The *TEAM* Project

Peter Denes[1]
On behalf of the *TEAM* Collaboration

1. Engineering Division, Lawrence Berkeley National Laboratory, 1 Cyclotron Road, Berkeley, CA 94720 USA

pdenes@lbl.gov
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The Transmission Electron Aberration-corrected Microscope (TEAM) project [1] grew out of a number of workshops on Aberration Correction in Electron Microscopy starting in 2000, was proposed to the Office of Science of the US Department of Energy (DOE) in 2003 and will successfully complete in 2009. The project is unique in the history of electron microscopy, combining the efforts of all of the DOE electron beam micro-characterization centers (National Center for Electron Microscopy at the Lawrence Berkeley National Laboratory, Electron Microscopy Center at the Argonne National Laboratory, Shared Research Equipment Program at the Oak Ridge National Laboratory and the Center for Microanalysis of Materials at the Frederick Seitz Materials Research Laboratory) together with two selected manufacturers, FEI and CEOS. The microscope delivered by TEAM aims to enable, among other things, tomography at the atomic scale through simultaneous advances in electron optics (stable column and site, aberration correction, high brightness source), stages and detectors.

The project's primary technical measure of success is a single instrument capable of obtaining 0.5Å spatial resolution in TEM and STEM. Recognizing that TEAM was fundamentally an integration project, the first step was to identify a suitable platform, and what is now known as the FEI Titan [2] microscope was selected. Obtaining 0.5Å in both TEM and STEM required advances beyond the state of the art in aberration correction, and CEOS [3] was selected to develop both an aberration corrector capable of forming an 0.5Å probe, as well as a novel C_S/C_C corrector for TEM.

Achieving the 0.5Å goal required parallel developments in both instrumentation and technique. This was accomplished with a number of separate, specialized instruments deployed throughout the project. Figure 1 shows a timeline together with the five instruments associated with the project:

1. For 0.5Å STEM resolution, a Titan column at ORNL was originally equipped with a standard, monochromated FEG and a hexapole C_S corrector. The hexapole C_S corrector fully corrects 3rd order aberrations and partially corrects 5th order aberrations. Since the residual 5th order aberrations were considered to be a limitation for 0.5Å resolution, an improved probe corrector was developed by CEOS, and prototyped on this instrument. Further, achieving a useable 0.5Å probe required an increase in brightness, and a high-brightness FEG was also prototyped on this machine.
2. The various improved probe correctors, as well as the prototype C_S/C_C corrector were tested on the column which is now at ANL. Although this microscope was predominantly used throughout the project at CEOS, in 2009 it became the world's first C_C-corrected TEM user instrument (Figure 2a) when it was delivered to ANL. The first demonstration of successful Cc corrected TEM imaging is shown in Figure 3.

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3. Development of stages, detectors and software are carried out on a dedicated instrumentation development column at NCEM.
4. The longest-lead item in the project was the C_C corrector. Since a principal goal of the TEAM project was to deliver enhanced electron microscopy capabilities to the DOE Nanoscale Science Research Centers [4] as early as possible, a first instrument, TEAM 0.5 (Figure 2b) – incorporating a high brightness, monochromated gun and improved probe-forming corrector – was planned as an early user facility, to be followed by the final TEAM I instrument.
   The key factory acceptance tests for TEAM 0.5 in 2007 (0.5Å, 0.1 eV) are shown in Figure 4, at a brightness of 3-6x10^9 A/cm^2/sr (tunable for different ΔE). The instrument was delivered to Berkeley in November, 2007 and has been operating as a user facility since October, 2008. (See Figure 5 for examples of early work with high visibility; for additional references of results from TEAM 0.5, see [1]).
5. The final instrument is TEAM I, which incorporates the features of TEAM 0.5, together with the C_C/C_S TEM corrector. The key factory acceptance tests for TEAM I in 2008 (0.5Å, 0.1 eV) are shown in Figure 6, at a brightness of 3-6x10^9 A/cm^2/sr. For one year since then, TEAM I was located at CEOS to incorporate the C_C corrector, and at the end of June 2009, the instrument was accepted at Berkeley.

In addition to these electron optical advancements, a core TEAM objective was to advance other areas: stages, detectors, and software / remote operation. Within the TEAM project, a novel in-column, 5-axis, piezo stage has been developed (Figure 7) as well as a direct detection CMOS Active Pixel Sensor detector (Figure 8). Further, remote microscopy with TEAM, via ESnet [5] has been demonstrated.

