R&D activities on PSD bar design and preparation for CERN test-beam

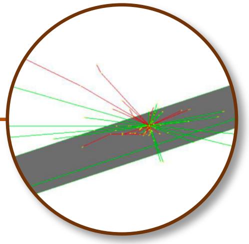
Felicia Barbato – GSSI & INFN

on behalf of GSSI, Lecce and IHEP groups

HERD PSD activity organization

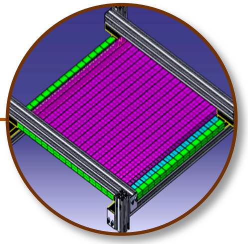
Lab activities

- Sipm characterization
- Comparison of different size bars
- Measurements with radioactive sources



Simulations

- SiPM characteristics
- Sr90 decay in bars



Mechanics

- 2021 Beam test prototype
- Design for a possible full scale configuration

Lab activities

LNGS –Electronics Lab

Bars with different size

+

SiPMs from different brands

Lab activity roadmap

Tests on SiPMs (gain, dark)

↳ Comparison of the performances

↳ Assembly of equal bars with different SiPMs

↳ Comparison of the performances

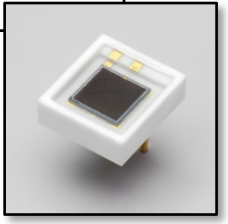
↳ Assembly of different bars with equal SiPMs

↳ Comparison of the performances

SiPMs characterization

Hamamatsu S13360-3025CS

Effective photosensitive area	3x3 mm
Number of pixels	14400
Pixel size	25 µm
Peak sensitivity wavelength (typ.)	450 nm
Dark count (typ.)	400 kcps
PDE	25%
Gain (typ.)	7.0×10^5



ADVANSID ASD-NUV3S

Effective photosensitive area	3x3 mm
Number of pixels	5520
Pixel size	40 µm
Peak sensitivity wavelength (typ.)	420 nm
Dark count (typ.)	<900 kcps
PDE	43%
Gain (typ.)	3.6×10^6

SiPMs characterization

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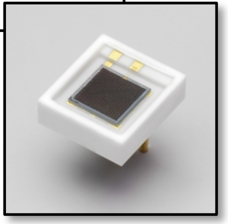

- ☺ High pixel number
- ☺ Low DCR
- ☹ Low PDE

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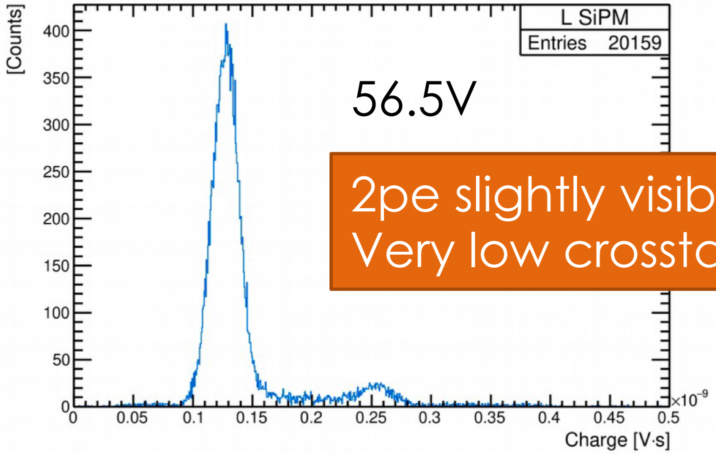
- ☹ High DCR
- ☺ High PDE

SiPMs characterization

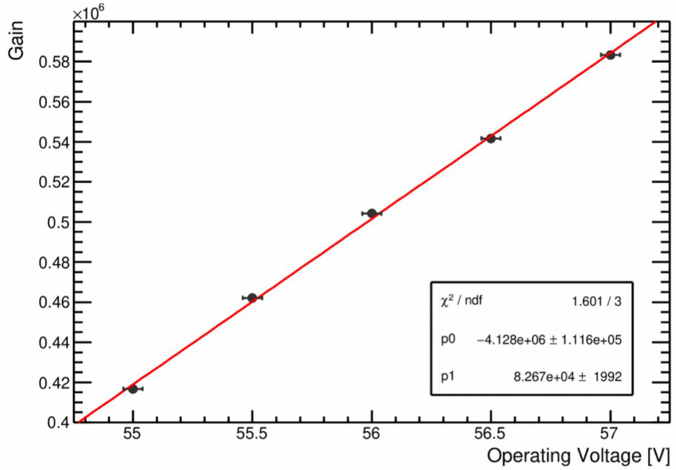
Hamamatsu S13360-3025CS

6 tested samples



56.5V

2pe slightly visible
Very low crosstalk



Dark Spectrum

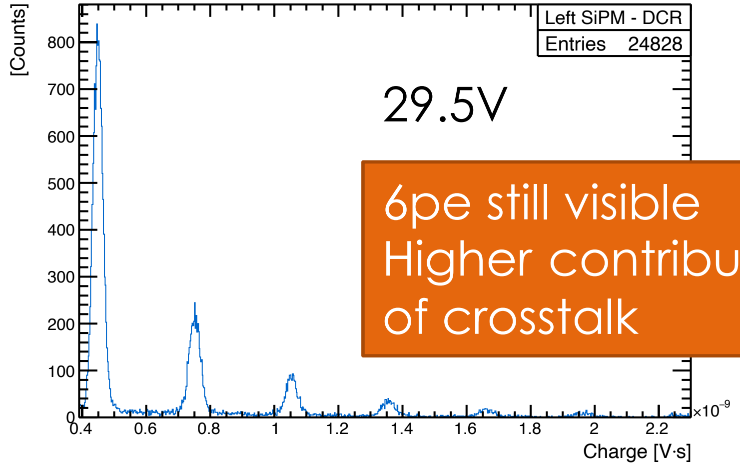
Gain

Calculated from the peak distance in the dark spectrum

$$G = \frac{\Delta A}{R \cdot e \cdot Ampl}$$

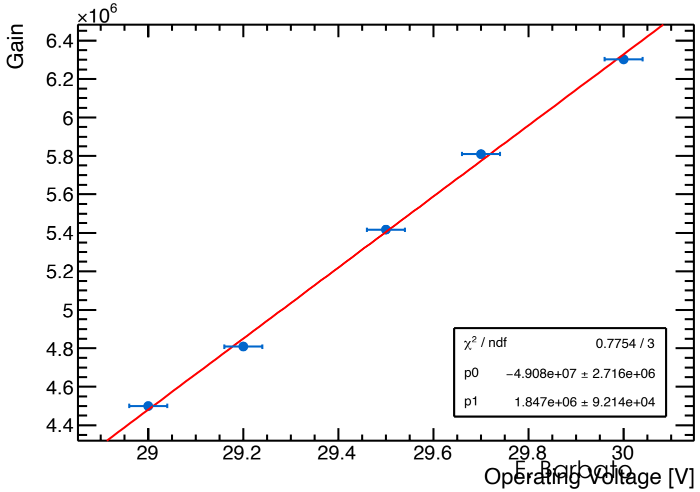
ADVANSID ASD-NUV3S

2 tested samples



29.5V

6pe still visible
Higher contribution of crosstalk

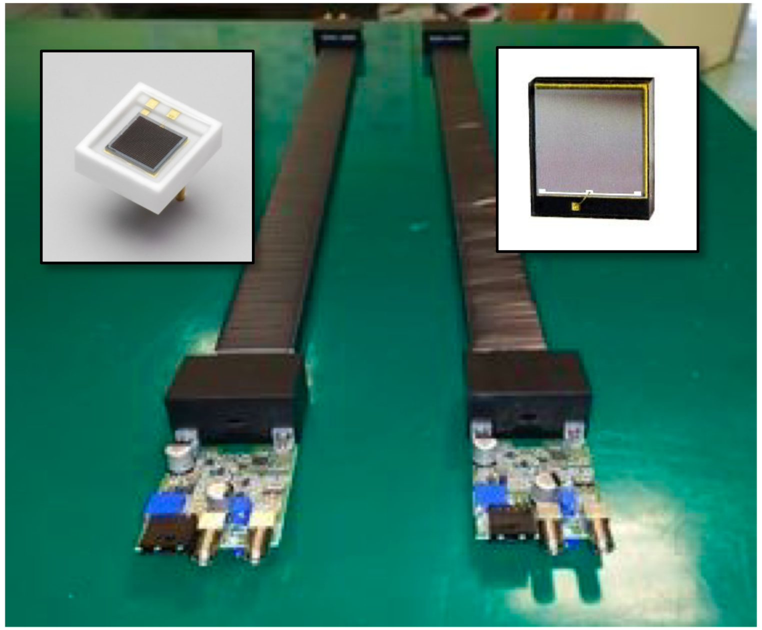


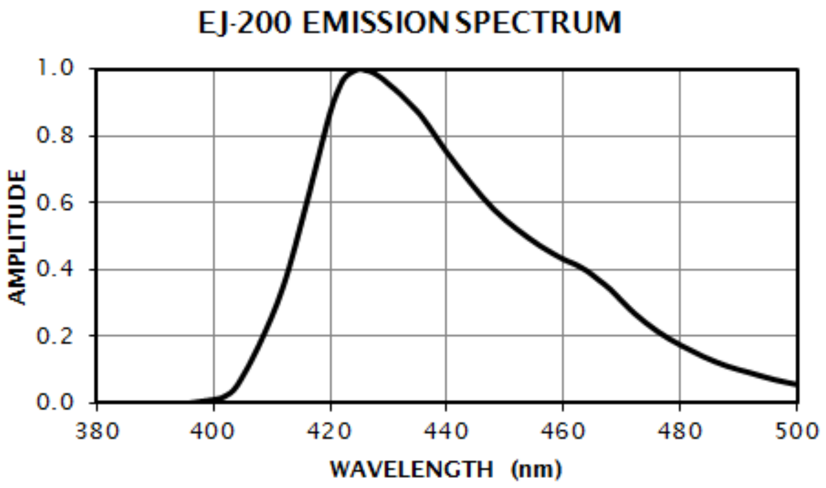
Small bar assembly

ELJEN TECHNOLOGY LJ-200

Scintillation Efficiency (photons/1 MeV e^-)	10,000
Wavelength of Maximum Emission (nm)	425
Light Attenuation Length (cm)	380
Rise Time (ns)	0.9
Decay Time (ns)	2.1
Pulse Width, FWHM (ns)	2.5
Density (g/cm^3)	1.023
Polymer Base	Polyvinyltoluene
Refractive Index	1.58
Softening Point	75°C
Vapor Pressure	Vacuum-compatible
Light Output vs. Temperature	No change from 20°C to -60°
Temperature Range	-20°C to 60°C

Small bar	3 x 50 x 1 cm^3	1 SiPM/side





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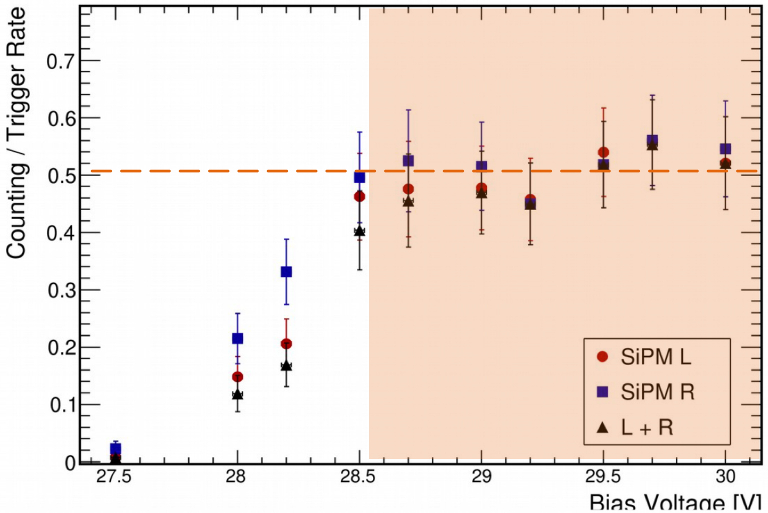
Small bar - Muons



