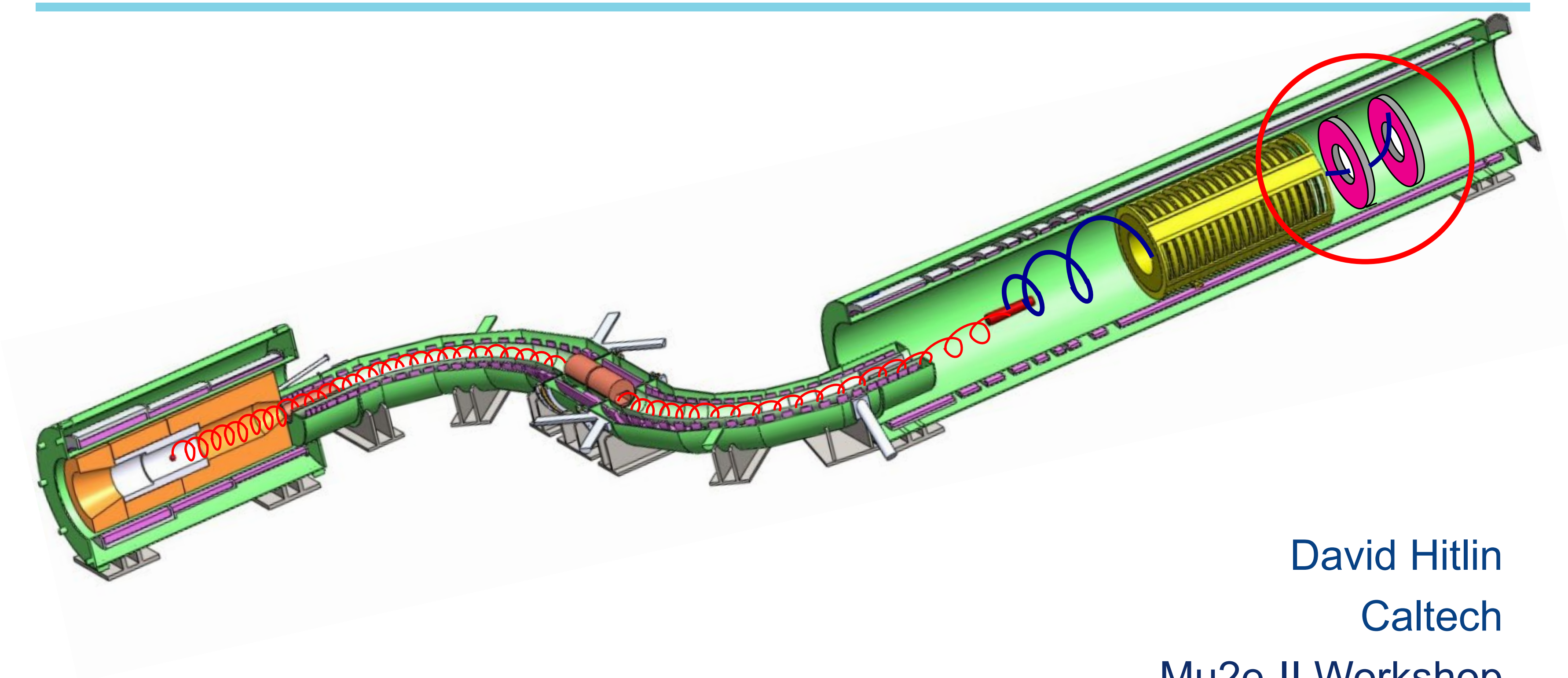
Calorimeter Subgroup Progress Report



David Hitlin

Caltech

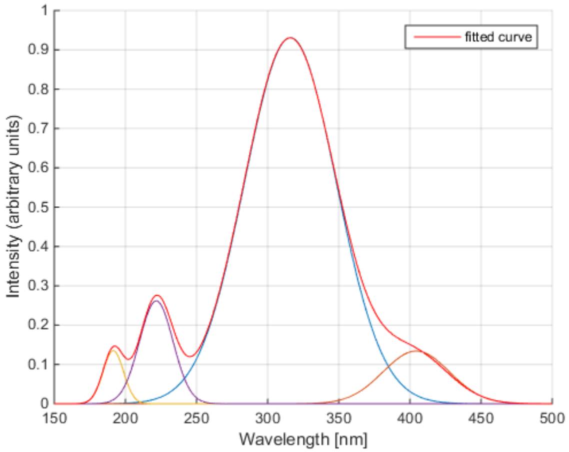
Mu2e-II Workshop
July 21, 2021

Mu2e-II calorimeter subgroup

- The only R&D effort that has been communicated to our subgroup over the last year or so is the work at Caltech on doped barium fluoride and on a SiPM for BaF_2 readout
- Neither of these efforts is currently funded
  - COVID-19 restrictions have impacted the work, but there has been some progress
  - We have submitted three proposals seeking funding
    - Rothenberg Innovation Initiative (Caltech) – not funded
    - DOE Advanced Detector Research – excellent reviews, but not funded
    - Caltech/JPL President’s and Director's Research and Development Fund - pending
- We want to organize another calorimeter workshop, but we haven’t detected sufficient activity to warrant one
