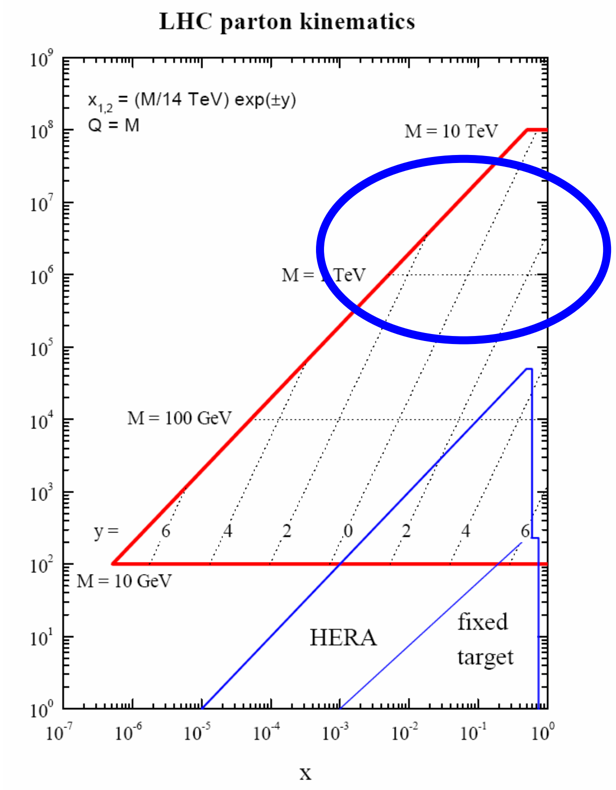
15th International Workshop on Deep Inelastic Scattering

LHeC and Physics Beyond the Standard Model

Emmanuelle Perez
CERN

- Sensitivity to new physics in ep collisions at 1.4 TeV :
  quark radius, leptoquarks, SUSY,
  eeqq contact interactions.
  Complementarity w.r.t. pp.

- LHeC w.r.t. the interpretation of LHC discoveries :
  are there limitations due to our limited
  knowledge of high x pdfs ?
  See also M. Cooper-Sarkar and C.P.Yuan talks



LHeC : a future DIS experiment at the LHC ?

hep-ex/0306016 - JINST 1:P10001,2006

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

Abstract

The physics, and a design, of a Large Hadron Electron Collider (LHeC) are sketched. With high luminosity, $10^{33}\text{cm}^{-2}\text{s}^{-1}$, and high energy, $\sqrt{s} =$ 1.4 TeV, such a collider can be built in which a 70 GeV electron (positron) beam in the LHC tunnel is in collision with one of the LHC hadron beams and which operates simultaneously with the LHC. The LHeC makes possible deep-inelastic lepton-hadron (ep, eD and eA) scattering for momentum transfers Q^2 beyond $10^6\,\text{GeV}^2$ and for Bjorken x down to the 10^{-6}. New sensitivity to the existence of new states of matter, primarily in the lepton-quark sector and in dense partonic systems, is achieved. The precision possible with an electron-hadron experiment brings in addition crucial accuracy in the determination of hadron structure, as described in Quantum Chromodynamics, and of parton dynamics at the TeV energy scale. The LHeC thus complements the proton-proton and ion programmes, adds substantial new discovery potential to them, and is important for a full understanding of physics in the LHC energy range.

*Contributed to the Open Symposium on European Strategy for Particle Physics Research, LAL Orsay, France, January 30[th] to February 1[st], 2006.

J.B. Dainton, M. Klein, P. Newman, F. Willeke, EP

Consider the feasibility of pursuing the DIS programme using the 7 TeV LHC proton (A) beam and bringing it in collision with a 70 GeV electron beam in the LHC tunnel: LHeC.

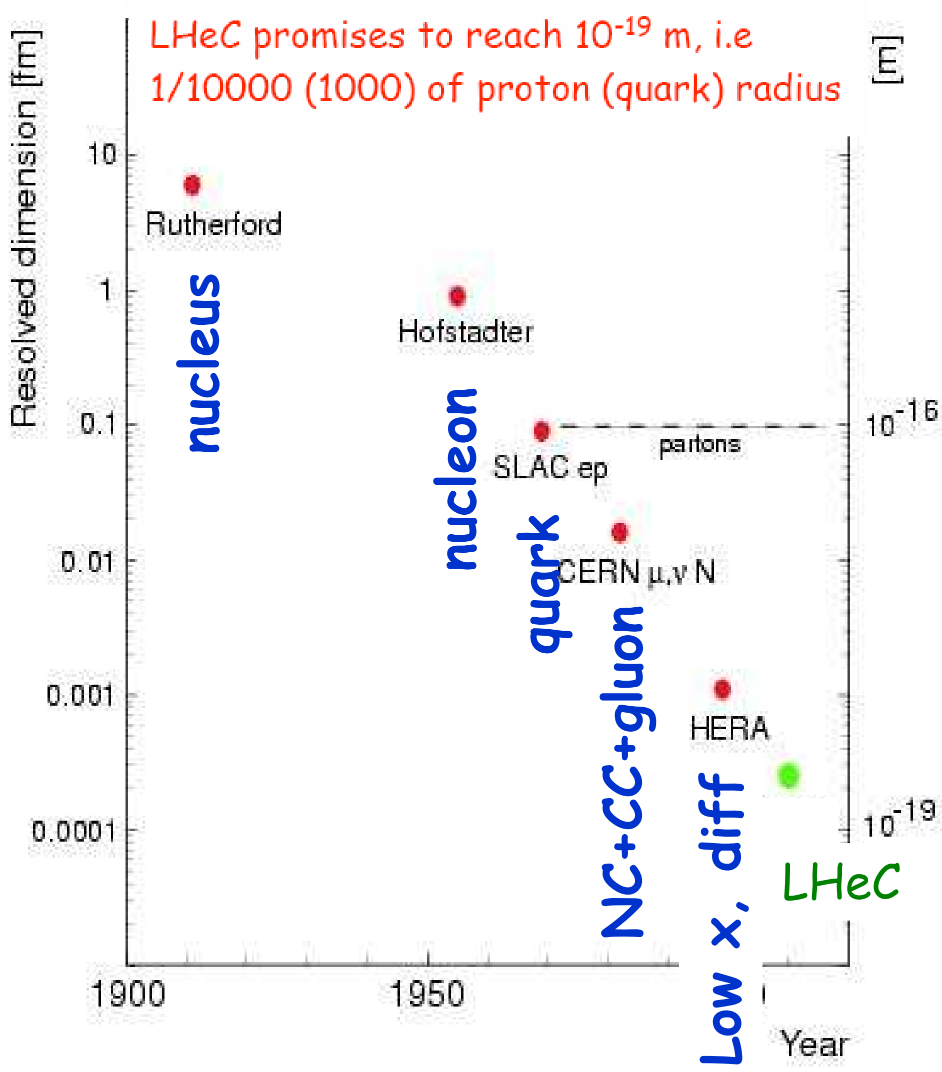
$\sqrt{s}$ = 1.4 TeV i.e. Q^2 up to 2. 10^6 GeV^2

Lumi ~ 10^{33} cm^{-2} s^{-1}, i.e. integrated luminosities of about
10 fb^{-1} per year can be considered.
Polarised e beam.