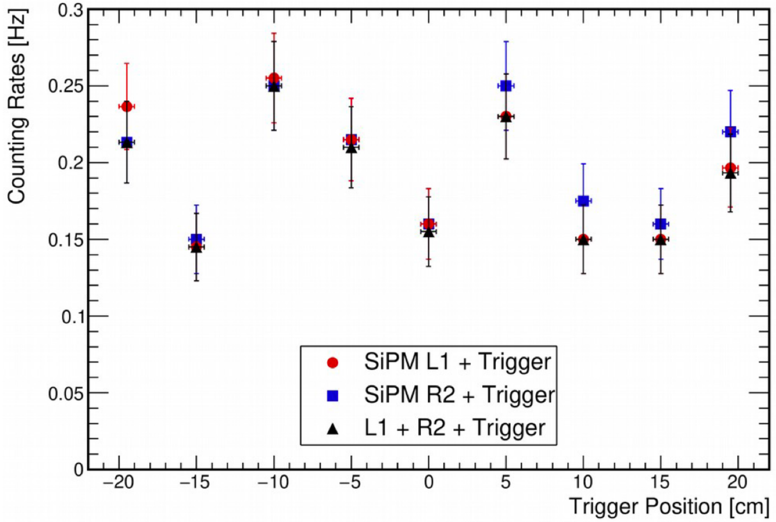
Operating point

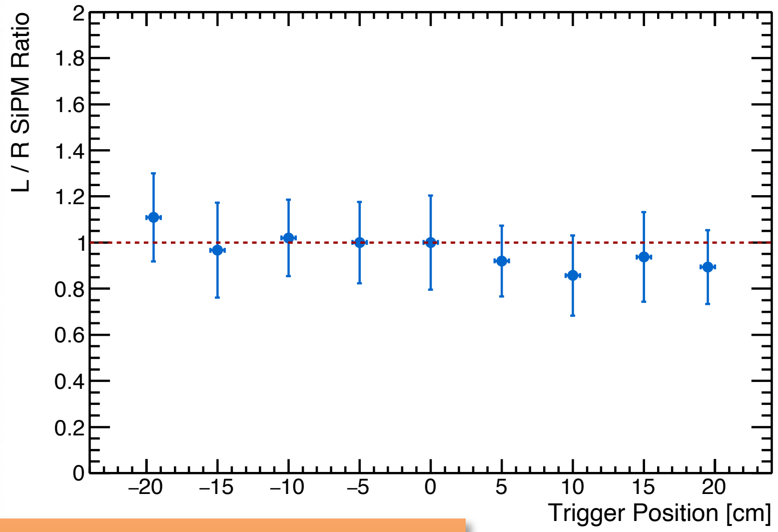
Advansid ASD-NUV3S	3 x 50 x 1 cm^3	1 SiPM/side
Gain	5.5 x 10^6	

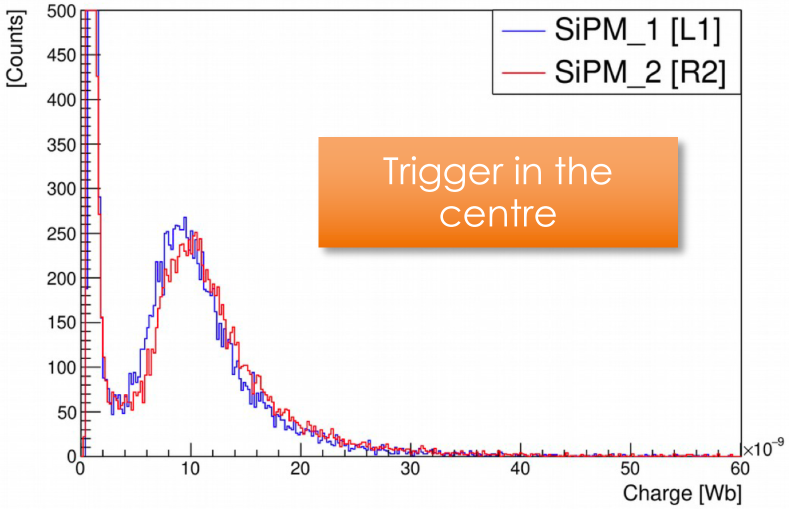
Trigger Logic for DAQ

Ext1	Ext2	R	L	Out
1	1	1	0	R
1	1	0	1	L
1	1	1	1	R+L

Configuration centered







Trigger in the centre

Counting rate at different positions

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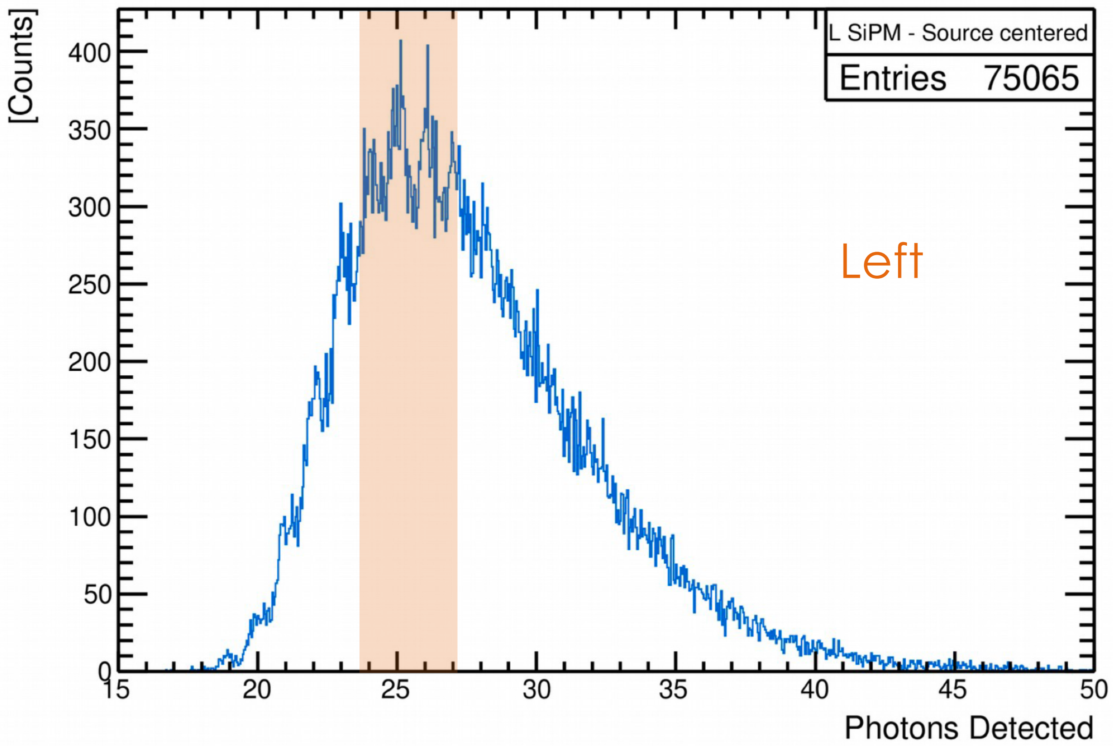
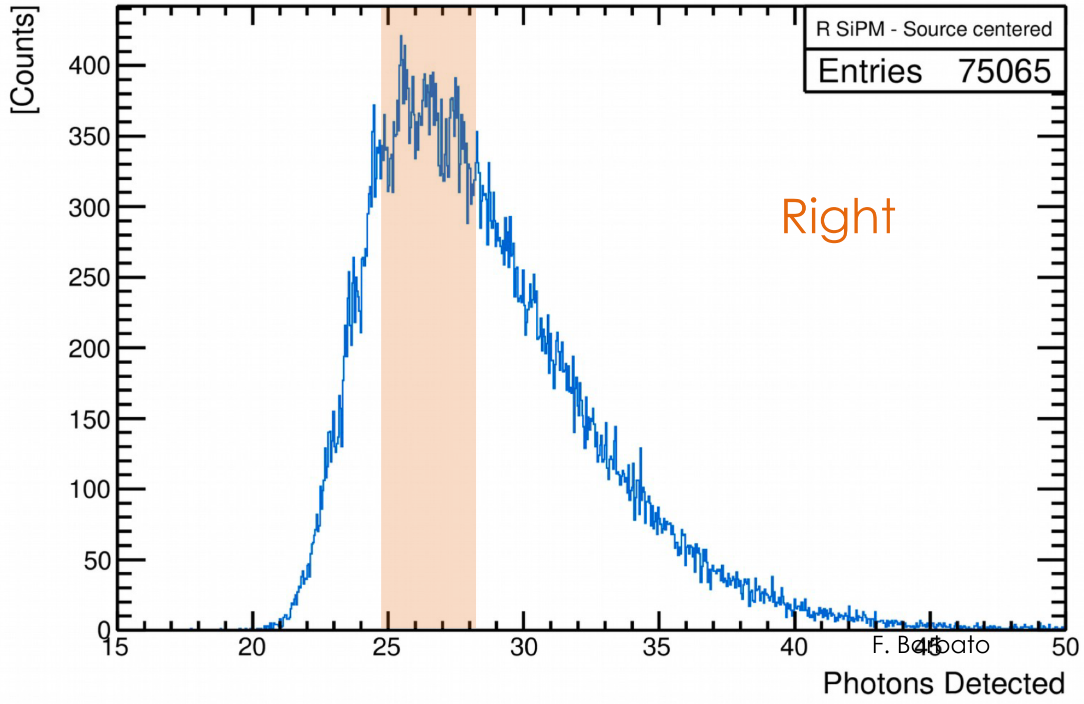
Small bar - ^{90}Sr

Hamamatsu Small bar	3 x 50 x 1 cm^3	1 SiPM/side
Gain	5.5 x 10^5	
Trigger Logic	R ∧ L	



Good agreement among the two sides



Wide bar assembly

Wide bar	6 x 50 x 1 cm^3	2 SiPM/side

ELJEN TECHNOLOGY LJ-200

Scintillation Efficiency (photons/1 MeV e^-)	10,000
Wavelength of Maximum Emission (nm)	425
Light Attenuation Length (cm)	380
Rise Time (ns)	0.9
Decay Time (ns)	2.1
Pulse Width, FWHM (ns)	2.5
Density (g/cm^3)	1.023
Polymer Base	Polyvinyltoluene
Refractive Index	1.58
Softening Point	75°C
Vapor Pressure	Vacuum-compatible
Light Output vs. Temperature	No change from 20°C to -60°
Temperature Range	-20°C to 60°C

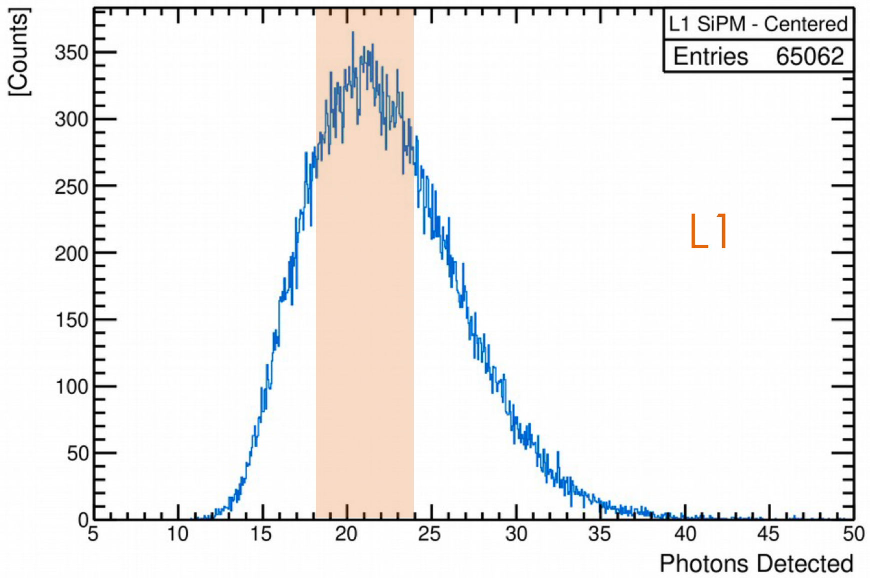
Trigger Logic for DAQ

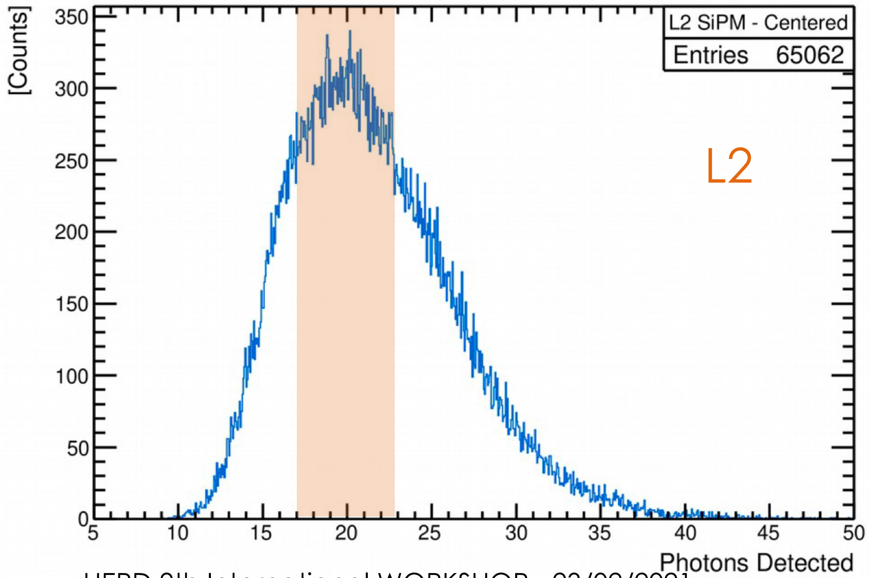
L1	L2	R1	R2	Output
1	1	0	0	L
0	0	1	1	R
1	1	1	1	$R \wedge L$

