NEW PHYSICS AT LARGE SCALES

Emmanuelle Perez, CERN

Georg Weiglein, IPPP Durham

Divonne, 09/2008

Introduction

- What are we after? Why now?
- Exciting early LHC results may provide us with a window of opportunity to bring a new major facility on the way and in this way to secure a long-term future of the field

→ We need to be in a position to make a well-informed decision on what is the best option for the future

Goal: a CDR for the LHeC

- Thorough study of physics potential required
- Results need to be compared with the capabilities of the LHC, the ILC, CLIC, ...
- The studies must be sufficiently advanced and realistic to stand the comparison with the analyses carried out for other colliders

⇒ A lot of work will be needed to achieve this

LHeC-specific issues

- Ring-Ring (RR) vs. Linac-Ring (LR) option
- RR: energy limited (70 GeV), better prospects for higher luminosity
- LR: energy not physics limited, 140 GeV; which luminosity can be reached with how much electrical power?
- Impact of beam polarisation: e^-, e^+?
- Detector requirements, angular acceptance, …

Should we agree on a common set of parameters (energy, integrated lumi, …) for all studies?

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?

New Physics Working Group at Divonne

- Dedicated New Physics session: 4 talks
- Joint session with electroweak WG: 5 talks

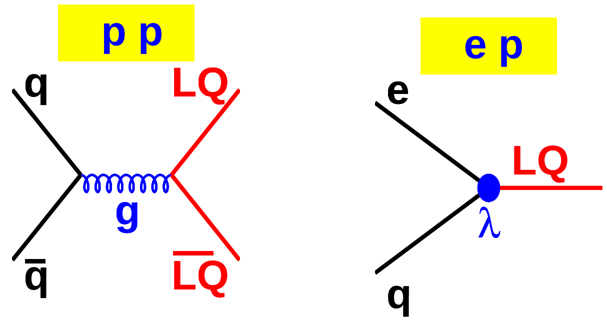
Very active sessions, thanks a lot to all contributors!

Definition used in the summary talks:
Higgs = new physics
Drell-Yan = electroweak

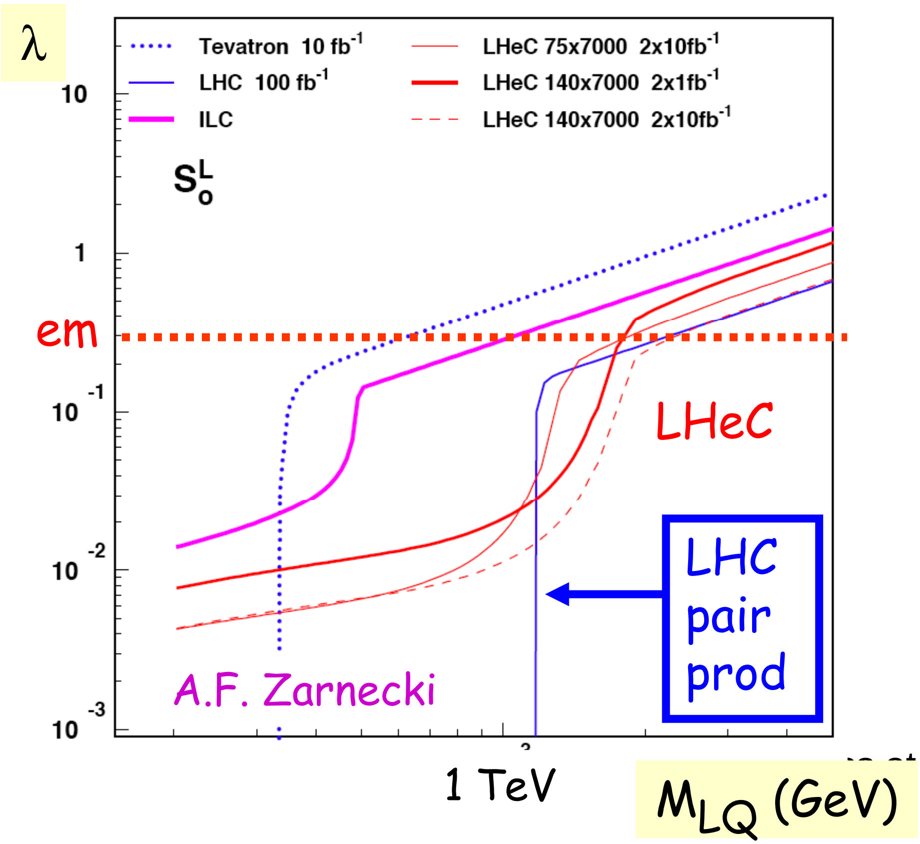
Electron-quark resonances

E. Perez

- "Leptoquarks" (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 : 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.

ep : golden machine to study LQ properties

E. Perez

F = 0 or 2 ?	Compare rates in e^-p and e^+p
Spin ?	Angular distributions
Chiral couplings ?	Play with polarisation of lepton beam
Couples to ν ?	Easy to see since good S/B in νj channel

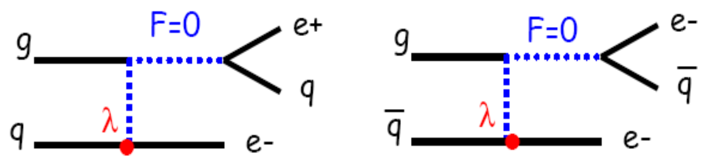
Classification in the table below relies on minimal assumptions.
ep observables would allow to disentangle most of the possibilities (having a polarised p beam would complete the picture).

		$S_{0,L}$	$S_{1,L}$	$\tilde{S}_{0,R}$	$S_{0,R}$	$S_{1/2,L}$	$\tilde{S}_{1/2,L}$	$S_{1/2,R}$
F = 2	$S_{0,L}$		β_ν	P_e	P_e			
	$S_{1,L}$	β_ν		P_e	P_e		e^+/e^-	
	$\tilde{S}_{0,R}$	P_e	P_e		P_p			
	$S_{0,R}$	P_e	P_e	P_p				
F = 0	$S_{1/2,L}$						P_p	P_e
	$\tilde{S}_{1/2,L}$			e^+/e^-		P_p		P_e
	$S_{1/2,R}$					P_e	P_e	

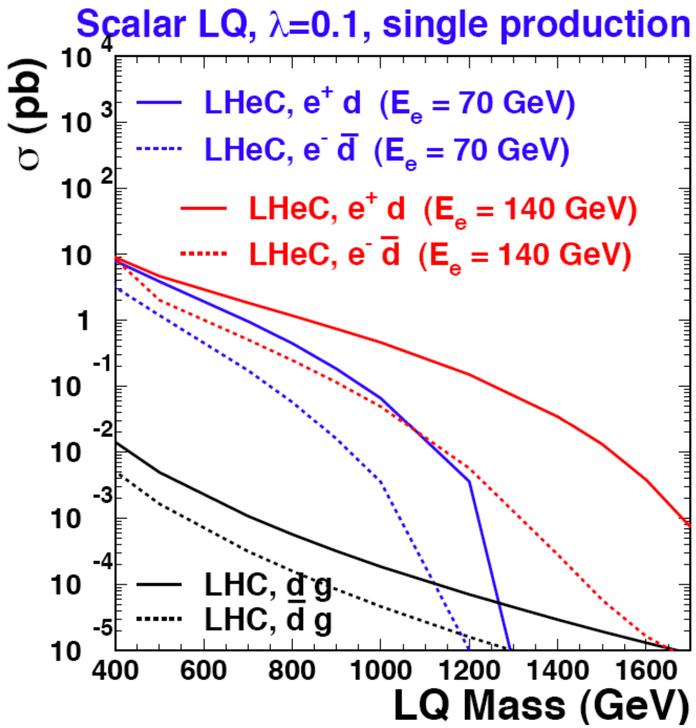
If LHC observes a LQ-like resonance, M below 1 – 1.5 TeV, LHeC could solve the possibly remaining ambiguities (if λ is not too small)

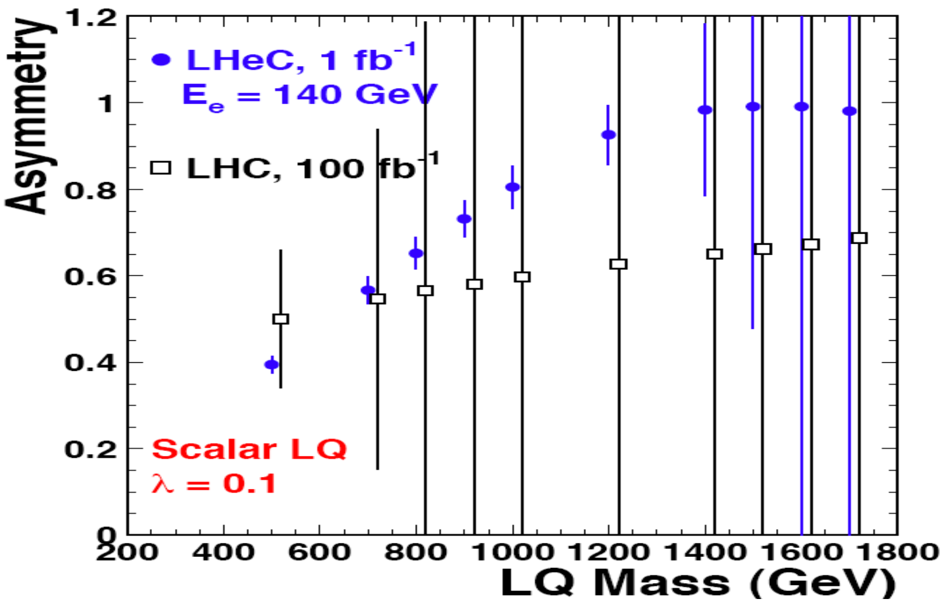
"LQ spectroscopy" : LHeC versus single LQ production at LHC

E. Perez



$\gamma \rightarrow$ ee followed by eq -> LQ not considered yet. Sasha Belyaev (Southampton) proposed to work on this.





