The Photon Collider at NLC

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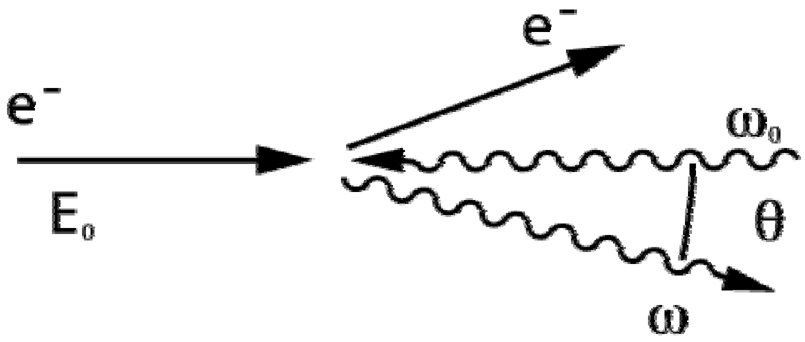
Outline

- Review the basic principles behind photon production through Compton back-scattering.
- Discuss the engineering required to actually realize a photon collider.
  - Lasers
  - Optics
  - Interaction Region design

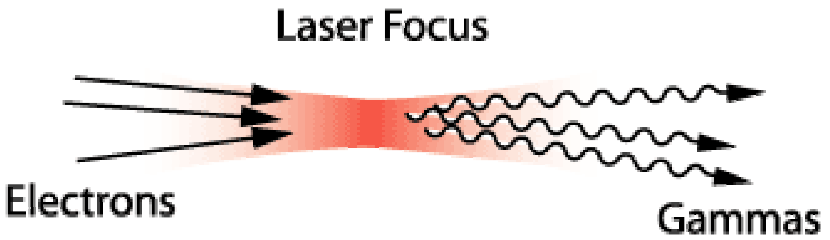
Basic components exist (laser, optics, IR design)
Complete engineering design for Snowmass

Compton back-scattering

- Two body process
  - Correlation between outgoing photon angle and energy
  - Maximum energy when the photon is co-linear with the incoming electron

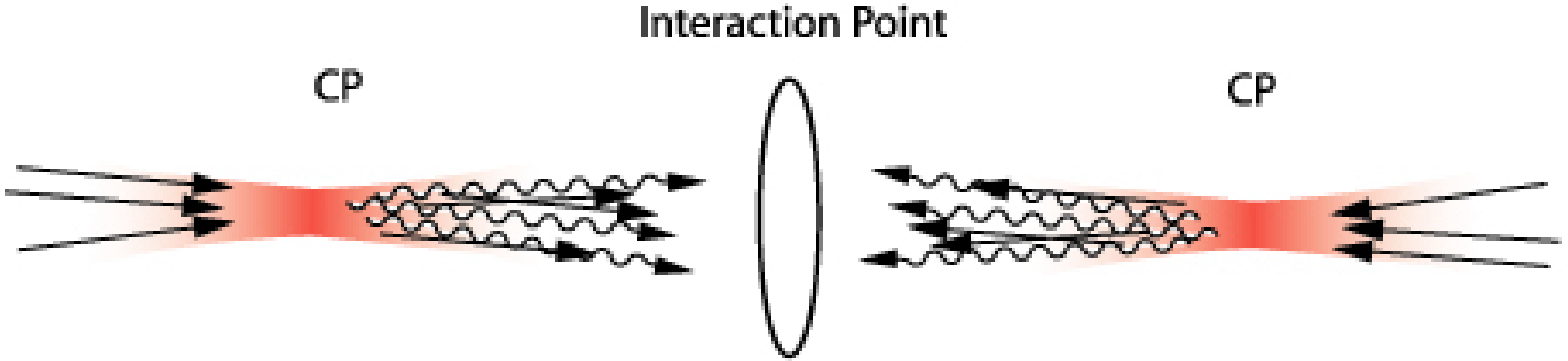


- Proposed by Ginzburg et al. (1982) for producing a photon collider
  - Collide a high power laser pulse with an electron beam to produce a high energy photon beam



Gamma-Gamma collisions

- Since high energy photons are co-linear with the incoming electron direction they focus to the same spot.
  - Lasers are powerful enough to convert most of the incoming electrons
  - High energy $\gamma\gamma$ luminosity is large
- Low energy photons and electrons also travel to the IP and produce a tail of low energy interactions.
- The beam - beam interaction at the IP
  - Produces additional low energy beamstrahlung photons
  - Deflects the low energy spent electrons.

