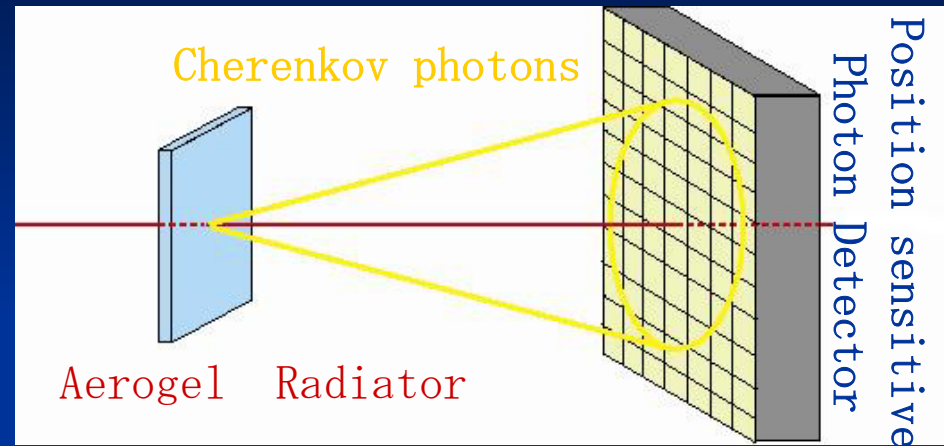


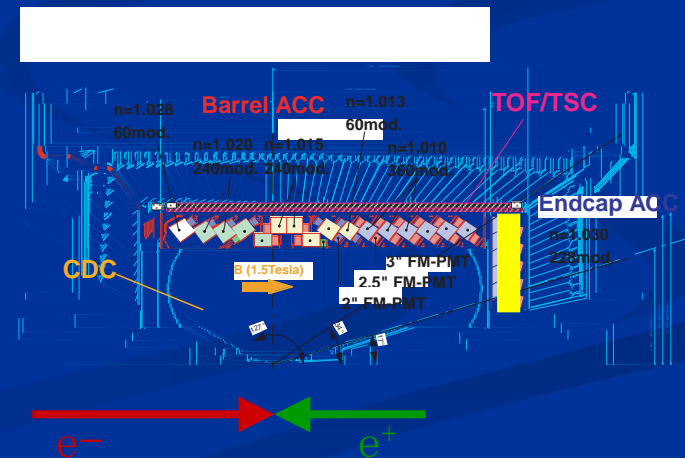


# Development of HPD (HAPD)

- Photon-detector for the Aerogel RICH
- Development of HPD and HAPD
  - Prototype Test
- Readout Electronics
- Summary
  - PID upgrade for the forward end-cap region.



## Concept of the Aerogel RICH





## *Photon-detector for the Aerogel RICH*

### ■ Requirements

- Can detect a single-photon with high efficiency.
- Have sensitivity to  $\sim 400\text{nm}$  photons from aerogel radiators (due to Rayleigh scattering).
- Can detect the position of photons with a resolution  $\sim$  a few mm.
- Immune to the high magnetic field (1.5 Tesla).



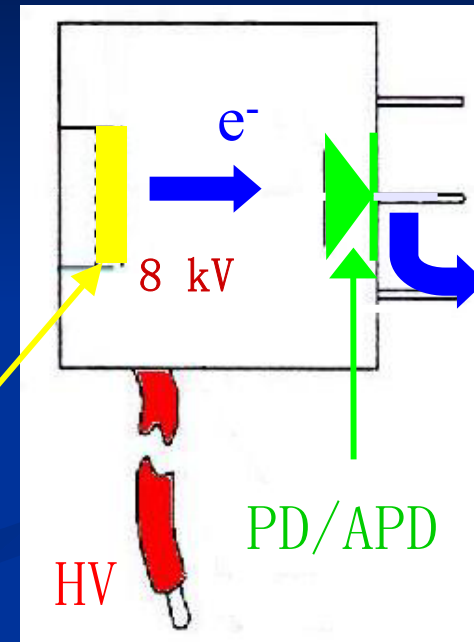
- HPD or HAPD may be the best candidates for the Photon-detector of the Aerogel RICH.
  - Fine-mesh PMT: Poor resolution for single photons.
  - MCP-PMT: 60% collection efficiency.



# Development of HPD and HAPD

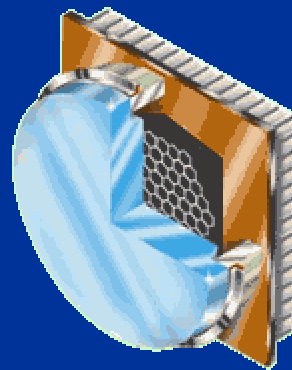
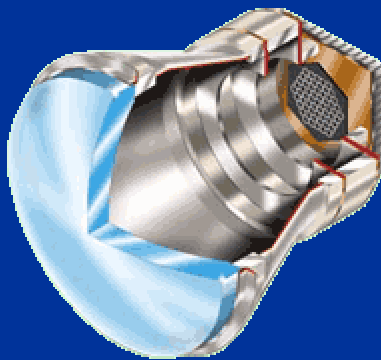
- Develop a multi-anode HPD/HAPD with proximity focus.
- Make the effective area as large as possible.

