



# Experimental study of the time resolution of SiPM coupled to scintillator

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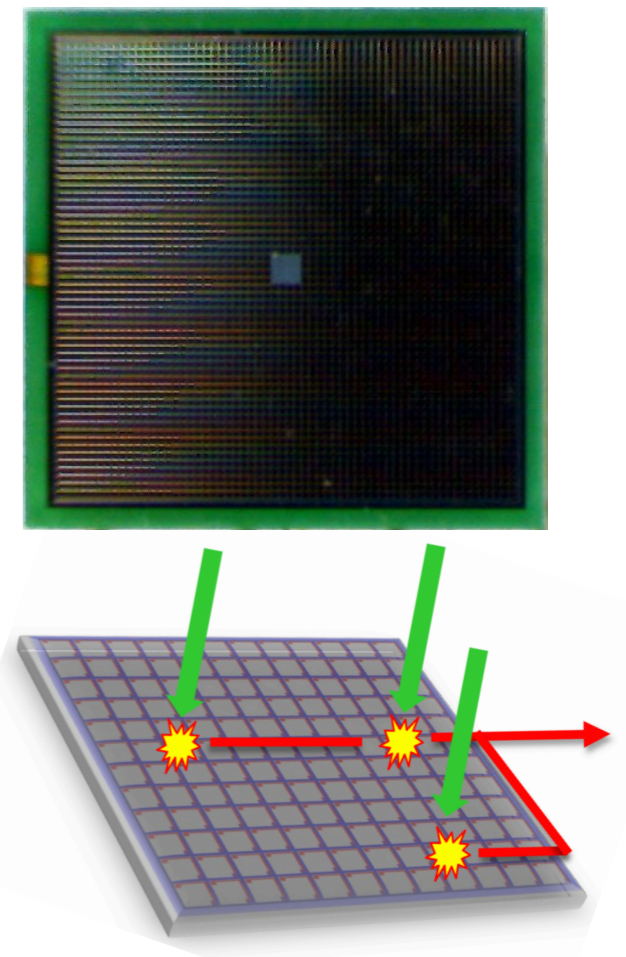
SiPM workshop: from fundamental research to industrial applications  
2-4 October 2019 Università di Bari



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**University and INFN of Bologna, Centro Fermi Roma**

# SiPM

- **Insensitive to B**
- High photon-detection efficiency
- Single photo detection capabilities
- Low power consumption
- High light yield
- Low Bias Voltage
- Low background radioactivity
- Low cost
- Compact → high active area



If **coupled** with **scintillator** → several possible applications

# Why improve time resolution

requirements → some 10's ps

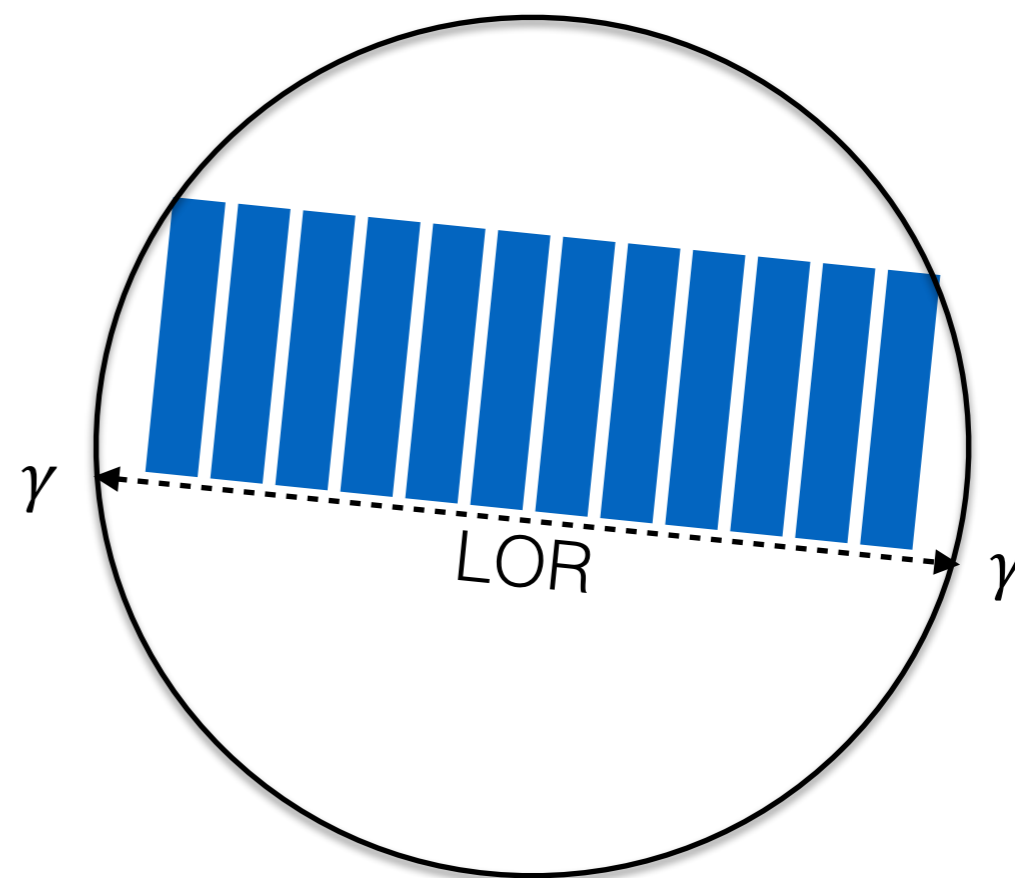
- Medical Physic
- HEP Physic
  - ▶ PID
  - ▶ Pile-up issue
  - ▶ Calorimetry

# Why improve time resolution

requirements  $\rightarrow$  some 10's ps

- **Medical Physic**  $\rightarrow$  **PET** : higher SNR, less dose
- HEP Physic
  - PID
  - Pile-up issue
  - Calorimetry

Conventional **PET**





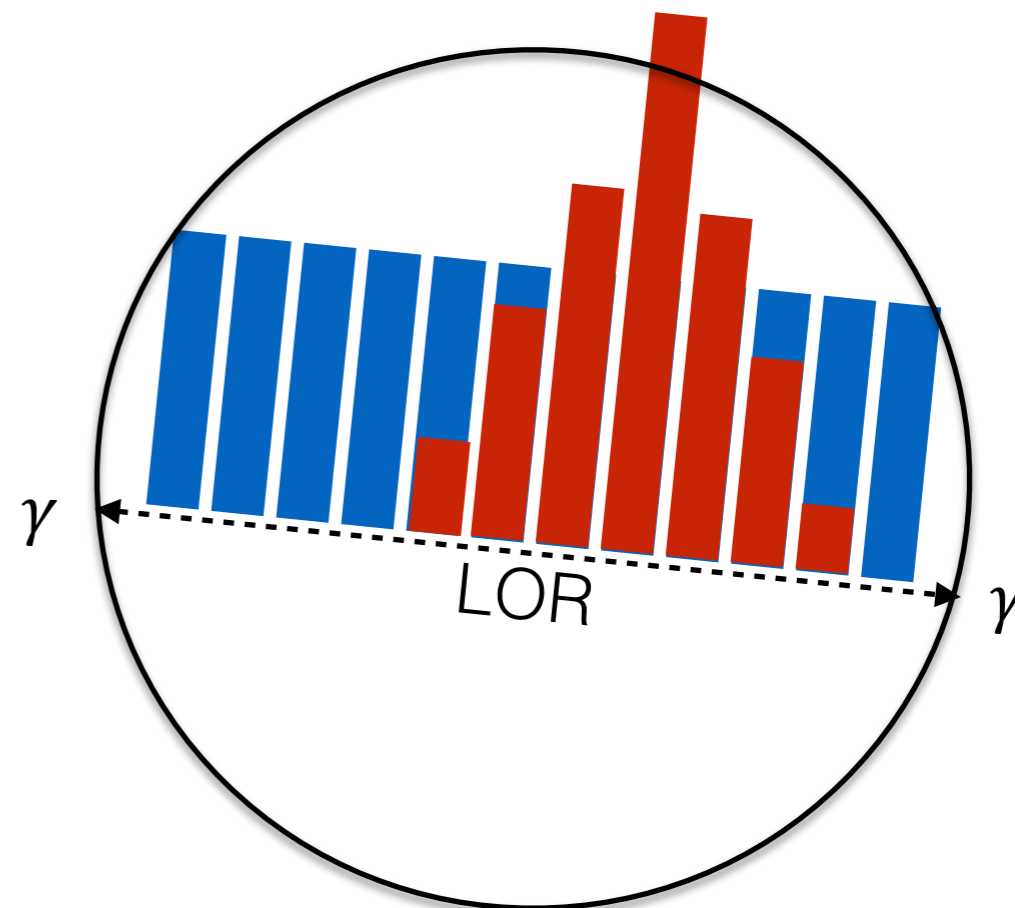
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Conventional **PET**

