LHeC and New Physics at High Scales: Overview of the CDR

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Introduction

LHeC unlikely to be a discovery machine:

In general, new physics accessible at LHeC would be observed before at LHC (large energy, pair-production via annihilation processes)
Although in some cases (e.g. new leptons) LHeC could see new phenomena that the LHC could have missed.

But, in certain cases, ep could bring some added value to the LHC discoveries :

- resolving ambiguities :
  - ➔ eeqq contact interactions
- measurement of properties of new particles / interactions
  - ➔ in eq interactions: leptoquarks
  - ➔ in eγ interactions: new leptons
  - ➔ in γp interactions: new heavy quarks, new physics in γqQ, diquarks
- coupling of Higgs to bbar -> See next talk.

New physics in high Q2 DIS: effective approach

New physics in eq -> eq amplitudes would lead to a deviation of the high Q2 distribution w.r.t. the SM expectation.
-> look at the Q2 dependence of DIS, dσ/dQ2

- quark compositeness :

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

$$\frac{d\sigma}{dQ^2} = \frac{d\sigma^{SM}}{dQ^2} f_e^2(Q^2)\, f_q^2(Q^2) .$$

- Large extra-dimensions

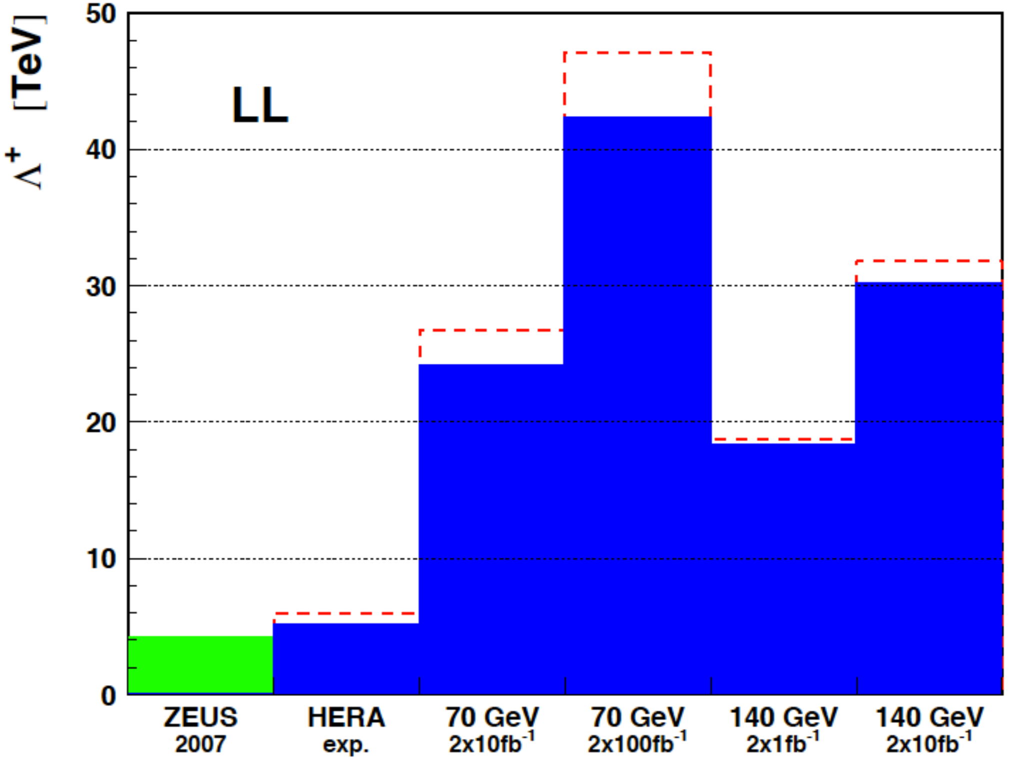
- Contact interactions eeqq :

$$\mathcal{L}_V = \sum_{q=u,d} \{\eta^q_{LL}\,(\bar{e}_L\gamma_\mu e_L)(\bar{q}_L\gamma^\mu q_L) + \eta^q_{LR}\,(\bar{e}_L\gamma_\mu e_L)(\bar{q}_R\gamma^\mu q_R) + \eta^q_{RL}\,(\bar{e}_R\gamma_\mu e_R)(\bar{q}_L\gamma^\mu q_L) + \eta^q_{RR}\,(\bar{e}_R\gamma_\mu e_R)(\bar{q}_R\gamma^\mu q_R)\} ,$$

$$\eta^q_{ab} \equiv \epsilon \frac{g^2}{{\Lambda^q_{ab}}^2} ,$$

Convention: g = 4π, ε = ± 1. The sign determines whether the interference with the SM amplitudes is constructive or destructive.

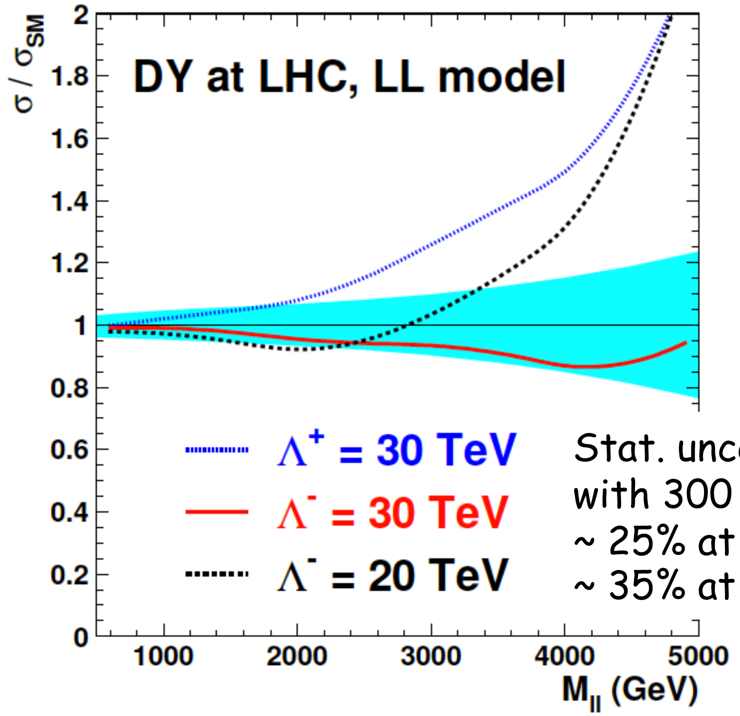
New physics in high Q2 DIS: effective approach



Sensitivity on the scale Λ at LHeC : between ~ 25 and ~ 45 TeV, depending on the models.

Comparable to the LHC sensitivity, where the same terms would affect the Drell-Yan at high mass, q q ➔ ee .

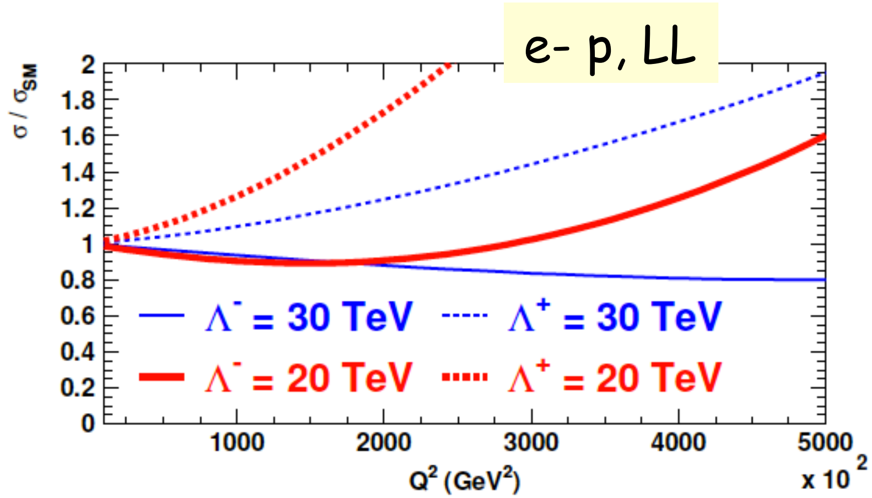
New physics in high Q2 DIS: effective approach

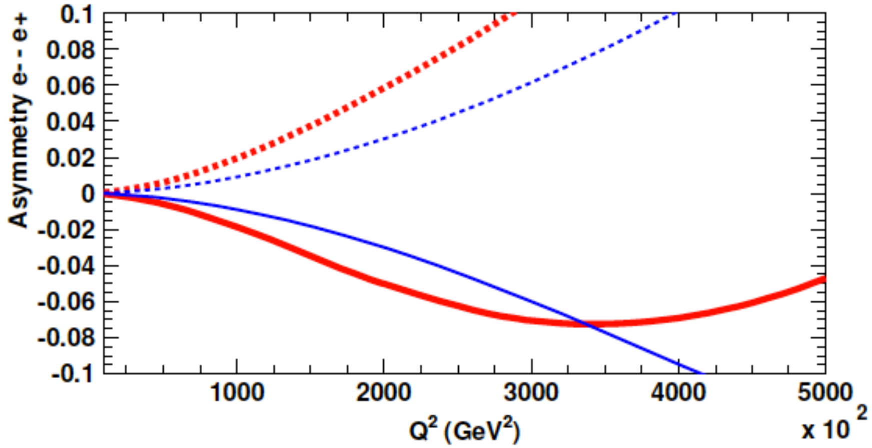


Stat. uncertainty with 300 fb-1:
~ 25% at Mee = 3 TeV
~ 35% at Mee = 4 TeV

PDF uncertainty (CTEQ6) on the SM prediction.

