Laboratory Infrastructure for Instrumentation Development: A whirlwind tour

D. MacFarlane

April 18, 2013

With contributions from M. Demarteau (Argonne), G. Gilchriese (LBNL), D.Lissauer (BNL), E. Ramberg (Fermilab), & G. Haller (SLAC); apologies to LANL, LLNL, PNNL

U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Facilities at Argonne

- Atomic Layer Deposition Reactor
  - » MCP functionalization for LAPPD
- Plasma enhanced Atomic Layer Deposition System
- Large Assembly Facilities
- Photocathode Growth Facility

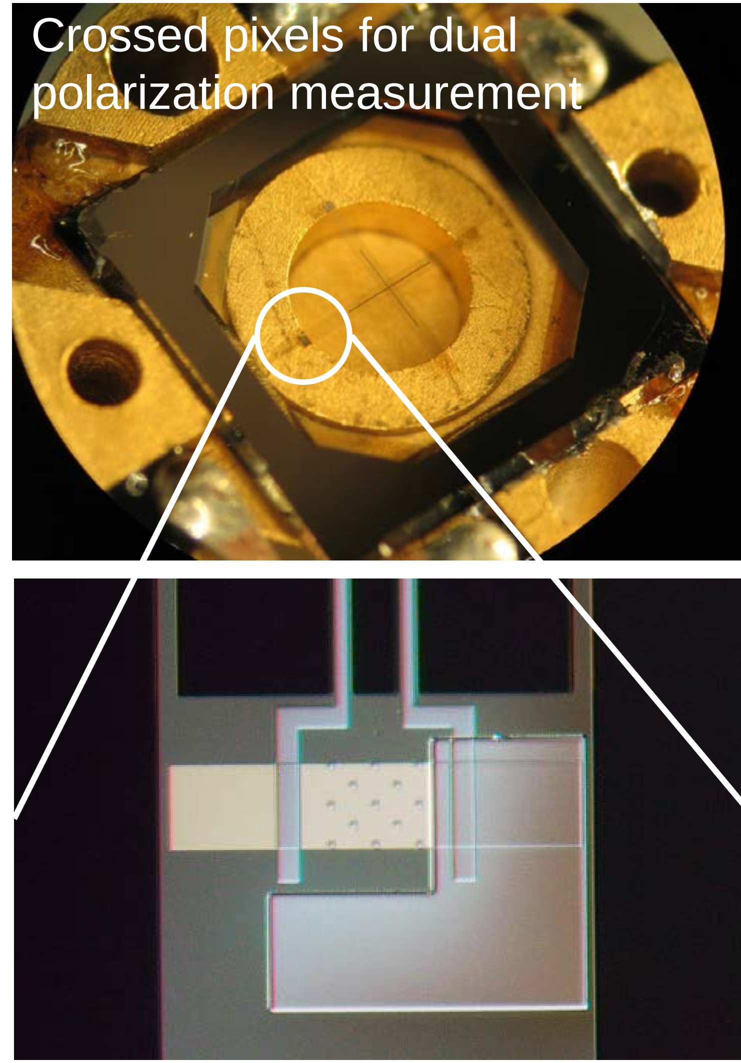

Beneq ALD reactor


Photocathode growth


Large construction facility

Superconducting Thin Film Deposition

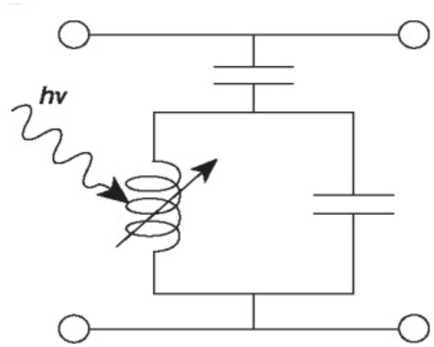
Materials Science Deposition System for superconducting detectors



- Using thin film deposition techniques, develop Transition Edge Sensors from scratch
- Engineer superconducting structures to shape the R-V relation
  - » 8 μm × 1186 μm PdAu dipole on 200 μm×2100 μm SiN
- Magnetic materials to regulate the thermal bandwidth

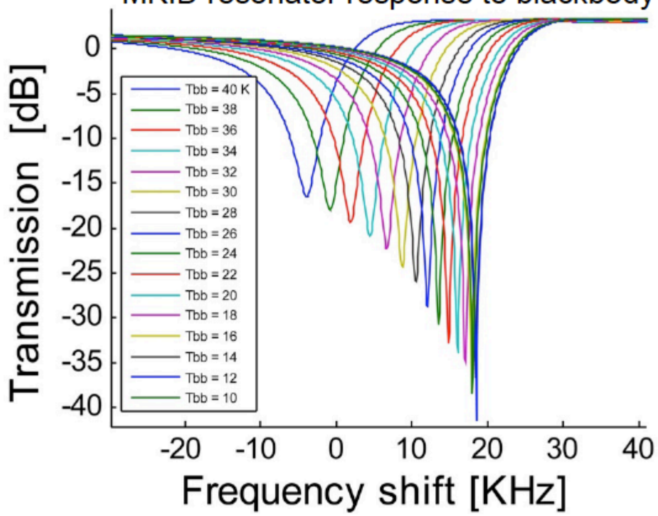
Microwave Kinetic Inductance Detector Fabrication

- Next generation more sensitive CMB detectors: MKIDs
- Superconducting resonator-based photon detectors
  - Sub-millimeter to X-ray detection
  - Each pixel at different resonant frequency
  - Potentially simple multiplexing
- Measure incident power (pW) by change in resonator frequency and quality factor (Q)



MKID - Microwave Kinetic Inductance Detector

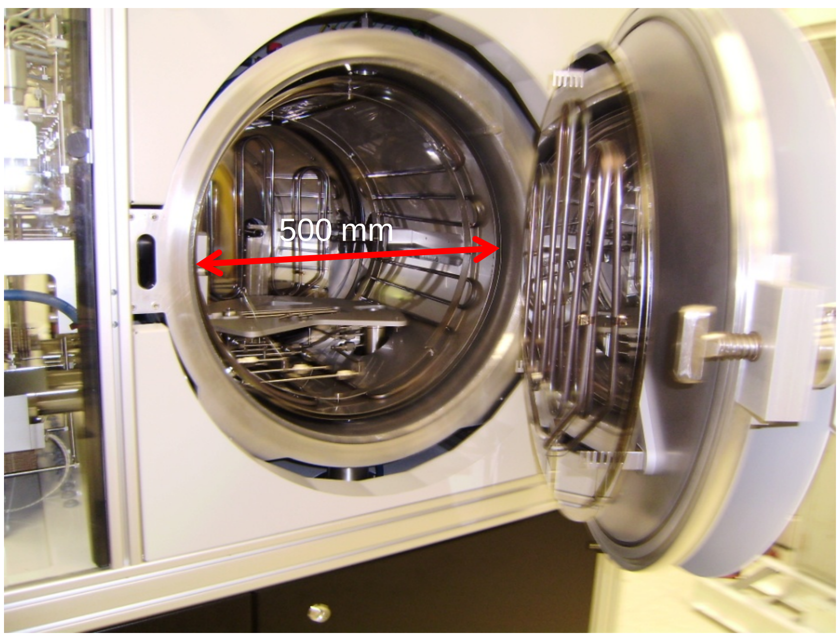
MKID resonator response to blackbody radiation

