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)

Excited Quark Production at CLIC*LHC Based ep and γp Colliders

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Content

- ep and γp Colliders:
  - QCD Explorer
  - Energy Frontier
- Preliminary results of Excited quark production at ep 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

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

- **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]

$$D_e \Delta Q_p \leq 4\nu_s$$

where D_e is disruption parameter of the electron beam and ν_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 $L = 10^{28}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$

- **Possible LHC upgrades:**

β^* 50 cm → 10 cm an increase of luminosity by a factor of 5.
Bunch spacing 25 ns → 12.5 ns an increase in luminosity by a factor of 2.

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

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

at the expense of IBS: τ_{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 → 10^{31} cm^{-2}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	2.0×10^{10} m^{-1}	2.1×10^{12} 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	$\gamma\epsilon_{x,y}$	73 μm	3.75 μm
collision frequency	f_{coll}	100 Hz	
luminosity	L	1.1×10^{31} cm^{-2}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

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

- $L = 1.1\mathrm{x}10^{31}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$

Energy frontier ep colliders:

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

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

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

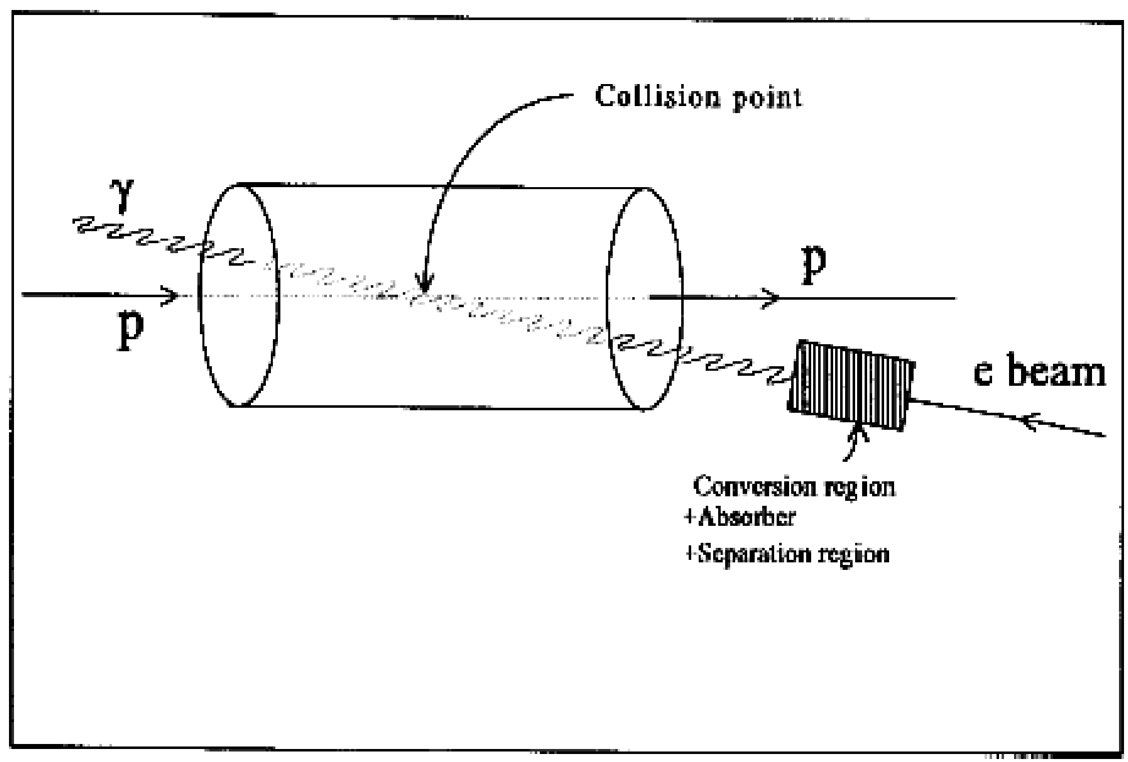
- Upgraded ep Energy Frontier ($L= 10^{31}\ cm^{-2}s^{-1}$)*

*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 γe 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

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

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

$$\sigma_c^0 = \frac{\pi\alpha^2}{x\, m_e^2} \left[(2 + \frac{4}{x}) \ln(x+1) - 5 + \frac{2}{x+1} - \frac{1}{(x+1)^2} \right]$$

- 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 Θγ)

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

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.

