Estimating laser power requirements for electron polarimetry

Richard Petti

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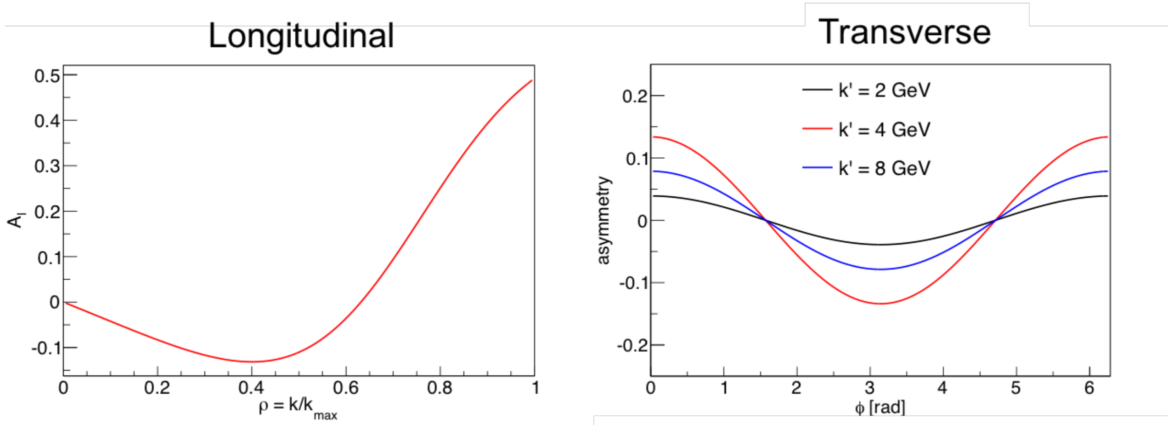
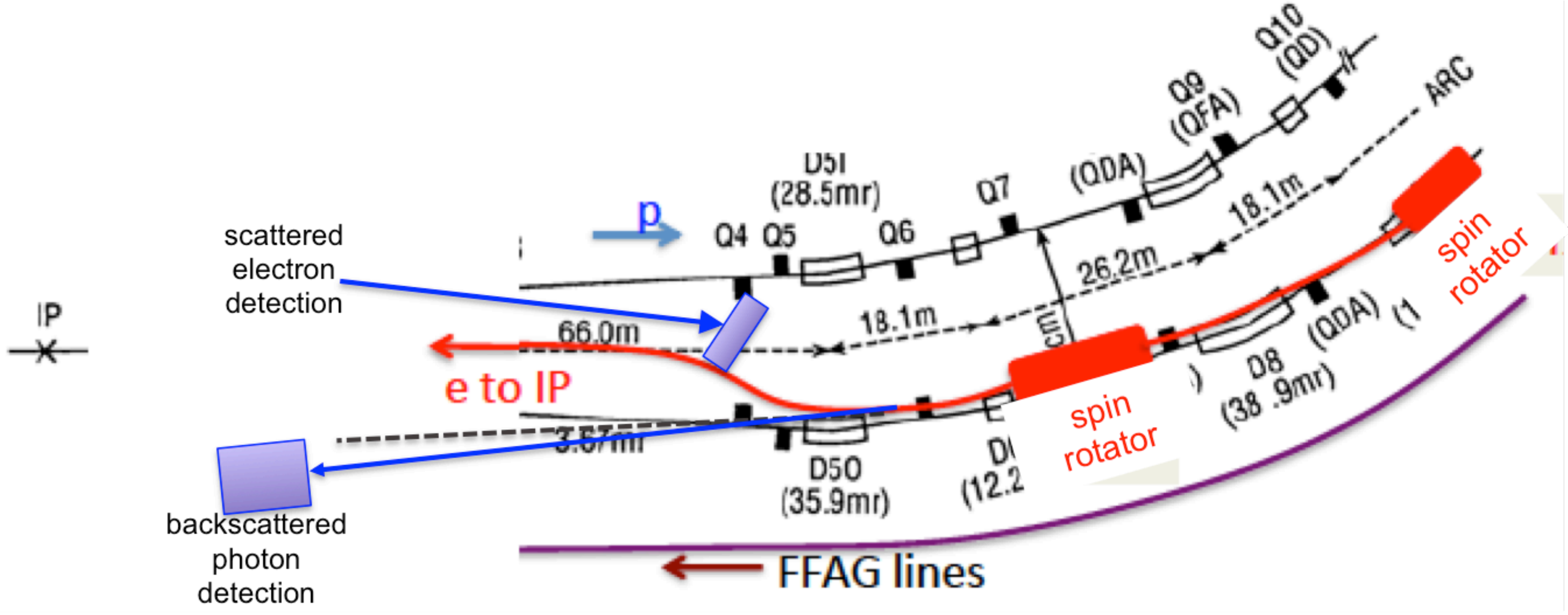
Reminder of e pol plan



