Requirements on the LHeC Detector

Plan for Section Det.1

Physics
Acceptance+ E variation
Resolution
Calibration

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Physics requirements

Inclusive deep inelastic scattering – e and hadrons

Etmiss and Rad Corr's: 4π acceptance

New particles: High resolution calorimetry [H → bb]

Asymmetric energies: highly energetic forward production

High x: forward jets

DIS from $Q^2 = 1\text{-}10^6$ GeV^2 [extreme backward … extreme fwd]

Diffractive physics: tag p, n, d [fwd]

Luminosity Measurement: tag photons [bwd]

Photoproduction: tag electrons [bwd]

Charm, Beauty: tag [c,b] in NC

Strange, Top: tag [c,b] in CC

Muons e.g. for vector mesons …

A high precision, 4π collider detector, the dimensions of which are largely determined by E_p and the polar angle acceptance

[may wish to foresee E_p=15 TeV p beam energy instead of 7.5 combined with 60 → 140 GeV]

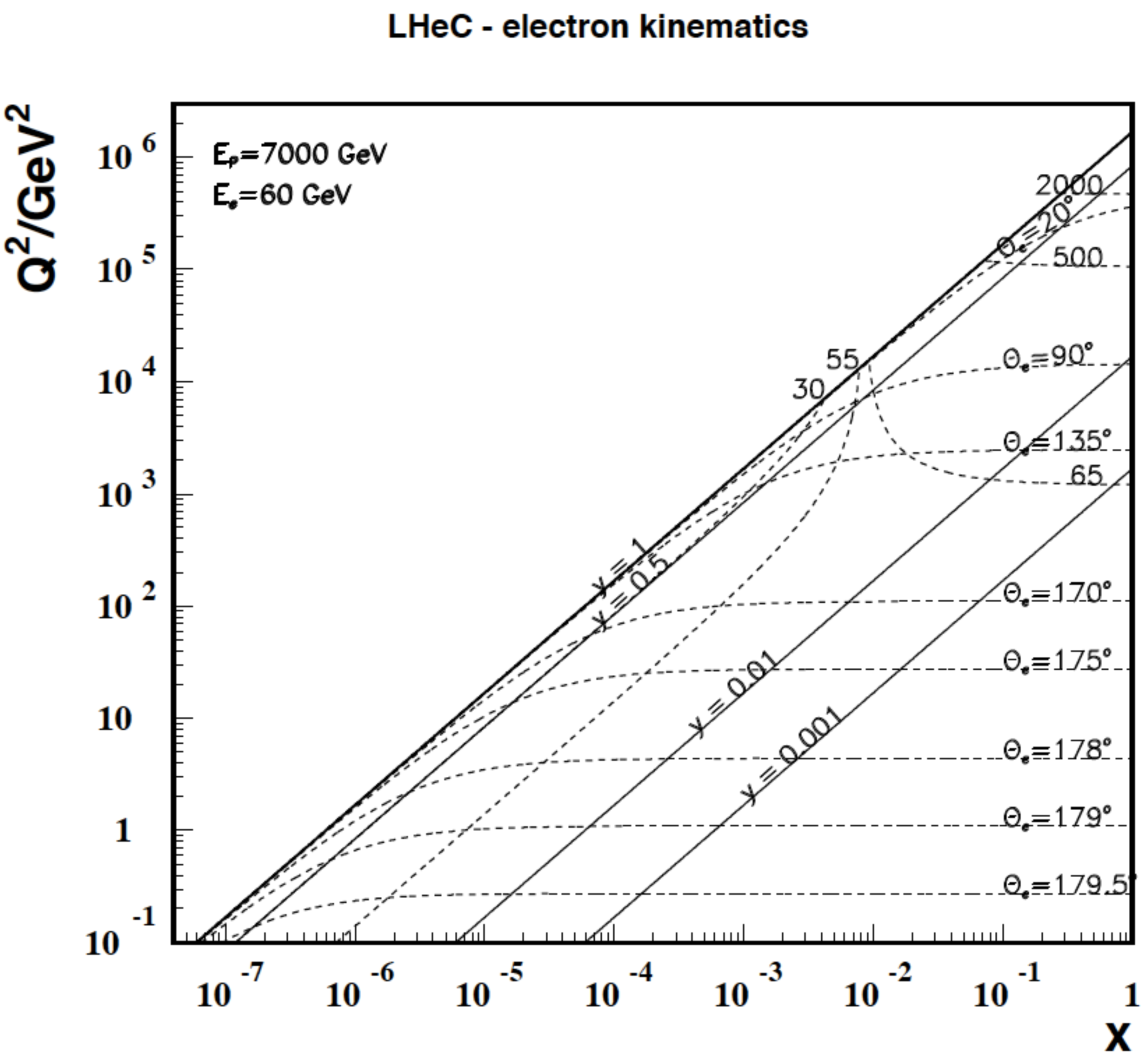
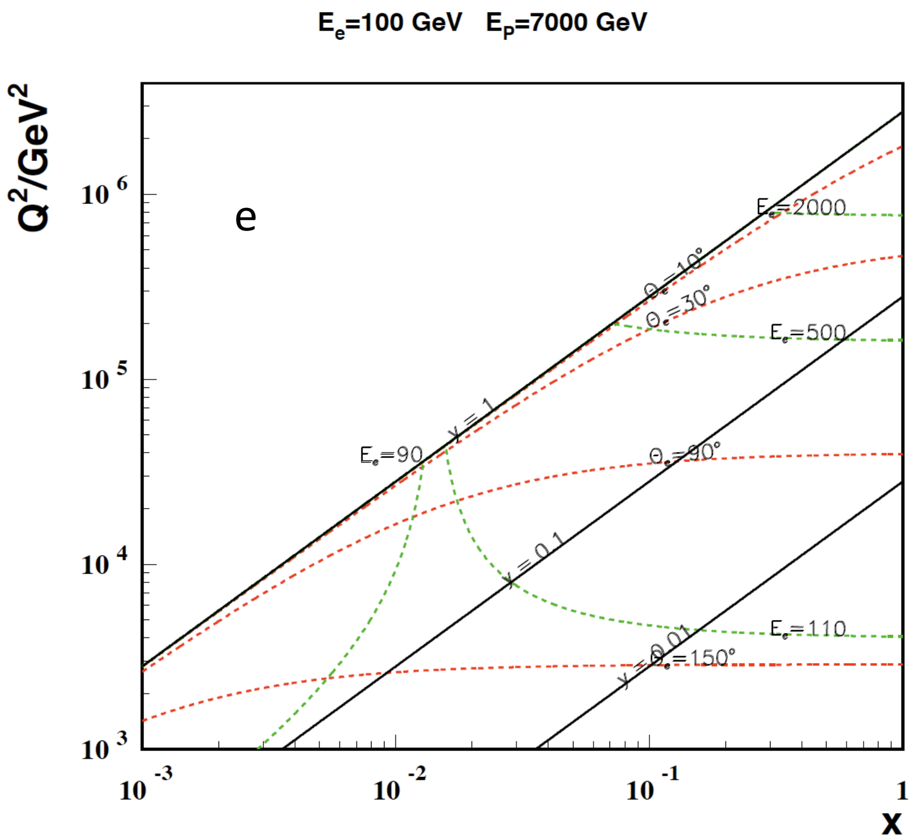


