Lawrence Livermore National Laboratory

Future Linear Collider R&D for detector and accelerator

Jeff Gronberg (PI), Tom Piggott (Lead Engineer), Jay Javedani, Ryan Abbott, Ed Cook, Craig Brooksby, Charles Brown, Brent Stuart

Doug Wright, Sean Walston, Lenny Summers

Lawrence Livermore National Laboratory, P. O. Box 808, Livermore, CA 94551

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344

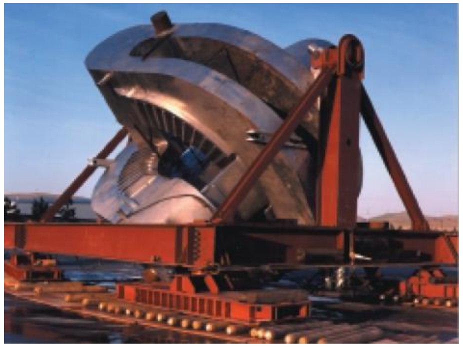
LLNL-PRES-471095

LLNL has a successful history of partnering with the HEP labs to bring engineering capabilities to DOE HEP projects.

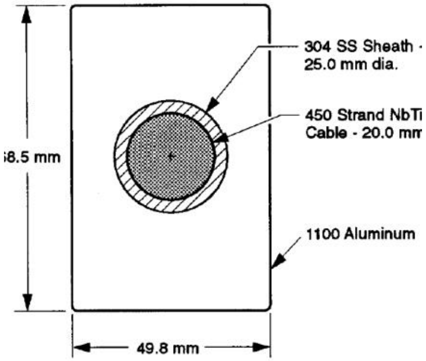
- The Large Hadron Collider is running well and opening up a new era in particle physics
- A lepton linear collider is the logical next step to understand the particles discovered at LHC in detail
- LLNL partnering with HEP for over a decade on this R&D project
  - first with SLAC on the Next Linear Collider R&D
  - Then directly with the Global Design Effort of the International Linear Collider

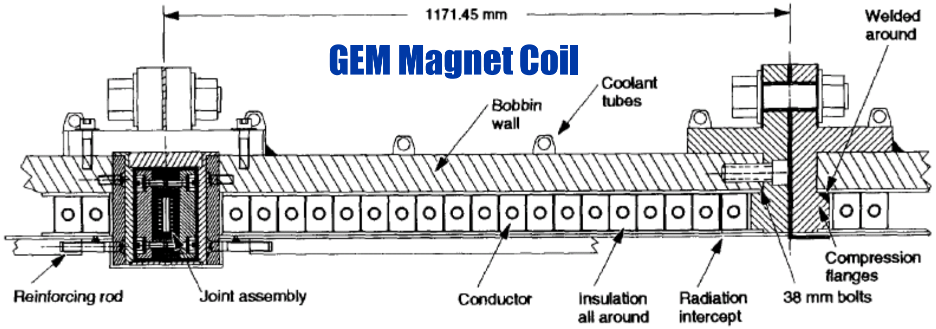
Big Magnets for detectors are an LLNL specialty

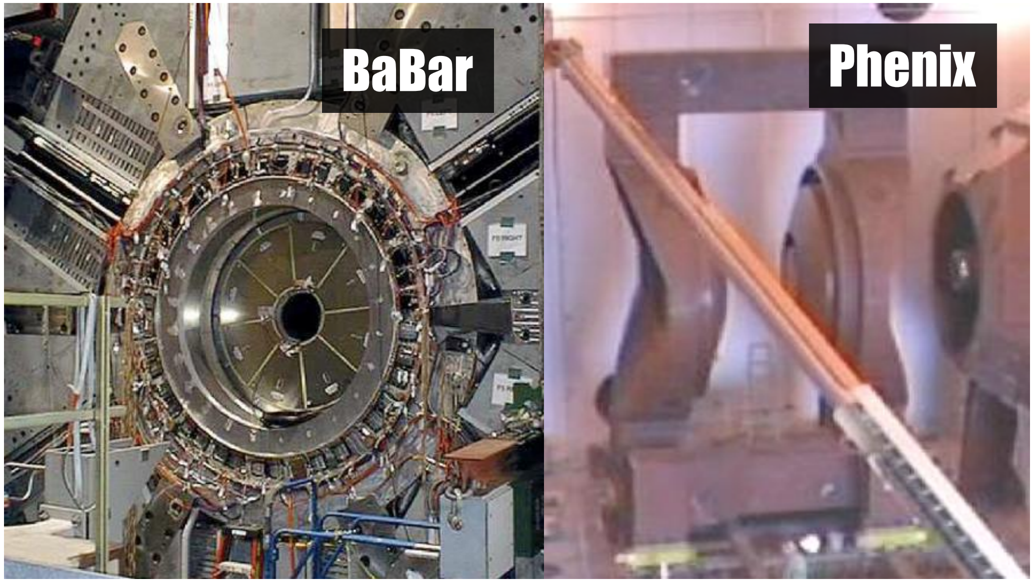
MFTF Magnet



GEM Conductor



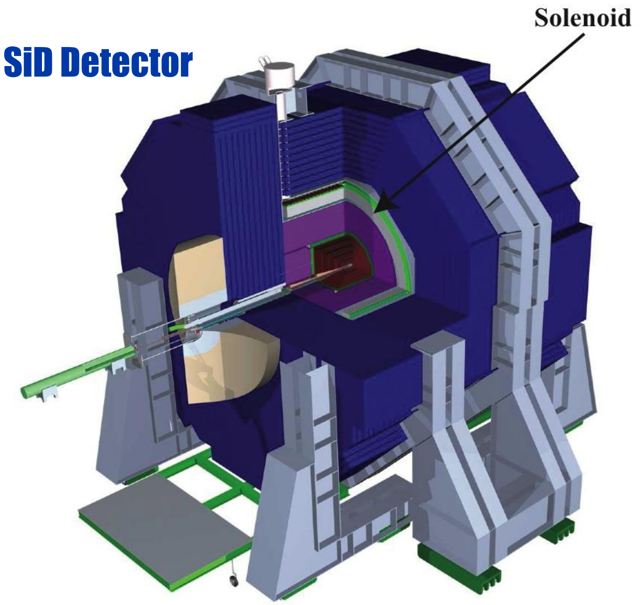


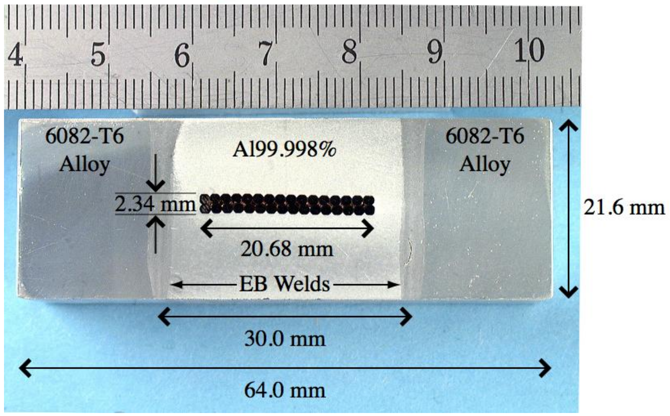


- LLNL entered the field of HEP with the design of the GEM magnet for SSC
- Designed, fabricated and installed the superconducting magnet for BaBar at PEP-II
- Designed, fabricated and tested the normal conducting Phenix magnet at RHIC