LHC would see a deviation corresponding to Λ+ ~ 30 TeV or to Λ- ~ 20 TeV, but would not determine the structure of the interaction, e.g. the sign of ε .



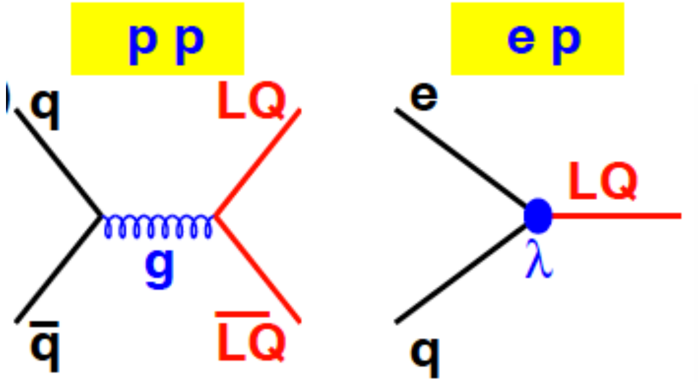


At LHeC, sign of the interference can be determined by looking at the asym. between σ/SM in e^- and e^+.

And polarization would help determine the chiral structure of the interaction.

Electron-parton resonances: "Leptoquarks"

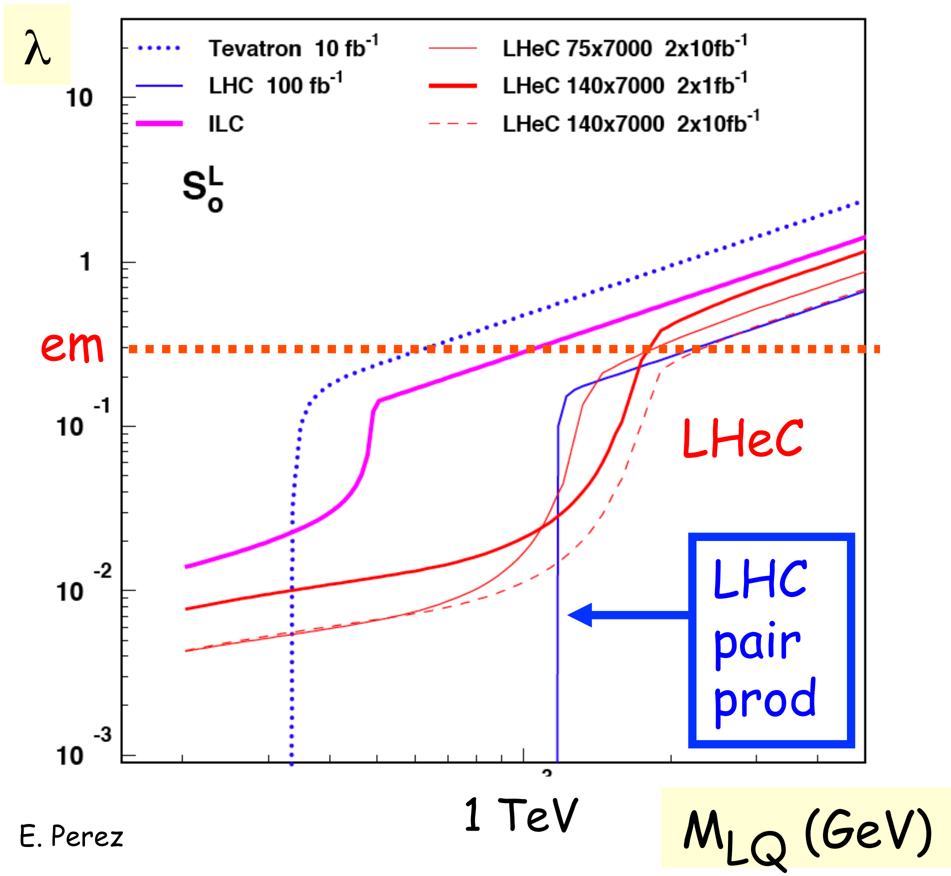
- "Leptoquarks" (LQs) appear in many extensions of SM
- Scalar or Vector color triplet bosons
- Carry both L and B, frac. em. Charge
- Also squarks in R-parity violating SUSY



LQ decays into (lq) or (νq) :

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

[A.F. Zarnecki]



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

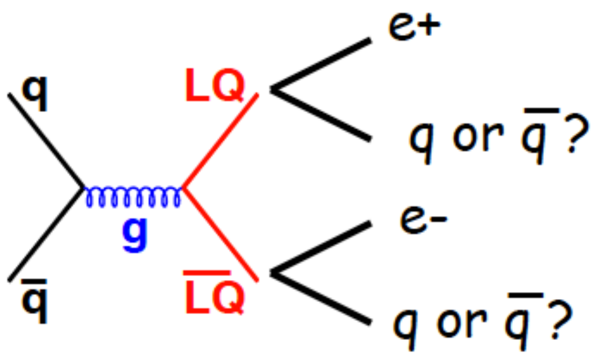
Quantum numbers ? Might be difficult to determine in this mode.

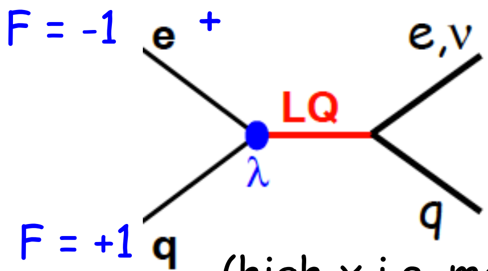
Determination of LQ properties

pp, pair production

ep, resonant production

- Fermion number



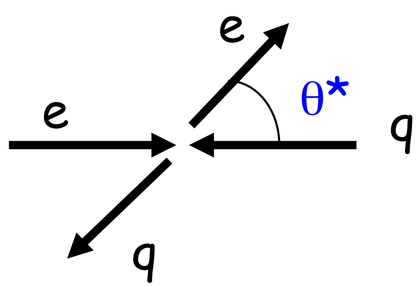


F=0 LQs : $\sigma(e^+)$ higher
F=2 LQs : $\sigma(e^-)$ higher

(high x i.e. mostly q in initial state)

- 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(θ*) distribution gives the LQ spin.

- Chiral couplings

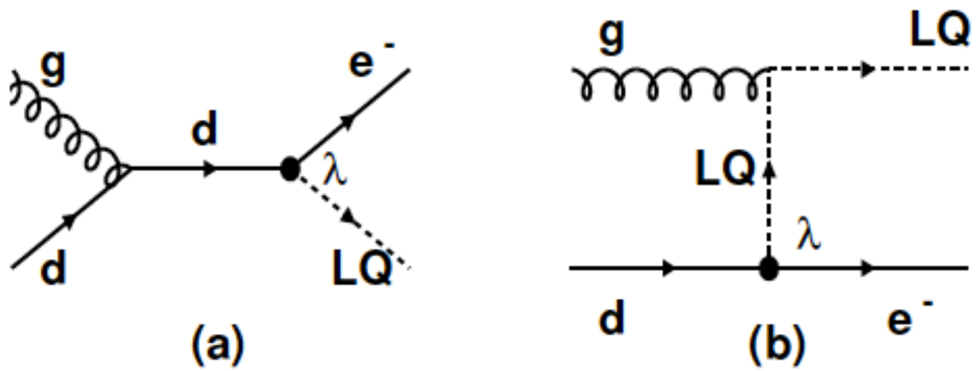
?