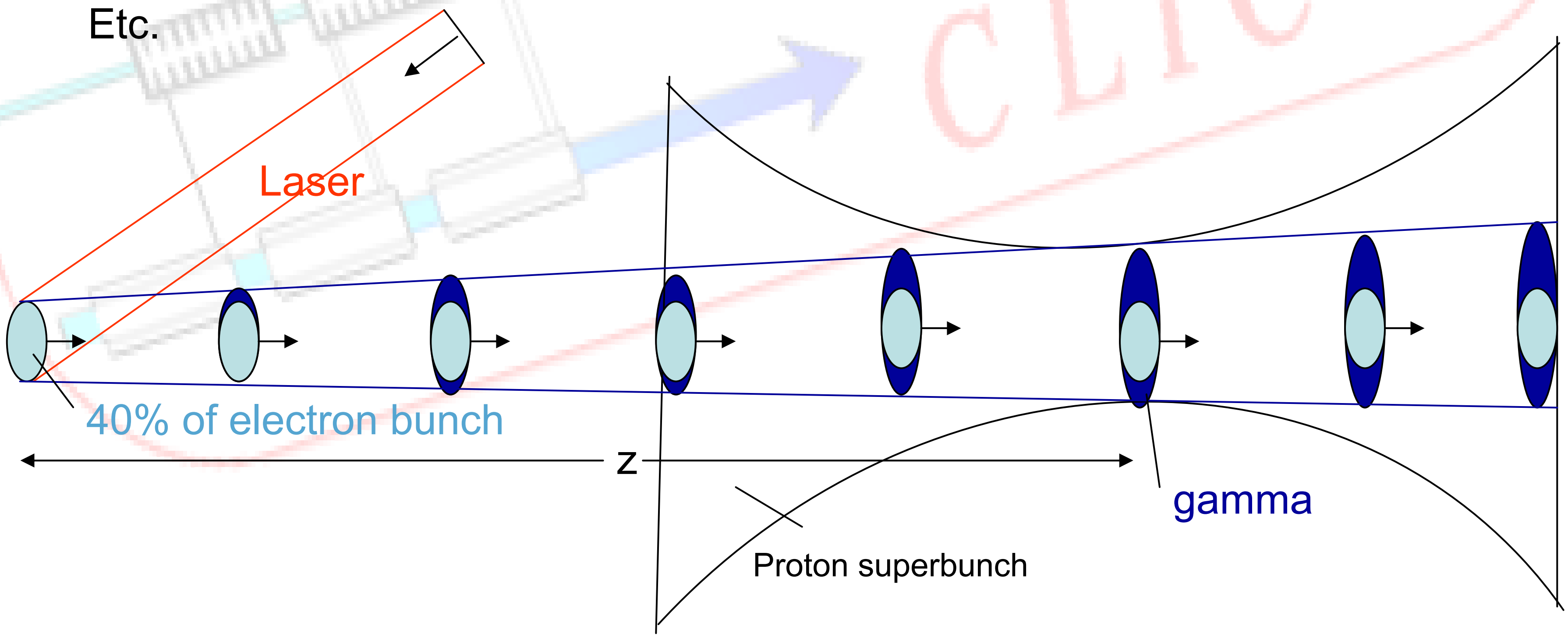
- The differential luminosity with respect to γp invariant mass which takes the conversion to collision distance (z) into consideration is given by

