

MINIWORKSHOP
ON
MACHINE AND PHYSICS ASPECTS OF CLIC
BASED FUTURE COLLIDER OPTIONS

Monday, 30th August 2004 at 9.30 a.m.
PS Auditorium (Building 6 / 2-024)

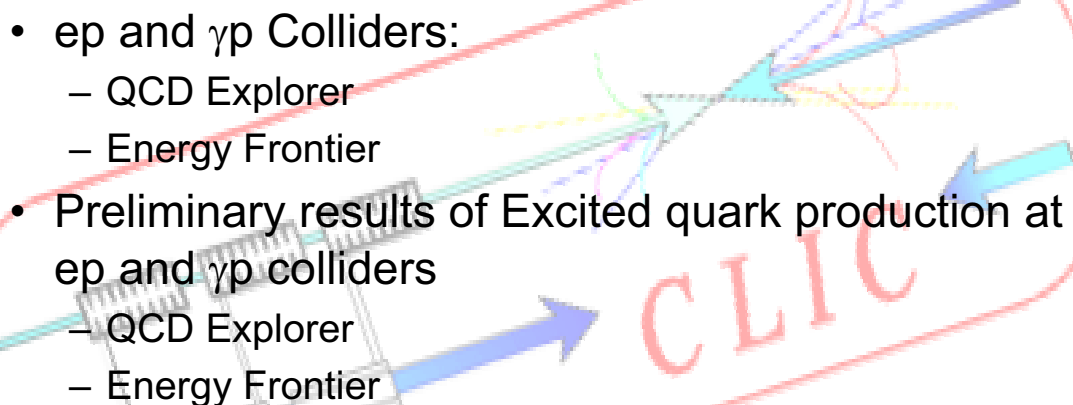
A schematic diagram of the CLIC (Compact Linear Collider) accelerator. It shows a long, narrow structure with several stages of particle acceleration. Two main beams are shown: a blue beam entering from the right and a green beam entering from the left. They meet at a central interaction point where various colored lines (red, yellow, purple) represent particle production or radiation. The word 'CLIC' is written in large, red, semi-transparent letters across the diagram.

Excited Quark Production at CLIC*LHC Based $e\bar{p}$ and γp Colliders

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Content

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- A schematic diagram of the CLIC (Compact Linear Collider) accelerator, identical to the one in the top slide. It shows a long, narrow structure with several stages of particle acceleration. Two main beams are shown: a blue beam entering from the right and a green beam entering from the left. They meet at a central interaction point where various colored lines (red, yellow, purple) represent particle production or radiation. The word 'CLIC' is written in large, red, semi-transparent letters across the diagram.
- $e\bar{p}$ and γp Colliders:
 - QCD Explorer
 - Energy Frontier
 - Preliminary results of Excited quark production at $e\bar{p}$ and γp colliders
 - QCD Explorer
 - Energy Frontier

CLIC*LHC based electron proton collider

• QCD Explorer:

- An ep collider based on 75 GeV CLIC e beam and 7 TeV LHC protons is named QCD Explorer [1-4].
- Even though this machine with $\sqrt{s} \approx 1.4$ TeV has the same center of mass energy region with THERA, it is more suitable to explore low x physics.
- For QCD Explorer two variants are proposed up to day; **the first of them [1-3] requires upgrade of both LHC and CLIC parameters** and **the second one [4] is based on superbunched LHC.**

[1] A. De Roeck et al. Informal meeting on CLIC*LHC interface at CERN, Aug. 23, 2002.

[2] E. Arık and S. Sultansoy, E-print Arxiv: hep-ph/0302012

[3] S. Sultansoy, *Eur. Phys. J. C* (2004) (DOI)10.1140/epjcd/s2004-03-1716-2

[4] D. Schulte and F. Zimmerman, LHC Project Note 333 (2004)

Luminosity and limitations (?) of linac-ring type ep collider

- The most transparent expression for the luminosity of linac-ring type ep colliders is

$$L_{ep} = \frac{N_e N_p f_c \gamma_p}{4\pi \epsilon_p \beta_p^*} = \frac{1}{4\pi} \cdot \frac{P_e}{E_e} \cdot \frac{N_p}{\epsilon_p^N} \cdot \frac{\gamma_p}{\beta_p^*}$$