ILC Detector Superconducting Solenoid – a $200M subsystem and major cost driver

SiD Detector





CMS Conductor

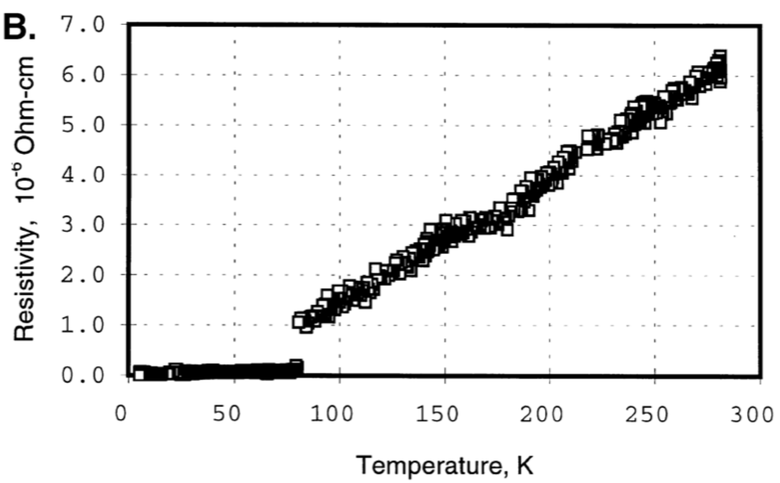
- Solenoid magnet is the most expensive subsystem in a future ILC detector
- CMS magnet is the closest equivalent to what SiD would require
- CMS conductor fabrication required an expensive and convoluted process
  - Rutherford NbTi cables co-extruded with pure aluminum stabilizer
  - Stronger aluminum alloy electron beam welded on both side for structural strength
- Cost reduction requires better materials and/or fabrication processes
  - New materials are available since the CMS magnet was designed
- Better conductors can lead to energy storage systems for alternative energy

Novel Material:
Aluminum-Carbon Nanotube (Al-CNT) Composite

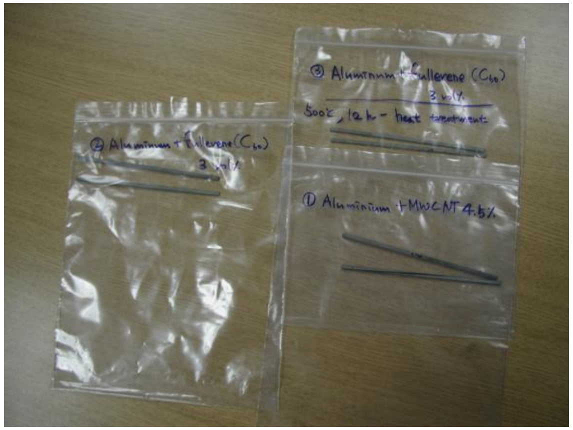
- Can produce very strong composites
  - H. Choi et al., J. Mater. Res., Vol. 24, No 8, Aug 2009

Materials	Grain size (nm)	Density (g/cc)	Young's modulus (GPa)	Yield strength (MPa)	K_{IC} (MPa·mm$^{1/2}$)
Starting aluminum	40,000 ± 2,000	2.693	70.063	40	8.21
Aluminum milled + hot-rolled	152 ± 13	2.68	70.02	262	33.22
Al/MWNT 1.5 vol% milled + hot-rolled	154 ± 17	2.67	82.54	386	41.74
Al/MWNT 3.0 vol% milled + hot-rolled	157 ± 11	2.67	95.13	483	50.05
Al/MWNT 4.5 vol% milled + hot-rolled	151 ± 15	2.65	110.05	610	60.79

- Exceptional electrical conductivity at low T
  - C.L. Xu et al., Carbon 37 855-858

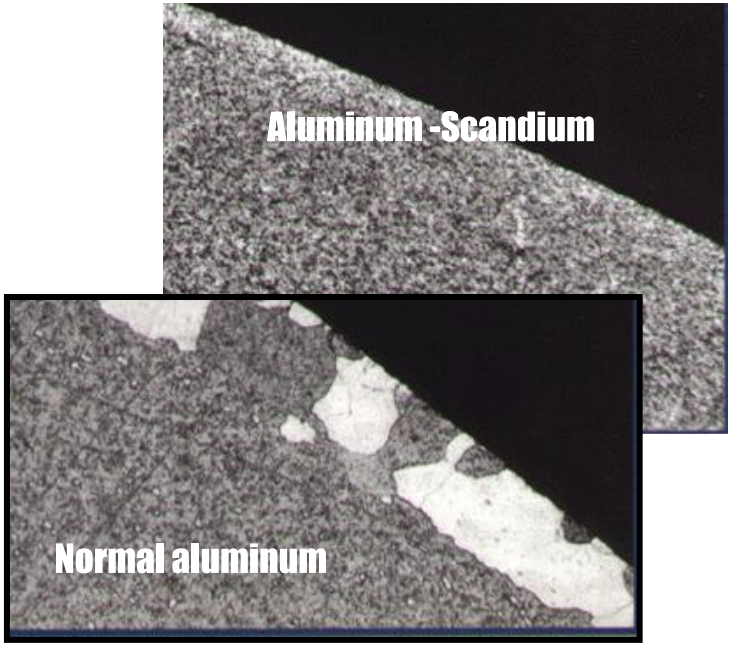


- We obtained six Al-CNT samples made by three different recipes from the Korean group of H. Choi et al.



Preparing to test material for electrical properties at Helium (4K) and Nitrogen (77K) temperatures

- Candidate material must have both strength and good thermal conductivity at 4K
  - Preparing to test materials at 4K and 77K
    - Aluminum – Carbon Nanotube
    - Pure aluminum with grain refiners
      - Aluminum-Boron
      - Aluminum-Titanium
      - Aluminum-Scandium (most potent grain refiner)
- Test setup being prepared

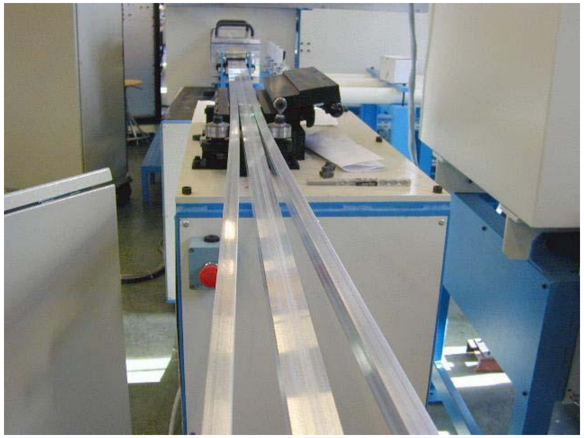


Our long term goal: to design a simpler, cheaper magnet around these new materials

