Single shot laser luminosity and analyzing powers

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Luminosity equation

$$L = f_b N_e N_\gamma G$$

Geometric factor:

$$G = \frac{1+\beta cos\theta}{2\pi\sqrt{\sigma_y^2+\sigma_{\gamma y}^2}\sqrt{\sigma_x^2(\beta+cos\theta)^2+\sigma_{\gamma x}^2(1+\beta cos\theta)^2+(\sigma_z^2+\sigma_{\gamma z}^2)sin^2\theta}}$$

Zhengqiao Z: Mar 3rd

- I couldn't find a reference that gives the exact geometric factor that Zhengqiao had but found an approximate equation for a non-zero angle crossing for two bunched beams (with non-equal longitudinal sizes)
  - Perhaps Zhengqiao has additional correction factors?
- This equation doesn't take the hourglass effect into account (10-15% effect)
  - What other corrections are missing below?

$$\mathscr{L} = f_0 N_1 N_2 \frac{\cos(\theta/2)}{2\pi} \frac{1}{\sqrt{\left(\sigma_{x,1}^2+\sigma_{x,2}^2\right)}} \times \frac{1}{\sqrt{\left(\sigma_{y,1}^2+\sigma_{y,2}^2\right)\cos^2(\theta/2)+\left(\sigma_{z,1}^2+\sigma_{z,2}^2\right)\sin^2(\theta/2)}} \quad (1)$$

S. Verdu-Andres (CAD): https://www.bnl.gov/isd/documents/95396.pdf

Luminosity equation

$$L = f_b N_e N_\gamma G$$

$$\delta P_e \approx \frac{1}{A\sqrt{N}}; N = time * L * \sigma_{Compton} * 0.8 * f_b/290;$$

Geometric factor:

$$G = \frac{1 + \beta cos\theta}{2\pi\sqrt{\sigma_y^2 + \sigma_{\gamma y}^2}\sqrt{\sigma_x^2(\beta + cos\theta)^2 + \sigma_{\gamma x}^2(1 + \beta cos\theta)^2 + (\sigma_z^2 + \sigma_{\gamma z}^2)sin^2\theta}}$$

- Was the frequency of the bunches used twice in the final calculation?
- It seems that the laser has quite a tight z constraint? (is that needed if the e- bunch is 7.5 times larger?)
- What are reasonable values for the emittance at IP12?

$$\sigma_{\gamma x} = 0.1mm; \sigma_{\gamma y} = 0.1mm; \sigma_{\gamma z} = 1.3mm;$$

$$\sigma_z = 10mm; \sigma_x = \sqrt{\epsilon_x \beta_x}, \beta_x = 10m; \beta_y = 50m;$$

Machine parameters

$f_b = 2.2852 \times 10^7; Ne = 6.2 \times 10^{10}; N_\gamma = 2.84974 \times 10^{12};$

Species	proton	electron
Energy [GeV]	275	18
CM energy [GeV]	140.7	
Bunch intensity [10^{10}]	20.5	6.2
No. of bunches	290	
Beam current [A]	0.74	0.227
RMS norm. emit., h/v [μm]	4.6/0.75	845/72
RMS emittance, h/v [nm]	16/2.6	24/2.0
β^*, h/v [cm]]	90/4.0	59/5.0
IP RMS beam size, h/v [μm]	119/10	
K_x	11.8	
RMS $\Delta\theta$, h/v [μrad]	132/253	202/202
BB parameter, h/v [10^{-3}]	3/2	100/100
RMS long. emittance [10^{-3}, eV·sec]	36	
RMS bunch length [cm]	6	0.9
RMS $\Delta p/p$ [10^{-4}]	6.8	10.9
Max. space charge	0.006	neglig.
Piwinski angle [rad]	5.6	0.8
Long. IBS time [h]	2.1	
Transv. IBS time [h]	2	
Hourglass factor H	0.86	
Luminosity [10^{33}cm^{-2}sec^{-1}]	1.65	

