UNIVERSITAT DE BARCELONA

Advances towards a tracker based on APD sensors

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VI Jornadas Futuros Aceleradores Lineales
Granada 16-17 May 2011

ICCUB

Department of Electronics
Universitat de Barcelona

Roadmap (1) – SiLC

SiLC timeline and current personnel responsible

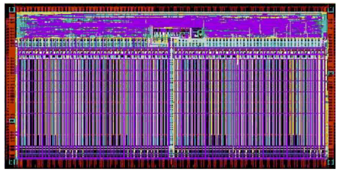
FPA2008-04122-E
FPA2008-05979-C04-02

AIDA

2007 — 2008 — 2009 — 2010 — 2011

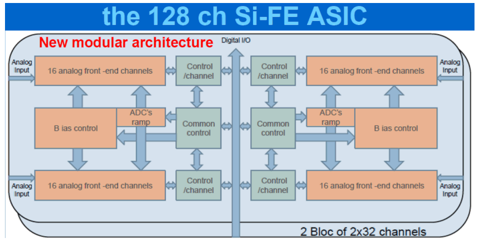
2007: Start of collaboration with IN2P3. Design of the digital part

2008: SiTR-88-130UMC



(1st mixed signal chip)

2009–2010: Definition of new architecture



2011: Complete new design (responsability of UB)

- Verilog A modelization of building blocks (AM, RC)
- Architecture (RC, AD)
- Architecture exploration (AM, RC, AD)
- Simulations (AM)
- Layout (TBD)
- Verification (TBD)
- Basic building blocks → Channel → Chip

Andreu Montiel (FBG)

Raimon Casanova (post-doc UB)

Angel Diéguez (UB professor)

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Roadmap (2) – DEPFETs

o DEPFETs timeline and current personnel responsible

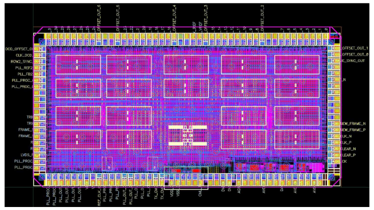
FPA2008-05979-C04-02

FPA2010-21549-C04-01

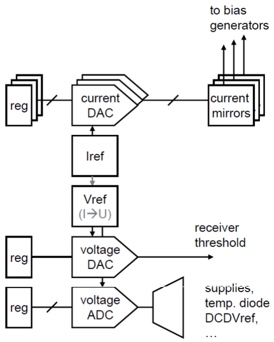
2009 — 2010 — 2011

Slow control
Digital (JTAG)
Analog blocks for configuration and basic blocks (bandgap, DAC, ADC, amplifier)

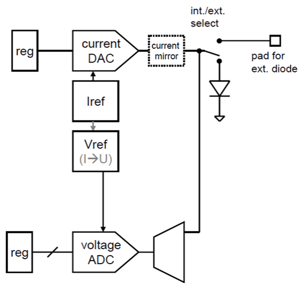
DHPv1



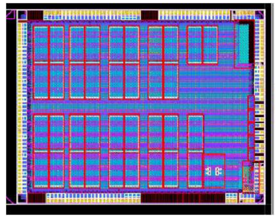
Starf of DHPv2



Sensor T



DHPv2



IBM 90nm
LAST RUN!!!

Current ADC (OA)

Iref (OA)

ADC (RC)

Amplifier (RC)

Diode (RC)

Floorplanning & integration (RC, Bonn)

Oscar Alonso (FPA2010 technician)

Raimon Casanova (post-doc UB)

Angel Diéguez (UB professor)

Overall guidance (AD)

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APDs timeline and current personnel responsible

FPA2008-05979-C04-02

FPA2010-21549-C04-01

AIDA

AMS R1
STM R1
STM R2
AMS R2
AMS R3

2008 | 2009 | 2010 | 2011 | 2012

Technology investigation
Technology exploration (STM, HV-AMS)
Analyses of structures (STI)
Sensor characterization
(I(V), noise, dynamic behavior & range))
Studies of sensitive area with FIB

Pixel development
Low noise digital pixels
Integrated readout

Studies of run to run variations
Studies of die to die variations

Array development
1mm x 1mm array that fits T.B. requirements

Prove of concept
Test beam
Radiation tests (sensor, electronics)
Investigate tech.

Technological development

- Technological investigation (EV, OA, AV, AD)
- Pixel design & characterization (EV, OA, AV, AD)

Test Beam preparation

- Array design & test (EV, AD)
- Off-chip electronics (EV, OA, AD)
- Geant4 simulations (JT, MV, LG)
- Test Beam set-up (EV, OA, JT, MV, AD)

Eva Vilella (Grant UB)
Oscar Alonso (FPA2010 tech.)
Juan Trenado (FPA2010 tech.)
Marcel Vos (IFIC)
Anna Vilà (UB professor)
David Gascon (UB tech.)
Lluís Garrido (UB professor)
Angel Diéguez (UB professor)

► Outline

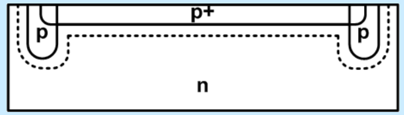
- AMS R2 – APDs Chip 2010
  - Readout electronics for low noise pixel detectors
  - 3 x 3 GAPD array
  - Results
- AMS R3 – FLC_APD_v1 2011
  - Submitted chip and circuits
  - 1mm x 1mm GAPD array
- Test beam preparation
- Conclusions

AMS R2 - APDs Chip 2010 (1)

- **Geiger mode Avalanche Photodiodes (GAPDs)**
  - **Pros**
    - ✓ High intrinsic gain
    - ✓ Accurate time response with possible single BX detection
    - ✓ Compatible with standard CMOS processes
  - **Cons**
    - × Afterpulses
    - × Dark counts

      } → Noise hits, indistinguishable from real events
    - × Reduction of detector performance
    - × Increase of memory area to store the total hits

Avalanche photodiodes in standard CMOS technologies



- **It is mandatory to reduce noise hits! How?**
  - Using HV-AMS 0.35µm technology
  - Introducing readout electronics for low noise GAPD pixels

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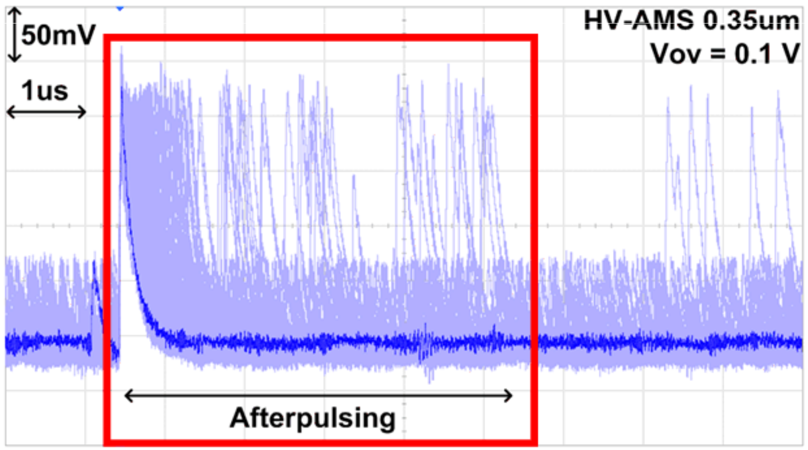
o Intrinsic noise sources

