Overview and Future Plans of Fermilab Detector Research and Development

PAC Meeting
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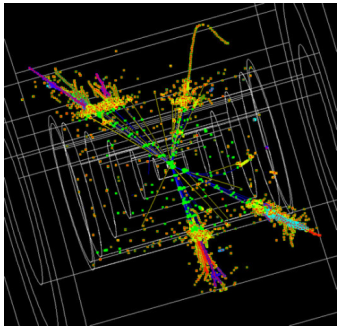
Expanding the Frontiers in Detector R&D

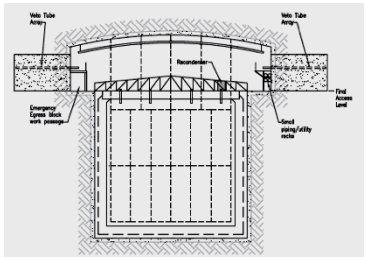
Energy Frontier:

- Vertex sensors that can withstand a fluence of 10^{16} particles/cm^2
- Innovative 3D ASIC track triggers
- Hadronic jet energy resolutions of ~10%/sqrt(E)



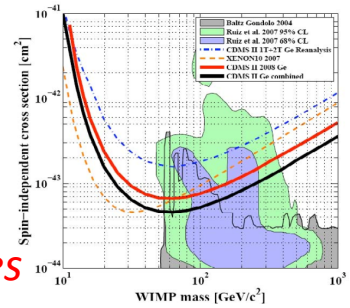
Intensity Frontier:

- Low-cost, efficient photodetectors for rare decays or neutrinos
- Ultra-fast timing trackers and calorimetry (~10 psec)
- High-performance, low cost multi-kton liquid Argon TPC detector



Cosmic Frontier:

- Dark matter detectors w/background at level of 1 nuclear recoil per ton per year
- Low-cost alternatives to spectrophotometry
- Investigations of space-time



Note: much of the technology development crosses frontier boundaries

Fermilab Assets for Detector Research

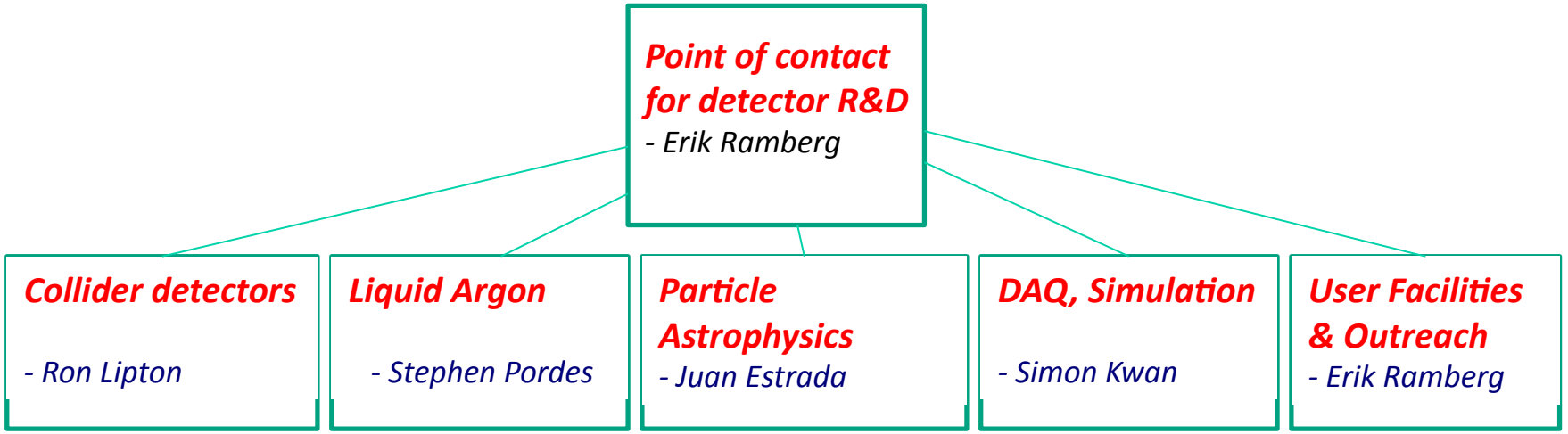
- Detector R&D program at Fermilab is geared towards our institutional strengths, such as:
  - Presence of unique facilities like the Test Beam Facility, NICADD scintillator extrusion facility, CCD characterization facility, or Thin-Film Facility
  - Experienced, well established engineering groups, such as ASIC development and Cryogenics
  - Construction of large prototypes that require substantial investments of manpower, time and/or money
- We already encourage a high degree of collaboration with the university community and other (inter)national labs, and we would like to advertise further the capabilities in detector support that Fermilab can contribute.

Liquid Argon Purity Demonstrator

Inspection at SiDet

CALICE at the test beam

Fermilab Detector R&D Organization



- In response to the 2009 review by DOE, Fermilab has significantly improved its detector R&D organization by creating a detector R&D advisory group

- The Detector Advisory Group:
  - consists of scientists active in detector R&D
  - has PPD and CD representatives
  - meets twice a month
  - monitors and reports on progress in each thrust
  - facilitates reviews of projects in each thrust
  - gives advice on the future of the program

KA15 R&D Detector Projects

PROJECT	TASK	DESCRIPTION
Collider Detectors	Tracking ASIC R&D	Development of 3D ASIC's with large international collaboration
	Tracking Mechanical	Mechanical support and cooling designs for lepton colliders
	Calorimetry	Dual readout techniques, SiPM characterization, new QIE design
	psec Time-of-Flight	Contribution to the LAPPD phototube program at ANL
	Scintillators	Scintillator extrusion and testing for community
Liquid Argon	20 Ton Demonstrator	Large scale liquid Argon purification test
	Materials Test Stand	Testing materials for LAr TPC
	Cold Electronics	Cold electronics in conjunction with BNL (digital) and MSU (analog)
	Low backgrounds	Production of clean, low background Ar for dark matter community
Astrophysics	CCD R&D	Low noise readout & dark matter & neutron imaging
	Bubble Chamber	Acoustic rejection of α background
	Laser interferometry	New high finesse laser lab for space-time measurements
	Solid Xenon	New type of dark matter/axion detector
DAQ	Sensor DAQ	Radiation hardness testing in new sensors for community
	Optical DAQ	Large collaboration to work on multi-Gbit optical links
	μTCA and ATCA	Evaluation of newest data-flow architecture
Facilities, Outreach	Tools	Upgrading R&D tools as needed
	ASIC support	Supporting software for ASIC development
	Test beam equipment	Pixel telescope support for FNAL Test Beam Facility
	Mcenter test beam	Development of second test beam line
	General Initiatives	New program to support University initiatives
	Detector School	EDIT 2012 graduate student school

Comprehensive Approach to Silicon Tracking R&D

Creating a tracking and trigger system that can withstand the projected LHC luminosities is perhaps the most important detector challenge in the field.

Sensor — *Radiation hardness in new sensors (3D columnar + Diamond)*

↘

Front End — *New 3D ASIC developments to give integrated track segment information*

↘

L1 Trigger — *Track trigger using 3D techniques & Associative Memory trigger at L1*

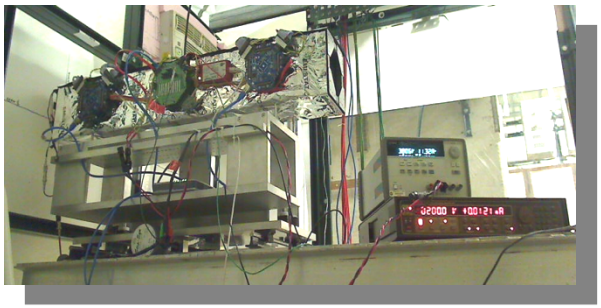
↘

Data Transmission — *Multi-wavelength optical DAQ*

↘

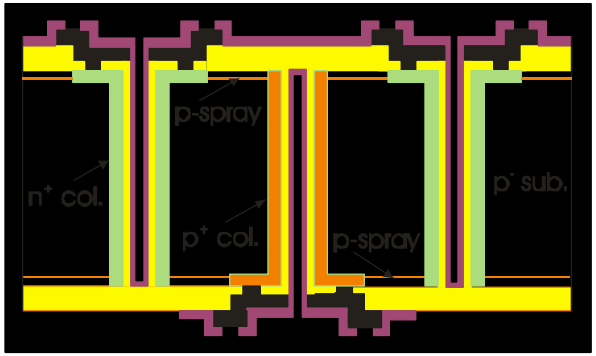
Track Fitting — *GPU's in ATCA architecture*