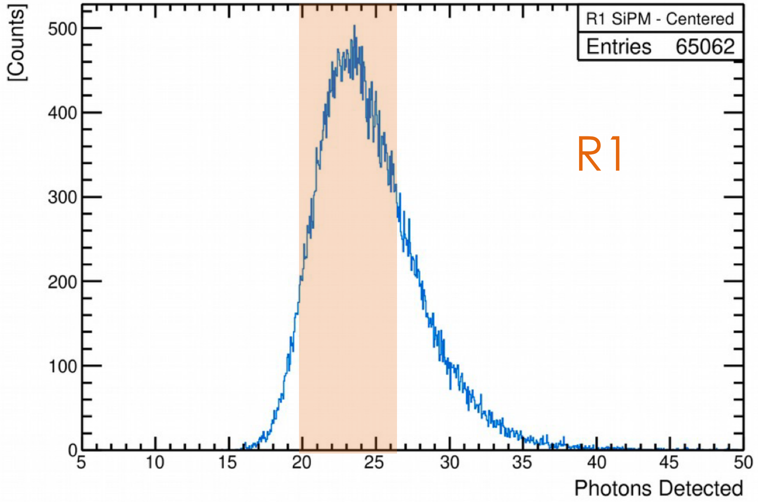
F. Barbato

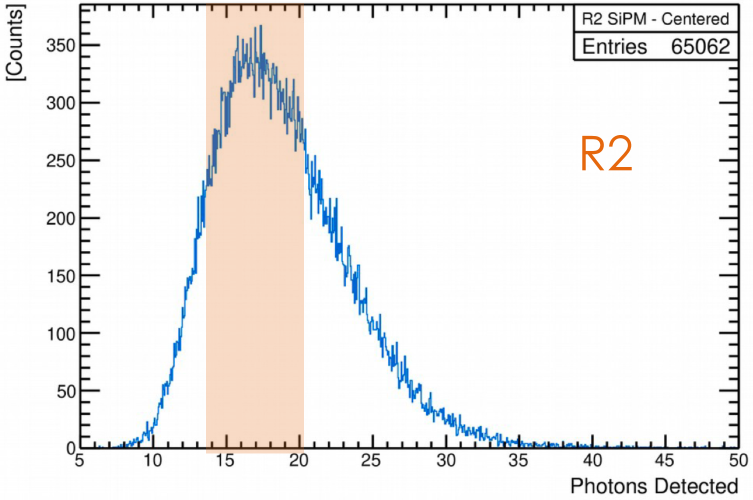
Wide bar - ^{90}Sr

Hamamatsu wide bar	6 x 50 x 1 cm^3	2 SiPM/side
Gain	5.5×10^5	
Trigger Logic	R ∧ L	









Simulations roadmap

Simulating ^{90}Sr source decay in small bars

↳ Evaluating boundary conditions

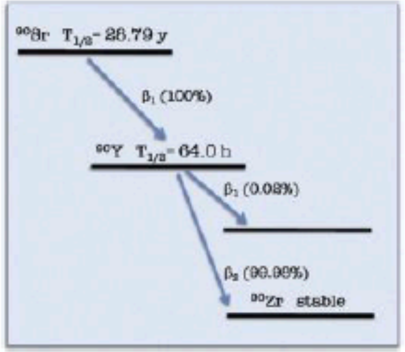
↳ Simulating ^{90}Sr source decay in the wide bar

↳ Simulating light distribution at the optical interface

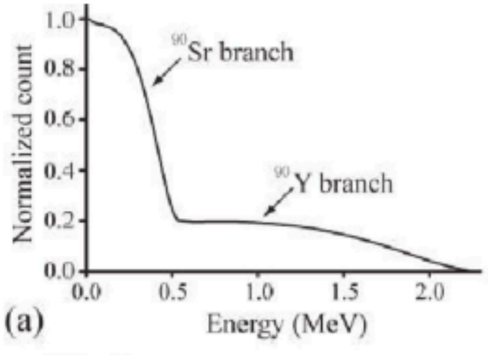
Simulations setup

Simulation details:

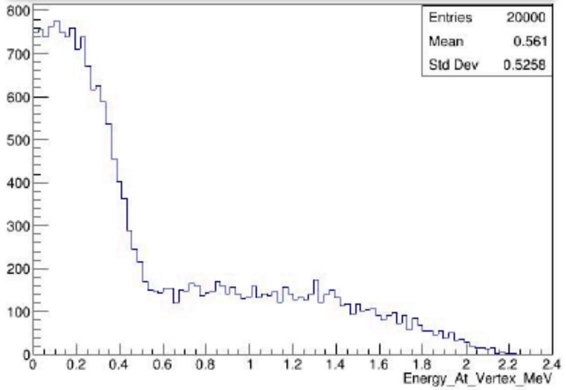
- ^{90}Sr radioactive source 138kBq
- 10k decays simulated
- Source at bar centre
- One 3x3 mm^2 SiPM per side
- PDE+crosstalk correction

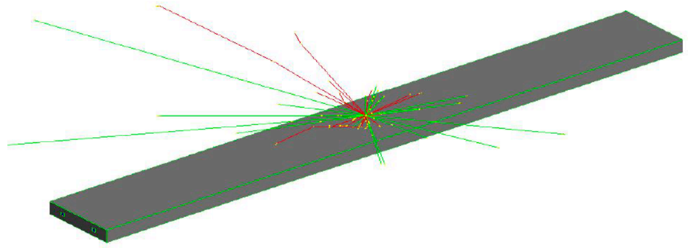


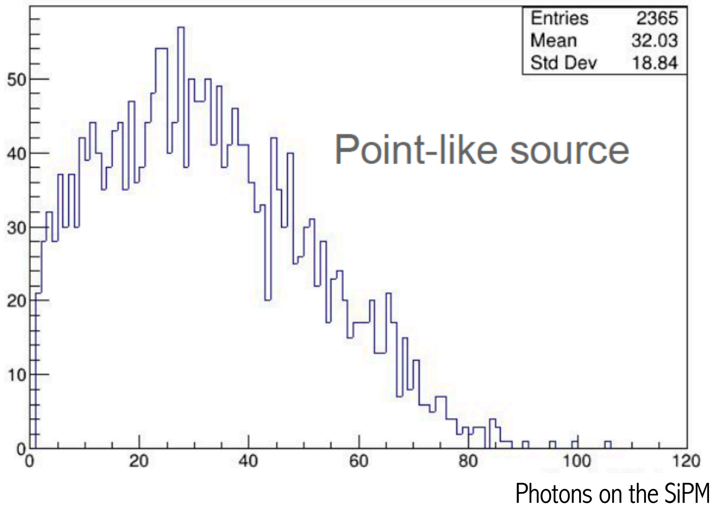
Theoretical spectrum

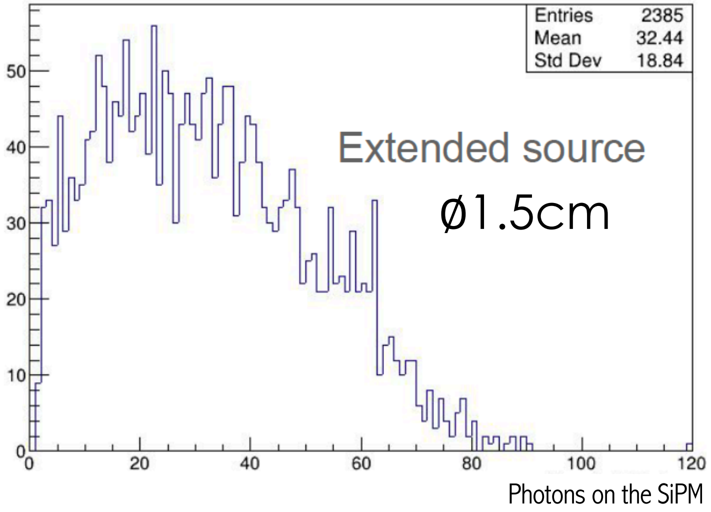


Simulated spectrum





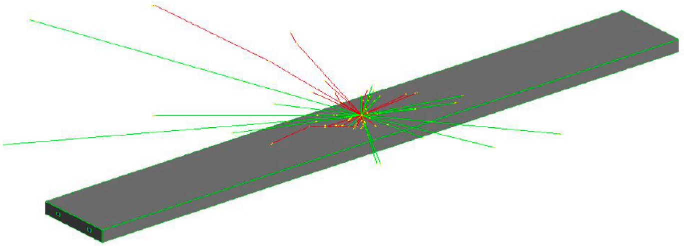


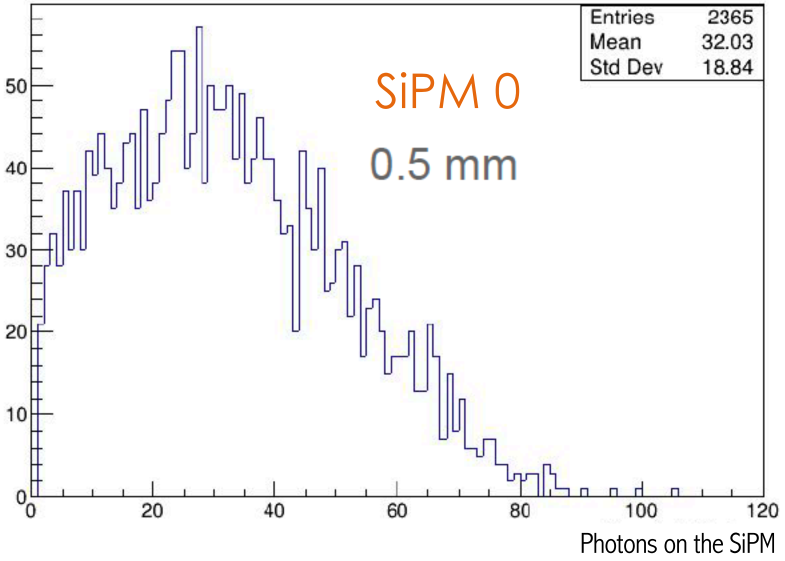


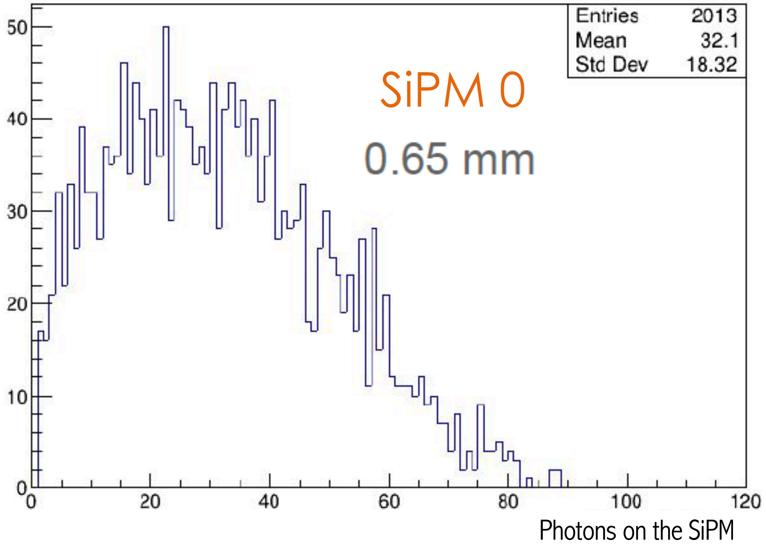
Negligible effects

Evaluation of the wrapping effects

Hamamatsu S13360-3025CS	6 x 50 x 1 cm^3	1 SiPM/side







Wrapping methods

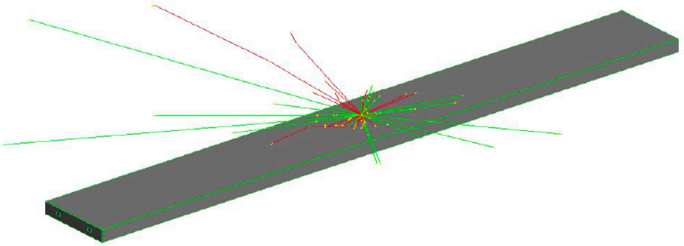
Black tape: 1.3 g/cm^3 (soft PVC), 0.25 mm thick
Teflon tape: 2.2 g/cm^3, 0.5 mm thick