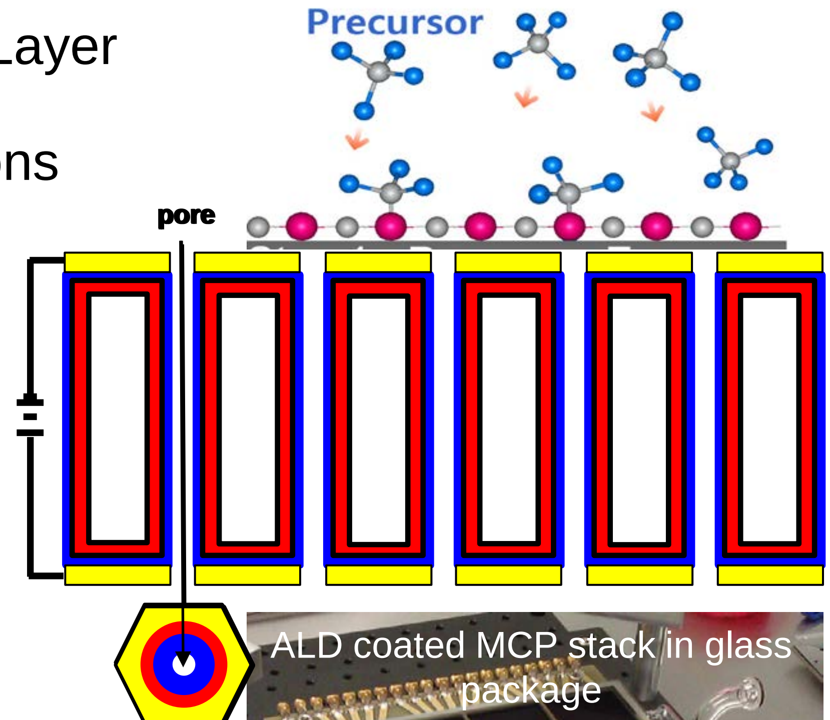


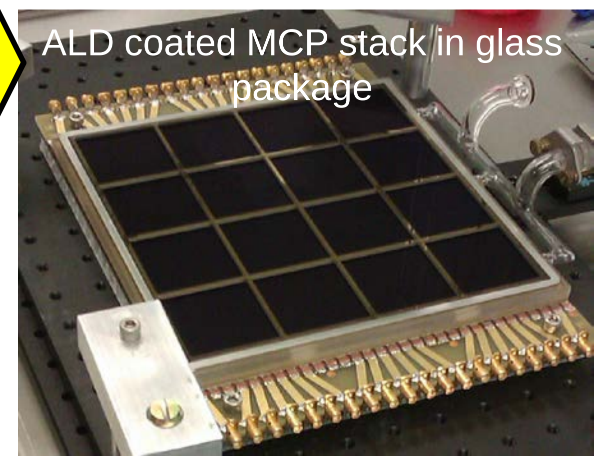
Argonne NATIONAL LABORATORY

Atomic Layer Deposition Facilities

- Many reactors available for Atomic Layer Deposition
- Alternating surface/molecule reactions
  - » MOCVD: partly gas phase rxns
  - » PVD preformed pieces + surface reassembly
- Deposition of single atomic layers

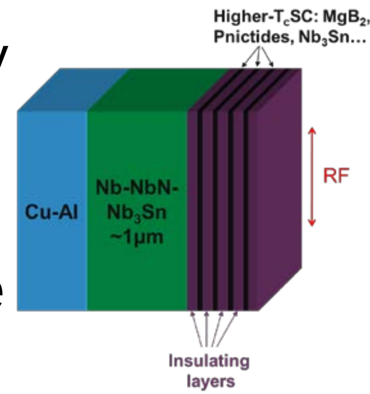


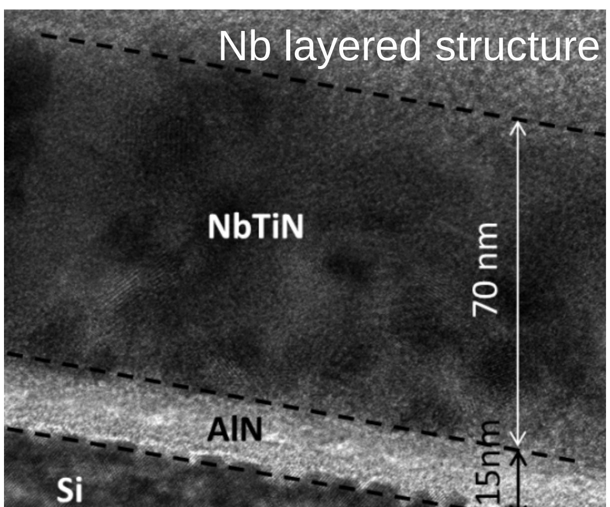


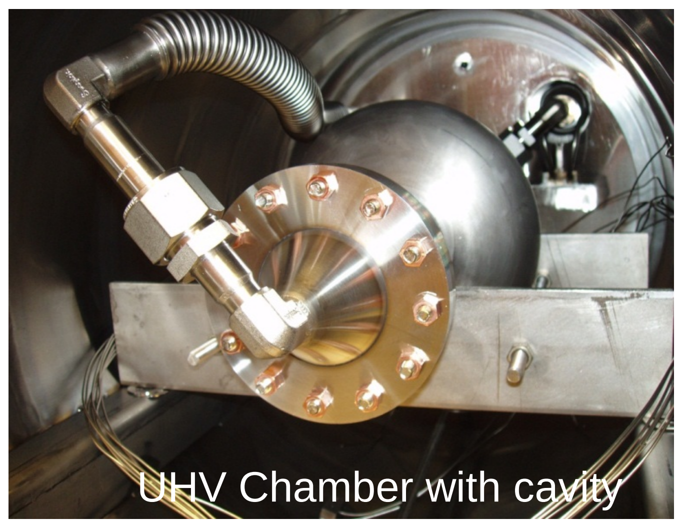


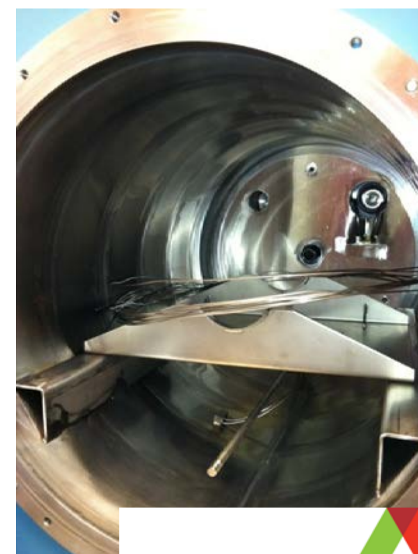
Superconductor Cavities through ALD

- Able to synthesize better superconductors than Niobium:
  - NbTiN with new ALD chemistry is very pure (<0.05%)
  - NbTiN Tc= 14K for 60 nm thick film (bulk=16K)
- Multilayer structure: Aluminum Nitride (AlN) + NbTiN works perfectly: (15 nm AlN/ 70 nm NbTiN) x n





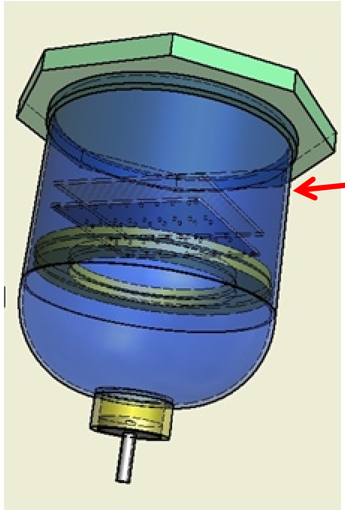


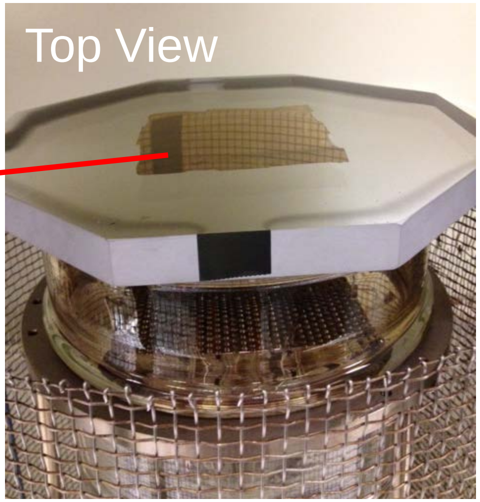


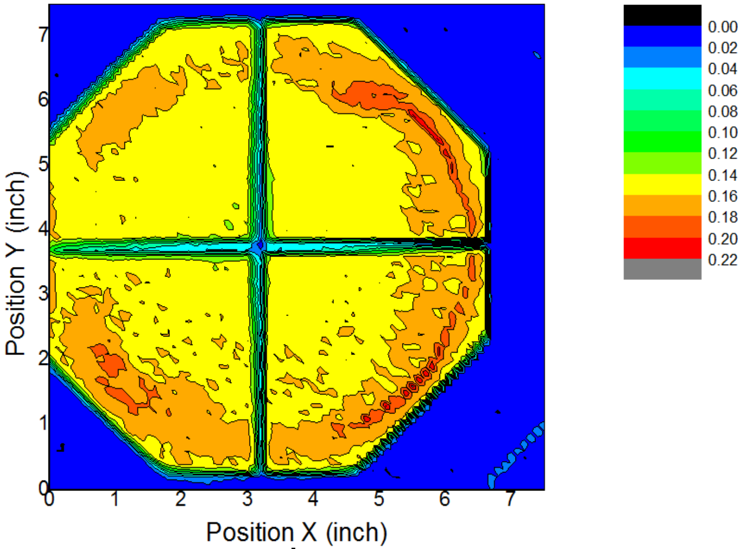
Argonne NATIONAL LABORATORY

Photocathode Growth Facility

- Facilities for small and large area bi-alkali photocathodes







Evaporation process

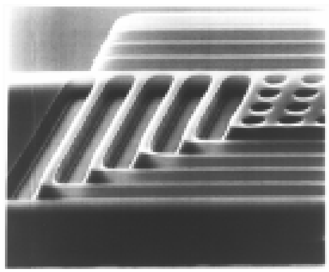
- In the process of developing facility for production fabrication of large-area, planar, cost-effective photodetectors

Facilities at LBNL

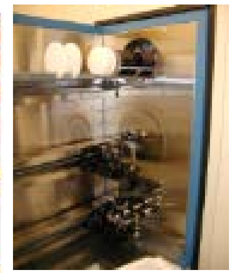
- Physics Division operates or established three unique facilities:
  - Micro Systems Lab (MSL) – established and operates
  - LBNL IC design group – established
  - LBNL Composites Facility – established
- A large number of other facilities are operated by the LBNL Engineering Division, other divisions, or UC Berkeley
- Physics Division also maintains critical in-house capabilities (e.g. silicon detector assembly, clean rooms, etc.)
- Equipment in all facilities is important and often valuable
- But the expertise of the personnel is invaluable- takes years of projects and R&D to build up capability

Micro-Systems Lab (MSL)

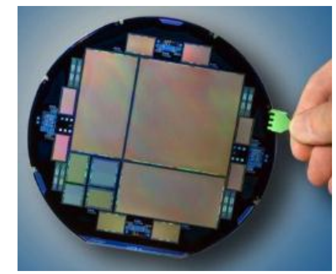
- Core team: 3 expert engineers and 5 expert technicians
- Design + 700 ft^2 of class 10 area with full line processing-lithography, thermal processing, thin films, CVD, fry etching, etc.

