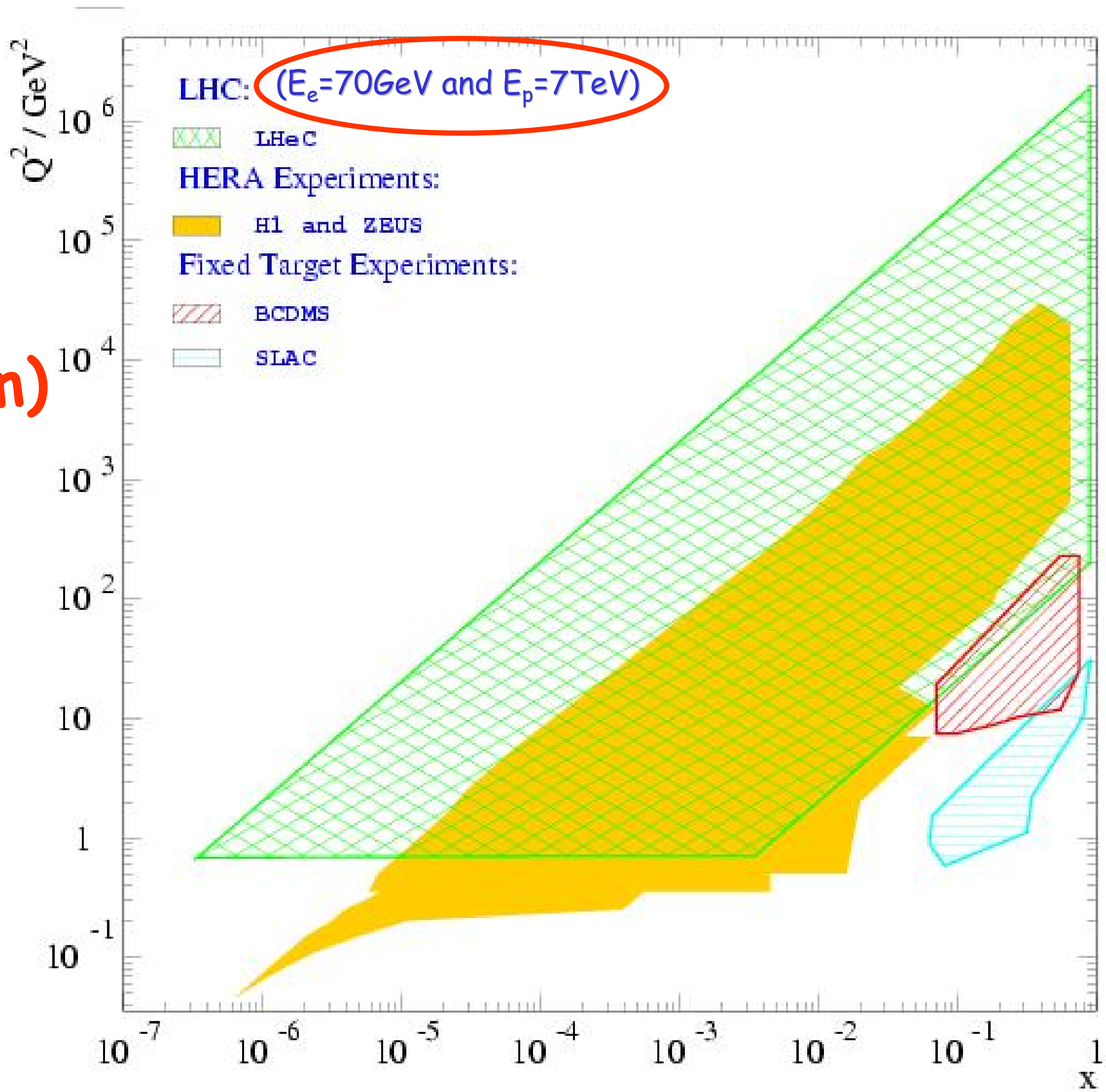
DIS after HERA? The LHeC Project

Paul Newman
(University of Birmingham)

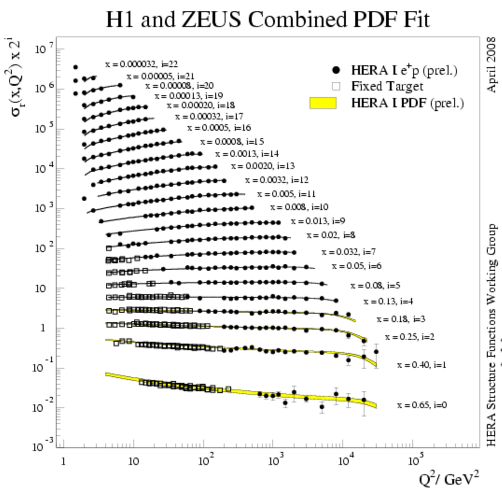
IPPP Seminar
20 November 2008

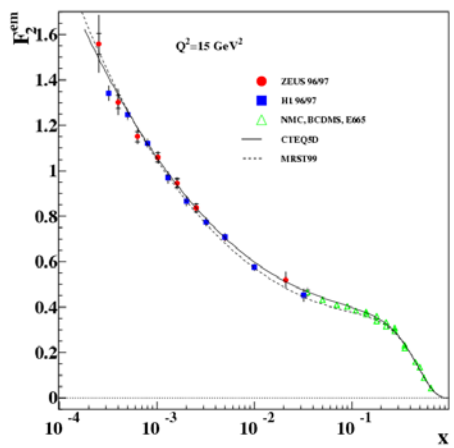


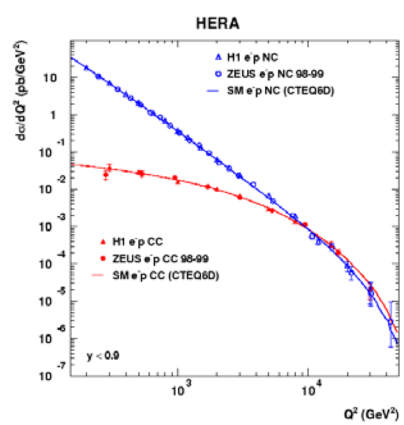
- Where HERA leaves us
- Physics case for high luminosity TeV Scale DIS
- First Physics studies
- Accelerator & Detector

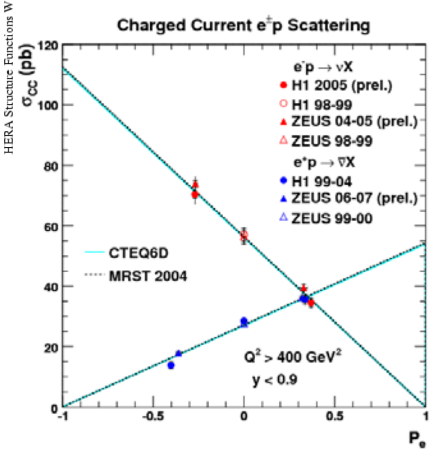
http://www.lhec.org.uk

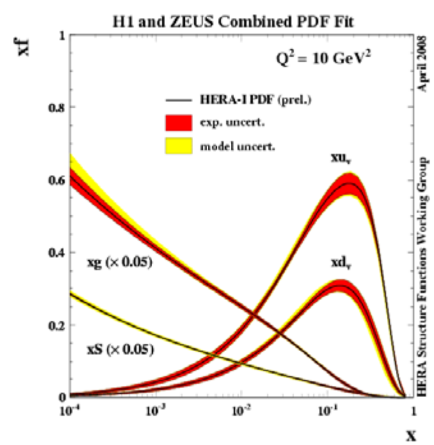
Collage of "Text-Book" HERA Plots

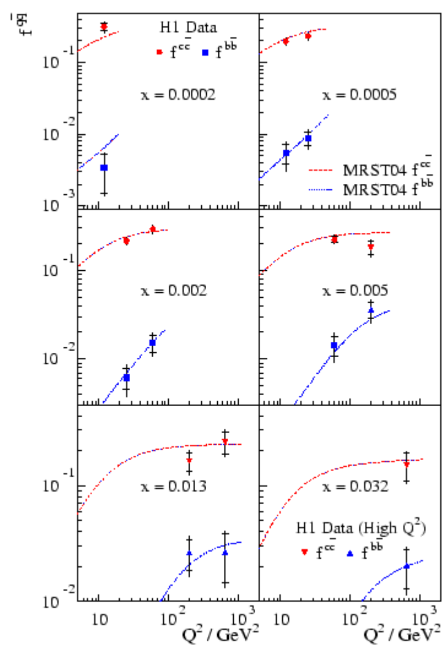


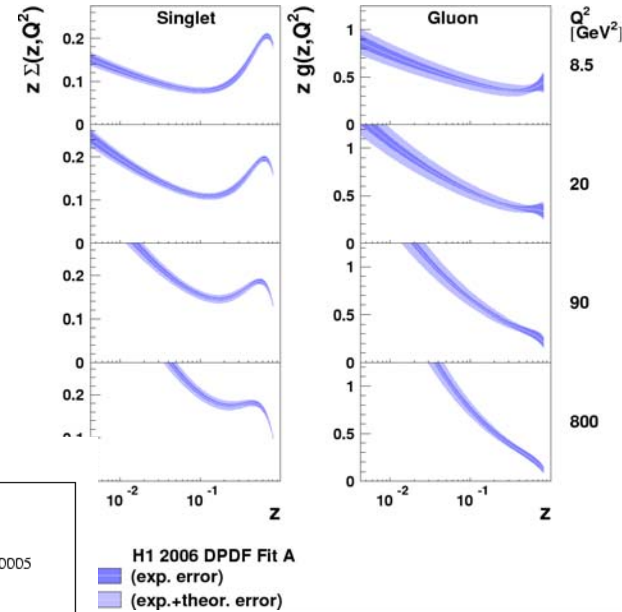


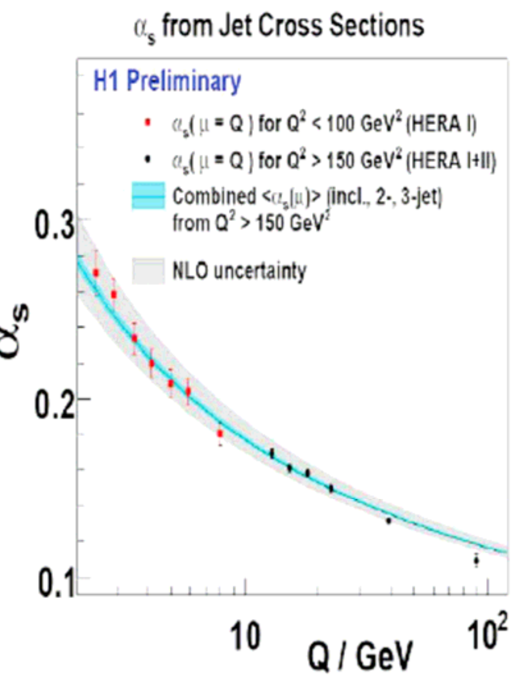






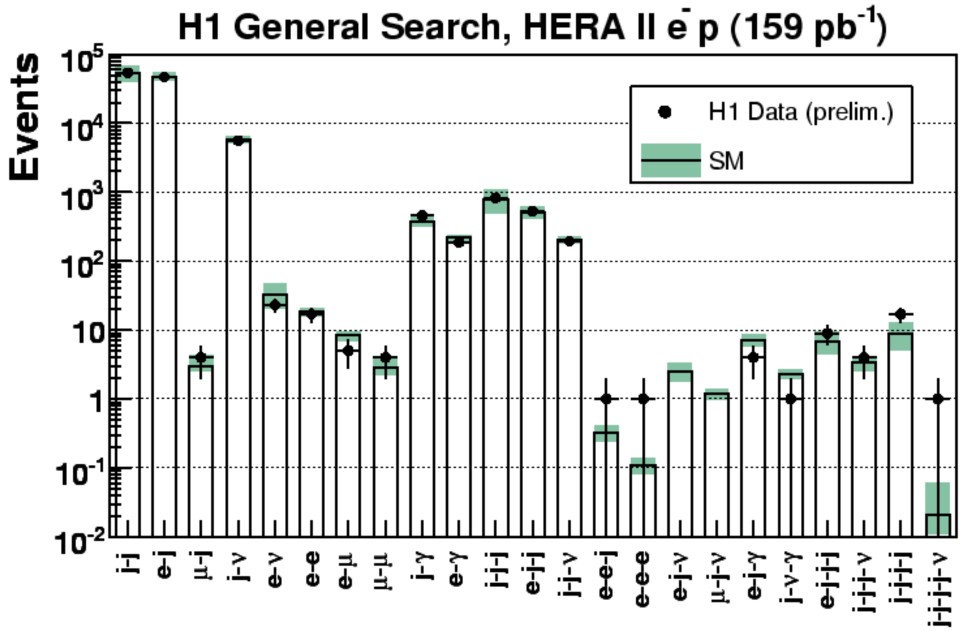


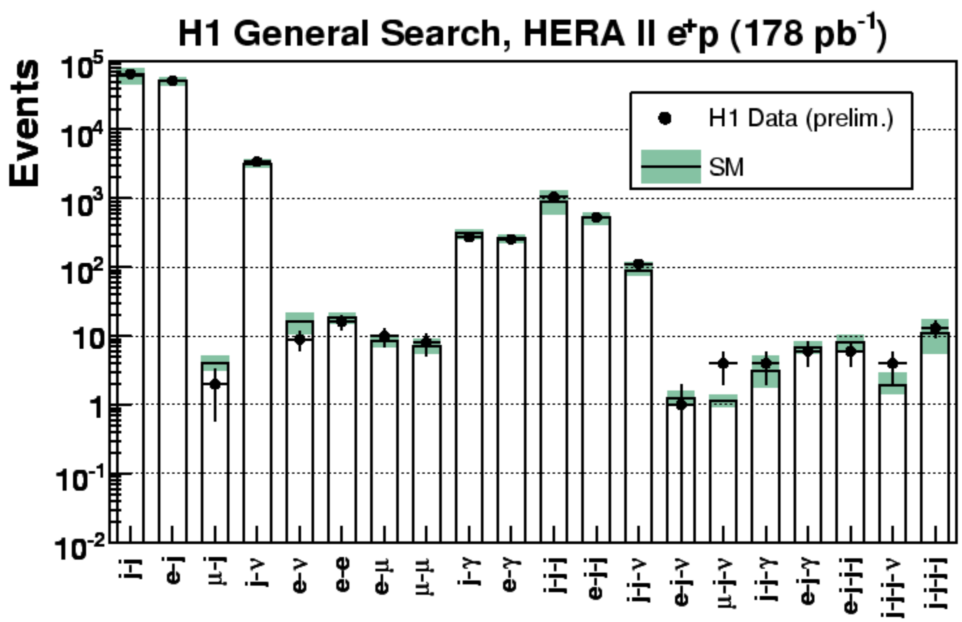




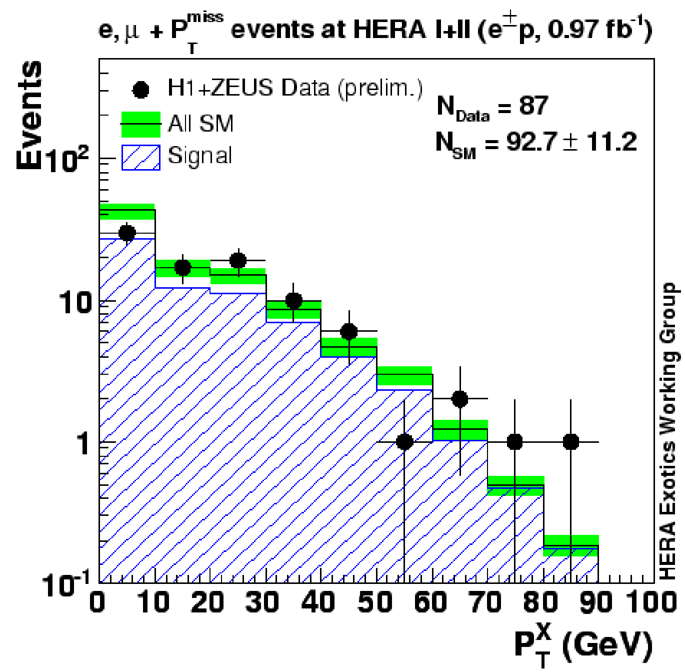
Further progress often limited by energy and luminosity ...

Is HERA finished?



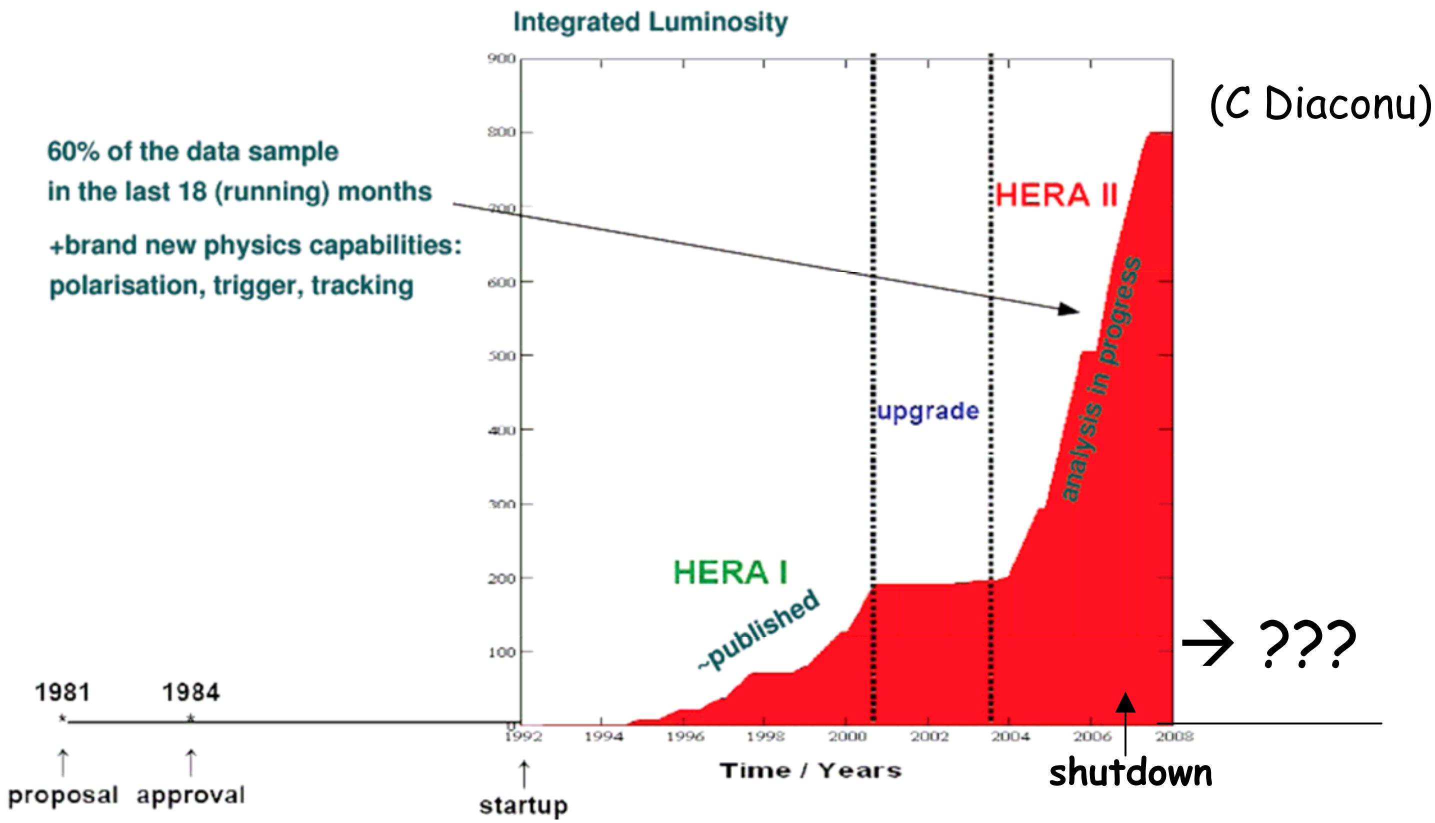


… perhaps yes for searches



- Combined HERA results clarify e.g. H1 isolated high pt leptons with missing pt
- No really significant signals
- Detectors well understood!

A(nother) HERA Timeline



… very few publications on HERA-II so far!.. best still to come
… complicated final states take time (& experts) to analyse!

"UK physicists are still very much engaged in getting the most accurate data analysed and published on subjects of key importance for HERA, for QCD and in the preparation For the LHC. The projects require modest travel and common Fund support (mainly computing) in order to produce the final publications which capitalise on two decades of UK investment" [Particle Physics Consultation Panel to STFC Programmatic Review:]

The LHC is the Future!

