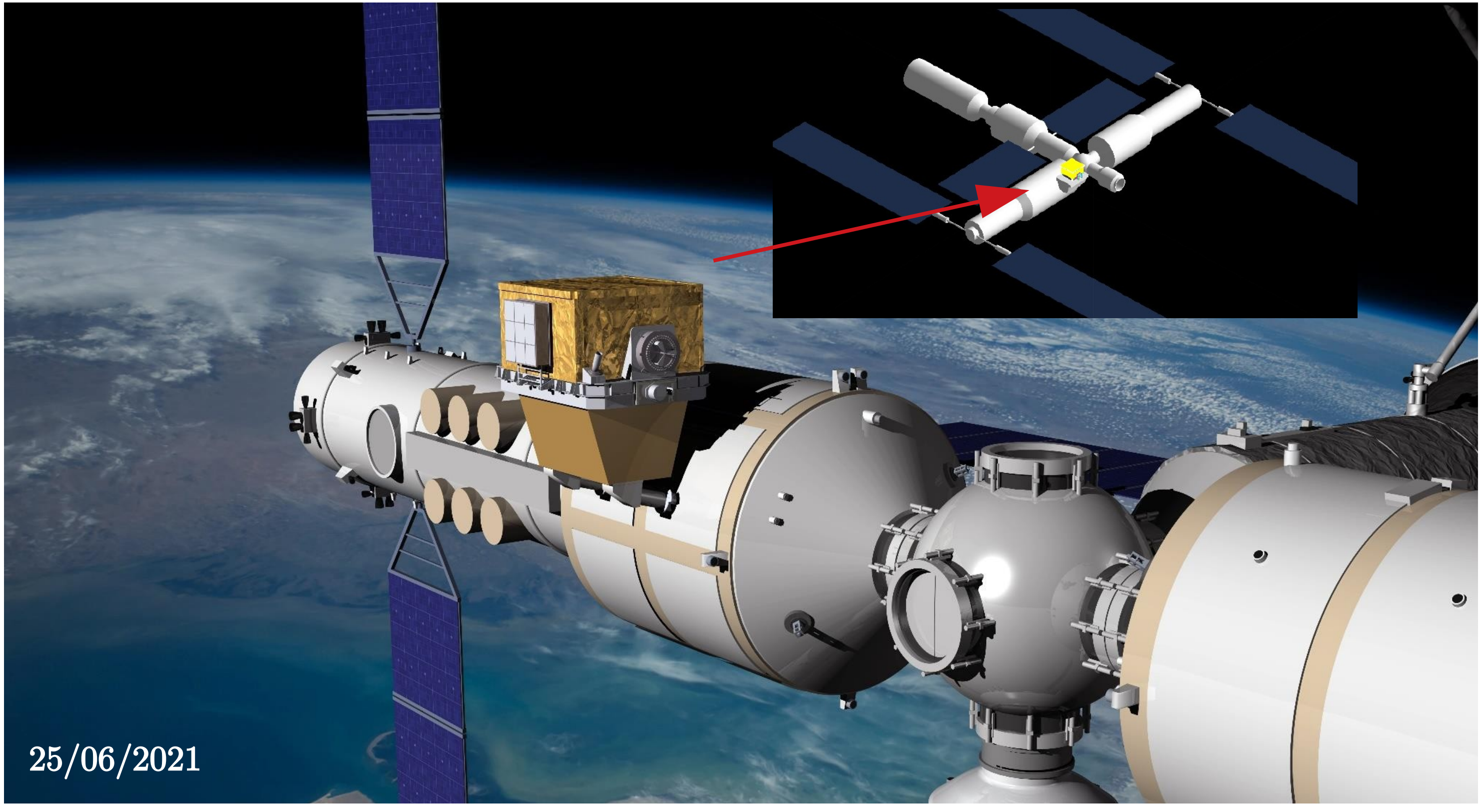
The HERD space mission



Updates on attenuation length studies (Lab & MC)

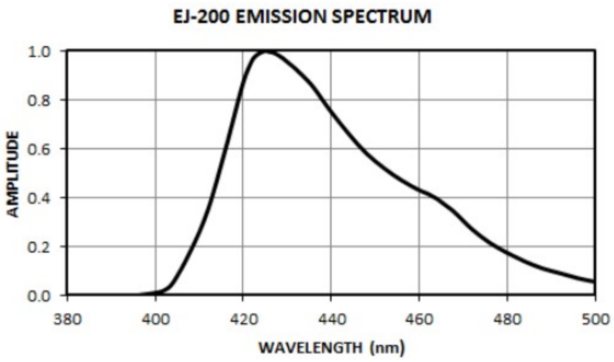
Dimitrios Kyratzis, Felicia Barbato, Francesca Alemanno & Andrea Parenti
for the GSSI Group