Photons



Output

Photocathode

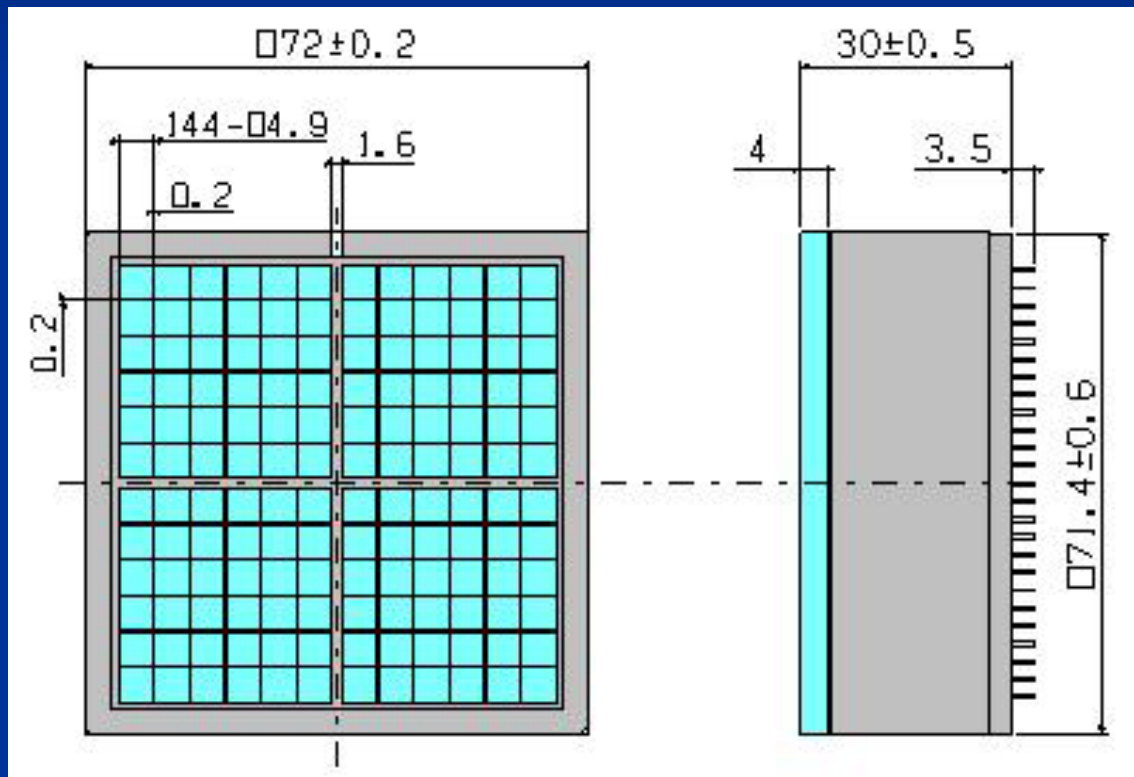


DEP catalogue



## Development of HPD and HAPD

- Multi-anode (144ch) HPD/HAPD are under development in the cooperative work between Belle and HPK.



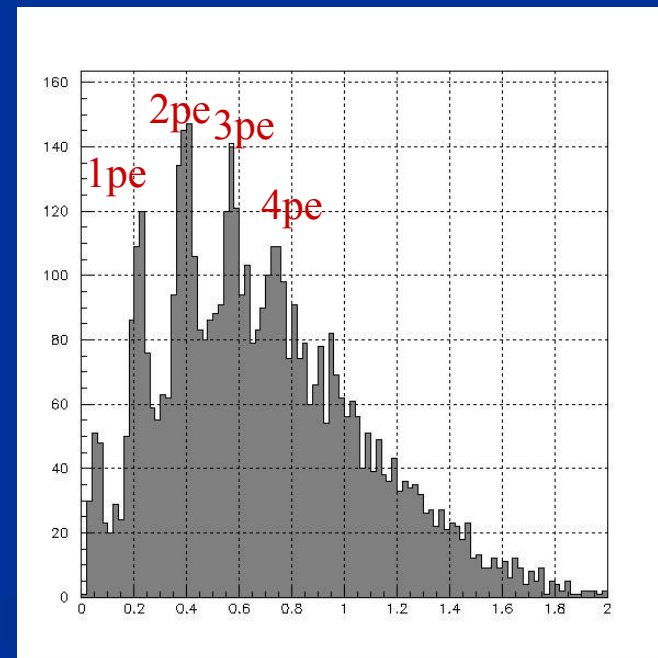
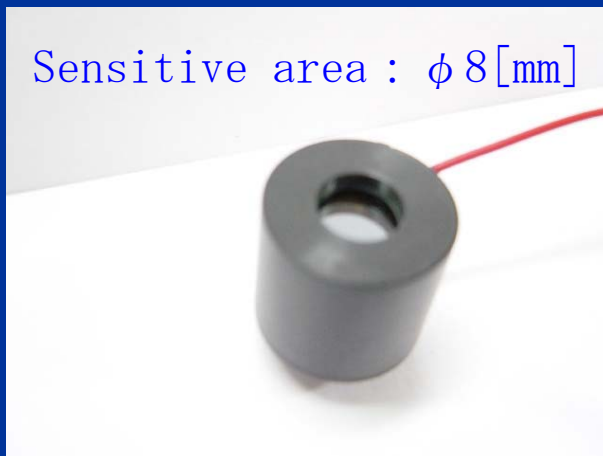
Outer:  $72 \times 72 \text{ mm}^2$   
Effective :  $59 \times 59 \text{ mm}^2$  (65%)  
Multi-anode:  $12 \times 12 = 144 \text{ ch.}$   
Pixel Size:  $4.9 \times 4.9 \text{ mm}^2$



# Prototype Test -Single Channel HPD-

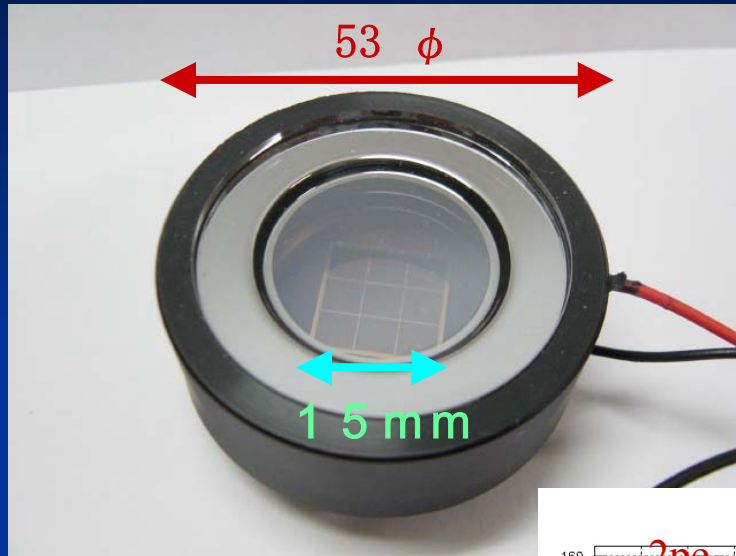
## ■ Single channel HPD

- Leak current : 4 [nA]
- Detector capacitance : 20 [pF]
- Gain (8kV) : 1500 [electron/photon]
- Bias voltage : 80 [V]



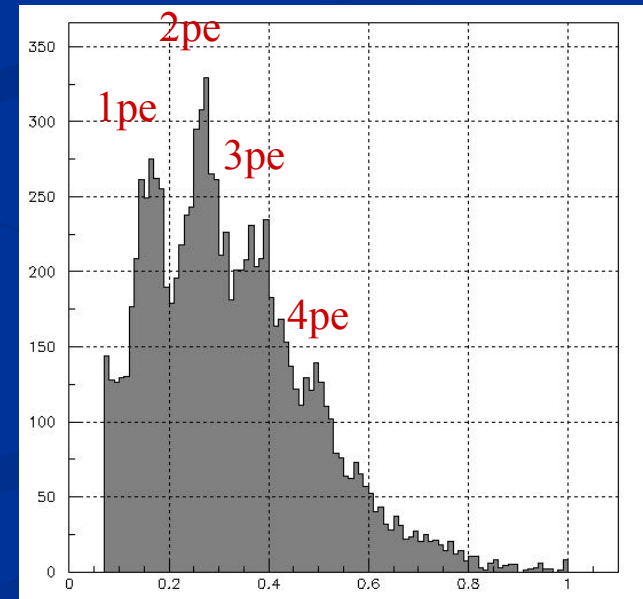
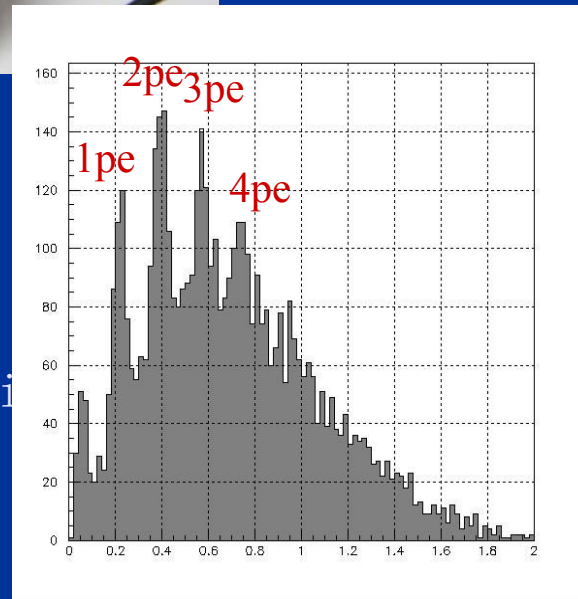


