Towards a new generation of photodetectors: the VSiPMT

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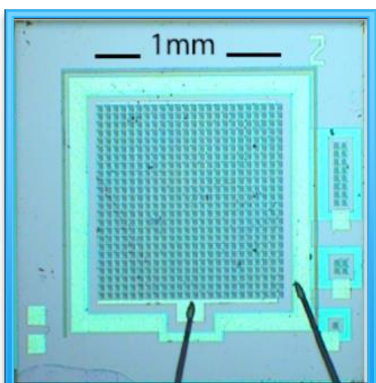
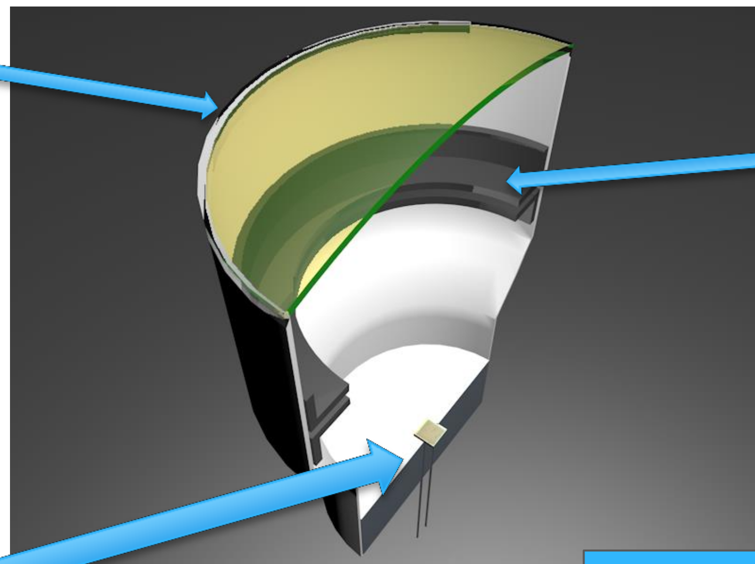
Our project: SiPM surface increase

Vacuum Silicon PhotoMultiplier Tube (VSiPMT)

Photocathode

SiPM





Focusing Ring

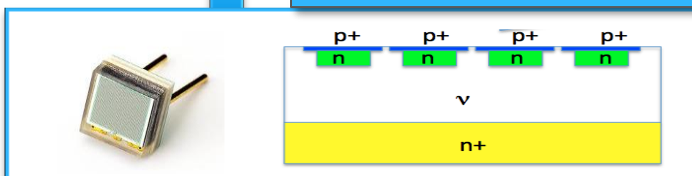
The classical dynode chain of a PMT is replaced with a SiPM, acting as an electron multiplying detector.

An innovative design for a modern hybrid photodetector based on the combination of a Silicon PhotoMultiplier (SiPM) with a hemispherical vacuum glass PMT standard envelope

Introduction

MAIN IDEA: SiPM as electron multiplier

FUNDAMENTAL ADVANTAGE:
Low Voltage Amplification

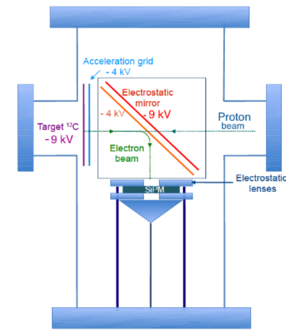


SPECIAL SiPM:

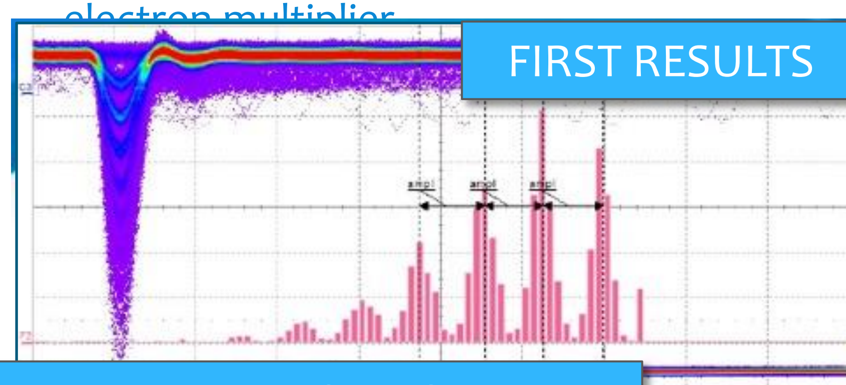
- No windowed
- Thin SiO_2 layer
- Mandatory configuration p^+nn^+

THE BEGINNIG: test with an electron beam

Experimental setup at TTT3-Accelerator of Naples: an electron beam was extracted to test a special SiPM as electron multiplier



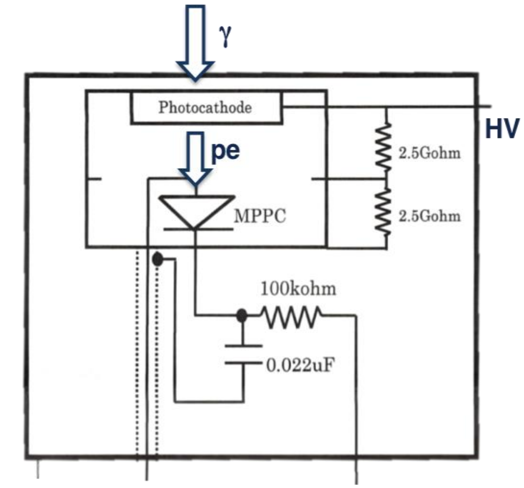
FIRST RESULTS

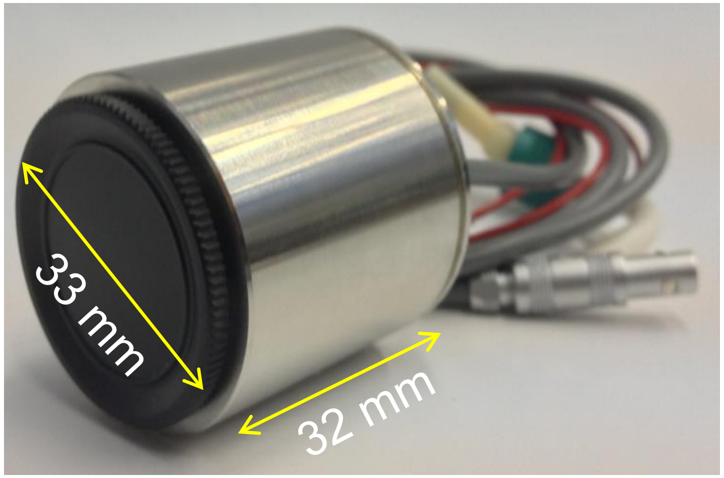


EXCELLENT ELECTRON COUNTING CAPABILITY

The prototypes

HAMAMATSU
PHOTON IS OUR BUSINESS





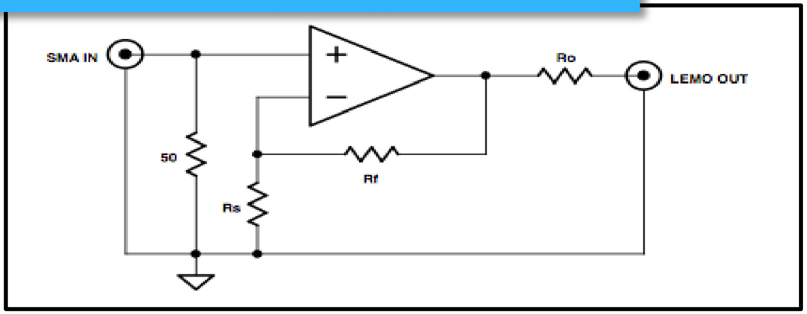
7x7 mm^2 Borosilicate glass entrance window
3 mm diameter GaAsP photocathode
2 protoypes:
MPPC 1 mm^2 / 50 μm / 400 cells
MPPC 1 mm^2 /100 μm / 100 cells

$p^+n\nu n^+$ configuration, special non-windowed series for ε optimization.
Lower voltage required wrt standard $n^+p\pi p^+$ devices (-2,5/3 kV expected).

