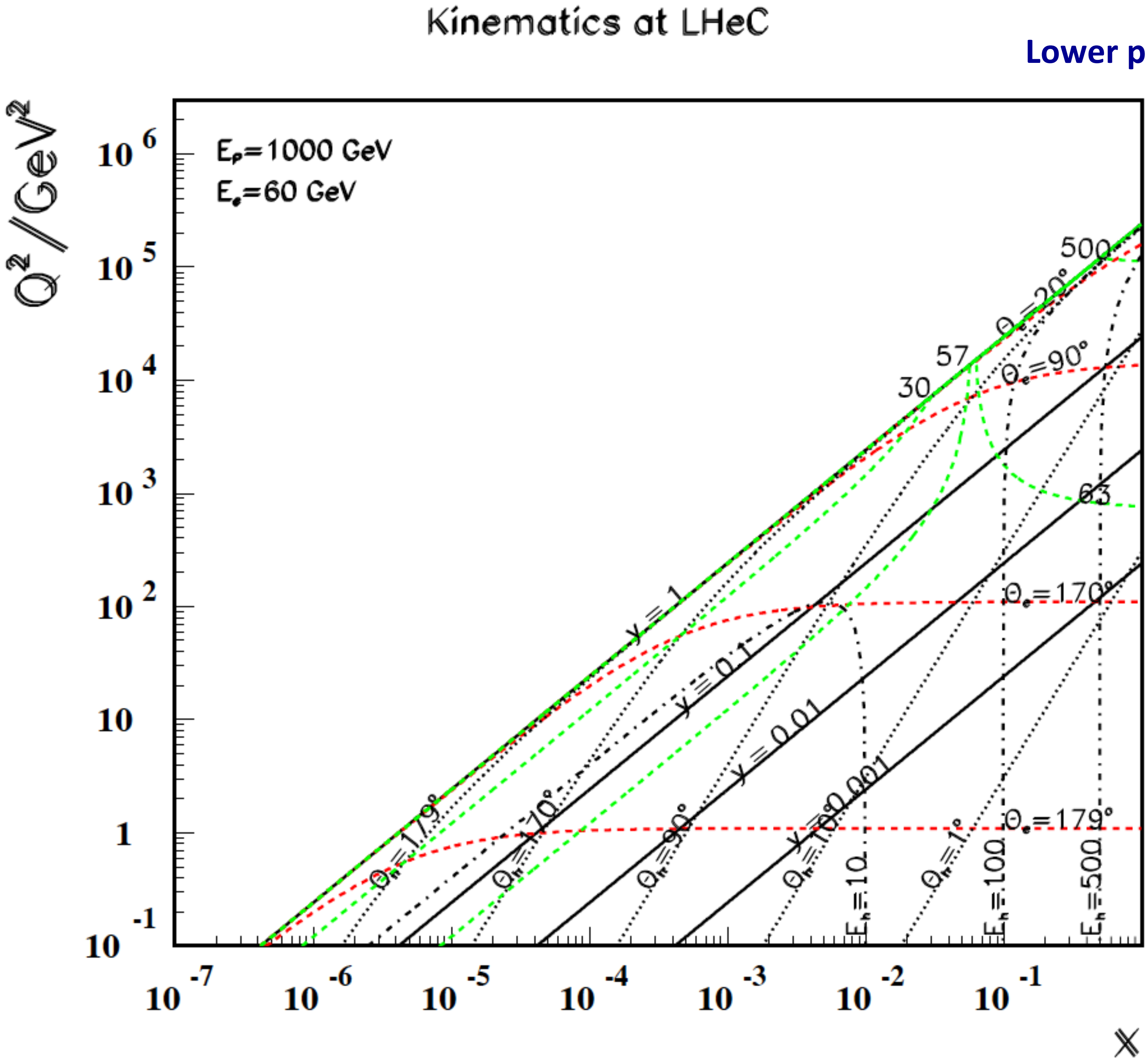
Good angular coverage but at high x low Q2

High Q^2 to 10^6
CC at large x > 0.0001

Low Q^2 High x
Very fwd hadrons:

High y =0.9 → 6 GeV
F_L "easy"

Lower proton energy

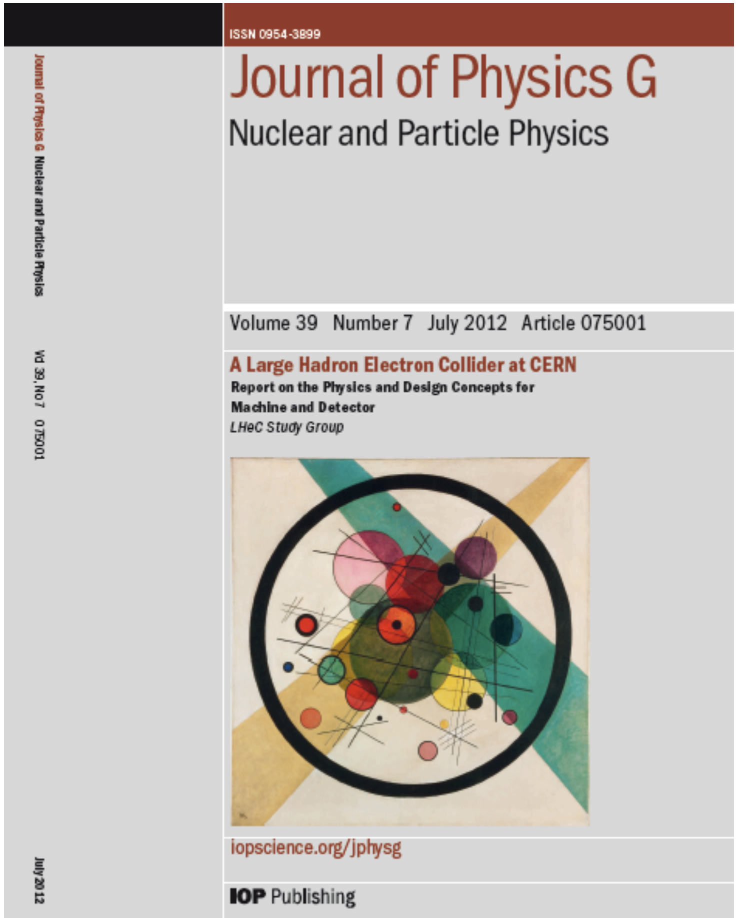


← EIC

Lower E_p to access high x at lower Q^2

Modest Luminosity required

Design Report 2012



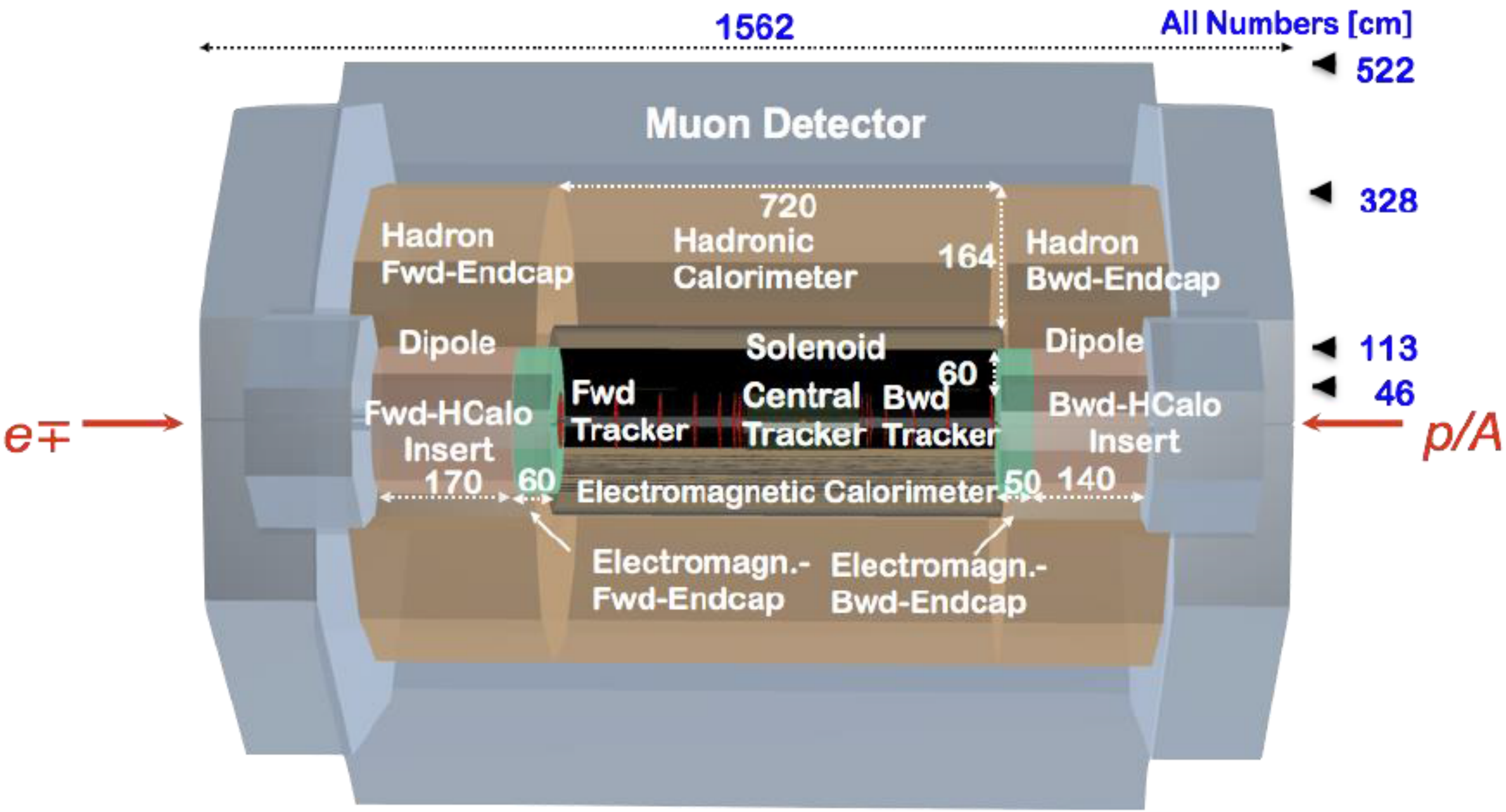
arXiv:1206.2913

CERN Referees

Ring Ring Design
Kurt Huebner (CERN)
Alexander N. Skrinsky (INP Novosibirsk)
Ferdinand Willeke (BNL)
Linac Ring Design
Reinhard Brinkmann (DESY)
Andy Wolski (Cockcroft)
Kaoru Yokoya (KEK)
Energy Recovery
Georg Hoffstaetter (Cornell)
Ilan Ben Zvi (BNL)
Magnets
Neil Marks (Cockcroft)
Martin Wilson (CERN)
Interaction Region
Daniel Pitzl (DESY)
Mike Sullivan (SLAC)
Detector Design
Philippe Bloch (CERN)
Roland Horisberger (PSI)
Installation and Infrastructure
Sylvain Weisz (CERN)
New Physics at Large Scales
Cristinel Diaconu (IN2P3 Marseille)
Gian Giudice (CERN)
Michelangelo Mangano (CERN)
Precision QCD and Electroweak
Guido Altarelli (Roma)
Vladimir Chekelian (MPI Munich)
Alan Martin (Durham)
Physics at High Parton Densities
Alfred Mueller (Columbia)
Raju Venugopalan (BNL)
Michele Arneodo (INFN Torino)

600 pages. Physics, Detector and Two Accelerator Options
ring-ring which may be of interest in the HE-LHC context and linac-ring, the default LH(e)C

HE-LHC LHeC detector



- Present HE-LHC design of the central detector firs 16.0m x 10.5m
- Dimensions still compatible with the insertion of the detector in the L3/ALICE magnet (11.20 min diameter). More precise studies needed.