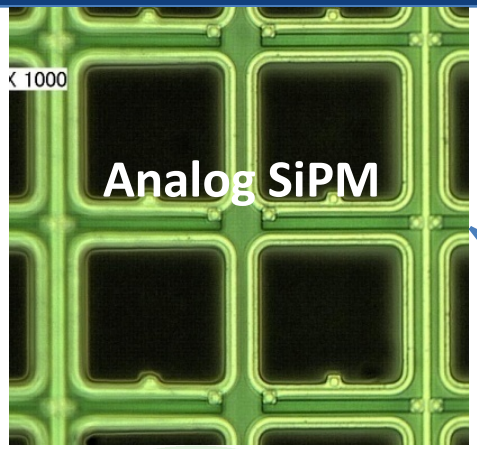
TRIUMF

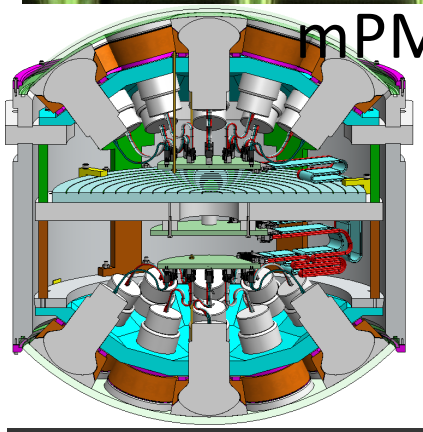
Canada's national laboratory
for particle and nuclear physics
and accelerator-based science

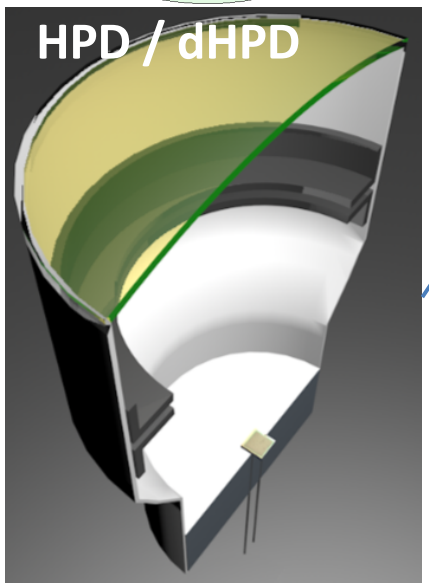
From Photon Detection to Science Technology Infrastructure

F. Retière

A physicist view of the photo-detector technology evolution







Project driven R&D

2007-2010

T2K, ILC-CALICE

2015-2020

nEXO, DarkSide-20k, NuPRISM, HK

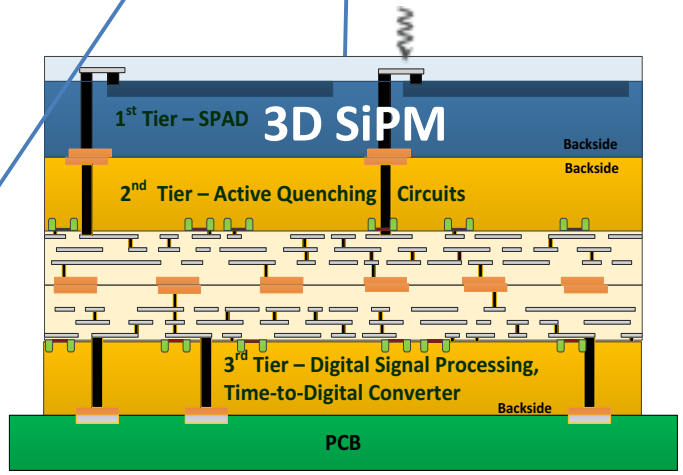
Complete projects

2010-2020

T2K, PET, fluorescence, uSR, ALPHAg, …

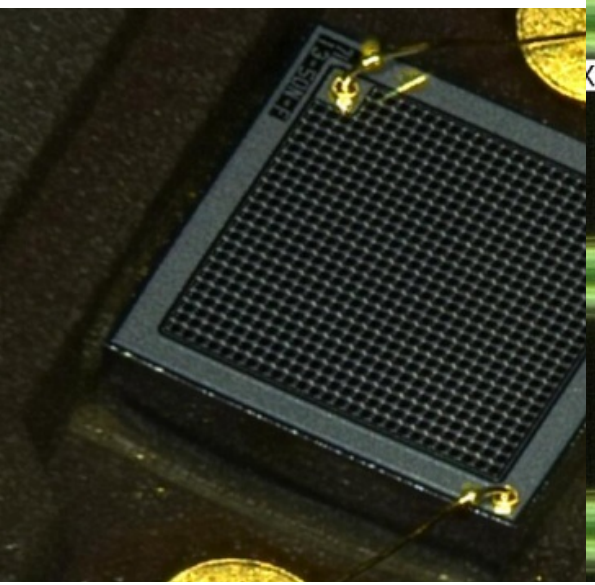
2020-2030

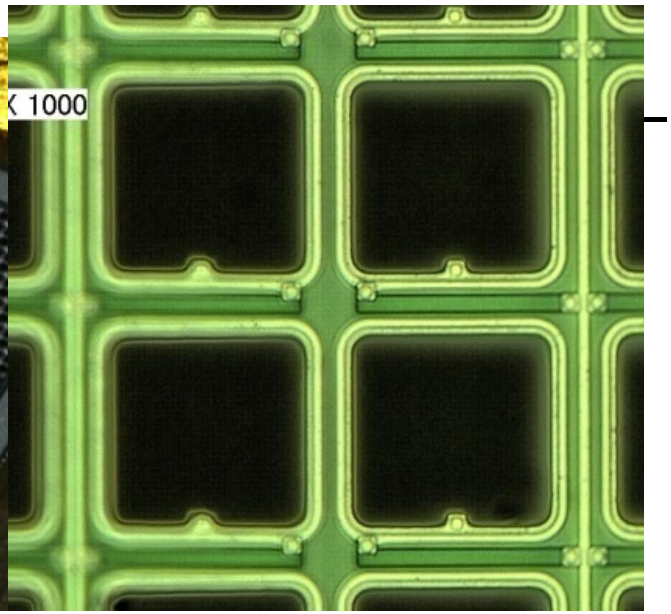
TOF-PET, LIDAR, Container scanner,…



Single photon detector types

- SiPM
  - Photo-detection efficiency up to 50%
  - Dark noise 100kHz/mm2 at 20C, 0.1Hz/mm2 at -100C
  - Timing ~100ps
    - Digital SiPM promise 10ps
  - Insensitive to magnetic field, low radioactivity





- Vacuum/gas
  - Common features
    - photocathode, Max QE ~40%, Dark noise ~10Hz/cm^2
    - Sensitive to magnetic field
    - Fairly radioactive
  - PMT
    - High gain, timing>100ps
  - Micro Channel Plate
    - High gain, timing <100ps, expensive
  - Gas gain
    - Moderate gain

- Neutrino-less double beta decay in nEXO
  - Only SiPMs viable because PMTs too radioactive
  - 175nm sensitivity required
  - 4-5 m^2 with very stringent power dissipation requirements
- Dark matter search (LUX/LZ, XENON, DARWIN)
  - Too high dark noise to meet low mass WIMP search requirement
- Search for Coherent neutrino scattering
- Positron Emission Tomography
  - XEMIS at Subatech (Nantes, France)

Liquid Argon application

- Dark matter search in DEAP-3600, DarkSide-20k and next generation 100t+ detector at SNOLAB
- 8 m^2 with 255 8” PMTs in DEAP-3600 (operating)
- 15 m^2 with SiPMs for DarkSide-20k (final design)
- 100 m^2 required for 200t single phase LAr detector (concept)
  - SiPM compelling thanks to low radioactivity, high granularity, timing resolution, cryogenic operation, compact, but what about $$$?

Water Cerenkov & liquid scintillator applications

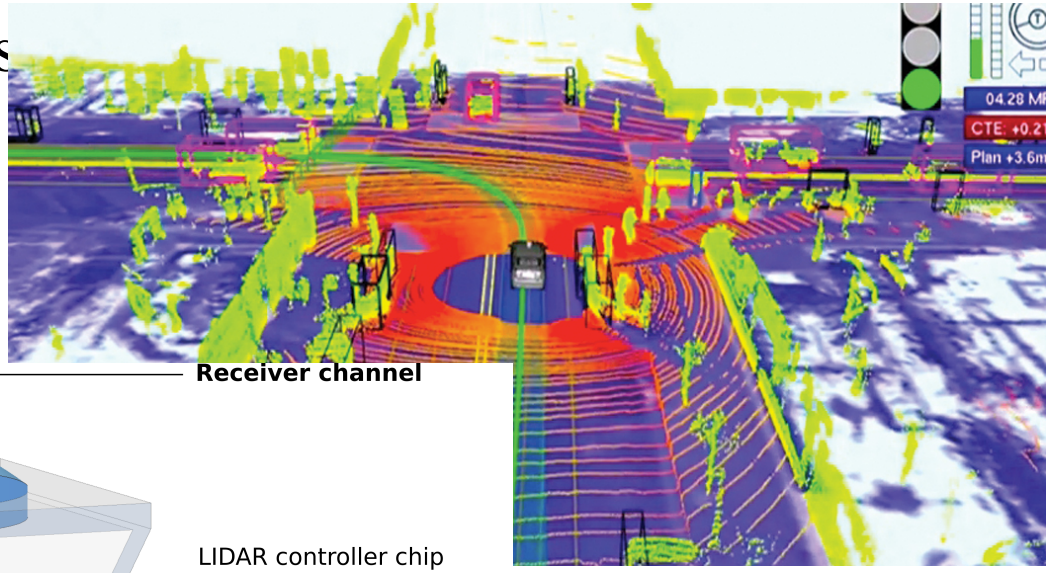
- Water Cerenkov: NuPRISM, Hyper-K, IceCube, water shields (DEAP, nEXO)
- Liquid scintillator: SNO+