- **Beam-beam kink instability:** A relative offset between the heads of the proton and electron bunches causes to a beam-beam force, which deflects electrons. Interaction between deflected electrons and the tail of the proton bunch causes beam-beam kick, which can drive proton beam unstable. A stability criterion given under linear approximation is [5,6]

$$D_e \Delta Q_p \leq 4v_s$$

where D_e is disruption parameter of the electron beam and v_s is the synchrotron tune of the proton beam. **IF THIS INSTABILITY IS CORRECT CLIC HAS TOO HIGH DISRUPTION! Should get confirmation from Lia Merminga!**

[5] L. Merminga et al., presented at "The 18th International Conference on High Energy Accelerators" 26-30 March 2001, Tsukuba, Japan.

[6] R. Li et al., *Proc. of PAC 2001*, PAC-2001-THPH151, Aug. 2001, Chicago, IL, USA.

QCD-E Standard Approach:

- In this case the CLIC pulse contains only 5 bunches (instead of 154) in order to meet the LHC bunch spacing. The resulting luminosity amounts to $L = 10^{28} \text{ cm}^{-2} \text{ s}^{-1}$

- Possible LHC upgrades:**

β^* 50 cm \rightarrow 10 cm
 Bunch spacing 25 ns \rightarrow 12.5 ns

an increase of luminosity by a factor of 5.
 an increase in luminosity by a factor of 2.

$$N_p = 10^{11} \rightarrow 5 \cdot 10^{11}$$

$$\varepsilon_p = 0.5 \cdot 10^{-9} \pi \text{ rad} \cdot \text{m} \rightarrow 0.1 \cdot 10^{-9} \pi \text{ rad} \cdot \text{m}$$

at the expense of IBS: $\tau_{\text{IBS}} = 5$ hrs requiring a serious redesign of injector chain, would give an increase of luminosity by factor 20.

- Possible CLIC upgrades:**

$$N_e = 4 \cdot 10^9 \rightarrow 10 \cdot 10^9$$

an increase of luminosity by a factor 2.5.

Increase of the effective repetition frequency by increasing the number of trains per RF pulse (a la CLICHE) results in an increase of luminosity by a factor ~ 10 .

$$L \rightarrow 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$$

QCD-E Superbunched Approach:

- Superbunched QCD-E has been studied by D. Schulte and F. Zimmerman.

parameter	symbol	electrons	protons
beam energy	E_b	75 GeV	7 TeV
bunch population	N_b	4×10^9	6.5×10^{13}
rms bunch length	σ_z	35 μm (Gaussian)	9 m (uniform)
bunch spacing	L_{sep}	0.66 ns	N/A
number of bunches	n_b	154	1
(effective) pulse line density	λ	$2.0 \times 10^{10} \text{ m}^{-1}$	$2.1 \times 10^{12} \text{ m}^{-1}$
IP beta function	$\beta_{x,y}^*$	0.25 m	0.25 m
spot size at IP	$\sigma_{x,y}$	11 μm	11 μm
full length of interaction region	l		2 m
normalized transv. rms emittances	$\gamma \varepsilon_{x,y}$	73 μm	3.75 μm
collision frequency	f_{coll}		100 Hz
luminosity	L	$1.1 \times 10^{31} \text{ cm}^{-2} \text{ s}^{-1}$	
beam-beam shift	$\xi_{x,y}$	N/A	0.004

- The proton beam parameters are those considered for an LHC superbunch upgrade, while the electron beam is relaxed compared with the ultimate CLIC target values.
- For simplicity equal beta functions and equal geometric emittances are considered for two beams.
- The luminosity for head-on collisions is given by

$$L = f_{coll} \frac{\ell_b \lambda_e \lambda_p}{2\pi \varepsilon_{x,y}} \int_{-1/2\beta^*}^{1/2\beta^*} \frac{1}{1+u^2} du = f_{coll} \frac{\ell_b \lambda_e \lambda_p}{\pi \varepsilon_{x,y}} \arctan\left(\frac{l}{2\beta^*}\right)$$

- $L = 1.1 \times 10^{31} \text{ cm}^{-2}\text{s}^{-1}$

Energy frontier ep colliders:

- e beam (0.5 TeV, 1.5 TeV) X p beam (7 TeV)

$$\sqrt{s} = 3.74 \text{ TeV}, 6.48 \text{ TeV}$$

– Same as QCD-E, with the exception of CLICHE upgrade!