# Prototype Test - 3x3 multi-channel HPD -



- Diode :  $\square 5$  [mm/ch]
- Gain : 26000 [electron/photon]
- $C_d$  : 73 [pF]
- $I_L$  : 14 [nA] (average/ch)
- Condition:  $V_{HV}=8$  [KV],  $V_{BIAS}=320$  [V]

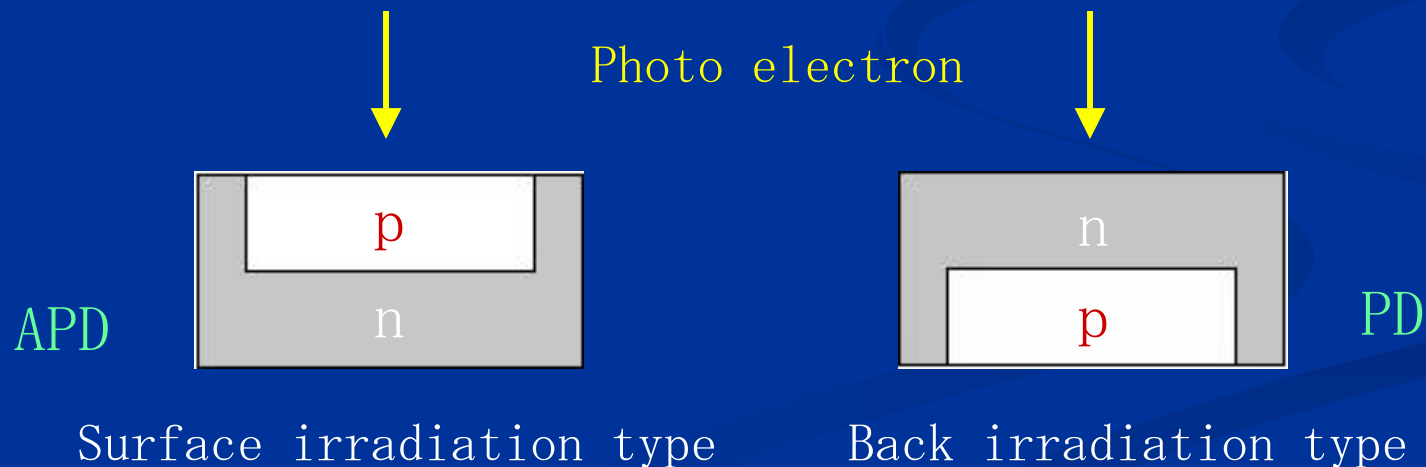
Although the gain of the HPD, noise level large detector capacity. The HPD shows better





# Structure of HPD and HAPD

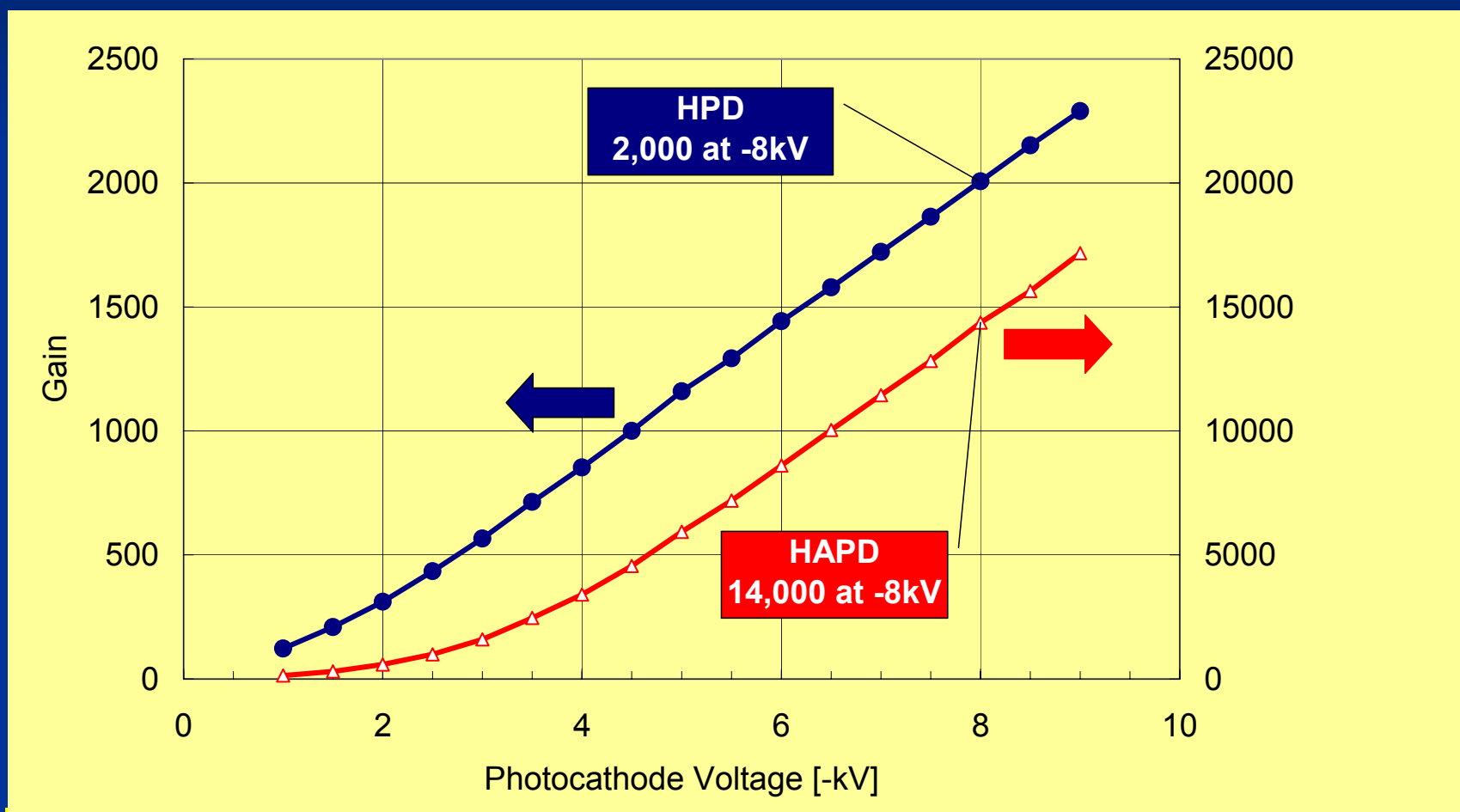
- Two types of photodiodes are under development for the 4x(6x6) type HPD/HAPD.
  - APD: surface irradiation type.
  - PD ; back irradiation type.
    - Can reduce dead area btw pixels (0.2→0.1mm)





# Total gains of HPD and HAPD

- Gain vs PC Voltage.