  - Other potential avenues of inquiry include different crystals (*e.g.*, LYSO), nanoparticle wavelength shifters, microchannel PMTs, LAAPDs, …

Photosensor options for BaF_2 readout

- BaF_2 is an excellent candidate for a fast, high rate, radiation-hard crystal for the Mu2e-II calorimeter, provided that one has a way of utilizing the 220 nm fast component without undue interference from the larger 320 nm slow component
  - There are actually two fast components (τ = 0.6 ns) at 195 and 220 nm and two slow components (τ = 630 ns) at 320 and 400 nm



- Our approach

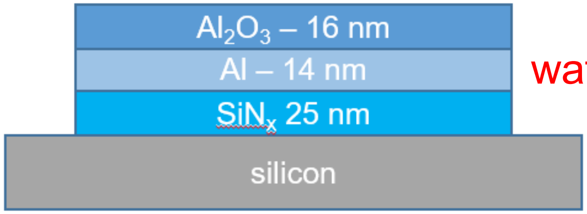
  Suppress the BaF_2 slow component by Y doping, as developed by Zhu *et al.*,: a major advance, although R&D remains to be done

  Develop a SiPM that is sensitive only to the fast component

  This is being done by a Caltech/JPL/FBK collaboration:

Caltech	B. Echenard, D. Hitlin, J. Oyang, J. Trevor, L. Zhang, R-Y. Zhu
JPL	J. Hennessy, M. Hoenk, A. Jewell
FBK	A. Ficorella, A. Gola, G. Paternoster