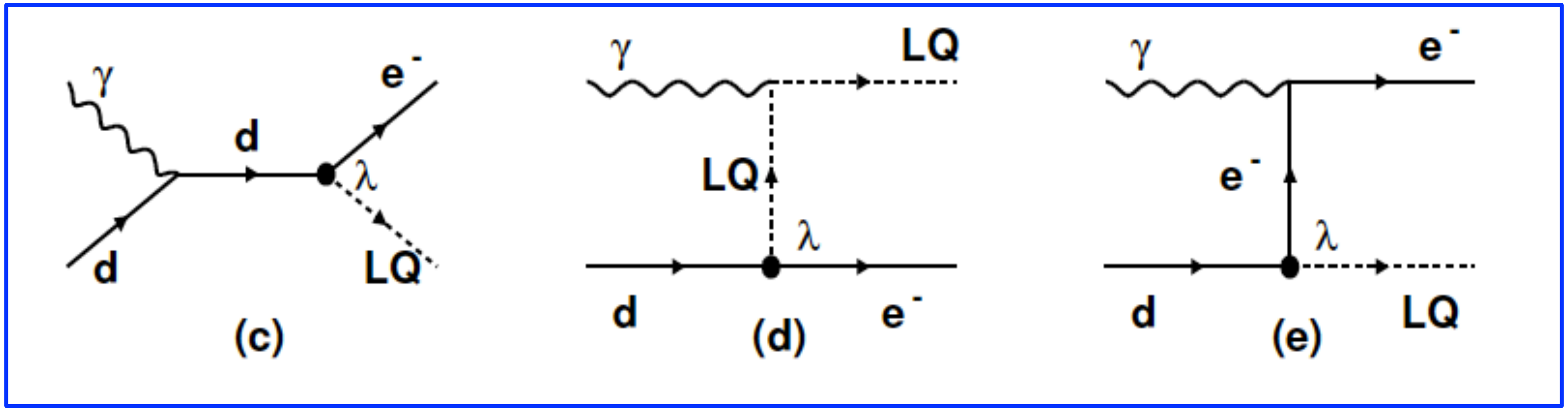
Play with lepton beam polarisation.

Single LQ production at LHC

Single LQ production is better suited to study “LQ spectroscopy”.

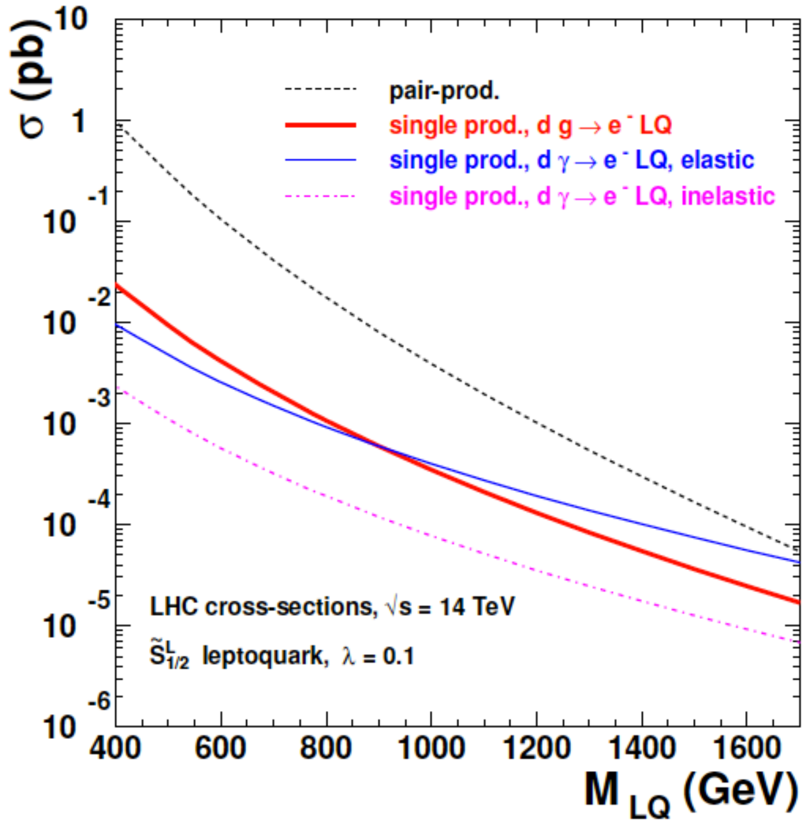
Also possible in pp – although not much considered yet experimentally :

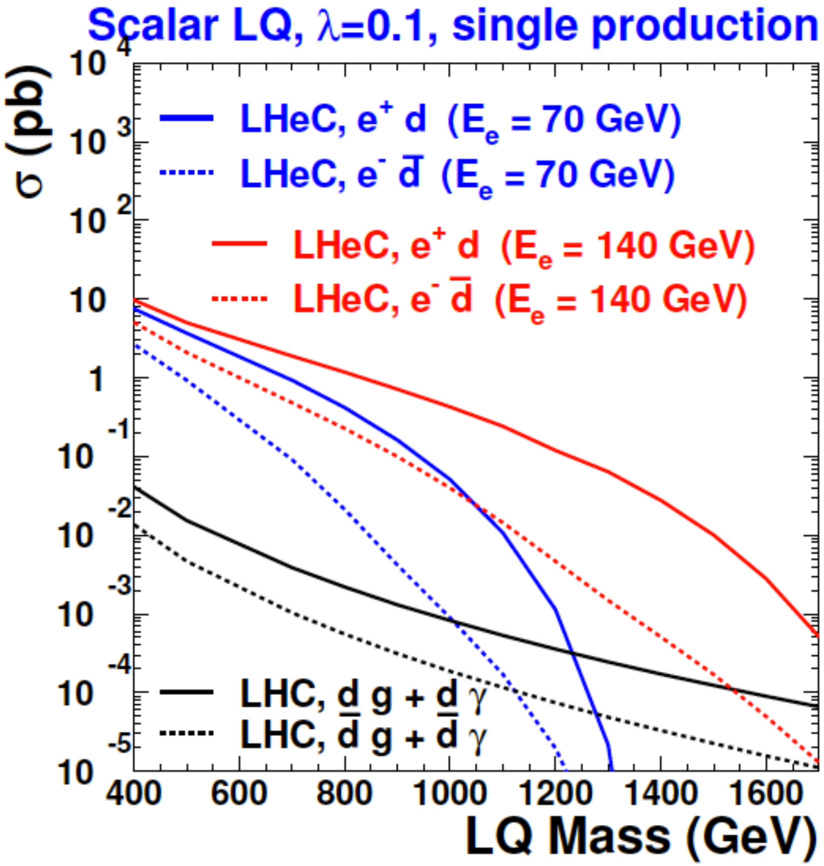




γq production considered in the framework of this study (both elastic and inelastic contributions) S. Belyaev

Single LQ production





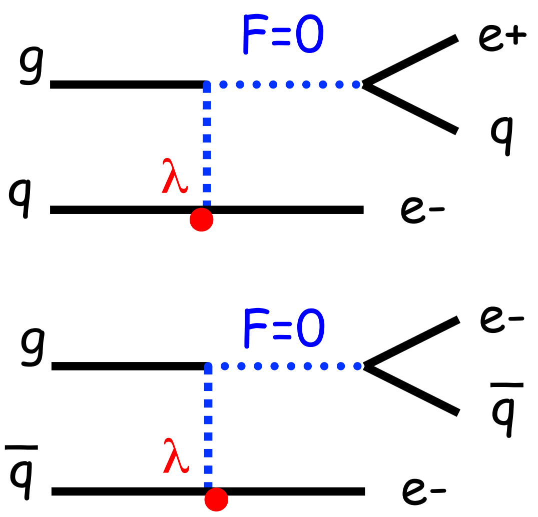
γq process increases the x-section for single LQ production at the LHC.
But it is still much lower (O(100)) than the x-section in ep.

Can we still use single LQ production at the HLC to determine the LQ properties ?