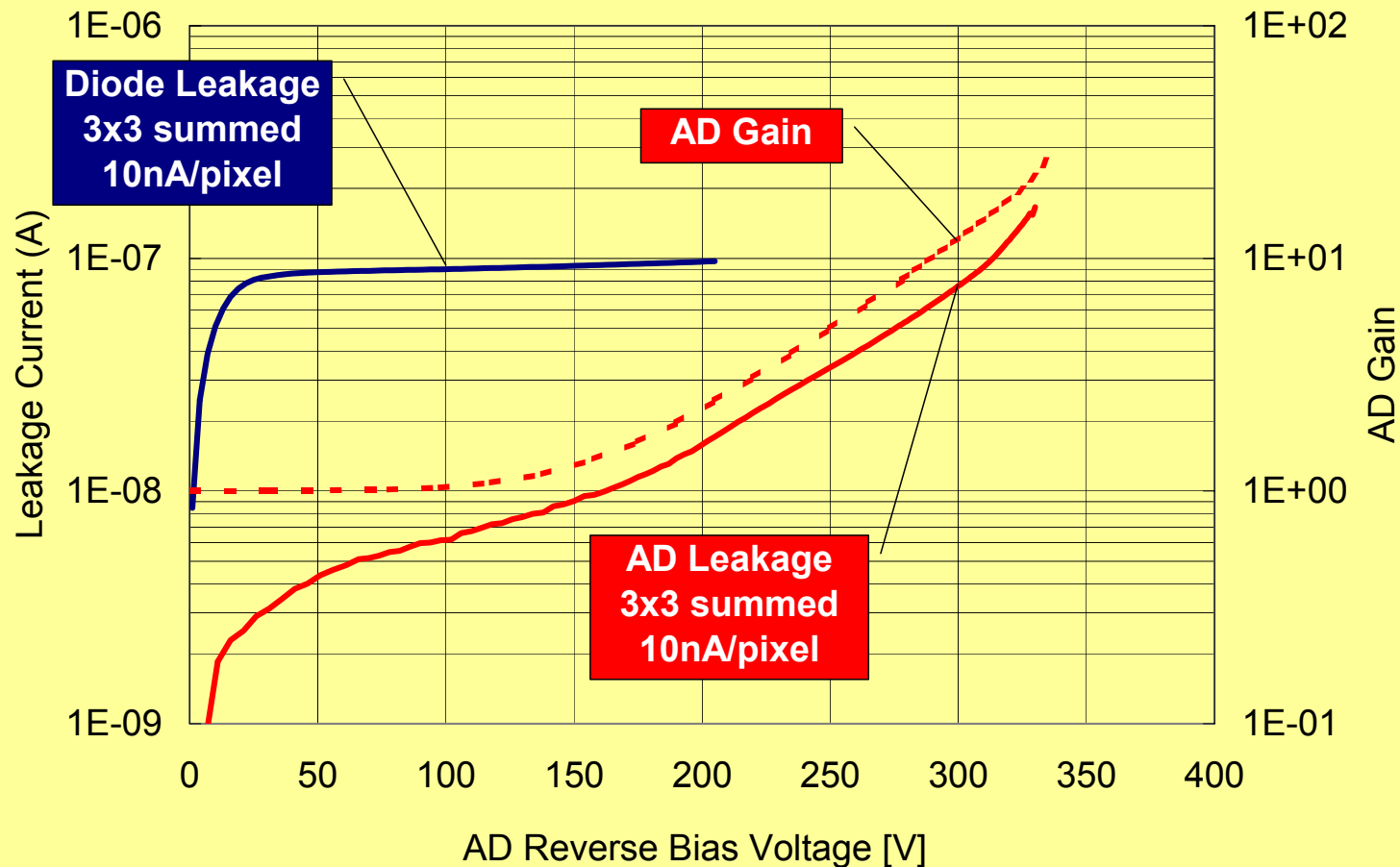






# Development of HPD and HAPD

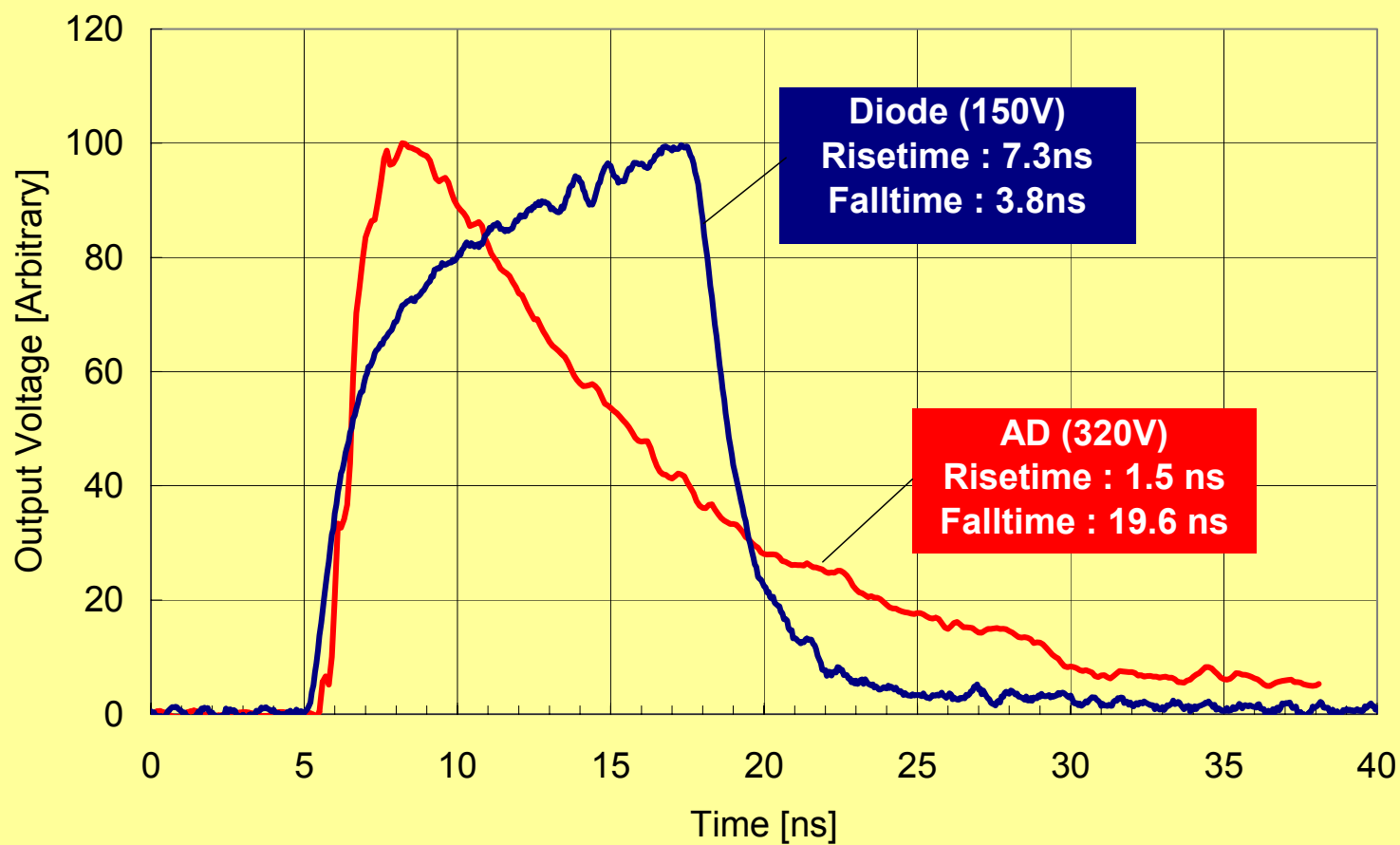
- Leakage current vs Bias voltage.