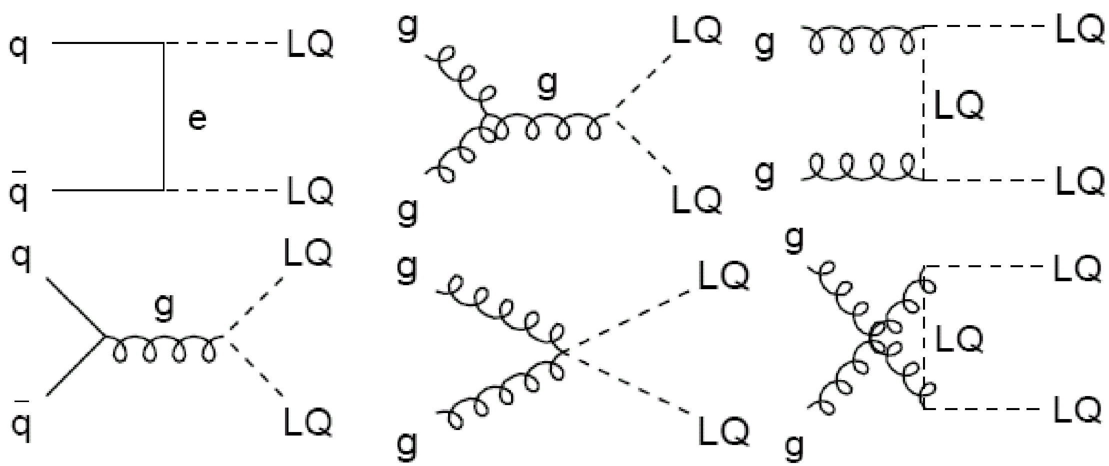
LHC potential for determining the LQ fermion number – crude analysis as done for the JNST paper.

Single LQ at the LHC, with realistic background simulation: see talk by Theodora Papadopoulou (Athens).

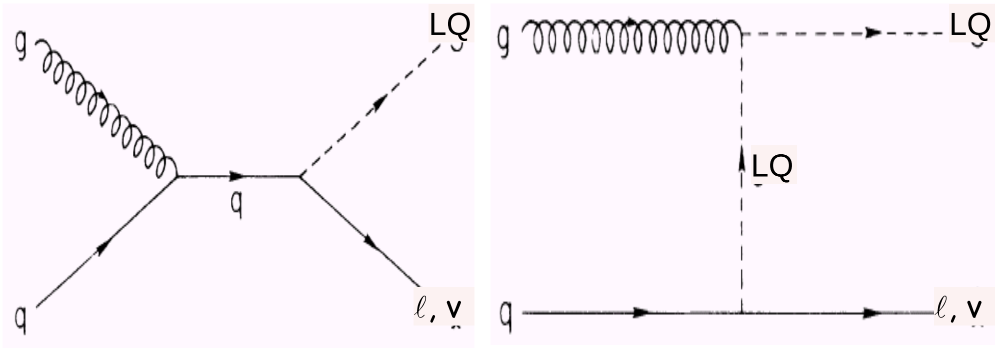
LQ production at LHC

Th. Papadopoulo

- **Pair production**
  - **Practically independent of Yukawa coupling λ**
  - **Depends mainly on LQ mass**



- **Single production**
  - **strongly depends on λ**
  - **possible signatures:**
    - **ℓ⁺ℓ⁻ + jet**
    - **ℓν + jet**
    - **νν + jet**



❖ **Both categories (Pair and Single) LQs are complementary for LHC searches**

Cut flow for Single LQ (m=400 GeV)

Th. Papadopoulo

PRELIMINARY RESULTS

Physics sample	Before cuts	Baseline cuts	$pT_{max}\mu_{1,2} \geq 100$ GeV $pT_{max}j \geq 100$ GeV b-tag weight ≤ 4	SPT ≥ 500 GeV	$M_{\mu\mu} \geq$ 200 GeV	LQ mass window (±2σ)
MLQ = 400 GeV	3680	2432	666	613	457	402
Z/DY ≥ 150 GeV	72780	33626	689	586	360	118
t tbar	420000?	86581	42	28	28	14

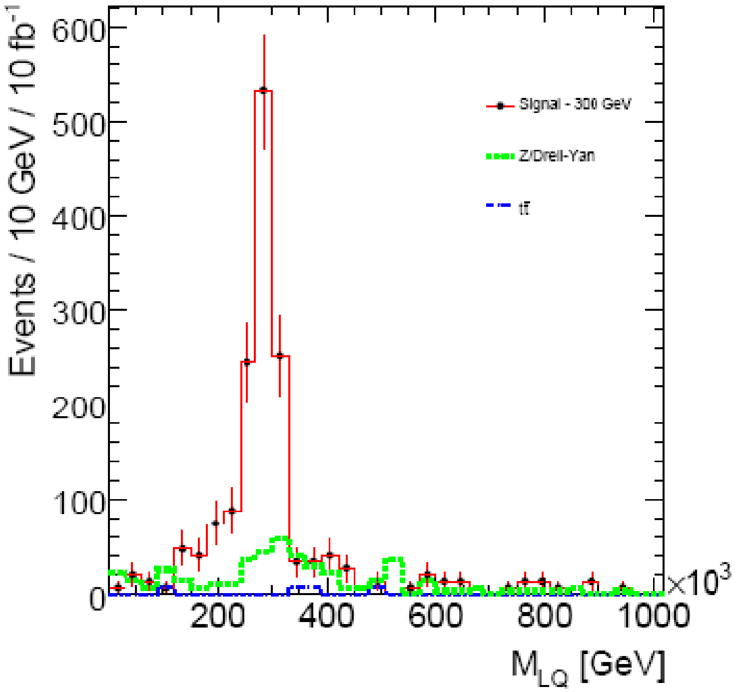
- **Single Scalar LQ → u μ (Q = -1/3)**

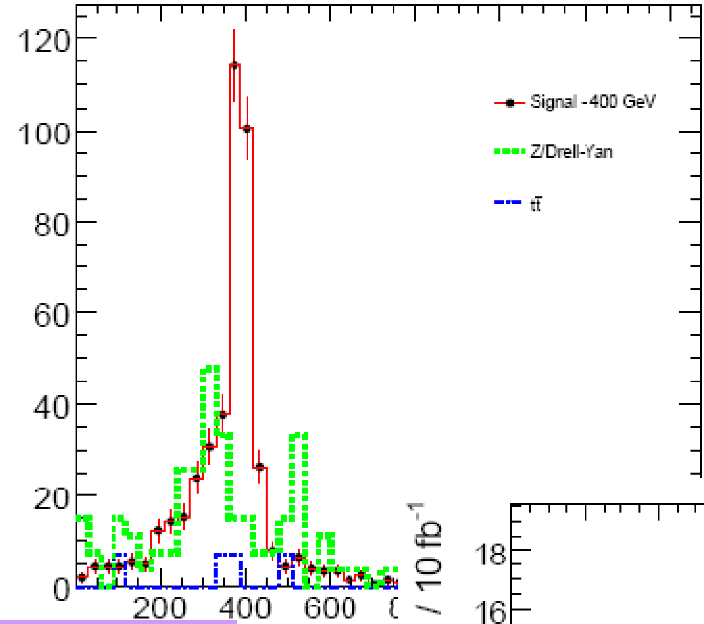
- **Optimized for the smallest integrated luminosity needed for a discovery with 5σ and normalized for an integrated luminosity of 10 fb^{-1}**

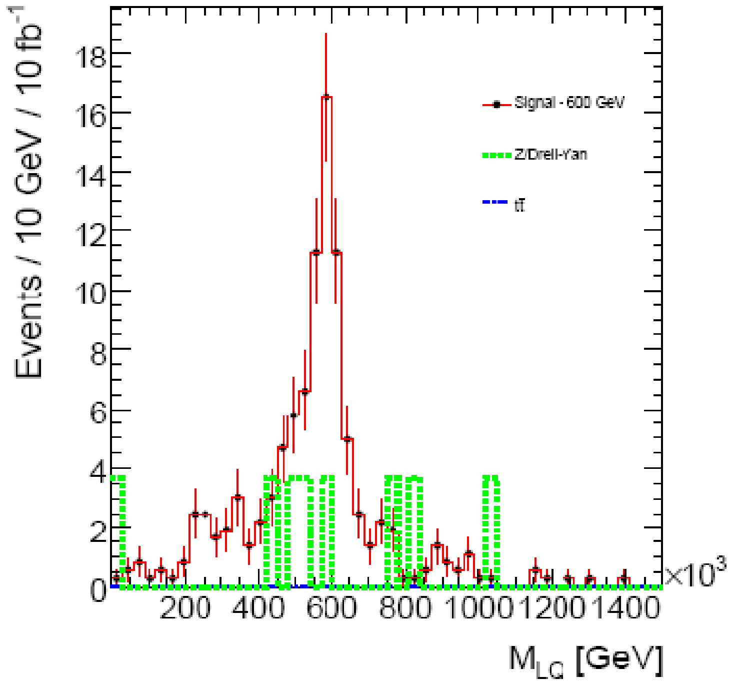
- **All other background are negligible**

Invariant mass μj pair

Th. Papadopoulo







PRELIMINARY RESULTS

Early LHC Single LQ searches !