- First: characterize the new materials strength and electrical properties
- Next: determine
  - Conductor configurations
  - Extrusion process parameters
  - Fabrication techniques
- Lastly: Manufacture prototypes
  - Measure performance characteristics

superconductor – stabilizer Extrusion process for CMS

E-beam welding of the support pieces to the CMS conductor

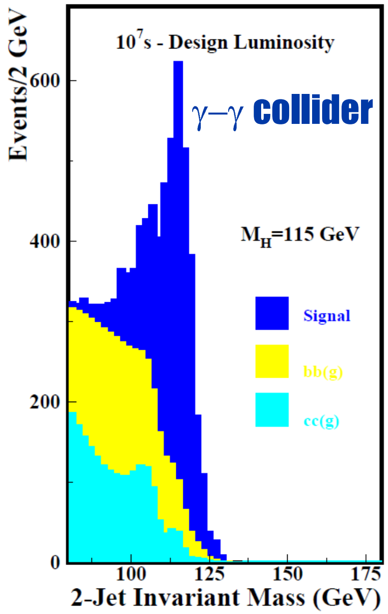


Accelerator R&D

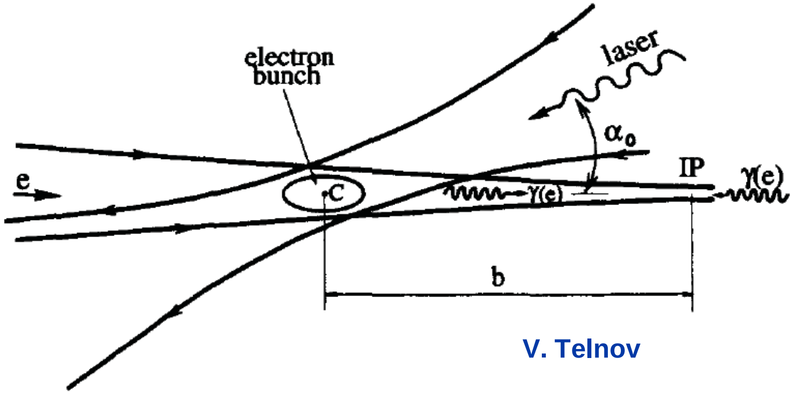
The early years (1995-2004)

Next Linear Collider

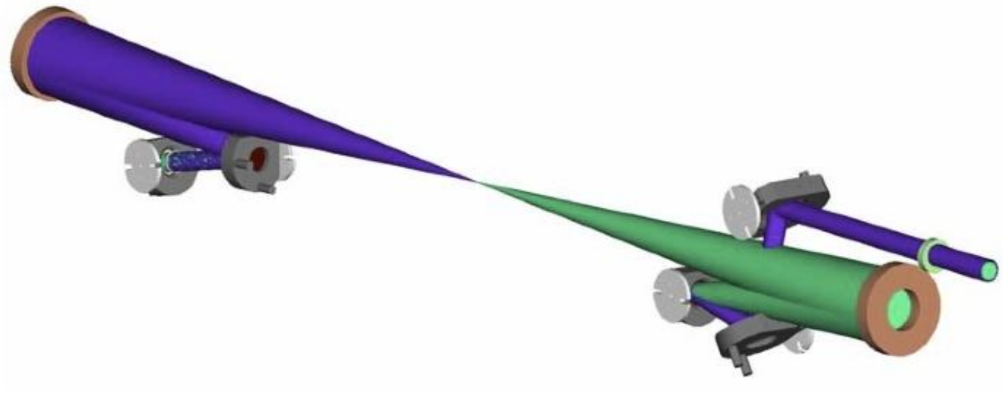
We developed the technology and physics case for the NLC photon collider option



- Photon-photon collisions open the possibility of seeing the Higgs in direct production
  - Sensitivity to all virtual charged particles at all mass scales
- Requires intersecting every electron bunch with a 1 Joule laser pulse inside the detector ~1mm away from the interaction point
  - Laser based on technology for Inertial Confinement Fusion
  - Optical system designed to fit within the detector



V. Telnov



We based our design around the MERCURY laser which had the power and repetition rate that we needed.

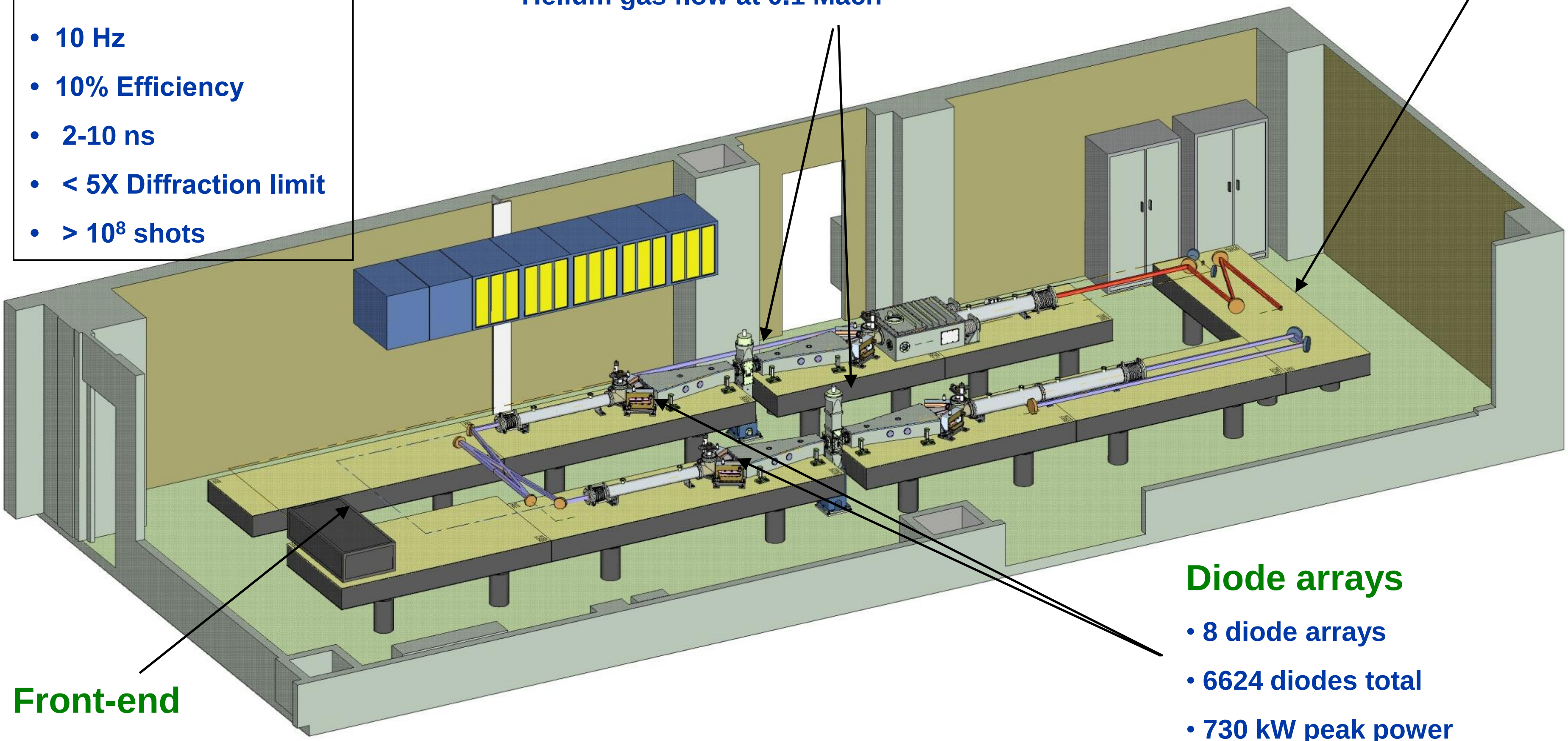
Goal:

- 100 J
- 10 Hz
- 10% Efficiency
- 2-10 ns
- < 5X Diffraction limit
- > 10^8 shots

Gas-cooled amplifier heads

- Helium gas flow at 0.1 Mach

Output



Diode arrays

- 8 diode arrays
- 6624 diodes total
- 730 kW peak power

Front-end

- 300 mJ

Pulsed power technology was our main contribution to the Next Linear Collider (1999-2004)

- Developed a solid-state modulator based on Integrated Gate Bipolar Transistors (IGBTs) to drive 8 NLC klystrons
  - Swapable circuit boards for soft failure modes and easy replacement
  - High power conversion efficiency

Metallurgical expertise was brought to bear to understand the failure of the SLC positron target

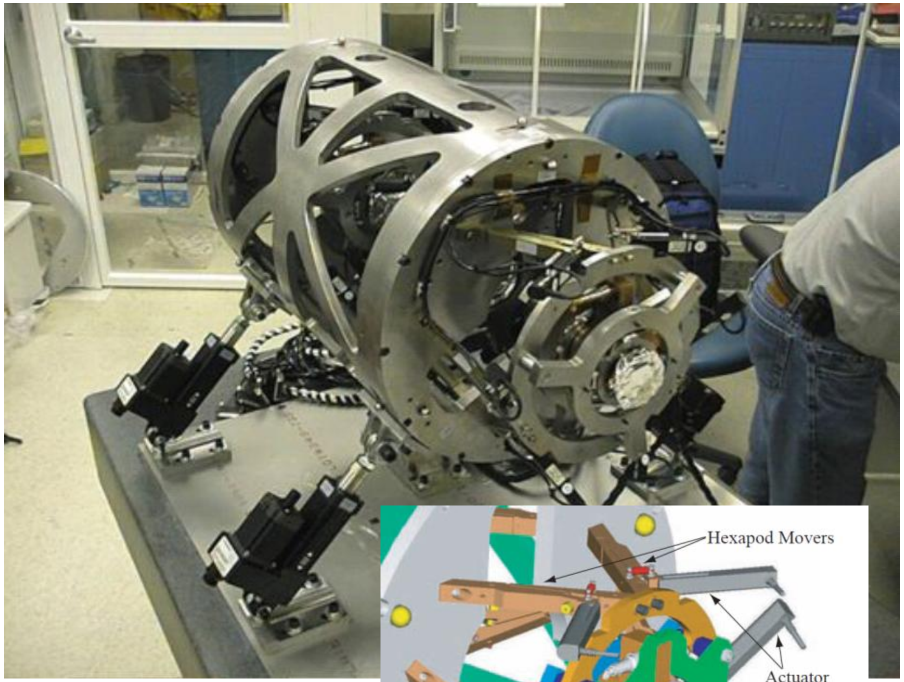
- Energy deposition causes shockwaves in the material
  - If shock exceeds strain limit of material chunks can spall from the face
- The SLC target showed spall damage after radiation damage had weakened the target material.
- Calculation had predicted no problems

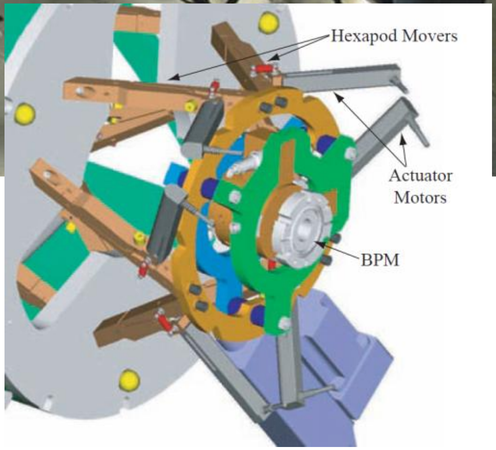
- LLNL studies showed that the Tungsten-Rhenium material had been sintered
  - Lower tensile strength than thought

SLC Positron Target Exit Face

Precision engineering used to create ultra-stable beam position monitors

- Colliding Nanometer beams was a challenge for NLC.
  - Testing the stabilization schemes required the existence of nano-meter precision beam position monitors
- We created a precision alignment frame to hold three cavity BPMs steady
  - Rigid frame creates a system resistant to vibration.
  - Hexapod flextures allow 6D adjustment within a small range.
- Achieved world record system performance of 16 nm





After the RF technology shoot-out (2004) we reoriented our efforts for the superconducting technology

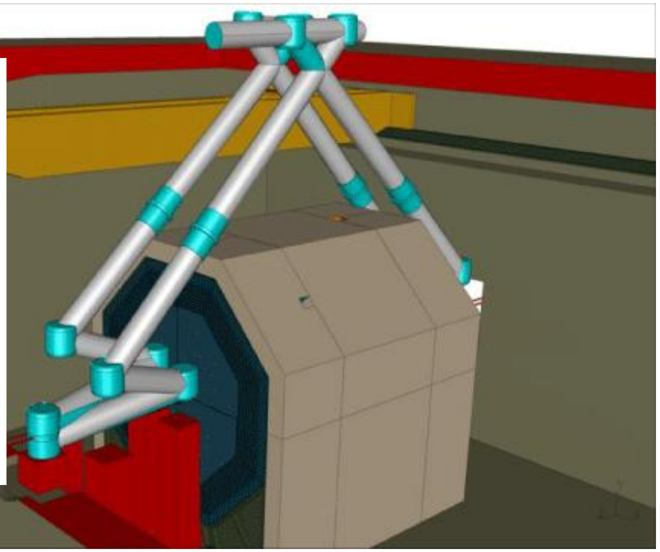
- The different time structure of the beam between X-band and super-conducting has many engineering implications:
  - X-band – bunch trains at 120 Hz
    - Bunch trains of 100 bunches with 2.8 ns separation
    - 300 ns total train length
  - Superconducting – bunch trains at 5 Hz
    - Bunch trains of 2820 bunches with 337 ns separation
    - 1 ms total train length