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]

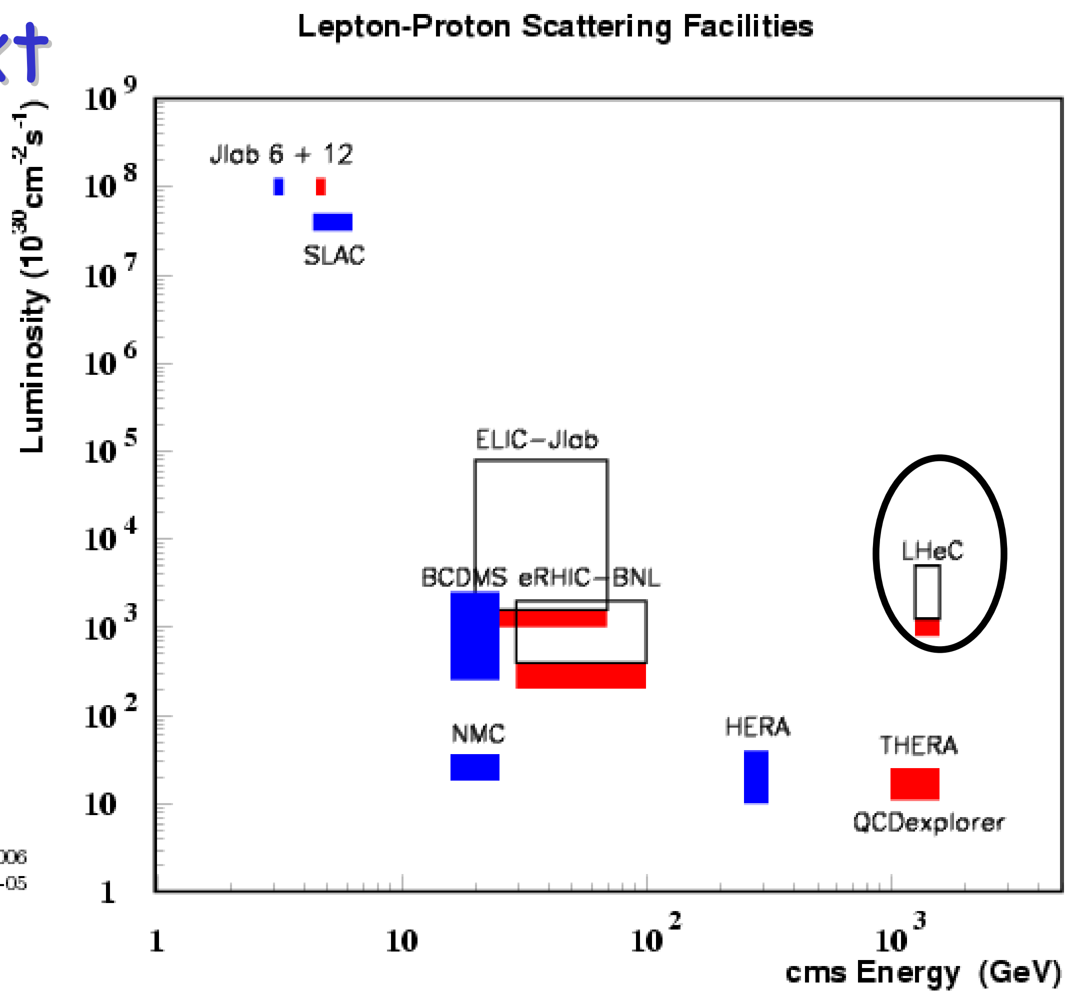
HERA-LHC Workshop … (see also PDF4LHC)

AIMS

- Identify & prioritise HERA measurements needed for LHC
- Transfer of knowledge between HERA & LHC communities
- Establish ongoing interaction HERA & LHC communities
- Quantify implication of HERA results
- Develop new experimental / theoretical tools
- Encourage theory / phenomenology efforts

Some LHeC Context

The LHeC is not the first proposal for higher energy 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]

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

NuPECC

- 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 - Autone (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 - Autone (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 - Autone (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

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	

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

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 - Autone (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

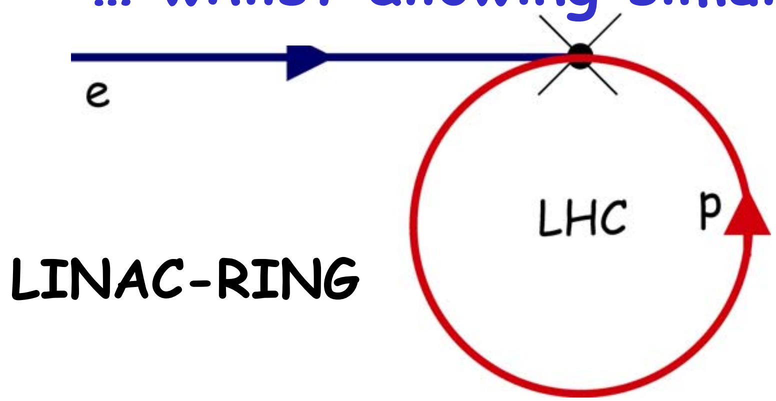
Wednesday 03 September 2008

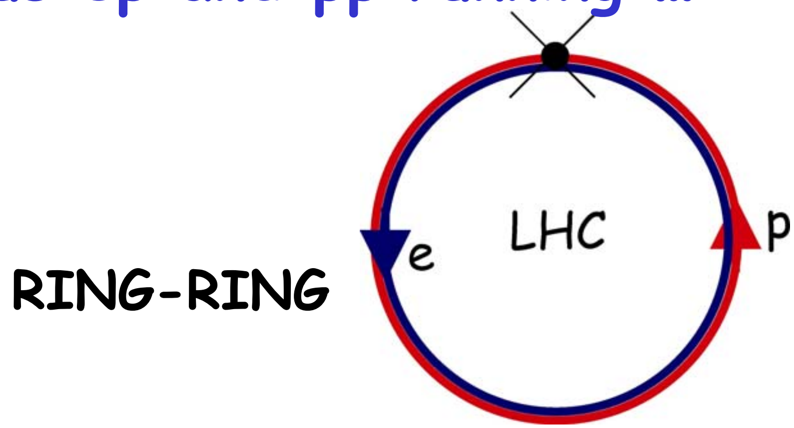
Reports from Working Groups - Amphitheatre (09:00-12:30)

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

How Could ep be Done using LHC?

… whilst allowing simultaneous ep and pp running …

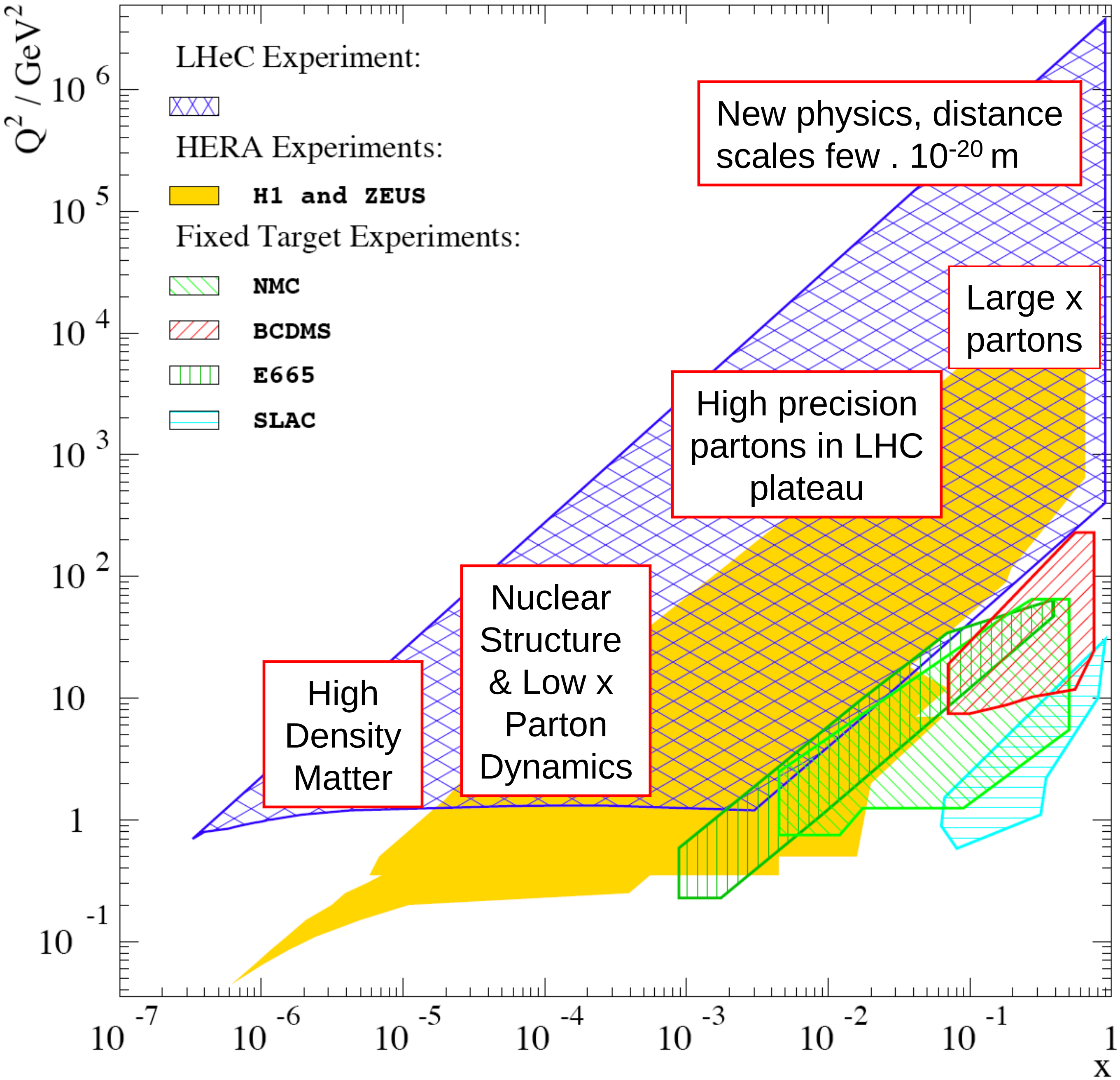




- Previously considered as `QCD explorer' (also THERA)
- Reconsideration (Chattopadhyay, Zimmermann et al.) recently
- Main advantages: low interference with LHC, $E_e \rightarrow$ 140 GeV ++, LC relation
- Main difficulties: lower luminosity ~0.5.10^{32} cm^{-2} s^{-1} (?) at reasonable power, no previous experience exists

- First considered (as LEPxLHC) in 1984 ECFA workshop
- Recent detailed re-evaluation with new e ring (Willeke)
- Main advantage: high peak lumi obtainable (10^{33} cm^{-2} s^{-1})
- Main difficulties: building round existing LHC, synchrtoron limits e beam energy (70GeV) and lifetime

Kinematics & Motivation (70 GeV x 7 TeV ep)



$\sqrt{s} = 1.4$ TeV

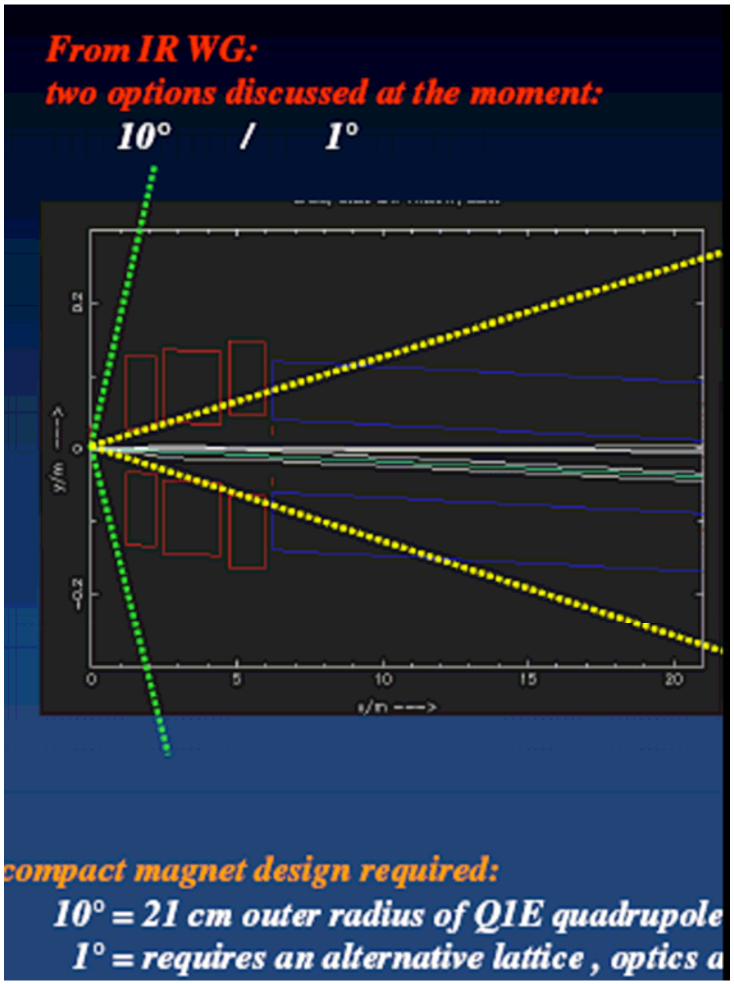
- High mass (M_{eq}, Q^2) frontier
- EW & Higgs
- Q^2 lever-arm at moderate & high x → PDFs
- Low x frontier → novel QCD …

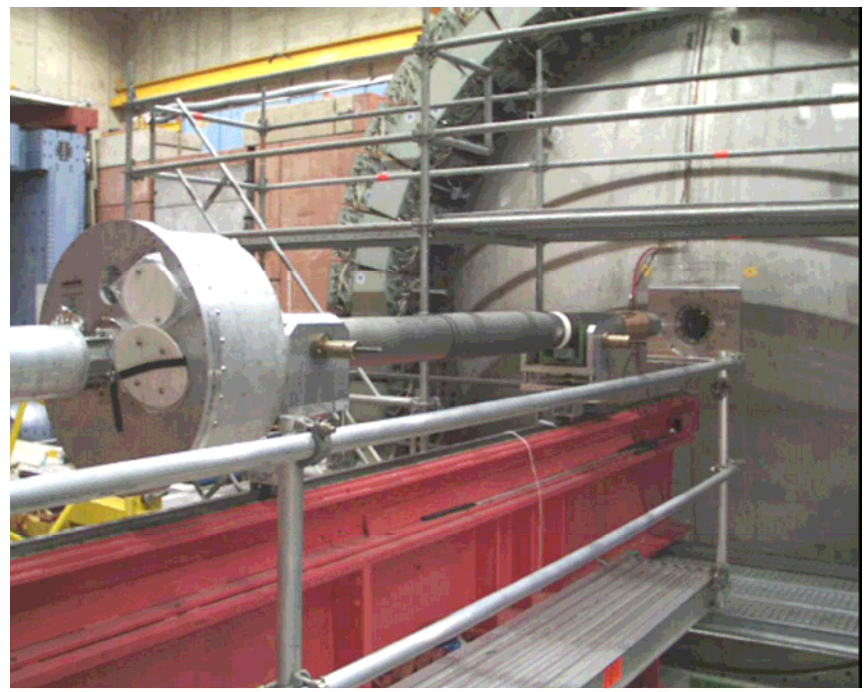
$x \geq 5.10^{-7}$ at $Q^2 \leq 1\ \text{GeV}^2$

The Luminosity v Acceptance Conundrum

- As for HERA-I v HERA-II, low β focusing quadrupoles 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





A Working Scenario for First Physics Studies

Assume a 70 GeV electron beam and lumi of 1-10 fb^{-1} / year
Requirements to reach a per-mil α_s (c.f. 1-2% now) …

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° (→179°?)	(HERA 7-177°)
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 …

Working Group on New Physics at High Scales

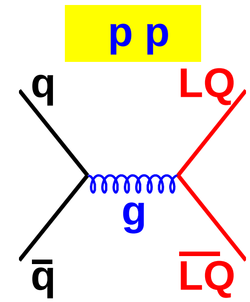
[Weiglein]

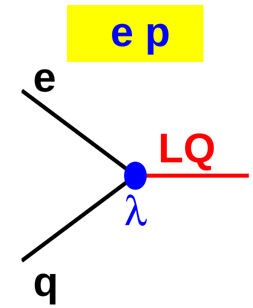
New physics at large scales: what is the physics potential of LHeC?

- Is there potential for new physics studies beyond the eeqq contact interaction (see G. Altarelli's talk)?
- Can new physics be observed at the LHeC that did not show up at the LHC?
- If not, can LHeC + LHC measurements yield added value compared to LHC alone?

… LHeC may have competitive sensitivity to LHC in BSM areas where HERA was also strong compared with Tevatron …

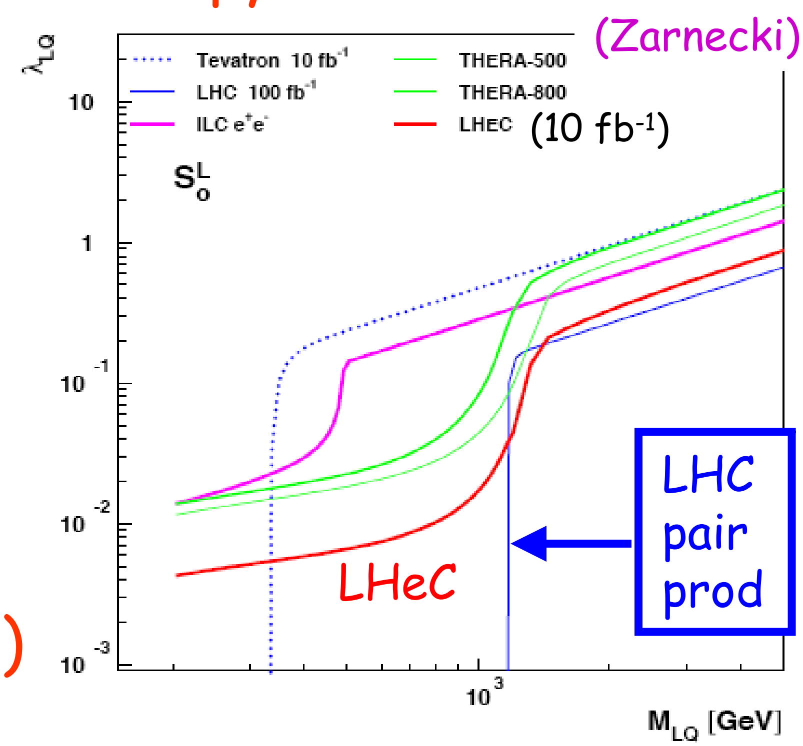
Lepton-quark Bound States



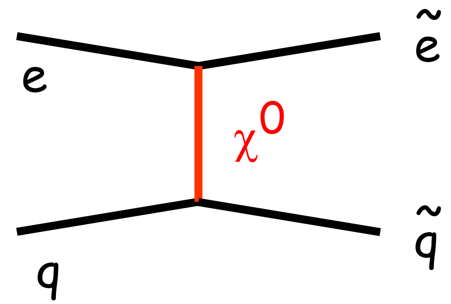


Yukawa coupling, λ

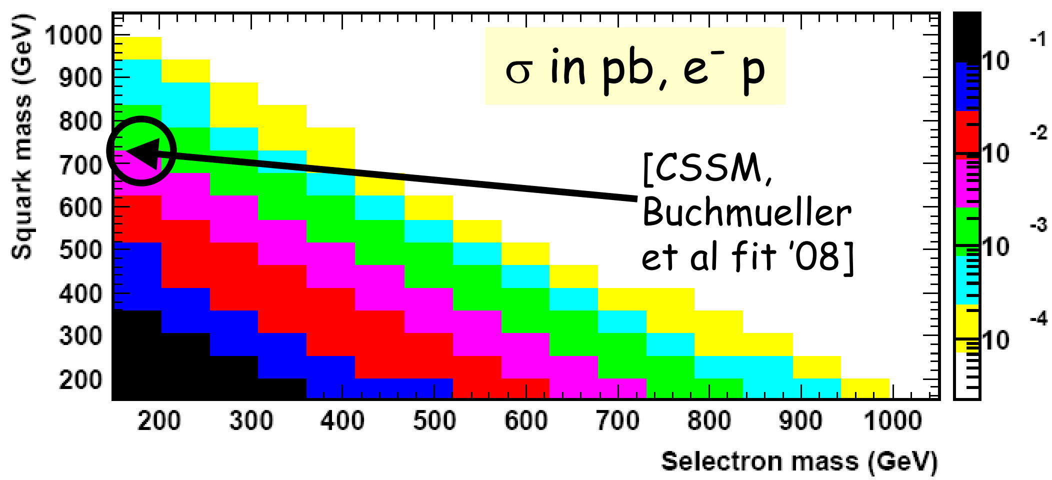
- Leptoquarks appear in many extensions to SM… explain apparent symmetry between lepton and quark sectors.
- Scalar or Vector color triplet bosons carrying L, B and fractional Q, complex spectroscopy?
- (Mostly) pair produced in pp, single production in ep.
- LHeC sensitivity (to ~1.5 TeV) similar to LHC, but can determine quantum numbers / spectroscopy (fermion #, spin, chiral couplings …)

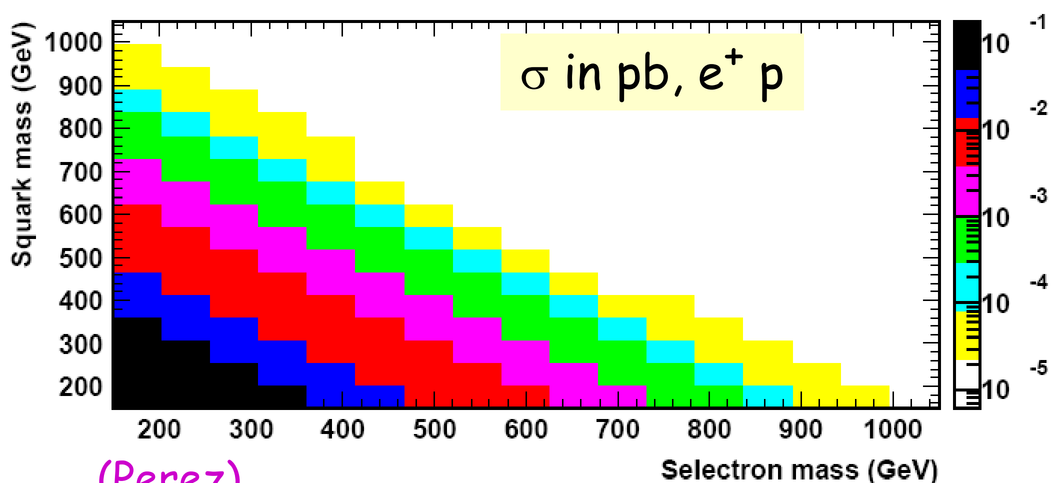


Rp Conserving Supersymmetry



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





(Perez)

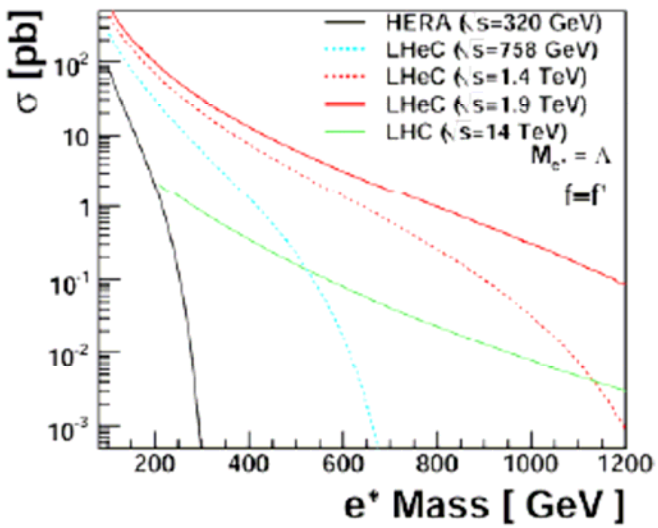
Pair production via t-channel exchange of a neutralino.

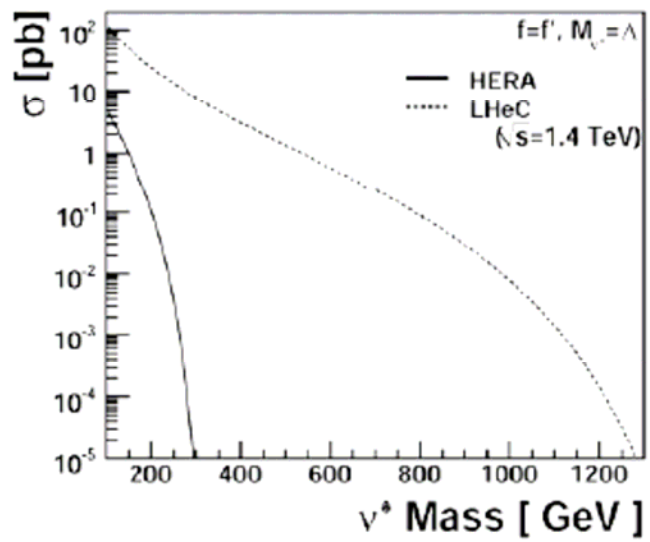
Cross-section sizeable for ΣM < 1 TeV
i.e. if squarks are "light", could observe selectrons up to ~ 500 GeV, a little beyond LHC?

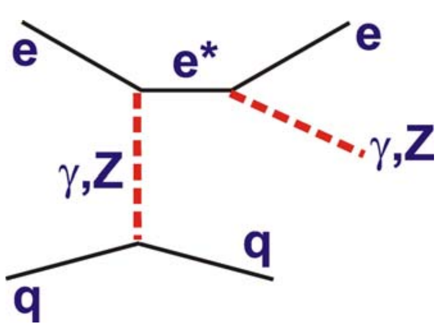
Excited Leptons

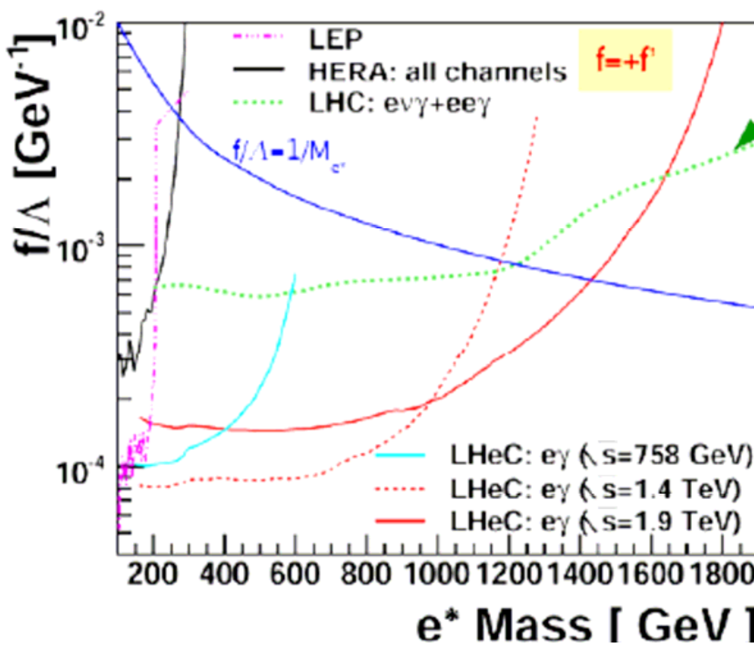
[Trinh]

- 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 …

Precision Electroweak and QCD Group

Electroweak & QCD Wishlist for LheC

[Behnke]

WW-> Higgs

Precise electroweak couplings aq,vq

alpha_s @ ~1% precision

u/d for x --> 1

g(x) for x>0.1

intrinsic c,b,t x>0.1?
Effective b-density at x=0.01

XF3 valence quarks down to small x

Direct s(x)

Precise Fl and g(x) at low x

+much much many more...