- **LQ mass from 300 – 600 GeV**
- **plots are normalized to L= 10 fb^{-1}**

Outlook

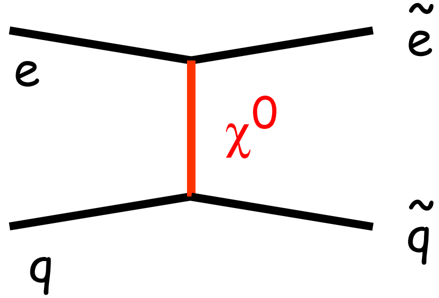
Th. Papadopoulo

- Pair and Single LQ studies at LHC are complementary
- First studies on Single LQ with ATLAS/LHC are underway towards the final results at early LHC
- Results presented are PRELIMINARY
- Use of the LHC results to predictions for the LHeC are important for the LHeC expectations on the potential of

LHeC New physics

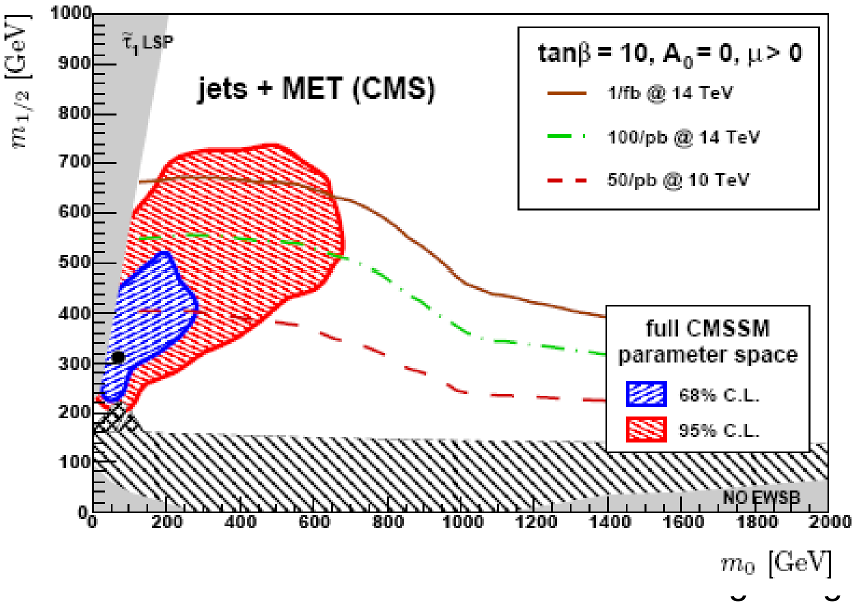
Beyond LQs: SUSY with R-parity conservation

Pair production via t-channel exchange of a neutralino.



Cross-section sizeable when ΣM below ~ 1 TeV.

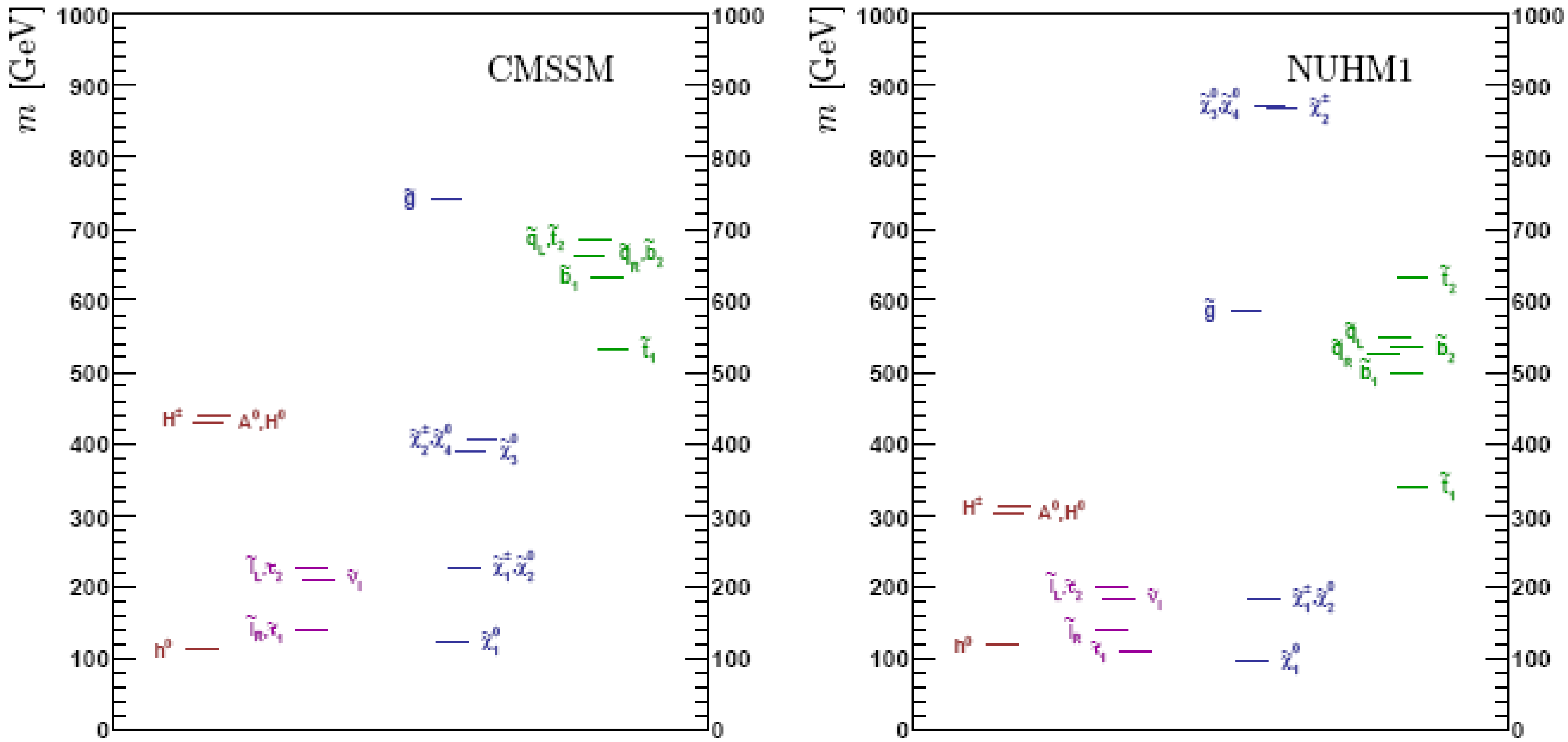
Comparison: SUSY fit to ew precision observables, B-physics observables, cosmological constraints: CMSSM, NUHM *O. Buchmueller et al, '08*



