Photon Collider Laser Work at LLNL

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LLNL

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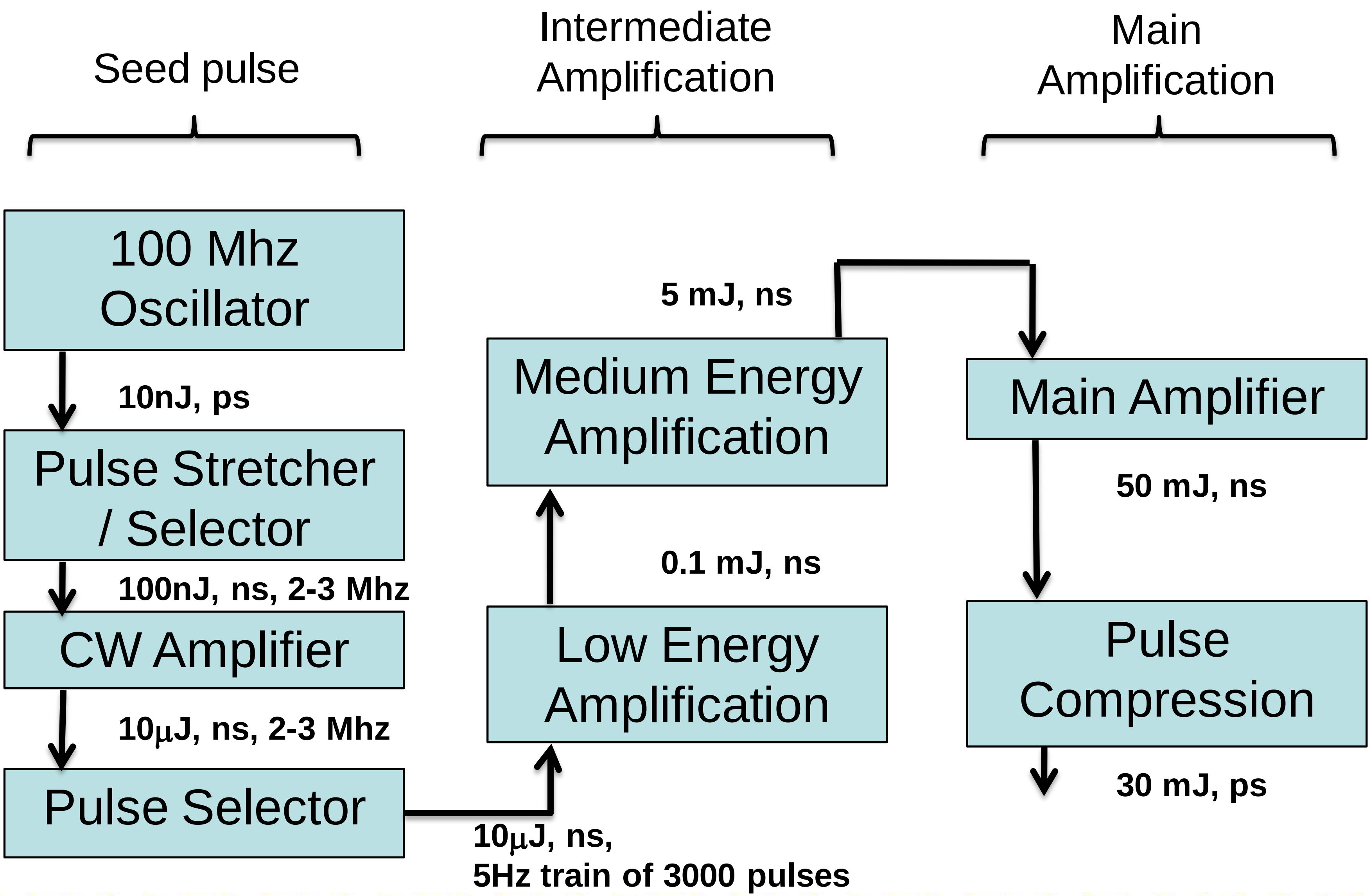
Laser requirements:

- Pulse train matched to the ILC bunch structure + ~300 extra pulses per train to initially fill the cavity
- 30mJ / pulse around 1kW average power
- Beam quality able to drive the cavity:
  - **Pointing stability**
  - **Phase matching**
  - **Wavefront quality**

Basic system layout



Pulse injection

100 Mhz Oscillator

↓ **10nJ, ps**

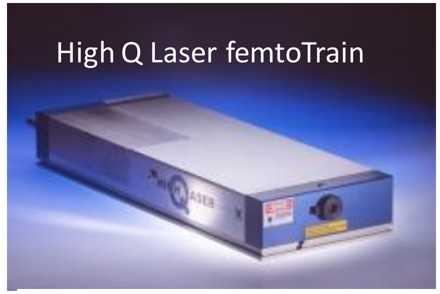
Pulse Stretcher / Selector

↓ **100nJ, ns, 2-3 Mhz**

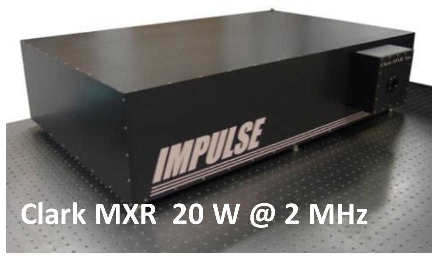
CW Amplifier

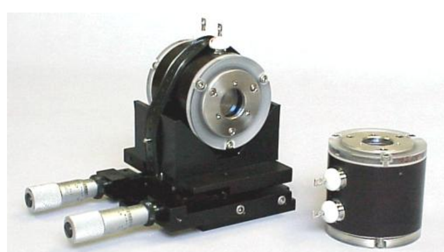
↓ **10μJ, ns, 2-3 Mhz**

Pulse Selector




KM Labs pulse stretcher/compressor




Lasermetrics Pockels cell and driver

- Off-the-shelf technology
- Similar to lasers for ILC photogun
- Special photon collider requirements:
  - **Higher pointing stability**
  - **Higher bandwidth for narrower pulses**
  - **Tighter wavefront quality**

Intermediate Amplification

5 mJ, ns

Medium Energy Amplification

0.1 mJ, ns

Low Energy Amplification

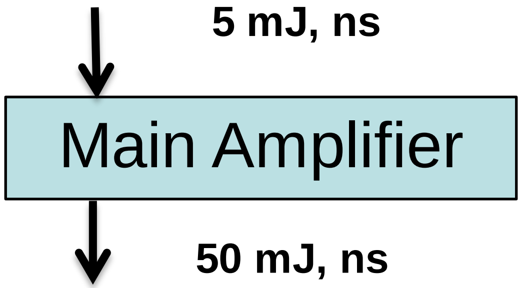
$10\mu J$, ns,
5Hz train of 3000 pulses

Cutting Edge Optronics' slab pumphead, the Whisper MiniSlab™

Cutting Edge Optronics RBA PowerPULSE

- Off-the-shelf technology exists to reach this power level
- At this level non-linear and thermal effects begin to be important

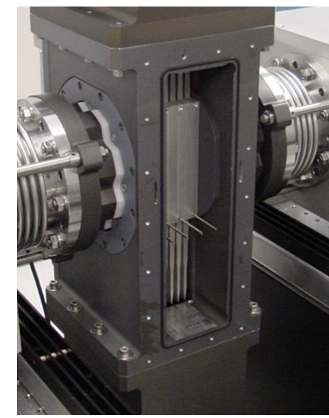
Main Amplifier



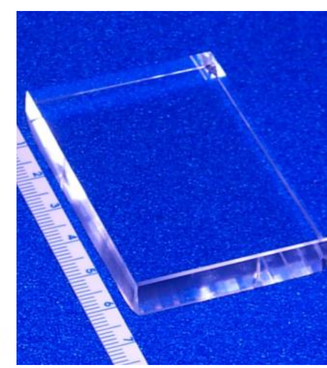
- Not commercially available
- Basic enabling technologies exist:
  - **Diode pumping**
  - **Thermal management**
  - **Long upper state lifetime materials**