TEAM is part of the DOE's Office of Science 20 year outlook for Facilities for the Future of Science [6]

1. http://ncem.lbl.gov/TEAM-project/index.html
2. http://www.fei.com/products/families/titan-family.aspx
3. http://www.ceos-gmbh.de/
4. http://www.sc.doe.gov/bes/BESfacilities.htm#NSRC
5. http://www.es.net/
6. The TEAM project is supported by the Office of Basic Energy Sciences, Office of Science, US Department of Energy.

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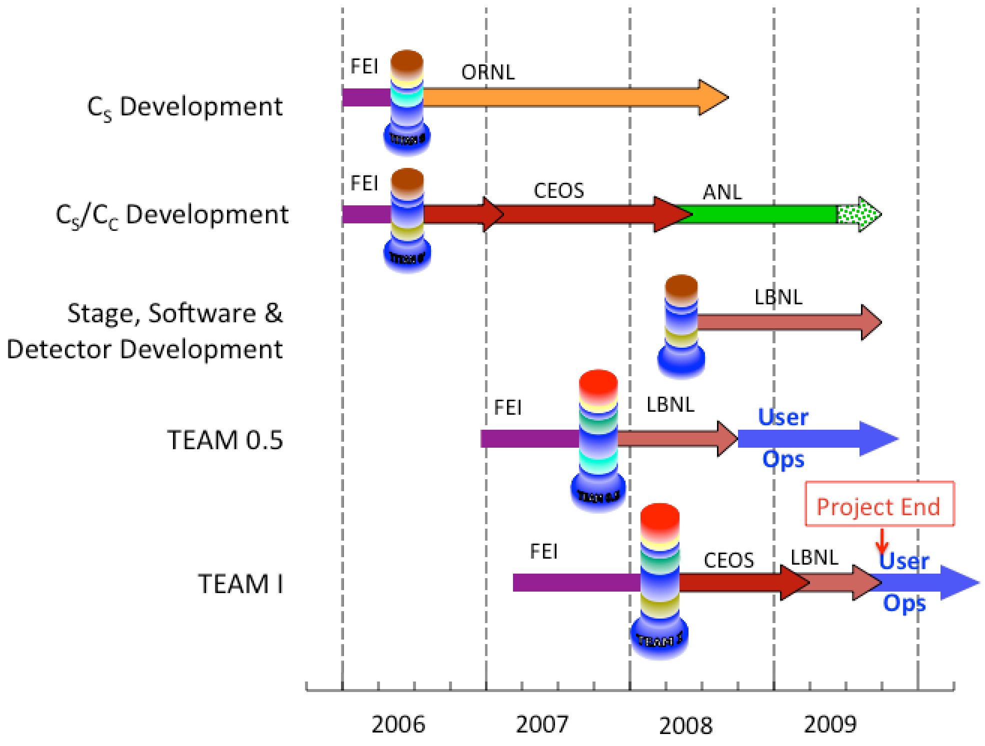

Figure 1. TEAM project timeline, together with development and user facility microscopes.