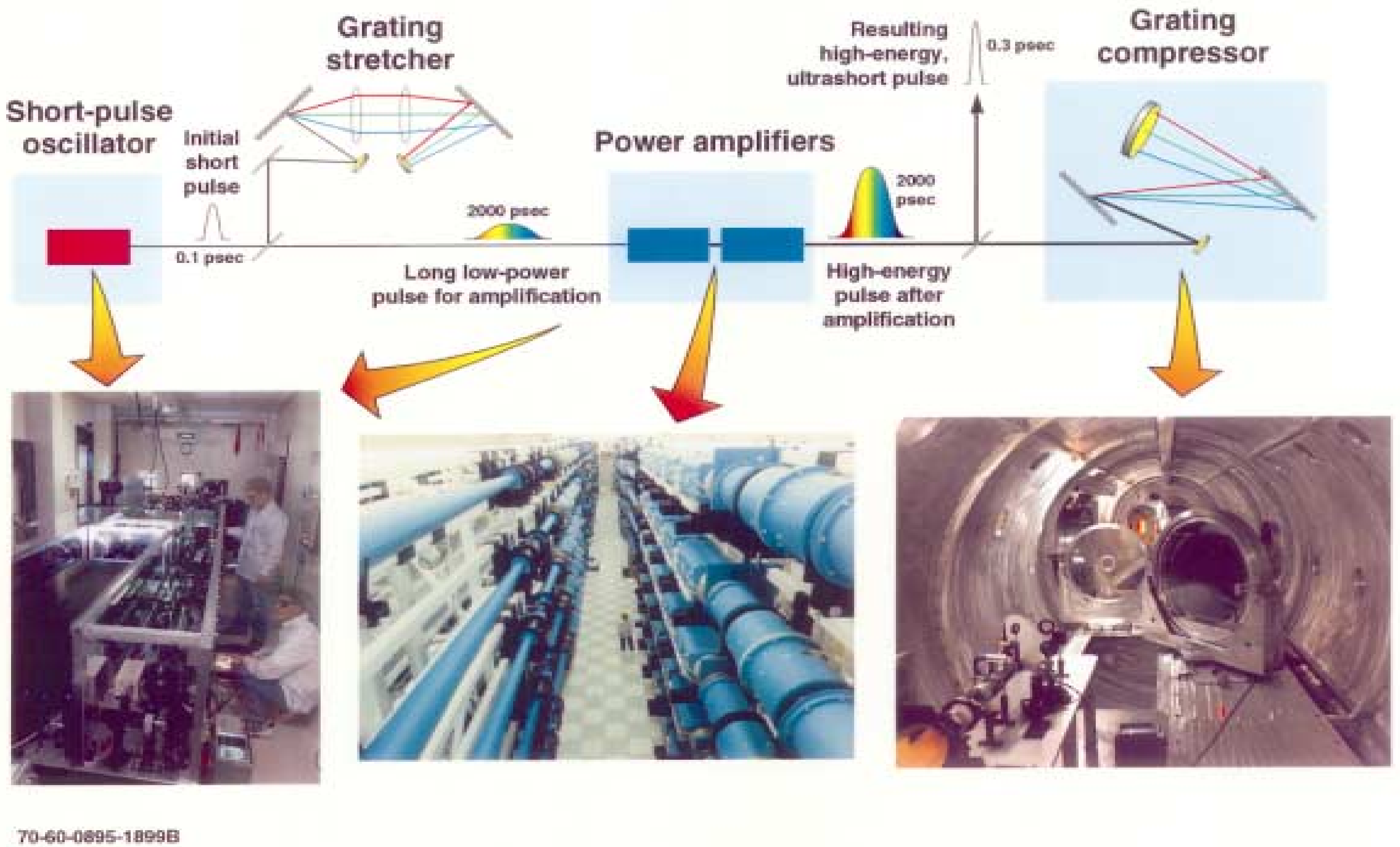


Lasers requirements

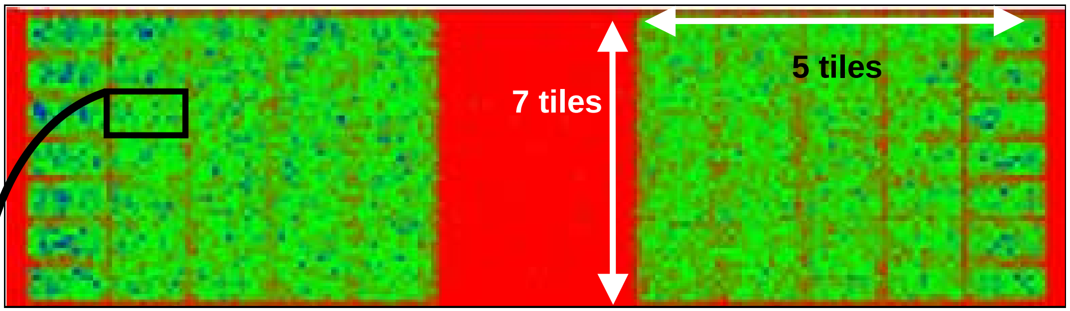
- Laser pulses of
  - 1 Joule, 1.8 ps FWHM, 1 micron wavelength
- One for each electron bunch
  - 95 bunches / train x 120 Hz = 11400 pulses / second
    - Total laser power 10kW
  - 2.8 ns between bunches

- Requires:
  - High peak power (1 TeraWatt)
  - High Average power (10 kW)
  - Correct pulse format (95 pulses @ 2.8 ns spacing x 120 Hz)

Chirped pulse amplification allows high peak power picosecond pulses

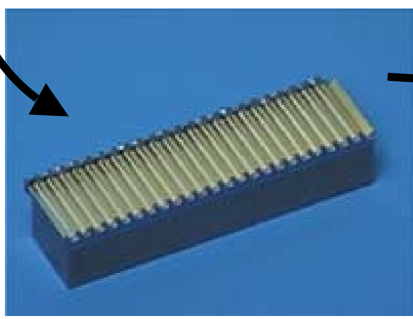


Diode pumping enables high average power
Matching diode output wavelength to the laser amplifier pump band gives 25% power efficiency

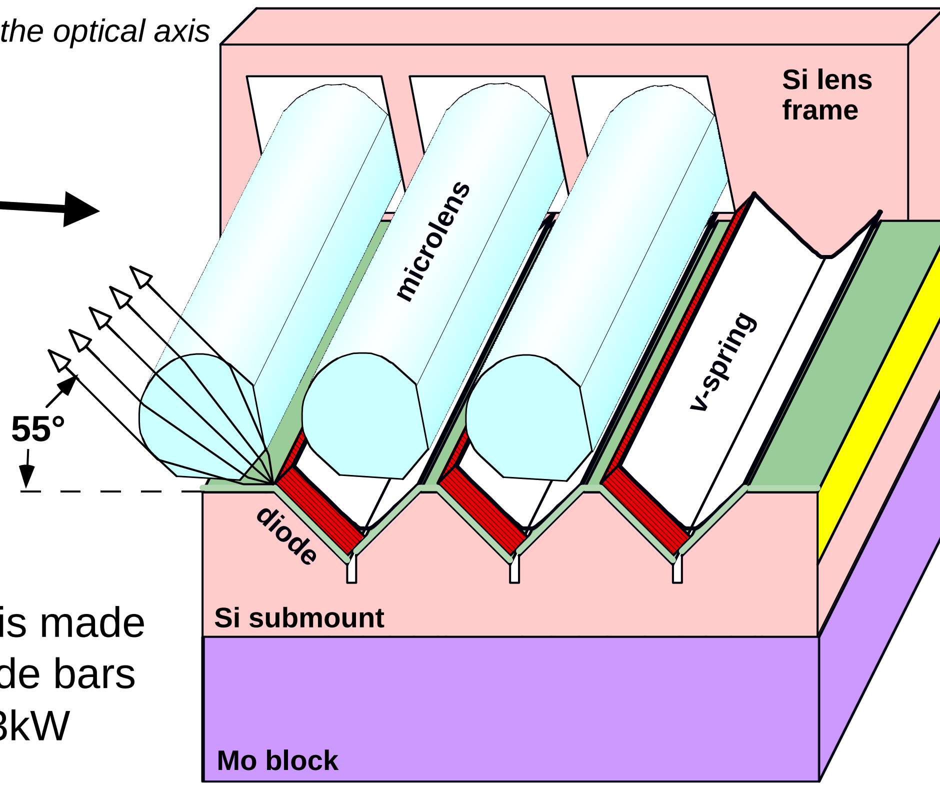


Diode light distribution (green) obtained in a plane normal to the optical axis

4 pairs of diode arrays like these are required for Mercury ⇒ 644 kW



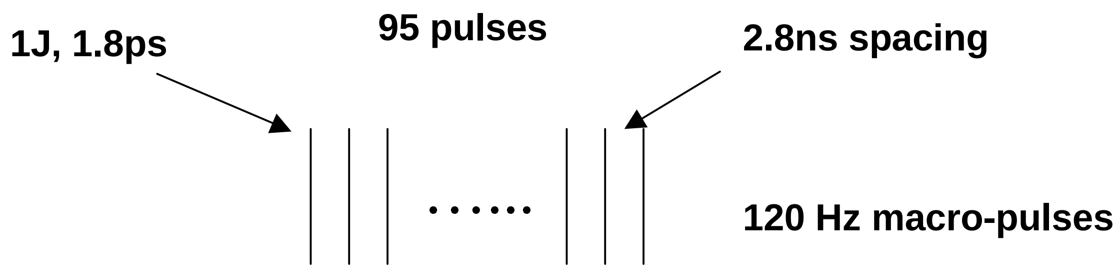
Each array is made of 5x7 =35 tiles per array ⇒ 161 kW