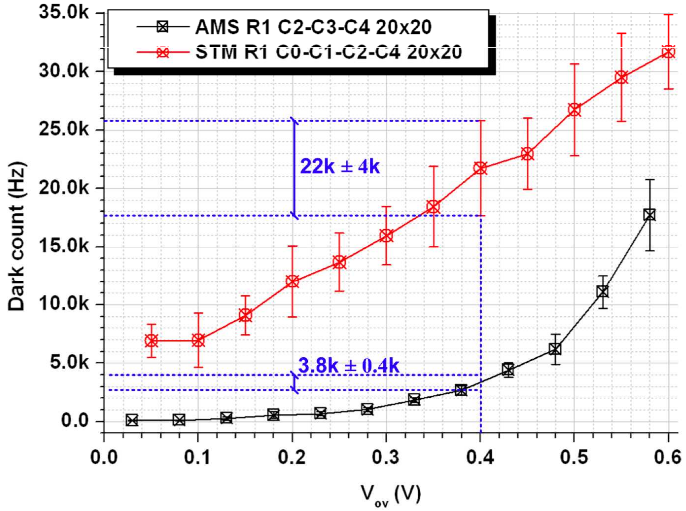
Afterpulses.

- Correlated pulses due to the random release of carriers that were trapped during a previous avalanche.
- Depends on the trap density and I_{diode}.



Dark counts.

- Spurious avalanches caused by thermal or tunnel carriers.
- Depends on the technology, the sensitive area, V_{OV} and T.



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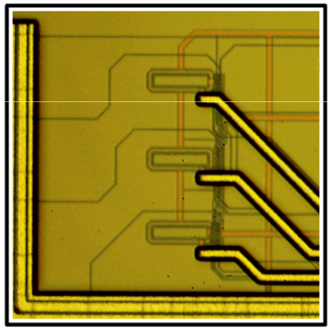
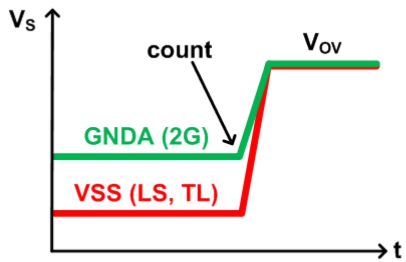
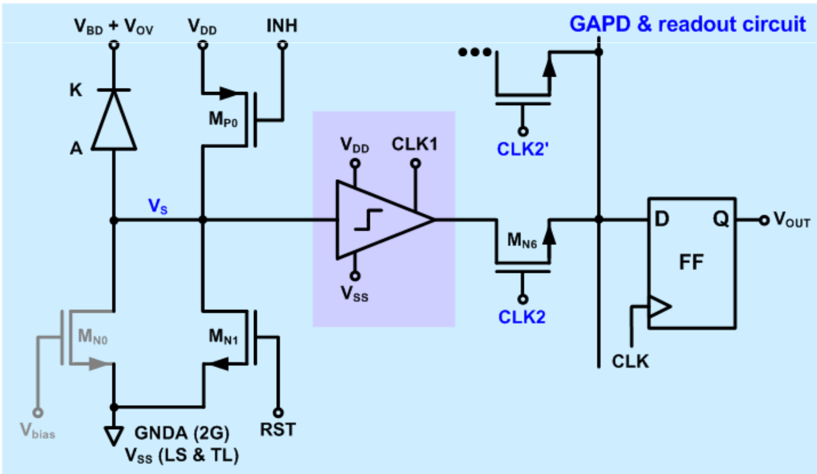
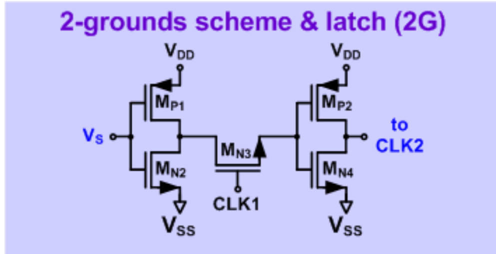
AMS R2 - APDs Chip 2010 (2)

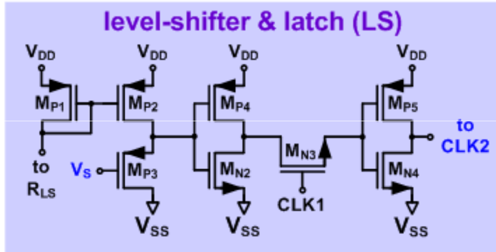
- **We developed readout circuits for low noise GAPD pixels**
  - Monolithically integrated with the sensor
  - Comprised of quenching transistor **and 3 different readout circuits**
  - Digital output

