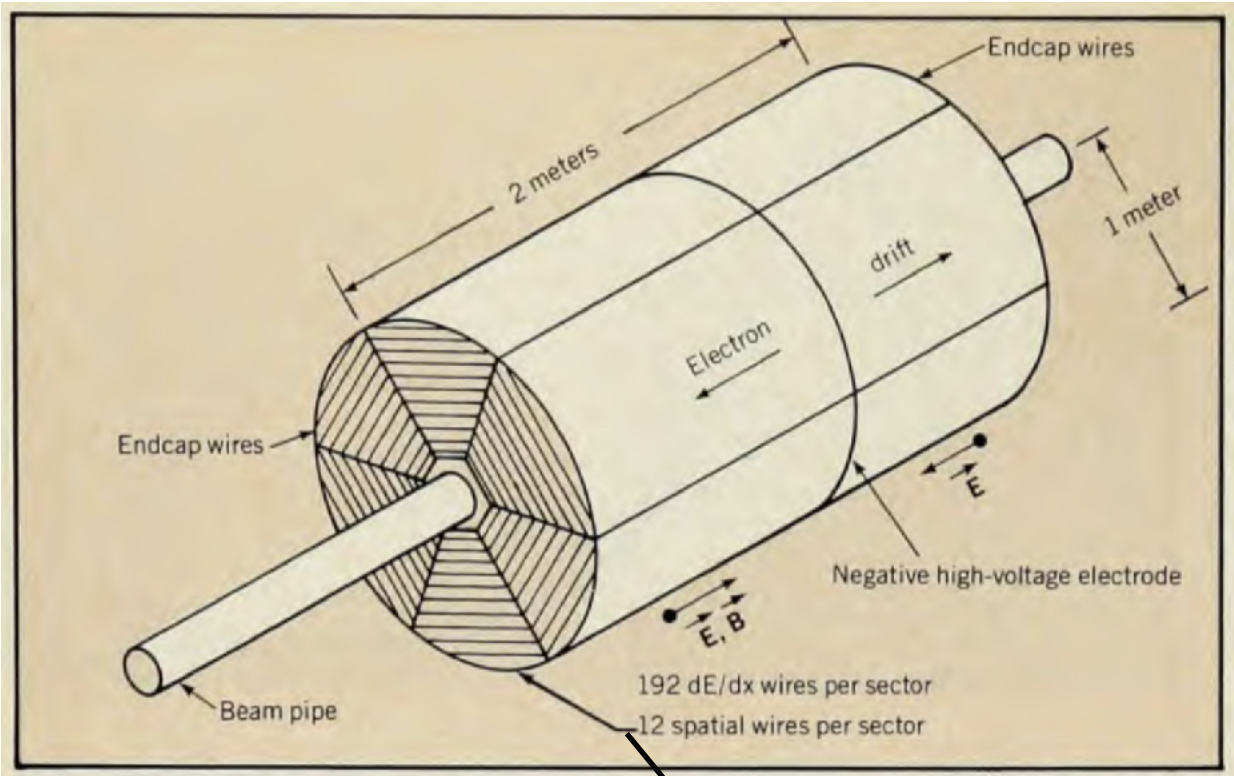
CMOS Sensor for the Cold and Tiny

Yuan Mei

Lawrence Berkeley National Laboratory

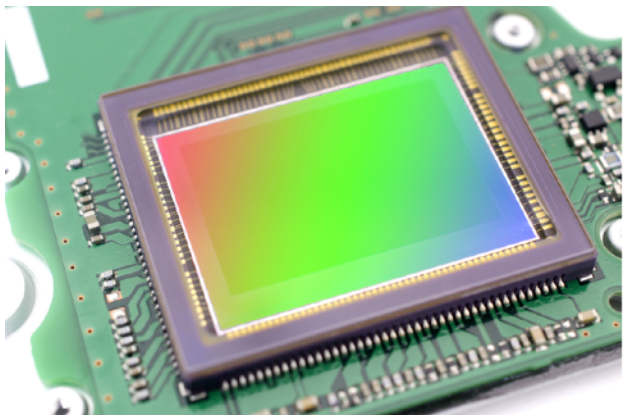
TPC is wonderful



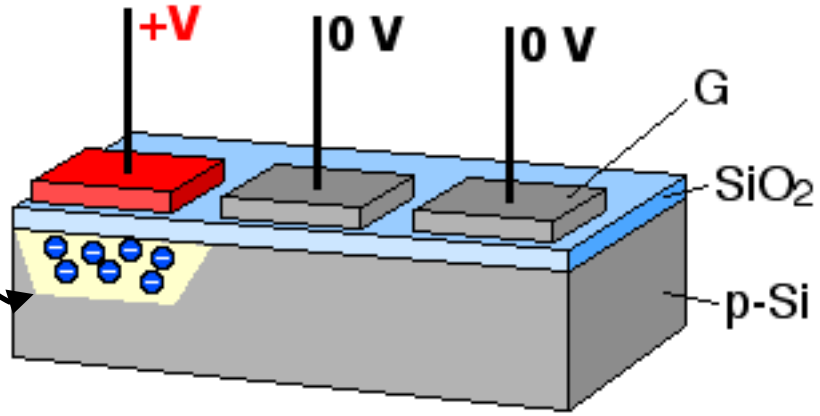
Schematic of the Time Projection Chamber. Magnetic and drift electric fields are parallel to the cylinder axis and beam direction. Not all the readout-plane wires are shown. Figure 4

Physics Today 31(10), 46 (1978)

Signal extraction remains a challenge

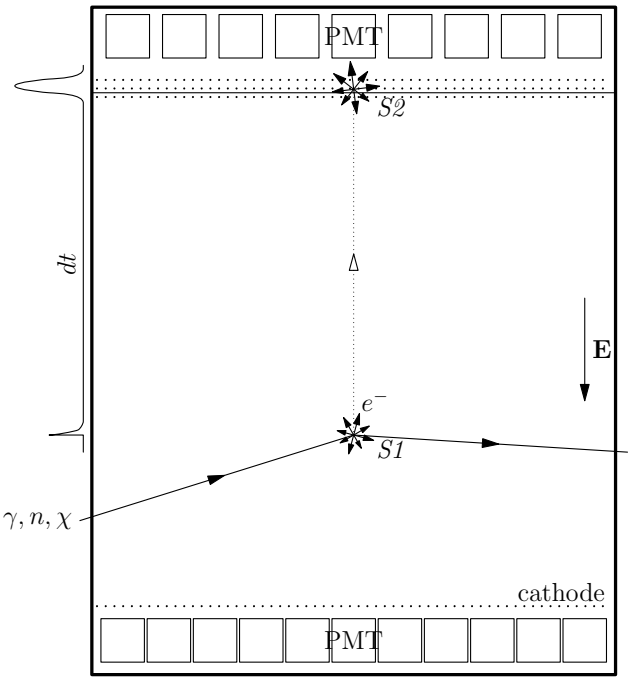


https://www.visiononline.org/blog-article.cfm/CCD-vs-CMOS-Image-Sensors-Which-are-Better/82



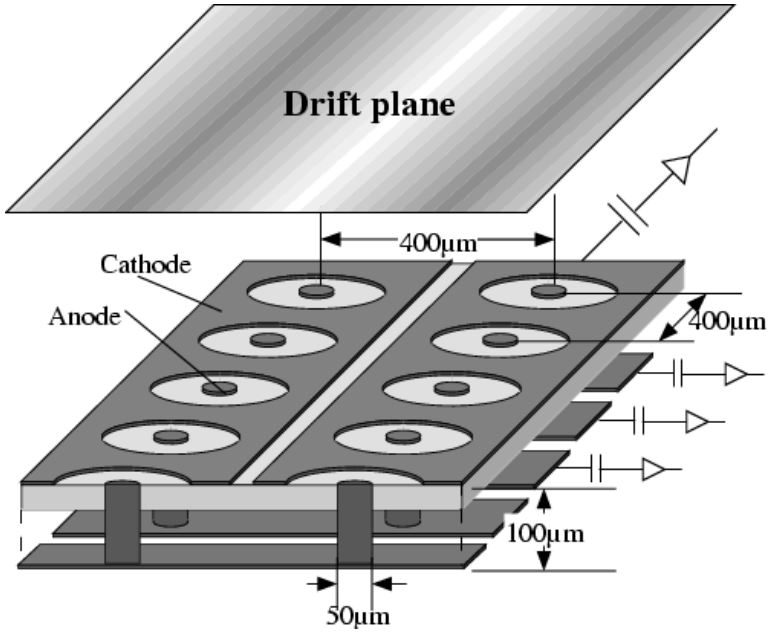
CCD, W. Boyle & G. Smith @ Bell Labs, 1969

TPC signal extraction

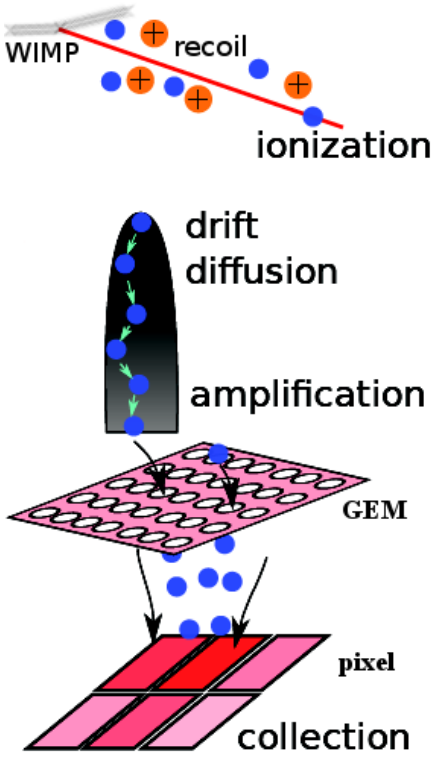


XENON, LUX, LZ, etc.

- Liquid Xenon TPC
- Time Projection Chamber
- Wire and/or light readout
- mm~cm spatial resolution



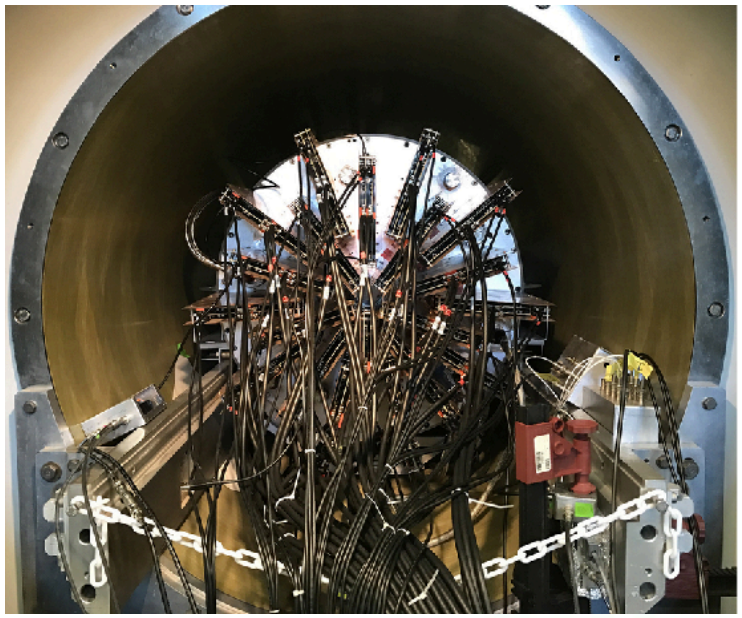
- µ-PIC (Micro Pixel Chamber)
- Printed Circuit Board technology
- 400µm pitch
- Some electron gain in gas
- Difficult for readout and scale-up