Each tile is made of 23 diode bars ⇒ 2.3kW

Pulse Format drives the Laser architecture

NLC bunch format



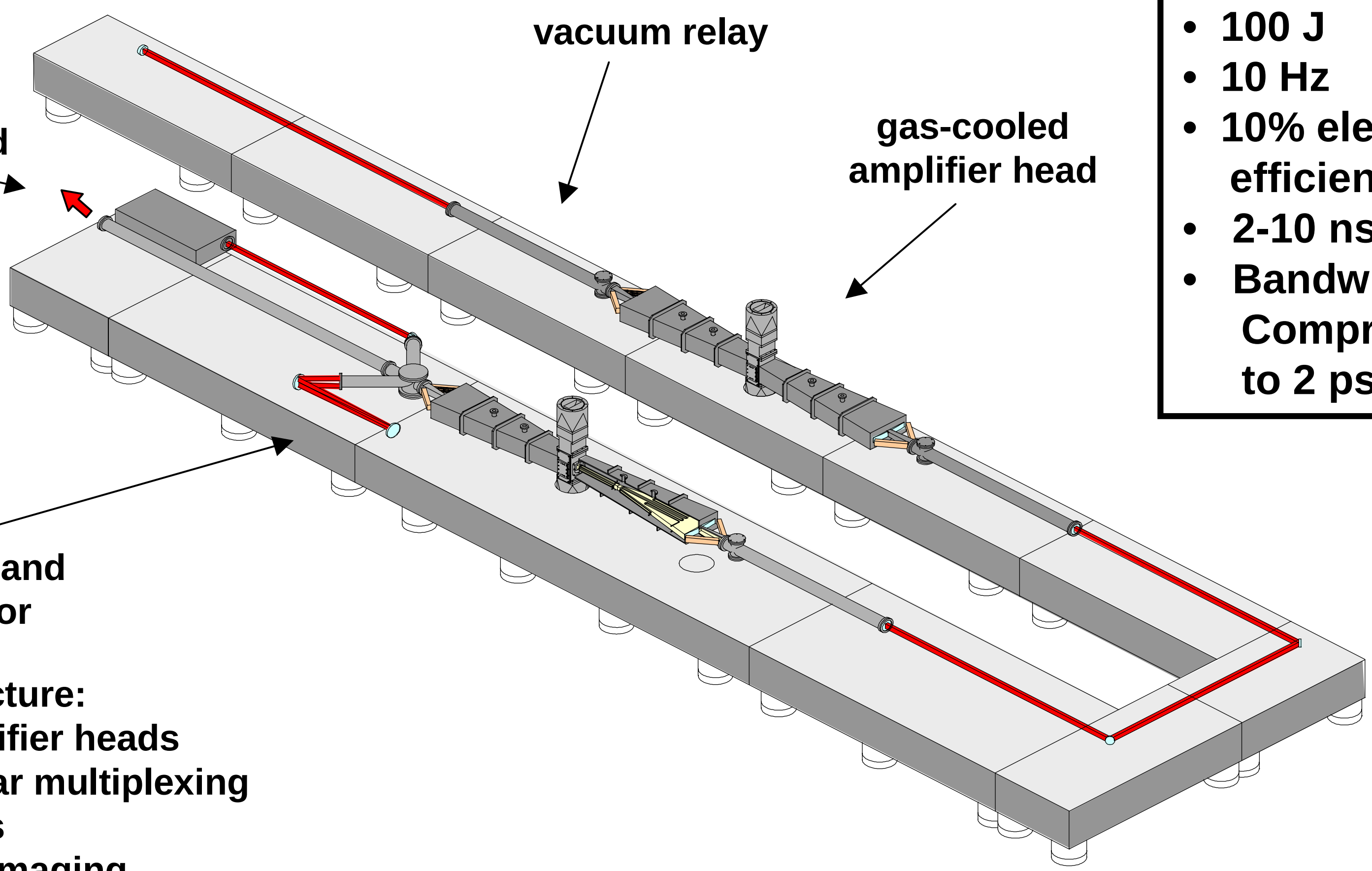
ZDR 1996

100 small lasers
1 J, 100 Hz
ns switches to spatially and temporally
Combine sub-pulses to macro-pulse

New Mercury option

12 larger lasers
100 J, 10 Hz
Simple 10 Hz spatial combiner
Break macro-pulse into sub-pulses

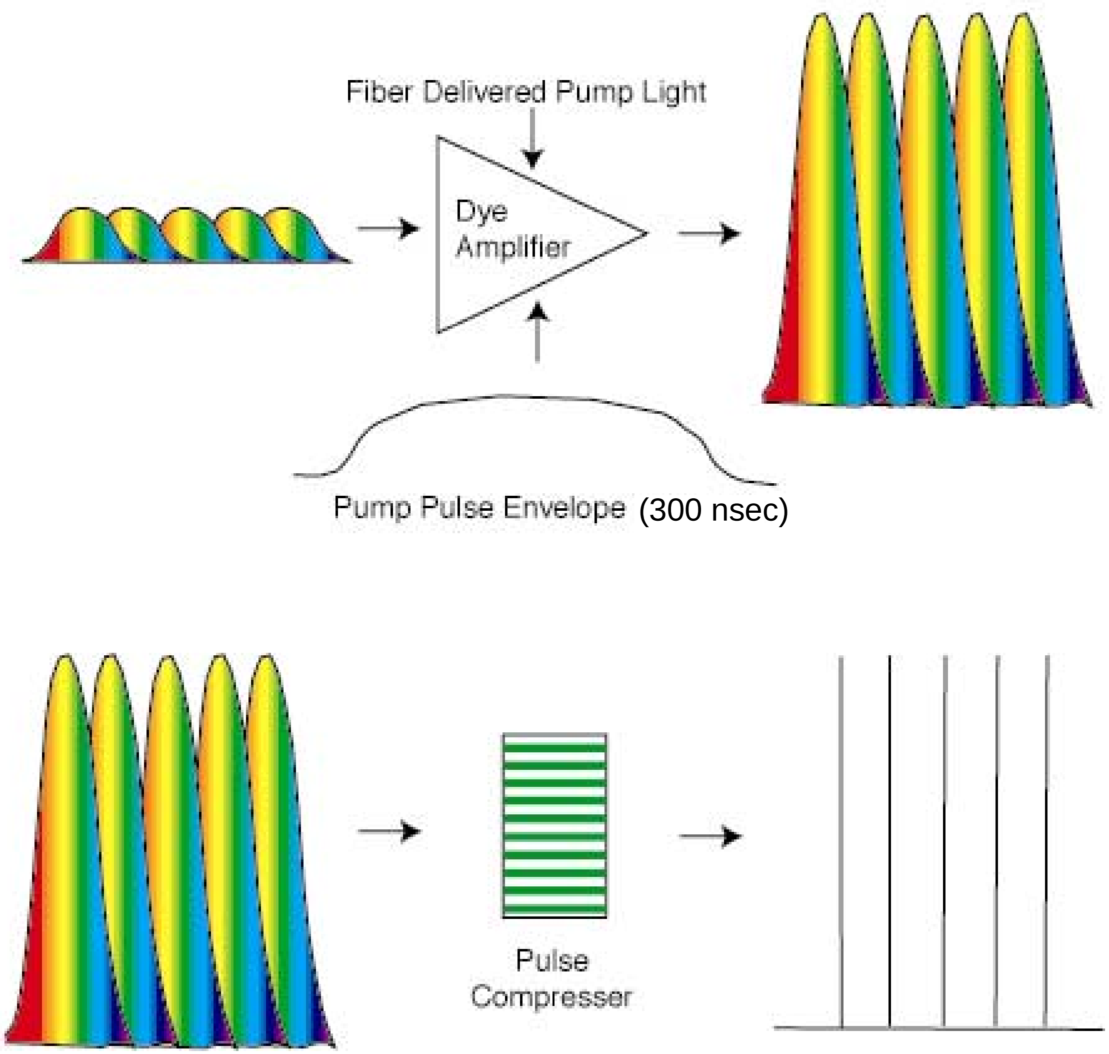
The Mercury laser will utilize three key technologies: gas cooling, diodes, and Yb:S-FAP crystals