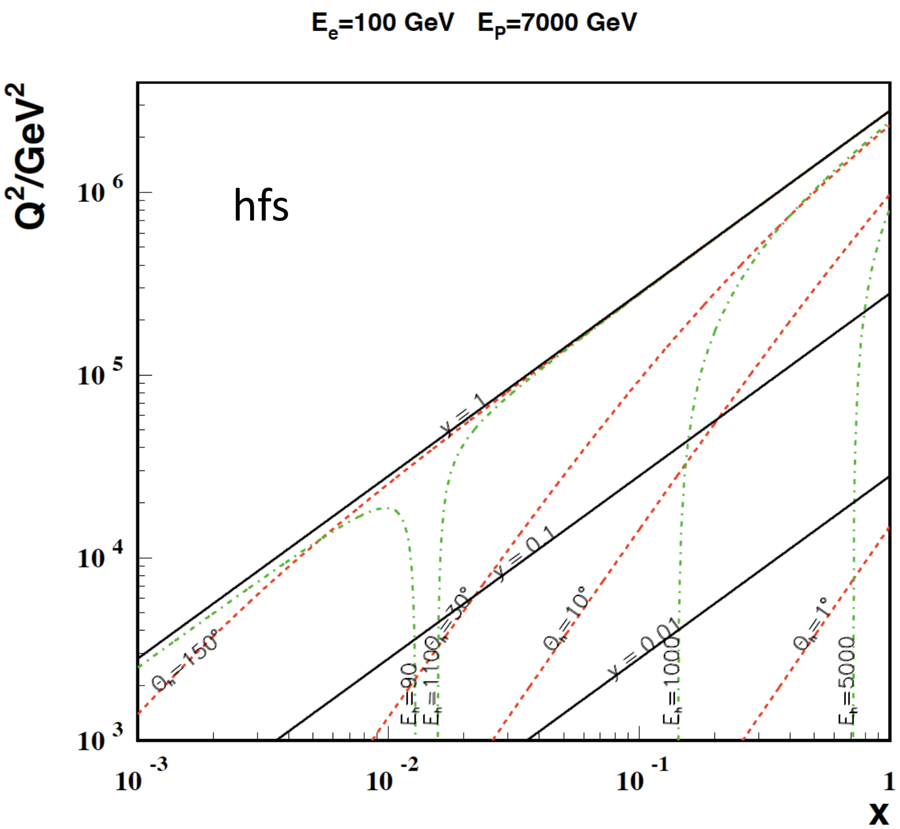
Figure 6.1: Kinematics of electron detection at the LHeC. Lines of constant scattering angle θ_e and energy, in GeV, are drawn. The region of low $Q^2 \lesssim 10^2\,\mathrm{GeV}^2$, comprising the lowest x region, requires to measure electrons scattered backwards with energies not exceeding E_e. At small energies, for $y \lesssim 0.5$ a good e/h separation is important to suppress hadronic background, as from photoprodocution. The barrel calorimeter part, of about $90 \pm 45°$, measures scattered electrons of energy not exceeding a few hundreds of GeV, while the forward calorimeter has to reconstruct electron energies of a few TeV. Both the barrel and the forward calorimeters measure the high x part, which requires very good scale calibration as the uncertainties diverge $\propto 1/(1-x)$ towards large x.

Kinematics – high Q^2



The electron kinematics at high Q^2 is no big problem, apart from extreme backscattering at very high Q^2 of electrons of a few TeV energy.