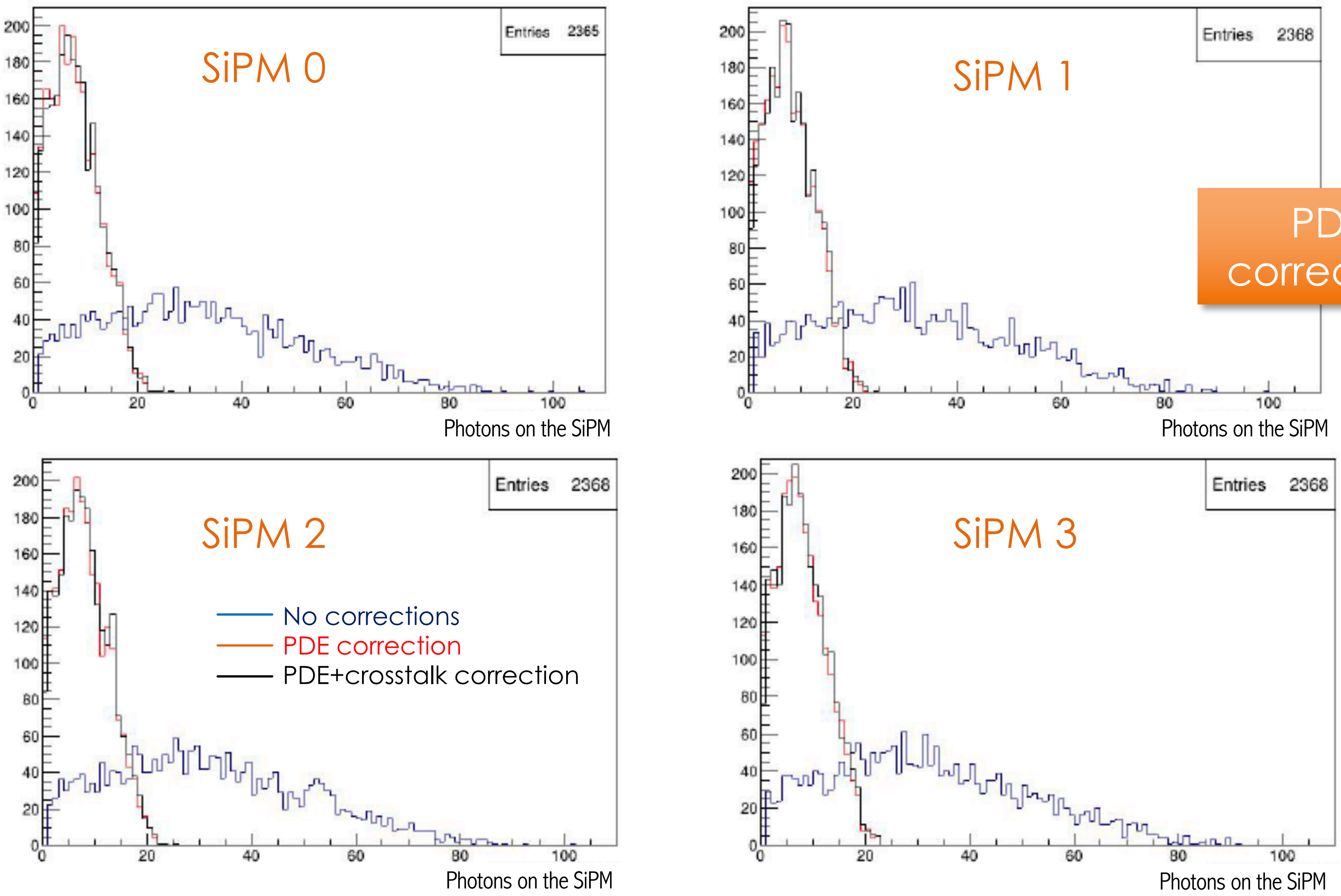
$$\rho_{wr}\Delta\tilde{x}_{wr} = \rho_{wr}\Delta x_{wr} + \rho_{bt}\Delta x_{bt}$$

Teflon equivalent: 0.65 mm thick

Wide bar - ^{90}Sr source at the centre

Hamamatsu S13360-3025CS | 6 x 50 x 1 cm^3 | 2 SiPM/side





PDE correction

Photons on the SiPM

~32 without corrections

~8 PDE correction

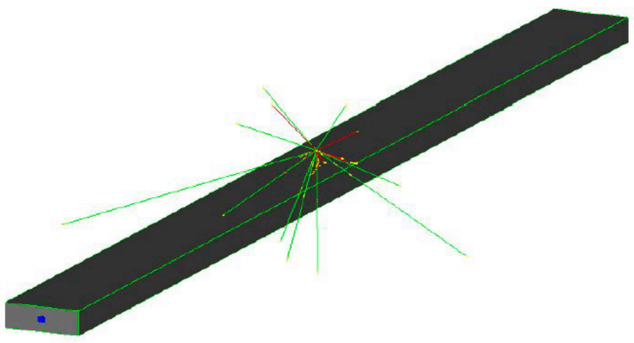
~8 PDE+Crosstalk correction

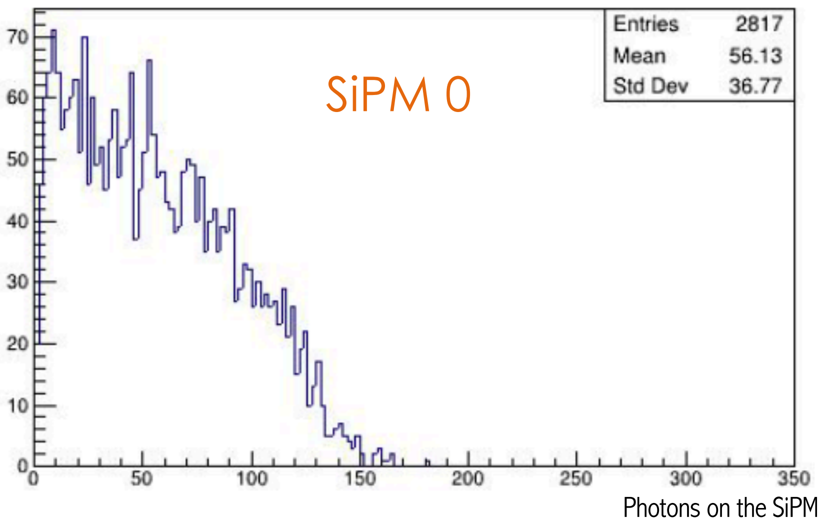
PDE ~ 25%

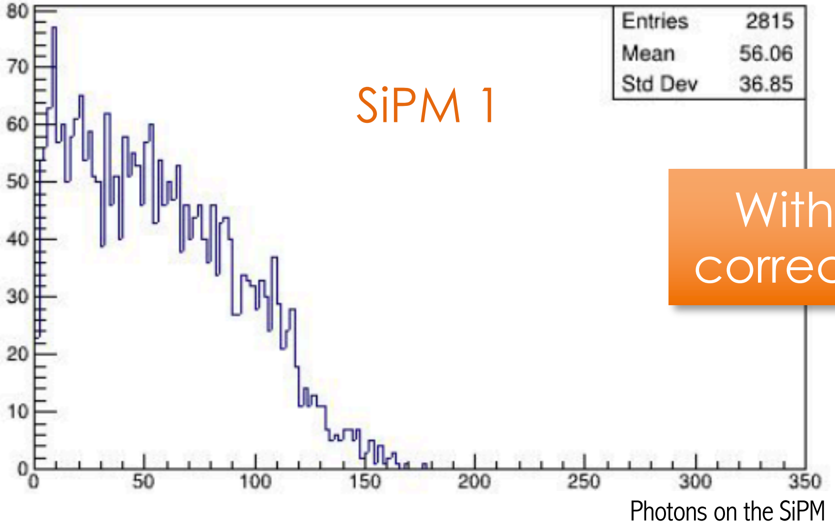
$P_{crosstalk}$ ~1%

Small bar - ^{90}Sr source at the centre

Advansid ASD-NUV3S | 3 x 50 x 1 cm^3 | 1 SiPM/side



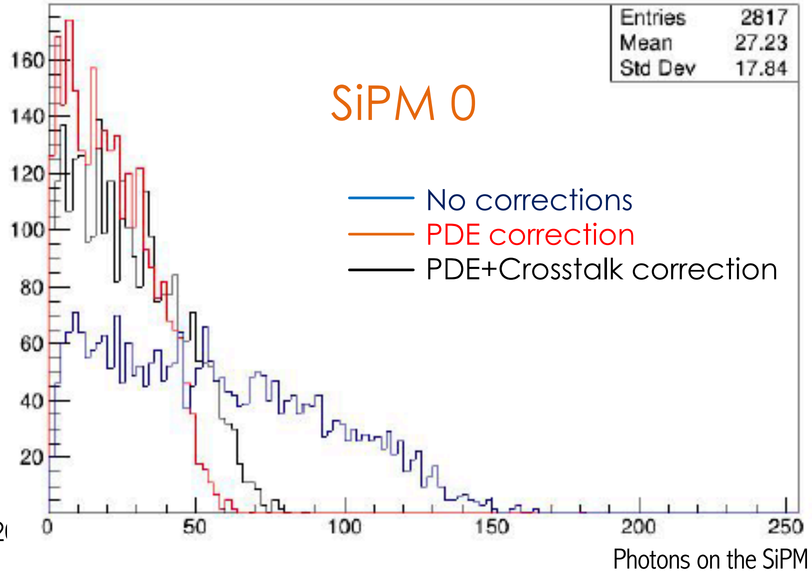


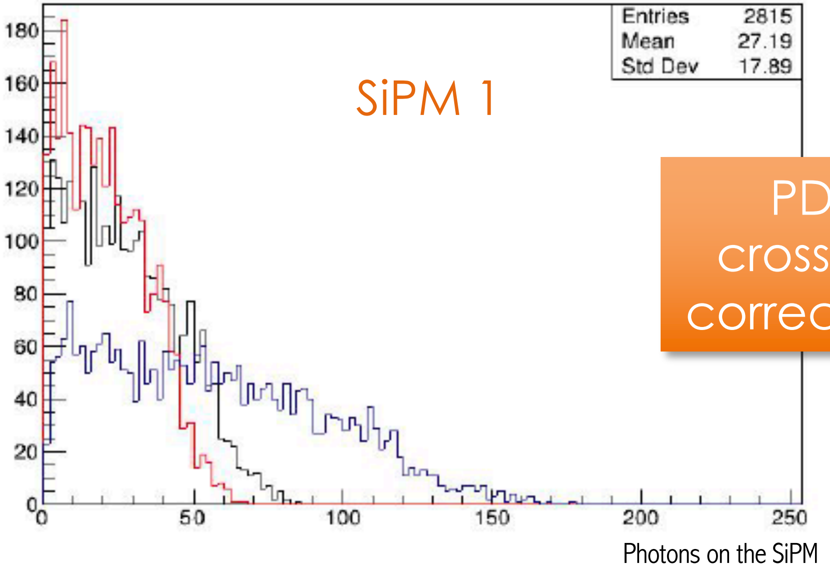


Without corrections

Photons on the SiPM
~50 without corrections
~21 PDE correction
~27 PDE+Crosstalk correction