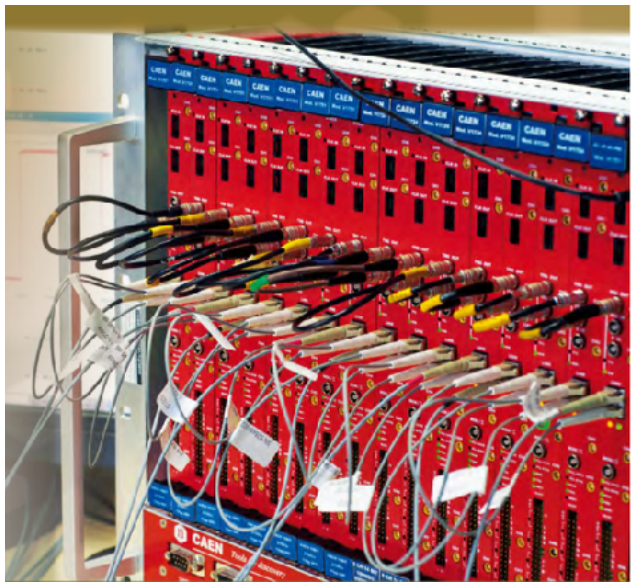


S.E. Vahsen et al.
http://arxiv.org/abs/1110.3401

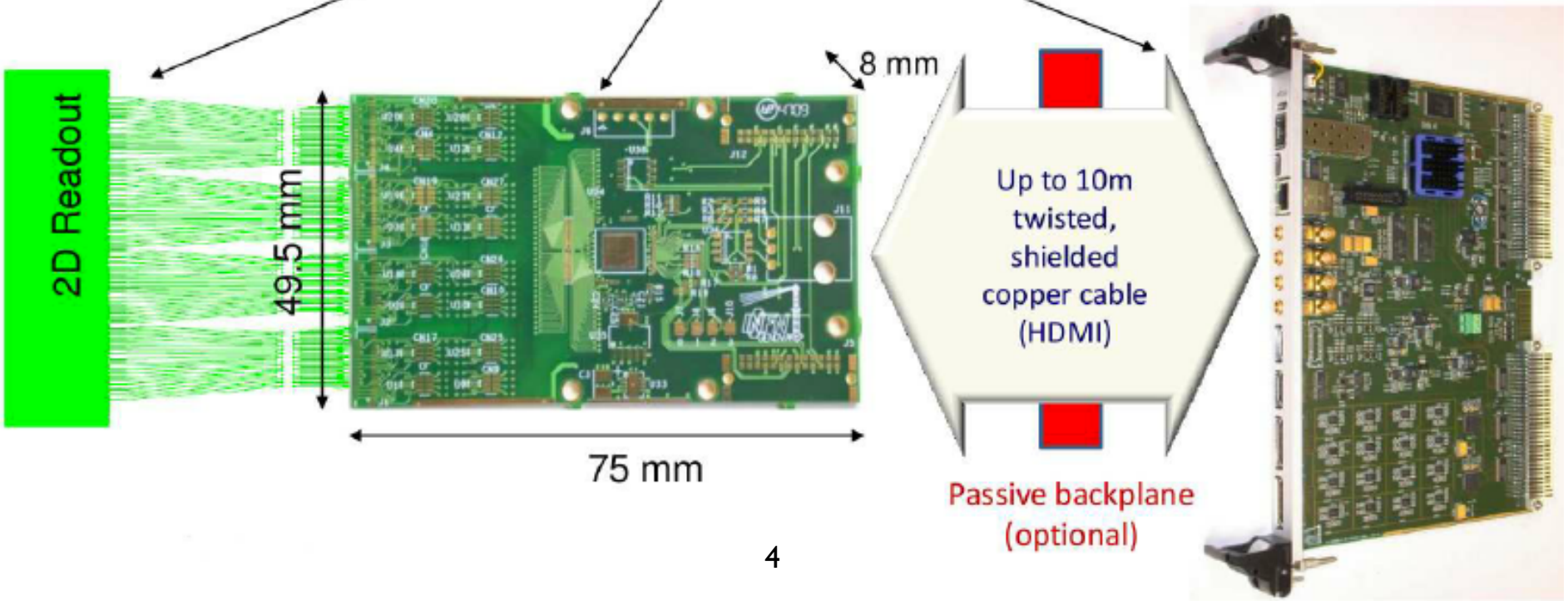
- D³, InGrid etc.
- Charge multiplication stage
- Non-specific ASIC readout
  - FE-I3/-I4
  - TimePix

Readout?

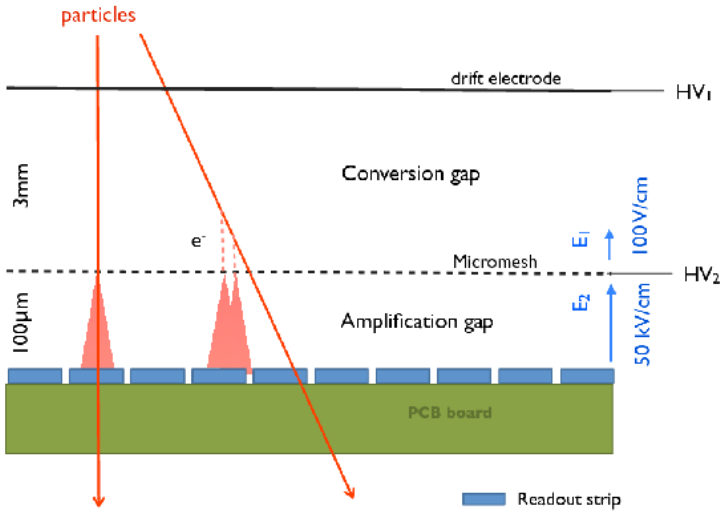


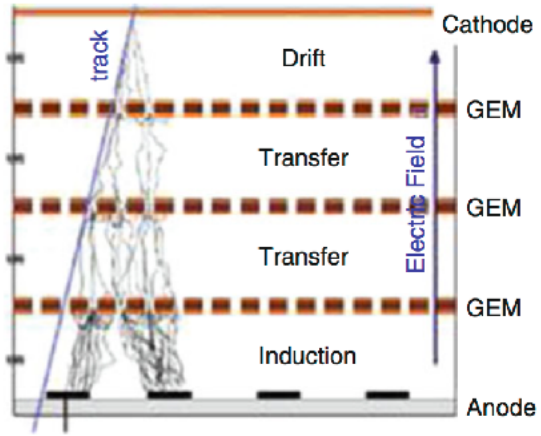


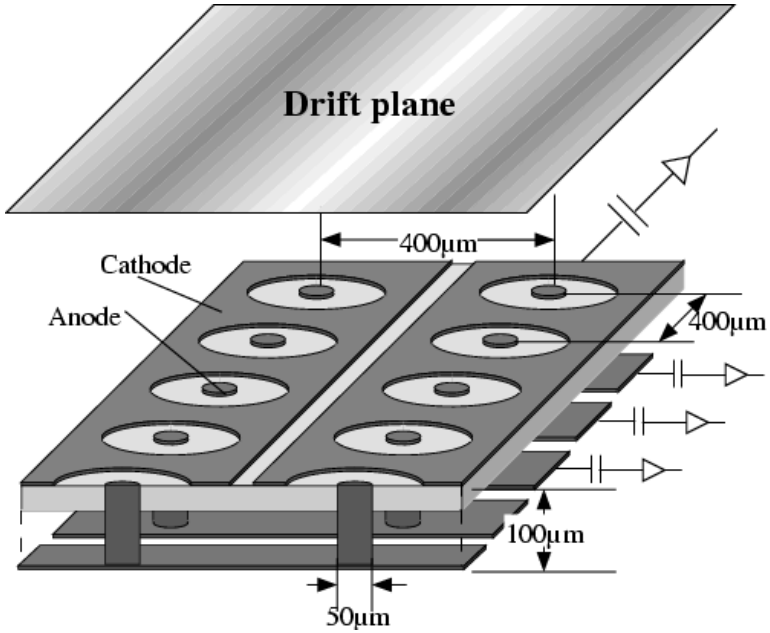
GEM ⇒ FEC ⇒ MPD ⇒ DAQ



Avalanche gain?







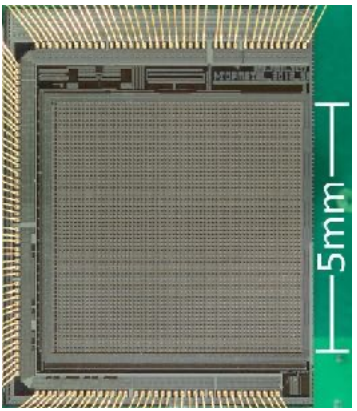
- MicroMegas
- Micromesh placed (very) close to readout PCB

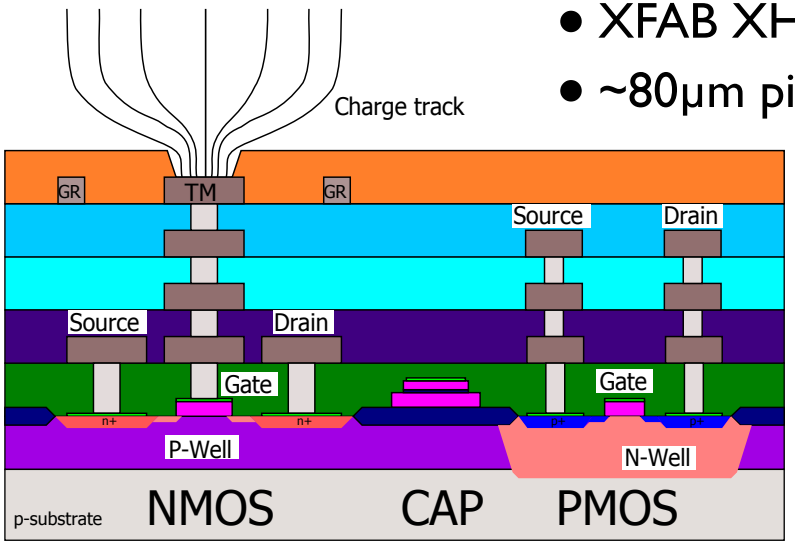
- GEM
- Array of micro-holes in thin foils with conductor cladding on both sides

- µ-PIC (Micro Pixel Chamber)
- Printed Circuit Board technology

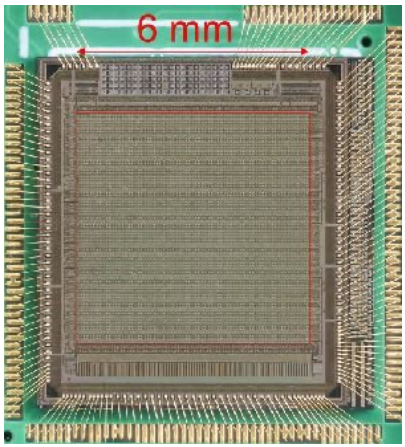
- Catch charge as early as possible, convert to digital information immediately
- Low noise
- Full 3D information
  - Truly (massively) pixelated (2D)
  - Adequate timing (waveform digitization)
- Affordable