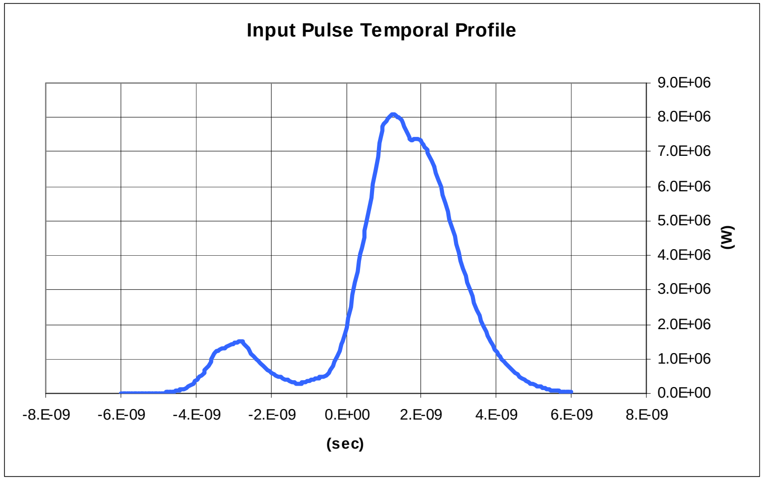
Goals:
- 100 J
- 10 Hz
- 10% electrical efficiency
- 2-10 ns
- Bandwidth to Compress to 2 ps

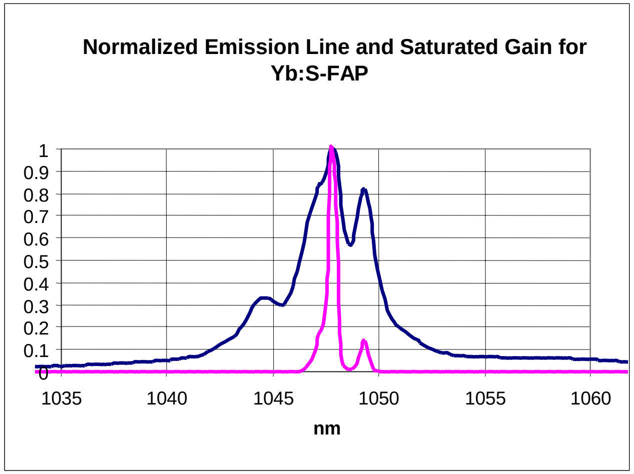
Architecture:
- 2 amplifier heads
- angular multiplexing
- 4 pass
- relay imaging
- wavefront correction

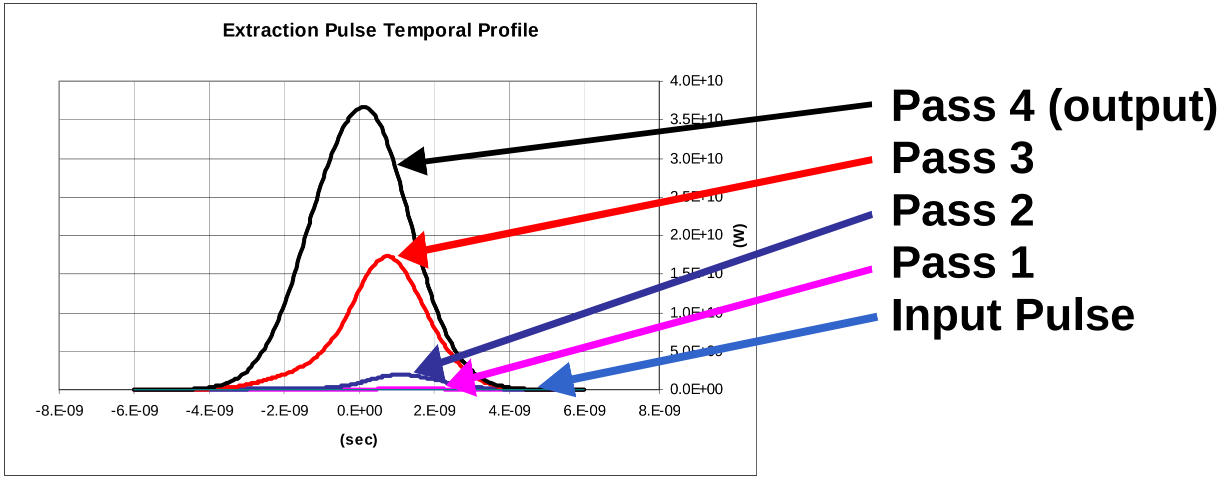
Wide band amplifier allows polychromatic components of the pulses to be linearly to amplified. Subsequent re-compression gives short, separated pulses.



Appropriate spectral sculpting of the input pulse can lead to a linearly chirped gaussian output pulse (2 psec stretched output pulse case)

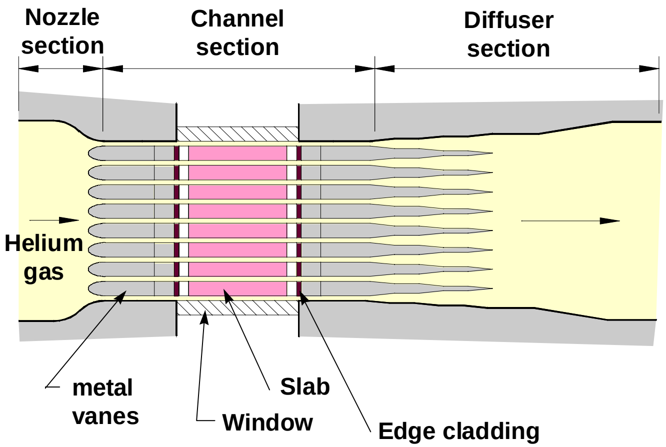




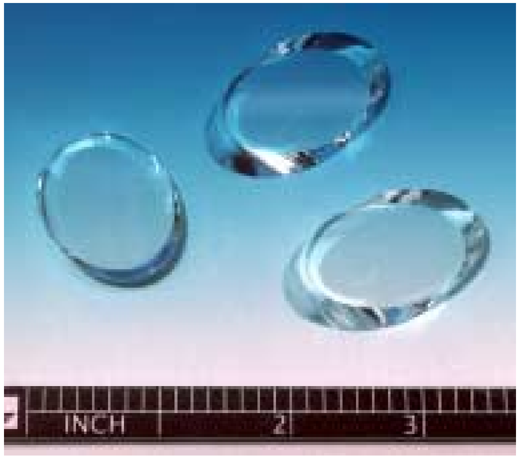


We are developing diode-pump solid state lasers as the next-generation fusion driver - Mercury will deliver 100 J at 10 Hz with 10% efficiency.