FBK SiPM with three-layer filter

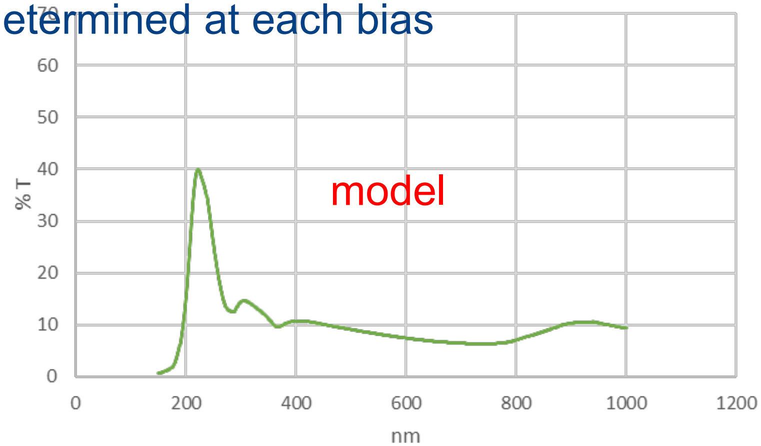


wafer 11

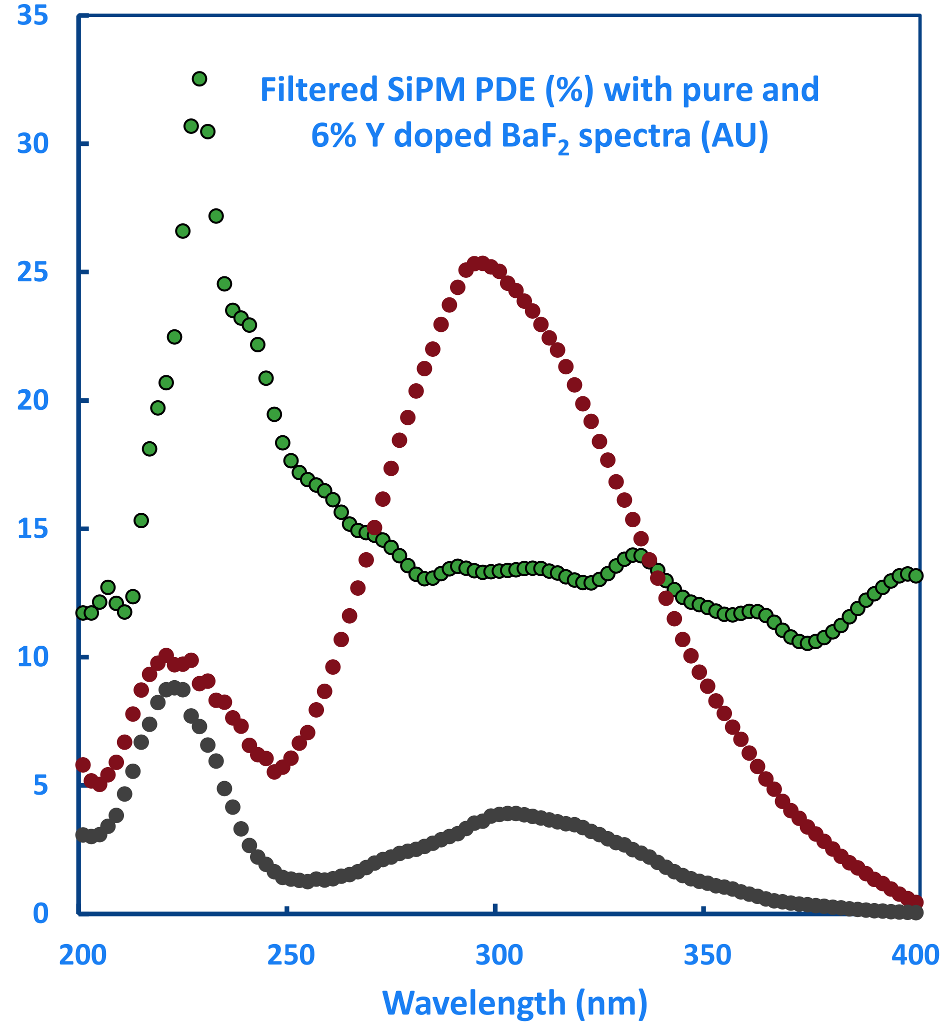
PDE scanned *vs.* wavelength at several bias voltages, with gain measured