Gran Sasso Science Institute (GSSI) & INFN-LNGS

Configuration Characteristics

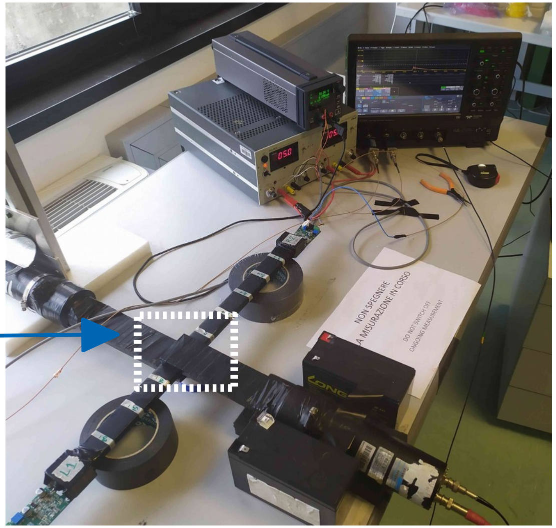
Eljen (EJ-200) [50 x 3 x 1 cm^3] scintillator bar coupled with 2 SiPMs/side [AdvanSiD NUV3S]

PROPERTIES	EJ-200
Light Output (% Anthracene)	64
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
H Atoms per cm³ ($\times 10^{22}$)	5.17
C Atoms per cm³ ($\times 10^{22}$)	4.69
Electrons per cm³ ($\times 10^{23}$)	3.33
Density (g/cm³)	1.023



SiPM model	ASD – NUV3S
Effective area (mm)	3 x 3
Cell count	5520
Cell size (µm)	40
Cell fill factor (%)	60
Response range (nm)	350 – 900
Peak sensitivity (nm)	420
PDE (%)	43
Breakdown voltage (V)	24 – 28
Overvoltage (V)	2 – 6
Dark count rate	50 – 100 (kHz/mm²)
Gain	3.6 x 10^6

Trigger imposed by 2 scint+PMTs in "sandwich" configuration and placed towards the bar center



Both SiPMs function around V_{bias} ~ 29.5 V*
*for this configuration

- Left ~ 29.4 V
- Right ~ 29.52 V

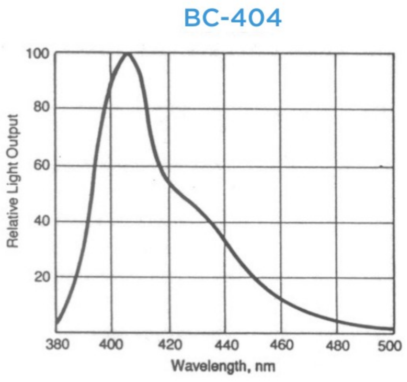
Scintillator Characteristics

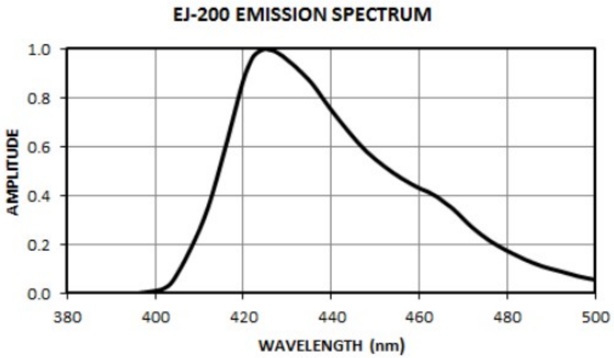
	BC-404
Radiation Detected	
<100keV X-rays	
100keV to 5MeV gamma rays	
>5MeV gamma rays	
Fast neutrons	
Alphas, betas	X
Charged particles,cosmic rays, muons, protons, etc.	
Principal Uses/Applications	fast counting
Scintillation Properties	
Light Output, %Anthracene	68
Rise Time, ns	0.7
Decay Time (ns)	1.8
Pulse Width, FWHM, ns	2.2
Wavelength of Max. Emission, nm	408
Light Attenuation Length, cm*	140
Bulk Light Attenuation Length, cm	160

PROPERTIES	EJ-200
Light Output (% Anthracene)	64
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
H Atoms per cm³ ($\times 10^{22}$)	5.17
C Atoms per cm³ ($\times 10^{22}$)	4.69
Electrons per cm³ ($\times 10^{23}$)	3.33
Density (g/cm³)	1.023

Comparison of characteristics between EJ-200 & BC-404

Such a comparison will be discussed in the following

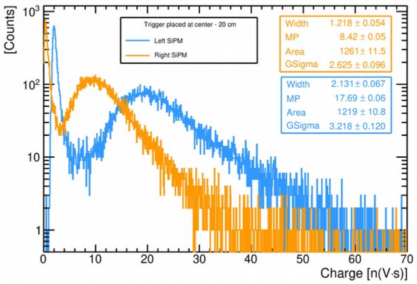


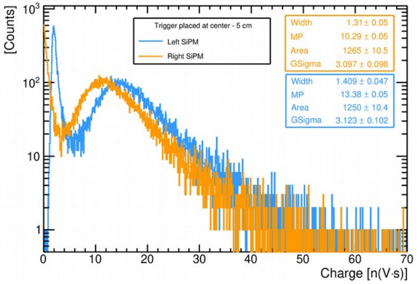


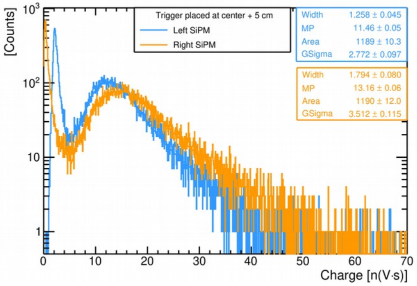
Summary of Muon Spectral Measurements

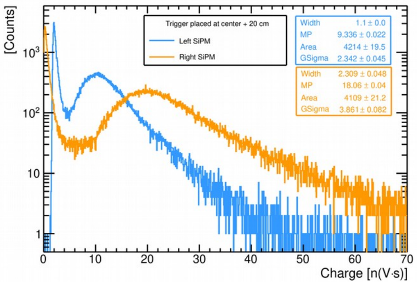
“Sandwich” trigger placed in various positions along the bar