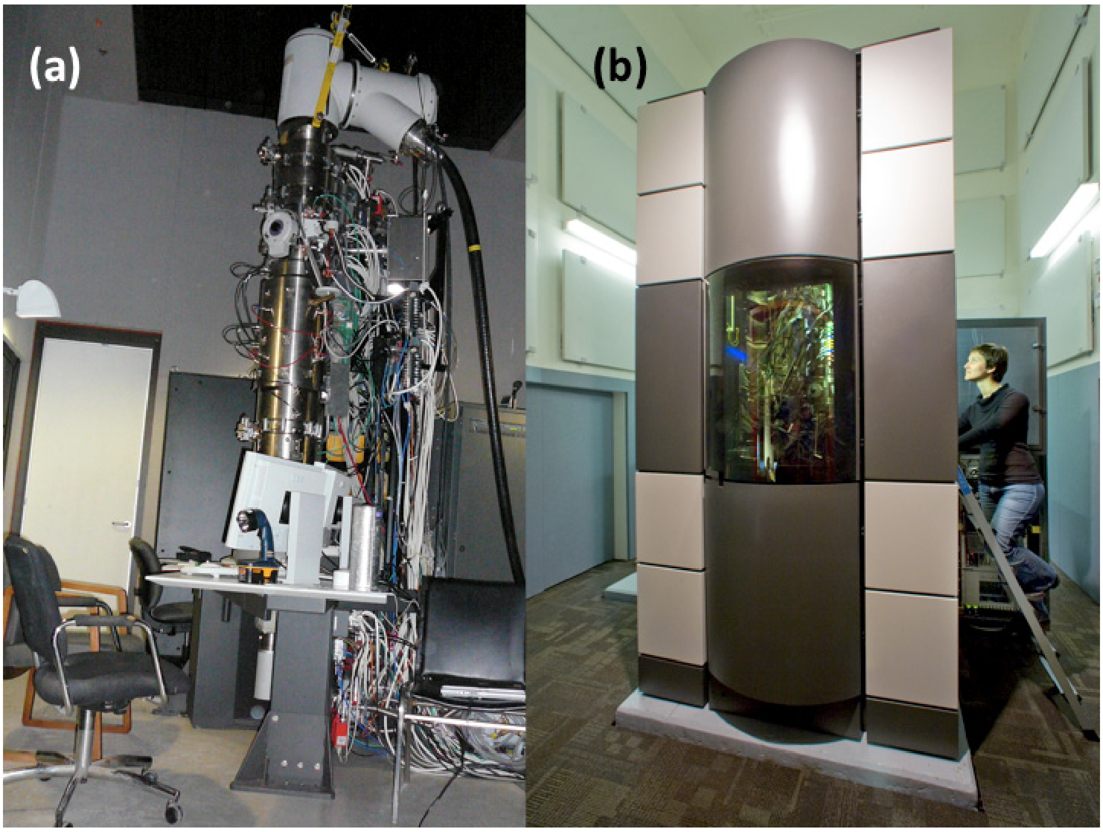

Figure 2. TEAM instruments: (a) C_C-corrected column in the SAMM lab at Argonne, (b) TEAM 0.5 at NCEM in Berkeley.

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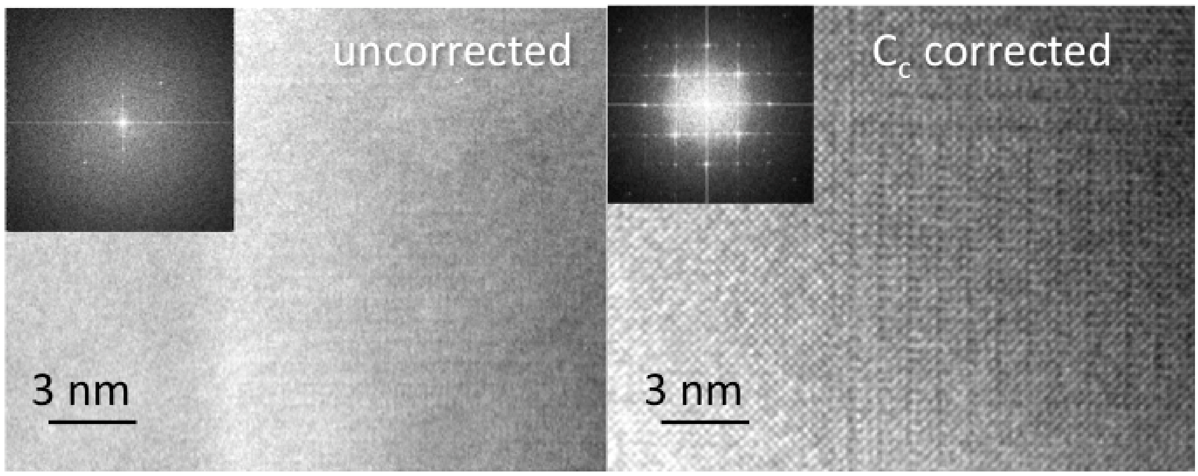

Figure 3. First C_C-corrected TEM images on LaCoO3with an energy window ΔE = 70eV