15 US universities
19 foreign institutions
5 laboratories
8 industrial partners



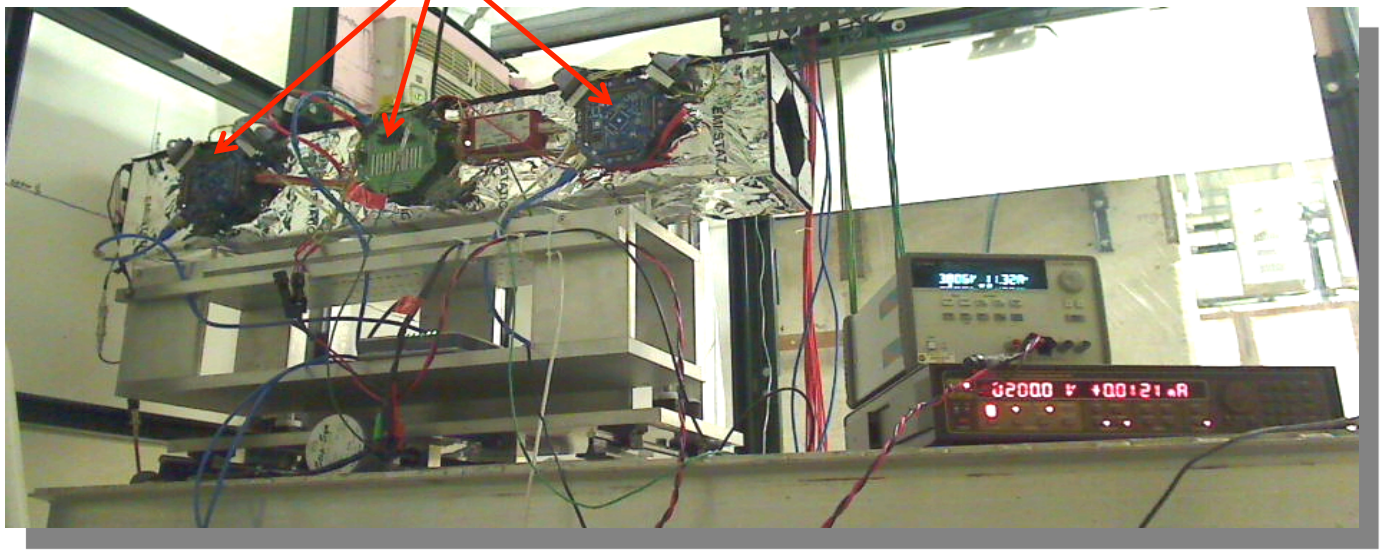
Sensor Test Beam at Fermilab

- Goal is to test detection efficiency of sensors, have them irradiated at SLHC levels, and test them again
  - Diamond sensors
  - 3D sensors
  - Magnetic Czochralski (MCz) planar silicon sensors
  - Float Zone (FZ) planar silicon, p-type silicon
- Have made connections with global effort on SLHC Sensor R&D
  - RD42 (diamond)
  - RD50 (rad-hard sensors, mostly on silicon)
  - 3d consortium (3d sensors)
  - ATLAS, CMS, and LHCb effort
- We test all sensor materials using the same readout electronics in the same environment and apparatus
  - fair comparison of all candidates



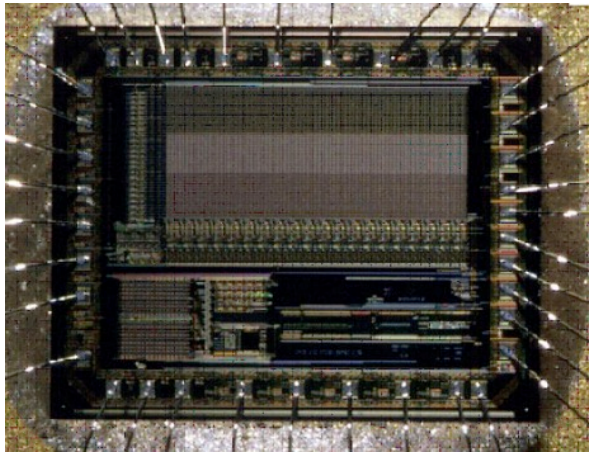
Advanced design from FBK for ATLAS: 3D-DDTC+: double-sided 3D with passing through columns

A Pixel Telescope in the Test Beam

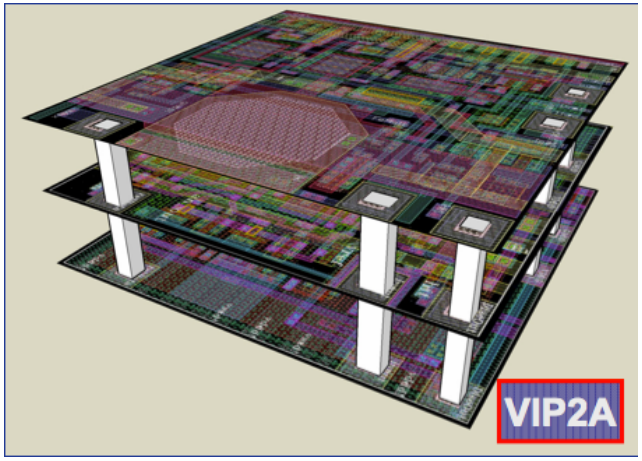


CAPTAN DAQ (200 Gb/s potential in vertical interconnect) developed by Fermilab Computing Division.
Uses conventional 3-dimensional architecture.
Same data acquisition system as used in IHEP silicon telescope

3-Dimensional ASIC program



Conventional Monolithic Active Pixel Sensor

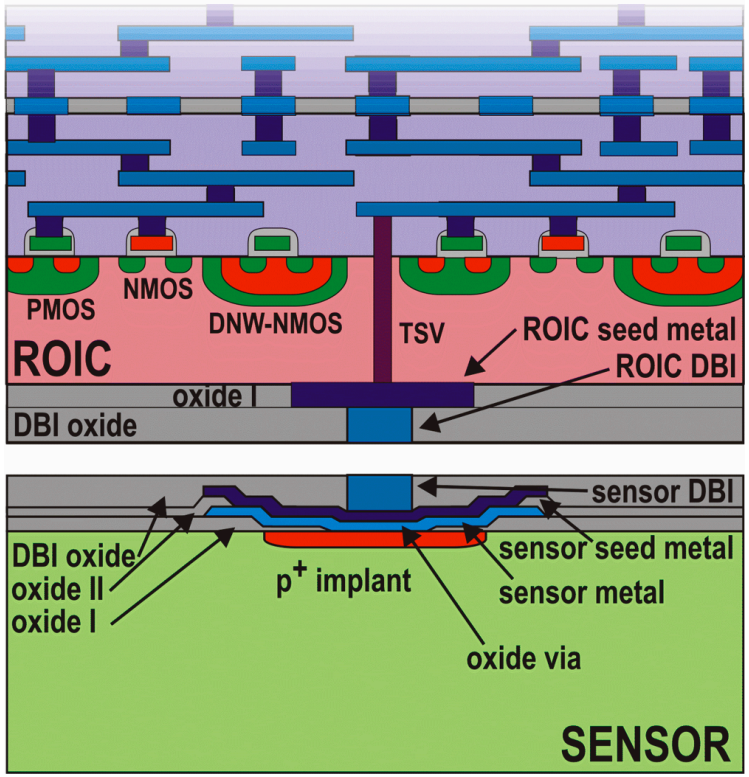


3 tier 3D stack for FNAL ILC vertex chip, fabricated by MIT-LL

- Fermilab has led the formation of a large international group (http://3dic.fnal.gov) addressing this new technology. This group of 17 members from 6 countries shared a multi-project run in 2009 and are still testing structures coming from that run. New devices are coming this year.

- A very important development has occurred in that the tools and techniques learned from this process have been adopted by the major silicon fabrication brokers: MOSIS, CMP and CMC.

FNAL, in Cooperation with Industry, Have Established Enabling Technologies



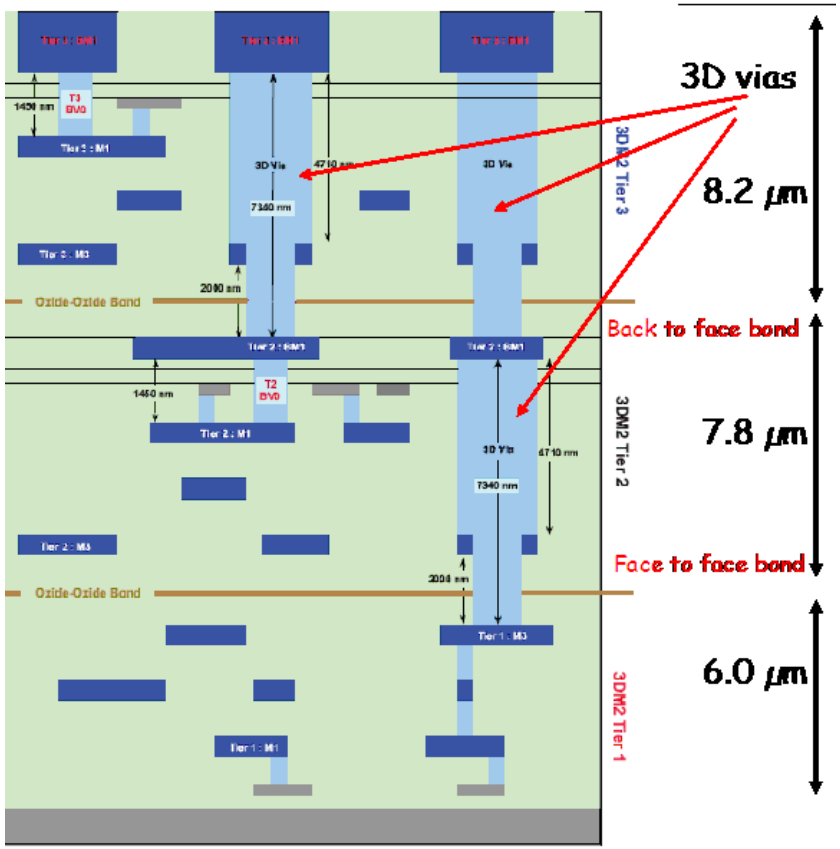
- Wafer bonding
- Thinning and annealing (with Cornell)
- Through-silicon interconnects
- Silicon on Insulator

Adds capabilities to classical amplifier/ discriminator:

- *Time stamping (LC, CMS,…)*
- *Time correlations (x-ray)*
- *Centroid finding (x-ray, CMS)*
- *Triggering (CMS, ATLAS, MC)*
- *Fast readout (CMS)*
- *Region of interest readout (CMS)*

Milestones Achieved in First HEP 3D Circuit called VIP1

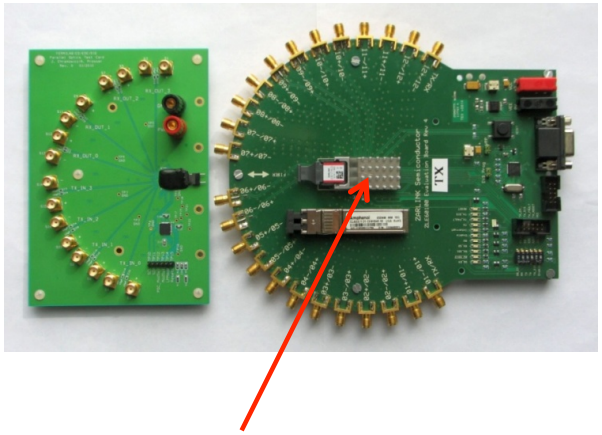
- Demonstrated increased circuit density by integrating 3 circuit tiers
- Showed that extreme circuit thinning (7um) was possible
- Showed that small vias (~1.5 um) were possible thus allowing for small pixel sizes. Used Deep Reactive Ion Etching.
- Showed that 3D vias and bonding were reliable
- We have encountered many difficulties in industrializing this process – mostly due to alignment issues in bonding the layers together
- Have received this month the latest bonded wafer. Testing results to come soon.