→**Need forward elm. calorimeter of few TeV energy range down to 10° and below with reasonable calibration accuracy.**

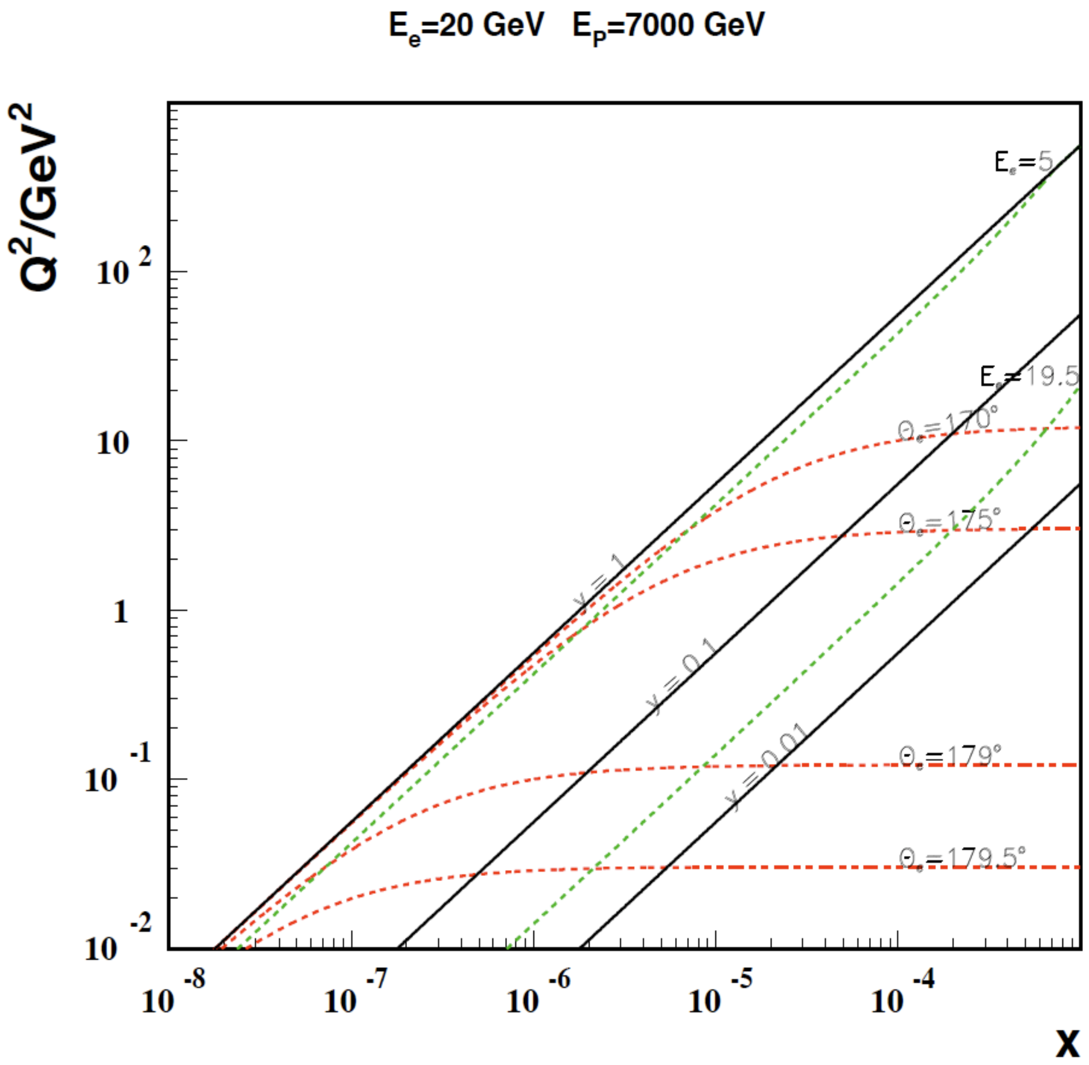


High x and high Q^2: few TeV HFS scattered forward:

→**Need forward had. calorimeter of few TeV energy range down to small angle, 1°. Mandatory for charged currents.**

Lowered E_e: access lower Q^2

$$Q^2(x,\theta_e) = sx/[1 + xE_p cot^2(\theta_e/2)/E_e] \simeq (2E_e cot(\theta_e/2))^2$$



If the 179° requirement for the bwd electron leads to a too long detector, we could consider 178°, i.e. halve the bwd length and do the lowest Q^2 with lower electron beam energy. This costs a small bit of low x at low Q^2