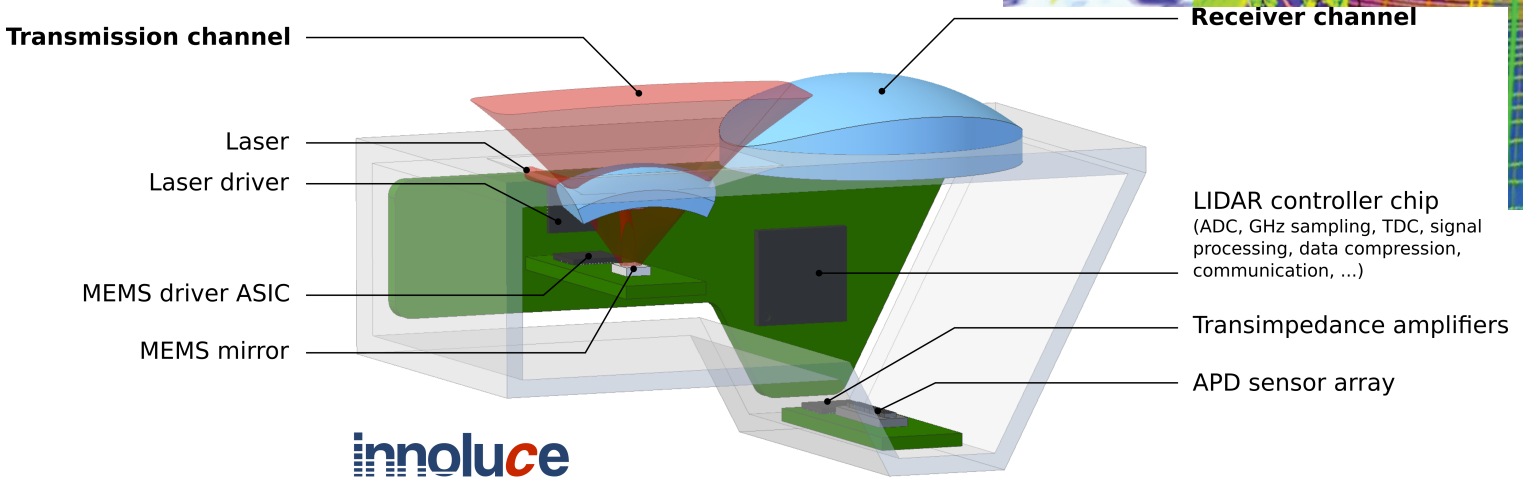
- SiPMs have too much dark noise
- PMTs only viable solution but
  - Expensive
  - Limited efficiency
  - Is there a way to build better/cheaper PMTs?

- SiPMs are replacing PMTs
  - For applications in magnetic field, compact, rugged,
  - Limitation
    - Dark noise in some case
    - Requiring some amplification and voltage distribution. Hoping to address this issue with the help of CPARC
- Small SiPM projects at TRIUMF
  - μSR spectrometer
  - ALPHAg barrel scintillator
  - PET-MR with U.Manitoba, UBC and McGill
  - Possible future project: βNMR, Compton shield for TITAN, TOF detector at ISAC

Commercial applications

- TOF PET revolution
  - 10 ps ~ few mm
- LiDAR
  - High precision (10ps~mm)
  - High rate
  - Possible imaging capabilities
  - Huge market: self driving cars, wearable,…
- Possible defense applications
  - Recent contacts with DRDC following our February application



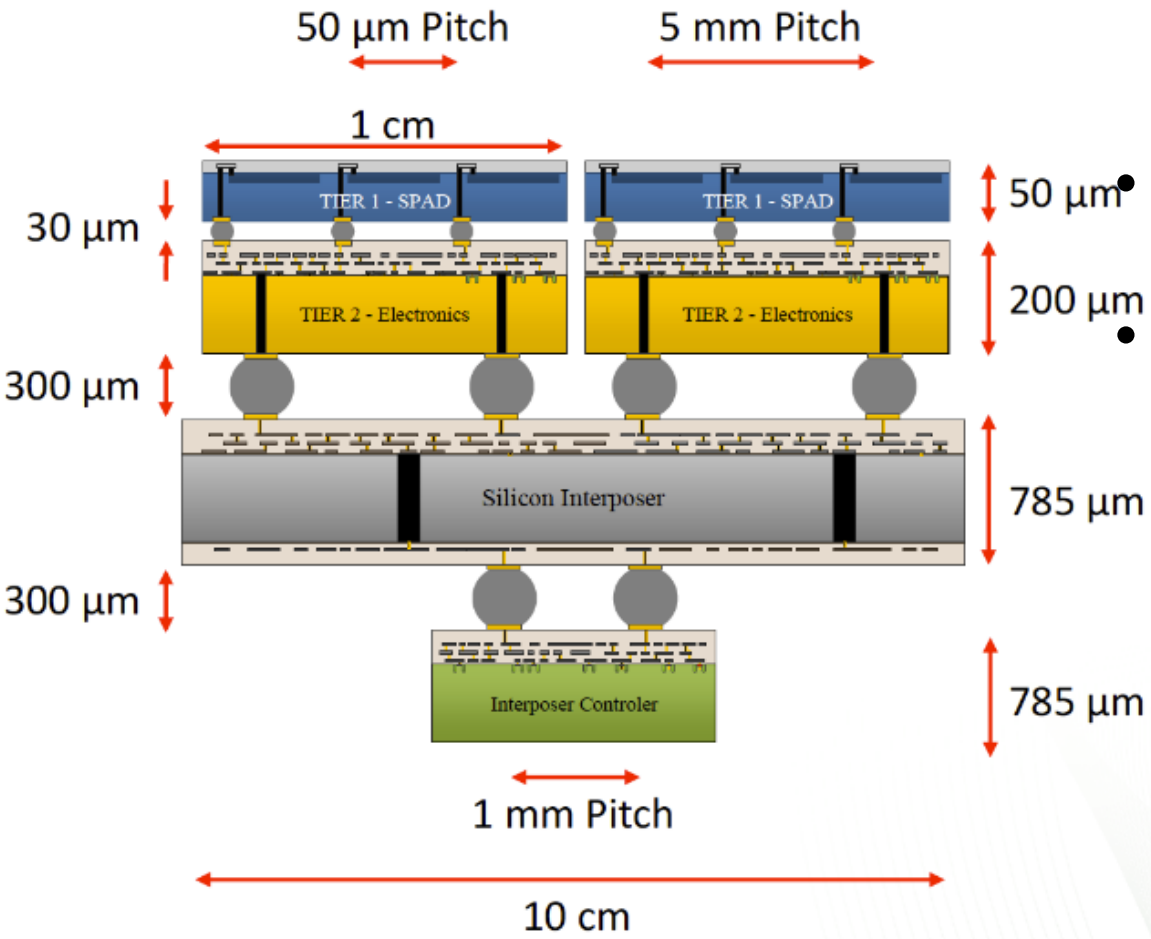


Working towards technological breakthrough(s)

- Aim
  - 100% efficiency
  - <10ps single photon timing resolution
  - Imaging capability
    - 1000 pixel per mm^2 for now
  - Manageable dark noise

- Solutions:
  - 3 dimensional integration
    - Tailor photo-detection (doping profile)
    - Tailor electronics
  - Tailored interference filter (anti-reflective)
  - Hybrid solution
  - Characterization tools

3D integration

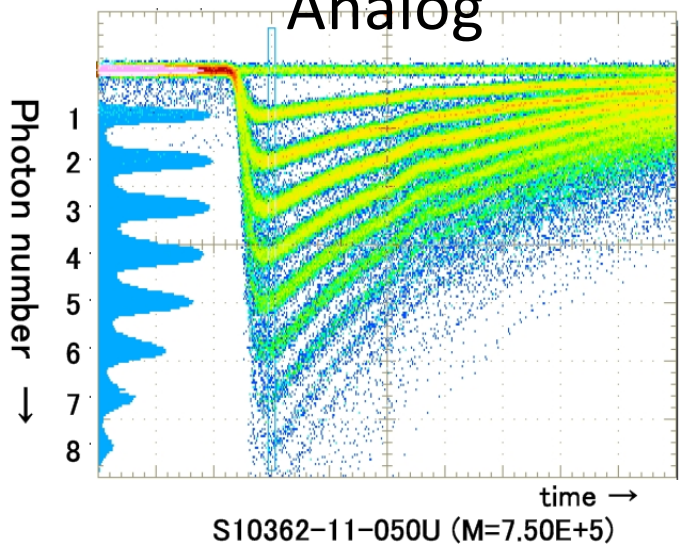


McGill – TRIUMF - Sherbrooke collaboration

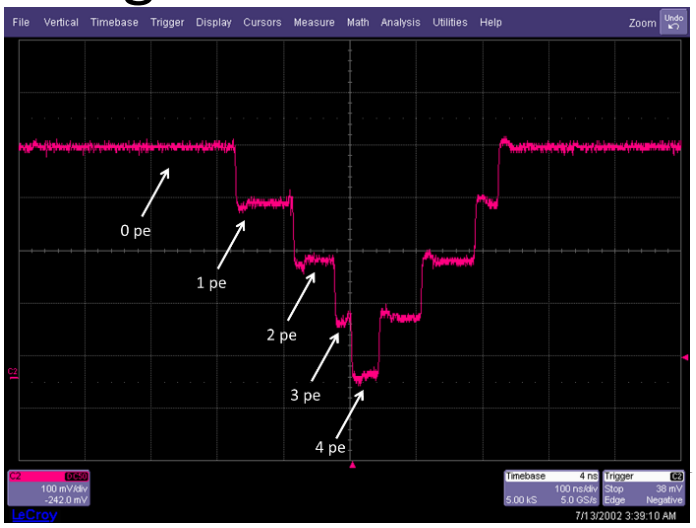
Tailored photo-detector and electronics

- VUV and low power for nEXO and beyond
  - Expecting ~1.5M$ to Sherbrooke from CFI through Carleton
- 10ps timing resolution for TOF-PET
- IR and imaging for LIDAR