Lithography

Thermal processing

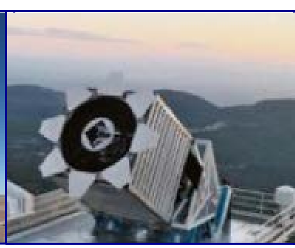


4k x 4k BigBOSS demo

- Plus packaging development, testing & characterization in separate spaces (not shown)

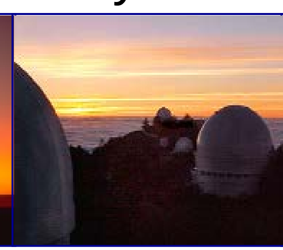
Powered by MSL CCDs:

CTIO/Blanco 4m
DEcam, COSMOS



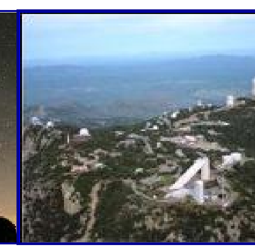
SDSS 2.5m
BOSS

Keck 10m
LRIS



Mt Hamilton
Lick- Echelle

Palomar 200”
SWIFT



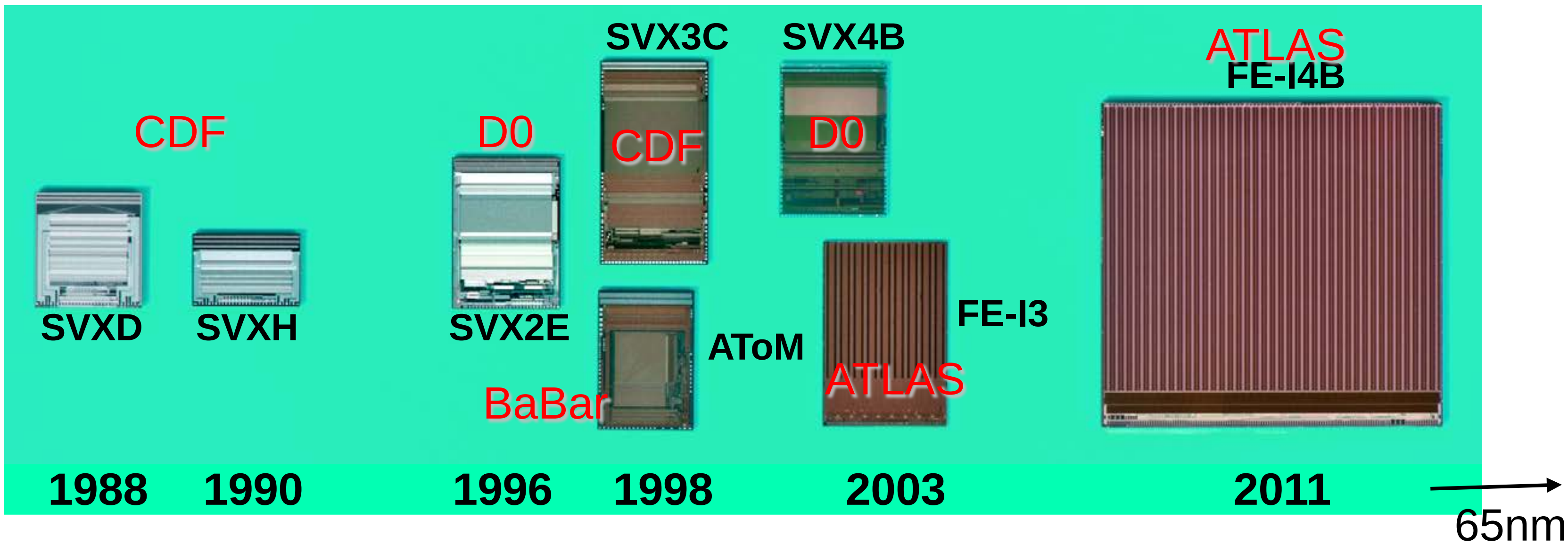
Kitt/ Mayall 4m
Mars, RC, KOSMOS

Mt. Hopkins 6.5m

IC Design Group

Core team: 5 IC design engineers

Example of Integrated Circuits for collider vertex detectors



Science enabled

Top quark	***Precision Standard Model & CKM Triangle***	***Higgs***	***Future Discoveries***

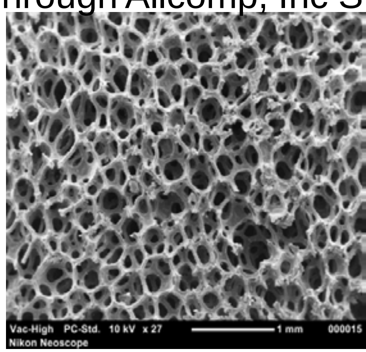
Composites Facility: R&D developments 2008-2012

Core team: 3 expert engineers and 3 expert technicians

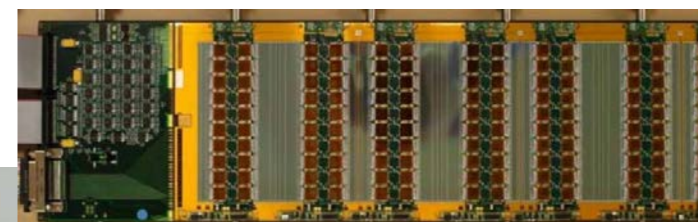
ATLAS pixels, 2006

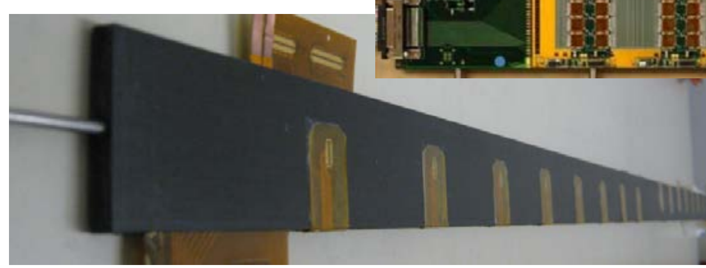
STAR and Phenix Upgrades, 2012

Through Allcomp, Inc SBIR



Thermally Conductive Carbon foam





Pixel and strip integrated structures, co-curin

Other available Facilities at LBNL

- Most LBNL and UC Berkeley facilities are available for use as needed, but are too numerous for a complete listing
- Some of the facilities used in Physics Division activities in recent years include:
  - 88” Cyclotron fro proton and ions irradiation
  - Advanced Light Source electron storage ring
  - Eng. Div. mechanical design, fabrication and metrology
  - Eng. Div. electronic design and assembly
  - Eng. Div. class 100 assembly clean room
  - Molecular Foundry nanofabrication facility
  - Earth Sciences Div. ICP mass spectrometer
  - Radiation Protection group and Low Background Counting facilities
  - Eng. Div. Molecular Beam Epitaxy facility
  - National Center for Electron Microscopy
  - National Energy Research Scientific Computing Center (NERSC)
  - UC Berkeley Nanolab

Physics Division in-House Capabilities

- Beyond the LBNL Engineering Division, the Physics Division maintains local capabilities used heavily for HEP detector work
  - 2 automatic wire bonders and associated preparation and QC equipment (only such facility at LBNL)
  - 3 coordinate measurement machines
  - Class 1000 ESD safe assembly clean room
  - Small machine shop
  - Electronic assembly and test space and equipment
  - Support for various R&D lab spaces, gasses, vents, vacuum, etc.
  - Electron microscope

Facilities at Brookhaven

- Design and fabrication of noble element detectors – gas- and liquid-based, for photons, charged particles and neutrons.
- Semiconductor detectors for photons, charged particles- silicon, diamond
- Advanced Mmicroelectronics for a wide range of sensor applications: low-noise ASIC R&D and ASIC design with CADENCE software as major tool
- Multiple Clean Rooms
- Printed Circuit Board Design, Fabrication and Assembly, including component assembly, ball grid arrays and X-ray diagnostics
- Wire Bonding and Bump Bonding for high channel count systems
- Photo-Cathode Research
- Gamma/Neutron Sources for Radiation Effects Studies

Summary Descriptions of BNL Infrastructure

- Noble Element Detectors
  - Unique expertise in detector simulation and design for fiducial volumes of one kton and more
  - Development of new gas detector concepts, using sealed radioactive sources, energized X-ray sources, and synchrotron beam lines
- Semiconductor Detectors
  - Fully equipped semiconductor detector development and processing laboratory, supporting detector and JFET technology in 4” and 6” high resistivity silicon wafers
  - New capabilities for design and fabrication of diamond detectors for synchrotron beam position and intensity measurement