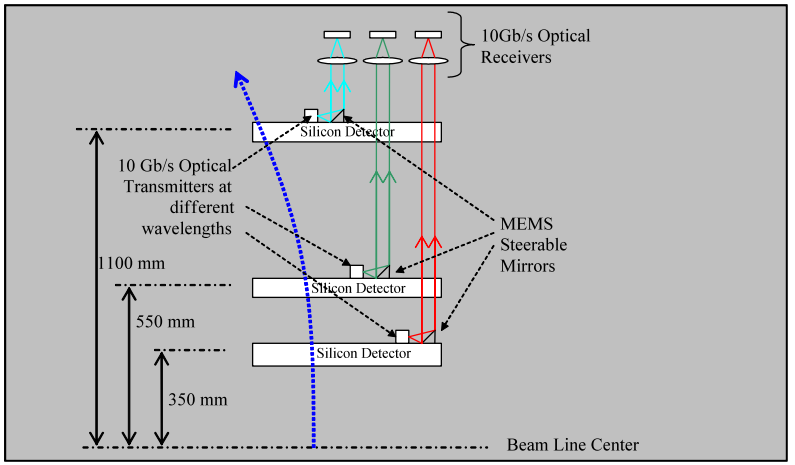
MIT LL 3 Tier Assembly

Parallel MultiWavelength Optical DAQ Device Evaluation

Collaborative Effort (CERN, ANL, industry) to Develop Low Power/Low Mass MultiGigabit Data Readout



Testing commercial devices (12 channel transmitter, 2.7 Gbps/channel) after irradiation

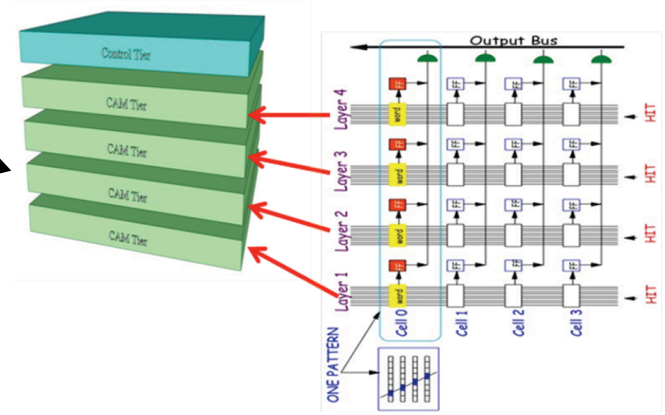


Can foresee using free space optical transmission through silicon, with multi-wavelengths centered on infrared band

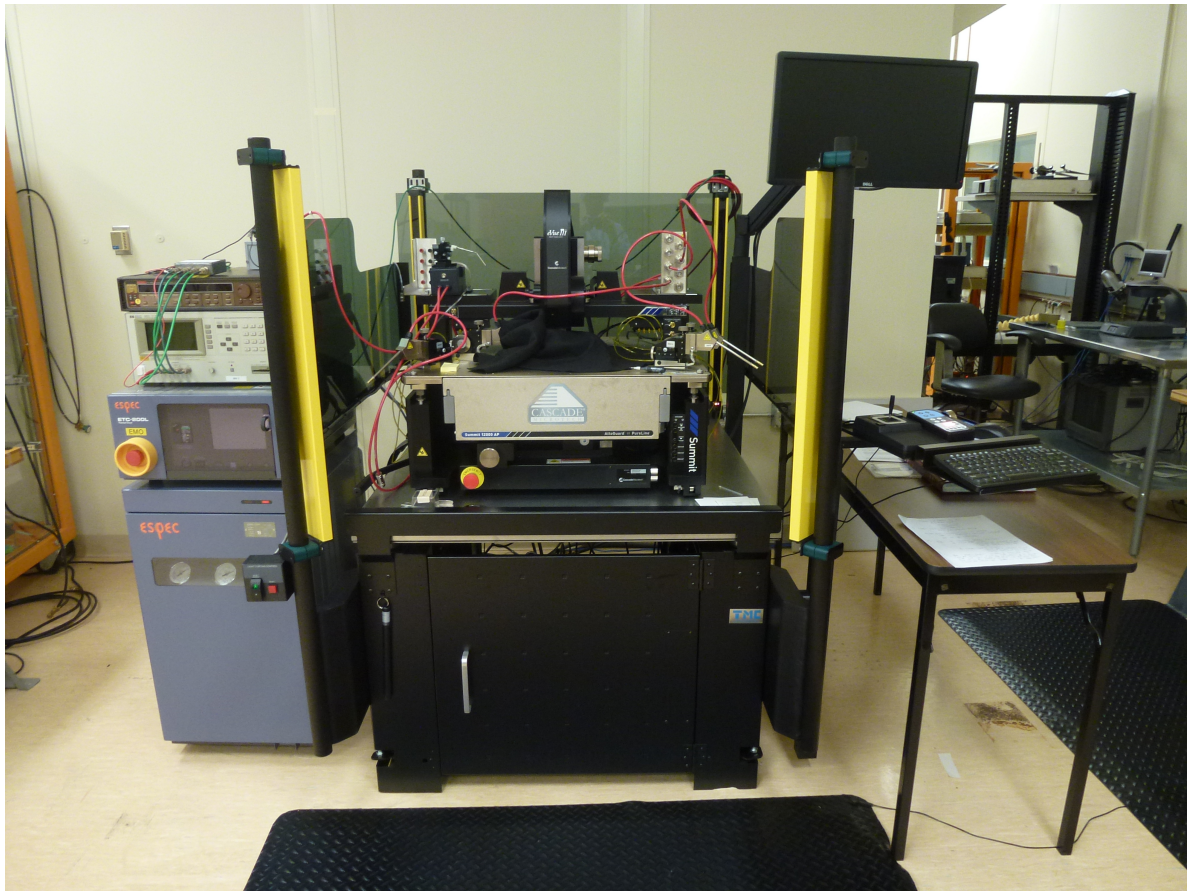
Moving to ATCA and μTCA DAQ Architecture

- ATCA = Advanced Telecommunications Computing Architecture.
- Large experiments (CMS, ATLAS, LHCb, PANDA) are considering xTCA over VME.
- Task force at Fermilab formed including engineers from CD, PPD, and AD. Collaboration with SLAC
- L1 with embedded Associative Memory
- L2 with Graphical Processing Units

12U 14-slot ATCA



A New Probe Station Facility



Cascade Microtech's 'TESLA' temperature controlled probe station

Collaborating Institutions on Tracking R&D

- Fermi national lab
- Argonne national lab
- Brookhaven national lab
- Lawrence Berkeley national lab
- CERN
- U. Chicago
- Brown University
- Cornell University
- UC Davis
- UC Santa Barbara
- U. Colorado
- Purdue University
- SUNY
- U. Mississippi
- Syracuse University
- U. of Tennessee
- Rutgers University
- Vegawave
- SMU
- U. of Minnesota
- Ohio State University
- American Semiconductor
- Tezzaron
- Ziptronix
- Voxtel
- Oxford
- INFN Milano
- Torino
- IN2P3 Strasbourg
- University at Bergamo
- University at Pavia
- University of Bonn
- AGH University of
- University at Perugia
- INFN Bologna
- INFN at Pisa
- Science Technology, Poland
- INFN at Rome
- CPPM, Marseilles
- IPHC, Strasbourg
- IRFU Saclay
- LAL, Orsay
- LPNHE 15 LPNHE, Paris
- CMP, Grenoble
- Sherbrooke University
- Canada Industrial collaborators
- OKI/Rolhm
- T-Micro (Japan)

The Liquid Argon Program

• *The development of low-cost, low background and highly efficient Liquid Argon TPC's are a national priority for both neutrino physics and dark matter physics.*

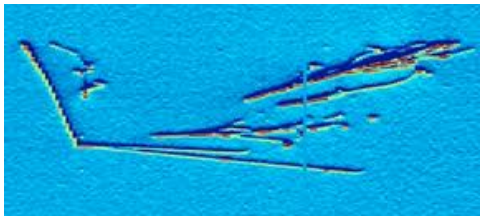
• *Fermilab has learned techniques from the international community and from our own test beam efforts (ArgoNEUT). The R&D is now paving the way for implementing truly large detectors (20-30 kton) with industrial techniques*

Institutions collaborating in hardware R & D:
- *Yale - Syracuse (ArgoNeuT)*
- *Michigan State University (TPC electronics)*
- *M.I.T and Indiana University (Light readout)*
- *BNL (TPC electronics and TPC design)*
- *Princeton (depleted Argon recovery)*
- *UCLA (development of infrastructure for QUPID)*

We offer a one-of-a-kind materials test stand for learning about purification degradation and recovery in liquid Argon.

Comprehensive Approach to Liquid Argon R&D

Neutrino Physics requires a detector which provides tracking, particle ID and calorimetry for unambiguous identification of rare processes => Liquid Argon TPC.



