Time-Resolving “Laser Wire” for Large Dynamic Range Measurements at low beam energy - *Design Considerations*

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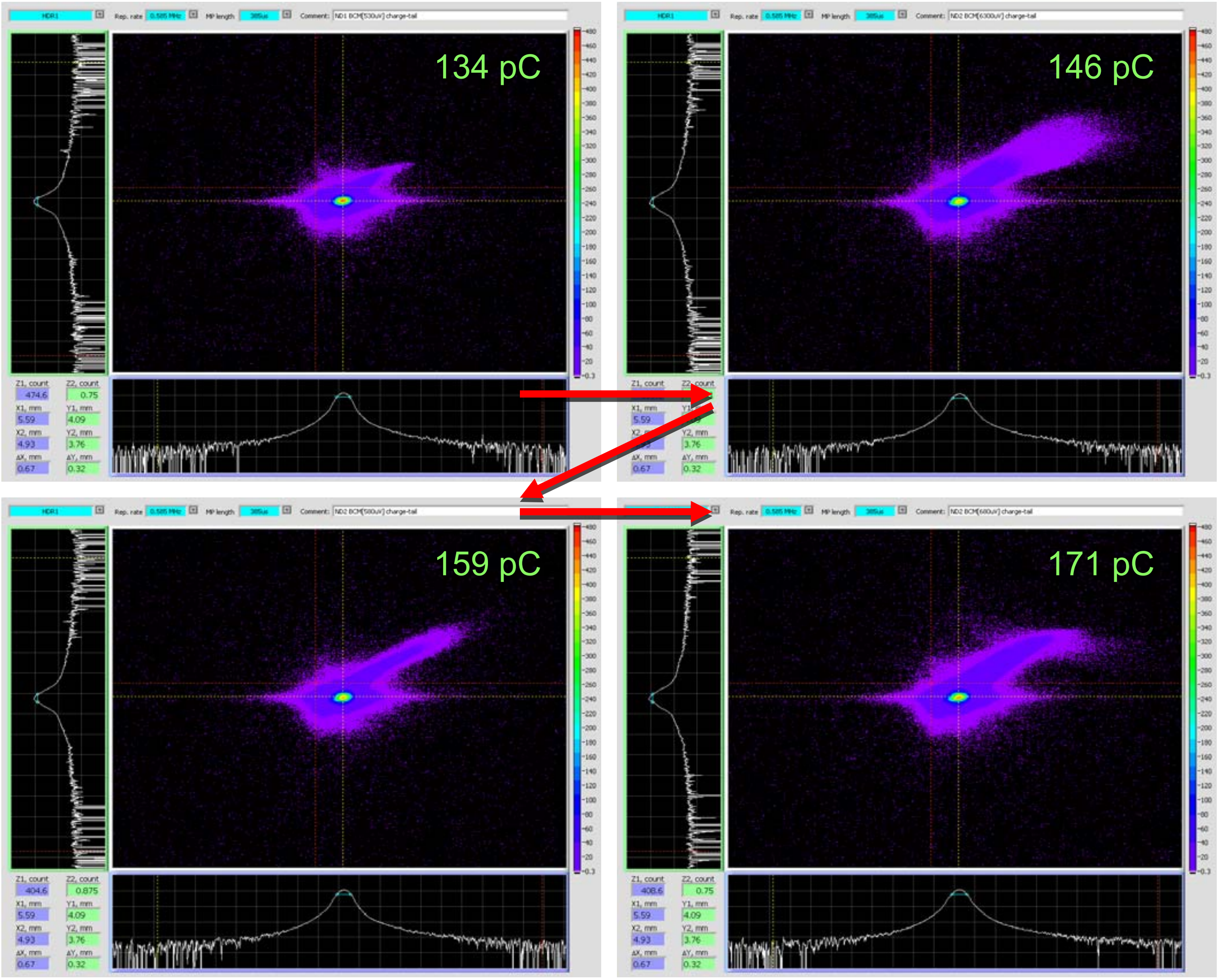
Why

