LHeC and New Physics at High Scales

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New co-convener: Georges Azuellos (Montreal)

LHeC unlikely to be a discovery machine:

New physics accessible at LHeC would be observed before at LHC.

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

- measurement of properties of new particles / interactions
- coupling of Higgs to bbar
- resolving ambiguities

Properties of BSM particles / interactions at LHeC: examples

- electron-quark resonances: nothing new at this workshop, but "typical" example.
  Work in progress by A.S. Belyaev (Southhampton) & G. Azzuelos joining us !

- Excited fermions: cf E. Sauvan & N. Trinh, Divonne 2008

- Diquarks : see Orhan Cakir

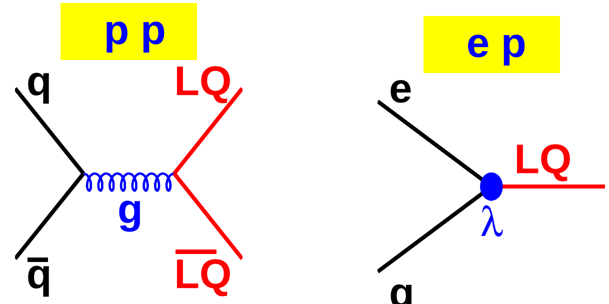
- Anomalous interactions of the top quark : e.g. $tq\gamma$ where q=u,c
  - in ep collisions: see G. Brandt at Divonne 2008
  - in γp collisions: see I. T. Cakir

- Anomalous interactions of 4th family leptons and quarks: see Abbas K. Cifti

- R-parity conserved SUSY: if $\Sigma M < \sim 1$ TeV, mass measurements more precise than what can be achieved at LHC ?

Electron-quark resonances

- "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

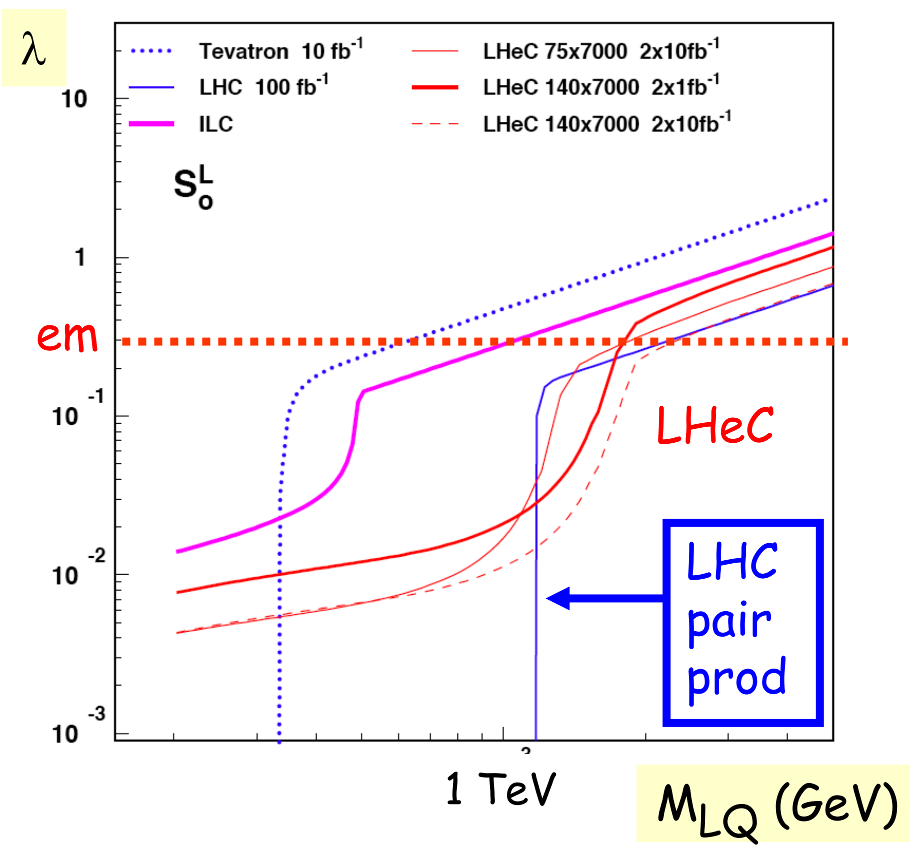


λ (unknown) coupling l-q-LQ

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.

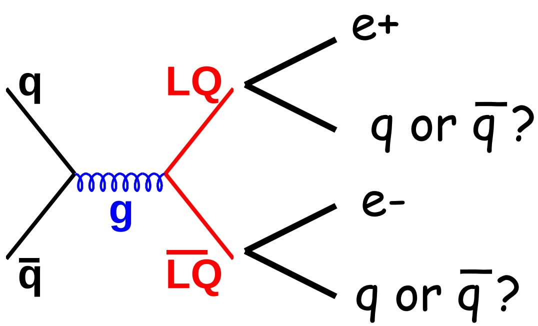
Quantum numbers ? Might be difficult to determine in this mode.

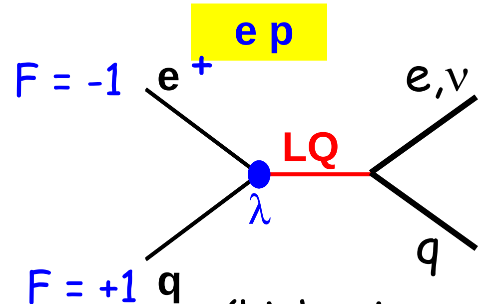
Determination of LQ properties

pp, pair production

ep, resonant production

- Fermion number



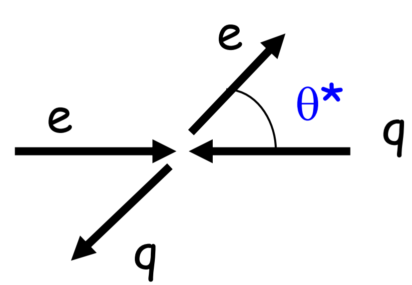


F=0 LQs : $\sigma(e^+)$ higher
F=2 LQs : $\sigma(e^-)$ higher

(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

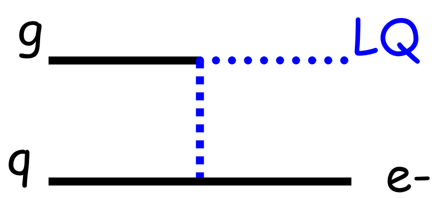
?

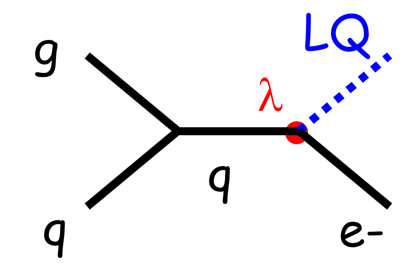
Play with lepton beam polarisation.

