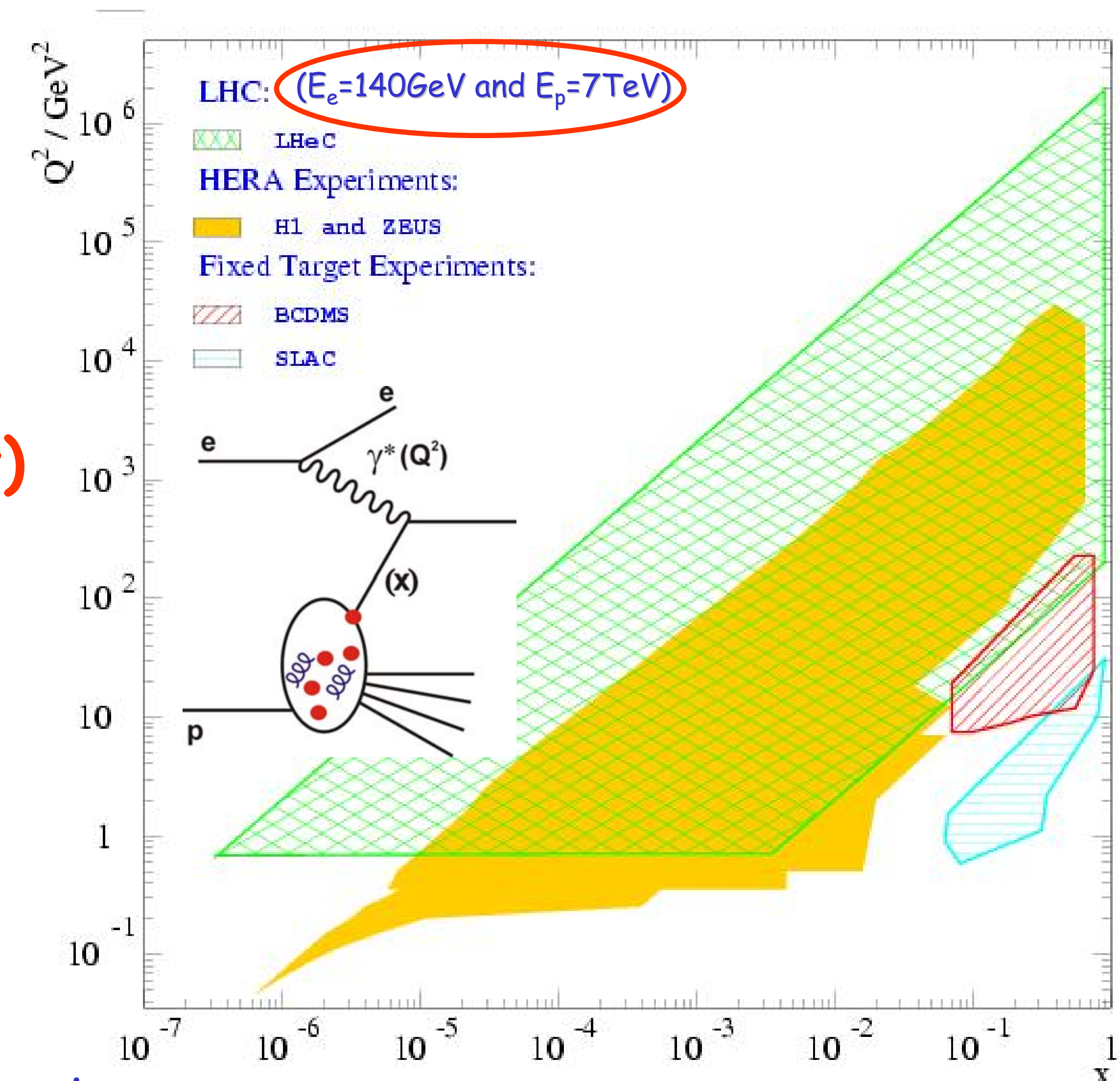
High Energy DIS after HERA?... The LHeC Project

Paul Newman
(Birmingham University)

Liverpool Seminar
11 June 2009



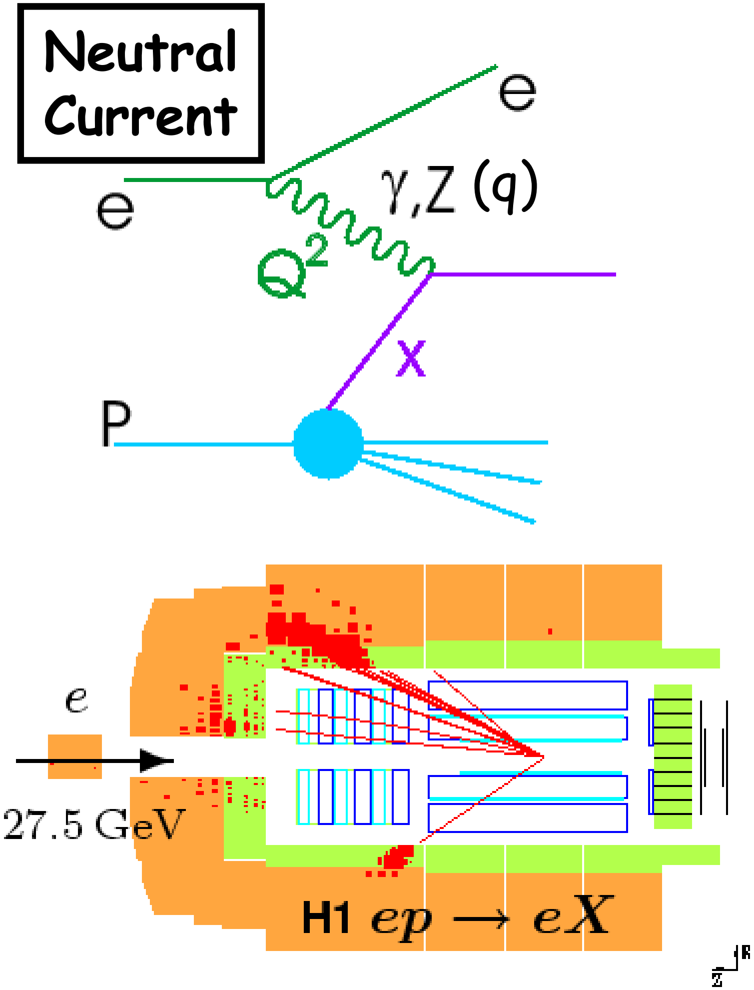
... based on the ongoing ECFA/CERN commissioned workshop on ep/eA physics possibilities at the LHC

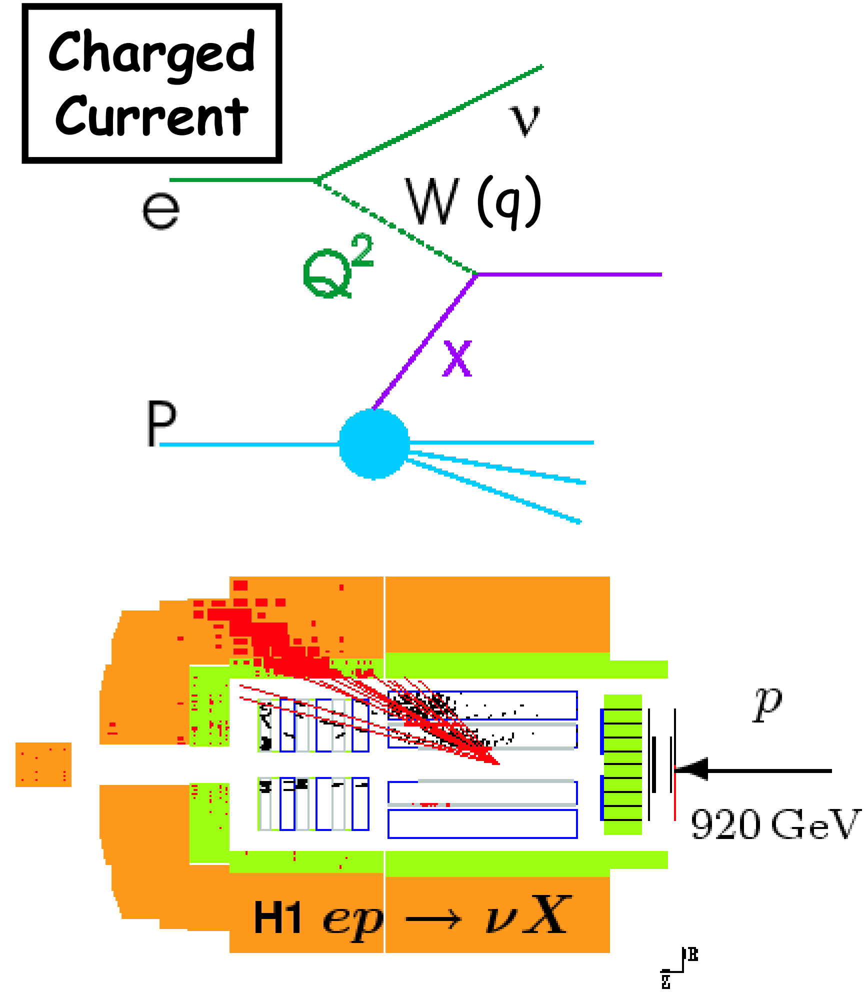
http://www.lhec.org.uk

… or … "How to Take G~~C~~oals to Newcastle"

- Much of the inspiration and work behind what I will show has come from people in Liverpool (MK, JBD and others)
- Apologies if I cover ground that is already well known here …
- I will focus mainly on physics motivation for TeV scale DIS

Basic Deep Inelastic Scattering Processes

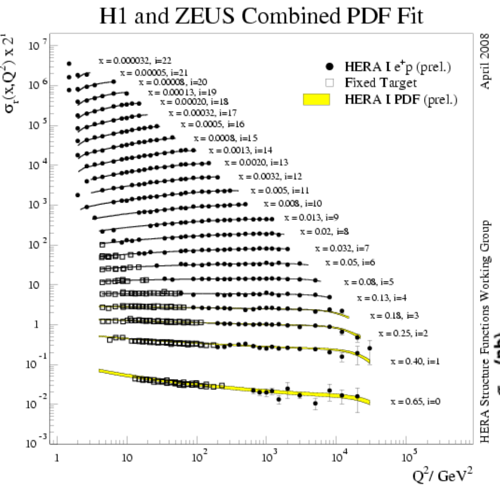


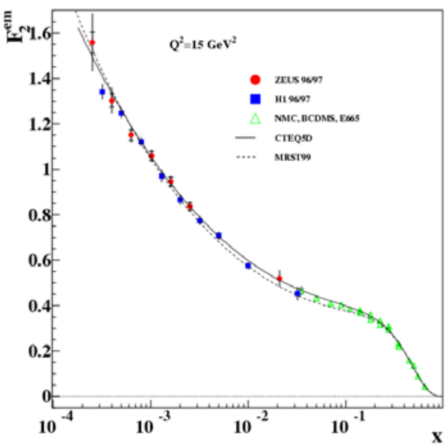


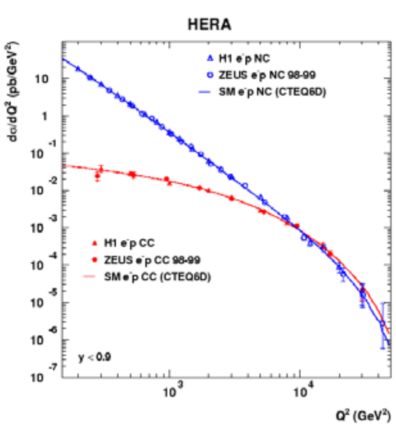
$Q^2 = -q^2$:resolving power of interaction

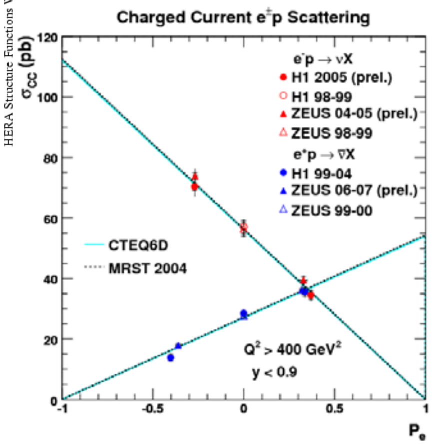
$x = Q^2 / 2q.p$: fraction of struck quark / proton momentum

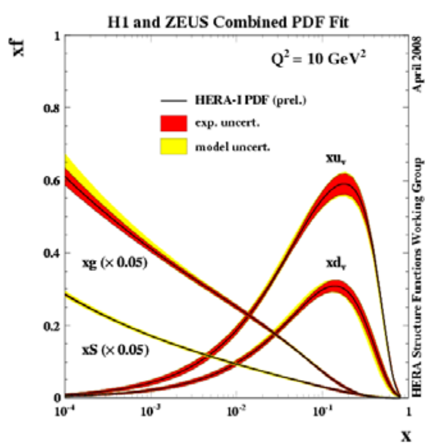
Collage of "Text-Book" HERA Plots

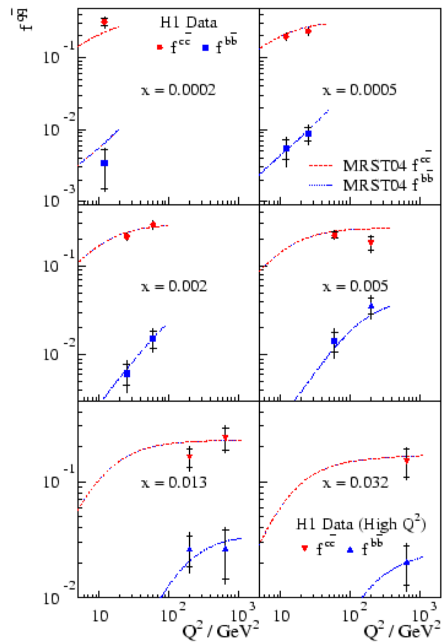


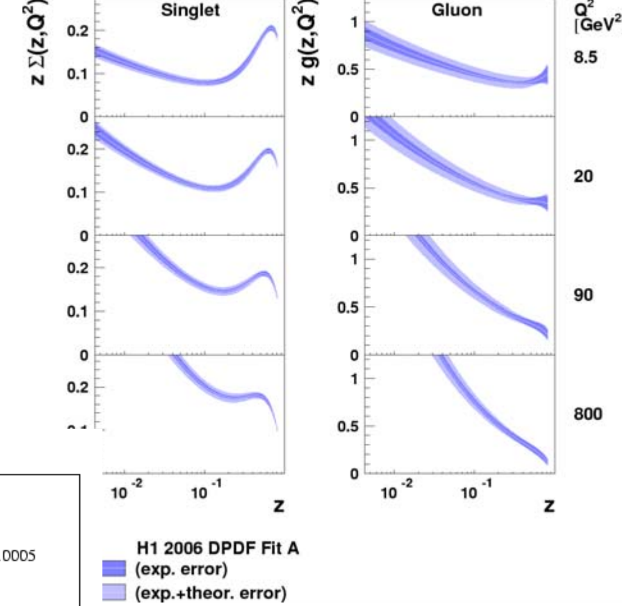


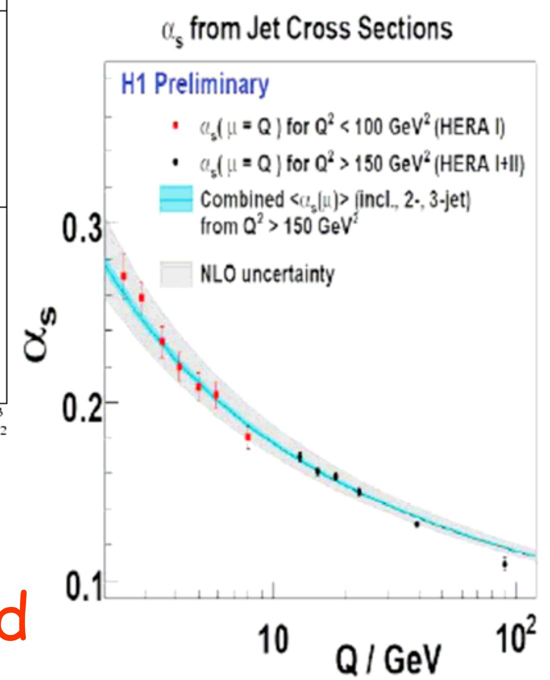












Further progress often limited by energy and luminosity …

HERA-LHC Workshop ... (see also PDF4LHC)

Workshop on the implications of HERA for the LHC

(partons, jets, heavy flavours, diffraction, MC tools ...)

807 pages!
(March 2009) →

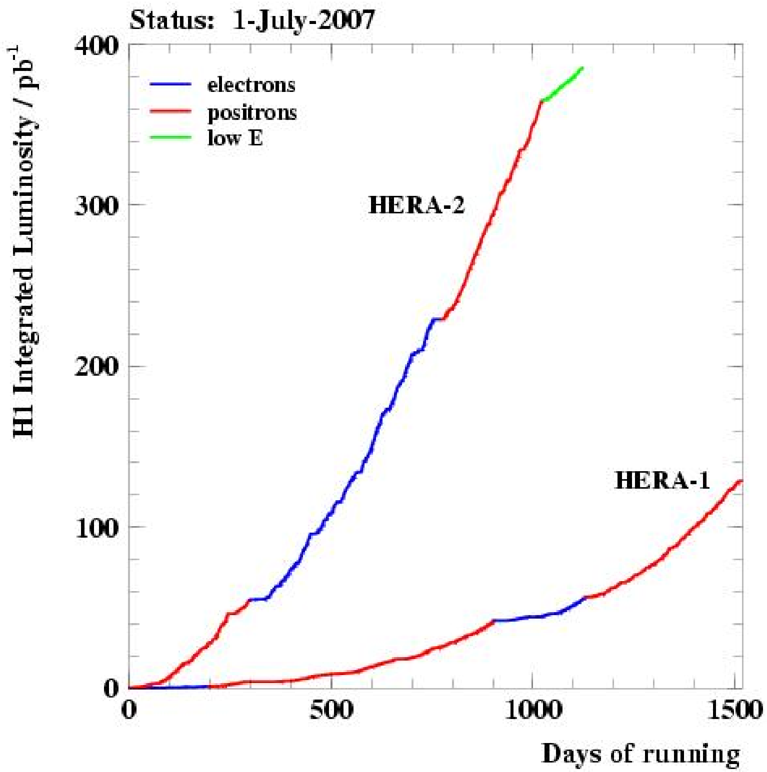
Impressum

Proceedings of the workshop
HERA and the LHC
2nd workshop on the implications of HERA for LHC physics
2006 - 2008, Hamburg - Geneva

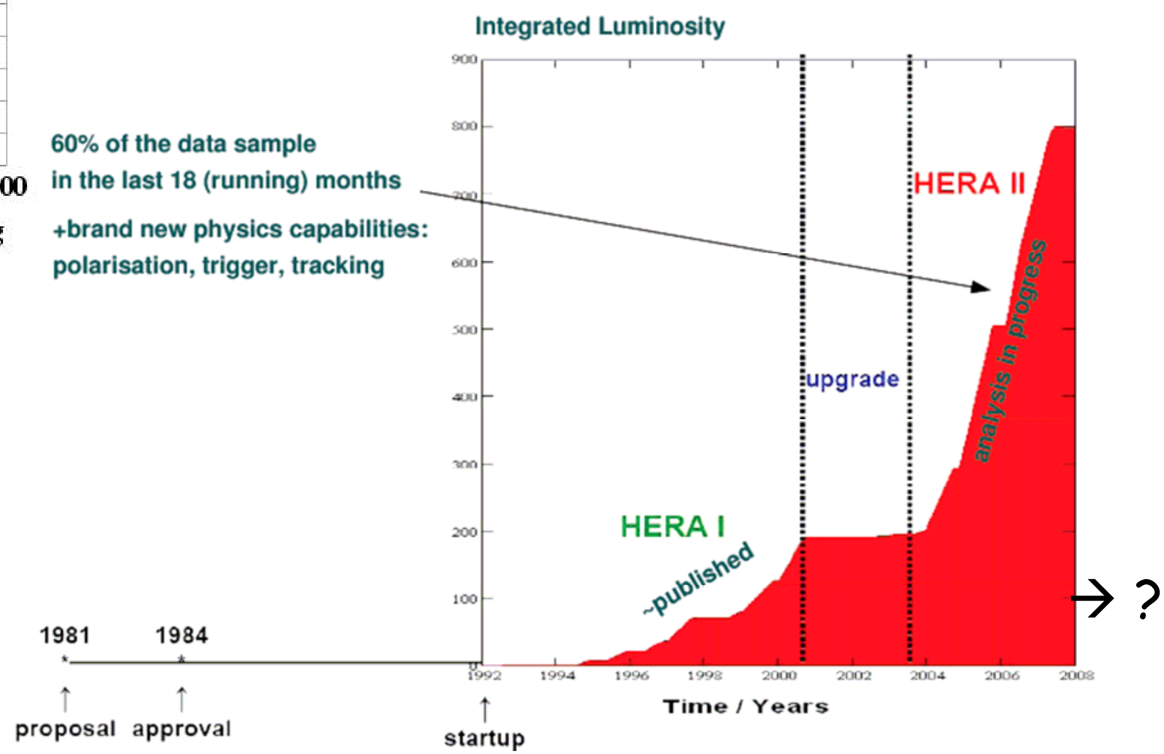
Conference homepage
http://www.desy.de/~heralhc

Online proceedings at
http://www.desy.de/~heralhc/proceedings-2008/proceedings.html

Luminosity and Status

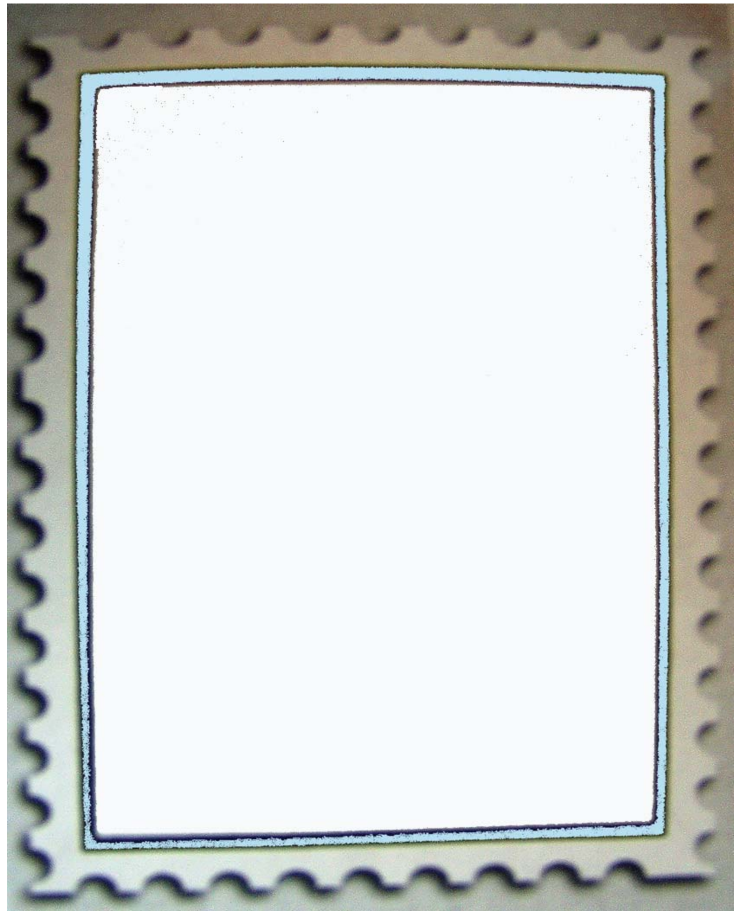


- Total of ~200 pb^{-1} e^-p, 300 pb^{-1} e^+p per experiment.
- Both lepton polarisation states
- ~25 pb^{-1} @ lower E_p = 575, 460 GeV



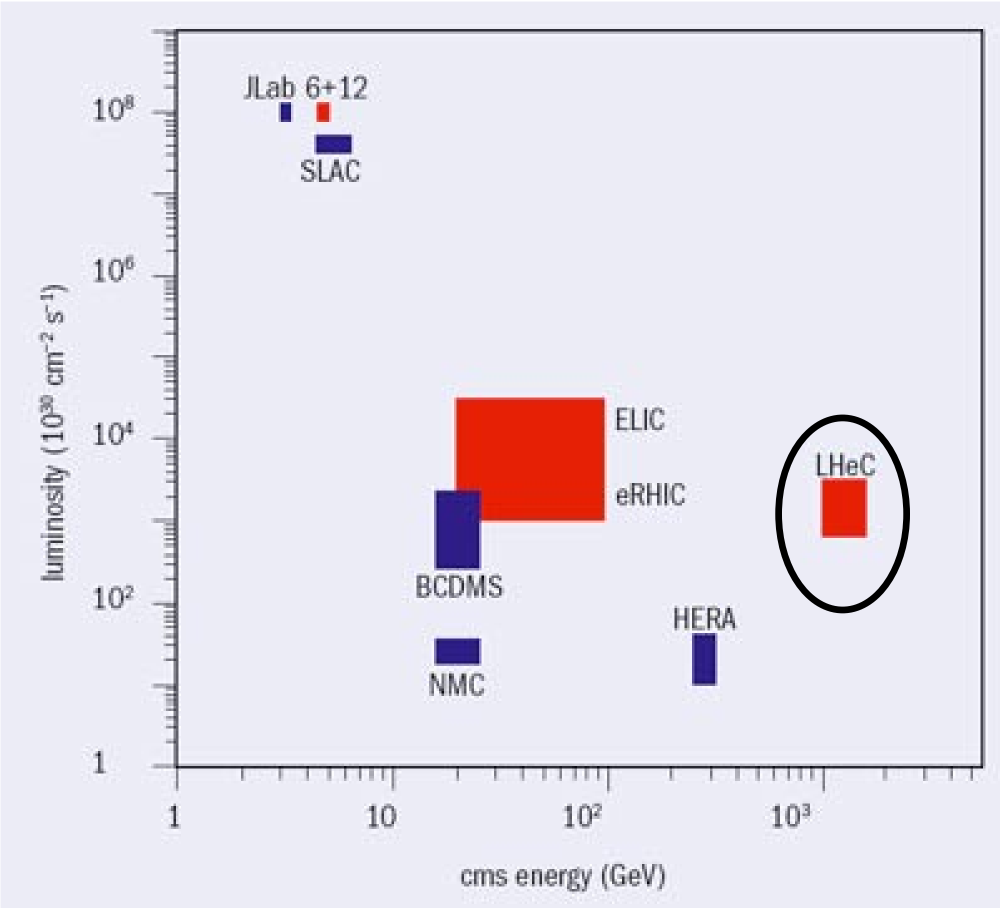
- HERA-I publications coming to an end.
- HERA-II searches largely complete
- Complicated final states take time (& UK experts) to analyse … but where is the longer term future?

Currently Approved Future of High Energy DIS



Some LHeC Context

The LHeC is not the first proposal for TeV scale DIS, but it is the first with the potential for significantly higher luminosity than HERA …



DESY 06-006
Cockcroft-06-05

Deep Inelastic Electron-Nucleon Scattering at the LHC*

J. B. Dainton[1], M. Klein[2], P. Newman[3], E. Perez[4], F. Willeke[2]

[1] Cockcroft Institute of Accelerator Science and Technology, Daresbury International Science Park, UK
[2] DESY, Hamburg and Zeuthen, Germany
[3] School of Physics and Astronomy, University of Birmingham, UK
[4] CE Saclay, DSM/DAPNIA/Spp, Gif-sur-Yvette, France

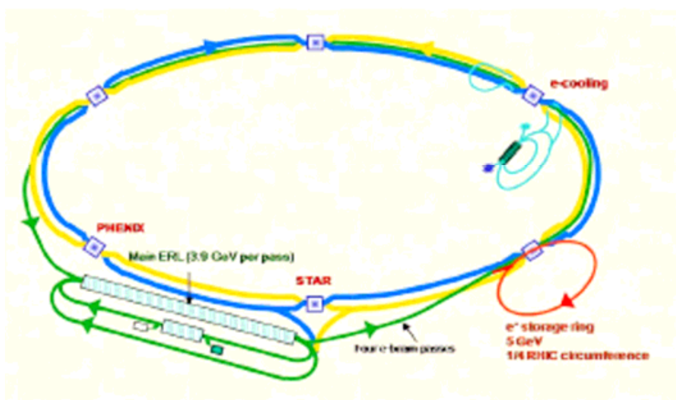
… achievable with a new electron accelerator at the LHC …

[JINST 1 (2006) P10001]

The Electron-Ion Collider (BNL / Jlab)

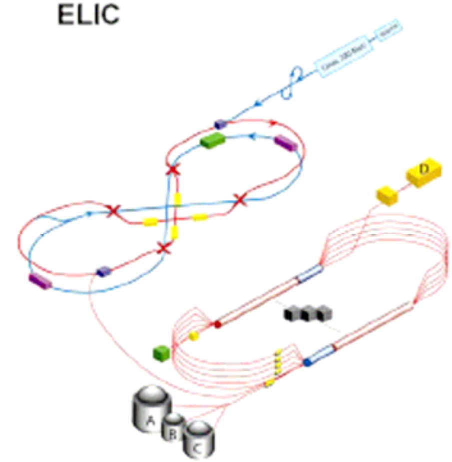
e.g. 10 GeV $e^{+/-}$ and 250 GeV polarised p/A

eRHIC



Peak lumi ~ 2.6 x $10^{33}cm^{-2}s^{-1}$

ELIC



Peak lumi ~ 6 x $10^{34}cm^{-2}s^{-1}$

- Limited in energy → but 100 times HERA luminosity
- Polarised hadrons → **spin** → long-term successor to HERMES, COMPASS?...
- Heavy ions → huge step forward for eA kinematic range

[More info at http://web.mit.edu/eicc]

The LHC is the future of the high energy frontier!