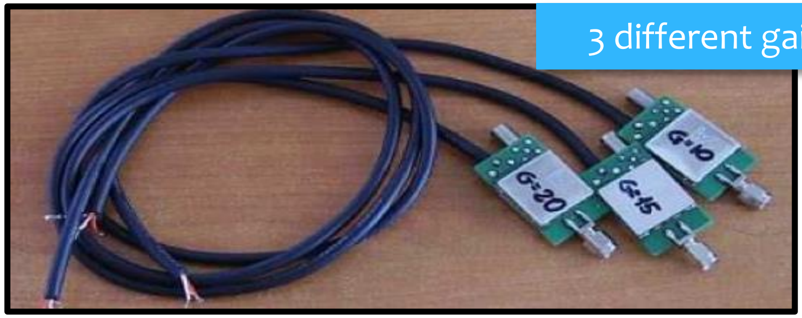
<u>No voltage divider:</u> no power dissipation nor complicated circuits to reduce the dissipation
Only a very simple amplifier is required (typ. < 5mW).

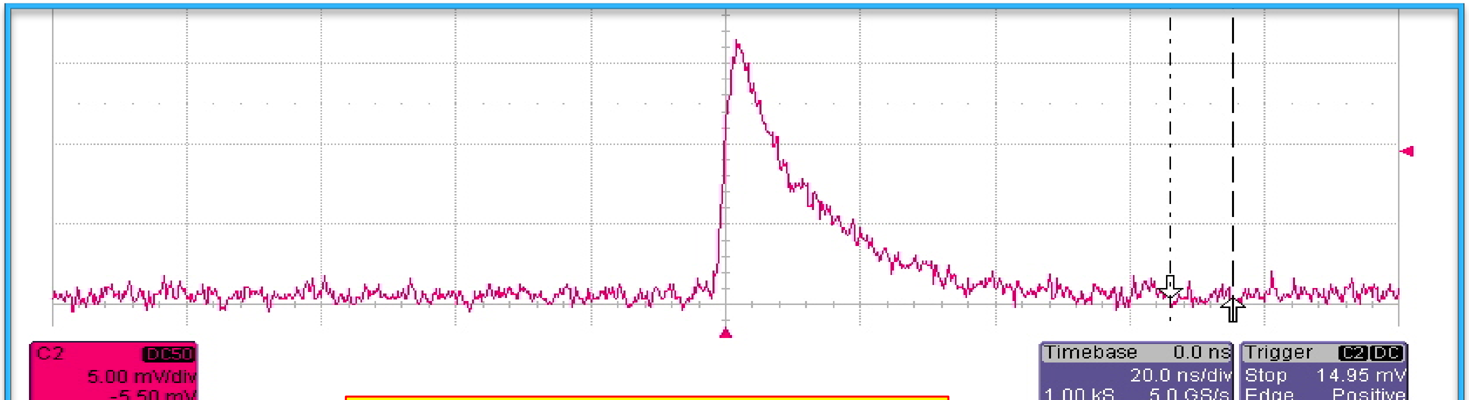
Amplification

Single-state amplifiers based on an OP-AMP in non inverting configuration.