Topmetal CMOS direct charge sensor



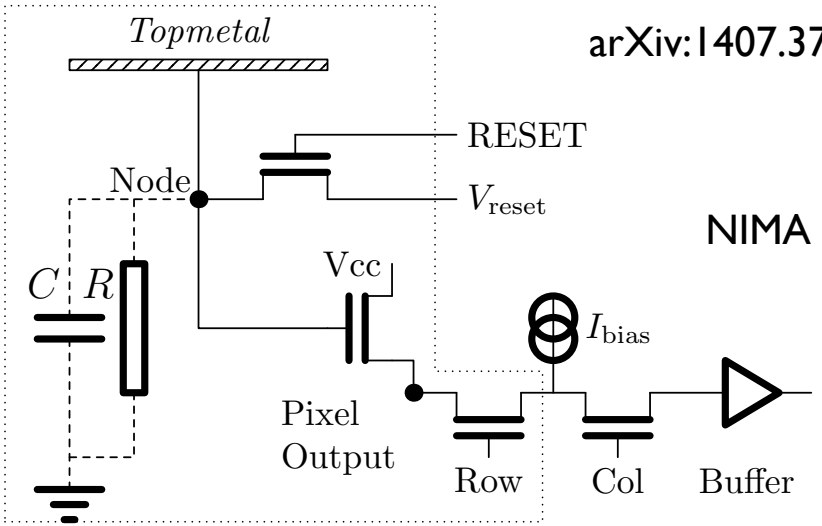


- XFAB XH035 Process
- ~80μm pixel size



Topmetal-I

- Direct voltage readout
- High analog bandwidth



arXiv:1407.3712

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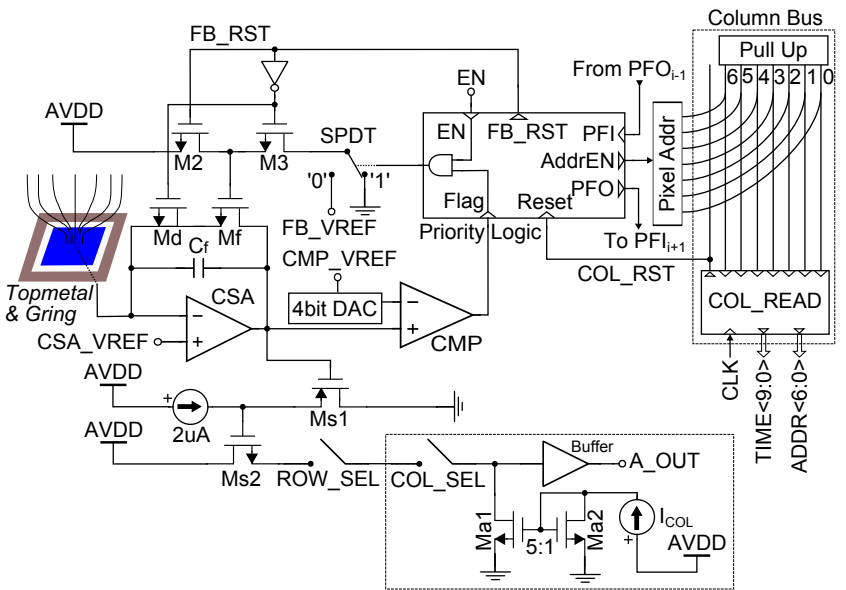
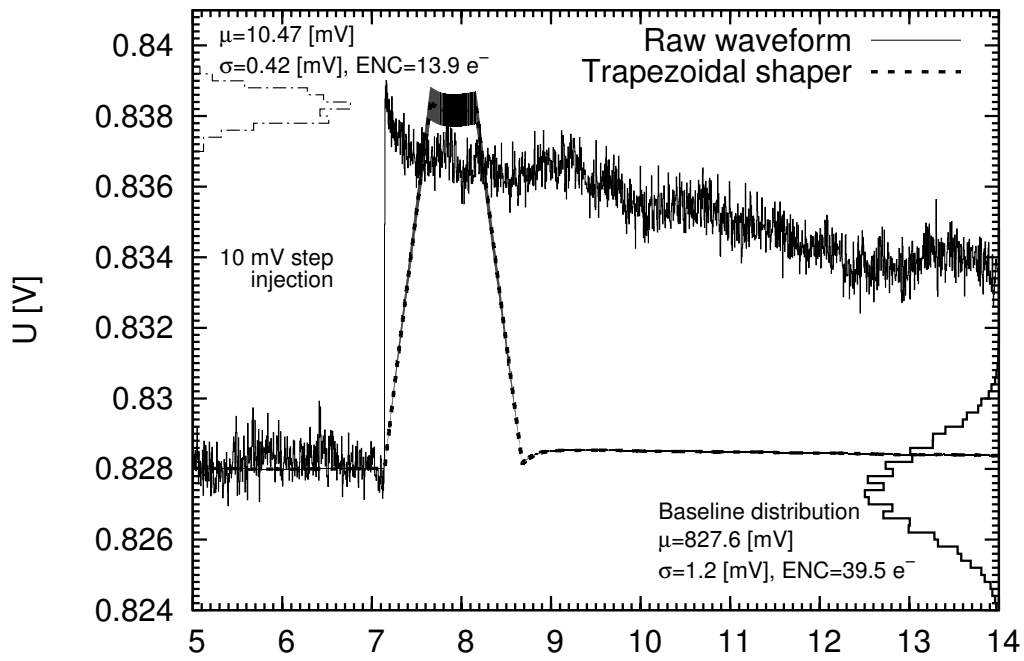
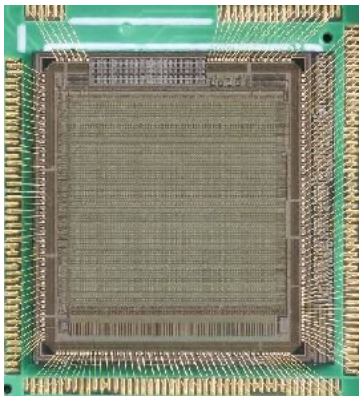
Topmetal-II-

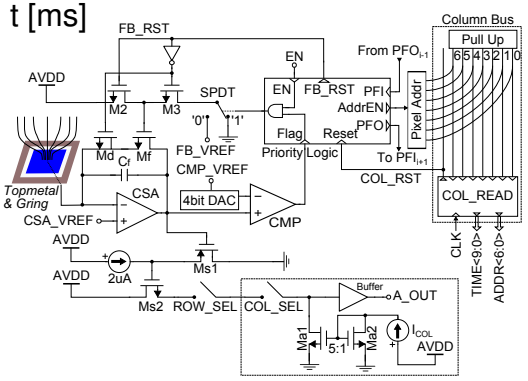
- Charge sensitive amplifier, <15e- noise
- Clock-less, frame-less logic hits readout

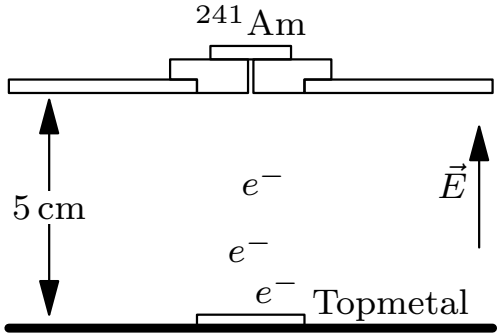


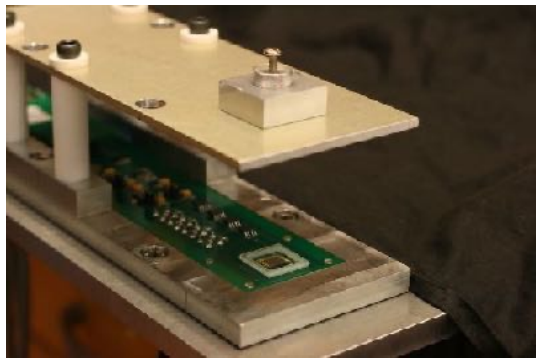
Topmetal-II- seeing alpha (ion) tracks in air