**TOF-PET**



# Why improve time resolution

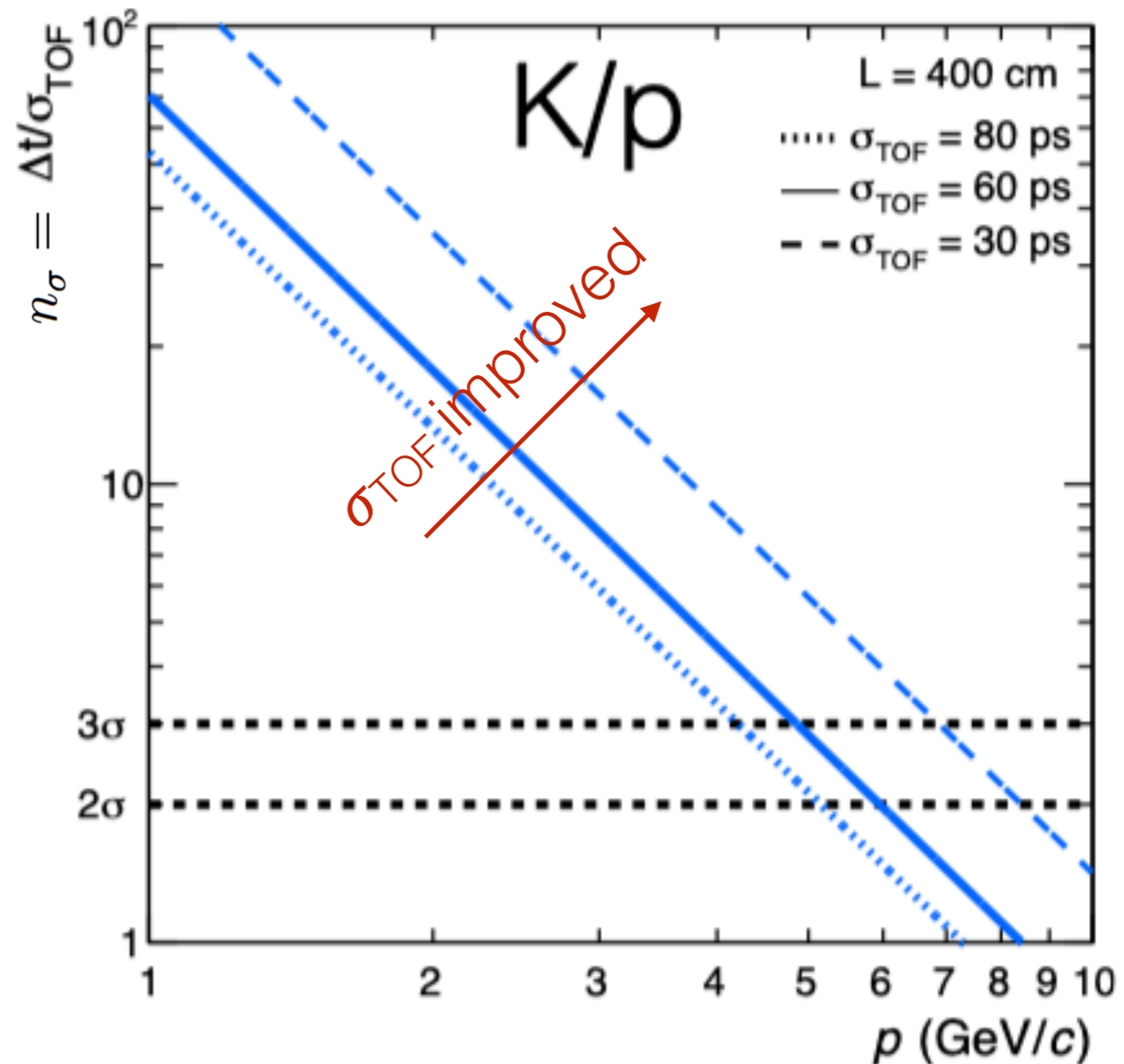
requirements → some 10's ps

- Medical Physic → PET : higher SNR, less dose

- **HEP Physic**

- ▶ **PID** → separation to higher momenta
- ▶ Pile-up issue
- ▶ Calorimetry

$$m = \frac{p}{c} \sqrt{\frac{c^2 t^2}{L^2} - 1}$$



# Why improve time resolution

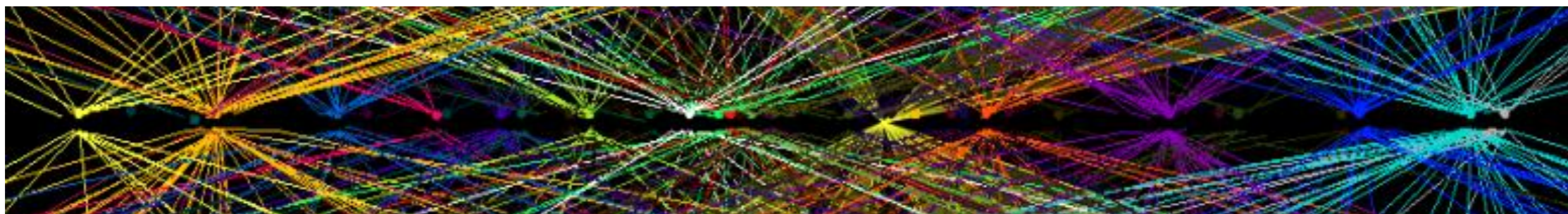
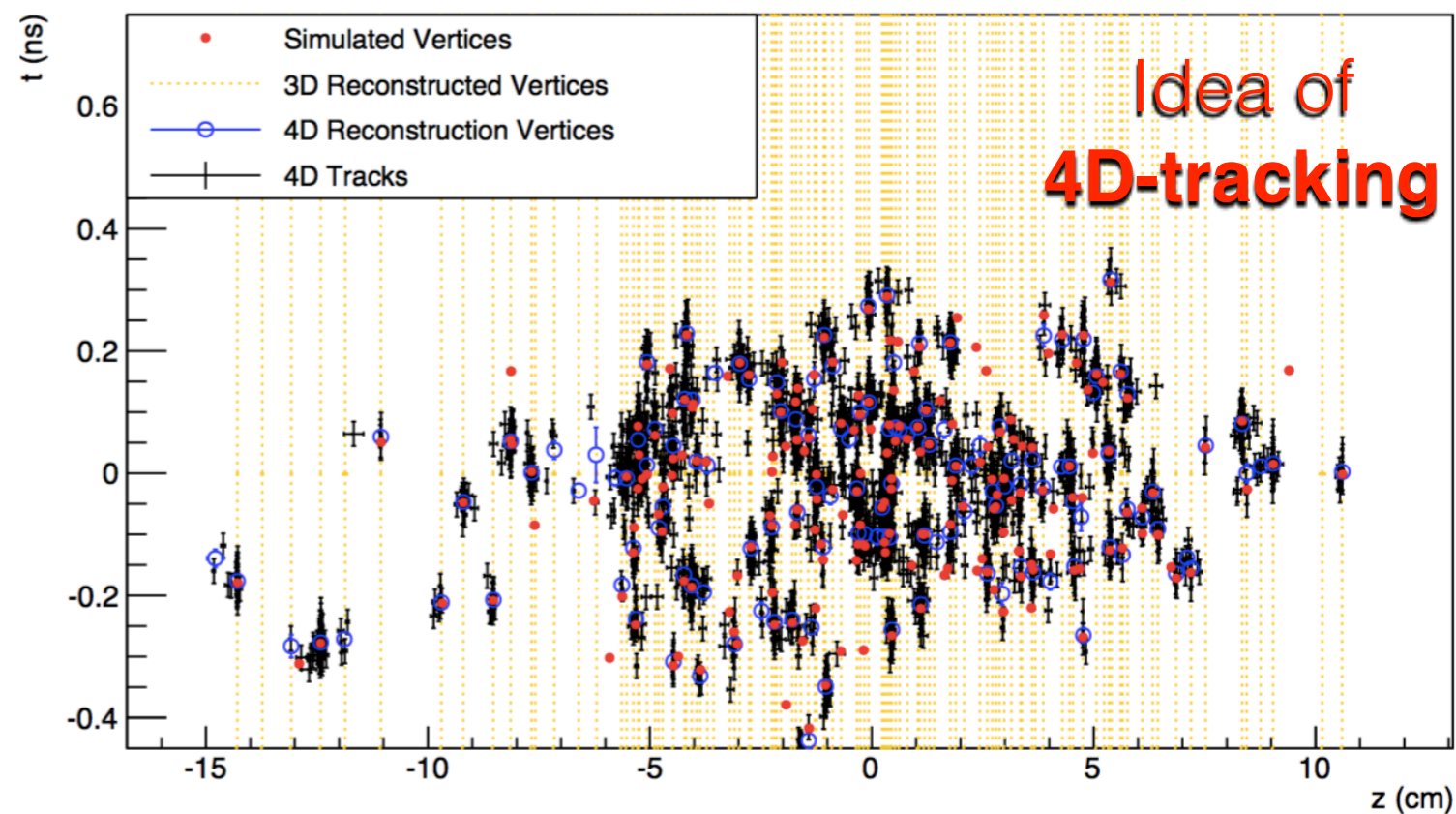
requirements → some 10's ps

- Medical Physic → PET : higher SNR, less dose
- **HEP Physic**
  - ▶ PID → separation to higher momenta
  - ▶ **Pile-up issue** → alleviated
  - ▶ Calorimetry

CMS Simulation

$\langle \mu \rangle$	3D Merged Vertex Fraction	4D Merged Vertex Fraction	Ratio of 3D/4D
50	3.3%	0.5%	6.6
200	13.4%	1.5%	8.9

With the next generation of colliders (HL-LHC, FCC) probability of merged vertices > 10%



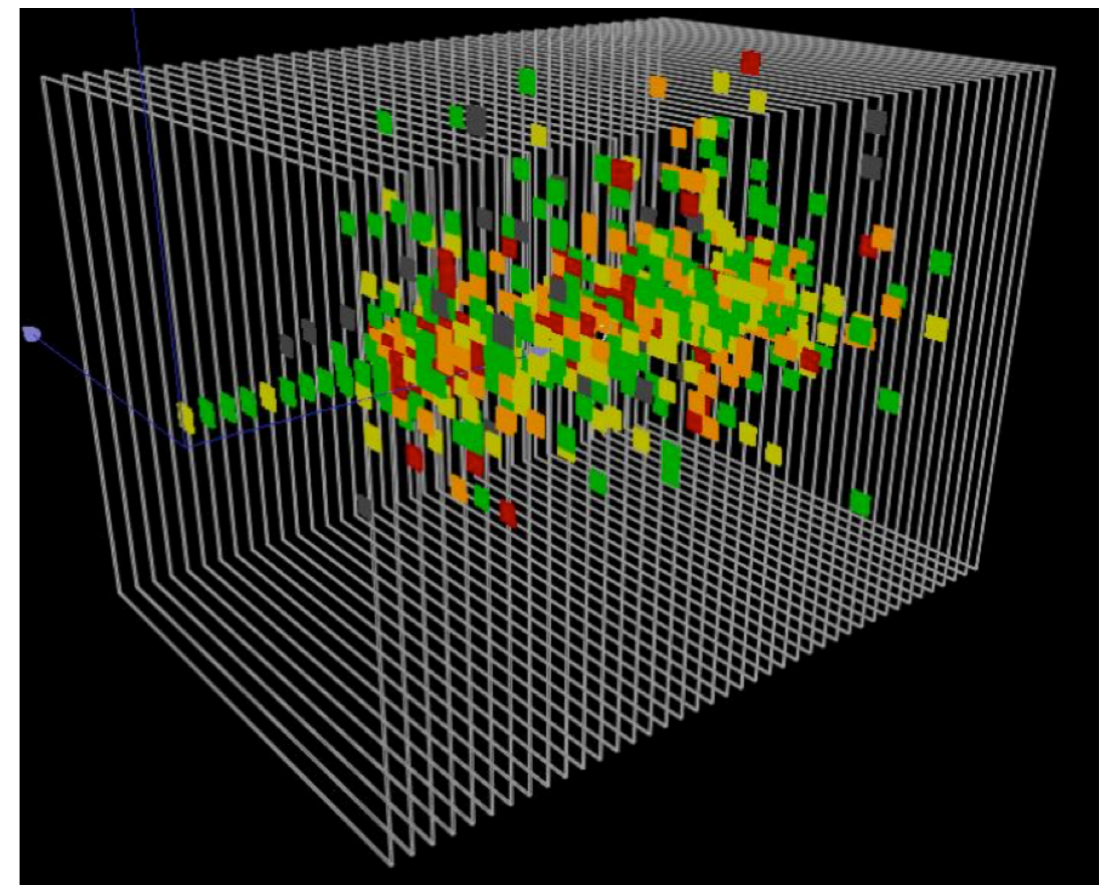
HL-LHC: beamspot time spread (150-180) ps, pileup 150 - 200



# Why improve time resolution

requirements → some 10's ps

- Medical Physic → PET : higher SNR, less dose
- **HEP Physic**
  - ▶ PID → separation to higher momenta
  - ▶ Pile-up issue → alleviated
  - ▶ **Calorimetry** → improve energy resolution in imaging calorimeter