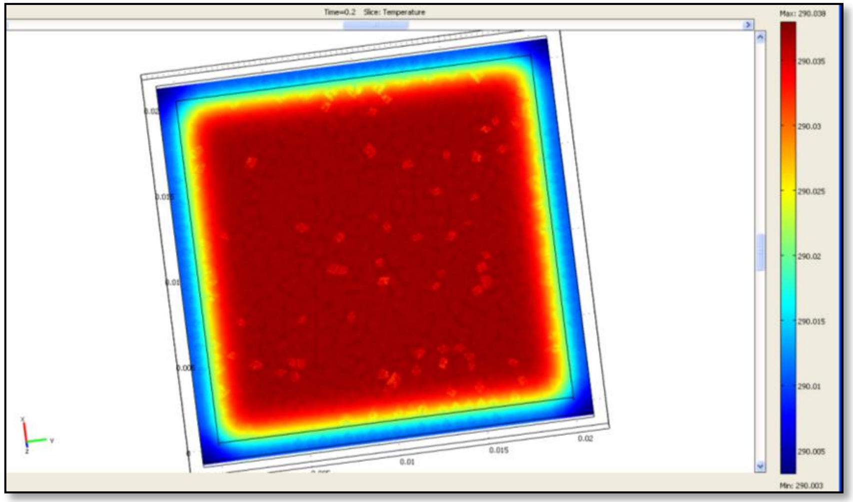
- Impacts on the:
  - Target design
  - Modulators to power the klystrons
  - Photon collider technology

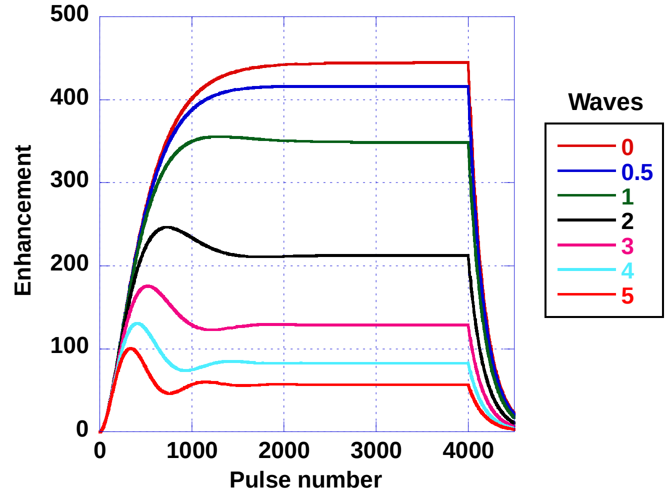
Photon collider technology -
Recirculating cavity allows great reduction in laser power

MBI/DESY laser stacking cavity design:

- **337 ns path length**
- **factor 300 reduction in total laser power**

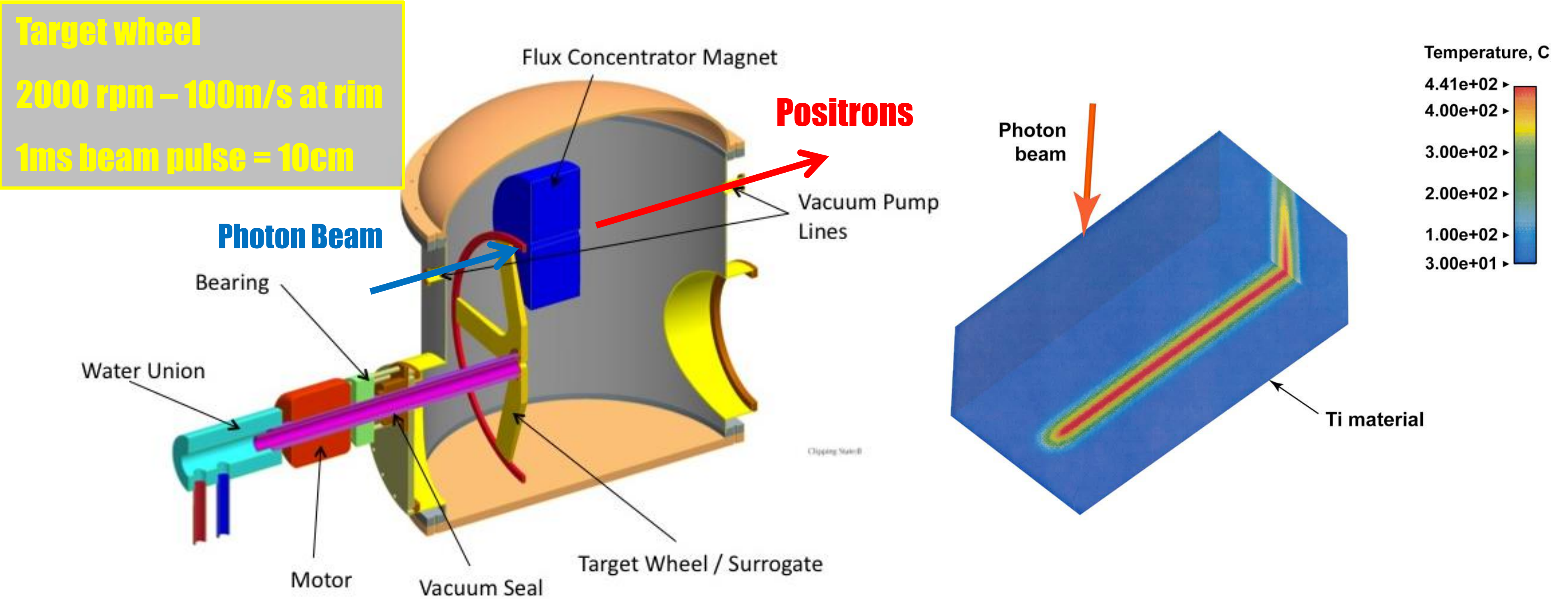






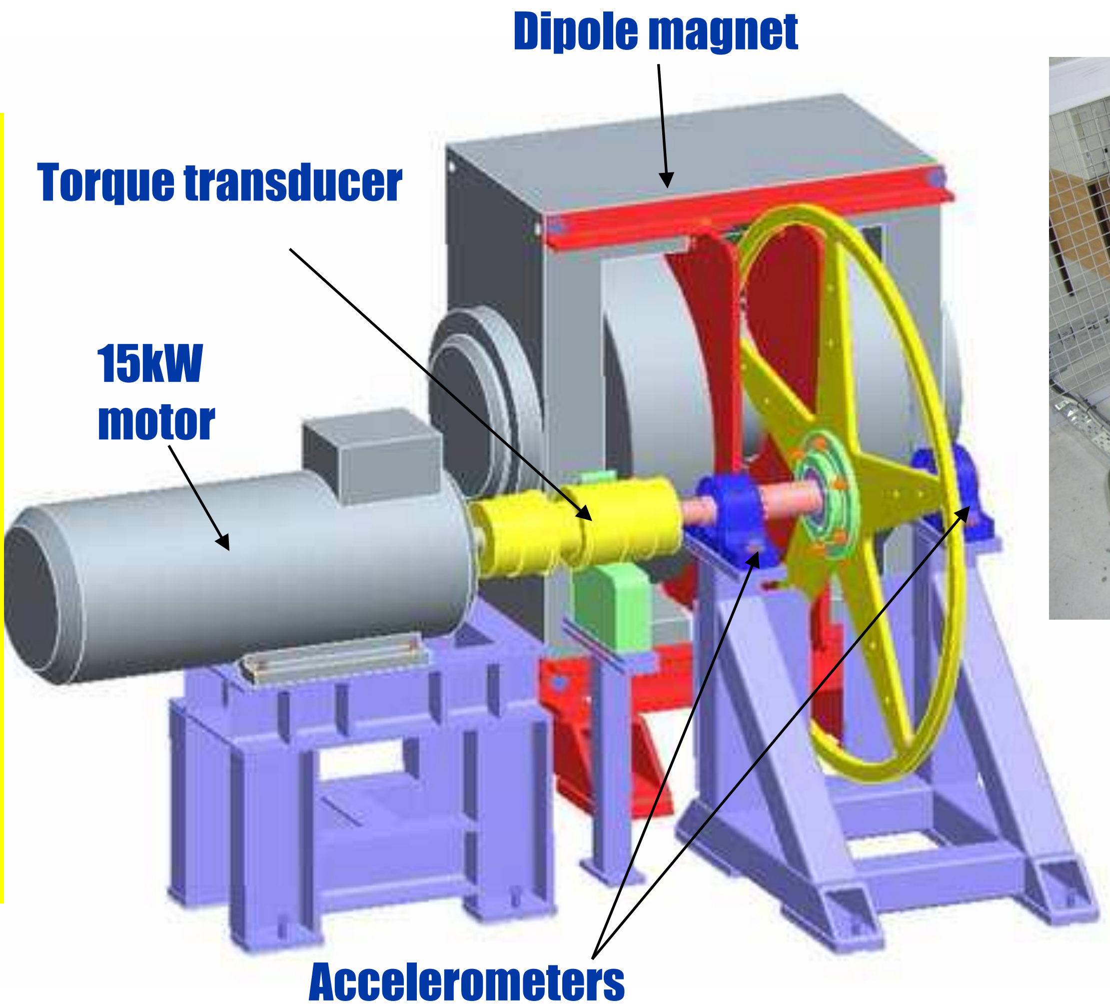
- We have studied the laser requirements to drive this cavity – report in preparation
- With good control of optical distortion and phase effect the factor 300 enhancement can be achieved.
- Laser system is now around $20M instead of the billion estimated in 2000.
- Laser pump diodes are no longer the dominant cost

LLNL created concept for rotating target wheel to spread the beam energy over a large area



- Rotation disperses the energy of the 1 ms beam train over 10 cm
- Flux concentrator magnet focuses the positrons for injection into the accelerator

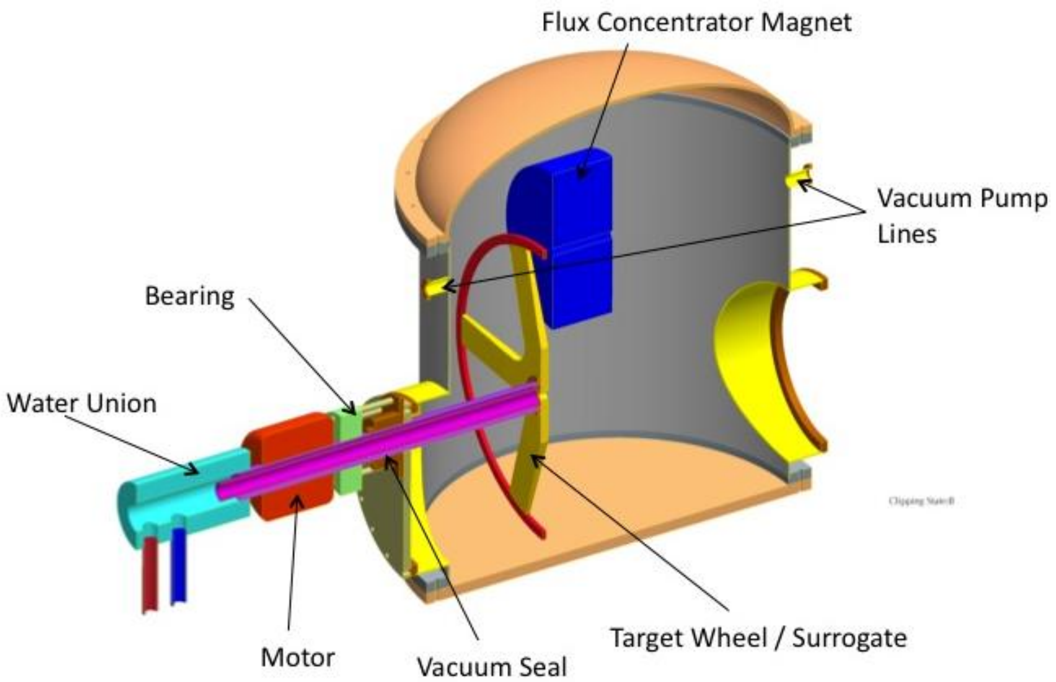
Collaborated with Daresbury lab to test prototype for rotordynamics and eddy current heating.



Ken Davies - Daresbury Laboratory

- Test – Rotordynamics
- Test – Mechanical stability
- Benchmark – Eddy current heating from capture magnet

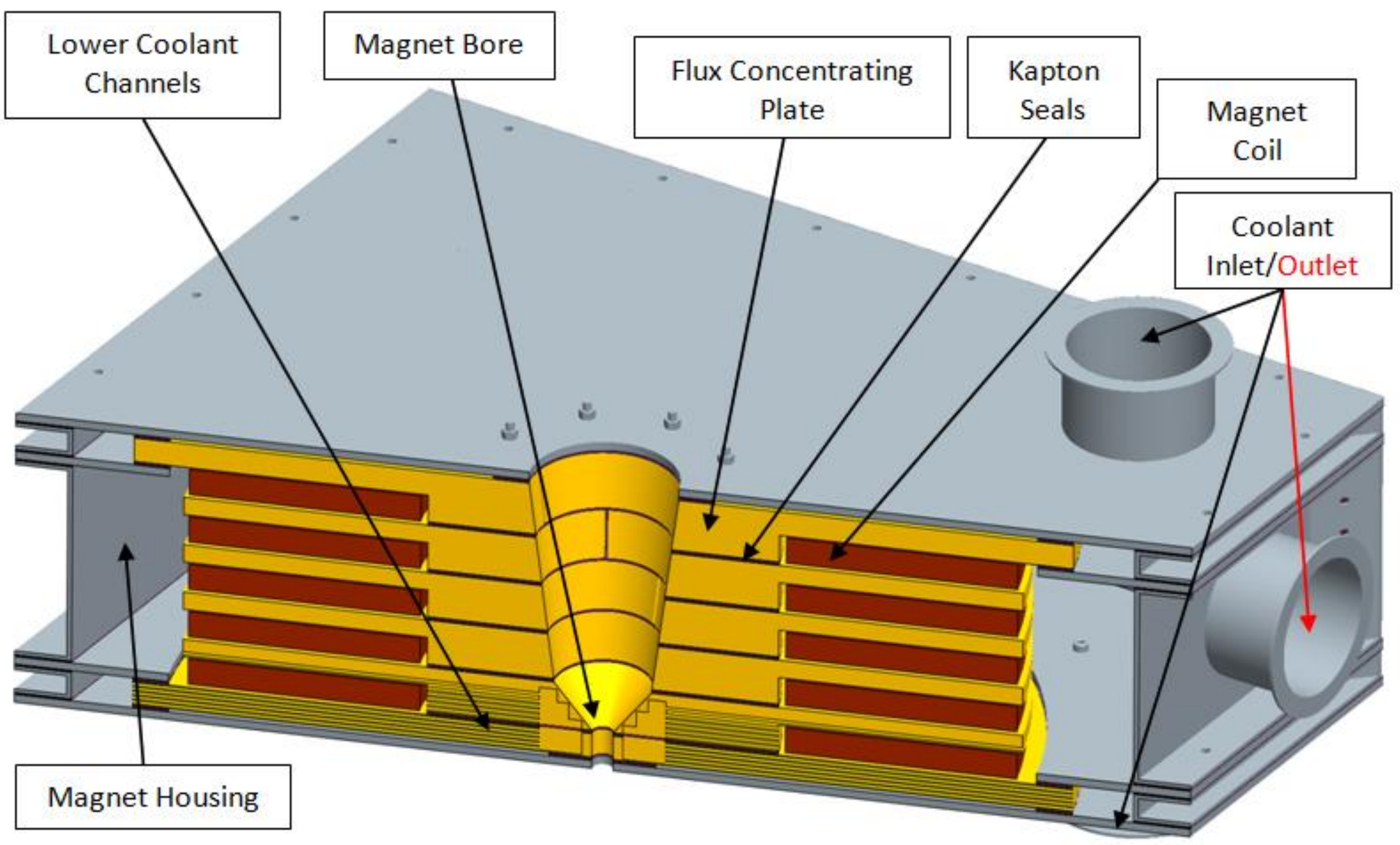
Building Test Stand at LLNL for validation of rotating ferro-fluidic vacuum seal.