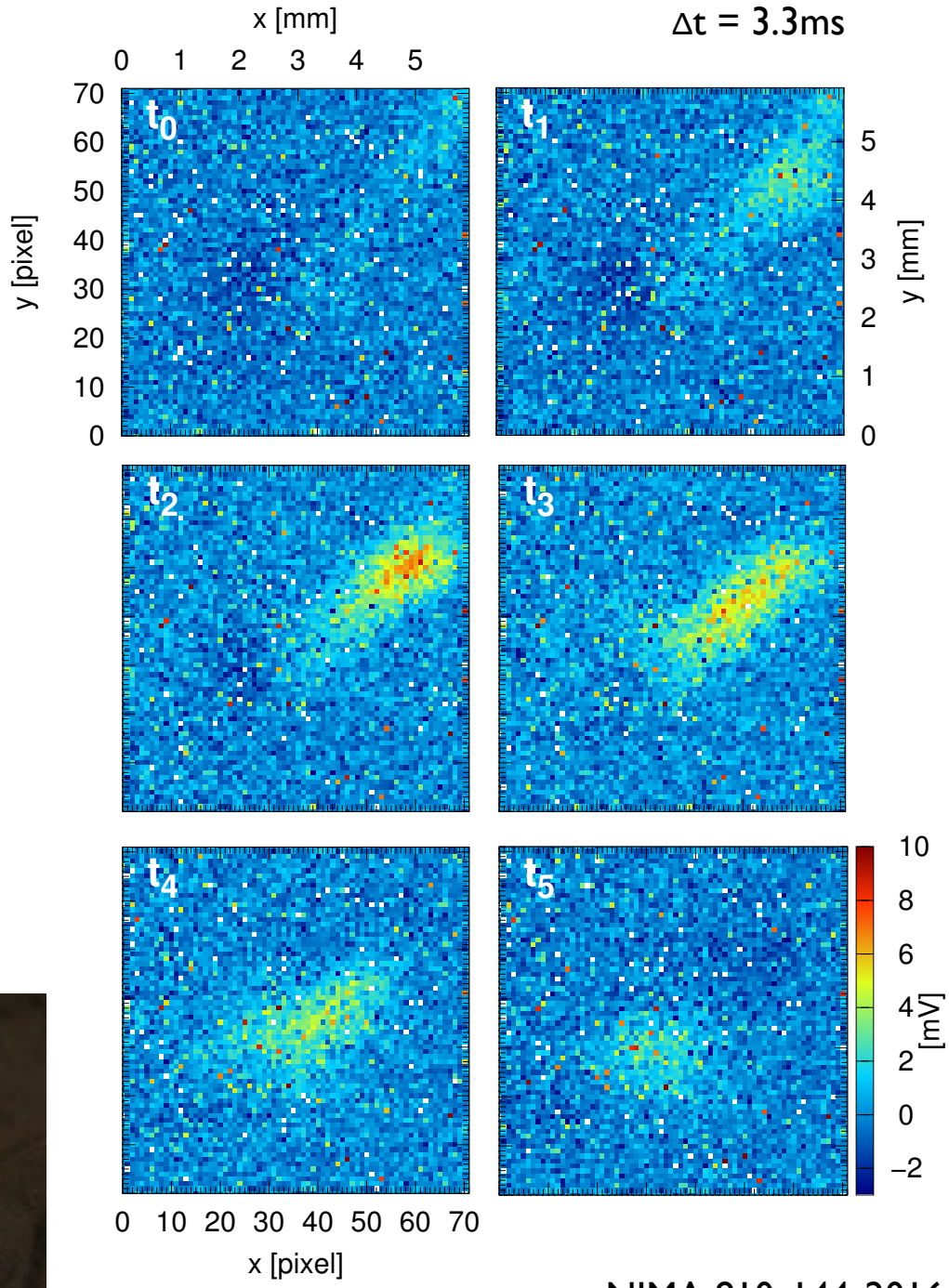






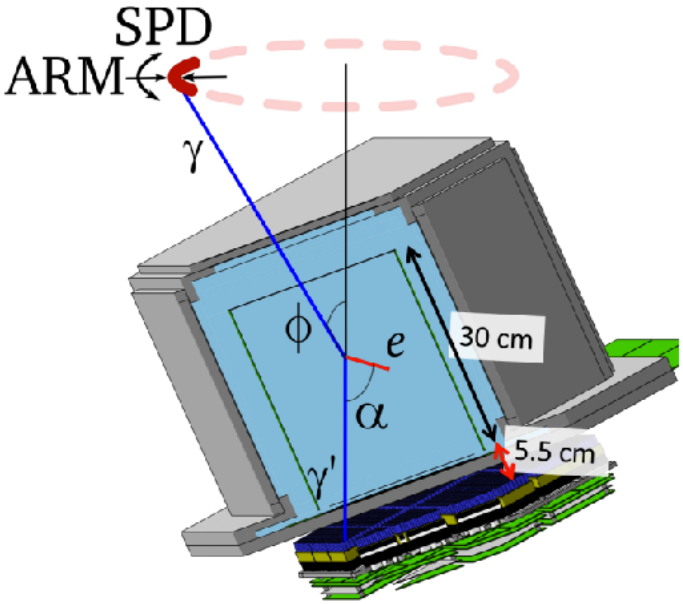


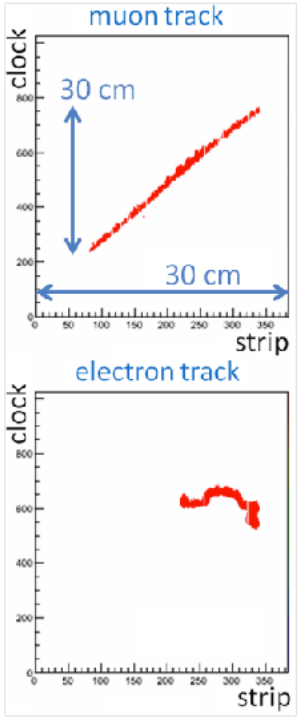




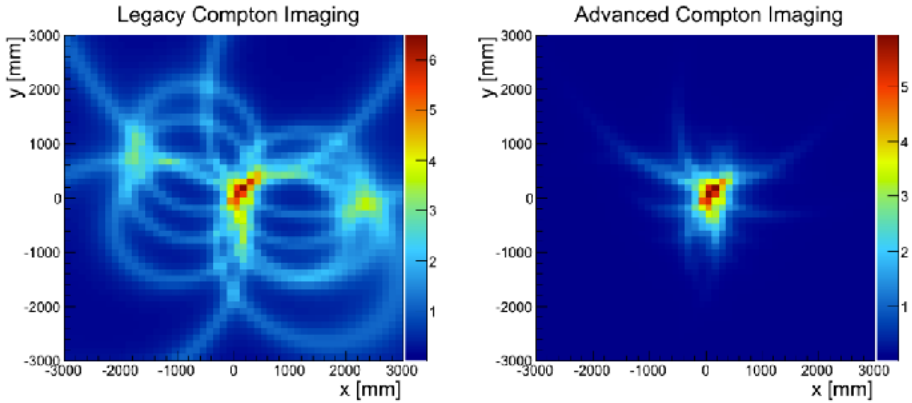
NIMA 810, 144, 2016

Electron-track Compton Imaging



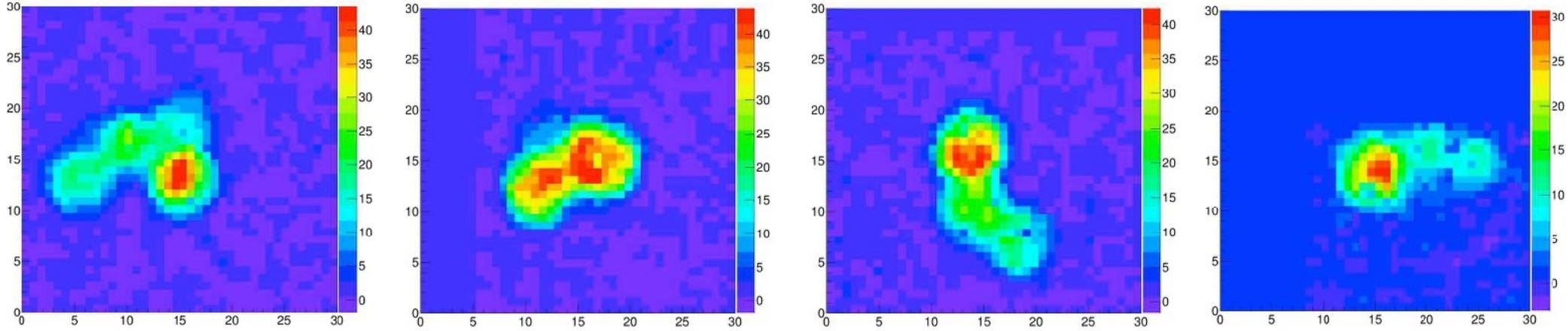


- Medical Imaging
- Gamma (X-ray) Astronomy



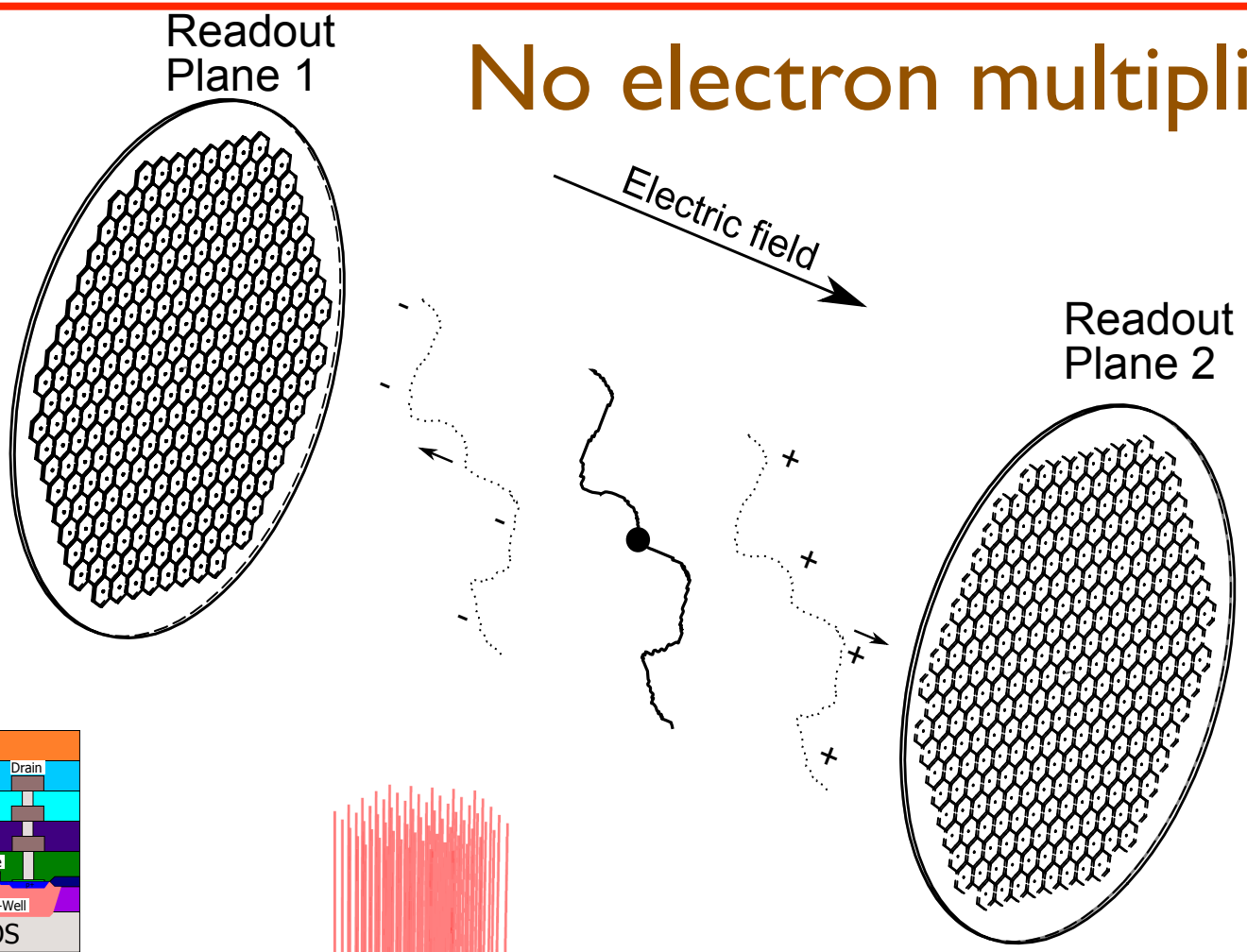
http://www-cr.scphys.kyoto-u.ac.jp/research/MeV-gamma/wiki/wiki.cgi?page=Top_en

Ne(90%)+DME(10%) @ 80kPa, ^{55}Fe events (5.9keV X-ray), GEM on *Topmetal-II-*

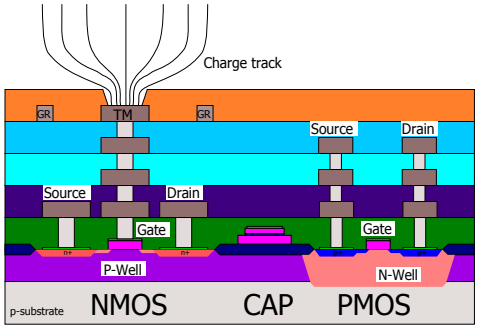


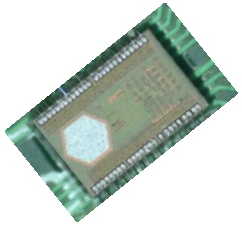
2.5 x 2.5 mm field of view

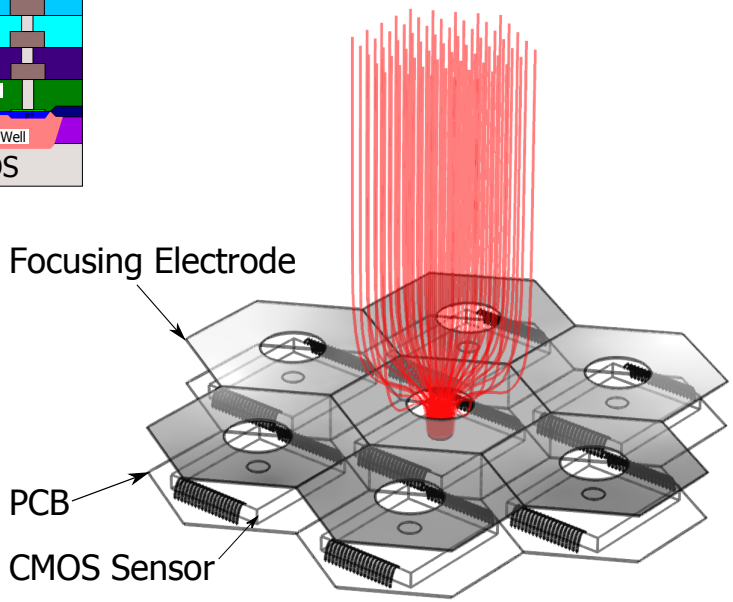
CMOS charge sensor array for 0νββ



No electron multiplication!