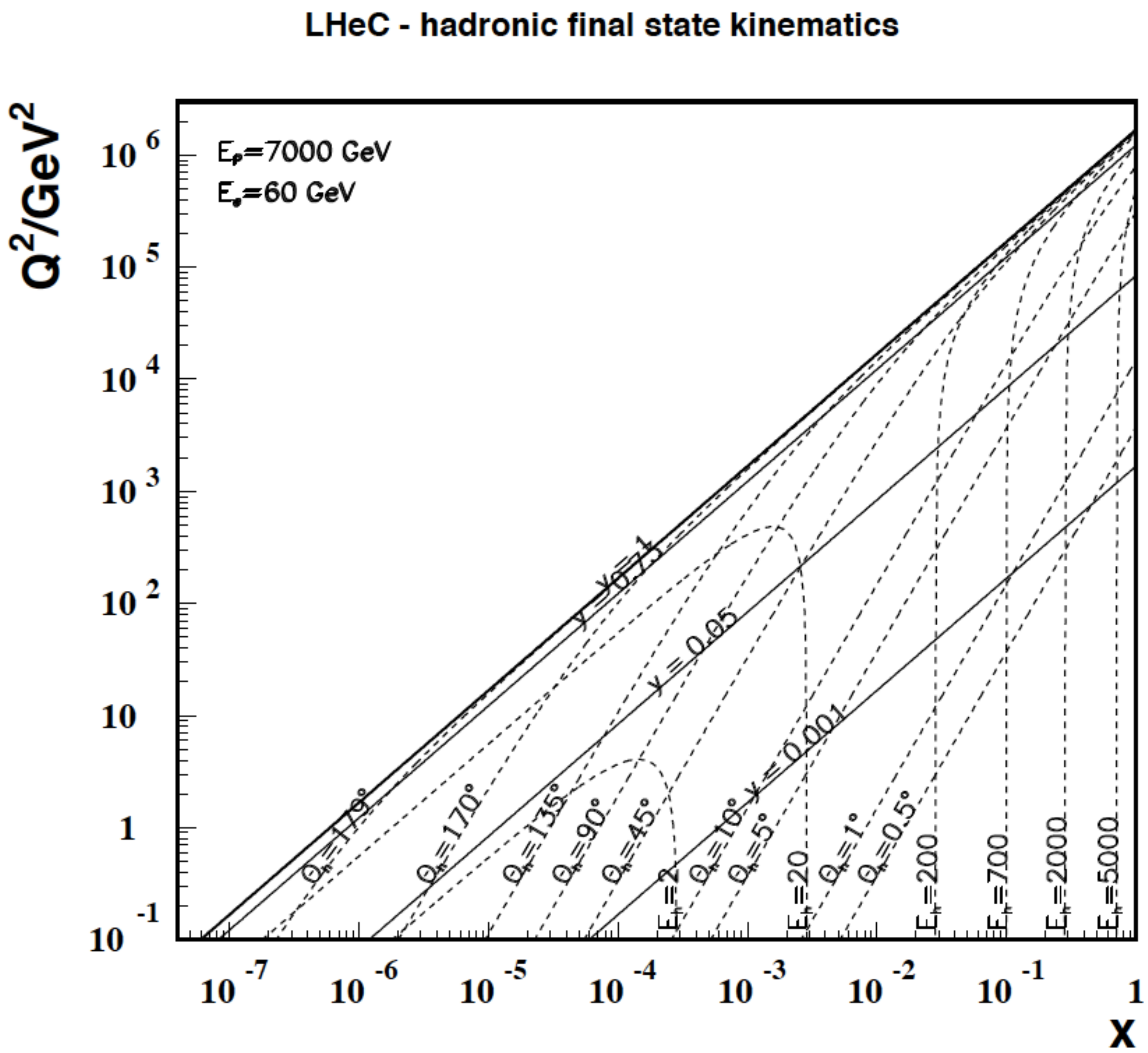


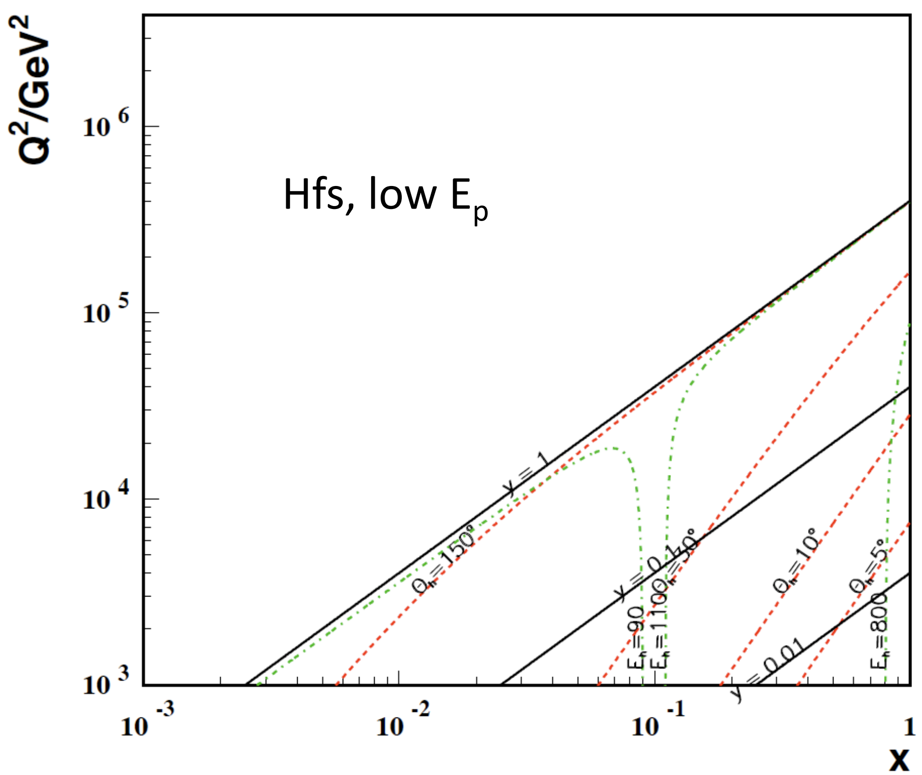
Figure 6.2: Kinematics of hadronic final state detection at the LHeC. Lines of constant energy and angle of the hadronic final state are drawn, as represented by simple kinematics of the struck quark. One easily recognises that the most demanding region is the large x domain, where very high energetic final state particles are scattered into the region of the proton beam. The barrel region, of about $90 \pm 45°$, is rather modest in its requirements. At low x the final state is not very energetic, $E_h + E'_e \simeq E_e$, and scattered into the backward detector region.