See talks of M. Klein and P. Newman at this session.

DIS at the high energy frontier

Going higher in Q^2 : towards quark substructure ?



Assign a finite size < r > to the EW charge distributions :

$$d\sigma/dQ^2 = SM_{value} \times f(Q^2)$$

$$f(Q^2) = 1 - \frac{\langle r^2 \rangle}{6} Q^2$$

Global fit of PDFs and < r > using $d\sigma/dxdQ^2$ from LHeC simulation, 10 fb^{-1} per charge, Q^2 up to 500000 GeV^2 :

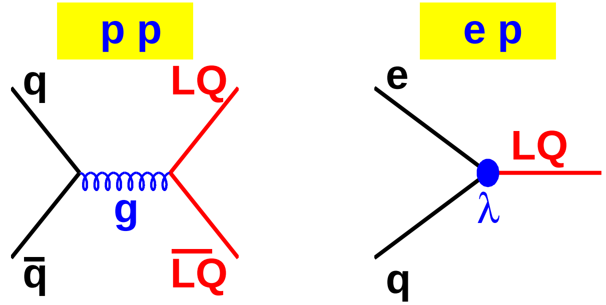
$$\langle r_q \rangle < 8.\ 10^{-20}\ m$$

One order of mag. better than current bounds.

Leptoquarks

Apparent symmetry between the lepton & quark sectors ?
Exact cancellation of QED triangular anomaly ?

- LQs appear in many extensions of SM
- Scalar or Vector color triplet bosons
- Carry both L and B, frac. em. charge

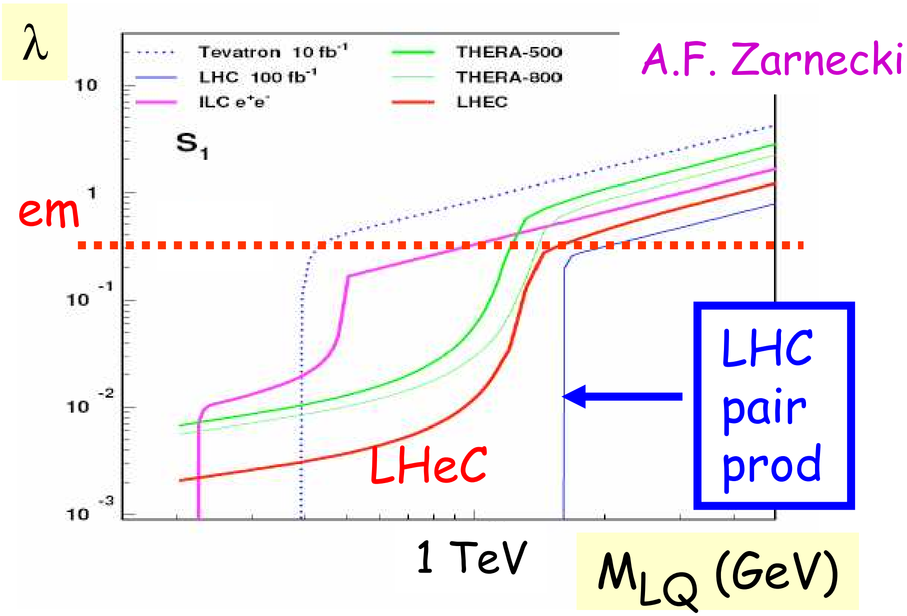


λ (unknown) coupling l-q-LQ

LQ decays into (lq) or (νq) :

ep		pp		
eq	νq	llqq	lνqq	ννqq
NC DIS	CC DIS	Z/DY + jj QCD	W + jj	W/Z + jj QCD

- ep : resonant peak, ang. distr.
- pp : high E_T lljj events



LHC could discover eq resonances with a mass of up to 1.5 – 2 TeV via pair production.

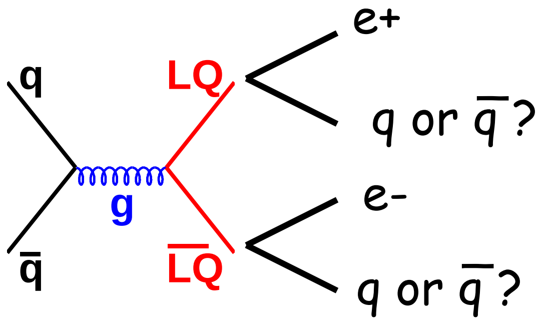
Quantum numbers ? Might be difficult to determine in this mode.

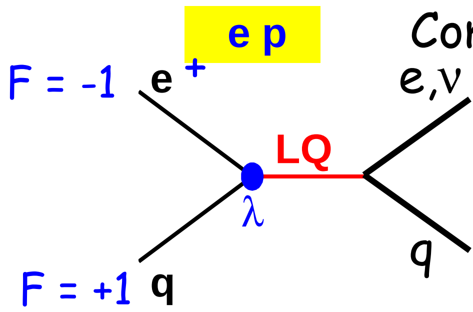
Determination of LQ properties

pp, pair production

ep, resonant production

- Fermion number



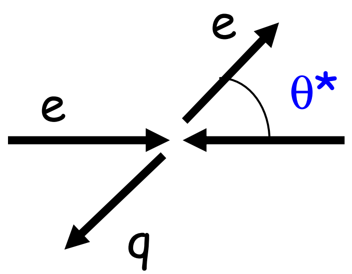


Compare σ with e+ and e- :

F=0 LQs : $\sigma(e^+)$ higher
F=2 LQs : $\sigma(e^-)$ higher

- Scalar or Vector

$q\bar{q} \rightarrow g \rightarrow LQ\ \overline{LQ}$:
angular distributions
depend on the structure
of g-LQ-LQ. If coupling
similar to γWW, vector LQs
would be produced unpolarised…