Diode pumped
Higher efficiency and reliability

Forced cooling
Allows 10-Hz operation



Yb:crystals
Increased energy storage and efficiency (Yb:S-FAP)



MERCURY laser is an existence proof

- MERCURY:
  - **10 Hz**
  - **60 J/pulse**
  - **Good wavefront quality**
- But there are differences going from single pulse to a pulse train
  - **Non-linear effects are lower**
  - **Thermal distortions will change over the trains**

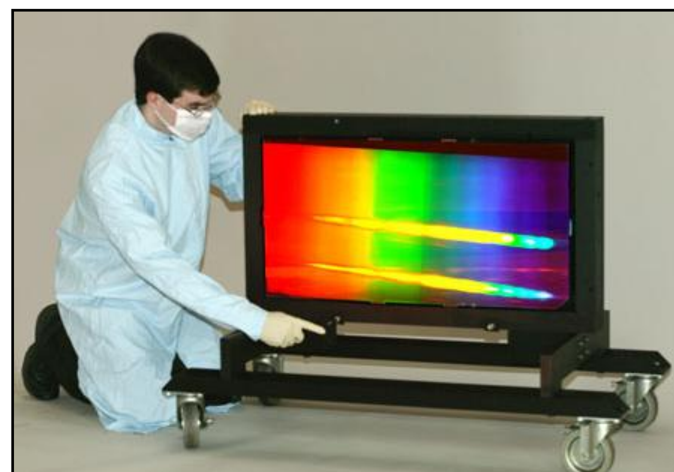
Pulse Compression

50 mJ, ns → **Pulse Compression** → 30 mJ, ps

Vacuum compressor (Titan – LLNL)

- System will be in vacuum after compression
- Large gratings are needed to keep power levels low

World's largest dielectric gratings (LLNL)



Prototyping: Stage 0 (Now)

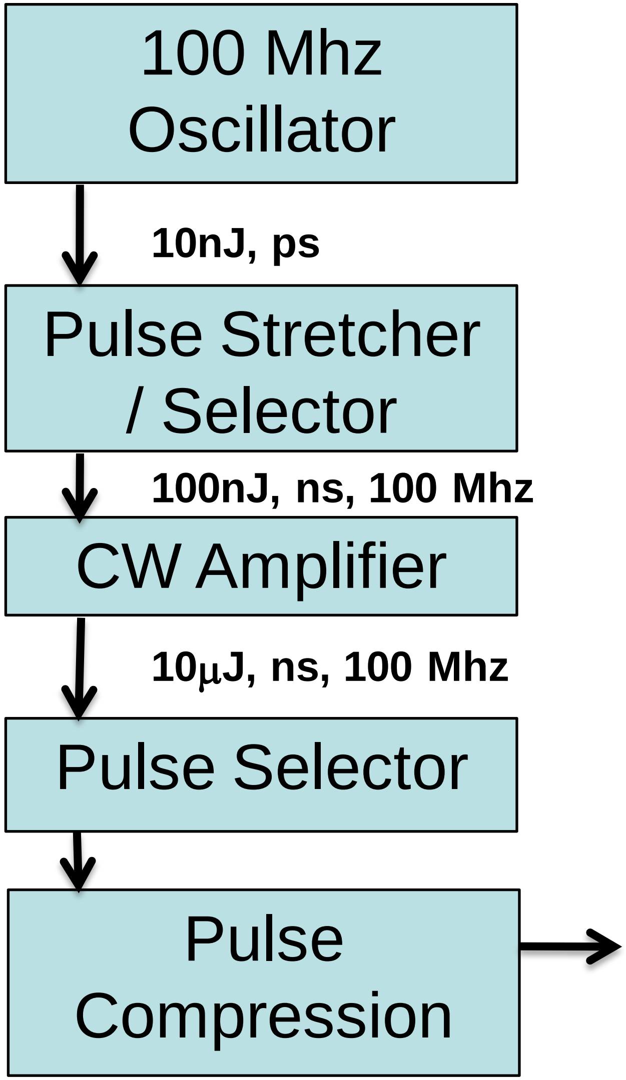
- Pre-conceptual design and simulation of the system. Is there a solution?
  - **Create a pulse train and get it to 30mJ/pulse**
  - ? **Couple pulses to cavity**