Good prospects for early SUSY discovery at the LHC

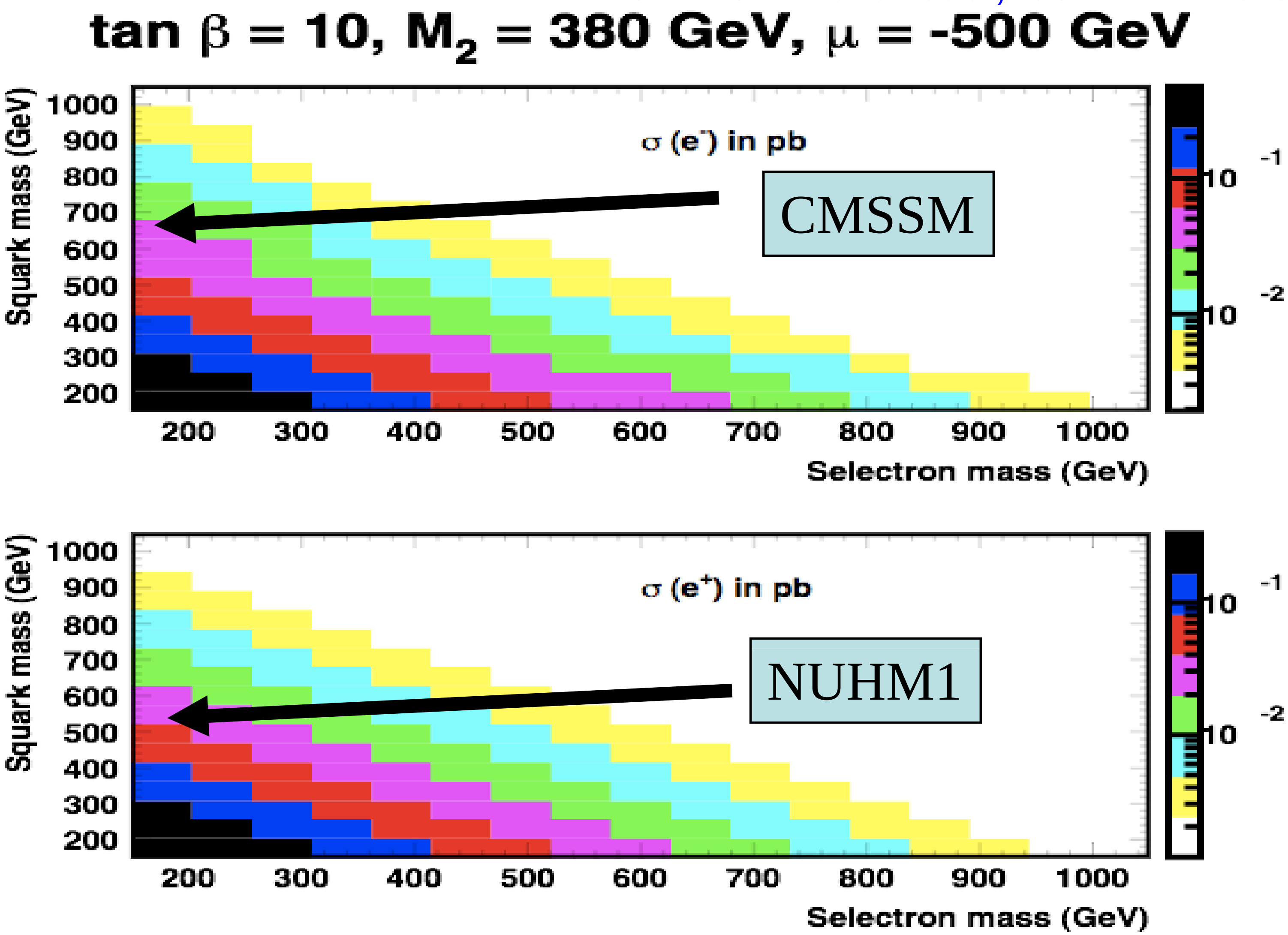
Spectra of best-fit points: CMSSM and NUHM1

O. Buchmueller et al, ‘08



Cross section for selectron + squark production at LHeC

O. Buchmueller et al, '08 *E. Perez*



Cross section for selectron + squark production at LHeC

→ σ ~ 15 fb for best fit points

E. Perez

Added value w.r.t. LHC to be studied :

- could extend a bit over the LHC slepton sensitivity
- precise mass measurements
- relevant information on neutralino sector

1st ECFA-CERN LHeC Workshop
Divonne-les-Bains, 1-3 September 2008

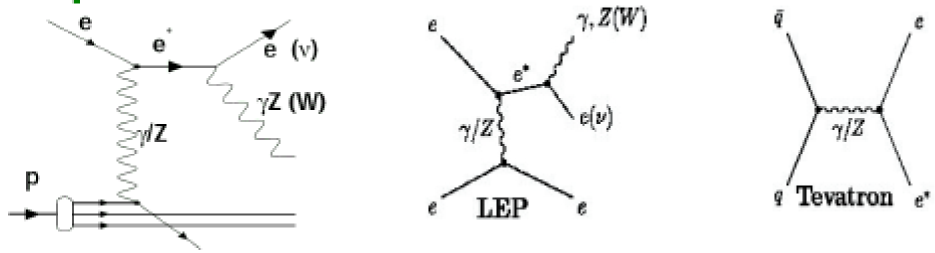
Single Production of Excited Leptons @ LHeC

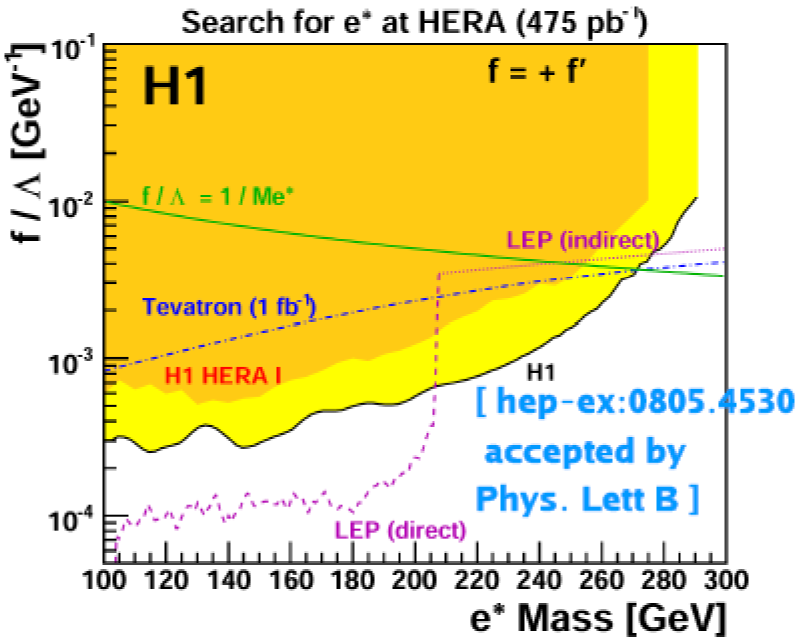
T. Nguyet TRINH, Emmanuel SAUVAN
Centre de Physique des Particules de Marseille, France

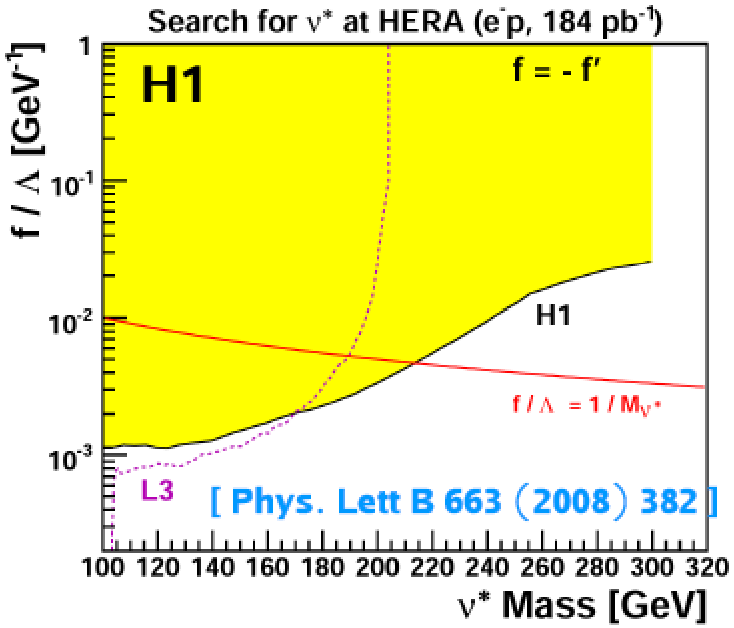
T. N. Trinh

Existing limits from present colliders

- At LEP, HERA, Tevatron colliders:





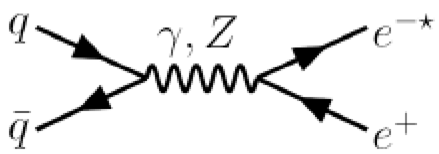


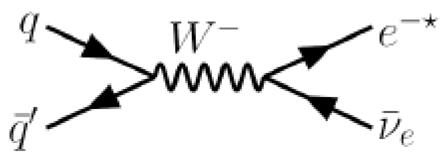
- ν^* at HERA: best sensitivity to masses beyond the LEP reach
- e* at HERA: new H1 limit is more stringent than present LEP or Tevatron results in the intermediate e* mass range

T. N. Trinh

Excited leptons at future LHC, ILC, <u>LHeC</u> colliders

- Single production of excited leptons at LHC collider (with √s=14 TeV):





[Phys. Rev D 65 (2002) 075003]

[Phys. Rev D 70 (2004) 075011]

↘ assuming f=f'=1 and M*=Λ, the LHC will be able to extend considerably the range of excited lepton masses that can be probe up to about **<u>1-2 TeV</u>**

- At ILC collider (with √s ~ 500 GeV): **[Phys. Rev D 56 (1997) 2920]**

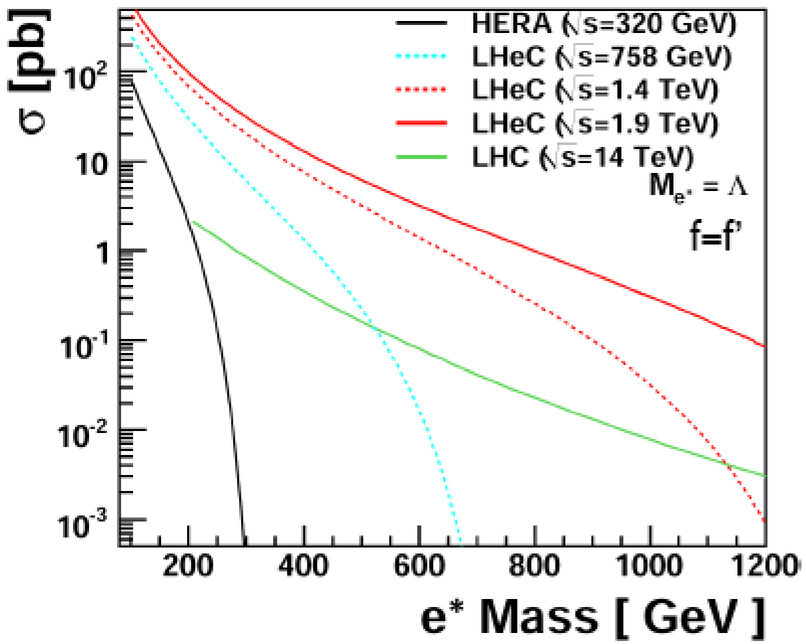
↘ assuming f=f'=1 and M*=Λ, the ILC can discover excited leptons up to the kinematical limit