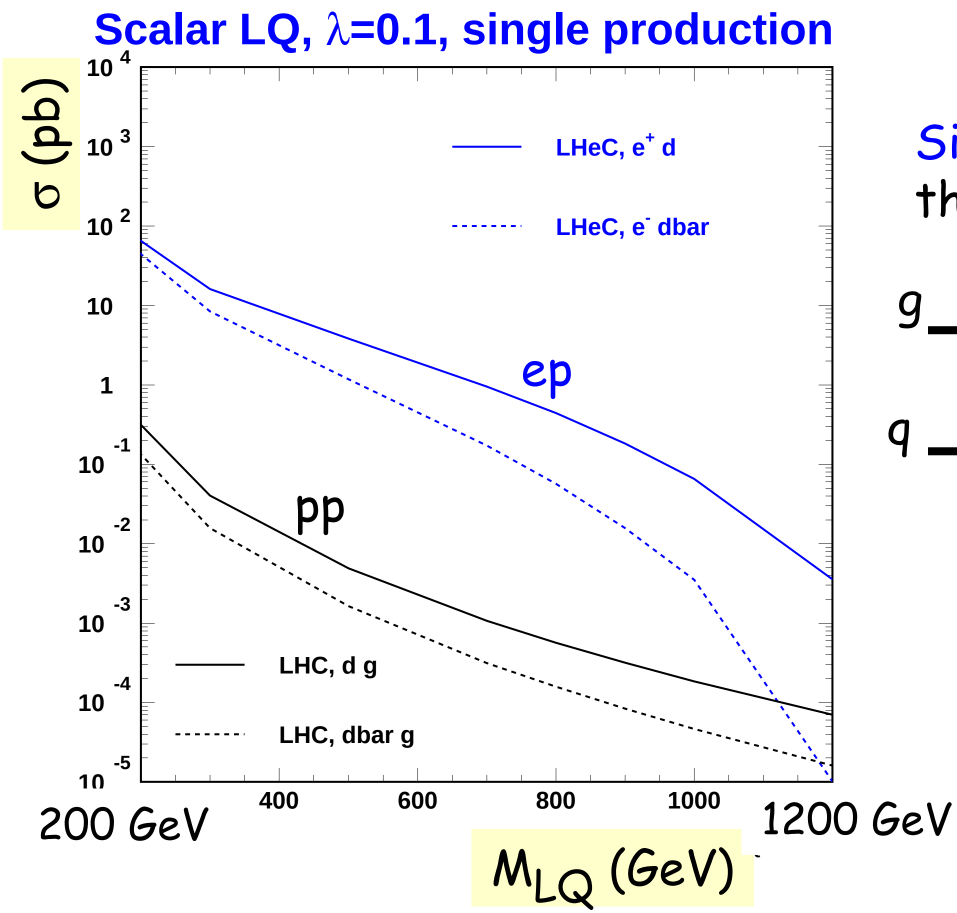
$\cos(\theta^*)$
distribution
gives the
LQ spin.

- Chiral couplings

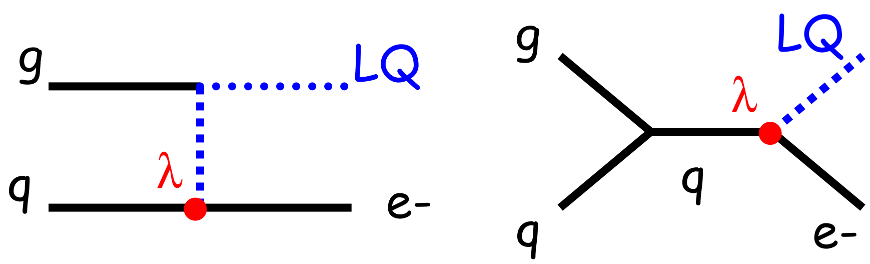
?

Play with lepton beam
polarisation.

Single LQ production at LHC



Single LQ production also possible at the LHC.



$\gamma \rightarrow$ ee followed by eq -> LQ not considered yet. Not expected to change much the results shown here (Tevatron).

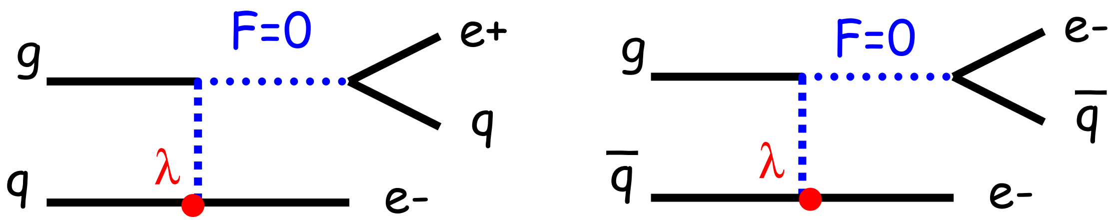
Smaller x-section than at LHeC.
And large background from Z + 1 jet.

Can be used in principle to determine the LQ properties in pp.

Single LQ production at LHC

Single LQ production at LHC to determine the LQ properties ?
Example : Fermion number :

Look at signal separately when resonance is formed by (e^+ + jet) and (e^- + jet) :