Summary Descriptions of BNL Infrastructure

- Advanced Microelectronics
  - Expertise in low-noise ASIC system level design, transistor klevel design, mask layout, fabrication and testing
  - Cold electronics designs for MicroBooNE & LBNE (~ 90° K)
- Clean Rooms
  - 550 ft^2 class 100 clean room dedicated solely to silicon processing, primarily 4” and 6” high resistivity wafers
  - Equipped with oxidation, lithography, developing, metallization, inspection and measuring systems
  - 350 ft^2 class 1,000 clean room for fabrication, inspection and assembly of gas-based detectors and systems requiring particulate-free environment

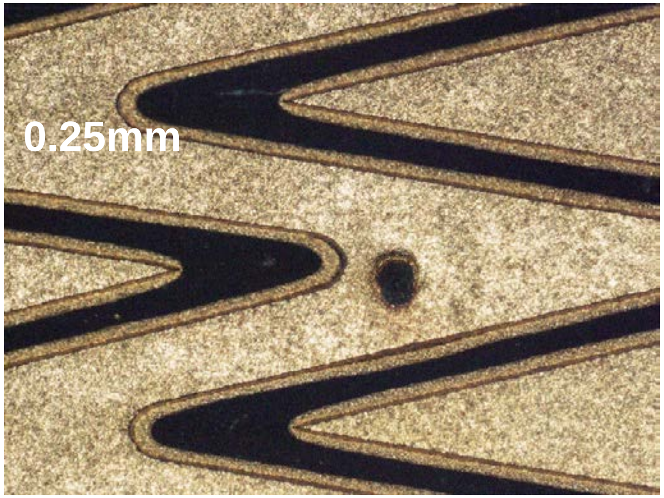
Summary Descriptions of BNL Infrastructure

- Printed Circuit Board Design, Fabrication and Assembly
  - » Personnel, software and equipment supporting production of high-precision multi-layer circuit boards
  - » Mentor Graphics software and laser photo-plotting
  - » Fabrication capabilities include multilayer boards (up to 12), rigid-flex boards, optical inspection of individual layers, computer-controlled drilling and routing
- Wire Bonding and Bump Bonding
  - » Manual and automatic machines for wire bonding pixels or strips on silicon/diamond detectors to respective inputs on circuit boards containing ASICs
  - » New techniques being developed for bump bonding of small-pixel sensors to ASICs

Summary Descriptions of BNL Infrastructure

- Photo-Cathode Research
  - » Electron transport characteristic measurements LAr, using photoemission from gold photocathode immersed in Lar excited by fast laser pulse
  - » Broader program of photo-cathode studies using antimony, multi-alkali photocathode coatings for photo-injectors that also contributes to better understanding of properties and photo-efficency of conventional photocathodes.
- Gamma/Neutron Sources
  - » Radiation effects facility containing 5kCi 60Co source, 3mCi thermal neutron source, and 14 MeV energized neutron source.

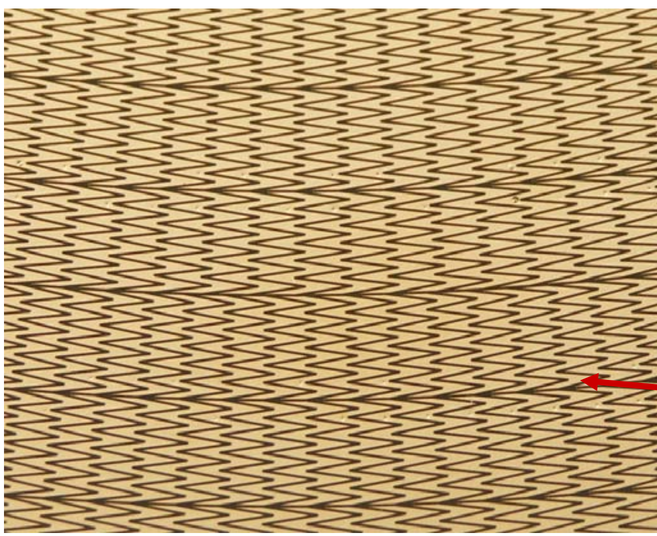
Example of Anode Pad /ASIC Board for Gas TPC