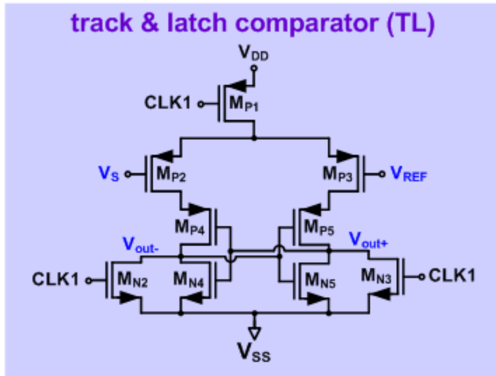












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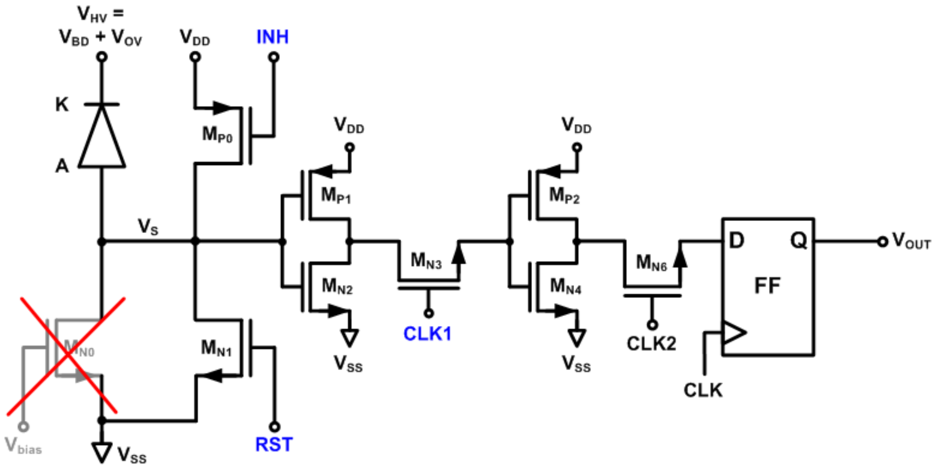
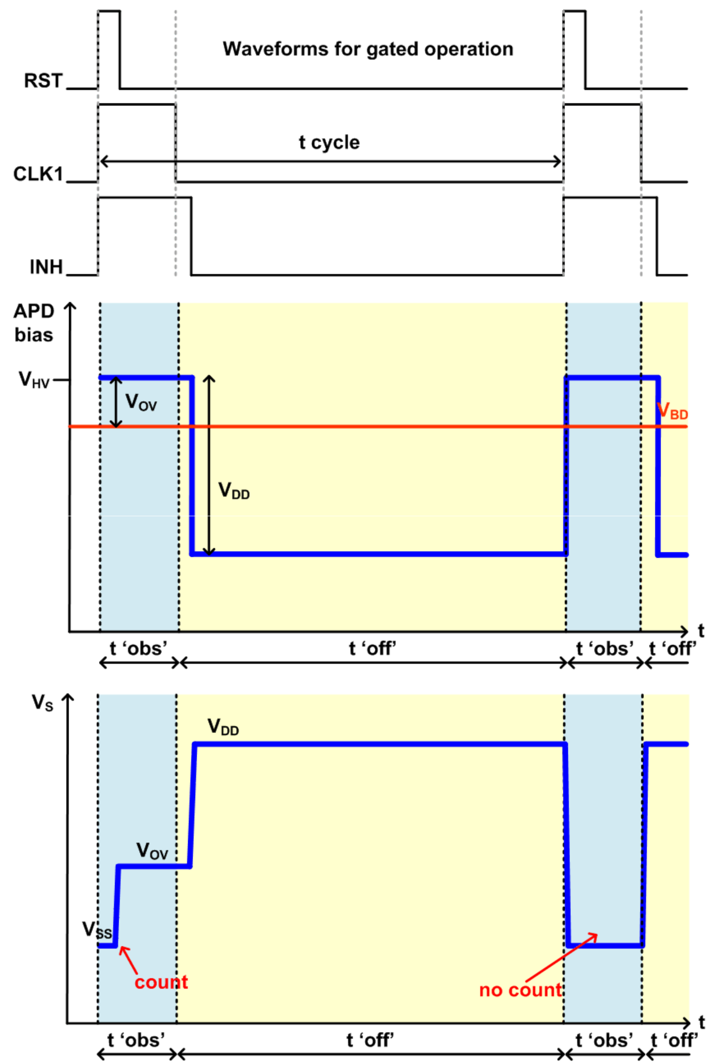
Gated operation

- **Free running**
  - The APD is always active.
- **Gated operation**
  - The APD is active for short periods of time by using a triggering signal.
  - Avoids afterpulsing
  - Reduces dark count
  - Improves detector performance

Good!





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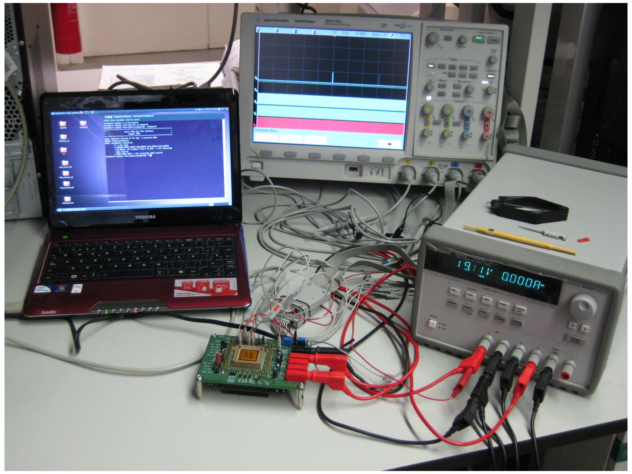
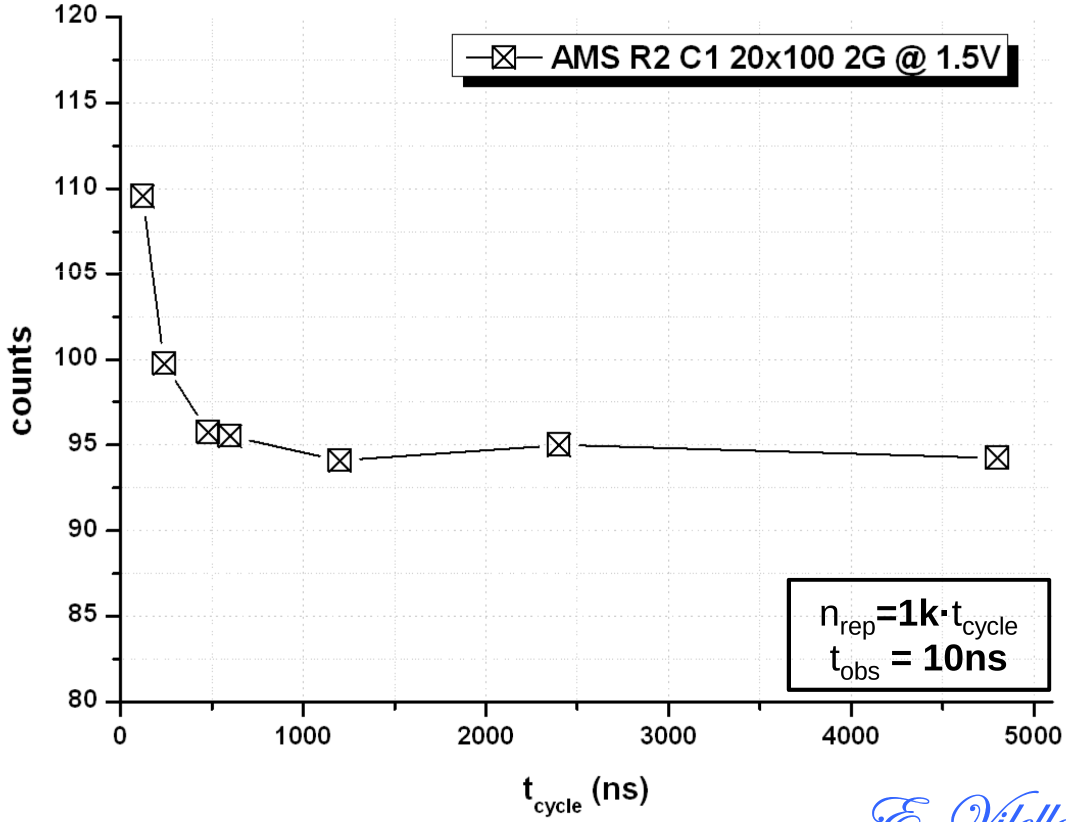
AMS R2 - APDs Chip 2010 (3)

- **It is possible to eliminate the afterpulsing probability by means of the gated operation.**
  - Leaving long enough t 'off' periods of 300ns.