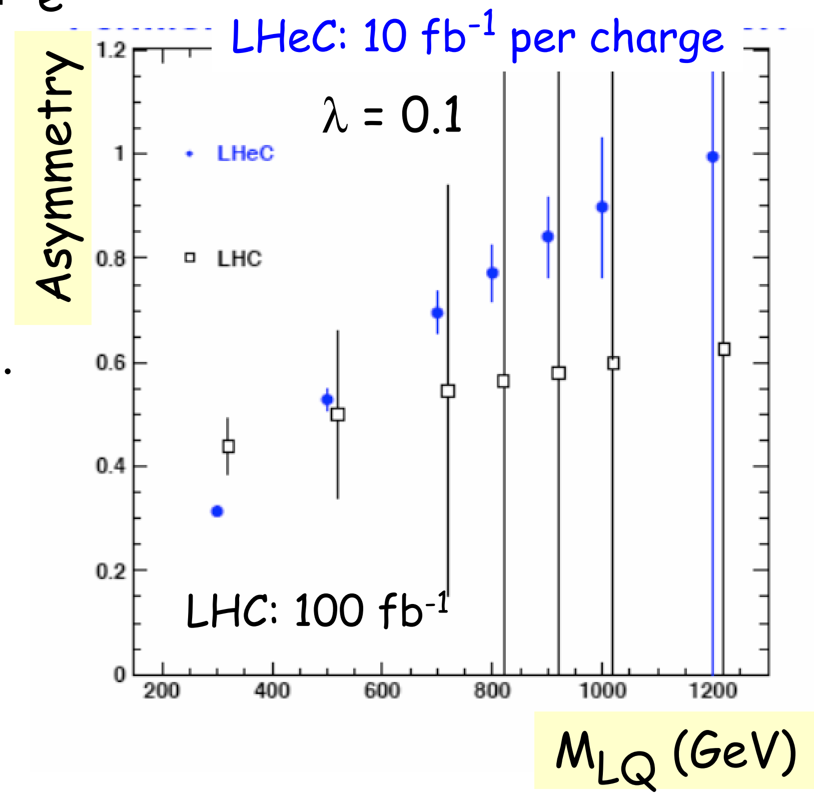


$\sigma(e+) > \sigma(e-)$

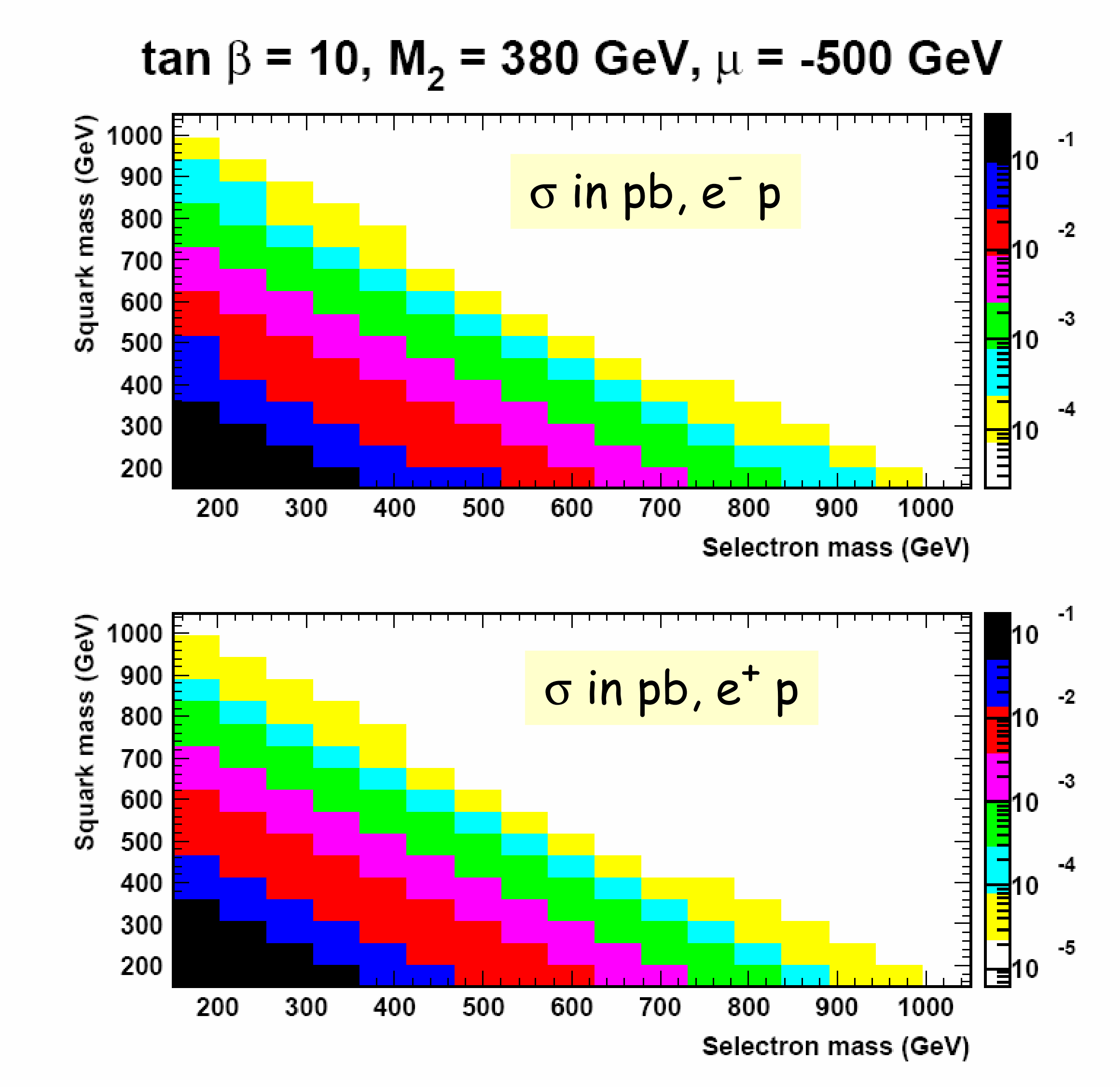
Sign of the asymmetry gives F, but could be statistically limited at LHC. Easier in ep !

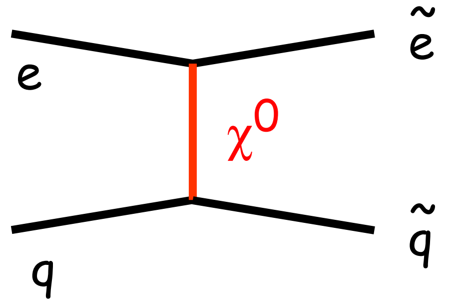
Idem for the simultaneous determination of coupling λ at e-q-LQ and the quark flavor q.

If LHC observes a LQ-like resonance, M < 1 TeV, with indications (single prod) that λ not too small, LHeC would solve the possibly remaining ambiguities.



Supersymmetry





Pair production via t-channel exchange of a neutralino.

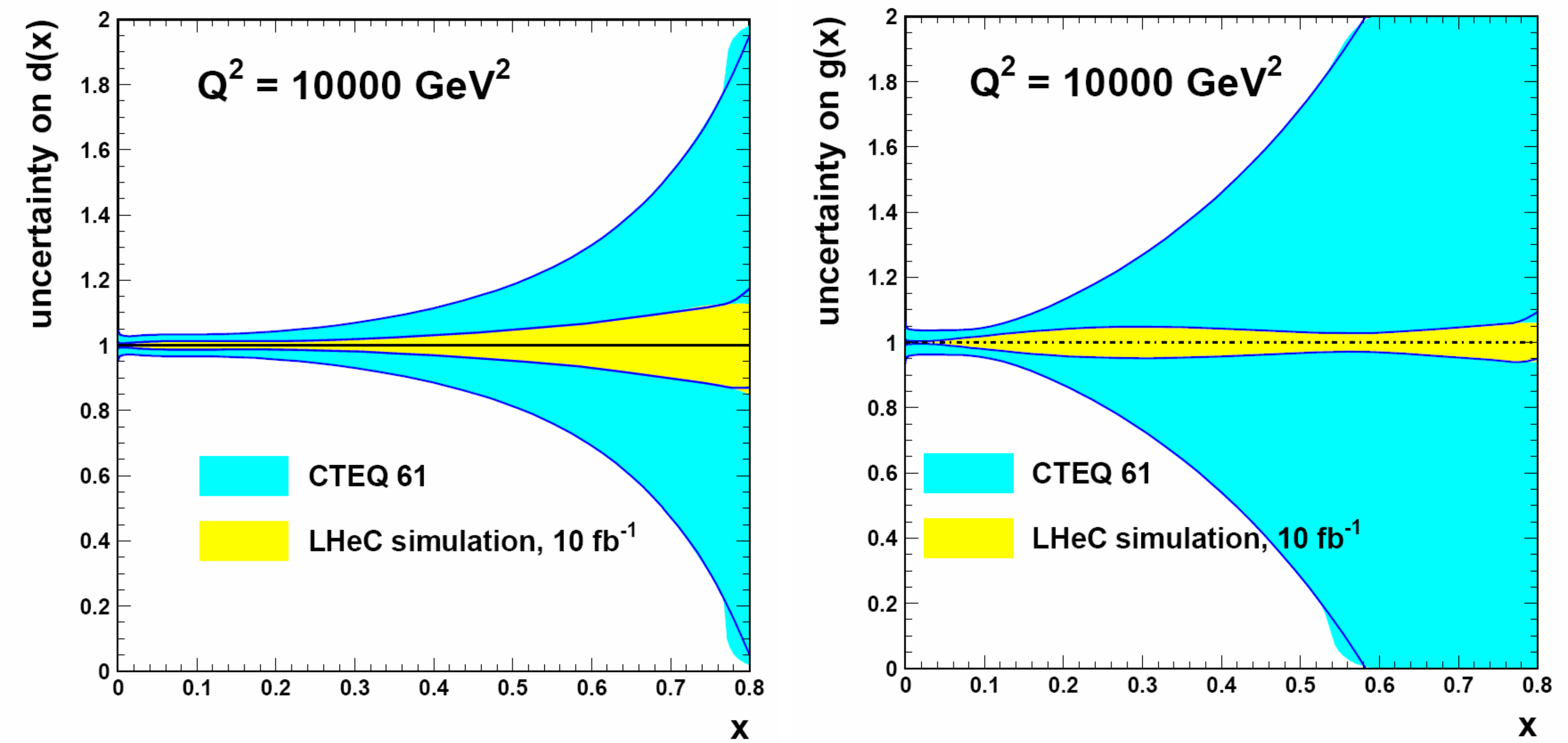
Cross-section sizeable when $\Sigma M < 1$ TeV i.e. if squarks are "light", could observe selectrons up to ~ 500 GeV.