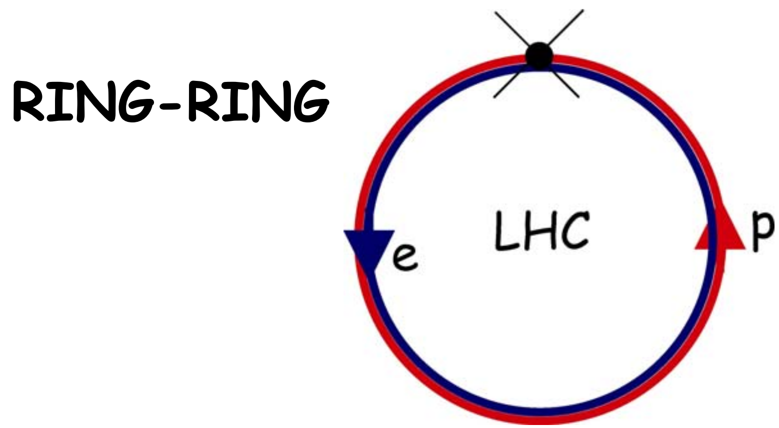
Can the unprecedented LHC energy and intensity be exploited for DIS?

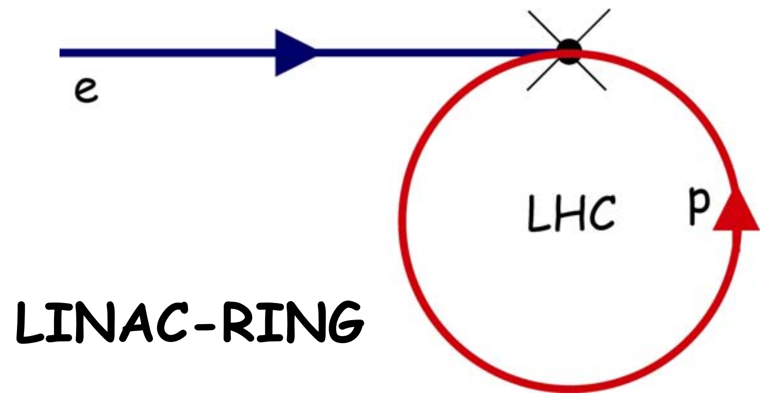
"... the LHeC is already half built" [J Engelen]

"... 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]

How Could ep be Done using LHC?

… whilst allowing simultaneous ep and pp running …

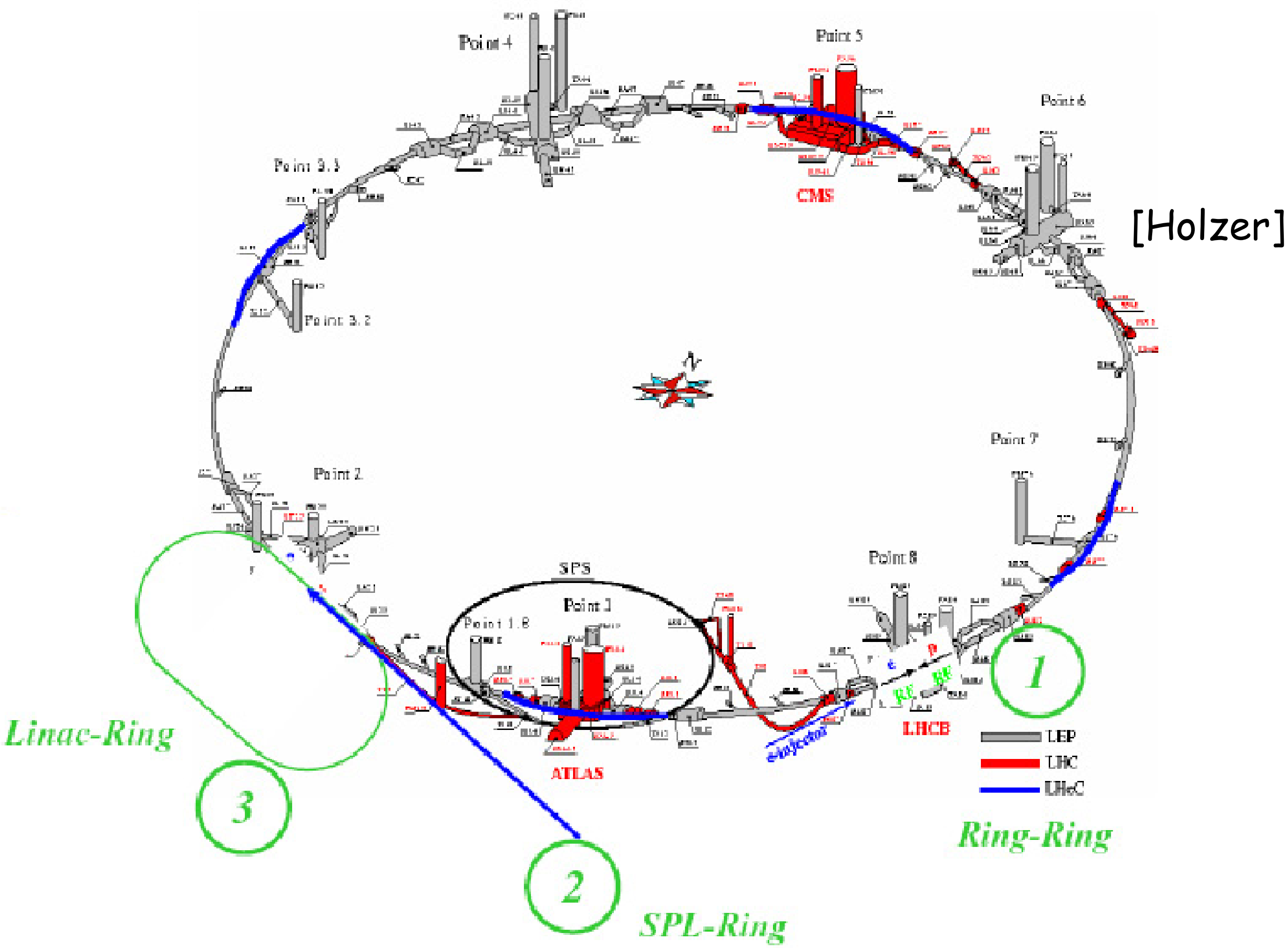




- First considered (as LEPxLHC) in 1984 ECFA workshop
- Main advantage: high peak lumi obtainable (~3.10^{33} cm^{-2} s^{-1})
- Main difficulties: building round existing LHC, e beam energy (50GeV?) and lifetime limited by synchrotron radiation

- Previously considered as `QCD explorer' (also THERA)
- Main advantages: low interference with LHC, high E_e (→ 150 GeV?) and lepton polarisation, LC relation
- Main difficulties: lower luminosity ~3.10^{32} cm^{-2} s^{-1} (?) at reasonable power, no previous experience exists

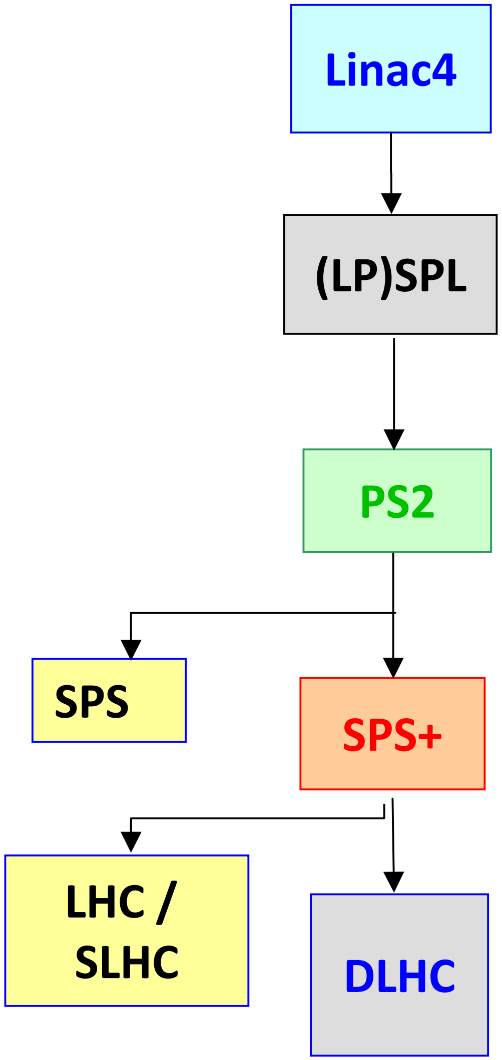
Three Possible Lay-outs for Collisions at IP2

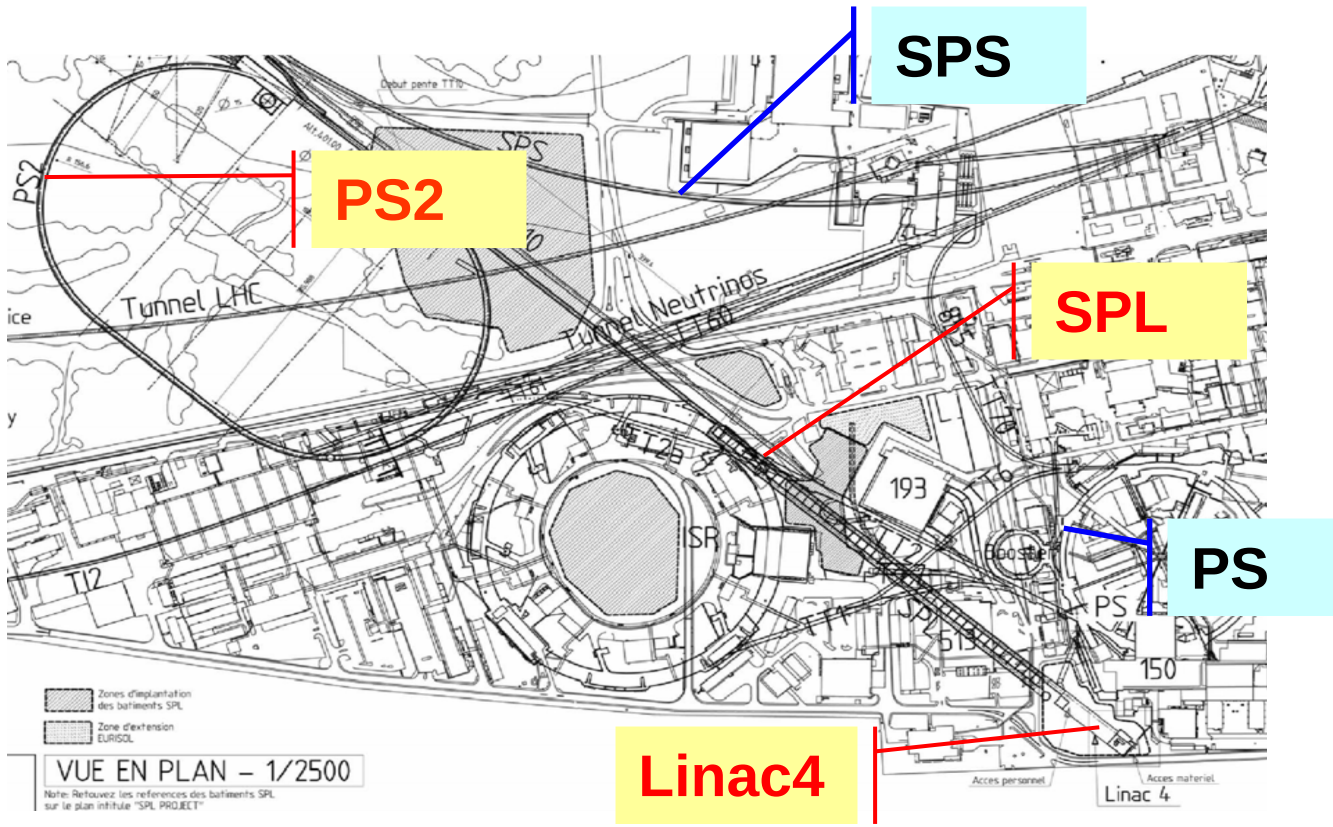


- Detailed design within constraints of simultaneous ep and pp running and power consumption < 100 MW
- CERN, BNL, Cockcroft, Jlab, SLAC, DESY, Novisibirsk …

Electrons in the SPL?

SPL (Superconducting Proton Linac) is part of proposed CERN p-accelerator upgrade programme.
… could be used with simple transfer line as electron **injector** or to provide up to **~30 GeV electrons** for collisions





R. Garoby, CARE-HHH BEAM07, October'07; L. Evans, LHCC, 20 Feb '08

Ring-Ring Solution

• Benefits from long experience of colliding beam facilites

• By-passes around ATLAS and CMS
Based on existing survey tunnels (~1.5km of new tunnelling)

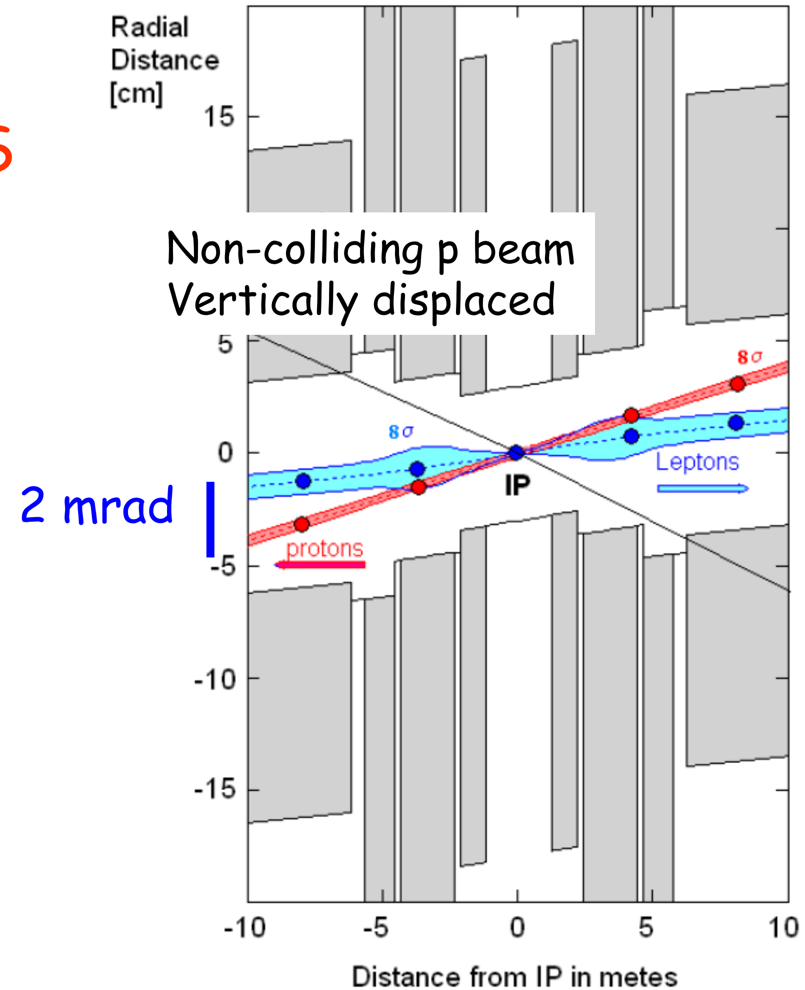
• LHC fixes p beam parameters, e beam matches p shape & sizes

• Fast separation of beams with tolerable synchrotron power requires ~2 mrad crossing angle

• E_e ~ 50 GeV for acceptable synchrotron power at 3.10^{33} cm^{-1} s^{-1}

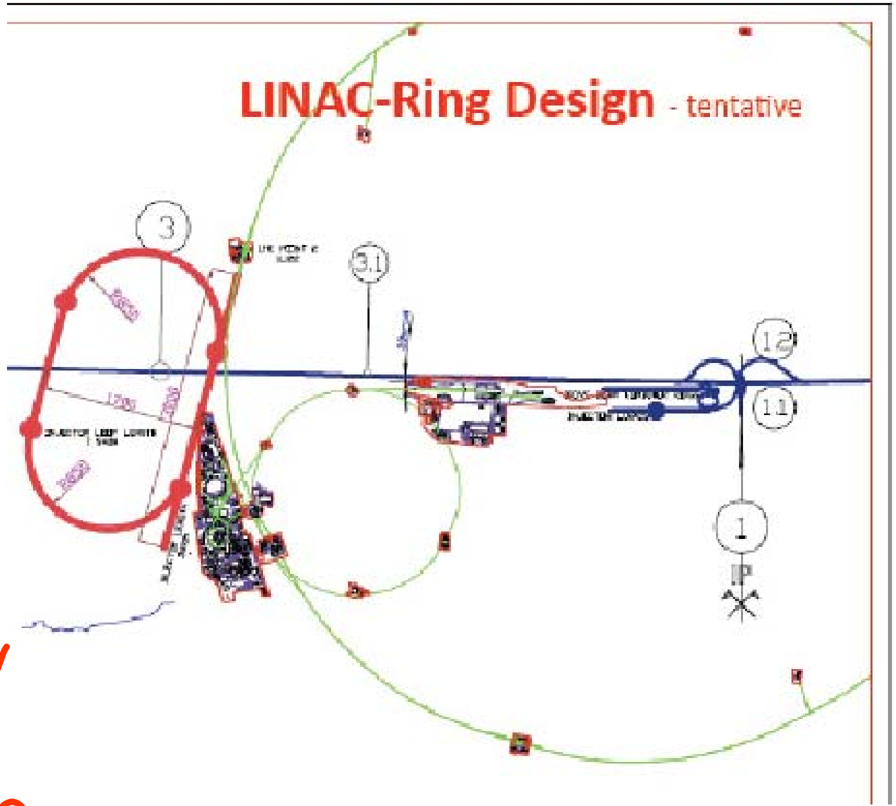
[Willeke, Holzer et al.]

Top view



Linac-Ring Solutions

[Zimmermann et al.]



Many lay-outs proposed

Tentative design with acceleration of electrons via racetrack construction

Somewhat reduced lumi
~ 3.10^{32} cm^{-2} s^{-1} for E_e ~ 100 GeV at acceptable power consumption → energy recovery?

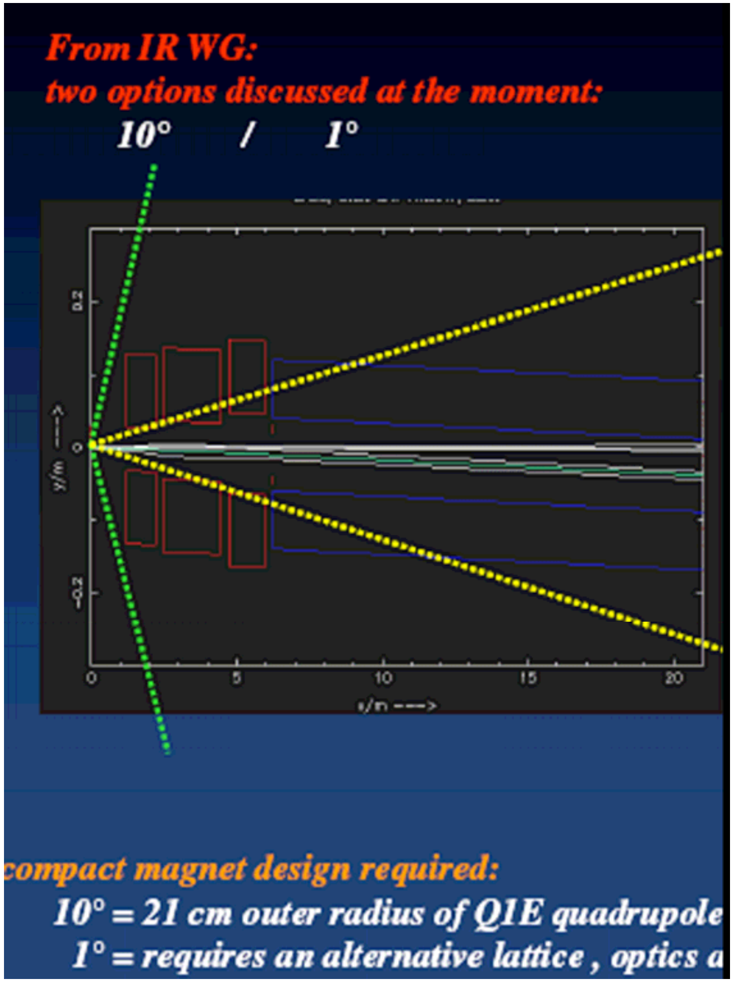
Higher energy (→ E_e = 150 GeV) possible at reduced lumi

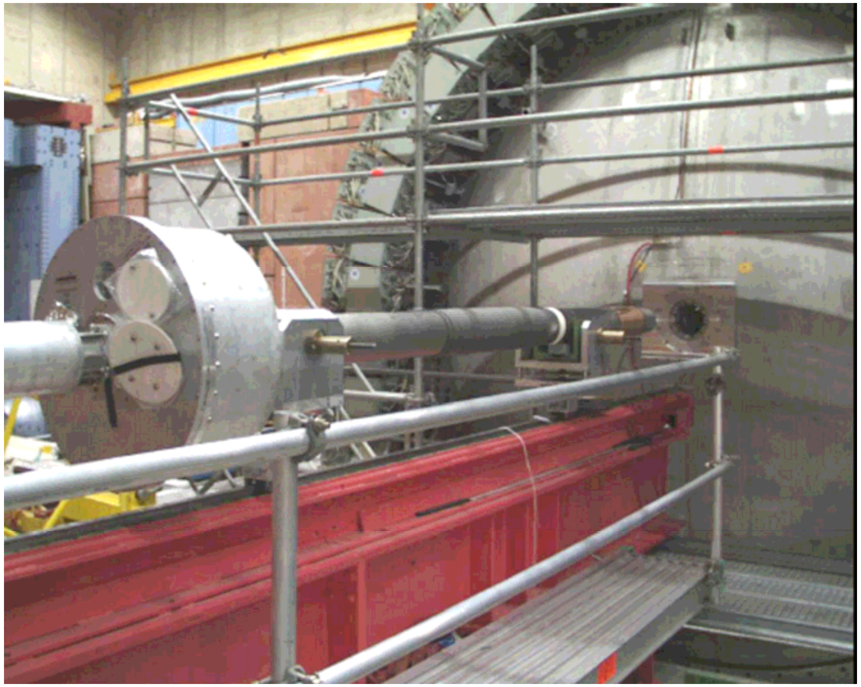
New concept for colliders … lots of R&D required …

The Luminosity v Acceptance Question

- As for HERA-I v HERA-II, low β focusing beam elements around interaction region can improve lumi by a factor ~10
- However, acceptance near beam-pipe is compromised

→ loss of low x / Q^2 acceptance
→ loss of high M acceptance
→ poorer HFS measurements





Beam Scenarios for First Physics Studies

Several scenarios under study … see later for justification

config.	E(e)	E(N)	N	$\int L(e^+)$	$\int L(e^-)$	|Pol|	$L/10^{32}$	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 hiQ^2
C	50	7	p	1	1	0.4	1	30	1	RR lo x
D	100	7	p	5	10	0.9	2.5	40	2	LR
E	150	7	p	3	6	0.9	1.8	40	2	LR
F	50	3.5	D	1	1	--	0.5	30	1	eD
G	50	2.7	Pb	0.1	0.1	0.4	0.1	30	1	ePb
H	50	1	p	--	1	--	25	30	1	lowEp

ep Studies based on a 20-150 GeV electron beam
and lumi of 1-10 fb^{-1} / year

Scenario for Experimental Precision

Requirements to reach a per-mil α_s (c.f. 1-2% now) …

[Klein, Kluge …]

The new collider …

- should be ~100 times more luminous than HERA

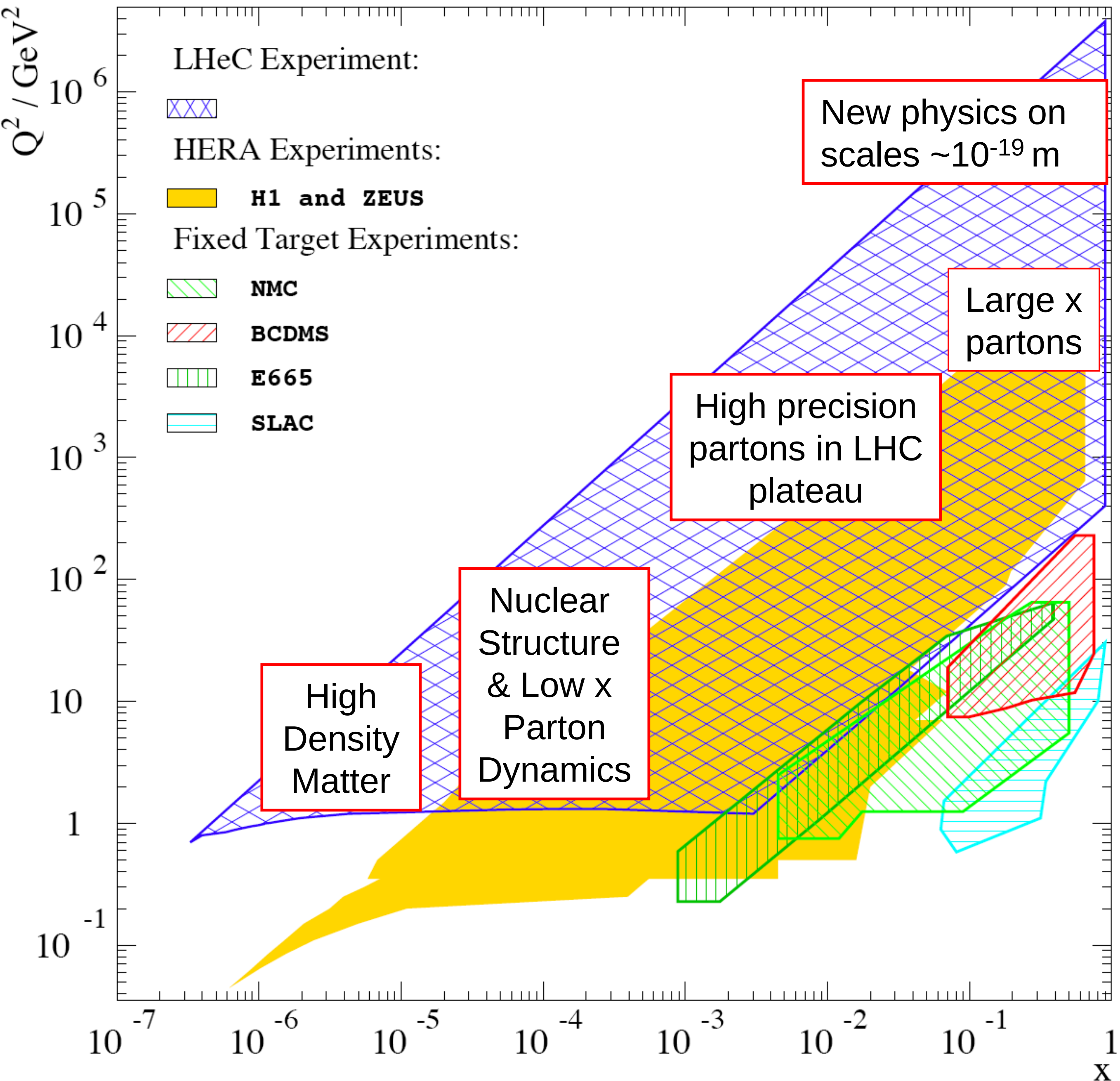
The new detector

- should be at least 2 times better than H1 / ZEUS

Lumi = 10^{33} cm^{-2} s^{-1}	(HERA 1-5 x 10^{31} cm^{-2} s^{-1})
Acceptance 10-170^{o} ($\rightarrow$179^{o}?)	(HERA 7-177^{o})
Tracking to 0.1 mrad	(HERA 0.2 – 1 mrad)
EM Calorimetry to 0.1%	(HERA 0.2-0.5%)
Had calorimtry to 0.5%	(HERA 1%)
Luminosity to 0.5%	(HERA 1%)

First `pseudo-data' for F_2, F_L, F_2^D …produced on this basis …

Kinematics & Motivation (140 GeV x 7 TeV)

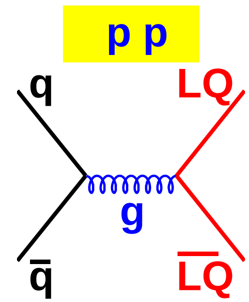


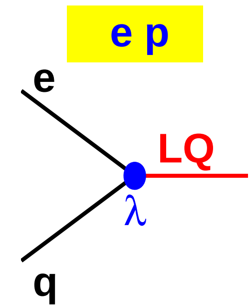
$\sqrt{s} = 2$ TeV

- High mass (M_{eq}, Q^2) frontier
- EW & Higgs
- Q^2 lever-arm at moderate & high x → PDFs
- Low x frontier → novel QCD …

$x \geq 5.10^{-7}$ at $Q^2 \leq 1$ GeV^2

Lepton-quark Bound States





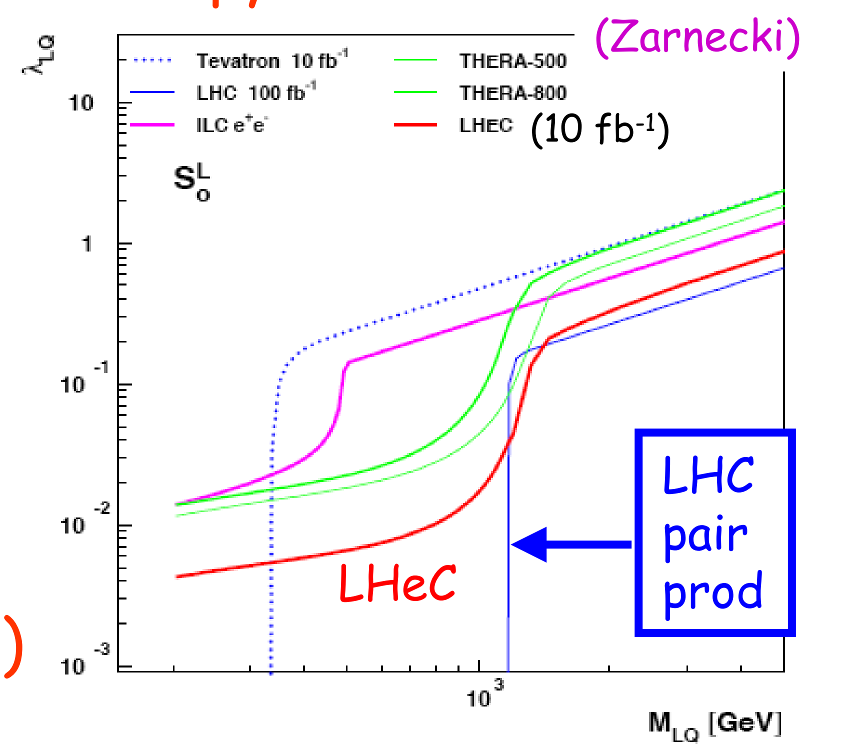
Yukawa coupling, λ

- Leptoquarks appear in many extensions to SM… explain apparent symmetry between lepton and quark sectors.