Another version of the wish list …

Novel Aspects of QCD in ep scattering

- **Clash of DGLAP and BFKL with unitarity: saturation phenomena; off-shell effects at high x**
- **Heavy quark distributions do not derive exclusively from DGLAP or gluon splitting -- component intrinsic to hadron wavefunction:**
  Intrinsic c(x,Q), b(x,Q), t(x,Q):
- **Hidden-Color of Nuclear Wavefunction**
- **Antishadowing is quark specific!**
- **Polarized u(x) and d(x) at large x; duality**
- **Virtual Compton scattering : DVCS, DVMS, GPDs; J=0 fixed pole reflects elementary source of electromagnetic current**
- **Initial-and Final-State Interactions: leading twist SSA, DDIS**
- **Direct Higher-Twist Processes; Color Transparency**

ECFA-CERN LHeC Workshop
Divonne, September 1, 2008

LHeC Physics Overview
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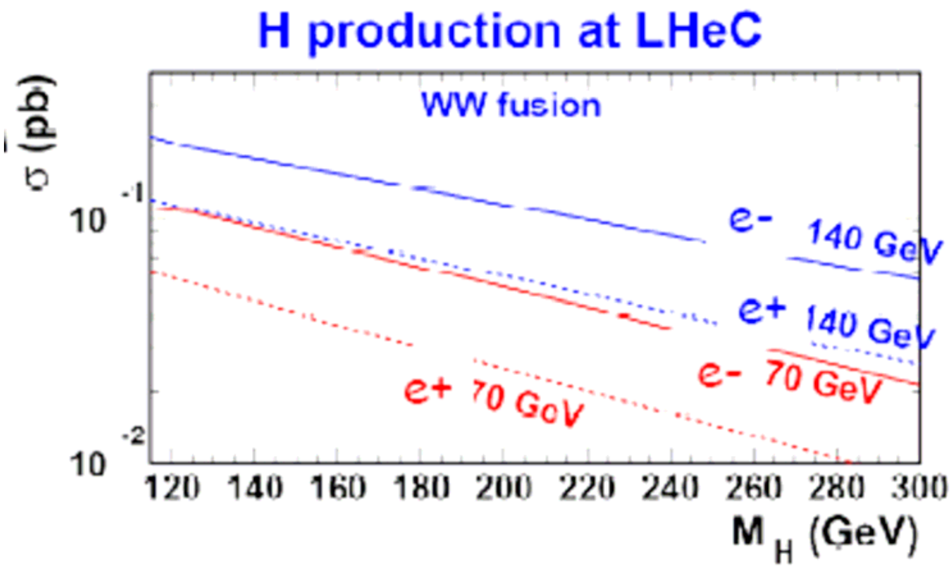
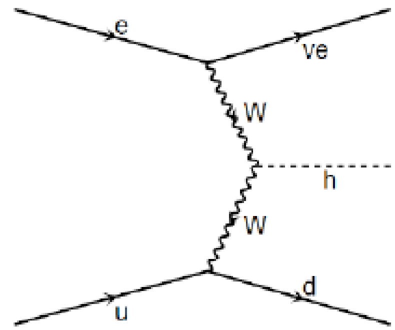
Stan Brodsky, SLAC

… some examples follow …

Higgs Production

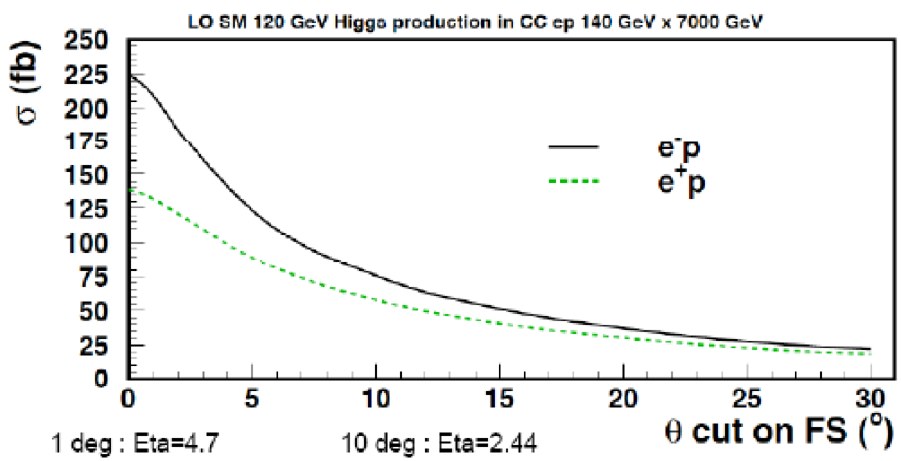




[U Klein, Kniehl, Perez, Khuze]

Sizeable CC (WW) x-section (NC factor ~5 smaller)

- Apply eta cuts on ALL final states

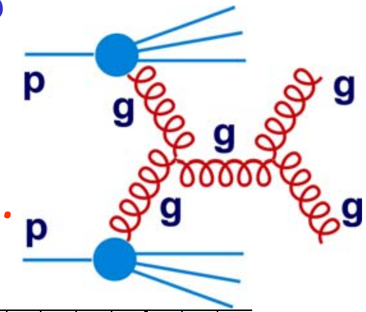


→ Novel production mechanism
→ Clean(ish) … H + j + p_t^{miss}
→ bbbar coupling to light H?

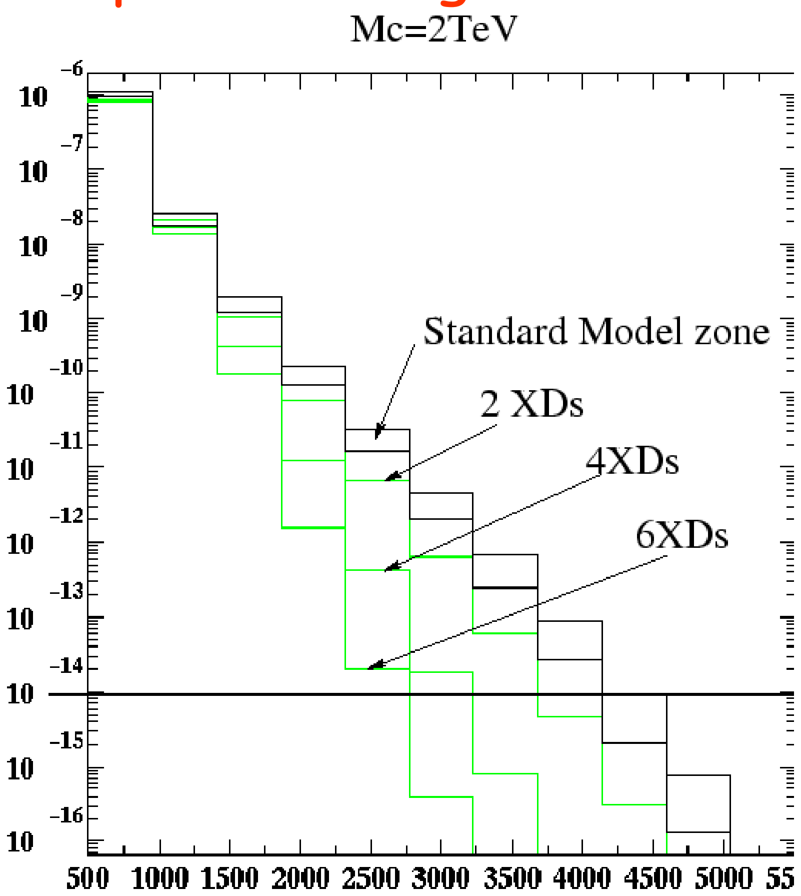
Acceptance is an issue …

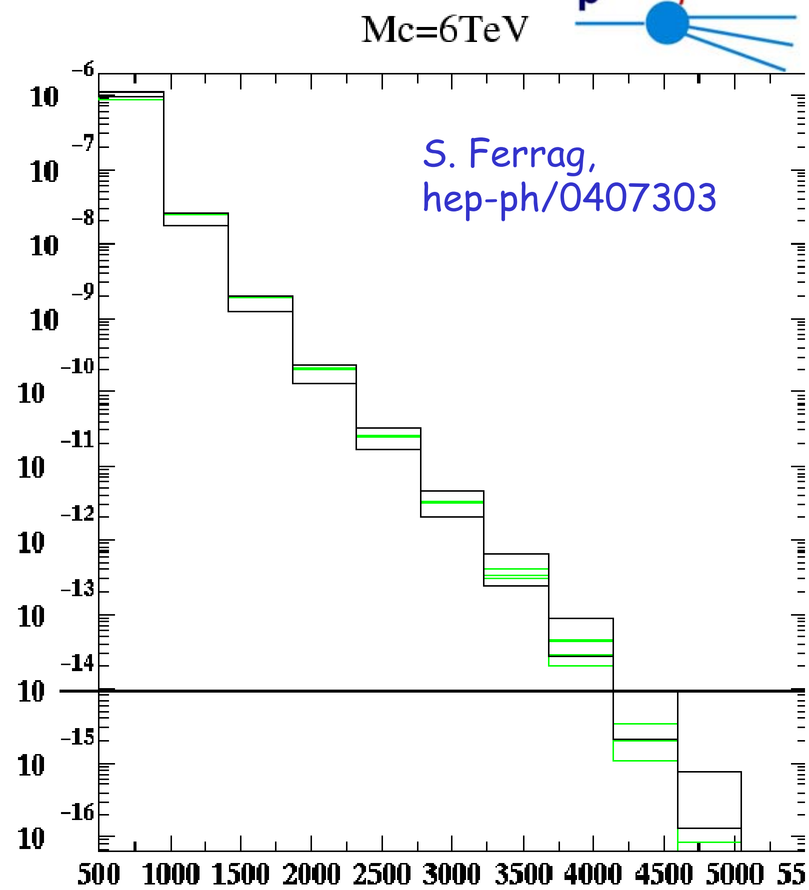
First background studies (jets in CC) underway …

High x Partons Limiting LHC Searches



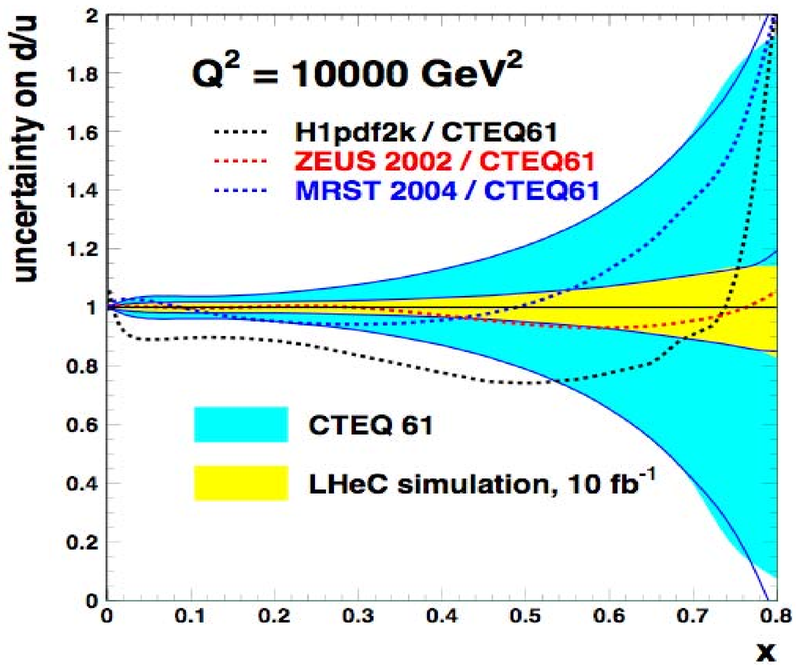
Some BSM scenarios give deviations in high mass dijet spectra … e.g. a model with extra dimensions …

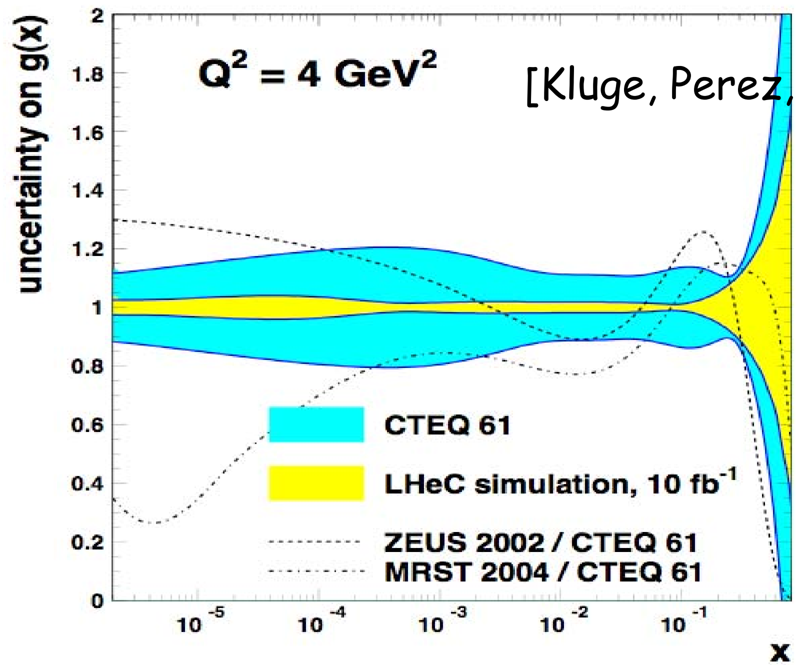




… in this example, high x PDF uncertainties reduce sensitivity to compactification scales from 6 TeV to 2 TeV for 2XDs

LHeC Impact on High x Partons and α_s





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

… full flavour decomposition possible

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

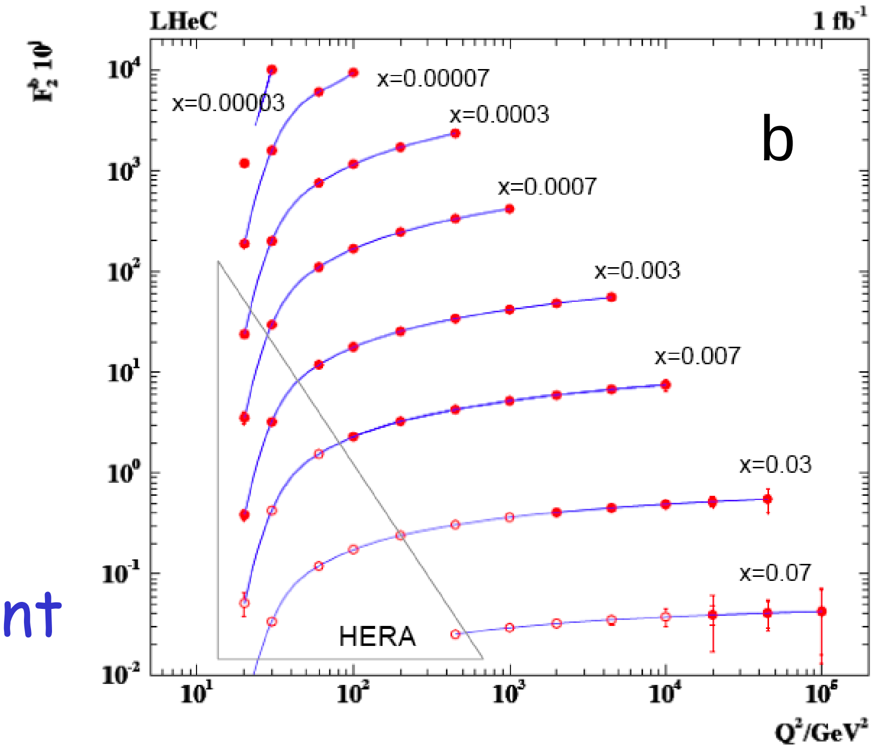
[Some of highest x improvement from param^n extrapolation]

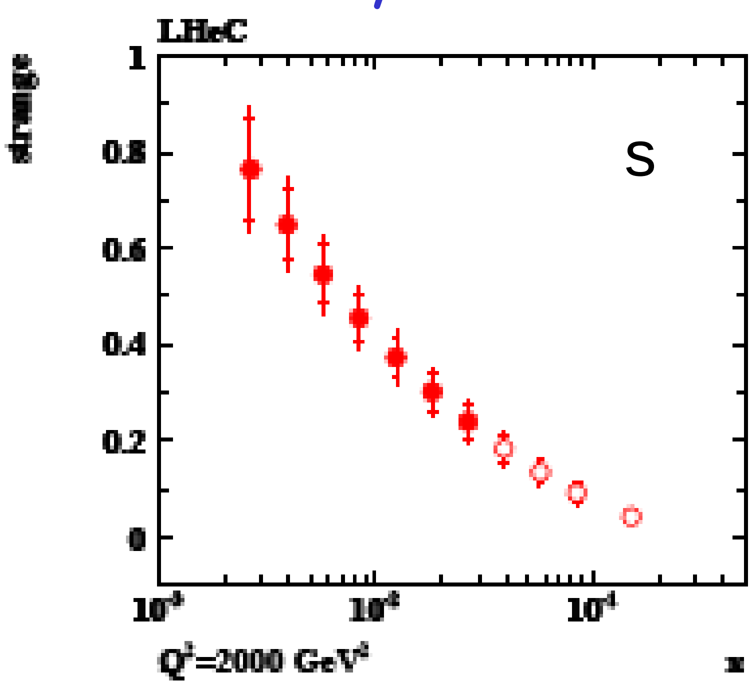
Flavour Decomposition

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?

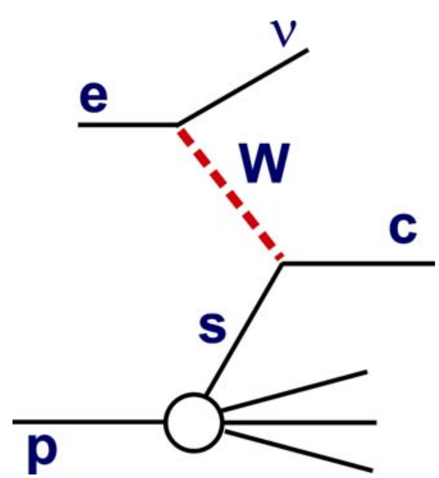




● LHeC 10° acceptance

○ LHEC 1° acceptance

[Mehta, Klein]

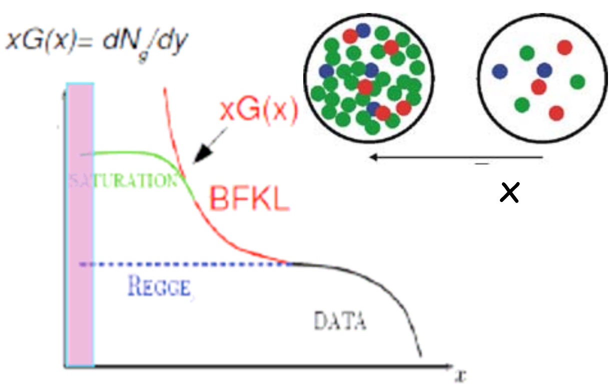


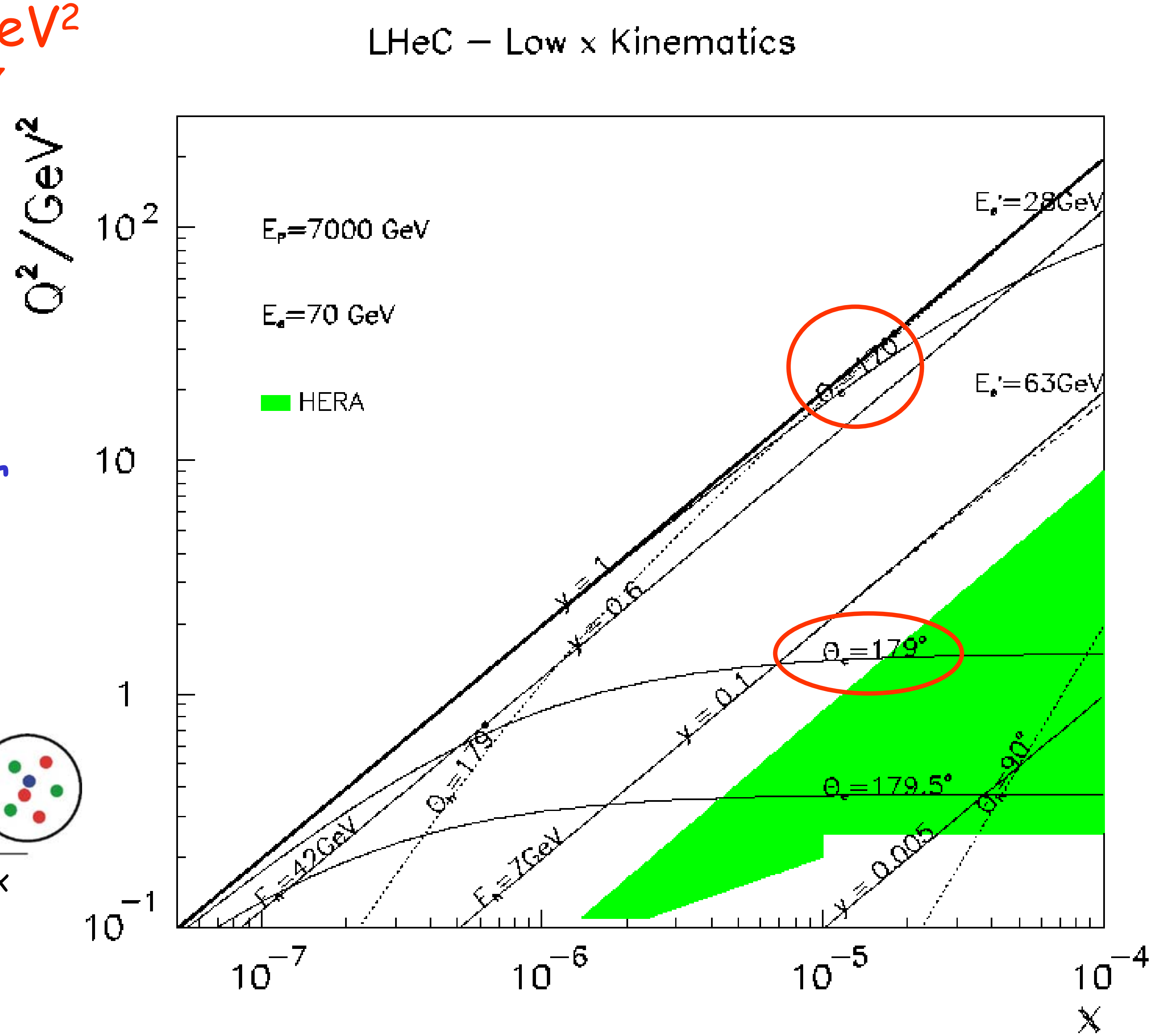
(Assumes 1 fb^{-1} and
- 50% beauty, 10% charm efficiency
- 1% uds → c mistag probability.
- 10% c → b mistag)

LHeC Kinematics for Low x Investigations

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

→ Without low β quads ~ 1 fb^{-1} / yr … definitive low x facility (parton saturation ?…)





More Low x Detector Considerations

• Low x studies require electron acceptance to 1° to beampipe

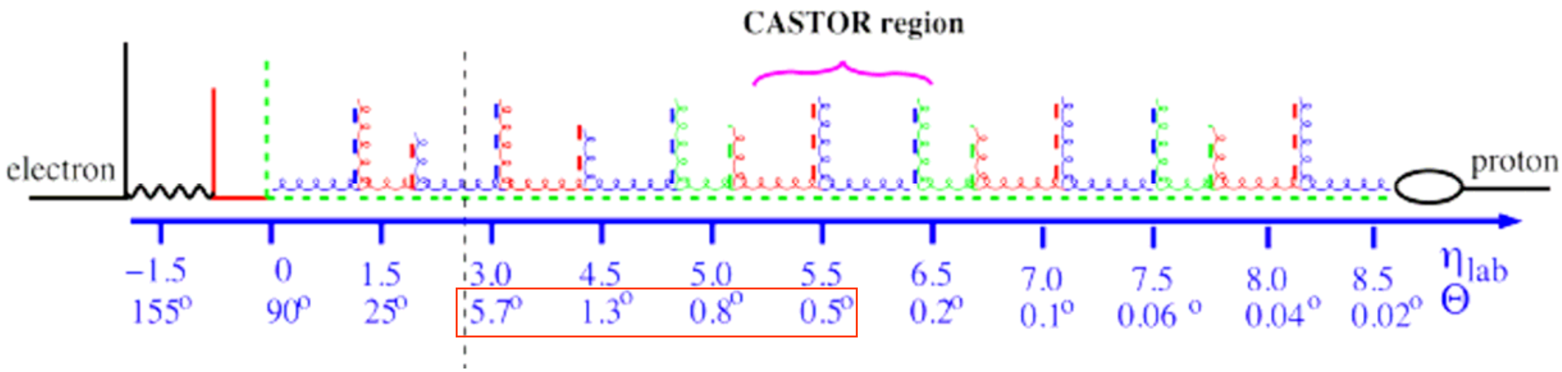
HERA	E_e=30GeV →	← E_p=920GeV
LHeC	E_e=70GeV	E_p=7000GeV

• Considerably more asymmetric beam energies than HERA!