- Setup/Tune-up and operation of high current systems (JLab FEL) approach so is:
  1. make detailed beam measurements and tuning with very low duty cycle beam
  2. monitor some of the beam parameters, not necessarily making detailed measurements with high power beam
- To monitor the transverse match is one the challenges in a linac. At high beam energy if bends are available and with SR monitors properly placed in the lattice (low dispersion locations) it can be done. However, at low beam energy in the injector (~10 MeV) SR is very far-IR.
- **Thus, it is not trivial to monitoring transverse beam size in an ERL injector**
- The same is true for longitudinal distribution measuremenst of the beam with sub-ps resolution at the low beam energy.
- "Longitudinal halo" i.e. long temporal tails can be easily converted in to transverse halo due to strong, time dependent focusing by SRF linac.
- One possible solution is to do wire scanner-like measurements, but replacing the physical wire, which would not survive high current beam, with a laser beam and use Thomson scattering

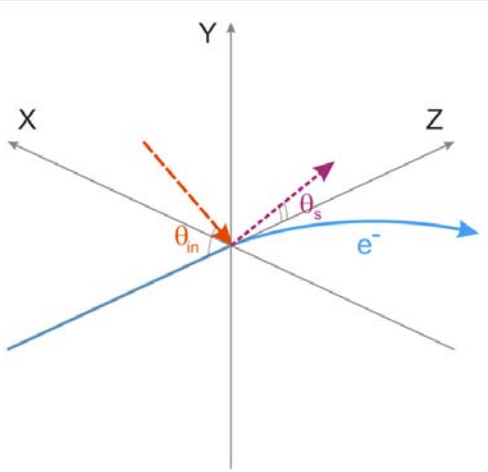
"Tails" Longitudinal to Transverse



- Measured at JLab FEL, at DarkLight beam test target mockup
- Starting from *nominal* 135 pC setup
- Bunch charge increased by ~ 10 %
- Injector left unadjusted
- Observed a transverse tail rapidly changing with the bunch charge
- Found that the buncher cavity at injector has the strongest effect on the tail
- **The beam dynamics in injector: transverse and longitudinal planes are coupled via space change**
- Longitudinal *tails* from injector affect trans. match but also energy spread and energy *tails*
- Injector needs to be setup without significant long. tails

CW-LW: Thomson Scattering

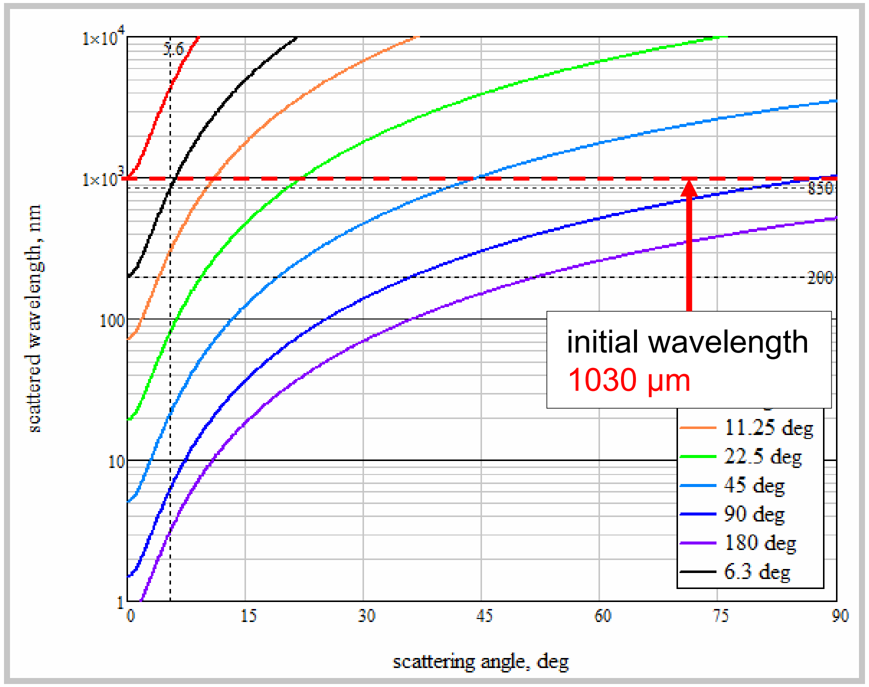
Wavelength conversion assuming:
- beam energy 9 MeV
- laser wavelength 1030 μm