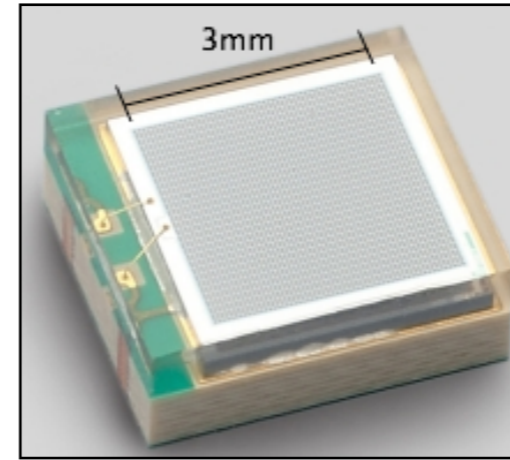


# SiPM used

## Bologna INFN Laboratory

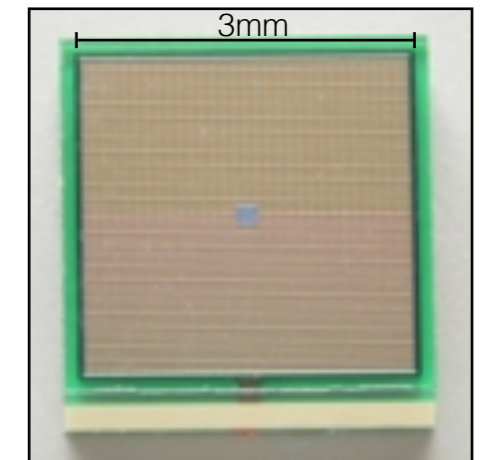
Preliminary measurements:

- I-V
- Gain
- C-V
- DCR



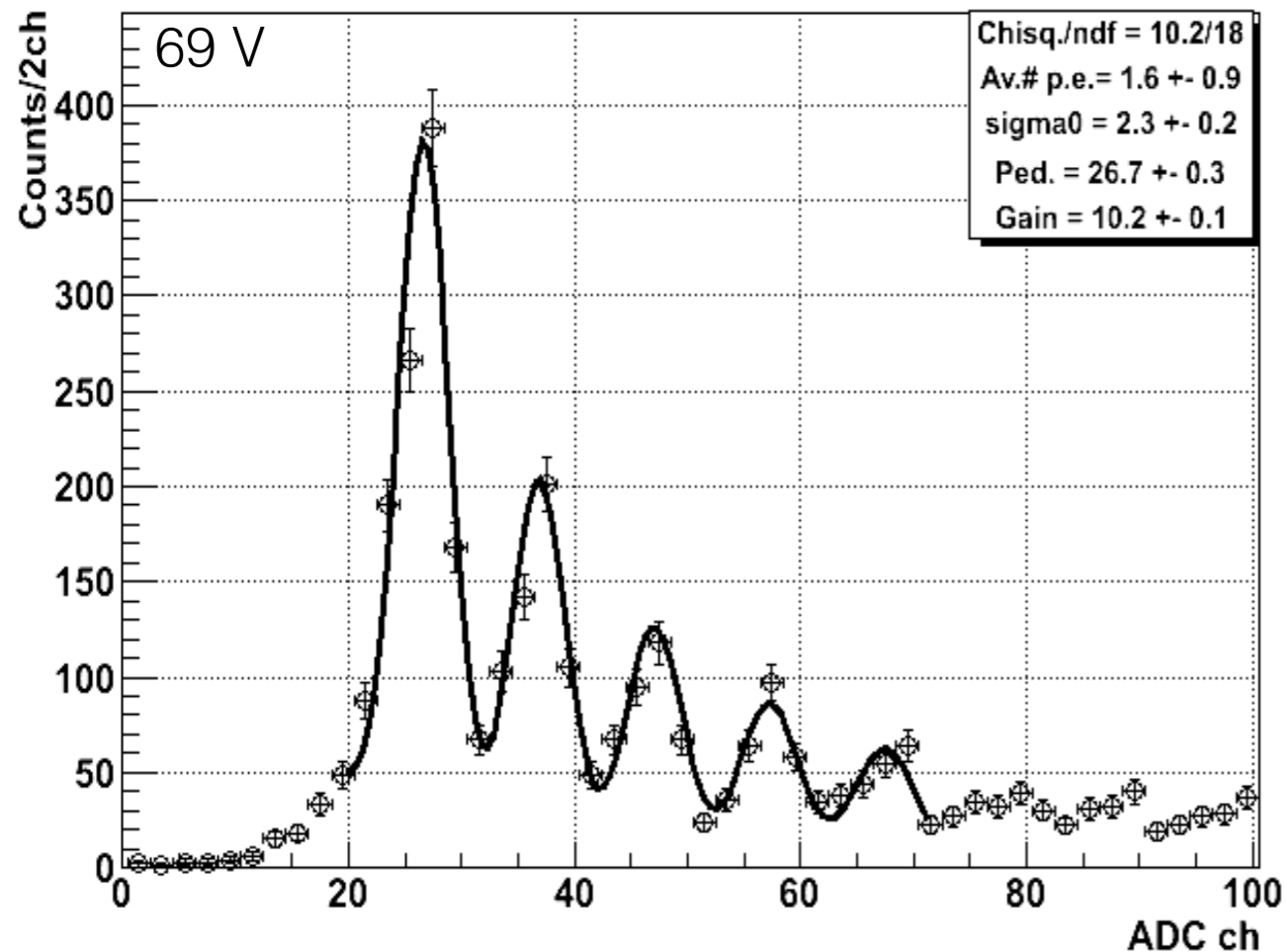
SiPM S12572-050P Hamamatsu

**SiPM-A**



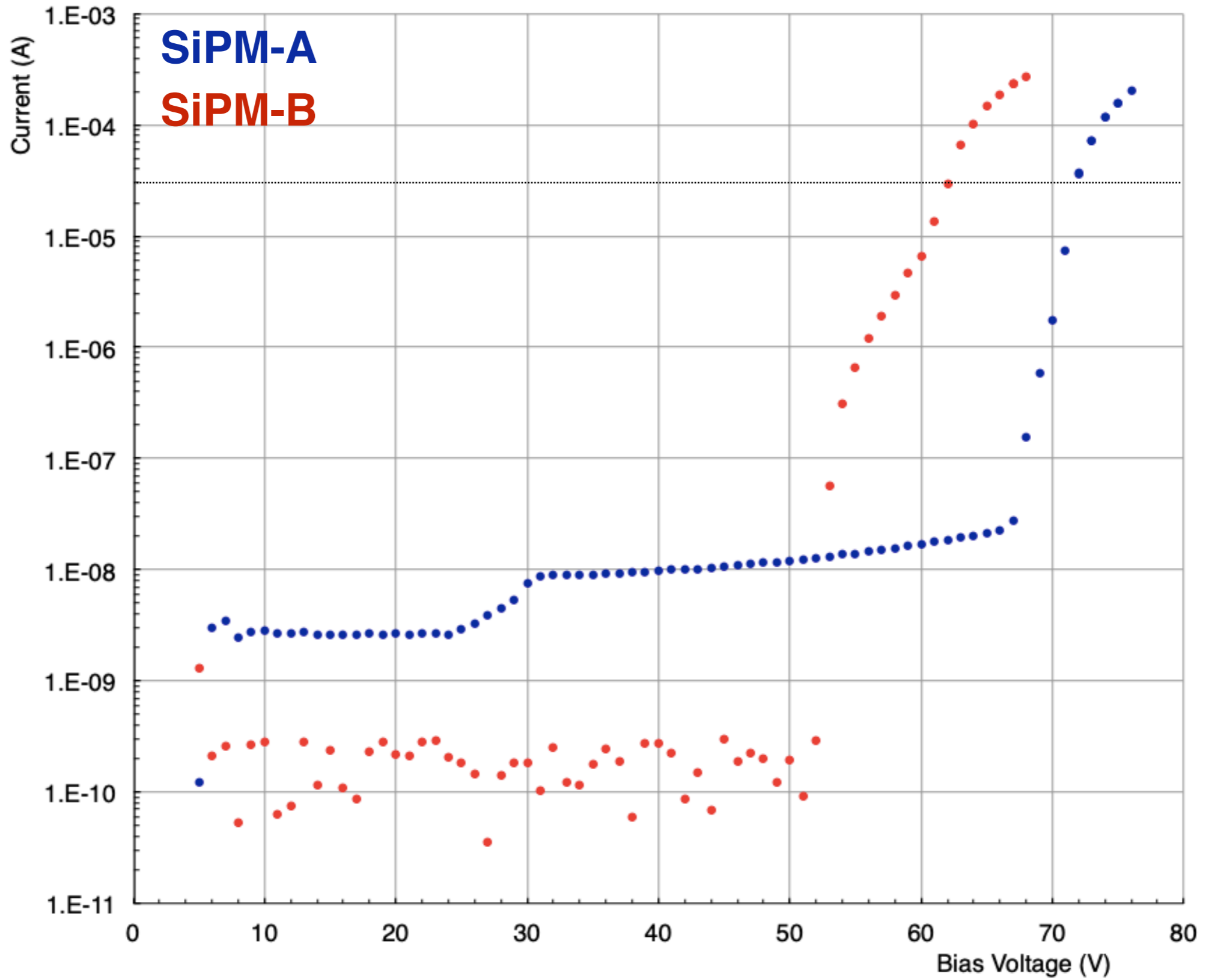
SiPM S13360-3050VE Hamamatsu

**SiPM-B**

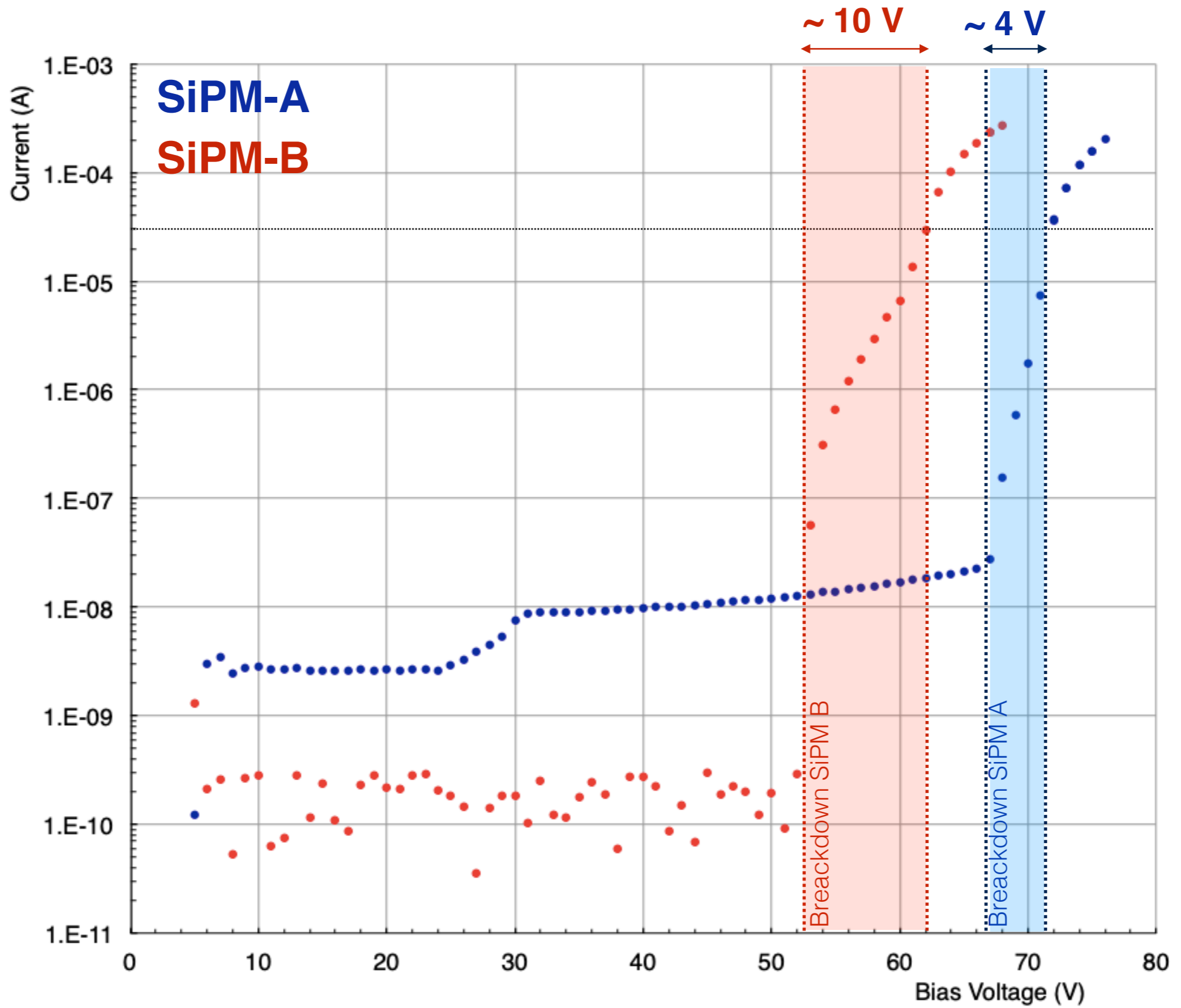


$$G = \frac{Q_{p.e.}}{q_e} = 1.6 \cdot 10^6$$

# I - V



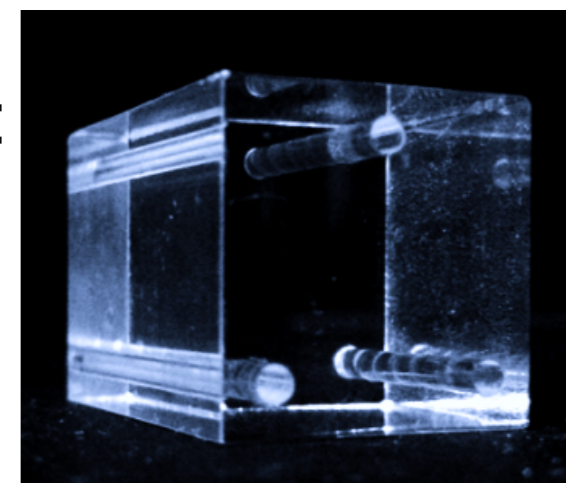
# I - V



# SiPM coupled to scintillator

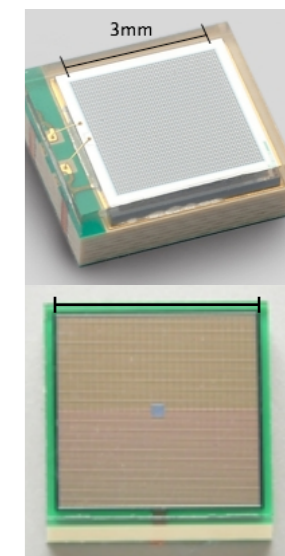
Several configurations for different purposes:

- Different coupling to scintillator
- Two different scintillator size
- Direct coupling, 2 different way:



Plastic scintillator BC-420

+

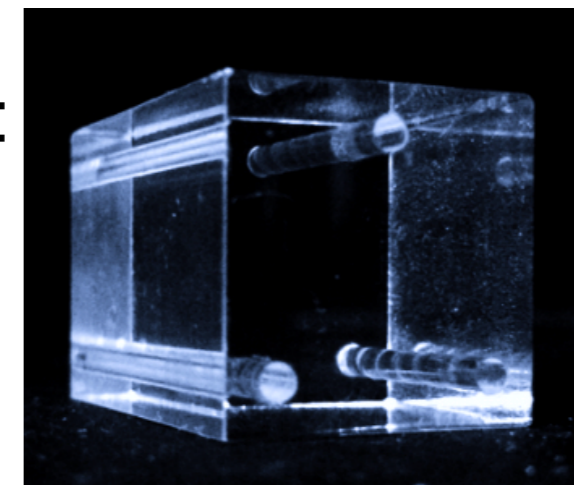




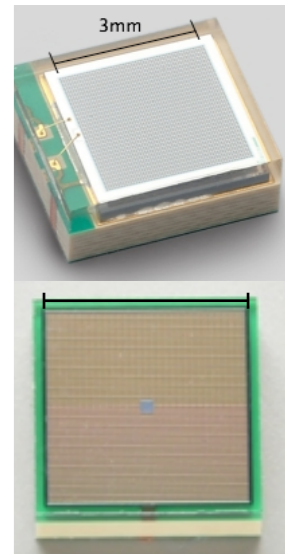
# SiPM coupled to scintillator

Several configurations for different purposes:

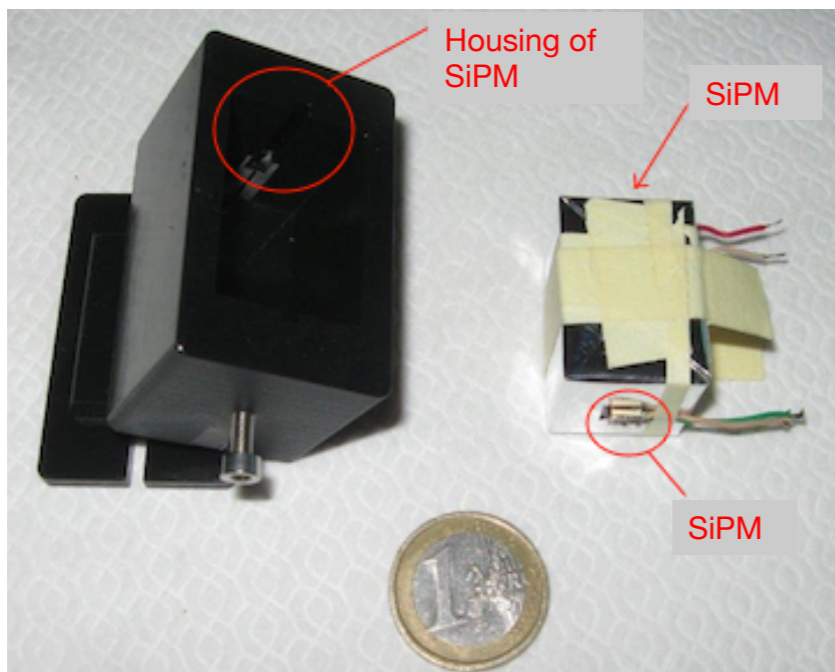
- **Different coupling to scintillator**
- Two different scintillator size
- Direct coupling, 2 different way:



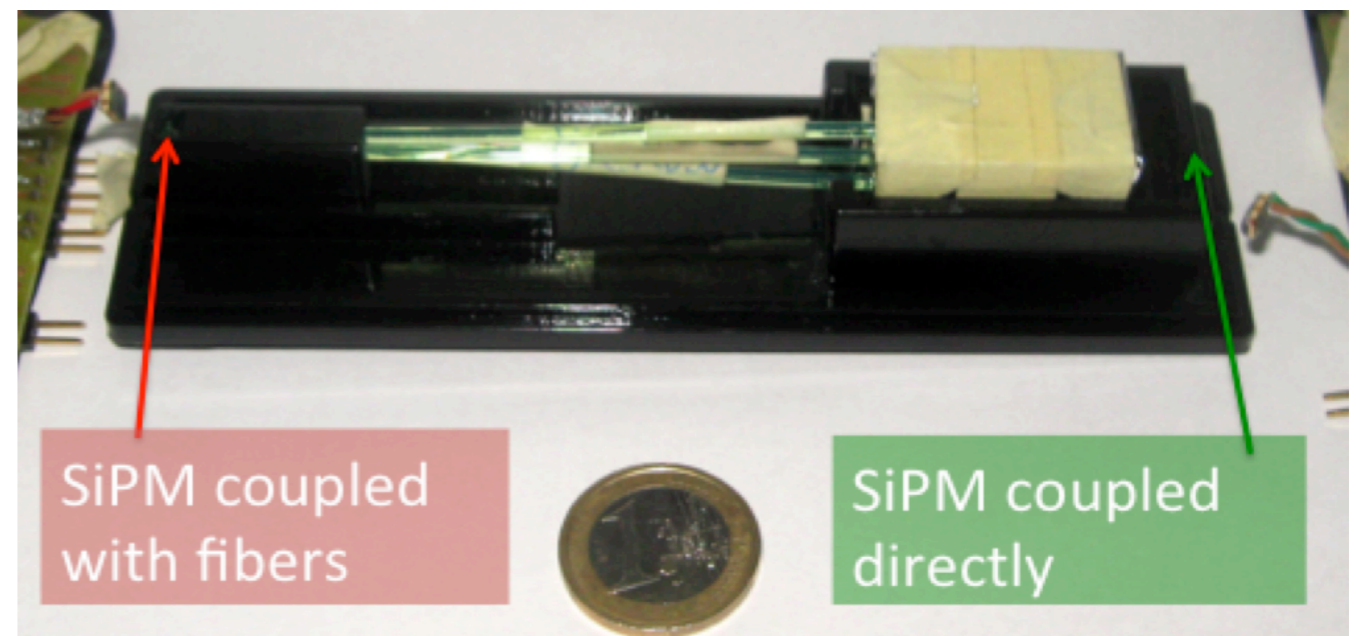
Plastic scintillator BC-420



WLS BCF-92 **fibers**, 2 mm diameter



**Direct coupling**



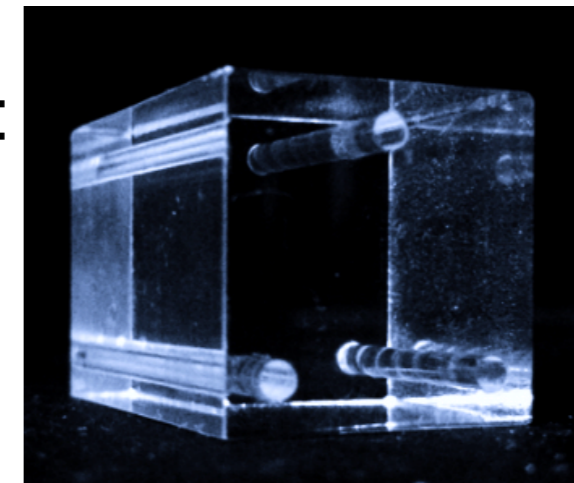
**Fibers** coupling to scintillator  
**Two different lengths:**