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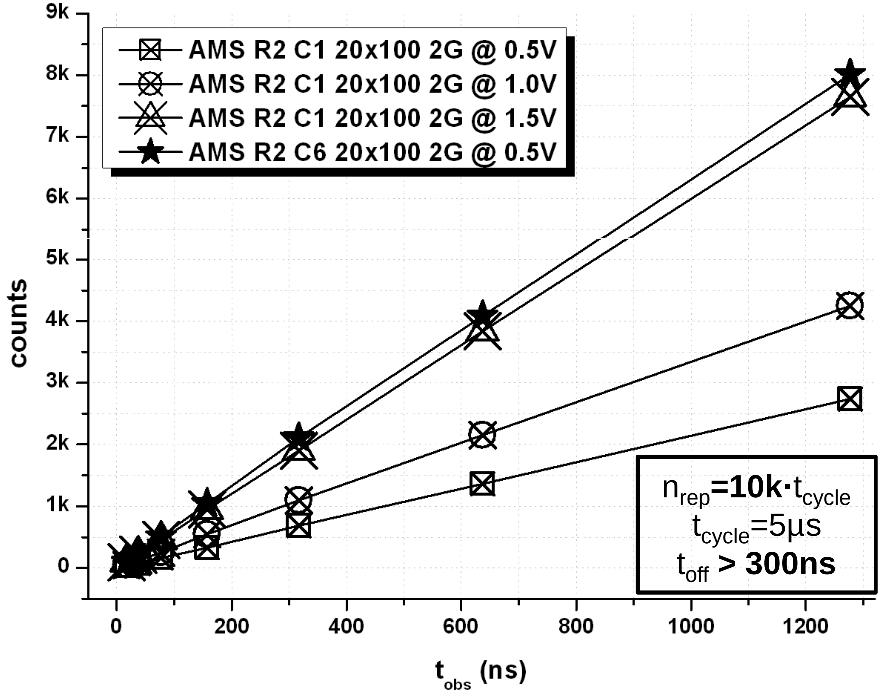
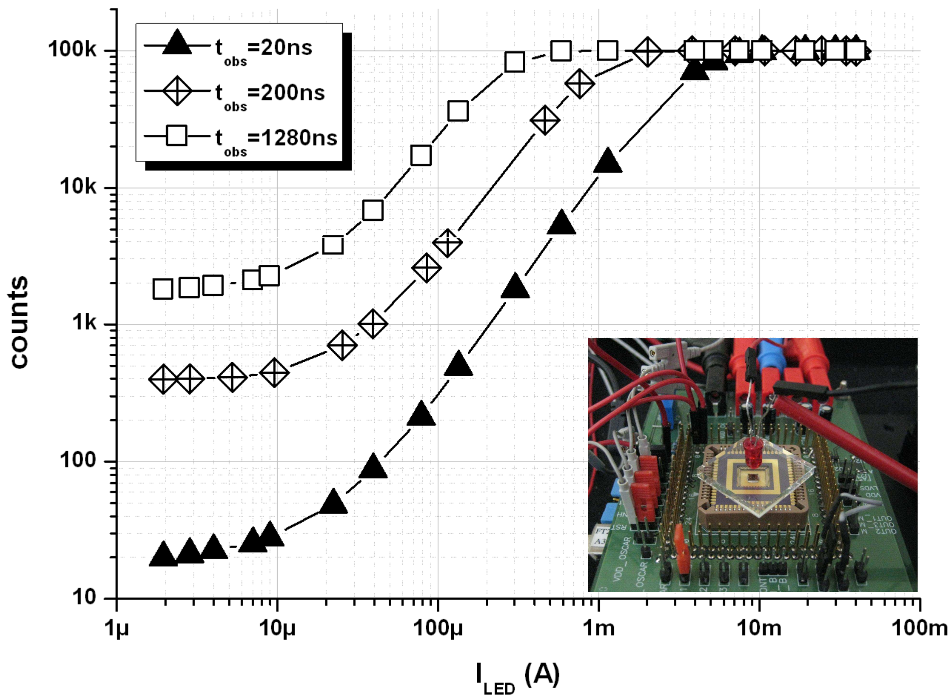
AMS R2 - APDs Chip 2010 (4)

- **Dark counts are reduced by using low overvoltages and short t_{obs}.**
- **Reducing noise hits, the dynamic range is extended.**





Dynamic range increased rom 9 to 14 bits

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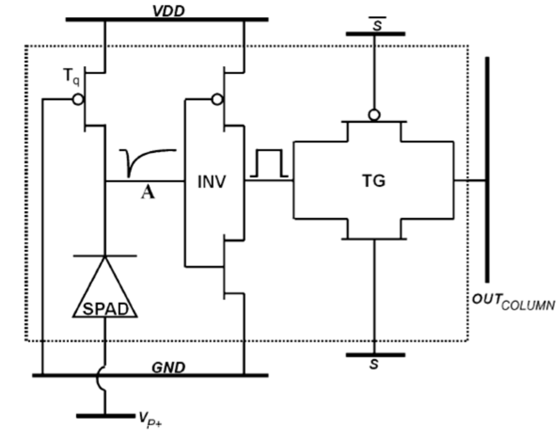
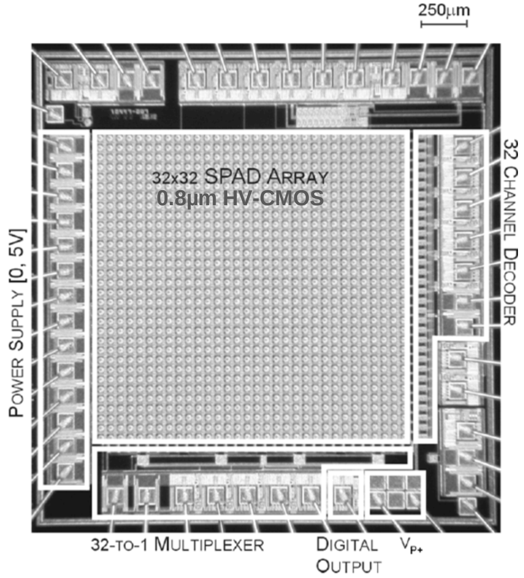
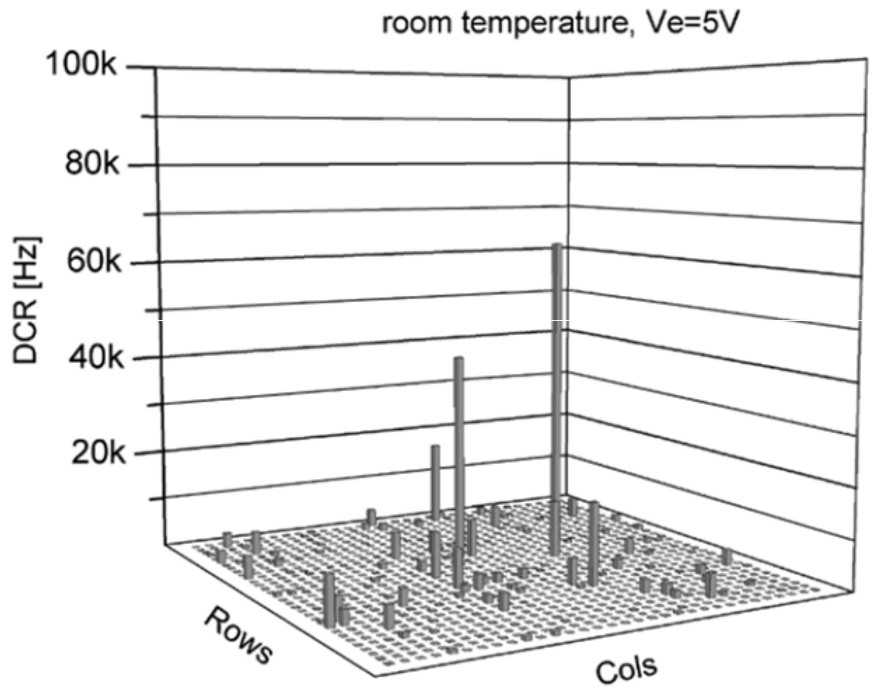
- Presence of dead pixels in GAPD arrays.