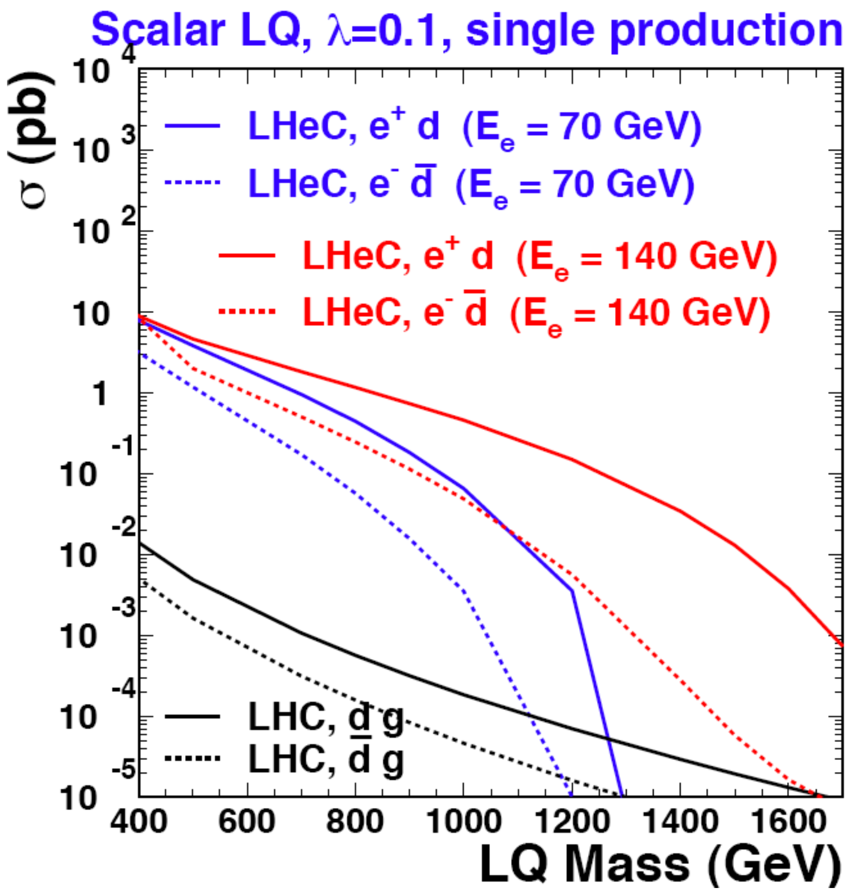
Single LQ production at LHC

Single LQ production is better suited to study "LQ spectroscopy".

Also possible in pp :







($\gamma \to ee$ followed by $eq \to LQ$ not considered yet.
Work in progress.)

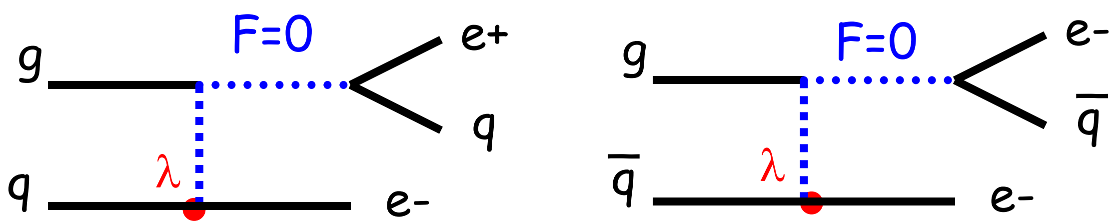
But with a much smaller x-section than at LHeC.
And large background from Z + 1 jet.

Not much considered yet by LHC experimental groups.

Pheno. study focusing on the extension of the discovery potential:
A.S. Belyaev et al, JHEP 0509 (2005) 005

Determination of LQ properties in single production: e.g. Fermion Number

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



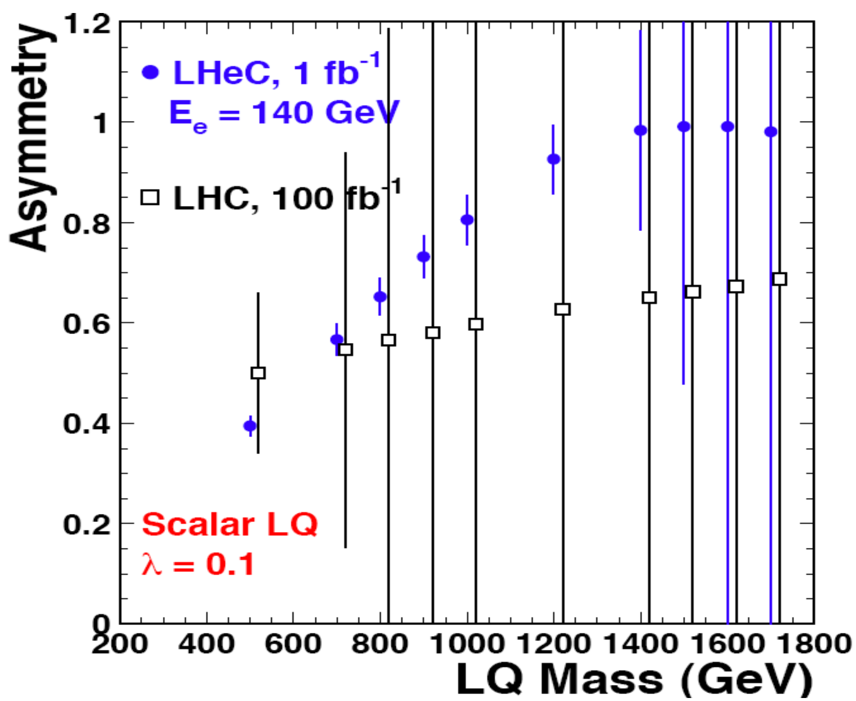
$\sigma(e^+_{out}) > \sigma(e^-_{out})$
for F=0

Sign of the asymmetry gives F, but could be statistically limited at LHC. (*)

Easier in ep ! Just look at the signal with incident e+ and incident e-, build the asymmetry between $\sigma(e^+_{in})$ and $\sigma(e^-_{in})$.

If LHC observes a LQ-like resonance, M < 1 - 1.5 TeV, LHeC could determine F if λ not too small.

(*) First rough study done for the 2006 paper.
Need to check / refine with a full analysis of signal and backgrounds.

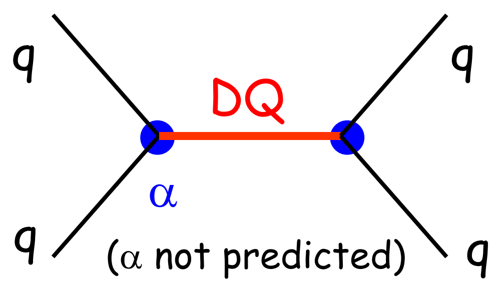


Orhan Cakir

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^*	1	2/3	1/3	$u_L d_L (g_{1L})$, $u_R d_R (g_{1R})$
$\widetilde{DQ}_1$	3^*	1	−4/3	2/3	$d_R d_R (\tilde{g}_{1R})$
$\widetilde{DQ}'_1$	3^*	1	8/3	4/3	$u_R u_R (\tilde{g}'_{1R})$
DQ_3	3^*	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^*	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^*	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:



Existing constraints :

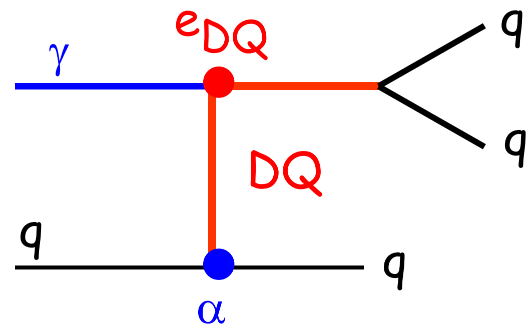
M(DQ) > ~ 650 GeV (CDF)

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 ??

Orhan Cakir

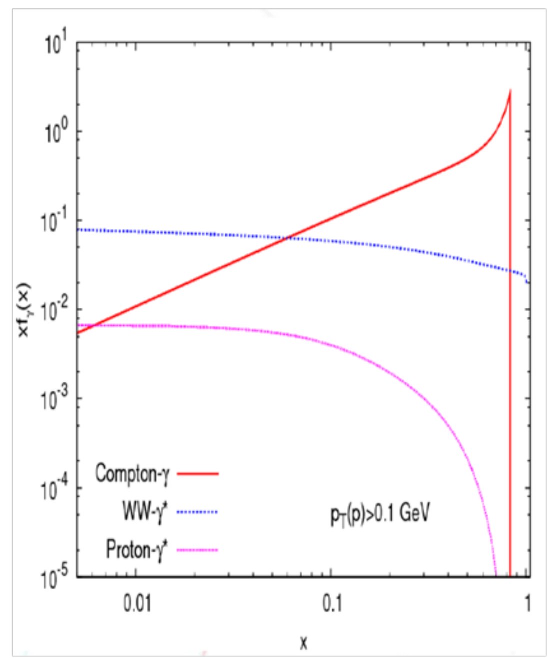
Single DQ production in γp collisions:



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



LHeC as a γp collider: see talk of Sultansoy on Tuesday.