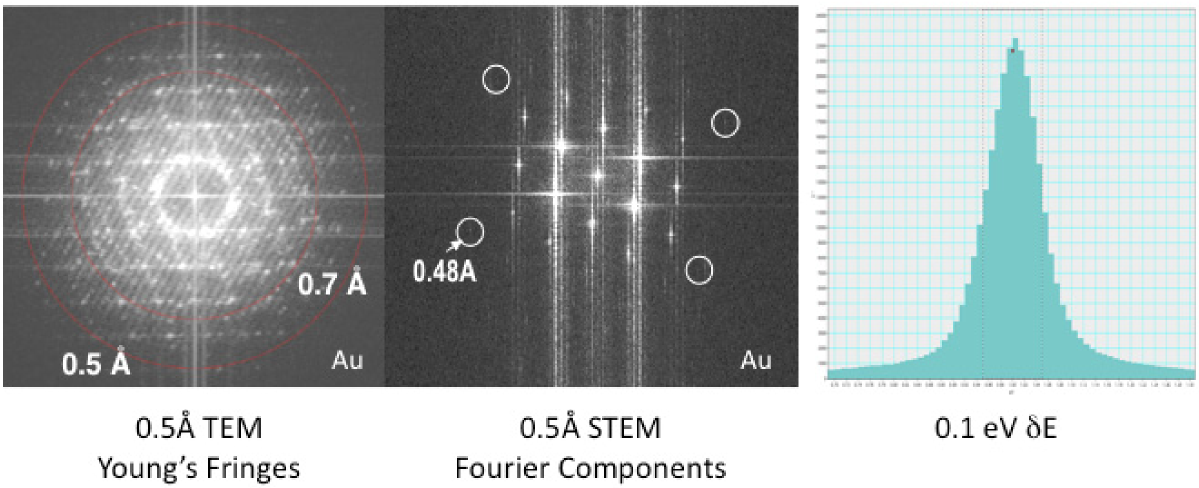

Figure 4. TEAM 0.5 Factory acceptance tests in August, 2007, demonstrating Young's fringes and Fourier components to 0.5Å, together with 0.1 eV energy resolution

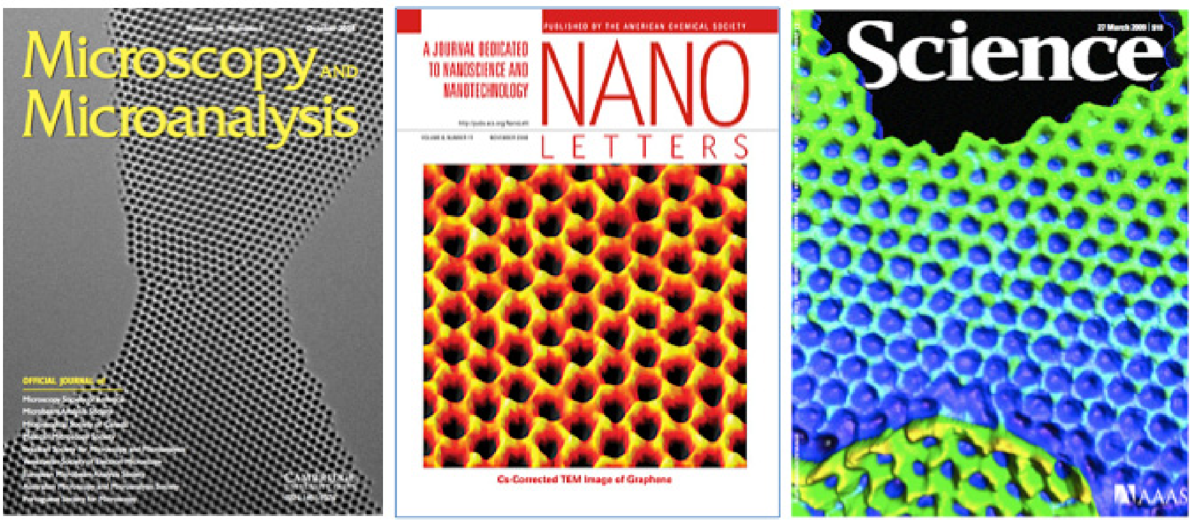

Figure 5. Selected initial TEAM 0.5 publications.