Table 1: Maximum Luminosity Parameters

Parameter	***hadron***	***electron***
Center-of-Mass Energy [GeV]	104.9	
Energy [GeV]	275	10
Number of Bunches	1320	
Particles per Bunch [10^{10}]	6.0	15.1
Beam Current [A]	1.0	2.5
Horizontal Emittance [nm]	9.2	20.0
Vertical Emittance [nm]	1.3	1.0
Hor. β-function at IP β_x^* [cm]	90	42
Vert. β-function at IPβ_y^* [cm]	4.0	5.0
Hor./Vert. Fractional Betatron Tunes	0.3/0.31	0.08/0.06
Horizontal Divergence at IP [mrad]	0.101	0.219
Vertical Divergence at IP [mrad]	0.179	0.143
Horizontal Beam-Beam Parameter ξ_x	0.013	0.064
Vertical Beam-Beam Parameter ξ_y	0.007	0.1
IBS Growth Time longitudinal/horizontal [hours]	2.2/2.1	-
Synchrotron Radiation Power [MW]	-	9.18
Bunch Length [cm]	5	1.9
Hourglass and Crab Reduction Factor	0.87	
Luminosity [10^{34}cm-2sec-1]	1.05	

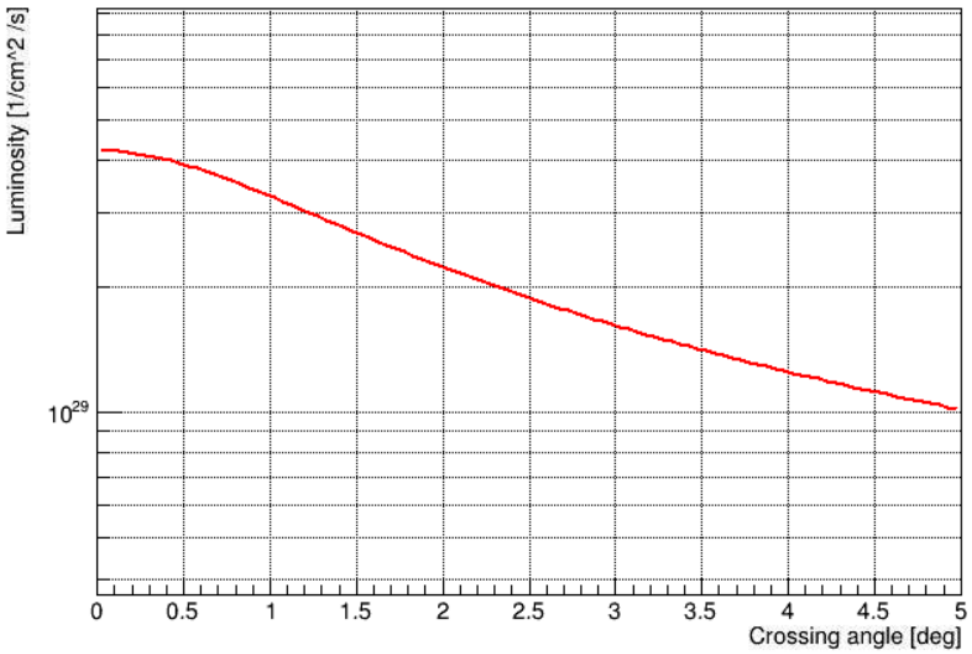
Beam Dynamics Newsletter: No. 74 Aug 2018

- It seems Zhengqiao used 290 bunches for his calculation
  - Has there been a change in the machine design?
  - If so what is the new bunch spacing? (so far we used 10ns and a frequency of ~100MHz)
- How about the number of particles per bunch?
- What kind of laser was assumed here? (wavelength)
  - For 532nm laser with 10W and 10ns bunch spacing we get about 2.6e11 photons per laser bunch

Luminosity formula

$$\mathscr{L} = f_0 N_1 N_2 \frac{\cos(\theta/2)}{2\pi} \frac{1}{\sqrt{\left(\sigma_{x,1}^2 + \sigma_{x,2}^2\right)}} \times \frac{1}{\sqrt{\left(\sigma_{y,1}^2 + \sigma_{y,2}^2\right)\cos^2(\theta/2) + \left(\sigma_{z,1}^2 + \sigma_{z,2}^2\right)\sin^2(\theta/2)}} \quad (1)$$