LQ Fermion number determination

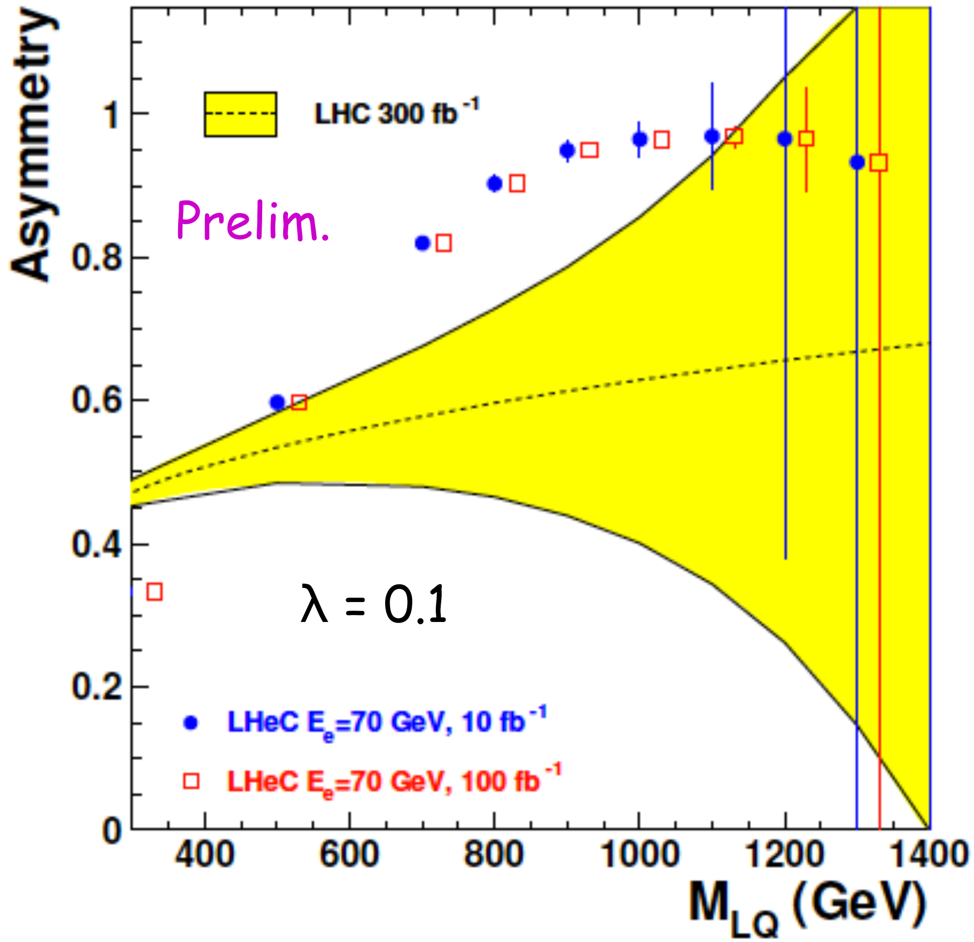
- in ep: compare the x-sections σ(e+ p ➔ LQ) and σ(e- p ➔ LQ).
  The sign of the asymmetry ($\sigma^+ - \sigma^-$) / ($\sigma^+ + \sigma^-$) tells whether F=0 or 2.

- in pp : similar but with e^+_{out} / e^-_{out} instead of e^+_{in} / e^-_{in}, i.e.
  look at signal separately when resonance is formed by (e^+ + jet) and (e^- + jet) :



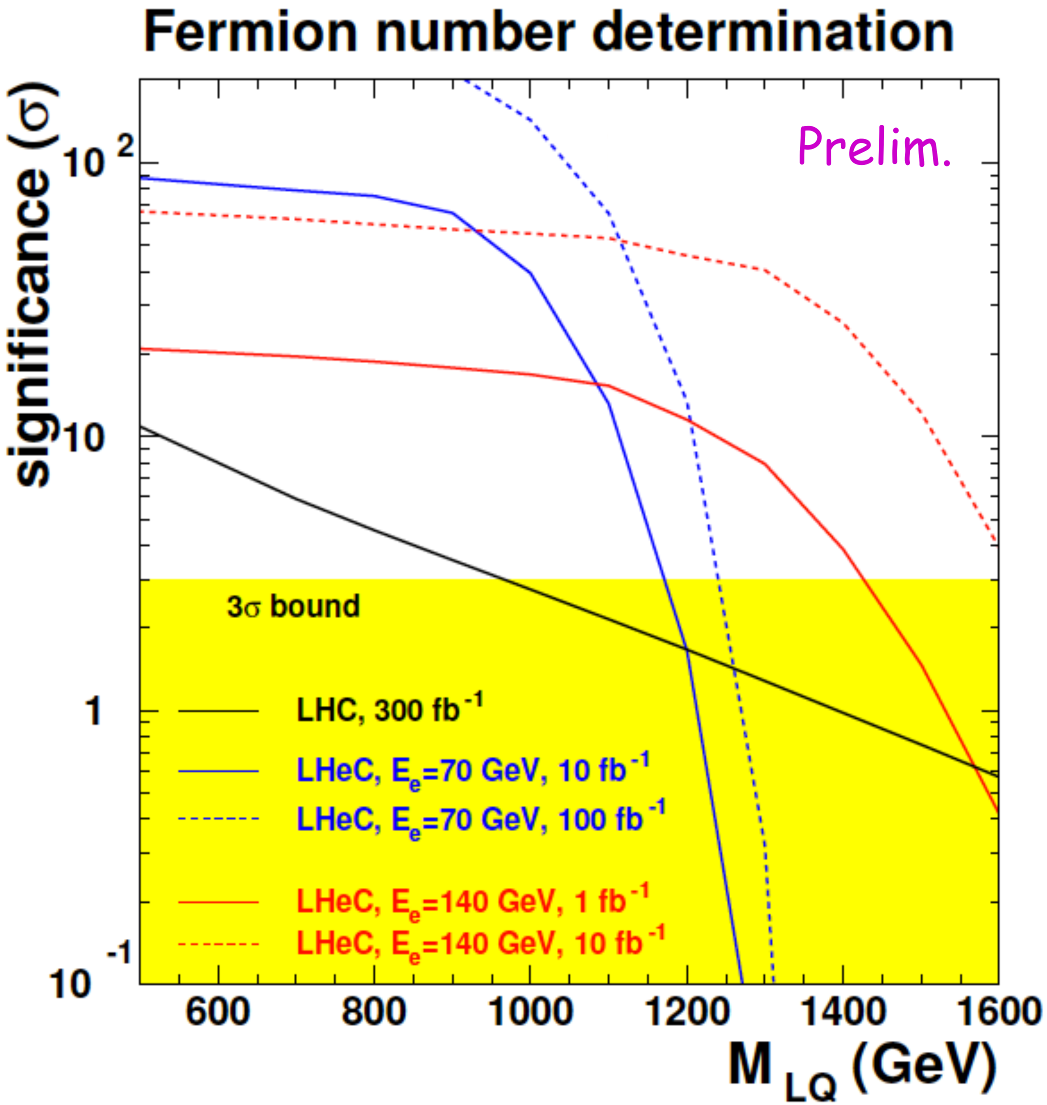
$\sigma(e^+_{out}) > \sigma(e^-_{out})$ for F=0
$<$ for F=2

Sign of the asym. gives F.



E. Perez

LQ Fermion number determination



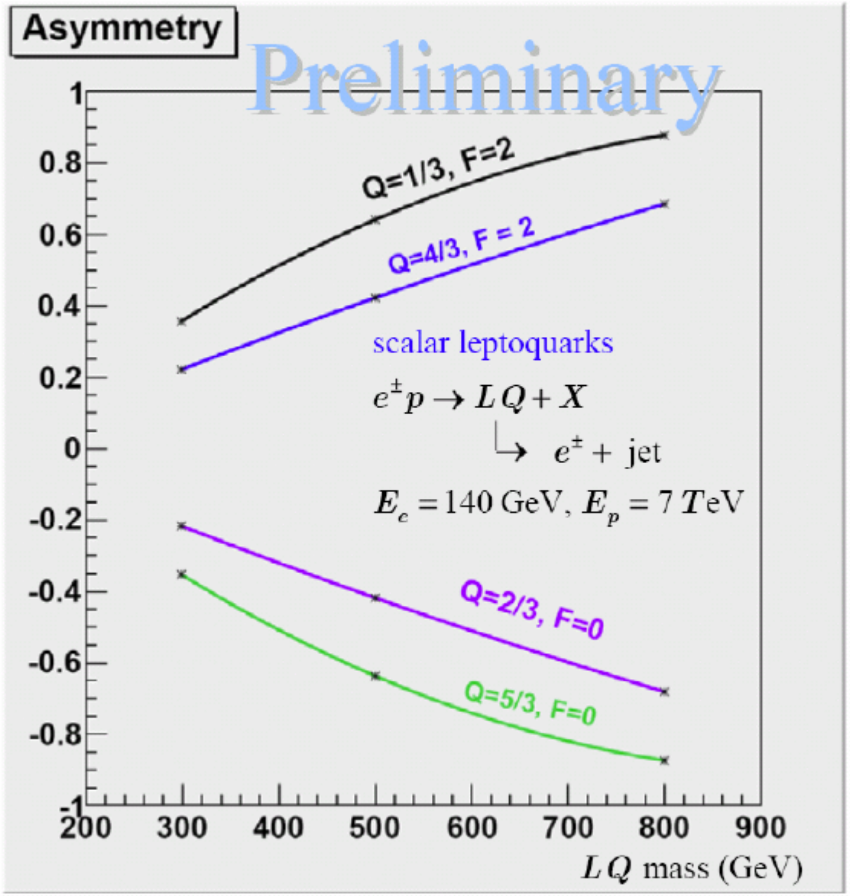
Example (here $\lambda = 0.1$ is assumed, also depends on the LQ type) :

At the LHC, no information on F can be extracted for masses above ~ 0.8 - 1 TeV.