PDE ~ 38%
$P_{crosstalk}$ ~21.65%

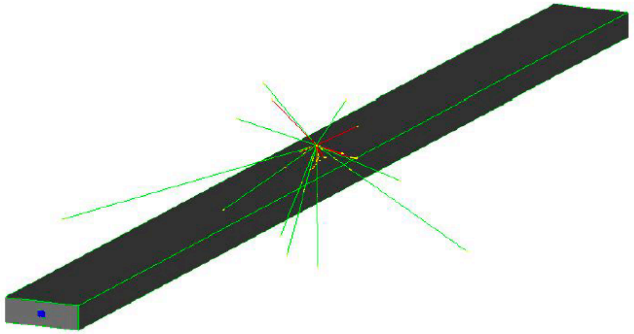


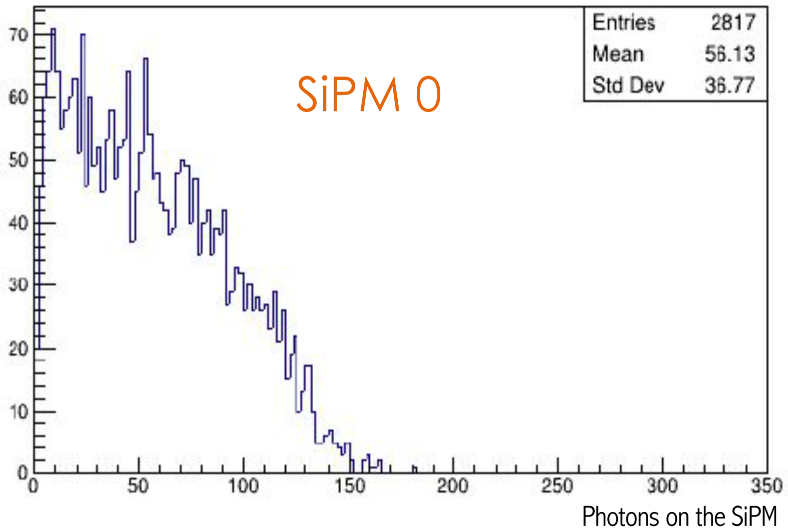


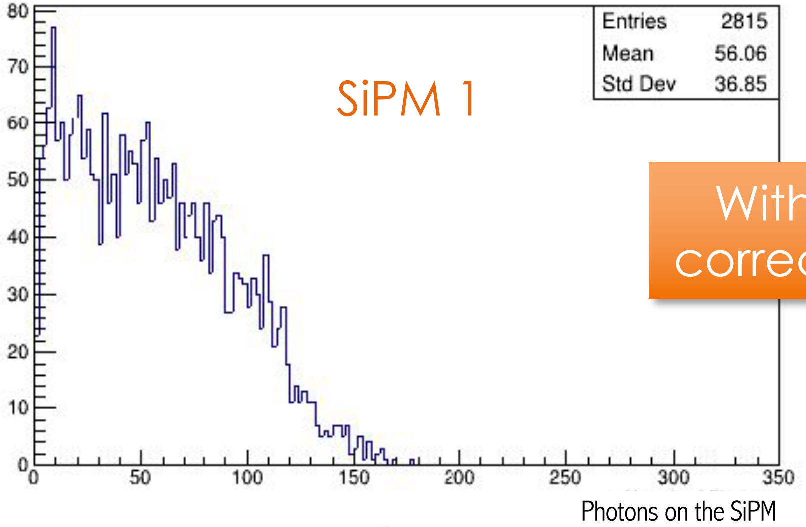
PDE crosstalk corrections

Small bar - ^{90}Sr source at the centre

Hamamatsu S13360-3025CS | 3 x 50 x 1 cm^3 | 1 SiPM/side







Without corrections

Photons on the SiPM

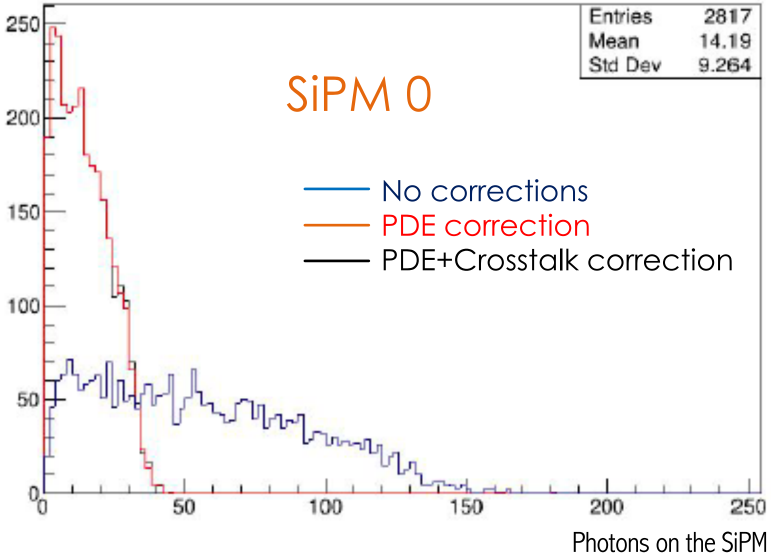
~56 without corrections

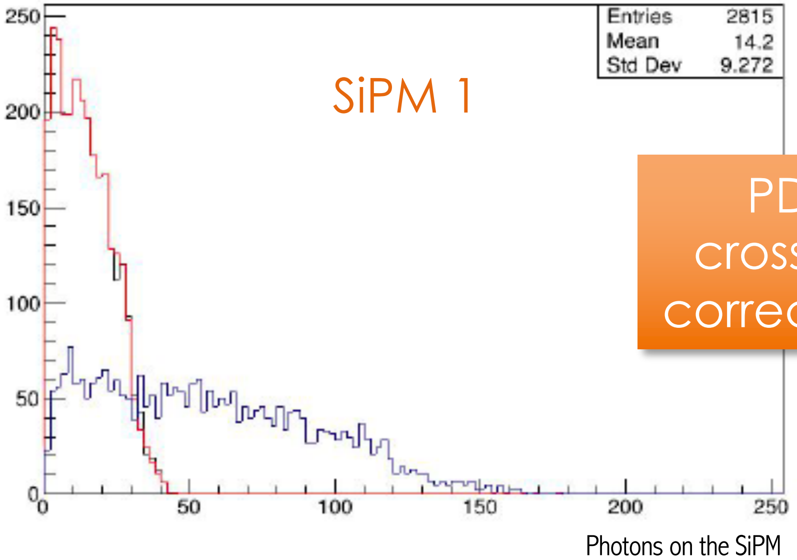
~14 PDE correction

~14 PDE+Crosstalk correction

PDE ~ 25%

$P_{crosstalk}$ ~1%

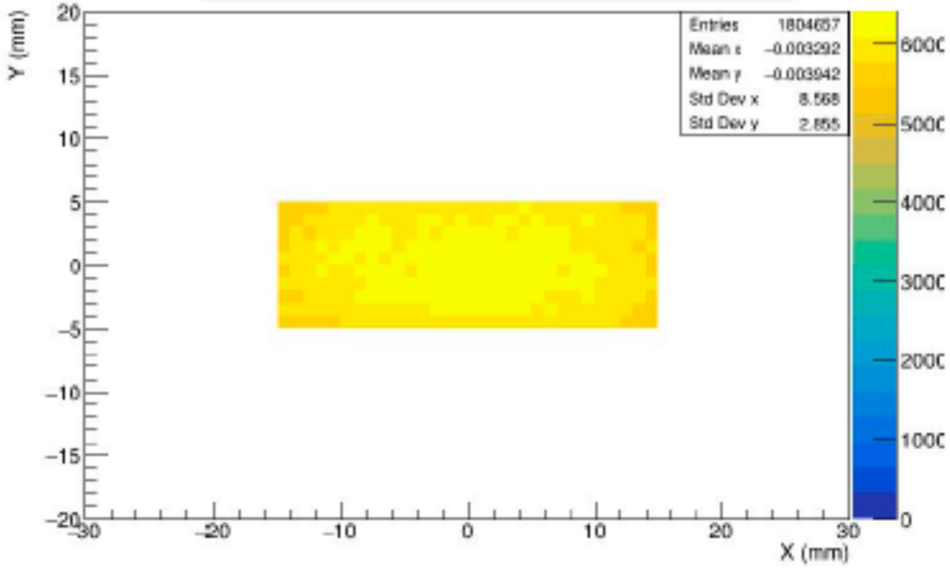




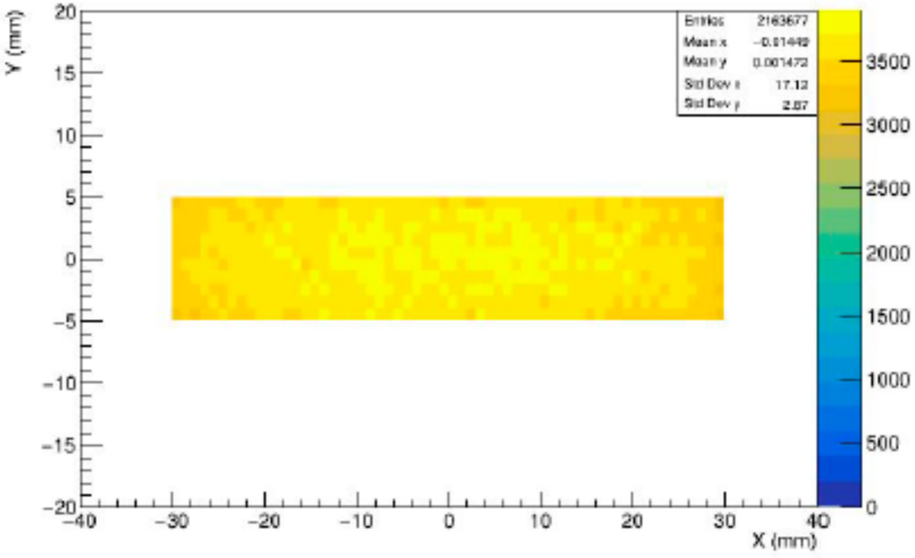
PDE crosstalk corrections

Bar optical interface

Small bar

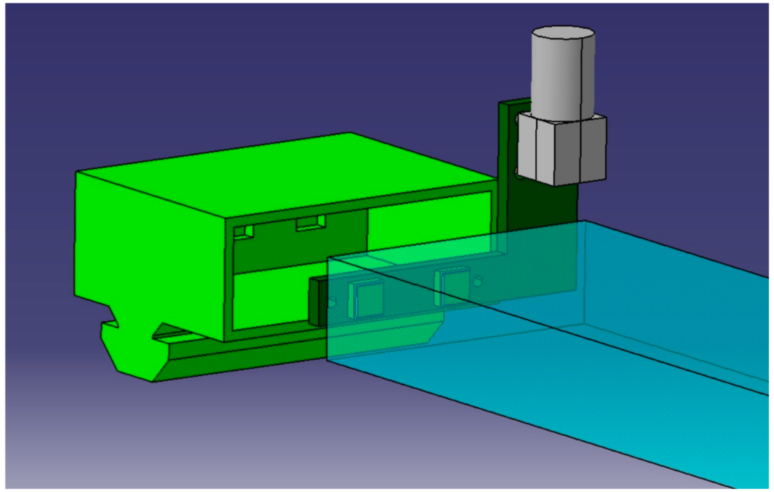


Wide bar



Photons generated by ^{90}Sr source positioned at the centre of each bar
The small bar shows a higher number of photons at the interface and more uniform distribution

Hints on wrapping methods



Comparison of different wrapping materials [1]

Wrapping material	PE per 10 mm	%
VM2000	412	100
Tyvec (loose)	241	58
Teflon tape	196	48
Tyvec (tight)	196	48
Aluminum foil	181	44
Bare scintillator	168	41
Black paper	140	34

Shown is the yield of photoelectrons observed in a bar of dimensions 700 mm × 20 mm × 6.4 mm. The yield has been scaled to a thickness of 10 mm.

BC-600 optical cement is a clear epoxy resin which sets at room temperature and has a refractive index close to that of our premium plastic scintillators. It is therefore ideal for optically cementing these scintillators to light pipes or optical windows. It is not recommended for coupling scintillators to photomultiplier tubes. For that application we recommend BC-630.

BC-630 Silicone Optical Grease is a clear, colorless, silicone, optical coupling compound which features excellent light transmission and low evaporation and bleed at 25°C. It has a specific gravity of 1.06 and an Index of Refraction of 1.465.

We supply this single-component formulation in 60 ml jars or in 500 ml quantities.