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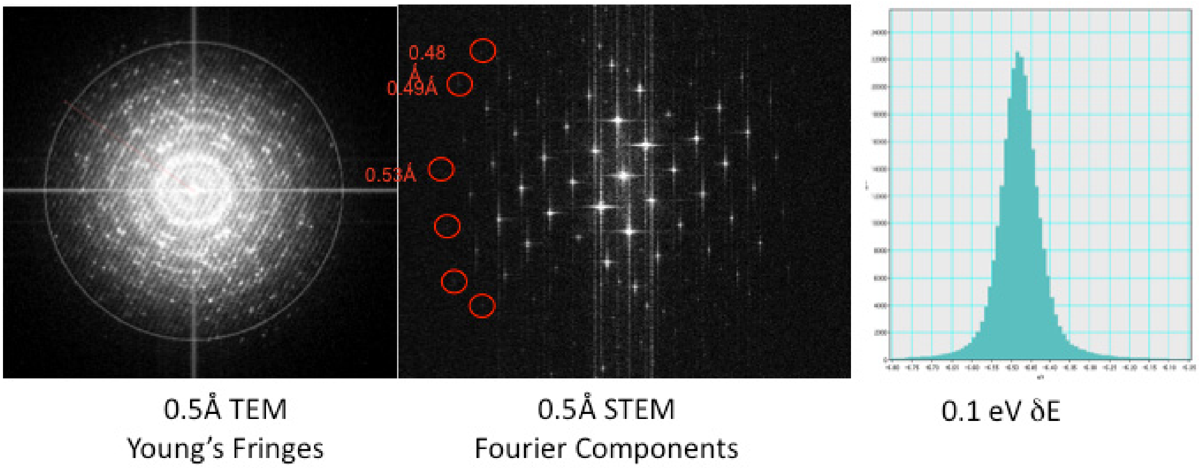

Figure 6. TEAM I Factory acceptance tests in May, 2008, demonstrating Young's fringes and Fourier components to 0.5Å, together with 0.1 eV energy resolution