# Timing structure of HPD and HAPD

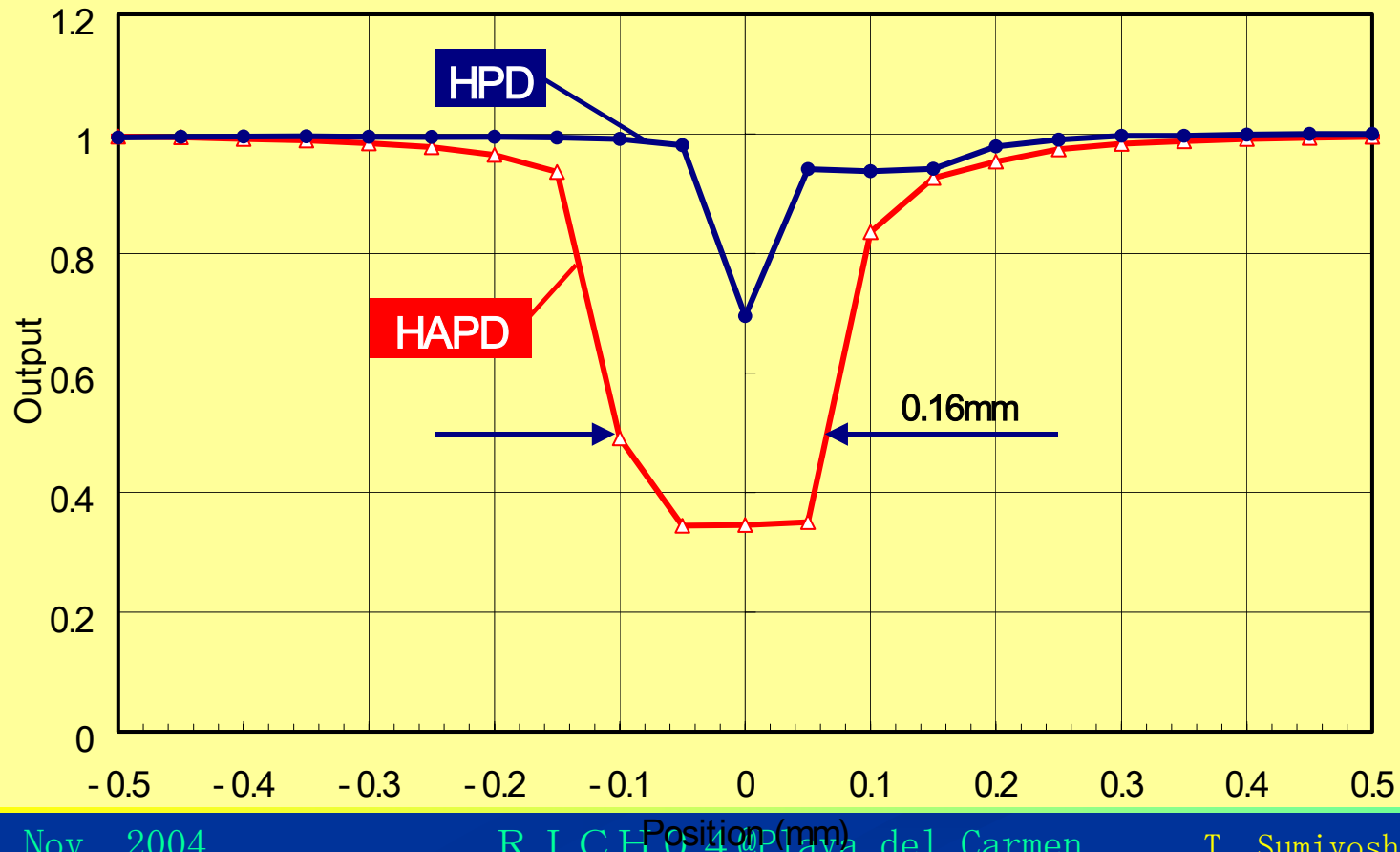
## ■ Rise time





# Dead region of HPD and HAPD

- Dead region between the pads.



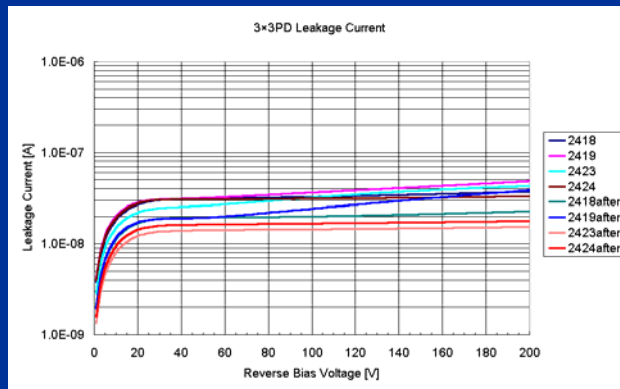


# Development of HPD and HAPD

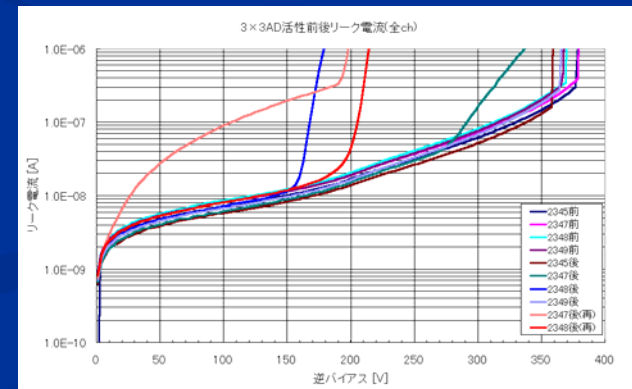
- Basic performance has been studied with the 3x3 type HPD /HAPD.
  - 3x3 ch HPD
    - No serious problem
    - Higher EB gain than expected (1500 → 2100).
  - 3x3 ch HAPD
    - Low yield of good quality APD's.
    - There is a HV leak from photocathode.
    - High gain but very noisy.
    - Further investigation is underway with a new production batch.