ArgoNeut event

Argon — *Purification techniques and cryogenics design*

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TPC — *Materials qualification and design*

↘

Readout — *Low-noise amplifiers in liquid*

↘

Full System in Neutrino Beam — *ArgoNeuT*

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Automated Reconstruction — *LArSoft Simulation*

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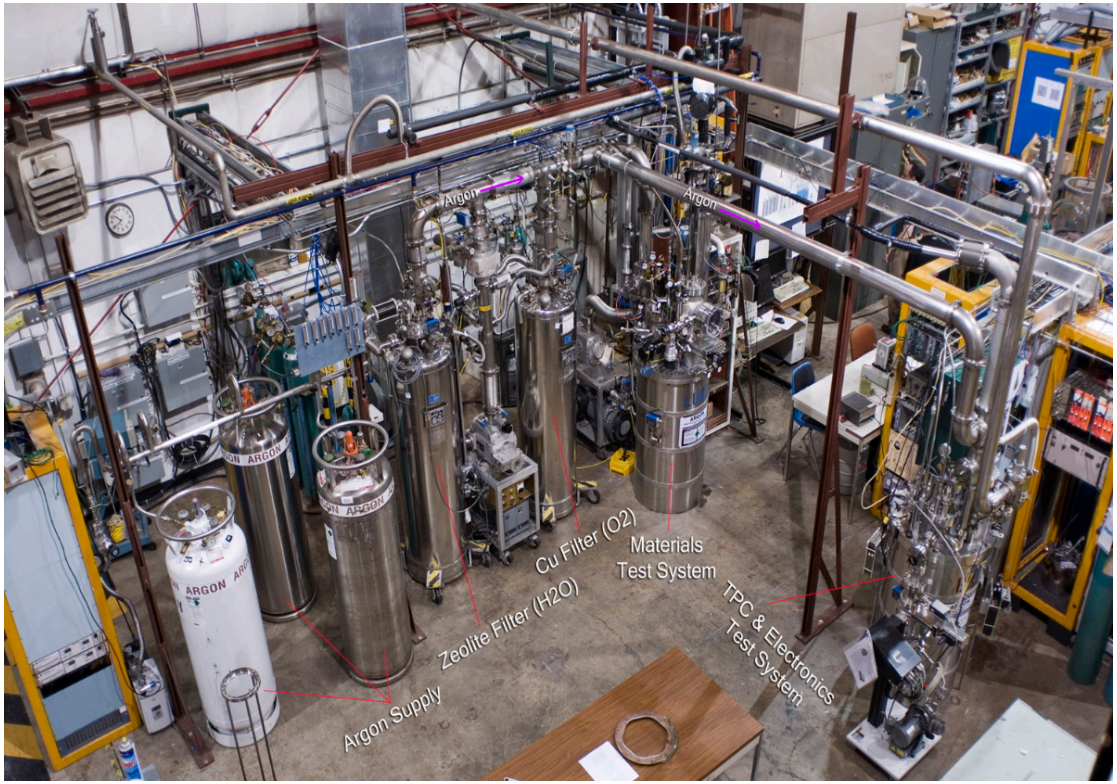
Synergies — *Dark Matter, Solid Xenon*

Materials Testing in Liquid Argon



Argon Source and Materials Test System, &
Electronics Tests for TPC's - constructed 2006 - 2009

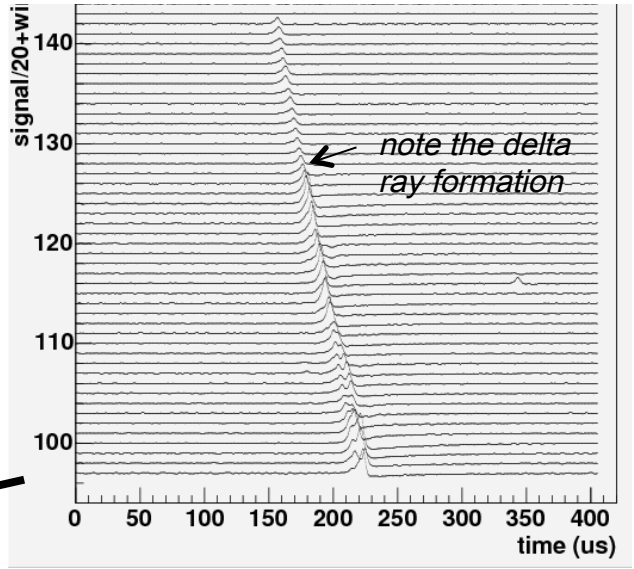
Materials Testing in Liquid Argon

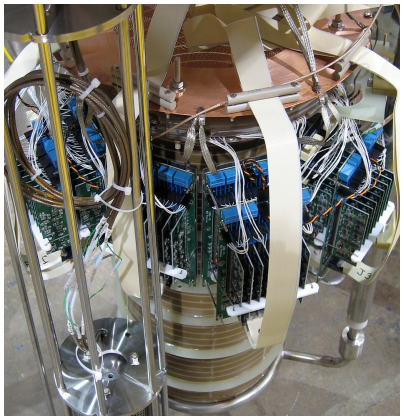
`A system to test the effects of materials on the electron drift lifetime in liquid argon and observations on the effect of water' R. Andrews et al., Nucl.Instrum.Meth.A608:251-258,2009.

Material	Date test started	Preparation	Tests	Water [ppb]	Lifetime [ms]	LogBook #
Cleaning Solution	6/29/09	evac. 24 h	vapor/liquid	4	5	946
Vespel	7/9/09	evac. overnite	liquid/vapor	5-7	2-5, 4-6	960
MasterBond glue	7/16/09	purged 18 h	vapor/liquid	1.6	1.3- 2.9	974
LEDs	7/31/09	purged 38 h	vapor	3.5	5	993
Carbon filter material	8/12/09	evac. 24 h	liquid/vapor	2	4-9	1000
962 FeedTru Board V2	10/12/09	evac. 24 h	vapor/warm	85	1-5	1062
Teflon cable	1/9/10	purged 28 h	warm/liquid/vapor	8-20	2-5	1175
3M "Hans" connectors	1/29/10	purged 46 h	warm/liquid/vapor	5-12	3	1198
962 capacitors	3/2/10	evac. 24 h	warm/liquid/vapor	6-14	3-6	1228
962 polyolefin cable	4/12/10	evac. 16 days	warm	25-60	2	1237
Rigaku feedthrough	4/20/10	purged 7.5 h	warm	15	3	1250
Rogers board (Teppei)	4/23/10	purged 26 h	warm/liquid/vapor	40	2, 6-10	1254
Arlon Board (Teppei)	5/14/10	evac. 0.5 h, pur.2 days	warm/vapor	300, 80	1.3, 3.5	1263
Polyethylene tubing	5/24/10	evac. 6 h, pur. 66 h	warm	300-500	1	1278
Teflon tubing	5/27/10	evac. 1 h, pur.17 h	warm	9-13	4-5	1283
Jonghee board	5/28/10	evac. 6 h, pur. 1.5 h	warm/vapor	100,28	1.2, 5-8	1285
Jonghee connectors	6/4/10	evac. 3.5 h, pur. 16 h	warm/vapor	50	2-3	1290
PVC cable	6/14/10	evac. 29 h, pur.1 h	warm	120	1-2	1296
Teppei TPB samples	8/3/10	purged 26 h	warm	600-1600	0.7	1342
Teppei TPB samples	9/4/10	purged 37 h	liquid /vapor	15, 300	6	
PrM feed tru (baked)	10/5/10	purged 25 h	warm/vapor	35, 20	3, 2	1396
Copper foil on mylar film	10/14/10	purged 26 h	warm/liquid/vapor	15, 10, 9	3, 8, 7	1409
Teppei SHV connector	10/25/10	purged 25 h	warm/vapor/liquid	35, 11, 0	2, 6, 6	1415
FR4	11/16/10	purged 25 h	warm/liquid/vapor	180, 20, 65	1.5, 6, 2.5	1429
Gaskets	3/11/11	purged 24 h	warm/liquid/vapor	8, 10	2.5, 8 , 7	1521
LBNE AP-219 Color. Developer	4/13/11	purged 25 h	warm/vapor	65, 15	4, >6	1722
LBNE RPUF Foam	4/22/11	evac. 26 h, pur.1 h.	warm	800	0.2	1729
LAPD LEDs	5/12/11	purged 49 h	vapor	0.6 ppb	10	1769

TPC Electronics Test System

with external amplifiers (as used in ArgoNeut)





State of the Art:

in-liquid amplifiers from MSU

- *PMOS based design*
- *Operates very well at 90K*
- *Improves Signal to Noise*
- *Multiplexing reduces cable plant*
- *Can be converted to ASIC*

Liquid Argon Purity Demonstration

Most LAr TPC detectors have been evacuated before filling. Not practical for kiloton detectors.

Goal is to demonstrate good life-time in an industrial vessel without evacuation.

It is the first multi-ton purification system designed and built at Fermilab.

Commissioning started in October :

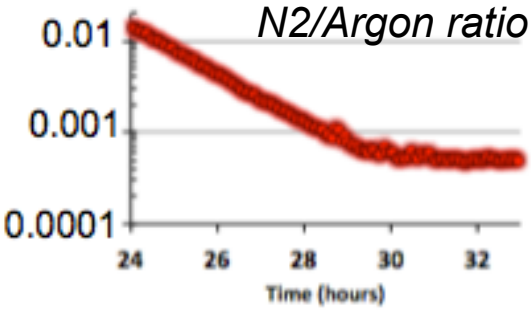
Stage 1 – bare tank
HAVE ACHIEVED 3 MILLISECOND LIFETIME (4.5 meter) IN 1/3 FULL VESSEL.