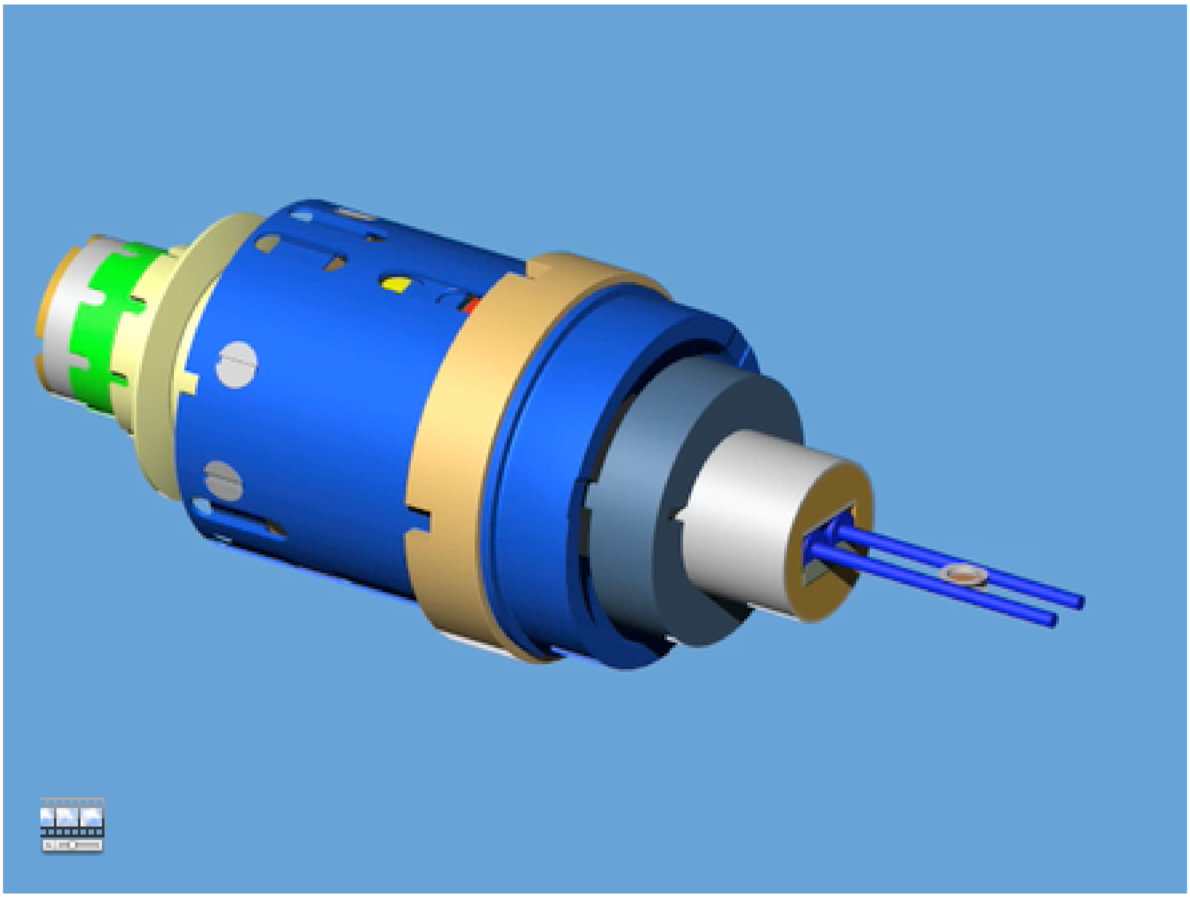

Figure 7. TEAM stage.

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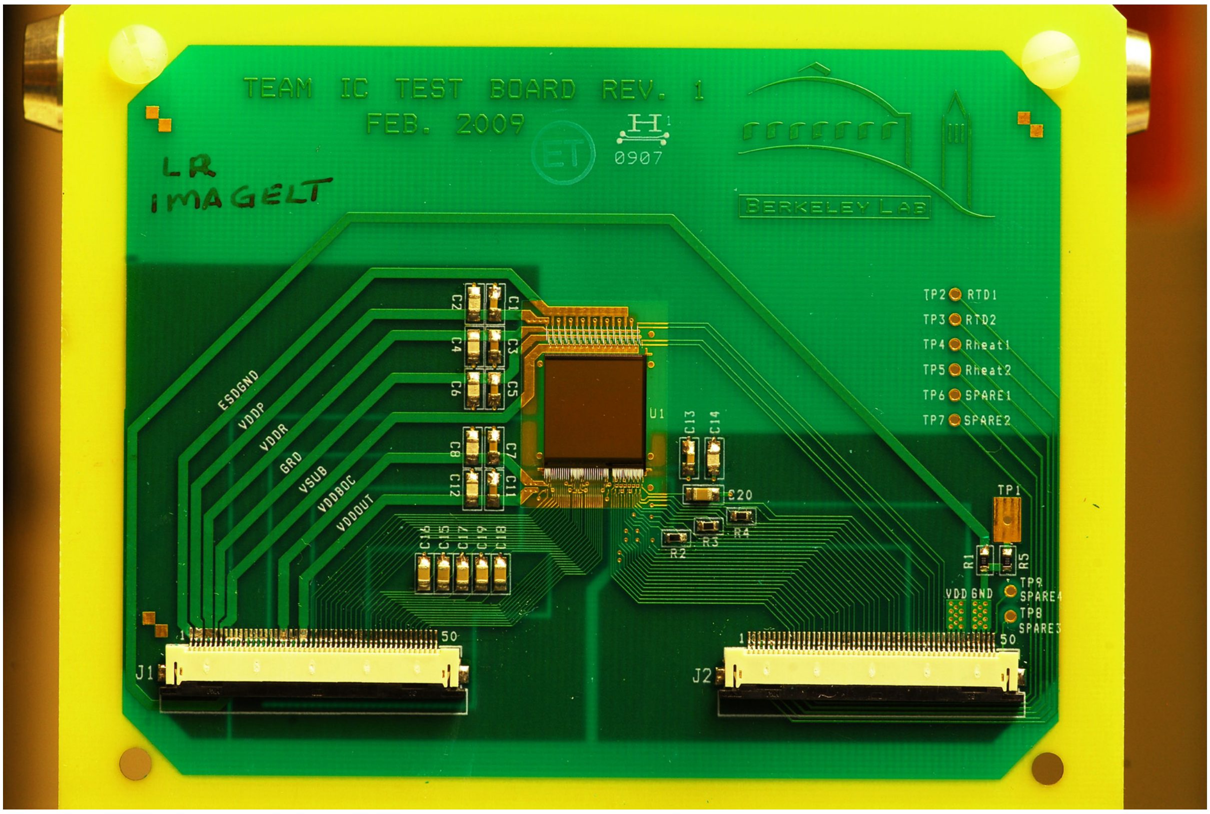

Figure 8. TEAM detector mounted on its circuit board. This initial 1k 400 fps detector will be updated to a 2k 400 fps detector for TEAM I.

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