NIM A 576 (2007) 287

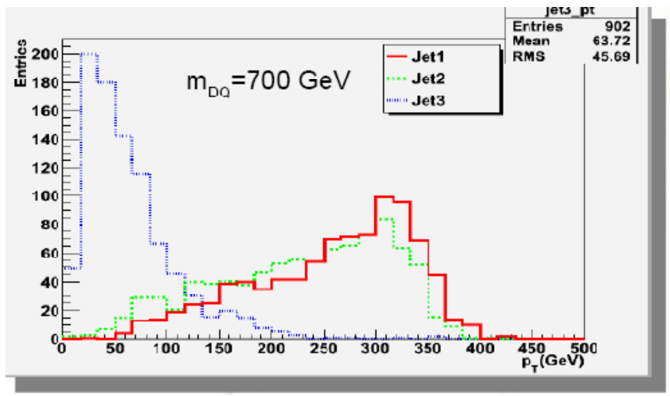
- 65% (max) of electrons can be converted.
- But no hour-glass effect (which reduces lumi) in contrast to ep

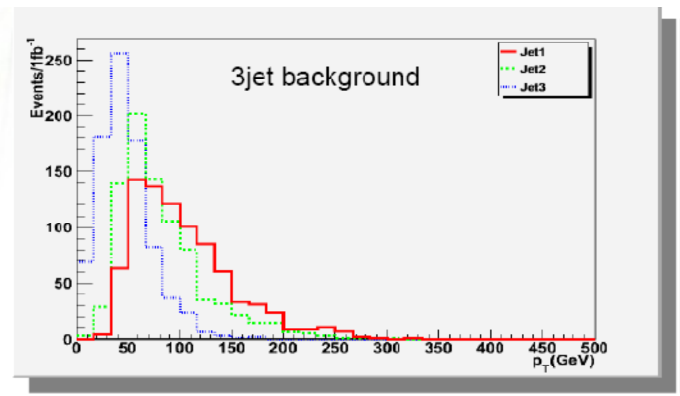
$W_{\gamma p}$ at LHeC >> $W_{\gamma p}$ at LHC

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)

Signal & 3-jet bckgd generated with CalcHEP + Pythia + PGS simul.





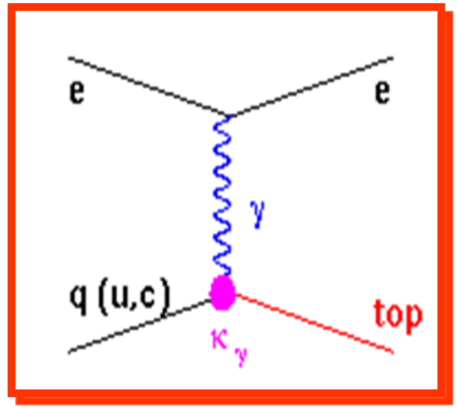
With 10 fb-1 :

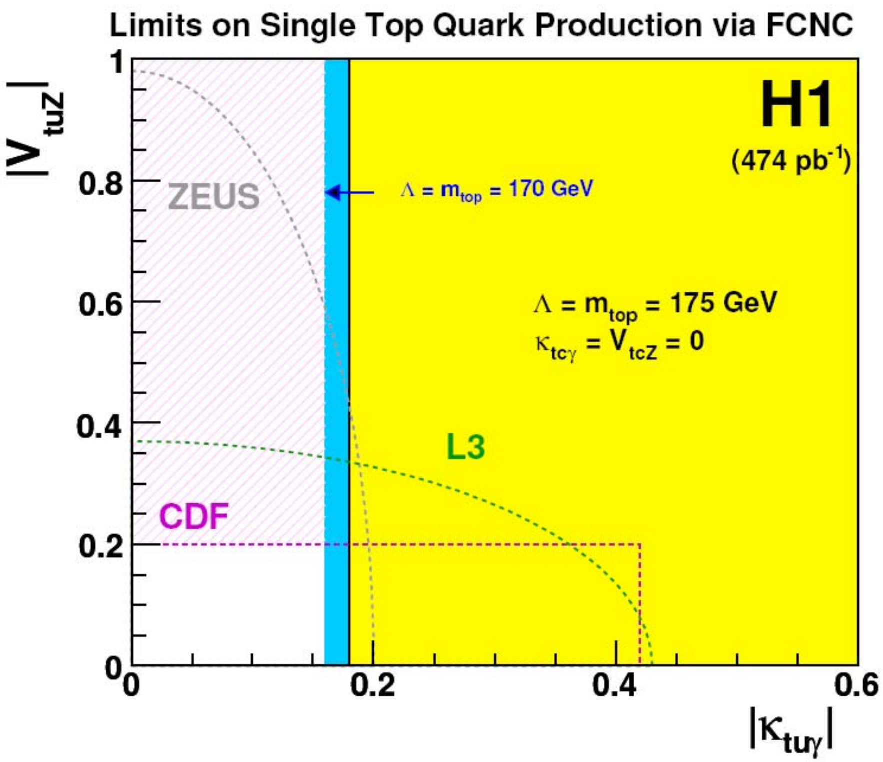
~ 5σ for a scalar DQ of 700 GeV at Ee = 70 GeV

~ 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.

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





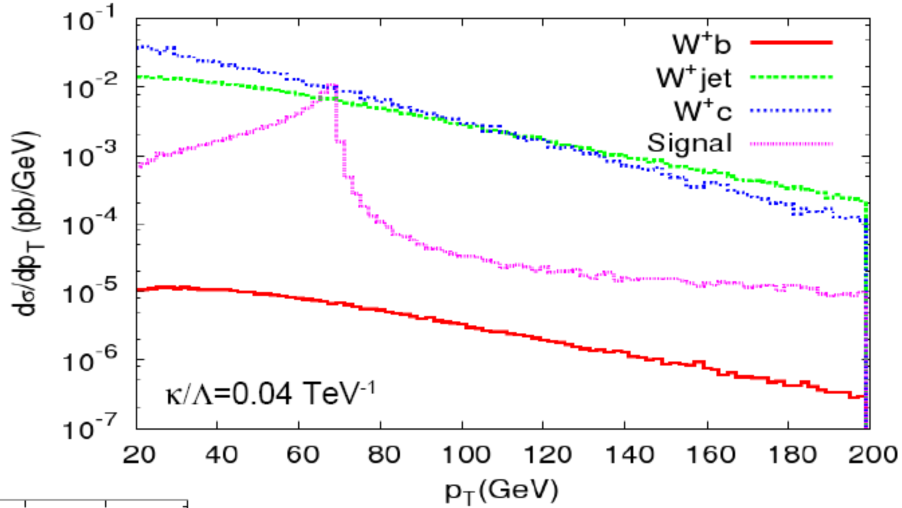
Investigated at HERA, LEP and Tevatron ($t \to q\gamma$)