At LHeC, thanks to the larger single prod. cross-section, F could be determined up to ~ 1.4 – 1.6 TeV.

Other LQ properties

- spin is trivial to determine in ep. Could be ambiguous in pp
- Polarization of lepton beam provides information on the chiral couplings of the LQ.



- the charge asymmetry also allows to determine the electric charge of the LQ, i.e. the flavor of the quark to which the LQ couples.

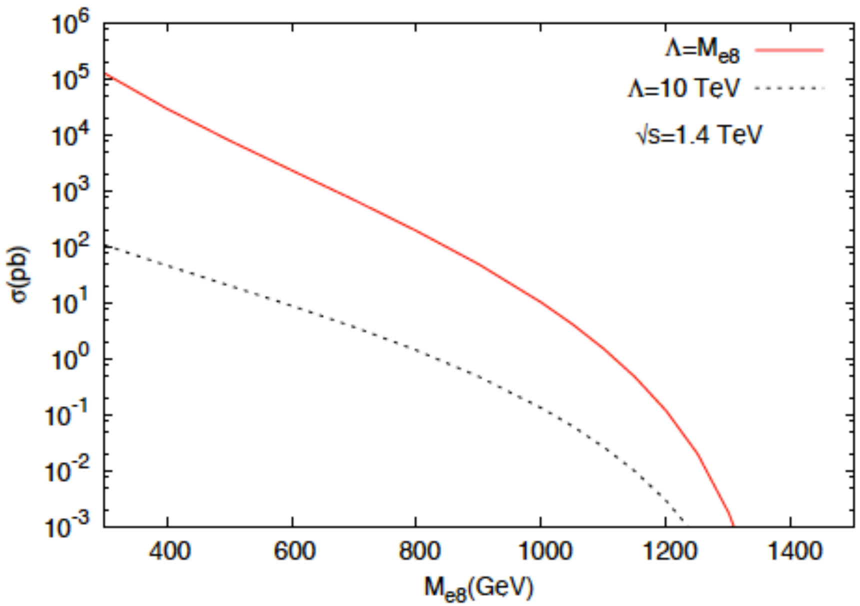
- Once this flavor is known, together with the spin, the ep cross-section allows to determine the coupling λ since

$$\sigma \quad \alpha \quad \lambda^2 q(x = M^2 / S)$$

Lepton-parton resonances: conclusions

If LHC discovers a LQ with a mass ~ 1 TeV and a coupling λ not too small, LHeC is the ideal machine to study its properties.

The case of leptogluons has also been considered.



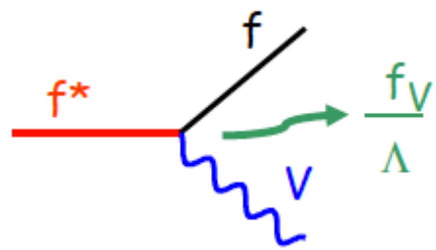
Example cross-section for leptogluon production at LHeC.

Mass reach ~ 1 TeV for Λ = 10 TeV.

Study of LG properties: similar to that of LQs.

New physics in eγ interactions: new leptons

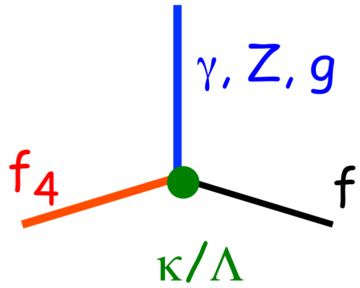
- Excited leptons :



Unambiguous signature for a new scale of matter :
observation of excited states of standard leptons.

$$\mathcal{L}_{GM} = \frac{1}{2\Lambda} \bar{F}^{*}_{R} \sigma^{\mu\nu} \left[g\, f \frac{\vec{\tau}}{2} \vec{W}_{\mu\nu} + g'\, f' \frac{Y}{2} B_{\mu\nu} + g_s\, f_s \frac{\vec{\lambda}}{2} \vec{G}_{\mu\nu} \right] F_L \; + \; h.c.,$$

- Leptons from a 4th generation :



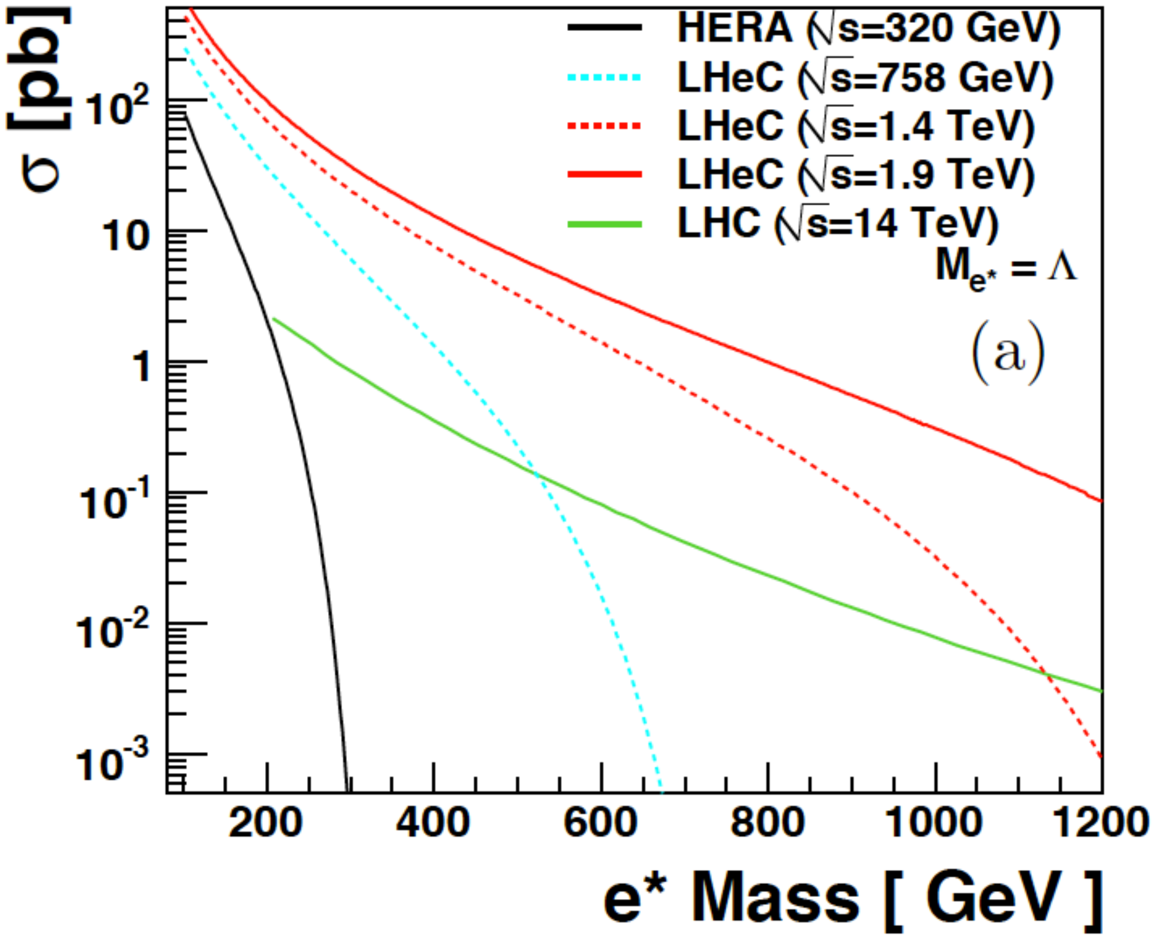
$$\mathcal{L}_{nc} = \left(\frac{\kappa_{\gamma}^{\ell_4 \ell_i}}{\Lambda} \right) e_\ell g_e \overline{\ell_4} \sigma_{\mu\nu} \ell_i F^{\mu\nu} + \left(\frac{\kappa_Z^{\ell_4 \ell_i}}{2\Lambda} \right) g_Z \overline{\ell_4} \sigma_{\mu\nu} \ell_i Z^{\mu\nu} + \left(\frac{g_Z}{2} \right) \overline{\nu_i} \frac{i}{2\Lambda} \kappa_Z^{\nu_4 \nu_i} \sigma_{\mu\nu} q^\nu P_L \nu_4 Z^\mu + h.c.$$

Could be pair-produced at LHC up to ~ 300 GeV.