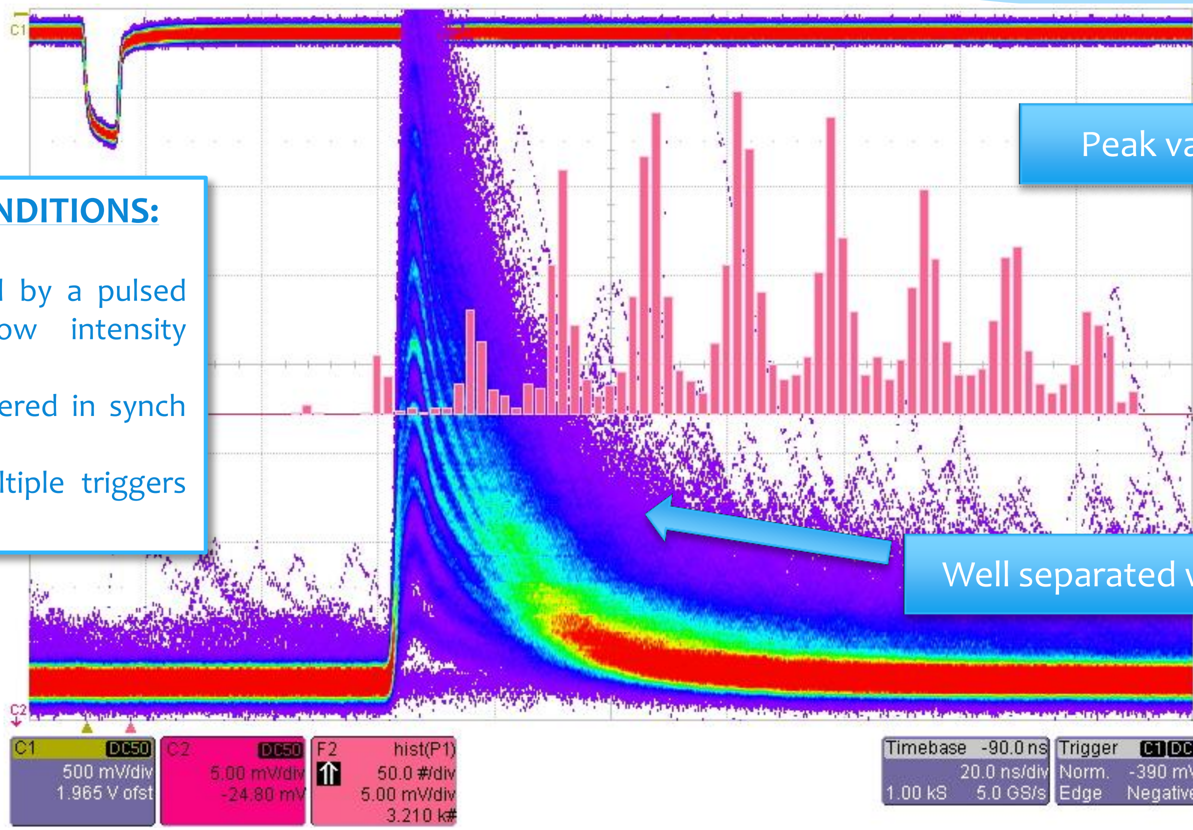
3 different gain





Power consumption < 5mW

Waveforms



Peak values istogram

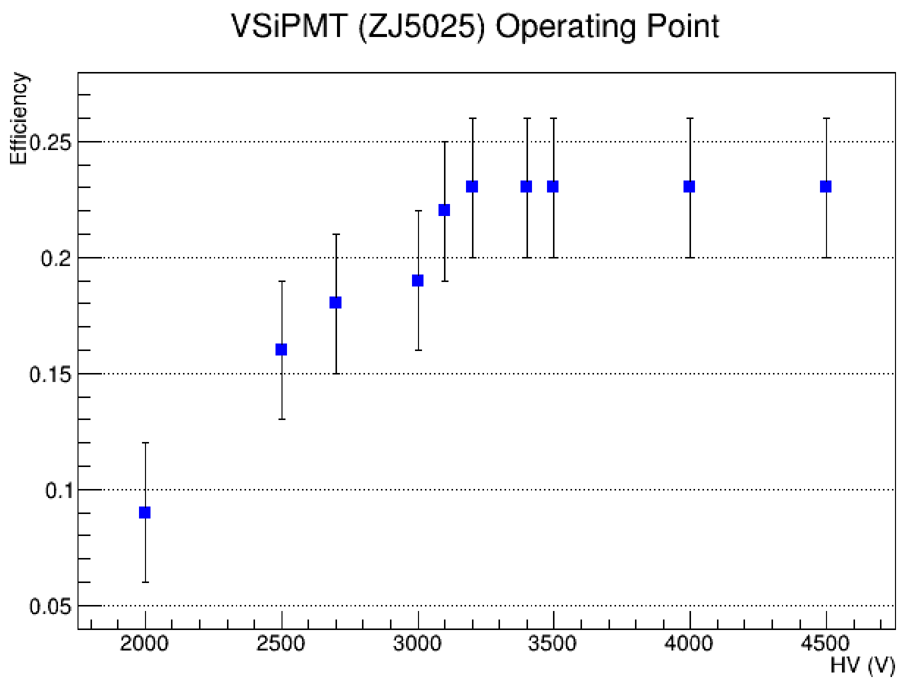
Well separated waveforms

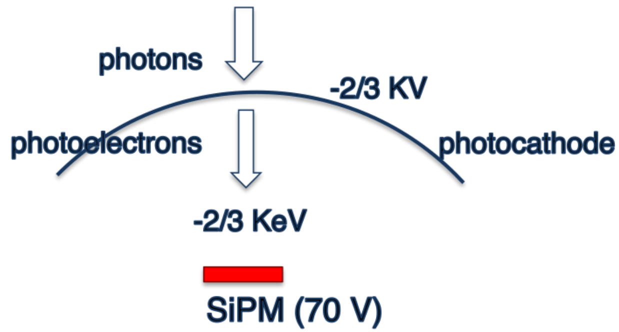
MEASUREMENT CONDITIONS:

- VSiPMT illuminated by a pulsed laser light at low intensity (407nm)
- Oscilloscope triggered in synch with the laser
- Responses for multiple triggers are overlaid

Excellent photon counting capability

Efficiency

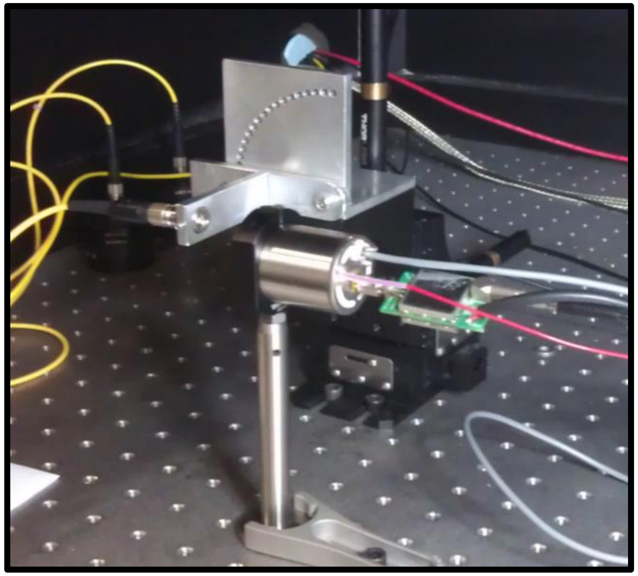




Efficiency is highly stable over 3200 V.
No need for high voltage stabilization.

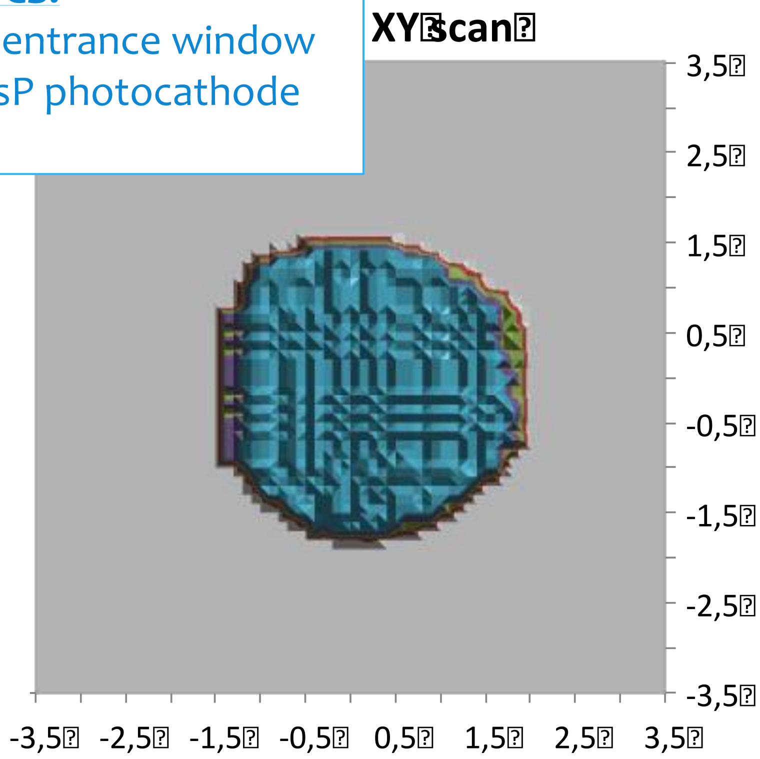
- HV: photoelectron transfer → NO power consumption (NULL current) unlike PMTs.
- LV-based gain → EASY STABILIZATION
- Reducing the SiO_2 coating layer it will be possible to reach the plateau region at even lower voltages.

Photocathode XY scan



CHARACTERISTICS:

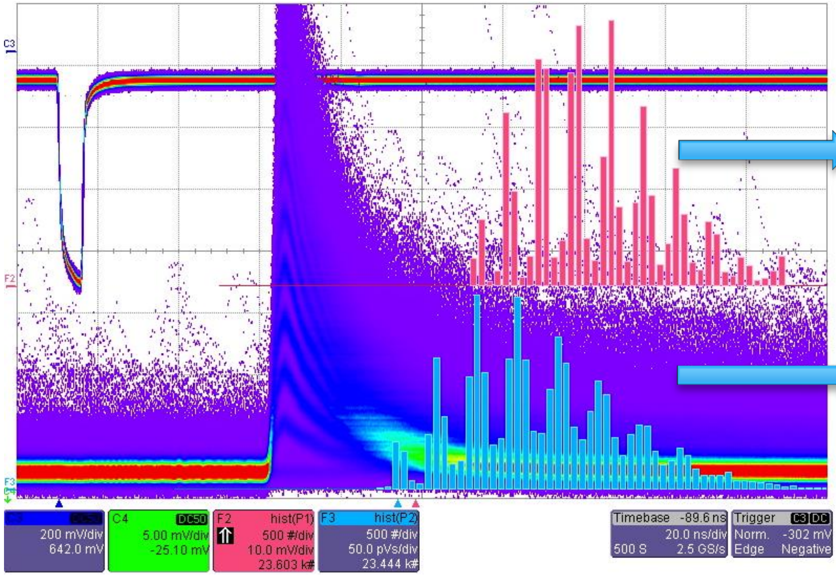
- 7mm x 7mm entrance window
- 3 mm Ø GaAsP photocathode
- $1mm^2$ MPPC



