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THERA Based γp and γA Colliders

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INTRODUCTION

THERA=TESLA⊕HERA

⊕TeV scale ep collider
⊕TeV scale γp collider
⊕eA collider
⊕γA collider
⊕FEL γ A collider

TeV scale ep collider is investigated by

- M. Tigner, B. Wiik and F. Willeke, *An Electron-Proton Collider in the TeV Range*, Proc. of the 1991 IEEE Particle Accelerators Conference (6-9 May 1991, San Francisco, California), vol. 5, p. 2910.
- R. Brinkmann and M. Dohlus, *A method to overcome the bunch length limitations on β_p^* for electron-proton colliders*, DESY-M-95-11 (1995).
- R. Brinkmann, *Interaction Region and Luminosity Limitations for the TESLA/HERA e/p Collider*, Turkish J. Phys. 22 (1998) 661. (1997 Ankara Meeting)
- R. Brinkmann et al., Linac-Ring Type Colliders: Fourth Way to TeV Scale, DESY 97-239 (1997).

TeV Scale γp and γA Colliders

One of the most important advantages and features of the linac-ring type colliders is the possibility of **constructing γp and γA colliders** based on them.

- S. F. Sultanov, *Prospects of the future ep and γp colliders: luminosity and physics*, IC/89/409, Trieste (1989).
- A. K. Ciftci, S. Sultansoy, S. Turkoz and O. Yavas, *Main parameters of TeV energy γp colliders*, Nucl. Instrum. Meth. A 365 (1995) 317.

High energy photon beams will be obtained by Compton backscattering of laser light off a beam of high energy electrons just as proposed in γe and γγ colliders based on linear colliders. Photon conversion rate is

$$\frac{N_\gamma}{N_e} = 0.65$$

- Novosibirsk Group, I. F. Ginzburg, V. Serbo, V. I. Telnov and Co.

Table I. Electron beam parameters

	Non-upgraded parameters	Upgraded parameters		
	(a)	(b)	(c)	(d)
Electron energy (GeV)	500	300	500	800
Number of electrons per bunch (10^{10})	2	1.8	1.5	1.41
Number of bunches Per pulse	2820	4640	4950	4430
Beam power (MW)	22.6	40	30	40
Bunch length (mm)	0.4	1	0.4	0.3
Bunch spacing (ns)	337	192	192	192
Repetition rate (Hz)	5	10	5	5
β_x^* / β_y^* (mm)	15/0.4	15/0.4	15/0.4	15/0.4
σ_x / σ_y at IP (nm)	535/5	535/5	535/5	535/5
σ_z (μm)	400	400	400	400

Table II. Proton beam parameters

	Non-upgraded parameters	Upgraded Parameters
	(a)	(b)
Proton energy (TeV)	0.92	0.92
Number of protons per bunch (10^{10})	7	30
Number of bunches per ring	180	90
Bunch separation (ns)	96	192
β_x^* / β_y^* (m)	7/0.5	0.2/0.2
σ_x / σ_y at IP (µm)	265/50	12.5/12.5
σ_z (cm)	8.5	15

Luminosity of γp Collider

Rough estimation of the luminosity

$$L = f_\gamma \frac{N_\gamma N_p}{2\pi\sqrt{(\sigma_{\gamma x}{}^2 + \sigma_{px}{}^2)(\sigma_{\gamma y}{}^2 + \sigma_{py}{}^2)}}$$

Here f_γ is the collision rate.

In the estimations, γ bunch transverse sizes (at z = 0) are taken equal to electron bunch sizes.