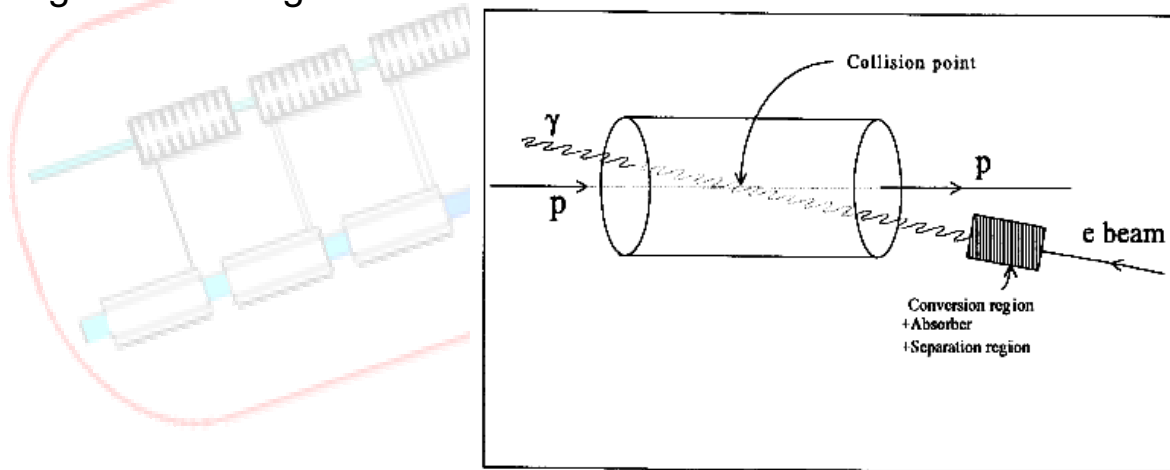
- Upgraded ep Energy Frontier ($L = 10^{31} \text{ cm}^{-2}\text{s}^{-1}$)*

*Detailed machine study is planned, Luminosities are projected or preliminary values.

CLIC*LHC based gamma-proton colliders:

General Consideration

Similar to the idea of building $\gamma\gamma$ colliders on the base of linear e^+e^- colliders one can think of building γp colliders on the base of LR type ep machines [7]. A schematic view of γp collider is given in the figure.



[7] A.K. Ciftci, S. Sultansoy, Ş. Türköz and Ö. Yavaş, *Nucl. Instr. Meth. A* 365 (1995) 317.

- The normalized differential Compton cross section

$$f(\omega) = \frac{1}{E_e \sigma_c} \frac{2\pi\alpha^2}{x m_e^2} \left[\frac{1}{1-y} + 1 - y - 4r(1-r) + \lambda_e \lambda_0 r x(1-2r)(2-y) \right]$$

where $y = \omega/E_e$, $r = y/[x(1-y)]$. The total Compton cross section is

$$\sigma_c = \sigma_c^0 + \lambda_e \lambda_0 \sigma_c^1$$

$$\sigma_c^0 = \frac{\pi\alpha^2}{x m_e^2} \left[\left(2 - \frac{8}{x} + \frac{16}{x^2}\right) \ln(x+1) + 1 + \frac{16}{x} - \frac{1}{(x+1)^2} \right]$$

$$\sigma_c^1 = \frac{\pi\alpha^2}{x m_e^2} \left[\left(2 + \frac{4}{x}\right) \ln(x+1) - 5 + \frac{2}{x+1} - \frac{1}{(x+1)^2} \right]$$

- In the equations above, λ_e and λ_0 are helicities of electron and laser photon.

- The angle between high energy photons with ω energy and electron beam direction. This angle is given by (for small Θ_γ)

$$\Theta_\gamma(\omega) = \frac{m_e}{E_e} \sqrt{\frac{E_e x}{\omega} - (x + 1)}$$

where $x = 4E_e\omega_0/m_e^2$, ω_0 is laser photon energy. In order to avoid e^+e^- pair creation in the conversion region, x should be less than 4.83.

- Max. energy of gamma beam equals 83% of e-beam energy. About 60 % of the electrons produces gamma beam.

