Electron beam lifetime

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July 30, 2020

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Introduction

- Original study was done by Krzysztof Piotrzkowski to determine limits on electron beam lifetime due to bremsstrahlung losses
- Electron is lost from the beam when 1% of its energy is emitted by the photon
- I've confirmed bremsstrahlung cross section in e-Au, in order of kb
- Mean number of bremsstrahlung photons in ep and e-Au was summarized in a writeup here
- Luminosity in EIC parameters tables in e-Au is effective luminosity per nucleon, observed luminosity is the effective luminosity scaled by $1/A$ of the Au nuclei
- Lifetime in e-Au imposed by bremsstrahlung losses is $\sim$1.5 hours

Bethe-Heitler bremsstrahlung cross section

- Ultra-relativistic approximation in QED texbook by Berestetskii, Lifshitz and Pitaevskii gives the total cross section for proton or nucleus as:

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\omega} = 4Z^2\alpha r_e^2 \frac{1}{\omega}\frac{\epsilon'}{\epsilon}\left(\frac{\epsilon}{\epsilon'} + \frac{\epsilon'}{\epsilon} - \frac{2}{3}\right)\left(\ln\frac{2\epsilon\epsilon'}{m_e\omega} - \frac{1}{2}\right), \tag{1}$$

- ω is photon energy and ϵ and ϵ' is initial and final electron energy respectively, all in target proton/nucleus rest frame
- Z = 79 for gold and 1 for proton, m_e is electron rest mass and αr_e^2 = 0.57946 mb

Luminosity per one bunch crossing

- Necessary for mean number of photons in bunch crossing
- Procedure was used by Bill for tagger multiplicity here
- Instantaneous luminosity L in $\mathrm{cm}^{-2}\mathrm{s}^{-1}$ is converted to luminosity per one bunch crossing $\mathcal{L}_b$ in mb^{-1} as:

$$\mathcal{L}_b = 10^{-27} L \frac{1}{n_b} \frac{l}{\beta c} \tag{2}$$

- n_b is number of bunches, β is velocity of the beam, l=3834 m is the machine circumference, c is the speed of light and $1\mathrm{mb} = 10^{-27}\mathrm{cm}^2$
- $l/(\beta c)$ is period of one orbit, about 13 µs at the top ep energy
- Mean number of bremsstrahlung photons in one bunch crossing is:

$$\lambda_{\mathrm{phot}} = \sigma_{\mathrm{BH}} \times \mathcal{L}_b \tag{3}$$

Beam lifetime

- Rate of electron losses is given by Bethe-Heitler total cross section σ_{BH} and instantaneous luminosity:

$$-\frac{\mathrm{d}N}{\mathrm{d}t} = \sigma_{\mathrm{BH}} \times L \tag{4}$$

- Initial electron population in the beam is $N_e = n_b \times I_b$ where n_b is number of bunches and I_b is bunch intensity
- Beam lifetime τ is then:

$$\tau = -\frac{N_e}{\mathrm{d}N/\mathrm{d}t} = \frac{N_e}{\sigma_{\mathrm{BH}} \times L} \tag{5}$$

- Total cross section σ_{BH} is obtained by integrating Eq. 1 from minimal photon energy

Results in e-Au

- First part is input from EIC parameter tables here
- Luminosity in parameter tables is L_{eN}, observed luminosity is $L = L_{eN}/A$
- Minimal photon energy $E_{\gamma,\min}$ is set as 1% of electron beam energy (electron is lost from the beam)

Species	Au ion	electron	Au ion	electron	Au ion	electron	Au ion	electron
Energy [GeV]	110	18	110	10	110	5	41	5
n_b	290		1160		1160		1160	
I_b [10^{10}]	7.29		17.2		17.2		17.2	
L_{eN} [10^{33} cm^{-2}s^{-1}]	0.59		4.76		4.77		1.67	
L [10^{31} cm^{-2}s^{-1}]	0.3		2.42		2.42		0.85	
$E_{\gamma,\min}$ [GeV]	0.18		0.1		0.05		0.05	
σ_{BH} [kb]	1.41		1.36		1.31		1.23	
$\mathcal{L}_b$ [b^{-1}]	0.132		0.266		0.267		0.093	
λ_{phot}	186		363		349		115	
τ [hour:min]	1:23		1:41		1:44		5:18	

Results in ep

- First part is input from EIC parameter tables here
- Minimal photon energy $E_{\gamma,\mathrm{min}}$ is set as 1% of electron beam energy (electron is lost from the beam)
- Beam lifetime τ is more than 12 hour for the top energy and more than a day for lower energies

Species	p	electron	p	electron	p	electron	p	electron	p	electron
Energy [GeV]	275	18	275	10	100	10	100	5	41	5
n_b	290		1160		1160		1160		1160	
L [10^{33} cm^{-2}s^{-1}]	1.65		10.05		4.35		3.16		0.44	
$E_{\gamma,\mathrm{min}}$ [GeV]	0.18		0.1		0.1		0.05		0.05	
σ_{BH} [mb]	236.8		229.6		217.1		208.5		197.5	
$\mathcal{L}_b$ [mb^{-1}]	0.073		0.111		0.048		0.035		0.005	
λ_{phot}	17.2		25.4		10.4		7.3		1.0	

Summary

- Large bremsstrahlung cross sections were found in e-Au
- In study by Krzysztof Piotrzkowski the cross section for e-Au at 110 $\times$ 10 GeV ranges from 1.58 kb to 1.86 kb depending on model parameters, approximately compatible with 1.36 kb found here
- Hundreds of bremsstrahlung photons per bunch crossing in e-Au
- Electron beam lifetime is about 1.5 hours in e-Au