BERKELEY LAB

R&D @ LBNL

RDC4 Meeting - 12.03.24

Timon Heim - LBNL
with input from LBNL Detector R&D group

Introduction

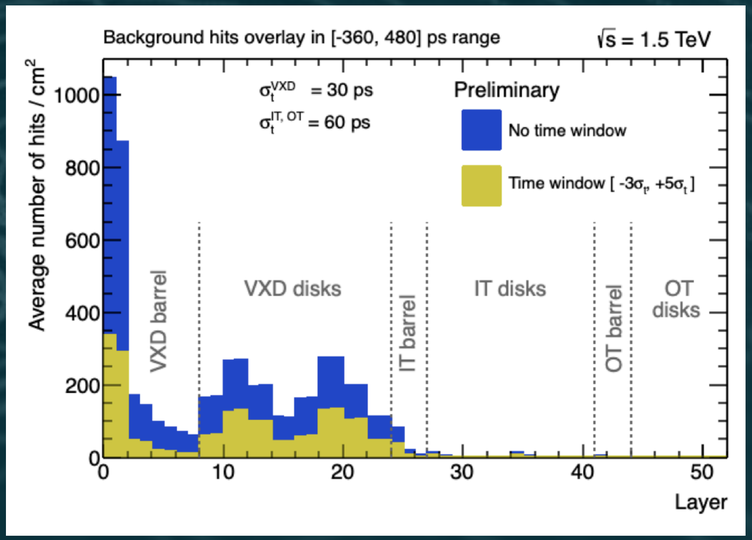
- Not covered:
  - eFPGA, AI/ML on-chip, and Skywater CMOS 180nm open source process (next week)
  - Cryogenic frequency multiplexed readout (RDC 8)
  - Novel CMOS sensors: integration of nano materials on CMOS (nanoCMOS), heterogeneous integration of sensor films on CMOS (RDC3)
  - Straw tracker readout towards mu2e-II

4D Tracking R&D

BERKELEY LAB

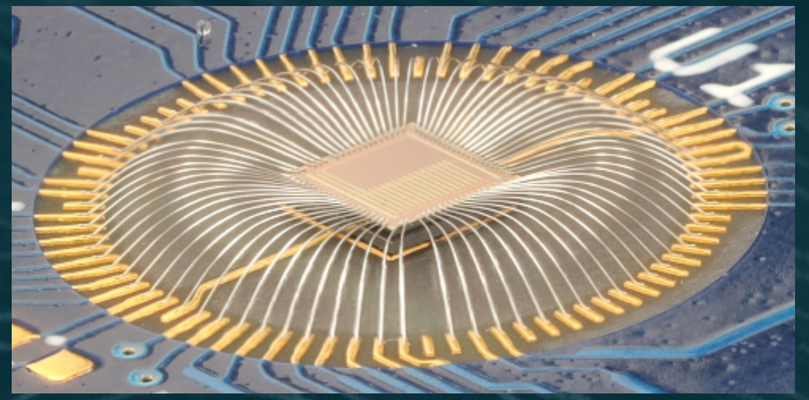
- High granularity 4D Tracking detectors key technology to unlock physics at future collider (in particular 10TeV pCM)
- Hybrid technology optimal to exploit technology to its most
- Multiple challenges to realize:
  - Fast highly segmented sensor
  - Readout ASIC with fast/low power/low noise preamp, TDC
  - On-chip data processing or advanced trigger capability
  - Data transmission
  - DAQ