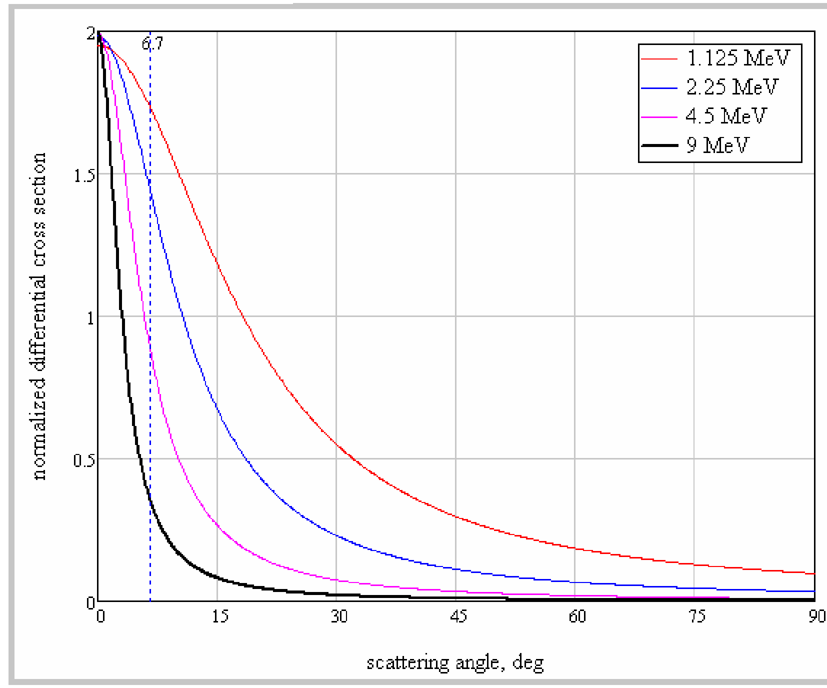


Differential cross section (divergency on the beam energies ~ 1/γ)

$$\lambda_S = \lambda_0 \frac{1-\beta\cos(\theta_S)}{1-\beta\cos(\theta_{ini})}$$