- Hadronic final state at newly accessed lowest x values goes central or backward in the detector ☺
- At x values typical of HERA (but larger Q^2), hadronic final state is boosted more in the forward direction.

• Study of low x / Q^2 and of range overlapping with HERA, with sensitivity to energy flow in outgoing proton direction requires <u>forward acceptance for hadrons to ~1°</u>

Forward Instrumentation and Jets



[Jung]

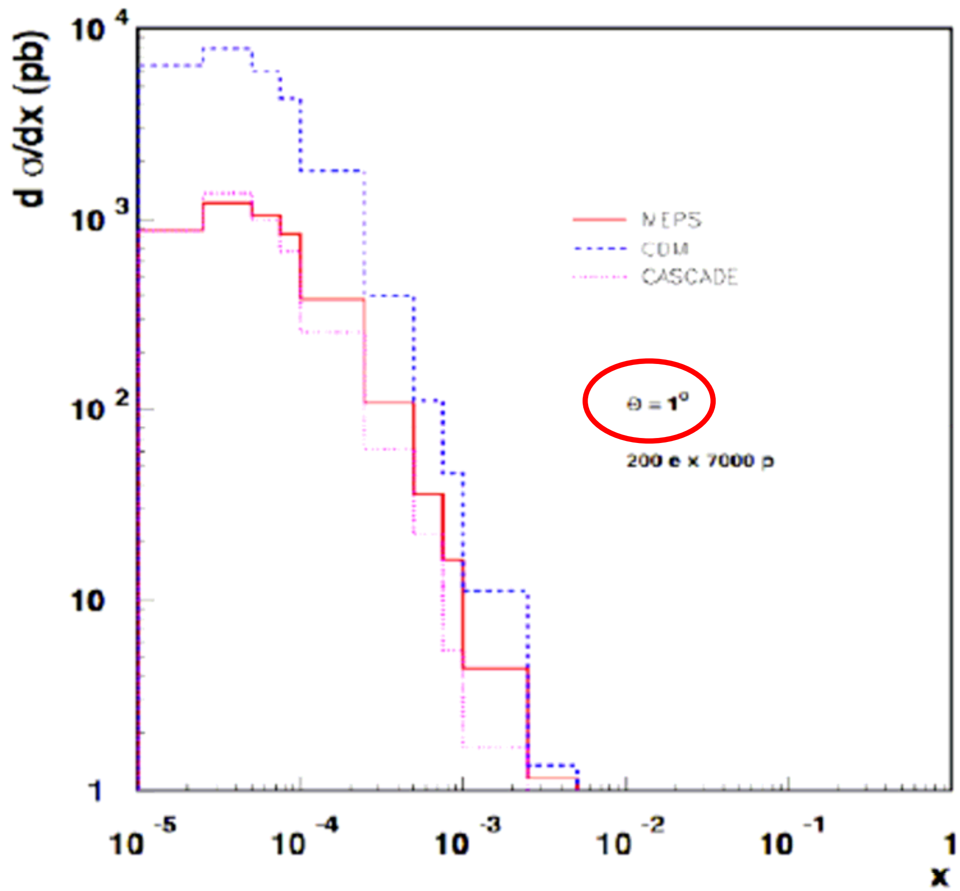
- DIS and forward jet:

$$x_{jet} > 0.03$$

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

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

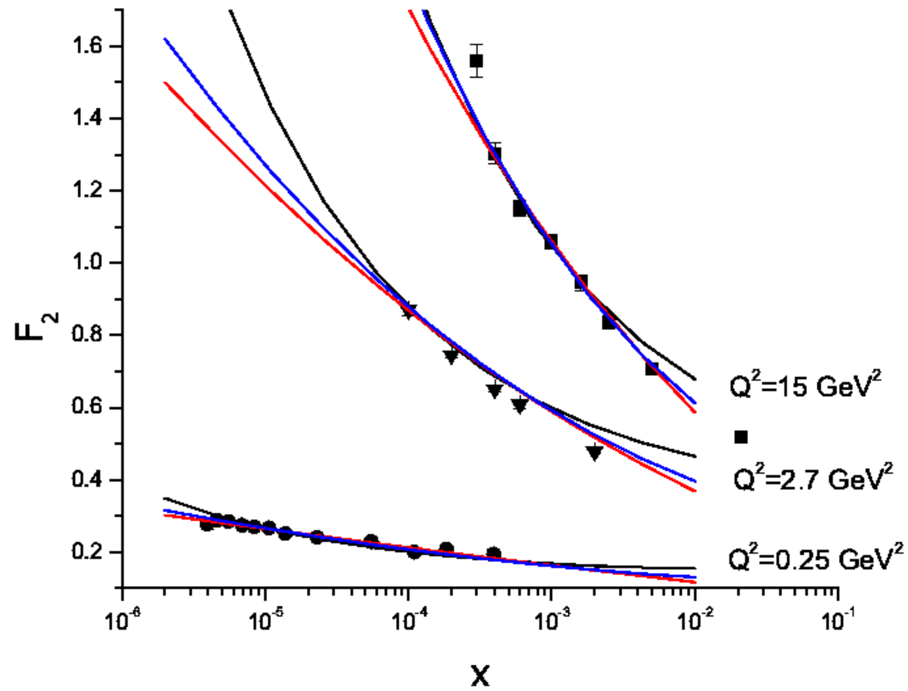
Similar conclusions for Δϕ decorrelations between jets



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>

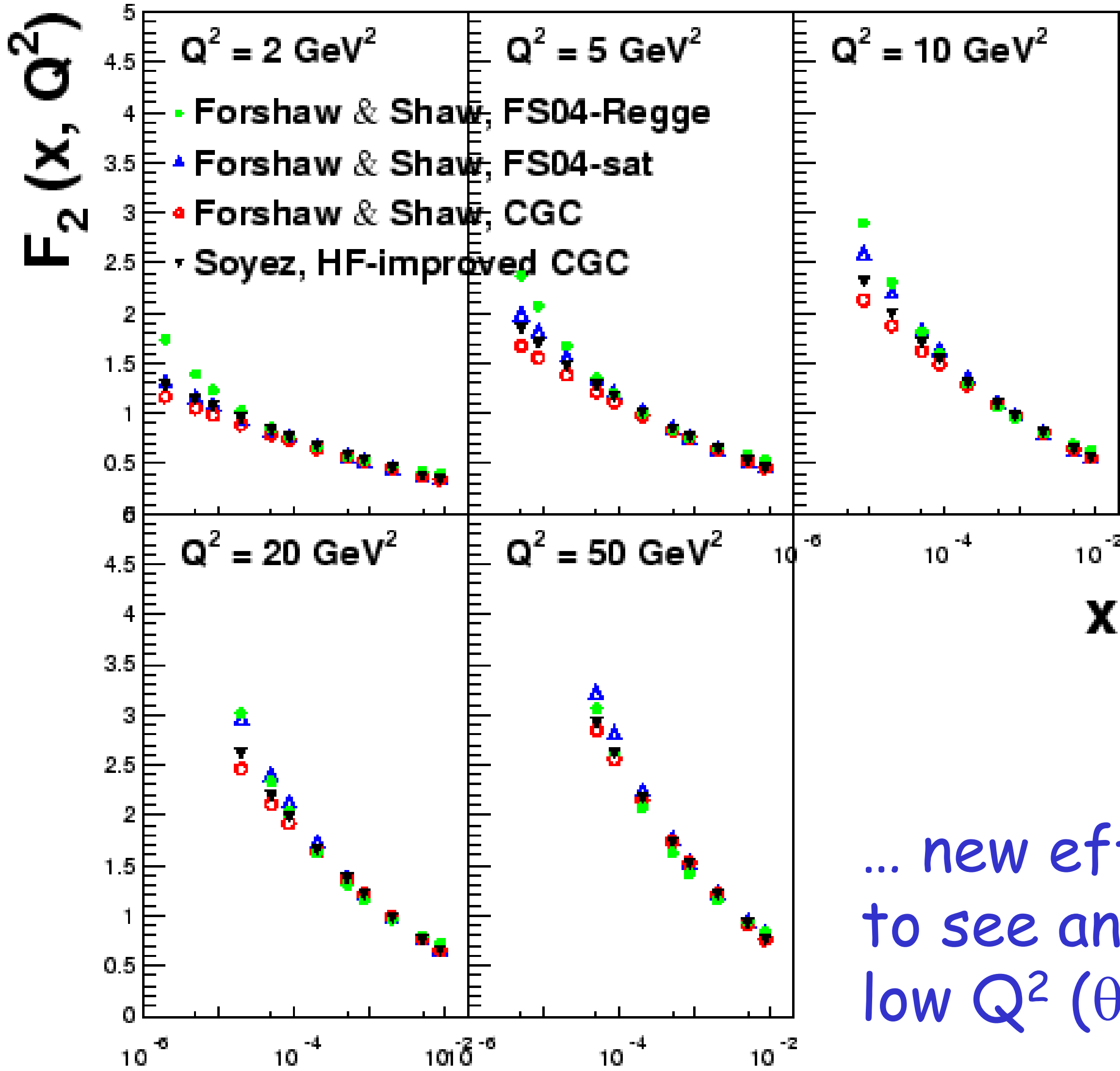
- All three models can describe data with $Q^2 > 1 GeV^2$, $x < 0.01$
- Only versions with saturation work for $0.045 < Q^2 < 1$ GeV^2

<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, $x > \sim 10^{-6}$

- 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 ($\theta \to 179°$) region …

FL Simulation

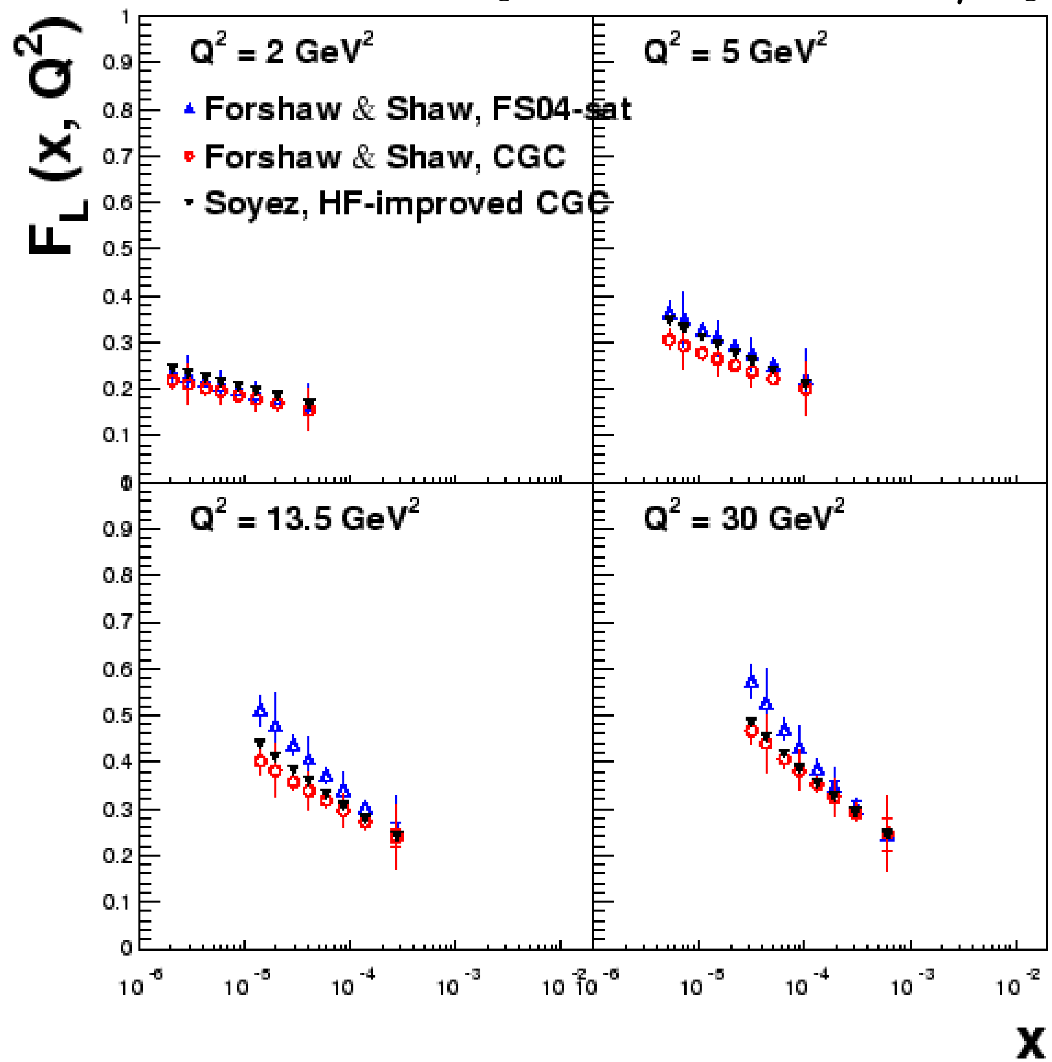
Vary proton beam energy as recently done at HERA ?...
→ example for 1 year ...

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

... sample lowest x data
Compared with 3 dipole
models including saturation ...

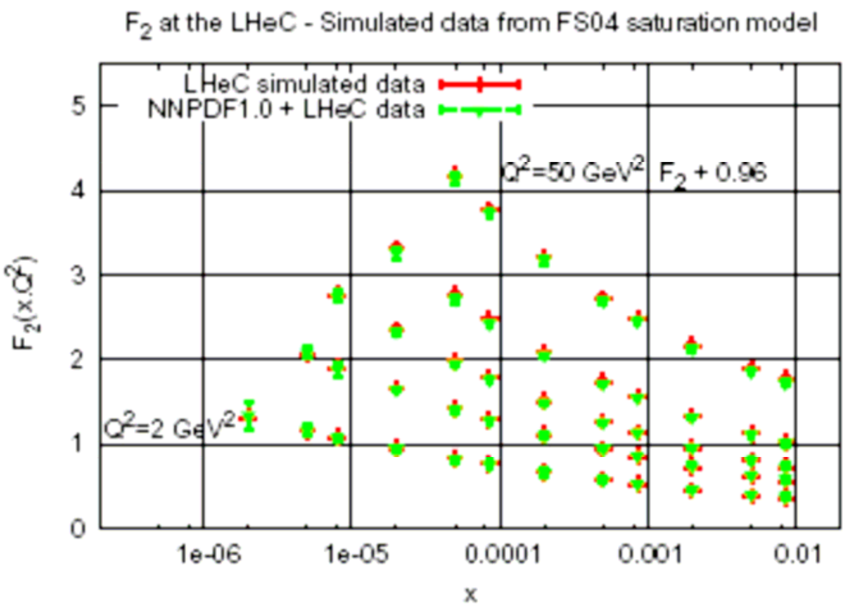
[Forshaw, Klein, PN, Soyez]

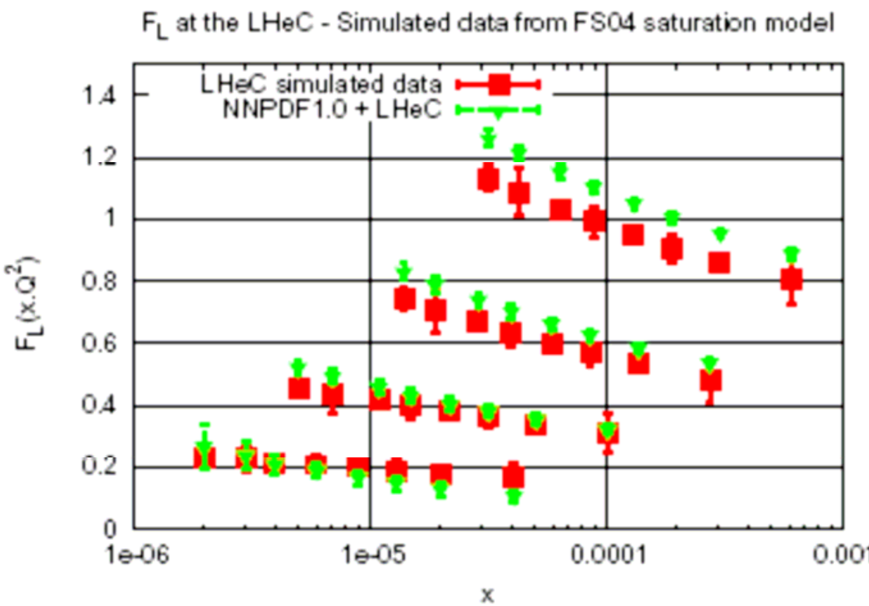


Can Parton Saturation be Established @ LHeC?

… effects may not be so large in ep → and may be hard to establish unambiguously with F_2 alone
… $A^{1/3}$ 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

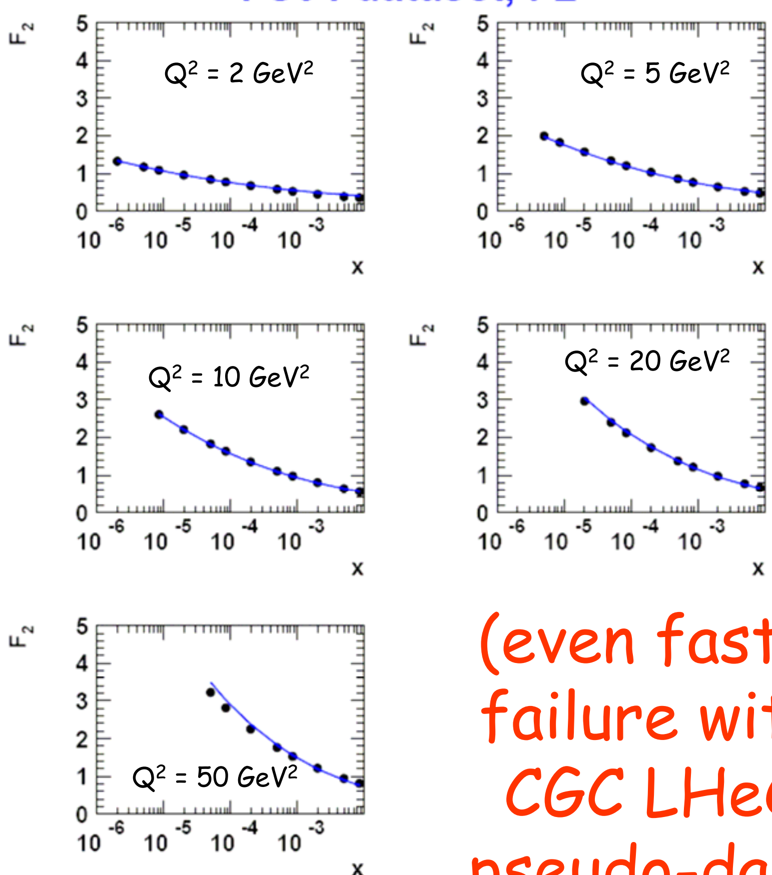
Can DGLAP adjust to fit LHeC sat models?