- Measure via Compton scattering
- $A = \frac{N^+ - N^-}{N^+ + N^-} = P_e P_\gamma A_{QED}$
- Shine circularly polarized laser on electron bunch, flipping the helicity of the laser and measure the asymmetry of scattered photons (or electrons)



Equation for estimating the luminosity at the Compton IP

- Lumi equation taken from the reference “Some aspects of Compton polarimetry for the ILC at the low beam energy around 5GeV” by Gideon Alexander and Pavel Staroviotov
- For a pulsed laser with a small crossing angle, vertical beam crossing and the transverse dimensions of the electron beam being small compared to the laser focus

$$L = \frac{f_b N_e N_\gamma}{2\pi \sigma_{x\gamma} \sigma_{y\gamma} \sqrt{1 + \left(0.5\theta \sigma_{z\gamma}/\sigma_{y\gamma}\right)^2}}$$

Some reasonable assumptions

- Assume a pulsed laser in sync with RHIC clock
  - Browsing one company site (Lumentum), looks like this is possible
- Assume size of laser pulse (in transverse and longitudinal directions) is the same as the electron beam bunch
- f_b = 9.4 MHz
- N_e = 0.07e11 (taken from eRHIC design report)
- sigma_x = sigma_y = 400um (not sure what this should be at the Compton IP, talk with Vadim about it, right now this is what JLab Hall A has)
- sigma_z = 0.4cm (from eRHIC design report)

Estimating the number of photons desired per pulse (thus the energy per pulse)

- Set the luminosity such that there is one Compton photon per beam crossing
- counts (per second) = L*sigma
- counts (per bunch) = L*sigma/f_b
- sigma ~ 400mb for 20GeV electrons with 2.33eV laser
- Setting counts per bunch = 1 and doing algebra to solve for N_{gamma}, we get:

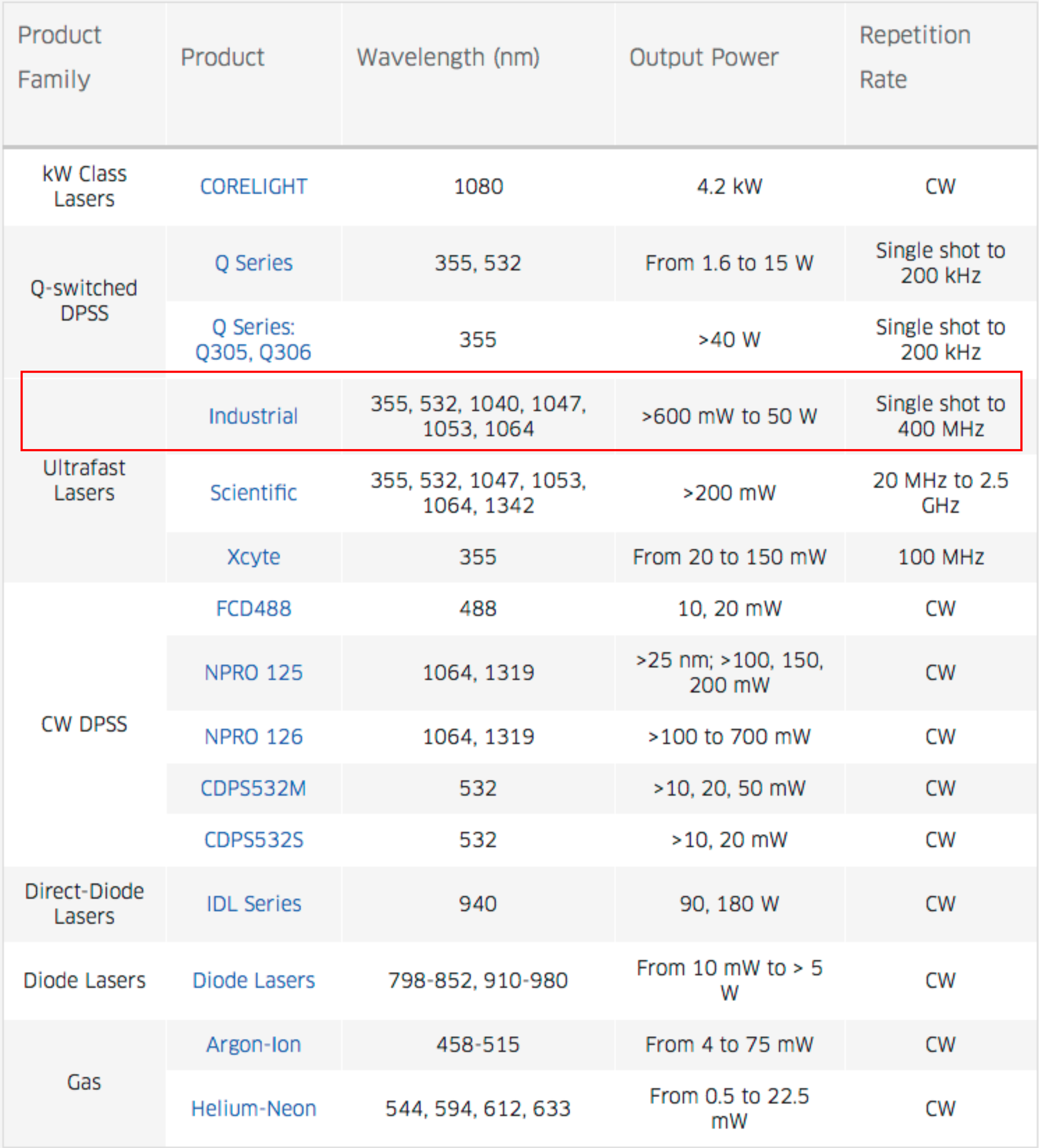
$$N_\gamma = \frac{2\pi\sigma_x\sigma_y\sqrt{1+\left(0.5\theta\sigma_z/\sigma_y\right)^2}}{N_e\sigma}$$