C. Niclass et al., "Design and characterization of a CMOS 3-D image sensor based on single photon avalanche diodes", IEEE Journal of Solid-State Circuits, vol. 40, no. 9, 2005.

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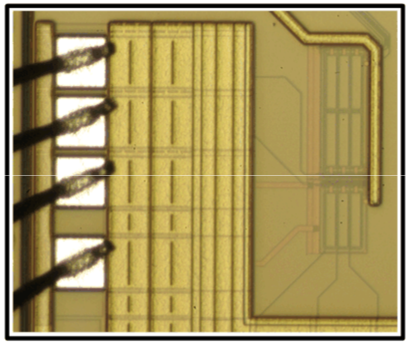
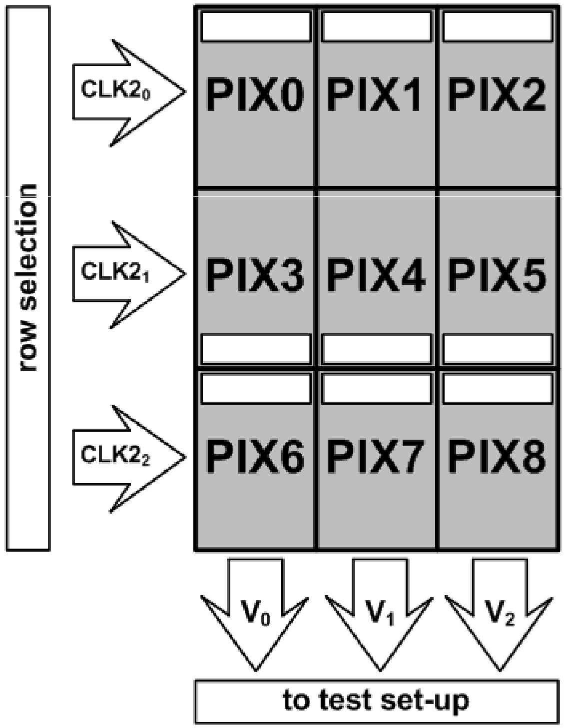
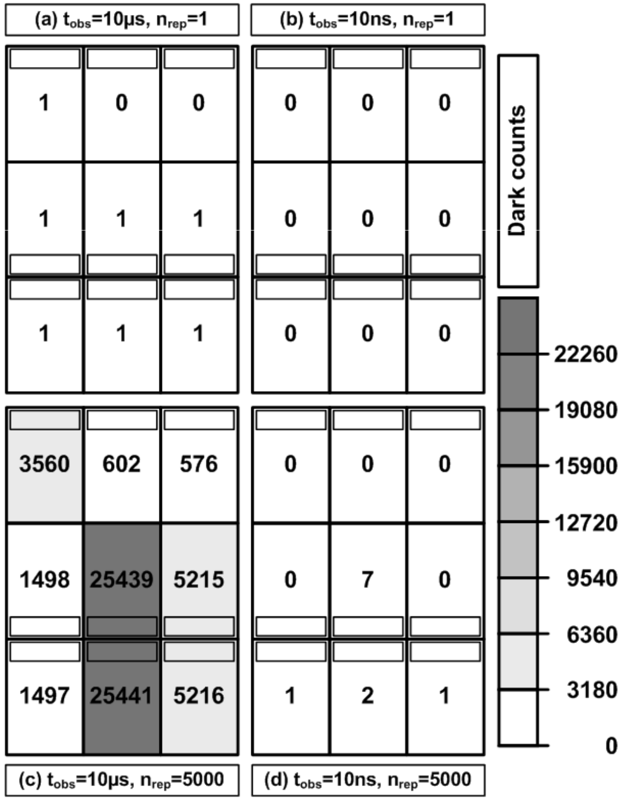
AMS R2 - APDs Chip 2010 (5)

- **The gated operation is also effective in reducing pixel-to-pixel disparities in GAPD arrays.**
  - 3 x 3 GAPD array with level-shifter sensing circuit.
  - Sequential reading by columns (CLK2 acts as a row selector).







No detector blindness because of the noise!

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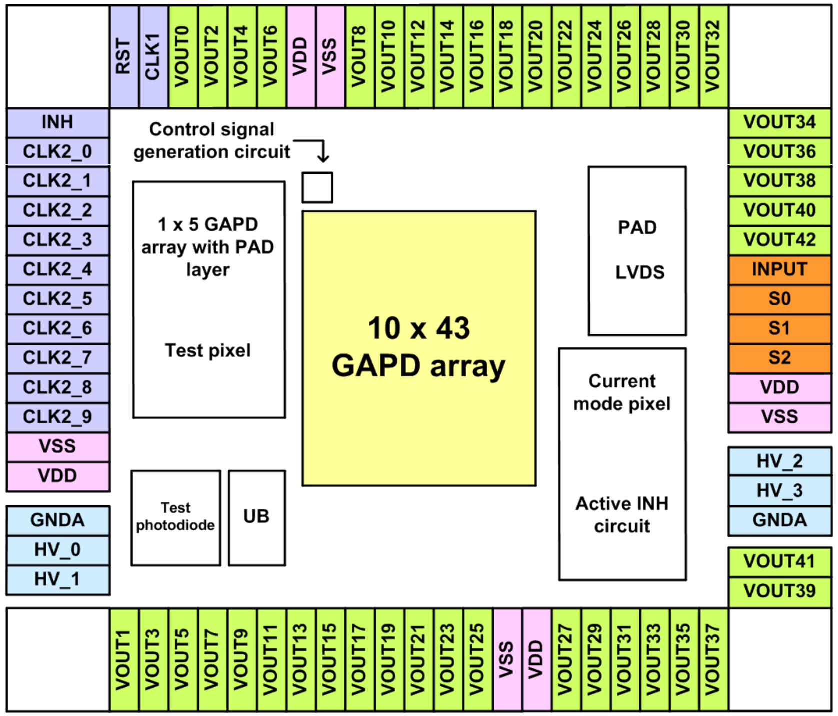
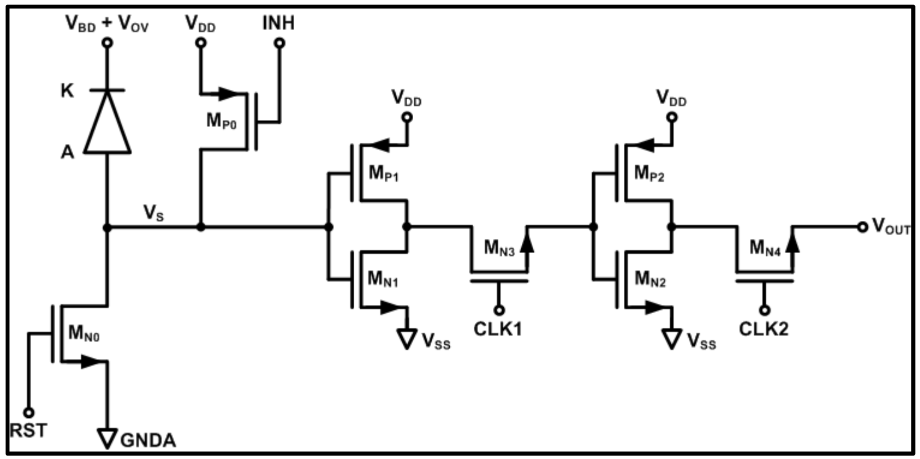
FLC_APD_v1 - AMS R3 (1)

o 10 x 43 GAPD array

- Total occupied **area** = 1025µm x 1400µm.
- **Pixel** comprised of GAPD, quenching transistor, sensing element (2-grounds scheme), storage element (latch) and pass-gate to allow sequential reading.
- GAPD mode of operation is **gated acquisition**.