[Forshaw, Klein, PN, Perez]

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

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

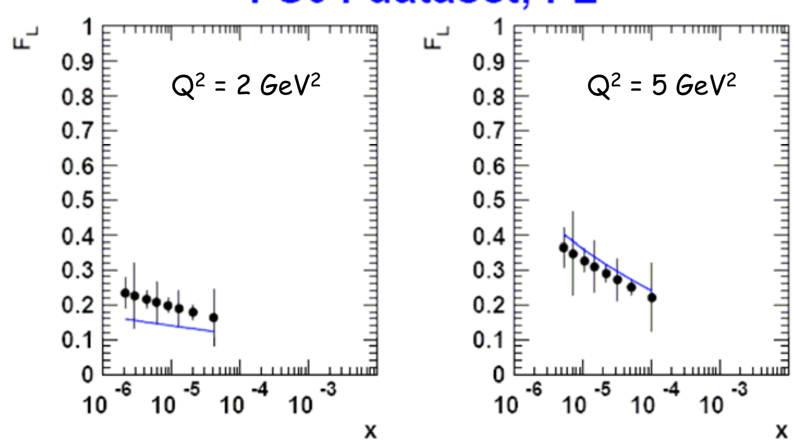
FS04 dataset, F2



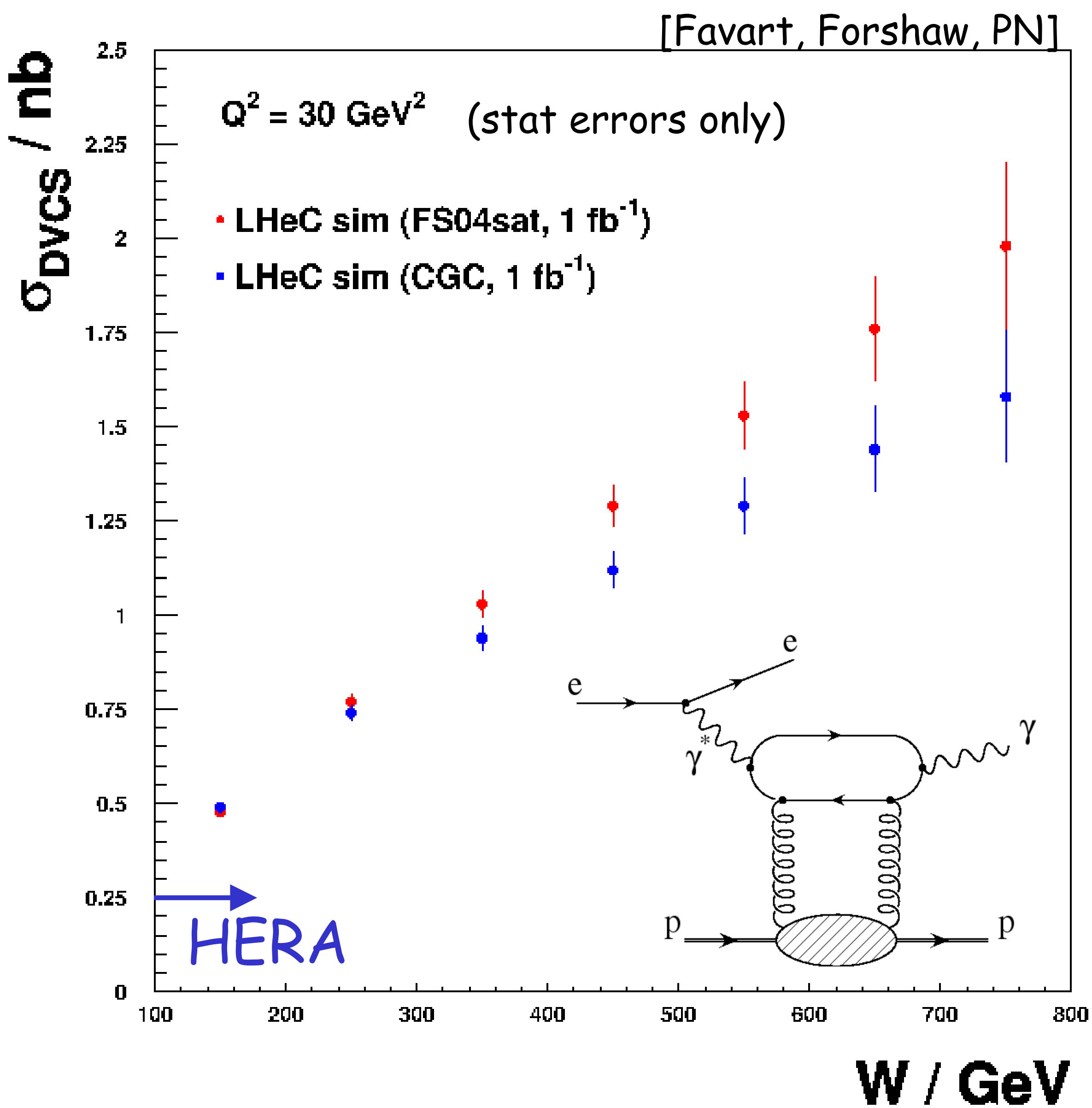
(even faster failure with CGC LHeC pseudo-data)

- 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

FS04 dataset, FL



DVCS at LHeC



(1° acceptance)

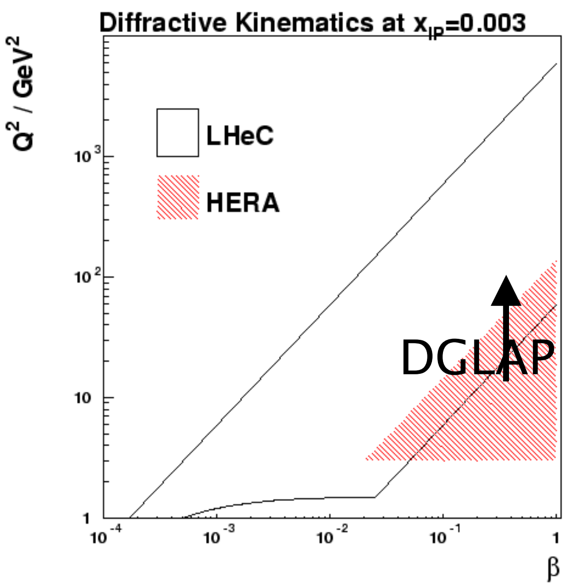
Statistical precision with 1fb^{-1} ~ 2-11%

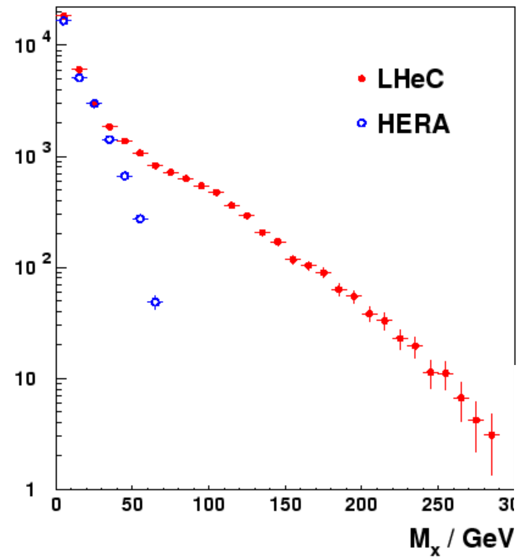
With F_2, F_L, could help establish saturation and distinguish between different models which contain it?

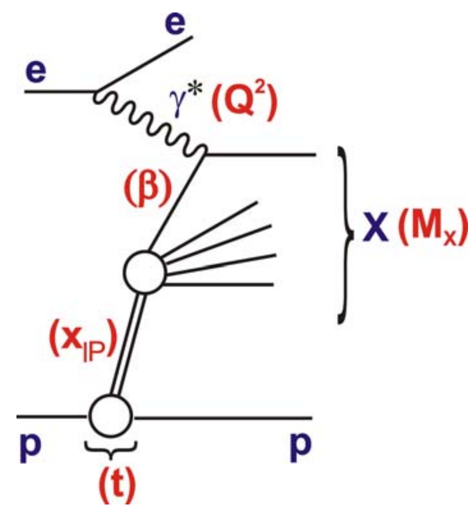
Cleaner interpretation in terms of GPDs at larger LHeC Q^2 values

VMs similar story?...
No work done so far ☹

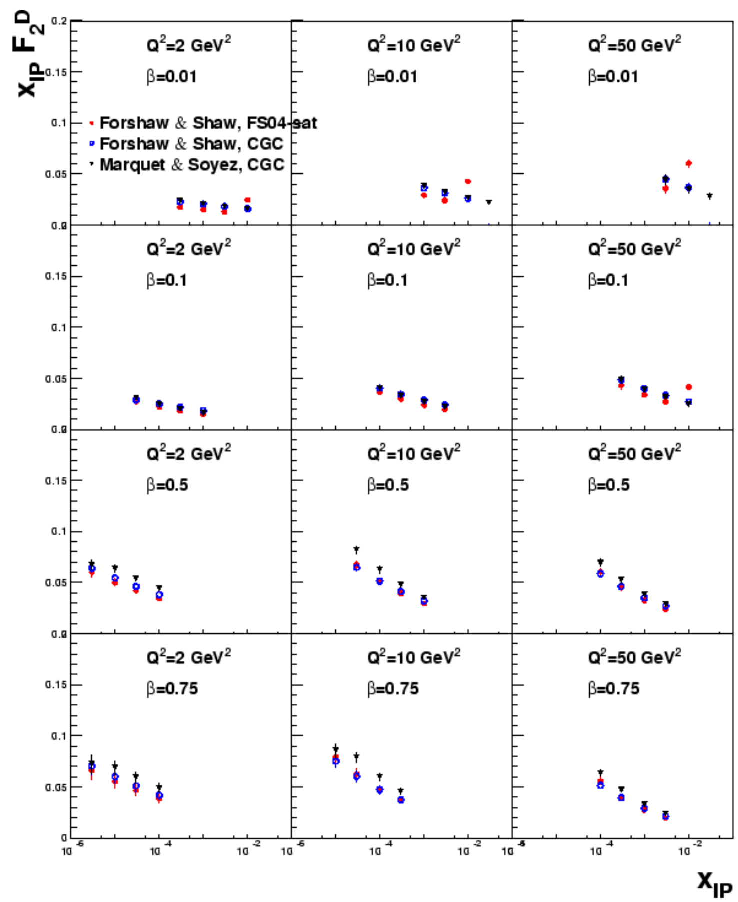
(Semi)-Inclusive Diffractive DIS







[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

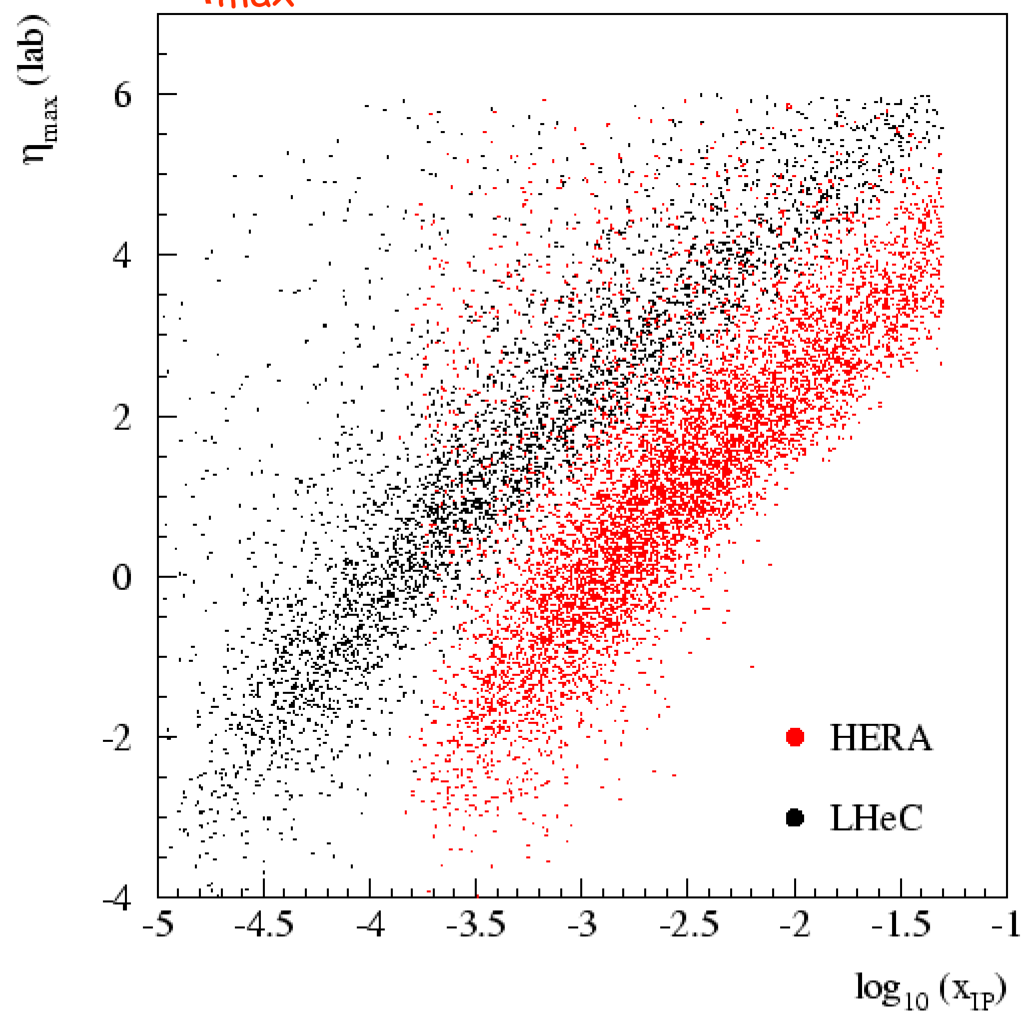
Forward and Diffractive Detectors

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

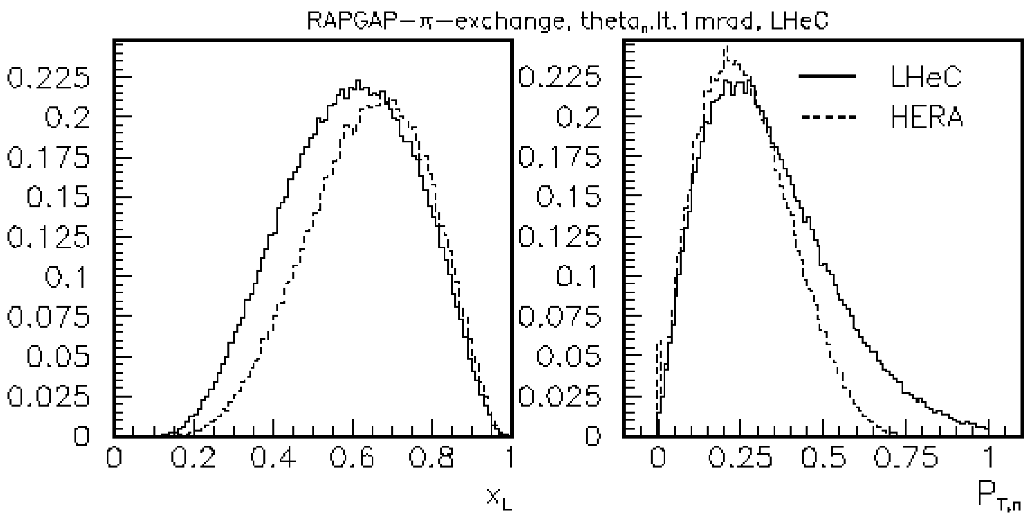
- Reaching $x_{IP} = 1 - E_p'/E_p = 0.01$ in diffraction with rapidity gap method requires η_{max} cut around 5 …forward instrumentation essential!

- 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 …

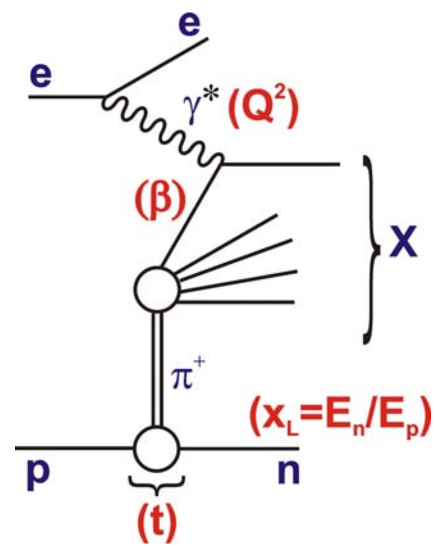


π Structure with Leading Neutrons



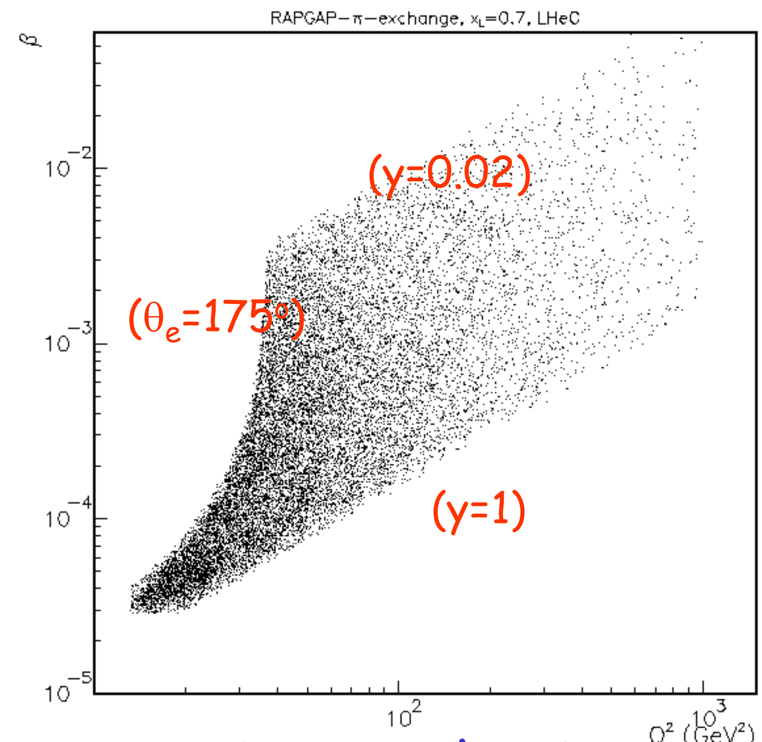
[Bunyatyan]

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



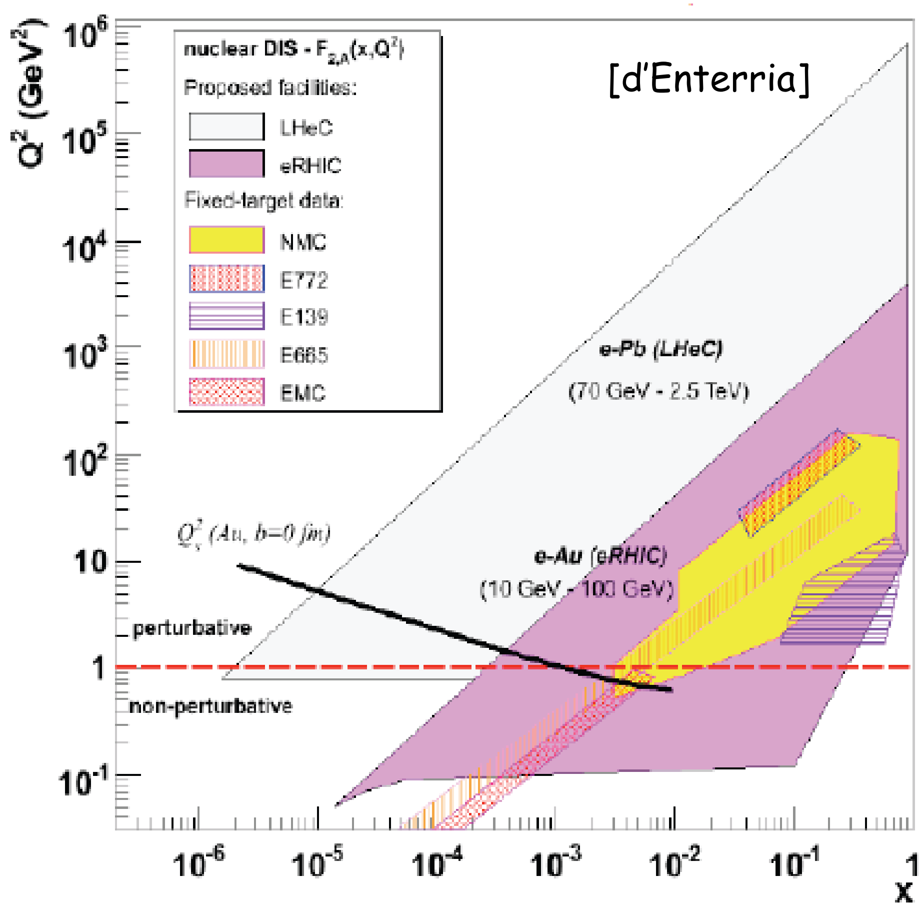
• With θ_n < 1 mrad, similar x_L and p_t ranges to HERA (a bit more p_t lever-arm for π flux).

• 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 …

With AA at LHC, LHeC is also an eA Collider



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

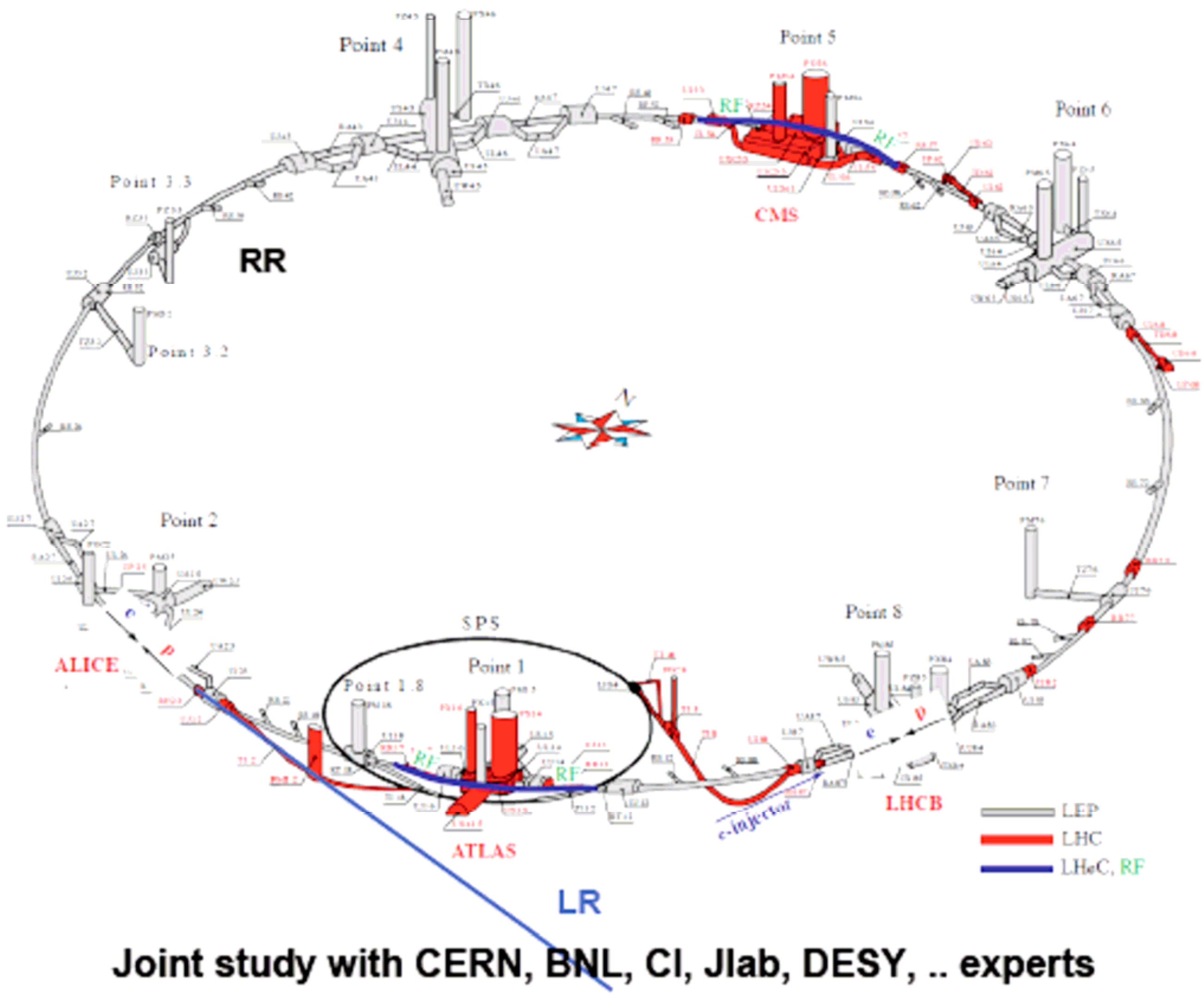
- LHeC extends kinematic range
- by 3-4 orders of magnitude

… opportunity to extract and understand nuclear parton densities in detail …

→ ~$A^{1/3}$ 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

Machine Considerations and Studies

high $E_{e,p,A}$, $e^{\pm}$ polarised, high Luminosity



Joint study with CERN, BNL, CI, Jlab, DESY, .. experts

Max Klein LHeC ICFA08

generalities

simultaneous ep and pp

power limit set to 100MW

IR at 2 or 8

p/A:

SLHC - high intensity p
(LPA/50ns or ESP/25ns)

Ions: via PS2
new source for deuterons

e Ring:

bypasses: 1 and 5
[use also for rf]

injector: SPL, or dedicated

e LINAC:

limited to ~6km (Rhone)
for IP2, longer for IP8
CLIC/ILC tunnel.?

Accelerator Group Summary

[Bruening]

"The discussions at this workshop showed that both options can in principle provide collisions at the TeV scale (e.g. collisions between 60 GeV lepton and 7 TeV proton beams) with a luminosity of $L = 10^{33}$ cm^{-2} sec^{-2} in a parasitic mode to the nominal p-p program."