Hfs Kinematics – large x

Low proton beam energy: access large x.
Needs high luminosity: $L \sim 1/E_p^2$

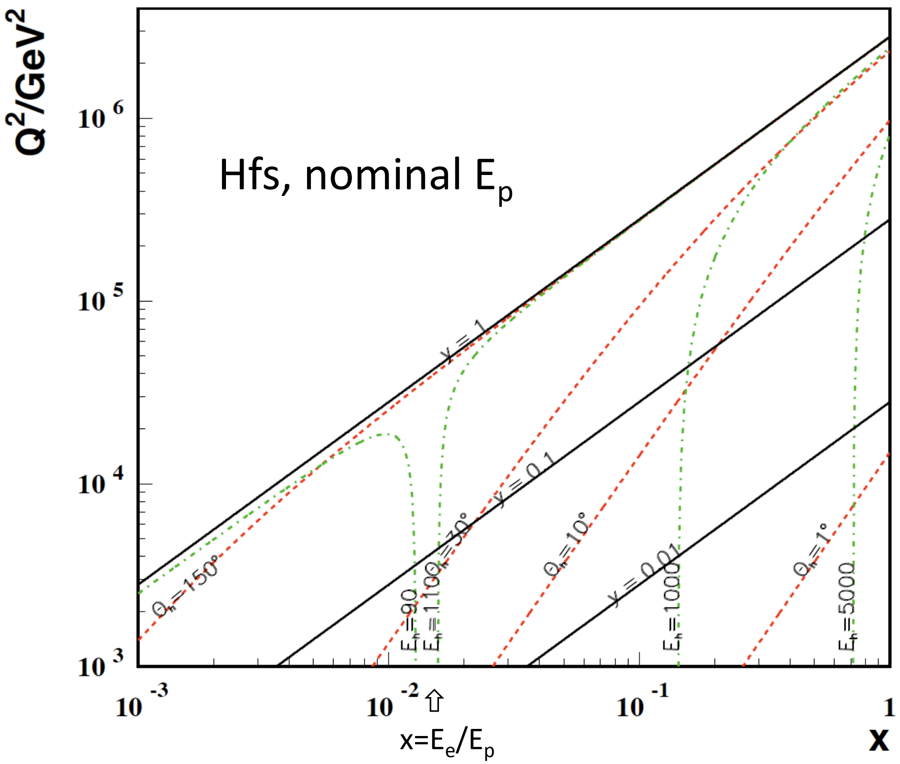
Nominal proton beam energy: need very fwd. angle acceptance for accessing large x

E_e=100 GeV E_p=1000 GeV

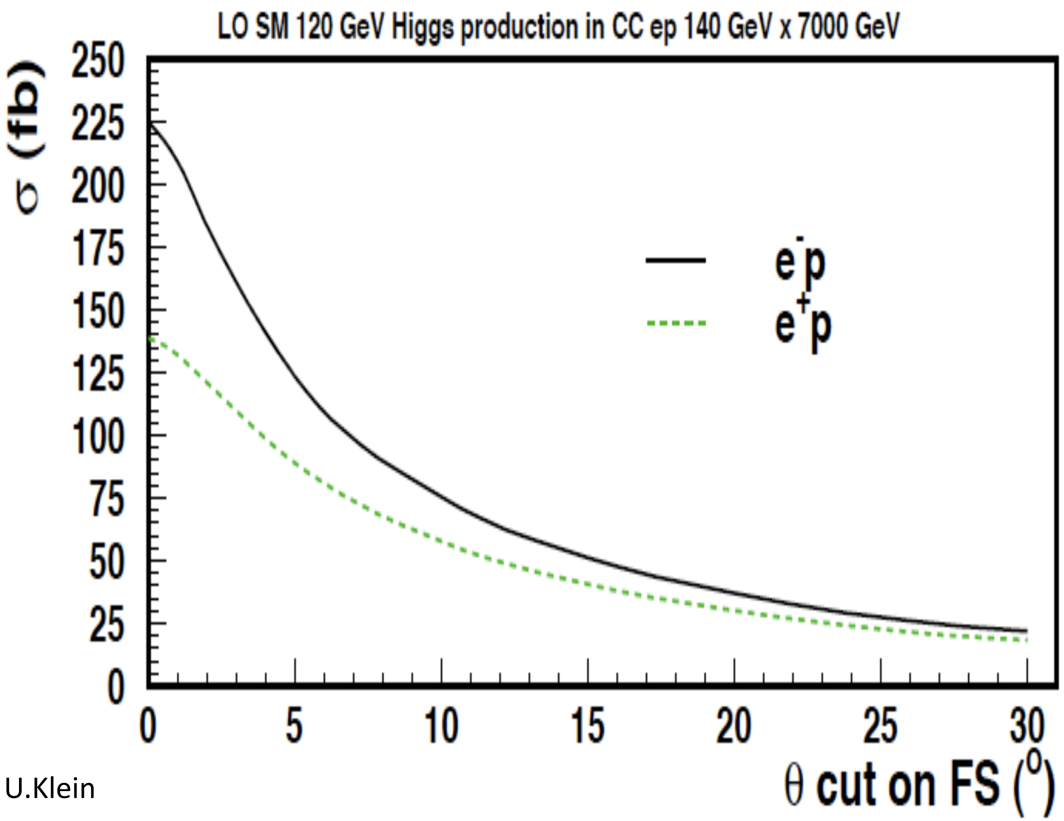


$$Q^2(x,\theta_h) = sx/[1 + E_e cot^2(\theta_h/2)/xE_p] \simeq (2xE_p cot(\theta_h/2))^2$$

E_e=100 GeV E_p=7000 GeV



Forward Acceptance



U.Klein

Higgs production cross section in charged currents: forward acceptance [tagging+resolution] important