- Could extend a bit over the LHC slepton sensitivity
- Possible information on couplings by playing with e+ / e- / L / R

p structure & interpretation of LHC discoveries

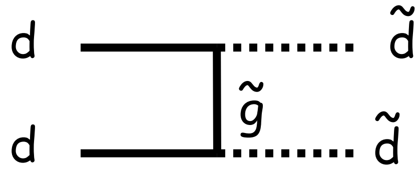
The interpretation of discoveries in AA at Alice may require direct measurements on pdfs in A – not covered.

Here, focus on ATLAS & CMS discoveries : highest masses → highest x.
Constraints on d and g at high x still limited :



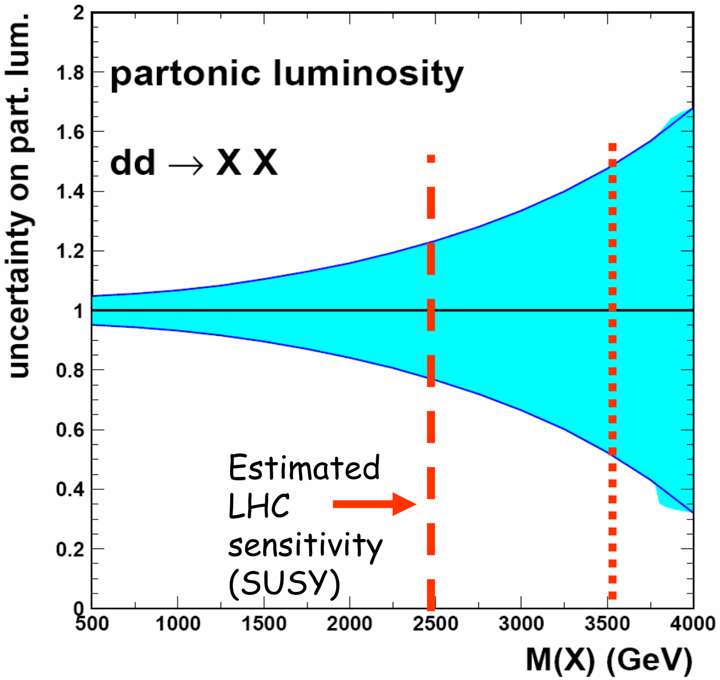
Current high x uncertainties and NP processes at LHC : quark-quark processes

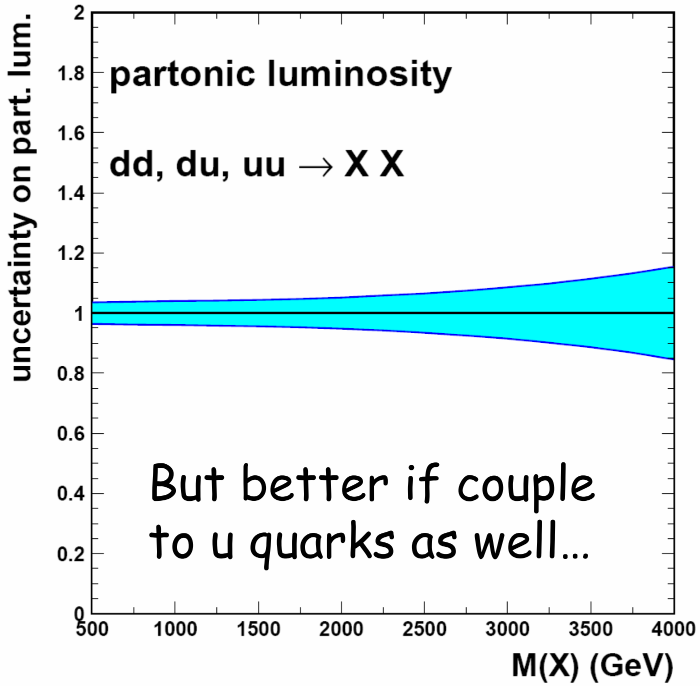
Example: squark production



(shown uncertainties: from CTEQ 61 sets)

δ(pdf) on the relevant partonic luminosities instead of that on the σ of a given BSM process.

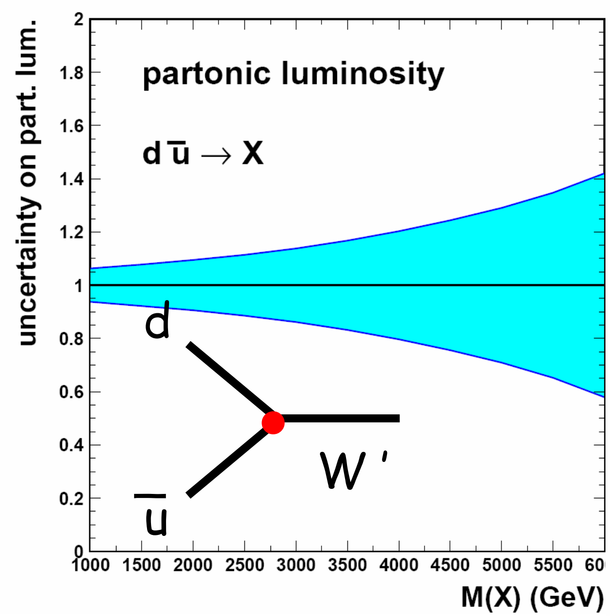


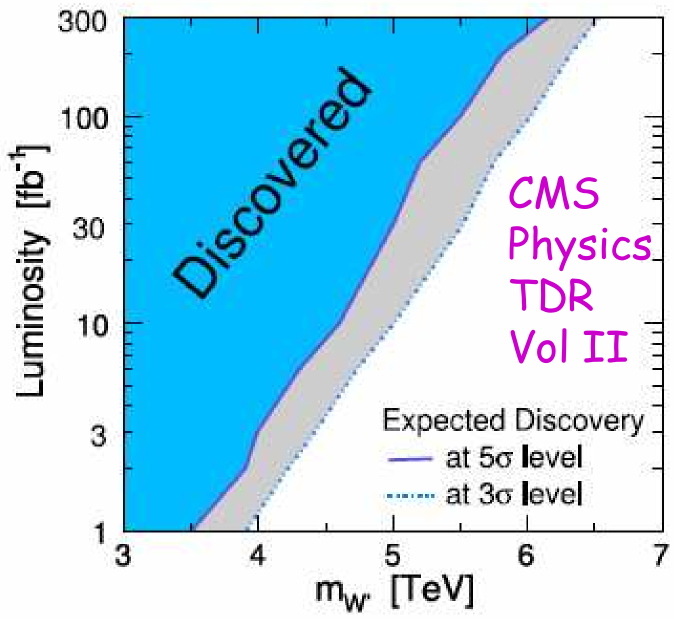


For a process involving high x d quarks, pdf uncertainty ~ 20% at the corner of the LHC phase space.
Could be ~ 50% with extended sensitivity (e.g. LHC upgrade)