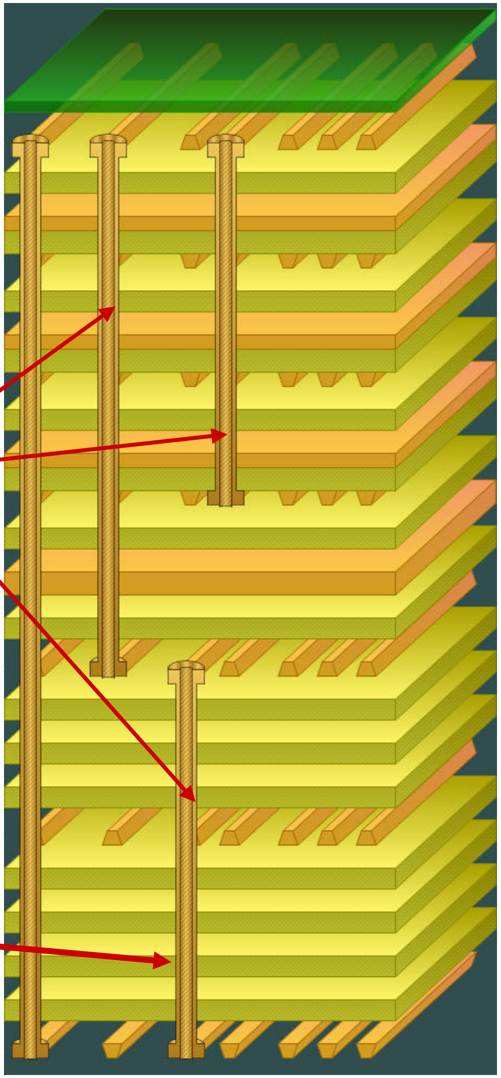
Close-up of
zig-zag pads

0.1mm

Blind Vias

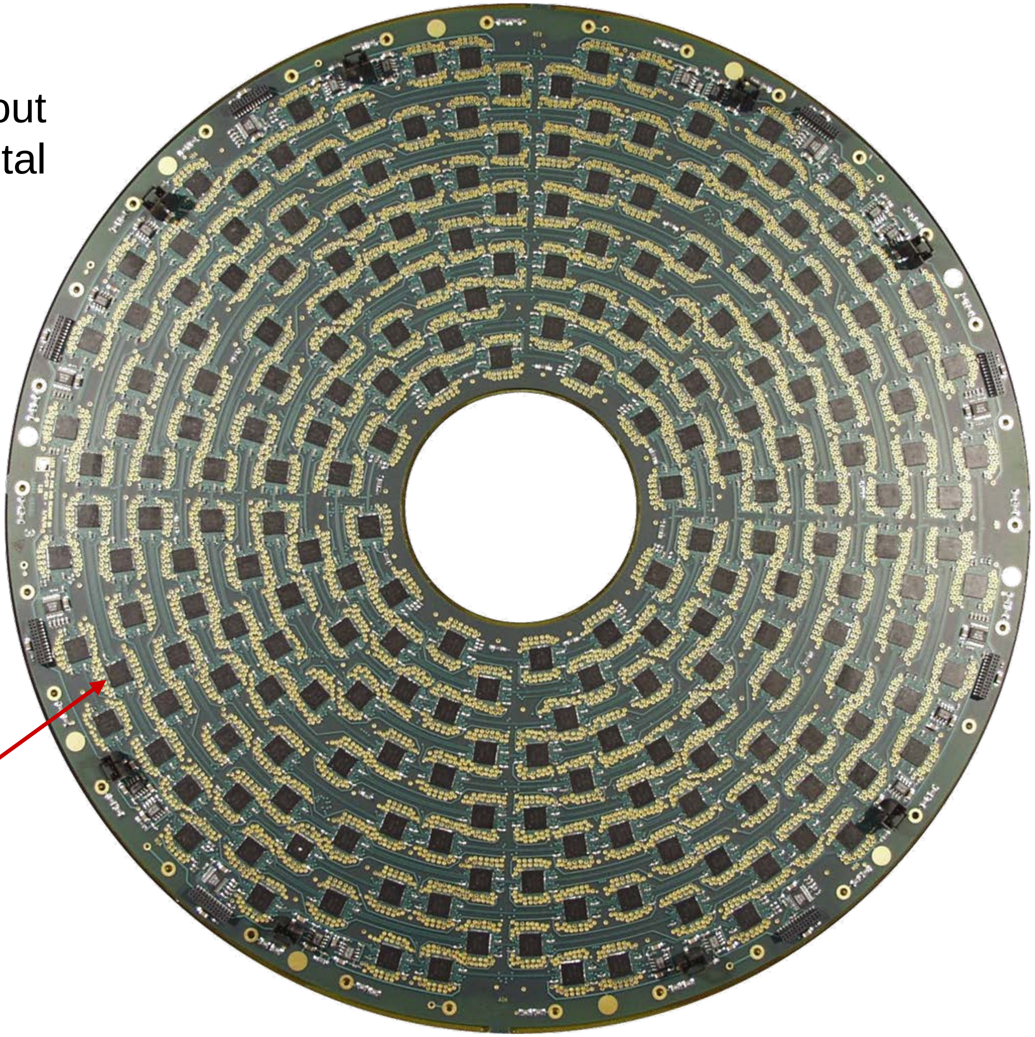


Zig-zag
pads



Example of Anode Pad /ASIC Board for Gas TPC

Rear of board:about 8000 channels total



32-channel ASIC

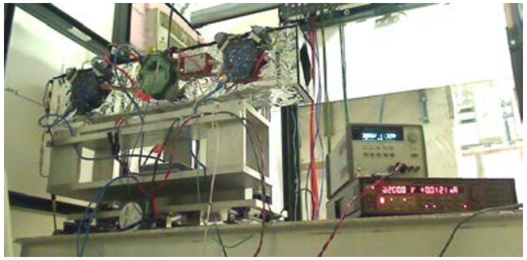
35 cm

Facilities at Fermilab

- Wide array of research capabilities:
  - Test beam facility
  - Silicon Detector facility
  - Liquid argon test facility
  - NICADD scintillator extrusion facility
  - CCD characterization facility
  - Thin-Film Facility
  - High power laser laboratory
- Experienced, well established engineering groups, such as
  - ASIC Development
  - Cryogenics Engineering
  - Data Acquisition

Scintillator extrusion at Lab 5

Clean rooms and metrology at SiDet



Pixel detector at test beam

Fermilab Silicon Detector Facility

CCD Testing Infrastructure

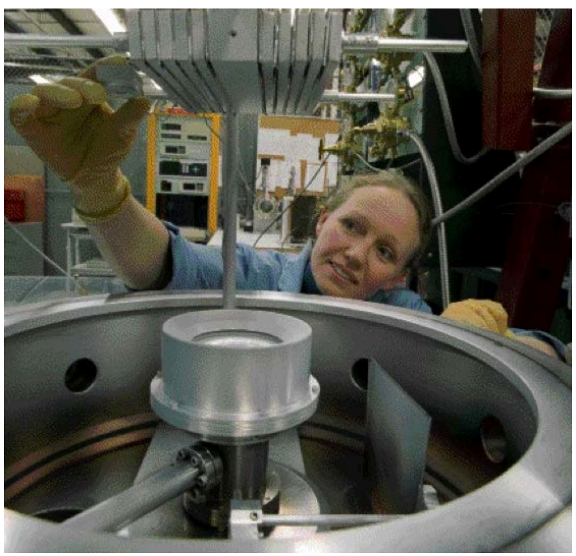
Wire bonding capability

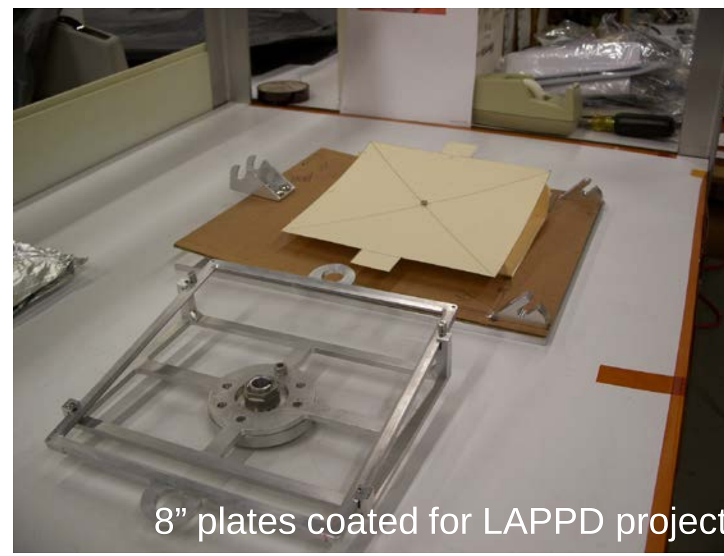
5000 ft^2 of class 10,000 clean rooms

Metrology and probe stations

Vacuum Deposition and Thin Film Coatings

- Facility in Lab 7 Run by Eileen Hahn
- High demand from outside Fermilab
- Vacuum deposited thin films of precise thickness from sputtering or evaporation.
- Film thickness as small as 10 Å to 2 micron or thicker.
- Other capabilities include fiber polishing and splicing, plasma etch cleaning and vacuum baking and annealing

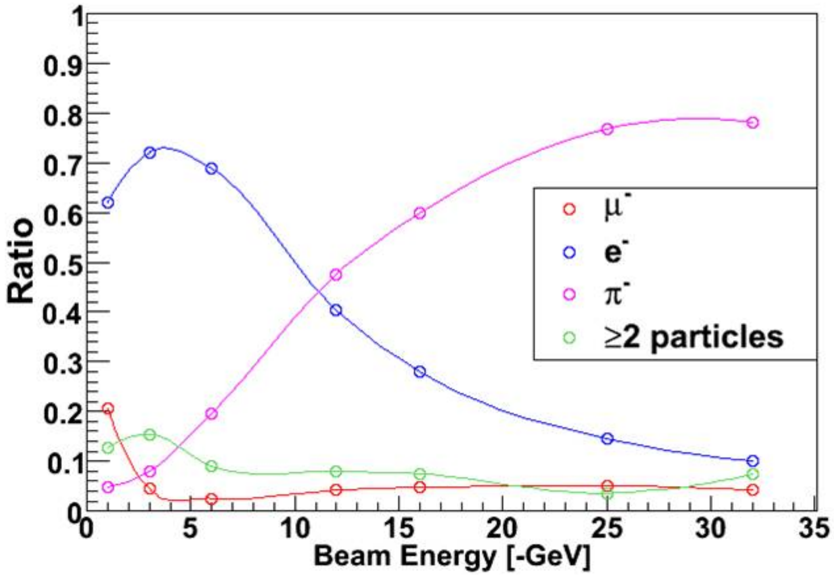




8” plates coated for LAPPD project

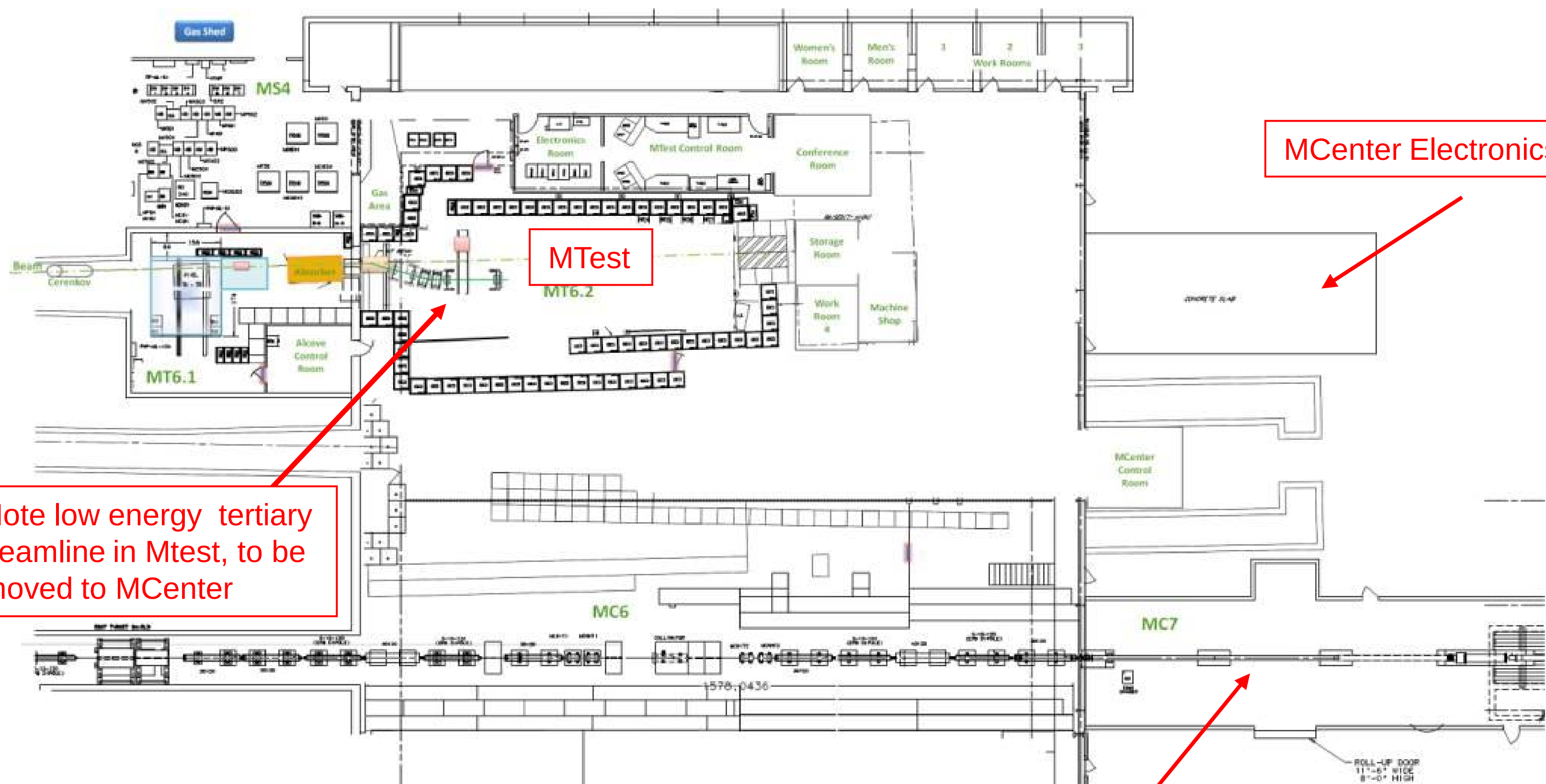
Fermilab MTest Test Beam Facility

- User amenities include:
  - 3 motion tables
  - Tagged cable plant for signals and HV
  - Gas delivery infrastructure
- Beam instrumentation including:
  - Pixel detector tracking,
  - Wire chamber tracking,
  - Time-of-flight,
  - Calorimetry
  - Differential Cerenkov