BC-634A Optical Interface is an optical interface material which gives you a consistent, reproducible, optical coupling between scintillators and PMTs. It is formulated for use within the temperature range of -10°C to +60°C.

We supply BC-634 as ready-to-use, flexible disks in specified diameters and in thicknesses of 3 and 6 mm. The standard formulation is just hard enough to keep you from tearing the interface while handling it.

BC-637 Optical Coupling is a silicone-adhesive, coupling compound formulated specifically for making optically clear bonds between scintillators and photomultiplier tubes (or between non-scintillating light pipes and photomultiplier tubes). We designed it to provide a reliable interface between these components in high temperature applications.

It comes as precast pads and is formulated for temperatures up to 200°C.

BC-638 Black Wrapping Tape is black adhesive tape 50.8 mm wide by .2 mm thick. Wrapping a plastic scintillator in one layer will give you a light-tight seal. We provide BC-638 in 32.9 m rolls.

BC-640 Plastic Masking Paper is an adhesive-backed, masking paper routinely used for protecting the surfaces of plastic scintillator during handling or storage.

We supply BC-640 in rolls 30.4 cm wide x 182.9 m long.

BC-642 PTFE Reflector Tape is a 0.08 mm thick (nominal) Teflon® tape, frequently used as a reflecting material for non-hygroscopic scintillators. Three layers give optimum reflectivity.

It comes in rolls 50.8 mm wide x 13.7 m long.

BC-620 Reflector Paint for Plastic Scintillators is a highly efficient reflector employing a special grade of titanium dioxide in a water soluble binder. It is applied directly onto plastic scintillators, acrylic light guides, glass and metals. It is not intended for direct contact with liquid scintillators (for this application, use BC-622A). It is a diffuse reflector and, therefore, should not be applied to sheets of scintillator or light guide material where the length is much longer than the thickness.

It is recommended mainly for all scintillators having emission spectra about 400 nm.

BC-620 is normally supplied in 1 liter containers.

BC-622A Reflector Paint for is intended for use with liquid scintillators and is particularly useful in large, steel or aluminum tanks which require application of the paint at the research site. It is a diffuse reflector and, therefore, should not be used on the major surfaces of long, narrow tanks (total internal reflection should be employed in these).

BC-622A is ideal for use with the benzene based BC-537 liquid scintillators.

BC-622A reflector normally comes in 500 ml and 1 liter quantities. The paint resin and hardener are supplied in separate containers.

Material	Description/Application	Commercial Equivalents	
		NE	S-G
EJ-500	Optical cement	NE-580	BC-600
EJ-510	White reflector paint for plastics	NE-560	BC-620
EJ-520	White reflector paint for liquids	NE-561	BC-622A
EJ-550	Optical grade silicone grease	–	BC-630
EJ-552	General purpose silicone grease	–	–
EJ-554	Black vinyl tape	–	BC-638
EJ-556	Protective adhesive paper masking	–	BC-640
EJ-558	Protective adhesive transparent plastic masking	–	–
EJ-560	Silicone rubber optical interface	–	BC-634A

[2-3] **Reflector + heat shrink tube**

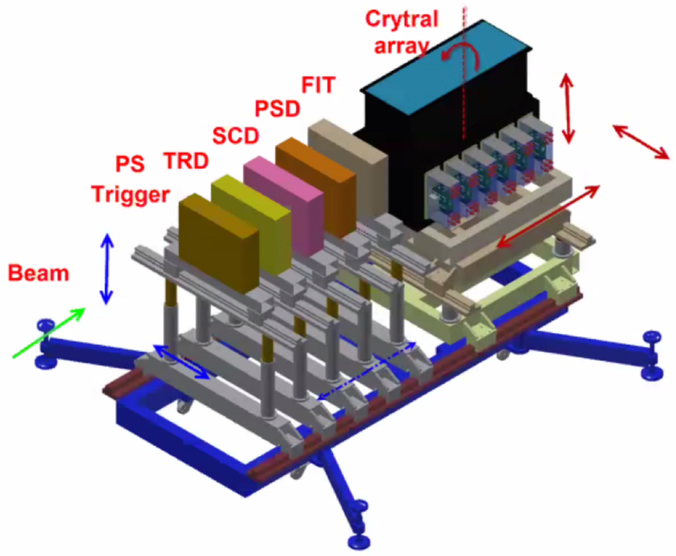
[1] Studies on wrapping materials and light collection geometries in plastic scintillators 10.1016/j.nima.2006.05.153
[2] Development of large area scintillators for the cosmic hodoscope for characterization of RPCs - Proceedings of the DAE Symp. on Nucl. Phys. 56 (2011)
[3] The design and flight performance of the PoGOLite Pathfinder balloon-borne hard X-ray polarimeter https://doi.org/10.1007/s10686-015-9474-x

PSD prototypes for 2021 beam test

2 PSD concept prototypes

- Small Bars
- Tiles

Mechanics will be designed in order to QUICKLY interchange them on the common platform



Beam test conditions

PARTICLES:

- Primary protons, 400 GeV/c
- Electrons, 20-200 GeV/c
- Muons, ~100 GeV/c

BEAM PROPERTIES:

- Intensity ~2000 particles/spill
- Spot 1x1 cm^2
- Trigger rate 200 Hz

To do tests

- Measuring backsplash effects from proton interaction in the calorimeter at different energies, up to the maximum energy possible, positions and angles.
- Position scan along the surface to study the light collection uniformity (STEPS ~2 cm)
- Overall efficiency of scintillators + SiPMs
- SiPMs bias voltage scan (optimize S/N)
- Joint regions scan (evaluate VETO inefficiency)
- Test of the readout electronics and trigger combined with other subdetectors