Homogeneous efficiency
≈ 0.2 over a $7mm^2$ surface

Surface increase factor ≈ 7

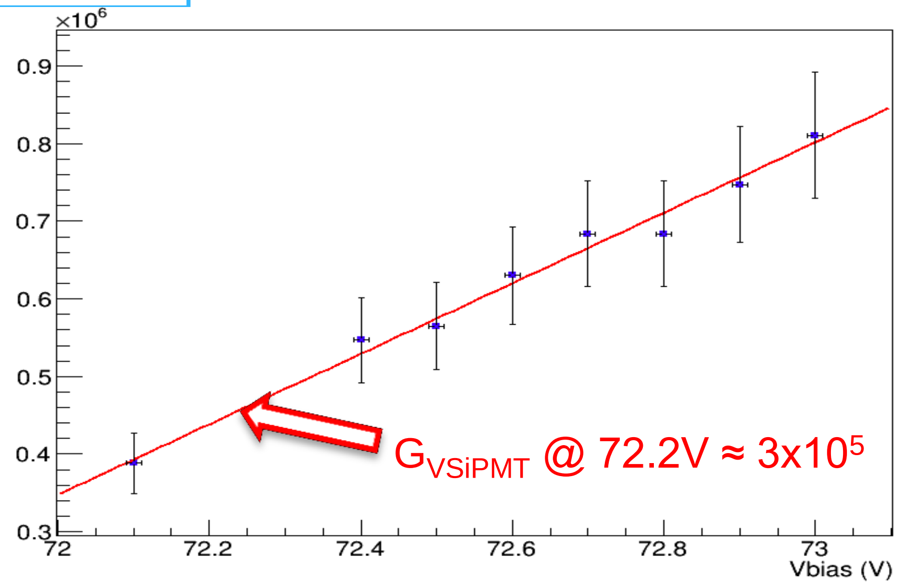
Gain



Peak values hystogram

Area hystogra

High gain ($10^5 \div 10^6$)
Linear trend



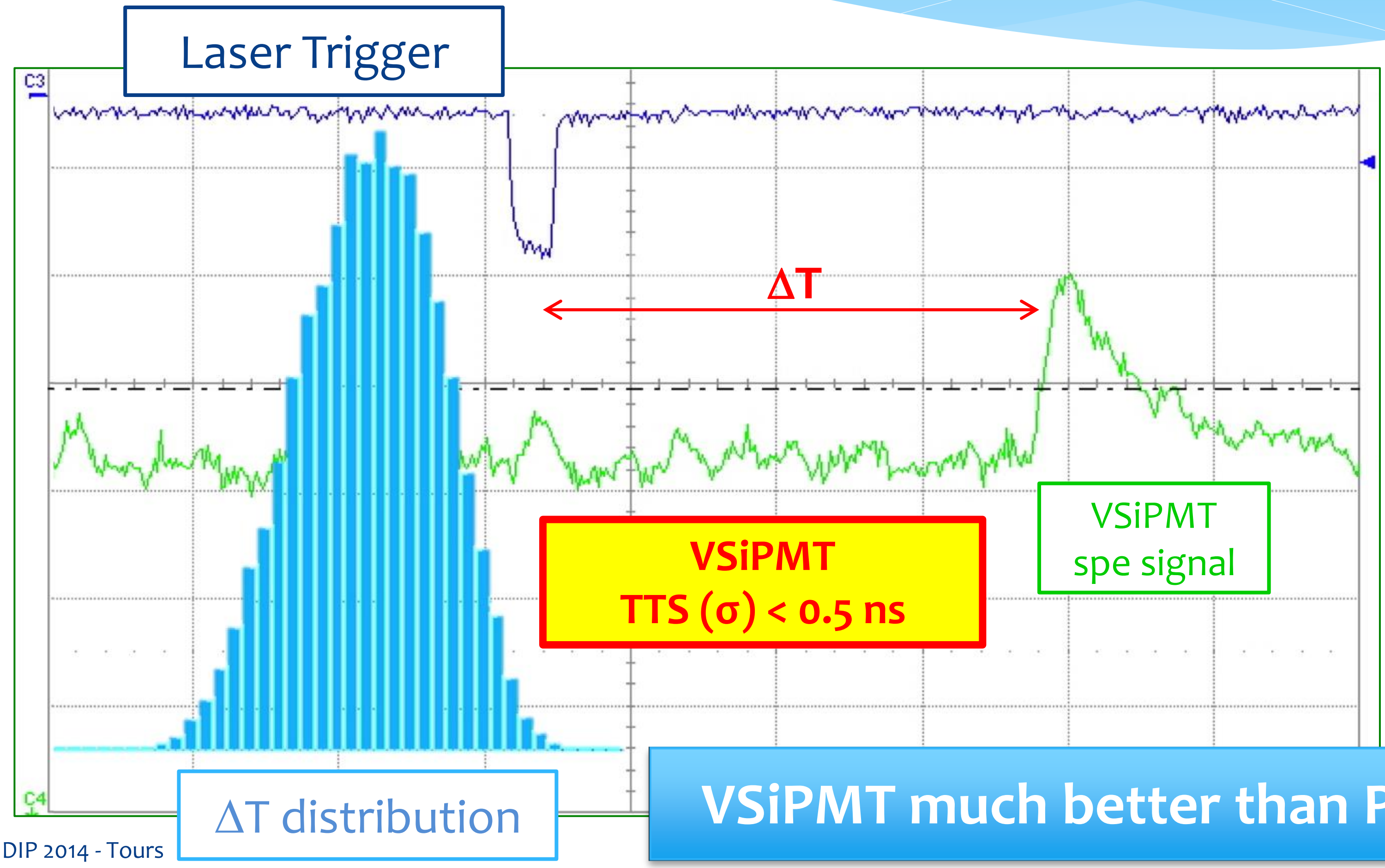
G_{VSiPMT} @ 72.2V ≈ 3×10^5

Total Gain = $G_{VSiPMT} \times G_{AMP}$

Ideal Working Point: 72.2V

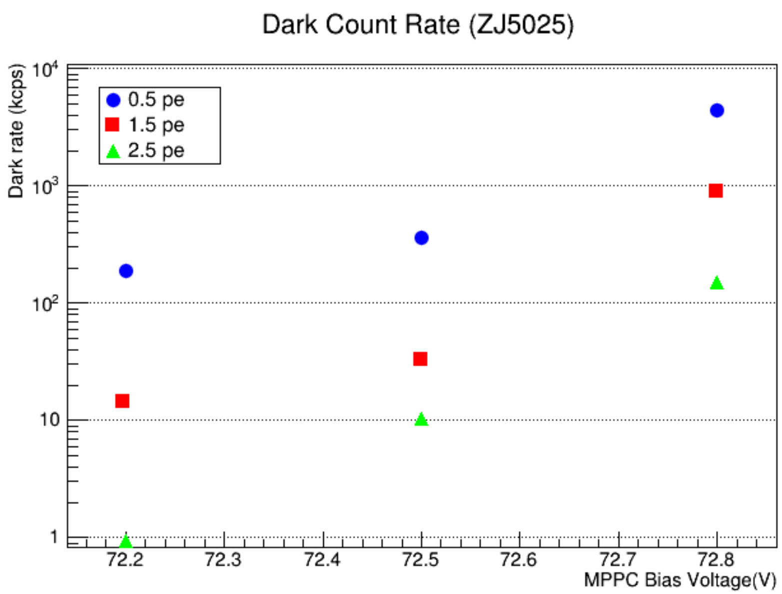
- G ≈ 6×10^6 ($G_{AMP} = 20$);
- Dark Count ≈ 60 kcps;