Stage 2 – install 2 meter TPC and fill completely with Argon

30 ton Vessel

LAr Distillation Column for Dark Matter (Princeton-Fermilab)

- *Atmospheric Argon: ~ 1 Bq/kg from ^{39}Ar - too high!*
- *Low background source comes from CO_2 wells - arrives at Fermilab as 5%Ar, 45% N_2, 55% He*
- *He escapes, N_2 needs to be distilled off*
- *Column commissioned 11/11 with atm. Argon*
- *Purified to >99.95% with 80% capture*

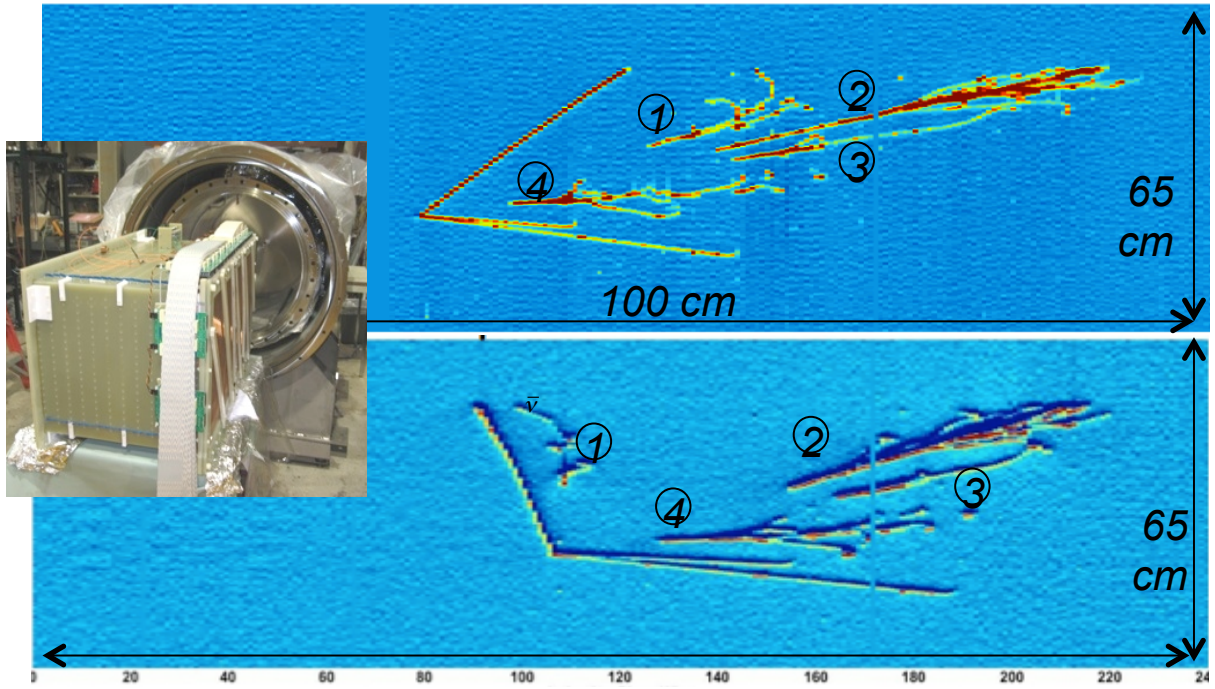


Sensitivity limit of gas analyzer

Aimed at Dark Matter community – Dark Side is first customer

ArgoNeuT in Test Beam (2009 – 2010)

ArgoNeut Event with 4 photon conversions (2 π^0) in NUMI Beam (2009-2010):

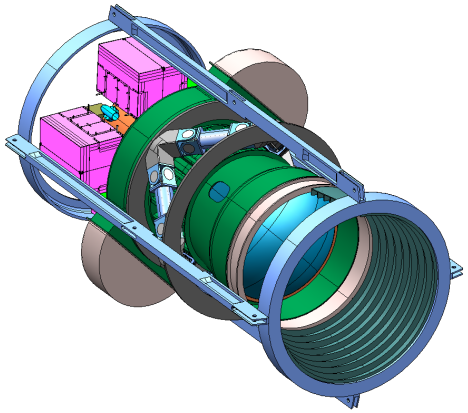


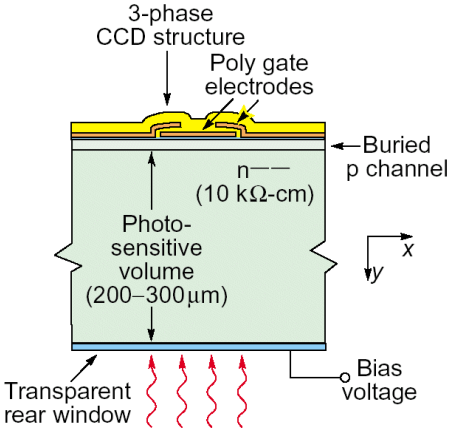
Invaluable data set: 1000's of ν interactions in Argon

Goal is to bring this to the new Mcenter Test Beam and perform tests on resolution with a known beam. Huge statistics from charged test beam will answer many questions.

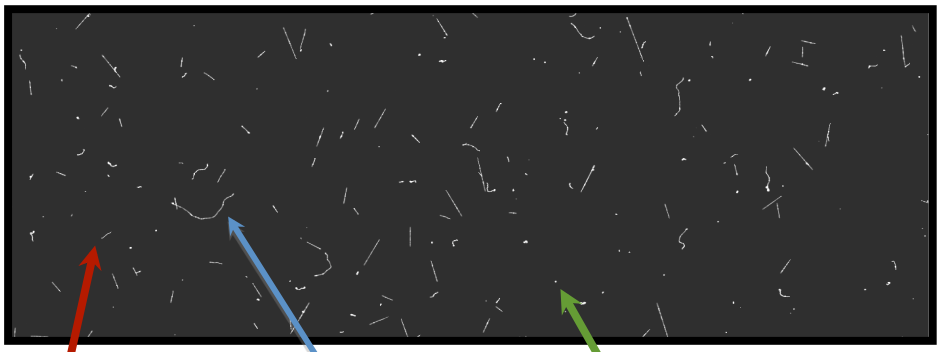
Dark Matter Search with CCD's (DAMIC)

DECam: wide field imager





To improve the efficiency in the near-IR, the DECAM detectors are extraordinarily thick: 250um instead of the typical 30 um for astronomical CCDs.
Very low noise: 2e- (RMS) !



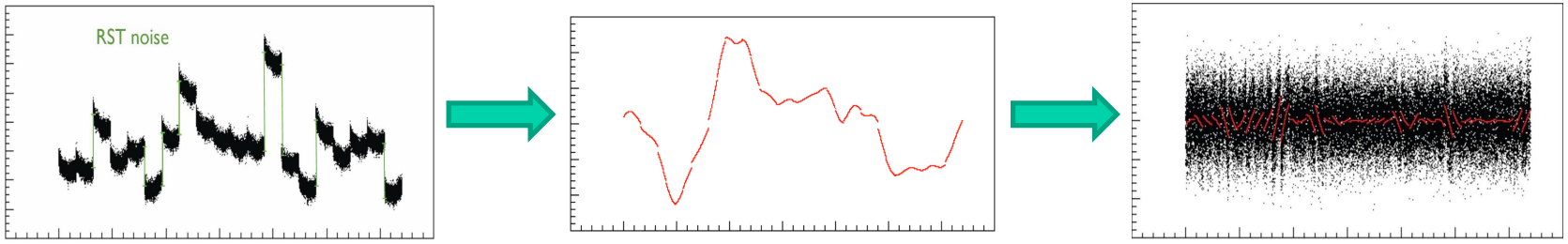
Muons *electrons* *diffusion limited hits.*

Particle Interaction Identification in DAMIC CCDs gives Dark Matter Limit in the Low Mass Region

This will be moving to SNOLAB this year.

CCD readout

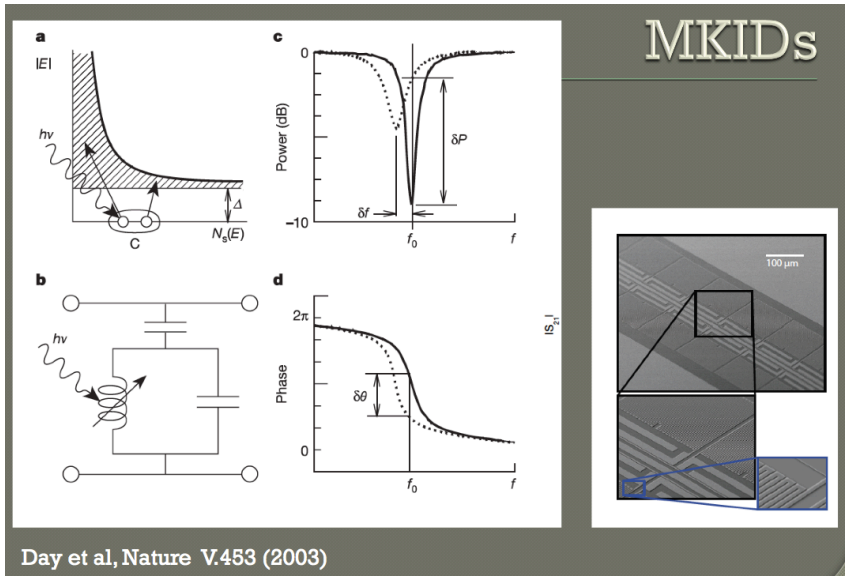
- Low Noise CCD Readout:
  - Digital sample the video output rather than just record the individual pixel charge.
  - Estimate the correlated noise of a string of pixels and subtract it.
  - Gives an amazing 0.4 e- noise.
  - Goal is to implement the estimator and the digital CDS in an FPGA to provide real-time low-noise CCD images.