Could be singly produced at LHC (q $\bar{q}$ ➔ e e*) and at LHeC (e q ➔ e* q)

Excited leptons

f = f' = 1

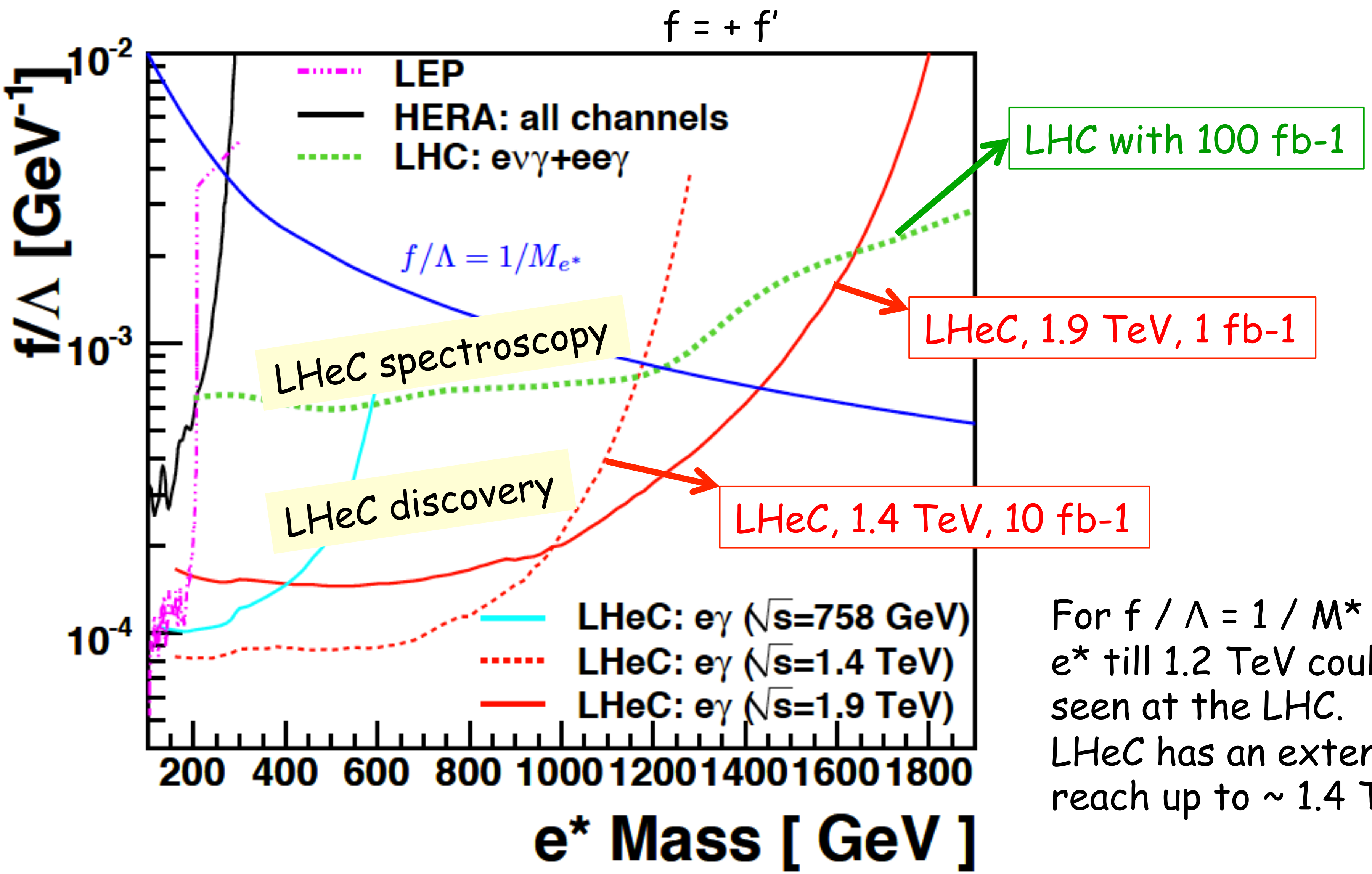


Single e* production:

Much larger cross-section at LHeC than at LHC (need to pick-up an antiquark in a proton)

Analysis carried out of the decay e* → eγ.

Excited leptons



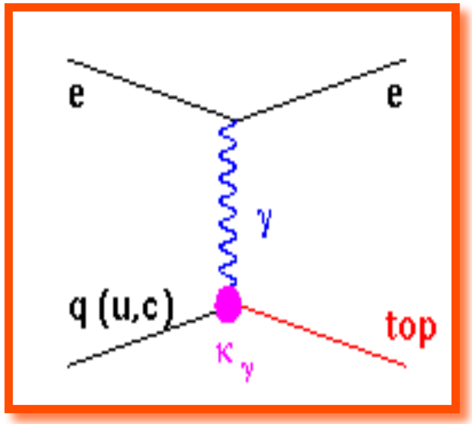
For f / Λ = 1 / M* :
e* till 1.2 TeV could be seen at the LHC.
LHeC has an extended reach up to ~ 1.4 TeV.

If LHC observes the single-production of e*: its properties could be studied at LHeC (larger single cross-section).

New physics in γqQ with Q = top or a new heavy quark

e.g. anomalous interactions of the top quark :

$$L = -g_e \sum_{q=u,c} Q_q \frac{\kappa_\gamma^q}{\Lambda} \bar{t}\, \sigma^{\mu\nu} (f_\gamma^q + h_\gamma^q \gamma_5) q A_{\mu\nu} + h.c.$$



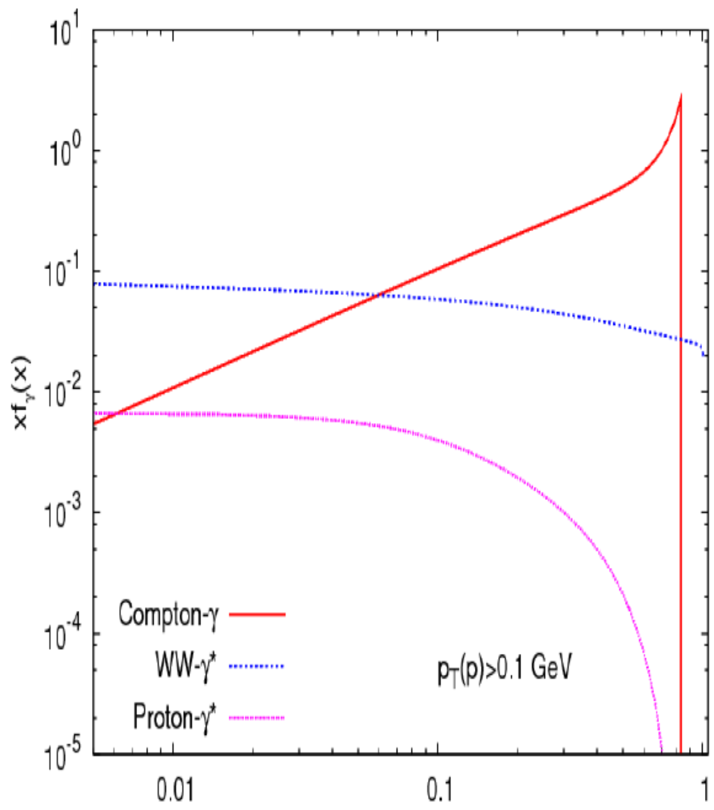
Or production of excited quarks, or of 4th generation quarks, via γqQ (or ZqQ) couplings

If coupling to the gluon, gqQ, is sizeable: LHC would probe a large mass domain.
If the coupling to the gluon is suppressed and only γqQ or ZqQ are sizeable, LHeC may bring some interesting information.

e.g. γqt : LHC 100 fb-1 should be able to probe anomalous couplings corresponding to BR(t ➔ qγ) down to 10^{-4} (100 better than the current bounds).
LHeC as an ep collider would not compete with that. However…

Anomalous top/Q production in γp collisions

Things look more promising if LHeC is operated in the γp mode (due to the larger $W_{\gamma p}$). Possible within the linac-ring option.