$$\frac{d\sigma}{d\Omega} = r_e^2 \frac{1-\beta^2}{1-\beta\cos(\theta_S)}$$





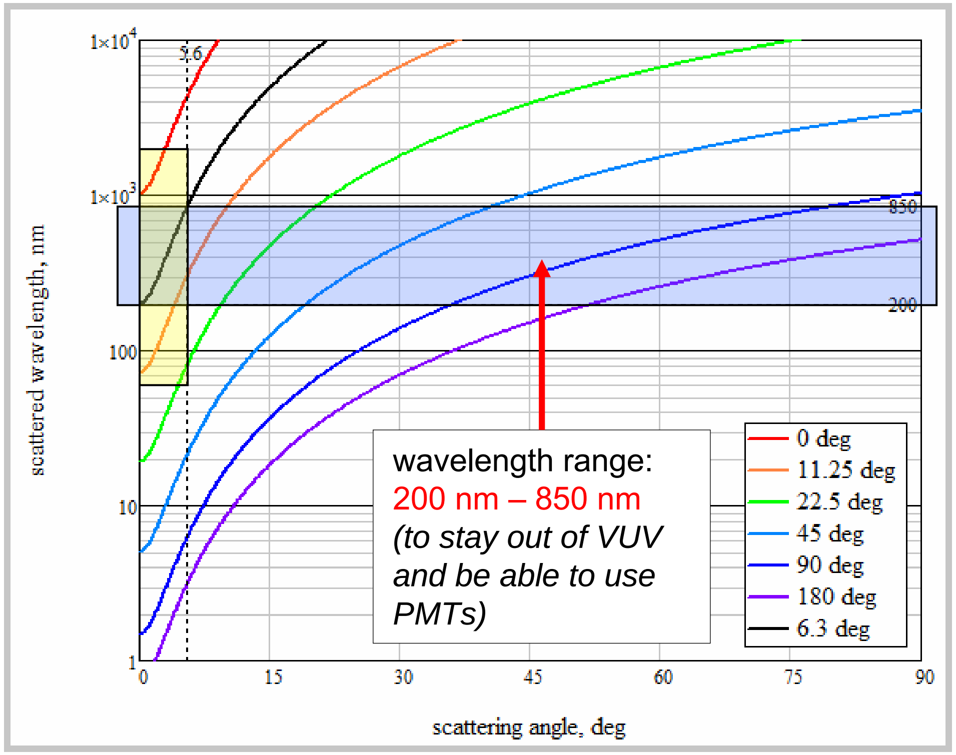
CW-LW: Collection Efficiency

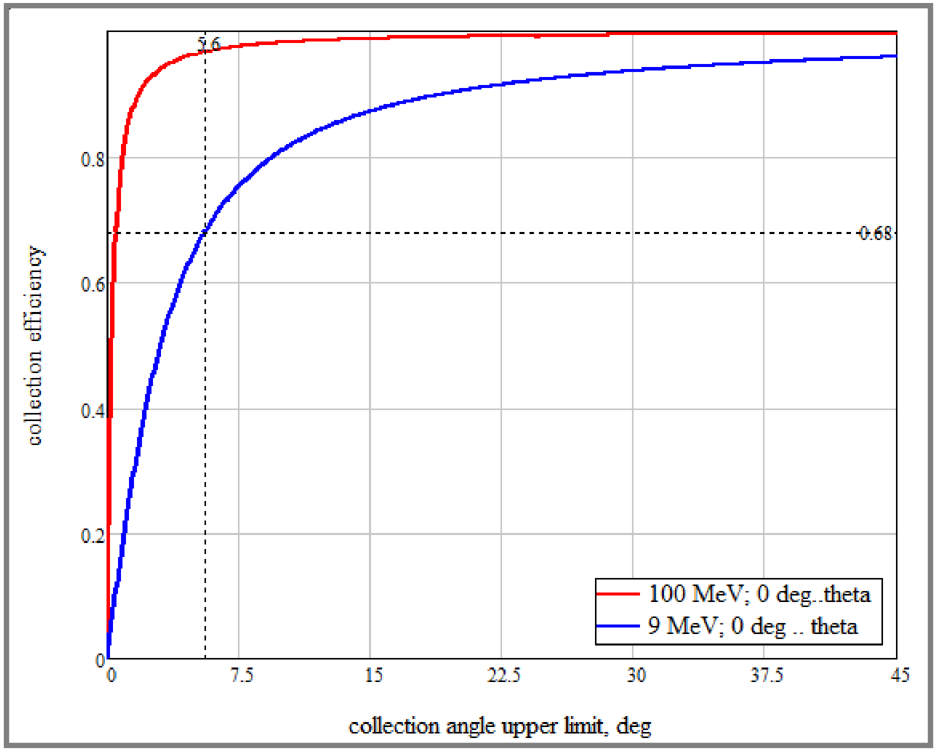
Wavelength conversion assuming:

- beam energy 9 MeV
- laser wavelength 1030 µm

$$\lambda_S = \lambda_0 \frac{1-\beta\cos(\theta_S)}{1-\beta\cos(\theta_{ini})}$$

Collecting forward scattered photons in relatively large solid angle θ=0..5.6 deg, gives very large collection efficiency of ~ 70 %.