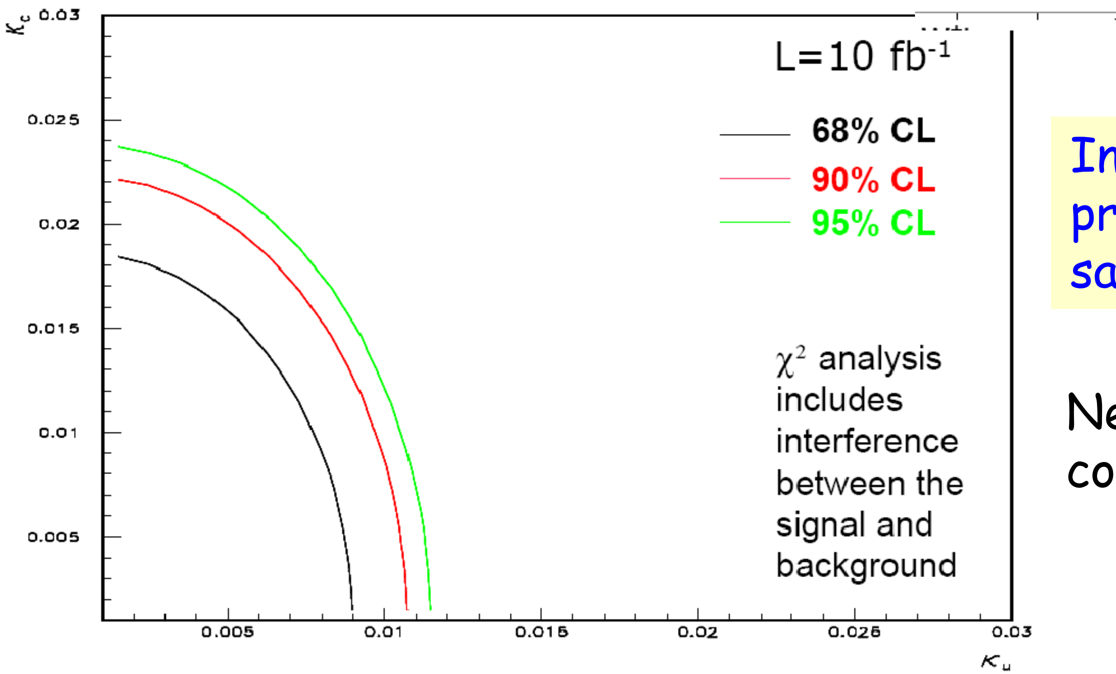
LHC 100 fb-1 should be able to probe anomalous couplings down to $\kappa \sim 0.01$.

Divonne 08: G. Brandt looked at FCNC top production at LHeC for $\kappa \sim 0.01$
→ Very low event rates.

Things look more promising if LHeC is operated in the γp mode (due to the larger $W_{\gamma p}$)

Background is large, though.
b-tagging is important in order to reduce the Wj bckgd to an acceptable level.





In the coupling range that LHC will probe, LHeC could provide large samples of FCNC top.

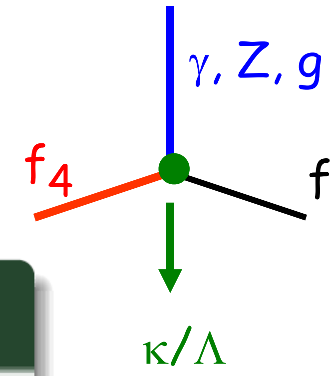
Next: study the added value / the complementarity w.r.t. LHC alone.

Fourth generation fermions

Abbas Ciftci

LHC : pp → $q_4\, q_4$ and pp → $l_4\, \nu_4$ via gauge couplings.

Large mass of f_4: anomalous couplings may exist.
→ Single production is then possible, similar to excited fermions.



☞ Anomalous single production of the fourth generation charged leptons at future ep colliders. ($E_e = 70 - 500$GeV)

- $ep \to l_4 X \to ZeX$
- A.K. Çiftçi et al., Mod. Phys. Lett. A23, 1047-1054 (2008).

☞ Anomalous single production of the fourth generation neutrino at future ep colliders. ($E_e = 70 - 500$GeV)

- $ep \to \nu_4 X \to \mu W X$
- $ep \to \nu_4 X \to e W X$
- A.K. Çiftçi et al., Phys. Lett. B660, 534-538 (2008).

☞ A Comparative Study of the Anomalous Single Production of the Fourth Generation Quarks at ep and γp Colliders. ($E_e = 60$GeV)

- $u_4(d_4) \to q\gamma$
- $u_4(d_4) \to qZ \to q\ell^+\ell^-$
- R. Çiftçi, A.K. Çiftçi, arXiv:0904.4489 [hep-ph].

Fourth generation leptons: single production

Abbas Ciftci

4^{th} generation leptons: cross-sections are much larger at LHeC than at LHC.
-> bigger sensitivity of LHeC.

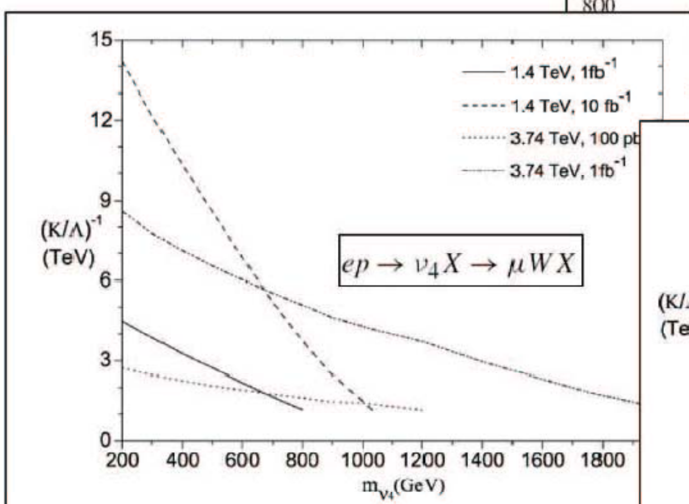
$$ep \rightarrow \nu_4 X \rightarrow W(e,\mu)X$$

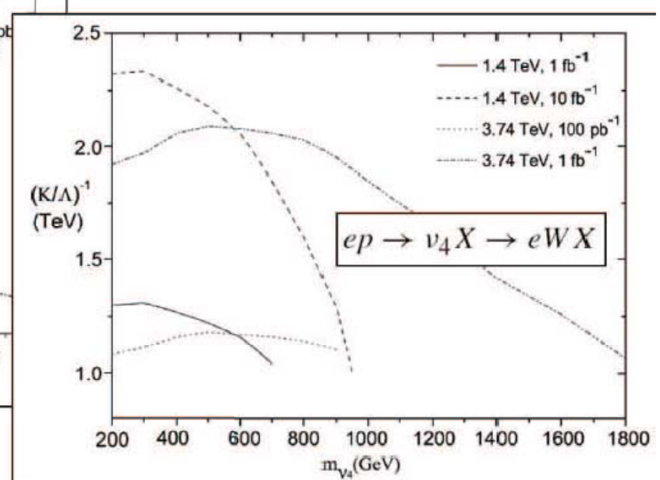
Event numbers of $ep \rightarrow \nu_4 X \rightarrow \mu W X$ for $\sqrt{s} = 1.4$ TeV, $(\kappa/\Lambda) = 1$ TeV^{-1}

m_{ν_4} (GeV)	N_S	
	$L_{int} = 1$ fb^{-1}	$L_{int} =$
200	201	2010
300	148	1480
400	106	1060
500	74	740
600	47	470
700	27	270
800	14	140
900	6	60
1000	2	22

The cross section of signal and background of $ep \rightarrow \nu_4 X \rightarrow eWX$ for $\sqrt{s} =$ 1.4 TeV, $(\kappa/\Lambda) = 1$ TeV^{-1}

m_{ν_4} (GeV)	σ_S (pb)	σ_B (pb)	SS	
			$L_{int} = 1$ fb^{-1}	$L_{int} = 10$ fb^{-1}
200	0.201	0.560	8.49	26.86
300	0.148	0.293	8.64	27.34
400	0.106	0.172	8.08	25.56
500	0.074	0.086	7.98	25.23
600	0.047	0.049	6.71	21.23
700	0.027	0.025	5.40	17.07
800	0.014	0.012	4.04	12.78
[illegible]	0.006	0.005	2.64	8.34
[illegible]	0.002	0.004	1.10	3.48





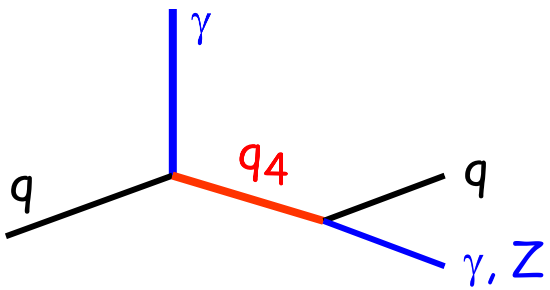
Similar conclusions on excited leptons by E. Sauvan and N. Trinh, Divonne 2008.