Calibrated with pulsed LED @ 465 nm for SiPM bias at 29 V

Excess noise factor determined at each bias



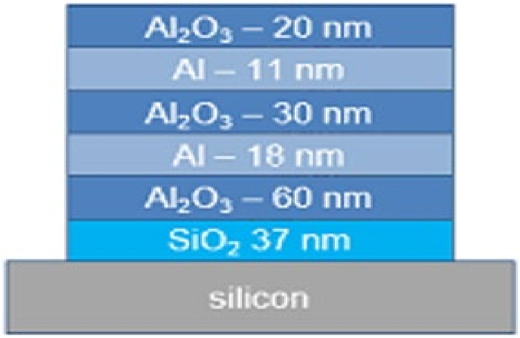
measurement

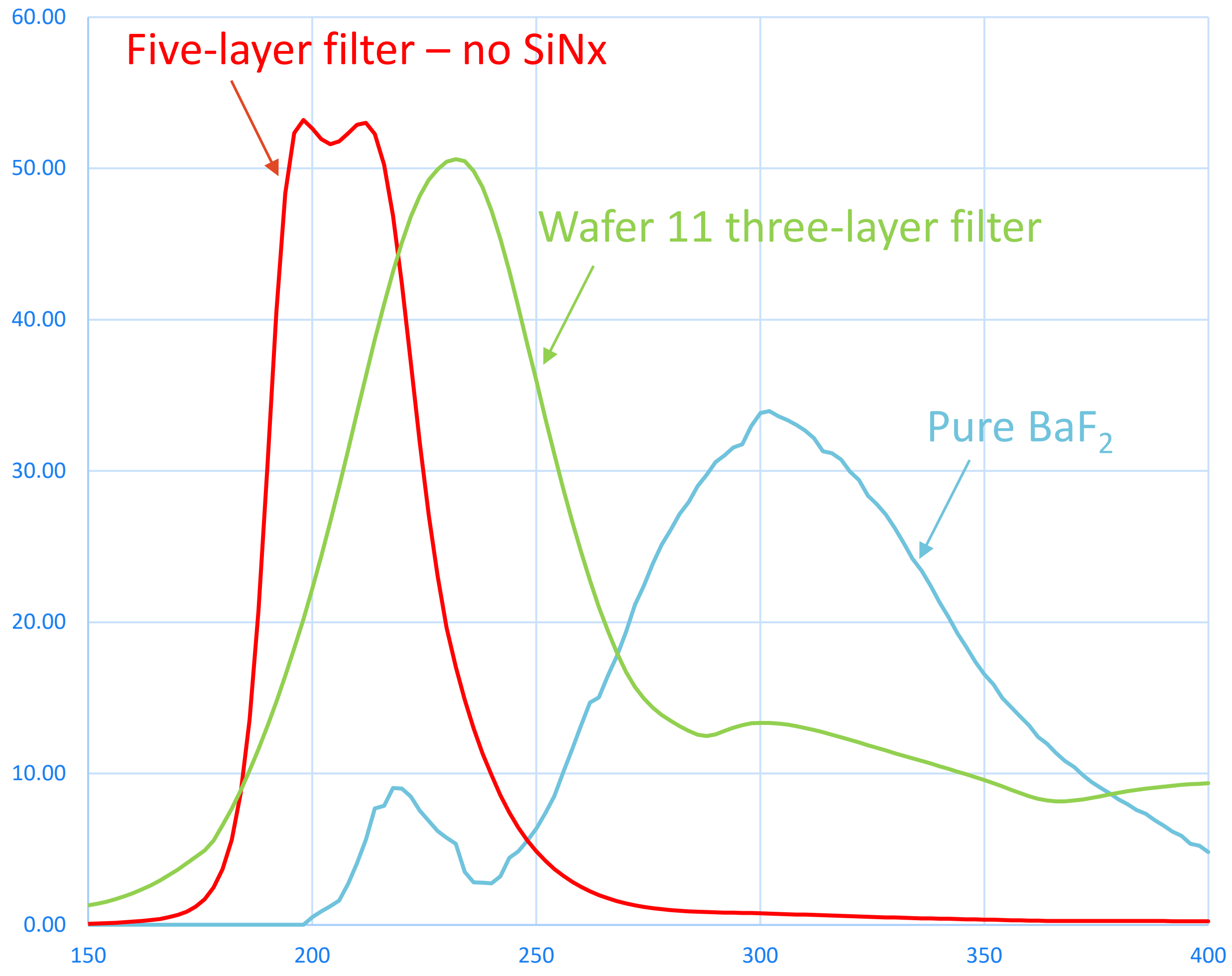


L. Zhang, J. Oyang

Five-layer filter design – calculation

- The bandpass of the five-layer filter (this design assumes complete removal of SiNx passivation) is narrower, encompasses the small 195nm fast component and has superior suppression of the slow component