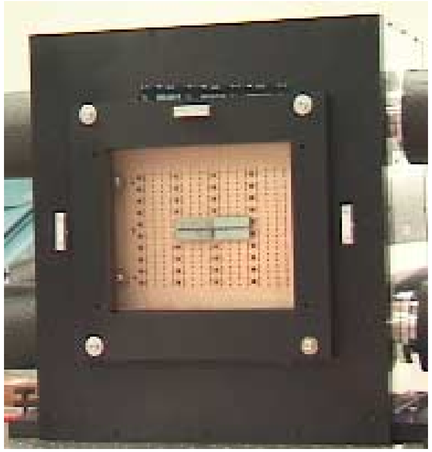
Gas flow concept



Mercury Lab

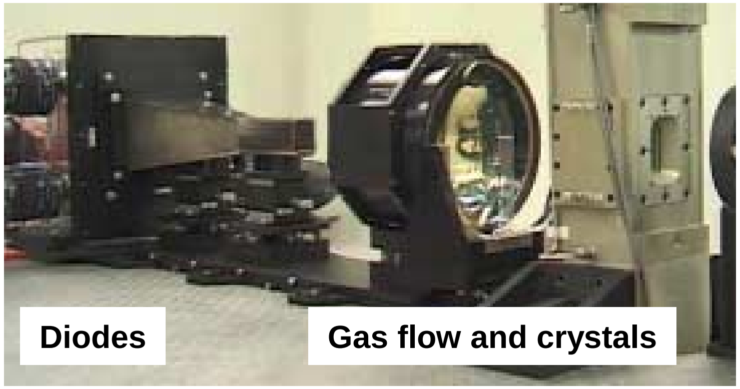


Yb:S-FAP crystals

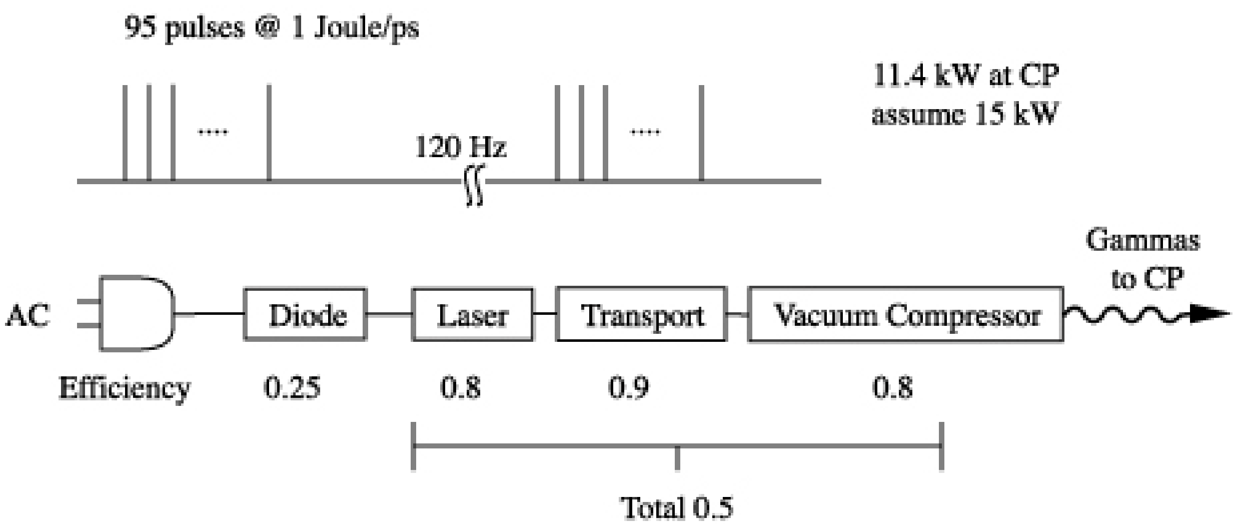


Diode array capable of 160 kW

Pump Delivery



Diode requirements



w/ 100% contingency
@ $5 / Watt

Total peak diode power

$$N_{lasers} \cdot \frac{Energy\,/\,pulse}{\varepsilon \cdot \tau_{upper}} = 12 \cdot \frac{100\,Joules}{0.5 \cdot 10^{-3}\,\text{sec}} \cong 2.5MW = \$24M$$

Average Power

$$\frac{\text{Total Power Required}}{\varepsilon_{\text{Tot}}} = \frac{15\text{ kW}}{0.1} = 150\text{ kW}$$

Tesla bunch structure

	τ_B ns	N_B	f Hz	σ_z μm	N 10^{10}
TESLA-500	337	2820	5	300	2.0
NLC-500H	2.8/1.4	95/190	120	110	1.5/0.75

Tesla bunch structure is very different
Major impact on Laser Architecture

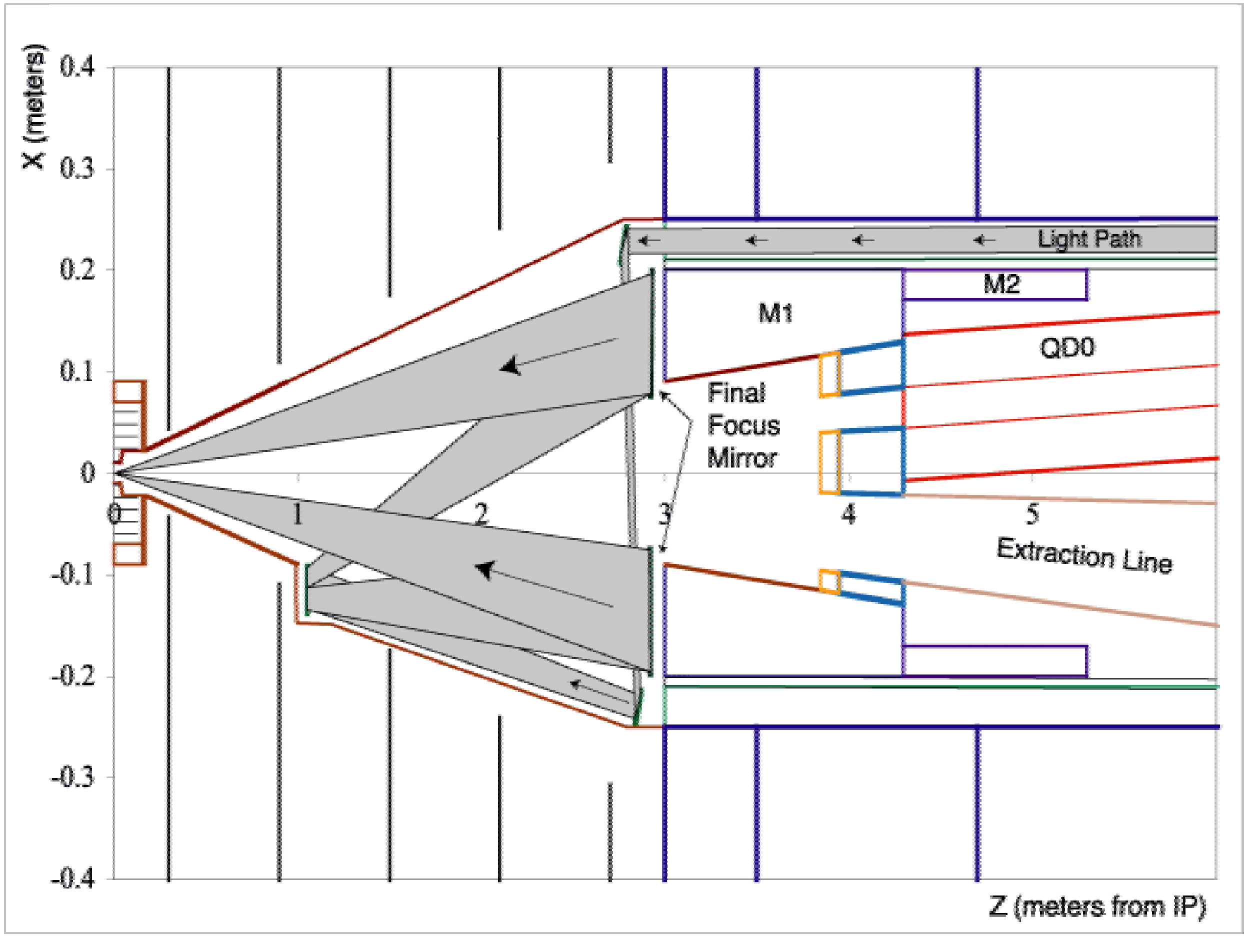
- 1 millisecond is the laser amplifier upper state lifetime
  - Tesla must produce 30 times as many pulses on that timescale
- Since most laser power goes unused they are investigating
  - Multipass optical cavities
  - Ring lasers
- No baseline design in TDR