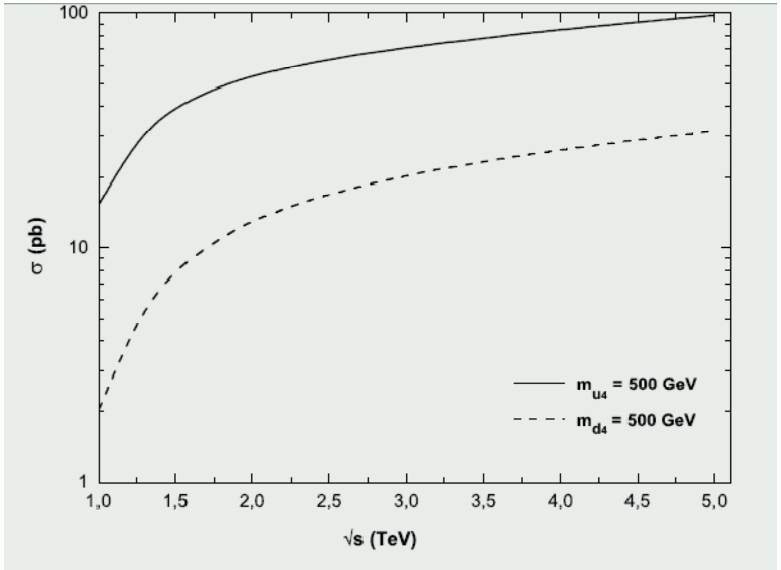
Fourth generation quarks: single production via $\kappa\gamma$ or κZ

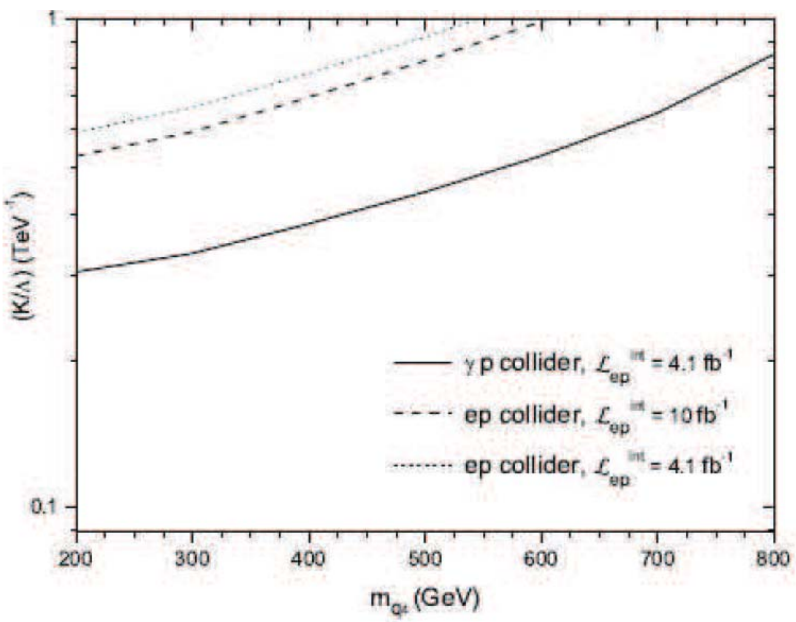
Abbas Ciftci

If coupling q_4 q g is large: large cross-section for single production in pp collisions. But if the only sizeable couplings are the EW ones ($\kappa g \sim 0$), LHC cross-sections are much lower.

In contrast, LHeC cross-sections can be large – especially in γp collisions:



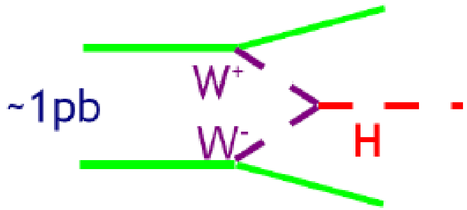


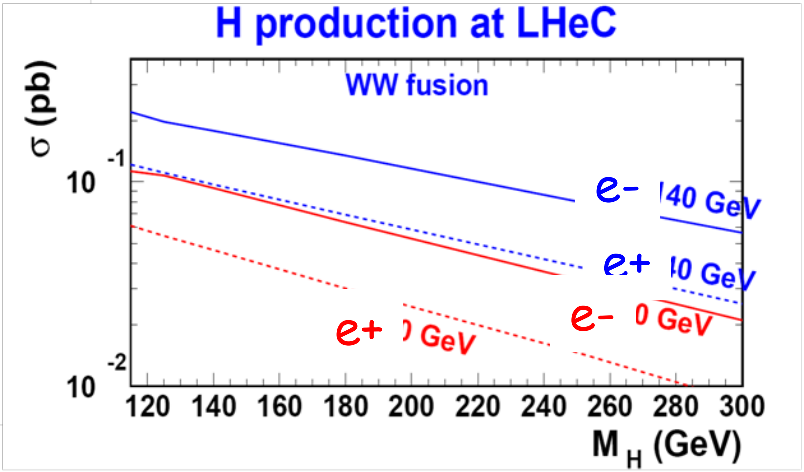


Event rates could be large enough that one could measure separately $\kappa\gamma$ and κZ.

Measurement of the Hbb coupling

- For light Higgs, e⁻p →νHX 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→bb events?





Uta Klein
Masahiro Kuze, Masaki Ishitsuka, Kengo Kimura and Junpei Maeda

SM Higgs production at LHeC

U. Klein, M. Kuze

First S/B estimates at Divonne 2008:
- signal: parton-level cuts on Ptb and Ptnu, no detector simulation
- CC background generated by DJANGO

Now:

use MadGraph to simulate both the signal and the background
- events are hadronized by PYTHIA
- Higgs decayed to bbar by PYTHIA
- interfaced to "PGS" (simulation of a LHC-like detector)

Many efforts by Uta & interactions with program authors to get MadGraph+PYTHIA work for ep as well. Was not trivial to get the partonic events "dressed" into ep events.

CC background: generated with MadGraph.
But differences between the two groups, esp. in the parton multiplicities & the cuts applied at the generator level.