Transit Time Spread

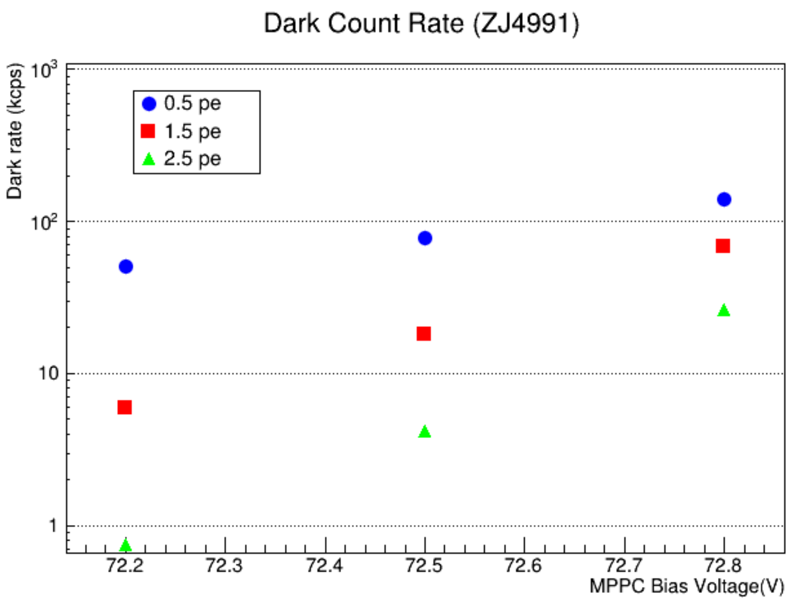


VSiPMT much better than PMTs

Dark count



High DC rates
100 – 1000 kcps

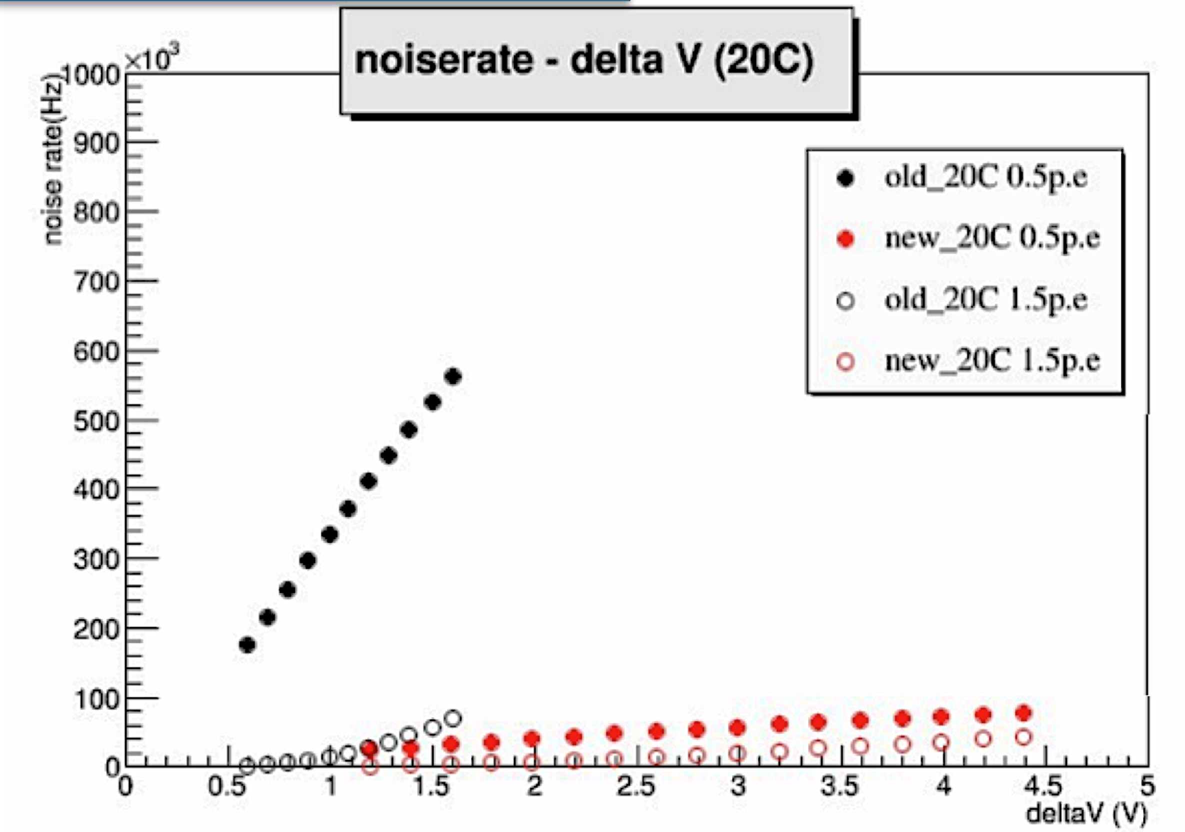


Decisively looks like a weak point

However...