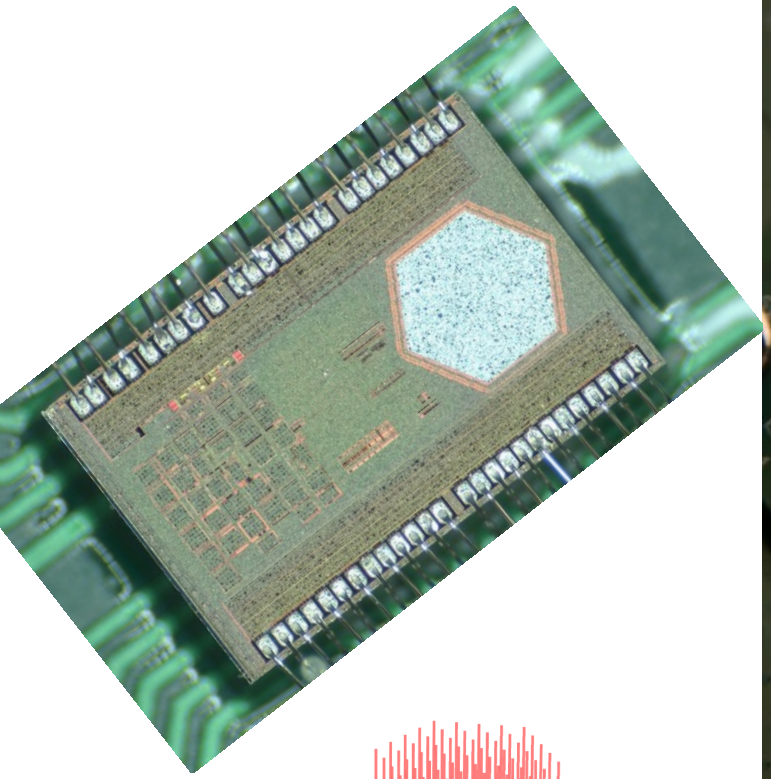


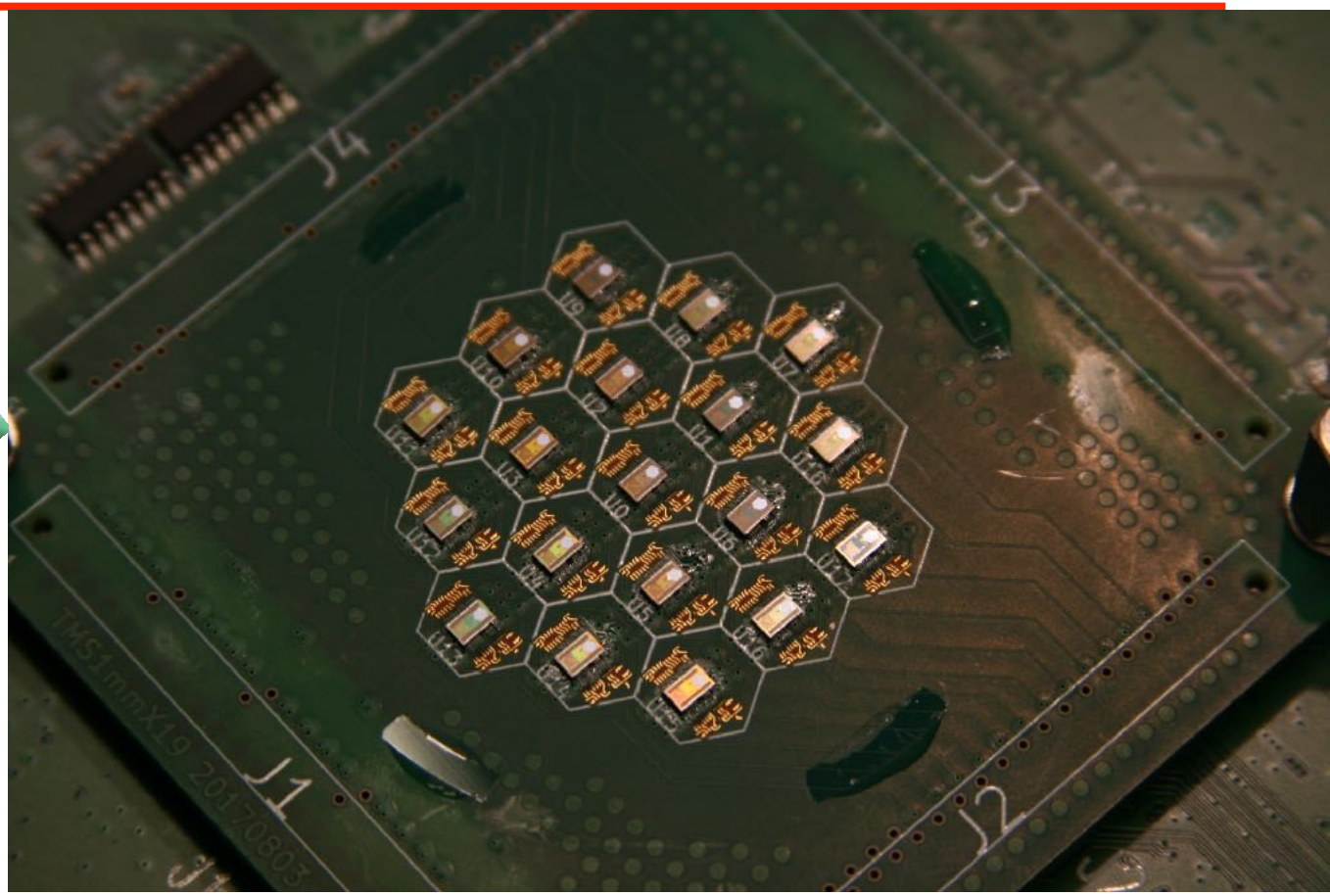




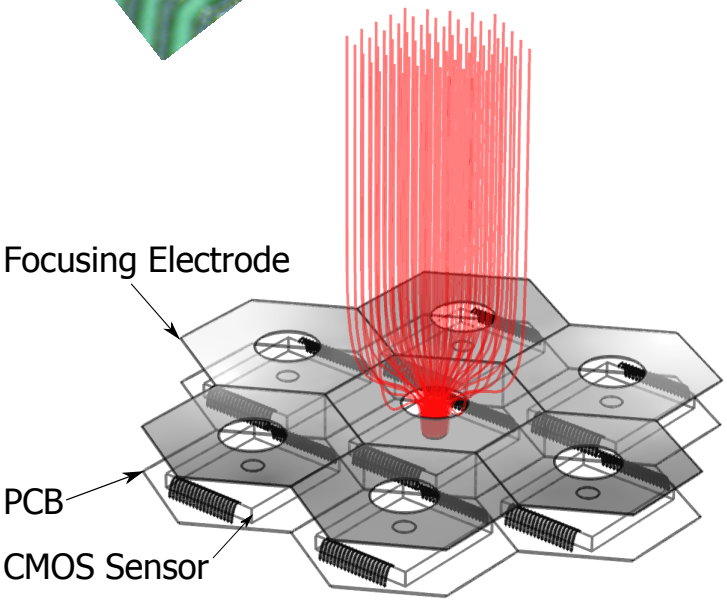
- Eliminate charge multiplication
- Focusing electrode 100% coll. eff.
- Direct charge collection in X-Y
- In-sensor digitization
- Inter-sensor network for digital data transmission