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

- 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

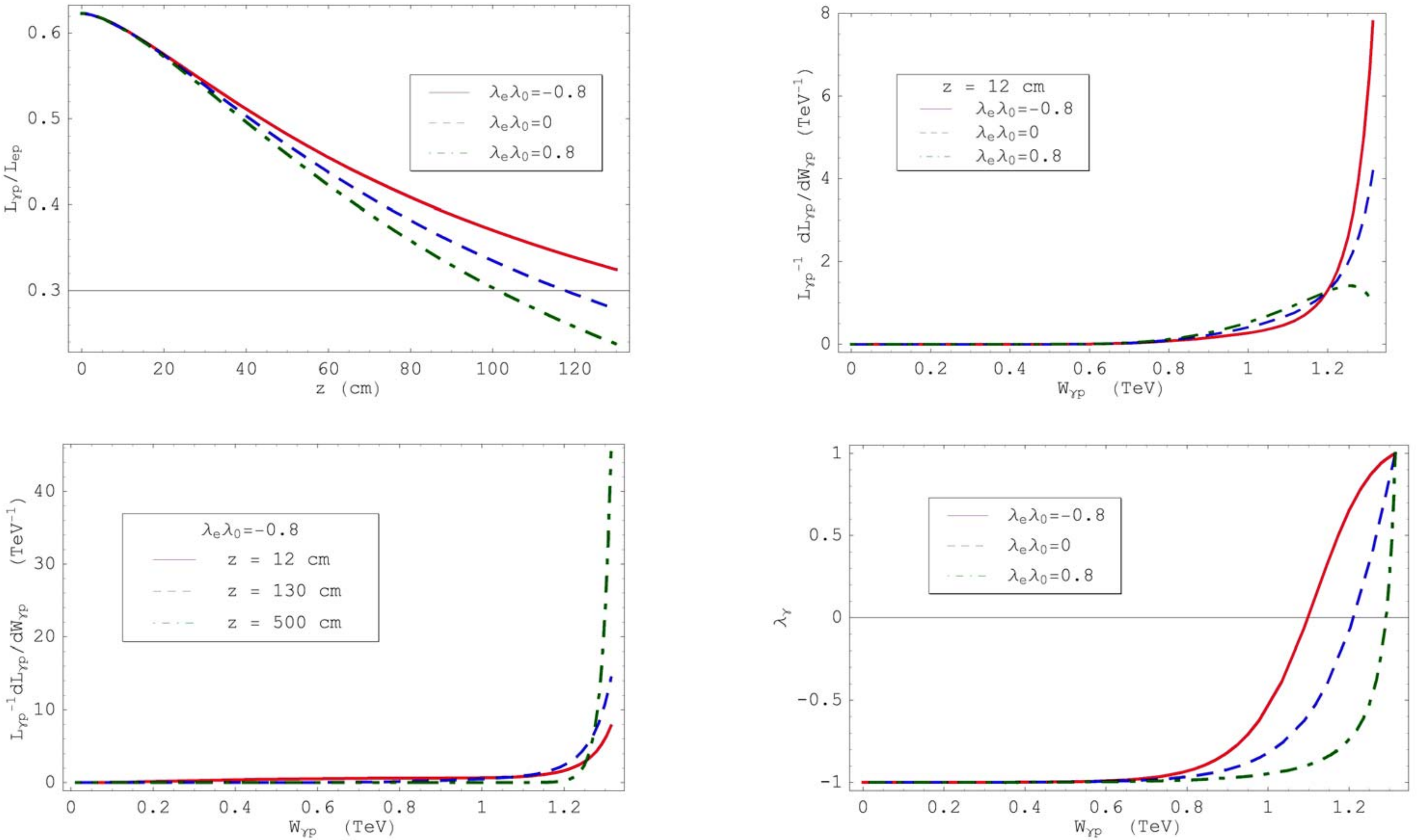
- Photon spot size at the main IP consists of three contributions: the e-beam divergence, the divergence of scattered photons and the e-beam spot size at conversion point. The optimum electron beta function at conversion point to get smallest photon spot size at main IP is equal to z. We con sider four 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:

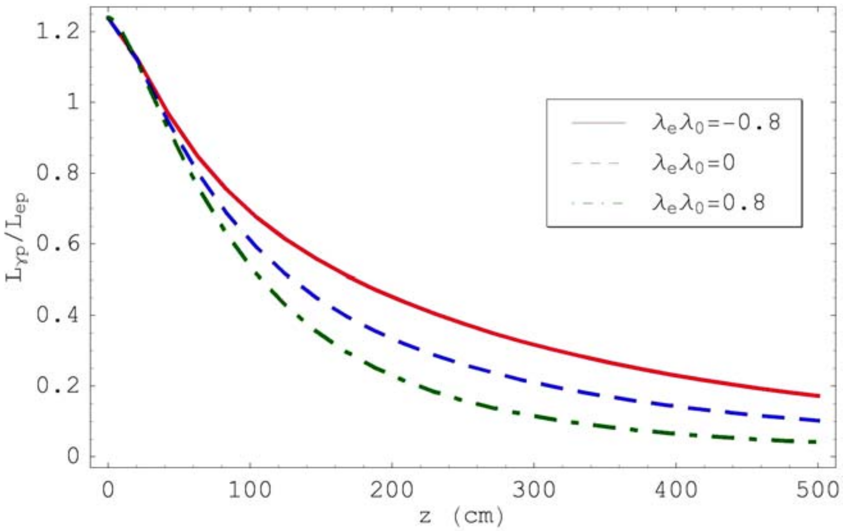
– z_{max} (where the rms photon beam size equals the rms size of the proton beam at IP) is either 16 μm (nominal LHC) or 11 μm (LHC upgrade).

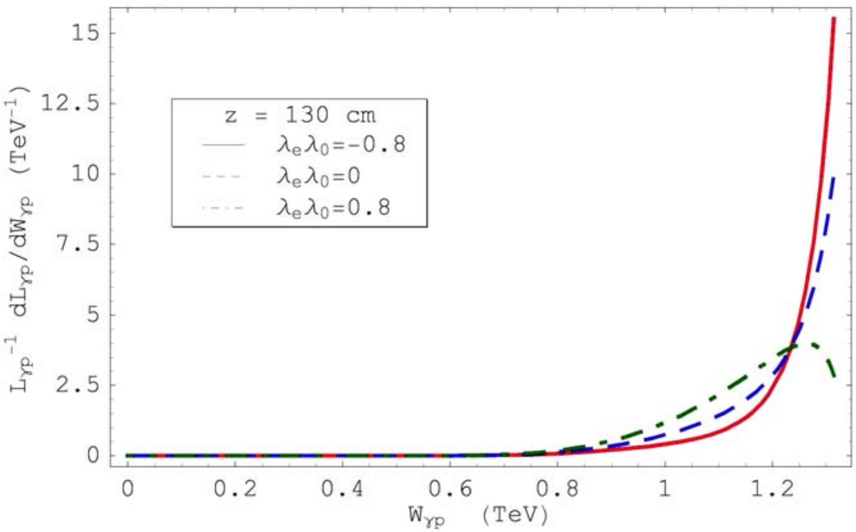
	QCD-E	QCD-E-2	High energy-1	High energy-2
ε_N [μm]	73	2	1.3	0.6
E_e [GeV]	75	75	500	1500
z_{max} [m] at σ^*=16μm	0.25	2.1	14.4	45.2
z_{max} [m] at σ^*=11μm	0.12	1.3	9.6	30.6