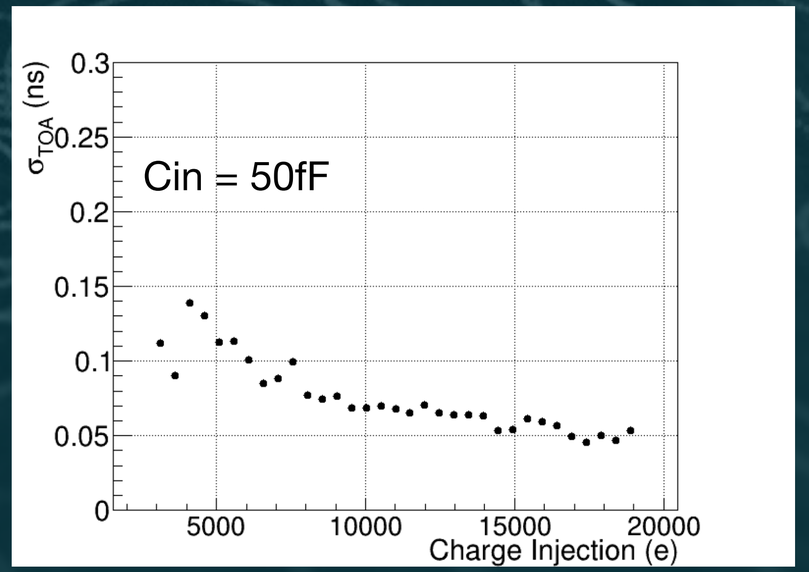
Track multiplicity at muon collider after 100ps cut and 30/60ps cut



4D Tracking R&D @ LBNL

- Started work towards 4D detectors from multiple directions:
  - SiC LGAD sensors
  - 28nm CMOS for high timing precision analog front-end and low power TDC
  - Silicon photonics ring-modulators for high speed data transmission
  - Flexible but fast DAQ for ASIC testing
- Additional interest
  - On-chip data processing (specifically in combination with detector simulation, already some on-going work for muon collider)
  - Understanding system requirements beyond single component specification