- Scalar or Vector color triplet bosons carrying L, B and fractional Q, complex spectroscopy?

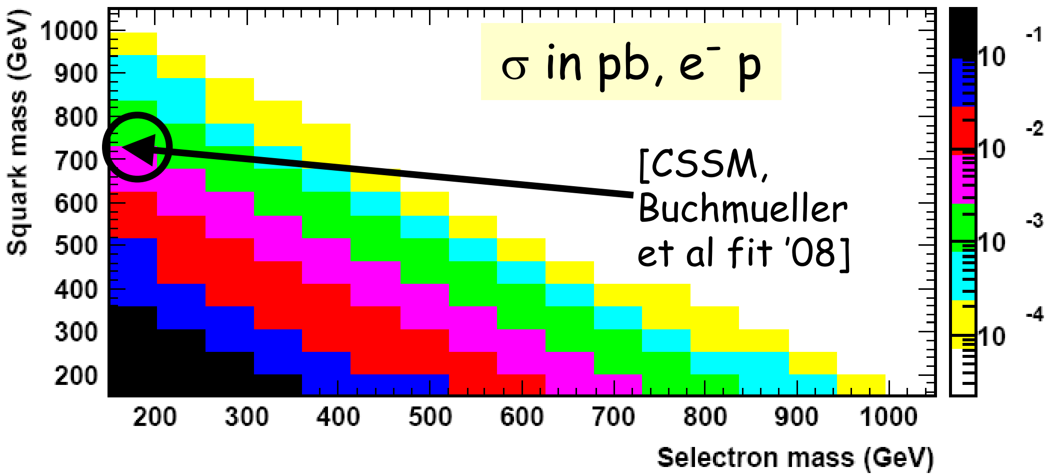
- (Mostly) pair produced in pp, single production in ep.

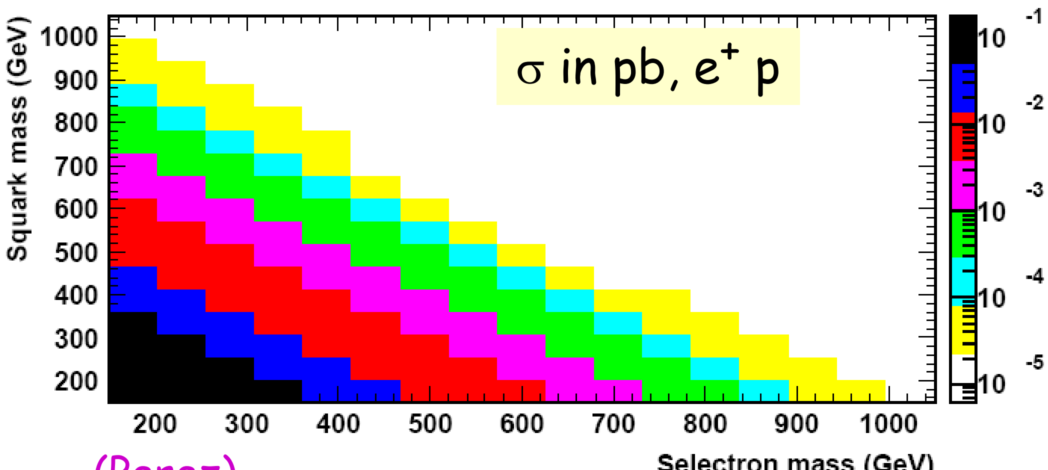
- LHeC sensitivity (to ~1.5 TeV) similar to LHC, but can determine quantum numbers / spectroscopy (fermion #, spin, chiral couplings …)



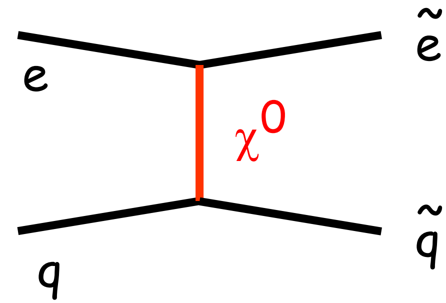
Rp Conserving Supersymmetry

tan β = 10, M_2 = 380 GeV, μ = -500 GeV





(Perez)



Pair production via t-channel exchange of a neutralino.

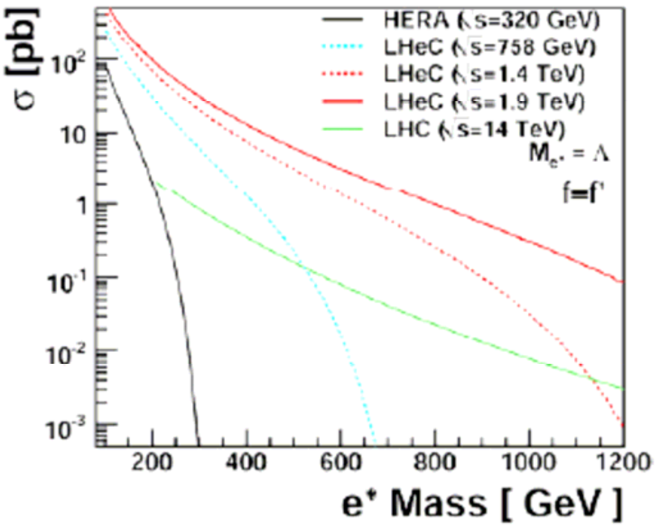
Cross-section sizeable for ΣM < 1 TeV

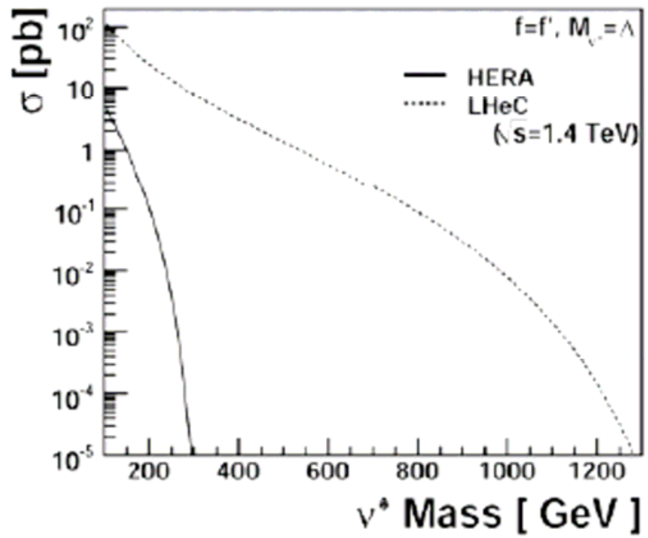
i.e. if squarks are "light", could observe selectrons up to ~ 500 GeV, a little beyond LHC?

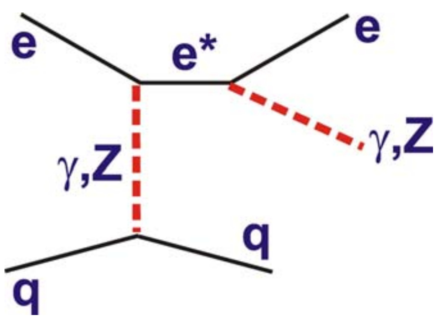
Excited Leptons

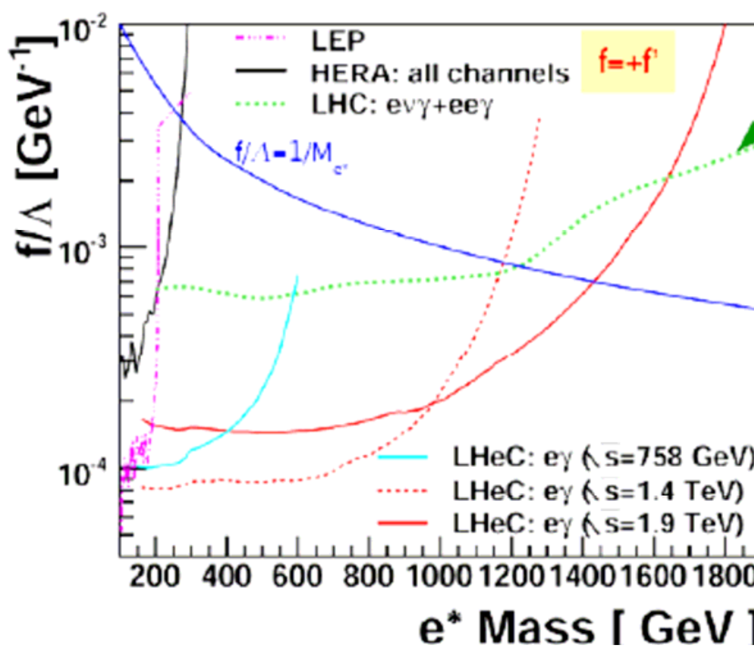
[Sauvan, Trinh]

- Total cross section for l* productions through GM interaction at LHeC, assuming M*=Λ
  - comparison with HERA and LHC







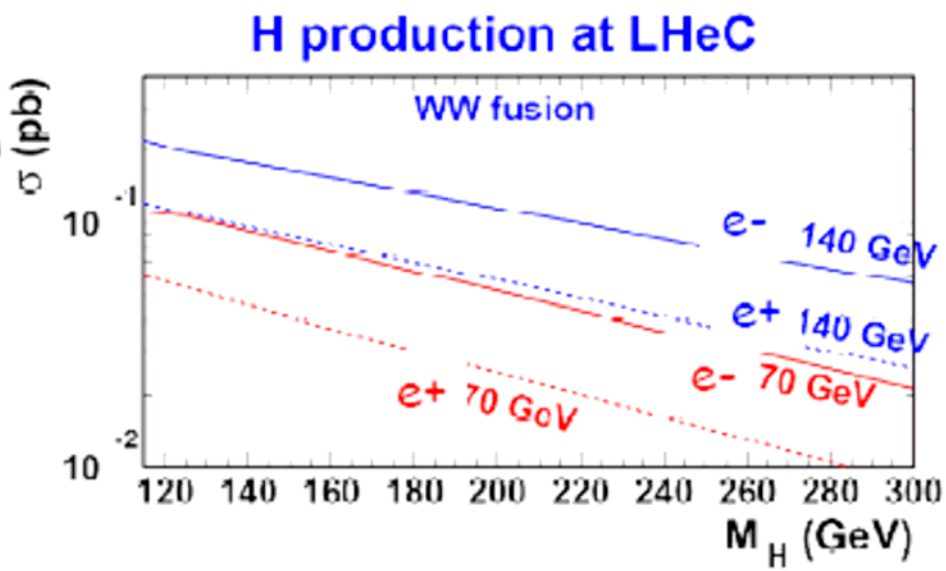


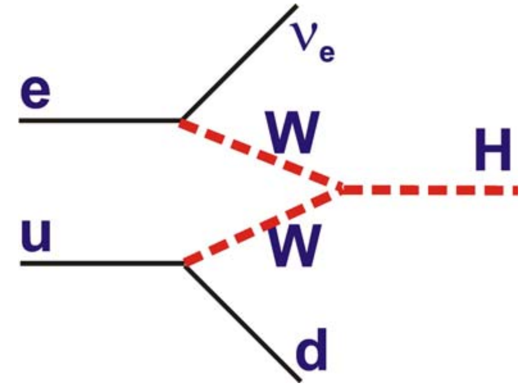
[Phys. Rev D 65 (2002) 075003]

LHeC sensitivity,
with L=10 fb^{-1} for Ee=70/20 GeV
with L=1 fb^{-1} for Ee=140 GeV

LHeC gives best sensitivity in this scenario …

Higgs Production



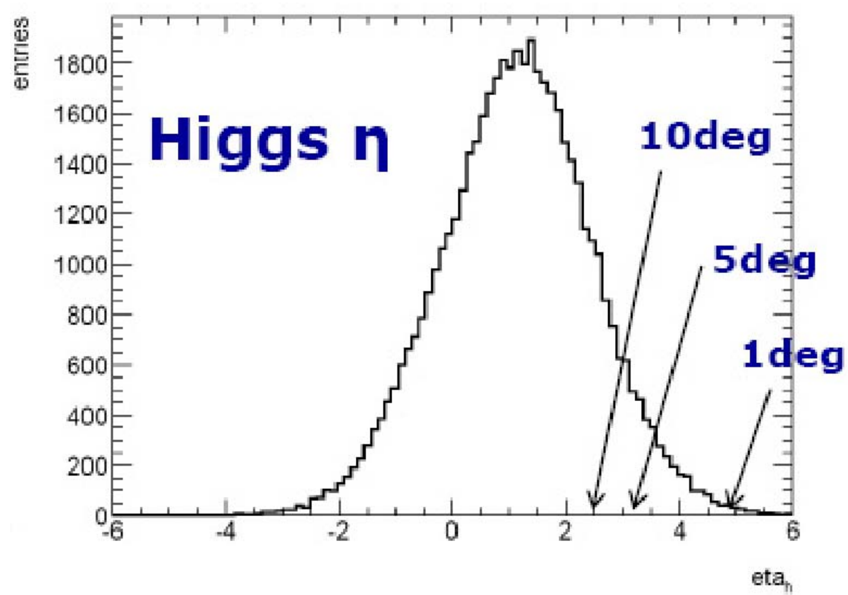


[U Klein, Kniehl, Perez, Khuze]

Sizeable CC (WW) x-section

~ few thousand events

Strongly dependent on m_H



→ Novel production mechanism

→ Clean(ish) … $H + j + p_t^{miss}$

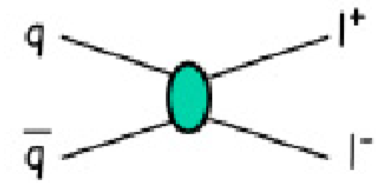
→ bbbar coupling to light H?

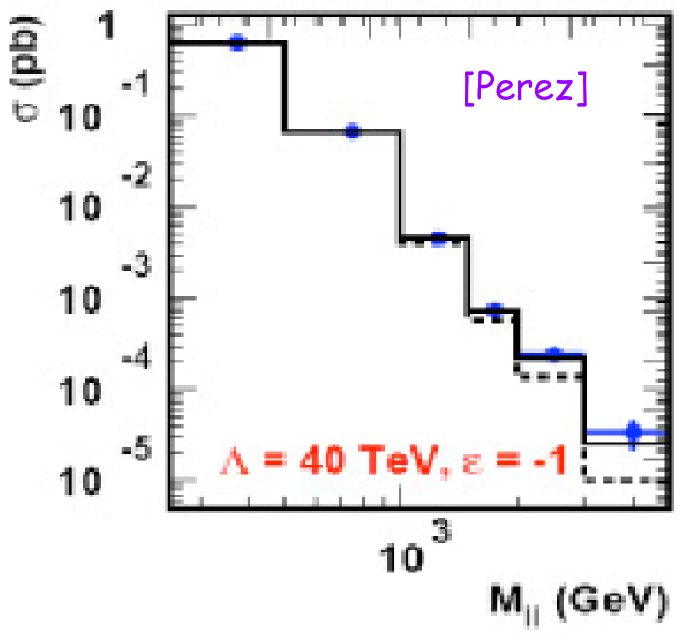
Forward acceptance is an issue

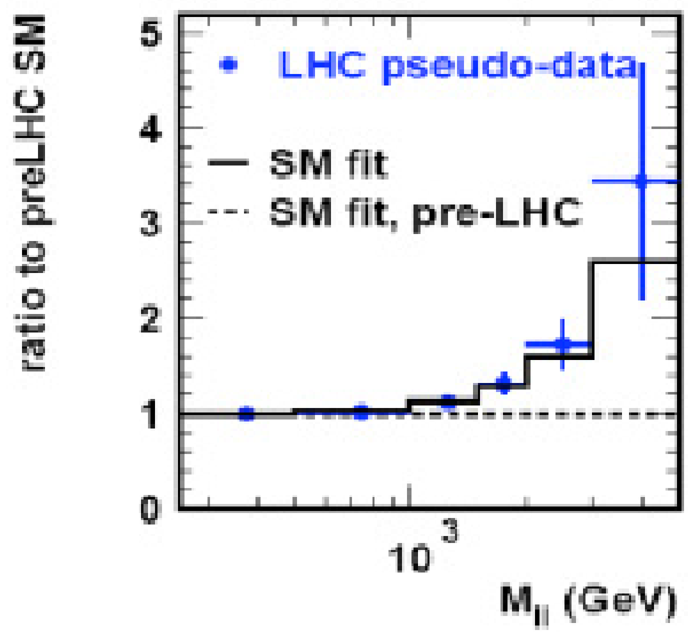
First background studies (jets in CC) underway …

Complementarity between LHC and LHeC

Contact interaction term introduced in LHC pseudo-data for high mass Drell-Yan

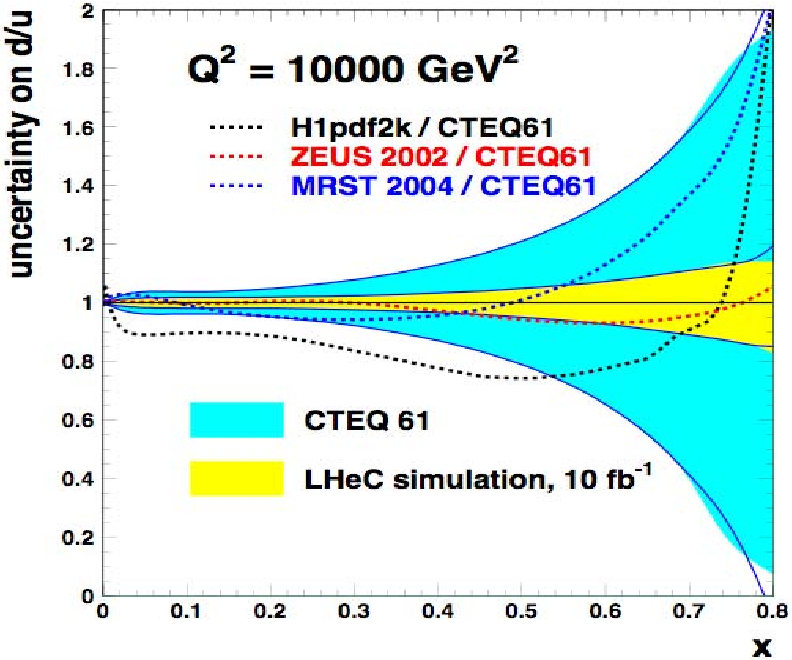


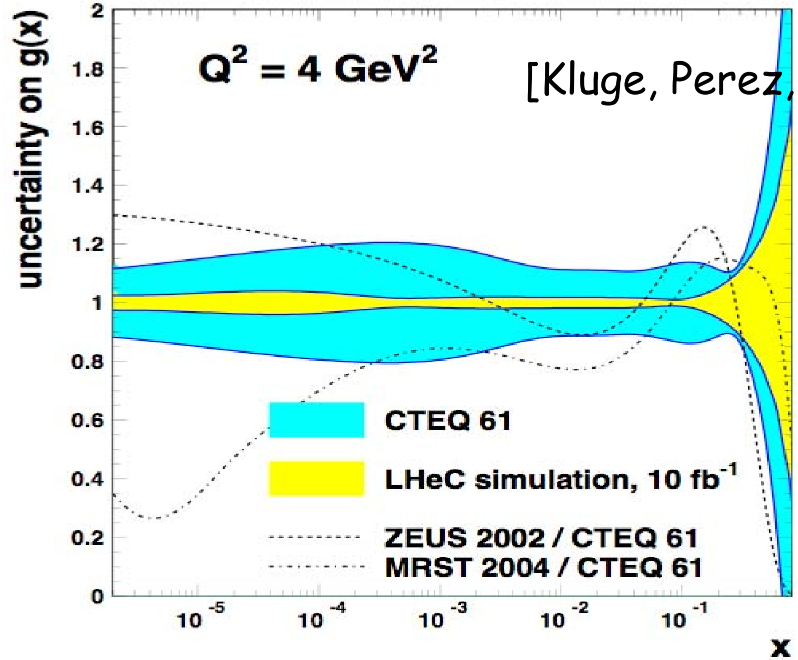




- Even if new physics looks rather different from SM, wide range of high x BSM effects can be accomodated in DGLAP fits due to poor current high x PDF constraints
- Better high x precision at high lumi LHeC could disentangle …

LHeC Impact on High x Partons and α_s





[Kluge, Perez, Klein]

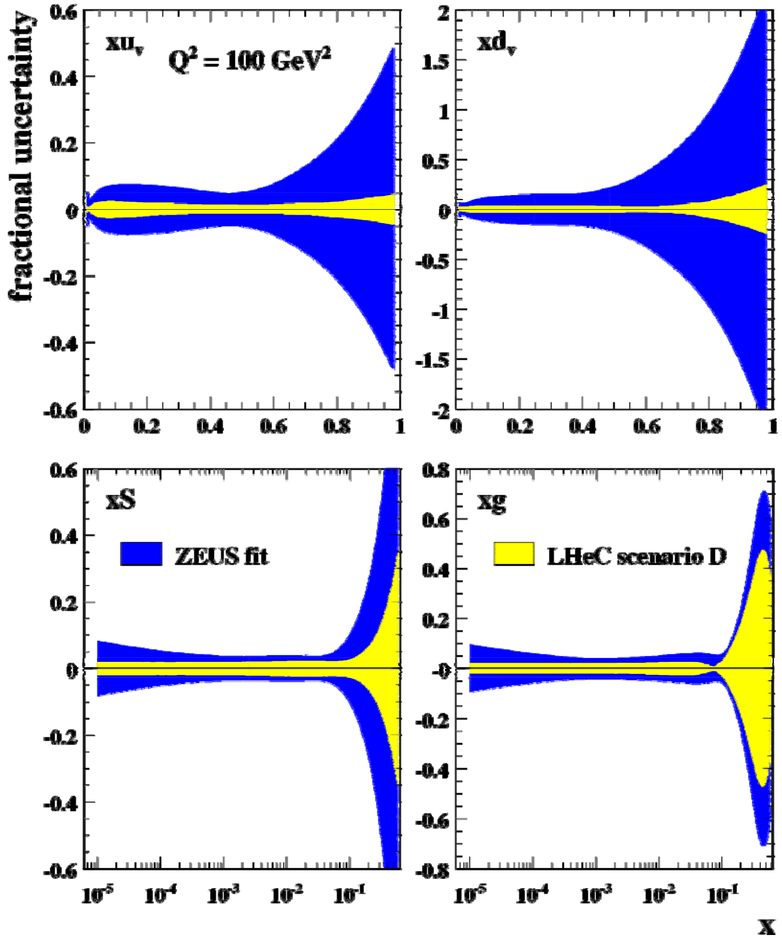
Full NC/CC sim (with systs giving per mil α_s) & NLO DGLAP fit using H1 technology…

… full flavour decomposition possible

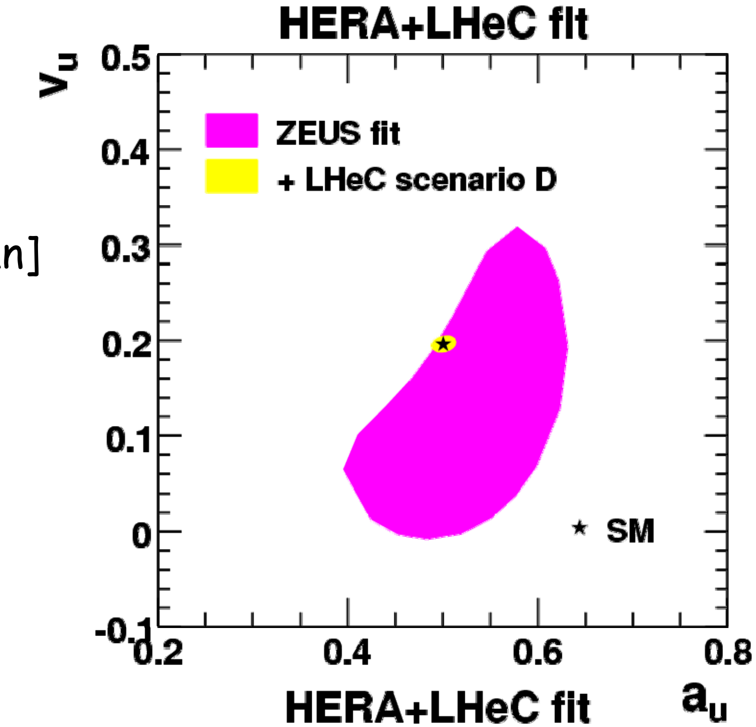
… high x pdfs → may help clarify LHC discoveries through interpretation of new states?