Digitized video signal *Stitching together parts* *Subtracting low frequency noise*

MKID detector development

There is a proposal from the CCD group at Fermilab to begin collaborative investigations of “Microwave Kinetic Inductance Detectors”

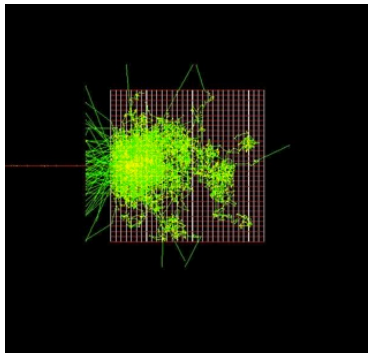


	Niobium $T_c = 9.25$ K $\Delta = 1.4$ meV	Tantalum $T_c = 4.47$ K $\Delta = .68$ meV	Aluminum $T_c = 1.175$ K $\Delta = .18$ meV	Titanium $T_c = 0.4$ K $\Delta = .06$ meV	Hafnium $T_c = 0.128$ K $\Delta = .02$ meV
IR (0.62 eV)	15	22	42	73	126
Optical (3.1 eV)	34	48	94	163	282
UV (10.3 eV)	61	88	171	297	514
X-ray (6 keV)	1500	2140	4000	7200	12500

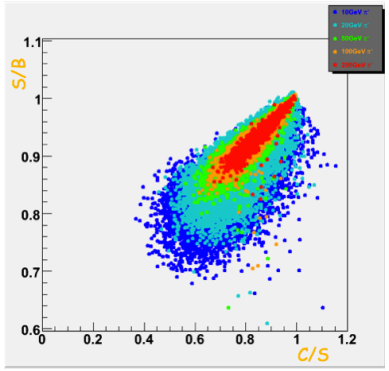
- Can multiplex thousands of sensors, with one RF feed
- Quasi-particle production gives milli-eV sensitivity
- These sensor arrays can be used for IR/Optical/UV/Xray
- Collaborate with UC Santa Barbara for optical photometry
- ANL is working on X-ray detection with MKID’s

Calorimetry

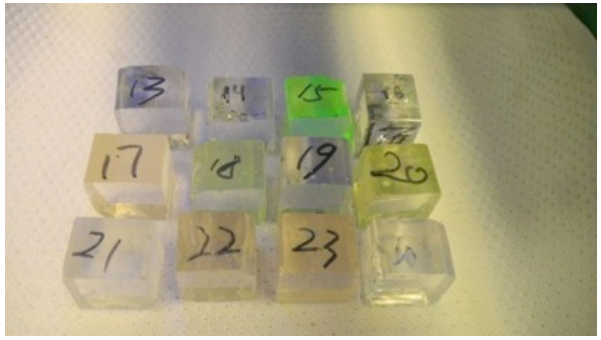
- Total Absorption Hadron Calorimetry
  - Simulation shows that a homogenous crystal calorimeter with SiPM dual readout could achieve 10%/sqrt(E) resolution using corrections for the binding energy losses:



Monte Carlo of TAHC w/pion shower



Reduced energy spread using dual readout



Samples of doped PbF2 from SICCAS

  - With CalTech and Argonne, we are searching for appropriate cost-effective material for this technique (doped PbF2? Scintillating ceramics??)
  - Improve characterizations of SiPM devices
  - Continue test beam studies
  - We obtained a CDRD grant to support this research

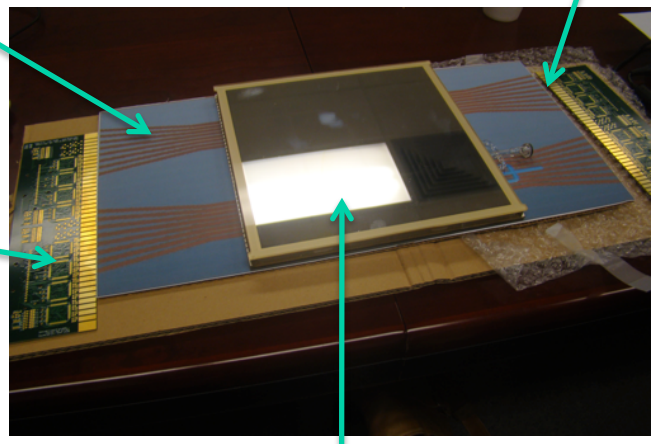
Fermilab is supporting the LAPPD project

- "Large Area Picosecond level Photo Detectors"
- Created new electrode coating chamber and were a key part in developing a photocathode research test stand

A mockup of the 8" MCP/PMT:

Readout on both ends gives 1 mm positional resolution

Transmission line readout retains superb timing resolution



U.C. is developing high speed digitizers (10-20 GHz)

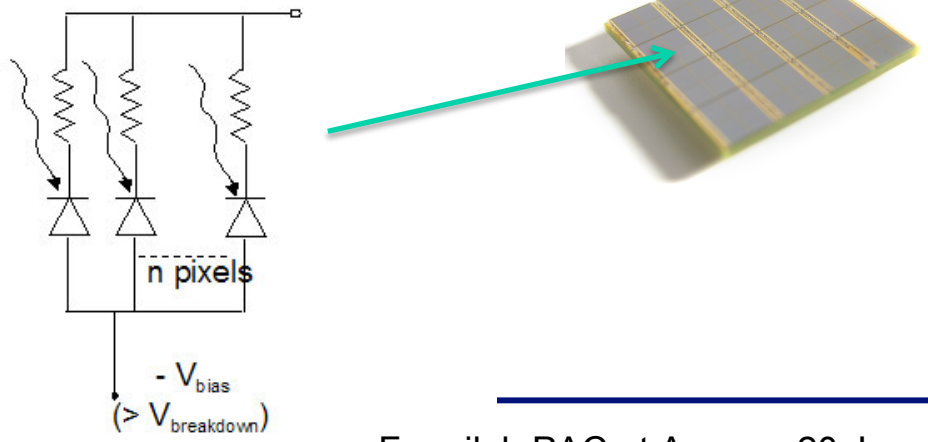
Micro Channel Plate has been developed with new process (ALD coating of drawn glass channels)

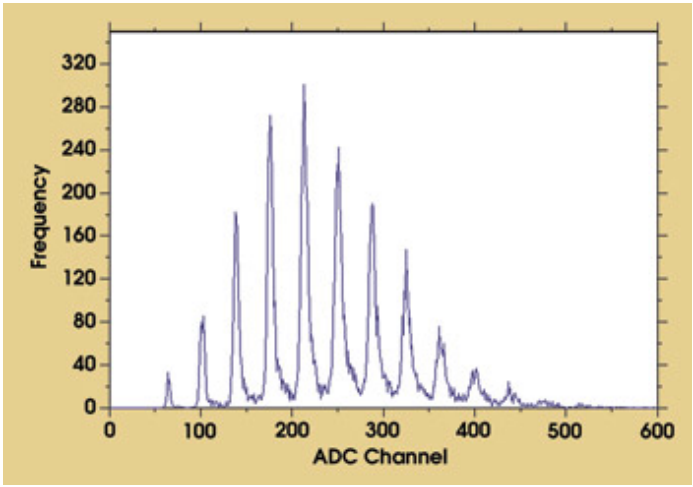
New thin film coating facility

The Silicon PhotoMultiplier (SiPM)

- These devices contain thousands of pixels of Geiger mode avalanche diodes – each one gives an output signal when a photon hits it
- Can distinguish 1 photon from 2 photons from 3 photons, etc.
- Typically noisy devices, so more useful in multi-photon counting
- Temperature and bias sensitive gain
- Can have low geometric acceptance because of 2D readout

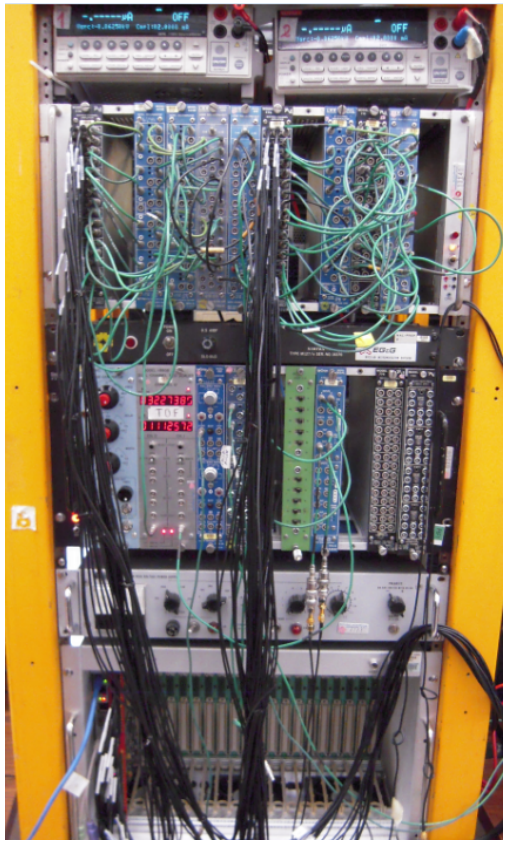
SiPM:
- matrix of n pixels (~1000) in parallel
- each pixel: GM-APD + $R_{quenching}$