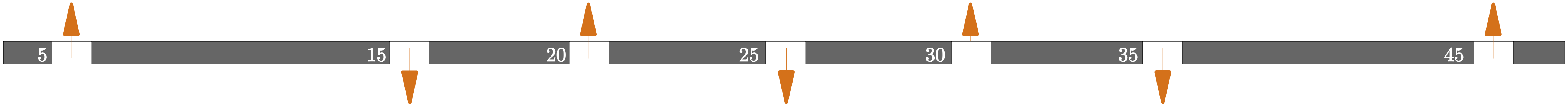
Left & Right SiPMs

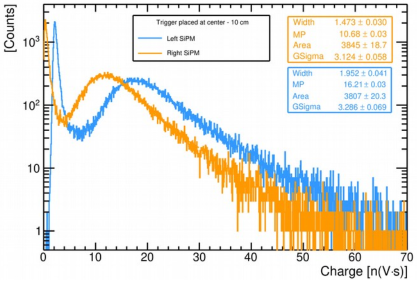


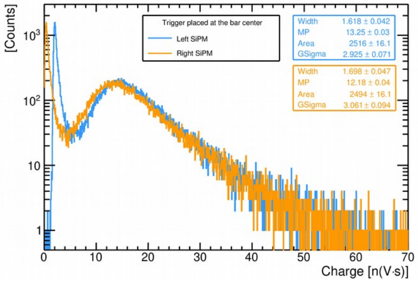


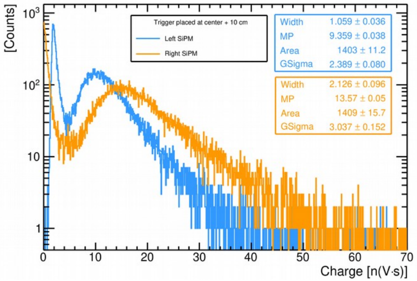












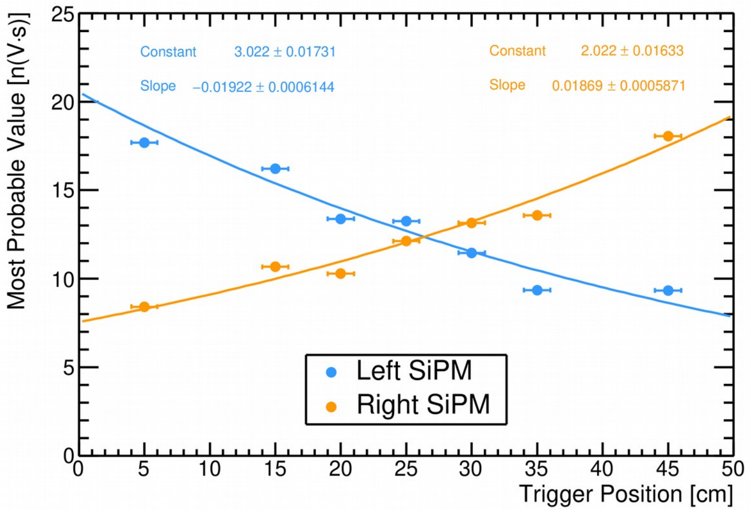
The full 50 cm bar is graphically illustrated with its trigger positions (in cm)

Muon Spectral Measurements

MPV of all SiPMs w/ expo fits

EJ – 200 w/ AdvanSiD SiPMs

a.k.a "Short Bar"

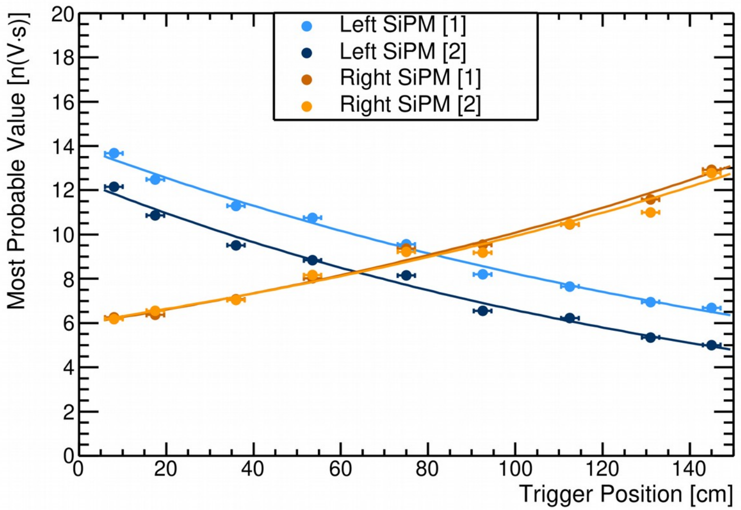


Bar Size: [50 x 3 x 1 cm^3]