Detector requirements

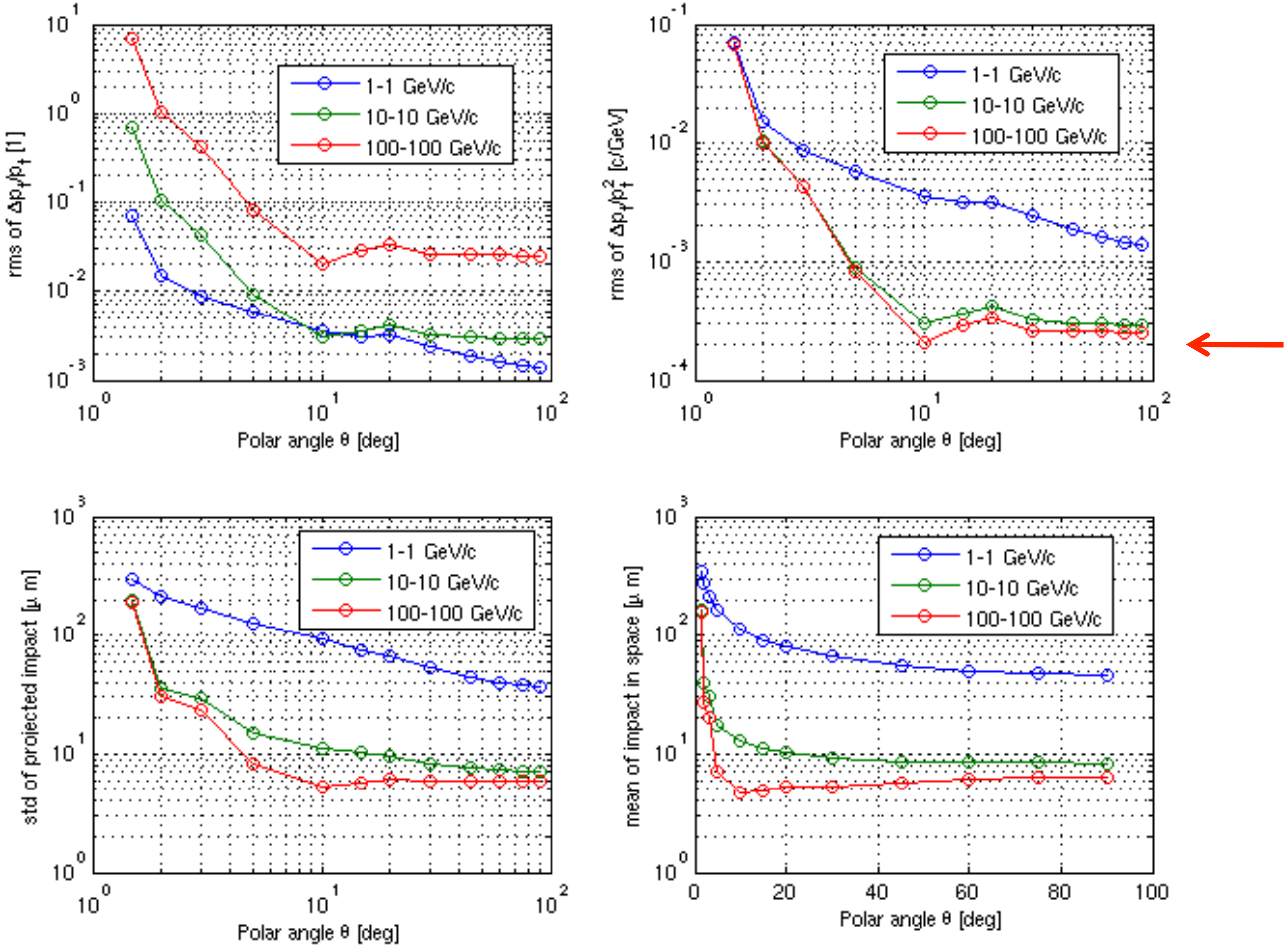
Requirement	LHeC	HERA	Comment
High luminosity to reach high Q^2 and large x	10^{33}	1-5 10^{31}	
Largest possible acceptance	1-179°	7-177°	Acceptance
High resolution tracking	0.1 mrad	0.2-1 mrad	Modern Si
Precision electromagnetic calorimetry	0.1%	0.2-0.5%	DA, kin peak, High statistics
Precision hadronic calorimetry	0.5%	1%	may be possible track+calo, e/h
High precision luminosity measurement	0.5%	1%	Lumi will be hard

Calorimeter - Resolutions and Scales

approximate angular range / degrees	backward 179 - 135	barrel 135 -45	forward 45-1
electron energy/GeV	3-100	10-400	50-5000
x_e	$10^{-7} - 1$	$10^{-4} - 1$	$10^{-2} - 1$
elm scale calibration in %	0.1	0.2	0.5
elm energy resolution $\delta E/E$ in $\% \cdot \sqrt{E/GeV}$	10	15	15
hadronic final state energy/GeV	3-100	3-200	3-5000
x_h	$10^{-7} - 10^{-3}$	$10^{-5} - 10^{-2}$	$10^{-4} - 1$
hadronic scale calibration in %	2	1	1
hadronic energy resolution in $\% \cdot \sqrt{E/GeV}$	60	50	40

Table 6.1: Summary of calorimeter kinematics and requirements for the default design energies of $60 \times 7000\,\mathrm{GeV}^2$, see text. The forward (backward) calorimetry has to extend to $1^\circ(179^\circ)$.