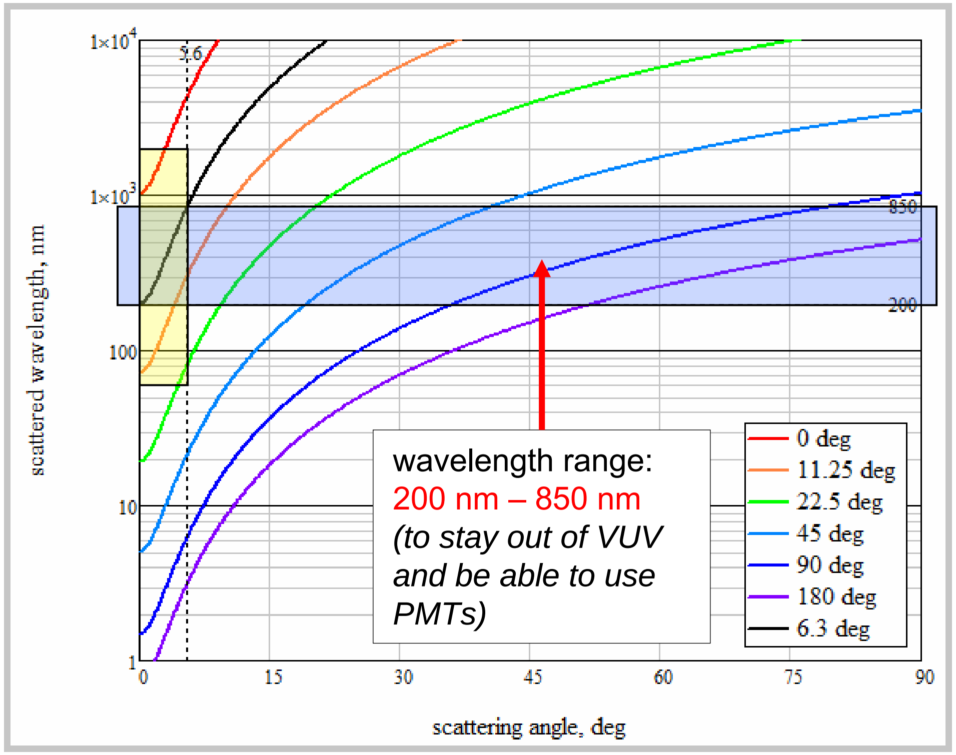




CW-LW: Signal Level

Wavelength conversion assuming:
- beam energy 9 MeV
- laser wavelength 1030 µm

$$\lambda_S = \lambda_0 \frac{1-\beta\cos(\theta_S)}{1-\beta\cos(\theta_{ini})}$$



$$f_S = f_{beam}\left(\frac{N_{\hbar\omega} N_e}{S}\frac{\tau_{lase}}{\tau_{beam}}\sigma_{Th}\right)\eta$$ - photon rate

Assuming:
- bunch charge 135 pC
- laser wavelength 1030 µm
- pulse energy ~10 µJ
- τ_{laser} 500 fs
- τ_{beam} 2.5 ps
- f_{beam} 1.169 MHz
- r_{laser} 100 µm