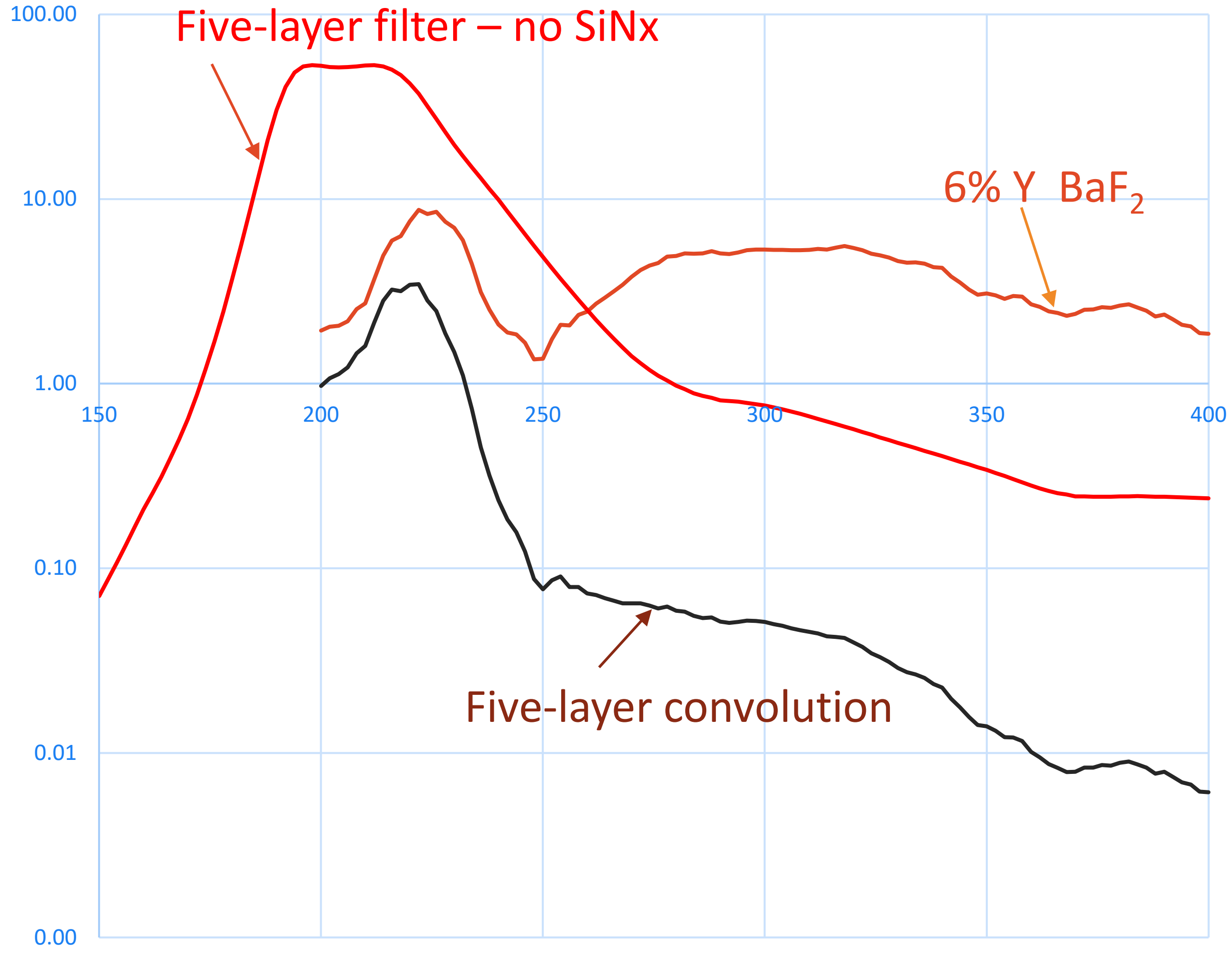




Further improvement of fast/slow performance

- Combining
  - 6% Y-doped BaF_2 and
  - SiPM with a five-layer filter

  provides further improvement in the ratio of fast-to-slow scintillation components
- This performance should be adequate for the Mu2e-II calorimeter and other high-rate applications



CIT/JPL/FBK SiPM - a phased approach

- Building on our experience with a large area APD developed with RMD, we have adopted a phased SiPM development approach

DONE

1. Build a three layer ALD filter on a 6x6 mm NUV SiPM structure, exploring different SiNx passivation layers, guard ring structures, …
2. Fabricate 2x3 arrays of the 6x6 mm chips, biased in series parallel configuration à la MEG and Mu2e to read out larger crystals