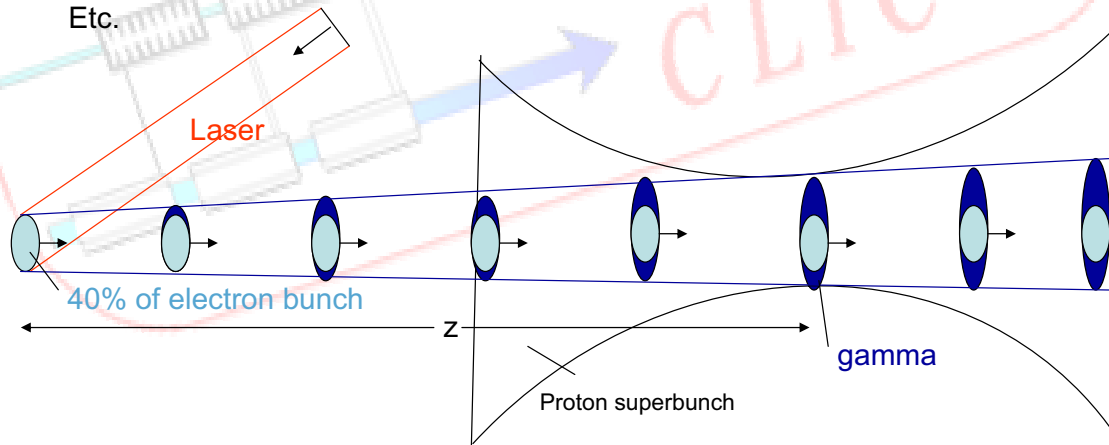
- The differential luminosity with respect to γp invariant mass which takes the conversion to collision distance (z) into consideration is given by

$$\frac{dL_{\gamma p}}{dW_{\gamma p}} = \frac{W_{\gamma p}^2 f\left(\frac{W_{\gamma p}}{4E_p}\right) N_\gamma N_p}{4\pi E_p \sqrt{(\sigma_{xe}^2 + \sigma_{xp}^2)(\sigma_{ye}^2 + \sigma_{yp}^2)}} \exp\left[-z^2 \Theta_\gamma^2 \left(\frac{W_{\gamma p}}{4E_p}\right) / 2\sqrt{(\sigma_{xe}^2 + \sigma_{xp}^2)(\sigma_{ye}^2 + \sigma_{yp}^2)}\right]$$

- Total luminosity can be determined with the integration differential luminosity over the invariant mass.

Luminosity related problems on Superbunched QCD-E

- Luminosity estimation on standard structured gamma-p collisions is as explained. When gamma and proton bunches match, gamma-p luminosity is 0.6 times of ep luminosity.
- The geometry of γ , e and superbunched proton collisions are given below figure. As it is seen from figure photon beam diverges. There are numbers of problems to resolve:
 - Effect of energy spread of electron beam
 - Effect of non-interacted electrons on proton beam
 - How to compute Luminosity of interacting photon bunch with changing the size. Etc.