Plugging in…

- Using the previously stated parameters, and a 25mrad crossing angle, to get 1 Compton photon per bunch crossing
- Number of laser photons per bunch = 3.6e12
- Resulting energy per bunch (assuming 2.33eV laser) = 1.3uJ
  - Or a 12 W laser
  - Do we need a Fabry-Perot cavity?
  - High-finesse Fabry-Perot cavity at JLab had a 1.74W laser with cavity boosted to 3.7kW
    - 532nm laser, e beam energy 1.06GeV, I=50uA, crossing angle=24mrad
  - HERA LPOL: 532nm laser, e beam energy 27.5GeV, rep rate 100Hz, 100mJ per pulse
- This would assume the desire to measure polarization in single photon mode

Lasers from one company

- From Lumentum



Product Family	Product	Wavelength (nm)	Output Power	Repetition Rate
kW Class Lasers	CORELIGHT	1080	4.2 kW	CW
Q-switched DPSS	Q Series	355, 532	From 1.6 to 15 W	Single shot to 200 kHz
	Q Series: Q305, Q306	355	>40 W	Single shot to 200 kHz
Ultrafast Lasers	Industrial	355, 532, 1040, 1047, 1053, 1064	>600 mW to 50 W	Single shot to 400 MHz
	Scientific	355, 532, 1047, 1053, 1064, 1342	>200 mW	20 MHz to 2.5 GHz
	Xcyte	355	From 20 to 150 mW	100 MHz
CW DPSS	FCD488	488	10, 20 mW	CW
	NPRO 125	1064, 1319	>25 nm; >100, 150, 200 mW	CW
	NPRO 126	1064, 1319	>100 to 700 mW	CW
	CDPS532M	532	>10, 20, 50 mW	CW
	CDPS532S	532	>10, 20 mW	CW
Direct-Diode Lasers	IDL Series	940	90, 180 W	CW
Diode Lasers	Diode Lasers	798-852, 910-980	From 10 mW to > 5 W	CW
Gas	Argon-Ion	458-515	From 4 to 75 mW	CW
	Helium-Neon	544, 594, 612, 633	From 0.5 to 22.5 mW	CW

Propagation of uncertainties for pol measurement

Polarization: $P = \frac{\Sigma}{A}$, with $\Sigma = \frac{N^+ - N^-}{N^+ + N^-} = \frac{N^+ - N^-}{N}$ as the asymmetry

define $N \equiv N^+ + N^-$

So the uncertainty on the polarization is: $\delta P = \frac{\delta\Sigma}{A}$

with

$$(\delta\Sigma)^2 = \left(\frac{\partial\Sigma}{\partial N^+}\right)^2 (\delta N^+)^2 + \left(\frac{\partial\Sigma}{\partial N^-}\right)^2 (\delta N^-)^2 = \left[\frac{-(N^+ - N^-)}{N^2} + \frac{1}{N}\right]^2 N^+ + \left[\frac{(N^+ - N^-)}{N^2} + \frac{1}{N}\right]^2 N^-$$