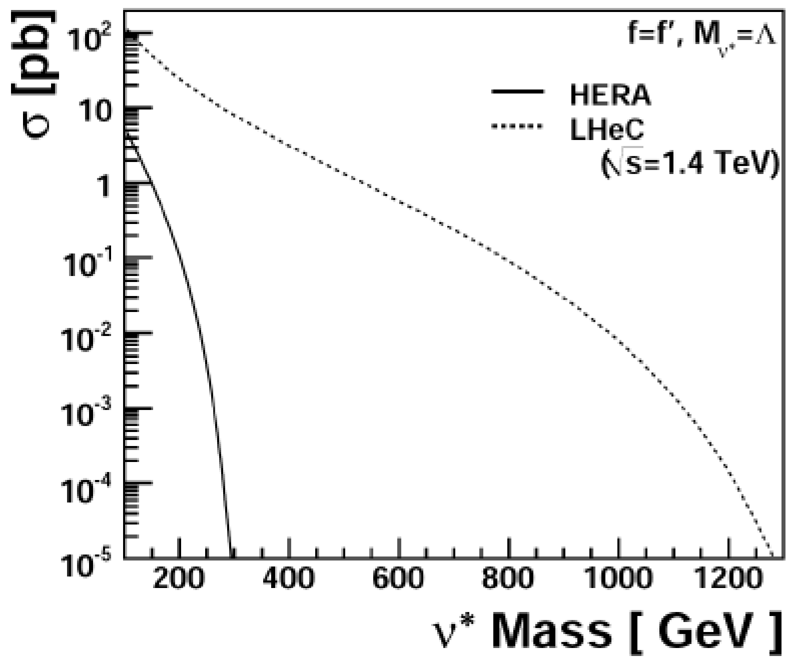
- At LHeC collider (with √s ~ 1.4 TeV or 758 GeV or 1.9TeV) ?

T. N. Trinh

Excited leptons @LHeC

- Total cross section for l* productions through GM interaction at LHeC, assuming $M^*=\Lambda$
  - ➘ comparison with HERA and LHC





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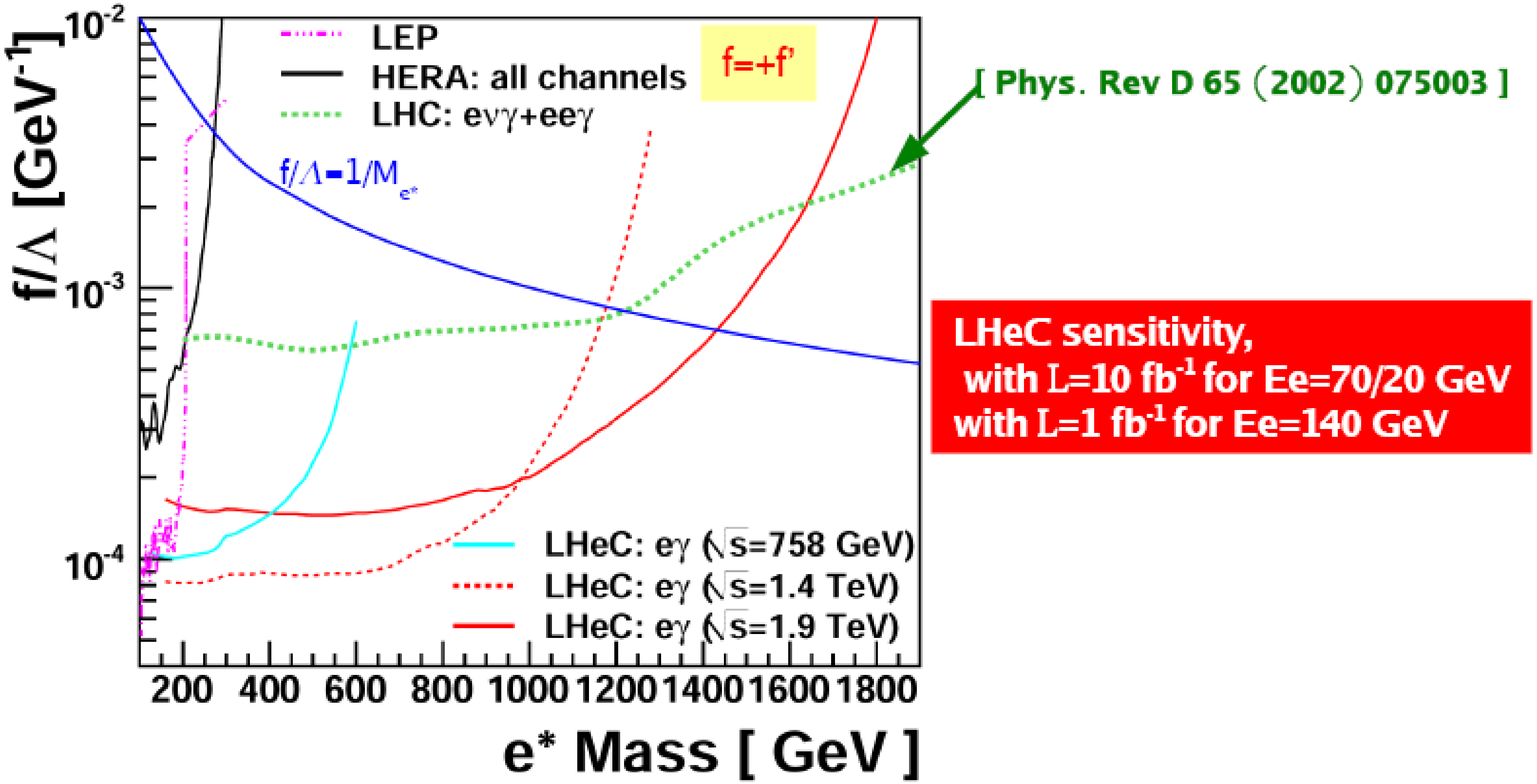
Expected limit at 95% C.L

- Expected limits derived at 95% C.L using Modified Frequentist Approach



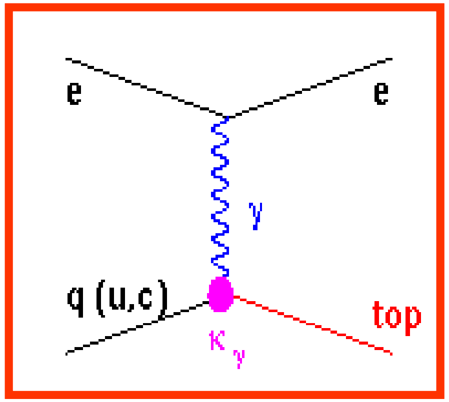
LHeC sensitivity,
with L=10 fb^{-1} for Ee=70/20 GeV
with L=1 fb^{-1} for Ee=140 GeV

- At LHeC, if $f/\Lambda=1/M_{e^*}$ and f=f': M_{e^*} < 1.2 (1.5) TeV are excluded, for $\sqrt{s}$=1.4 (1.9) TeV
- At LHC, if $f/\Lambda=1/M_{e^*}$ and f=f': M_{e^*} < ~1.2 TeV are excluded
  - Expected sensitivity of LheC is more stringent than others colliders

Anomalous top production

Models which predict new effects
- "easy" to see in ep because of low, well-understood backgrounds
- more difficult to establish in pp because of large bckgs

Example from HERA experience:
Anomalous top production via BSM coupling tuγ



Anomalous top production

G. Brandt

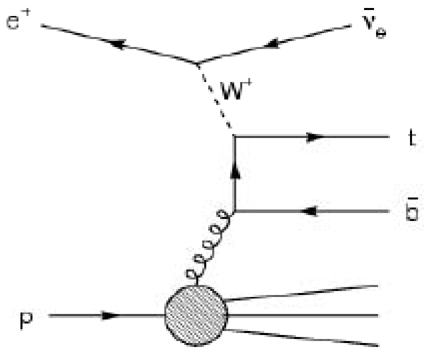
TeVatron LEP HERA	→	LHC ILC LHeC

- top Production (SM and FCNC) very interesting
  - M_{top} close to EWSB scale, sensitive to BSM
  - If BSM associated with mass generation, top especially sensitive

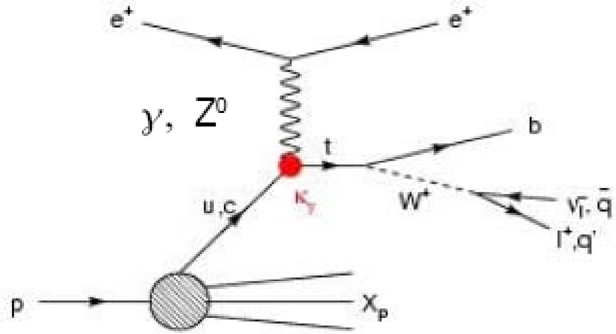
- Extensive top Programs at TeVatron, planned at LHC

- In *ep* collisions at HERA ($\sqrt{s}$ = 320 GeV)
  - SM: top production kinematically possible, but small cross section
  - FCNC: Excellent handle on anomalous tuγ coupling - competitive limits
  - What about LHeC?