Determining of optimum electron beam parameters

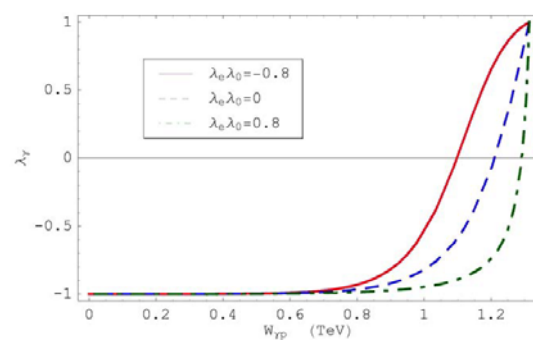
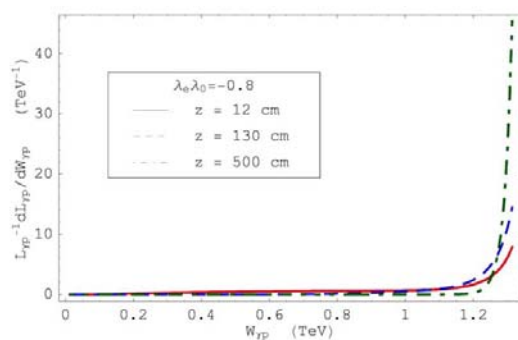
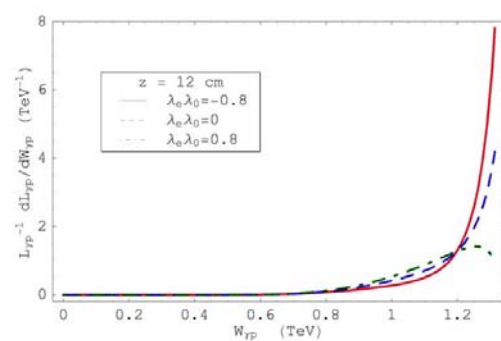
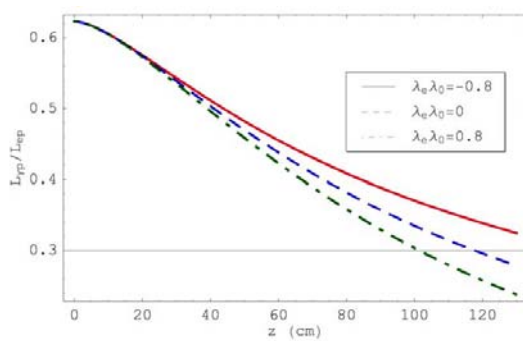
- Photon spot size at the main IP consists of three contributions: the e-beam divergence, the divergence of scattered photons and the e-beam spot size at conversion point. The optimum electron beta function at conversion point to get smallest photon spot size at main IP is equal to z . We consider four sets of example parameters, listed in Table:
 - The first set corresponds to QCD-E on ref. [4].
 - The second set has a smaller normalized emittance, about the smallest one might hope to extract from an rf gun and similar to the emittance expected from the NLC damping ring.
 - The third set is for 0.5 TeV beam energy and assumes the CLIC target emittance
 - The last set is for 1.5 TeV beam energy and assumes the CLIC target emittance.

Collider Problems to investigate:

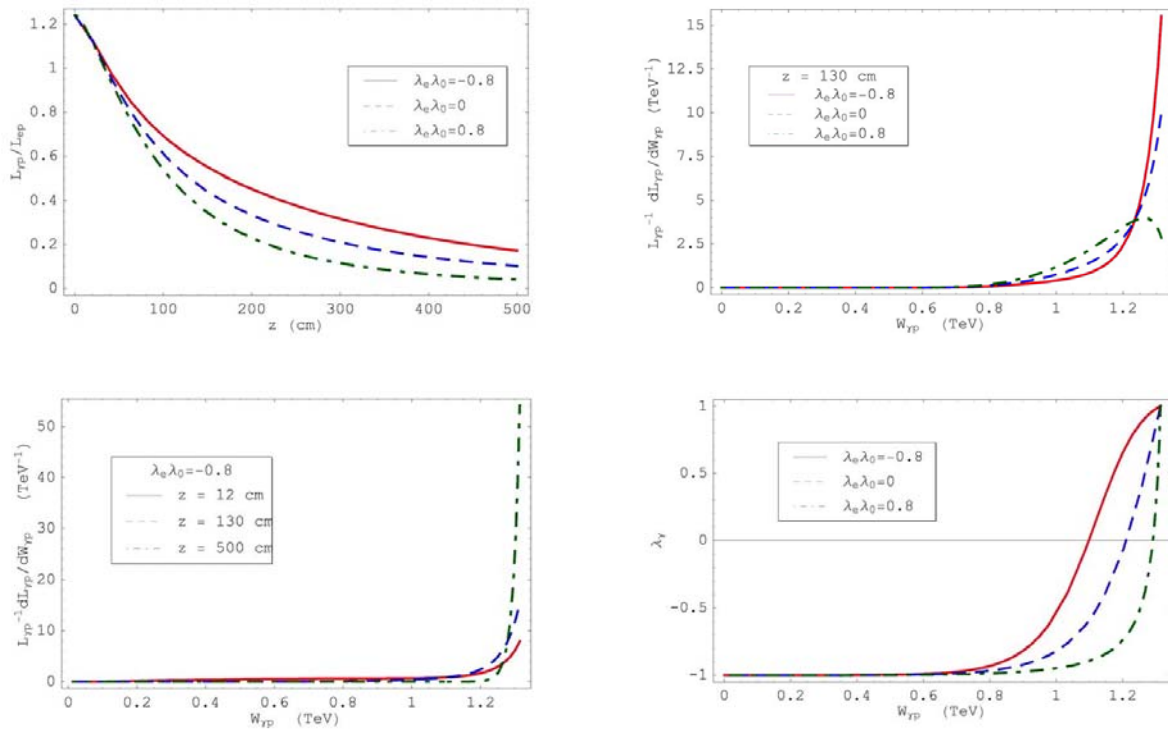
- Z_{\max} (where the rms photon beam size equals the rms size of the proton beam at IP) is either 16 μm (nominal LHC) or 11 μm (LHC upgrade).