Contact: Timon Heim

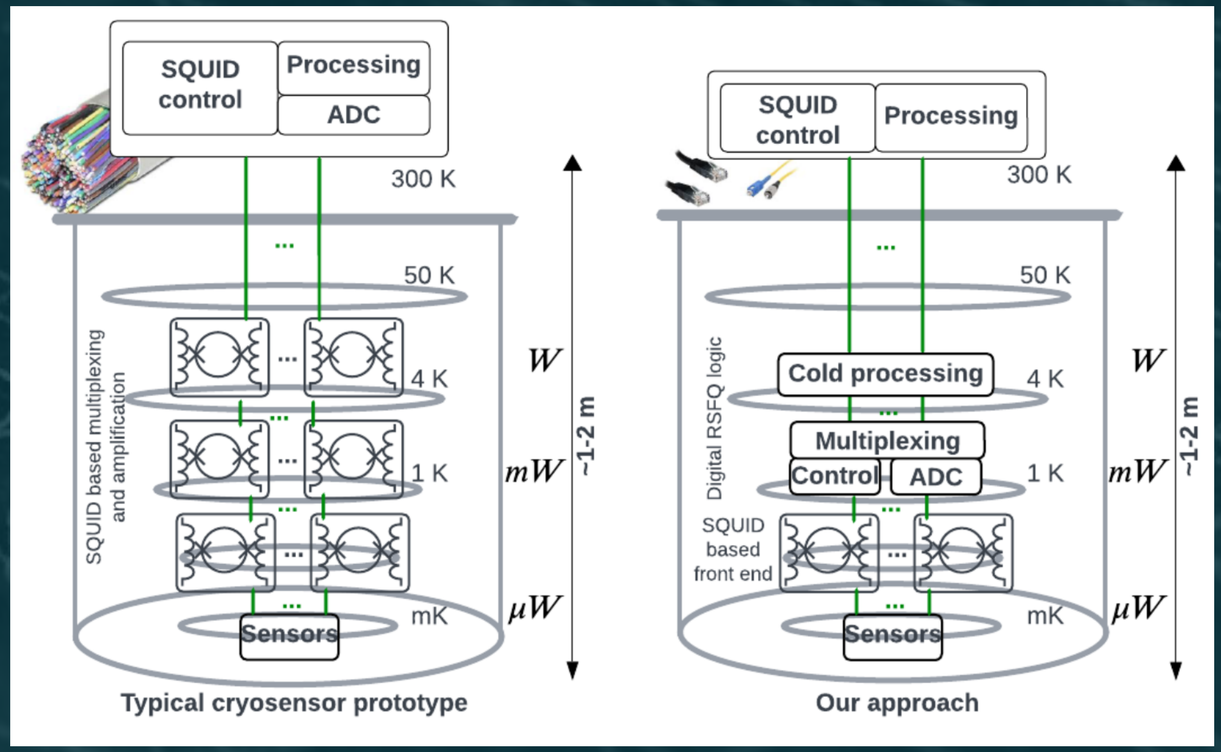
4D Tracker Work Package

- Past pixel detector ASICs often used for future sensor development (well understood environment, good testing support for bench test and test beam)
- Sensor development often precedes ASIC development
  - See advanced AC-LGAD and 3D sensor designs already capable of O(30ps) timing with high granularity
- Currently lacking ASIC with 4D tracking capability and rudimentary readout to enable realistic testing of sensor tech
- Need to actually run 4D tracking systems to understand if there are additional system requirements beyond single component specs

- Propose to build work package around building a 4D tracker testbed
  - Similar to “Timespot” effort from INFN
- At core should be a set of common requirements, that enable specific R&D direction and could naturally grow as technology advances
  - Requirements driven by a muon collider 10TeV pCM good choice as somewhat natural evolution of HL-LHC detectors
- Work package can center around ASIC development, but should also include sensor, data transmission, and DAQ component
  - Can use TSMC 28nm CERN frame contract (lots of momentum already and potential usable IPs already available through CERN)

Deep Cryo CMOS R&D

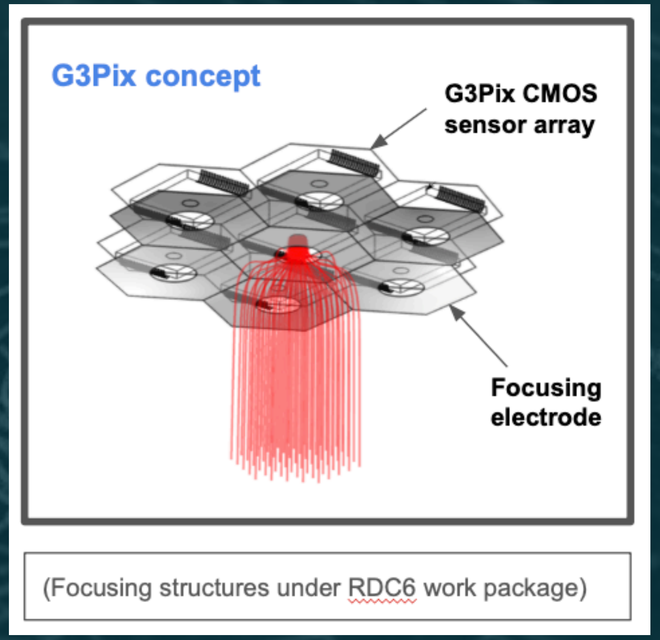
- Aims to move electronics into cryogenic environment
  - Currently working on electronics for 1K environment
  - Looking towards mK environment
- Reduces number of penetrations needed and parasitics added by long cables
- Key to useable deep cryo CMOS
  - Understand CMOS process at mK temperature
  - O(uW) power dissipation
- Known applications:
  - Superconducting sensors (TES, MKID, SNSPD, …)
  - Superconducting magnet diagnostics



Contact: Carl Grace

Single-digit electron Noise Pixel Sensors: G3Pix

- Could replace gain structures* in gas and possibly noble liquid detectors
  - Directional dark matter
  - Belle-II TPC upgrade proposal
  - G3 dark matter (replace S2 readout)
  - 0vbb
- Studied ENC vs input capacitance with PCB setup => 3 e- ENC should be achievable with O(100 fF) Cin.
- Exploring options for minimizing in-CMOS capacitance
  - TSMC 65 nm => 36 fF (50 x 60) um pads
  - TSMC 180 nm => 30 fF (60 x 70) um pads
  - Skywater 180 nm => in-progress