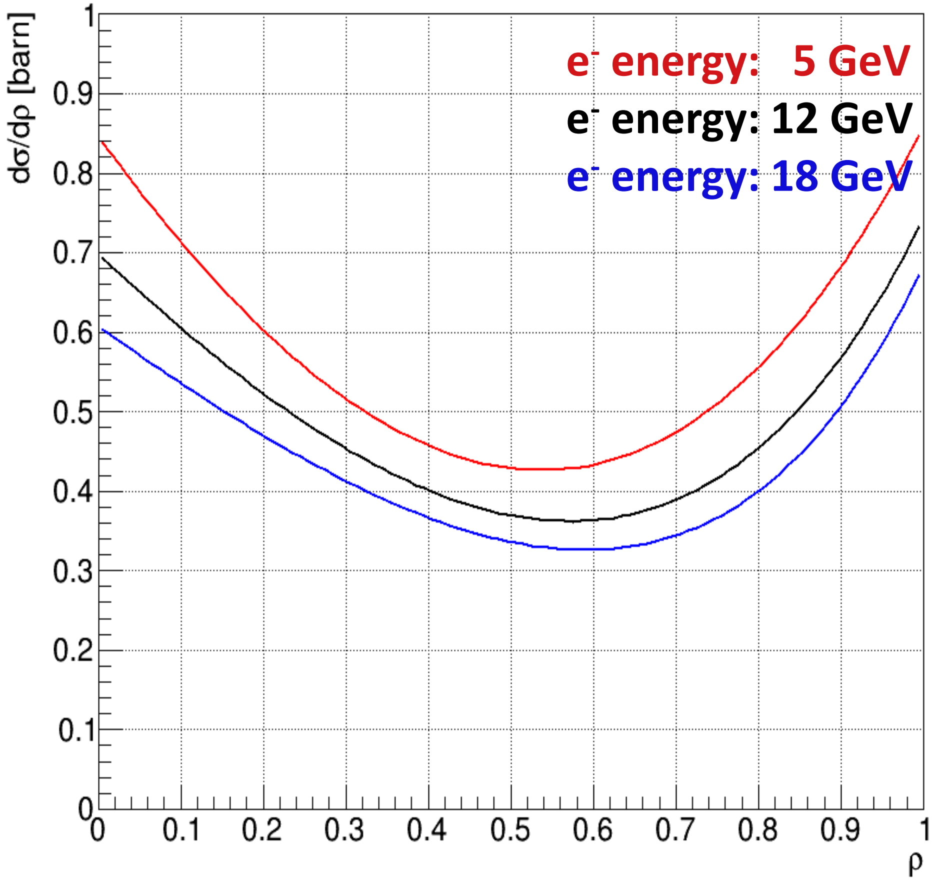
```
double eSigmaX = 400e-6; //m;
double eSigmaY = 400e-6/sqrt(5); //m;
double eSigmaL = 0.01; //m
double eFreq = 78e3;
double nElectron = 6.2e10; //number;
double nBunches = 1320; // 1320*78000 => bunch spacing of ~10ns


double lambda = 532e-9; //m
double gSigmaX = 100e-6; //m
double gSigmaY = 100e-6; //m
double gSigmaL = 12e-12 * clight; //3.6e-3 m -- 12ps FWHM; 4ps is 1.3mm
double lPower = 10; //W
double lBunchEnergy = lPower/(eFreq*nBunches);
double nGammaBunch = lBunchEnergy * lambda / (hplanck * clight) ;//number;
```



- Looking at just **one** bunch crossing with some changes to the parameters Zhengqiao used we obtained a luminosity of about 3e5 /barn/s

Differential measurement

$$N_{Compton} = \frac{\mathcal{L} \cdot \sigma_{unpol}}{f_{beam}}$$



- One can determine the needed luminosity for a differential measurement (counting mode) by requiring that one has 1 photon/electron interaction per crossing
- Taking one bunch frequency (~78kHz) one can obtain:
  - The time it would take to make such a measurement
  - The luminosity requirement