- Simulate full cavity behavior so that required tolerances can be specified for:
  - **Pointing tolerance**
  - **Phase accuracy**
  - **Feedback and control systems**
  - **Wavefront quality**

- Simulate the full laser system to determine if tolerances can be achieved

- Convene full outside review of the design
  - **Next year**

Prototyping: Stage 1



- Build CEP stabilized oscillator and two mirror cavity
  - **Demonstrate coherent addition and locking of oscillator to cavity**
- Add CW laser and demonstrate higher power operation
- Design next stage

Two mirror cavity at 100Mhz

Prototyping: Stage 2

100 Mhz Oscillator

↓ **10nJ, ps**

Pulse Stretcher / Selector

↓ **100nJ, ns, 19 Mhz**

CW Amplifier

↓ **10µJ, ns, 19 Mhz**

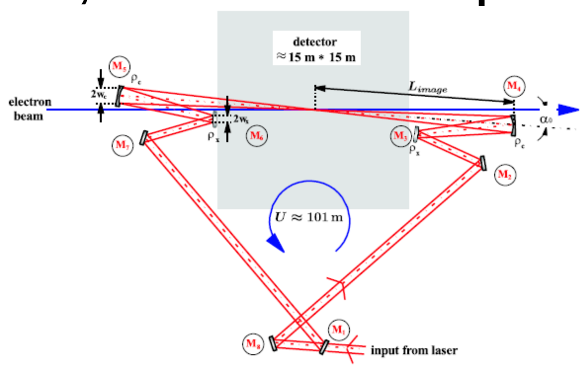
Pulse Selector

↓

Pulse Compression →

- Replace two mirror cavity with small-scale version of photon collider cavity
- Investigate and downselect materials for next amplifier stages
- Design next stage

Scaled version of gamma-gamma cavity
19-Mhz, 16m – fits on 5m optical table



Prototyping: Stage 3

100 Mhz Oscillator

↓ **10nJ, ps**

Pulse Stretcher / Selector

↓ **100nJ, ns, 19 Mhz**

CW Amplifier

↓ **10μJ, ns, 19 Mhz**

Pulse Selector

↓ **10μJ, ns, 5Hz train of 3000 pulses**

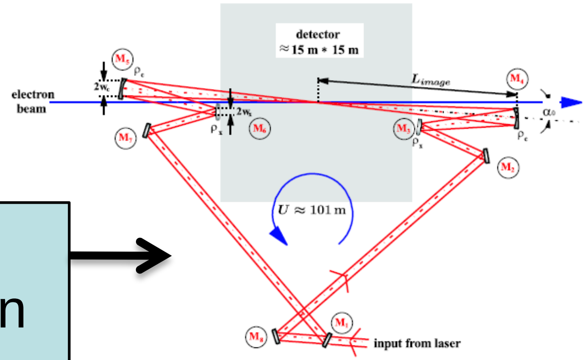
Low Energy Amplification

→ **0.1 mJ ns**

Pulse Compression →

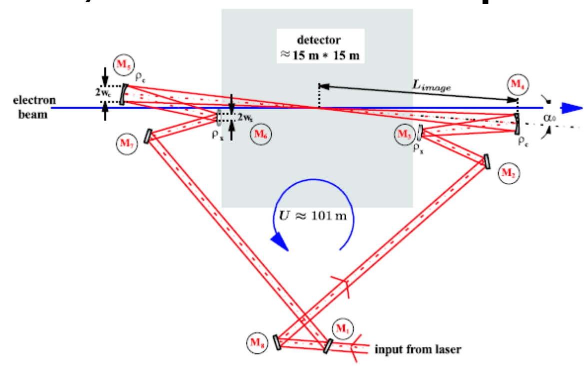
- Build and commission low-energy amplifier
  - **Demonstrate ILC pulse train with uniform gain**
  - **Demonstrate scaled cavity operation**
- Design next stage