Leakage current before and after activation of PC.

HPD



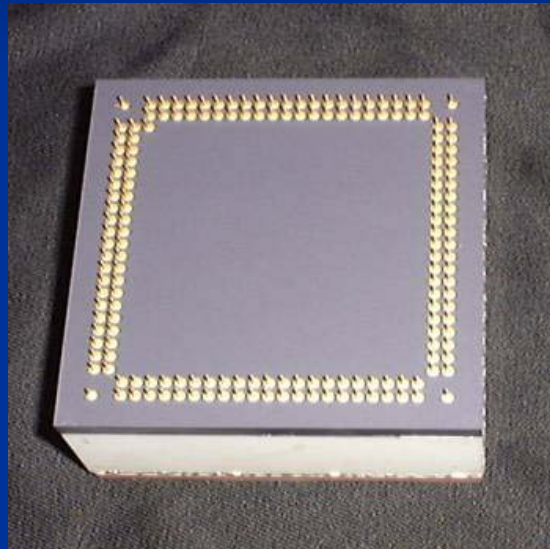
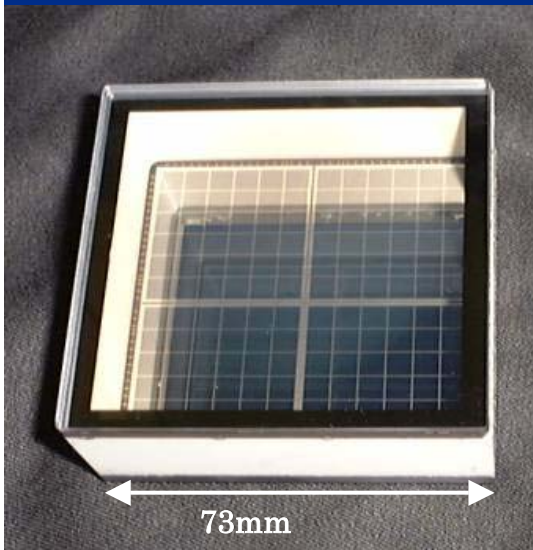
HAPD





## *Development of a 12x12 HAPD*

- Production of 12x12 multi-anode HAPD.
  - 4x (6x6) APD is assembled in this bulb by a transfer technology.



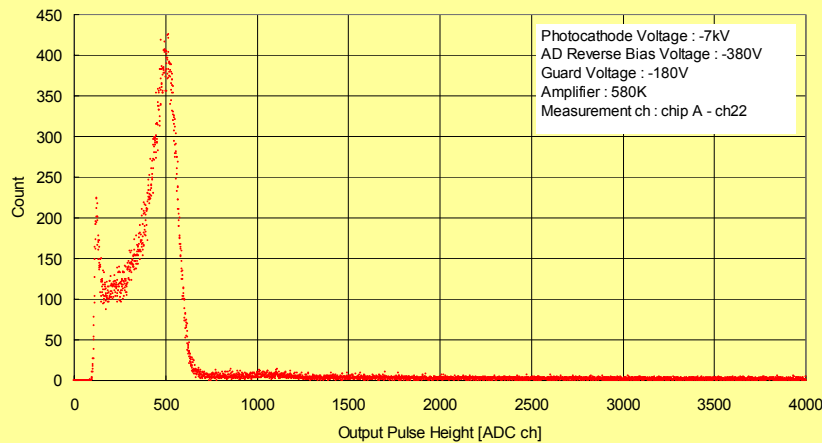
- After the activation many APD's can't sustain nominal bias voltage 380V.



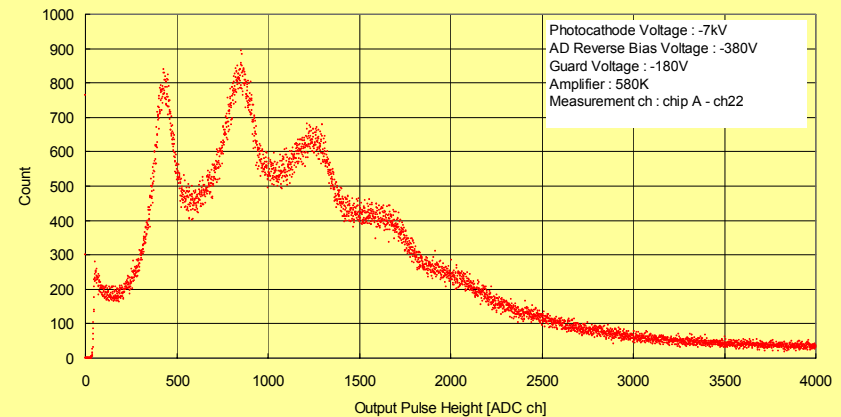
# Response of the 12x12 HAPD

- Response to a single photoelectron and multi-photoelectrons.