Quark-antiquark processes

Example: new W ', resonant slepton production in RpV SUSY

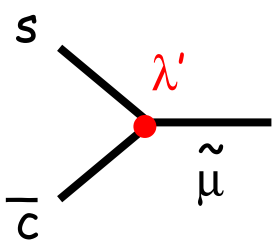




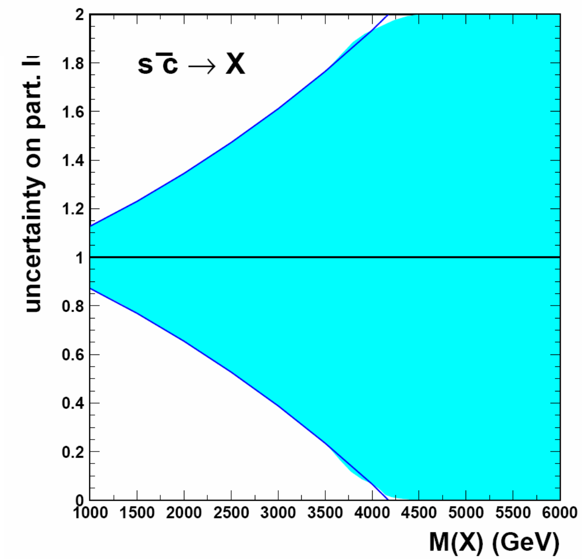
(reach for a W' with SM like couplings)

40% uncertainty on part. lum. For a 6 TeV W '.
→ g(W ') ?

RpV SUSY : reach would depend on the strength of the coupling λ' .

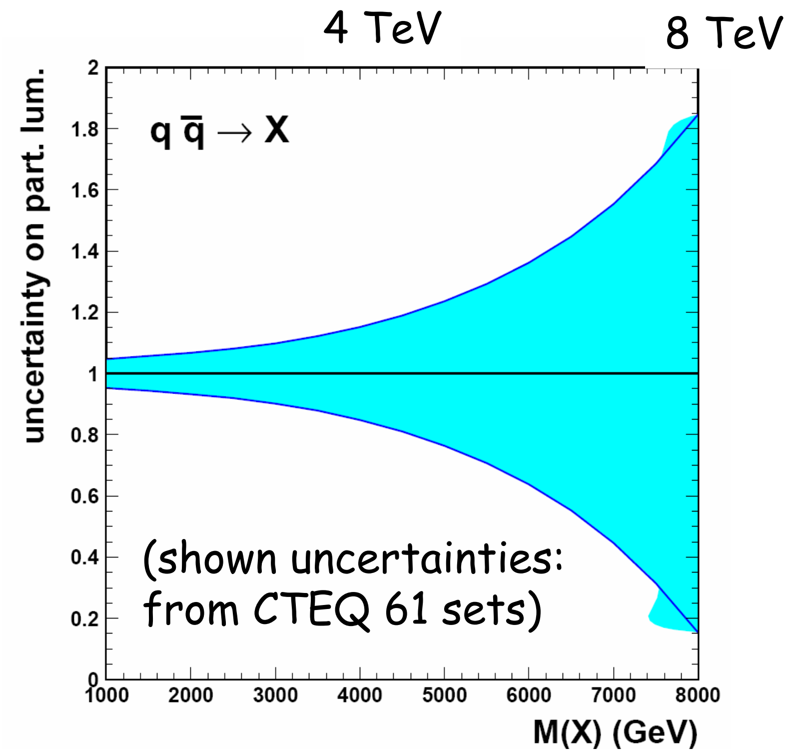


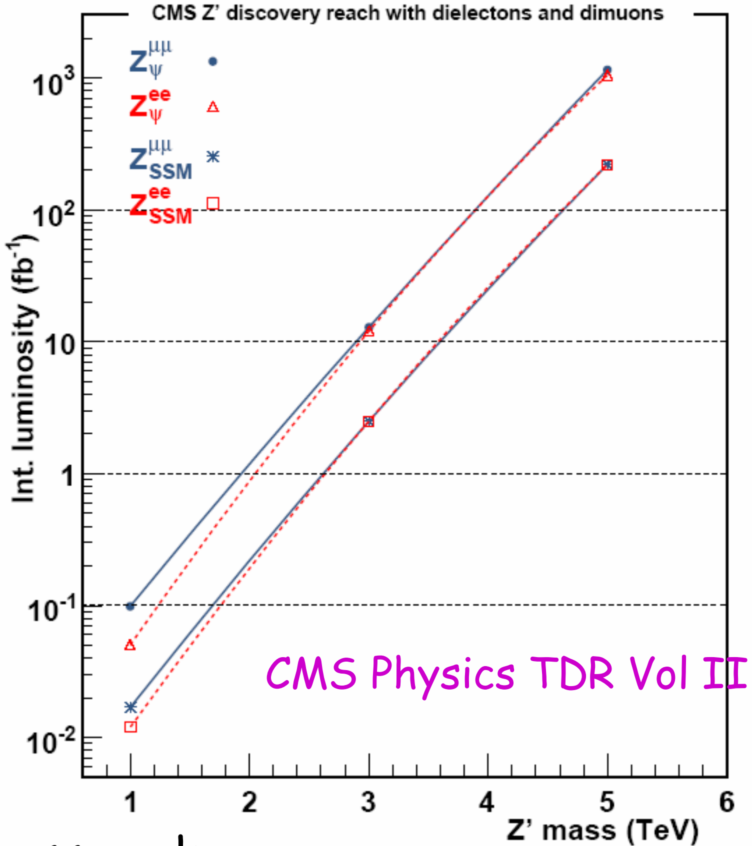
With sea quarks involved, uncertainties large already well below the kinematical limit.



Would make the measurement of the coupling difficult.

Quark-antiquark: DY mass spectrum





Example : new Z' boson, KK gravitons in Randall-Sundrum models etc.. Signal = a mass peak.

Partonic luminosities can be "normalised" to the side-bands data if enough stat.

But close to the discovery limit, couplings of a Z' boson may not be measured accurately.