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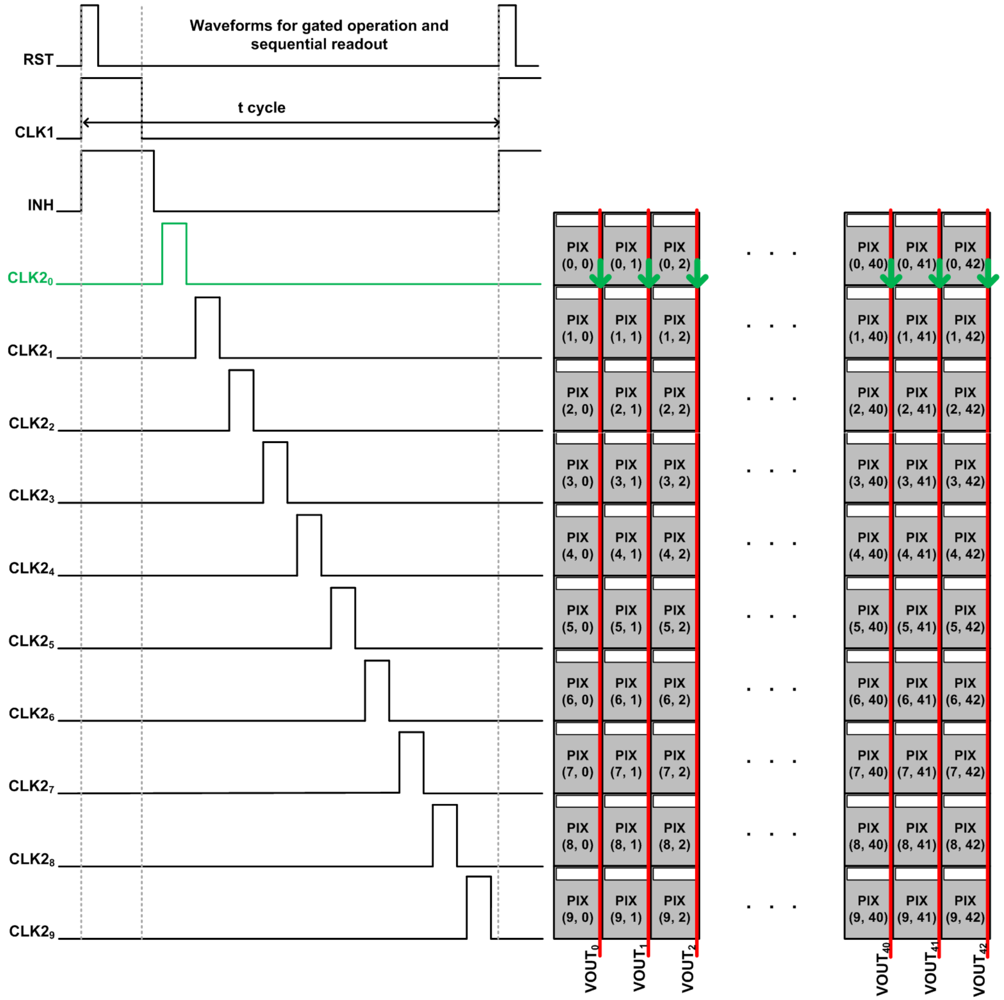
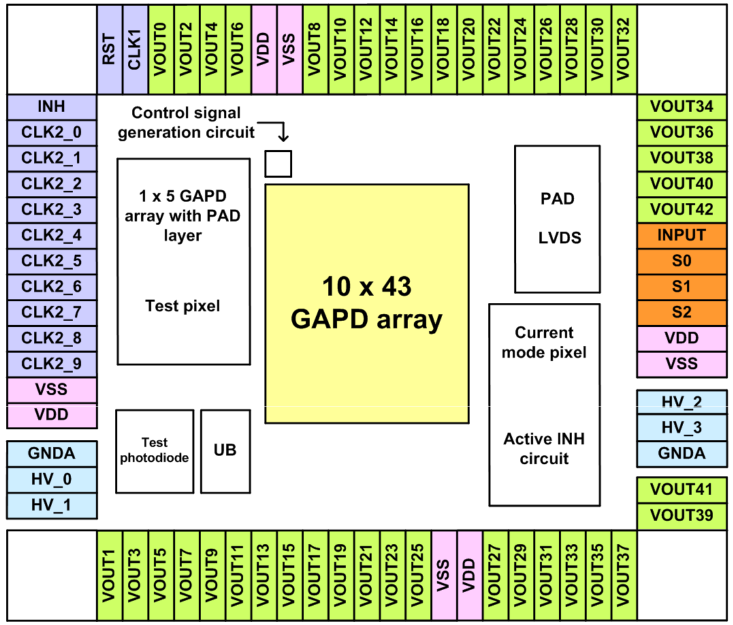
FLC_APD_v1 - AMS R3 (2)

- **Sequential reading by columns** (CLK2 acts as a row selector).





GAPD bias (4) and ground (2)
Electronics bias (4) and ground (4)
Selection signals (4)
Pixel control signals (13)
Pixel outputs (43)