Analog



Digital



- Anti-reflective coating
  - At 175nm, 65% of the photons are reflected on Silicon without AR coating
- Bandpass filter
  - Separate scintillation and Cerenkov light
    - Detection of Cerenkov photon in liquid Xenon
  - Separate Cerenkov light and wavelength shifted light
    - Photon traps for Hyper-K

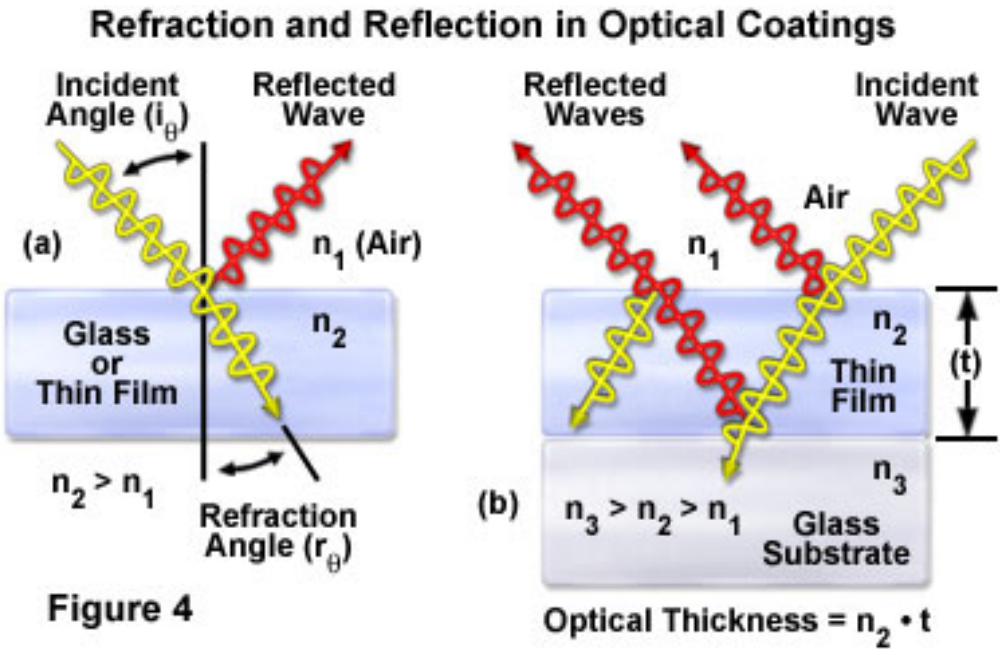
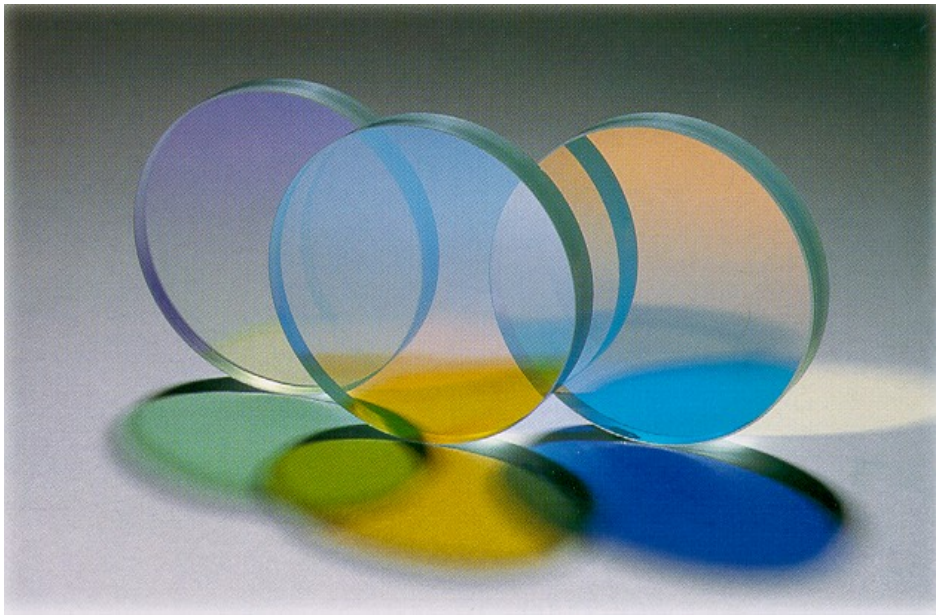
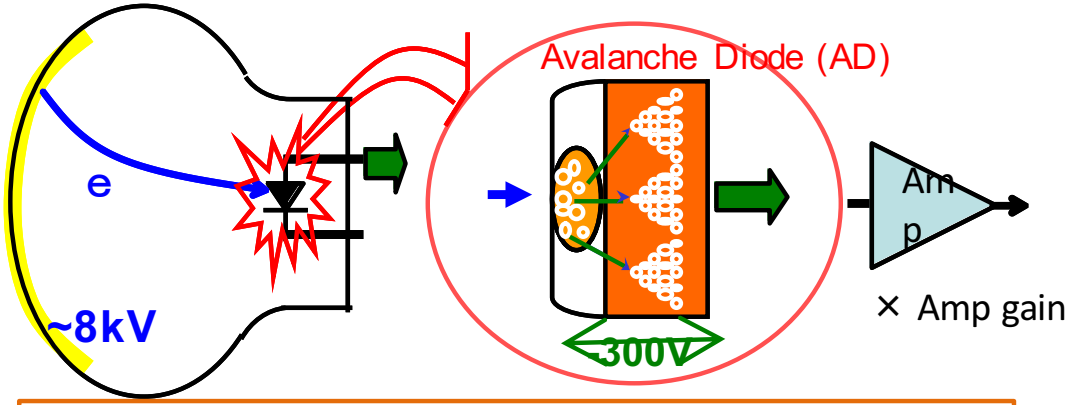