Dark count

New generation Hamamatsu MPPCs

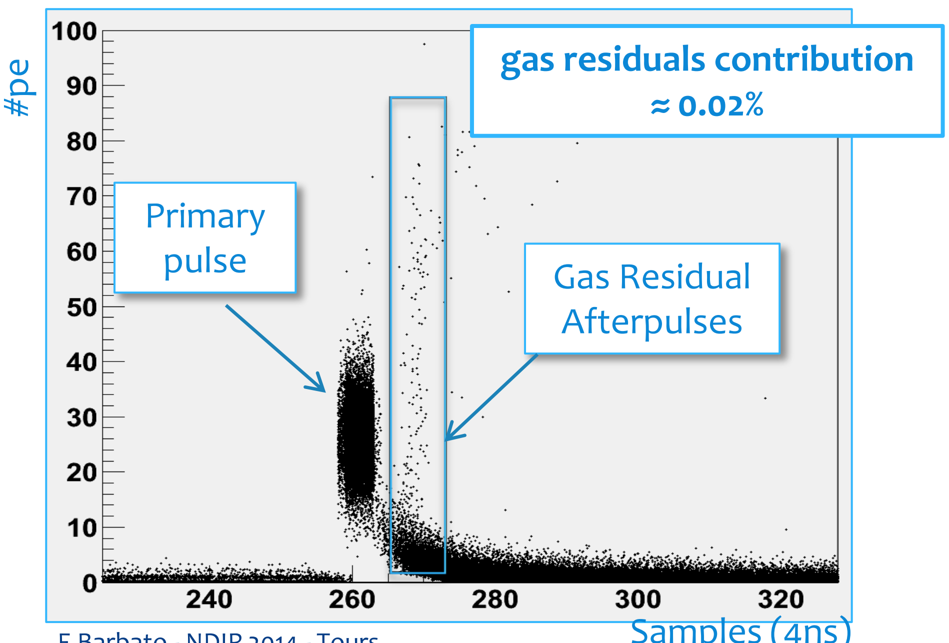


Afterpulses

SiPM internal afterpulses

NOW: <10%   NEW GENERATION OF SiPM: <0.3%

Ionization of residual gases



Residual gases afterpulse time distribution

Arrival time distribution and intensity as a function of HV

HV (kV)	Delay (ns)	Intensity (pe)
2	52.8	10-25
3	43.6	18-70
4	38.4	22-80

GAS RESIDUAL MOLECULE IONIZATION EFFECT

PMT vs VSIPMT

Features	PMT	VSiPMT	Comparison
Efficiency	$QE_{photocathode} x\ \varepsilon_{1dynode(0.8)}$	$QE_{photocathode} x$ $FillFactor_{(twd\ 1)}$	≈equivalent
Gain	10^6 - 10^7	10^5 - 10^6	PMT
Timing	ns	Fraction of ns (no dynode spread)	VSiPMT
Linearity	Depending on gain	Depending on #cells	≈equivalent
Power Consumption	Divider Dissipation	VSiPMT: No dissipation Amp. (G=10-20): <5mW	VSiPMT
Power Supply Stability	HV Stabilization	LV easy stabilization	VSiPMT
Dark counts rate (new)	≈ kHz @ 0.5pe	≈ few kHz @0.5pe	≈equivalent (today)
Photon Counting	Difficult	Excellent	VSiPMT
Afterpulse (new)	≈10% @0.5pe	<0,3% @0.5pe	VSiPMT (today)
Peak-to-valley ratio	≈3	>60	VSiPMT

Conclusions and Perspectives

VSiPMT is an innovative design for a modern hybrid photodetector based on the combination of a Silicon PhotoMultiplier (SiPM) with a Vacuum PMT standard envelope

It has many **UNPRECEDENTED** features, such as:

- Photon counting capability;
- Low power consumption;
- Large sensitive surface;
- Excellent timing performances (low TTS);
- High stability (not depending on HV).

making it a very attractive solution in many applications

STILL IMPROVABLE!!!

New generation of Hamamatsu MPPCs:

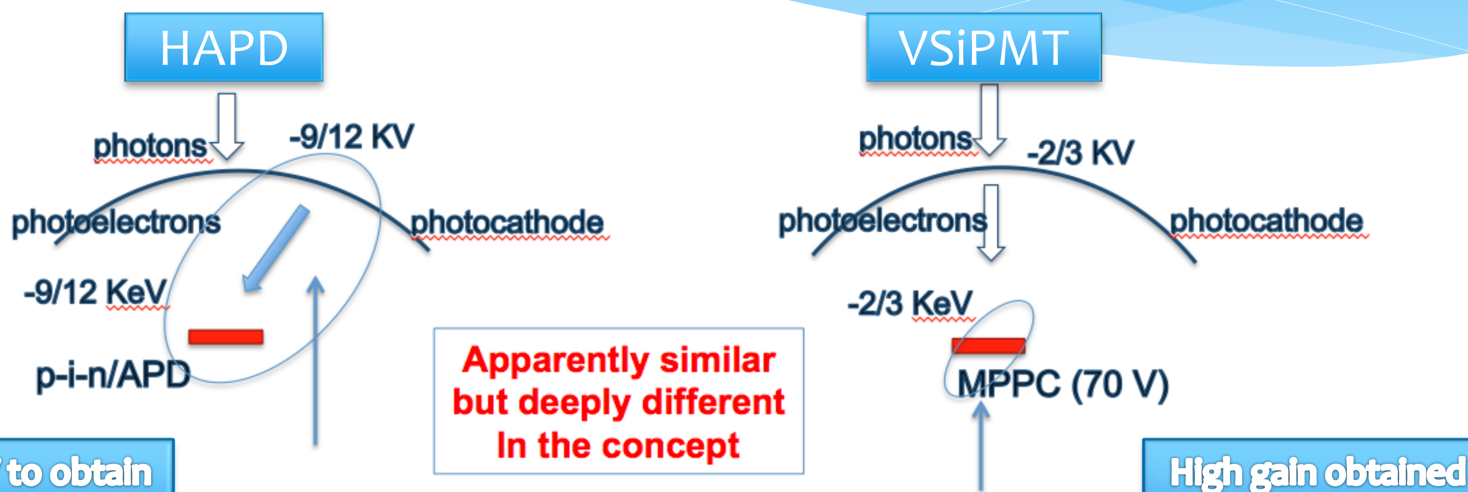
- sensibly lower afterpulse rates;
- lower noise: much reduced dark counts;
- higher gain ➔ no amplification required;
- focusing optimization required.

Thanks for your attention

See you at the *Chenonceau* Castle

Backup Slides

Differences between HAPD and VSiPMT



Need of HV to obtain a high gain

Apparently similar but deeply different In the concept

High gain obtained with low voltage in the SiPM

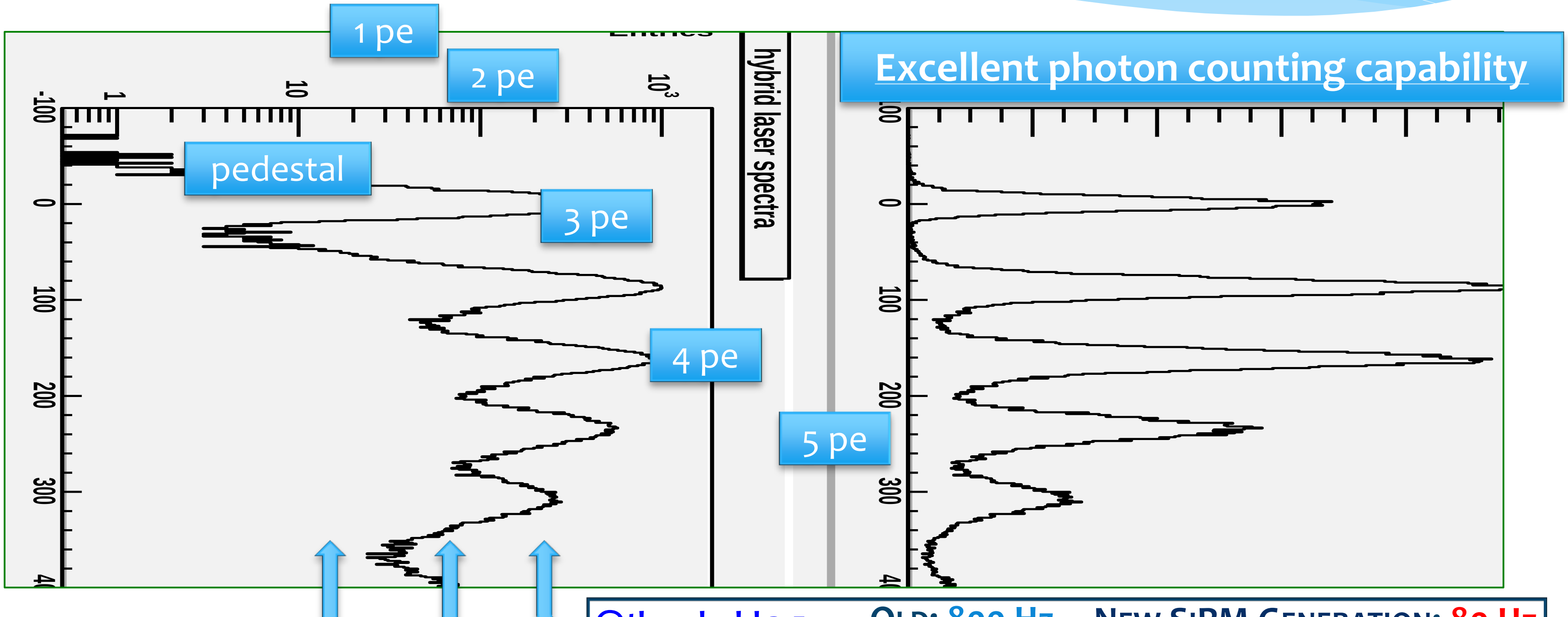
Drawback of APD solution

- $G=E_{phe}/E_{e,h} \approx 10^4\text{-}10^5$
- too **low Gain. HV gain**
- G **depending** on HV
- Need a strong HV critical **stabilization.**
- Difficult **and expensive insulation**