- 10 cm
- 35 cm

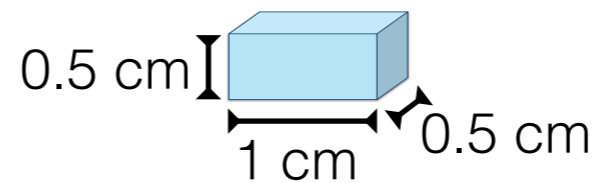
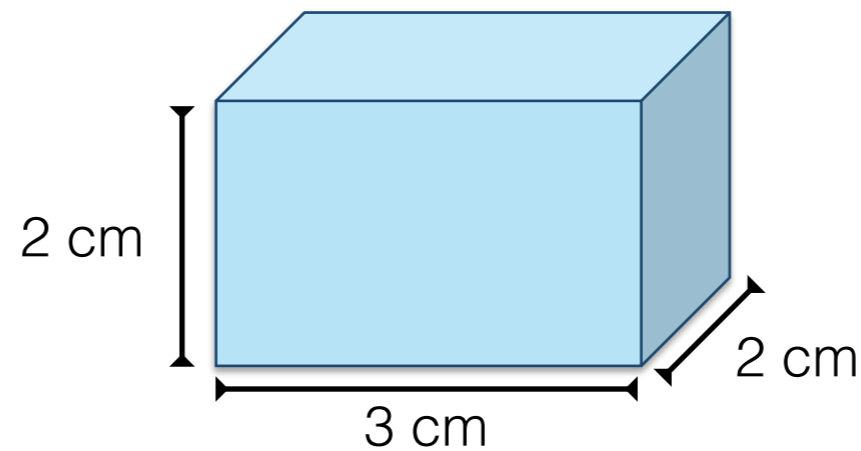
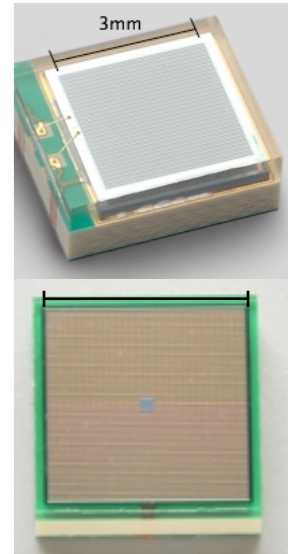
# SiPM coupled to scintillator

Several configurations for different purposes:

- Different coupling to scintillator
- **Two different scintillator size**
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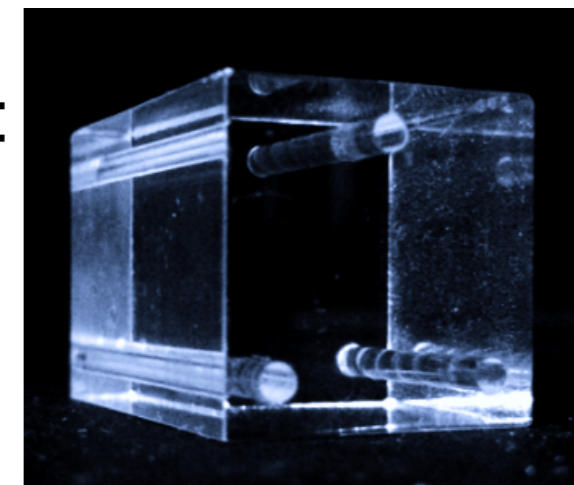
Plastic scintillator BC-420



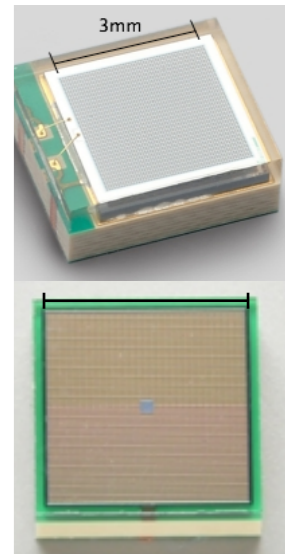
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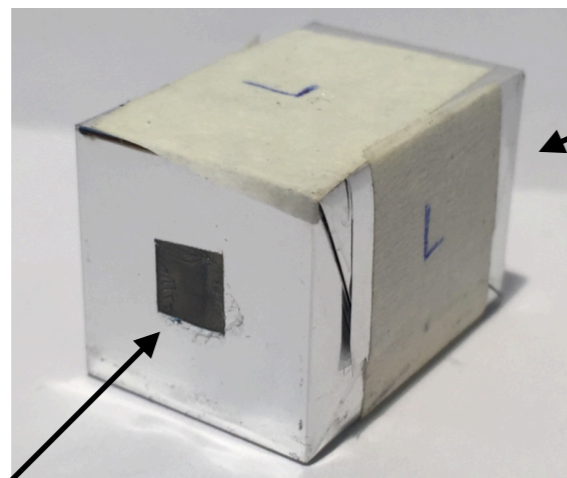
- Different coupling to scintillator
- Two different scintillator size
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Plastic scintillator BC-420



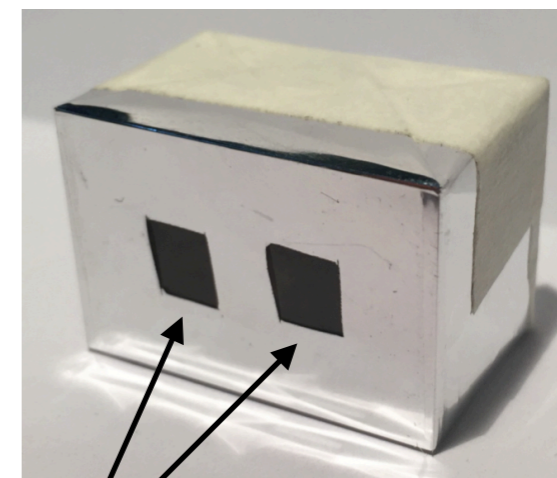
SiPMs at the **opposite**



SiPM window

SiPM window

SiPMs in the **same side**

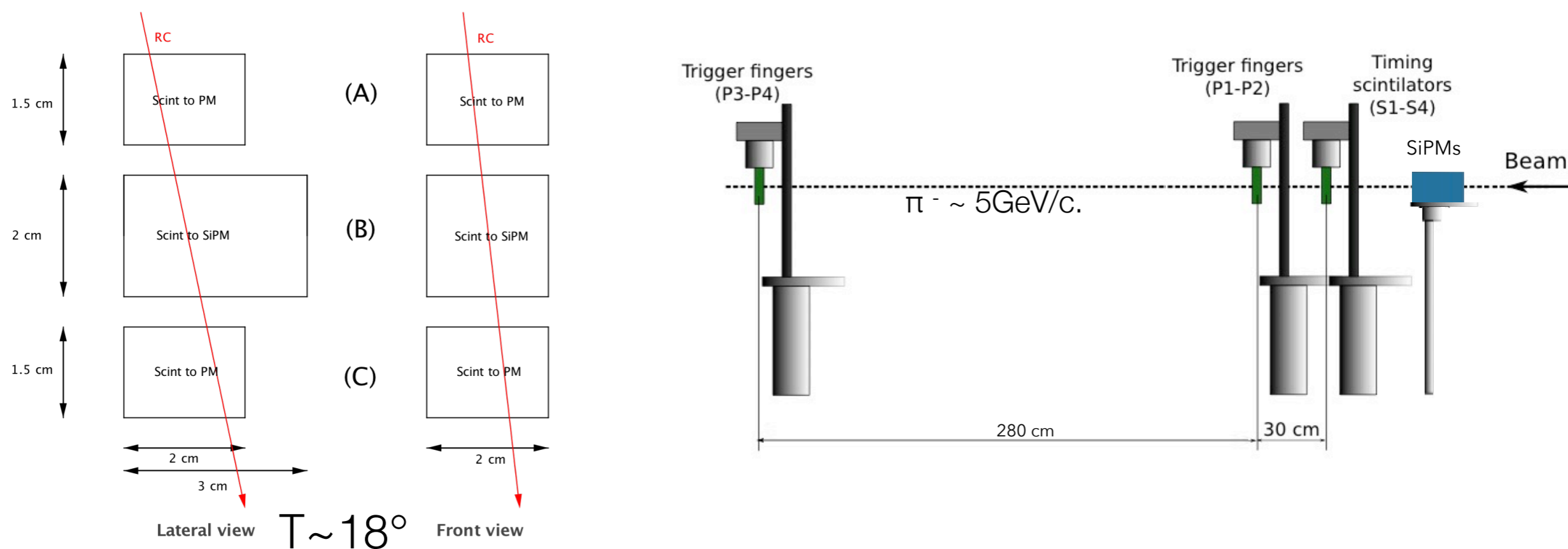


SiPM windows



# Setup

Tested both in INFN **Bologna** Laboratories, using **cosmic ray** setup, and in a **beam test** setup (T10), at **CERN**.