- Tunable secondary beams, with beam composition and energy spread (1-3%) a function of energy.
- 120 GeV proton beam has 7 mm spatial spread, 100 microrad divergence, with rates tunable from 100 Hz to 100,000 Hz

2nd Test Beam - MCenter - coming online this Summer



MCenter Electronics Room

MTest

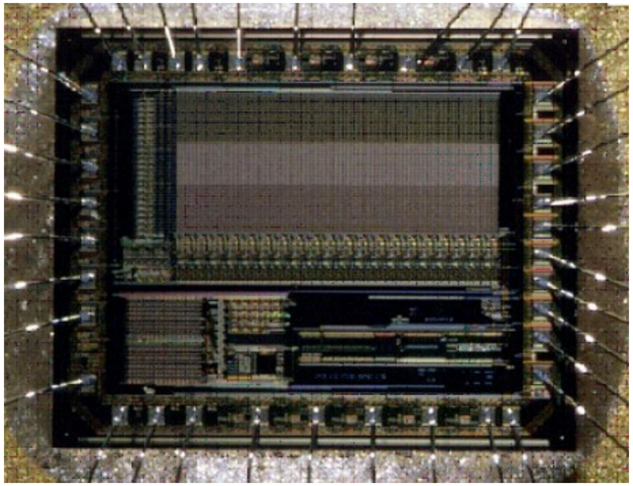
Note low energy tertiary beamline in Mtest, to be moved to MCenter

New MCenter User Test Beam Facility

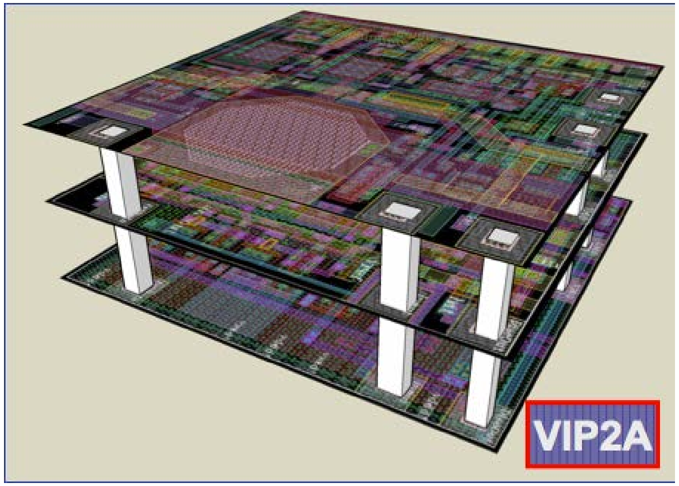
Fermilab

3-Dimensional ASIC Design Program

- Moving information to detector edges will eventually become untenable
  - Need to explore option of transmitting information vertically
- Fermilab has led the formation of a large international consortium (http://3dic.fnal.gov) addressing this technology
- Tools and techniques have been adopted by the major silicon fabrication brokers: MOSIS, CMP and CMC



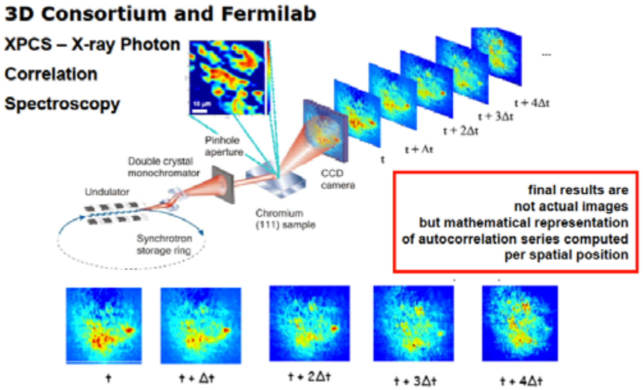
Conventional Monolithic Active Pixel Sensor

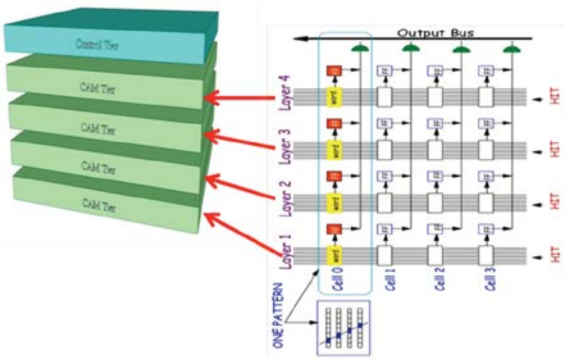


3 tier 3D stack for FNAL ILC vertex chip, fabricated by MIT-LL

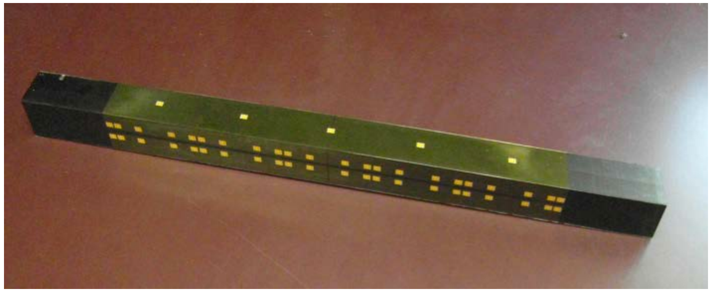
Current Activities in 3D ASICs

- 3D with Tezzaron
  - » VICTR track finder for CMS
  - » VIPIC for LC
  - » VIP for time correlated X-ray detection
- Silicon On Insulator
  - » MAMBO (OKI/KEK) for X-rays
- VICTR II data flow for CMS track trigger
- VIPRAM – 3D associative memory
- CMS Phase II pixel chip
- Mechanical Design
  - » Track trigger module and support
  - » LC supports and design
  - » Power delivery





VIPRAM 3D CAM Concept for triggering



CMS track trigger module box beam support for carbon fiber EMI testing

The Liquid Argon Program

- Low-cost, low background and highly efficient liquid argon TPC are critical for neutrino and dark matter physics
- Fermilab expanding on existing techniques and test beam efforts (ArgoNEUT)
  - R&D toward implementing truly large detectors (20-30 kton) with industrial techniques

ArgoNeut TPC field cage and installation in NUMI underground lab. Will be moved to MCenter.

Liquid Argon materials and electronics test stands

Distillation Column for LAr Purification

- CryoEngineering group has collaborated with Princeton to create a distillation apparatus to supply the dark matter community with low-39Ar obtained from gas wells
  - » More than two orders of magnitude improvement in background levels

A High Power Laser Lab

- Developed in an empty beamline (MEast) to support space-time and dark matter axion research
- Contains a 2 watt laser with cavity finesse of 1000, and thus 2 kW of stored power in a baseline of 40 meters
- Developed PZT controlled cavity mirrors instead of typical spring suspension, to reduce lower frequency (<1 kHz) noise

- Applications for control of high intensity optical beams:
  - Optical beam dump searches for axions, hidden-sector photons
  - Precision interferometric position measurements (Holometer)
  - Precision interferometric angular motion measurements (5^{th} force searches)

Access to Fermilab facilities

- Fermilab web site has useful links to detector organization and facilities, as well as links to the EDIT school and detector retreat: http://detectors.fnal.gov
- Useful Emails:
  - » FNAL detector point-of-contact: ramberg@fnal.gov
  - » Detector Advisory Committee: detector-advisory@fnal.gov
  - » Detector R&D mail list (94 members): detectors@fnal.gov
  - » Test beam users (116 members): test_beam@fnal.gov

Facilities at SLAC

- Building 33 detector assembly clean room
  - » Main space is 3500 ft^2 with an additional 850 ft^2 of high bay area
  - » Used for GLAST originally, now being modified for LSST camera
- Silicon Detector Laboratory in Building 84
  - » 500 ft^2 space for assembly & testing of semiconductor devices
  - » Finetech Lambda flip-chip wire bonding machine with 0.5 micron alignment precision
- Electronics and DAQ test lab