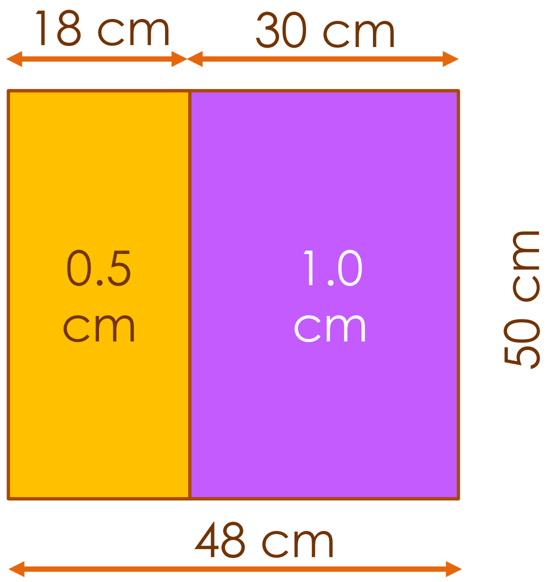
PSD bar prototype for 2021 beam test

Bar Size: 3x50x1 cm^3 / 3x50x0.5 cm^3

BAR REPORT		
SCINT. CODE	SAMPLES	SIZE
EJ - 200	5	3x50x1
BC-404	7	3x50x1
BC-404	7	3x50x0.5
EJ-204	15	3x50x1

Same scintillation properties

Evaluating bar performances with 0.5 cm and 1.0 cm thickness



Each bar will mount 4 SiPMs 2 each side

2 Layers
x-y measurements

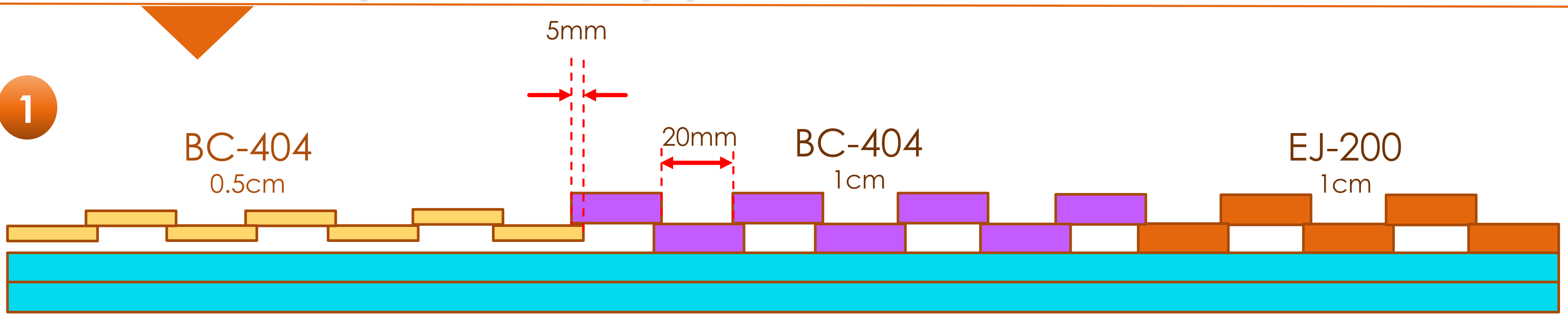
1) Staggered rectangular bars

2) Staggered trapezoidal bars

Evaluating hermeticity

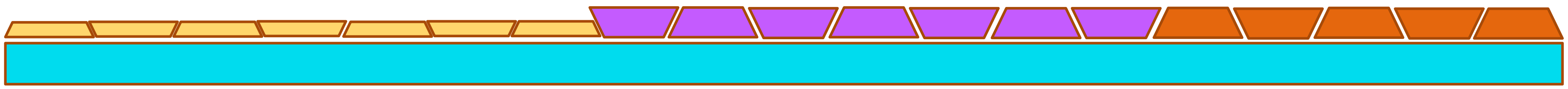
PSD bar prototype for 2021 beam test

1



- High hermeticity
- High thickness

2



- Compactness
- Hermeticity to be evaluated

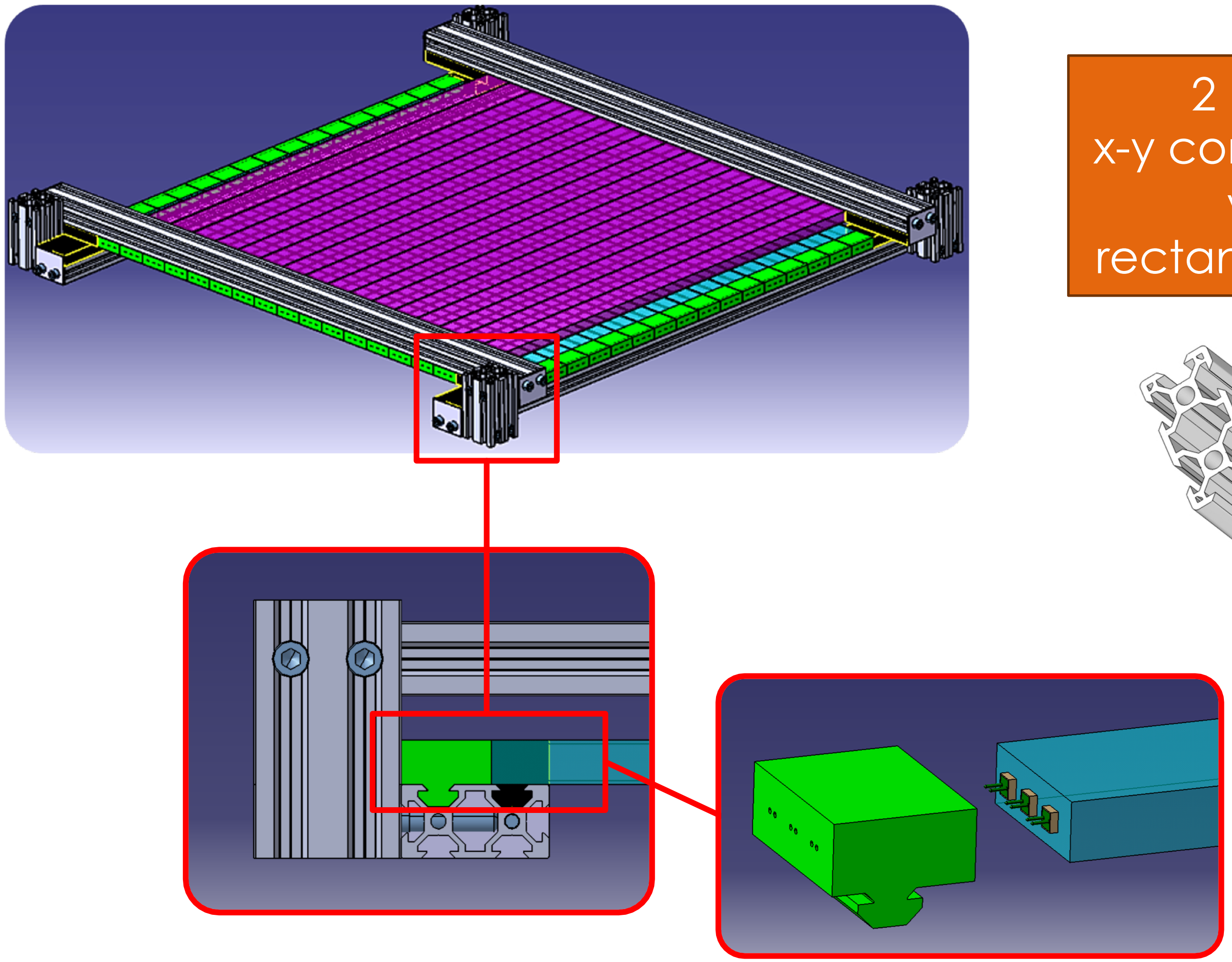
2 Layers
x-y measurements

1) Staggered rectangular bars

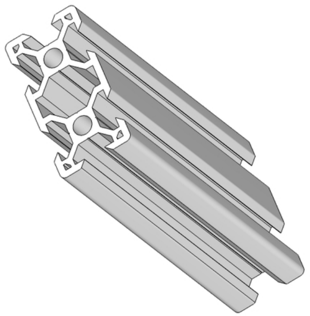
2) Staggered trapezoidal bars

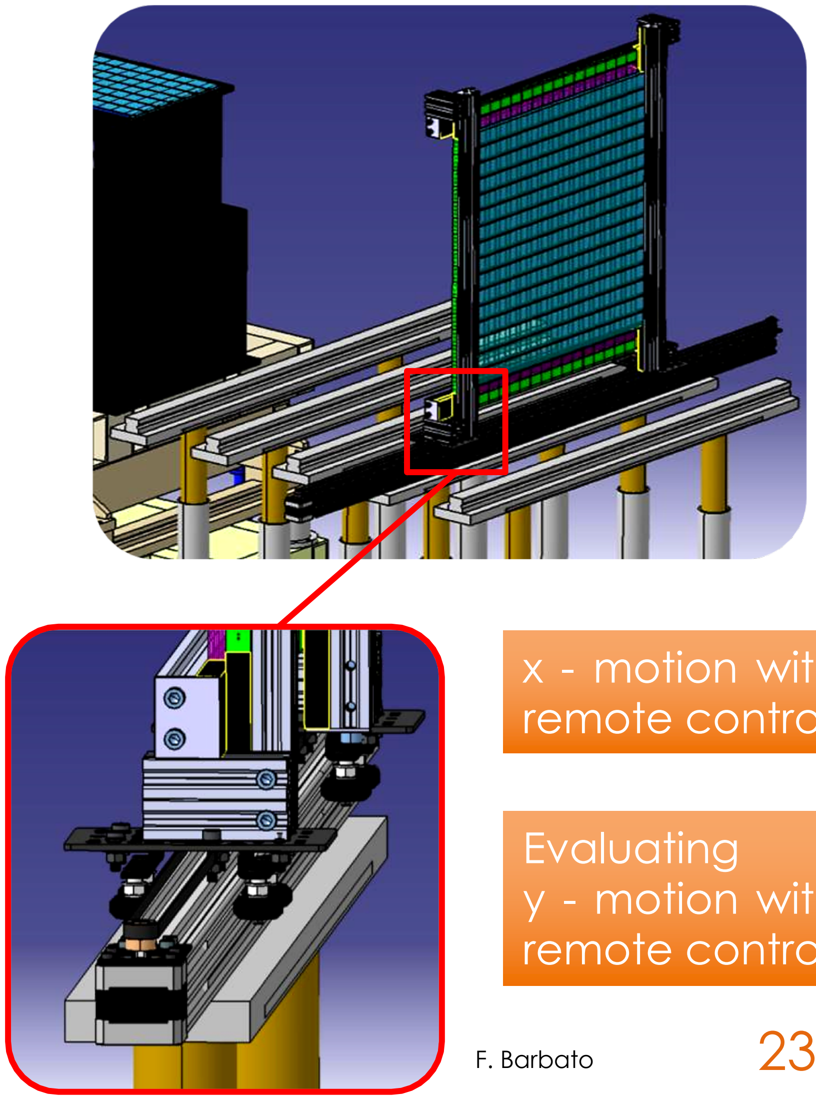
Preliminary mechanical design for 2021 beam test

Agreement between GSSI and UniNA



2 Layers
x-y configuration
with
rectangular bars





x - motion with remote control

Evaluating y - motion with remote control

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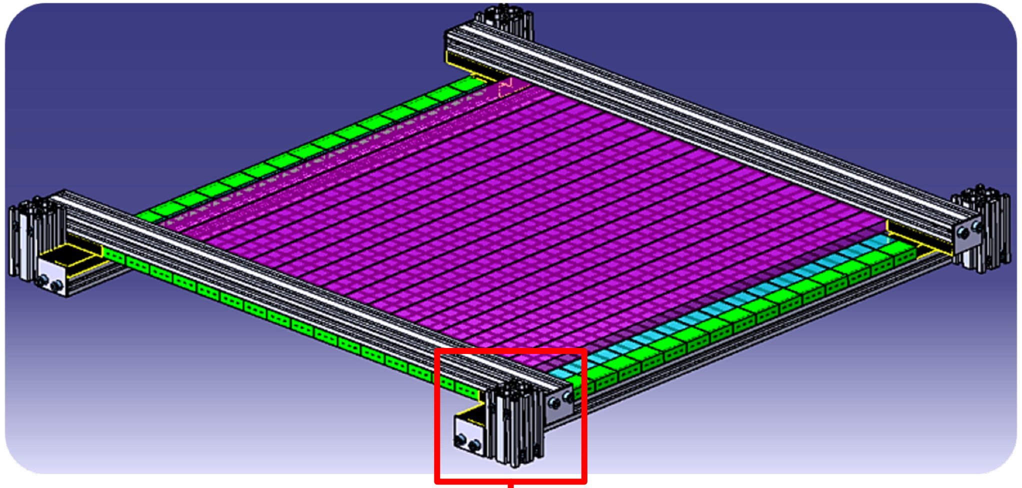
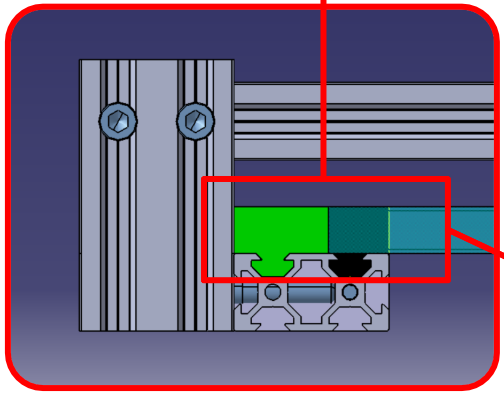
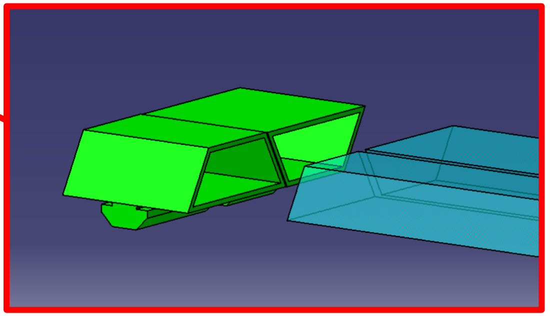
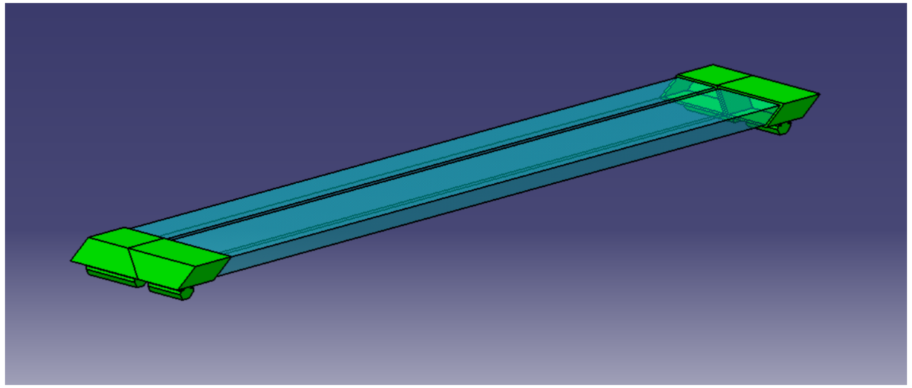
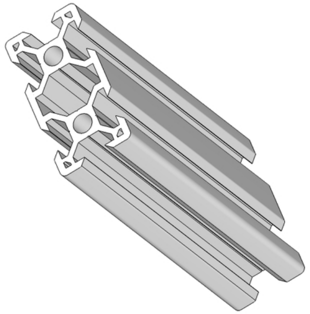




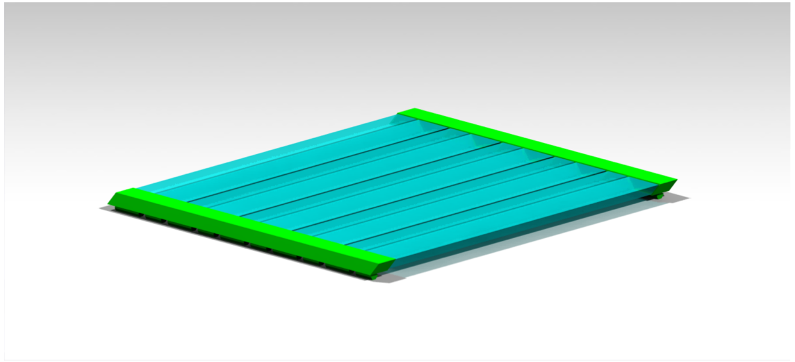


2 Layers
x-y configuration
with
trapezoidal bars



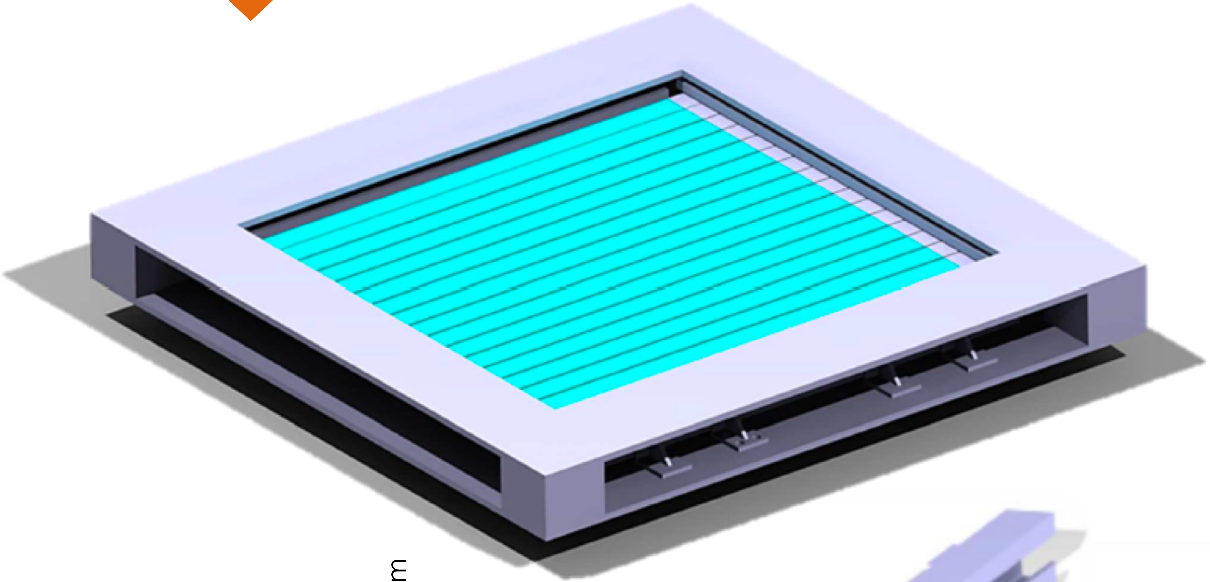


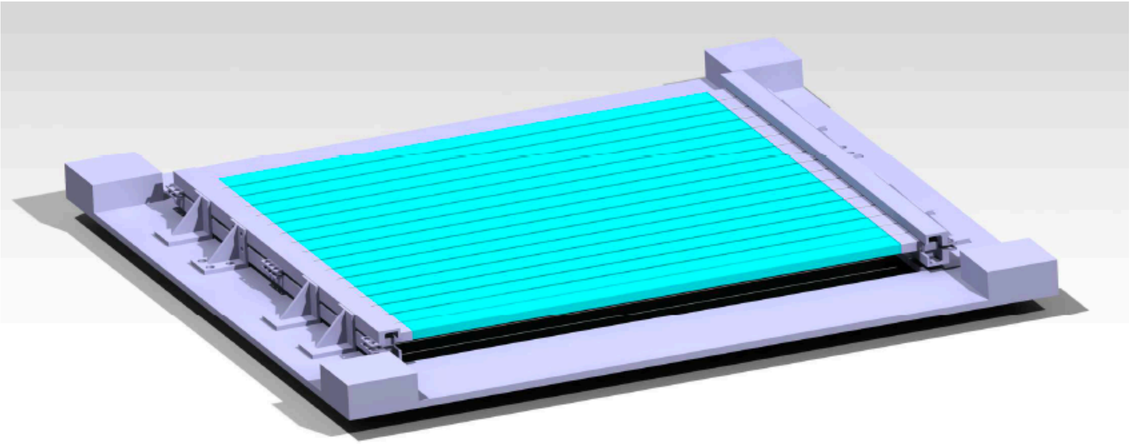
60° angle guarantees 5mm of overlap among bars