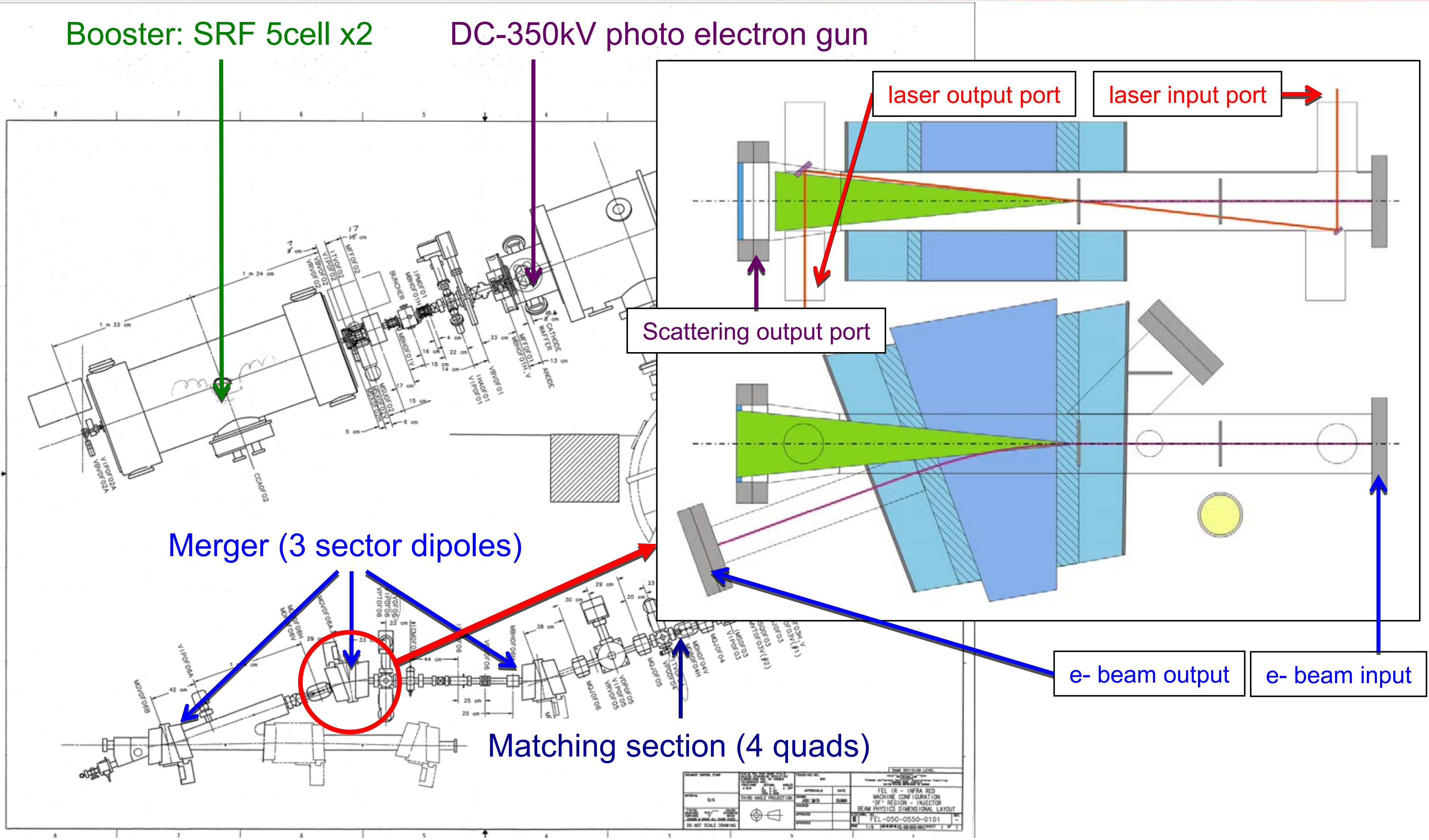
We get: $N_s \approx 12$, but $f_s = 14.7$ MHz !!!

Also, one can take advantage of **CW time structure** of the beam and use lock-in amplifier techniques.

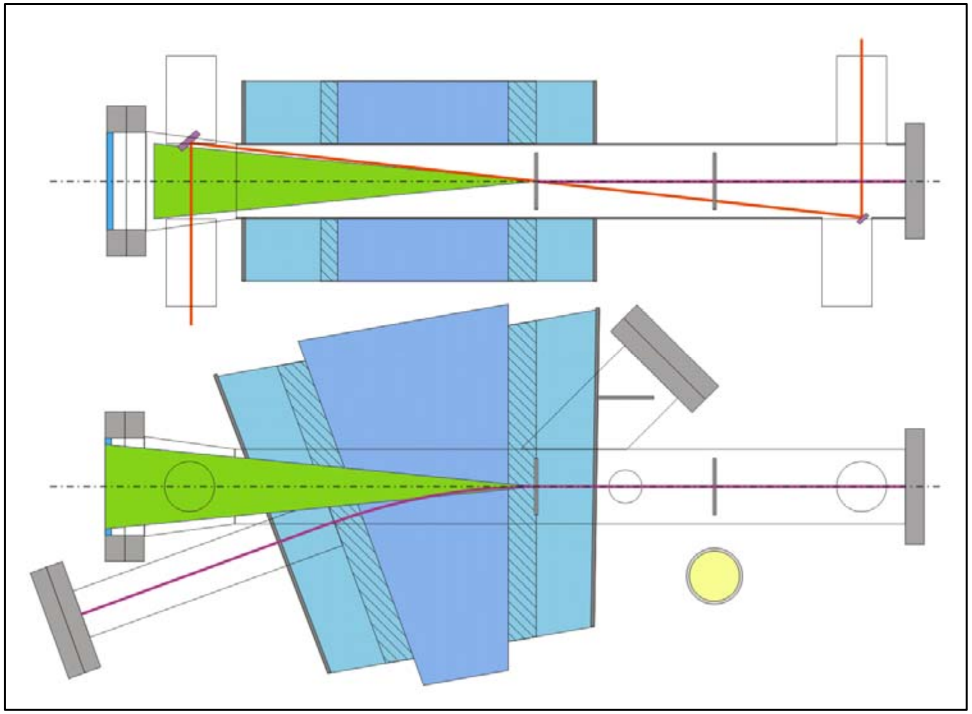
Lock-in amplifier improves SNR as:

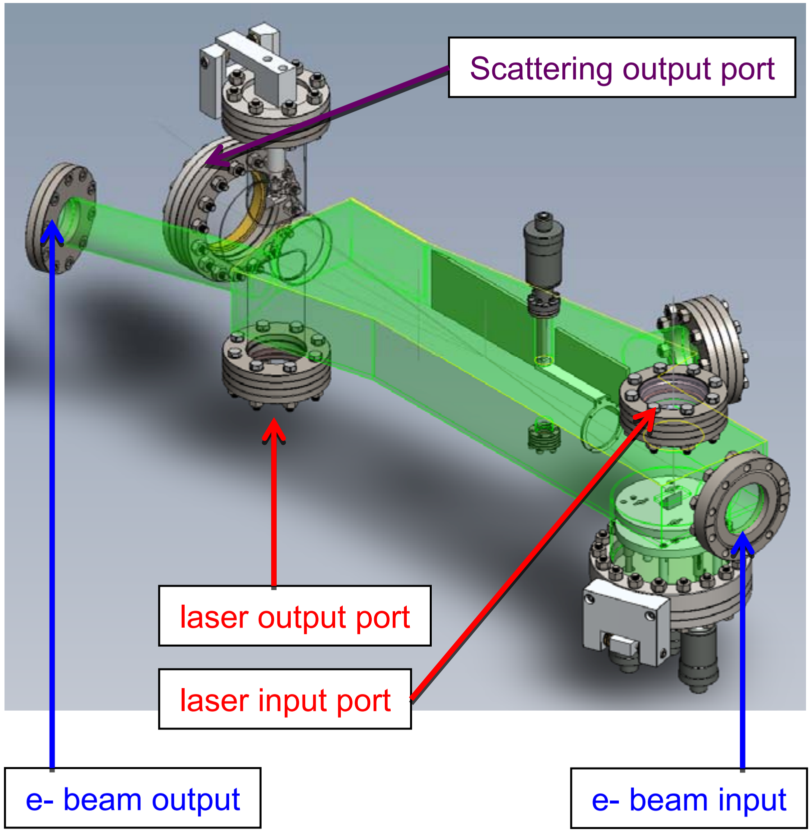
$$\boxed{\sqrt{f_0 \cdot \tau_{measure}} = \sqrt{1.169\ MHz \cdot 1s} = 1 \cdot 10^3}$$

CW-LW: location, geometry



CW-LW: interaction chamber





CW-LW: Laser

Laser with parameters far beyond the *required* ones were demonstrated:

~10 J, 2.34.. MHz, 25 W, 500 fs

Two technologies look particularly attractive;

1. large-mode-area fiber amplifiers **2.** thin-disk lasers (oscillators)

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90 W average power 100 μJ energy femtosecond fiber chirped-pulse amplification system

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We report on an ytterbium-doped fiber based chirped-pulse amplification system delivering 100 μJ pulse energy at a repetition rate of 900 kHz, corresponding to an average power of 90 W. The emitted pulses are as short as 500 fs. To the best of our knowledge, this is the highest average power ever reported for high-energy femtosecond solid-state laser systems. © 2007 Optical Society of America

OCIS codes: 060.2320, 320.7090.