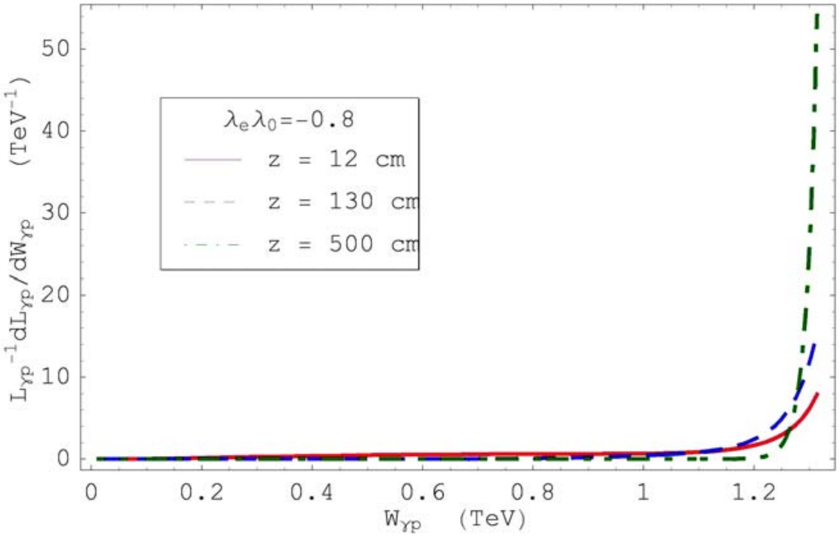
Luminosities for QCD-E

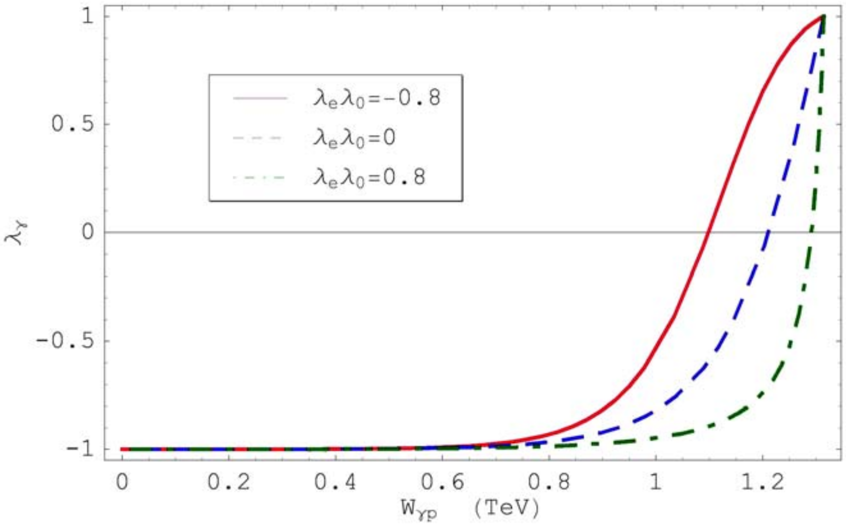


Luminosities for QCD-E-2









ep vs. γp for the small x_g investigation