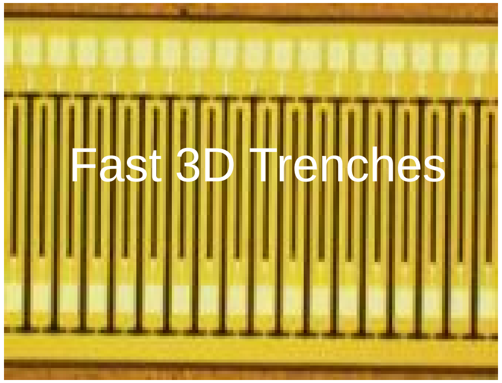
SLAC Building 33
Detector Assembly clean room

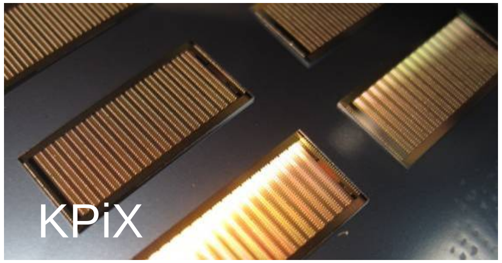
SLAC Building 84
Silicon Detector Laboratory

SLAC NATIONAL ACCELERATOR LABORATORY

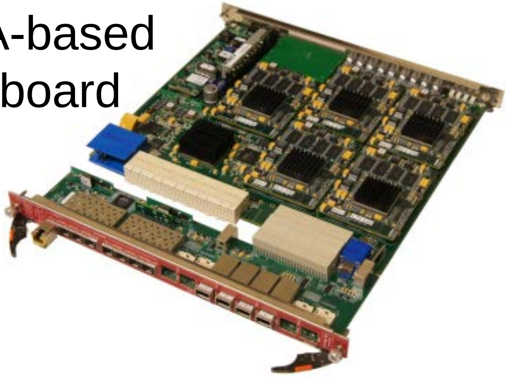
Core engineering capability

- Sensor and integrated electronics development R&D
  - Sensors for timing, energy, spatial resolution (fabricated at Stanford Nanofabrication Facility)
  - Ambitious plans for new sensors pushing silicon technology
  - System-on-a-chip designs, customs ASICs
- Detector systems R&D
  - High density, low mass, low power front-end systems for calorimetry and tracking
  - In detector high-speed signal transmission
  - Low-radioactivity readout electronics
  - Low-temperature electronics
- DAQ and computing development R&D
  - High-performance next generation DAQ systems
  - MDI studies, {detector simulation toolkit, PFA studies} and related tracking & calorimetry



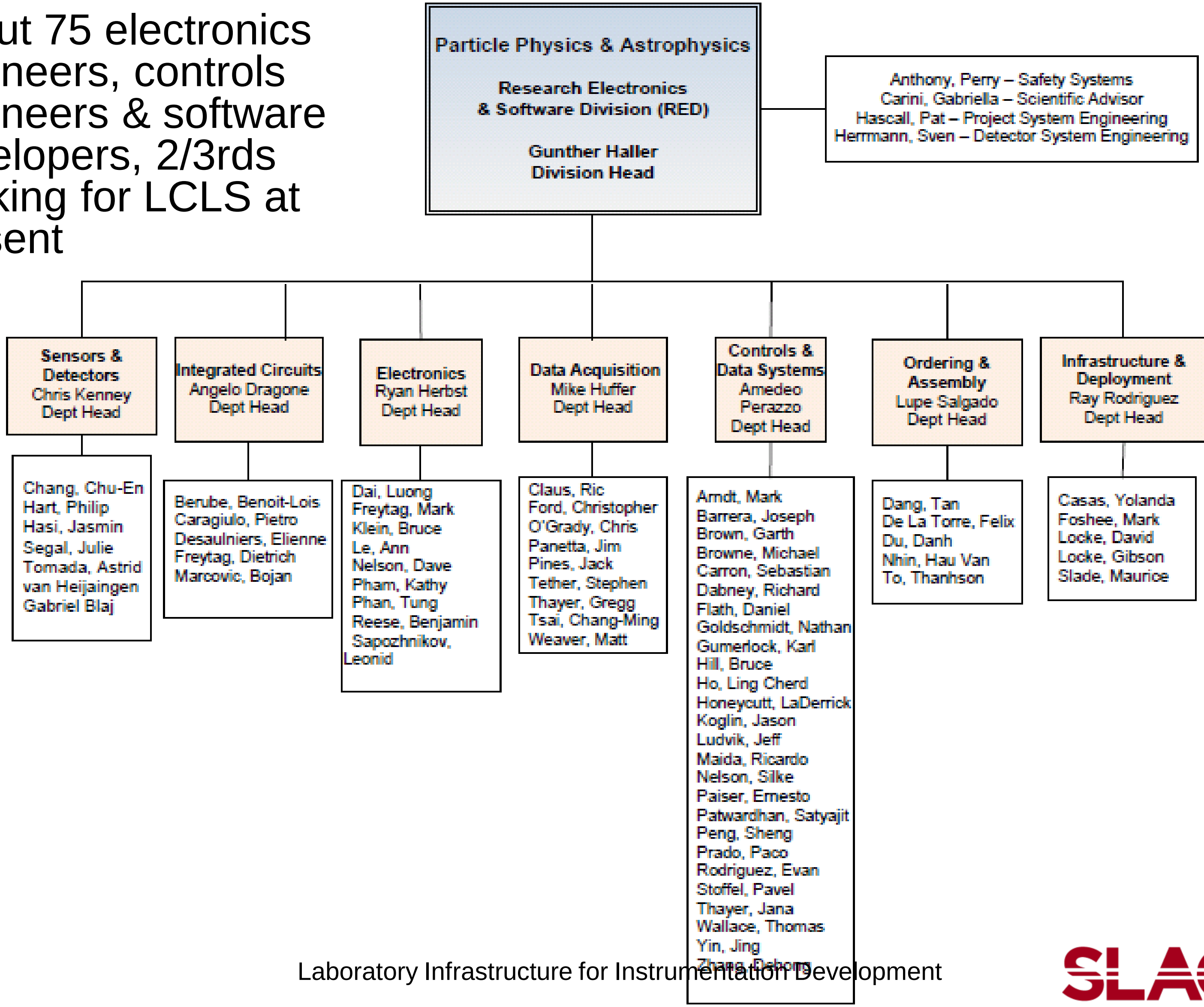


ACTA-based RCE board



Core electronics and software capability

- About 75 electronics engineers, controls engineers & software developers, 2/3rds working for LCLS at present



Sensor processing & characterization facilities

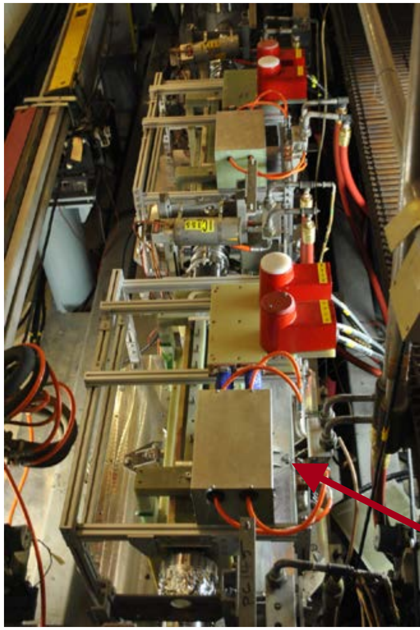
- Access to extensive existing micro and nano-fabrication infrastructure on Stanford campus
  - » SNF has full suite of micro and nano processing equipment: stepper, contact aligners, epitaxy reactors, 10 plasma etchers, 20 furnaces, 6 ALDs, etc
  - » Silicon Valley location facilitates use of services from specialized micro-electronics companies

Stanford Nano-Characerization Lab
TEMs, SEMs, Auger, XPS, XRD, etc.

Stanford Nano Center
140,000 ft^2, TEMs, ion mill, ebeam litho, etc.