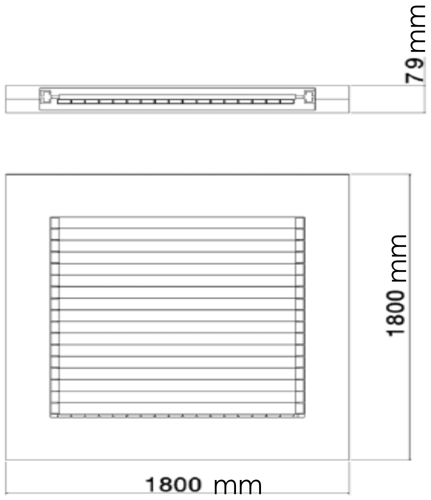


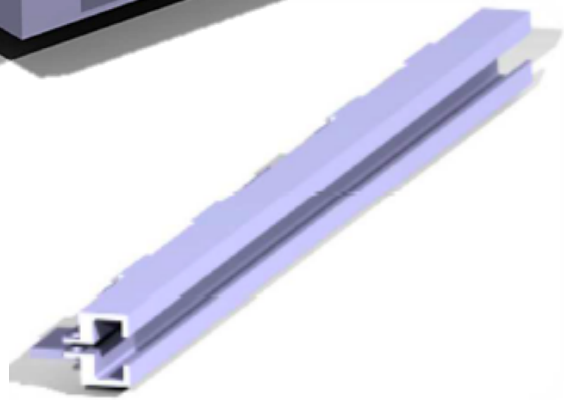
Preliminary mechanical design for full scale prototype

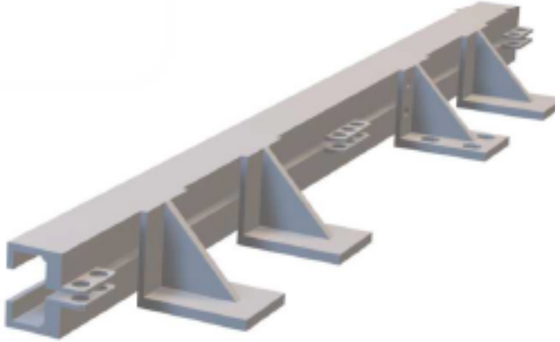
Agreement between GSSI and UniNA

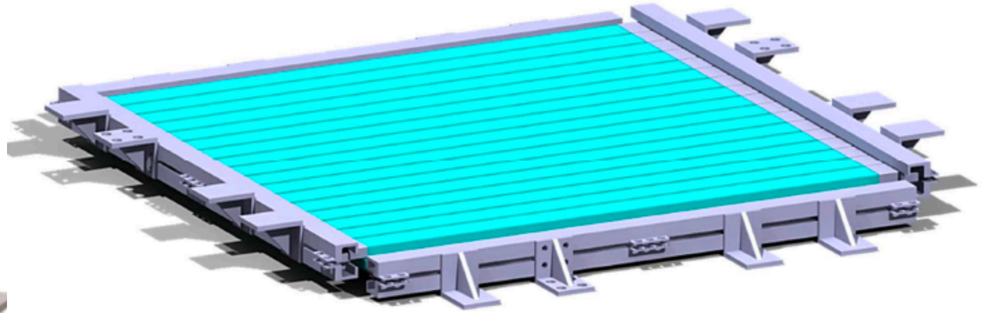












Preliminary mechanical design for full scale prototype

Agreement between GSSI and UniNA

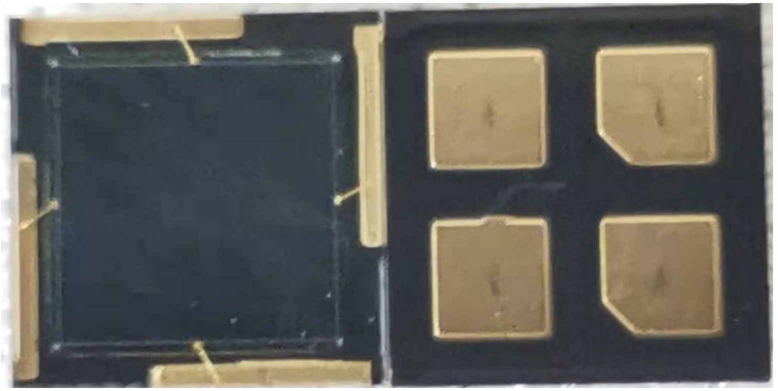
FRAME

- 1600x30x10 mm bars are encapsulated in a heat-shrinkable material sheath, which optically insulates them and protects them from stresses

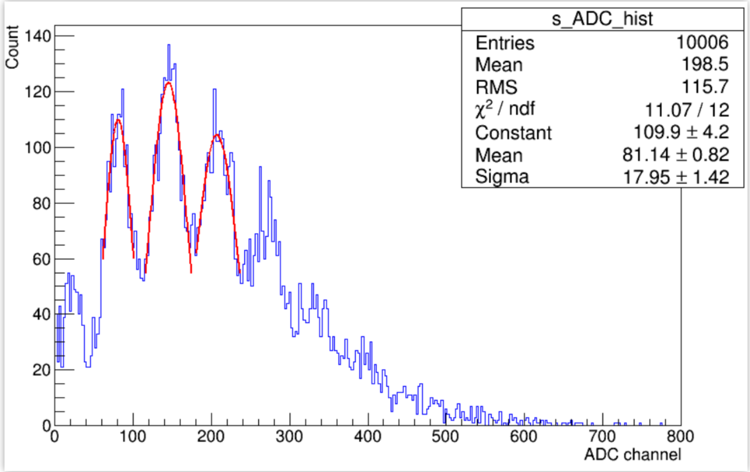
- A cover has been developed to secure it in the support structure shown later
- Three cut-out have been planned for the storage of the SiPMs, and to ensure their correct mounting, with holes for the power and read-out cables connection

SiPM study at IHEP

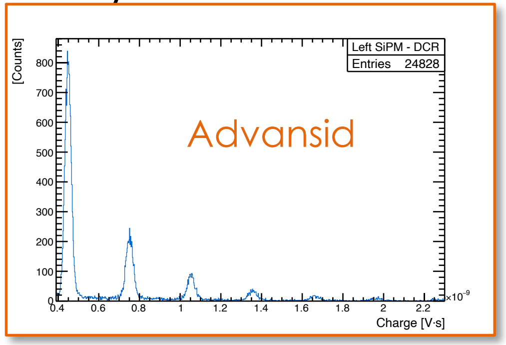
Dynamic range of SiPM is determined by it’s cell density.
SiPM with 6 μm cell size is developed by NDL(Novel Device Laboratory, China)

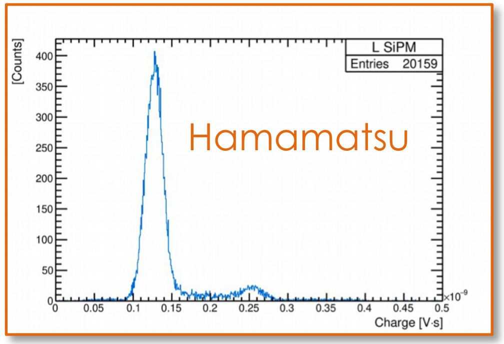


3×3 mm^2 NDL 6um SiPM



Height spectrum SiPM





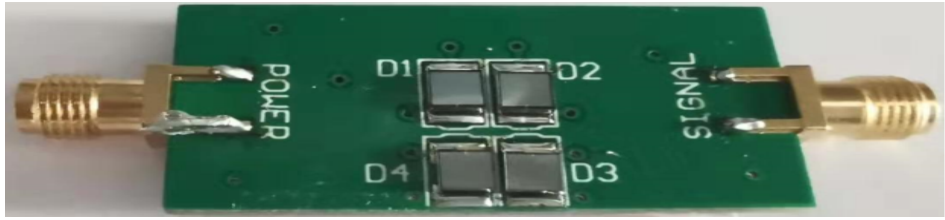
Plan in 2021

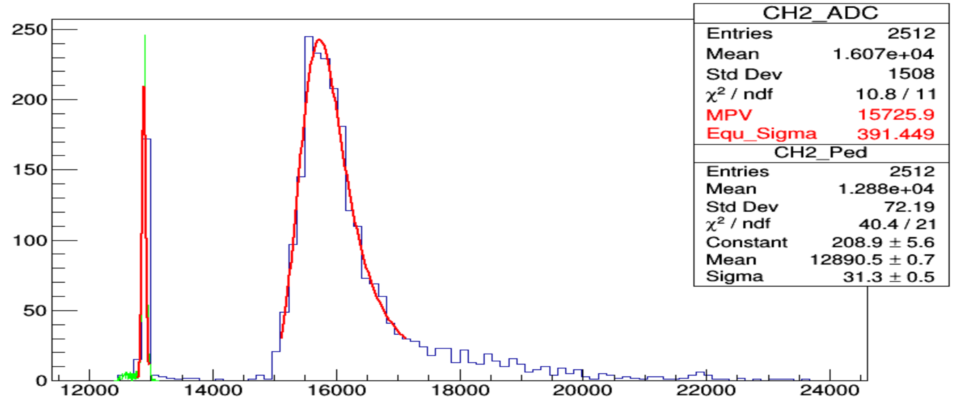
1. Performance study including dynamic range of the new NDL SiPM
2. Optimization of SiPM electronics including noise and dark current control
3. Study of radiation effect of SiPMs.

IHEP bar prototype for 2021 test beam

One PS bar (120×3×1 cm3, may be adapted to GSSI prototype if needed) equipped with 4 readout SiPMs channel will be prepared for beam test.

4 NDL SiPMs with 3×3 mm^2 designed as one readout channel.





MIP energy distribution

Readout options:

1, SiPM signal feed into preamplifier and acquired by DT5730.

+30V and ±5V DC power supply are required.

2, Merged into the bar prototype of GSSI to readout, if it is feasible.

Conclusions and perspectives

Lab activities & simulations

- Small bars showed higher uniformity in the response of the SiPMs at the two sides with respect to wide bar, also confirmed by simulations.
- Hamamatsu S13360-3025CS have incredibly low dark noise and PDE at 25%, while Advansid ASD-NUV3S are complementary (higher dark noise, higher PDE 43%).
- New SiPM series with improved performances will be tested. New scintillators from Saint Gobain will be tested.
- Wrapping plays an important role, simulations about it have already been started. We will test different wrapping method from the uniformity and hermeticity point of view.
- Preliminary designs for the full scale PSD have already been started in collaboration with UniNA.

Test beam 2021

- A PSD bar prototype with a detection surface 50x50cm^2 will be setup for the test beam. Small bars will be used. A small sample of small bars with reduced thickness (0.5 cm) will be accommodated in the prototype. Each bar will be readout by 2 SiPMs per side.
- Preliminary designs have been proposed by UniNA engineers collaborating with GSSI, they will be optimized on the basis of the simulations. Horizontal motion is already foresees to scan the different kind of bars. Vertical motion will be evaluated.
- A prototype with trapezoidal bars is under evaluation.