Both configurations are instumented with the same model of AdvanSiD SiPMs

BC – 404 w/ AdvanSiD SiPMs

a.k.a "Long Bar"



Bar Size: [150 x 5 x 1 cm^3]

10 % uncertainties in measurements due to:

- Minor instabilities in both SiPM bias voltages (~0.05 V)
- Possible cable disturbances during the data-taking procedure
- Bar wrapping effects & possible scintillator damage

Left side SiPMs show a small discrepancy due to:

Slightly different Gain
Variability in SiPM coupling

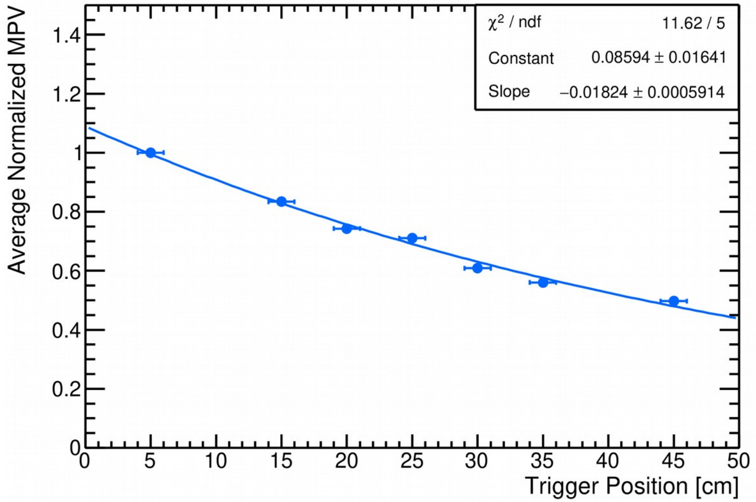
Muon Spectral Measurements

Average Normalized MPV of all SiPMs w/ expo fits

Both configurations are instumented with the same model of AdvanSiD SiPMs

EJ – 200 w/ AdvanSiD SiPMs

a.k.a "Short Bar"

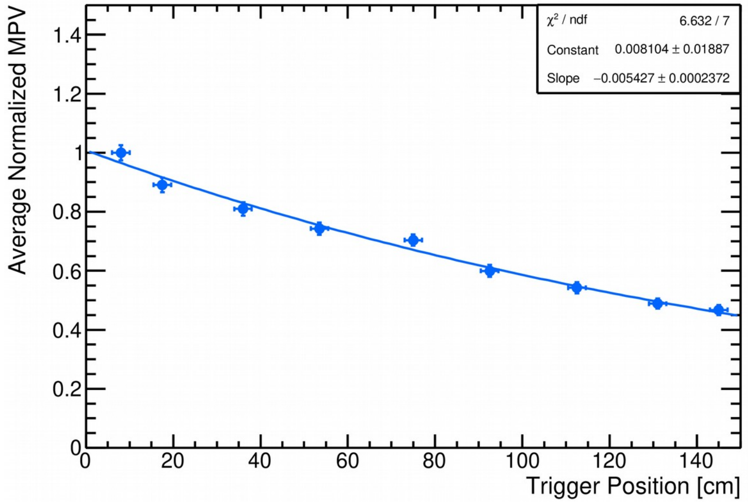


Bar Size: [50 x 3 x 1 cm^3]

Attenuation length:
$\Lambda = 55 \pm 7$ cm

BC – 404 w/ AdvanSiD SiPMs

a.k.a "Long Bar"



Bar Size: [150 x 5 x 1 cm^3]

Attenuation length:
$\Lambda = 184 \pm 13$ cm

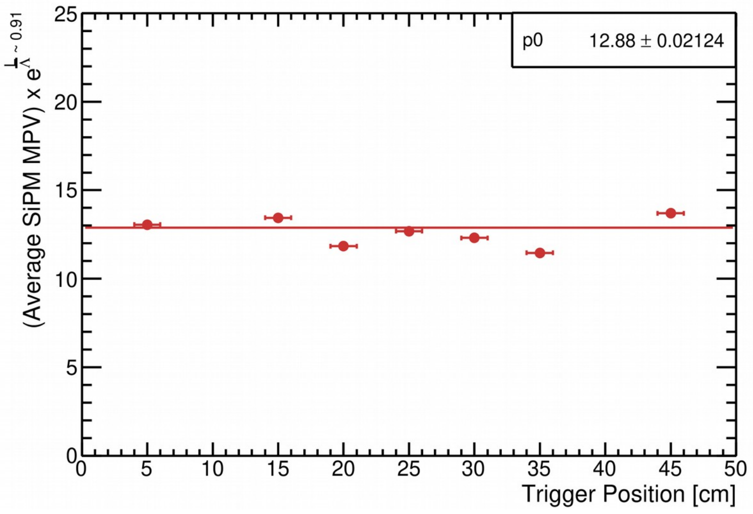
Keep in mind:
Short/Long bar SiPMs work with a ~0.5 V difference in V_{BIAS}
Short: ~29.4, 29.5 V, Long: ~30 V