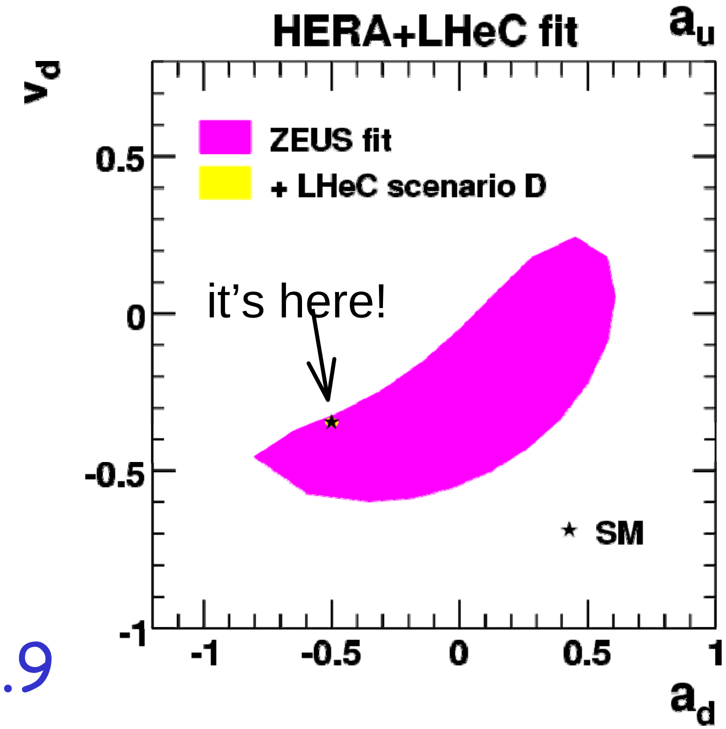
[Some of highest x improvement from param^n extrapolation]

PDFs & EW Couplings



[Gwenlan]

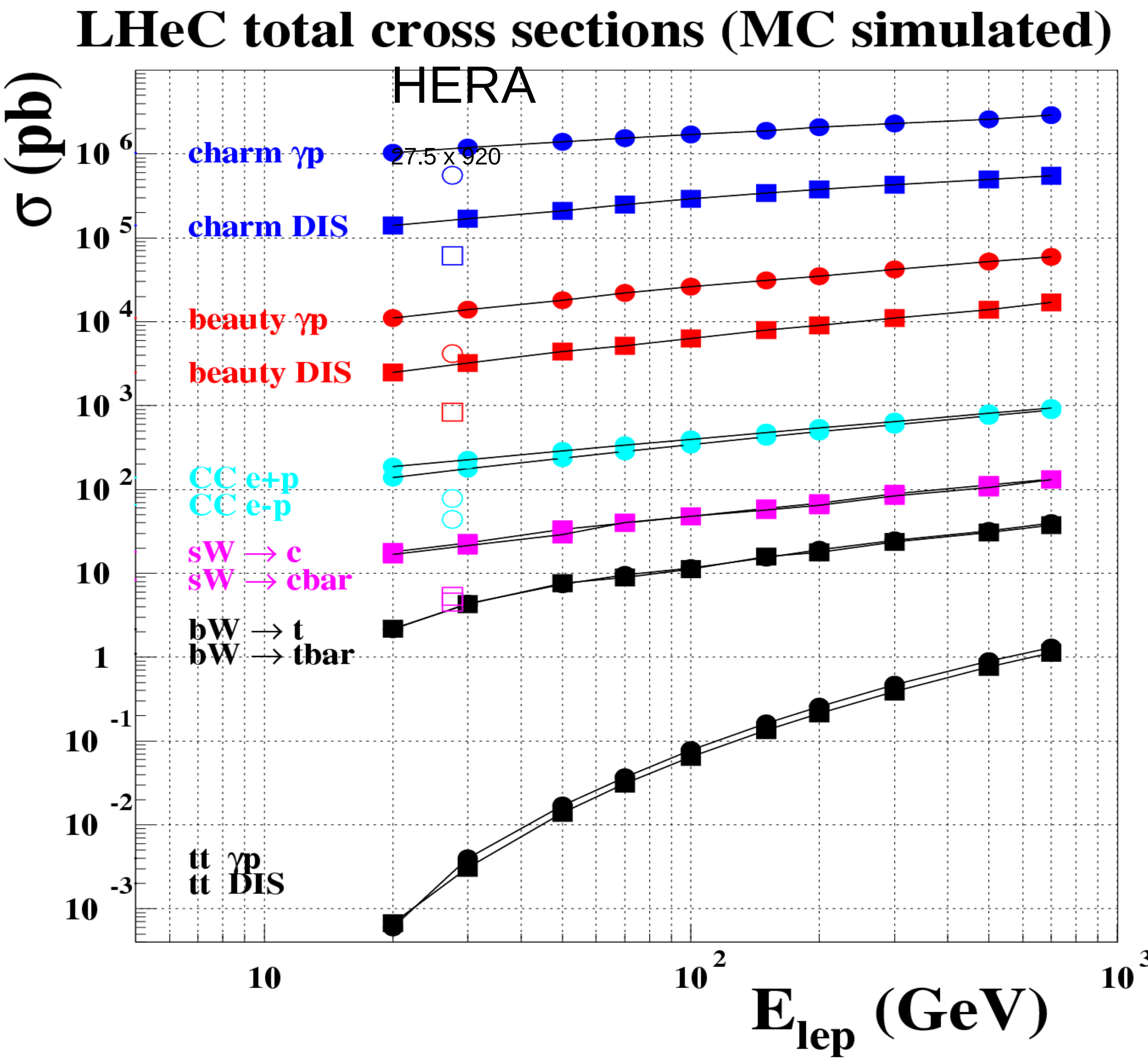




Using ZEUS fitting code, HERA + LHeC data … EW couplings free

E_e = 100 GeV, L = 10+5 fb^{-1}, P = +/- 0.9

Cross Sections and Rates for Heavy Flavours



Charm

[Behnke]

Beauty

cc

sW-> c

bW->top

ttbar

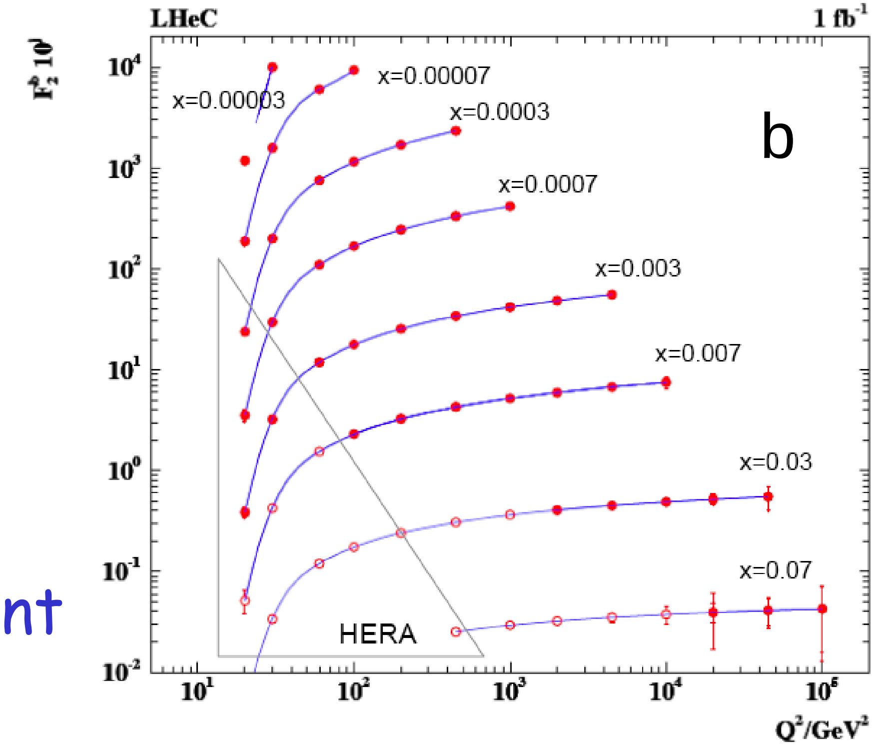
c.f. luminosity of ~10 fb-1 per year …

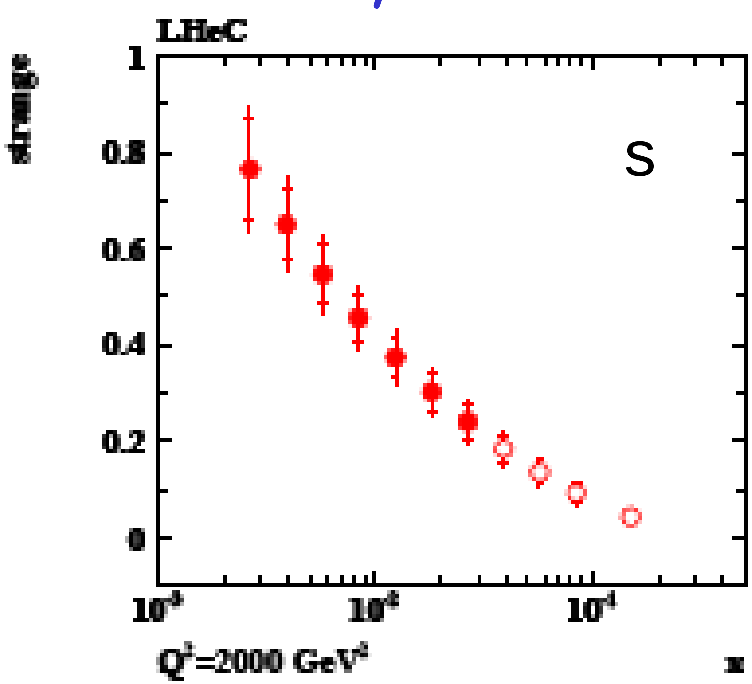
Flavour Decomposition

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

Systematics at 10% level

- → beauty is a low x observable!
- → s (& sbar) from charged current
- → Similarly Wb → t?

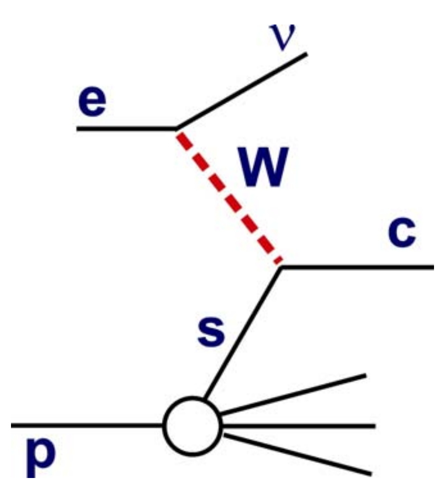




● LHeC 10° acceptance

○ LHEC 1° acceptance

[Mehta, Klein]



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

A high x Detector Acceptance Consideration

HERA E_e=30GeV E_p=920GeV

$\longrightarrow$ $\longleftarrow$

LHeC E_e=70GeV E_p=7000GeV

- Considerably more asymmetric beam energies than HERA!
  - Hadronic final state at newly accessed lowest x values goes central or backward in the detector ☺
  - As x grows at fixed Q^2, hadronic final state is boosted more and more in the forward direction … and hadrons are needed for good kinematic reconstruction as x gets large & electron method resolution deteriorates

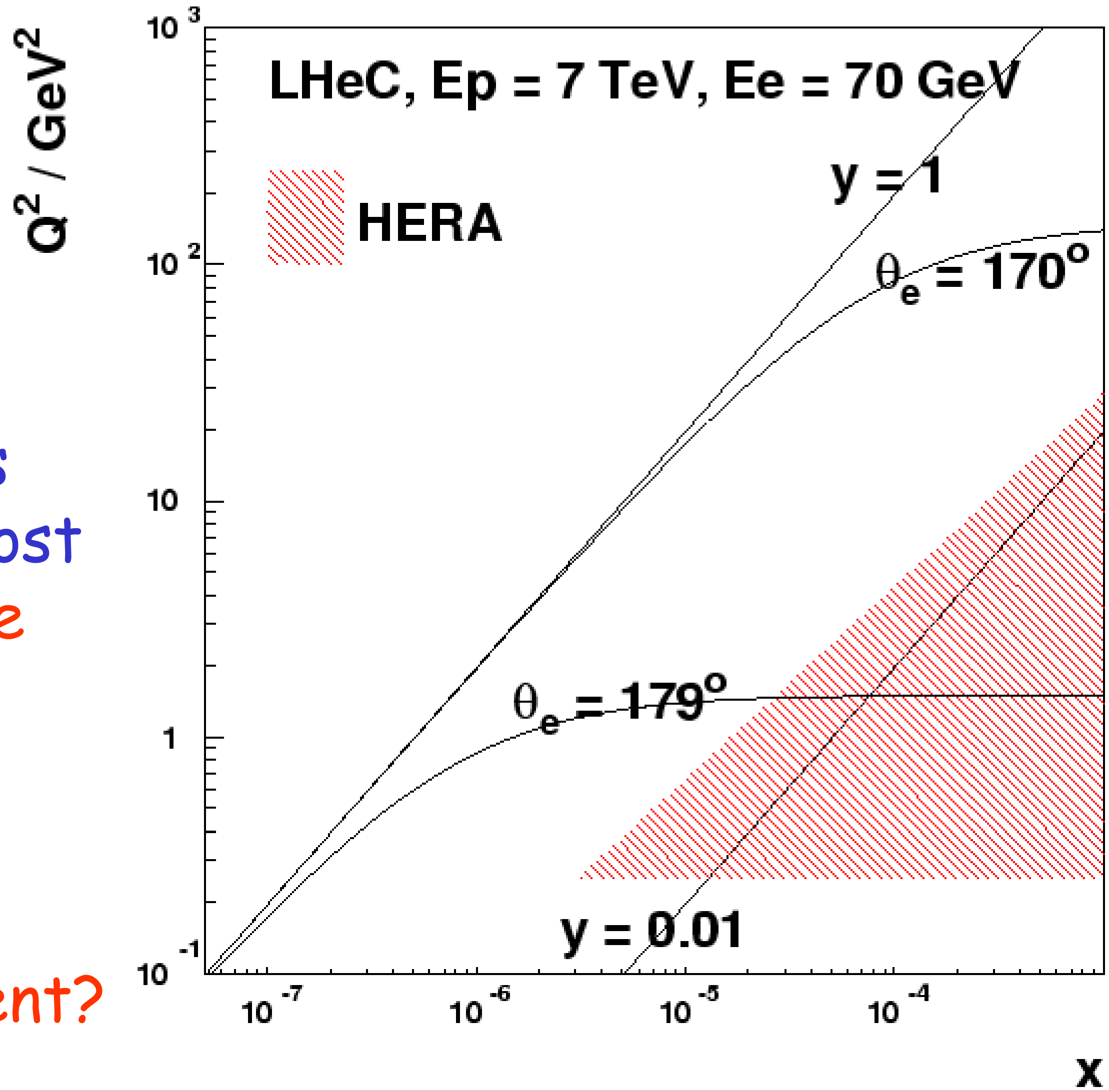
- Ideally need sensitivity to energy flow in outgoing proton direction <u>for hadrons to ~1°</u>

LHeC Kinematics for Low x Investigations

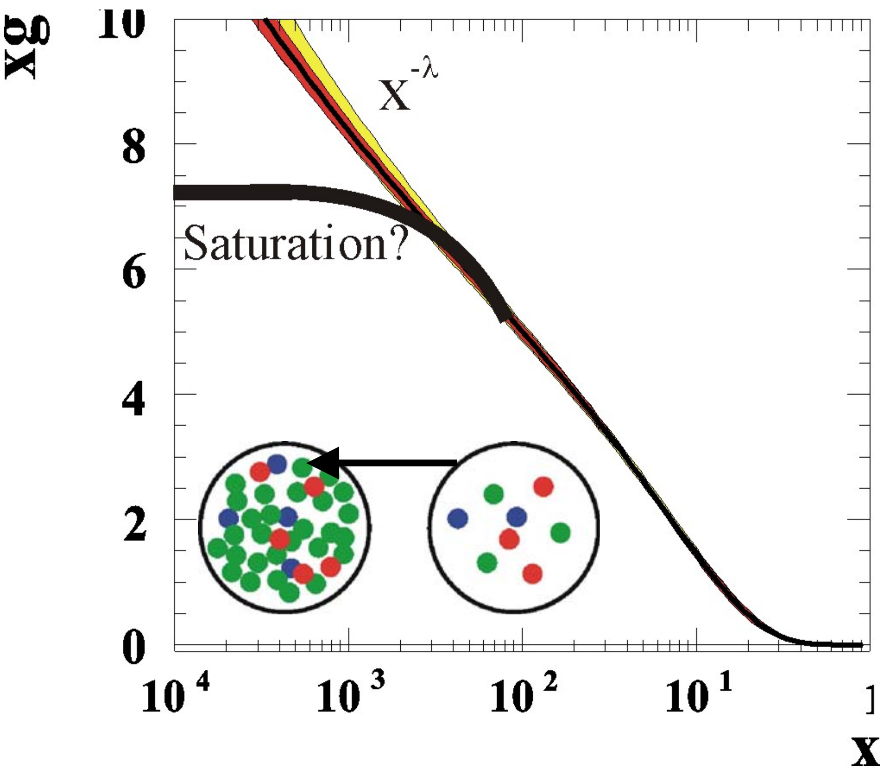
Access to Q^2=1 GeV^2 in ep mode for all $x > 5 \times 10^{-7}$ IF we have acceptance to 179°

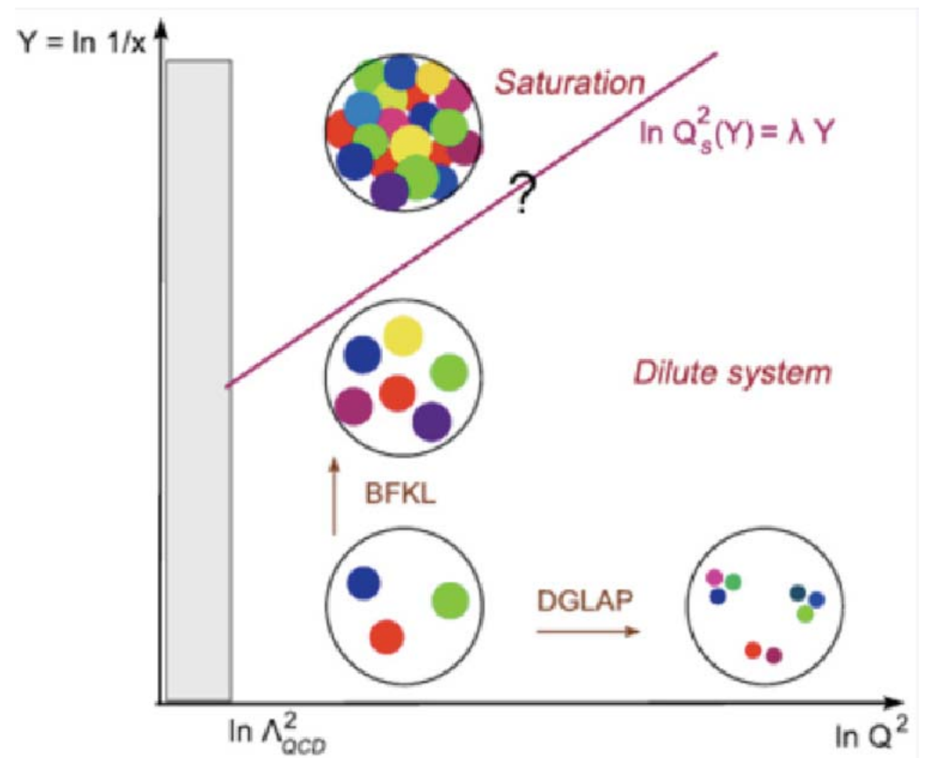
→Without low β magnets ~ 1 fb^{-1} / yr ample for most low x studies … definitive low x facility!

→parton saturation
→novel QCD evolution
→Relations to confinement?
→…



LHeC and Low x Physics



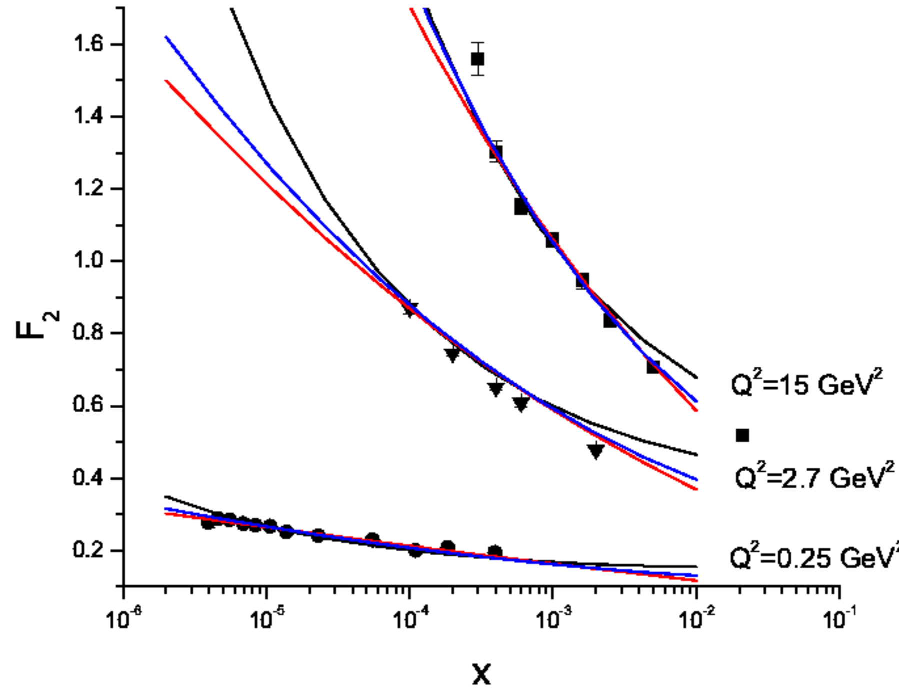


- Somewhere & somehow, low x growth of gluon density must saturate ("high energy catastrophe")
- Non-linear evolution beyond DGLAP, e.g. recombination gg → g
- Usually characterised in terms of an energy dependent saturation scale, $Q^2_s(x)$, to be determined experimentally
- Saturation scale $Q^2_s \sim Q^2_0.(A/x)^{1/3}$… factor of 6 for lead

Parton Saturation after HERA?

e.g. Forshaw, Sandapen, Shaw
hep-ph/0411337,0608161
… used for illustrations here

Fit inclusive HERA data using dipole models with and without parton saturation effects



FS04 Regge (~FKS): 2 pomeron model, <u>no saturation</u>

FS04 Satn: <u>Simple implementation of saturation</u>

CGC: <u>Colour Glass Condensate version of saturation</u>

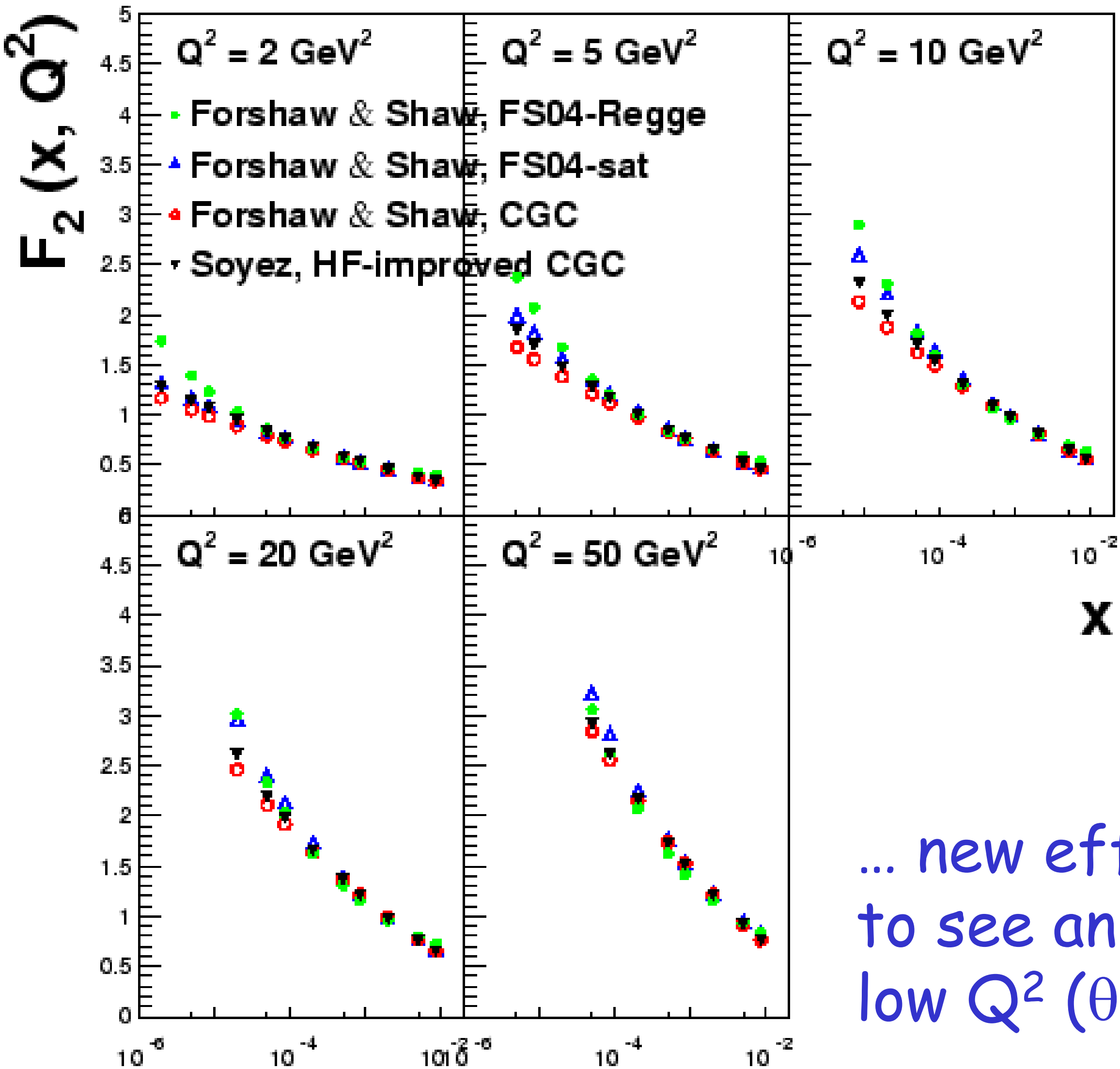
- All three models can describe data with $Q^2 > 1 GeV^2$, $x < 0.01$
- Only versions with saturation work for $0.045 < Q^2 < 1$ GeV^2

<u>… any saturation at HERA not easily interpreted partonically</u>

Some models of low x F_2 with LHeC Data

With 1 fb^{-1} (1 year at 10^{33} cm^{-2} s^{-1}), 1° detector:
stat. precision < 0.1%, syst, 1-3%

[Forshaw, Klein, PN, Soyez]



Precise data in LHeC region, x > ~10^{-6}

- Extrapolated HERA dipole models …
- FS04, CGC models including saturation suppressed at low x & Q^2 relative to non-sat FS04-Regge

… new effects may not be easy to see and will certainly need low Q^2 ($\theta \rightarrow 179°$) region …

F_L Simulation

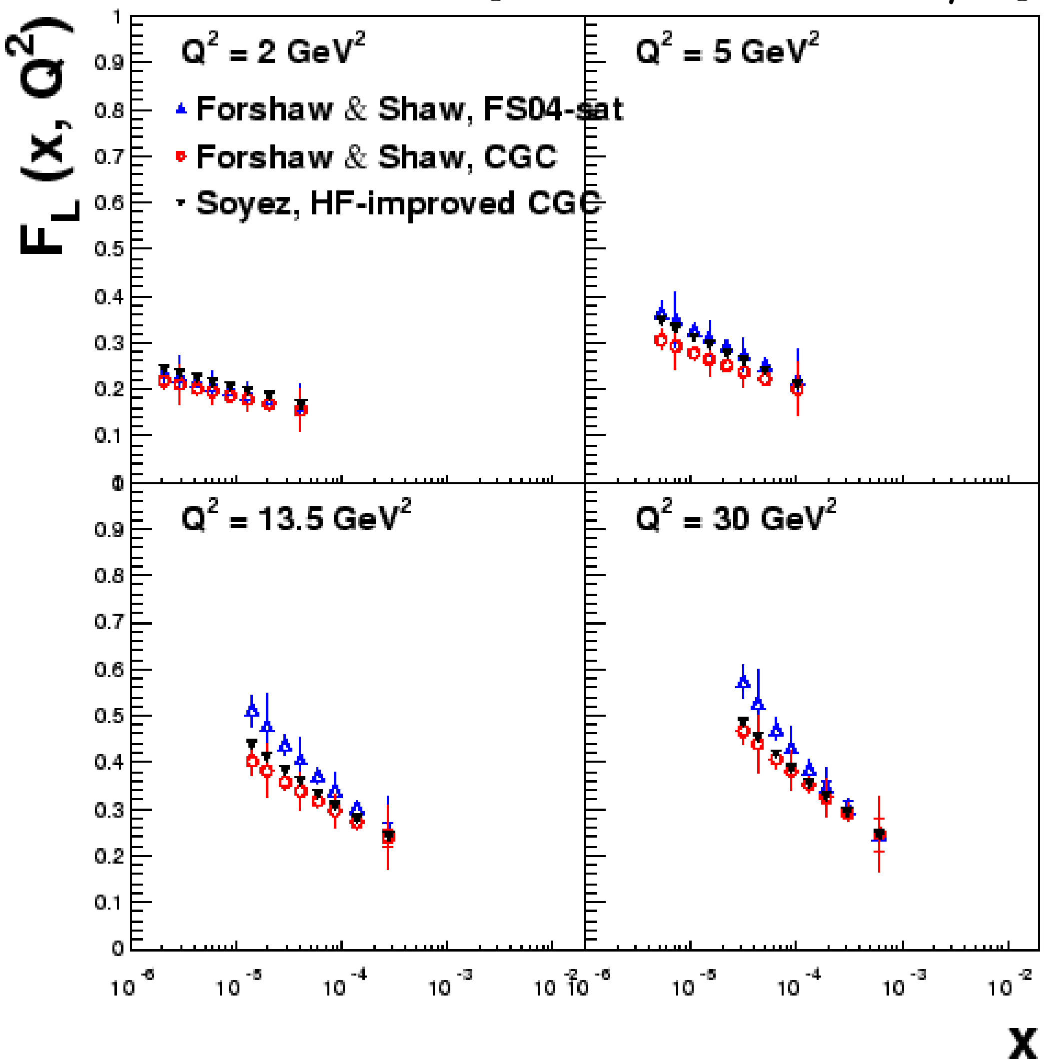
Vary proton beam energy as recently done at HERA ?…
→ example for 1 year …

E_p (TeV)	Lumi (fb^{-1})
7	1
4	0.8
2	0.2
1	0.05
[0.45	0.01]

… precision typically 5%
… stats limited for $Q^2 > 1000$ GeV^2

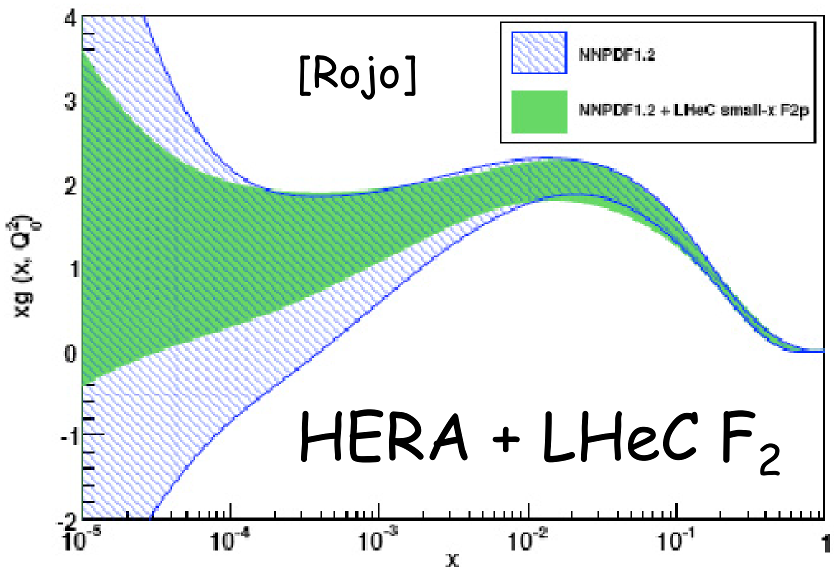
… selected lowest x data compared with 3 dipole models including saturation …

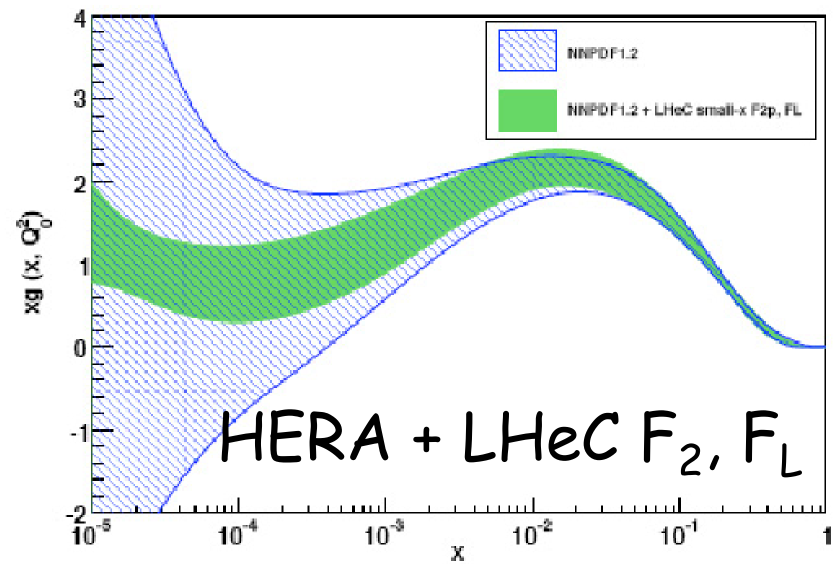
[Forshaw, Klein, PN, Soyez]



Can Parton Saturation be Established @ LHeC?