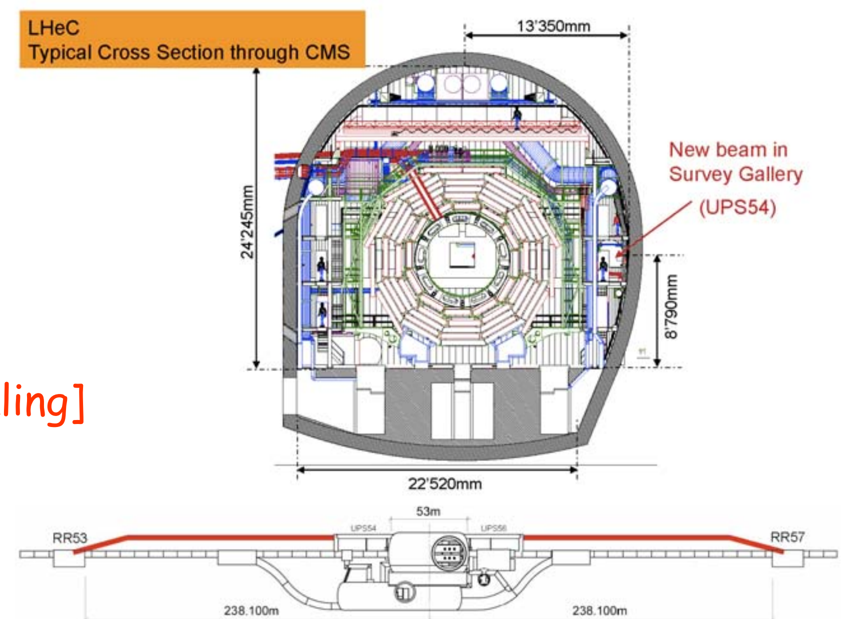
"The devil lies often in the details and insurmountable problems might only become visible during detailed studies."

➔ "Need to sketch both options for the LHeC in the conceptual design report"

Ring-Ring

"We have a lot of experience with the design of such a machine (LEP, HERA) and sophisticated tools are at hand for design & performance analysis" [Jowett, Kling]

"By-passes require a minimum of 1.5km tunnelling in the LHC" [Burkhard]



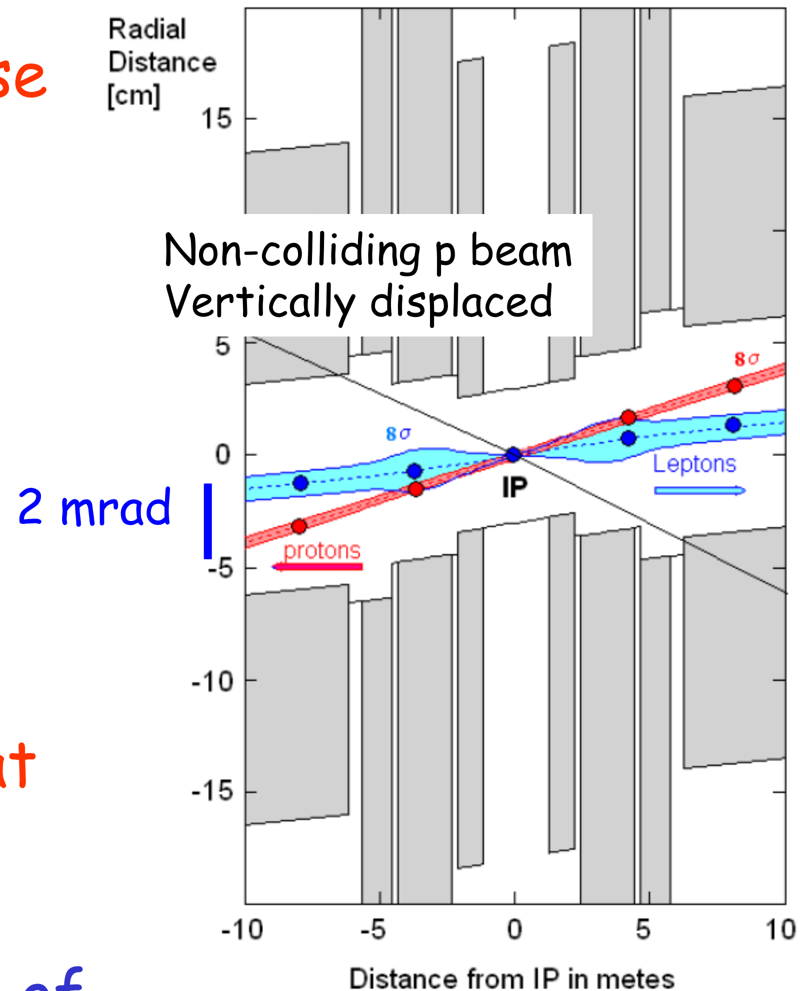
from J.A. Osborne CERN/TS

Ring-Ring Interaction Region Overview

[Willeke]

- LHC fixes p beam parameters
- 70 GeV electron beam, (compromise energy v synchrotron → 50 MW)
- Match e & p beam shapes, sizes
- Fast separation of beams with tolerable synchrotron power requires finite crossing angle
- 2 mrad angle gives 8σ separation at first parasitic crossing

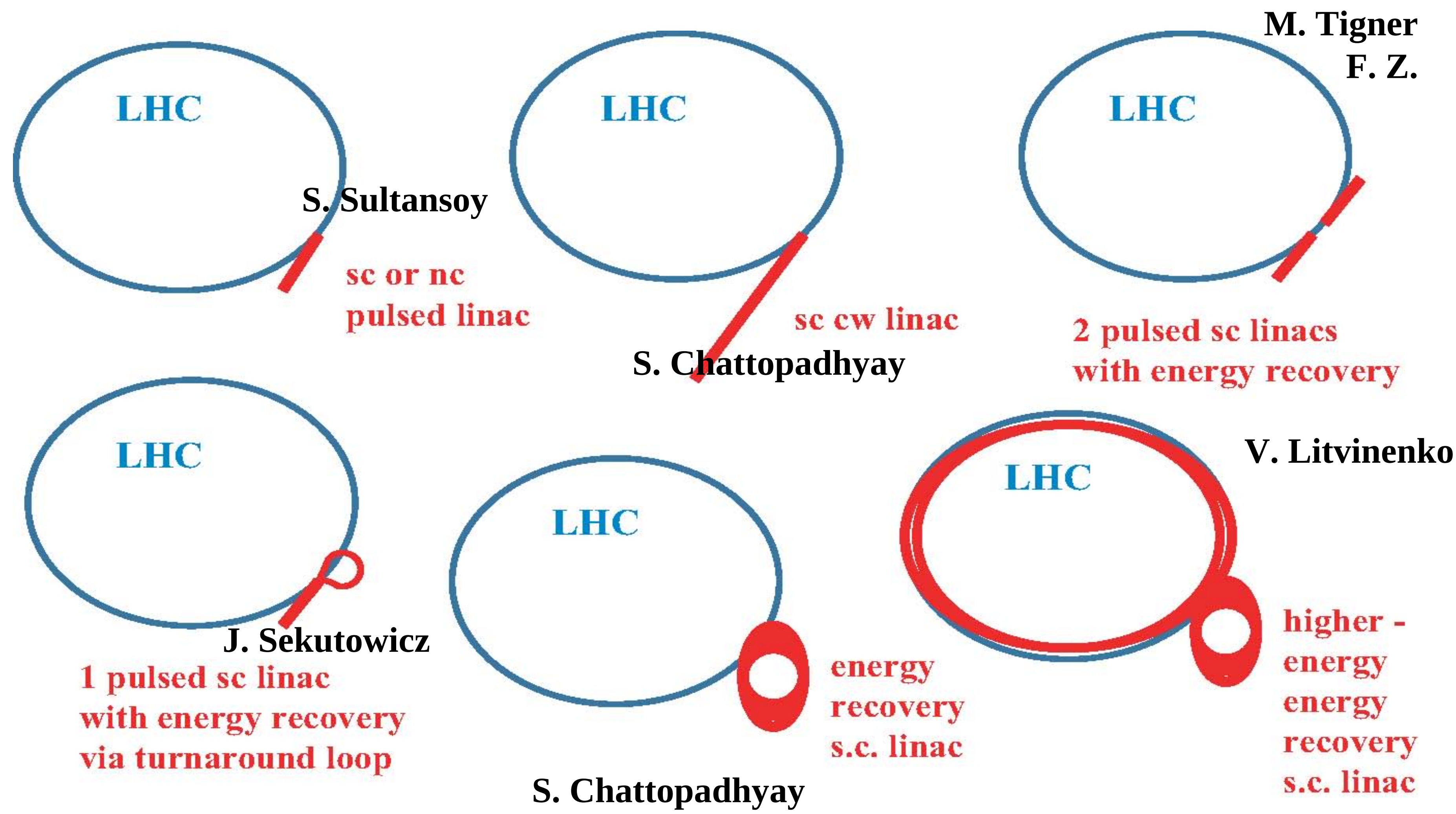
Top view



… **Linac-Ring** could get around some of this … and focusing quadrupoles could be further from IP?

Thoughts on Linac-Ring Layout Designs

[Zimmermann]

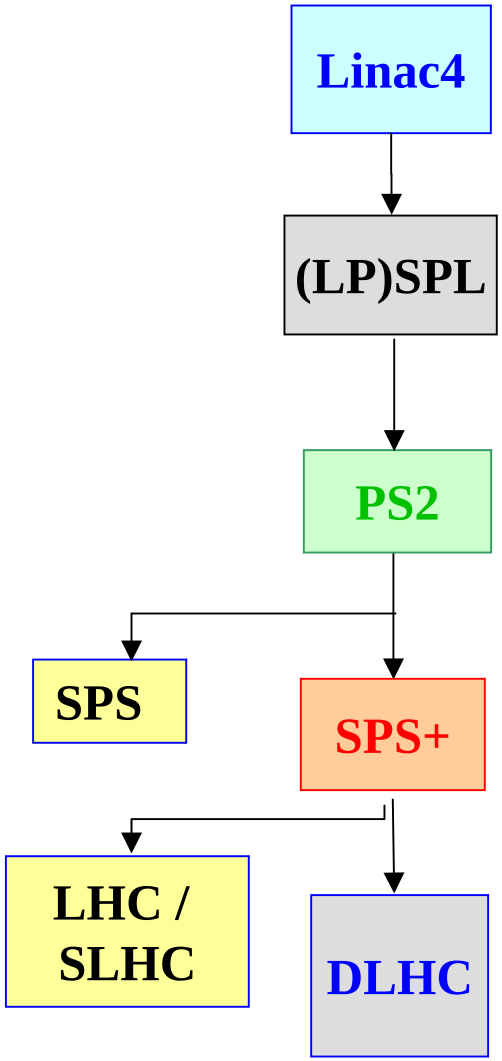


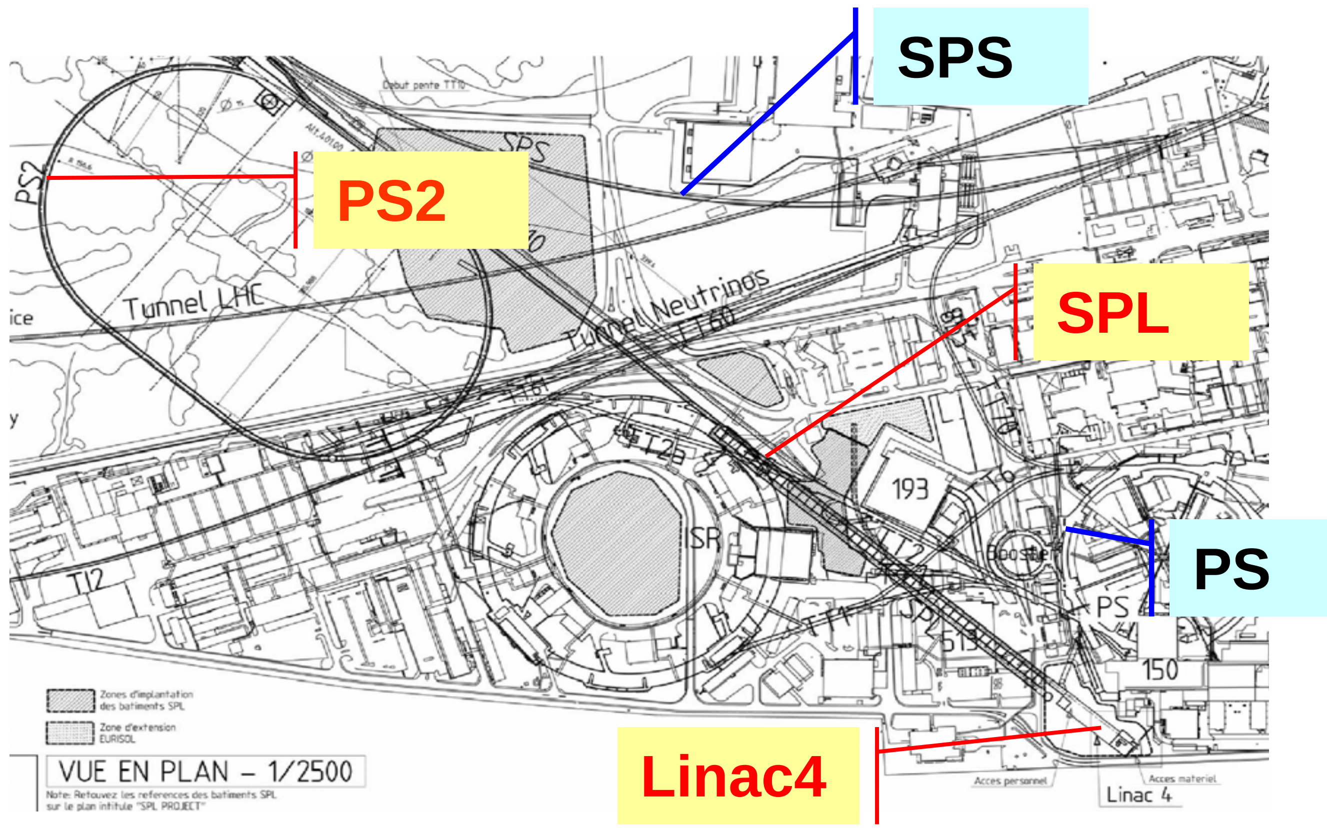
… lots of R&D required …

Another idea: electrons in the SPL?

SPL (Superconducting Proton Linac) is part of proposed CERN p-accelerator upgrade programme.

… could be used to provide up to **20 GeV electrons** (4 passes of 5 GeV)





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

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)

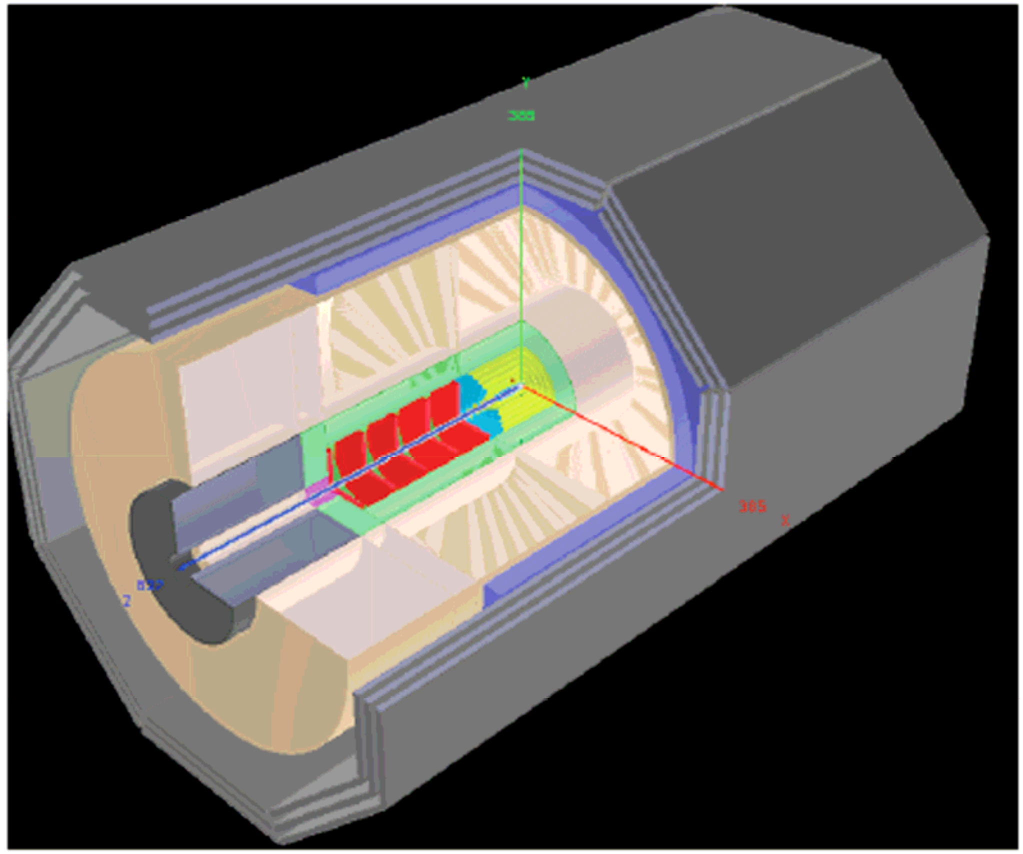
Fwd Spectrometer
(down to 1°)

Tracker
Calice (W/Si)
FwdHadrCalo

Bwd Spectrometer
(down to 179°)

Tracker
Spacal (elm, hadr)

L1 Detector: version for low x Physics



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

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)

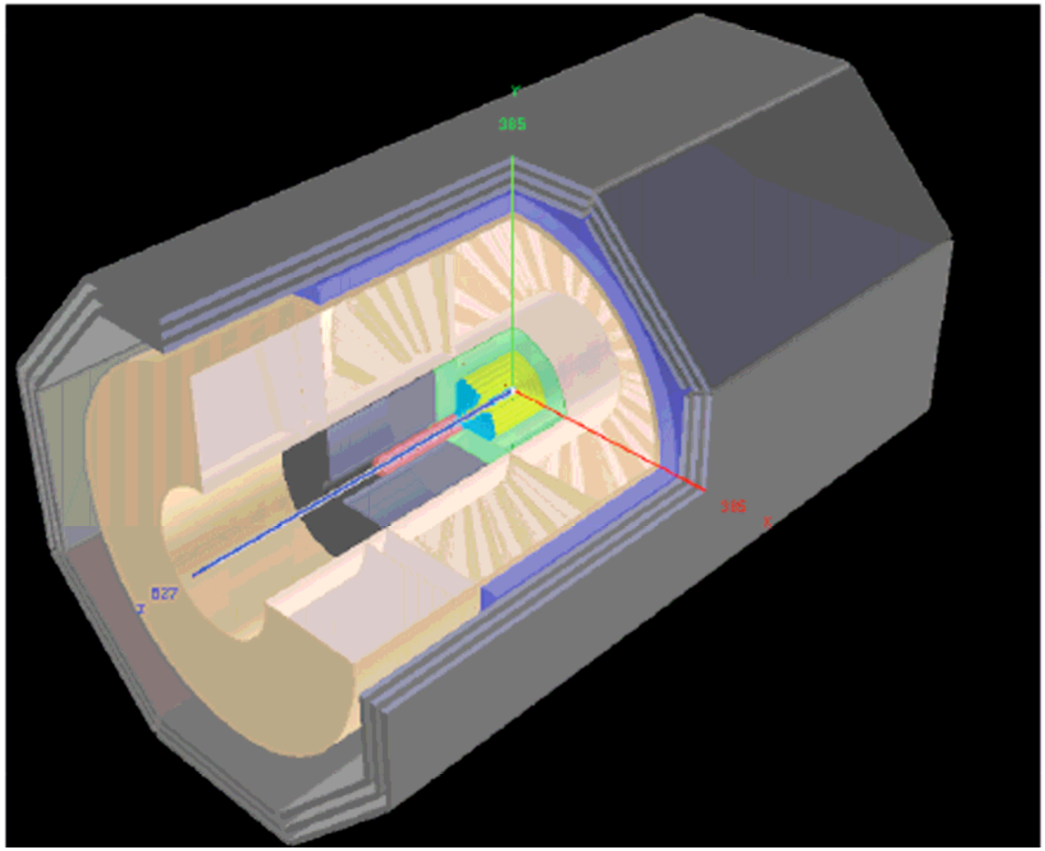
Fwd Calorimeter
(down to 10°)

Lepton low β magnets
FwdHadrCalo

Bwd Spectrometer
(down to 170°)

Lepton low β magnets
Spacal (elm, hadr)

L1 Detector: version for hiQ^2 Physics

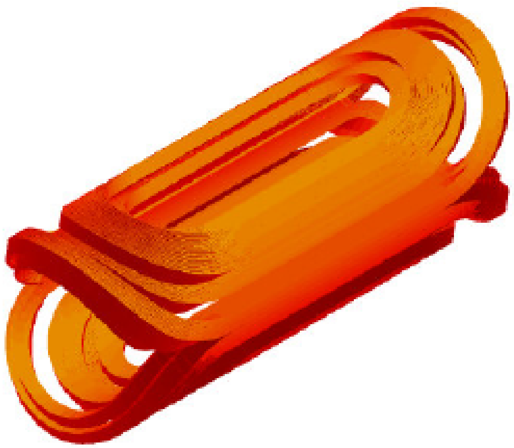


→ 2 interaction points / experiments?
→ 2 phases of single experiment (a la HERA)?
→ Other ideas

Developing a Combined Function "Magcal"?

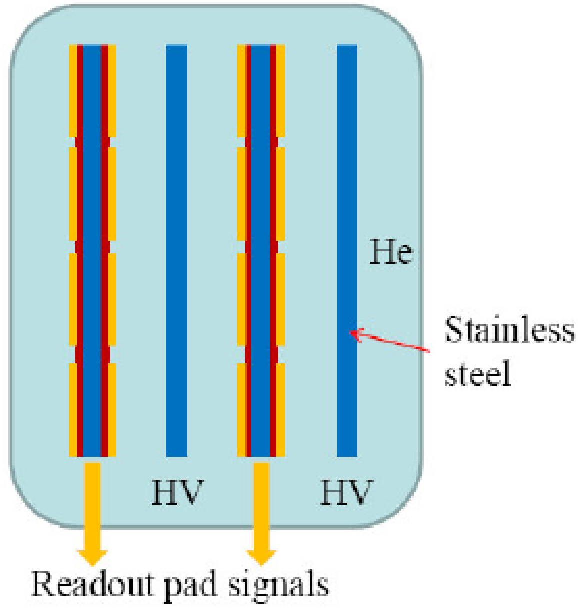
[Greenshaw]

- 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 scintilation of liquid He to get signal?...

... Calo is all edges!...

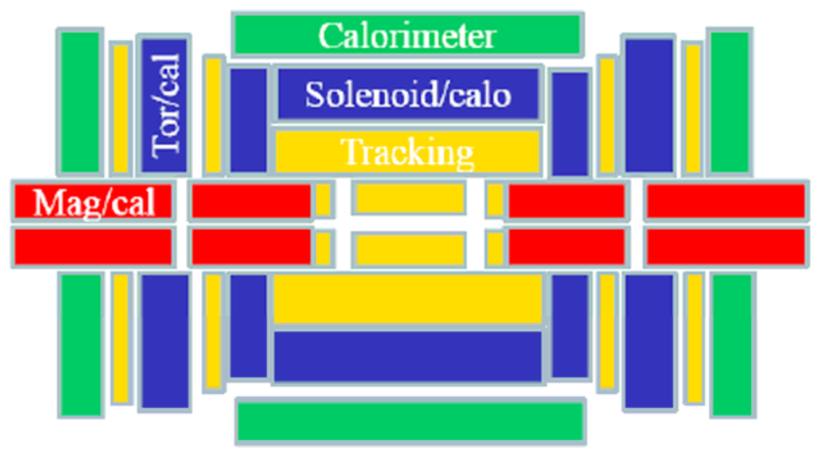
→ What sort of resolution is achievable?