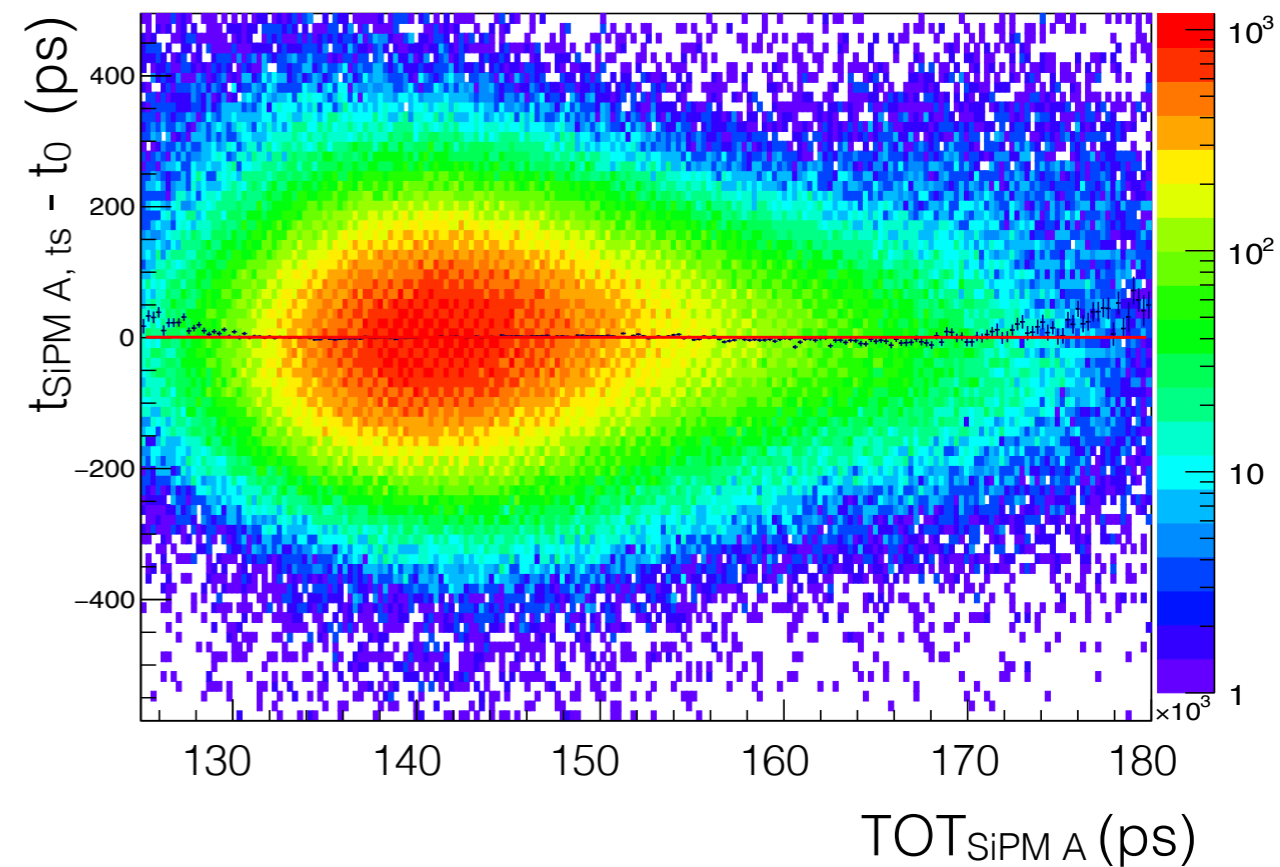
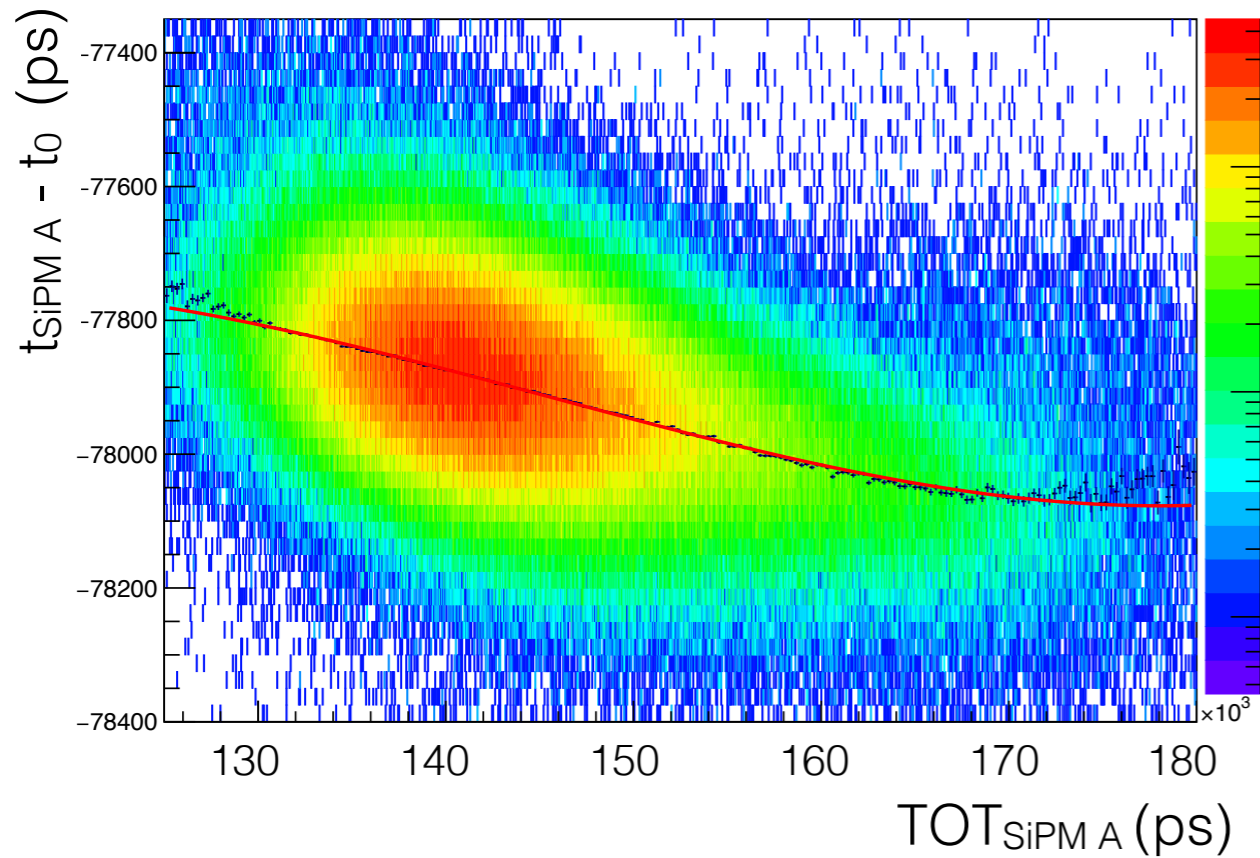
As **front-end** and **readout** electronics:

- Cosmic ray: **NINO+CAMAC modules** (TDC and CIA)
- Beam test : **NINO+ VME** module (**HPTDC**)