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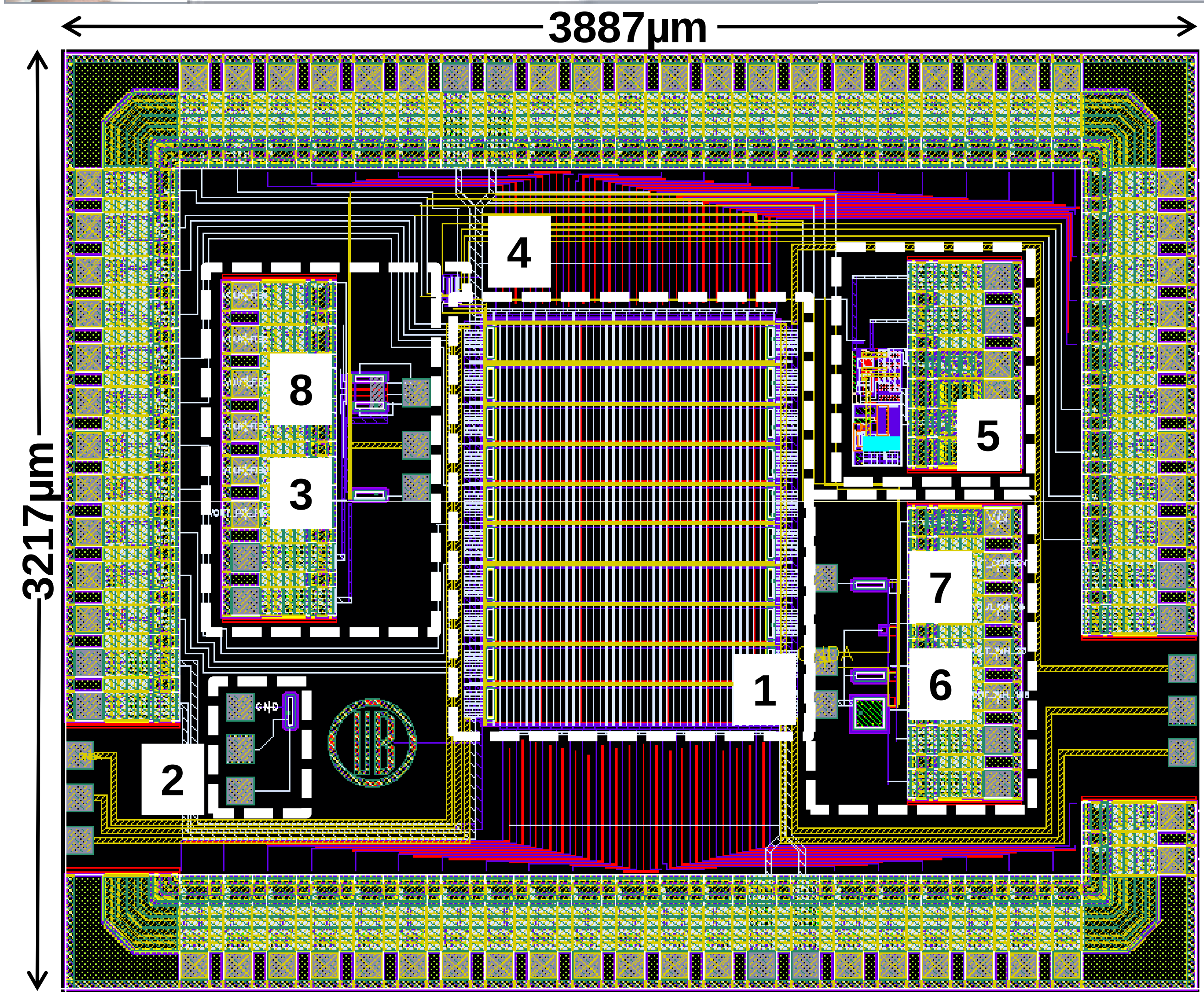
FLC_APD_v1 - AMS R3 (3)



1. 10 x 43 GAPD array
2. Test photodiode
3. Test pixel
4. Control signal generation circuit
5. Pad LVDS
6. Active inhibit pixel
7. Current mode pixel
8. 1 x 5 GAPD array with PAD layer

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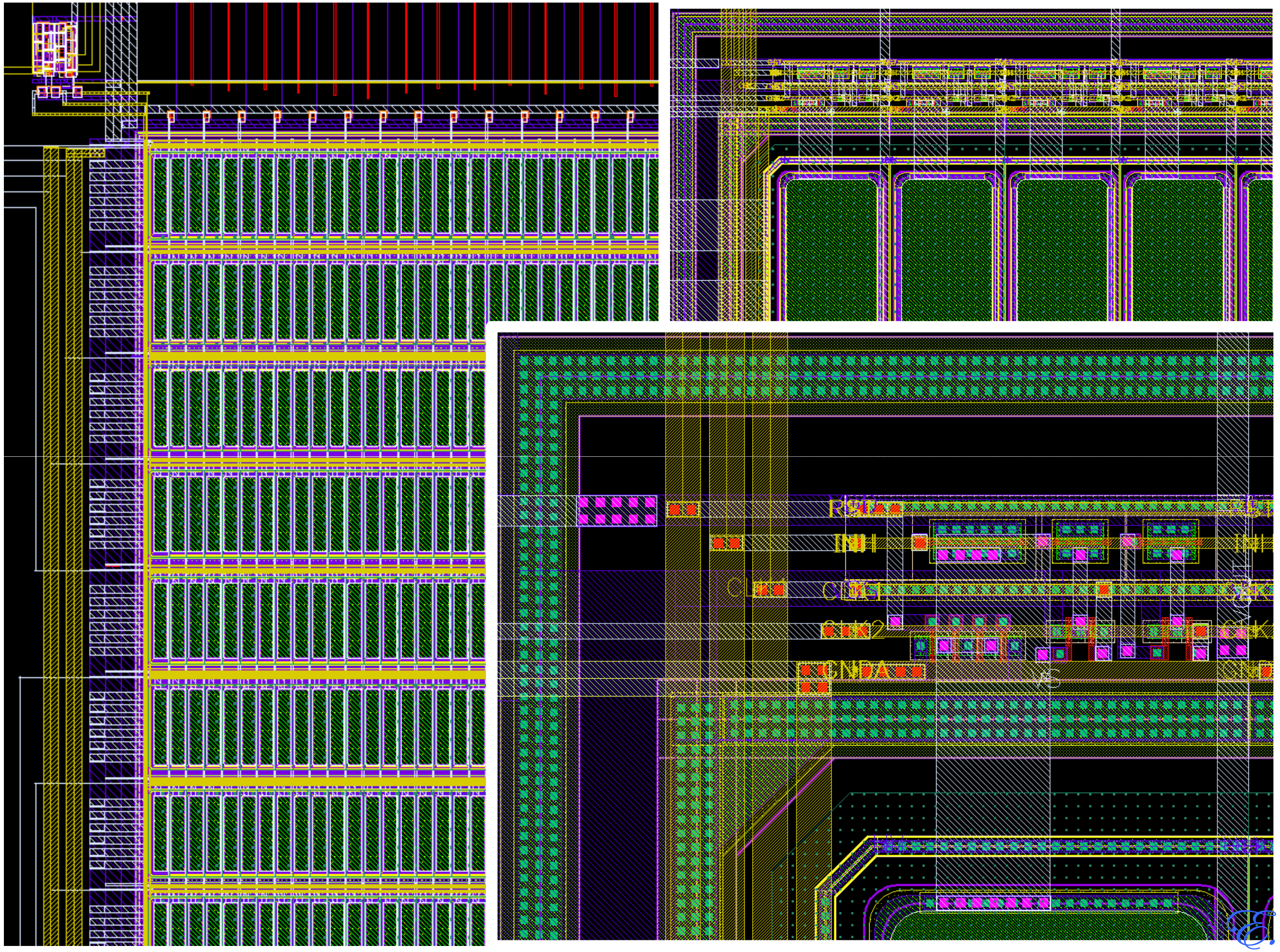
FLC_APD_v1 - AMS R3 (4)



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Test beams preparation (1)