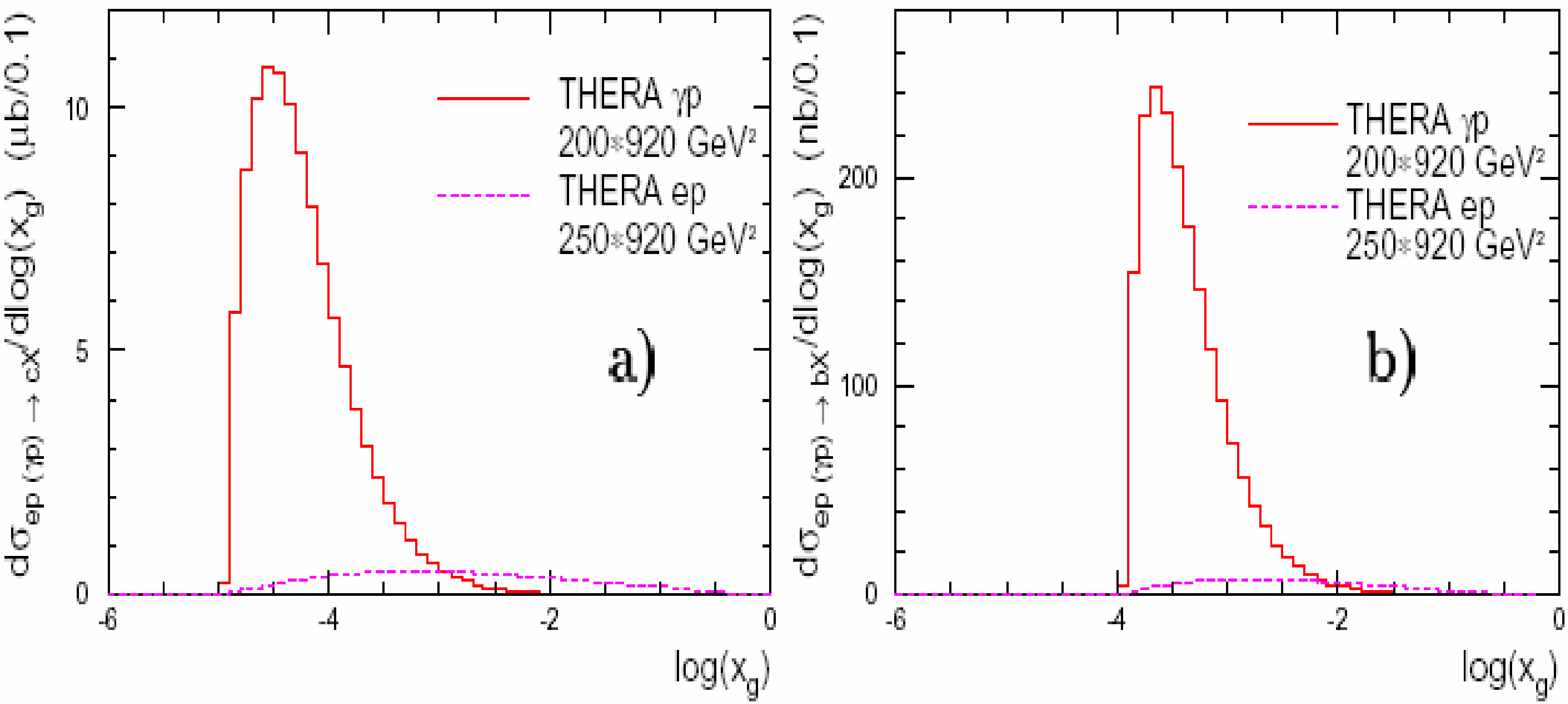
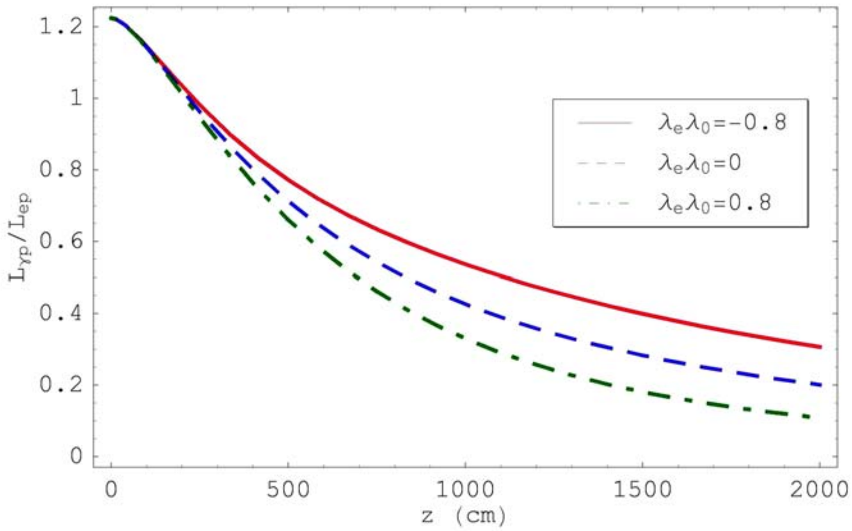
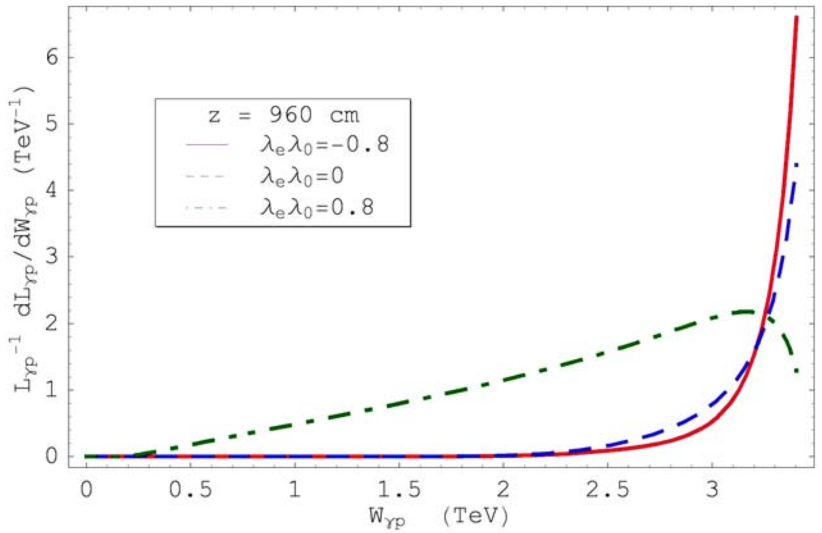
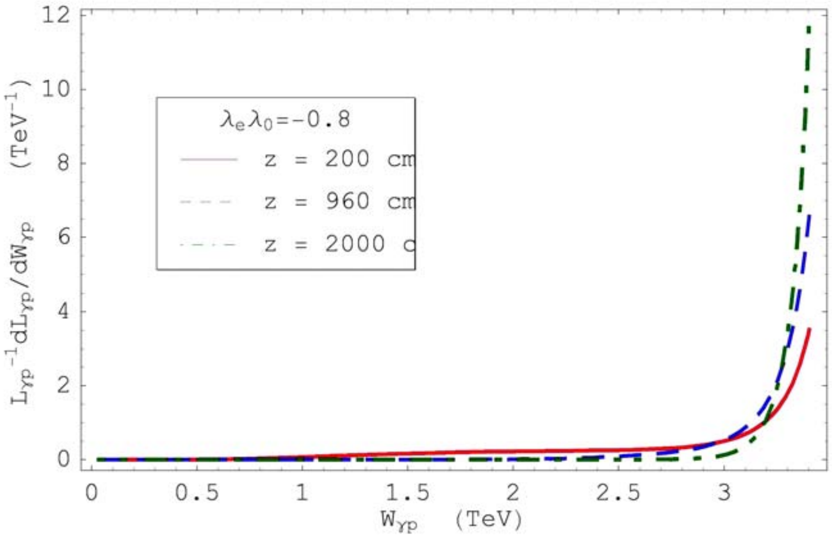