Lot of advantage in the SiPM solution

- **$G > 10^6$** : more of a factor 10.
- **Low HV,** only for photoelectron transfer
- **Normal insulation**
- **No HV stabilization**
- **Low voltage Gain:** easy to stabilize

Dark count rates



@threshold 2.5 pe OLD: 800 Hz NEW SIPM GENERATION: 80 Hz

@threshold 1.5 pe OLD: 10 kHz NEW SIPM GENERATION: <1 kHz

@threshold 2.5 pe OLD: 100 kHz NEW SIPM GENERATION: <10 kHz

Linearity

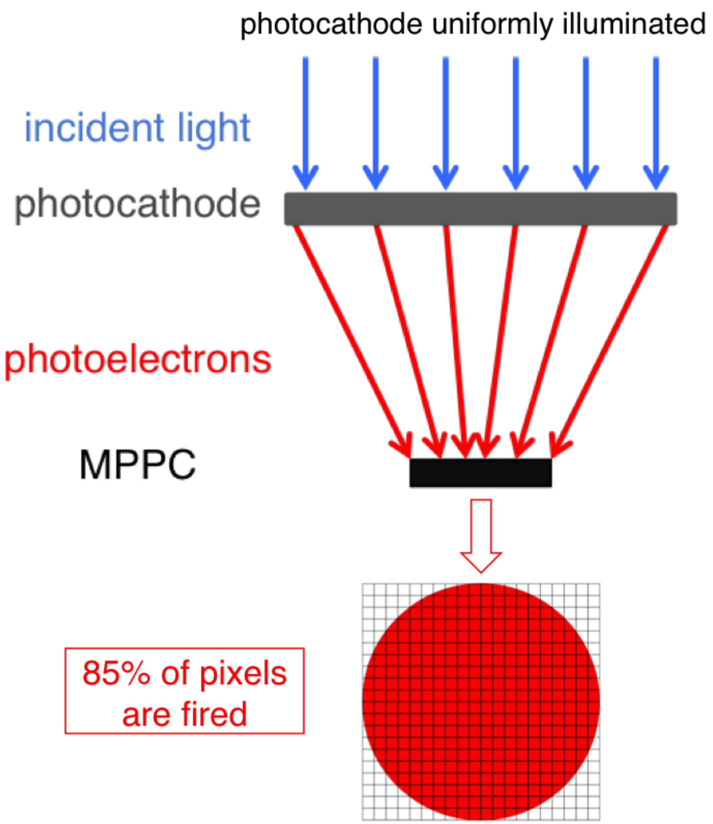
- **G-APD:**

linearity strongly related to the total number of pixels.

- **focusing:**

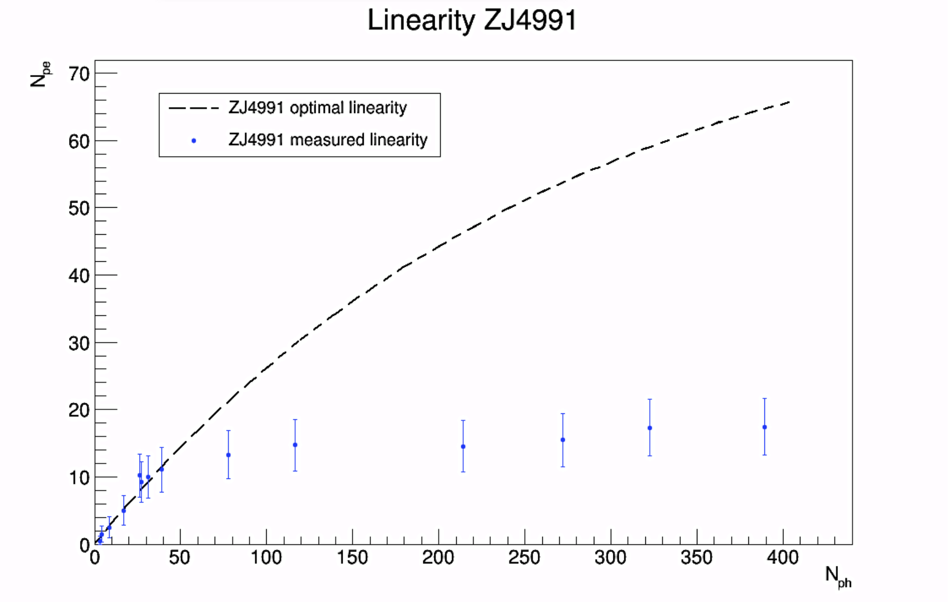
linearity is maximized if for a photocathode uniformly illuminated all pixels are hit by the accelerated photoelectrons.

Differently from the cases of a PMT or an HPD, a too strong focusing would be deleterious because **a too squeezed photoelectron spot means that not all pixels are involved, thus drastically reducing the linearity.**