… effects may not be so large in ep → and may be hard to establish unambiguously with F_2 alone
… Two first studies using F_2 and F_L in ep only …





Including LHeC data in NNPDF DGLAP fit approach …
- Sizeable improvement in error on low x gluon with F_2 & F_L
- Saturation effects at LHeC (FS04-sat) can't be absorbed into NNPDF DGLAP analysis if F_2 and F_L both fitted

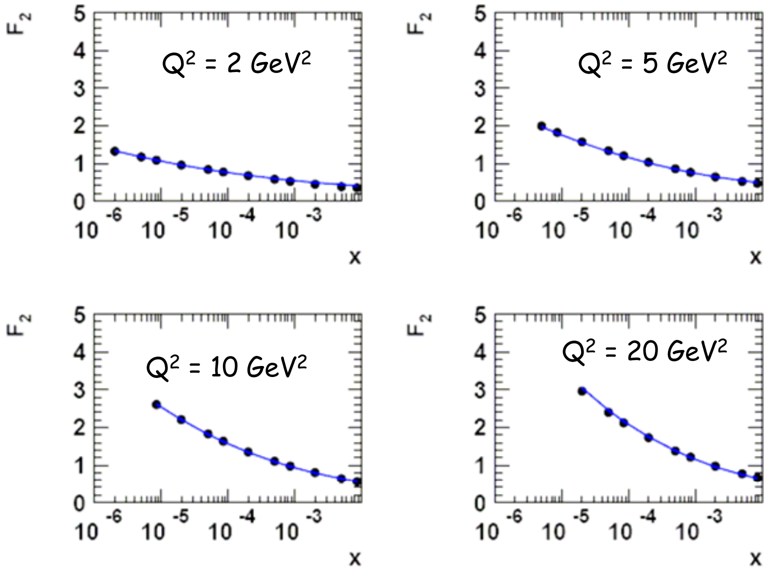
Can DGLAP adjust to fit LHeC sat models?

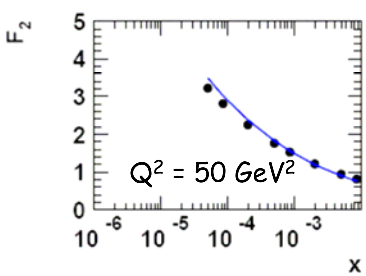
[Forshaw, Klein, PN, Perez]

- Attempt to fit ZEUS and LHeC saturated pseudo-data in increasingly narrow (low) Q^2 region until good fit obtained
- Use dipole-like (GBW) gluon parameterisation at Q_0^2

$$xg(x,Q_0^2) = A_g\left(1-\exp\left[-B_g\log^2\left(\frac{x}{x_0}\right)^{\lambda}\right]\right)(1-x)^{C_g}$$

FS04 dataset, F2

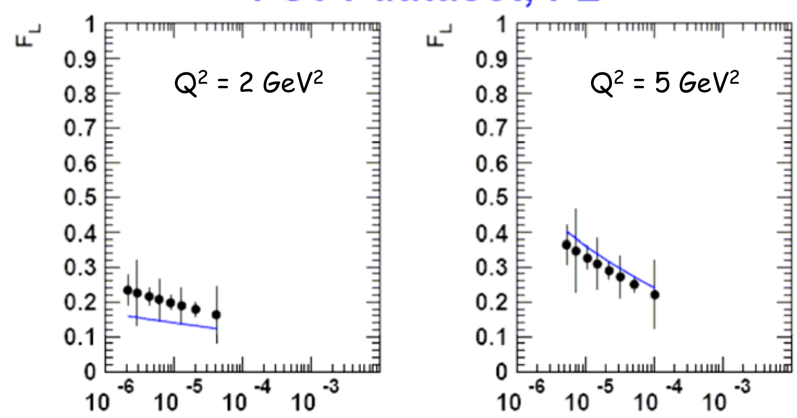




- Fitting F_2 only, a good fit cannot be obtained beyond the range $2 < Q^2 < 20$ GeV^2
- This fit fails to describe F_L

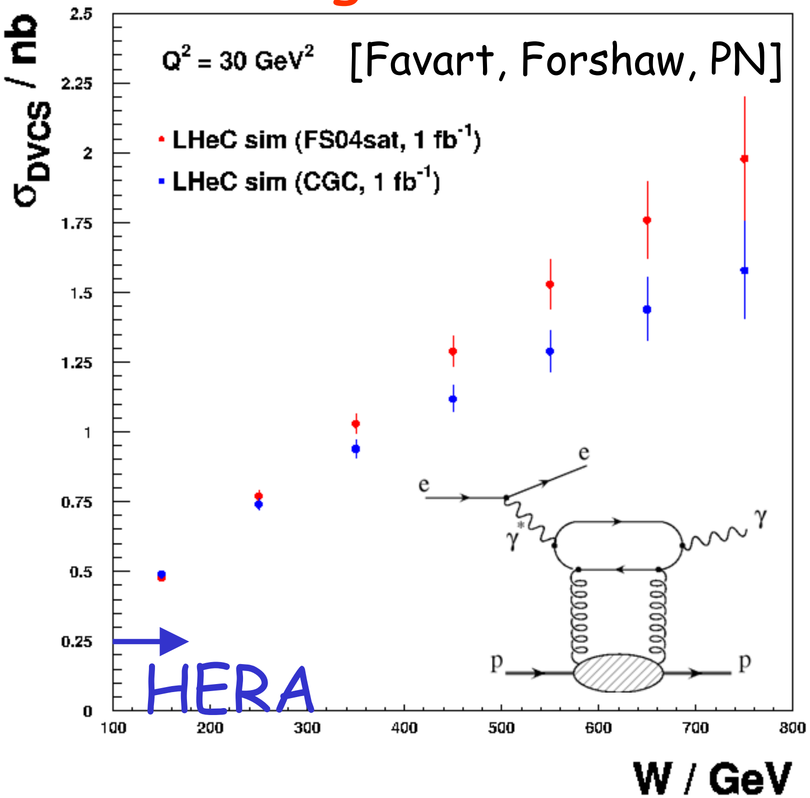
(even faster failure with CGC LHeC pseudo-data)

FS04 dataset, FL

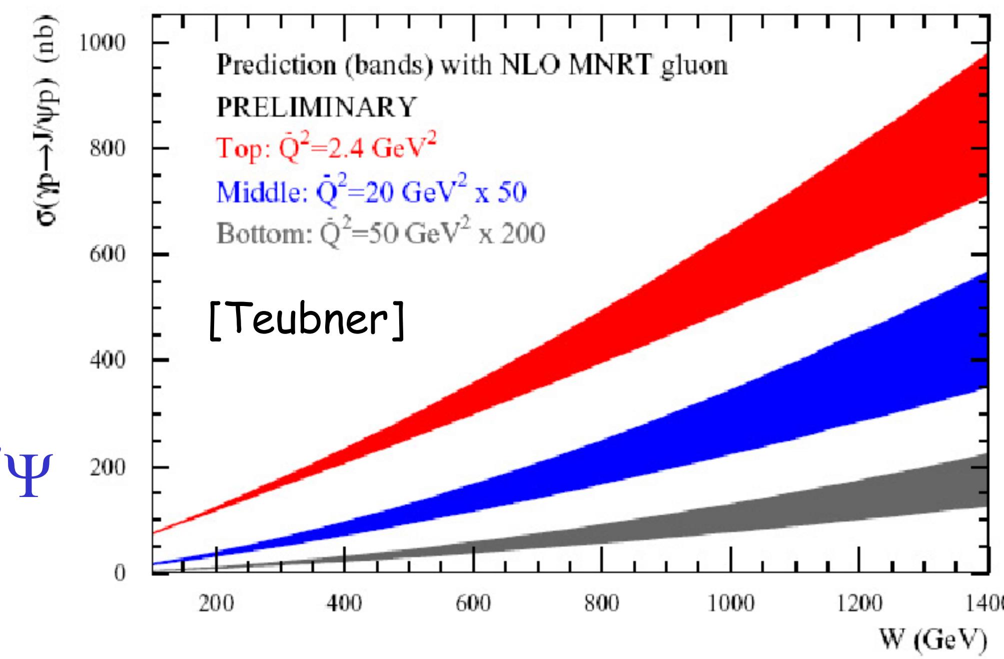


DVCS and Vector Mesons

With F_2, F_L, VM in ep and eA could help establish saturation and distinguish between different models which contain it?

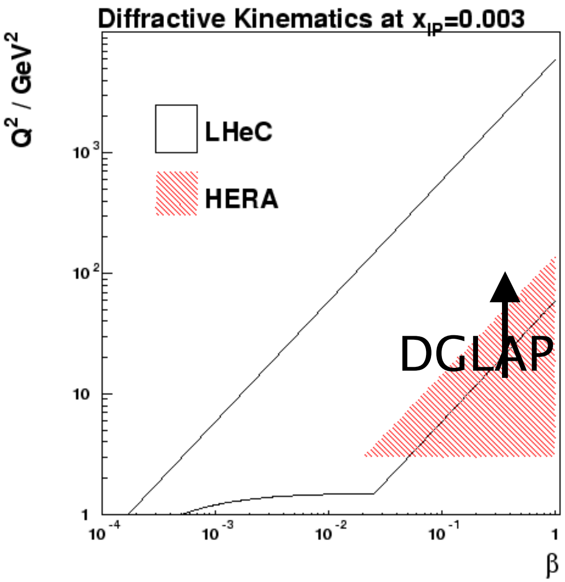


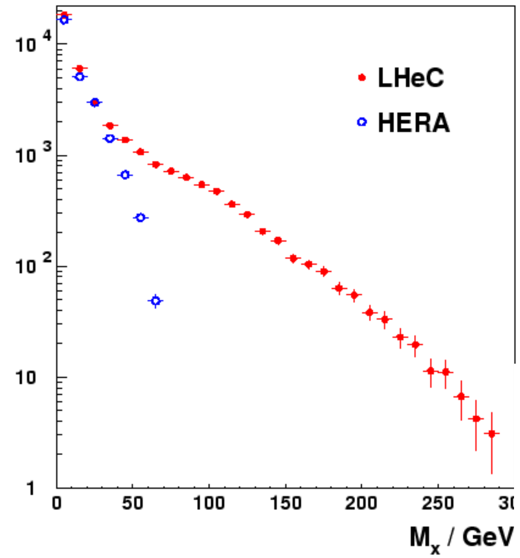
- DVCS study with 1° acceptance & 1fb^{-1} … 2-11% statistical errors
- Cleaner interpretation in terms of GPDs at larger LHeC Q^2 values

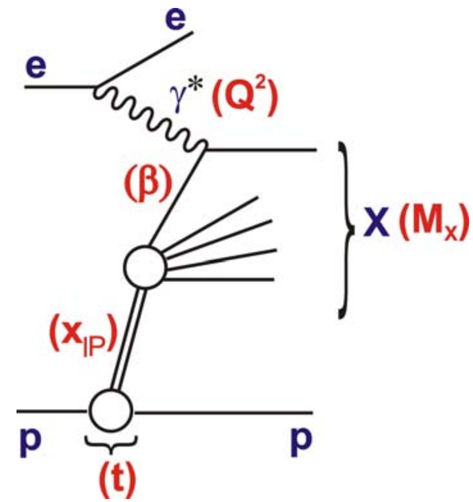


- First study of elastic J/Ψ … large direct sensitivity to gluon dynamics

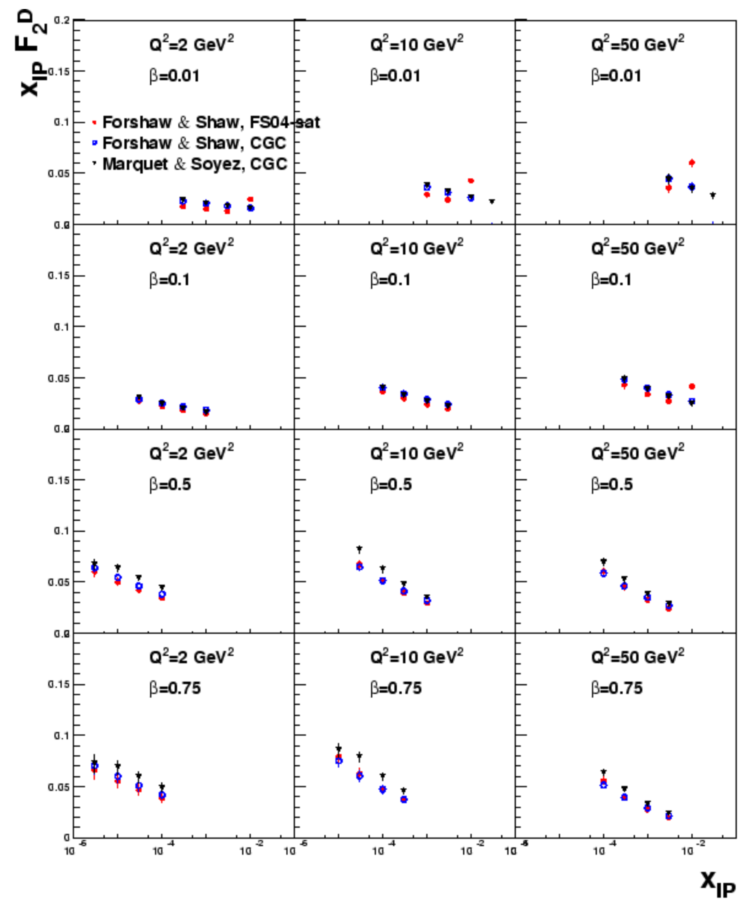
(Semi)-Inclusive Diffractive DIS







[Forshaw, Marquet, PN]



[Studies with 1° acceptance, 1 fb^{-1}]

- 5-10% data, depending on detector
- (D)PDFs / fac'n in much bigger range
- Enhanced parton satn sensitivity?
- Mx → 100 GeV with x_{IP} = 0.01 …
  → X including W, Z, b …
- Exclusive production of any 1^{-} state

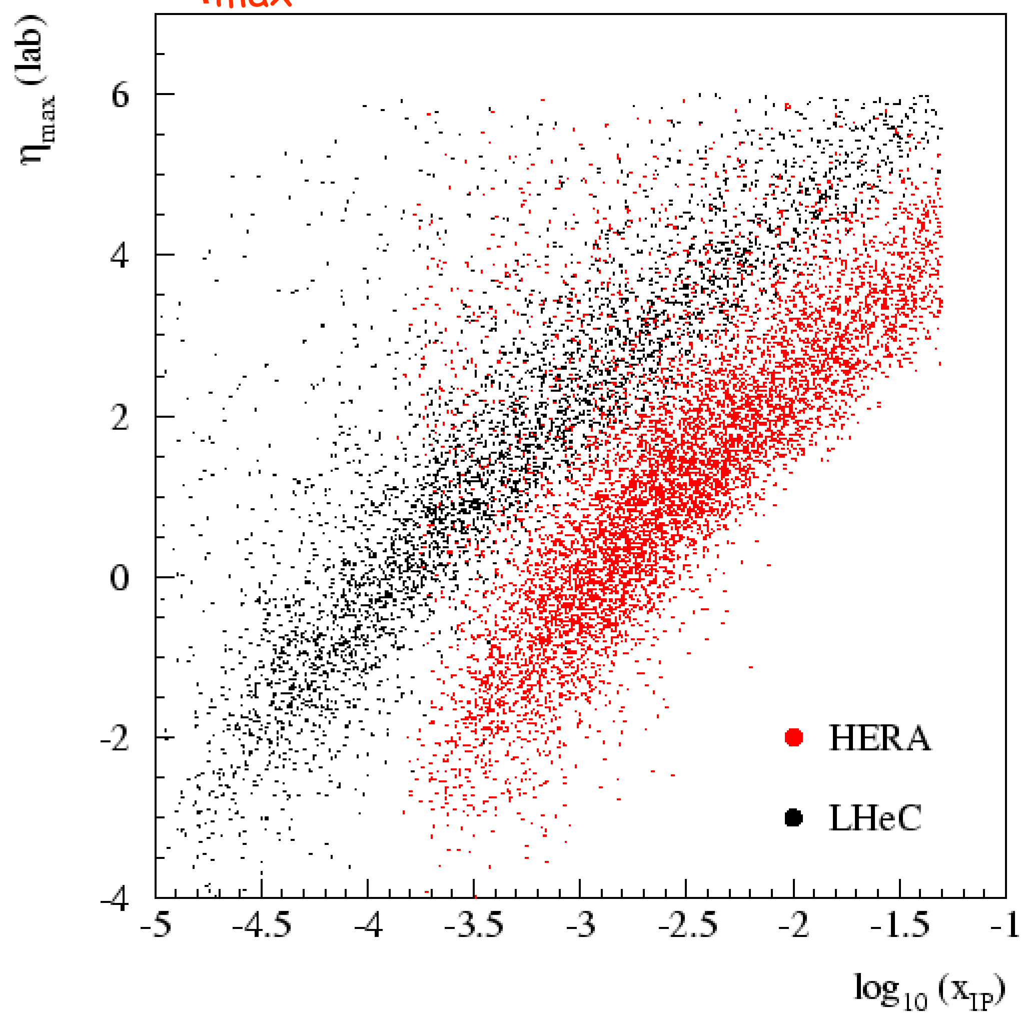
Forward and Diffractive Detectors

- Very forward tracking / calorimetry with good resolution …
- Proton and neutron spectrometers …

- Reaching $x_{IP} = 1 - E_p'/E_p = 0.01$ in diffraction with rapidity gap method requires η_{max} cut around 5 …forward instrumentation essential!

- Roman pots, FNC should clearly be an integral part.
  - Also for t measurements
  - Not new at LHC ☺
  - Being considered integrally with interaction region

η_{max} from LRG selection …

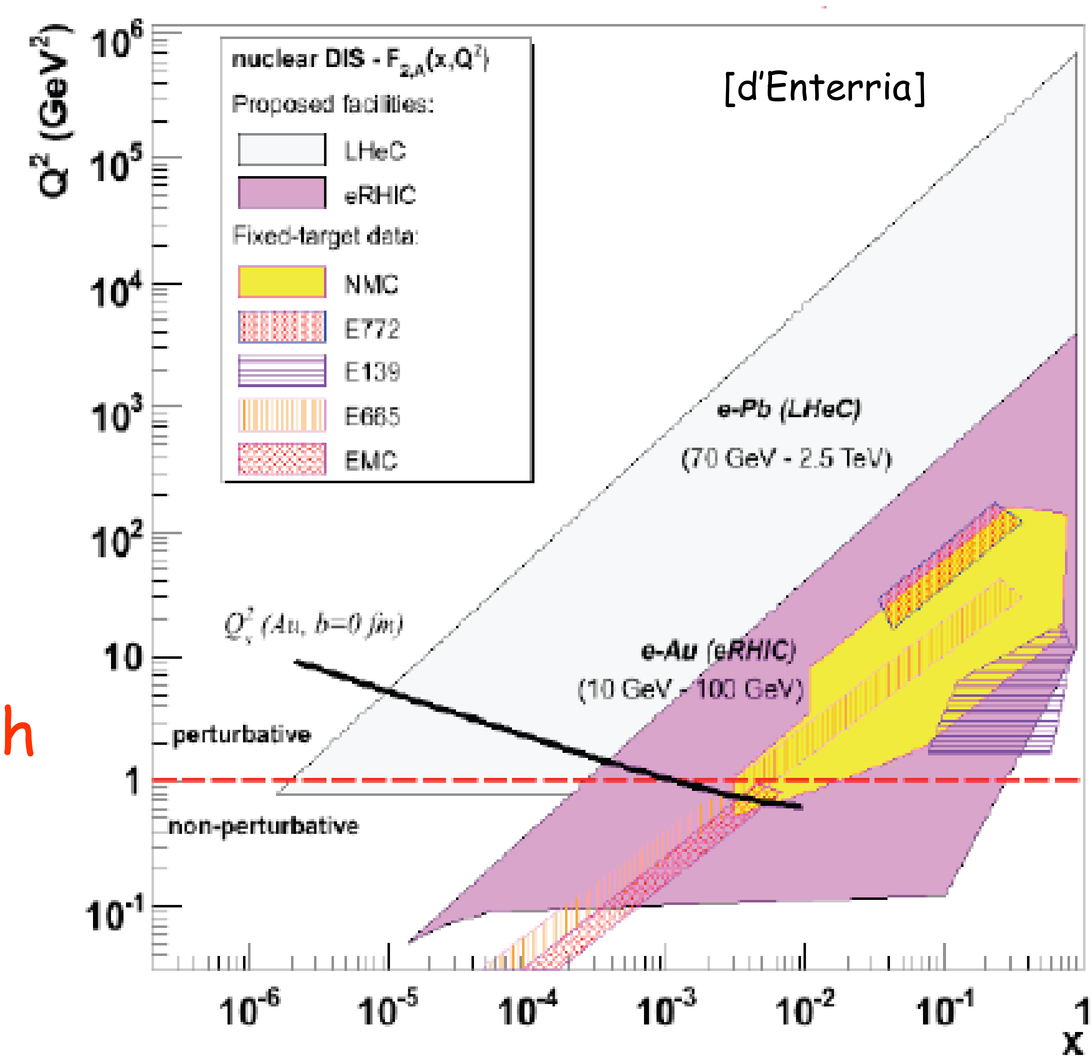


With AA at LHC, LHeC is also an eA Collider

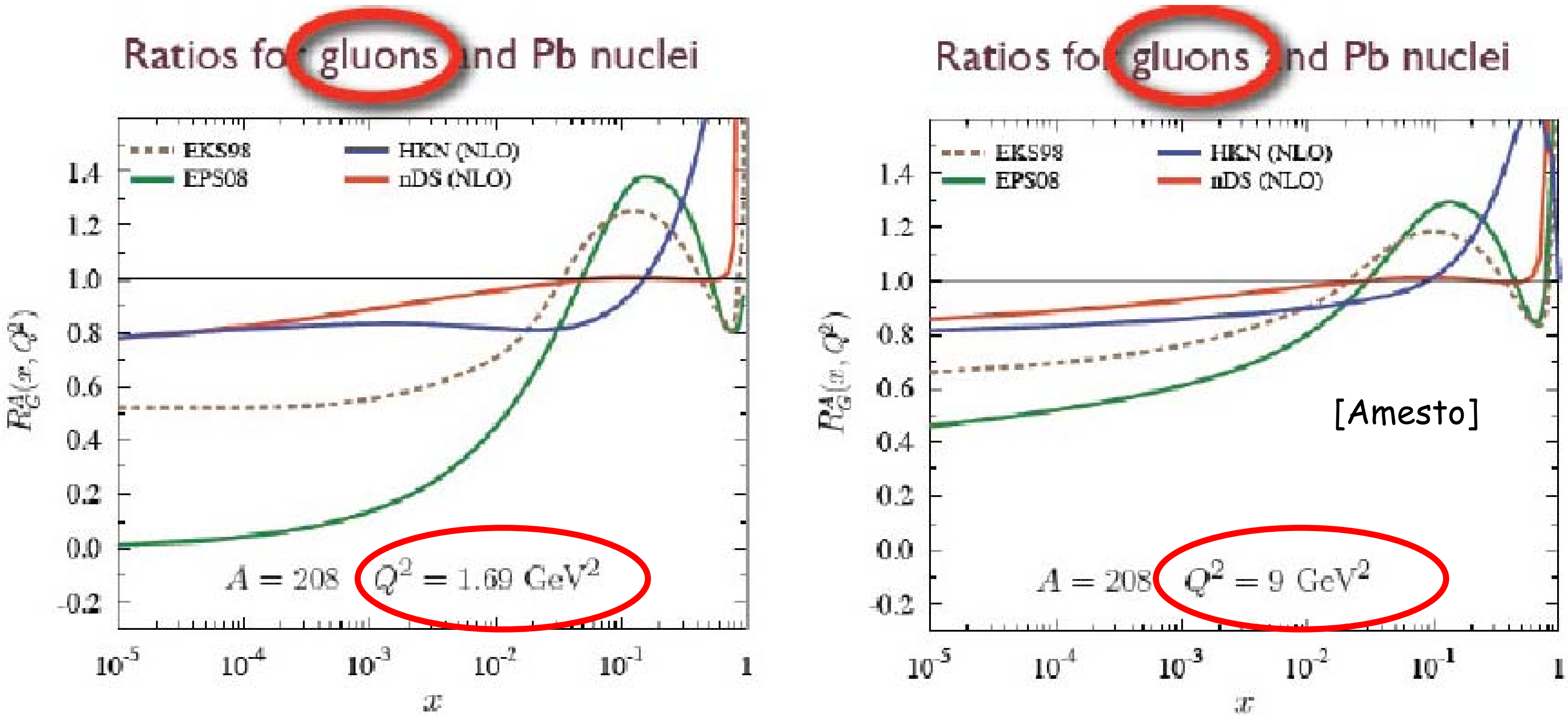
- Very limited x, Q^2 and A range for $F_2{}^A$ so far (unknown for x <~ 10^{-2}, gluon very poorly constrained)