# Data analysis

## Time slewing corrections:

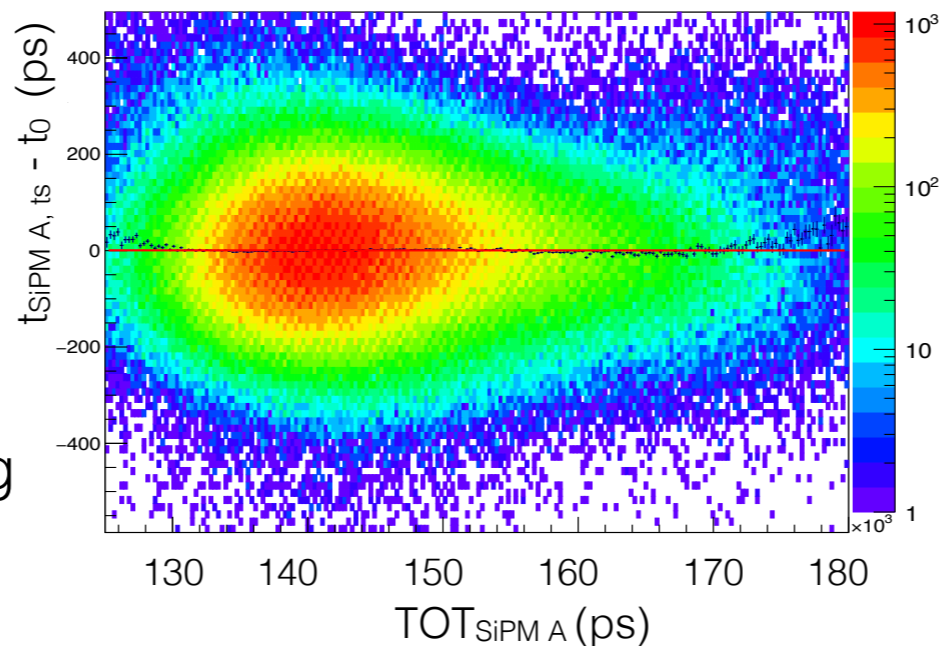


→ improvement up to 20% of time resolution

# Data analysis

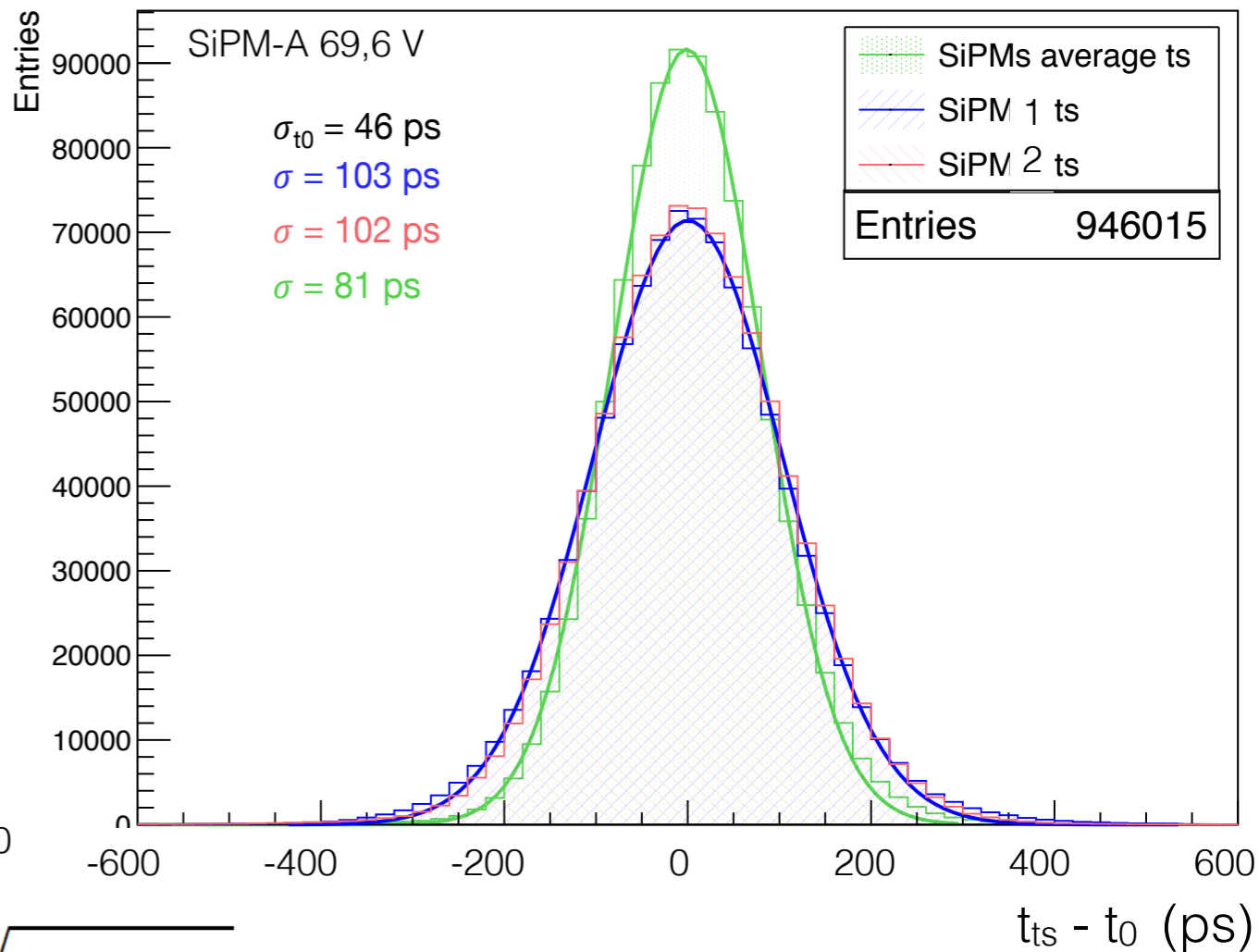
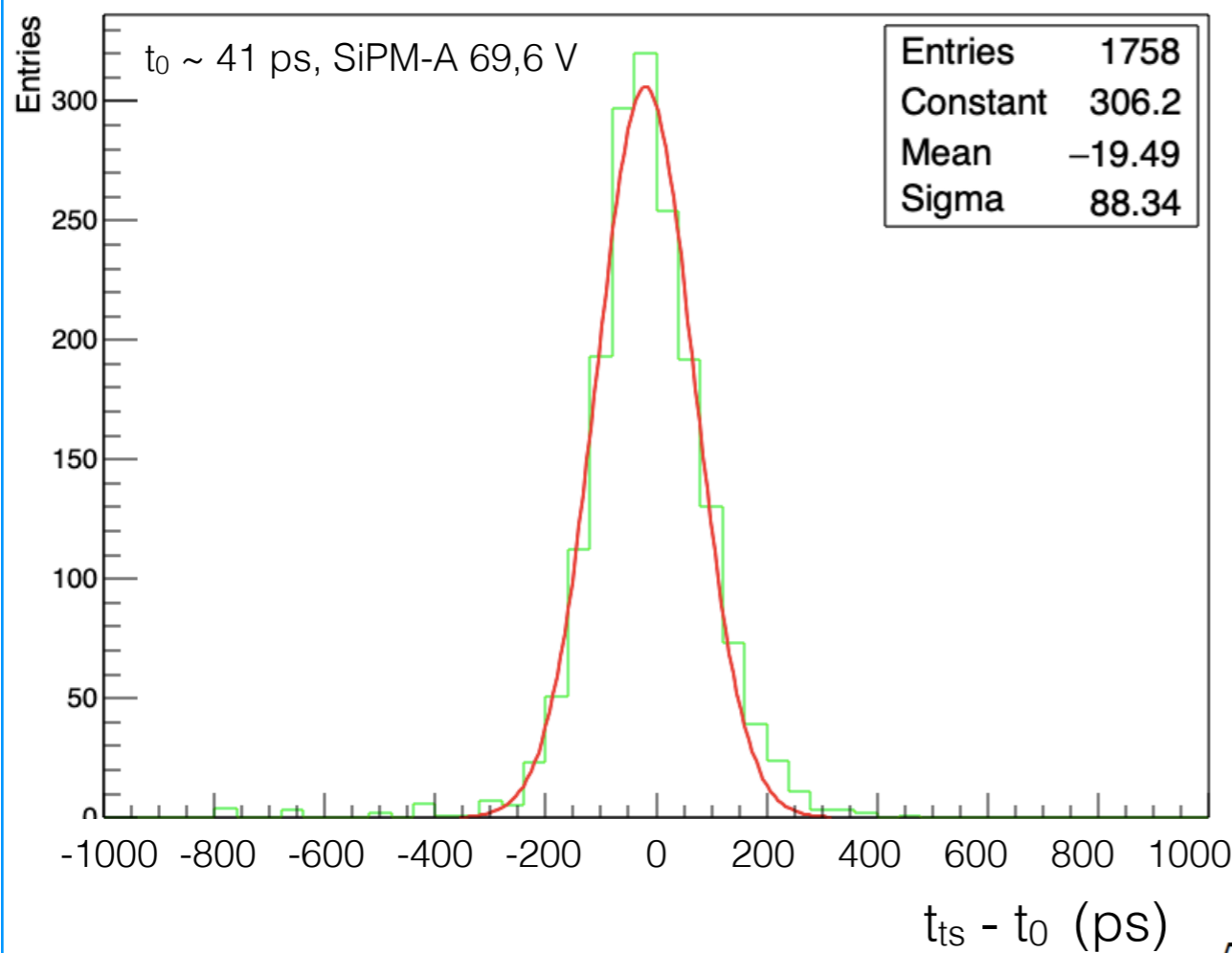
## Cosmic ray, direct coupling

- $(t_1 + t_2)/2 - t_0$



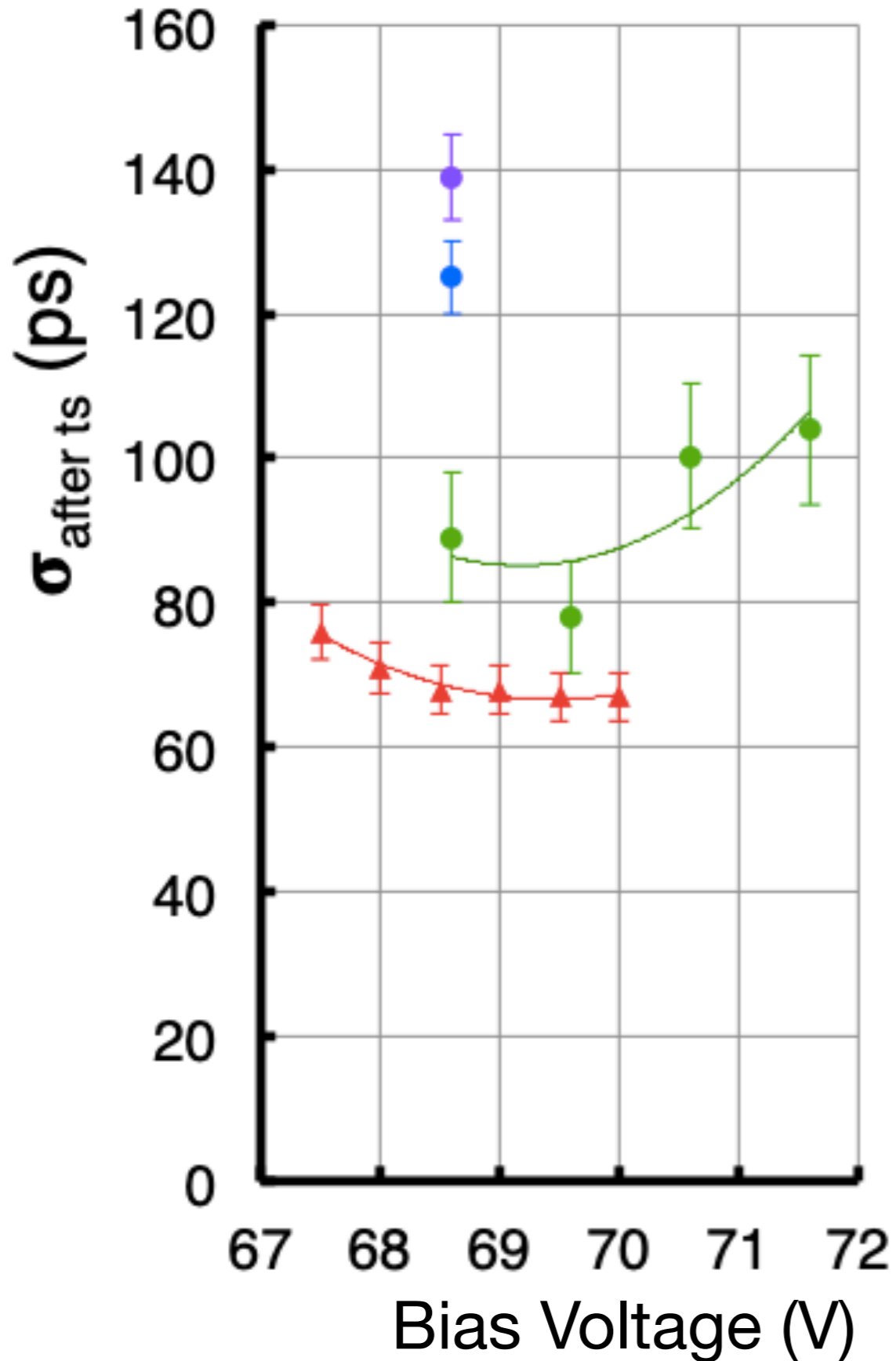
## Beam test, direct coupling

- $t_{SiPM} - t_0$
- $(t_1 + t_2)/2 - t_0$



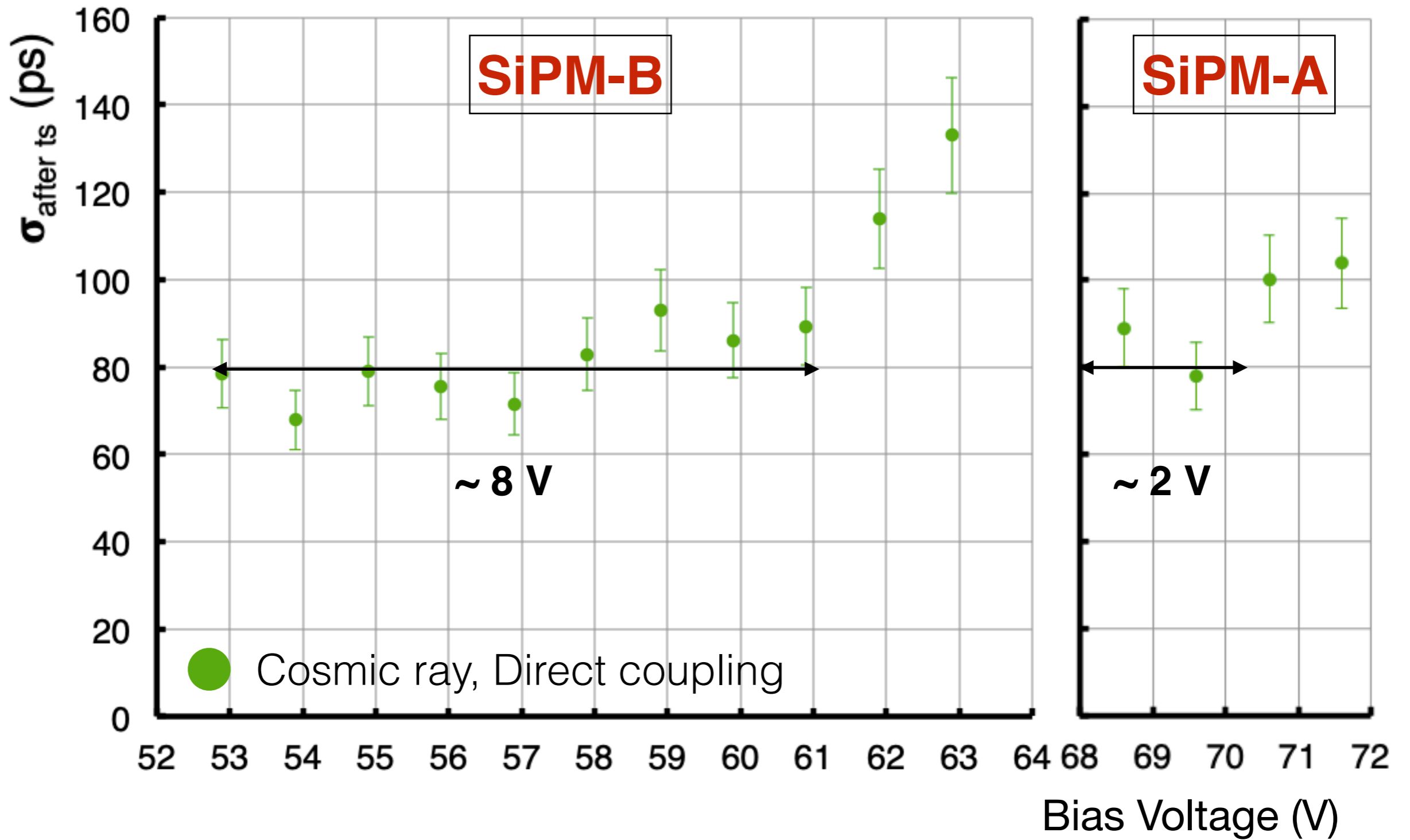
$$\sigma_{SiPM} = \sqrt{\sigma^2 - \sigma_{t_0}^2}$$