Femtosecond thin disk laser oscillator with pulse energy beyond the 10-microjoule level

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Abstract: We report on a passively mode-locked Yb:YAG thin disk laser oscillator that generates 11.3-μJ pulses without the use of any additional external amplification. A repetition rate of 4 MHz is obtained using a 23.4-m-long multiple-pass cavity that extends the resonator length to a total of 37 m. The nearly transform-limited pulses at 45 W of average output power have a duration of 791 fs with a 1.56-nm-broad spectrum centered at 1030 nm. The laser is operated in a helium atmosphere to eliminate the air nonlinearity inside the resonator that previously limited the pulse energy.

OCIS codes: (140.3480) Lasers, diode-pumped; (140.3580) Lasers, solid-state; (140.4050) Mode-locked lasers

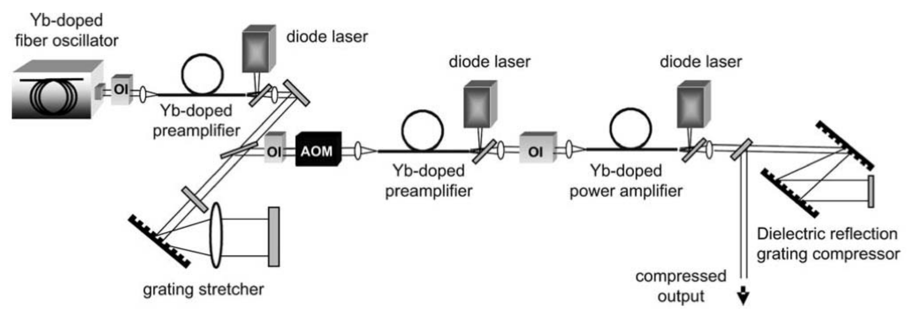

Fig. 1. Schematic setup of the high-average-power, high-energy fiber CPA system. OI, optical isolator; AOM, acousto-optical modulator.

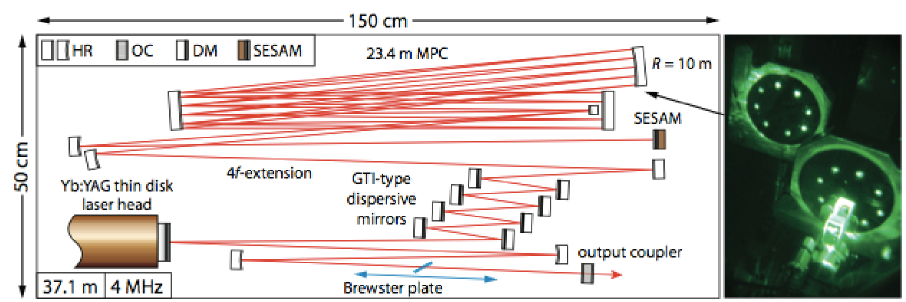

Fig. 3. Schematic of the laser setup with the 23.4-m-long MPC (not to scale). The total cavity length of 37 m results in a repetition rate of 4 MHz. The 1-mm-thick Brewster plate can be shifted along the direction of the divergent beam for fine-adjustment of the SPM and pulse duration. HR: highly reflective mirror, OC: output coupler (10%), DM: dispersive mirror, SESAM: semiconductor saturable absorber mirror.

Laser-Wire Potential

- Since it is a “wire scanner” ➔ counting mode ➔ **Large Dynamic Range (LDR)**
- Utilizing CW time structure of the beam and laser LDR measurements can be made without counting, by using lock-in detection techniques
- Laser pulses much shorter than beam can be used ➔ **sub-ps time resolution can be achieved quite easily**
- Can be made in dispersive location ➔ **energy resolved measurements**
- Combining all three above ➔ **LDR measurements of longitudinal phase space**
- Can also be used in non-dispersive location to monitor transverse match
- Would works for essentially any high current, but does not rely on high current CW beam (only ~ 160 uA, as described here)