→What is influence on final beam focus?

→ ...?

... also potentially interesting for SLHC 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

- First ECFA/CERN workshop successfully gathered accelerator, theory & experimental colleagues
  - → First debates on machine and detector layout
  - → First (often crude) tasters of physics
  - → Many uncovered topics (eA, VM, pots, γp …)

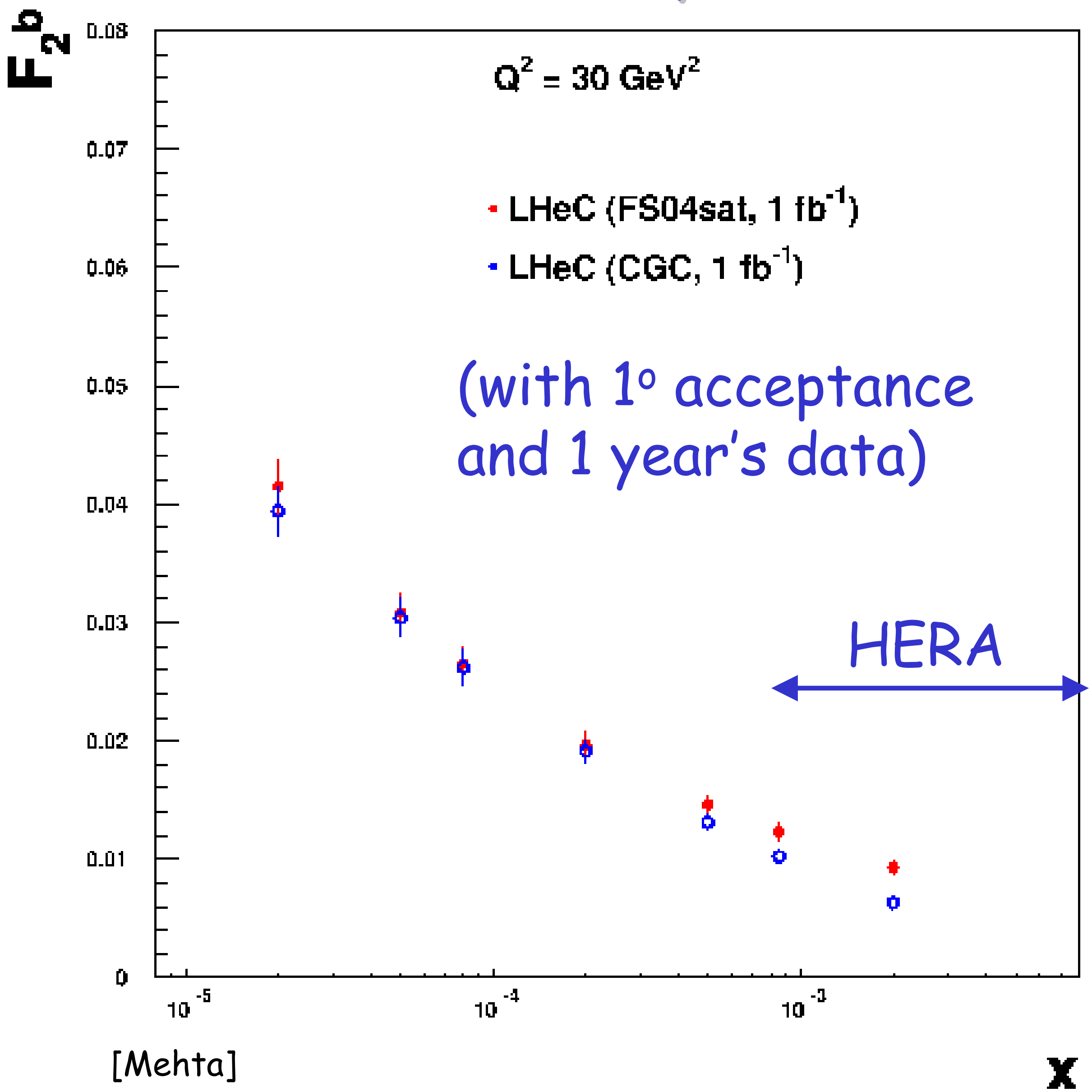
- Further meetings planned for April '09 and September '09
  - → Conceptual Design Report by early 2010
  - → Input to CERN strategy document mid 2010
  - → UK seedcorn funding request in near future

- All ideas and invovlement welcome!

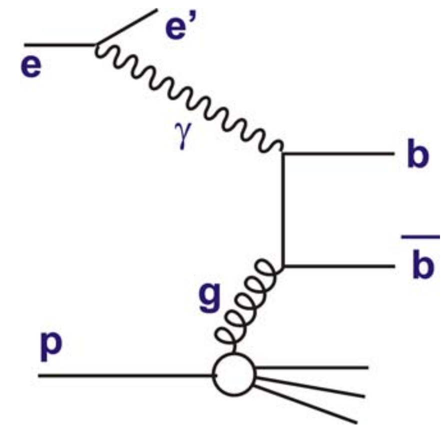
[More at www.lhec.org.uk]

Back-Ups Follow

Jets and Heavy Flavours



[Mehta]



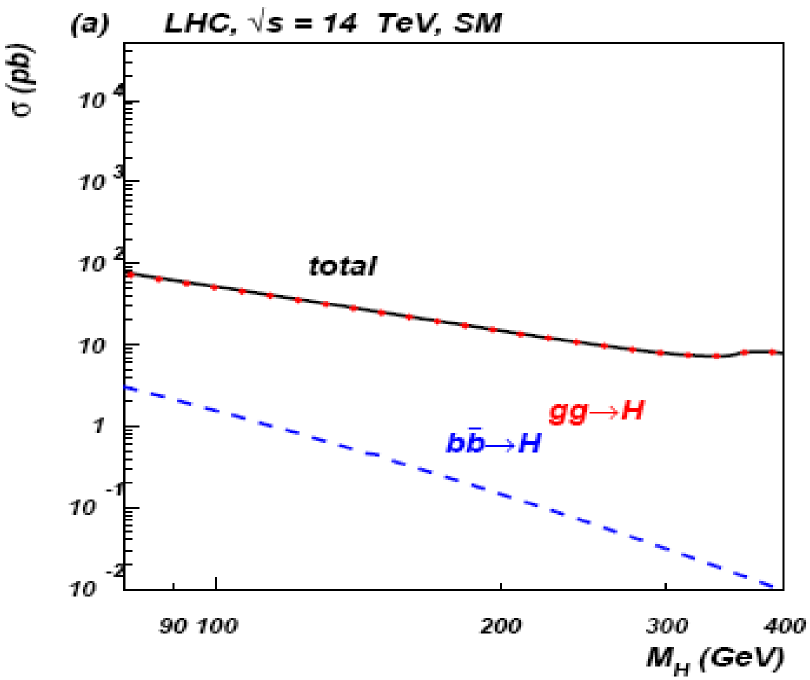
Constrain gluon (at Remarkably low x!) through jets and heavy flavour measurements

e.g. F_2^b to a few % constraining gluon down to x ~ 2.10^{-5}.

Heavy Quarks: HERA → LHC

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

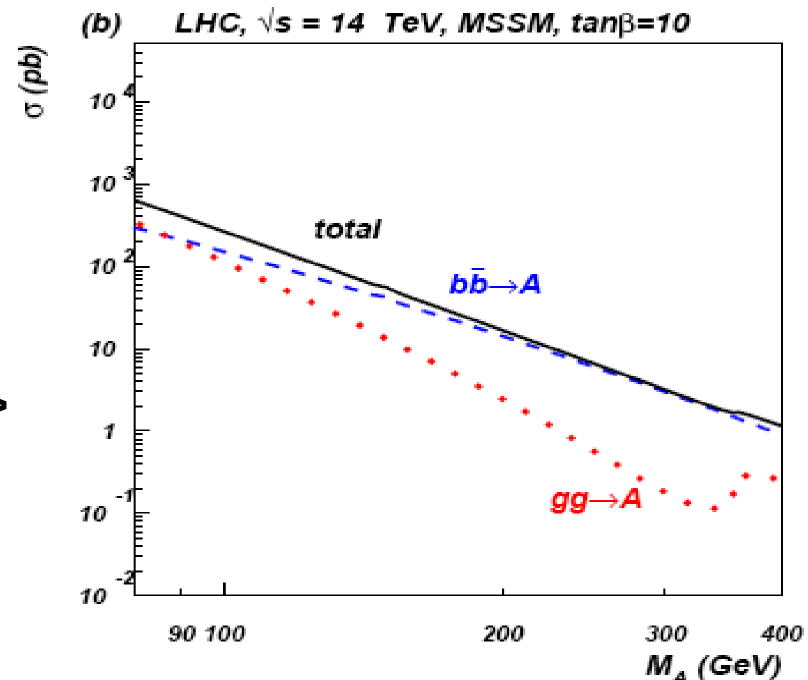
• Crucial for understanding LHC initial state for new processes (e.g. bbbar->H) and backgrounds.



Higgs

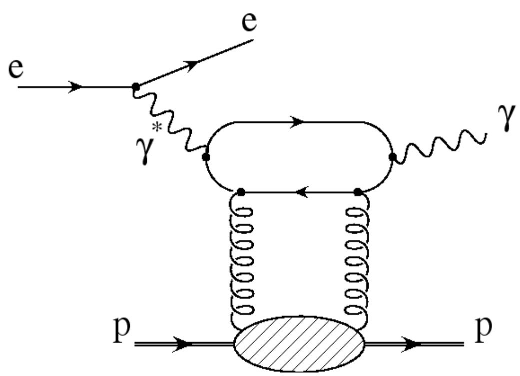
<-SM

MSSM->



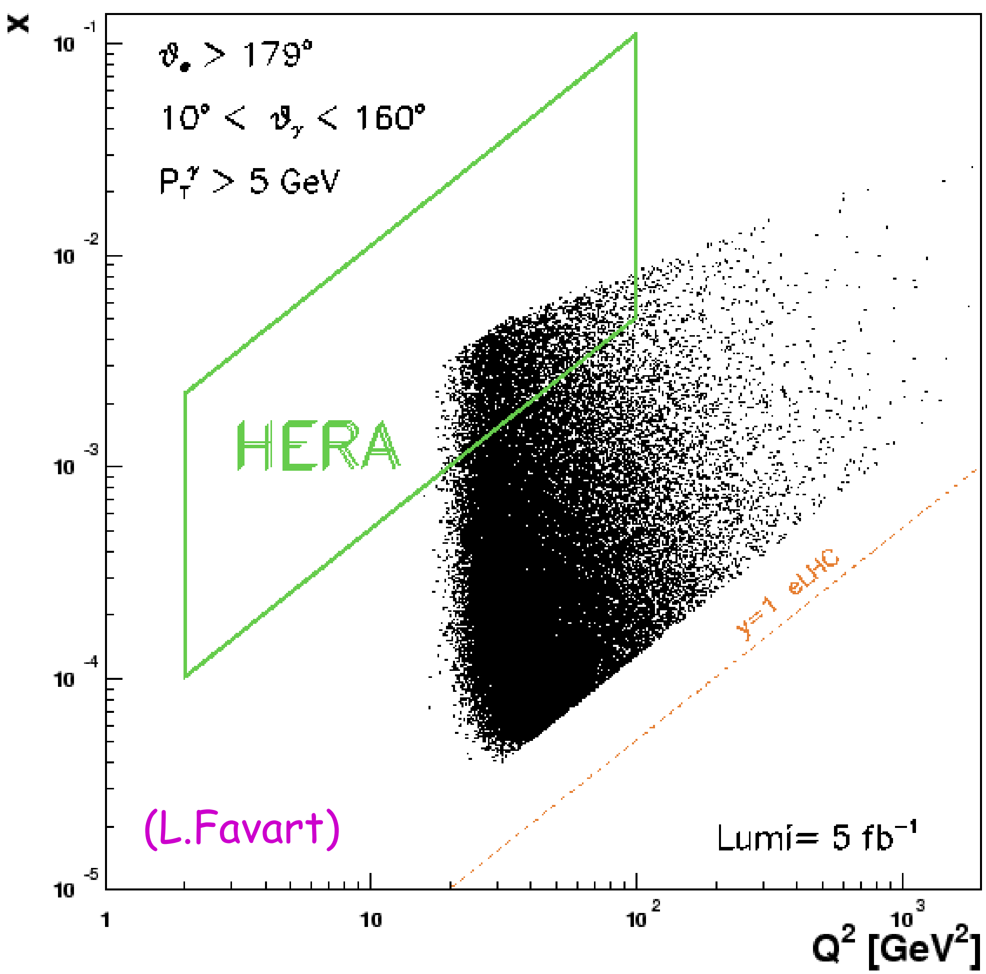
• LHC predictions rely strongly on extrapolations and pQCD (e.g. CTEQ: 7% effect on W,Z rates varying HF treatment).

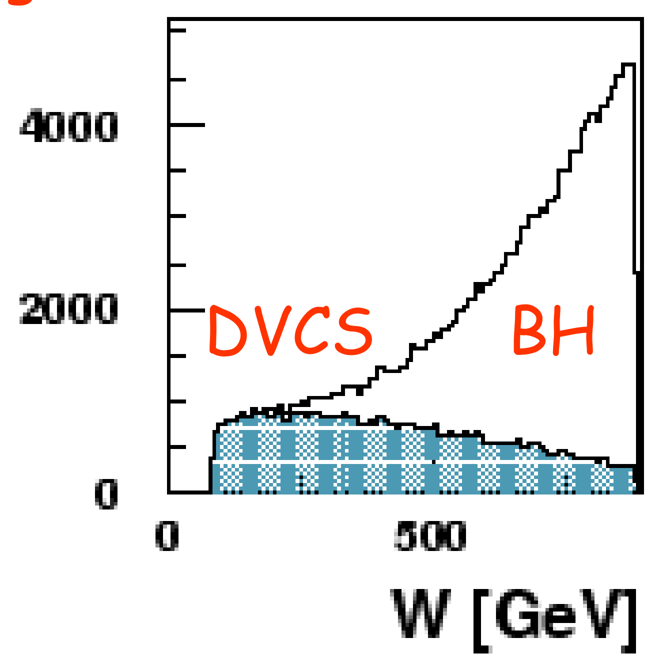
DVCS Measurement



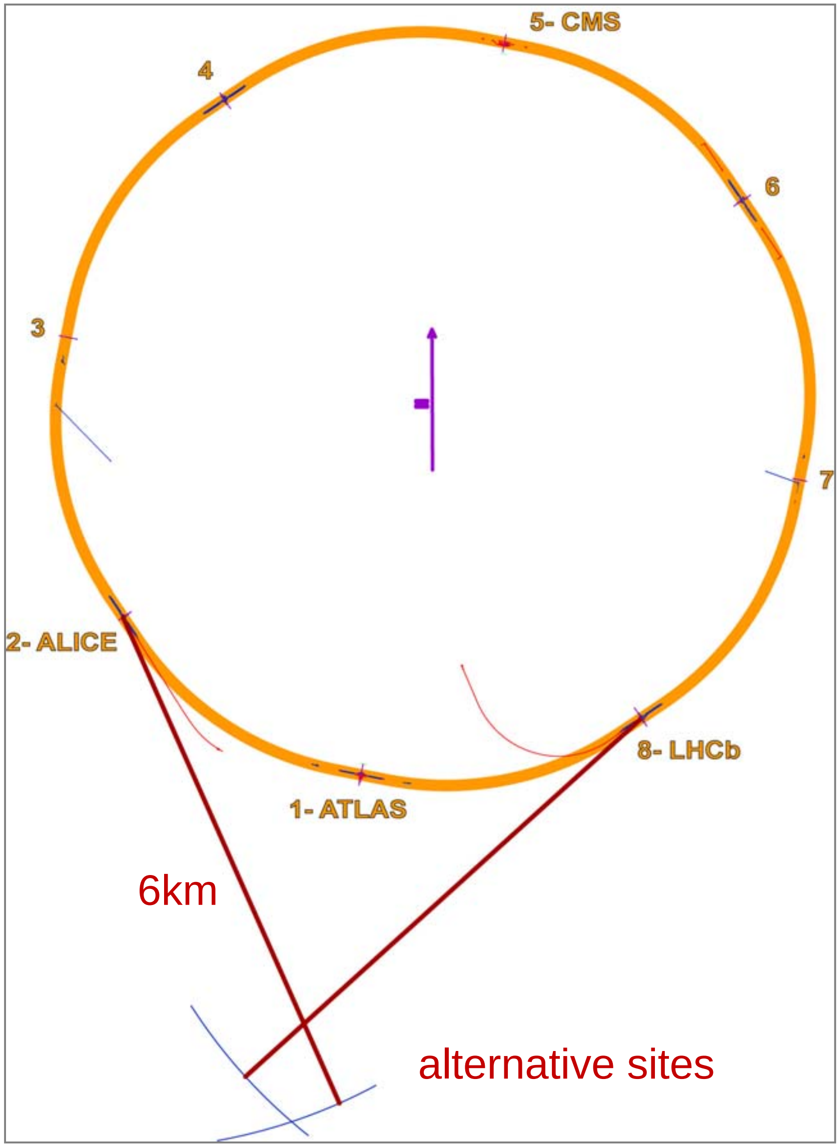
… the classic approach to `generalised parton densities' (GPDs)

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





Linac-Ring Design



- 140 GeV electron beam at 23 MV/m is 6km + gaps
- CMS energy → 2 TeV!

		ring-linac pulsed		ring-linac, cw , ~99% energy recovery	
	units	e-	p	e-	p
energy	GeV	70	7000	70	7000
punch population	10^{10}	2	17	2	17
σ_z	cm	0.03	7.55	0.03	7.55
beam current (pulsed)	mA	101	858	101	858
emittance $\varepsilon_{x,y}$	nm	0.5, 0.5			
$\beta^*_{x,y}$	cm	15, 15			
spacing	ns	25			
e-linac/ring length	km	3.5		7 (2 linacs)	
e- pulse length		1 ms		cw	
repetition rate		5 Hz		continuous	
e- beam power	MW	35		7000	
peak luminosity	**10^{32} cm^{-2}s^{-1}**	**0.6**		**2x110**	

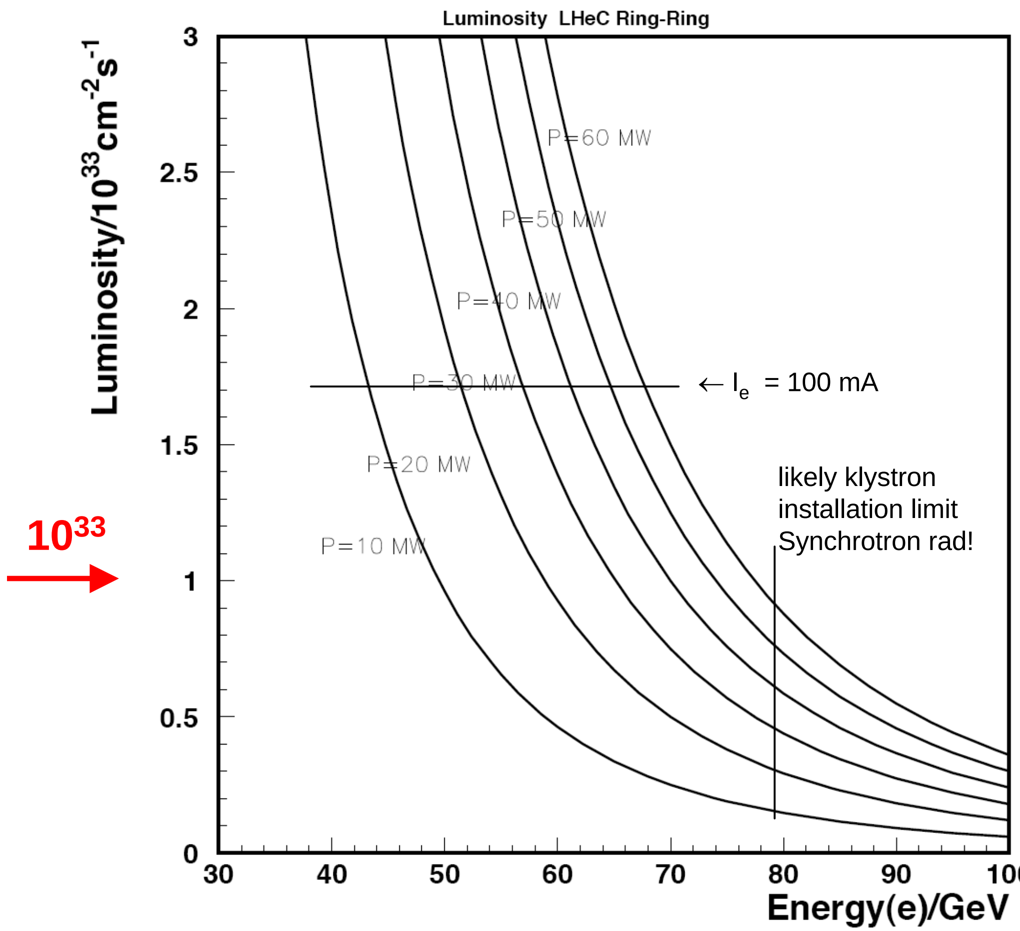
S. Chattopadhyay (Cockcroft), F.Zimmermann (CERN), et al.

Relatively low peak lumi, but good average lumi
Energy recovery (2 linacs?) ...else prohibitive power usage?