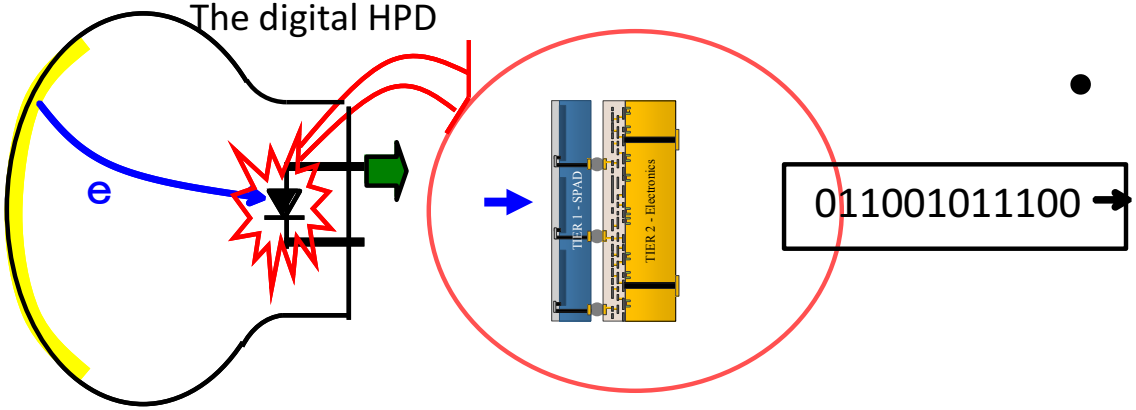
Figure 4



Analog HPD from Hamamatsu, Tokyo & Kyoto University



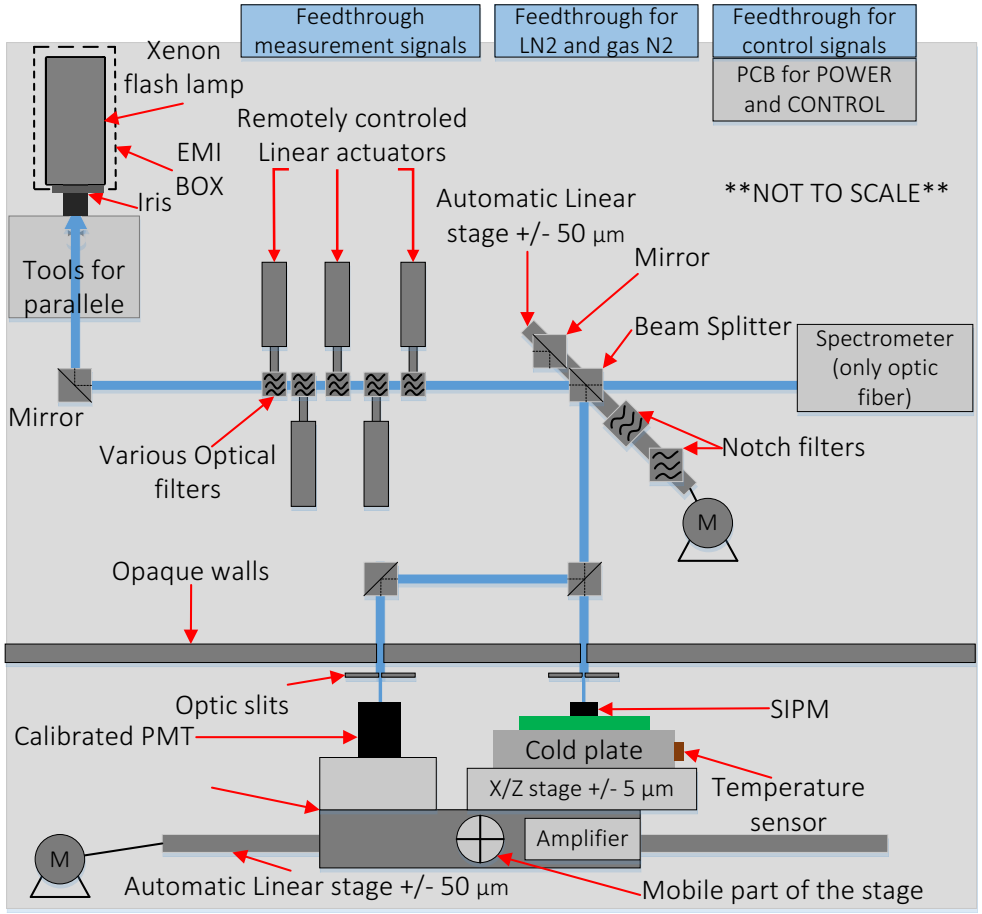
The digital HPD



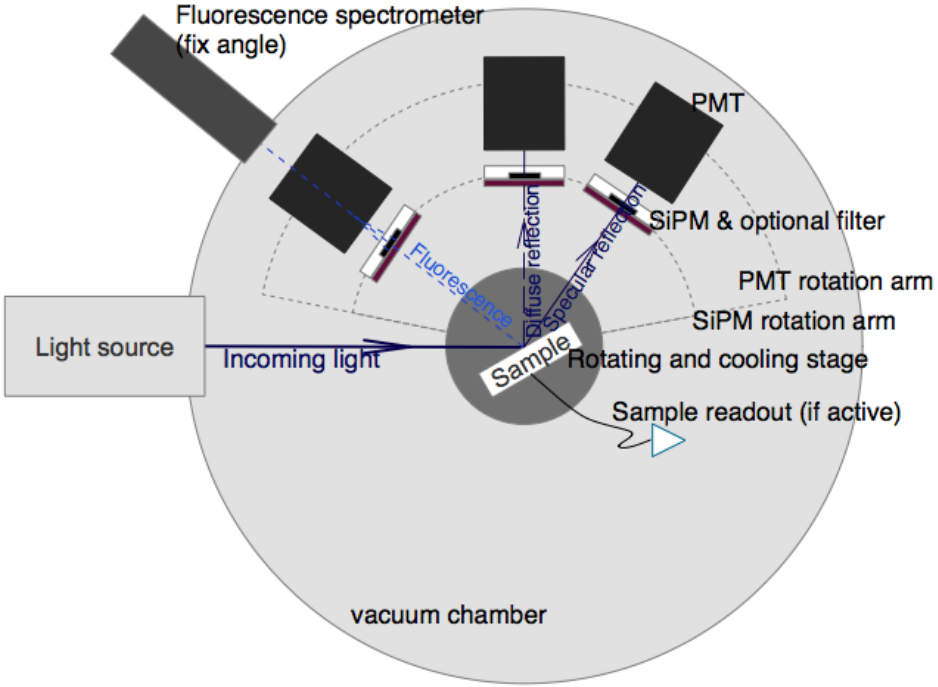
- Motivations
  - Much lower dark noise than SiPMs
  - Aim to be much cheaper than PMTs
  - Low gain fluctuation, high collection efficiency
- Our strategy: digital HPD
  - Rely on 3D integration
  - Collaboration with Alberta and Sherbrooke

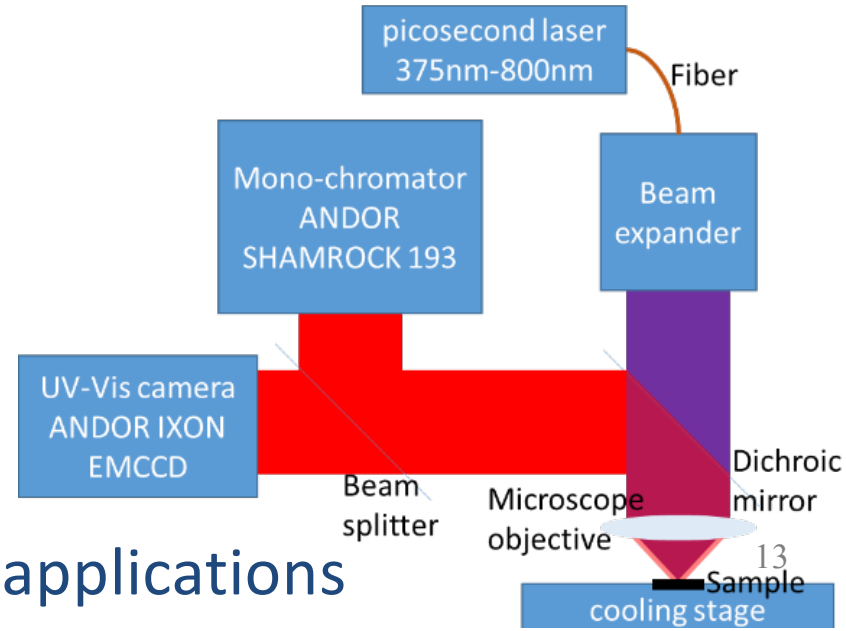
Photo-detector characterization tools

- PMT testing facility
- Current setup in operation (NSERC nEXO)



- Two new setups

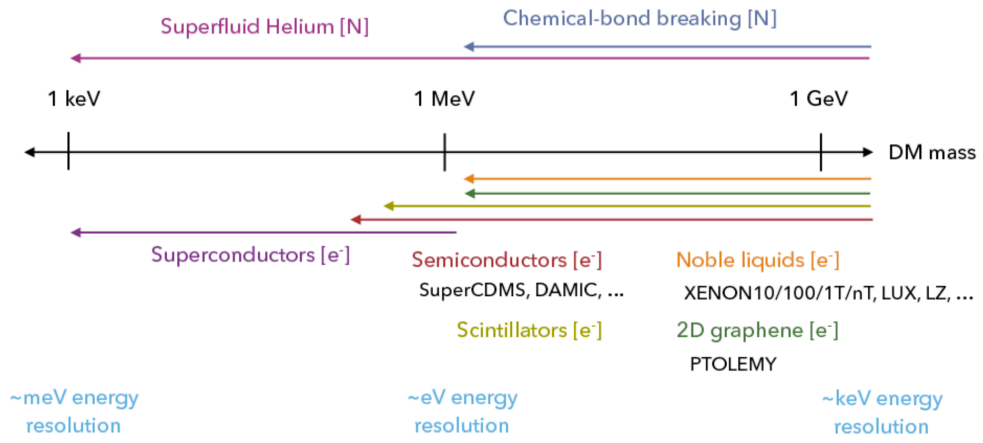




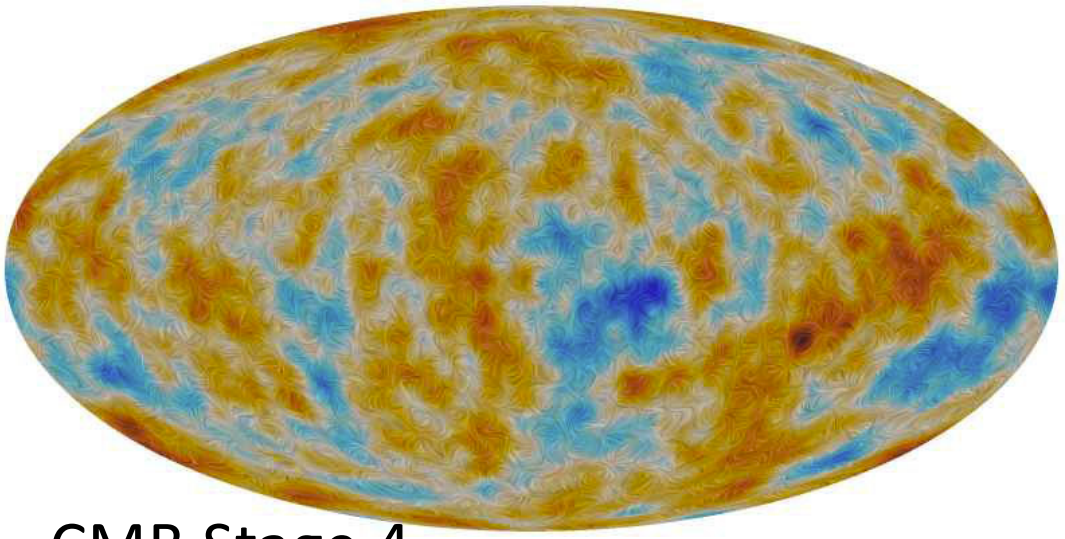
Need space and P&S to support this work & help with CPARC or commercial applications

- Sub-GeV DM searches need new detector technologies:

Stolen from David's talk



[Alexander *et al.*, Dark Sectors Community Report 2016]



CMB Stage 4

- Motivation
  - Low mass dark matter
  - CMB polarization and higher modes
    - Neutrino and dark matter physics
  - To some extent some "low energy physics" in UCN and ALPHAg
  - **A long term trend???**
- Expertise at TRIUMF
  - Some in cryogenic system
  - None (?) in SQUIDs
  - Some in RF detector
  - **Should we be involved???**

Science Technology department: technology development

- Photo-detector ➡ ILIDD Institute for Light and Ionizing radiation Detector Development
  - PP applications: nEXO, DEAP, SNO+, T2K, ALPHAg,
  - Expertise: SiPM, PMTs ➡ 3D integration, …
  - Synergies: NP, CMMS, commercial (LIDAR, PET) applications & charged particle detection applications
  - *Need from TRIUMF: support new facility (manpower and space) and commercial spin-of*
- Low energy physics
  - PP application: SuperCDMS, ”UCN”
  - Expertise: some cryogenic ➡
  - Synergies: astrophysics (UBC), commercial
  - *Need from TRIUMF: enhance cryogenic group, support research*
- On the fly data processing
  - PP applications: ATLAS, DEAP
  - Expertise: FPGA, networking, CPU ➡ ASIC, GPU, system, algorithm
  - Synergies: computing cluster, NP, astrophysics, commercial
  - *Need from TRIUMF: system computing, space for engineers*