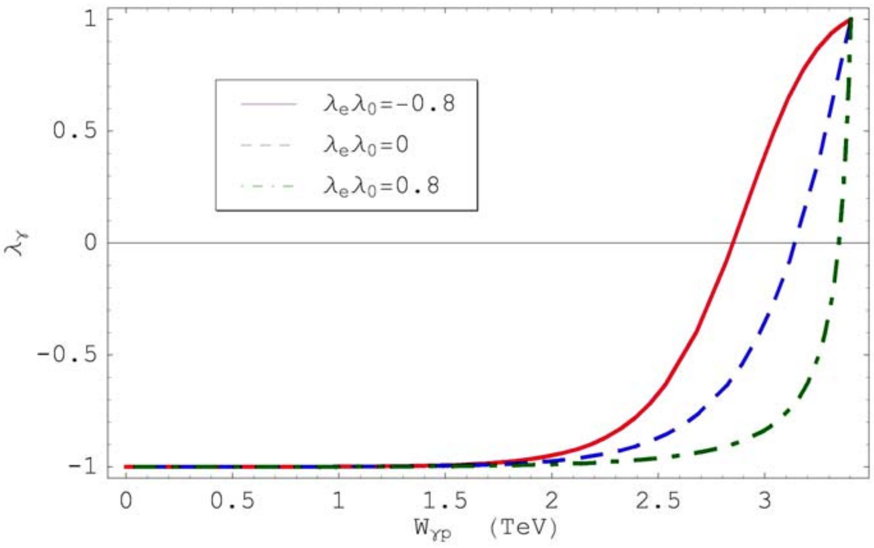
Figure 3: *Dependence of the differential cross section of (a) charm and (b) beauty production on x_g in γp and ep scattering at THERA.*