Table III. Luminosity for the various THERA γp collider combinations

Collider	I_a+II_a	I_a+II_b	I_c+II_a	I_b+II_b	I_c+II_b	I_d+II_b
$\sqrt{s}$ (TeV)	1.234	1.234	1.234	0.96	1.234	1.56
L (10^{31} $cm^{-2}s^{-1}$) at z = 0	0.0016	0.56	0.002	1.66	0.74	0.62

Total Luminosity as a function of z (z is the distance between the conversion region and the collision point):

$$L_{\gamma p} = \int_0^{\omega_{\max}} \frac{dL_{\gamma p}}{d\omega} d\omega$$

Differential Luminosity (ω is the energy of high energy photon):

$$\frac{dL_{\gamma p}}{d\omega} = \frac{f(\omega) N_\gamma N_p f_\gamma}{2\pi\sqrt{(\sigma_{\gamma x}{}^2 + \sigma_{px}{}^2)(\sigma_{\gamma y}{}^2 + \sigma_{py}{}^2)}} \exp[-\frac{z^2 \Theta_\gamma^2(\omega)}{2\sqrt{(\sigma_{\gamma x}{}^2 + \sigma_{px}{}^2)(\sigma_{\gamma y}{}^2 + \sigma_{py}{}^2)}}]$$

$\Theta(\omega)$ is the angle between high energy photons with energy ω and electron beam direction (for small Θ_γ):

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

where $x = 4E_e\omega_0/m_e^2 < 4.83$ and w_0 is the laser photon energy.

$f(\omega)$ is the normalized differential Compton cross section :

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

(where $y = \omega/E_e$, $r = y/[x(1-y)]$, λ_e is helicity of the electron, λ_0 is helicity of laser photon and maximum energy of the high energy photons is $\omega_{max} = E_e x/(x+1) = 0.83E_e$)

The total Compton cross section is

$$\sigma_C = \sigma_C^0 + \lambda_e \lambda_0,$$

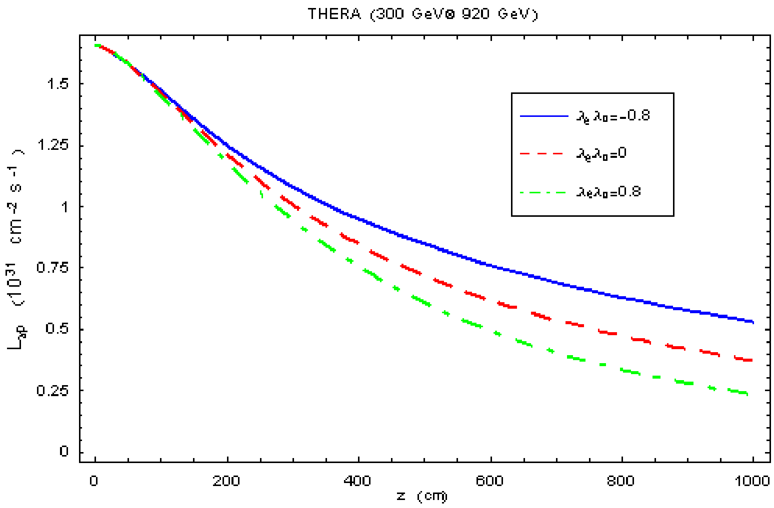
$$\sigma_C^0 = \frac{\pi\alpha^2}{x m_e^2}[(2 - \frac{8}{x} - \frac{16}{x^2})\ln(x+1) + 1 + \frac{16}{x} - \frac{1}{(x+1)^2}],$$

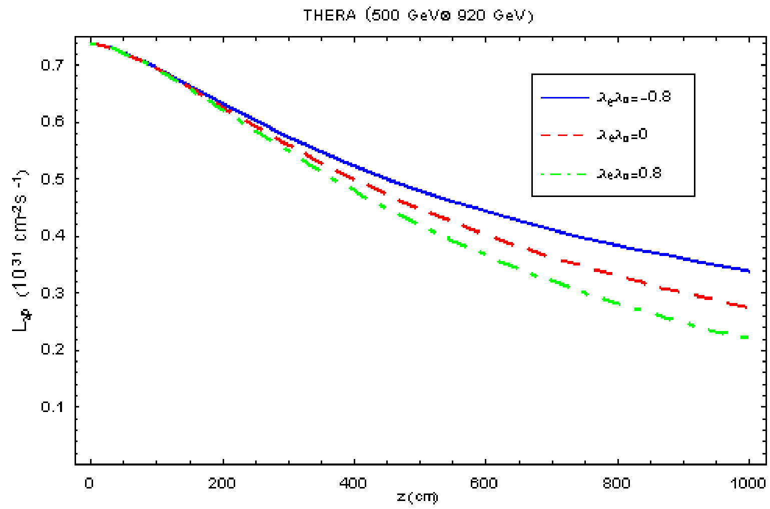
$$\sigma_C^1 = \frac{\pi\alpha^2}{x m_e^2}[(2 + \frac{4}{x})\ln(x+1) - 5 + \frac{2}{x+1} - \frac{1}{(x+1)^2}].$$

