OPTICS ≠ LASER FOR Yγ, eγ:
SNOWMASS ≠ (A LITTLE) BEYOND

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"A 2nd INTERACTION REGION FOR
γγ, eγ, e-e- FOR NLC"

LBLNL - 38985
LLNL - UCRL-1D 134182
SLAC-PUB-95-7192
Electron beam parameters

- Angles
  - crossing angle: ± 15 mrad
  - disrupted beams: ± 10 mrad

- Time structure
  - micro rep. rate: 90 bunches separated by 1.4 nsec
  - macro rep. rate: 180 hz

- $s_z = 100 \mu m$
- beam $E_o = 250$ GeV
- $N_e = 0.65 \cdot 10^{10} /$ bunch

"FLAT BEAMS"

LLNL-28 Aug 95
Laser beam parameters

- energy / micro pulse = 1 J
  - pulse length = 1.8 psec
  - wavelength = 1.05 μm

- time structure to match e⁻ beams
  - micro pulses / macro pulse = 90
  - time separation = 1.4 nsec
  - macro pulse rate = 180 hz
  - average power = 16 kW (each side)

- focusing
  - f / 10 (gaussian)
  - near defraction limited
  - needed to get $\sim 10^{18}$ W/cm²

- polarization
  - left, right, horizontal, vertical
THE ZDR REPRESENTED
A COMPLETE OPTICS SOLUTION

BY PRINTING OF ZDR:

- "1-PASS" SOLUTION
- SATISFIES:
  - ACCUMULATED NON-LINEAR PHASE CONDITION ("B-INTEGRAL")
  - DAMAGE THRESHOLD CONDITIONS
  - TIMING, etc.
  - ACCUMULATED ABERRATIONS...
- OPTIMIZED:
  - LASER-ELECTRON OVERLAP
  - ALIGNMENT & POINTING STABILITY REQ'TS

BY SNOWMASS:

- "2-PASS" SOLUTION
- DITTO
Laser beams must be nearly "on axis" with e⁻ beams

- Aspect ratio of the focused bunch is:

\[ \frac{1}{\theta_0} = 4f_\# = \frac{2z_R}{w_0} \]

- If the beam just touches the edge of the mirror, then the angle is:

\[ \theta = \frac{1}{2f_\#} \]

- Penalty in this case would be:

\[ \frac{1}{\sqrt{1 + \frac{\theta^2}{\theta_0^2}}} = \frac{1}{\sqrt{5}} = 0.45 \]

- Conclude -> e⁻ beam must go through mirror if possible. At \( \theta_0 / 2 \) the penalty is about 10% -> 12.5 mrad for f/10

  - (f/10 -> 50 mrad 1/2 angle)
Four Mirror Telescope

- Design worked out by Lynn Seppala at LLNL
  - Slightly elliptical beams increase acceptance of detector
  - Strehl ratio 0.90 with spherical surfaces (0.99 with one slight asphere)

<table>
<thead>
<tr>
<th>what</th>
<th>beam_size</th>
<th>location</th>
<th>radius of curvature</th>
<th>distance to next element</th>
</tr>
</thead>
<tbody>
<tr>
<td>fp</td>
<td>0 0</td>
<td>0 -1500</td>
<td>-</td>
<td>1500.0</td>
</tr>
<tr>
<td>M1</td>
<td>171.2 269.0</td>
<td>0 0</td>
<td>1207</td>
<td>730.27</td>
</tr>
<tr>
<td>M2</td>
<td>46.5 74.5</td>
<td>-76.33 -726.27</td>
<td>570</td>
<td>650.00</td>
</tr>
<tr>
<td>M3</td>
<td>44.5 71.8</td>
<td>-144.27 -79.83</td>
<td>6600</td>
<td>300.00</td>
</tr>
<tr>
<td>M4</td>
<td>48.5 75.8</td>
<td>149.51 -140.53</td>
<td>9227</td>
<td></td>
</tr>
</tbody>
</table>
Savings from double passing the laser

<table>
<thead>
<tr>
<th></th>
<th>1-pass</th>
<th>2-pass</th>
</tr>
</thead>
<tbody>
<tr>
<td>holes</td>
<td>1.13</td>
<td>1.13</td>
</tr>
<tr>
<td>off angle</td>
<td>1.0</td>
<td>1.176</td>
</tr>
<tr>
<td># pulses</td>
<td>2 x 90</td>
<td>90 + 16</td>
</tr>
<tr>
<td>overall</td>
<td>1.0(def)</td>
<td>0.69</td>
</tr>
</tbody>
</table>

30% reduction in laser power!

$$106 \cdot 1.18 \text{ J} \cdot 1.13 \cdot 180 \text{ hz} = 25.4 \text{ kW}$$
Laser damage of optics is an issue

- Optics have an area of 20 cm$^2$
  - short pulse (picosecond) limit
    - need 0.053 J/cm$^2$ at 1.8 ps
    - 0.7-2 J/cm$^2$ measured
  - long pulse (nanosecond) limit is less clear.
    - need 11.3 J/cm$^2$ at 126 ns
    - 100-200 J/cm$^2$ expected for uniform (in time) pulse
      - But, no data for a collection of short pulses
  - average power limit
    - need 2.0 kW/cm$^2$
    - 3-5 kW/cm$^2$ is routine at AVLIS
      - higher is possible
Interaction Region Parameters