### Single Photoelectron



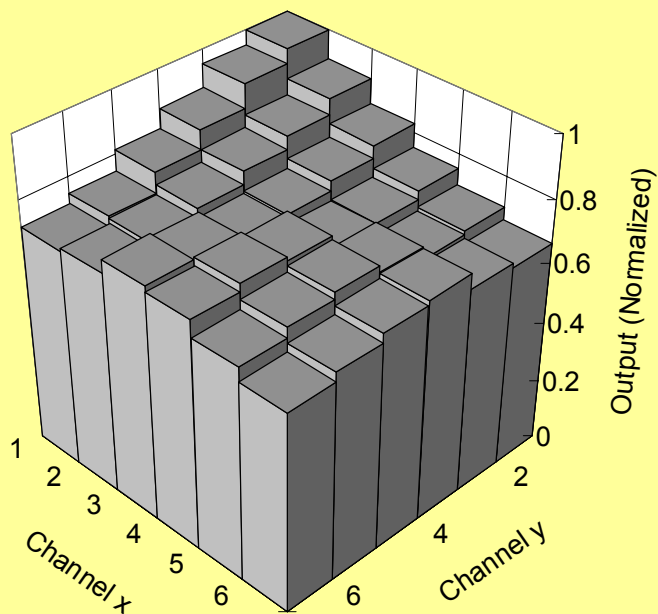
### Multi Photoelectron



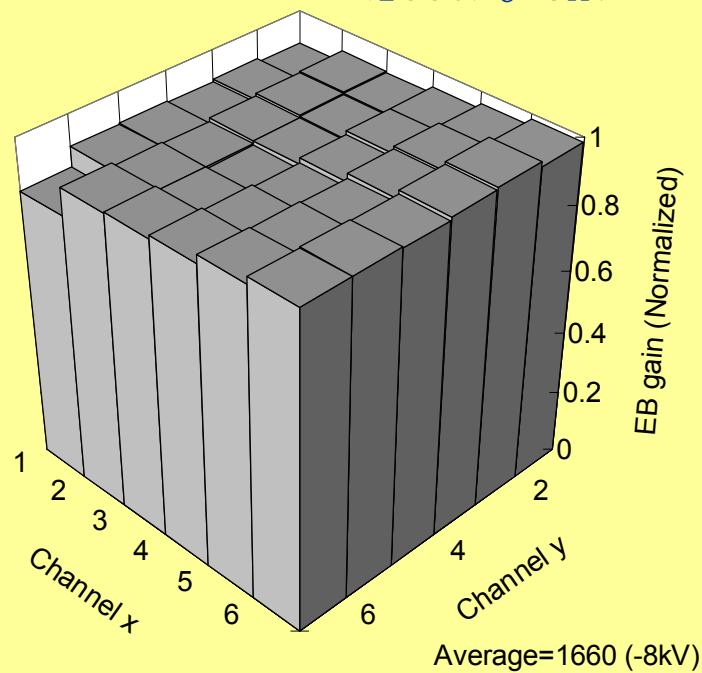


# Uniformity of a 6x6 APD

Photocathode



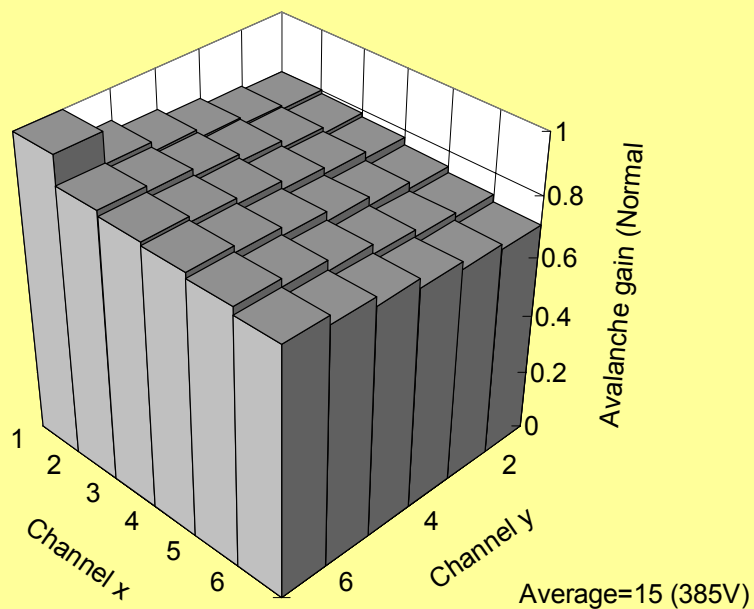
EB gain  
<1660>@-8kV



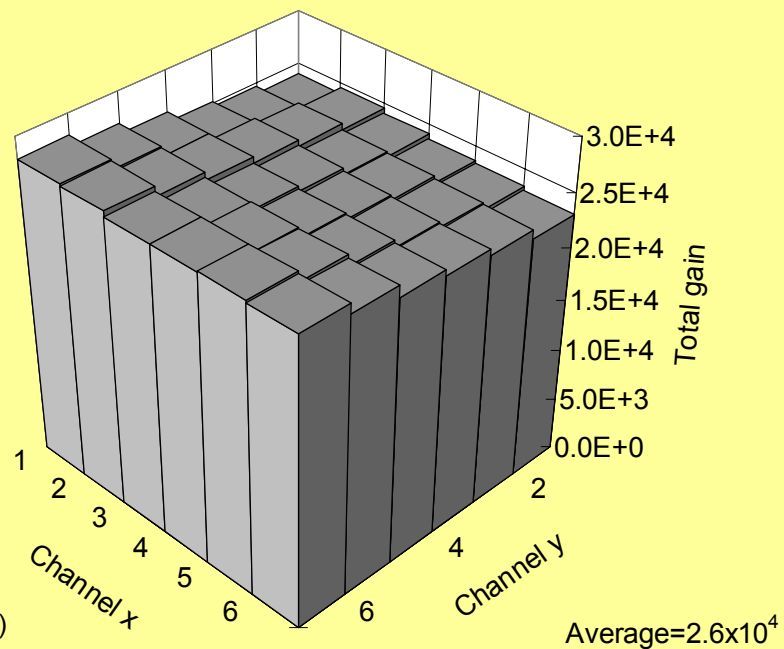


# Uniformity of a 6x6 APD

Avalanche gain  
 $\langle 15 \rangle$



Total gain  
 $\langle 2.6 \times 10^4 \rangle$

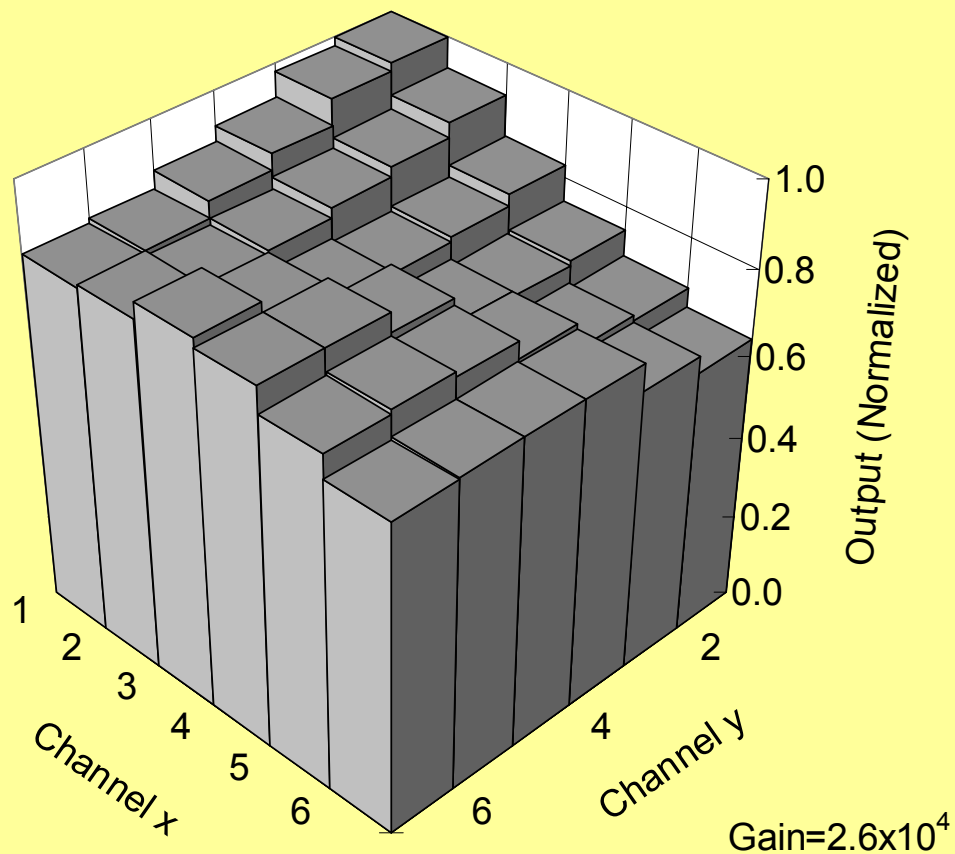






# Uniformity of a 6x6 APD

Over all response  
QE x gain





## Readout Electronics

- Total number of readout channels for the full detector amounts to 120k.
- Detector characteristics
  - Leakage current 10 or 25 [nA]
  - Detector capacitance ; 10 or 70 [pF/pixel]
  - signal ; 2000 or 20000 [electron/photon]



- Need high density front-end electronics.
- Need high gain with very low noise amplifiers.
- Deadtimeless readout scheme → Pipeline.