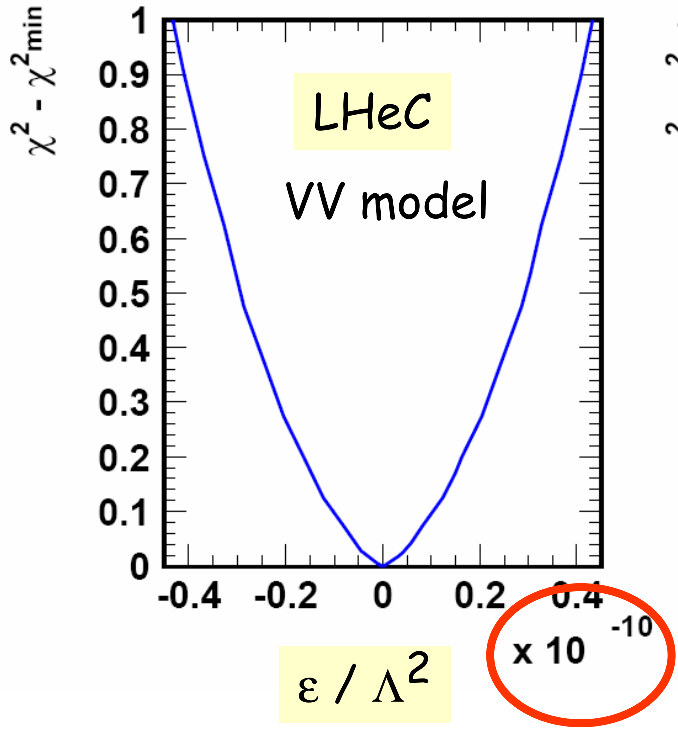
Quark-antiquark: DY mass spectrum

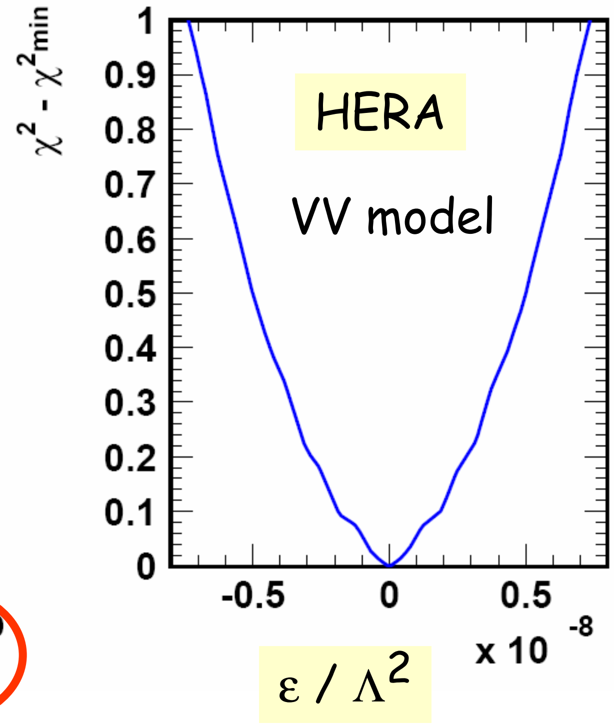
NP in Drell-Yan spectrum might not manifest itself as a mass peak…
e.g. large extra-dimensions, interference with very heavy boson etc…

Effective "contact-term" Lagrangian :

$$\mathcal{L}_{CI} = \sum_{i,j=L,R} \varepsilon_{ij}^{eq} \frac{4\pi}{\Lambda^2} (\bar{e}_i \gamma^\mu e_i)(\bar{q}_j \gamma_\mu q_j)$$

$d\sigma/ds = SM_{value} + \ldots \varepsilon\, s/\Lambda^2 + \ldots (s/\Lambda^2)^2$





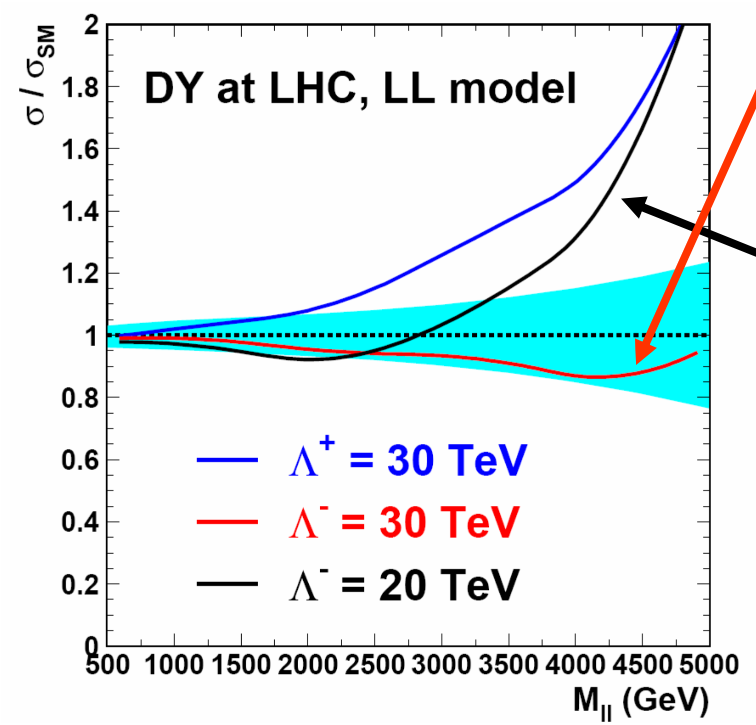
LHeC sensitivity ($10\ fb^{-1}$ e- & e+) :
25 - 45 TeV

depending on the model

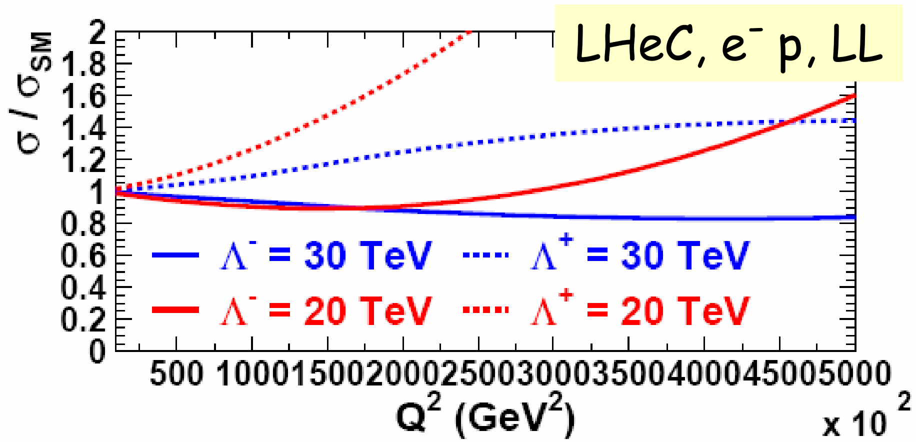
Similar to the expected sensitivity at LHC.