SM Higgs at LHeC: before b-tagging

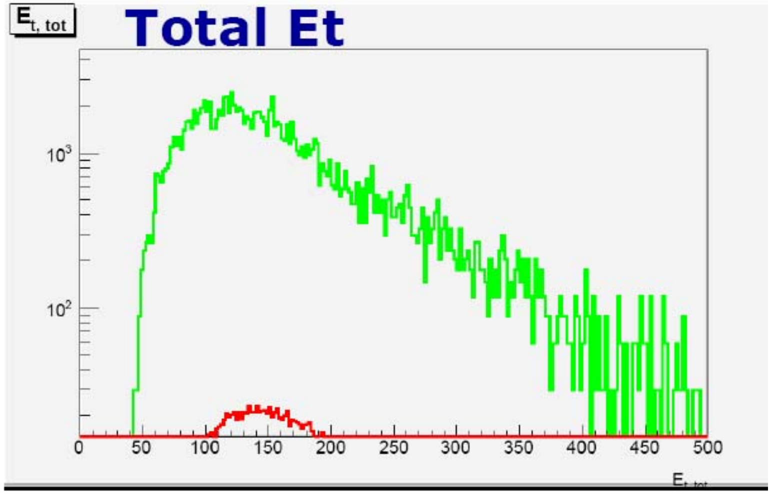
Uta Klein

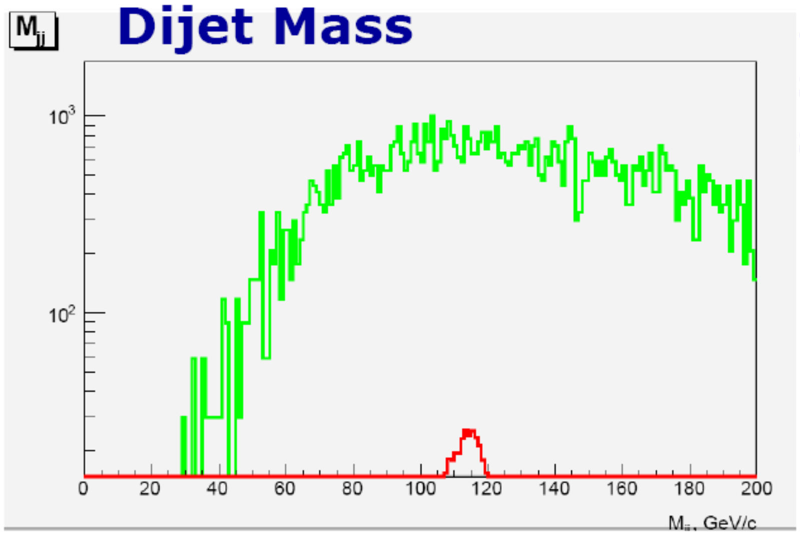
Ee = 150 GeV

MET > 20 GeV, at least 2 jets PT > 20 GeV

Signal and Background

- 10 fb-1
- 2-jets with lowest rapidity
- Total Et for pre-selected events (kin. cuts) is different for signal and background





80 < Mjj < 125 GeV

Signal (red) : 534.52

Signal + Background : 30873.2

Ratio S/(S+B) = 1.73 %

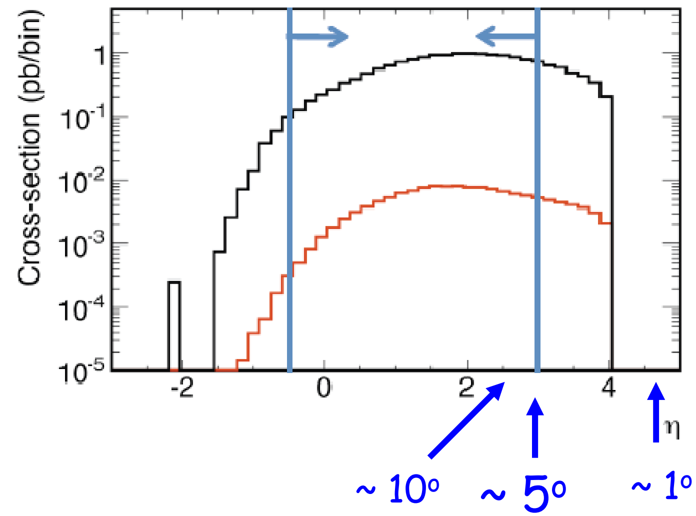
Ratio S/sqrt(S+B) = 3.04

B-tagging will be crucial.

SM Higgs at LHeC : applying b-tagging

Ee = 50 GeV

- MissEt > 20 GeV cut applied first.
- Njet >= 2 required, with Pt(jet) > 20 GeV and -0.5 < η(jet) < 3



Jet flavor tagging condition

1. Jet vertex: |z| < 60cm
2. Jet direction: |η| < 2.0

If *b* exists in 20 deg. cone of the jet => $f_b(E_T, \eta)$

Else if *c* exists in 20 deg. cone of the jet => $f_c(E_T, \eta)$

Else if *uds* or *gluon* exists in 20 deg. cone of the jet => $f_{udsg}(E_T, \eta)$

Consider a "loose" and a "tight" working points.

$f_b(E_T, \eta)$, $f_c(E_T, \eta)$ and $f_{udsg}(E_T, \eta)$ are b-tag efficiency functions from CDF Run 2.