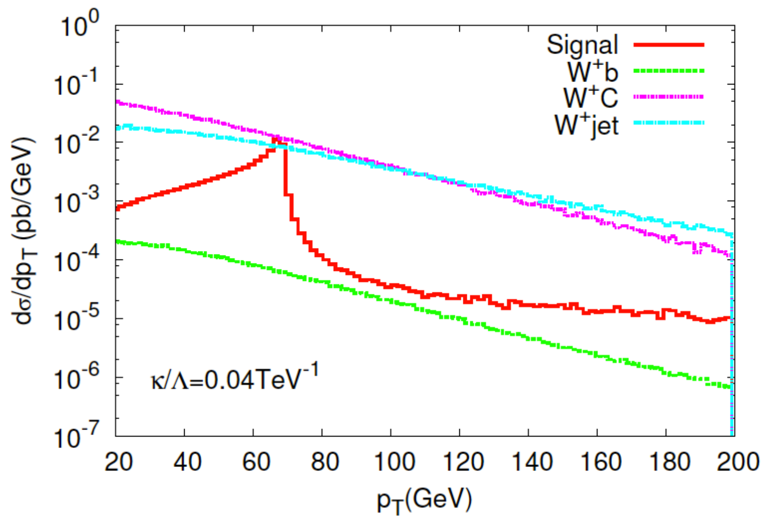


A laser hits the electrons and convert them into high energy real photons.

- 65% (max) of electrons can be converted – hence reduced the luminosity.
- on the other hand, no hour-glass in contrast to ep

Leads to much larger γp x-sections.

For single top: background is large, though.
b-tagging is important in order to reduce the Wj bckgd to an acceptable level.

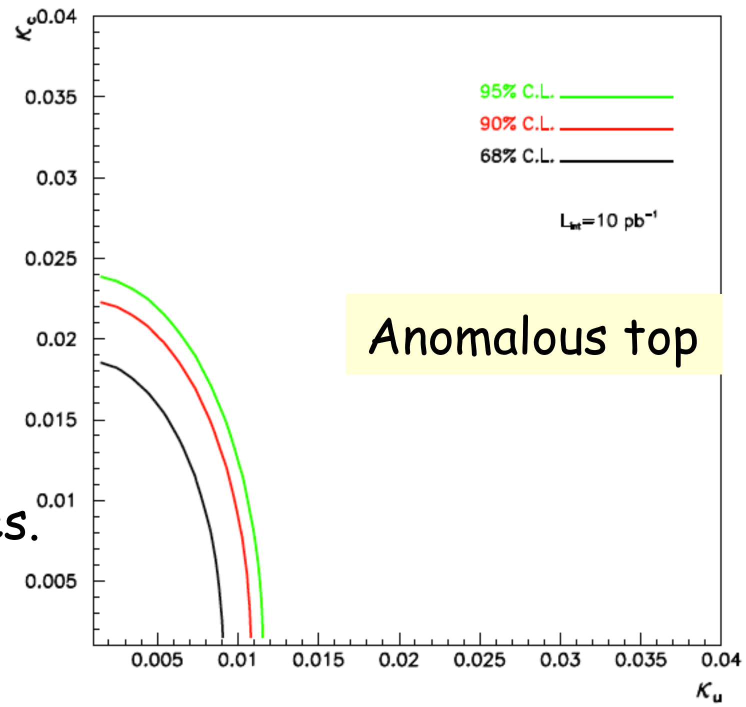


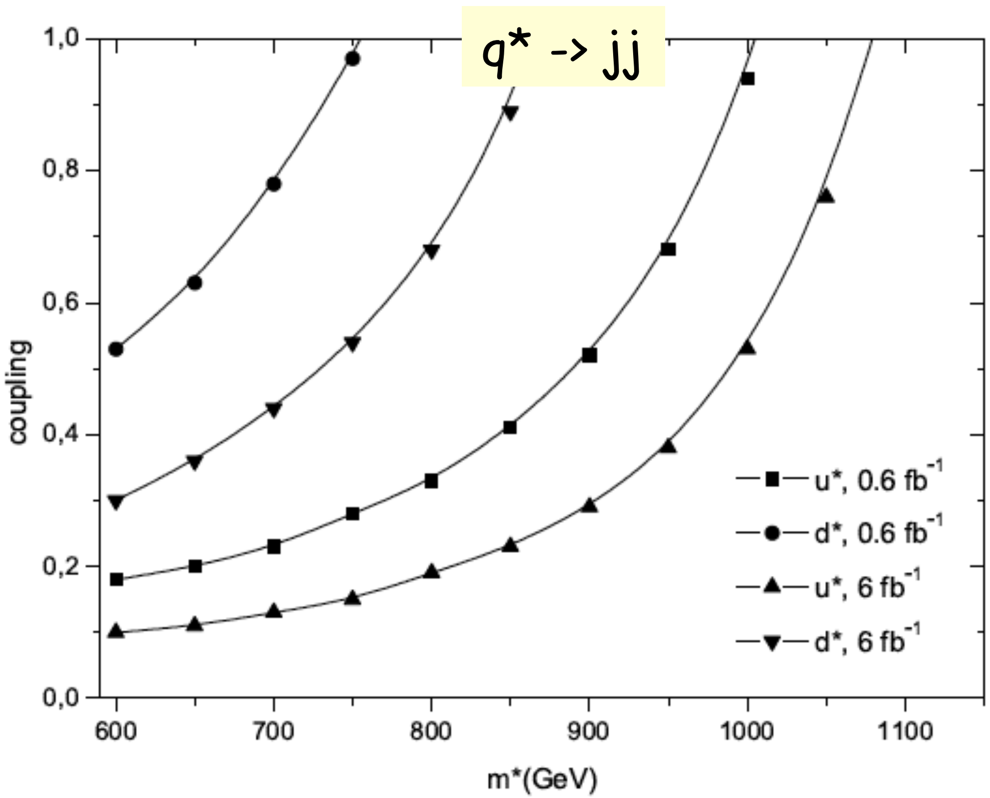
Examples of results

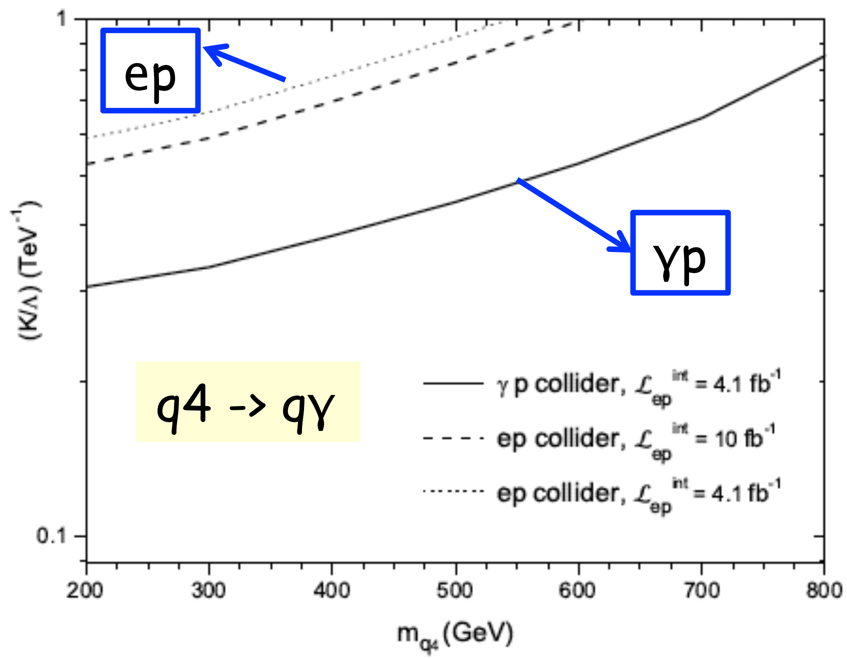
For 10 fb-1, sensitivity of κ/Λ ~ 0.01, i.e. wit the normalisation used BR (t ➔ qγ) ~ 2 10^{-6}

Could probe lower BR than the LHC.

Conversely: in the range of couplings that LHC could probe, LHeC would provide a large sample of FCNC top, for detailed studies.





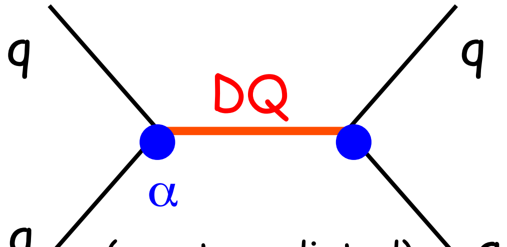


Diquarks (DQs) in γp collisions

Predicted in some superstring models. Scalar or Vector, can carry fractional electric charge.