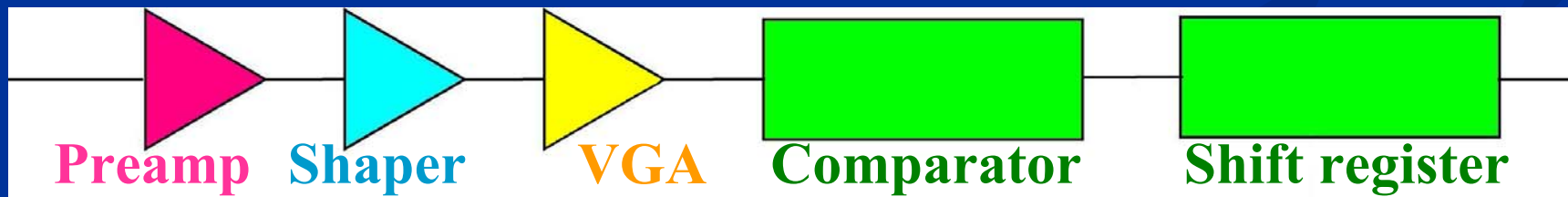
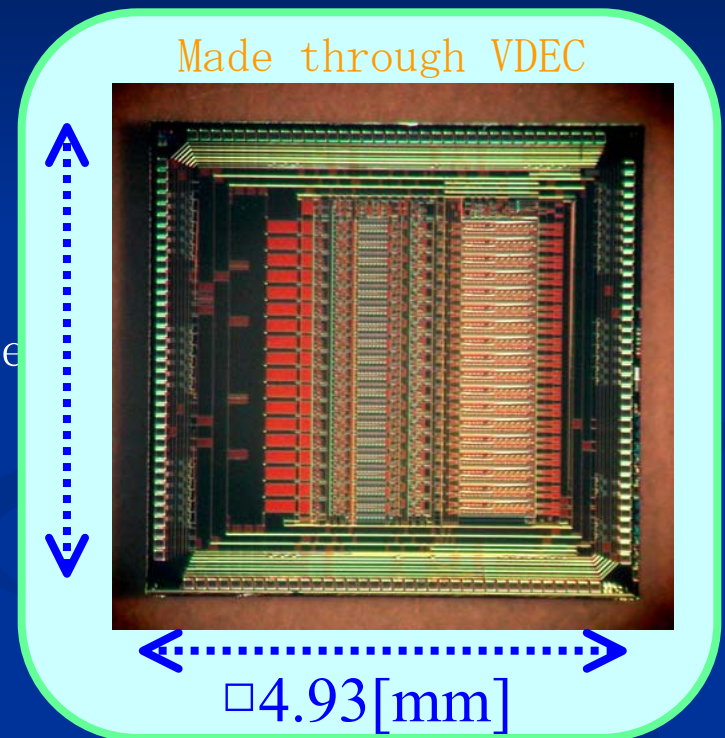
Develop an ASIC for the front-end electronics



# Readout Electronics

## ■ Basic parameters for the ASIC (Rohm CMOS 0.35 [ $\mu\text{m}$ ])

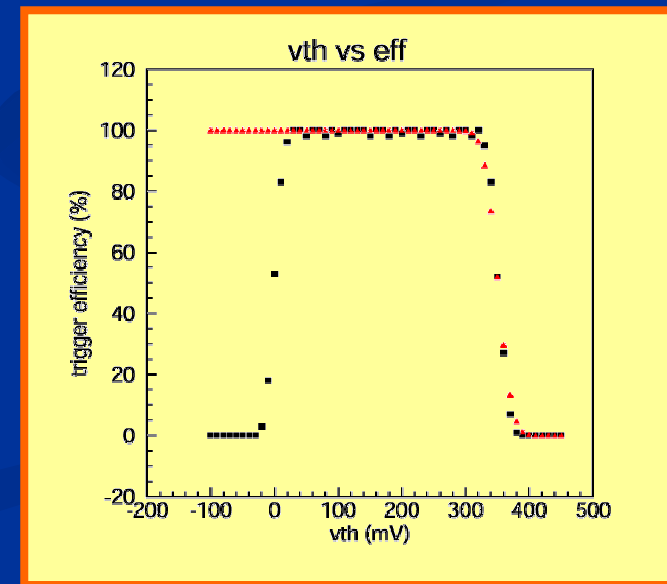
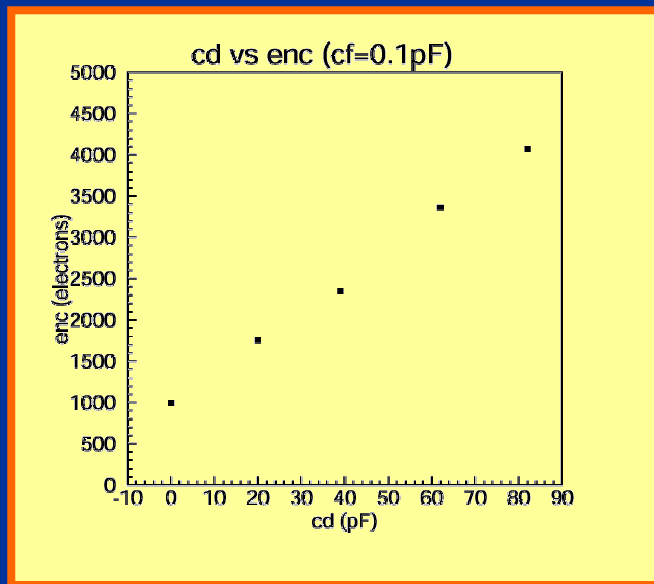
- Gain : 5 [V/pC]
- Shaping time : 0.15 [ $\mu\text{s}$ ]
- VGA : 1-16
- S/N : 8 (@2000[e])
- Readout : pipeline with shift register
- Package : 18 channels/chip
- Control : LVDS
- Power consumption : 5 m W/channel





# Readout Electronics

- Current noise performance
  - 4000 enc: about twice of SPICE simulation.
  - It could be made half in the next iteration.
- Threshold behavior.
  - It works as expected.





## Summary

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- 12x12 HAPD is under development for the photon detectors of the proximity focusing RICH which is a good candidate of the Belle PID system in future.
- There still remains some problems:
  - APD leakage current goes up after the activation of PC.
  - Some APD can't keep nominal bias voltage.
- For a readout of many anode signals (120k ch.), we have been developing an ASIC.
  - Basic performance was checked by test pulses.
  - Need minor modification for a further improvement of noise level (current S/N 5  $\rightarrow$  8) .