Underway

3. Improve slow component rejection with more sophisticated five-layer filters –ship to Caltech for measurement/test

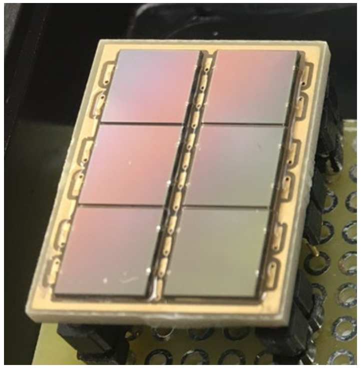
Unfunded

4. Use delta doping and backside illumination to improve PDE, the effectiveness of the filter and timing performance
   - First explore parameter space of MBE fab of delta-doping using diode structures of various sizes – reticles have been produced
   - Then fab back-illuminated SiPMs with five-layer filters and delta-doping

Estimated layer thicknesses April 2021

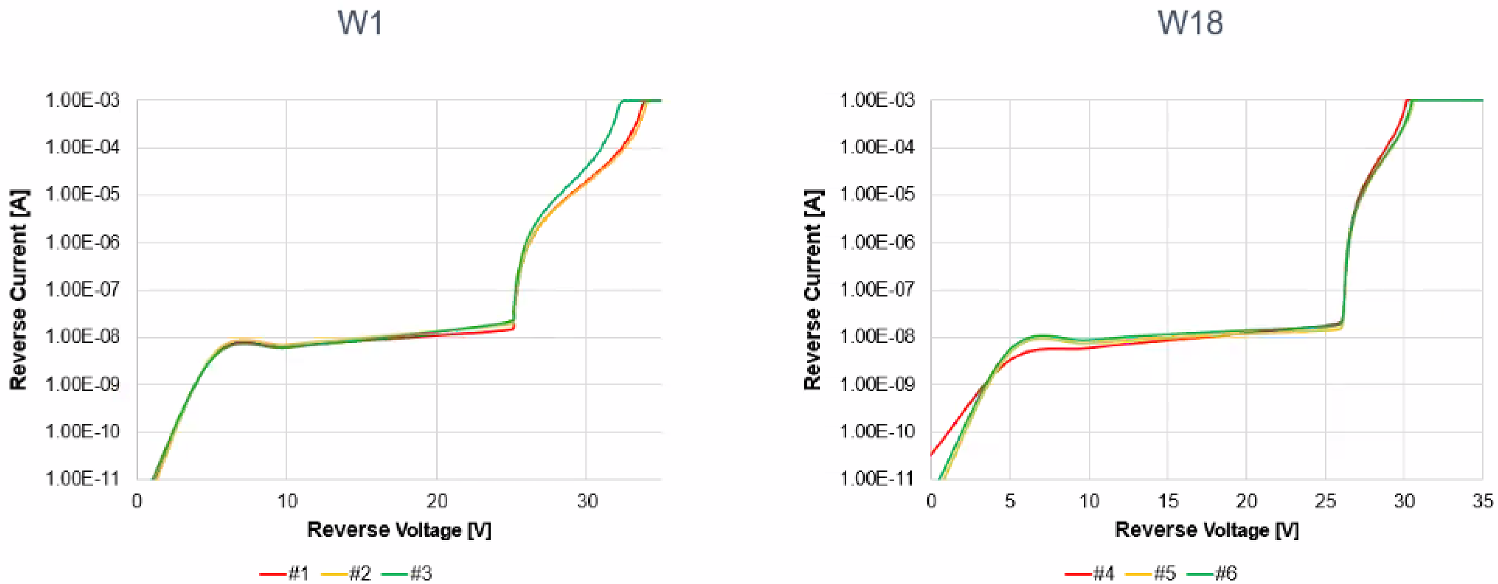
- JPL now has access to their ALD and MBE facilities
- We have now produced new five-layer filters on two existing wafers

- FBK wafers 1 and 18 have pre-existing passivation layers of SiN and SiO_2 respectively
- Dummy wafers B0330 and B0401B were also produced for etch testing, starting with bare silicon only
- These wafers have been sent to FBK for electrical testing, dicing into 6x6 mm chips and production of 3x2 arrays of the 6x6 mm chips
- Devices for measurement of PDE (6x6 mm) were shipped to Caltech yesterday. (3x2 arrays) for readout of large BaF_2 crystals will be shipped in a few weeks