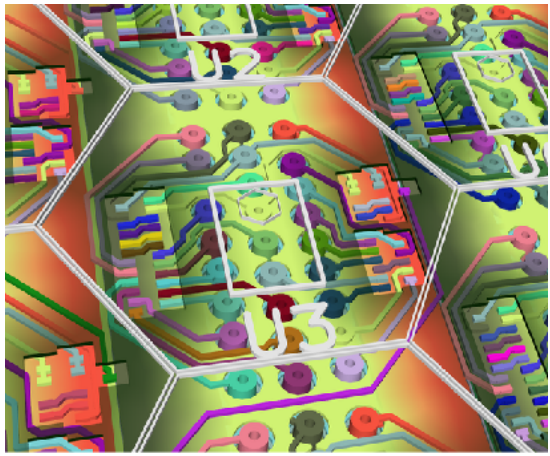
Sensor array



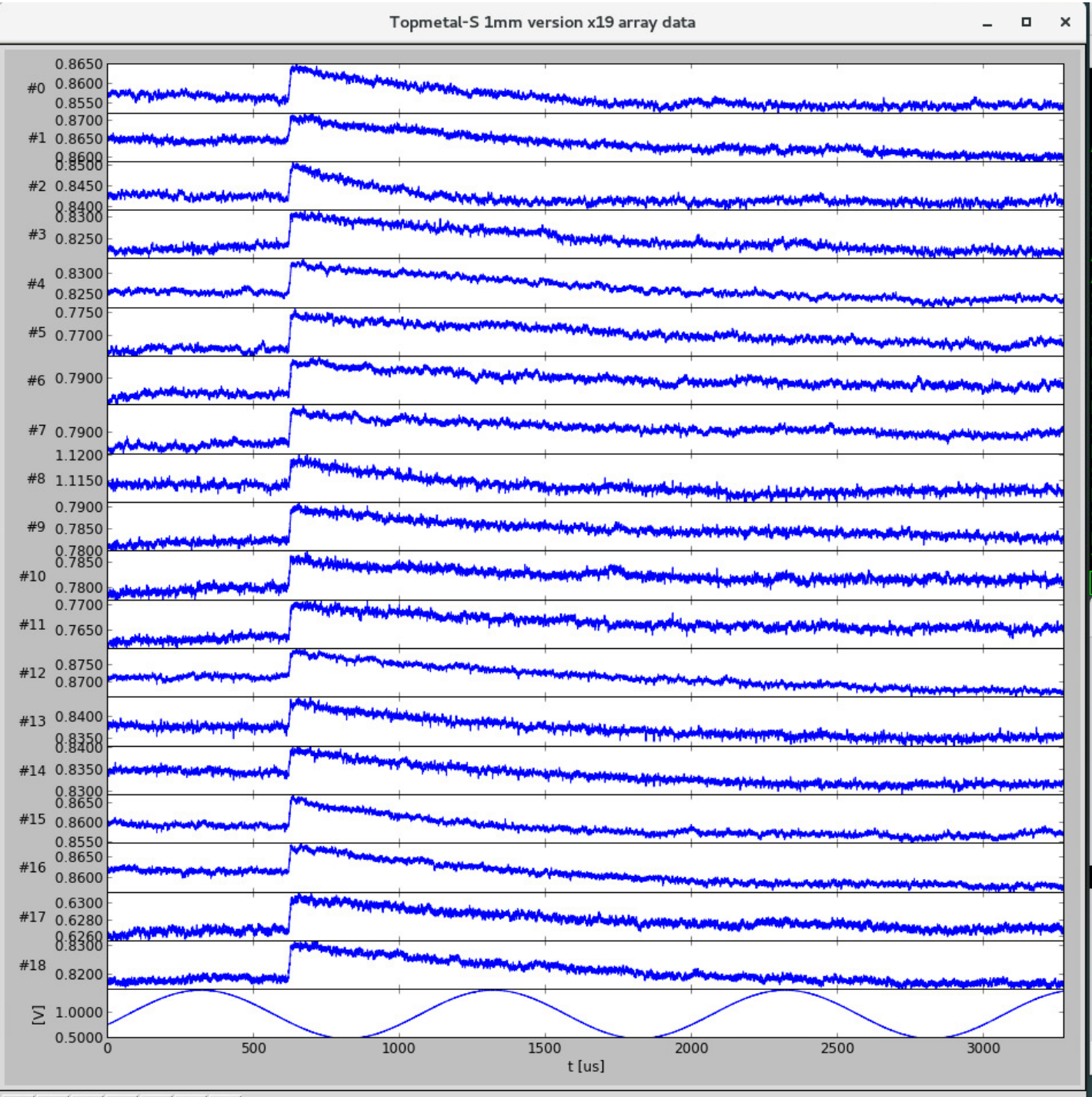


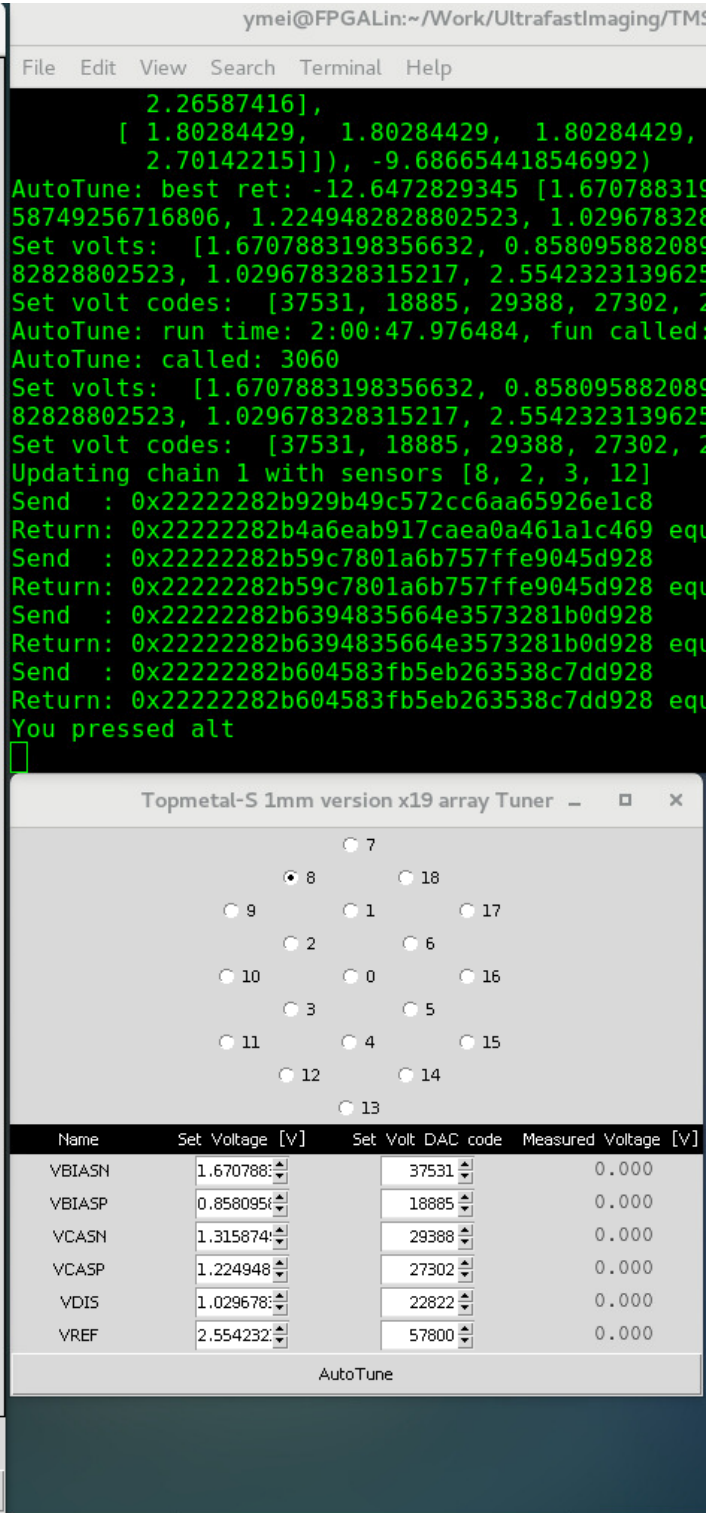
5cm



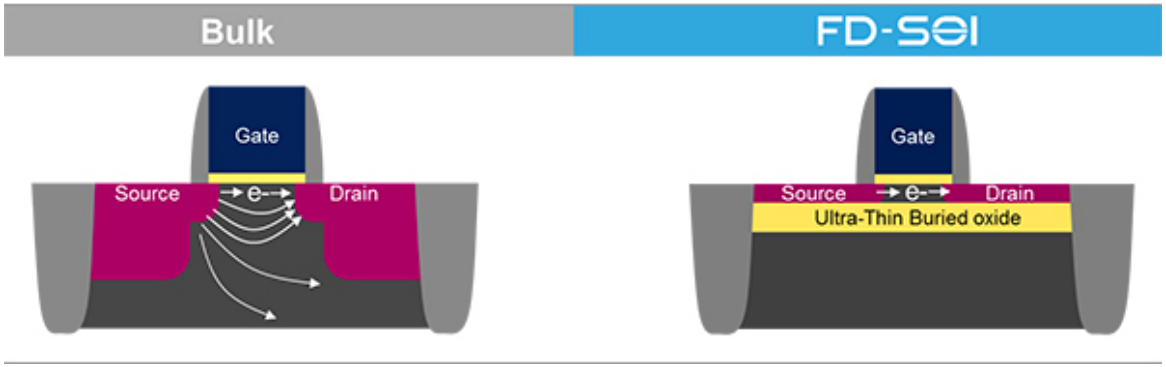


`python program` generated PCB, parametrized

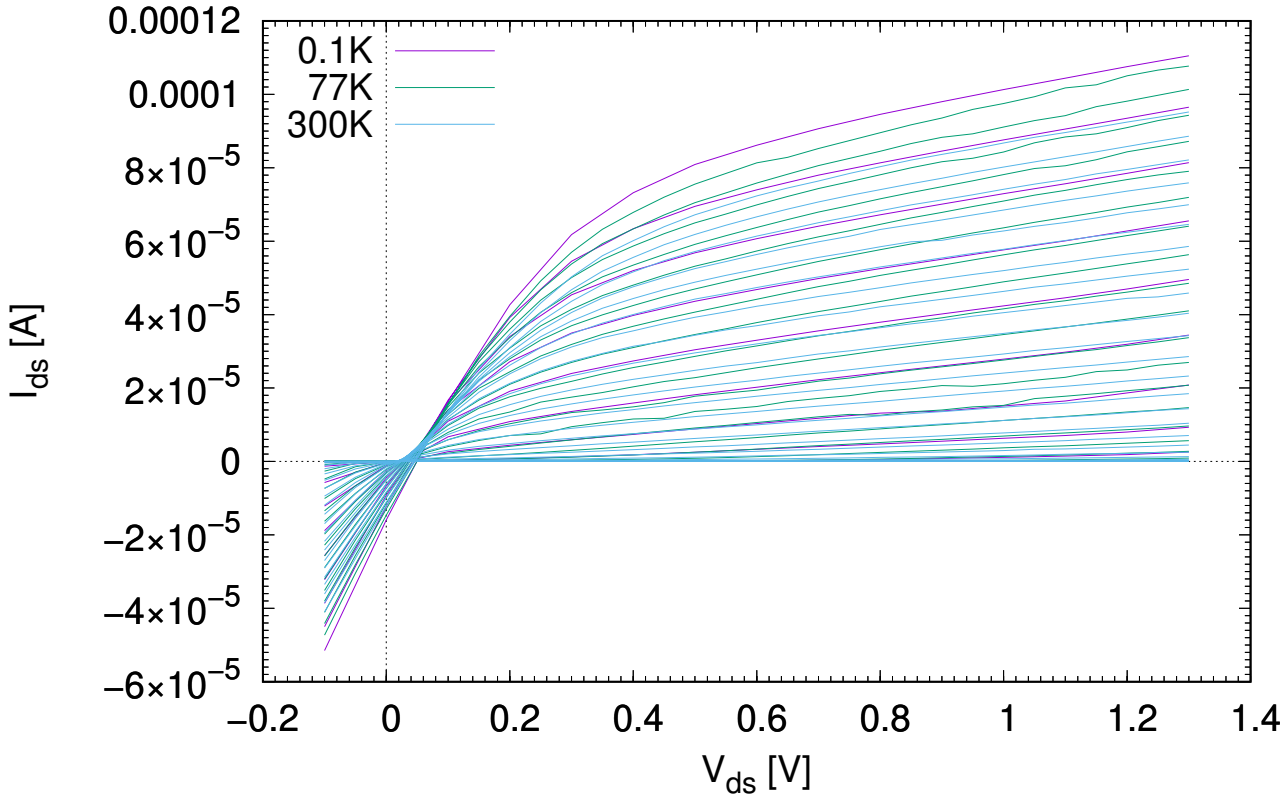

Topmetal-S 1mm version x19 array data
#0
#1
#2
#3
#4
#5
#6
#7
#8
#9
#10
#11
#12
#13
#14
#15
#16
#17
#18
[V]
0
500
1000
1500
2000
2500
3000
t [us]
Re-sample
Refresh


ymei@FPGALin:~/Work/UltrafastImaging/TMS
File Edit View Search Terminal Help
2.26587416],
[1.80284429, 1.80284429, 1.80284429,
2.70142215]]), -9.686654418546992)
AutoTune: best ret: -12.6472829345 [1.67078831
58749256716806, 1.2249482828802523, 1.029678328
Set volts: [1.6707883198356632, 0.85809588208
82828802523, 1.029678328315217, 2.554232313962
Set volt codes: [37531, 18885, 29388, 27302,
AutoTune: run time: 2:00:47.976484, fun called
AutoTune: called: 3060
Set volts: [1.6707883198356632, 0.85809588208
82828802523, 1.029678328315217, 2.554232313962
Set volt codes: [37531, 18885, 29388, 27302,
Updating chain 1 with sensors [8, 2, 3, 12]
Send : 0x22222282b929b49c572cc6aa65926e1c8
Return: 0x22222282b4a6eab917caea0a461a1c469 equ
Send : 0x22222282b59c7801a6b757ffe9045d928
Return: 0x22222282b59c7801a6b757ffe9045d928 equ
Send : 0x22222282b6394835664e3573281b0d928
Return: 0x22222282b6394835664e3573281b0d928 equ
Send : 0x22222282b604583fb5eb263538c7dd928
Return: 0x22222282b604583fb5eb263538c7dd928 equ
You pressed alt
Topmetal-S 1mm version x19 array Tuner
7
8
18
9
1
17
2
6
10
0
16
3
5
11
4
15
12
14
13
Name
Set Voltage [V]
Set Volt DAC code
Measured Voltage [V]
VBIASN
1.670788
37531
0.000
VBIASP
0.858095
18885
0.000
VCASN
1.315874
29388
0.000
VCASP
1.224948
27302
0.000
VDIS
1.029678
22822
0.000
VREF
2.554232
57800
0.000
AutoTune