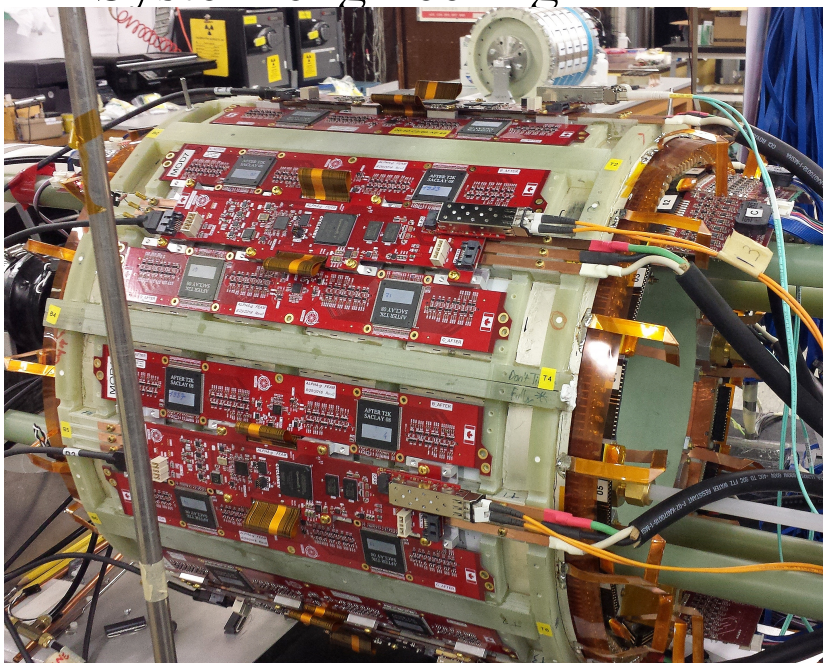
- Characterization / development infrastructure
  - Photo-detector, solid-state, and generic
- Detector and system design
- Special material machining
- In-house assembly
  - Quality assurance
- Analog and digital electronics
- On-the-fly data processing
- Data acquisition
- Project & resource management
- Working with the community

Detector characterization infrastructure

- Solid state detector infrastructure for ATLAS-Itk
  - Enabling delivering the module we committed to
- Leverage infrastructure for further development
  - The future is enhanced integration of detector and electronics
    - Timepix with CERN
    - 3D integration with Sherbrooke
  - Strong synergies with photo-detector test equipment
- Testing facility in MHESA
  - Design for gas system (easy venting)
  - Multi-purpose, also use for detector assembly
  - In very high demand
  - Too small and too dirty for twin purpose
- We need bigger and better (clean, temperature control, Faraday cage, dark space) space for state of the art development

Detector and system design

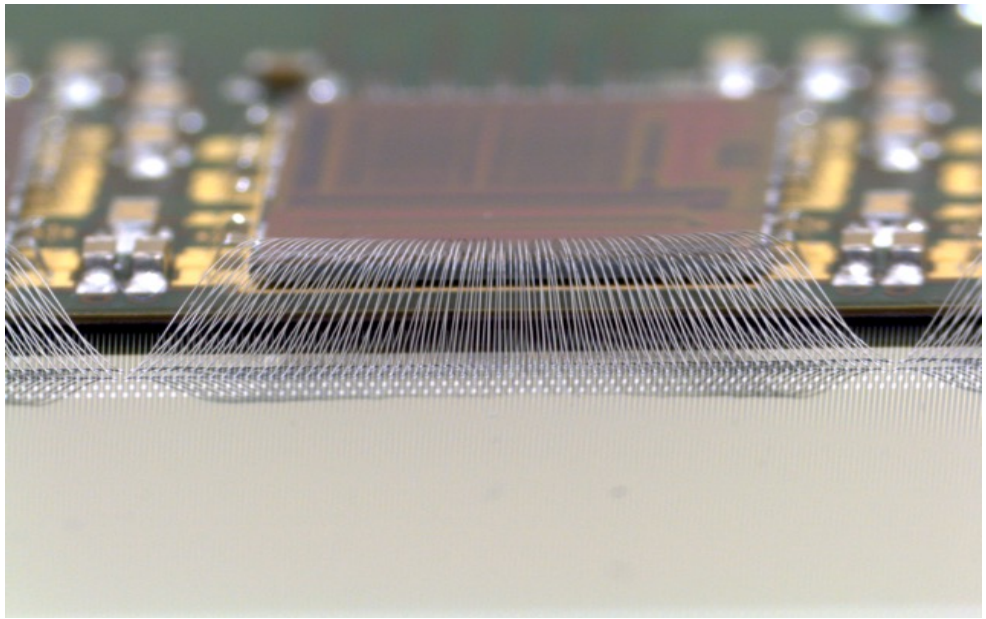
- Maintain simulation and conceptual design capabilities
  - Critical to support user with limited detector expertise
  - Need P&S support. Replace P. Gumplinger
  - BAE cannot support detail design outside their research
- Nurture expertise in Detector facility group
  - Ability to design complete cutting edge solution
    - E.g ALPHAg TPC
  - Retain expertise in gas detector
- Expand expertise
  - Cryogenic systems
    - Enhance support of UCN
    - Opportunities in “low energy” physics & astro-physics
  - Low mass mechanical system
    - ATLAS-ITK
    - nEXO photo-detector plane
  - System engineering



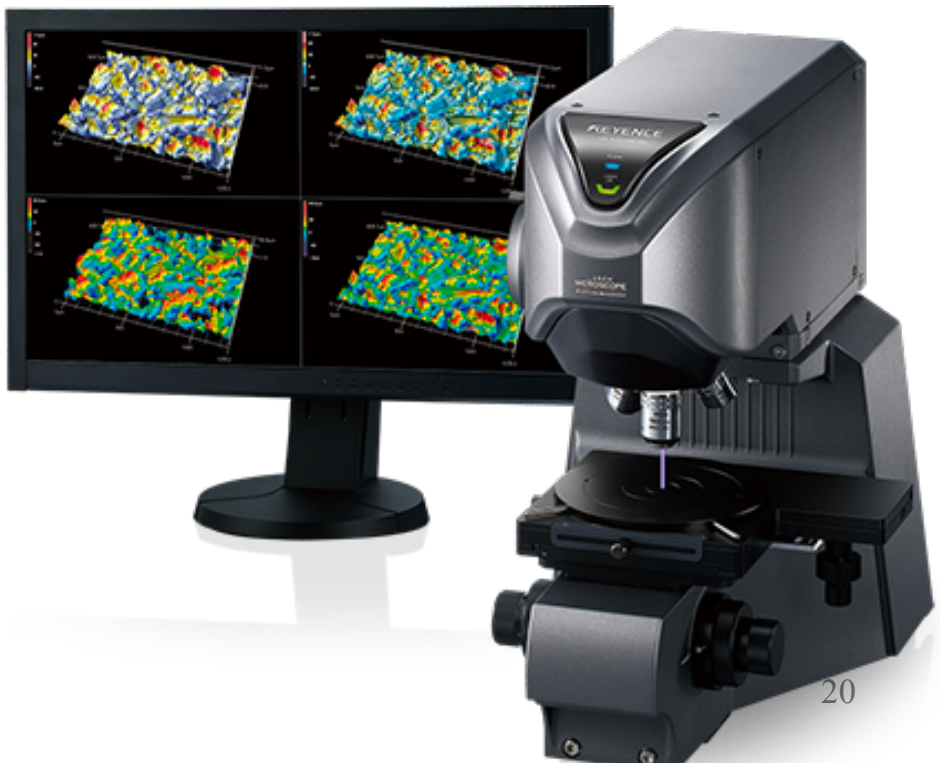
- Strategy
  - Nurture expertise in manufacturing tools: CNC, 3D printing
    - Outsource whenever possible
    - Develop local and international contact
  - When not possible develop specific material machining expertise: Ceramic, G10, …
- Facility. scintillator shop
- Upgrade needed:
  - CNC lathe
  - 3D printer for developing expertise
  - Equipment for handling carbon fiber
  - Equipment for handling quartz
    - Laser cutter for mill
  - Scintillator shop renovation

In-house assembly

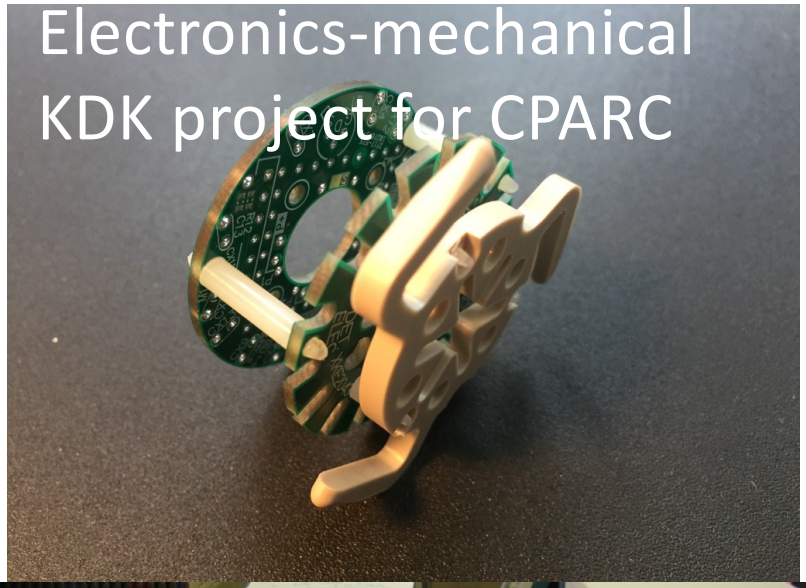
- New clean room
  - Meeting specifications for ATLAS-ITK assembly
  - Wire bonder and associated equipment for module and petal assembly
- Large clean room
- MHESA
  - Shared with testing infrastructure