Scaled version of gamma-gamma cavity 19-Mhz, 16m – fits on 5m optical table



Prototyping: Stage 4

Scaled version of gamma-gamma cavity
19-Mhz, 16m – fits on 5m optical table



100 Mhz Oscillator

↓ **10nJ, ps**

Pulse Stretcher / Selector

↓ **100nJ, ns, 19 Mhz**

CW Amplifier

↓ **10μJ, ns, 19 Mhz**

Pulse Selector

↓ **10μJ, ns, 5Hz train of 3000 pulses**

Low Energy Amplification

→ **0.1 mJ ns**

Medium Energy Amplification

↑ **5 mJ, ns**

Pulse Compression

↑ (to cavity)

- Decide on gain medium for next stages
- Build and demonstrate medium energy pulse train and cavity operation
- Add deformable mirror for wavefront correction
- Compton backscatter demo? (SLAC or ATF2)
- Design next stage

Prototyping: Stage 5

100 Mhz Oscillator

↓ **10nJ, ps**

Pulse Stretcher / Selector

↓ **100nJ, ns, 19 Mhz**

CW Amplifier

↓ **10μJ, ns, 19 Mhz**

Pulse Selector

↓ **10μJ, ns, 5Hz train of 3000 pulses**

Low Energy Amplification

→ **0.1 mJ ns**

Medium Energy Amplification

↑ **5 mJ, ns**

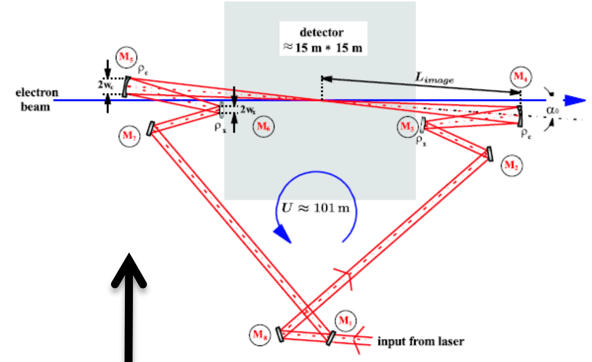
Main Amplifier

↑ **50 mJ, ns**

Pulse Compression

↑

Scaled version of gamma-gamma cavity
19-Mhz, 16m – fits on 5m optical table



- Build main amplifier
- Demonstrate full power operation at 19Mhz

Prototyping: Stage 6

100 Mhz Oscillator

↓ 10nJ, ps

Pulse Stretcher / Selector

↓ 100nJ, ns, 19 Mhz

CW Amplifier

↓ 10μJ, ns, 19 Mhz

Pulse Selector

↓ 10μJ, ns, 5Hz train of 3000 pulses

Low Energy Amplification

→ 0.1 mJ ns

Medium Energy Amplification

↑ 5 mJ, ns

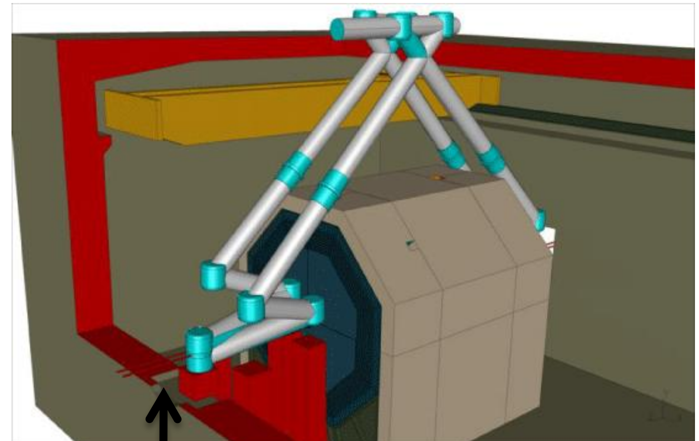
Main Amplifier

↑ 50 mJ, ns

Pulse Compression

↑

Full scale DESY/MBI cavity



- Build full scale cavity
- Demonstrate operation

Summary

- Creating a laser system that can create a train of pulses with the correct energy seems workable
- Still to be determined: the required tolerances on laser beam quality to allow it to drive the cavity
- Rough estimate of cost for a laser system is $20M once it is a known technology
- Prototyping program to build the first one is probably about double that.