# Results



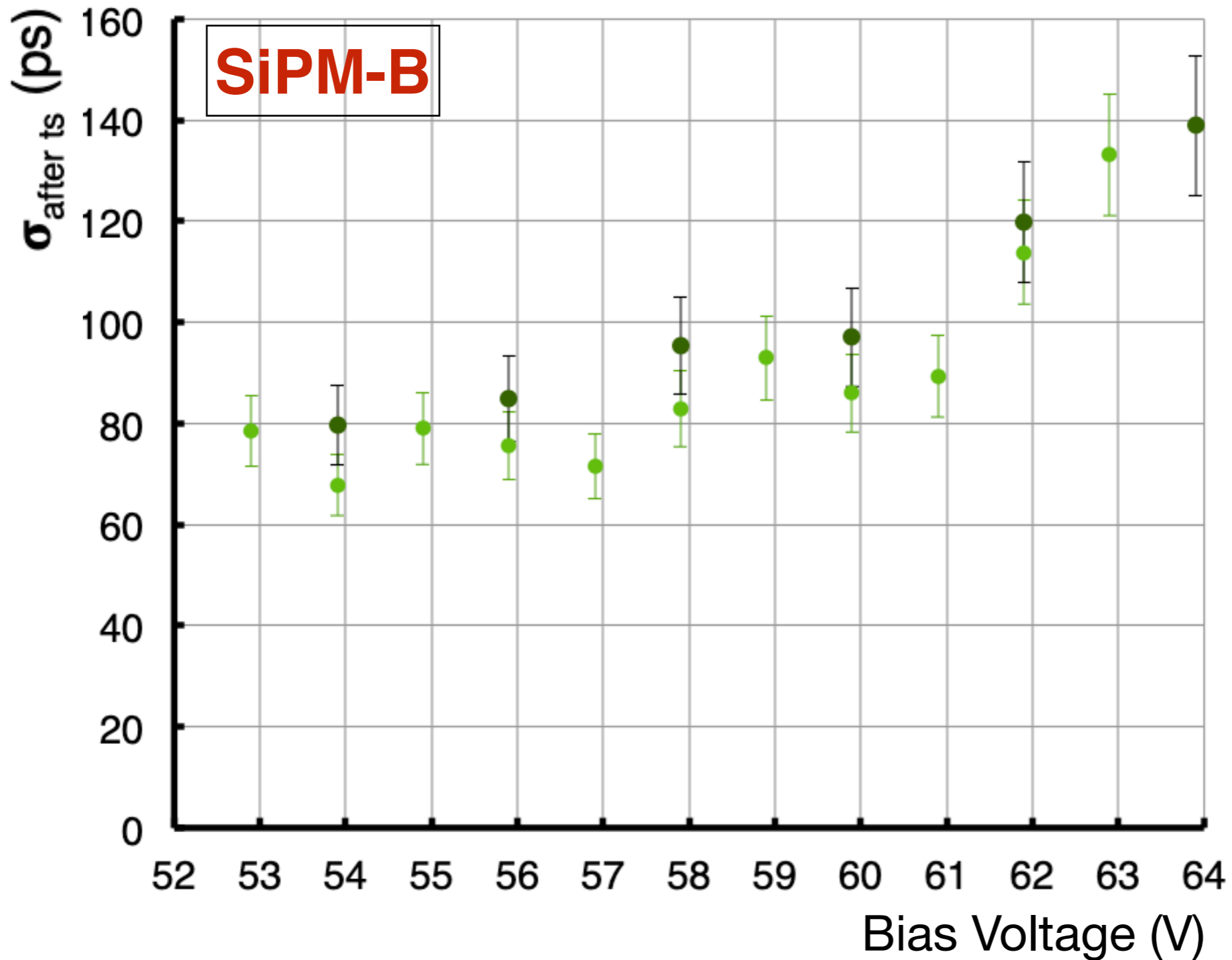
- Cosmic ray
- Direct coupling
- Fiber coupling 10 cm
- Fiber coupling 37 cm
- ▲ Beam test, Direct coupling

# Results



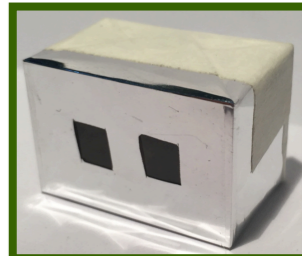
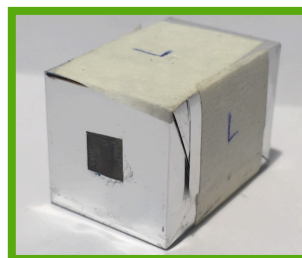


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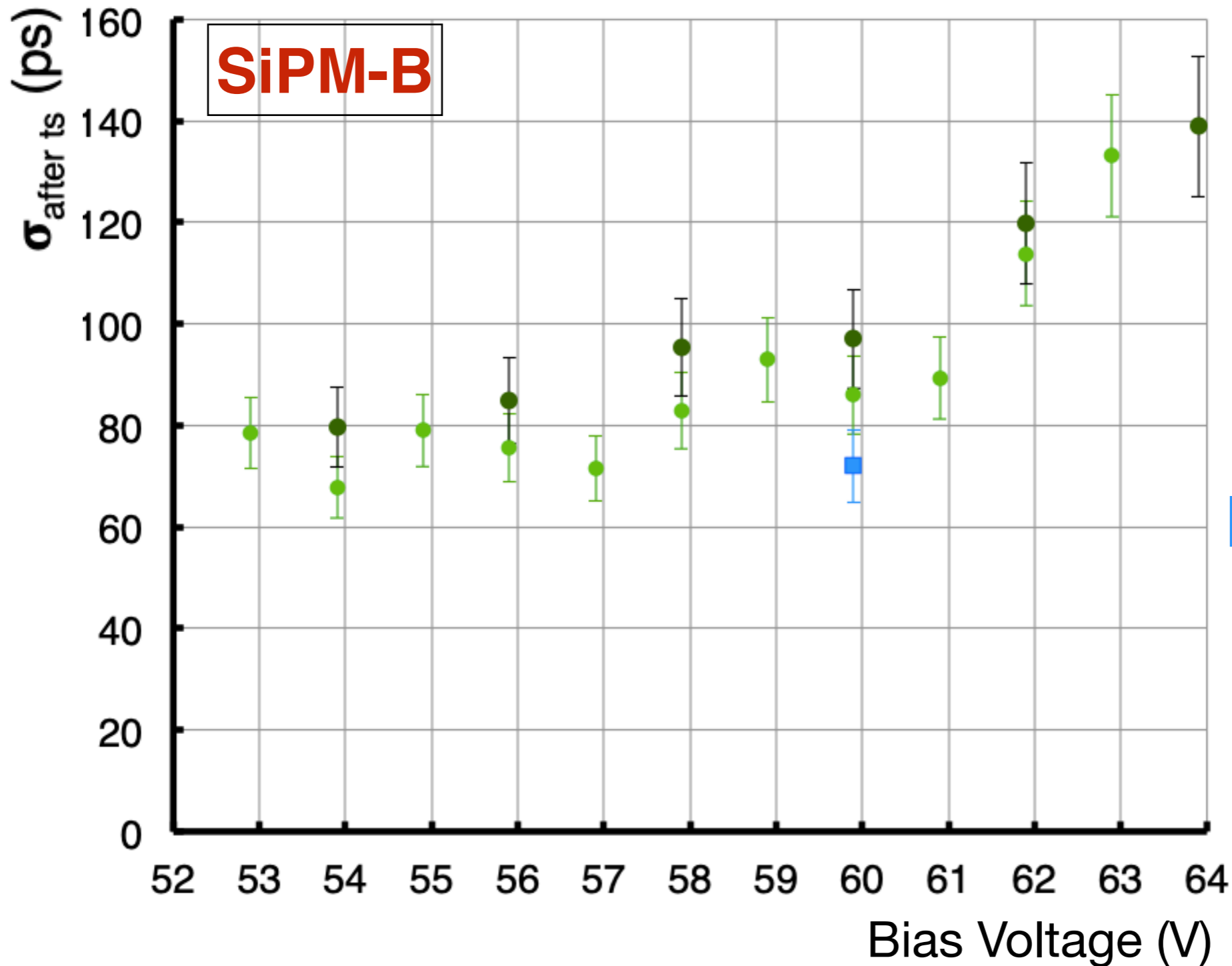



● Cosmic ray, Direct coupling, **SiPMs opposite**

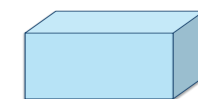
● Cosmic ray, Direct coupling, **SiPMs same side**



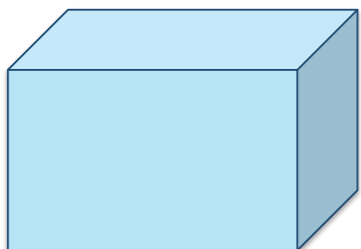
# Results



 Cosmic ray  
 Direct coupling  
 SiPMs opposite  
**smaller size scint**  
**1x0.5x0.5 cm<sup>3</sup>**

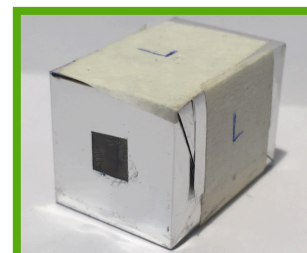


**3x2x2 cm<sup>3</sup>**



 Cosmic ray, Direct coupling, SiPMs opposite

 Cosmic ray, Direct coupling, SiPMs same side



# Conclusions

- **High-resolution timing** detectors are **ubiquitous** in both **particle and medical physics**.
  - For the **next generation of colliders**, a time resolution of **tens of picoseconds** will play a **fundamental role**
- The **time resolution** of **SiPMs coupled** to **scintillator** has been extensively studied
- A time resolution of about **67 ps** has been obtained both in a cosmic ray and beam test setup **including the entire electronic chain**
- **Next steps:**
  - deeper study using smaller scintillator size
  - custom front-end electronic
  - beam test