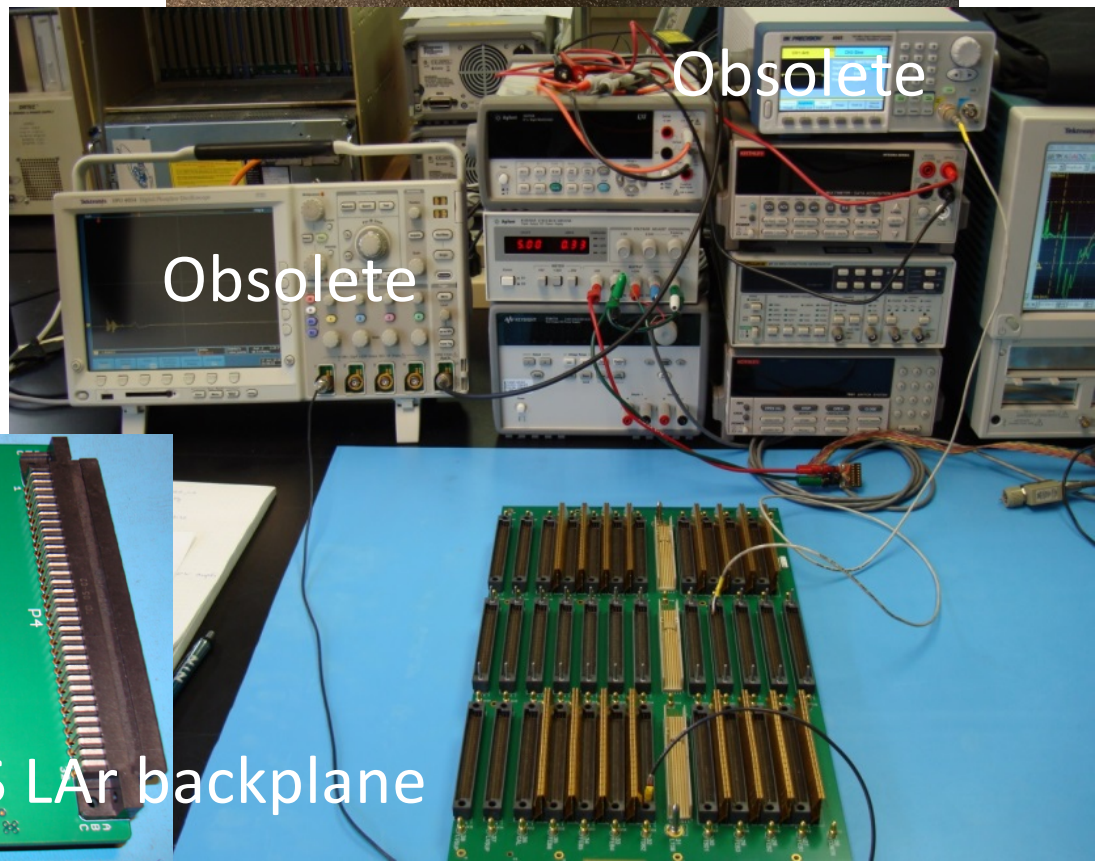


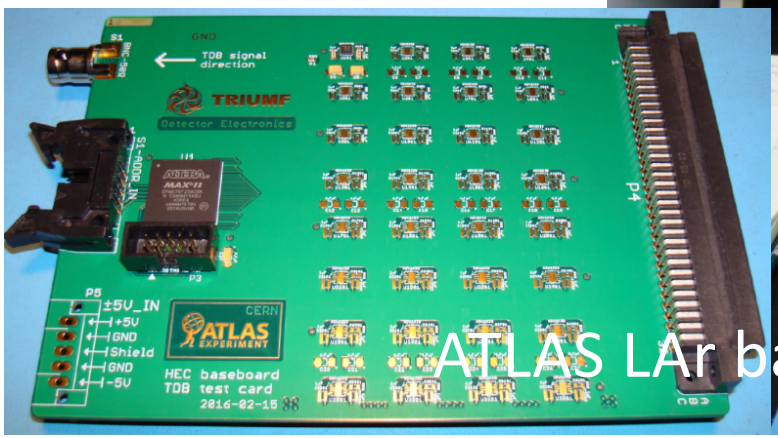
- Quality assurance equipment
  - Probe station
  - Touchless coordinate Measuring Machine (CMM)
  - Metrology microscope
  - Upgrade:
    - Touch probe CMM



- Delivering analog solutions for many projects
  - ATLAS, ALPHAg, μSR, …
- Recognized contribution to ATLAS
  - L. Kurchaninov convener of ATLAS LAr front end electronics group
- Developing ASIC design capabilities through CFI
- Using aging equipment
  - Especially obsolete oscilloscopes and pulser