CMOS works in the cold

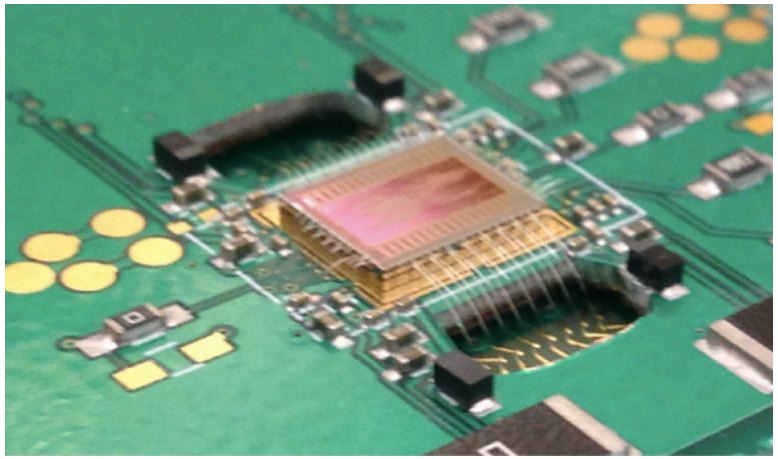


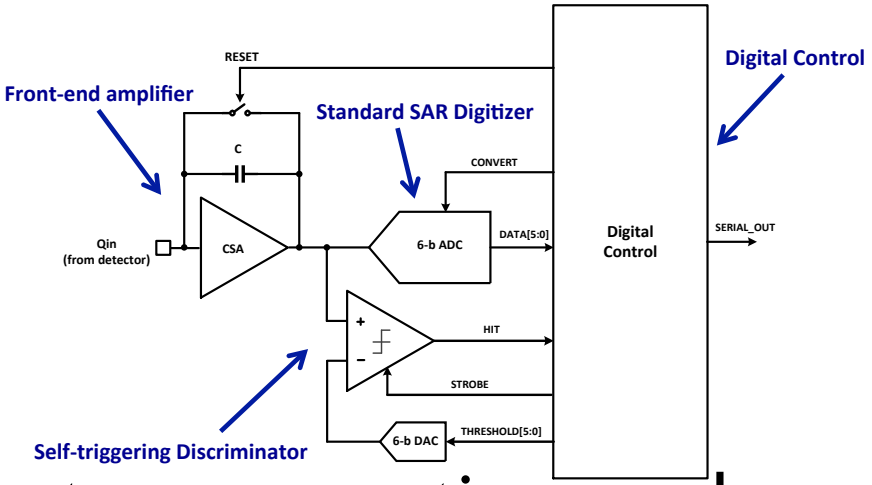
NMOS IV scan



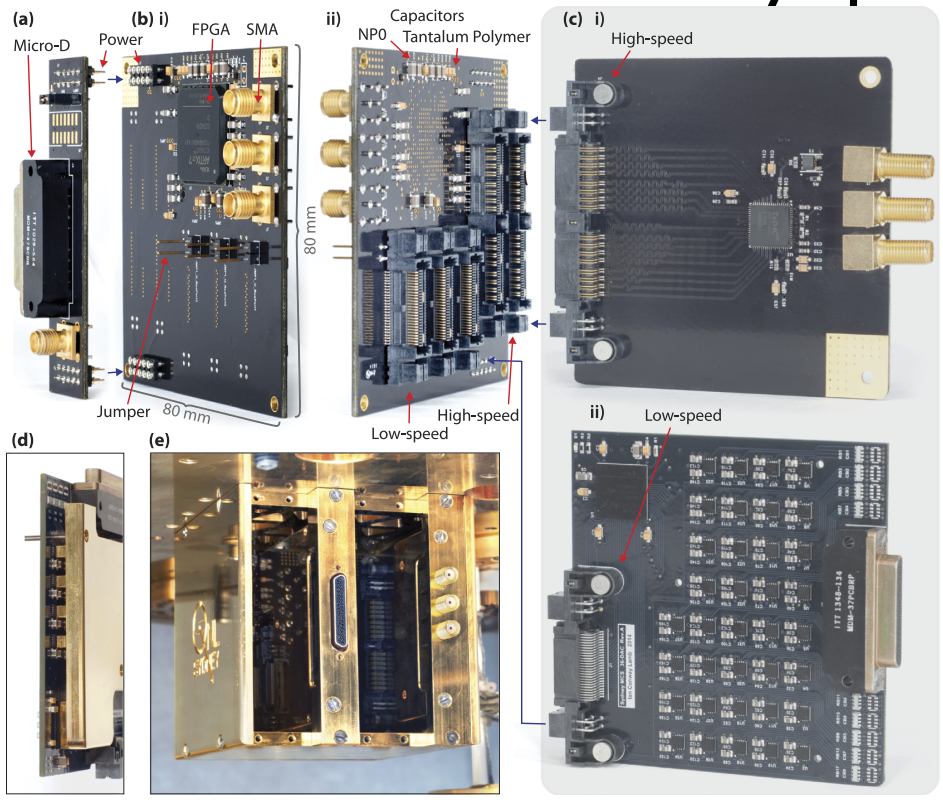
State-of-the-art cold electronics

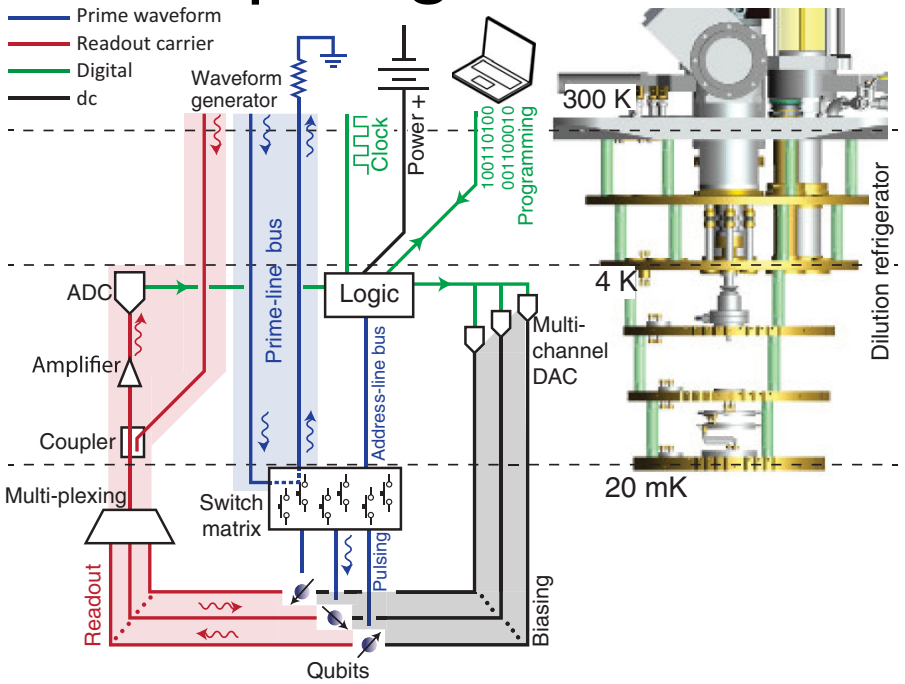
77K – LArPix, Q-Pix etc.





4K – FPGA etc. Driven by quantum computing needs

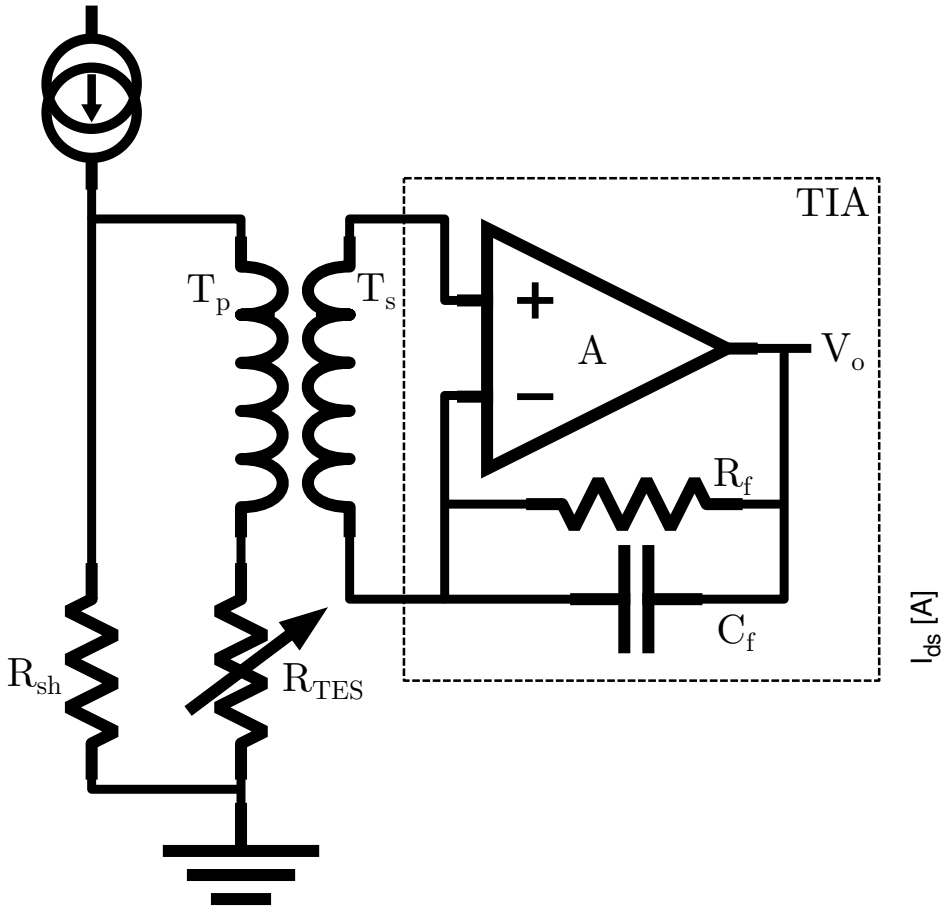




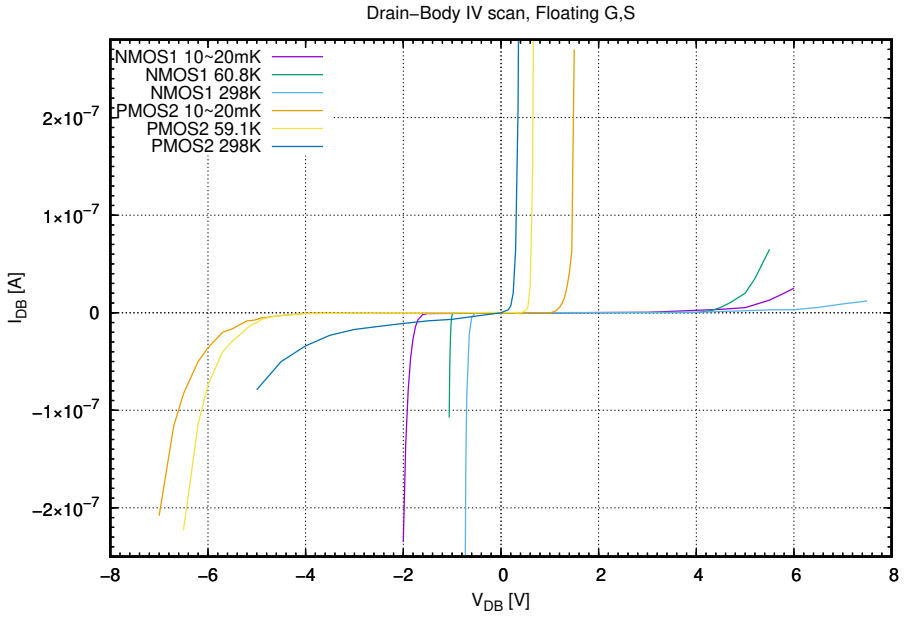
http://aip.scitation.org/doi/pdf/10.1063/1.4939094
http://aip.scitation.org/doi/pdf/10.1063/1.4979611
PhysRevApplied.3.024010

CMOS @ <4K

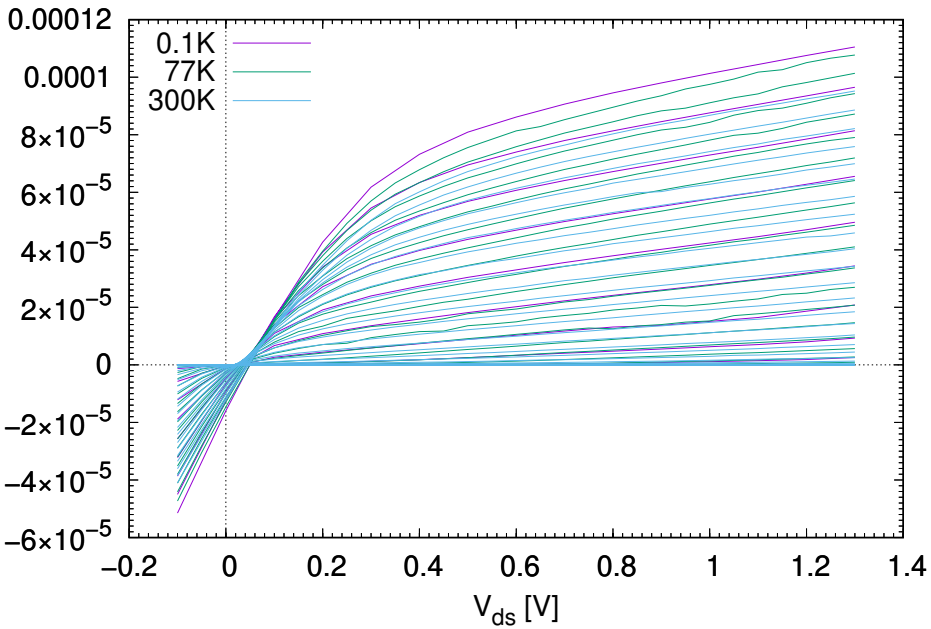
Conventional CMOS designed to work at <4K temperature.
Low-noise Transimpedance Amplifier (TIA) replaces SQUID



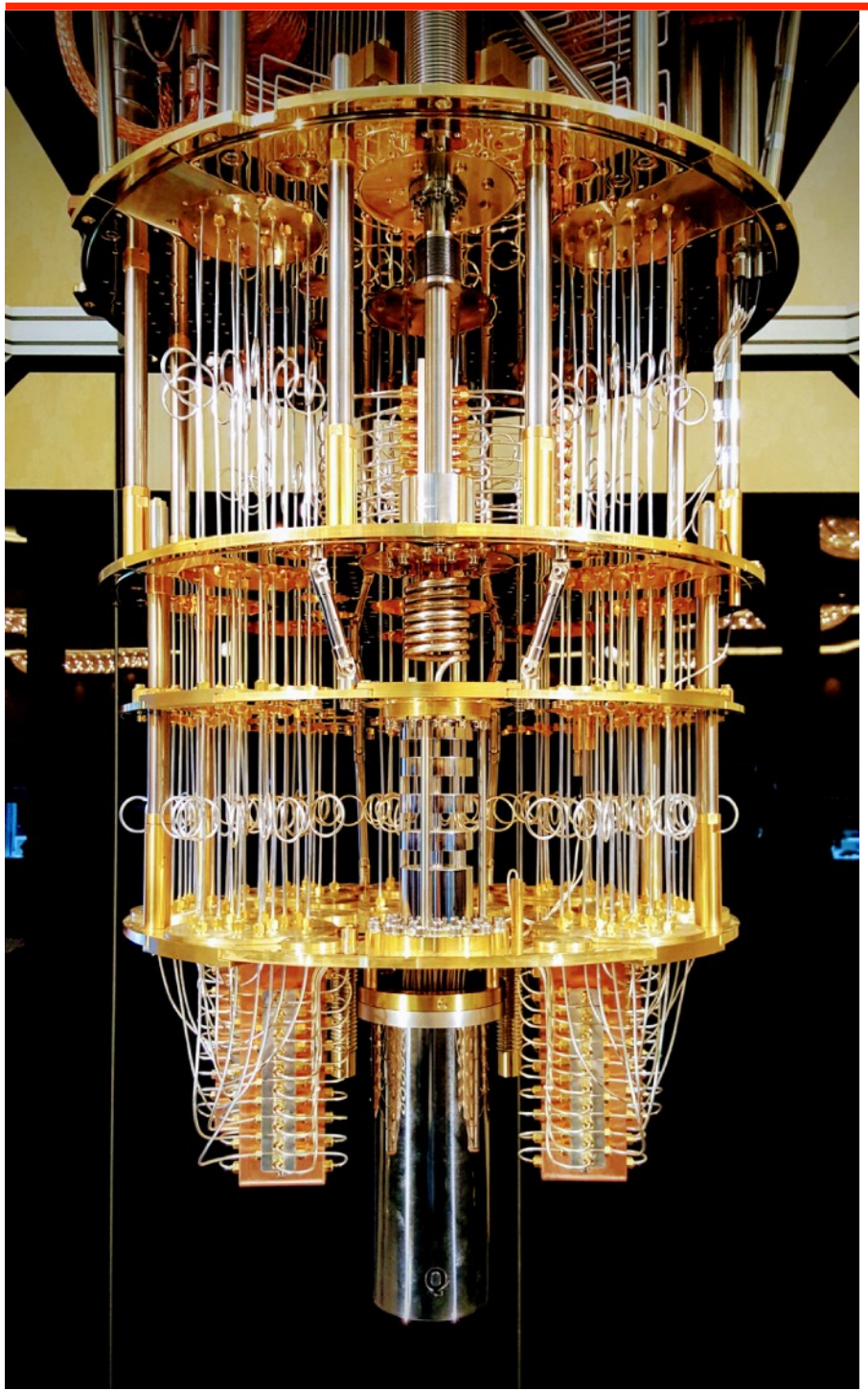
55nm CMOS devices proven to function down to ~10mK