SM



FCNC



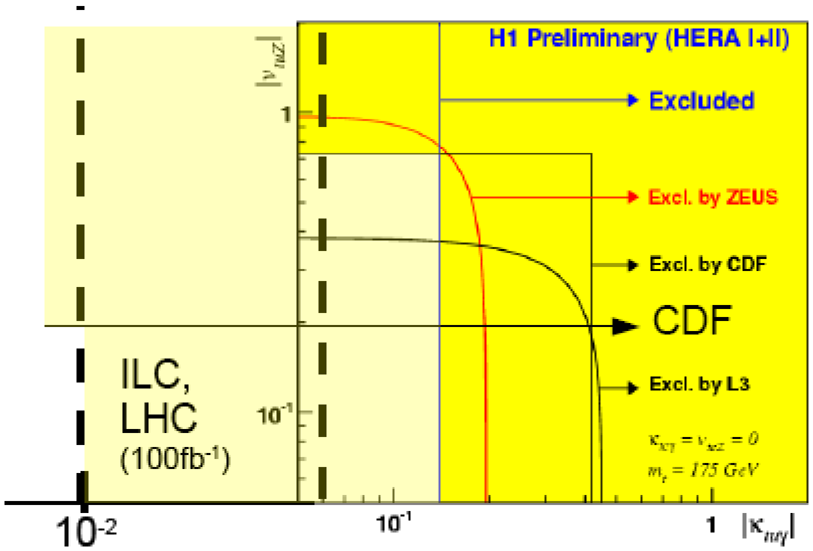
Summary of Limits on $\kappa_{tu\gamma}$

G. Brandt

Experiment	$\kappa_{tu\gamma}$	$Br(t \to u\gamma)$
L3	0.43	4.1e-2
CDF	0.41	3.2e-2
ZEUS	0.17	5.9e-3
H1	0.14	3.8e-3
ATLAS	0.059	6.8e-4
γP@LHC	0.029	1.6e-4
ILC (TESLA)	0.011	2.2e-5
LHC (100fb^{-1})	0.007	1.2e-5
SM	-	3.7e-16

measured

Use $\kappa_{tu\gamma}=0.01$ to estimate what happens at LHeC



SM *W* Production in *ep* Collisions

- Use EPVEC Generator
- Th. Error 30% (NLO Corrections not applied)
- CC and Z Production not considered

G. Brandt

LHeC (E_{e+} = 70 GeV, E_p = 7000 GeV)

$W \to e\nu$

DIS W+	1.38 pb
DIS W-	1.10 pb
RES W+	0.38 pb
RES W-	0.28 pb

$\sigma(W^+ \to l\nu)$ = 9.42 pb

σ_W = 31.4 pb

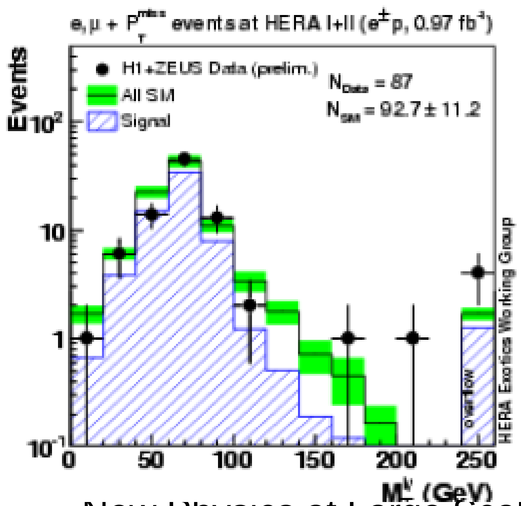
3.1x10^6 W's produced at LHeC in 100 fb^{-1}

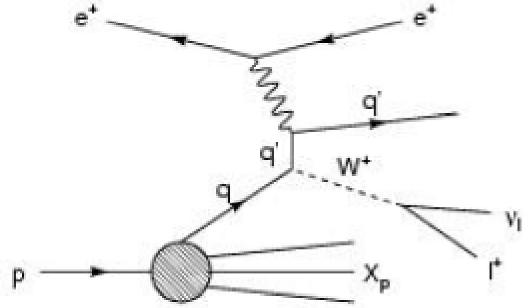
HERA

$\sigma(W^+ \to l\nu)$ = 0.4 pb

$\sigma(W^+ \to qq)$ = 1.0 pb

σ_W = 1.4 pb



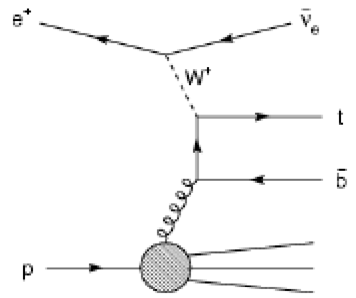


Dominating diagram (at HERA)

G. Brandt

SM Single top Cross Sections in *ep* Collisions

	HERA [fb]	LHeC [pb] (E_e=70 x E_p=7000)
PYTHIA 6.4		
CTEQ6l	0.39	1.62
CTEQ6m	1.19	
GRV98 (lo)	0.02	
MRST2002nlo	0.86	
PYTHIA 6.1		
GRV LO	0.97	
CompHEP		
CTEQ6L	0.42	1.93
CTEQ6D	2.13	2.40
CTEQ6M	1.27	2.3
CTEQ5L	0.71	2.0



- Use PYTHIA with Process
  $q_i + f_j \to Q_k + f_l$

dominating

HERA
- $\sigma \sim$ 1 fb^{-1} – not observable in ~1 fb^{-1}
- Sensitive to "*b*-density" in *p* at x > 0.3
- Not well constrained (but chance for measuring this quantity?)

LHeC
- $\sigma \sim$ 2 pb^{-1}

THERA
(E_e=500 x E_p=920)
(E. Perez)
$\sigma \sim$ 1 pb^{-1}

LHC
Single top production
(M. Beneke et al, 1999)

t-channel	245	± 27 pb
s-channel	10.2	± 0.7pb
Wt	51	± 9 pb

Top pair production
Sigma (pp->tt) 833 pb

Finally: Estimations at LHeC

$$N = c_\gamma \cdot \kappa_{tu\gamma}^2 \cdot L \cdot Br \cdot \varepsilon$$

($c_\gamma \cdot \kappa_{tu\gamma}^2 = \sigma$)

G. Brandt

Option	Ee [GeV]	Ep [GeV]	Int. Lumi [fb]	$\sigma(\kappa_{tu\gamma}=0.01)$ [pb]	N_{obs}	
LHeC (RR)	70	7000	100	0.0152 31.4 2	760 94000 10000	FCNC top SM W SM top
LHeC (LR)	140	7000	10	0.0207 pb	103	

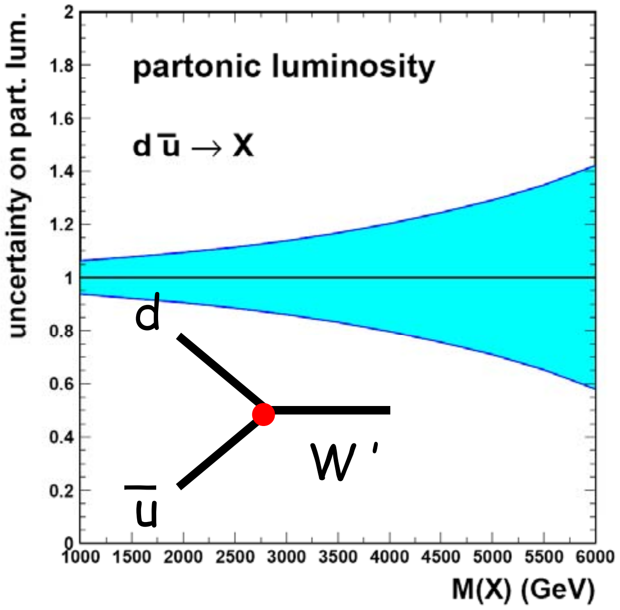
- Very difficult to help with FCNC top production at LHeC
- Large W sample, can measure cross-section, Mass, polarisations, $WW\gamma$, ...
- Large SM single top sample, nice top program possible -> *ideas in backup*
- If FCNC has strength of current HERA limit,
  SM and FCNC are of the same order of magnitude at LHeC:
  FCNC top $\sigma(\kappa_{tu\gamma}=0.14) = 3.0\ \text{pb}^{-1}$
- Higher energy LHeC LR option would not compensate lower lumi
  (Estimates for W, SM top not done...)