Luminosity: Ring-Ring

$$L = \frac{N_p \gamma}{4\pi e \varepsilon_{pn}} \cdot \frac{I_e}{\sqrt{\beta_{px}\beta_{py}}} = 8.3 10^{32} \cdot \frac{I_e}{50mA} \frac{m}{\sqrt{\beta_{px}\beta_{pn}}} cm^{-2} s^{-1}$$

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



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

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

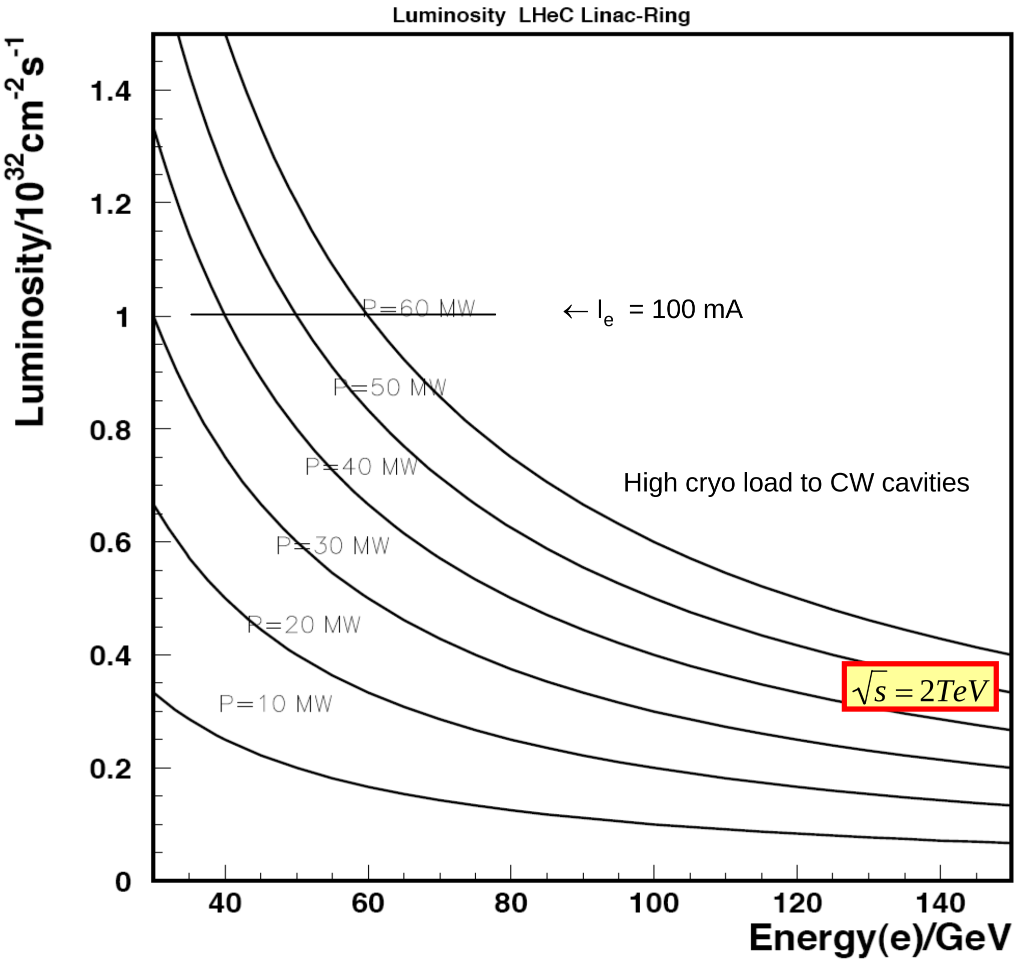
May reach 10^{34} with ERL in bypasses, or/and reduce power.
R&D performed at BNL/eRHIC

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

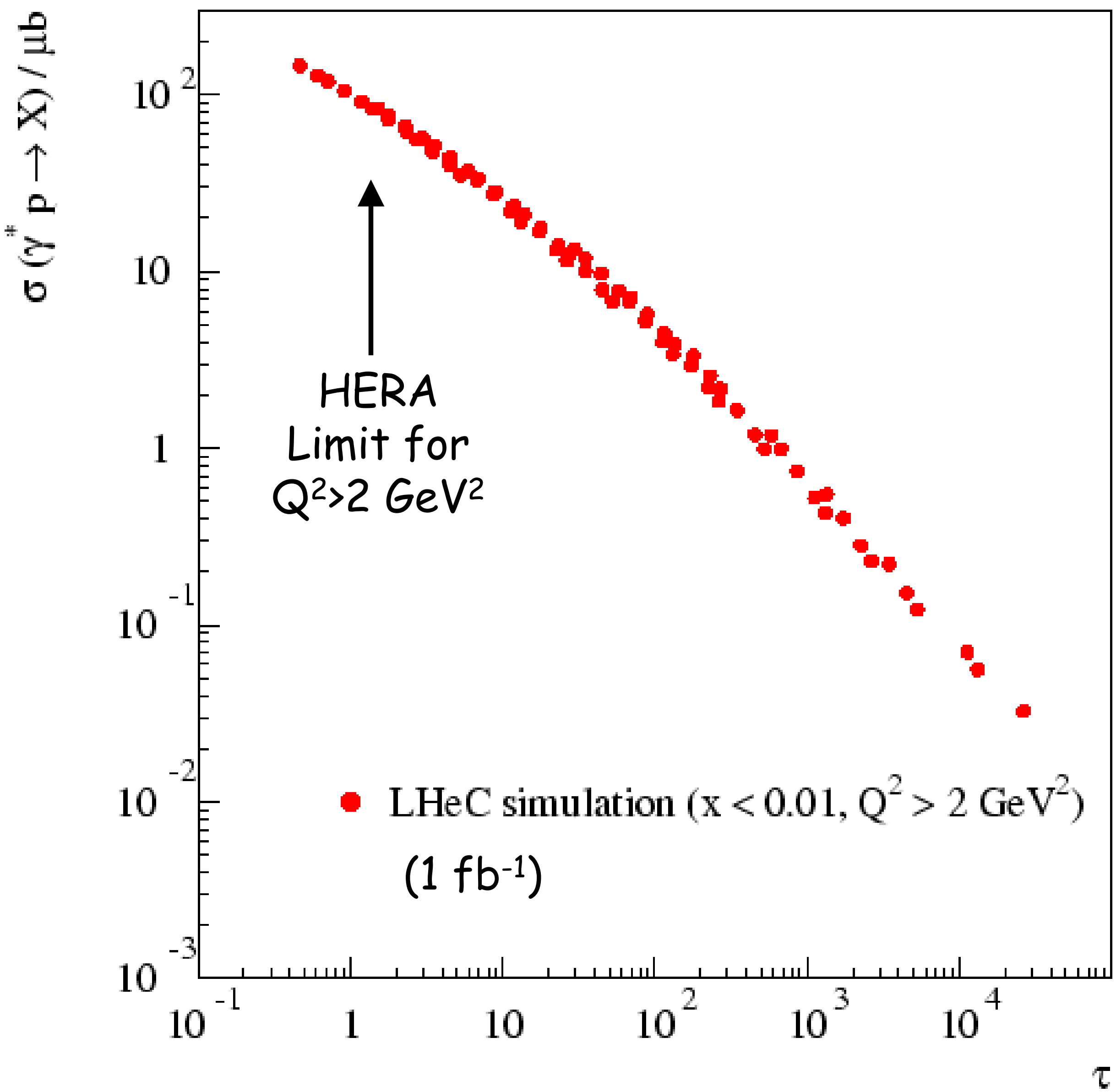
Luminosity horizon: high power:
ERL (2 Linacs?)

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	$10^{33}\text{cm}^{-2}\text{s}^{-1}$	1.1	

Geometric Scaling at the LHeC



LHeC reaches τ ~ 0.15 for Q^2=1 GeV^2 and τ ~ 0.4 for Q^2=2 GeV^2

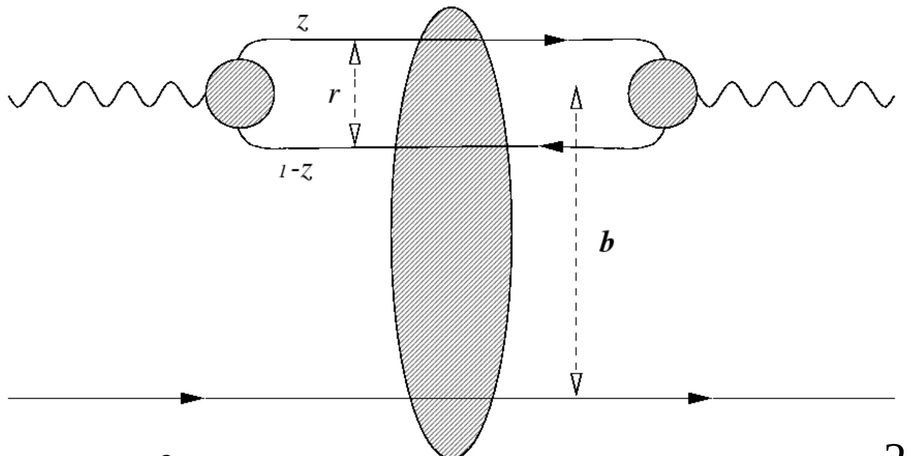
Some (though limited) acceptance for $Q^2 < Q^2_s$ with Q^2 "perturbative"

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 …



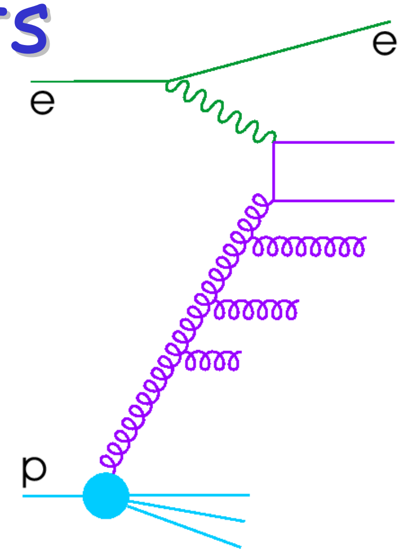
$$\sigma_{\gamma^* p}^{T,L}(x,Q^2) \sim \int \mathrm{dz}\ \mathrm{d}^2 r\ \left|\psi_{\gamma^*}^{T,L}(z,r,Q^2)\right|^2 \sigma_{dipole}(x,r,z)$$

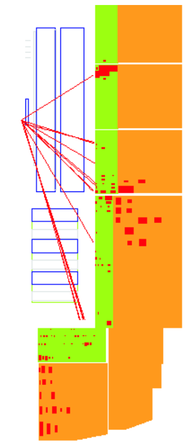
• Simple unified picture of many inclusive and exclusive processes … strong interaction physics in (universal) dipole cross section σ_{dipole}. Process dependence in wavefunction Ψ Factors

• qqbar-g dipoles also needed to describe inclusive diffraction

Forward Jets

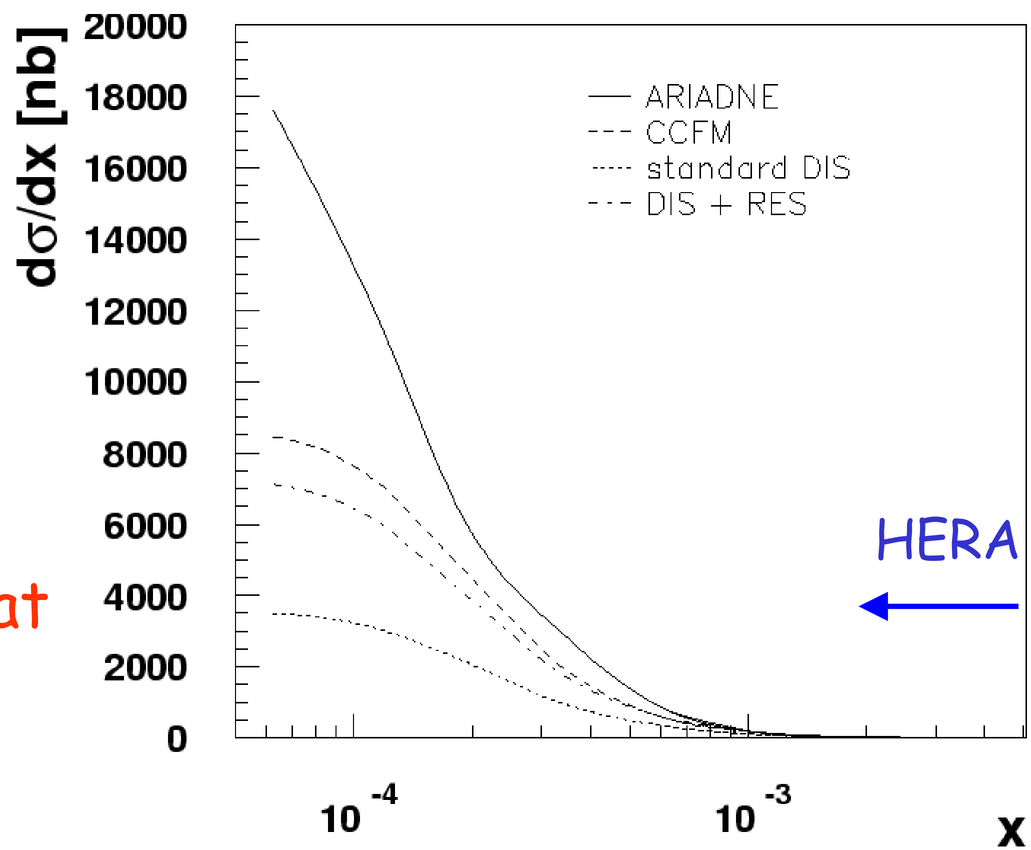
Long HERA program to understand parton cascade emissions by direct observation of jet pattern in the forward direction.
… DGLAP v BFKL v CCFM v resolved γ^*…





Conclusions limited by kinematic restriction to high x (>~ 2.10^{-3}) and detector acceptance.

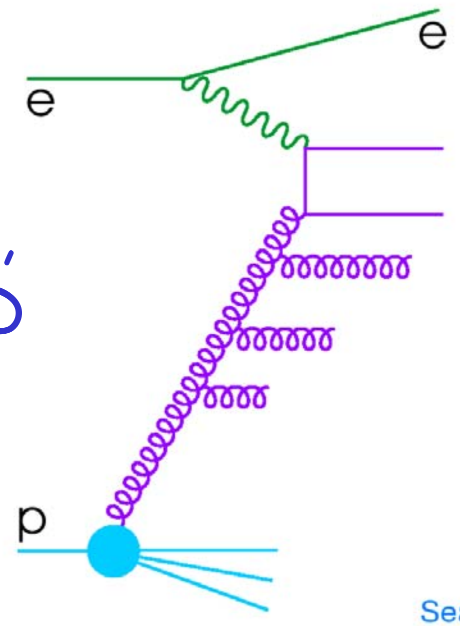
At LHeC … more emissions due to longer ladder & more instrumentation →measure at lower x where predictions really diverge.

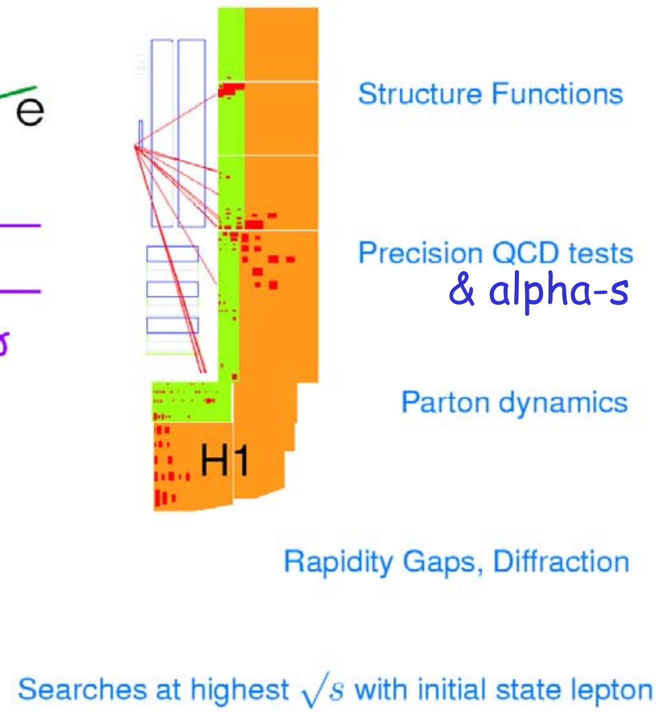


Beyond Inclusive Measurements

- Hadronic Final States:
  - Jets, heavy flavours
    → complementary pdf info, gluon directly, how to treat HF in QCD

  ? Usefulness of HERA data often limited by scale uncties in theory





- Forward Jets,
  - Direct tests of assumed parton evolution patterns

  ? Understanding limited by instrumentation near beam-pipe

- Diffraction
  - Unique clean probe of gap dynamics and elastic scattering

  ? Understanding limited by (forward) detectors …

Motivation for TeV Scale DIS

-New Physics of eq Bound States, ν*, Selectrons …
leptoquarks, RP violating SUSY, quark compositeness

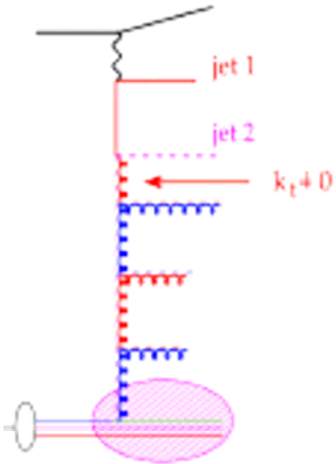
-The Low x Limit of Quantum Chromodynamics
high parton densities with low coupling
`saturating; the parton growth, new evolution dynamics
diffraction and confinement
quark-gluon dynamics and the origin of mass

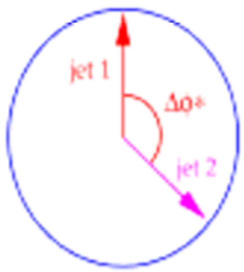
-Precision Proton Structure for the LHC and elsewhere
essential to know the initial state precisely (b, g …)

-Nuclear Parton Densities
eA with AA -> partons in nuclei, Quark Gluon Plasma

… some considerations follow with E_e = 70 GeV, E_p = 7 TeV,
lumi ~ 10^{33} cm^{-2} s^{-1} (~ 10 fb^{-1} $year^{-1}$)…

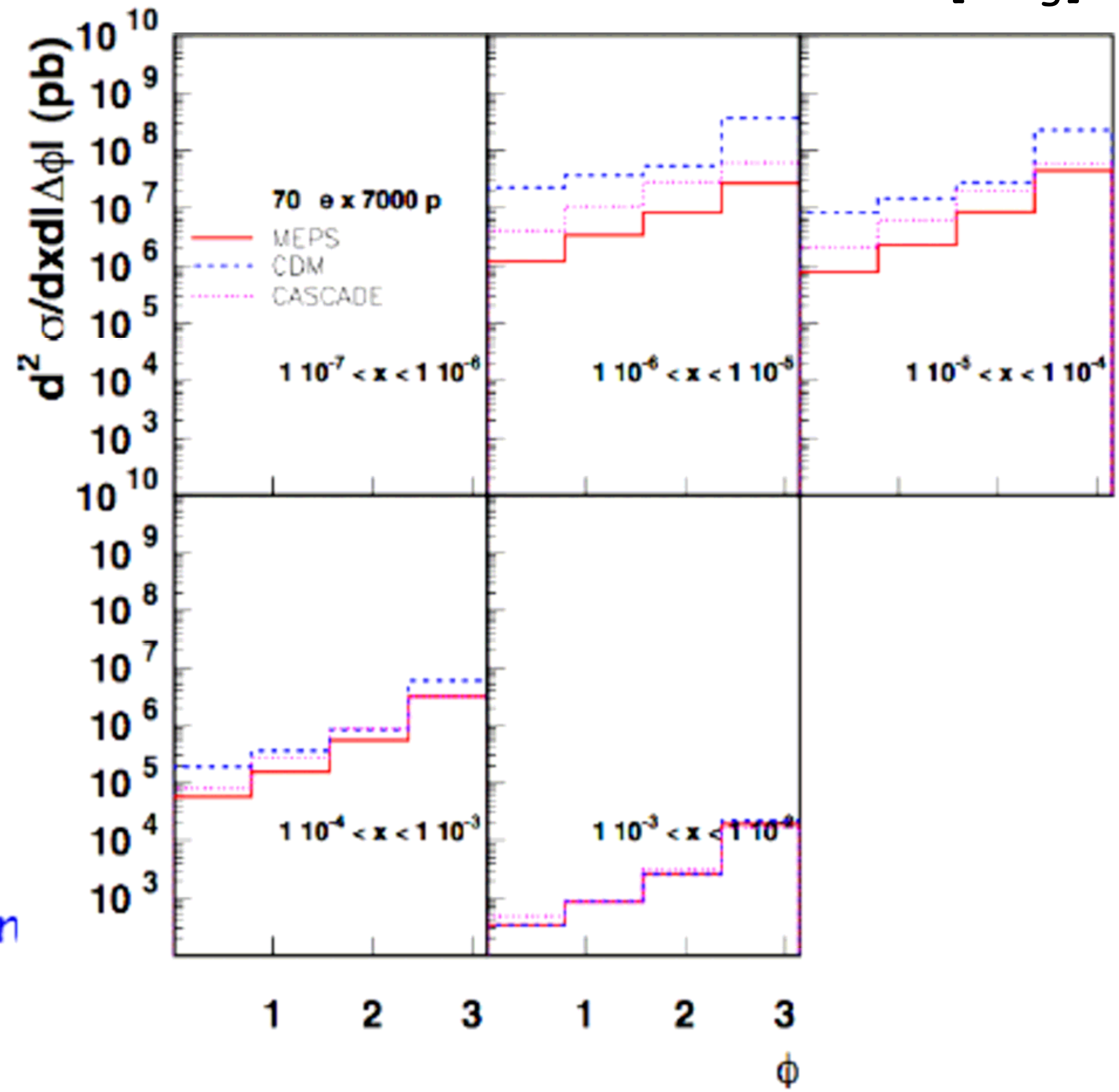
Azimuthal (de)correlations between Jets





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

[Jung]

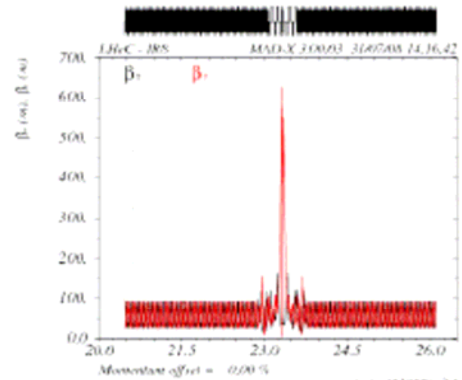


Some topics from Interaction Region Group

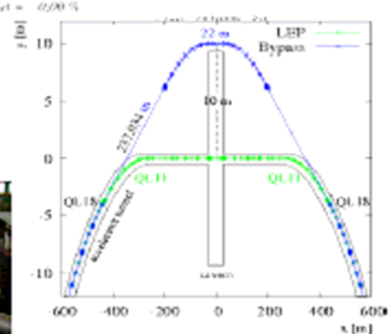
[Burkhard]

Interaction Region Design: ring ring option

detailed presentations about ...



* *e-optics: design of a low beta insertion,*
embedded into a LEP-2 like arc structure
(Alexander Kling, B.H.)

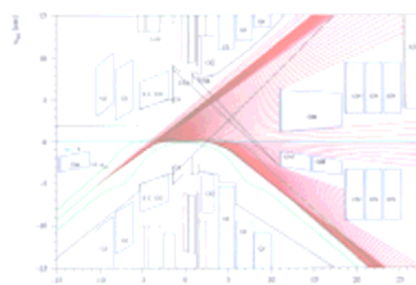


* *e-geometry: bypass regions, (Helmut Burkhardt)*

* *p-optics: low beta insertion combined with*
the LHC luminosity lattice (B.H.)

* *sc. IR magnets: first exotic (?) ideas about*
(Stephan Russenschuck)

* *sc. double magnet design, active magnets*
(Eugenio Paolomi, Simona Bettoni,Tim Greenshaw,)



* *synchrotron radiation: and beam separation (Boris Nagorny)*

* *rf cavities & power consumption (John Jowett, Trevor Linnecar)*

Detector Group

Agenda

DETECTOR SESSION Tuesday morning		
9:00h	PK,AP,RW	Introduction
9:15h	Norbert Wermes	Silicon Pixel Detectors for Tracking
10:00h	Michael Moll	RD50 and silicon hardness
10:30h		-coffee-
11:00h	Wesley Smith	Present and Future Collider Triggers
11:30h	Alex Cerri	Trigger and online displaced vertexing (CDF SVT)
12:00h	Andris Skuja	CMS Hadron Calorimeter
12:30h		-lunch-
COMMON SESSION DET/ACC/IR Tuesday afternoon		
14:00h	Tim Greenshaw	Instrumented Magnets
14:30h	Herman ten Kate	Magnet options for LHeC detector
DETECTOR SESSION Tuesday afternoon		
17:00h	Els Koffeman	Gossip gaseous pixel R&D
17:30h	Frank Simon	Calice calorimeters for the ILC
18:00h		Open Discussion

... lots of discussion of optimum detector technologies etc

A First Draft Detector?

Detector (1st draft):

- Barrel Solenoid Magnet:
- Barrel Liquid Argon Calorimeter
- Central-Forward-Backward TRT Gossip "particle ID" & tracking
- Central Forward-Backward Tracker
- Innermost layer of high Res Pixel (Monolithic CMOS)
- Forward Backward CALICE Type Calorimeters
- Instrumented low beta magnets

Still the issue of acceptance v luminosity optimisation remains …

→ 2 interaction points / experiments?

→ 2 phases of experiment (a la HERA)?

→ New idea: can we instrument the (superconducting) focusing quadrupoles so they provide calorimetry as well as focusing (and add some Si in front?)