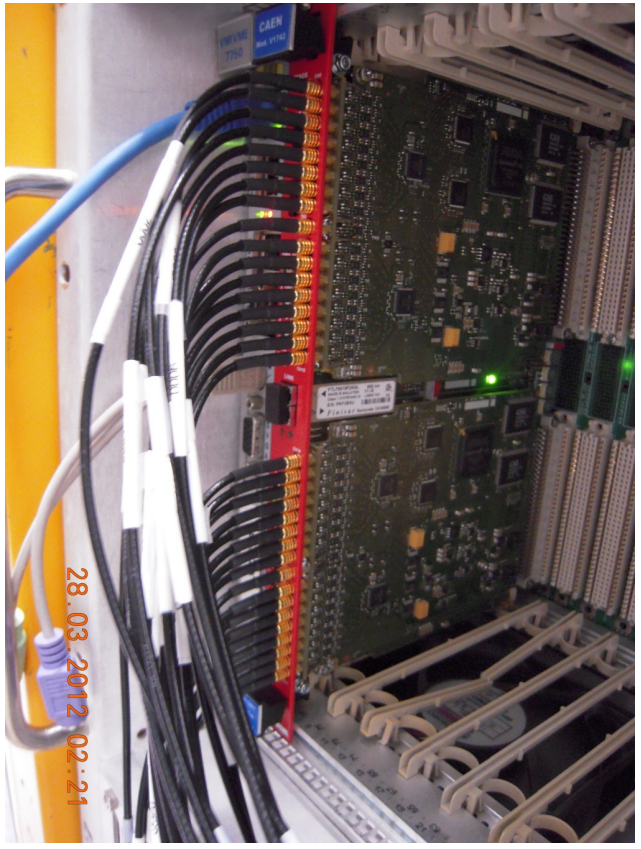


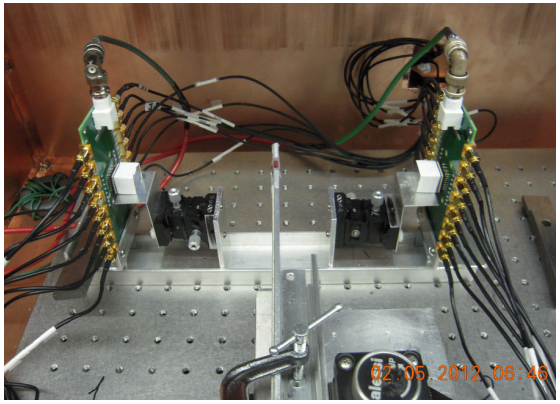


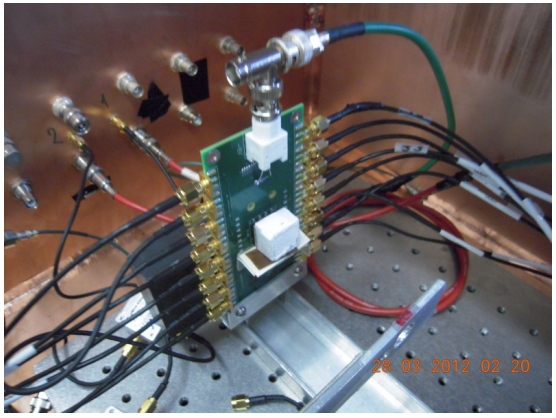
PET Imaging Studies with SiPM

CAEN V1742 (32 channels of 6 Gs/s), setup with 4x4 LYSO.

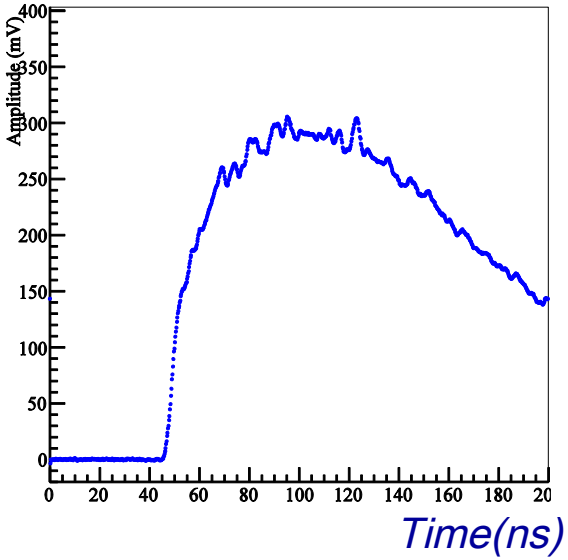


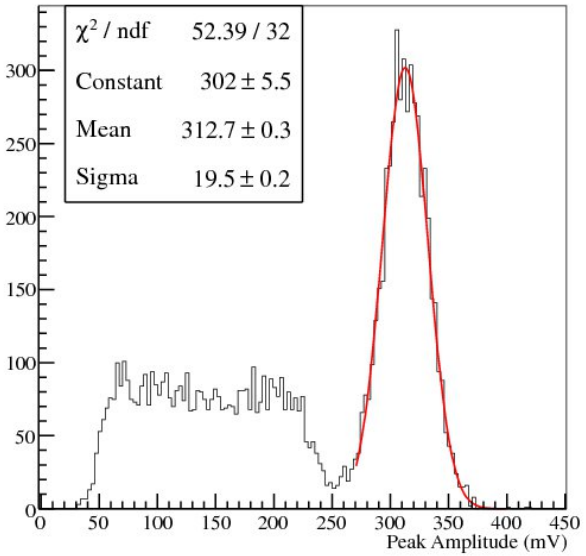


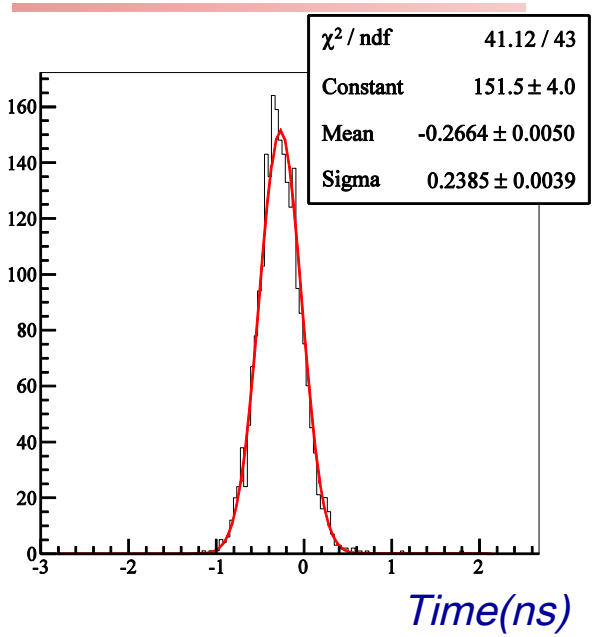




Coincidence time resolution







Left: Waveform of SiPM+LYSO by Caen digitizer

Sharp rise till ~half maximum amplitude. Rise time(10-90%) ~25ns

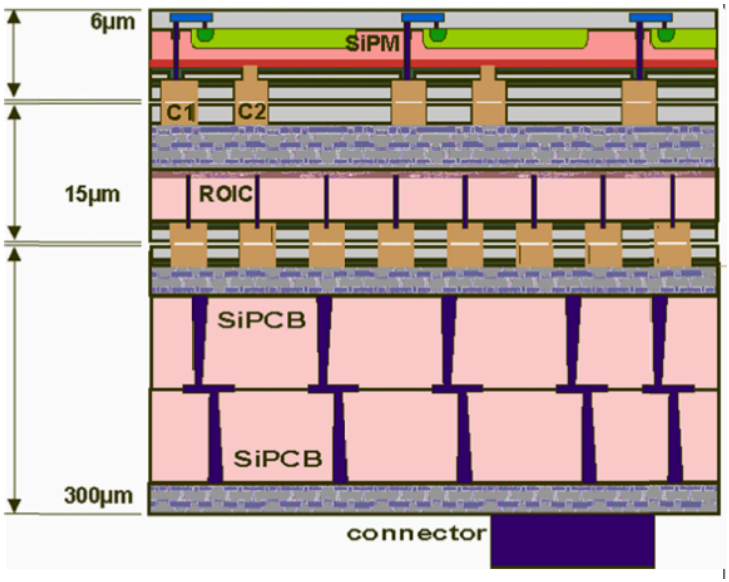
Middle: Peak amplitude distribution

14.6% FWHM at 511 keV peak.

Right: Coincidence time resolution of two SiPM+LYSOs (on strip-line boards).

~560 ps FWHM (cf. ~615 ps FWHM with the amplifiers)

Digital SiPM



Fermilab is planning on developing a 3D ASIC version of a digital SiPM, which would have complete timing and position information on every photon hit and would obtain information on correlated photon impacts. This would be a sea-change in photodetection.

Research Priorities

- Bring 3D ASIC designs (VIP, VICTR, VIPIC) to testing stage
- Start design of digital 3D SiPM
- Design and test triggerable tracking detectors for SLHC
- Design and build a LAr TPC detector (start with ArgoNeut detector) for long-term placement in the Test Beam Facility, to establish techniques for detecting and reconstructing interactions.
- Prove error-free >100 GBps optical DAQ that is radiation hard
- With ANL/UC, create 8” square PMT with 10 psec timing resolution
- Develop PET brain imager with TOF capability, using SiPM
- Develop crystal module with dual readout using SiPM’s for next generation hadron calorimetry
- Begin MKID R&D with goal of 10,000 pixel readout with single RF feed
- Design and build an optical Liquid Argon TPC module to demonstrate triggering techniques using scintillation light.
- Perform 10 KeV energy recoil dark matter detector calibration
- Implement < 1 electron noise CCD readout in an FPGA

Connecting with the Community

Collider Detector R&D Funding Opportunity

Fermilab was a part of many proposals prepared for the recently announced detector R&D funding opportunity. All were designed to increase our collaborative efforts with universities and other national labs.

Projects selected for funding include:

- *A Proposal to Develop a High Speed Data Link for Collider Experiments*
  - *(ANL, U.Mn., OSU., FNAL, SMU, VegaWave)*
  - *$300 K*
- *Development of 3D Vertically Integrated Pattern Recognition Associative Memory*
  - *(FNAL, U.Chicago, ANL, INFN (Padova), Tezzaron)*
  - *$180 K*
- *A Study of Total Absorption Homogenous Hadron Calorimetry*
  - *(ANL, CalTech, FNAL)*
  - *$210 K*

This funding will spur progress on these exciting projects.