IV curves for new wafers

IV measurement



Next steps – not currently funded

- We succeeded, using an SBIR grant with RMD several years ago to produce large area back-illuminated APDs with filters for the BaF_2 fast component
- SiPM structures are much more complex
  - We have adopted a two-phase approach
    1. Fabricate diode structures of varying sizes in order to use measurements of leakage current with many area vs. perimeter ratios to understand the effect of
       - Different etching procedures on metallization and other surface structures
       - Different MBE formulations

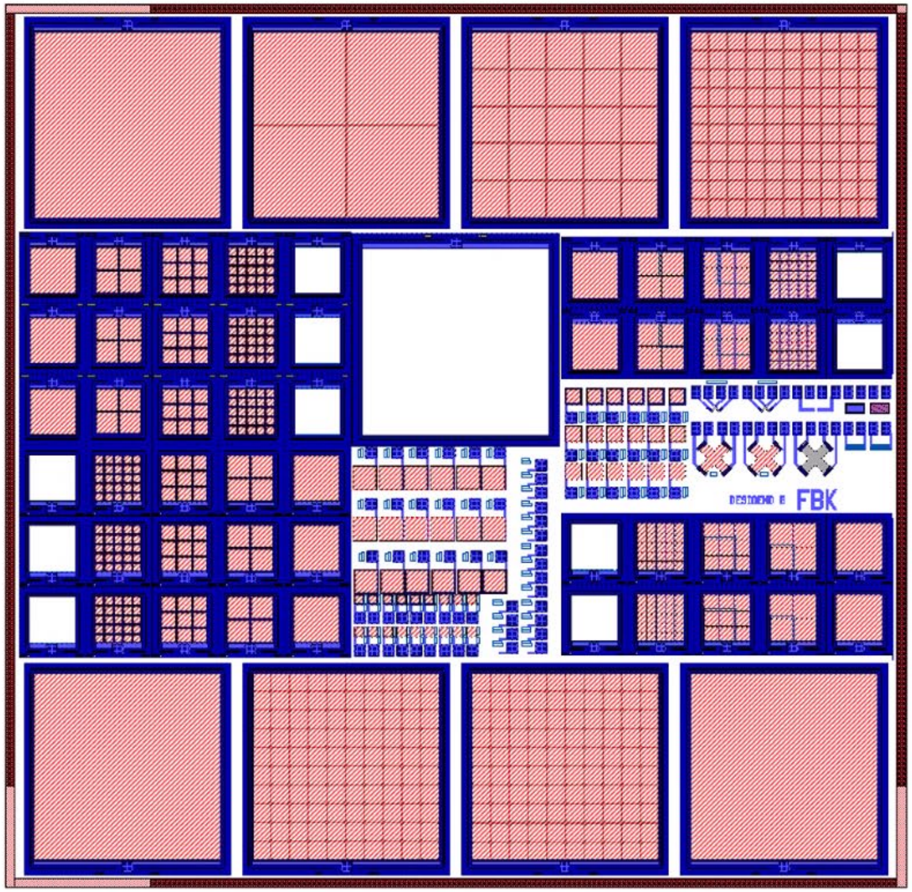
       on device electrical performance
    1. Use this information to optimize deep, delta-doped and filtered SiPM structures that can be back-illuminated

Photodiode wafers

FONDAZIONE BRUNO KESSLER

Shot composition

Splits	Layout	AA/SIR Overlap	Trench/ SIR
1	L1	Overlap1	no Dist
2	L1	Overlap2	no Dist
3	L1	Overlap1	Dist1
4	L1	Overlap2	Dist1
3	L1	Overlap1	Dist2
4	L1	Overlap2	Dist2
5	L2	Overlap1	no Dist
6	L2	Overlap2	no Dist
7	L2	Overlap1	Dist1
8	L2	Overlap2	Dist1
7	L2	Overlap1	Dist2
8	L2	Overlap2	Dist2
9	L3	Overlap1	no Dist
10	L3	Overlap2	no Dist
11	L3	Overlap1	Dist1
12	L3	Overlap2	Dist1
11	L3	Overlap1	Dist2
12	L3	Overlap2	Dist2



Shot size ~10x10mm^2

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Photodiode production schedule