Optics and IR

- Optics requirements
  - Keep accumulated wave-front aberrations small
  - Prevent damage to optics from high power pulses
    - All regimes; ps, 300 ns, continuous
  - Prevent accumulation of non-linear phase aberration
    - Vacuum transport lines
    - Reflective optics - transmissive optics only where necessary
- IR/Optics integration
  - Optics must be mounted in the IR
  - All hardware required to accomplish this must not:
    - Interfere with the accelerator
    - Degrade the performance of the detector
    - Generate backgrounds

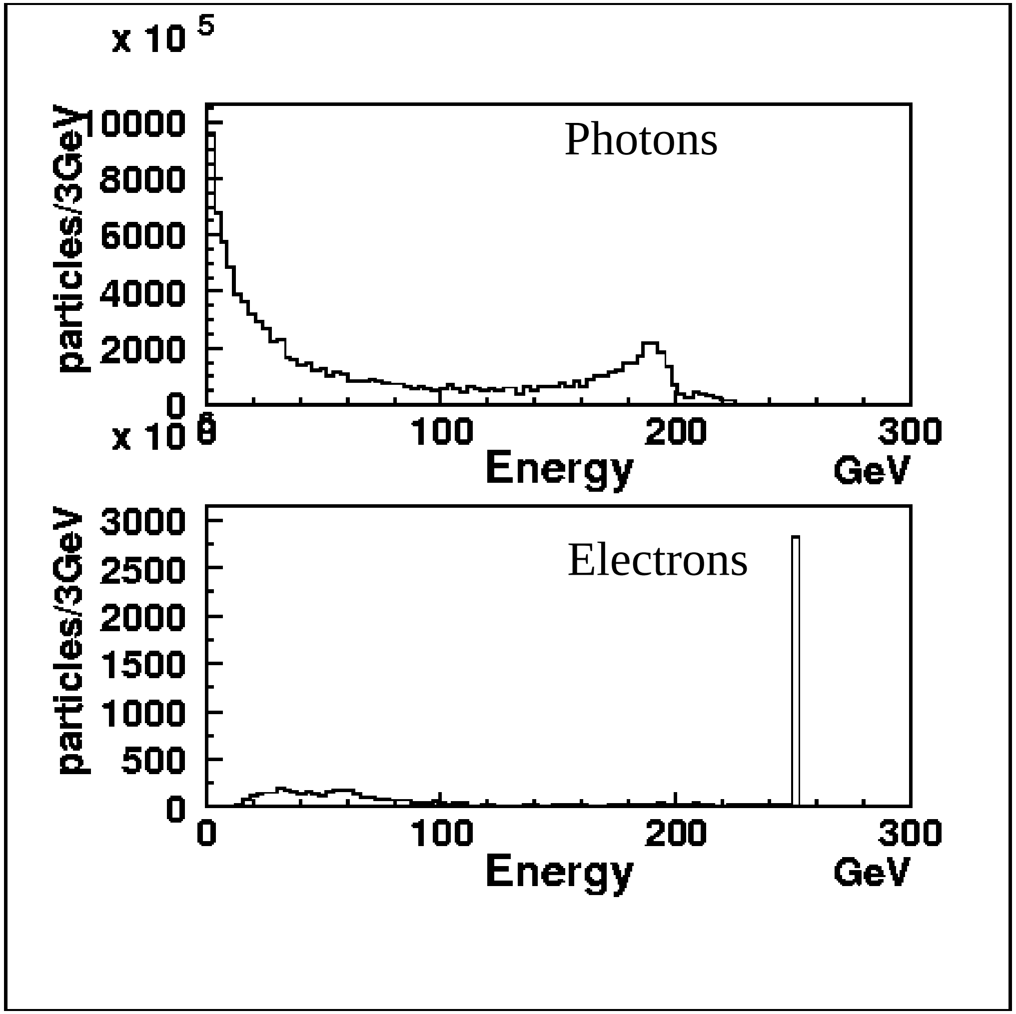
Focusing mirrors - tight fit

LCD - Large with new mirror placement



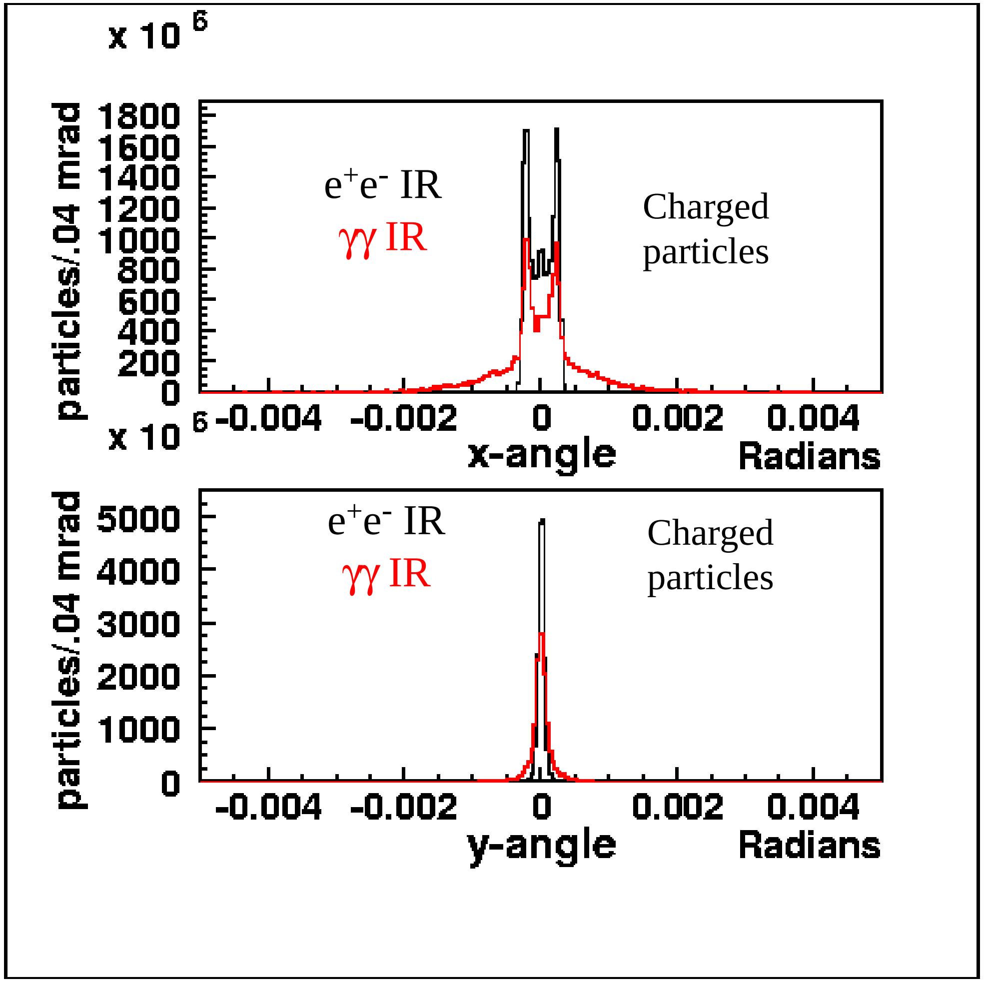
- Essentially identical to e^+e^- IR
- 30 mRad x-angle
- Extraction line ± 10 mRadian
- New mirror design 6 cm thick, with central hole 7 cm radius.
  - Remove all material from the flight path of the backgrounds