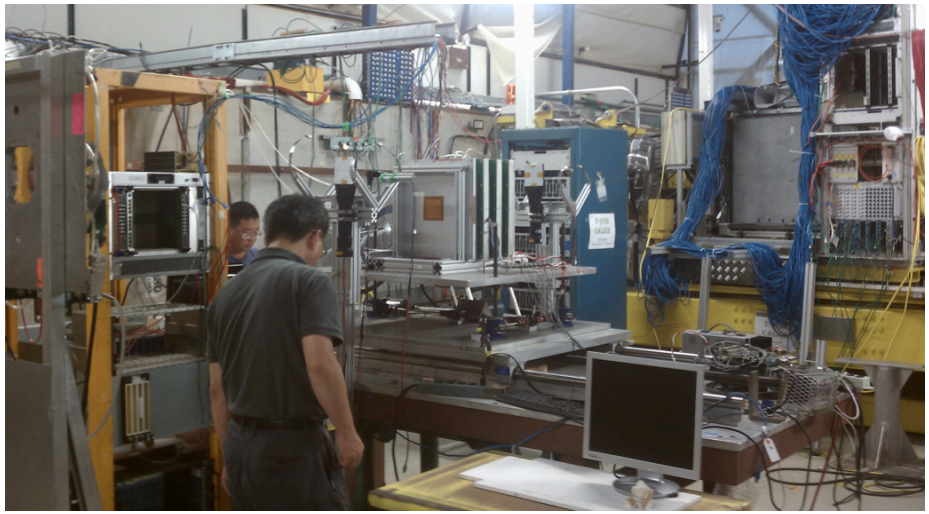
Collaborating with Industry

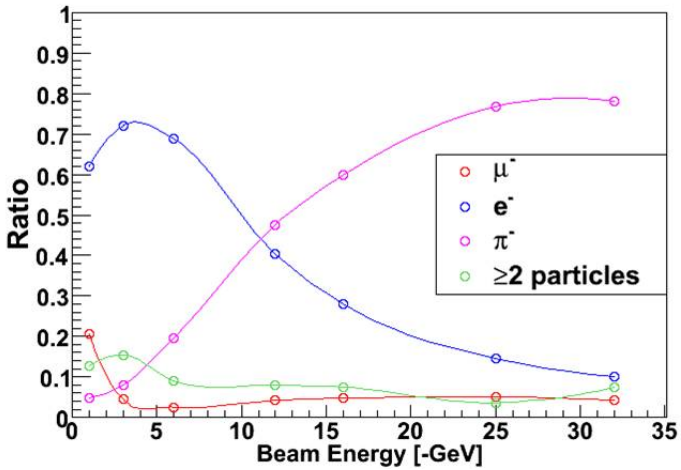
- Close ties with industry are critical to our detector R&D :
  - SBIR Title: "Fermion, a µTCA Blade for Data Analysis and Transmission"
    - Creative Electron Inc (CEI)
  - SBIR Title: "Optical Power Distribution in Next Generation HEP Experiments"
    - Vega Wave Systems
  - SBIR Title: "Development of SOI based detectors"
    - American Semiconductor
  - 3D ASIC collaboration
    - Tezzaron and Ziptronix.
  - 3D SOI collaboration
    - OKI (Japan)
  - Discussions on application of 3D ASICs to Silicon PM technology
    - Voxtel, Sensl and Siemens

An Emphasis on Outreach to the HEP Community

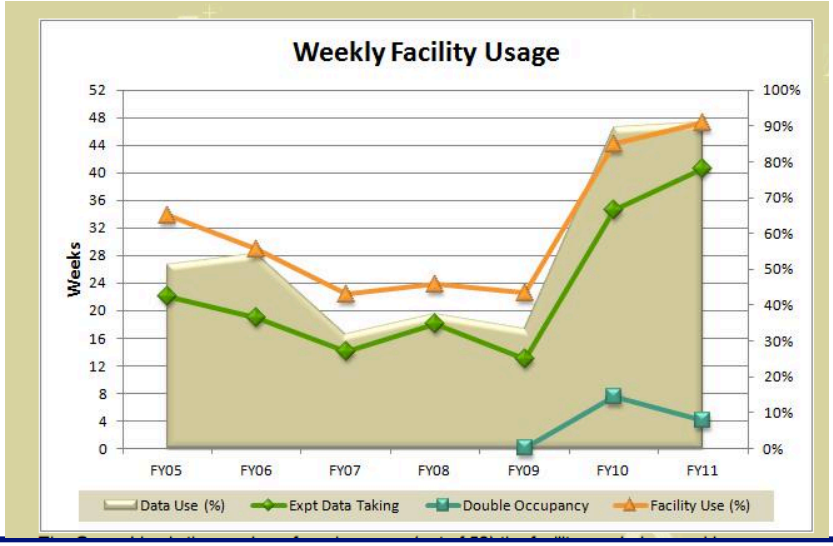
- **Workshop on National Coordination of HEP Detector R&D**
  - At Fermilab on October 7-9, 2010
  - Goal was to understand interplay between national labs and universities in detector R&D
- **Co-Hosted (with ANL) the 2nd TIPP Conference**
  - Technology and Instrumentation in Particle Physics, 9-14, June, 2011
- **Significant sponsoring of focused workshops**
  - Individual technologies such as 3-D ASICS, homogenous hadron calorimetry, optical DAQ.
- **Research Techniques Seminars**
  - Typically monthly lecture from visitors in the detector community. Plan is to support longer stays if research can benefit from Fermilab facilities.
- **Fermilab Detector 'Retreat'**
  - Attracted more than 50 Fermilab and local researchers to a one-day summary and discussion of detector issues. There was a great deal of discussion on the challenges of attracting and supporting young researchers. We will repeat this in September.
- **EDIT Detector School**
  - Very exciting 2 week school for 64 students from around the world
- **Project X Physics and Detector Study going on RIGHT NOW!**
  - We hope to conclude the workshop with the framework for actual Field Work Proposals

Fermilab Test Beam Facility

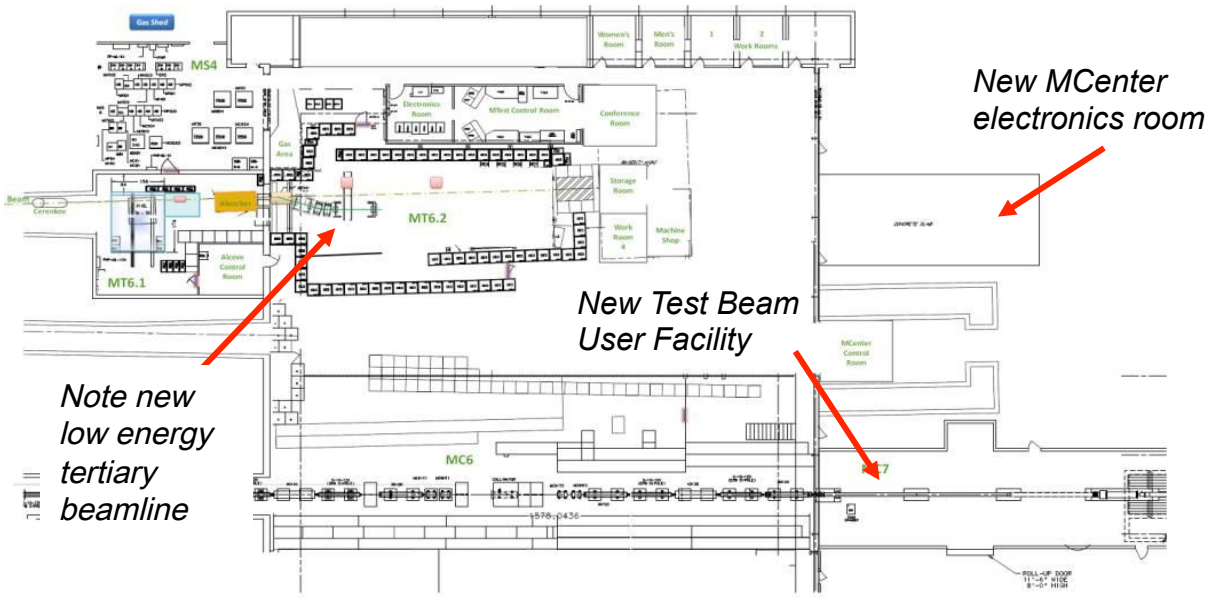




This facility is now typically booked 6 months in advance



New Test Beam Line – An Important tool for the Community



- The schedule for the Fermilab Test Beam Facility (FTBF) has been consistently full.
- Fermilab is commissioning a second beamline (MCenter), very similar to MTest
- We will improve our low energy (<1 GeV) tertiary spectrometer during 2012
- The vertex sensor development and liquid Argon program will likely use this facility heavily.
- CERN's test beam will be down in 2013, putting more visibility (and more pressure) on FTBF.

EDIT-2012 Detector School at Fermilab

"Excellence in Detector and Instrumentation Technology"

• In 2011, Adam Para and Ariel Cattai surveyed young researchers about the need for training in particle detectors.

• First school at CERN was a response to the strong desire for such

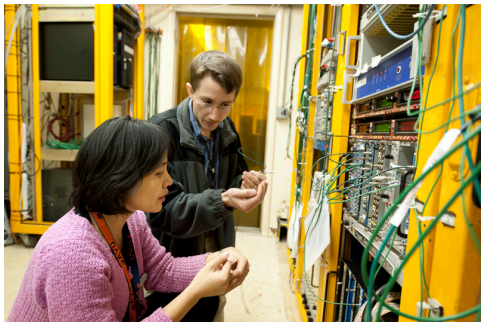
• EDIT 2011 was a big success, with 88 students participating.

• Fermilab committed to having next school in February, 2012

• 10 days of hands-on detector experience, including two days in the test beam. (We wanted this school to emphasize hands-on activities.)

• 205 applicants for 64 slots!

• Worst part of the school was jealousy: all the instructors wanted to take the courses!



Detectors studied in Test Beam Track (1 of 4):
• Cerenkov detector
• Multi-Wire Proportional Counter
• GEM detector
• GridPIX (micromegas with Time-Pix)
• Cosmic ray telescope triggering
• Lead Glass calorimeter
• Time-of-Flight

Thank you for your attention !

Our web site has links to our detector organization and facilities, as well as links to the EDIT school and our detector retreat:

http://detectors.fnal.gov

Email:

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