Momentum Resolution



O.Behnke
P.Kostka

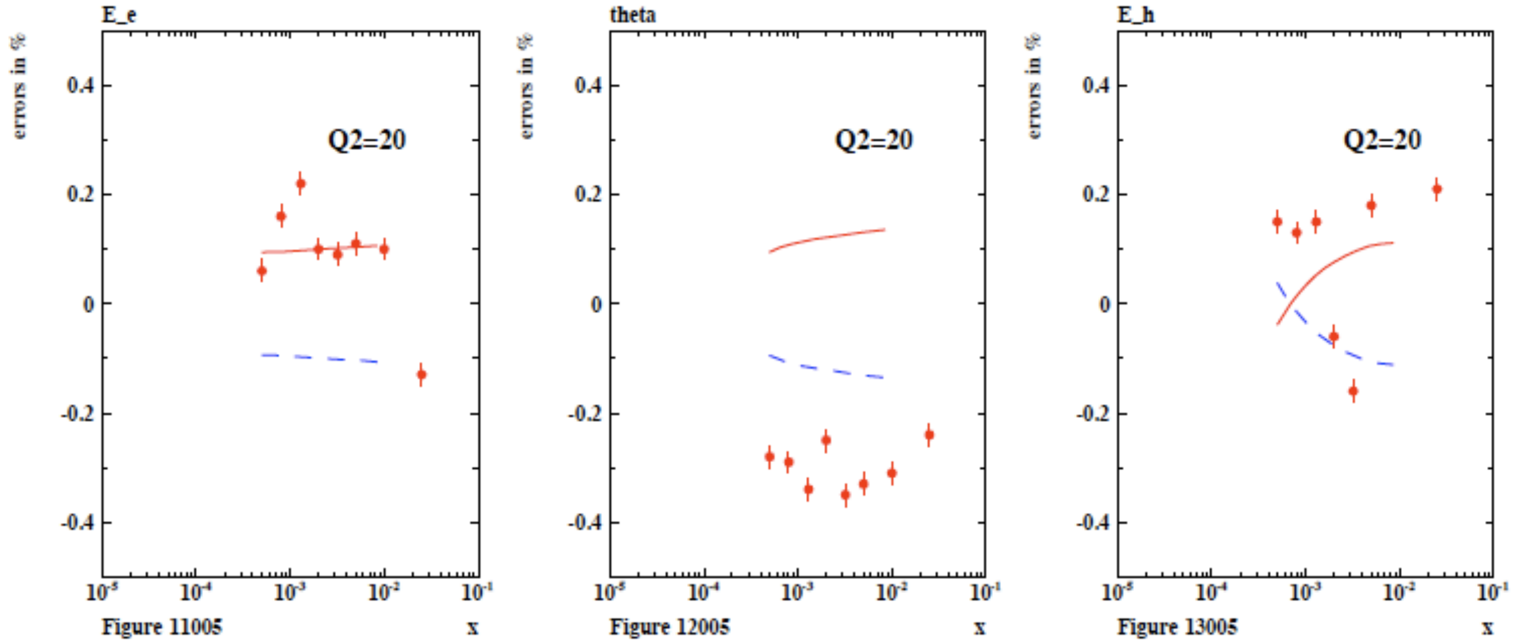
$$H1: CJC: \frac{\delta p_T}{p_T^2} := 3 \cdot 10^{-3}\, GeV^{-1}$$

$$B = 1.2T, \Delta \approx 200\mu m, N \approx 20 : L = 1m$$

$$\frac{\delta p_T}{p_T^2} = \frac{\Delta}{0.3BL^2} \cdot \sqrt{\frac{720}{N+4}} = 1.7 \cdot 10^{-4}\, GeV^{-1}$$