Muon Spectral Measurements

Average MPV of all SiPMs x ($e^{L/\Lambda}$)

EJ – 200 w/ AdvanSiD SiPMs

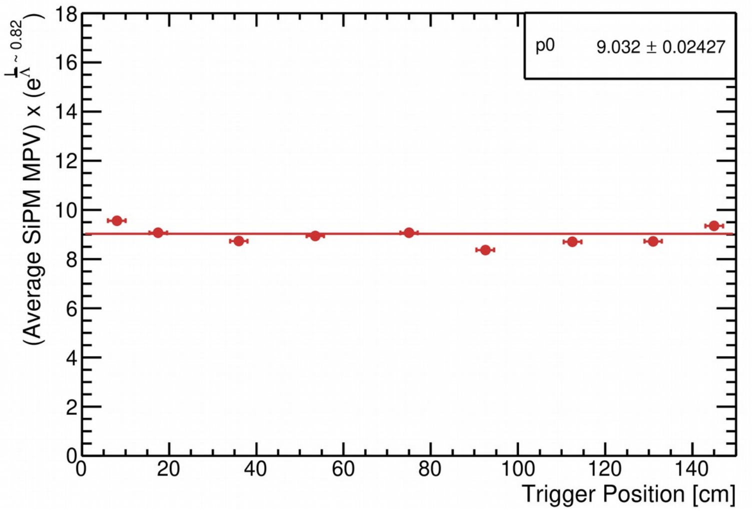
a.k.a "Short Bar"



Bar Size: [50 x 3 x 1 cm^3]

BC – 404 w/ AdvanSiD SiPMs

a.k.a "Long Bar"



Bar Size: [150 x 5 x 1 cm^3]

An exponential behavior from the various acquired trigger points is justifying an expected flat behavior in the Average SiPM MPV

The fit values correspond to the best fit of the average SiPM MPV

Summary [Lab activities]

Construction, calibration and test of 50 cm **EJ – 200 bar w/ AdvanSiD SiPMs**

Muon data acquired in **7 trigger positions**

LanGaus fits on all exported charge distributions

X – plot derived from all MPVs

Measurement of the **light attenuation length**

Comparison with results obtained from 1.5m BC – 404 w/ AdvanSiD SiPMs

All presented results and their conclusions will be compared to the ones obtained from the beam-test prototype bars

Attenuation length studies with simulation

Bulk and Technical attenuation lengths

Bulk attenuation length (BAL):

Pure attenuation length, depends on the **scintillator material** properties.

Describes the attenuation of a photon beam travelling in a straight line in a hypotetical infinite scintillator medium.

Technical attenuation length (TAL):

Depends on the scintillator **material properties**, on the bar **geometry** and on the **optical properties** of the wrapping.

Value obtained from **laboratory measurements**, fitting the normalized MPVs of the SiPM charge distribution for different trigger positions with an exponential.

Manufacturers may report one, the other, or both on the datasheet without quoting any uncertainties.

Aim of the simulation:

- **study TAL dependence on the bar cross section and wrapping reflectivity**
- **study the relationship between BAL and TAL**

TAL estimation from simulation

Simulation setup

Beam:

Monoenergetic muons: 1 GeV

Different positions along the bar: 0, 40, 67, 72.5 cm from the center

500 events for each position

Geometries (rectangular bars, two $3x3mm^2$ SiPMs per side):

- 200 x 3 x 0.5 cm^3
- 200 x 3 x 1 cm^3
- 200 x 5 x 1 cm^3
- 200 x 12 x 0.5 cm^3
- 200 x 12 x 1 cm^3
- 200 x 12 x 2 cm^3