Proton structure and interpretation of LHC discoveries

E. Perez

- We may need more precise pdf's :

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



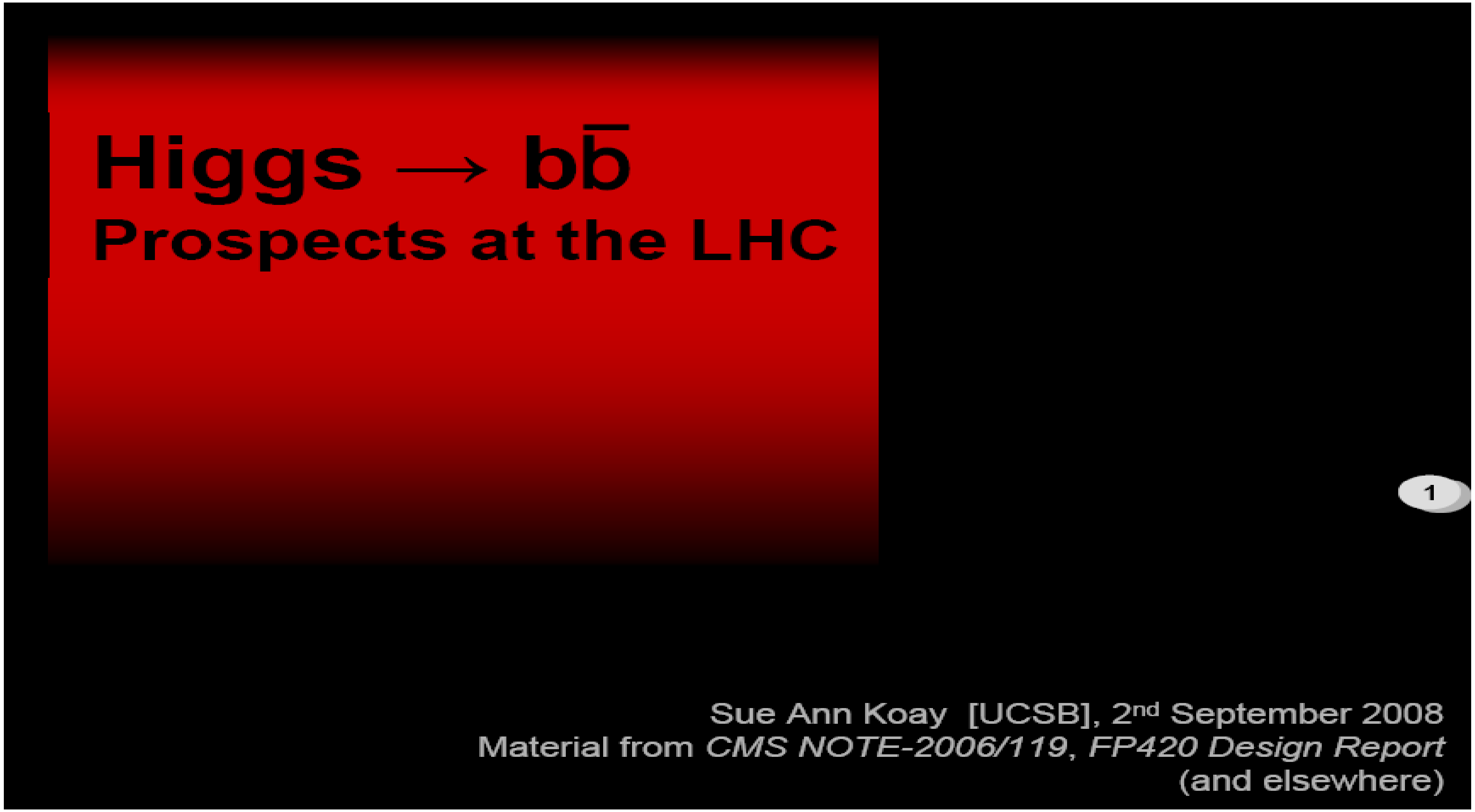
(DIS'07)

40% uncertainty on part. lum. for a 6 TeV W '. Translates into an uncertainty on the coupling of the W'.

Idem for the couplings of a new Z' close to the kinematic limit.

Higgs production at LHeC

S. A. Koay



Prospects for assessing the Hbb coupling at the LHC

ttH, H -> bb and diffractive Higgs production

Both are very challenging

Is there a chance at the LHeC?

ttH, H → bb at the LHC

S. A. Koay

The Verdict in 60 fb^{-1}

Standard uncertainties: JES, jet resolution, b-tagging

	m_H (GeV/c^2)	S	S/B (%)	S/$\sqrt{B}$	S/$\sqrt{(B+dB^2)}$
All-Hadron	115	350	2.0	2.6	0.07
	120	310	1.8	2.4	0.07
	130	210	1.2	1.6	0.05
Semi-lepton	115	147	7.0	3.1	0.20
	120	118	5.3	2.5	0.16
	130	80	3.6	1.7	0.11
Di-lepton	115	170	1.8	1.8	0.10
	120	130	1.5	1.4	0.08
	130	82	0.9	0.9	0.05

$H \rightarrow b\bar{b}$ Prospects
- **SM**
- **MSSM**

ttH @ CMS
- **All hadronic**
- **Semi-leptonic**
- **Di-leptonic**

FP420
- **Overview**
- **CEP of H→bb**

18

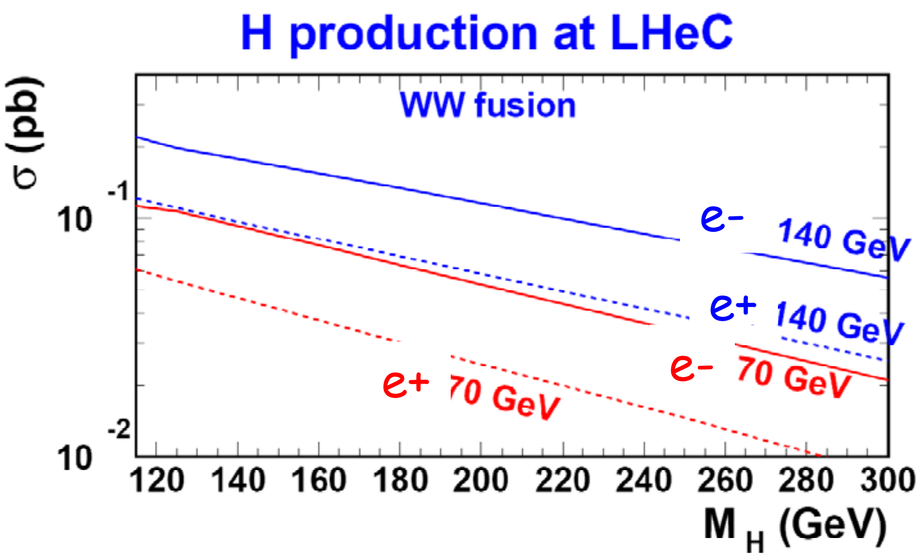
Reality happened : systematics ~ 18% – 34%

Higgs production at LHeC

E. Perez

Production cross-section for a 120 GeV Higgs at LHeC (Ee = 140 GeV) is sizeable.

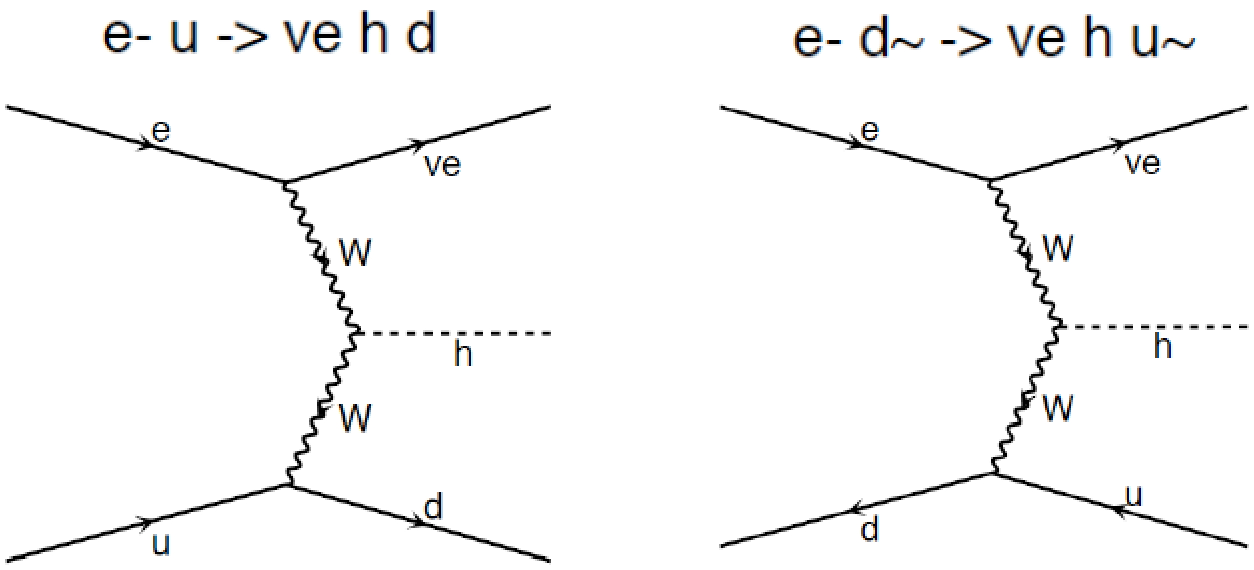
Plot shows LO x-sections from CompHep.
Good qualitative agreement with cross section calculations by Uta Klein and Bernd Kniehl



U. Klein

CC : LO SM Higgs Production

e-p (swap charges for e+p)