- LHeC extends kinematic range by 3-4 orders of magnitude with very large A

- $A^{1/3} \sim 6$ for lead



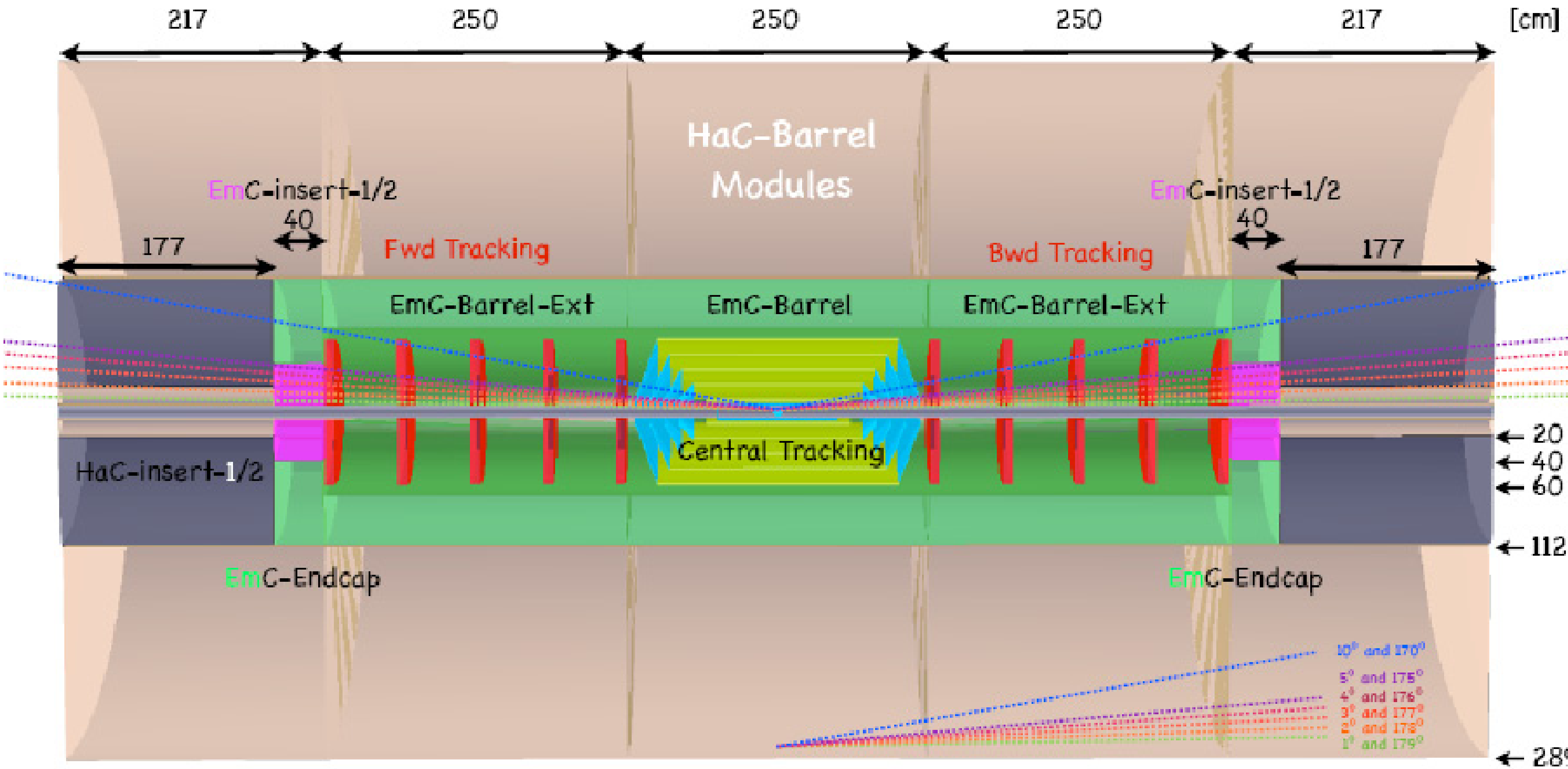
Nuclear Gluon Density



… opportunity to understand nuclear parton densities in detail

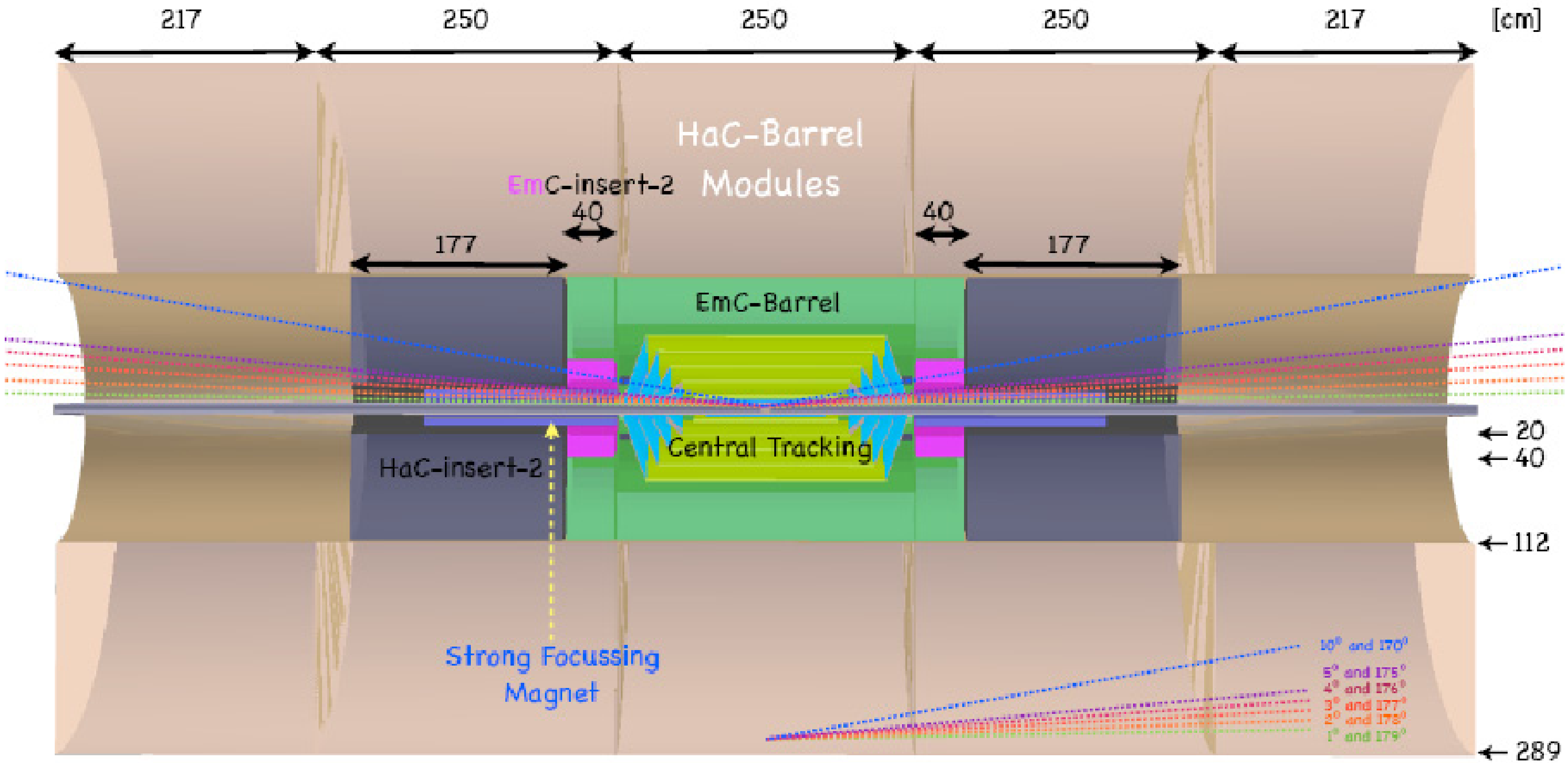
→ $\sim A^{1/3}$ enhanced gluon density → additional sat^n sensitivity
→ initial state in AA quark-gluon plasma studies @ LHC / RHIC
→ relations between diffraction and shadowing
→ neutron structure & singlet PDF evolution from deuterons

First Detector Concepts - Low x Optimised



- Full angular coverage, long tracking region → 1°
- Dimensions determined by synchrotron radiation fan
- Modular Low material budget High precision
- Technologies under discussion (lots of ideas!)

First Detector Concepts - High Q^2 Optimised

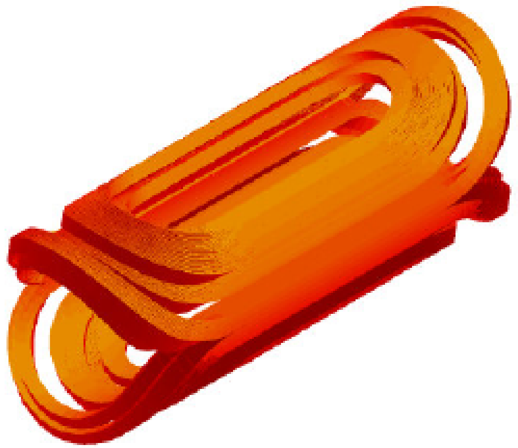


- Sacrifice low angle acceptance to beam focusing magnets
- Calorimeter inserts slide inwards
- 2 phases of operation a la HERA?
- Alternatively 2 interaction points (RR only)?

Developing a Combined Function "Magcal"?

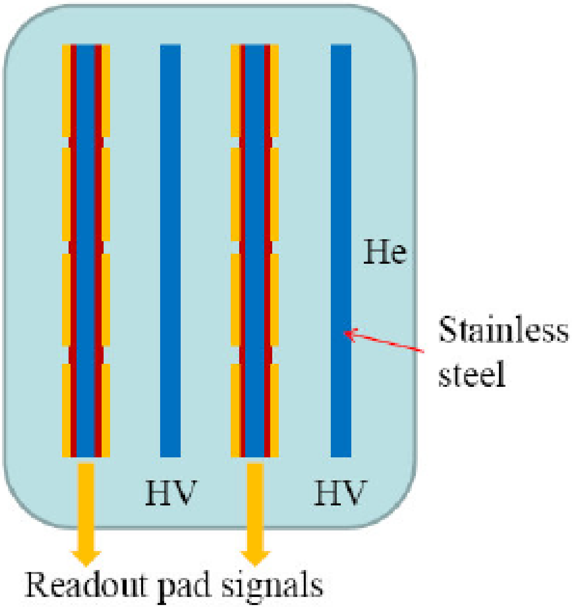
[Greenshaw]

- Helium cooled SC magnet.
- Coils in He bath.



- Space for calorimeter using He as active component?

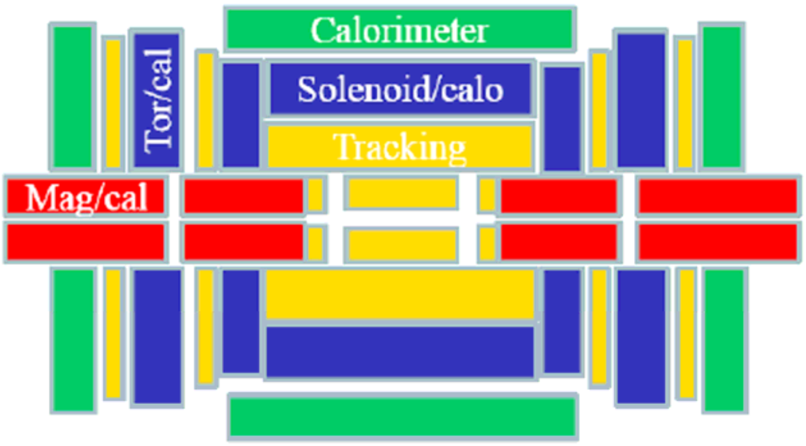
- Could add stainless steel plates as absorber with readout pads:



Use scintillation of liquid He to get signal?...
... Calo is all edges!...
→ What sort of resolution is achievable?
→What is influence on final beam focus?
→ ...?

... also potentially interesting for medical physics and elsewhere?

... could even think of doing the same with solenoids / toroids?



Summary

• LHC is a totally new world of energy and luminosity! LHeC proposal aims to exploit this for TeV lepton-hadron scattering
→ ep complementing next generation pp, ee facilities

• Ongoing ECFA/CERN workshop has gathered many accelerator, theory & experimental colleagues
→ First debates on machine and detector layout
→ Increasingly sophisticated physics studies
→ No show-stoppers, but lots still to do in many areas

• Next workshop planned for September '09
→ Conceptual Design Report by early 2010
→ Input to CERN strategy document mid 2010
→ UK seedcorn funding request in near future

• All ideas and involvement welcome!

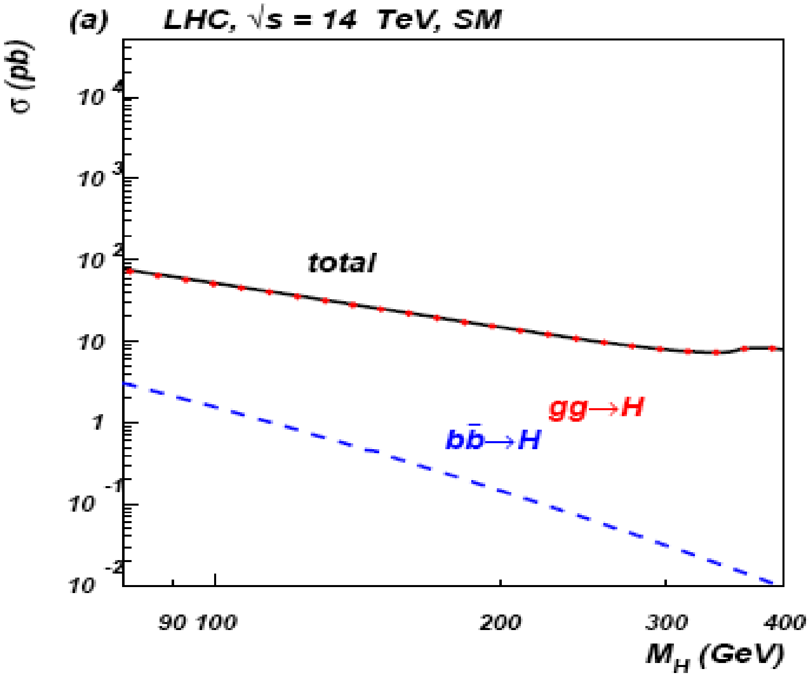
[More at www.lhec.org.uk]

Back-Ups Follow

Heavy Quarks: HERA → LHC

• HERA HF information limited by kinematic range and lumi (reasonable charm, some beauty, almost no strange)

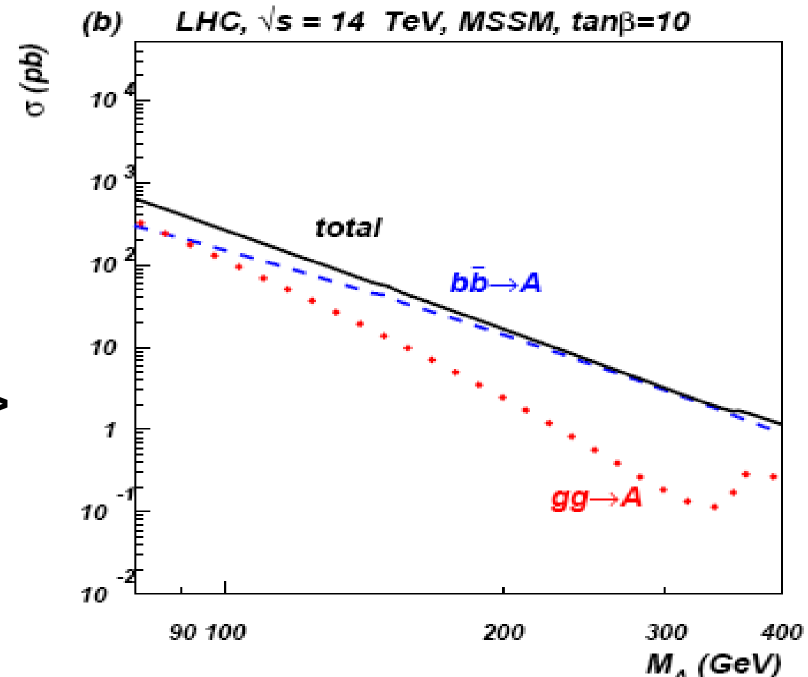
• Crucial for understanding LHC initial state for new processes (e.g. bbbar->H) and backgrounds.



Higgs

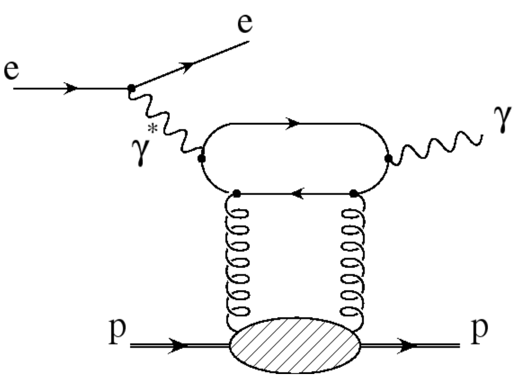
<-SM

MSSM->

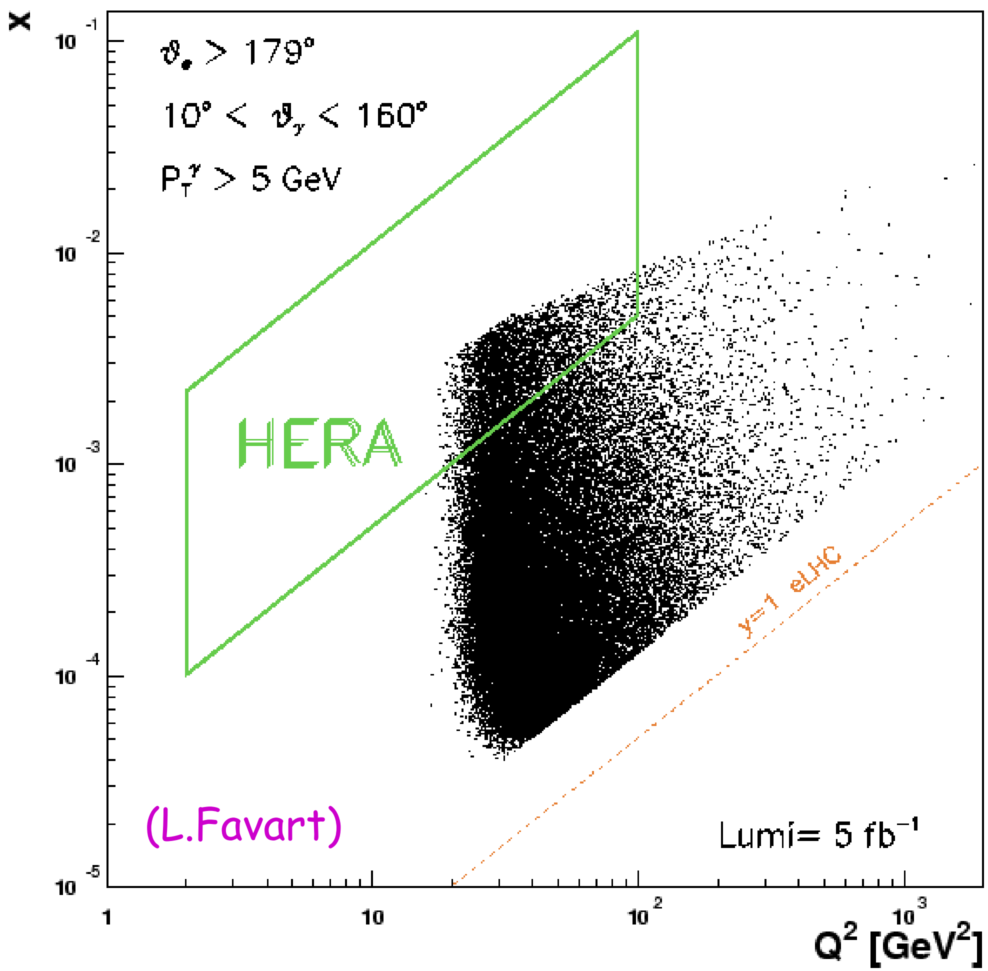


• LHC predictions rely strongly on extrapolations and pQCD (e.g. CTEQ: 7% effect on W,Z rates varying HF treatment).

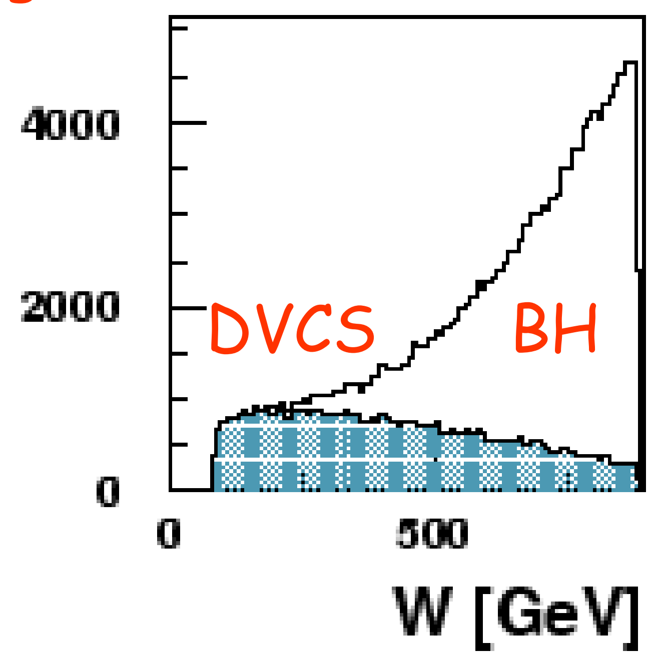
DVCS Measurement



… the classic approach to `generalised parton densities' (GPDs)



… can be tackled as at HERA through inclusive selection of ep → epγ and statistical subtraction of Bethe-Heitler background

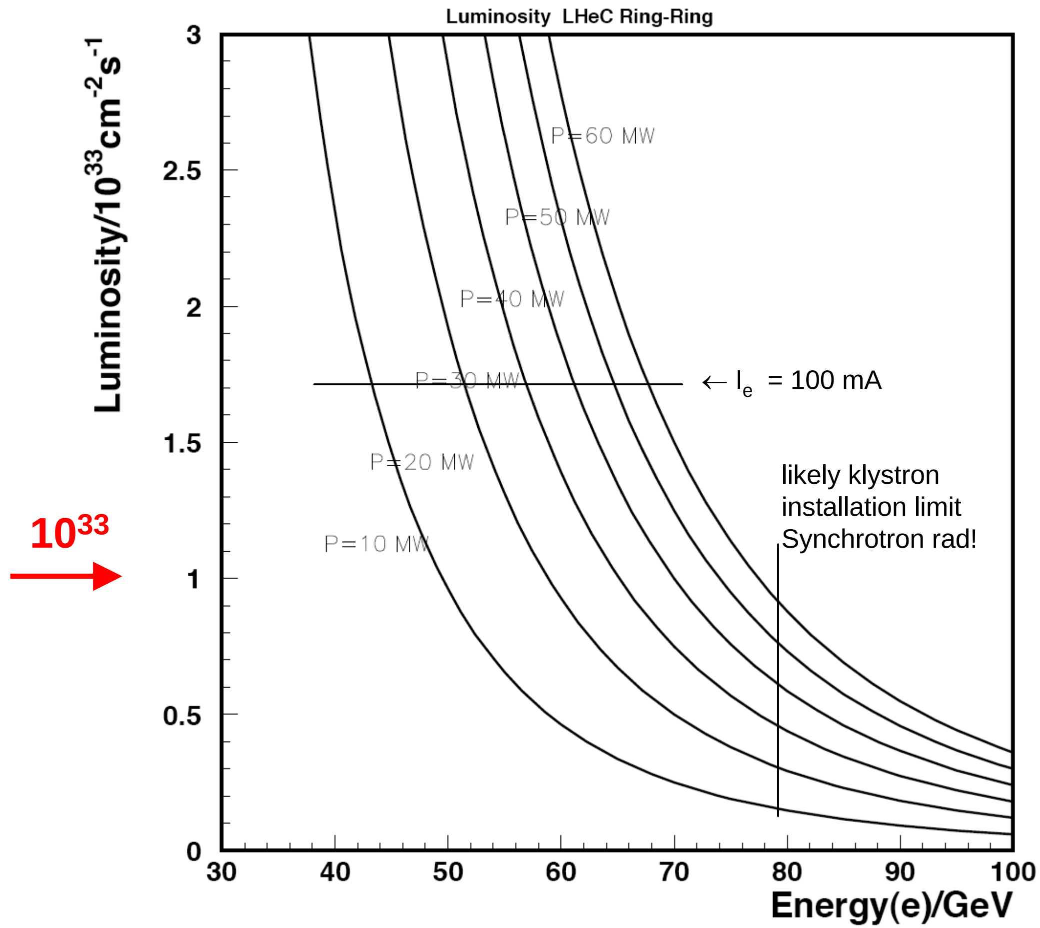


Luminosity: Ring-Ring

$$L = \frac{N_p \gamma}{4\pi e \varepsilon_{pn}} \cdot \frac{I_e}{\sqrt{\beta_{px}\beta_{py}}} = 8.310^{32} \cdot \frac{I_e}{50mA} \frac{m}{\sqrt{\beta_{px}\beta_{pn}}} cm^{-2}s^{-1}$$

$$\varepsilon_{pn} = 3.8\mu m$$
$$N_p = 1.7 \cdot 10^{11}$$
$$\sigma_{p(x,y)} = \sigma_{e(x,y)}$$
$$\beta_{px} = 1.8m$$
$$\beta_{py} = 0.5m$$

$$I_e = 0.35mA \cdot \frac{P}{MW} \cdot \left(\frac{100GeV}{E_e}\right)^4$$



10^{33} can be reached in RR
E_e = 40-80 GeV & P = 5-60 MW.

HERA was 1-4 10^{31} cm^{-2} s^{-1}
huge gain with SLHC p beam

F.Willeke in hep-ex/0603016:
Design of interaction region
for 10^{33} : 50 MW, 70 GeV

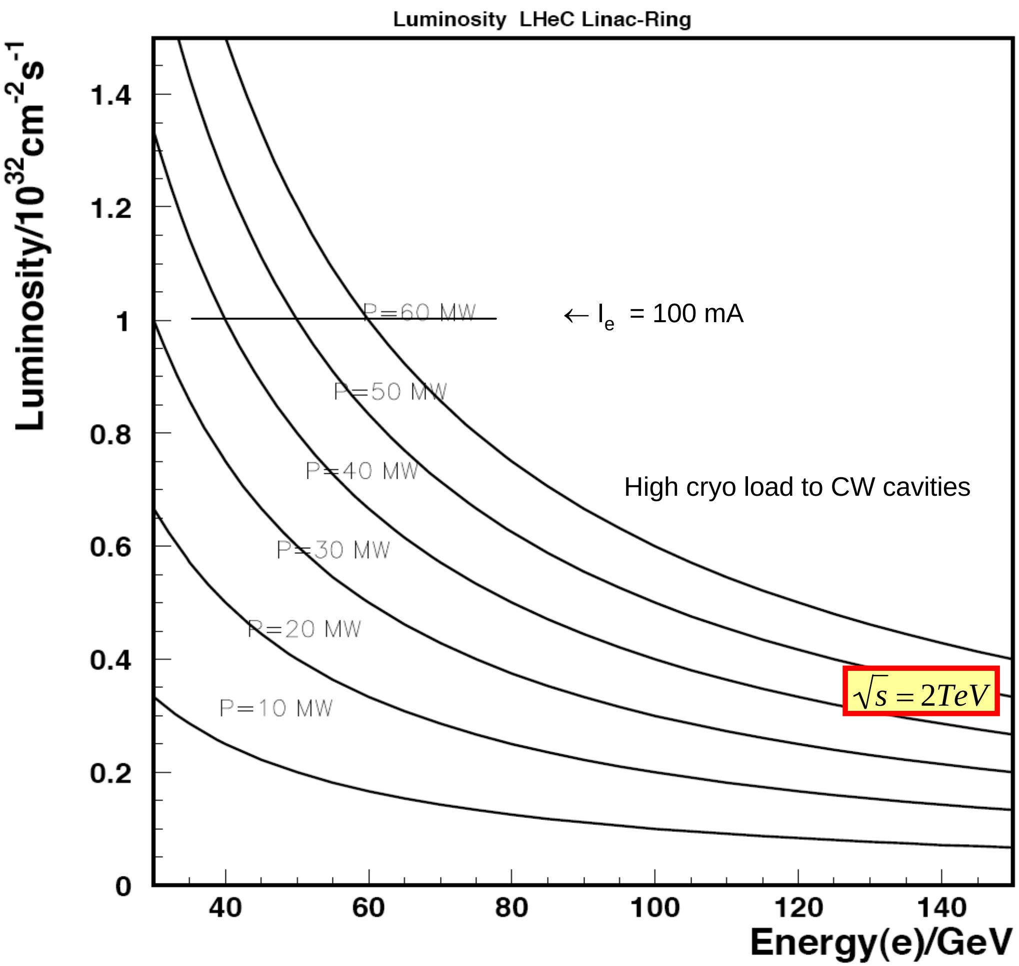
May reach 10^{34} with ERL in
bypasses, or/and reduce power.
R&D performed at BNL/eRHIC

cf also A.Verdier 1990, E.Keil 1986

Luminosity: Linac-Ring

$$L = \frac{N_p \gamma}{4\pi e \varepsilon_{pn} \beta^*} \cdot \frac{P}{E_e} = 1 \cdot 10^{32} \cdot \frac{P/MW}{E_e/GeV} cm^{-2} s^{-1}$$

$$\varepsilon_{pn} = 3.8 \mu m$$
$$N_p = 1.7 \cdot 10^{11}$$
$$\beta^* = 0.15 m$$



$$I_e = 100 mA \cdot \frac{P}{MW} \cdot \frac{GeV}{E_e}$$

LHeC as Linac-Ring version
can be as luminous as HERA II:

4 10^{31} can be reached with LR:
E_e = 40-140 GeV & P=20-60 MW
LR: average lumi close to peak

140 GeV at 23 MV/m is 6km +gaps

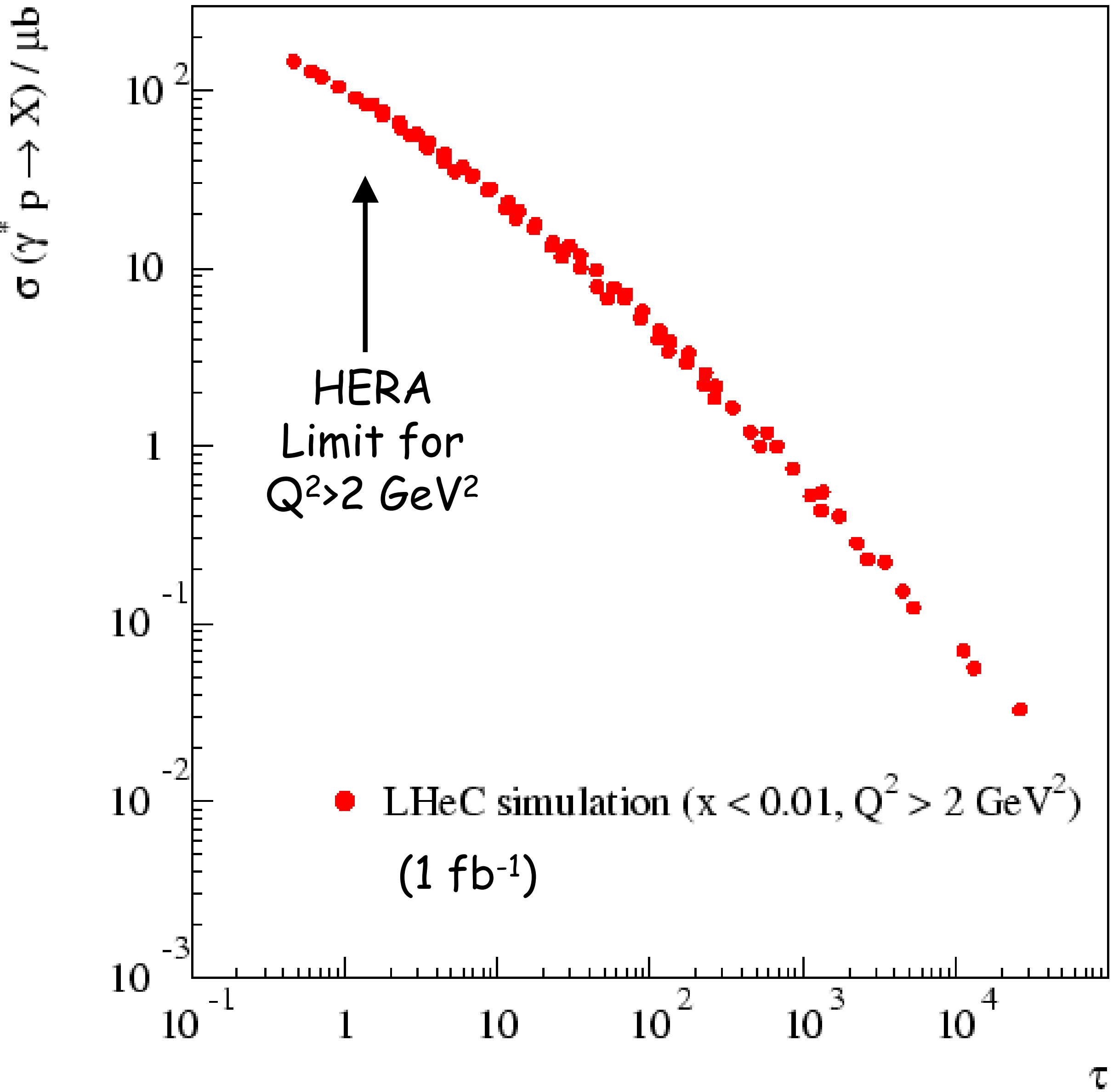
Luminosity horizon: high power:
ERL (2 Linacs?)