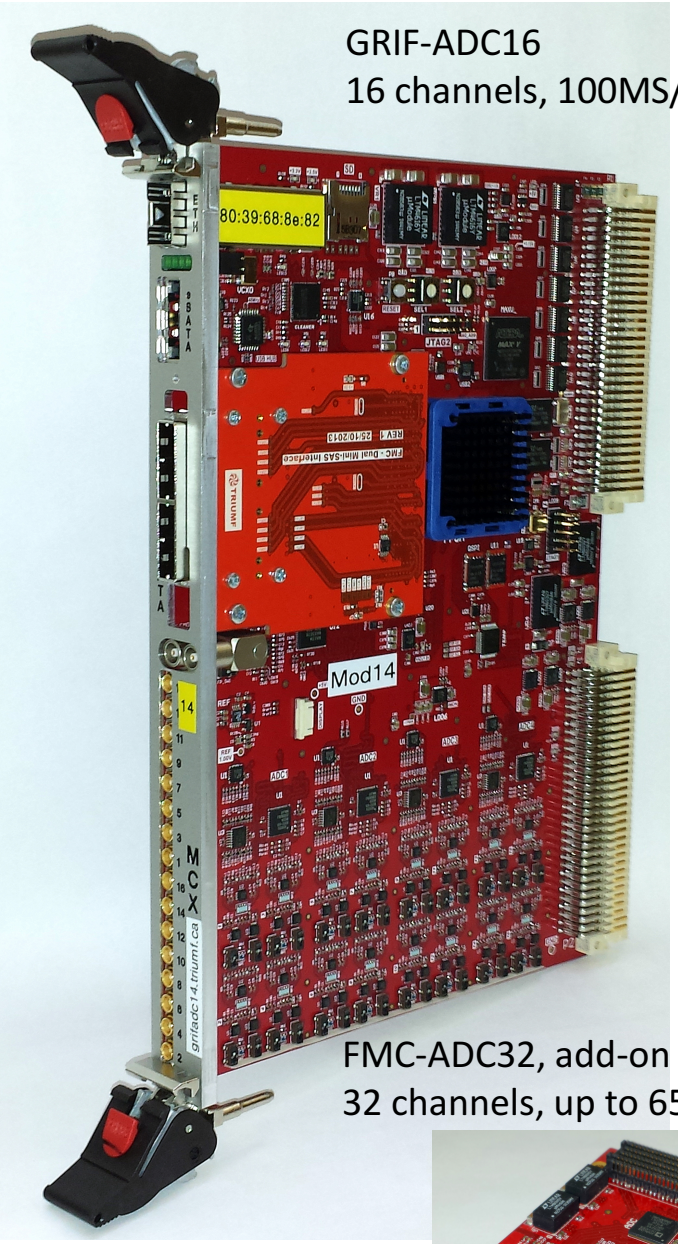






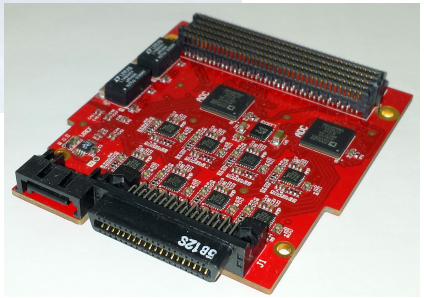
ATLAS LAr backplane

Analog & digital electronics

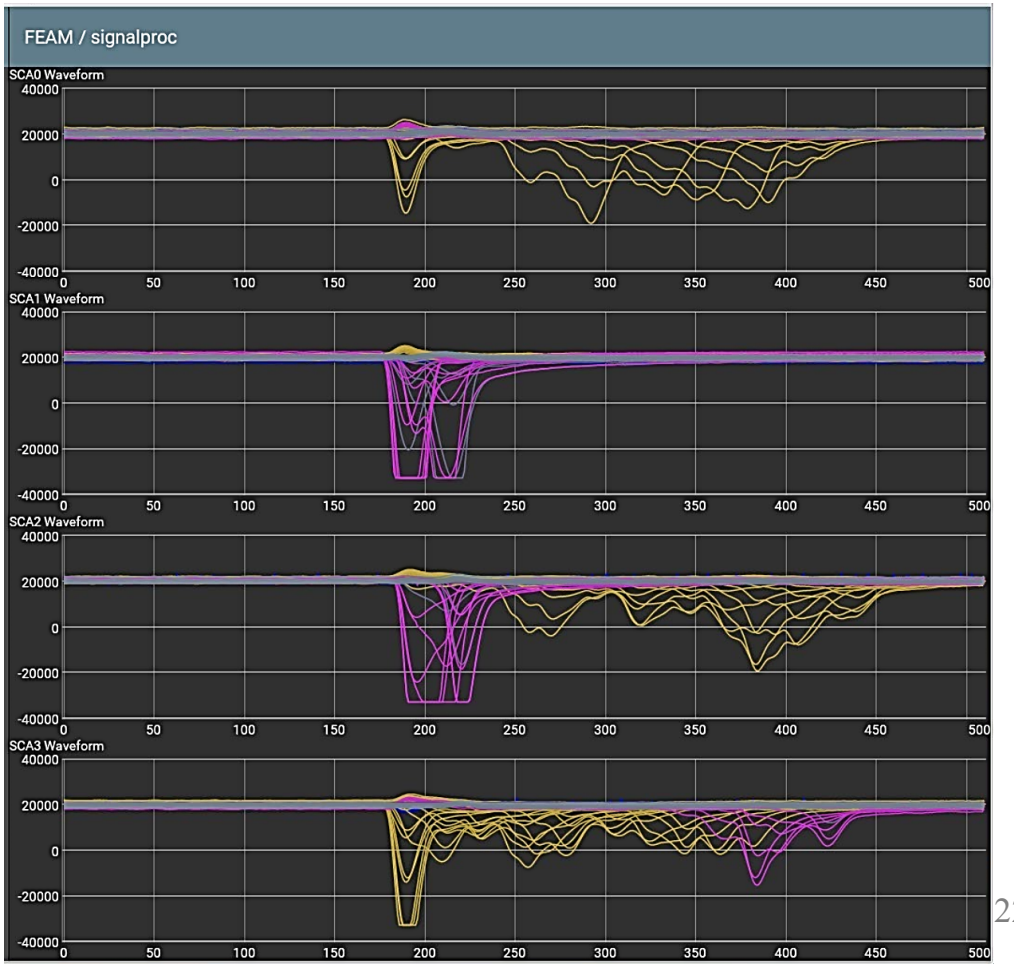


GRIF-ADC16
16 channels, 100MS/s

FMC-ADC32, add-on for GRIF-ADC16
32 channels, up to 65MS/s



- Strong synergies between Particle Physics (DEAP, ALPHAg) and Nuclear physics (GRIFFIN, TIGRESS)
- High demand for analog and digital electronics and for FPGA development
- Groups are being strengthened: 1 tech and 1 eng. (CPARC)
- Commercial opportunities



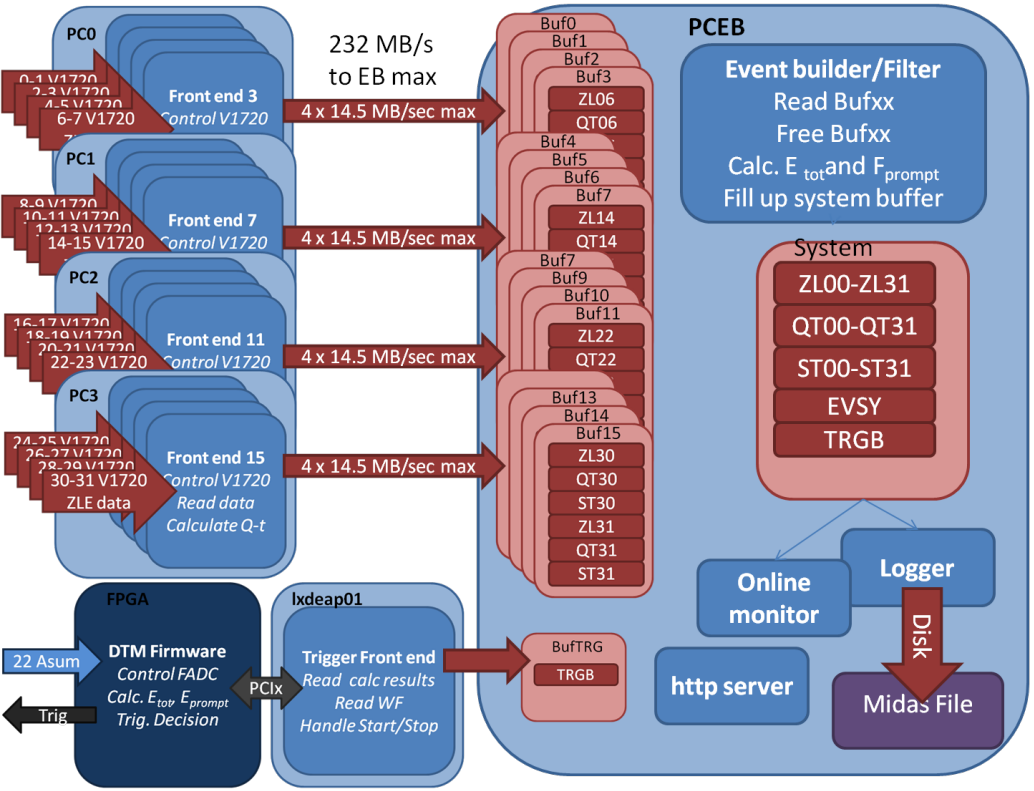
On the fly data processing

- Advent of digitizers leads very large data throughput
  - CHIME, CMB S4: ~TB/s
  - ATLAS: ~TB/s
  - GRIFFIN: 300MB/s
  - DEAP-3600: 300MB/s ➡ 5MB/s
- On the fly data reduction highly desirable
- Highly relevant for commercial applications

- Solution
  - FPGA. Very powerful and versatile
    - Need highly specialized expertise. 3 developers at TRIUMF currently.
    - Digital ASIC for enhance performance or low cost
  - Networking (pushing data at high speed)
    - One expert at TRIUMF
  - Software in GPU
    - Somewhat specialized
  - Software in CPU
    - "Anyone" can do

Compelling expertise to nurture and enhance
Provide associated computing infrastructure
Connection to computing cluster

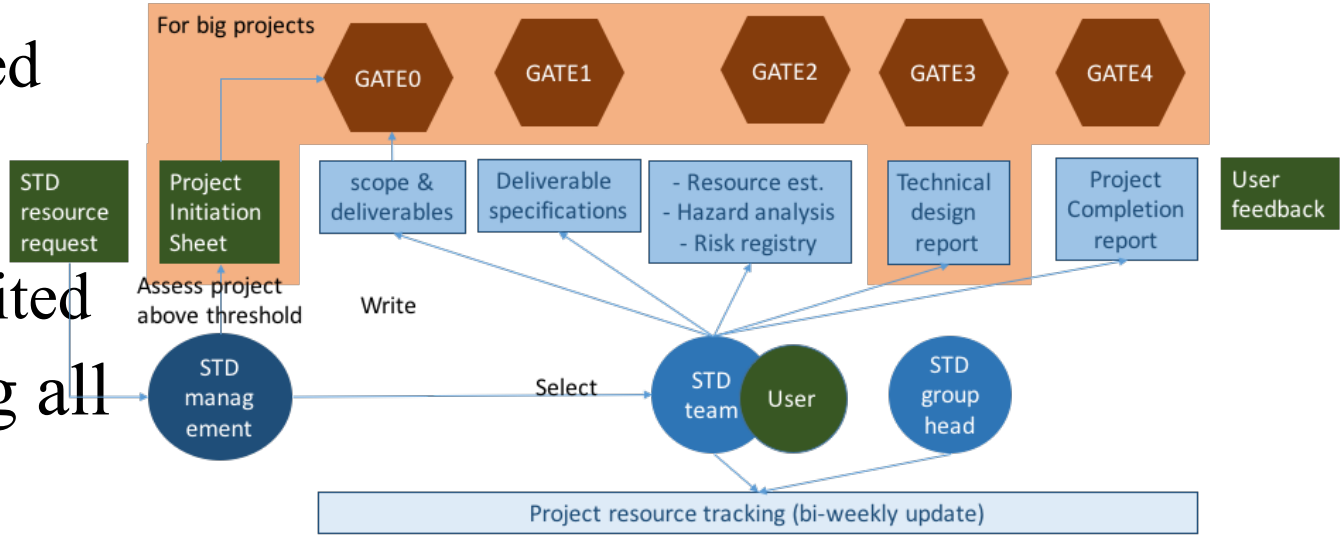
- Using MIDAS as a single platform
  - Scalable system

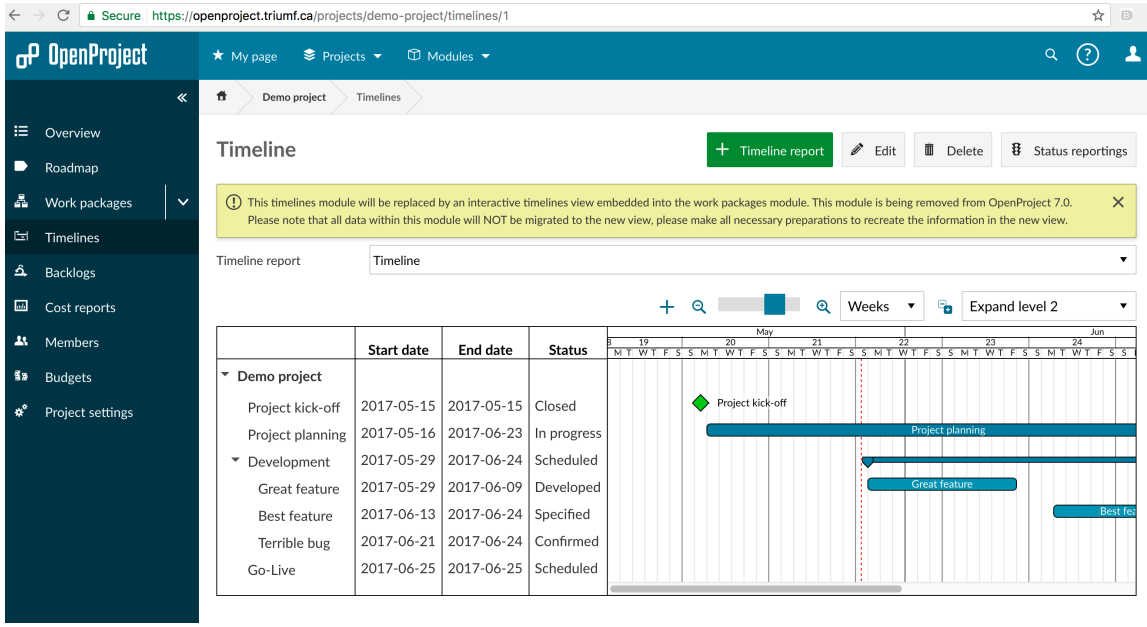


- Implemented for T2K, DEAP-3600 and SuperCDMS
- Supporting essentially all the experiments at TRIUMF
- And providing storage, backup and some computing capabilities
  - Tie up with proposed computing cluster

Project and resource management

- Efficient management of large projects
  - Though reporting need improvement
  - Though space for temporary hire is limited
- Difficulty in managing all projects
  - Currently 30!
- Our team based short turn around management works well
  - Respond quickly to technical issues
- Developing solution for resource management





Connecting to the community

- Internally at TRIUMF
  - Commercialization ➡ TRIUMF innovation
  - Nuclear physics ➡ Enhance sci tech dept contribution to nuclear physics
  - Accelerator and engineering divisions ➡ tackled specific projects
  - Project/resource management ➡ Enhance visibility to community and documentation
- Externally
  - In Canada:
    - MRS: enhancing our connections (participating to MRS boards)
    - Targeted collaboration to address technical challenges: Sherbrooke for 3D and ASIC, Alberta for dHPD, UBC astronomy for on the fly data processing
  - International
    - Should also connect with labs for specific development

Summary and outlook

- A strong development program with compelling applications
- New infrastructure enabling silicon vertex detector construction
  - And future silicon detector development
- Outstanding technical expertise in charged particle detector and associated electronics
  - Benefitting many projects
  - And future projects: ATLAS, UCN, photo-detector, μSR, PICO?