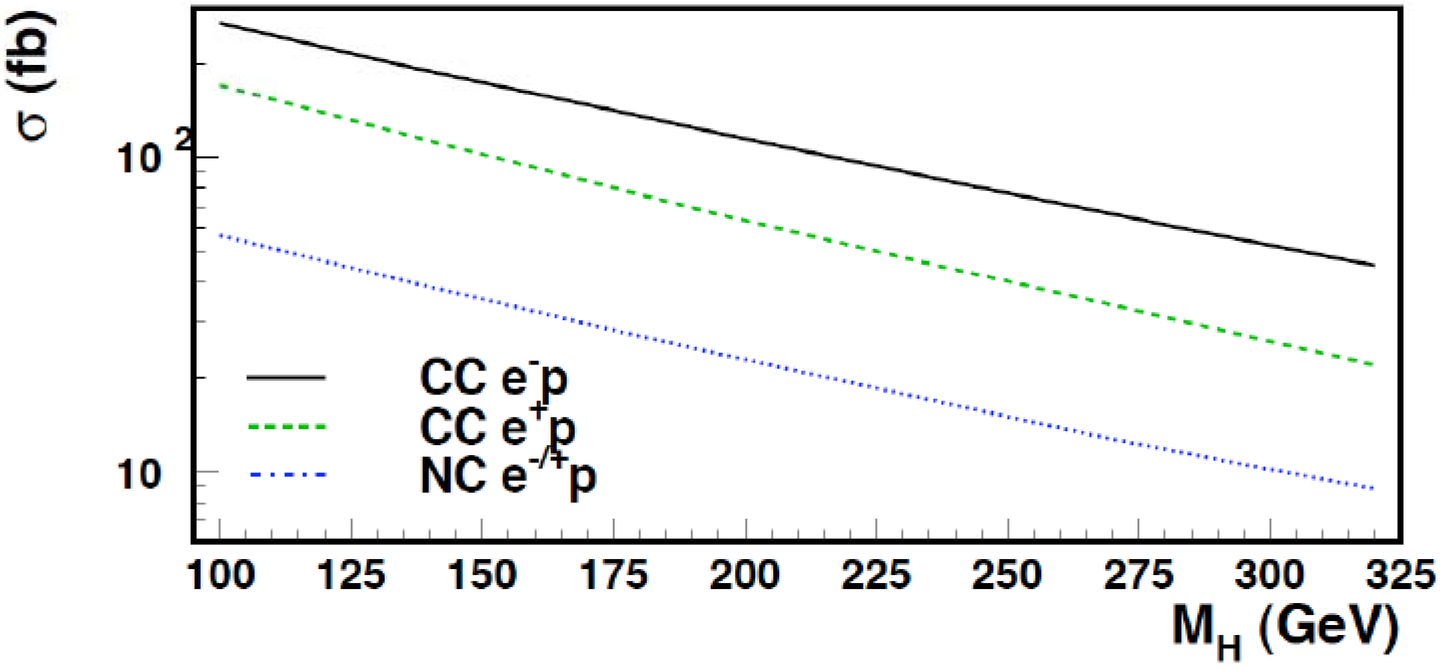


around 90-80%

around 10-20%

U. Klein

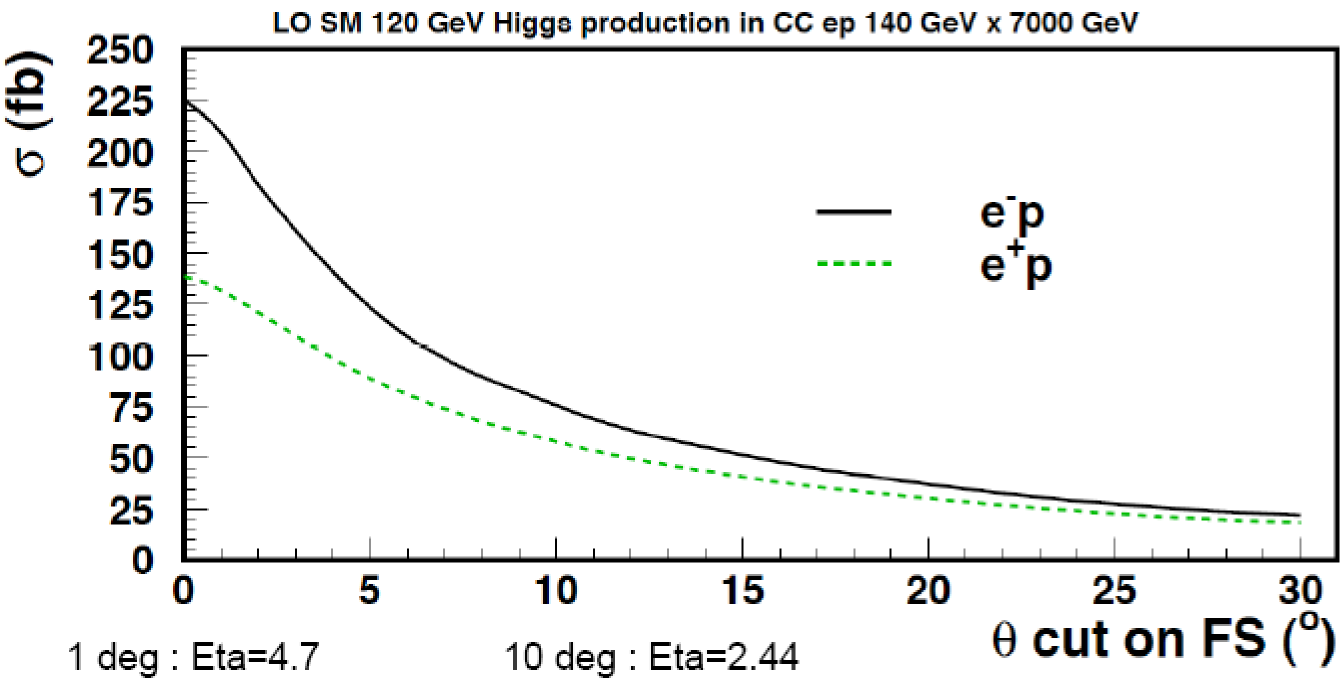
140 GeV x 7000 GeV



U. Klein

Effect of Detector Acceptance

- Apply eta cuts on ALL final states



1 deg : Eta=4.7   10 deg : Eta=2.44

U. Klein

Some Thoughts

- The SM Higgs cross sections are sizeable.
- LHeC may open an unique access to light Higgs via bbar via ZZ and WW fusion
- May we profit from e-beam polarization?

- Tag the Higgs via bbar (75%)
  -> Check topologies, bbar tagging efficiencies…

- HO contributions for signal and background ?

- Background : jets in CC, single top…

Backgrounds to Higgs production at the LHeC

Masahiro Kuze
Tokyo Institute of Technology
Emmanuelle Perez
CERN

LHeC WS, Divonne-les-Bains, 2/Sep/2008

(with a lot of help from
J. Maeda, K. Nagano and H. Spiesberger)

Cross section with parton-level cuts

M. Kuze

(E_{e^-}=140GeV, M_H=115GeV)

missPt> / Pt(b)>	25GeV	50GeV	75GeV
20GeV	0.099	0.063	0.037
40GeV	0.057	0.037	0.023

(in pb; b-jet angle cut of $10 < \theta < 170$ applied.)

Background study

M. Kuze

- Generate DJANGOH $Q^2 > 400\,GeV^2$ CC events at LHeC energy, run through ZEUS detector MC.
- 140GeV e^-p. σ_{tot} = 383.31 pb. 10,000 events (very CPU consuming...)
- Run kt jet-finder, cut on missPt and Pt(jets) (jet $|\eta|<3$), count events in dijet-mass bin ($M_H \pm$width).
- Compare w/ signal (parton-level cut), calculate S/N and $S/\sqrt{N}$ (for $L=10fb^{-1}$)

M. Kuze

Width=10GeV, LHeC 10fb^{-1}

missPt> / Pt(jet)>	25GeV	50GeV	75GeV
20GeV	990/39098 S/N=0.025 S/√N=5.0	630/26065 S/N=0.024 S/√N=3.9	370/16482 S/N=0.022 S/√N=2.9
40GeV	570/17632 S/N=0.032 S/√N=4.3	370/12266 S/N=0.030 S/√N=3.3	230/7666 S/N=0.030 S/√N=2.6

M. Kuze

post-Remark

- Yesterday, I learned that $10fb^{-1}$ (1yr@10^{33}) with Ee=140GeV may be 'ultimate goal'.
- For L=$1fb^{-1}$ (1yr@10^{32}) and 140GeV: S→1/10, N→1/10: S/N→same, S/√N→1/3
- For Ee=70GeV and $10fb^{-1}$: S→~1/2, N→~0.7(?) (CC σ_{tot}=280.16pb) (MC generation needed for actual dijet bg)

M. Kuze

Summary

- A very preliminary look at CC bgd to light Higgs production at the LHeC.
- Mass bump could be seen (5.0 sigma), but tough N/S (>30) for coupling study?
- MissPt slope is similar. Hard cut on Pt(jet) improves S/N (but worsens $S/\sqrt{N}$)
- More thoughts on cuts needed.
  b-tag (vertex), forward jet, ... (signal MC!)
- Photoproduction and other bgd sources?

Conclusions

- Many ideas, encouraging level of activities
- Interesting studies have been started
- But: still a long way to go towards a CDR

- Dates for the diary:
  CERN Theory Institute: “From the LHC to a Future Collider”, Feb. 9-27, 2009