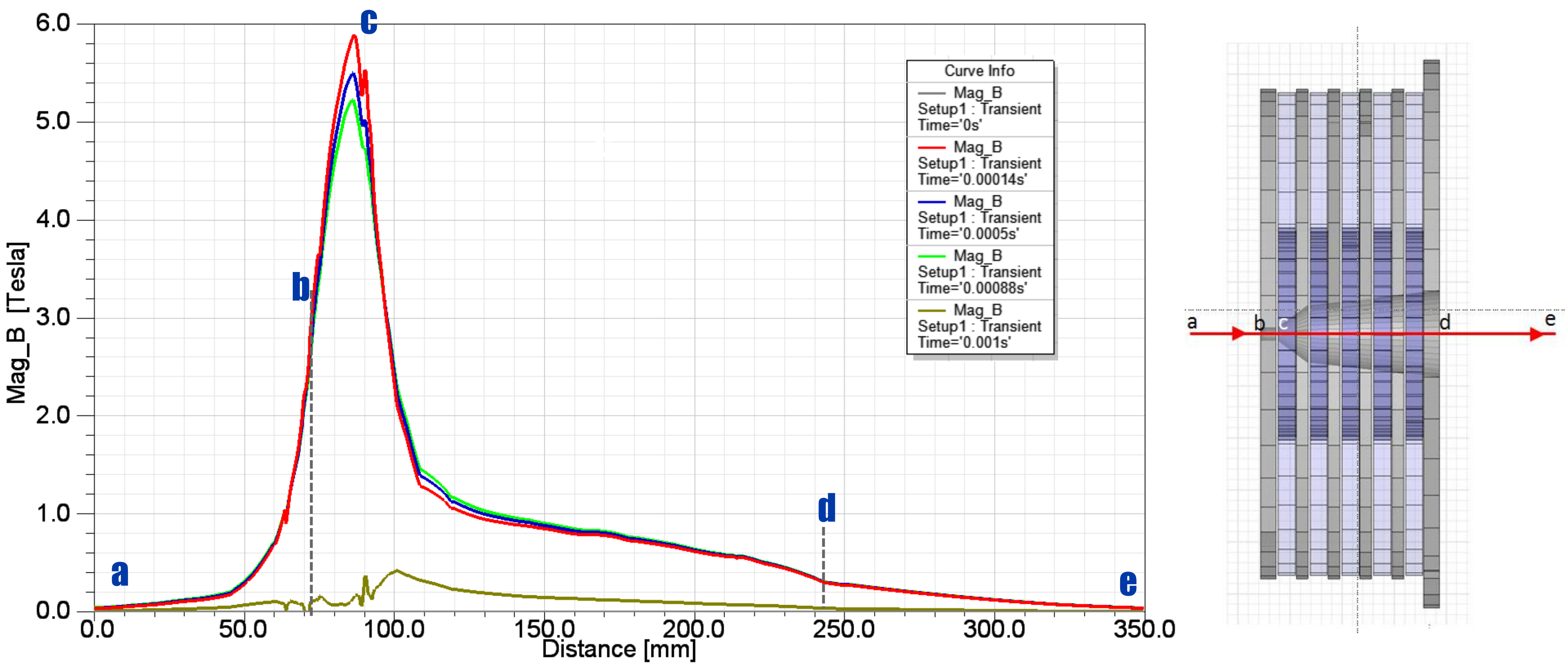
- Current design has rotating ferrofluidic vacuum seals
- Cooling water flows along the shaft

- Test leakage of vaccum/fluids from:
  - Vibration
  - Magnetic field effects

We created a design for a cryogenic pulsed flux concentrator magnet for the positron target capture optics.



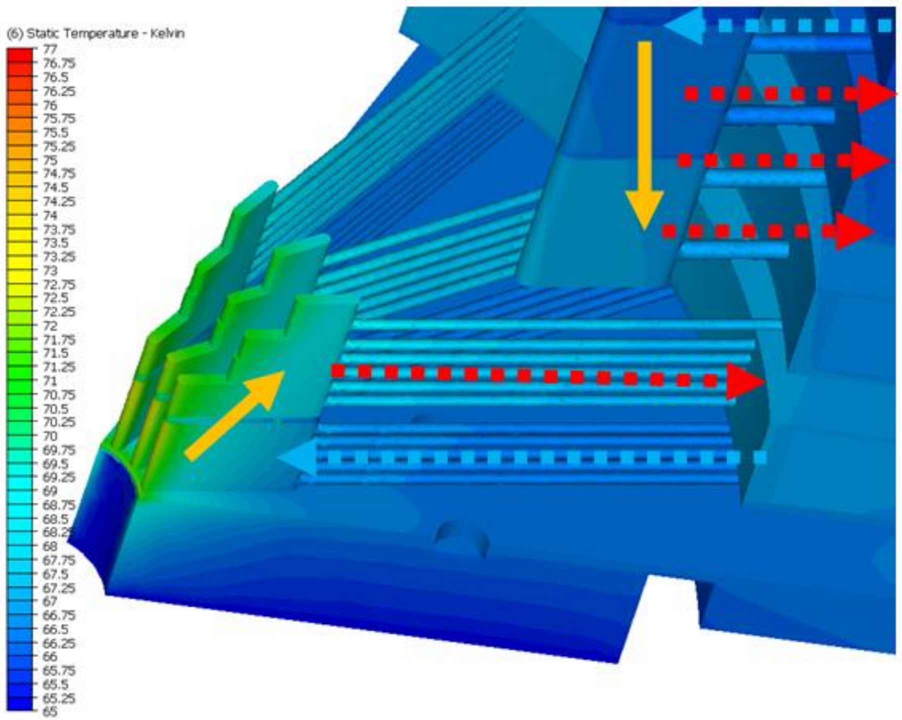
Magnet is cooled to liquid nitrogen temperature to attain the 1 ms flat top needed for ILC