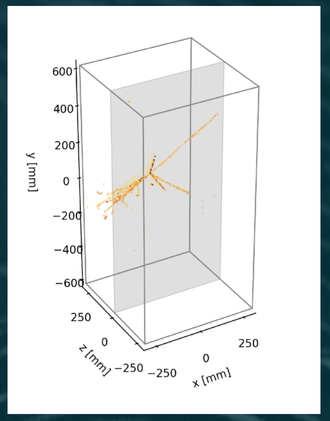


Contact: Peter Sorensen

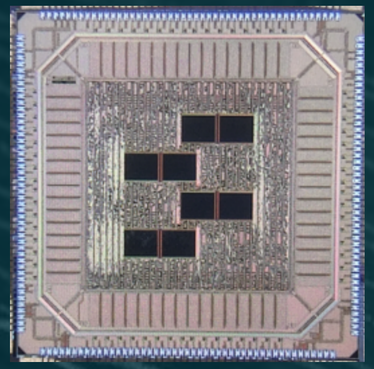
Scalable Charge & Light Readout

- LArPix
  - True 3D pixelated charge readout for LArTPCs
  - Low-noise, low-power, cryogenic-compatible
  - Scalable anode design leverages commercial production
  - Four recent 80k-pixel ton-scale prototypes exceeded expectations
  - Production costs on-par with existing readout technologies
  - Baseline technology for the DUNE Near Detector
- LightPix
  - Integrated readout for detectors with many SiPMs
  - Reuses LArPix design to provide unique channel for every SiPM
  - Successful operation of a LightPix VUV sensor in a pixel LArTPC

Dune Near Detector Prototype

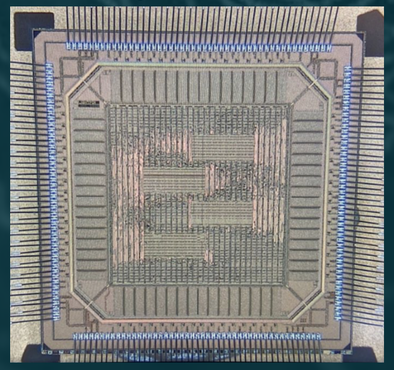


LArPix-v2

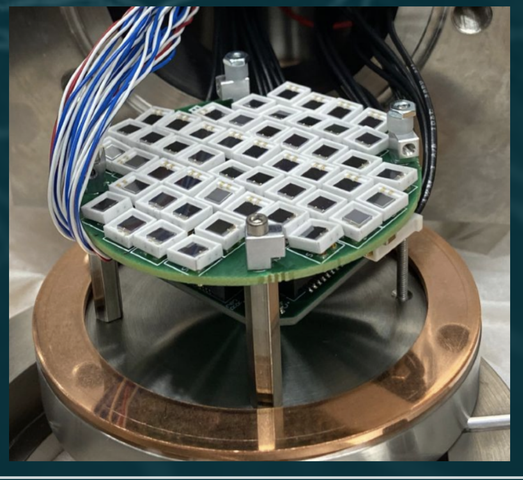


LArPix Tile with VUV SiPM read out by LightPix

LightPix-v1



Prototype 50 SiPM for high pressure He Detector



Contact: Dan Dwyer

Backup

Muon Collider Requirements

	muC Tracker			ATLAS ITk	
	Vertex Detector	Inner Tracker	Outer Tracker	Pixel	Strips
Resolution [um x um]	25x25	50x1,000	50x10,000	50x50	75x2500
Channels	1200M	290M	170M	5000M	60M
Area [m^2]	0.75	14.5	85	13	165
Double Layer Spacing [mm]	2mm			N/A	5
Total Ionizing Dose [Mrad]*	200	10		1,000	75
Fluence [1MeV neq/cm^2]*	$3x10^{15}$	$1x10^{16}$	$<1x10^{15}$	$2x10^{16}$	$2x10^{15}$
Time resolution	30ps	60ps		25ns (1.5ns)	25ns
Hit density [mm-2]	3.7**	0.5**	0.03**	0.6	0.003
Collision rate	100kHz			40MHz	
Readout percentage	100% (trigger-less)			2.5% (triggered)	
Data Bandwidth	~30Tbps**			13.5Tbps	

*assume 10 year run-time **after ns timing cuts