- **GAPD array particle detection efficiency?**
  - Next steps
    - ↗ Test beam at **DESY** with 6GeV electrons (2011)
      Distinguish detection between **neighbour pixels**
    - ↘ Test beam at **CERN** with 120GeV pions (2012)
      Distinguish detection in an **specific region of the pixel**

- **Meanwhile working on the test set-up…**
  - Main worries → Distortion in the particle path caused by test set-up materials
  - Different ideas to reduce total material thickness
    - FLC_APD_v1 with thin silicon wafer of 250µm
    - No chip package & wire bond the chip directly to the PCB
    - PCB perforated under the chip
  - Running simulations with **Geant4**
    - Software to simulate the passage of particles through matter

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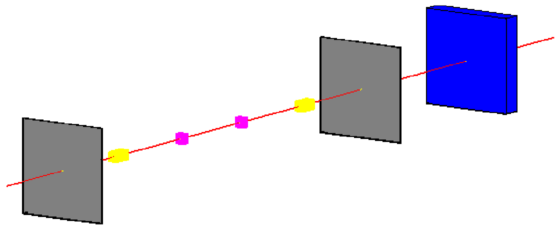
Test beam preparation (2)

Geant4 studies

- Performed using 2 silicon wafers, 2 aluminum layers and 2 or 4 scintillators (test beam set-up)
- Sources → electrons (6GeV) and pions (120GeV)



Results so far

	Detector at 2cm	X-Mean (µm)	X-Sigma (µm)	Y-Mean (µm)	Y-Sigma (µm)	Peak (µm)	R-Sigma (µm)
electrons	T.B. with 2 Sc.	-0.0801	16.2	0.008922	16.2	13	12.48
	T.B. with 4 Sc.	0.1474	17.6	0.07584	17.68	13	13.34
pions	T.B. with 2 Sc.	0.008092	0.7767	0.001725	0.7814	0.7	0.5769
	T.B. with 4 Sc.	0.0001457	0.8606	0.003204	0.8625	0.8	0.6955

	Detector at 10cm	X-Mean (µm)	X-Sigma (µm)	Y-Mean (µm)	Y-Sigma (µm)	Peak (µm)	R-Sigma (µm)
electrons	T.B. with 2 Sc.	-0.2033	16.91	0.18	46.88	35	39.25
	T.B. with 4 Sc.	0.3413	50.18	-0.06107	50.39	37	41.75
pions	T.B. with 2 Sc.	0.004929	2.092	0.00374	2.1	1.8	1.614
	T.B. with 4 Sc.	0.000984	2.301	0.00865	2.308	1.9	1.749

We need distortion lower than pixel width (20µm)!

- T.B. at DESY (electrons) → distortion is ~16µm
- Complicated to characterize (further studies are needed)
- T.B. at CERN (pions) → distortion is ~0.5µm
- To measure detector resolution and active regions we need 1-2µm precision

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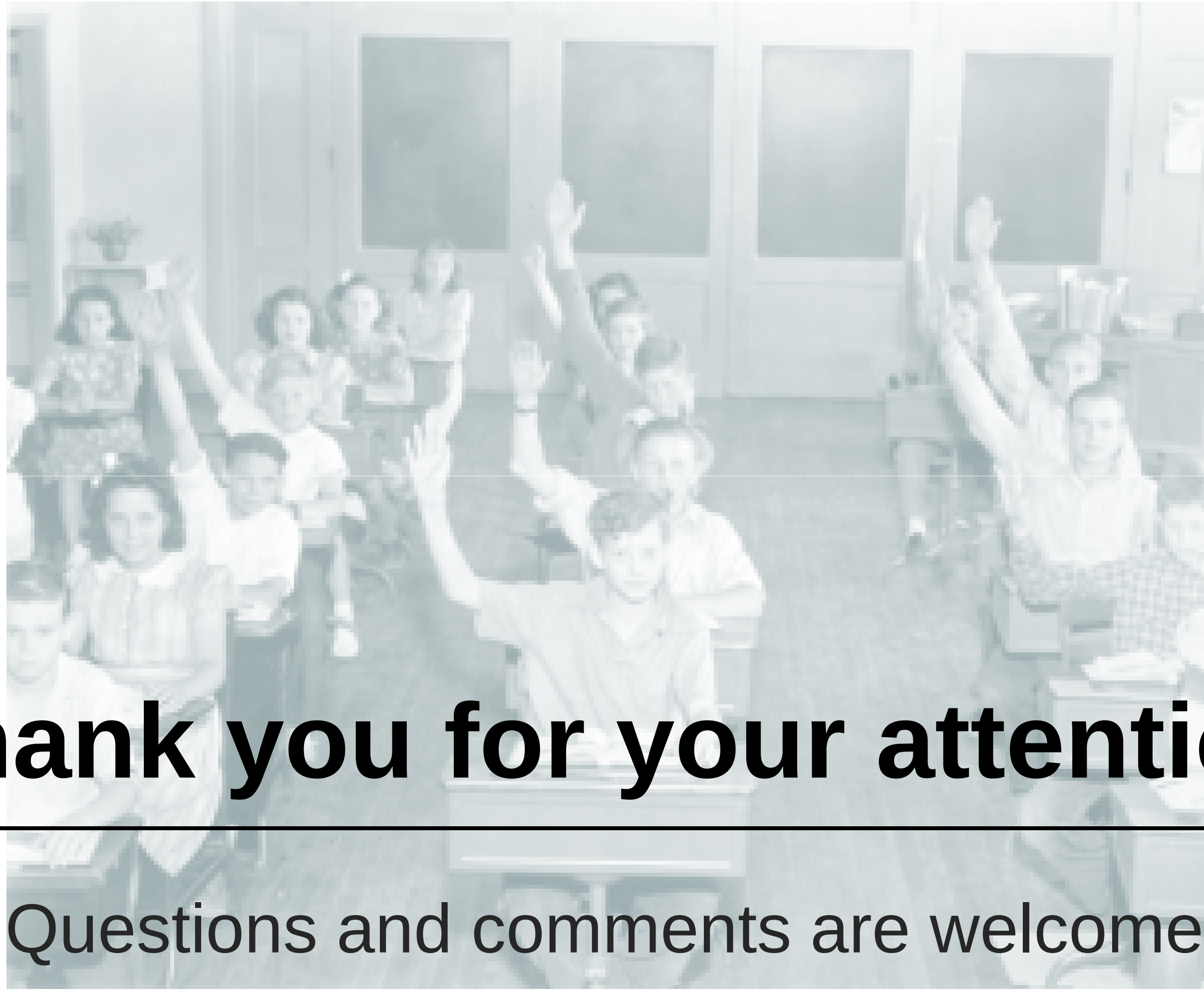
o Conclusions

- The gated acquisition is the best mode of operation for synchronized systems.
  - Avoids afterpulses and reduces dark count.
  - Eliminates dead pixels.
  - Uniformzes noise characteristics.

- We expect to receive the 1mm x 1mm GAPD array next August.
  - It will allow us to test if GAPD arrays with HV-AMS 0.35µm standard technology are efficient in particle detection.



Thank you for your attention

Questions and comments are welcome