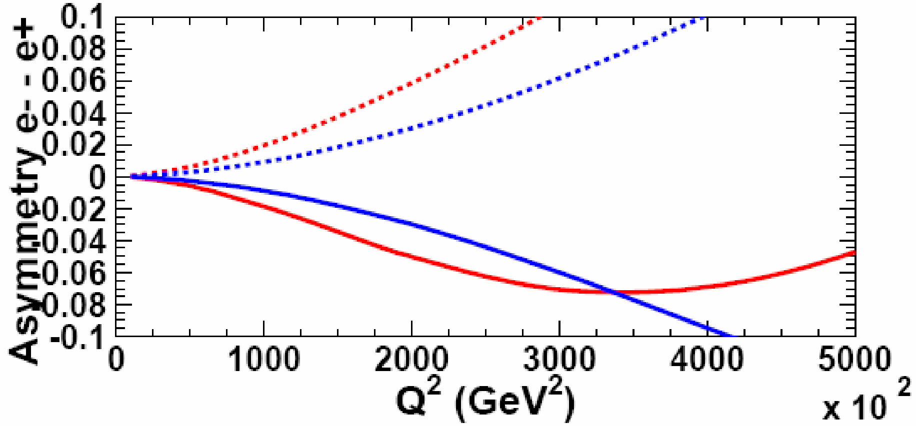
(GeV^{-2})

"eeqq" contact-term in DY and DIS



- LL model, Λ = 30 TeV, sign = -1 : effect in DY can be "absorbed" in pdf unc.
- In some cases, may be difficult to determine the sign of the interference of the new amplitude with SM.



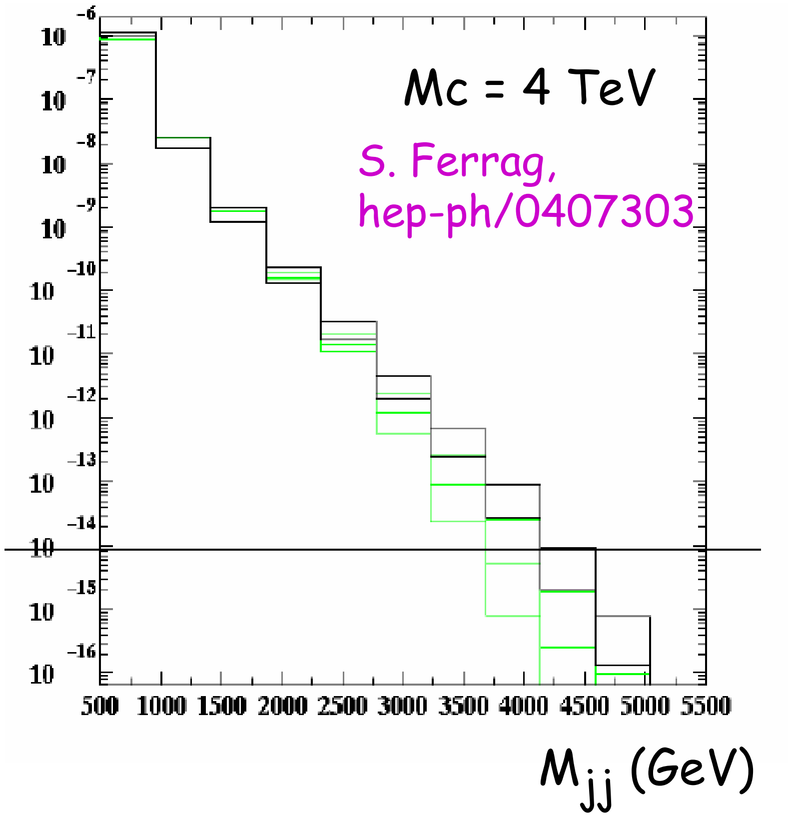


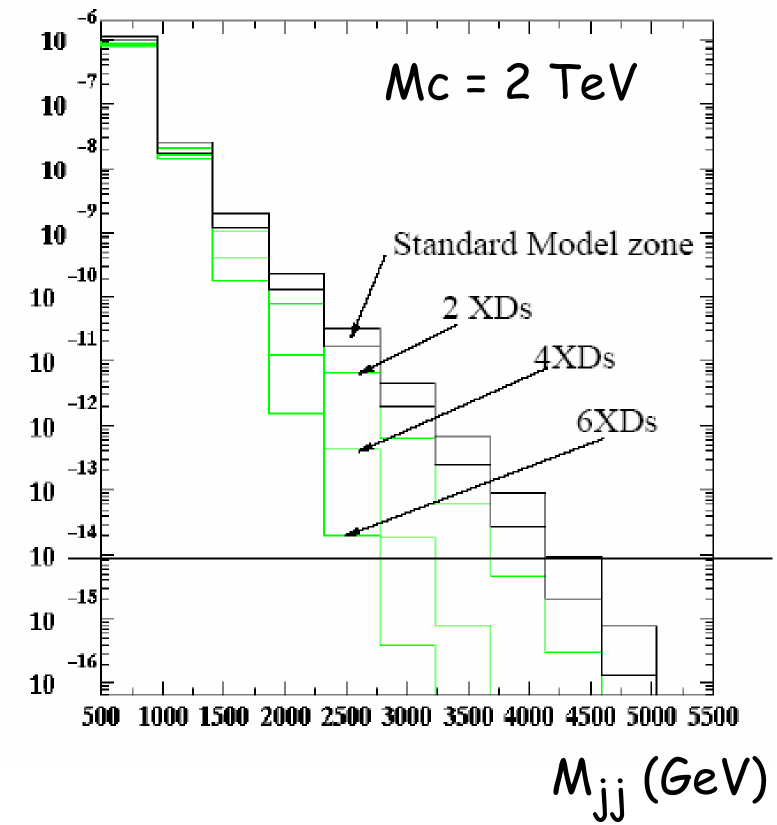
- At LHeC, sign of the interference can be determined by looking at the asym. between σ/SM in e^- and e^+. Polarisation can further help disentangle various models.

E. Perez

High x gluon and dijets at LHC

Some NP models predict deviations in dijet mass spectrum at high mass.
Example : some extra-dimension models. See A. Cooper-Sarkar, SF-2





Due to pdf uncertainties, sensitivity to compactification scales reduced from 6 TeV to 2 TeV in this example.

Conclusions

For "new physics" phenomena "coupling" directly electrons and quarks (e.g. leptoquarks, eeqq contact interactions) : LHeC has a sensitivity similar to that of LHC.

The further study, in ep, of such phenomena would bring important insights : leptoquark quantum numbers, structure of the "eeqq" new interaction. These studies may be difficult, if possible at all, in pp.

LHC sensitivity to new (directly produced) particles not much limited by our pdf knowledge. "Contact-interactions" deviations may be more demanding (both on theo. and on exp. side).

However, the interpretation of discoveries at LHC may require a better knowledge of the high x pdfs : e.g. determination of the couplings of a W ' or Z ' if "at the edge" .