	QCD-E	QCD-E-2	High energy-1	High energy-2
ϵ_N [μm]	73	2	1.3	0.6
E_e [GeV]	75	75	500	1500
Z_{\max} [m] at $\sigma^*=16\mu\text{m}$	0.25	2.1	14.4	45.2
Z_{\max} [m] at $\sigma^*=11\mu\text{m}$	0.12	1.3	9.6	30.6

Luminosities for QCD-E



Luminosities for QCD-E-2



ep vs. γp for the small x_g investigation

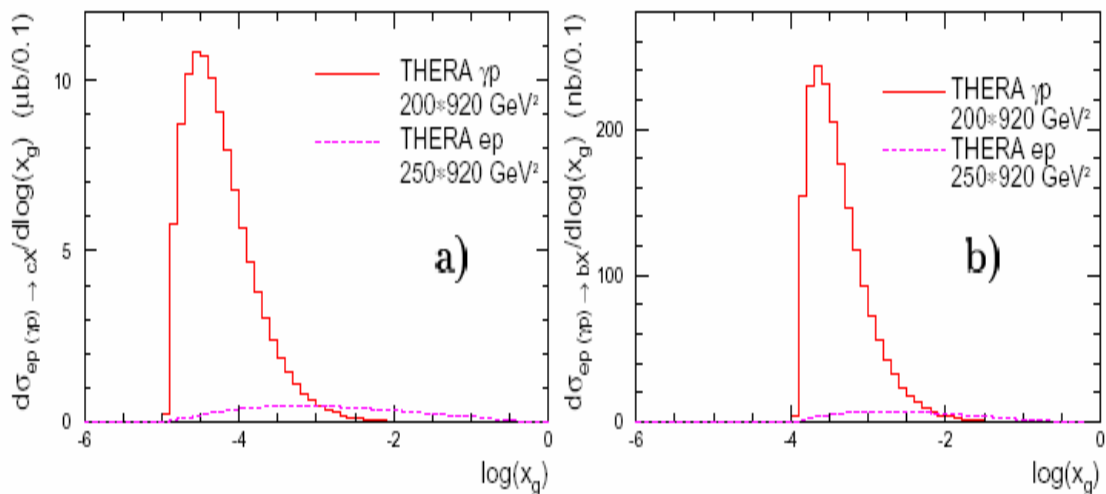
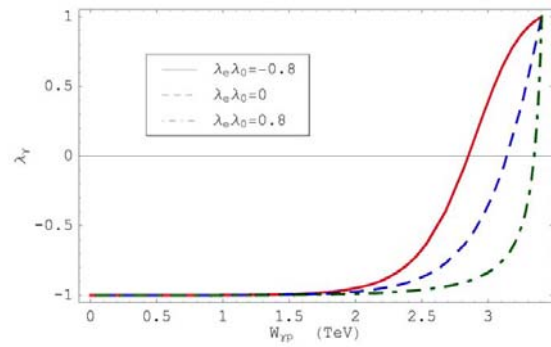
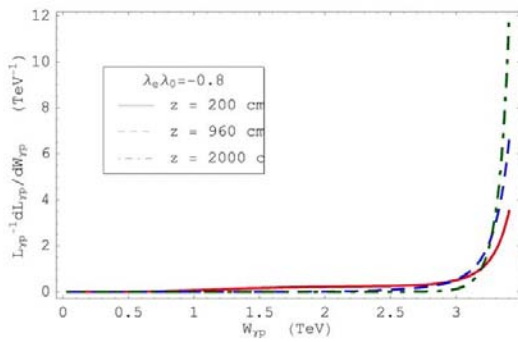
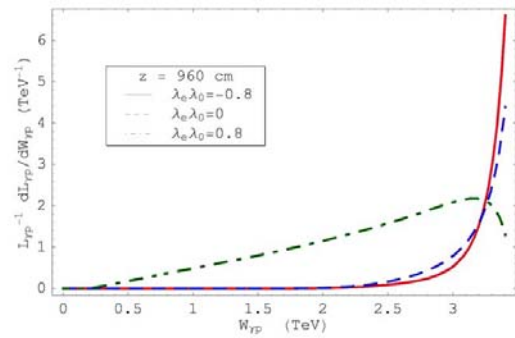
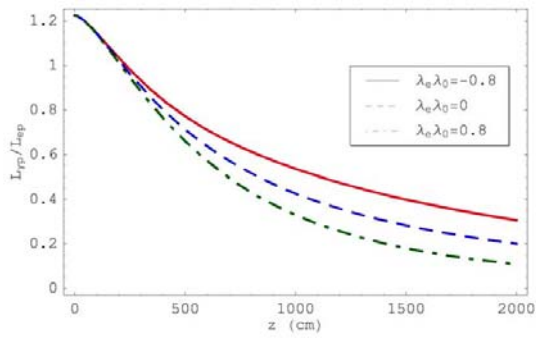
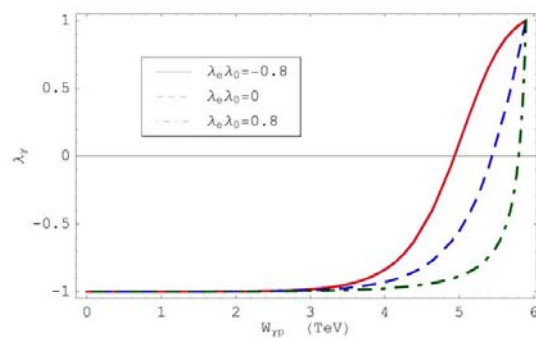
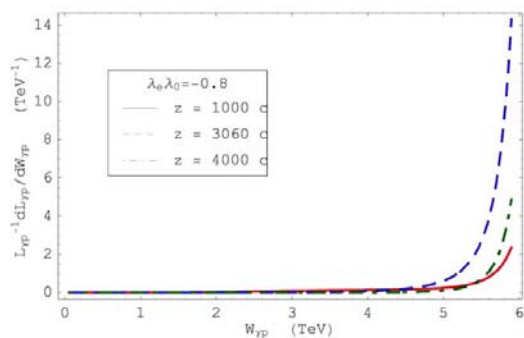
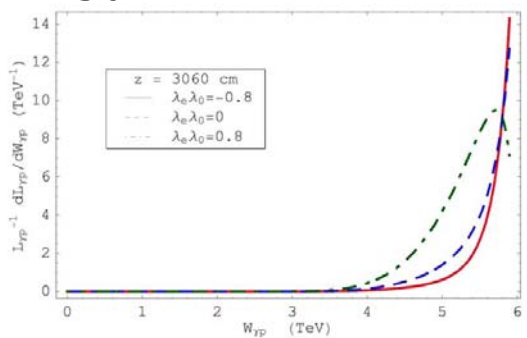
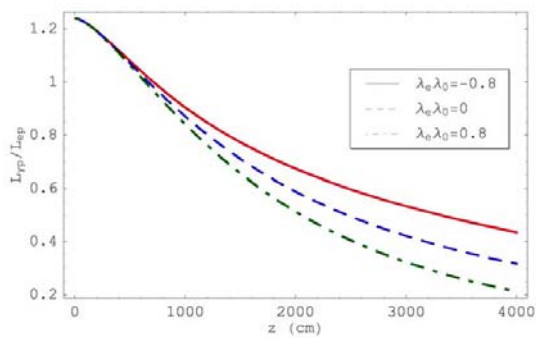


Figure 3: Dependence of the differential cross section of (a) charm and (b) beauty production on x_g in γp and ep scattering at THERA.

Luminosities for Energy Frontier-1



Luminosities for Energy Frontier-2



Discovery limits for excited quarks

- Current limits
 - $m > 570$ GeV (Tevatron)
 - $m > 200$ GeV (HERA)
- Discovery limits (100 events per working year) for QCD-Explorer
 - 0.6 TeV at ep option
 - 0.9 TeV at γp option
- Discovery limits for Energy Frontier-1 (3.74 TeV)
 - 1.2 TeV at ep option
 - 1.8 TeV at γp option
- Of course these regions will be covered opportunity by LHC!
- If excited quark in this region discovered at LHC, ep and especially γp colliders will give to investigate qq^* vertex in details.