Overview of LHeC Parameters

Table 3: *Main Parameters of the Lepton-Proton Collider*

Property	Unit	Leptons	Protons
Beam Energies	GeV	70	7000
Total Beam Current	mA	74	544
Number of Particles / bunch	10^{10}	1.04	17.0
Horizontal Beam Emittance	nm	7.6	0.501
Vertical Beam Emittance	nm	3.8	0.501
Horizontal β-functions at IP	cm	12.7	180
Vertical β-function at the IP	cm	7.1	50
Energy loss per turn	GeV	0.707	$6 \cdot 10^{-6}$
Radiated Energy	MW	50	0.003
Bunch frequency / bunch spacing	MHz / ns	40 / 25	
Center of Mass Energy	GeV	1400	
Luminosity	$10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$	1.1	

Geometric Scaling at the LHeC



LHeC reaches $\tau \sim 0.15$ for Q^2=1 GeV^2 and $\tau \sim 0.4$ for Q^2=2 GeV^2

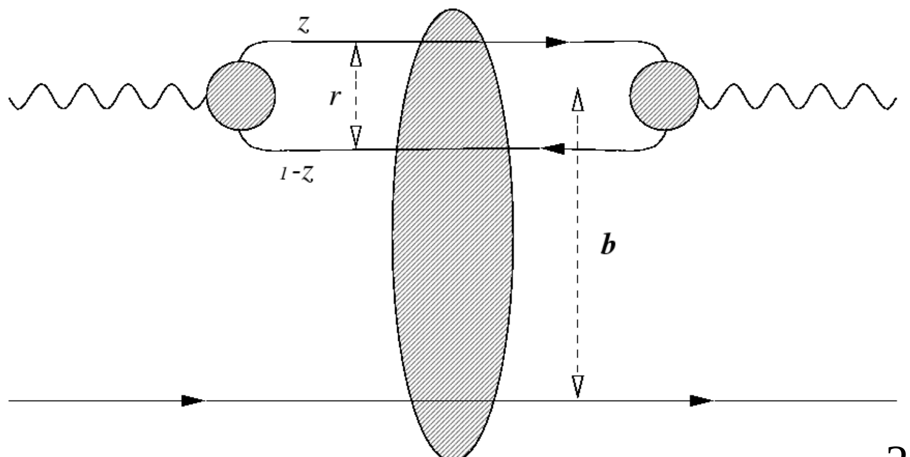
Some (though limited) acceptance for $Q^2 < Q^2_s$ with Q^2 "perturbative"

Could be enhanced with nuclei.

$Q^2 < 1$ GeV^2 accessible in special runs?

Reminder : Dipole models

• Unified description of low x region, including region where Q^2 small and partons not appropriate degrees of freedom …



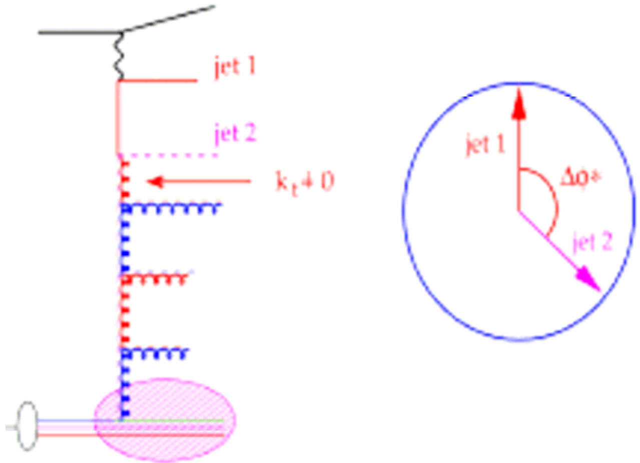
$$\sigma^{T,L}_{\gamma^* p}(x,Q^2) \sim \int dz\, d^2r \left|\psi^{T,L}_{\gamma^*}(z,r,Q^2)\right|^2 \sigma_{dipole}(x,r,z)$$

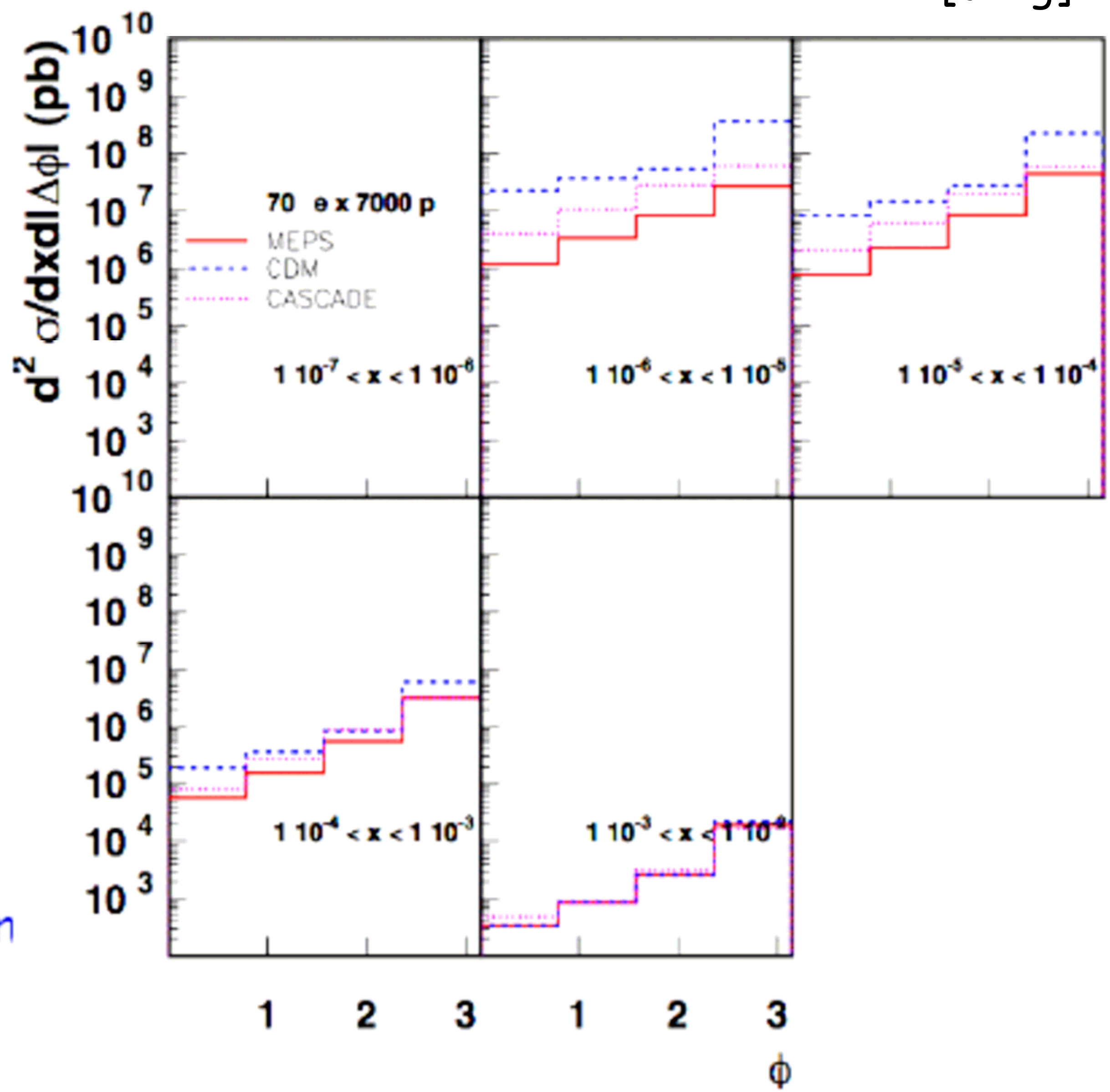
• Simple unified picture of many inclusive and exclusive processes … strong interaction physics in (universal) dipole cross section σ_{dipole}. Process dependence in wavefunction Ψ Factors

• qqbar-g dipoles also needed to describe inclusive diffraction

Azimuthal (de)correlations between Jets

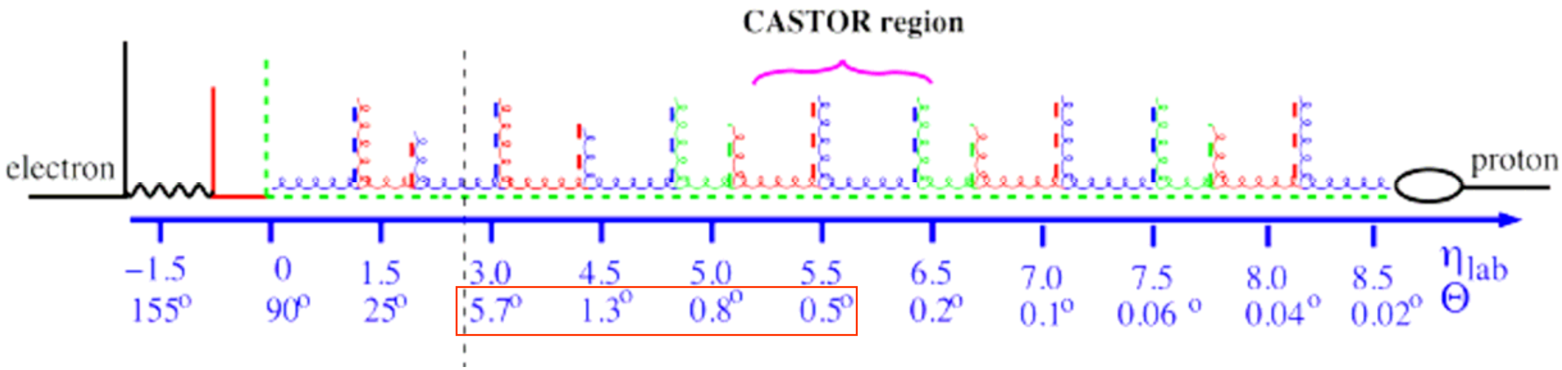
[Jung]





- $$5 < Q^2 < 100 \text{ GeV}^2$$
  $$-1 < \eta < 2.5$$
  $$E_T > 5 \text{ GeV}$$
- small k_t $\rightarrow \Delta\phi \sim 180$
- large k_t from evolution

Forward Instrumentation and Jets



[Jung]

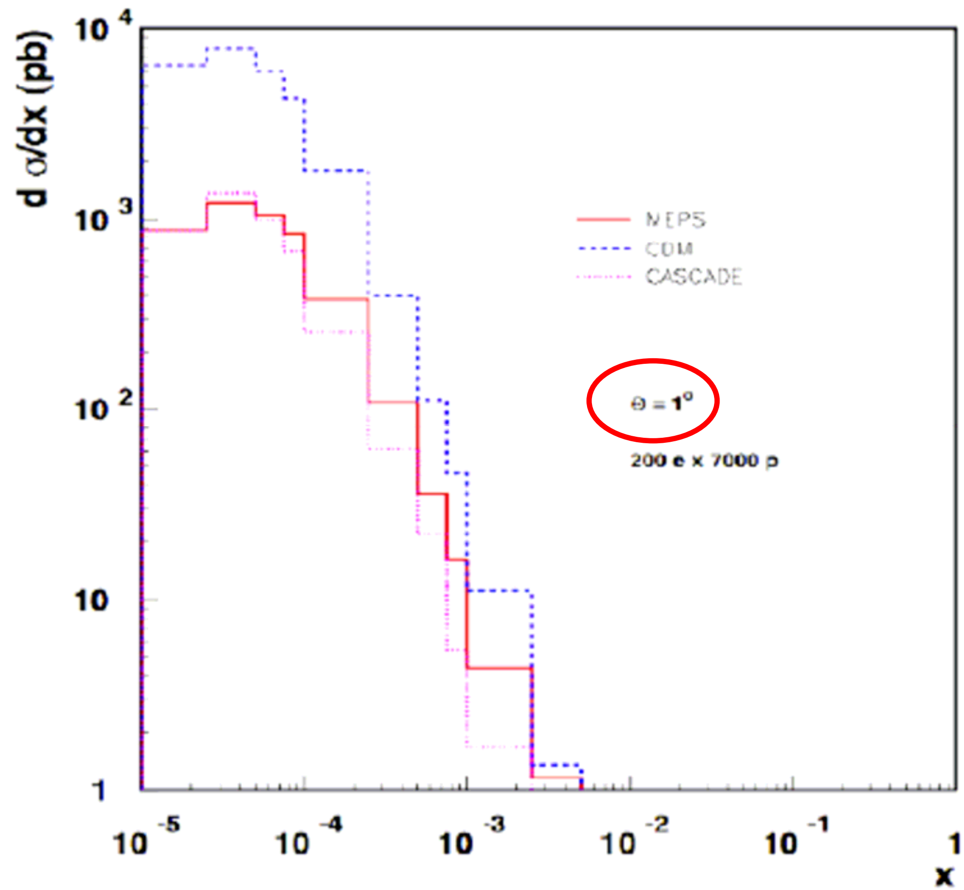
- DIS and forward jet:

$$x_{jet} > 0.03$$

$$0.5 < \frac{p_{t\,jet}^2}{Q^2} < 2$$

x range (and sensitivity to novel QCD effects) strongly depend on θ cut

Similar conclusions for Δϕ decorrelations between jets



Some committees were set up …

… after further studies, discussions with CERN accelerator experts and a presentation to plenary ECFA (M Klein) …

Summary and Proposal as endorsed by ECFA (30.11.2007)

As an add-on to the LHC, the LHeC delivers in excess of 1 TeV to the electron-quark cms system. It accesses high parton densities 'beyond' what is expected to be the unitarity limit. Its physics is thus fundamental and deserves to be further worked out, also with respect to the findings at the LHC and the final results of the Tevatron and of HERA.

First considerations of a ring-ring and a linac-ring accelerator layout lead to an unprecedented combination of energy and luminosity in lepton-hadron physics, exploiting the latest developments in accelerator and detector technology.

It is thus proposed to hold two workshops (2008 and 2009), under the auspices of ECFA and CERN, with the goal of having a Conceptual Design Report on the accelerator, the experiment and the physics. A Technical Design report will then follow if appropriate.

… Nuclear physics also took an interest …

Electron-Proton/Ion Collider

- Options
  - Europe
    - LHeC
    - $\vec{e} + \vec{p}$ Collider @ FAIR
  - USA
    - ELIC @ JLab
    - eRHIC @ BNL

28 members from
20 countries

- Chair: Brian Fulton (York)
- Chair Elect: Günther Rosner (Glasgow)
- 3 meetings a year in different countries

- NuPECC working group
  - Tullio Bressani, Jens Jørgen Gaardhøje, G. Rosner (chair), H. Ströher
- Input to
  - NuPECC Report 2009
  - NuPECC's next Long Range Plan
    - Start preparation @ mtg. in Glasgow, Oct. 2008
    - Town meetings, working groups in 2009/10
    - Publication ~2010/11

… a working group structure agreed and convenors invited …

First ECFA-CERN Workshop on the LHeC Divonne 1.-3.9.08

Accelerator Design [RR and LR]
Oliver Bruening (CERN),
John Dainton (CI/Liverpool)

Interaction Region and Fwd/Bwd
Bernhard Holzer (DESY),
Uwe Schneeekloth (DESY),
Pierre van Mechelen (Antwerpen)

Detector Design
Peter Kostka (DESY),
Rainer Wallny (UCLA),
Alessandro Polini (Bologna)

New Physics at Large Scales
Emmanuelle Perez (CERN),
Georg Weiglein (Durham)

Precision QCD and Electroweak
Olaf Behnke (DESY),
Paolo Gambino (Torino),
Thomas Gehrmann (Zuerich)

Physics at High Parton Densities
Nestor Armesto (CERN),
Brian Cole (Columbia),
Paul Newman (B'ham),
Anna Stasto (MSU)

… first workshop took place in September 2008, Divonne …
→ Eclectic mix of accelerator experts, experimentalists and theorists (91 participants)

Agenda of Divonne Workshop

Monday 01 September 2008

Registration - Hall d'accueil (12:30-14:00)

Opening - Amphitheatre (14:00-16:30)

- Conveners: Ellis, John

time	[id] title	presenter
14:00	[0] Welcome Address	ENGELEN, Jos
14:15	[1] Opening Remarks from ECFA	MEIER, Karlheinz
14:30	[4] Opening Remarks from NuPECC	ROSNER, Guenther
14:45	[2] Opening Lecture - "Deep Inelastic Scattering in the LHC time"	ALTARELLI, Guido
15:45	[3] Steering Group Report	KLEIN, Max

Accelerator Overview - Ausone (17:00-19:05)

time	[id] title	presenter
17:00	[41] Discussion	
17:45	[37] Boundary conditions for the Interaction Region design	SCHNEEKLOTH, Uwe
18:15	[38] Interaction Region design for a ring-ring option	HOLZER, Bernhard
18:40	[39] Interaction Region design for a ring-linac option	TOMAS, Rogelio

Physics Overview - Barbilaine (17:00-19:00)

time	[id] title	presenter
17:00	[9] LHeC Physics Overview	BRODSKY, Stan
18:00	[10] QCD in the High Energy Limit	BARTELS, Jochen

Tuesday 02 September 2008

Accelerator & IR Design - Ausone (09:00-12:00)

time	[id] title	presenter
09:00	[40] Ring-Linac option: various operation modes and performance reaches	ZIMMERMANN, Frank
09:30	[42] Magnet design issues and options for an LHeC Interaction Region	RUSSENSCHUCK, Stephan
10:00	[43] Operation with large crossing angles and the required CRAB cavity parameters	CALAGA, Rama
10:30	coffee break	
11:00	[44] Summary of the main parameters for the ring-ring option	JOWETT, John
11:30	[45] Ring-ring layout and bypass design	BURKHARDT, Helmut

Detector Design - Barbilaine (09:00-12:00)

time	[id] title	presenter
09:00	[62] Introduction and session organization	POLINI, Alessandro KOSTKA, Peter WALLNY, Rainer
09:15	[63] Silicon Pixel detectors for Tracking	WERMES, Norbert
10:00	[64] RD50 and silicon radiation hardness	MOLL, Michael
10:30	coffee break	
11:00	[65] Present & Future Collider Triggers	SMITH, Wesley
11:20	[66] Trigger and displaced vertexing (CDF SVT)	CERRI, Alessandro
11:40	[67] The CMS Hadron Calorimeter and upgrade scenarios	SKUJA, Andris

QCD and Low x ep Observables and PDFs - Amphitheatre (09:00-12:00)

time	[id] title	presenter
09:00	[11] Precision Physics with Parton Distributions	VOGT, Andreas
09:30	[12] Structure Functions and PDFs at/from LHeC	KLEIN, Max
09:50	[13] Neural network approach to parton distributions	ROJO-CHACON, Juan
10:10	[14] Expectations for alpha_s	KLUGE, Thomas
10:30	coffe break	
11:00	[15] Heavy Flavour and Jet Observables at the LHeC	BEHNKE, Olaf
11:20	[17] More Low-x Observables at the LHeC	NEWMAN, Paul
11:40	[16] Forward Jets/Parton Cascade Dynamics at LHeC (tbc)	JUNG, Hannes

Accelerator & IR & Detector - Ausone (14:00-16:00)

time	[id] title	presenter
14:00	[49] Active magnets	GREENSHAW, Tim
14:20	[48] Magnet Options for LHeC detector	TEN KATE, Herman
14:40	[46] e-RHIC machine aspects	LITVINENKO, Vladimir
15:00	[47] IR Design for the e-RHIC project	MONTAG, Christoph
15:20	[50] IR Design proton optics	HOLZER, Bernhard
15:40	[51] IR Design: electron optics	KLING, Alexander

16:30	[26] Higgs -> b bbar Coupling at LHC	KOAY, Sue Ann
16:50	[80] Higgs cross sections at LHeC	KLEIN, Uta
17:10	[27] Backgrounds to Higgs production at the LHeC	KUZE, Masahiro
17:30	[28] Drell-Yan, new physics and high x PDFs	PEREZ, Emmanuelle
17:50	[29] Electroweak precision physics before and after LHC	DEGRASSI, Giuseppe

Low x ep and eA Physics at LHC and LHeC - Barbilaine (16:30-19:00)

time	[id] title	presenter
16:30	[32] Low x QCD with protons and nuclei at LHC	D'ENTERRIA, David
16:50	[33] What to expect on low x from ATLAS	CAMPANELLI, Mario
17:10	[34] From ep to AB Collisions	ARMESTO, Néstor
17:30	[36] Prompt photons as a tool for nuclear PDFs	ARLEO, Francois
17:50	[35] Concluding discussion and plans on low x	

New Physics at the LHeC - Barbilaine (14:00-16:01)

time	[id] title	presenter
14:00	[18] Introduction	PEREZ, Emmanuelle
14:30	[19] Excited Fermions	TRINH, Nguyet
15:00	[20] Single Leptoquark Production in pp	PAPADOPOULOU, Theodora
15:30	[30] Single Top Production	BRANDT, Gerhard

Parton Saturation at the LHeC - theory and experiment - Amphitheatre (14:00-16:00)

time	[id] title	presenter
14:00	[21] Gluon density in BFKL DAF-Pomeron at HERA and its implication for LHC and LHeC	KOWALSKI, Henri
14:20	[22] Saturation effects in final states and total cross sections due to CCFM with absorptive boundary	KUTAK, Krzysztof
14:40	[23] 5D tiny black holes and perturbative saturation	SABIO VERA, Agustin
15:00	[24] Establishing/falsifying saturation at LHeC	ROJO-CHACON, Juan
15:20	[25] Establishing/falsifying parton saturation in low x ep at LHeC	NEWMAN, Paul

Accelerator & IR Design - Ausone (16:30-19:00)

time	[id] title	presenter
16:30	[74] Space requirements for cavities, Klystrons and power converters in the LHC tunnel/ bypass areas	LINNECAR, Trevor
16:50	[75] Synergies of the required LHeC R efforts with other existing projects	NN
17:10	[76] Polarisation	BARBER, Desmond
17:30	[77] Double Quad Design	PAOLONI, Eugenio BETTONI, Simona
17:50	[78] Synchrotron Light	NAGORNY, Boris
18:10	[79] Discussion	

Detector design - Foyer des artistes (16:30-19:00)

time	[id] title	presenter
16:30	[71] Gossip gaseous pixel detector R&D	KOFFEMAN, Els
17:00	[72] CALICE calorimeters for the ILC	SIMON, Frank
17:30	[73] Detector Design WG open discussion	NN

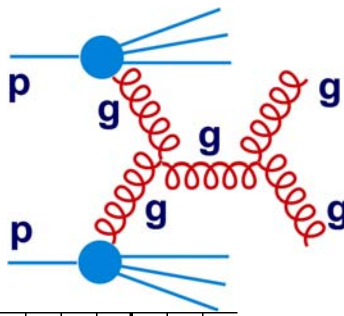
Wednesday 03 September 2008

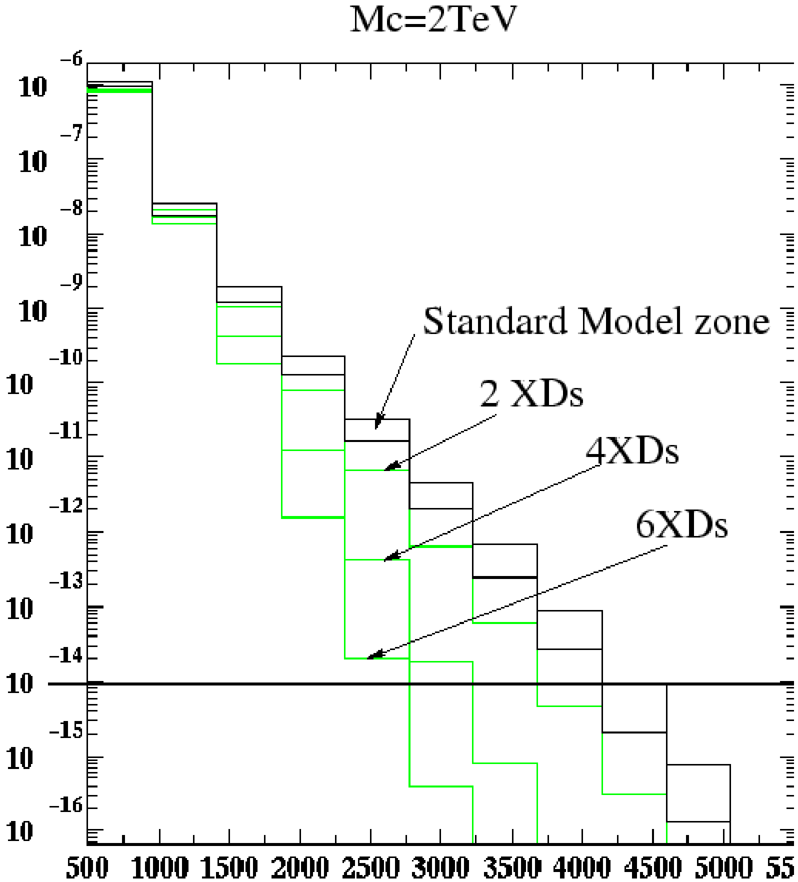
Reports from Working Groups - Amphitheatre (09:00-12:30)

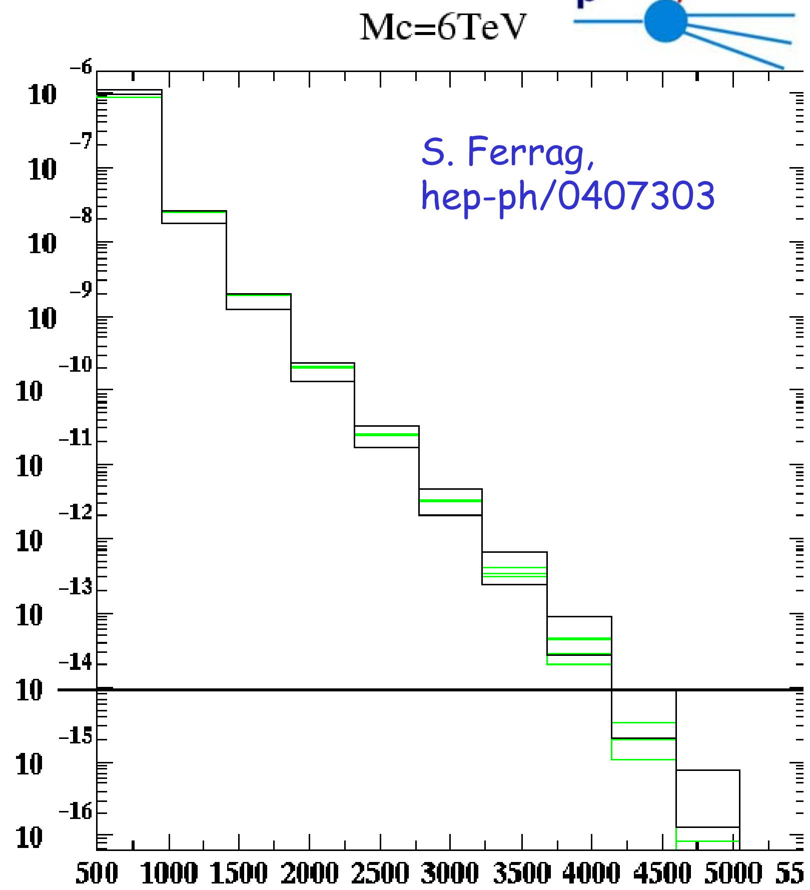
time	[id] title	presenter
09:00	[56] Physics at High Parton Densities (ep and eA)	ARMESTO, Néstor NEWMAN, Paul
09:30	[57] Precision Investigations of QCD and Electroweak Interactions	BEHNKE, Olaf
10:00	[58] New Physics at Large Scales	WEIGLEIN, Georg
10:30	coffee break	
11:00	[59] Detector Design	POLINI, Alessandro WALLNY, Rainer KOSTKA, Peter
11:30	[60] Interaction region and Forward/Backward Detectors	HOLZER, Bernhard
12:00	[61] Accelerator Design	BRUNING, Oliver

High x Partons Limiting LHC Searches

Some BSM scenarios give deviations in high mass dijet spectra … e.g. a model with extra dimensions …





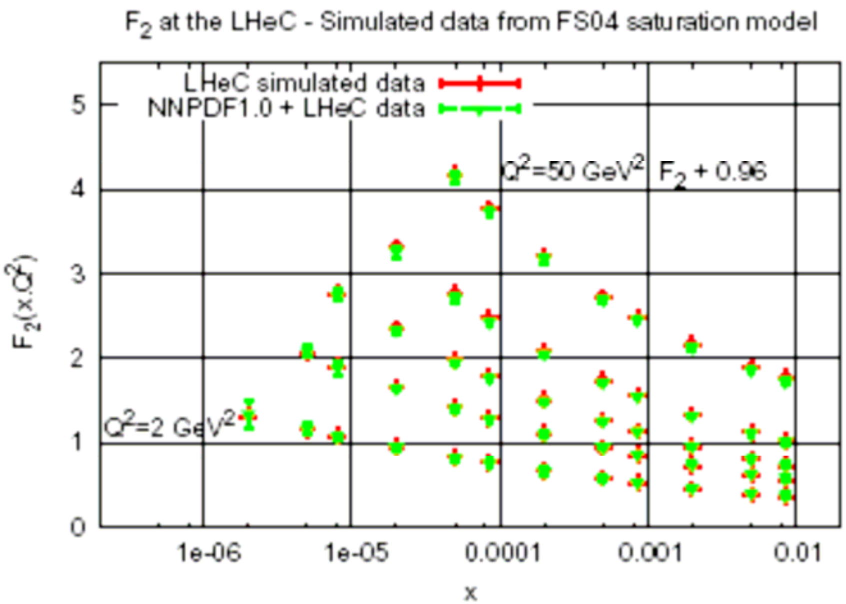


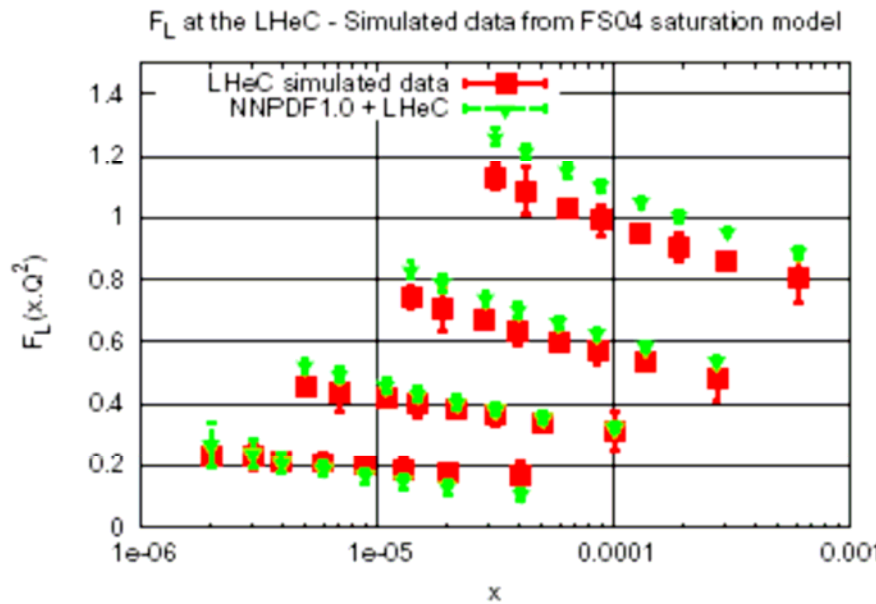
… in this example, high x PDF uncertainties reduce sensitivity to compactification scales from 6 TeV to 2 TeV for 2XDs

Can Parton Saturation be Established @ LHeC?