- electron beams
  - offset
  - divergence (exit)  
- laser
  - wavelength
  - beam profile:
  - energy
  - length
  - microbunches
  - rep. rate
  - power
- optics
  - $f_0$ (flat top)
  - distance to first mirror
  - fractional area of hole
  - fluence on smallest mirror
- vertex chamber
  - inner/outer radius
  - total length
  - solid angle (inner/outer)
- distance to 1st quad.
- masking

+/- 15 mrad
+/- 10 mrad

1.05 µm
7.58 cm x 4.85 cm flat top
1.33 J / pulse (off-angle + holes)
1.8 psec
106 @ 1.4 nsec
180 Hz
25.4 kW

8.76 / 5.58 (± 57 mrad / 90 mrad)
150 cm
5.8%
0.053 J/cm² / pulse

2 / 6 cm
24 cm
$\cos(\theta) = 0.986 / 0.97$
> about 160 cm
135 - 185 mrad
Small angle detectors, 
$\cos \theta > 0.99$

- Mirrors occupy this region
  - could probably instrument region behind mirrors
  - typical mirror will have thickness 1/6 of diameter
  - plus brackets, motors, etc.
- from $135 < \theta < 70$ mrad
  - small mirrors, only part of azimuth
  - 1.1 cm of fused quartz = 10% of a radiation length
- inside 70 mrad
  - large mirror - all azimuth
  - 3.6 cm of fusec quartz = 32% of a radiation length
Conclusions

**OPTICS:**
- No show stoppers so far
  - Laser damage looks ok, but more work needed
- Many, many issues still require work
  - Radiation damage of optics
  - Effects laser damage threshold?
  - Detector backgrounds - better calculations
  - Synchrotron radiation, degraded electrons
  - Effect of sweeping magnet
  - Luminosity measurements
    - Wide angle vs. small angle
  - Heat loads due to mirror leakage
- **RF HEATING**

**LASER:**
- Doesn't exist - yet
- But progress is rapid
- Guaranteed to be ready by NLC
CHIRPED-PULSE AMPLIFICATION

FIRST GRATING PAIR - STRETCH PULSE BY $\times 10^3$

SHORT PULSE OSCILLATOR

POWER AMPLIFIER CHAIN

SECOND GRATING PAIR (REVIRIES DISPERSION)

HIGH ENERGY SHORT PULSE
The 40 kW laser system would be constructed from 1 kW unit cells.

**Laser Requirements**

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repetition rate</td>
<td>= {90 micropulses/macropulse, 180Hz macropulse}</td>
</tr>
<tr>
<td>Micropulse separation</td>
<td>= 1.4 nsec</td>
</tr>
<tr>
<td>Micro pulse energy</td>
<td>= 2 Joules</td>
</tr>
<tr>
<td>Pulse duration</td>
<td>= 2 psec</td>
</tr>
<tr>
<td>Micropulse peak power</td>
<td>= 1 TW</td>
</tr>
<tr>
<td>Synchronization</td>
<td>= 1 psec</td>
</tr>
<tr>
<td>Beam quality</td>
<td>= Near diffraction-limited</td>
</tr>
<tr>
<td>Wavelength</td>
<td>= 500 to 1100 nm</td>
</tr>
</tbody>
</table>

**Master Oscillator and Unit Cell**

- **Unit cell 1 kW average power**
  - Diode laser pump source
  - G = 10^7
  - Linear Regenerative amplifier
  - Diode laser pump source
  - G = 33
  - Multipass power amplifier
  - Diode laser pump source
  - G = 6
  - Single-pass power amplifier

- **Pump laser**
  - Mode-locked oscillator
  - 11 W
  - 2 nJ
  - 90 fsec
  - 800 pJ
  - 1 nsec

- **Pulse stretcher**
  - 2 nJ
  - 90 fsec
  - 800 pJ
  - 1 nsec

**Pulse Combiner**

- **Unit cell 1 kW avg power**
  - Thin-film polarizer (TFP)
  - Pockels cell
  - Imaging aperture
  - Mirror 560 HR
  - Polarization control
  - Pockels cell
  - 0.2% leakage laser diagnostics

**Optical Storage Ring Polarization Control**

- **TFP 1**
  - TFP
  - Pockels cell

- **Input**
  - 400 cm

- **e-beam**
PROGRESS IN HIGH-AVERAGE POWER SHORT PULSE LASERS

Huge effort world-wide

Examples at LLNL:

FALCON (operating)

\[ T_i: \text{SAPPH} \]
\[ 825 \text{ nm} \]
\[ T = 30 \text{ fs} \]
\[ 20 J @ 5 \text{ Hz} \Rightarrow 0.1 \text{ kW} \]
\[ \sim 1999 \? \]

MERCURY (~ 2000?)

\[ \text{Yb: S-FAP} \]
\[ \sim 1 \mu \text{m} \]
\[ 5 \times \text{ DIFF LTD.} \]
\[ 1 \text{ kW} \Rightarrow \{ \]
\[ 100 J @ 10 \text{ Hz} \] (long pulse: 1-10 ns)
\[ 80 J @ 10 \text{ Hz} \] (CPA: 10- few 100 ps)

Can be compressed to 2-3 ps, but energy falls precipitously.

Not quite our laser, but getting close