where $\delta N^\pm = \sqrt{N^\pm}$

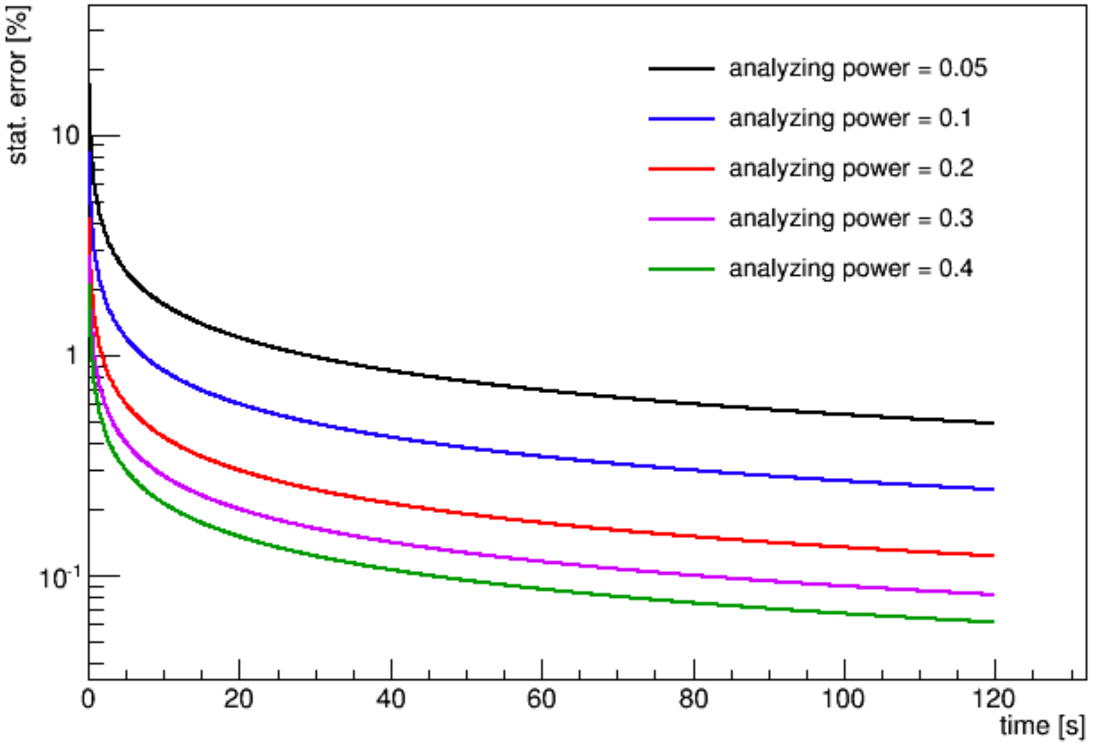
In the limit where N+ and N- are large (and the difference is small): $(\delta\Sigma)^2 \approx \frac{1}{N} \quad \Rightarrow \quad \delta\Sigma \approx \frac{1}{\sqrt{N}}$

Thus: $\delta P \approx \frac{1}{\sqrt{N}}\frac{1}{A}$, where N is the total number of photons measured

Some numerical estimates

- Maximum asymmetry (for 20GeV electron on 2.33eV photon) is about 0.4
- We consider here the linac-ring design and cathode by cathode monitoring
  - 120 total bunches, but only 111 of them are filled
  - Gattling gun approach has 20 cathodes
  - Presumably half of the bunches will have a particular polarization
  - Thus the rate for seeing bunches from a single cathode with a particular polarization is:
    - 9.4e6*(111/120)*(1/20)*(1/2) = 2.2e5 Hz
- so the effective rate is 2.2e5 Hz (= R)
- We still assume one photon per bunch crossing
- Also assume the maximum polarization fraction of 0.8
- N = R*t, with R = photon rate = effective bunch rate
- A is the analyzing power

$$\frac{\delta P}{P} \approx \frac{1}{P}\frac{1}{\sqrt{N}}\frac{1}{A}$$



- Time required depends on the analyzing power
- Analyzing power depends on physical asymmetry along with detector response
- Looks like a reasonably precise measurement could be made in about 2 minutes, even with low analyzing power

Pros and cons to single/multi-photon mode

Single photon mode

- Advantages:
  - Can choose large asymmetry
  - Easy comparison with cross-section
- Disadvantages:
  - Needs (relatively) longer time to achieve good precision
  - Detector is more complex

Multi-photon mode:

- Advantages:
  - Essentially independent of Brem. Background and detector cutoff energy
  - Need shorter time for data collection
- Disadvantages:
  - No easy monitoring for calo performance