Compton Backscattering



- After backscattering the bunch contains both high energy photons and electrons.
- Angular spread photons ~ $1/\gamma$
  - Micro radian at 250 GeV
- 63% Conversion efficiency
- Low energy tail due to electrons scattering more than once.

Disrupted Beam



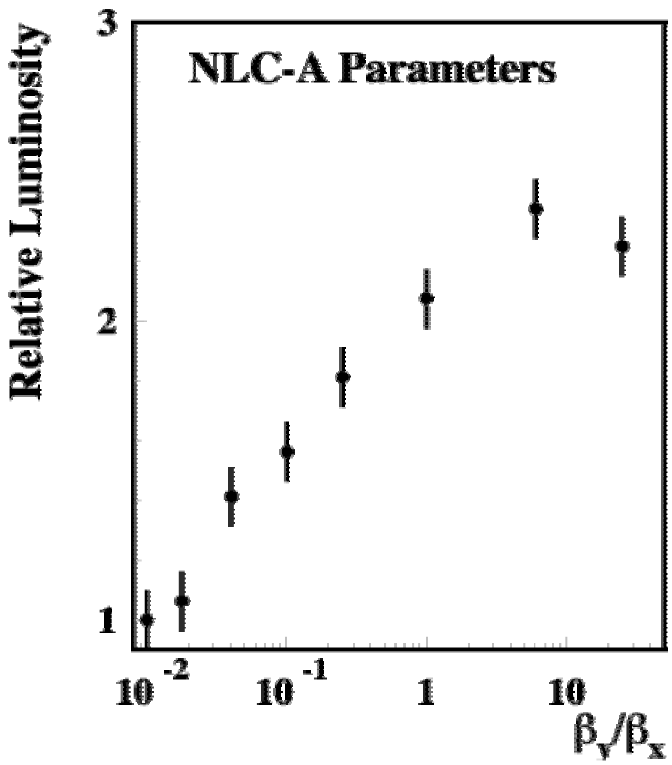
- High Energy photons means low energy electrons.
  - Large beam-beam deflection
  - Large rotation in solenoid field
- Requires extraction line aperture +/- 10 milliradians
- Leads to increase in crossing angle to avoid conflict between final quadrupole and extraction line.
- Zero field extraction line, no optics.

IR Background changes from e^+e^-

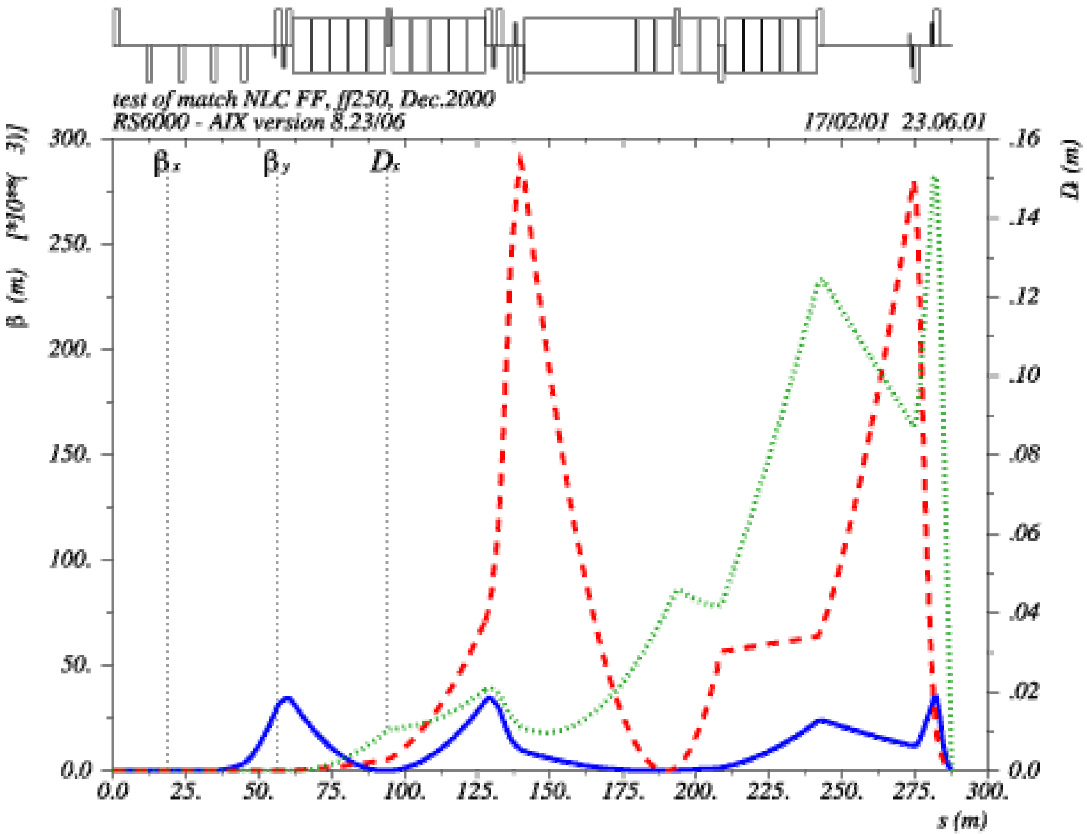
- Increased disruption of beam, Larger extraction line
  - ± 10 milliradians extraction line
    - Crossing angle increased to 30 milliradians to avoid conflict with incoming quad. Should be reduced to minimum when final design of quad is known.
  - First two layers of SVX now have line of sight to the beam dump
    - Fluence of neutrons 10^{11} /cm^2/year
    - Need rad hard SVX
- Higher rate of $\gamma\gamma \rightarrow qq$, minijets
  - Currently evaluating in pythia

Accelerator differences

- None needed - Some desired
  - Rounder beams
    - Relaxes requirements on beam stabilization
    - Increases luminosity by factor 2
  - More bunch charge, fewer bunches
    - Most laser power unused no cost for increased bunch charge
    - Fewer bunches, more time between bunches
      - Laser architecture easier
    - Halving the number of bunches and doubling the bunch charge increases luminosity by factor 2
  - e^-e^- running
    - Electrons are easier to polarize
    - Reduce e^+e^- physics backgrounds
    - Reduce beamstrahlung photons



New Final Focus



- Maximally compatible with e+e- running.
- One new quadrupole after the big bend.
- Spot size 15nm x 60 nm.
- Luminosity increase of a factor ~2.