… effects may not be so large in ep → and may be hard to establish unambiguously with F_2 alone
… $A^{1/3}$ amplification in gluon in eA (~6 for Pb) may be needed
… Two first studies using F_2 and F_L in ep only …

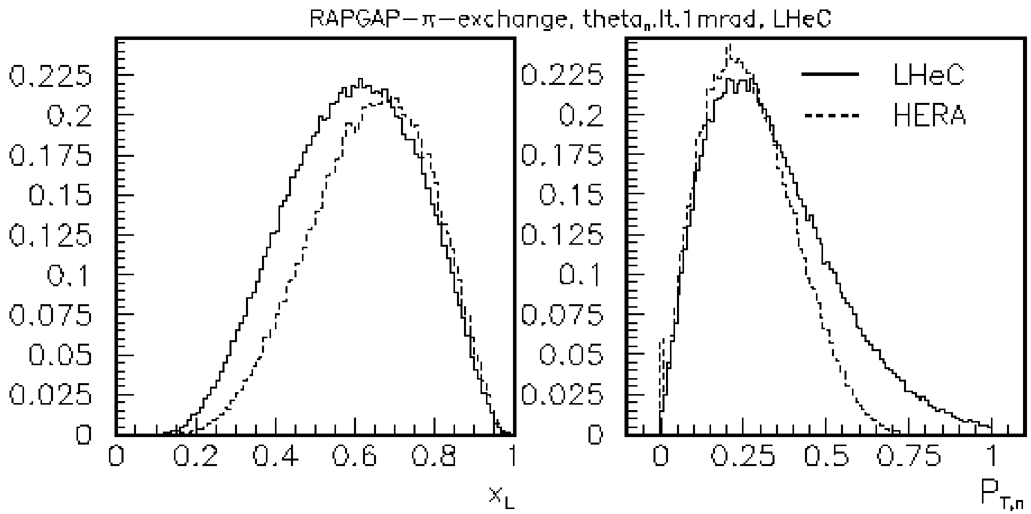
[Rojo]





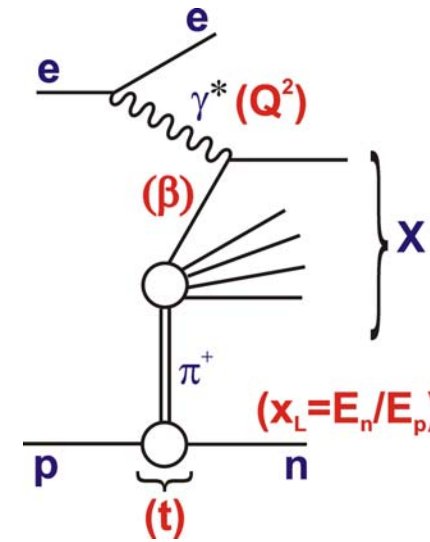
Saturation effects at LHeC (FS04-sat) cannot be absorbed into NNPDF1.0 DGLAP PDF analysis if F_2 and F_L both fitted

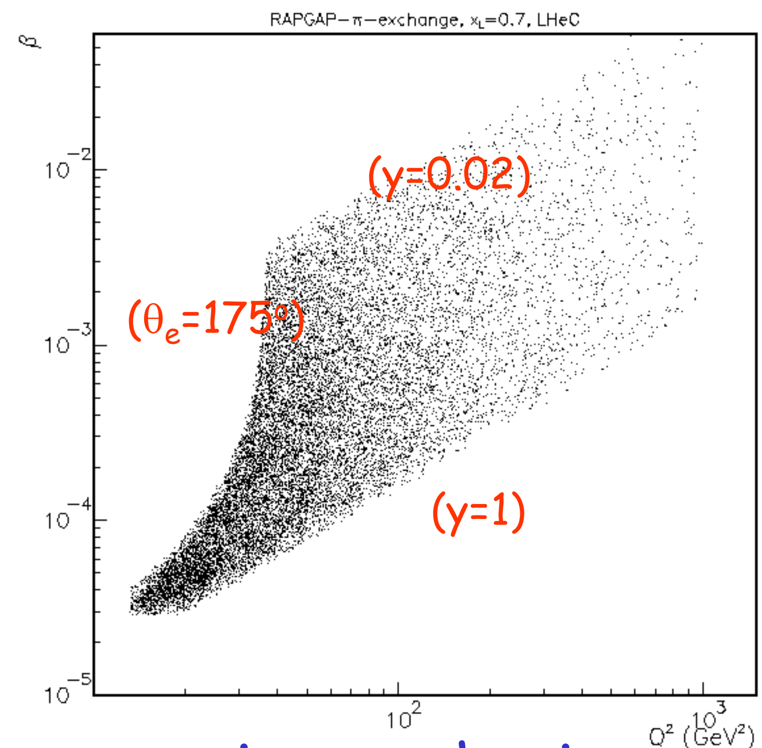
π Structure with Leading Neutrons



[Bunyatyan]

(RAPGAP MC model, E_p=7TeV, E_e=70GeV)





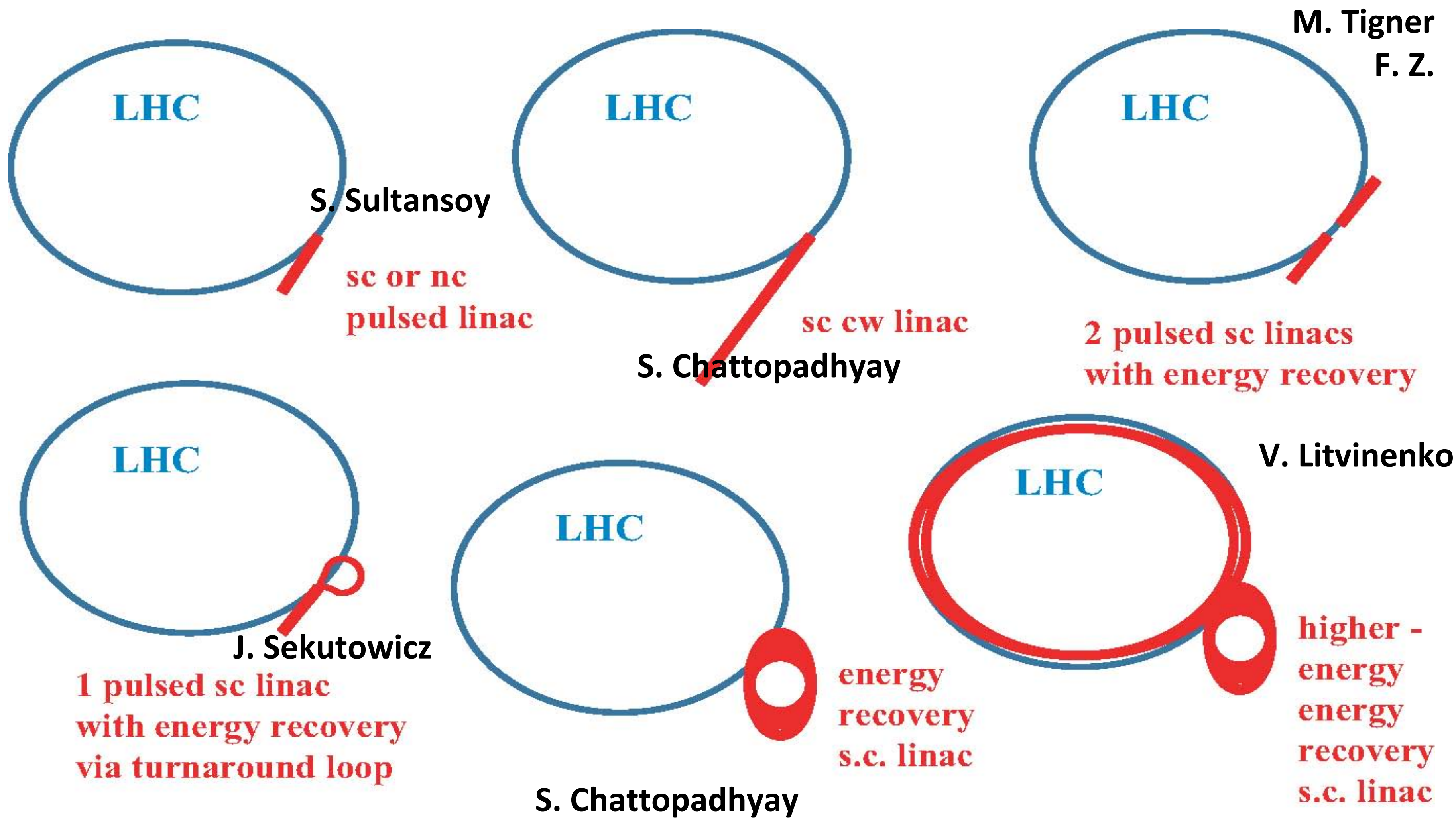
- With θ_n < 1 mrad, similar x_L and p_t ranges to HERA (a bit more p_t lever-arm for π flux).

- Extentions to lower β and higher Q^2 as in leading proton case. → F_2^{π} At β<5.10^{-5} (cf HERA reaches β~10^{-3})

Also relevant to absorptive corrections, cosmic ray physics …

Linac-Ring Solutions

[Zimmermann]



… lots of R&D required …

First Detector Concepts

Muon chambers
(fwd,bwd,central)

Coil (r=3m l=8.5m, 2T)

Central Detector

Hadronic Calo (Fe/LAr)
El.magn. Calo (Pb,Sc)
GOSSIP (fwd+central)
Pixels
Elliptic pipe (~3cm)

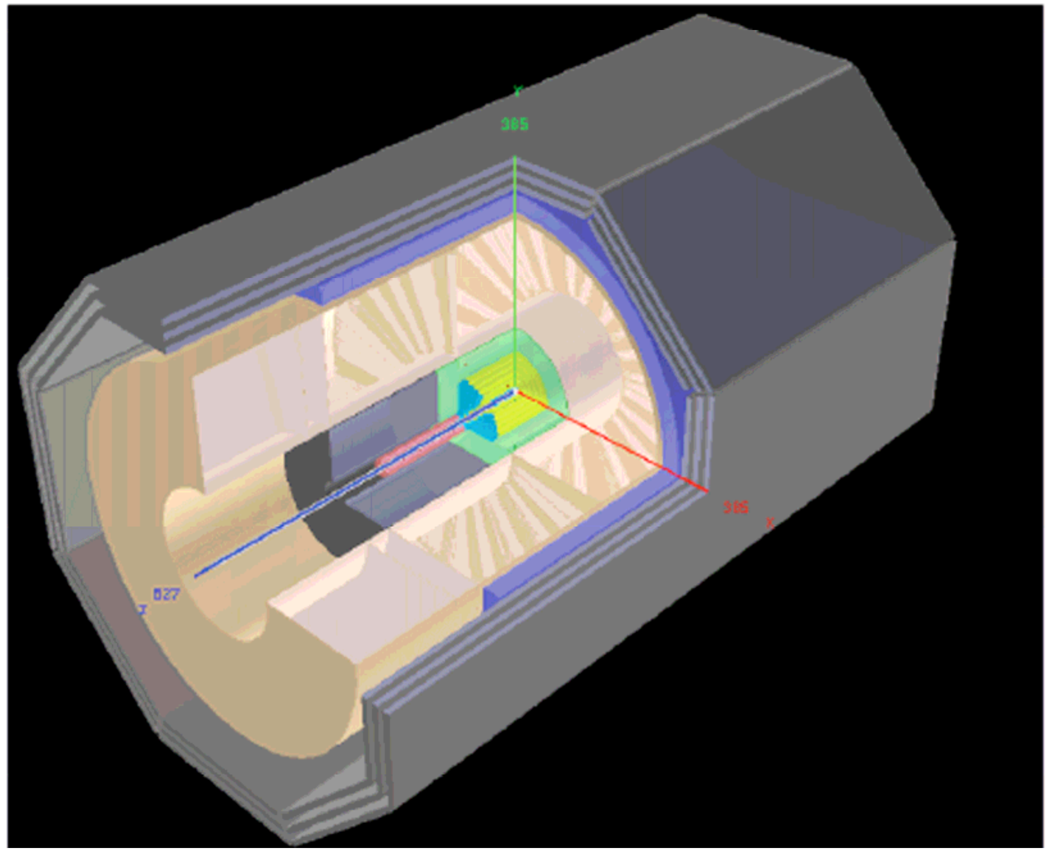
Fwd Calorimeter
(down to 10°)

Lepton low β magnets
FwdHadrCalo

Bwd Spectrometer
(down to 170°)

Lepton low β magnets
Spacal (elm, hadr)

L1 Detector: version for hiQ^2 Physics



→ 2 interaction points / experiments?
→ 2 phases of single experiment (a la HERA)?
→ Other ideas

First Detector Concepts

Muon chambers
(fwd,bwd,central)

Coil (r=3m l=8.5m, 2T)
[Return Fe not drawn]

Central Detector

Hadronic Calo (Fe/LAr)
El.magn. Calo (Pb,Sc)
GOSSIP (fwd+central)
[Gas on Slimmed Si Pixels]
[0.6m radius for 0.05% * pt in 2T field]
Pixels
Elliptic beam pipe (~3cm)

Fwd Spectrometer
(down to 1°)

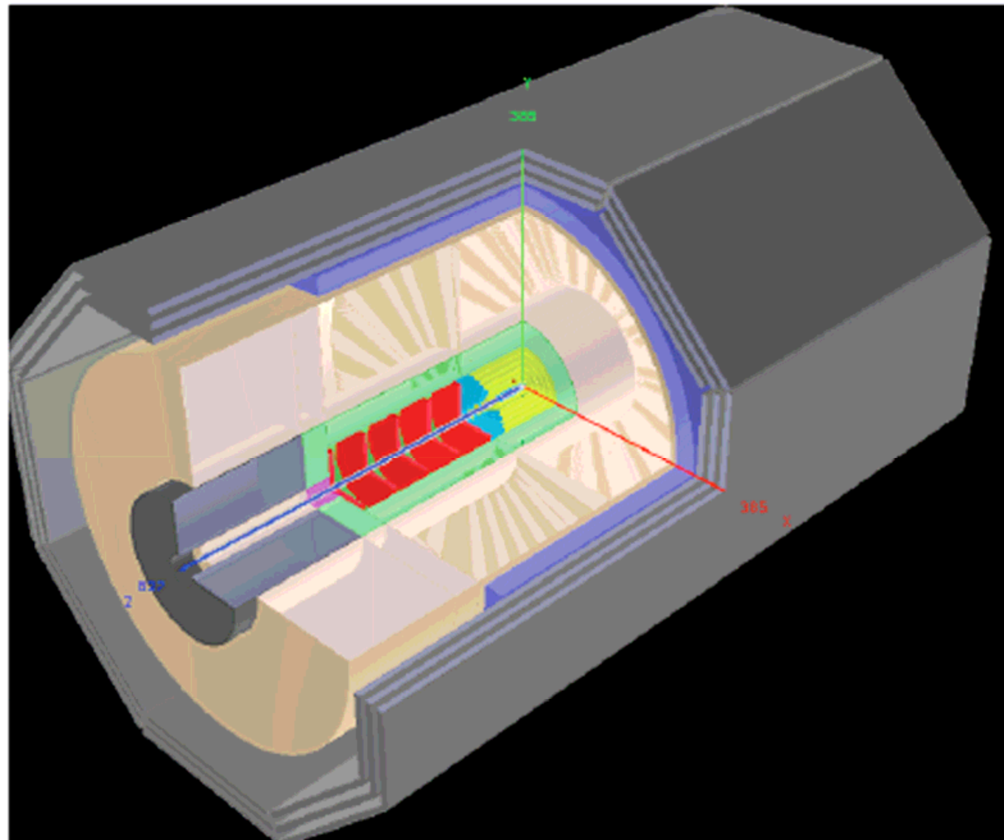
Tracker
Calice (W/Si)
FwdHadrCalo

Bwd Spectrometer
(down to 179°)

Tracker
Spacal (elm, hadr)

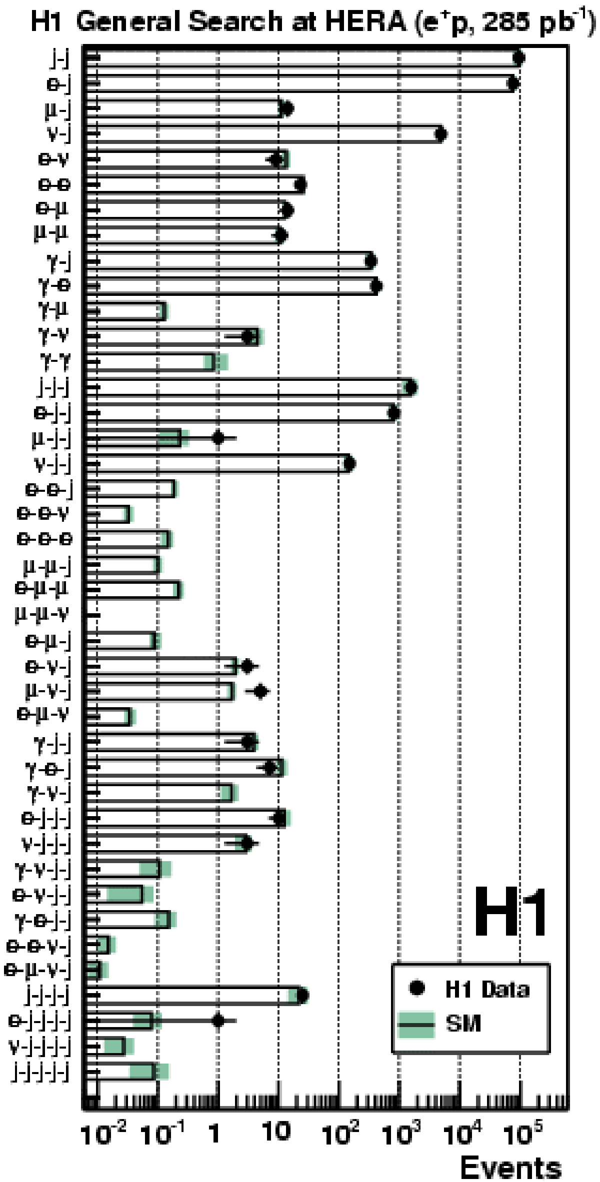
Max Klein LHeC ICFA08

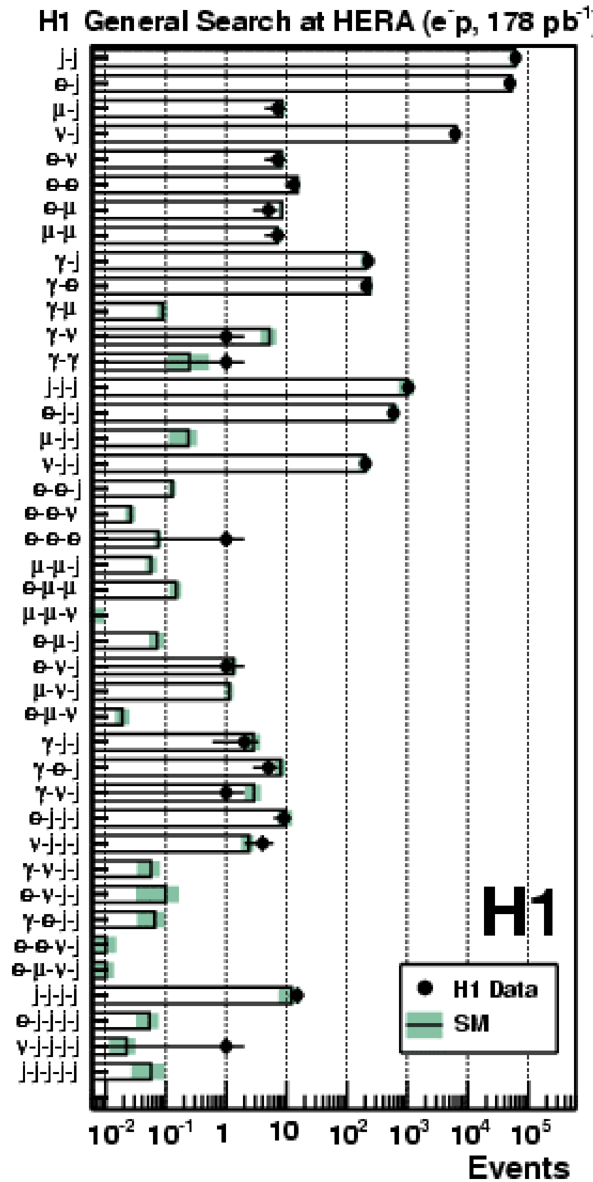
L1 Detector: version for low x Physics



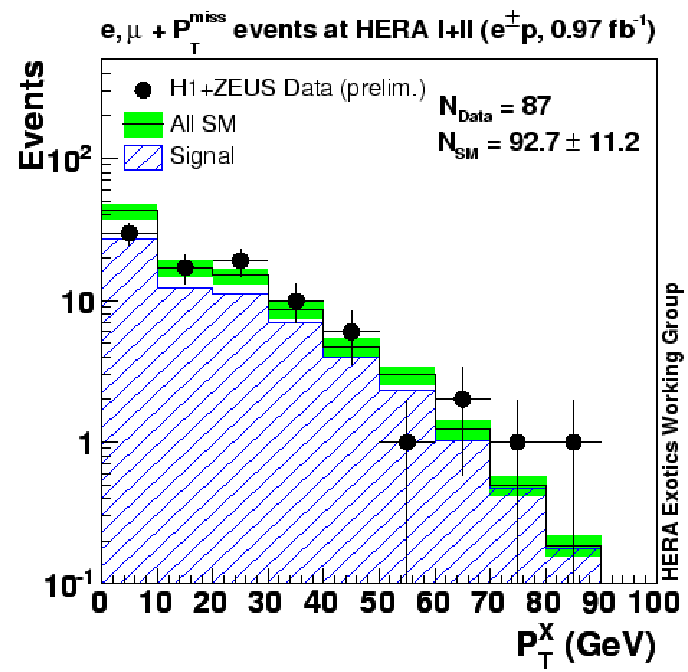
To be extended further in fwd direction. Tag p,n,d. Also e,γ (bwd)

Is HERA Finished? - H1 high pt Summary





… perhaps yes for searches …



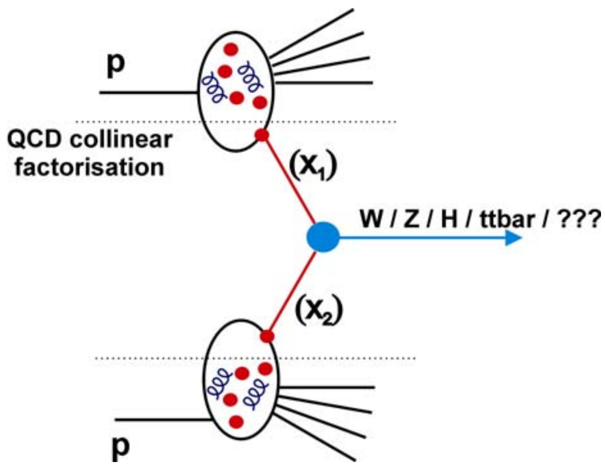
- Detectors and physics processes well understood!

The Standard Model & HERA part as good friends!

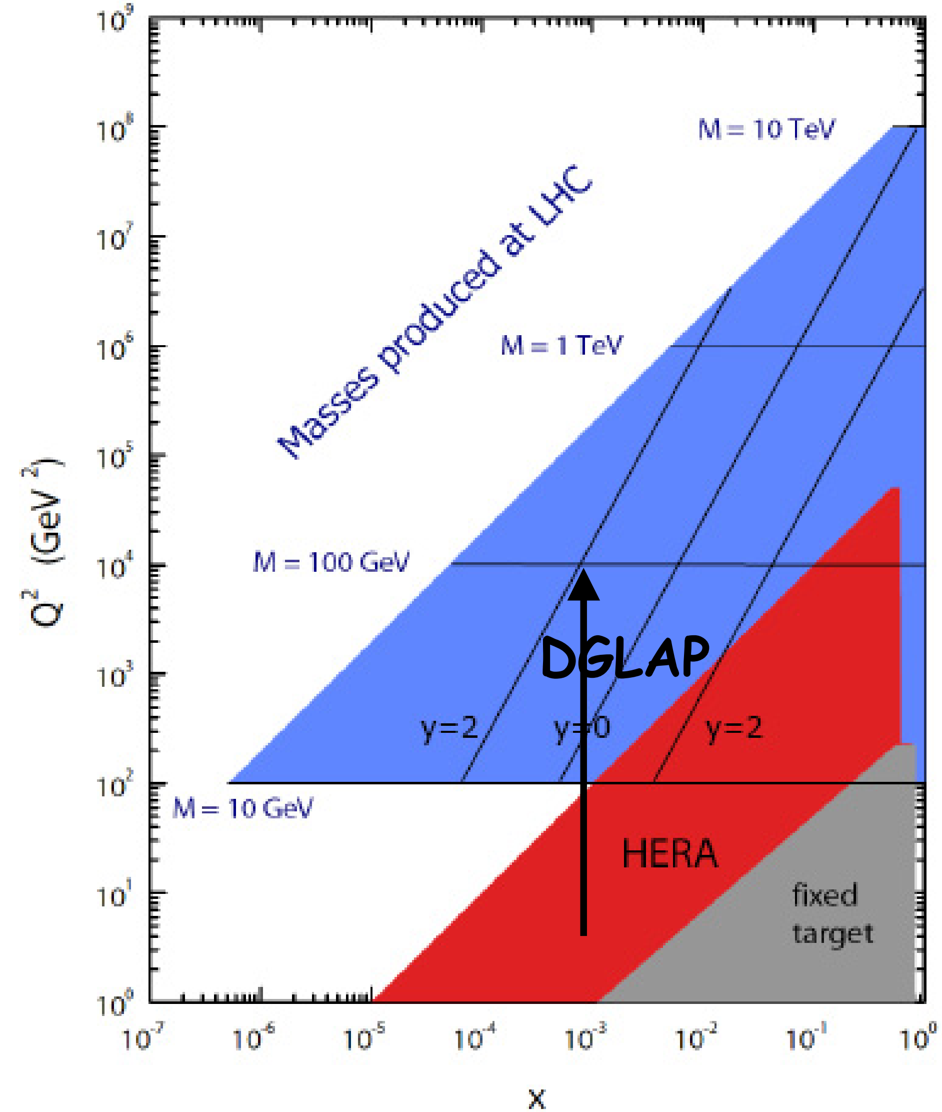
HERA Input to LHC

• Unprecedented low x and high Q^2 coverage in DIS

• HERA + **QCD factorisation** →parton densities in full x range of LHC rapidity plateau



• Well established `**DGLAP**' **evolution** equations generalise to any scale (for not too small x)



e.g. pp dijets at central rapidity: $x_1 = x_2 = 2p_t / \sqrt{s}$