ε_b up to ~ 50%, ε_c ~ 10%, ε_{light} ~ 2%

SM Higgs at LHeC : applying b-tagging

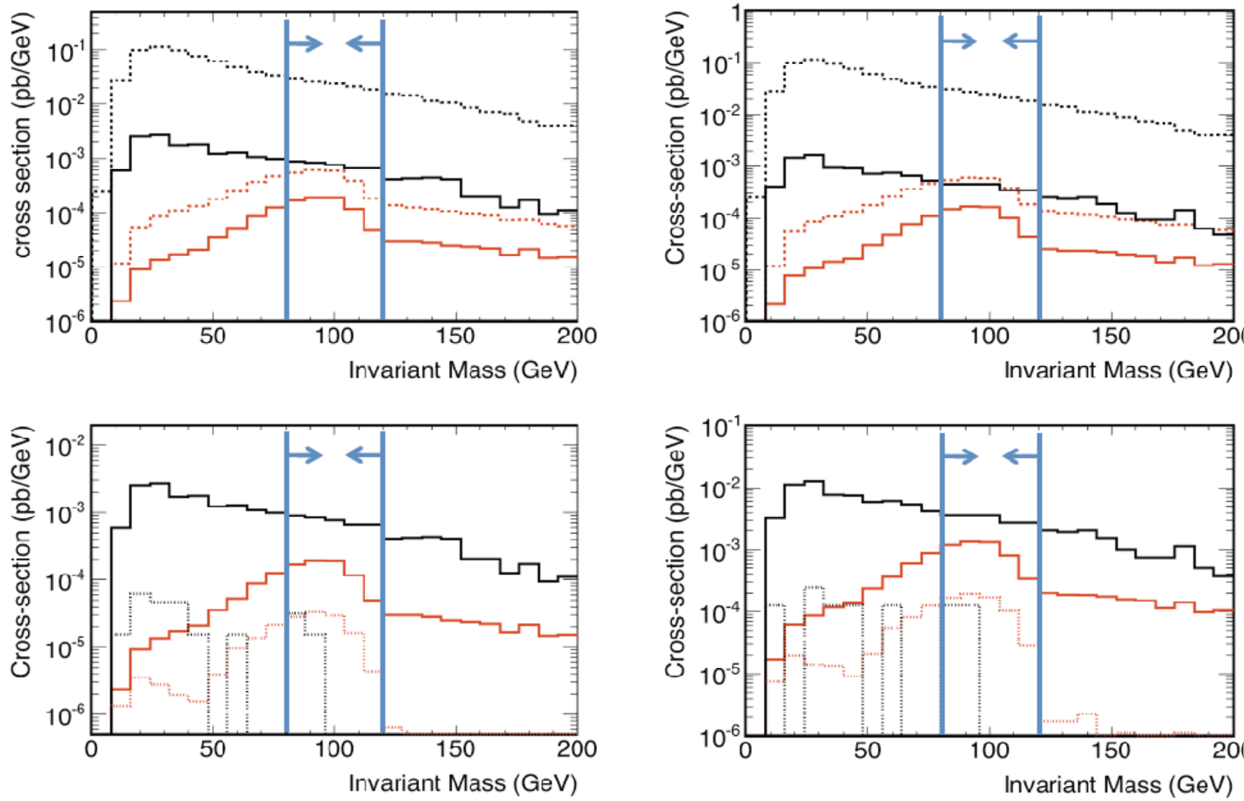
M. Kuze

$E_{electron}$ = 50GeV

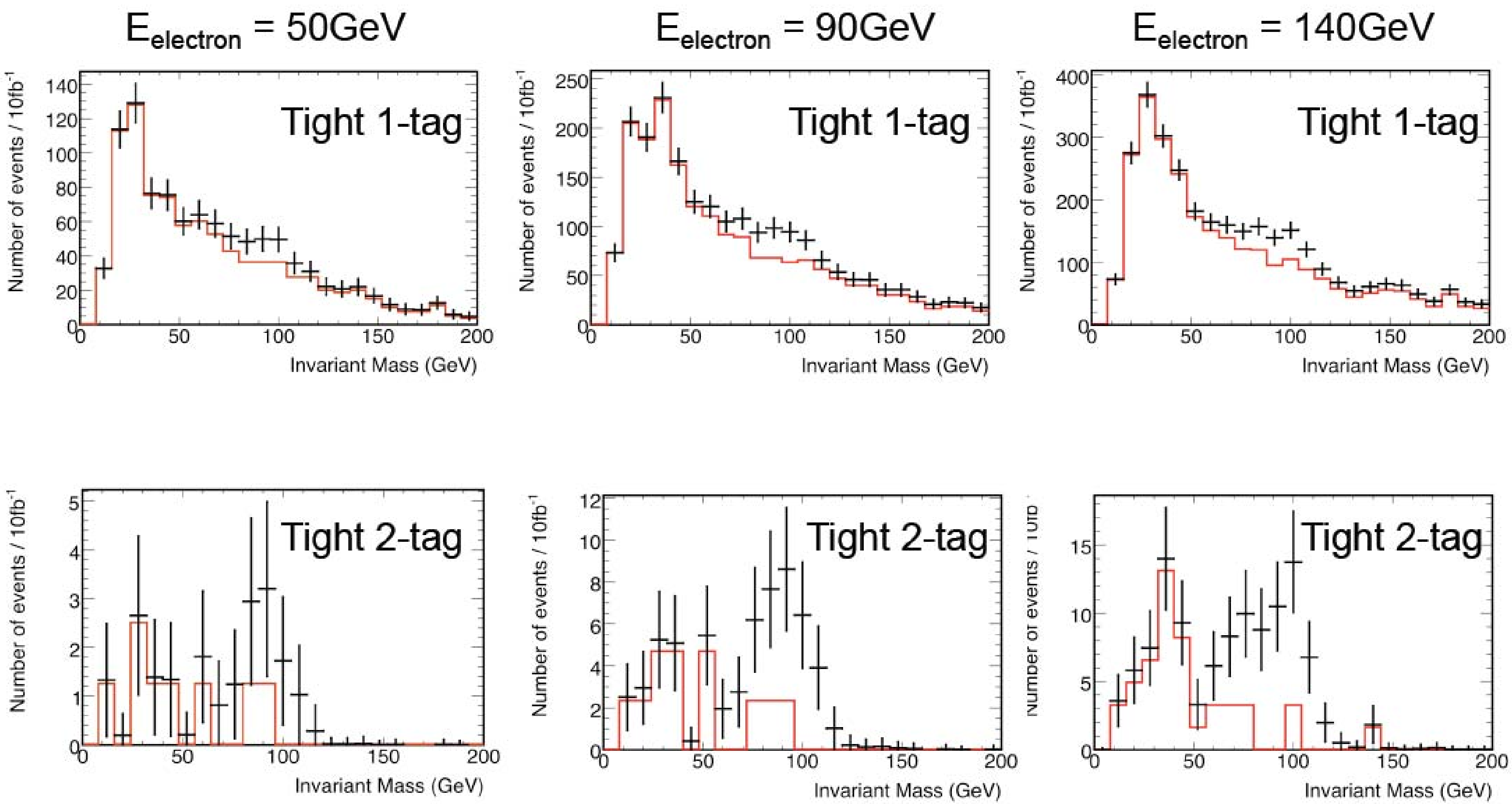
- **1-tag**
  dashed: before b-tag
  solid: single b-tag

- **2-tag**
  solid: single b-tag
  dotted: double b-tag

Loose | Tight



Of course, higher E_e is nice…



Number of events for $10fb^{-1}$

M. Kuze

- Mass window set to 80 < Mjj < 120 GeV

- #Higgs/#CC table for E_e and b-tag setting

	50GeV	90GeV	140GeV
Loose 1-tag	57.7/306	132/591	199/776
Loose 2-tag	8.88/3.77	31.5/7.06	53.1/11.5
Tight 1-tag	50.2/165	116/322	176/483
Tight 2-tag	6.68/2.51	22.9/4.71	38.5/3.28

(CC numbers for 2-tag cases are MC statistics limited)

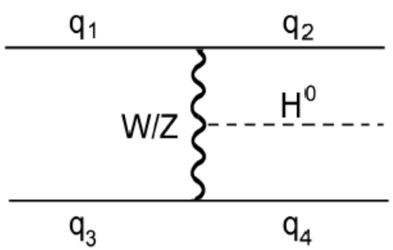
- S/N of 0.19(0.31) could be achieved for loose(tight) 1-tag with 58(50) Higgs candidates in mass peak. (with 50 GeV beam and 10 fb^{-1})
- For 2-tag, S/N will be 2.4(2.7) for 8.9(6.7) events.

Increase S/B using forward tagging ?

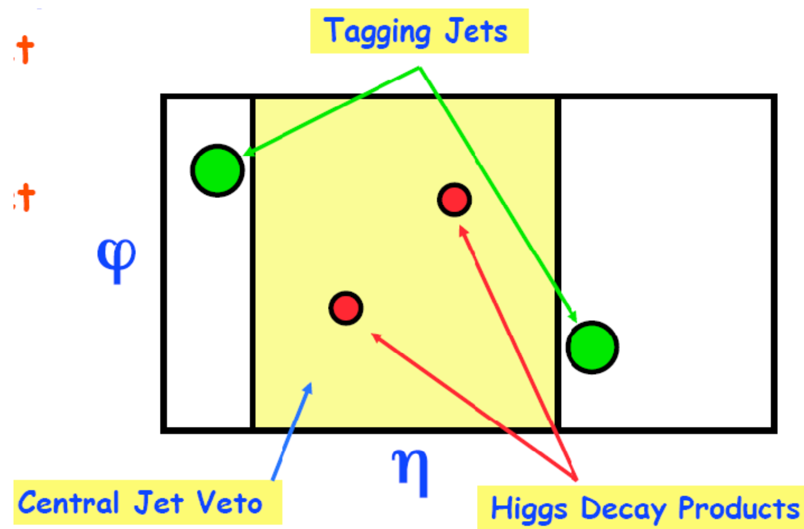
T. Han, B. Mellado

(slides linked to the agenda)

cf. WW → H analyses at LHC:



- **Unlike QCD partons that scale like $1/P_T^2$, here P_T~sqrt(1-x)M_W**



Ee = 140 GeV

- ep analysis done with MadGraph
- CC background: tb, bbj, jjj
- part of photo-prod background
- no hadronization; smear partons; param. b-tagging

T. Han, B. Mellado

Note increase of S/B as forward parton tagging and M_{HJ} cuts are applied

Obtain S/B ~ 5 at Ee = 140 GeV, with ~ 100 Higgs events in 10 fb-1

S/B decreases from ~ 5 to ~ 2.2 when σ_E/E degrades (7% at 100 GeV → 9%)

- **Use of forward jet tagging to isolate the Higgs signal at LHeC very important**
  - **Forward jet tagging secures feasibility of the Higgs search in CC and NC events**
- **Excellent hadronic jet resolution and high b-jet tagging efficiency are critical experimental issues**
  - **Lowering jet P_T thresholds to 20 GeV (parton-level) leads to significant enhancement of signal yield**
  - **Good control of top background required**
- **The sensitivity can be improved significantly**

- this analysis takes into account more background processes than Uta or Masahiro et al (e.g. explicitly simulate tb)
    - need to converge on that for the CDR
- Nice to see that this can still be controlled via e.g. fwd tagging, i.e. we do have some safety margin.

Resolving ambiguities

Examples:

- New Z' model, or eeqq contact interactions : pp data alone can not determine the whole structure of the new interaction.
  Need e.g. ep data to get the full picture.