Increase bunch charge

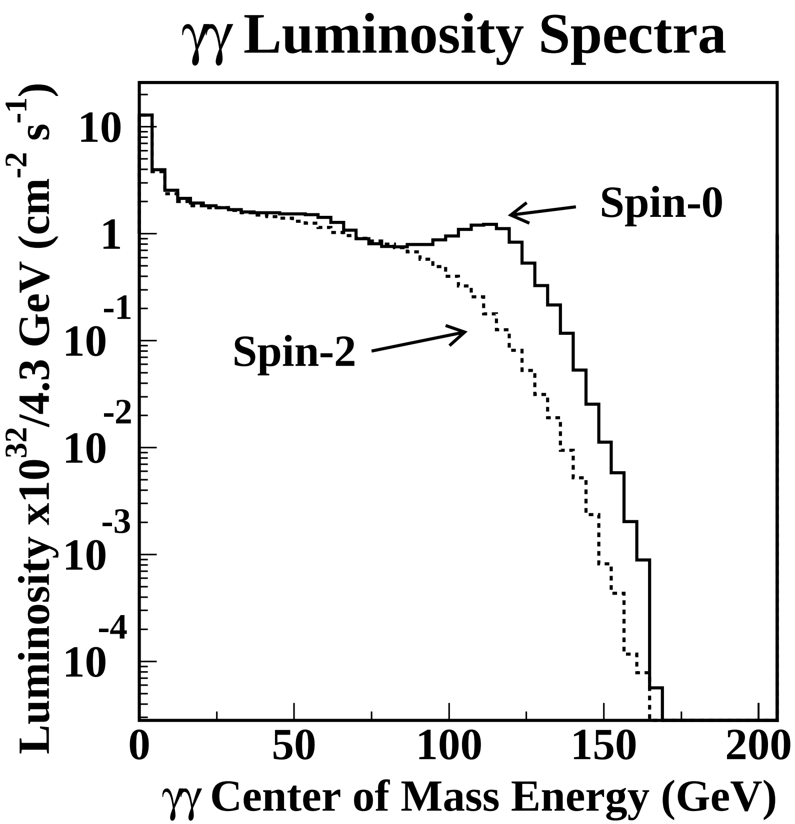
- Lasers prefer bunch spacing of 2.8 ns
  - Current 190 bunch 1.4 ns machine parameter sets are not optimal
- Tor Raubenheimer provides optimized machine parameters for $\gamma\gamma$
  - 95 bunches, 2.8 ns spacing
  - All other parameters as per NLC-A
  - Twice the bunch charge

In the high energy peak the $\gamma\gamma$ luminosity is now ~4 times higher than for the standard machine parameters

e^-e^- running

- Easy (sort of)
  - Changeover requires rotating all quads in one arm of the linac
    - Order 1 month required
  - Polarized electron production needed in the positron injection complex with positron target bypass
- The base e^-e^- luminosity is down a factor of 3 from the e^+e^- luminosity. The beam beam attraction become repulsion.
  - Beam-beam interaction has no effect of high energy $\gamma\gamma$ peak
  - Improved polarization increases luminosity in the high energy $\gamma\gamma$ peak
  - Most ee backgrounds reduced by a factor 3

Realistic luminosity spectrum

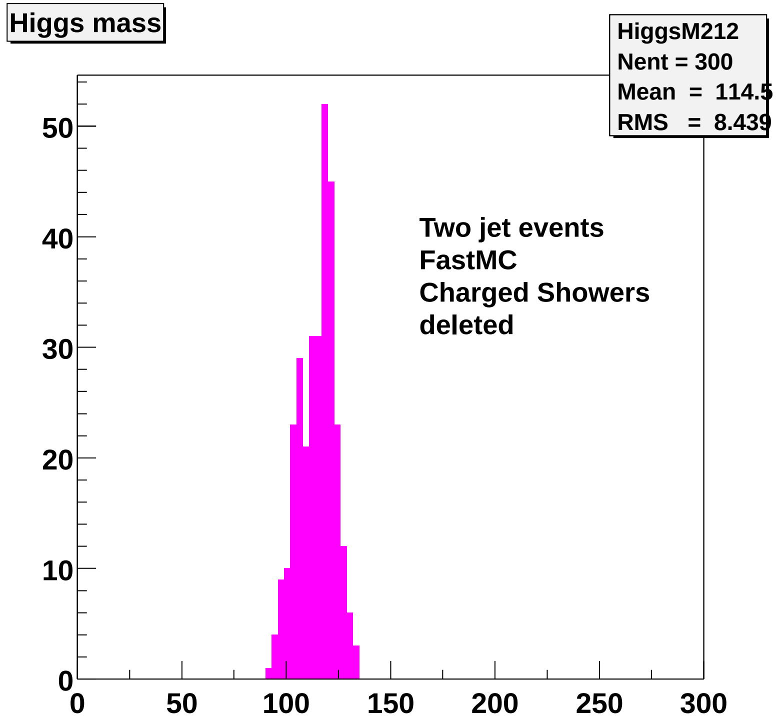


- For 120 GeV Higgs on-peak running
- Polarization control enhances spin-0 and suppresses spin-2
  - Higgs is spin-0
  - Dominant, $\gamma\gamma \rightarrow bb$, background is spin-2
    - $\gamma\gamma \rightarrow bbg$ breaks the suppression
- Expect ~5400 Higgs / Year

Benchmark Higgs mode

- For new machine parameters and round beams
  - ~5000 Higgs / year
- Evaluating Higgs @
  - 120, 140, 160 GeV/c mass
  - bb, WW, ZZ modes
- UC Davis students evaluating
  - $\gamma\gamma \rightarrow$ chargino pairs
  - $e\gamma \rightarrow$ Lightest SUSY partner

Still plenty of physics modes to be evaluated



Ongoing Physics efforts

- Groundswell of interest in $\gamma\gamma$

Virtuous circle

Theoretical work

↓↑

Engineering work

- NWU and FNAL physicists have organized an international workshop on gamma-gamma interactions @ FNAL, March 14-17.
  - http://diablo.phys.nwu.edu/ggws/
- $\gamma\gamma$ parallel session @ JHU LC
  - http://hep.pha.jhu.edu/~morris/lcw
- $\gamma\gamma$ session at Snowmass
  - http://snowmass2001.org

Missing Monte Carlo evaluations of physics mode analyses

Machine Optimization

- Basic design of photon collider exists.
- Detailed choices about machine configuration must be driven by physics analyses.
  - How important is electron polarization?
  - Must the low energy tail be suppressed?
  - Is it important to do Higgs runs on peak or can we take advantage of higher luminosity in the tail while running at max energy for SUSY / new physics searchs.

Conclusion

- Livermore is proceeding with a complete engineering design of a photon collider for Snowmass
- No show stoppers have been found for either the laser technology, optics or the IR integration

All enabling technologies exist
Task is mainly engineering now