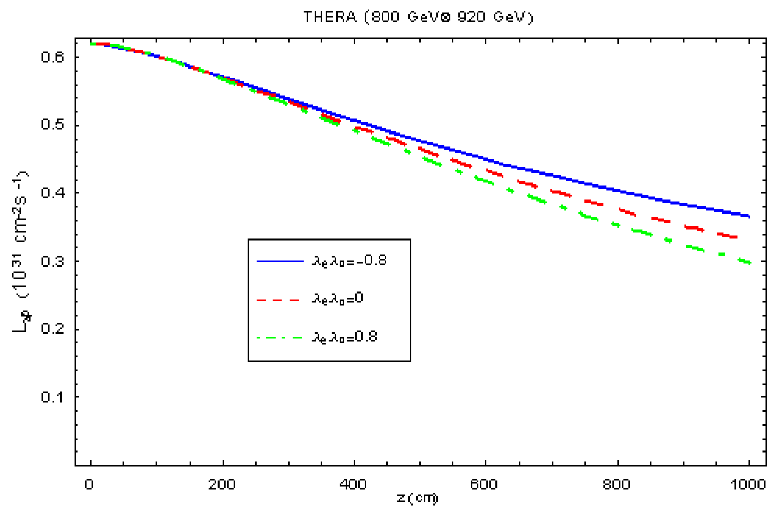
The helicity of high energy photons is

$$\lambda_\gamma(\omega) = \frac{\lambda_0(1-2r)(1-y+1/(1-y)) + \lambda_e r x[1 + (1-y)(1-2r)^2]}{1 - y + 1/(1-y) - 4r(1-r) - \lambda_e \lambda_0 r x(2r-1)(2-y)}.$$

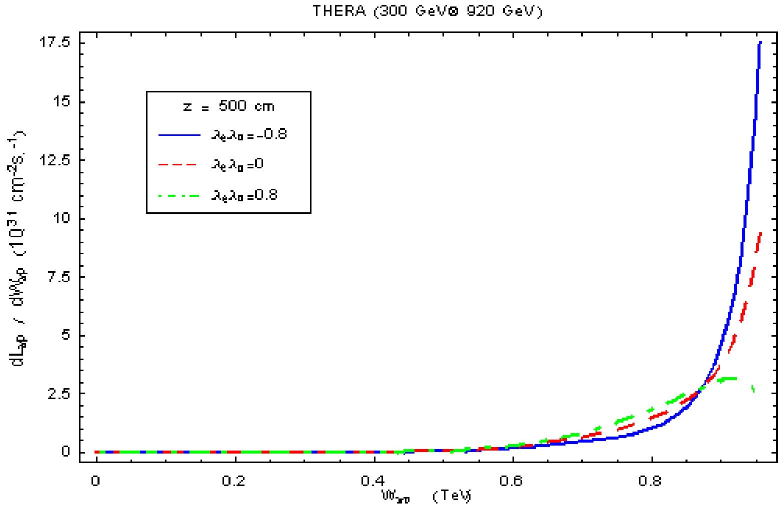
Luminosity dependence on distance for upgraded versions:

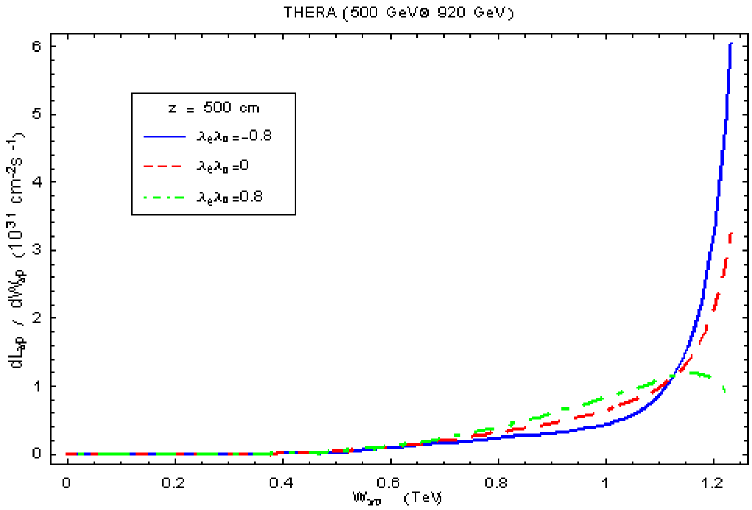


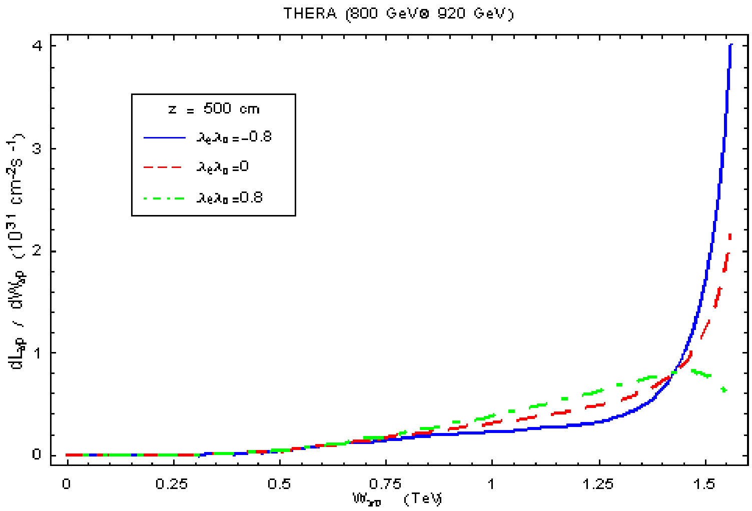




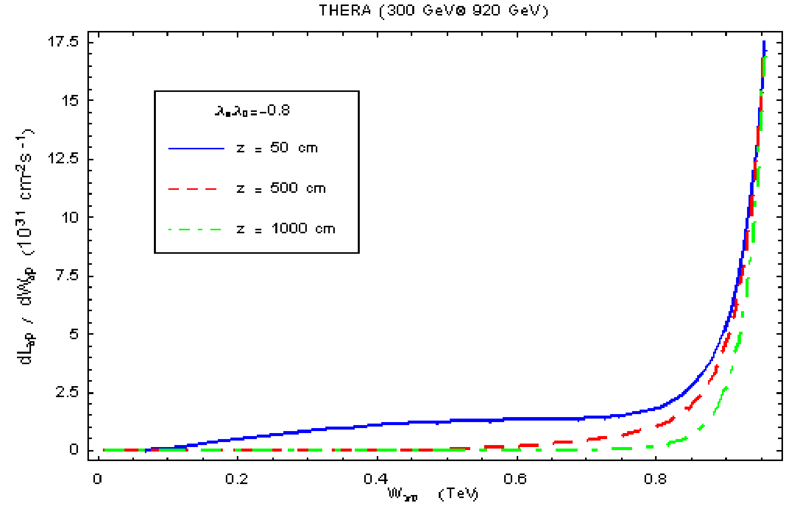
Luminosity distribution as a function of γp invariant mass at z=5m:

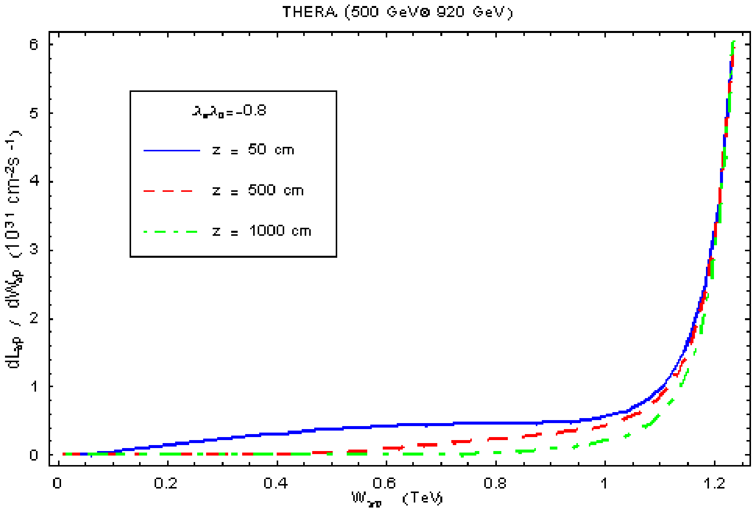


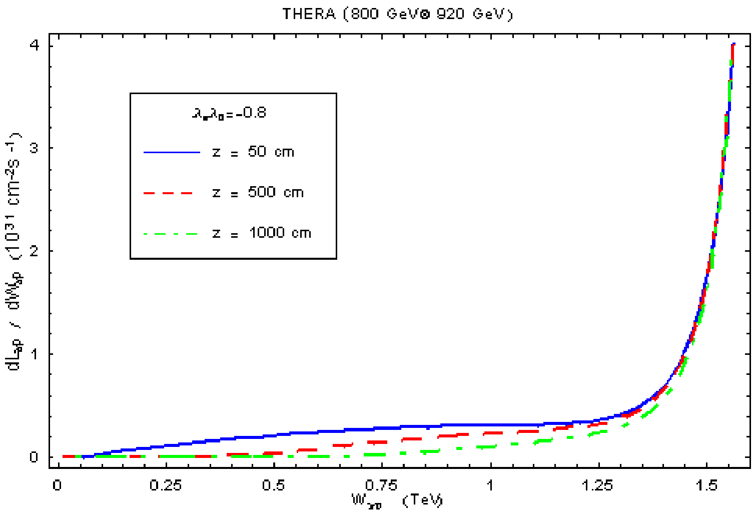




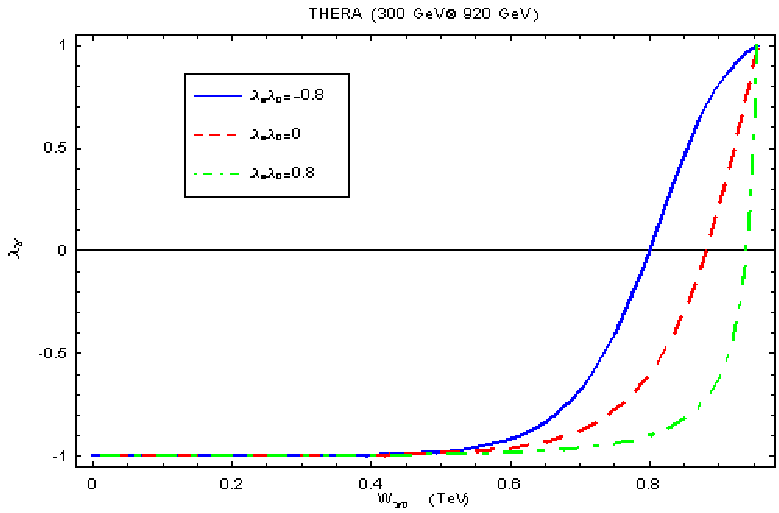
Luminosity distribution as a function of γp invariant mass for $\lambda_e \lambda_0 = -0.8$ at three different distance values:

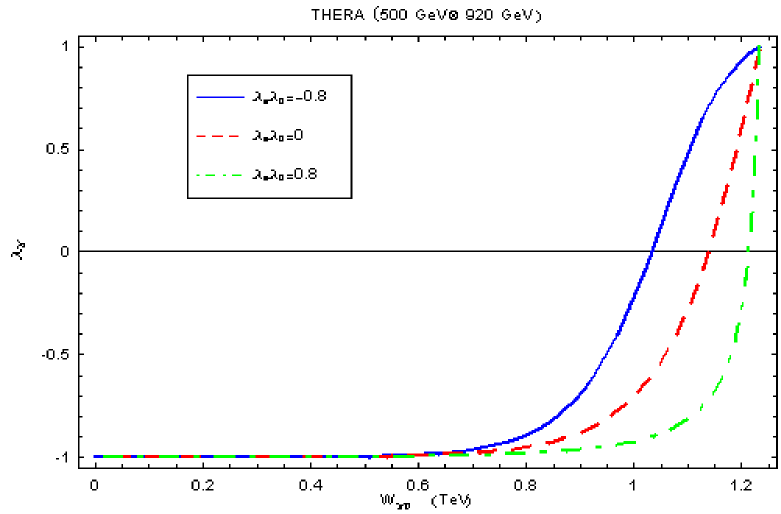


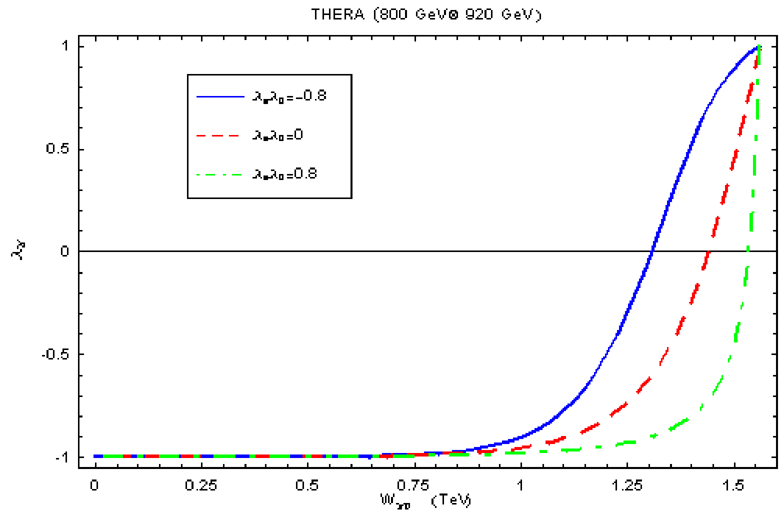




High energy photon helicity as a function of γp invariant mass:







Luminosity of γA Collider

We consider light nuclei, such as Carbon, for the acceleration.

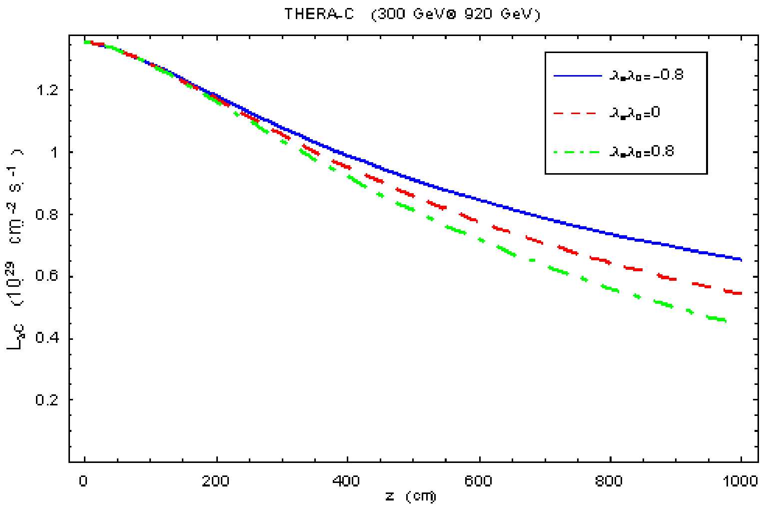
Table IV. Beam parameters for Carbon nuclei.