Luminosities for Energy Frontier-1

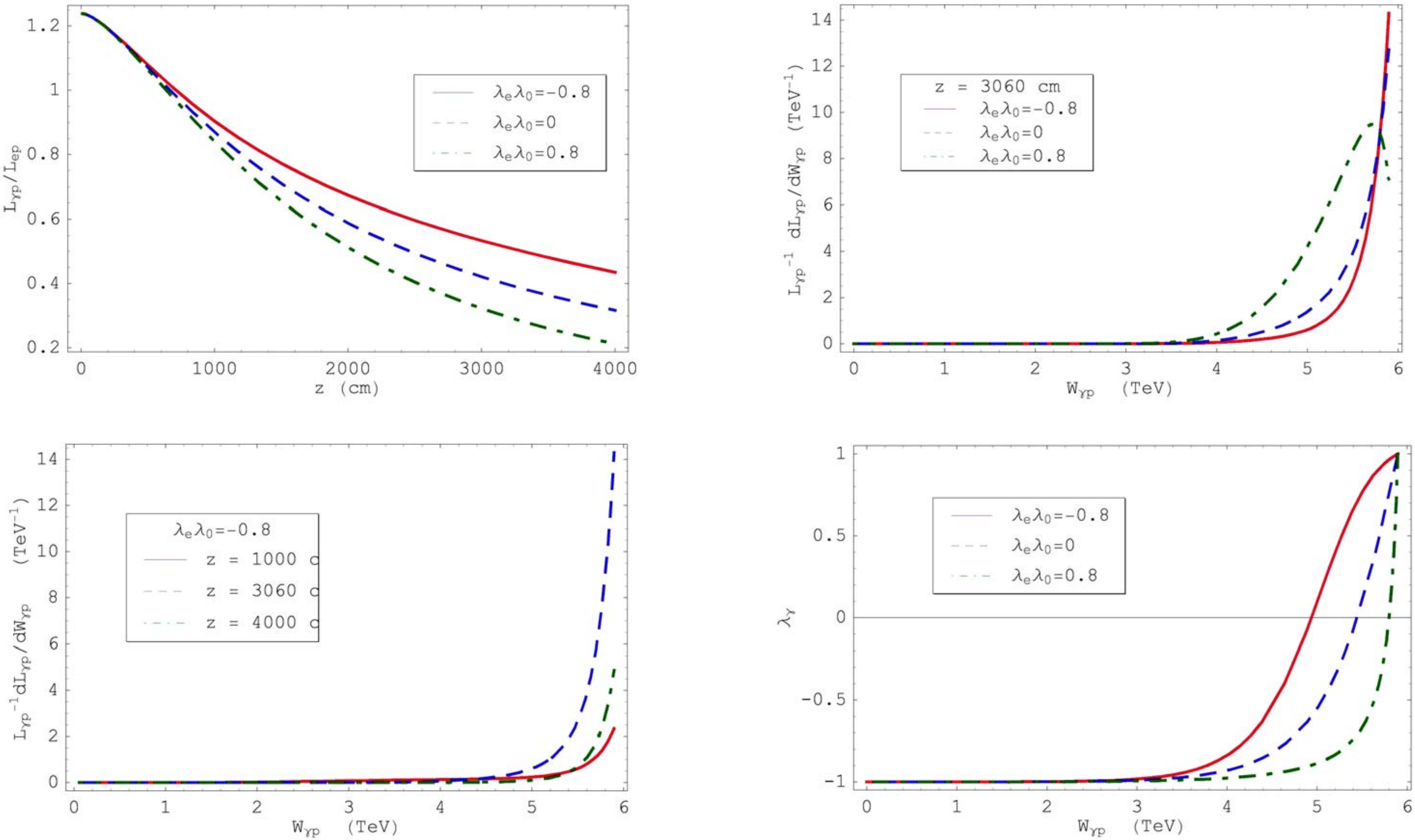








Luminosities for Energy Frontier-2



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.