$$B = 3.5T, \Delta \approx 10\mu m, N \approx 2*5+3 : L = 0.6m$$

Systematic Error Calculation

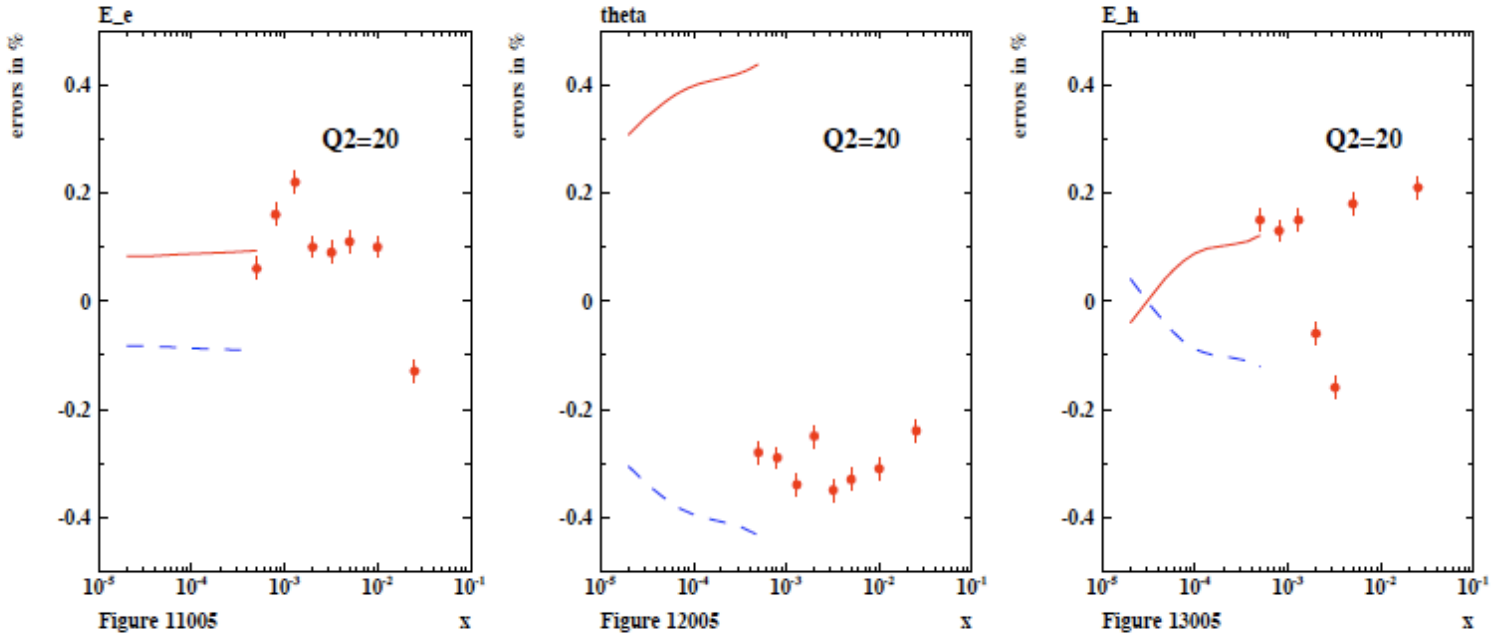


Numeric calculation (J.Bluemlein, MK, 1989) using cross section derivatives to $E_{e,}'$, θ_e, E_h
Reproduces MC calculation rather well

assume: 0.2 for E', 1mrad for polar angle and 1% for E_h
compares ok with MC calculation of H12000 paper (0.2%, 2mrad, 2%)

In addition for QCD fits required
0.5% extra efficiency, 1% yp for y>0.7, 0.5% RadCor, noise at y < 0.01

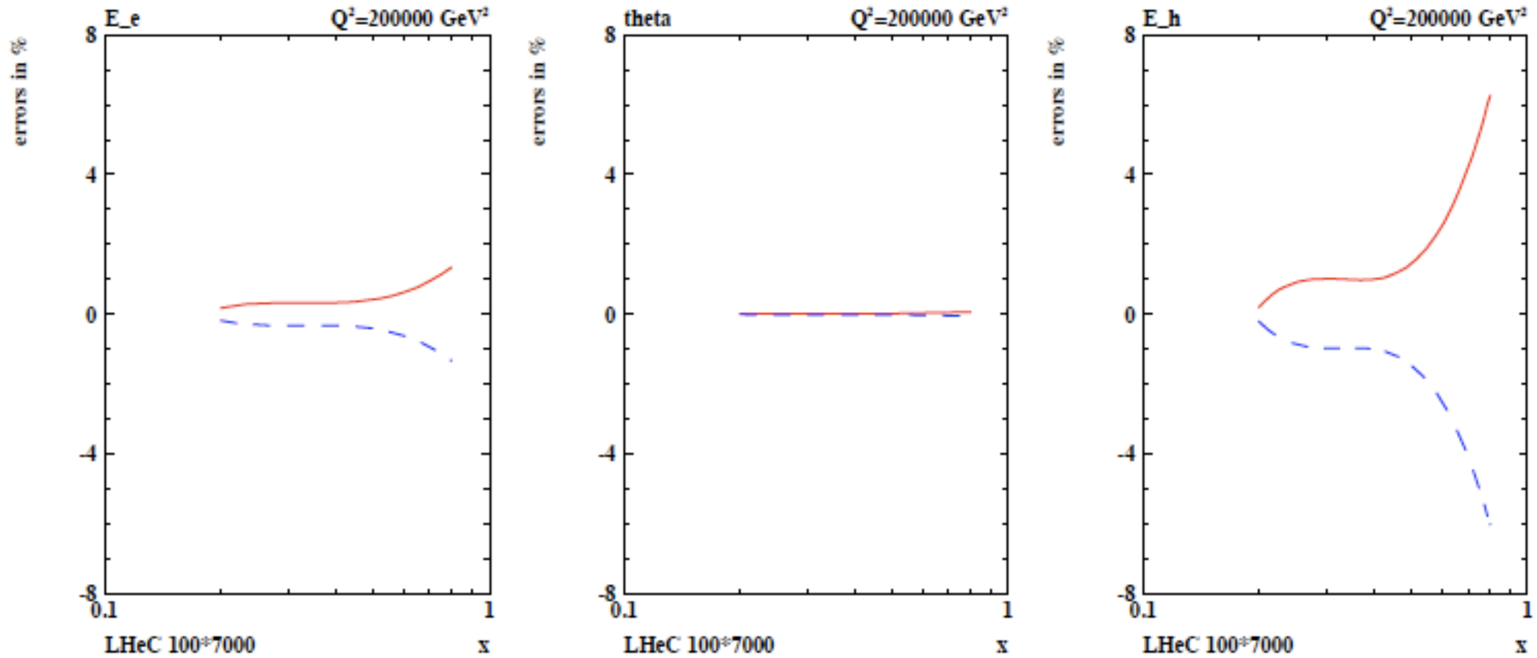
Systematic Error Calculation – Low x



Same error requirements for D (100 GeV * 7000 GeV): reach lower x
Polar angle error contribution rises. 0.2 mrad would imply 1% error!

→ Need very accurate polar angle measurement at large bwd angles.

Systematic Error Calculation



At high Q^2: measure at large x: 0.2% on E_e' may be relaxed a bit. Polar e angle may be much worse than 0.1mrad, but for high x need very accurate hadronic energy measurement (CC in particular).

→ Need ≤1% of hadronic energy scales at very large E_h

Remember cross section falls as $(1-x)^3$

Conclusions

The LHeC Detector should and can be a precision device:

Performance about 2 times better than H1 [new technology, higher statistics]

Angular acceptance: HFS: down to smallest possible angles ≤1° [low E_p]
Electron: 179° desirable, 178° tolerable [low E_e]

Backward electron angle measurement should be very accurate

Forward electron angle measurement not crucial

Forward jet hadronic energy resolution – high x - challenging

Resolutions as quoted

→**No requirement beyond what looks achievable based on H1 experience and modern technology [LHC detectors/upgrade + ILC developments]** title