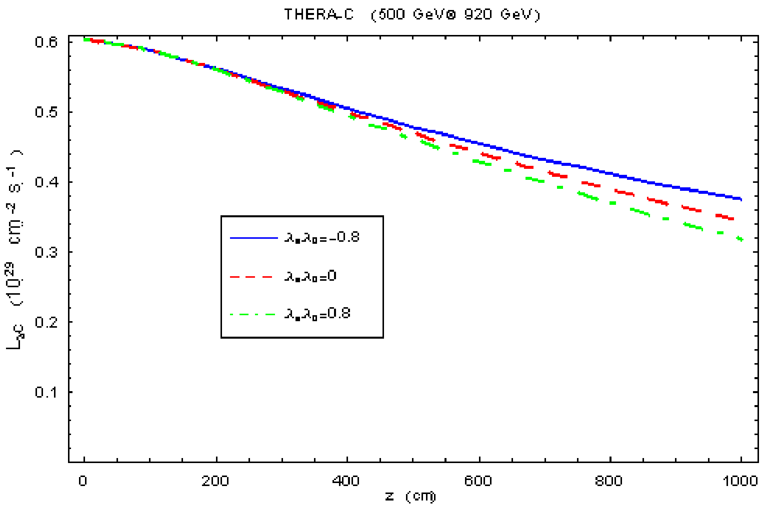
Energy of C nuclei (TeV)	5.52
Number of C per bunch (10^9)	8
Number of bunches per ring	90
Bunch separation (ns)	192
β_x^* / β_y^* (m)	0.2/0.2
σ_x / σ_y at IP (μm)	50/50
σ_z (cm)	15

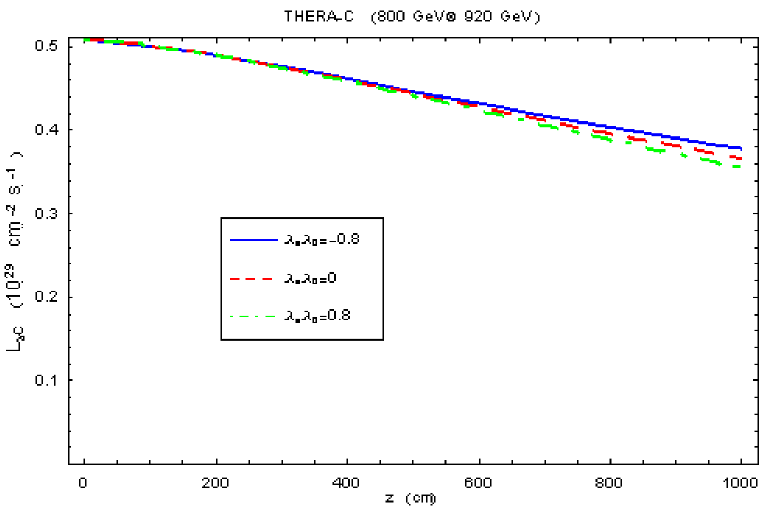
The main limit for acceleration of nuclei is the intra-beam scattering. ($\propto Z^4 A^{-2} \gamma_A^{-3}$)

It is good to investigate small x_g region in nuclear medium.

γC Luminosity dependence on distance and polarization:







Design Problems

There are two possibilities:

1. Head-on collisions
2. Collisions with angle.

Also, for both possibilities, there are two options:

a) Deflection of the electron beam

Problem: synchrotron radiation on p-beam line and detector

b) Without deflecting

Problem: beam-beam tune shift affects proton or nuclei beam.

If one does not want to deflect electron beam, possible remedy might be:

i) Using matched electron beam

Problem: loosing the half of the luminosity.

ii) Defocusing the e-beam after conversion point

?

iii) Rotation of e-bunch around x-axis

??

iv) Combinations of above options.

Conclusion

Advantages of γp and γA options are:

1. Better spectrum of converted photon vs. Weizsäcker-Williams photon
2. Good kinematics

(Energy of the γ beam is close to the energy of the valence quark $\rightarrow$ events at wider angles)

3. Highly polarized γ beam
4. These options will be unique to THERA complex and can not be realized at LEP*LHC.

Design problems can be overcome.

One might increase luminosity by cooling of p-beam and/or "dynamic focusing" of p-beam.

It is too good to leave!!