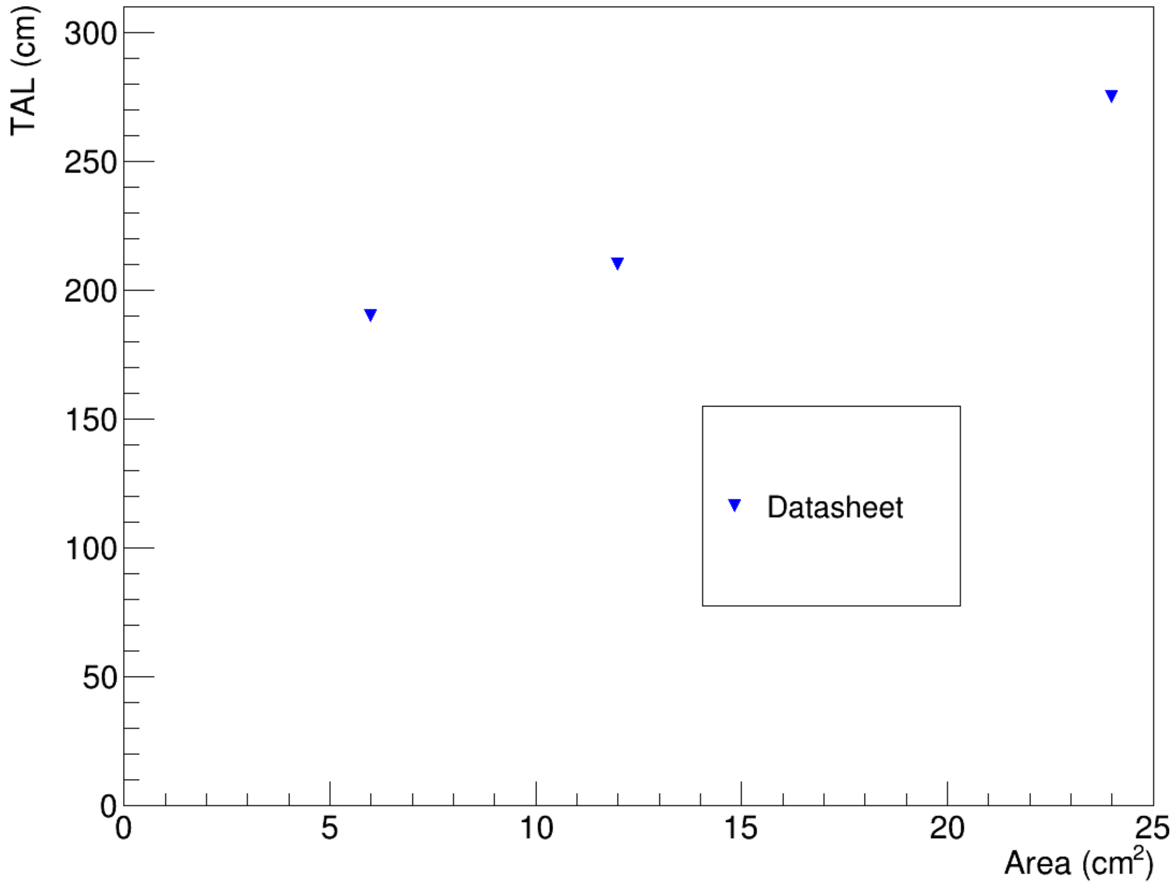
Parameters :

- MC Attenuation Length = 200 cm (to be normalized)
- BC-404 emission spectrum and light yield
- Wrapping thickness: 0.5 mm
- 100% or 97% wrapping reflectivity

TAL estimation: for each geometry, fit average number of photons collected by a SiPM as a function of the beam position with an exponential.

TAL as a function of the bar cross section area

Simulation results



From Saint-Gobain datasheet (link): study on BC-408 bars

Typical **BAL** = 380 cm

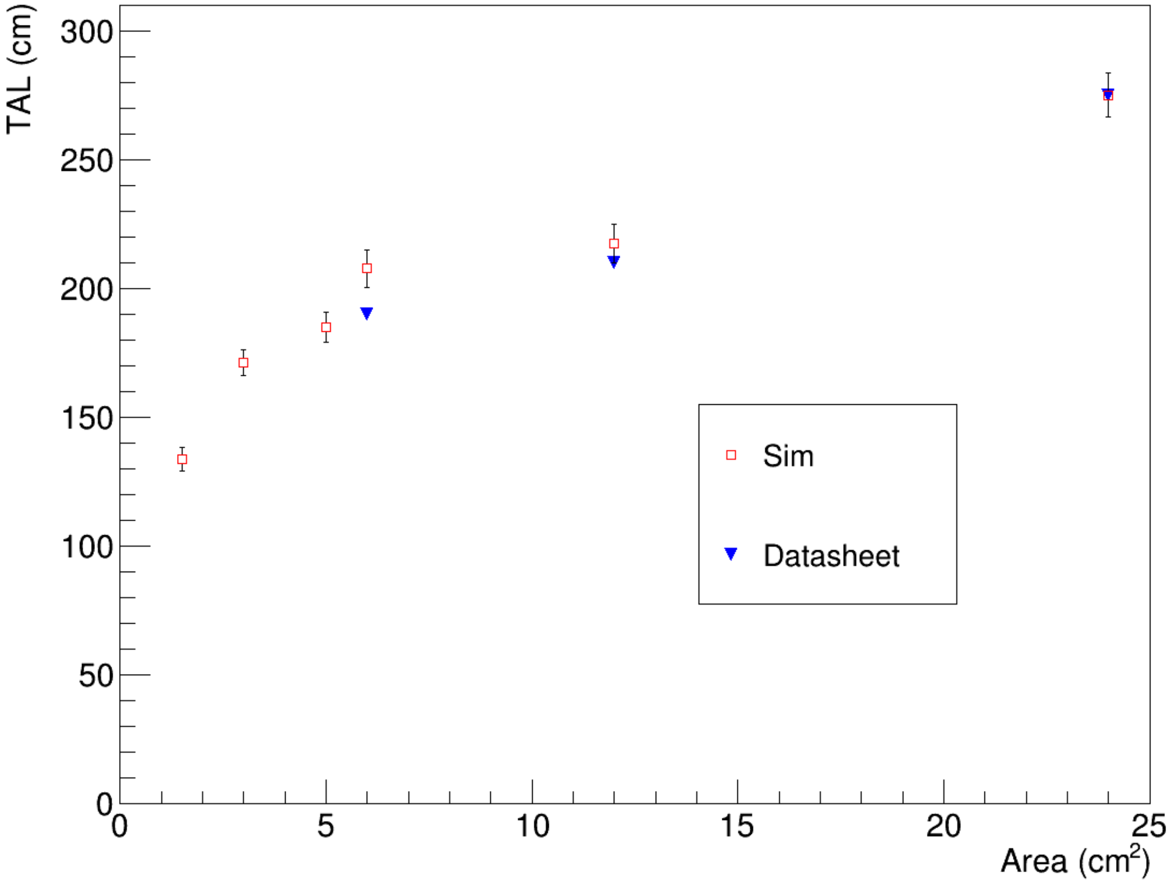
For 200 cm long x 12 cm wide cast sheets they report:

5 mm thick TAL = 190 cm
10 mm thick TAL = 210 cm
20 mm thick TAL = 275 cm

Plot TAL as a funciton of the bar cross section area.