- We lack space
  - Testing and office space
- We lack equipment
  - Last major investment more than 10 years ago
  - Working towards next CFI IF competition: multi-institution (overall SAP technical support) discovery enabling infrastructure
- We lack specific manpower
  - Detector development infrastructure operation
  - Connection to nuclear physics
  - Commercial applications
  - (online) computing infrastructure
  - Project management and reporting (new software may alleviate need)

TRIUMF

Canada's national laboratory
for particle and nuclear physics
and accelerator-based science

TRIUMF: Alberta | British Columbia | Calgary | Carleton | Guelph | Manitoba | McGill | McMaster | Montréal | Northern British Columbia | Queen's | Regina | Saint Mary's | Simon Fraser | Toronto | Victoria | Western | Winnipeg | York

Thank you!
Merci!

Follow us at TRIUMFLab

History in photo-detector development

- 2004-2007 SiPM R&D for T2K
- 2007-2009 T2K FGD construction with 8848 1.3x.13mm2 Hamamatsu MPPC, including electronics
  - FGD in operation since 2009
- 2009-2015 electronics for reading out DEAP-3600 255 PMTs
- 2010-2014 SiPM for PET
  - Contribution to micro-PET MR insert at U.Manitoba completed in 2015
    - Commercial product
- 2012-now development of SiPM based muSR spectrometers
- 2014-now operation of PMT testing facility funded by H. Tanaka CFI
- 2014-now development of SiPM for nEXO (175nm, 5m2)
- 2015-now development of mPMT for νPRISM, IceCube and HK
- 2015-now development of 3DdSiPM with U.Sherbrooke

Capabilities at TRIUMF (Sci. Tech. Dept)

- Instrumentation physics group (conceptual design and R&D)
  - 3 physicists (2 grant eligible)
  - CPARC funded technician/engineer being hired
- Detector facility group (detector design and construction)
  - 4 engineers/physicists & 2 technicians
  - Scintillator shop: 1 engineer & 2 machinists
- Detector electronics group (focus on analog electronics)
  - 2 engineers & 1 technician + 1 CFI funded technician (ALPHAg)
- Electronics development group (focus on digital electronics)
  - 3 engineers + 1 temp. engineer and 1 temp. tech
- Data acquisition group (also helping with project management)
  - 5 engineer/physicists + 1 CFI funded physicist (ALPHAg)
- Scintillator shop
  - Machine shop with focus on non-metallic machining (G10, acrylic,…)
  - CNC mill, lathe, large CNC router,…
- Clean rooms
  - Large clean room
  - Upgraded clean room for silicon detector assembly (ATLAS Itk)
- Testing facility
  - Designed for handling flammable gas
  - Partial renovation planned for photo-detector testing
  - PMT testing facility (funded by H. Tanaka CFI)
  - Beam line for detector test (M11)

Projects

Sci Tech Dept projects

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	A	B	C	D	E	F	G	H	I	J	K
1	**Project**	**TRIUMF com-mitment #**	**TRIUMF gate level**	**Link to STD request**	**Risk driver**	**Request date**	**Desired completion date**	**Actual completion date**	**Requester**	**STD manager**	**Status**
2											
3	**CMMS**										
4	3T spectrometer	P150	Gate 1	None	Scope	2013			S. Kreitzman	M. Constables	Planning
5											
6	**Accelerator**										
7	ARIEL2 beam monitoring elec	Needed	ARIEL2 Gate	None	Time & money	11/01/17			E. Guetre	D. Bishop	Planning
8	ARIEL2 beam line installation	Needed	ARIEL2 Gate	None					E. Guetre	C. Lim	Definition
9	ARIEL2 yield station	P355	ARIEL2 Gate	None					E. Guetre	I. Nikonov	Initiation
10	Magnetometer maintenance	Needed		None					Needed	A. Sorokin	Op. support
11	eLinac MPS electronics	P363		None					M. Alcorta	L. Kurchaninov	prototyping
12	Vertical injection line								Needed	A. Sorokin	
13											
14	**Particle physics**										
15	ALPHAg TPC	P344	Gate April 25/17	None	Time?		Oct 2017		M. Fujiawara	PA Amaudruz	construction
16	ALPHAg cosmic veto	P344	Gate April 25/17	None	Scope		Mar 2018		M. Fujiawara	PA Amaudruz	Construction
17	ATLAS LAr R&D. Diamond sensors for mFCal	P246	Completed	None		2010		2013	R. McPherson	L. Kurchaninov	Completed
18	ATLAS LAr phase 2	P401	Gate2	None		2016/02/04			L. Kurchaninov	L. Kurchaninov	Definition
19	ATLAS Itk module-0 fabrication	P401	Gate2	Part of Itk		2016/02/04	Dec 2017		Oliver Stelzer	N. Hessey	
20	ATLAS Itk	P401	Gate2	https://edev.triumf.ca/issues/1456		2016/02/04	2025		Oliver Stelzer	N. Hessey	
21	ATLAS sTGC (muon phase1)	P318	Gate3	None					Oliver Stelzer	N. Hessey	Definition
22	ATLAS LAr (Calo phase1)	P318	Gate3	None					G. Oakham	L. Kurchaninov	Production
23	MOLLER	P404	Gate 1	None		07/01/16	?		M. Gericke	D. Bishop	Pending CFI
24	Multi-anode PMT readout	O66	No Gate	https://edev.triumf.ca/issues/1437		01/10/17			A. Konaka	T. Lindner	
25	NA62 LKr Monitor	P370	No Gate	https://edev.triumf.ca/issues/1453		03/23/17	09/01/17		D. Bryman	L. Kurchaninov	Initiation
26	NuPRISM (mPMT)									R. Henderson	
27	UCN	Needed	Needed	None					B. Franke	B. Franke	
28	S1249 in M15	P196	No Gate	https://edev.triumf.ca/issues/1452		03/15/17		07/11/17	G. Marshall	K.Olchanski	
29	T2K operational support		No Gate							R. Henderson	Op. support
30											
31	**Nuclear physics**										
32	DRAGON hybrid ionization chamber	Needed	Needed	https://edev.triumf.ca/issues/1405		07/13/17			C. Ruiz	R. Henderson	
33	DRAGON DAQ	Needed	Needed						C. Ruiz	PA. Amaudruz	
34	EMMA	P72	Needed						B. Davids	R. Henderson	
35	GRIFFIN electronics	Needed	Needed						A. Garnsworthy	D. Bishop	
36	SPICE electronics	O139	No Gate						A. Garnsworthy	L. Kurchaninov	
37	SPICE patch panel upgrade	O139	Operation	https://edev.triumf.ca/issues/1450		03/14/2017			J. Smallcombe	L. Kurchaninov	Move to Hubert's gr
38											
39	**SNOLAB**										
40	KDK electronics	Need PIS	Need review	https://edev.triumf.ca/issues/1451		03/15/2017	06/15/2017		P. Di Stefano	F. Retiere	Initiation
41	nEXO photo-detector	P338	No Gate	None					F.Retiere	F. Retiere	Op. support
42	VUV photo-detector testing facility	P408	Gate1	None					F. Retiere	F. Retiere	Pending CFI
43	SuperCDMS										

- Collecting all the information in one central (temporary) location

- … Only statistics because the list is too long
- Accelerator
  - 4 ARIEL (electronics, installation, mechanical design)
  - 2 cyclotron operation (magnetometer maintenance, vertical injection line)
- Physical science
  - 15 particle physics (e.g. ATLAS, ALPHAg, NuPRISM, T2K operation)
  - 4 involving SNOLAB
  - 6 nuclear physics (EMMA, DRAGON, GRIFFIN electronics,…)
  - 1 CMMS (SiPM based spectrometer)
  - Space renovation and hiring
- Innovation
  - 1 installation of DAQ software
- Next round of CFI expected to continue bringing cash to TRIUMF

Main focus for 2017

- Manage the possible inflows of new projects
  - CFI: ATLAS phase 2, UCN, Water Cerenkov, MOLLER, photo-detector development infrastructure
  - DRDC for 3DdSiPM but in this case indirect available
  - We may get overloaded.
    - May need to make hard decisions or find a way to “please” everyone
- Focus in 2017 will be on project management
  - Management for all projects not only large ones
  - Develop software infrastructure for project workflow management
  - Strengthen our team based management style
    - Minimize segregation between tech, engineer and physicists
    - Nurture expertise within team environment
- Continue engaging Canadian community for resource management
  - One key milestone is the next CFI IF round as we will need to request funds for upgrading our aging equipment. Need a champion for CFI grant. May be pan-Canadian
    - Or include our upgrade request in next 5 year plan