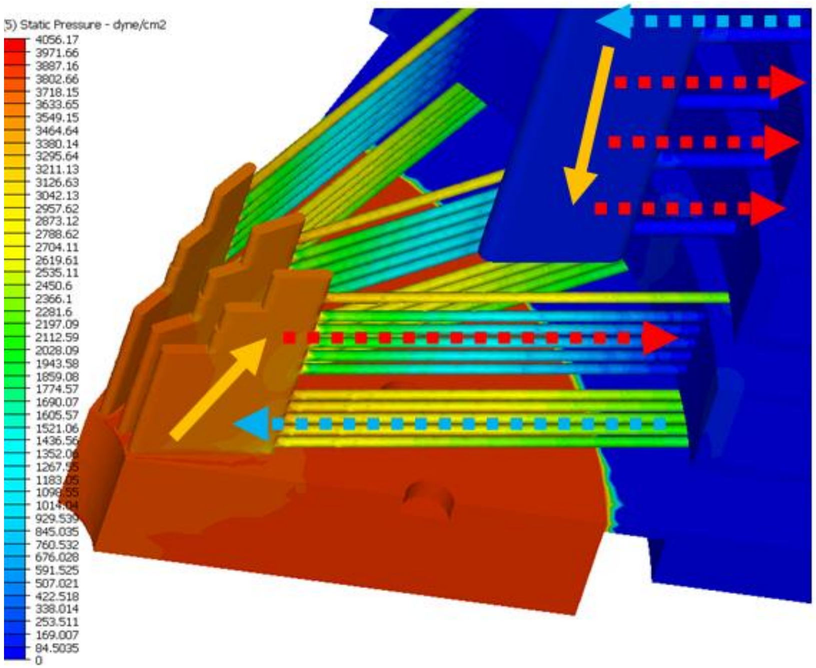
- Field shape optimized in simulations for capture
- Magnet requires 10 kW of liquid nitrogen cooling

System design and FEA analysis of cooling flows, stresses and magnetic fields are complete

Temperature



Pressure

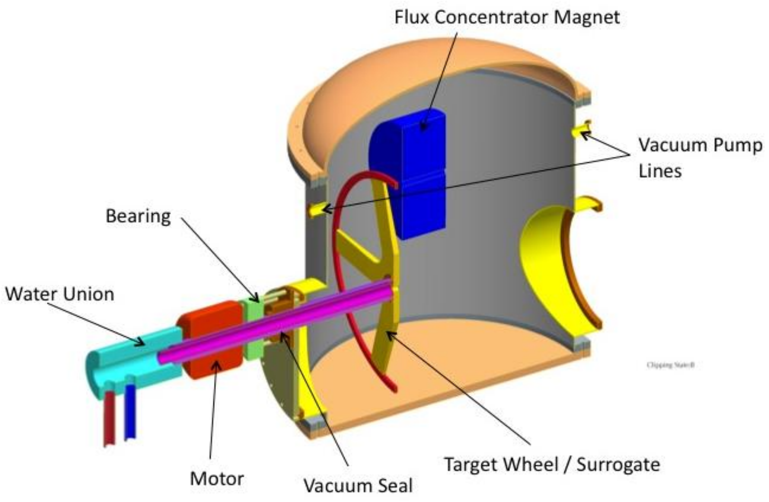


- Finishing detailed engineering designs to manufacture prototype
- Construction and testing at room temperature this year

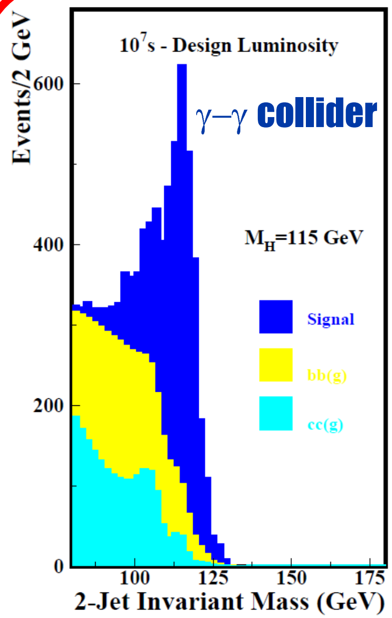
Prototyping of the Positron Target System will be our task for the next several years

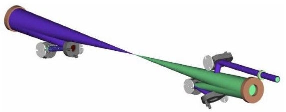
- Prototyping and demonstration tests of the system components will be a multi-year effort

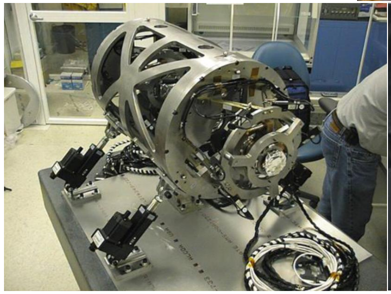
- Engineering of the remote handling system to remove and replace the target assembly once a year is still to be done

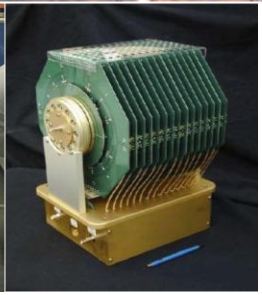


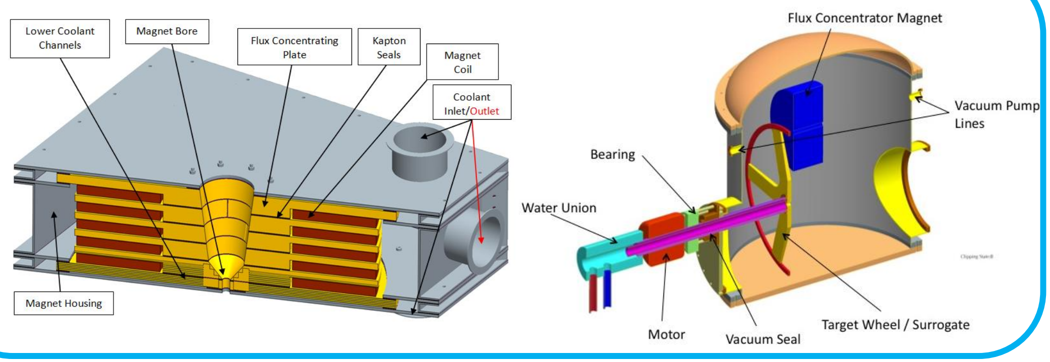
A rich history of contribution – and more to come











- LLNL is always looking for ways that its core engineering competencies can enhance the DOE mission in HEP

- We plan on being a vital part of that mission for the foreseeable future