TAL as a function of the bar cross section area

Simulation results



Try reproducing values from manual (BC-408) with simulation.

TAL plotted normalizing highest simulation value with highest value from the manual, referring to the same geometry.

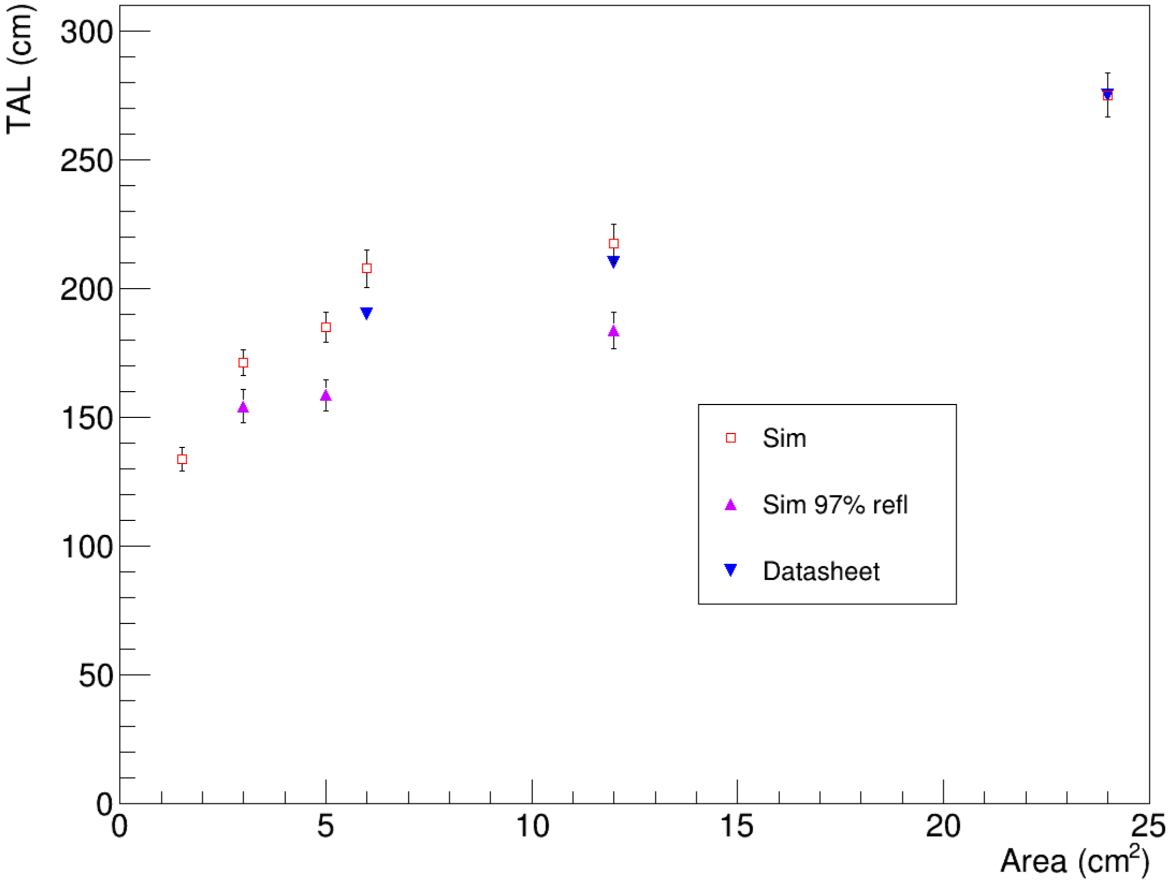
Good agreement between simulation and manual values.

Simulation wrapping has 100% reflectivity.