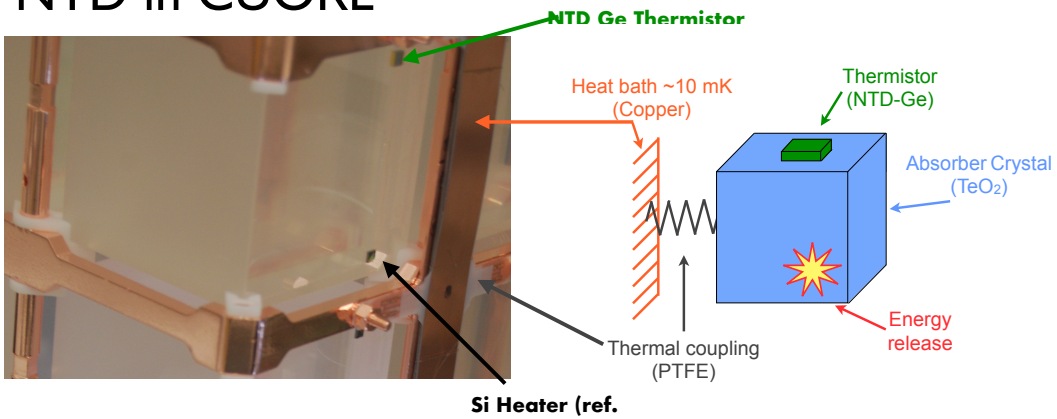
NMOS IV scan



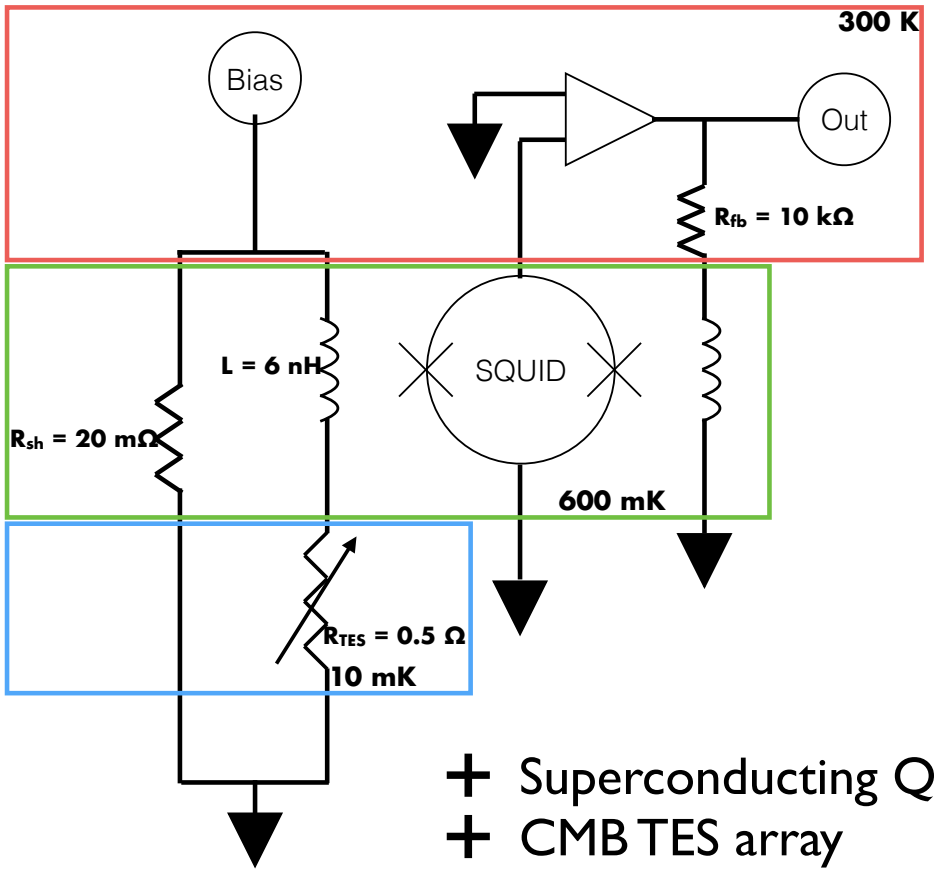
Interfacing quantum sensors



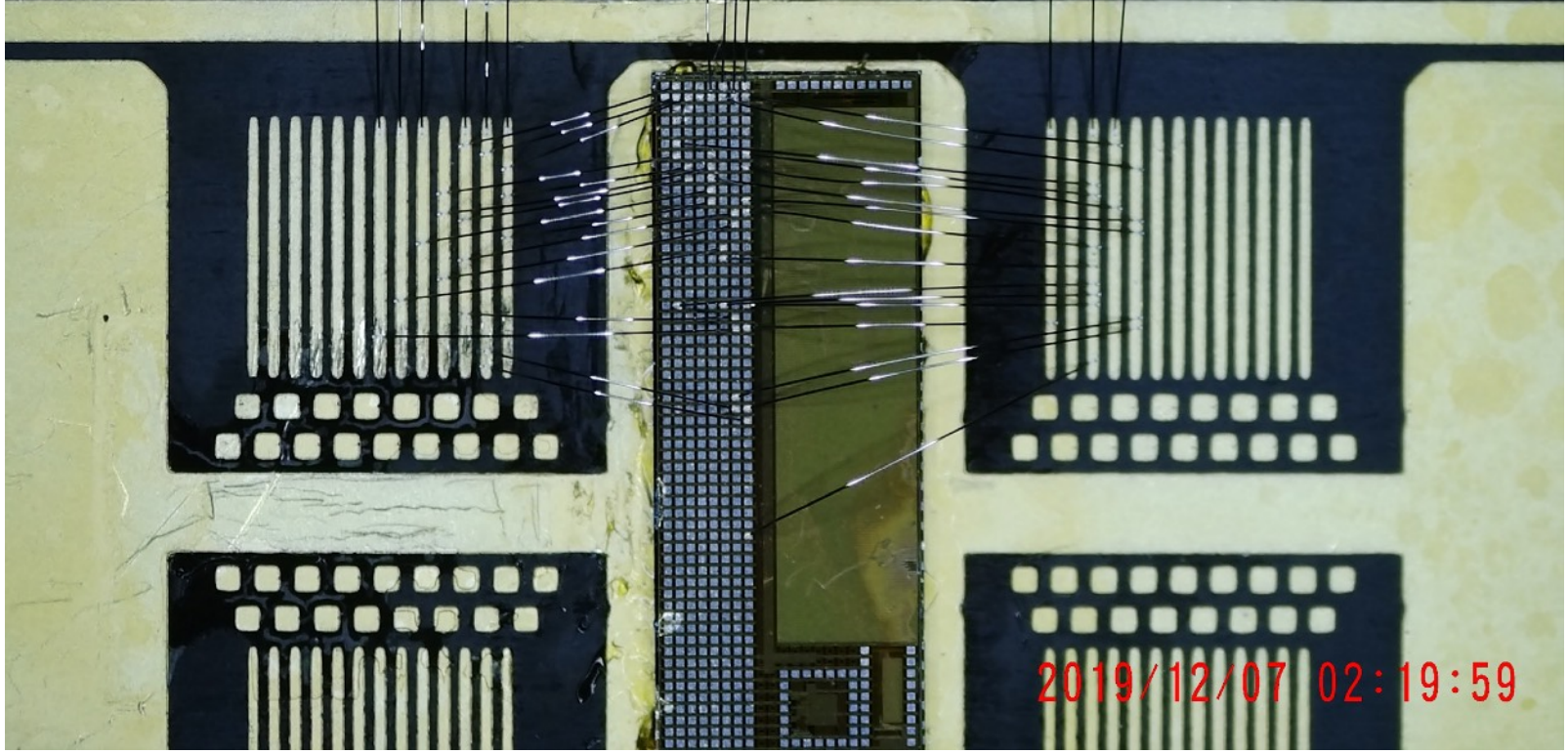
NTD in CUORE

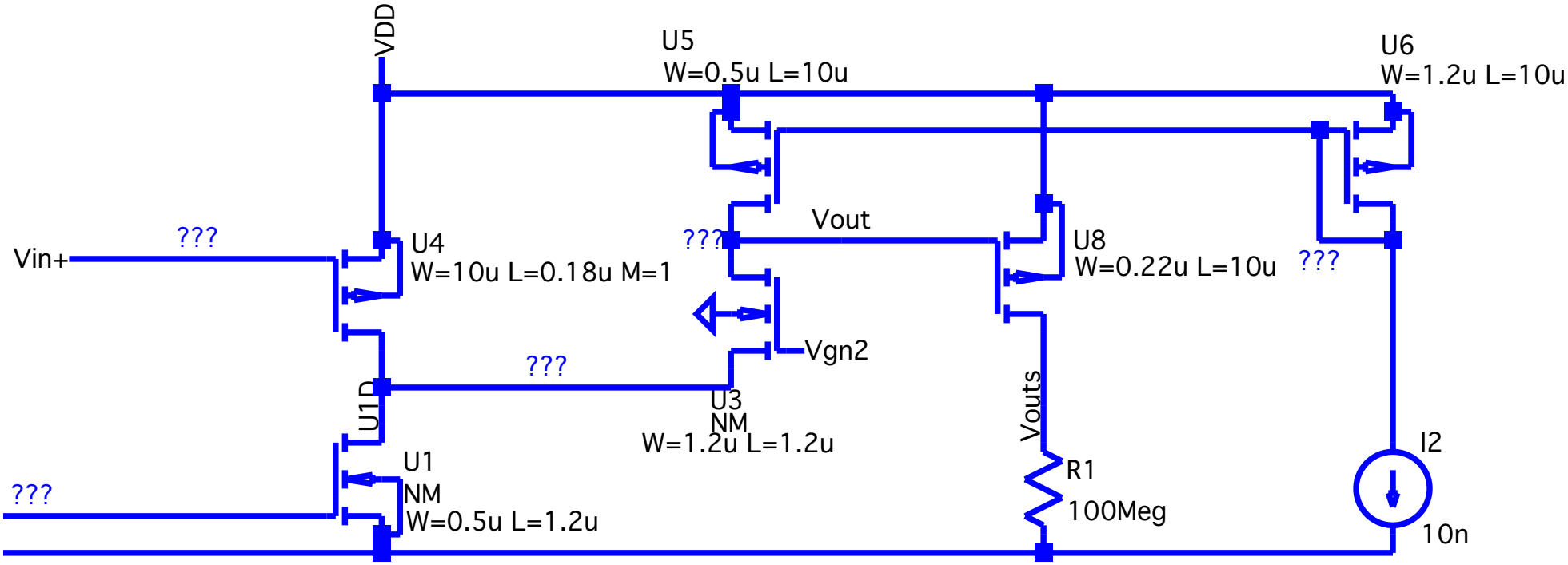


TES in CUPID



+ Superconducting Qubits
+ CMB TES array


2019/12/07 02:19:59


VDD
U5
W=0.5u L=10u
U6
W=1.2u L=10u
Vout
???
Vin+
???
U4
W=10u L=0.18u M=1
???
U8
W=0.22u L=10u
???
Vgn2
???
U1D
U3
NM
W=1.2u L=1.2u
Vouts
U1
NM
W=0.5u L=1.2u
???
R1
100Meg
I2
10n

Stay Tuned!

Contact
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