Linearity

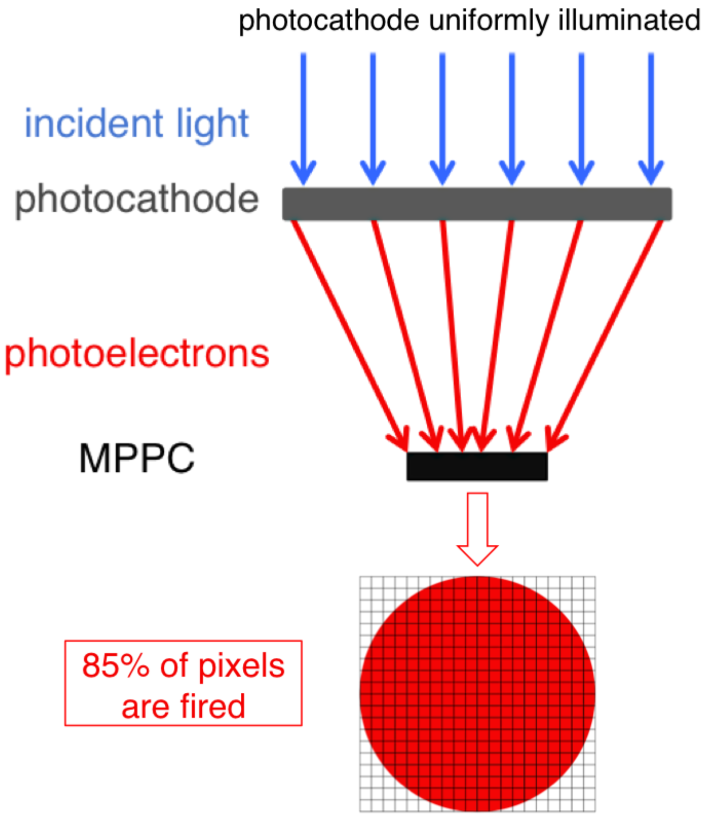
What we measured



ZJ4991 (100μm) has a too limited linearity

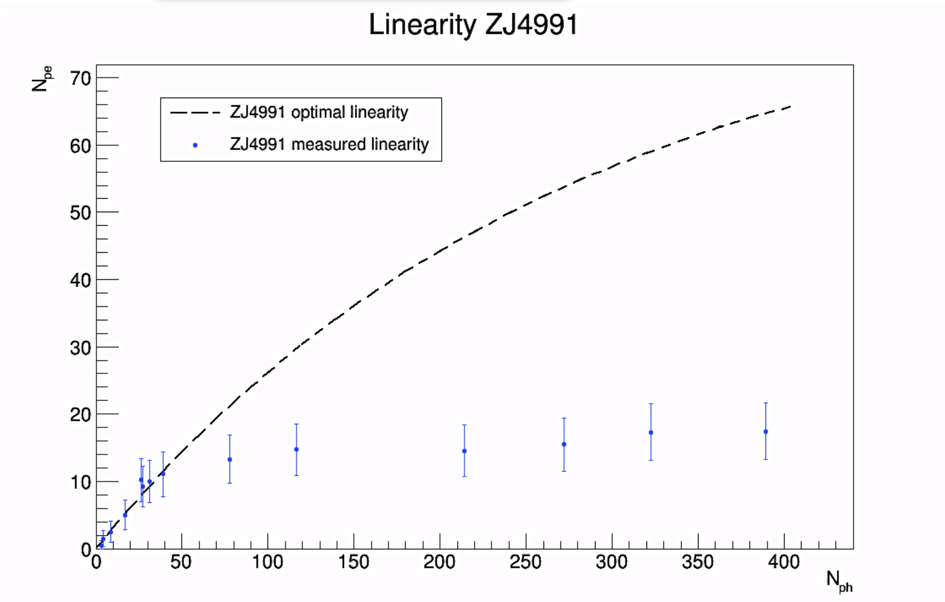
The output signal saturates soon, with N_{fired} not exceeding 20 even under high illumination conditions

The ideal case



Linearity

What we measured



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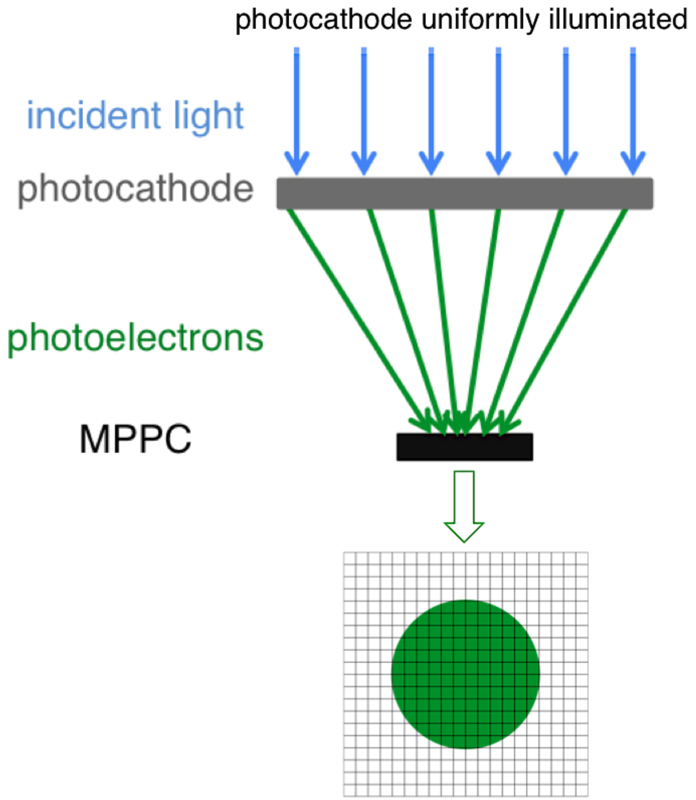
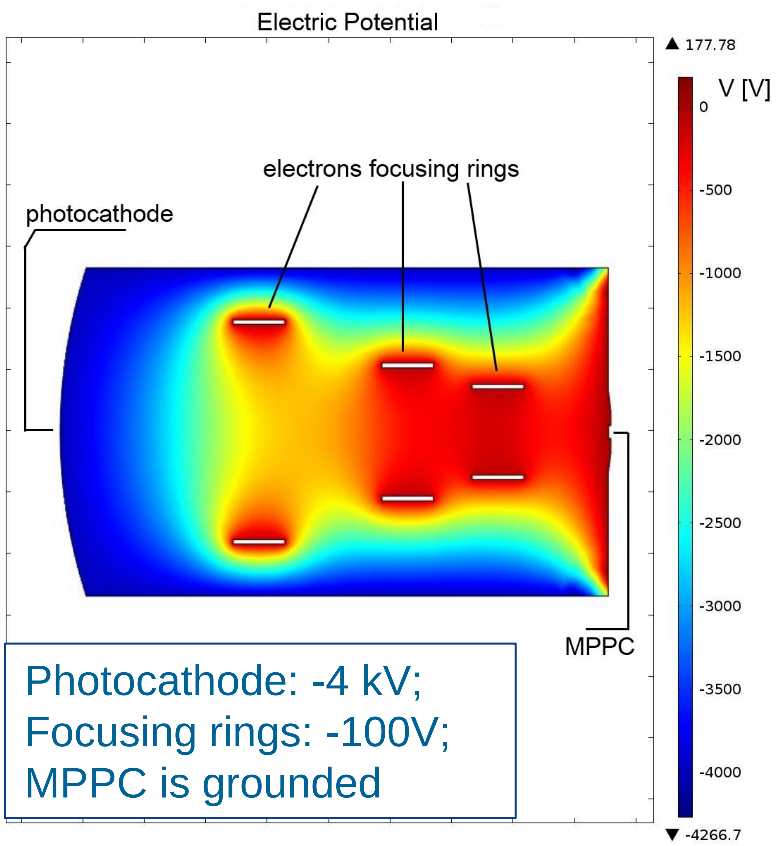
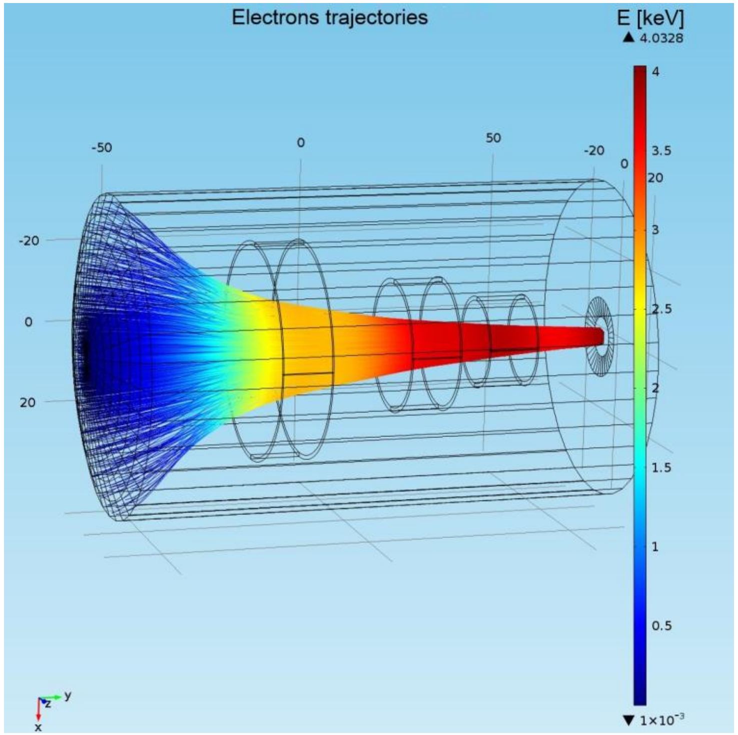
robust hint for a too strong focusing small size of the photoelectrons beam



Proposed solution

First focusing ring: time alignment of all possible electrons paths;
Second and third focusing rings: fine tuning of the electron beam focusing





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