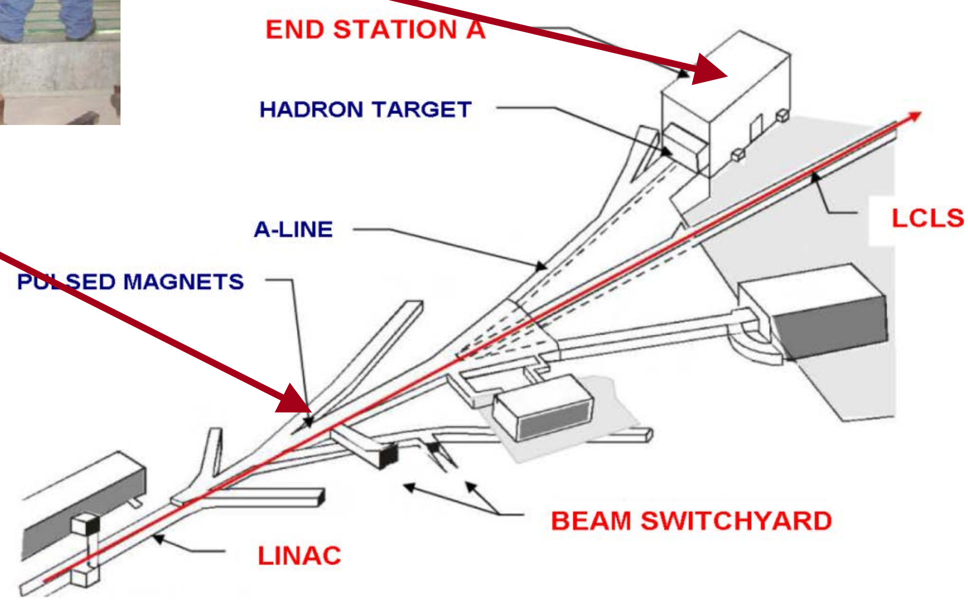
Stanford Nano-Fabrication Facility

End Station Test Beam (ESTB)

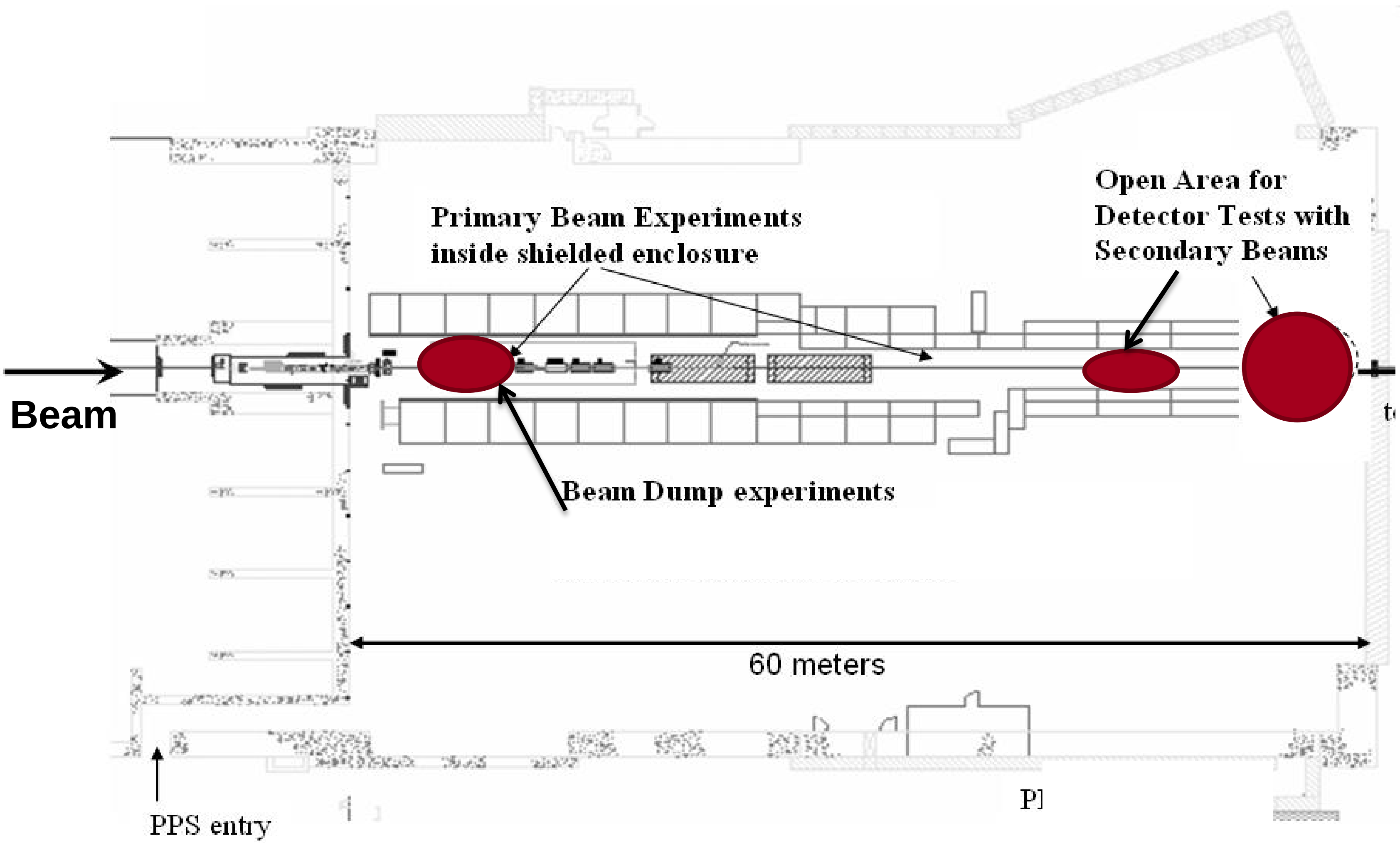


- World's only high-energy primary electron beam for MDI & beam instrumentation
- Exceptionally clean and well-defined primary and secondary electron beams

- Uses pulsed magnets in beam switch yard to parasitically extract LCLS beam to ESA
- First beams extracted March 26 to ESA beam dump

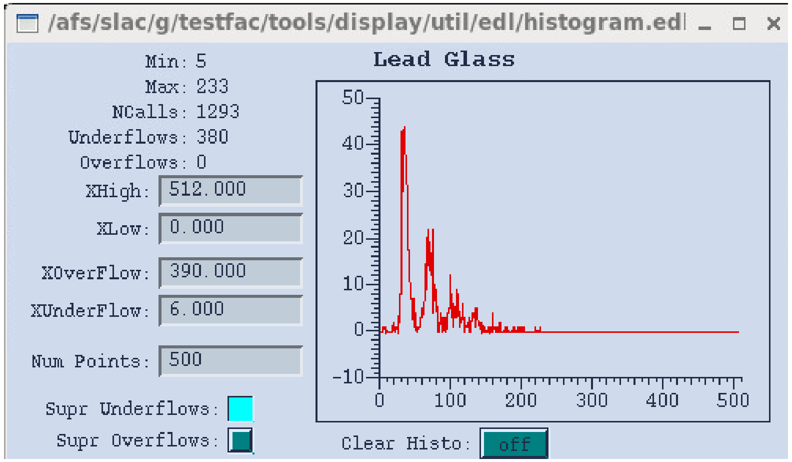


Layout for ESA



LCLS and ESTB Beams

- LCLS beam (min and max parameters)
  - » Energy: 2.2 –15.0 GeV; typical around 5 or 13 GeV
  - » Repetition rate: 120Hz
  - » Beam current: 20 to 250 pC; typical 150pC
  - » Beam availability > 95%!
- ESTB beam
  - » Kick the LCLS beam into ESA @ 5 Hz
  - » Primary beam 2.2 -15.0 GeV
    - Determined by LCLS
    - <1.5 x 109 e-/pulse (250 pC)
  - » Clean secondary electrons
    - 2 GeV to 13 GeV, 1 e-/pulse to 109 e-/pulse



Secondary particles on new Cu-target at the PM3 location in the BSY as recorded by a Lead Glass Counter

Users for April to July and beyond

- Approved proposals
  - T-505: Tests of 3D silicon pixel sensors for ATLAS, P. Grenier, SLAC
  - T-506: EM Shower Damage to Si Diode Sensors, Bruce Schumm, UCSC
  - T-507:Test of a RICH-Prototype Based on CsI-GEMs for an Electron-Ion Collider, K. Dehmelt, Stony Brook University
  - T-508: HERA-B ECal modules beam test in ESTB at SLAC for GEp(5) at Jefferson Lab, E. J. Brash, Christopher Newport University
  - T-509: Develop a Neutron Beam Line for Calibration of Dark Matter Detectors, J. Va'Vra, SLAC
- Proposals in development
  - Will receive the ATLAS Silicon Telescope in September for one year
    - Several Atlas R&D proposals in draft form
  - Performance confirmation of Belle II imaging Time of Propagation prototype counter, G. Varner, Univ. of Hawaii
  - Calibration of the g-2 calorimeter, D. Hertzog, Univ. of Washington
  - Test of a Silicon-Tungsten Electromagnetic Calorimeter for the ILC SiD, R. Fry, Univ. of Orgeon
  - Geosynchrotron radio emission from extensive air showers to detect ultra-high energetic neutrinos at Antarctica, K. Belov, UCLA

Detector R&D coordination among HEP labs

- HEP labs planning to organize a series of small specialized workshops with invited participation
  - Intent, in part, is to review capabilities, future needs, and move towards reducing duplicated effort where identified
- Tentative list of topics:
  - ICs and ASICs [LBNL this spring]
  - Sensors including strips, pixels and CCDs
  - DAQ and trigger
  - Noble liquid systems and cryogenic engineering
  - Low-background detector and materials development, including assay techniques
  - Specialized mechanical engineering, including low-mass materials and supports

Community access to lab facilities

- DOE generic detector R&D program created in FY2008
  - Has led to development of coherent organization structures for detector R&D efforts in laboratories
- Laboratories all have points-of-contact designated for community to request access and work with laboratories on new ideas
- Most laboratories moving towards Fermilab model of annual evaluation of opportunities and priorities
- CPAD also has a central role in communicating capabilities and providing community input on priorities and directions

Backup