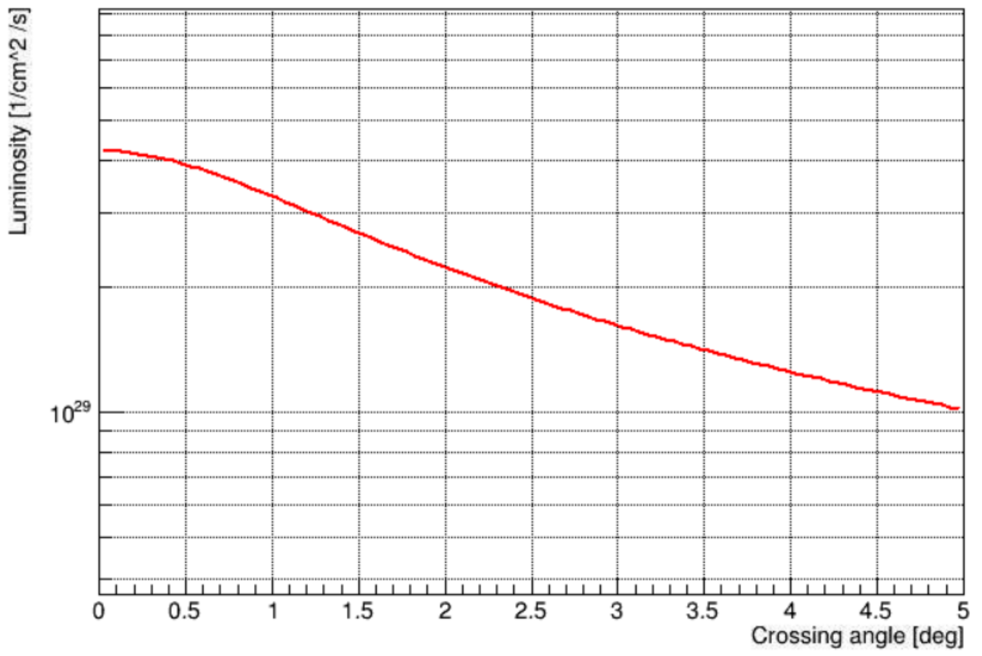
$$t_{meth} = \left(\mathcal{L}\ \sigma_{Compton}\ P_e^2 P_\gamma^2 \left(\frac{\Delta P_e}{P_e}\right)^2 A_{meth}^2 \right)^{-1}$$

G. Bardin, et al., Conceptual design report of a compton polarimeter in cebaf hall a, JLab Internal note.

beam energy [GeV]	Unpol Xsec[barn]	<A^2>	Pe	Pgamma	1/t(1%)	t[ms]	t[min]
5	0.568901	1.23E-03	0.85	1	6.96E-03	1.44E+02	2.39
12	0.482249	4.84E-03	0.85	1	2.74E-02	3.65E+01	0.61
18	0.432076	7.98E-03	0.85	1	4.51E-02	2.22E+01	0.37

Differential measurement: luminosity requirement

- One can determine the needed luminosity for a differential measurement (counting mode) by requiring that one has 1 photon/electron interaction per crossing
- Taking one bunch frequency (~78kHz) one can obtain:
  - The time it would take to make such a measurement
  - The luminosity requirement
- We can see that 10W (100MHz) pulsed laser will provide 1/3 more power than is needed for a differential measurement at 18GeV



beam energy [GeV]	Unpol Xsec [barn]	<A^2>	Pe	Pgamma	L (fbeam/xsection)
5	0.568901	1.23E-03	0.85	1	1.37E+05
12	0.482249	4.84E-03	0.85	1	1.62E+05
18	0.432076	7.98E-03	0.85	1	1.81E+05

Differential measurement: other considerations

beam energy [GeV]	Unpol Xsec [barn]	<A^2>	Pe	Pgamma	1/t(1%)	t[ms]	t[min]
5	0.568901	1.23E-03	0.85	1	6.96E-03	1.44E+02	2.39
12	0.482249	4.84E-03	0.85	1	2.74E-02	3.65E+01	0.61
18	0.432076	7.98E-03	0.85	1	4.51E-02	2.22E+01	0.37

- Can a differential measurement be properly done with higher luminosity? (factor of 2,4 more? – finer segmentation?)
  - If not this is a hard time limit for this measurement type;
- HERA had an issue with high backgrounds; this method of measurement is particularly susceptible to this problem
- Going this way will give us little headroom on the detector requirements (ie a 10ns detector response will be needed)
  - If we don't have a suitable detector for this the only way to get polarizations for all bunches is to go to an integrating method (higher laser power 100W with 100MHz frequency seems doable)
- This time estimate doesn't take into account time needed for a background measurement (twice longer?)
- Corrections (such as the hourglass effect) will probably not add more than 20% on top of this
  - Are there are corrections that are of this order?
- Would it be possible for us to contribute to the Compton simulation package?