	$SU(3)_C$	$SU(2)_W$	$U(1)_Y$	Q	Couplings
Scalar diquarks					
DQ_1	$3^\star$	1	2/3	1/3	$u_L d_L(g_{1L}), u_R d_R(g_{1R})$
$\widetilde{DQ}_1$	$3^\star$	1	−4/3	2/3	$d_R d_R(\tilde{g}_{1R})$
$\widetilde{DQ}'_1$	$3^\star$	1	8/3	4/3	$u_R u_R(\tilde{g}'_{1R})$
DQ_3	$3^\star$	3	2/3	$\begin{pmatrix} 4/3 \\ 1/3 \\ -2/3 \end{pmatrix}$	$\begin{pmatrix} u_L u_L(\sqrt{2} g_{3L}) \\ u_L d_L(-g_{3L}) \\ d_L d_L(-\sqrt{2} g_{3L}) \end{pmatrix}$
Vector diquarks					
$DQ_{2\mu}$	$3^\star$	2	−1/3	$\begin{pmatrix} 1/3 \\ -2/3 \end{pmatrix}$	$\begin{pmatrix} d_R u_L(g_2) \\ d_R d_L(-g_2) \end{pmatrix}$
$\widetilde{DQ}_{2\mu}$	$3^\star$	2	5/3	$\begin{pmatrix} 4/3 \\ 1/3 \end{pmatrix}$	$\begin{pmatrix} u_R u_L(\tilde{g}_2) \\ u_R d_L(-\tilde{g}_2) \end{pmatrix}$

Had. Collisions:



(α not predicted)

Existing constraints :

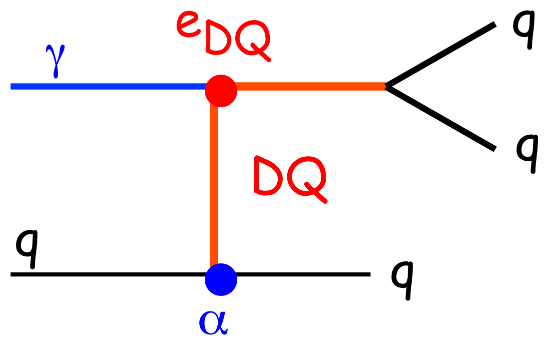
M(DQ) > ~ 650 GeV (CDF)

α < ~ 0.1

LHC could discover DQs up to large masses and measure the mass, spin, width. But what about e.g. the electric charge ??

Charge measurement of DQ

Single DQ production in γp collisions:



$\sigma = f\,(M, \alpha, e_{DQ})$ → e_{DQ}

↑↑ LHC

This diagram exist at LHC and in ep collisions. But much larger cross-section in γp collisions because of the much harder $E\gamma$ spectrum.

$W_{\gamma p}$ at LHeC >> $W_{\gamma p}$ at LHC

Hence can have larger cross-sections at LHeC !

γp collisions σ(fb)	LHeC(γp) Ee(GeV)		LHC(γp) (10TeV)	LHC(γp) (14TeV)
M_{DQ} (GeV)	70	140	5+5	7+7
700	36.56 (2.53)	189.37 (18.57)	8.29 (1.13)	12.23 (2.04)
1000	0.53 (0.03)	19.84 (1.39)	2.62 (0.30)	4.58 (0.64)

With 10 fb-1 :

~ 5σ for a scalar DQ of 700 GeV at Ee = 70 GeV

~ 7σ for a scalar DQ of 900 GeV at Ee = 140 GeV (1σ only at Ee = 70 GeV)

For α ~ 0.1, DQ can be studied up to ~ 1 TeV at LHeC.

Higgs at the LHeC

- For light Higgs, $e^- p \rightarrow \nu H X$ has sizeable cross section, O(0.1pb), at LHeC (WW fusion).
- Higgs should have been discovered at LHC, but Hbb coupling measurement might be tough in hadron collider environment.
- Using a cleaner environment, can LHeC do something interesting with $H \rightarrow bb$ events?

See the next talks.

Conclusions

Examples have been shown of cases where LHeC would bring some added value to the LHC discoveries :

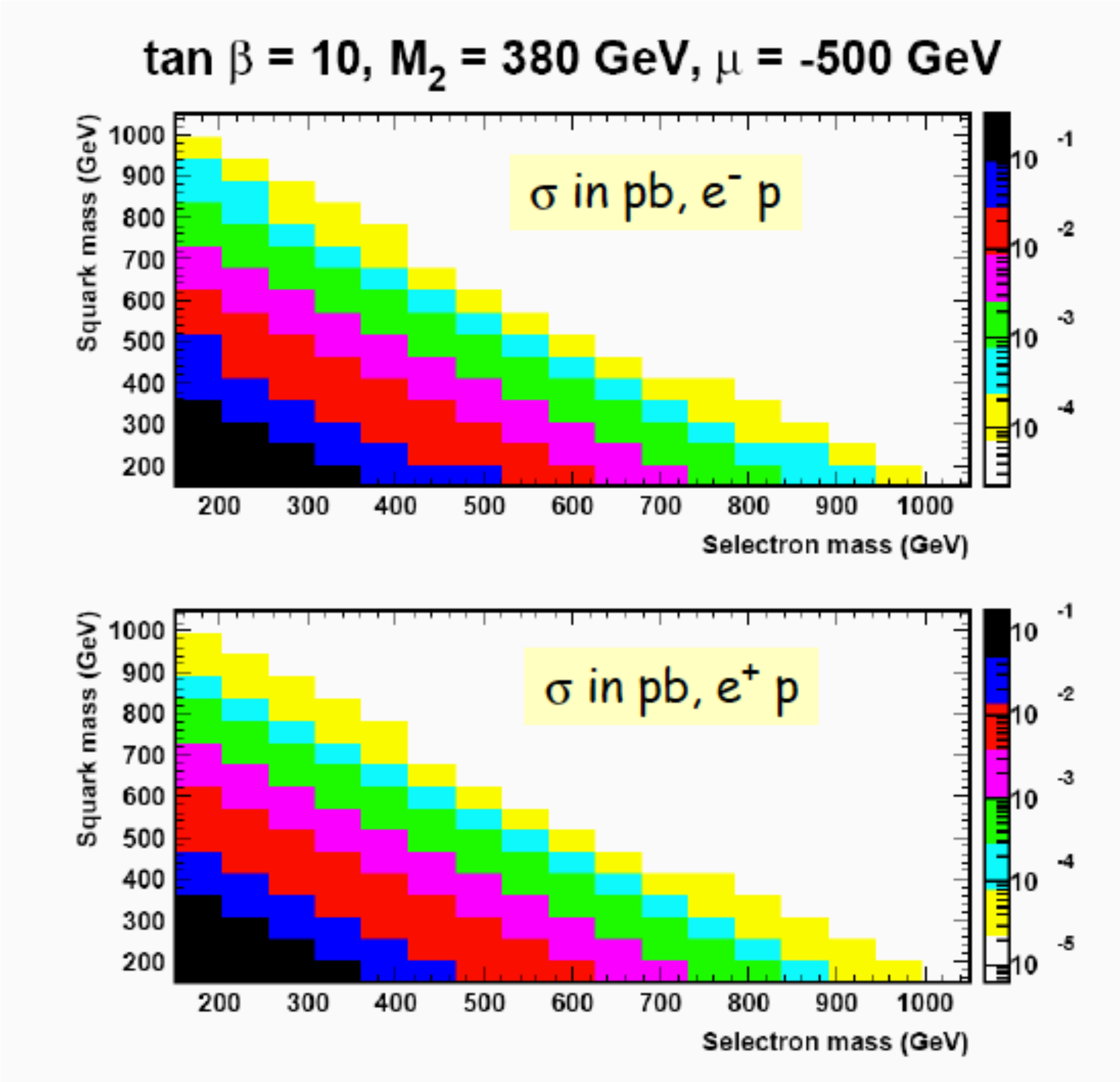
- resolving ambiguities :
  - ➔ eeqq contact interactions
- measurement of properties of new particles / interactions
  - ➔ in eq interactions: leptoquarks
  - ➔ in eγ interactions: new leptons
  - ➔ in γp interactions: new heavy quarks

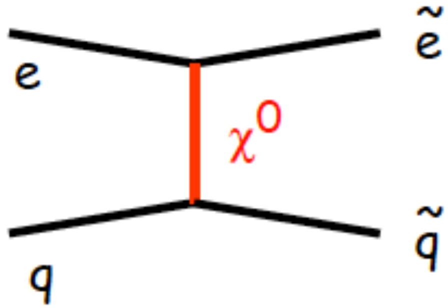
  also some discovery potential here …
- Higgs couplings

CDR chapter is in good shape. Will be ~ 40 pages.

Backups

SUSY





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