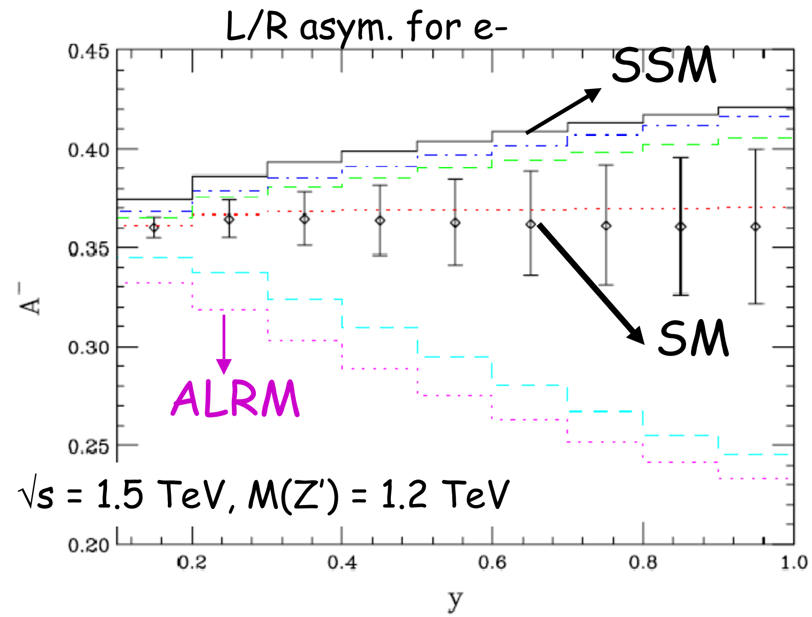
- Can we face ambiguities between new physics at LHC and pdf effects ?

Examples of new physics in eeqq amplitudes

- **new Z' boson**: pp measurements alone do not allow for a model-independent determination of all of the Z' couplings ($g_{L,R}^{e}$, $g_{L,R}^{u,d}$)

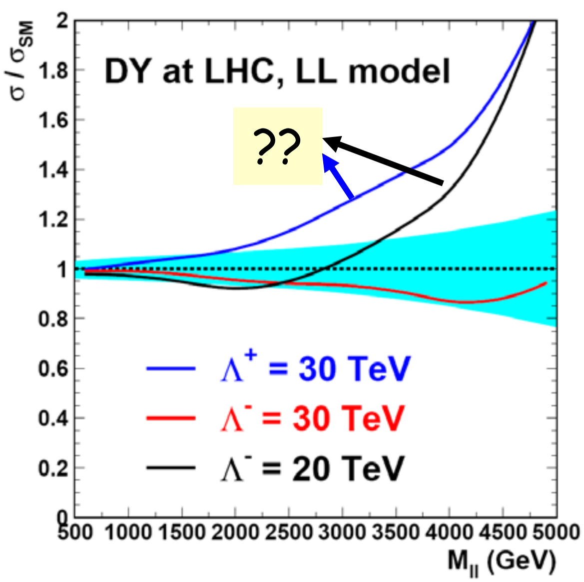
LHeC data may bring the necessary complementary information, before a LC.

T. Rizzo, PRD77 (2008) 115016

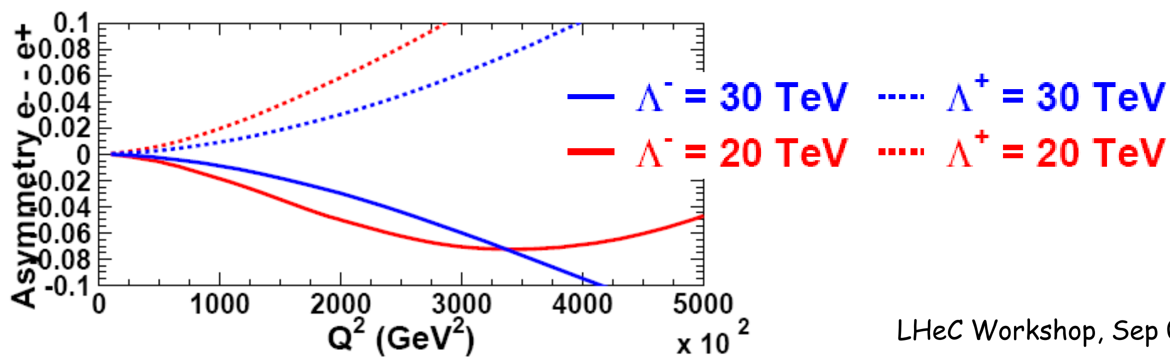


- **Contact Interactions:**

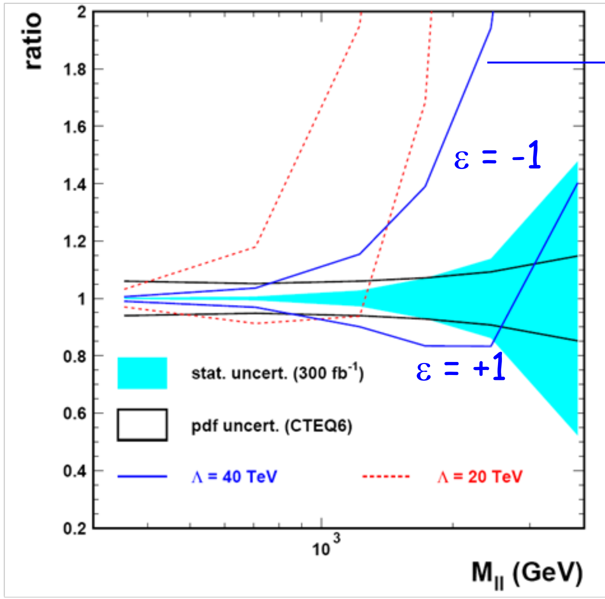
$$\mathcal{L}_{CI} = \sum_{i,j=L,R} \varepsilon_{ij}^{eq} \frac{4\pi}{\Lambda^2} (\bar{e}_i \gamma^\mu e_i)(\bar{q}_j \gamma_\mu q_j)$$



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



New Physics in Drell-Yan final states vs PDF effect

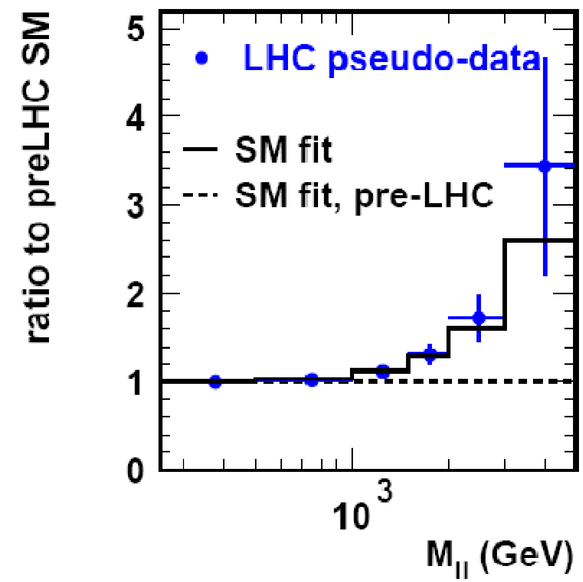


This example NP scenario leads to large deviations w.r.t. SM Drell-Yan.

New Physics ? Or SM with different Pdfs ?
Generate LHC pseudo-data within this NP scenario and include them in a DGLAP fit together with DIS data (HERA & BCDMS) .

the effects of this NP scenario can easily be accommodated within DGLAP !

(the fit increases the antiquarks at x ~ 0.1)



LHeC data would allow to disentangle between this NP scenario and increased antiquark pdfs.

Need to:
- check whether this statement remains true when more data are included in the fit (esp. E866 DY data bring constraints on antiquarks at high x…)
- study further what can be done at LHC (ratio central / less central, vary E..)

Conclusions

- Prospects for a measurement of Hbb at LHeC are encouraging.
  - big progress since last workshop
  - this physics case sets some constraints on the detector (b-tagging, Cal. Performance)

- New examples of precision measurements that could be done at LHeC, following the discovery at LHC of given NP scenarios : diquark electric charge; anomalous couplings to top or 4^{th} generation. In some cases, would gain to operate LHeC as a γp collider.