Simulation emission spectrum: BC-404

TAL as a function of the bar cross section area

Simulation results



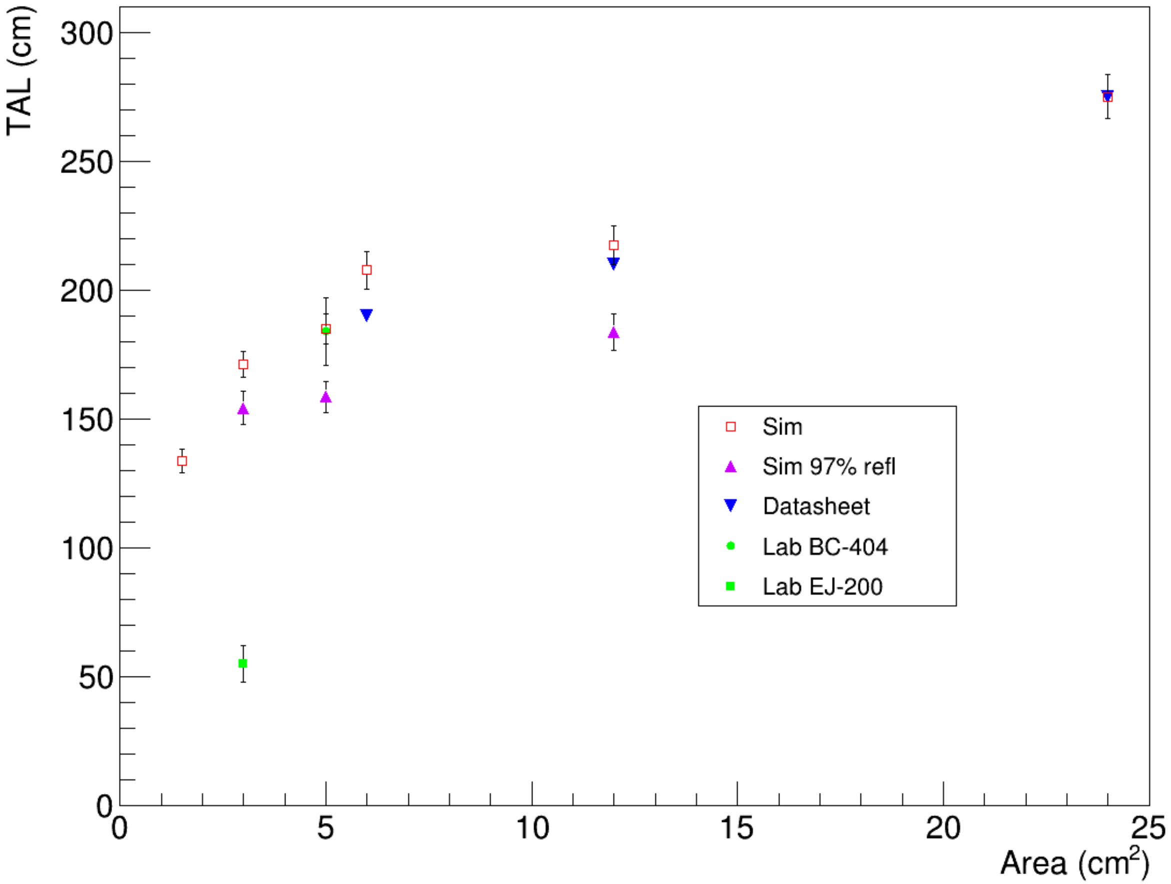
TAL decreases with wrapping reflectivity.

At 97% refelectivity the TAL is reduced by a factor 10/15%.

Light yield was increased by x10 to compensate for low photon counts at SiPMs.

TAL as a function of the bar cross section area

Simulation results



Increasing trend of the estimated TAL with the bar cross section area.

Lab points refer to different scintillators: EJ-200 and BC-404.

From datasheets:

EJ-200:

TAL = 380 cm for 300 x 20 x 2 cm^3

BC-404:

BAL = 160 cm

TAL = 140 cm for 200 x 20 x 1 cm^3

Summary [MC activities]

Aim of the simulation:
study TAL dependency on cross section area and wrapping reflectivity.
Observed behaviour is a TAL increase with the cross section area.

Six geometries were simulated: 200 m long **rectangular bars** with different cross section.
Wrapping reflectivity set to 100 % or 97%

Beam: 1 GeV muons in different positions along the bar

Estimation of **TAL** for different set-ups

Results:
TAL increases with bar cross section area
TAL decreases with wrapping reflectivity

To be also tested with trapezoidal bars

Back-up slides

TAL estimation from simulation

Simulation results (BAL set to 200 cm)

Geometry (cm^3)	Area (cm^2)	TAL (cm)
200 x 3 x 0.5	1.5	9.53 ± 0.18
200 x 3 x 1	3	12.19 ± 0.17
200 x 5 x 1	5	13.19 ± 0.22
200 x 12 x 0.5	6	14.8 ± 0.3
200 x 12 x 1	12	15.5 ± 0.3
200 x 12 x 2	24	19.6 ± 0.3

+ measurements from manual:

- 200 x 12 x 0.5, 1, 2 cm^3, BC-408

5 mm thick TAL = 190 cm
10 mm thick TAL = 210 cm
20 mm thick TAL = 275 cm

TAL estimation from simulation, 97% reflectivity

Simulation results (BAL set to 200 cm)

Geometry (cm^3)	Area (cm^2)	Reflectivity	TAL (cm)
200 x 3 x 1	3	100%	12.19 ± 0.17
200 x 3 x 1	3	97%	11.0 ± 0.3
200 x 5 x 1	5	100%	13.19 ± 0.22
200 x 5 x 1	5	97%	11.3 ± 0.2
200 x 12 x 1	12	100%	15.5 ± 0.3
200 x 12 x 1	12	97%	13.1 ± 0.3

Reflectivity set to **97%** for some geometries, increasing the light yield by x10 to compensate for photon counts at the SiPMs.

As a general trend the estimated TAL decreases with reflectivity.