Mechanical finite element analysis of the Preshower Calorimeter of the 12 GeV CLAS upgrade

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Abstract

For the 12 GeV upgrade of its accelerator facility, the Jefferson Laboratory will add a preshower calorimeter in front of the calorimeter of the CLAS spectrometer. A mechanical analysis using finite element analysis has been performed and this report provides an assessment of the current preliminary design. Made by stacking 15 layers of scintillators and lead plates, the design principle is the same as for the existing calorimeter. These components are inserted in a box made of aluminium sides and two sandwich panels in the active area. The results of this analysis are that the front panel deflects with a maximum of 0.74 mm under gravity and the stresses are well below the limiting criteria.

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1. Introduction

This report presents the mechanical assessment, using finite element analysis, of the new Preshower Calorimeter, as designed by the Jefferson Laboratory engineers.

2. Presentation of the detector

2.1. The CLAS 12 GeV upgrade

The CLAS experiment is located in Hall B of the Jefferson Laboratory Accelerator Facility. It will be upgraded in the next years to run at 12 GeV instead of the current 6 GeV [1]. Figure 1 illustrates the detector layout.

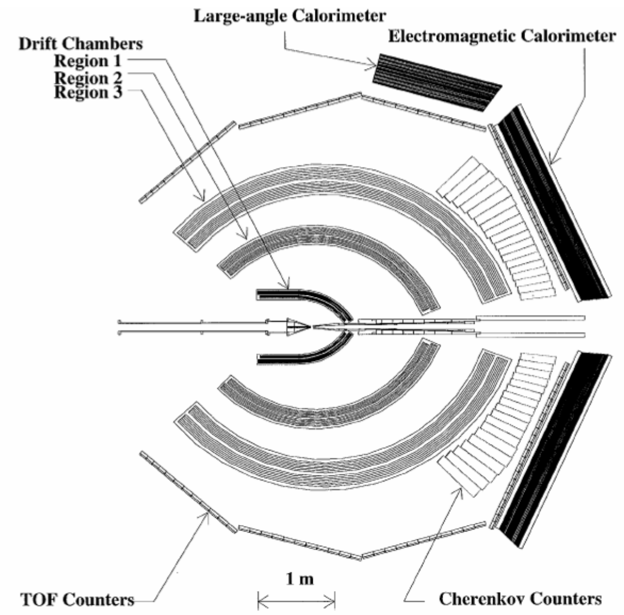

Figure 1: The current CLAS 6 GeV experiment

2.2. The Preshower Calorimeter

The electromagnetic calorimeter resolution will be bettered by adding a new preshower placed in front of the existing one, as shown in figure 2.

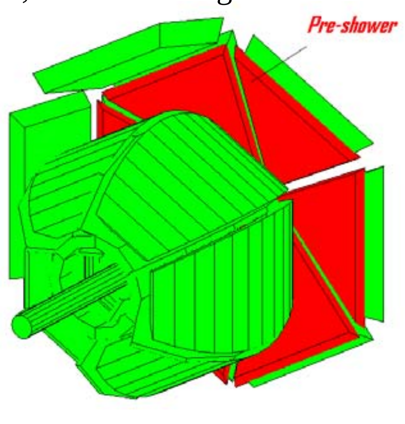

Figure 2: Insertion of the preshower calorimeter in front of the existing ECAL

The detection principle and size of this preshower are the same as for the current electromagnetic calorimeter [2], though the thickness is reduced to a stack of 15 layers of scintillators and lead (instead of 39 layers) as shown in figure 3.

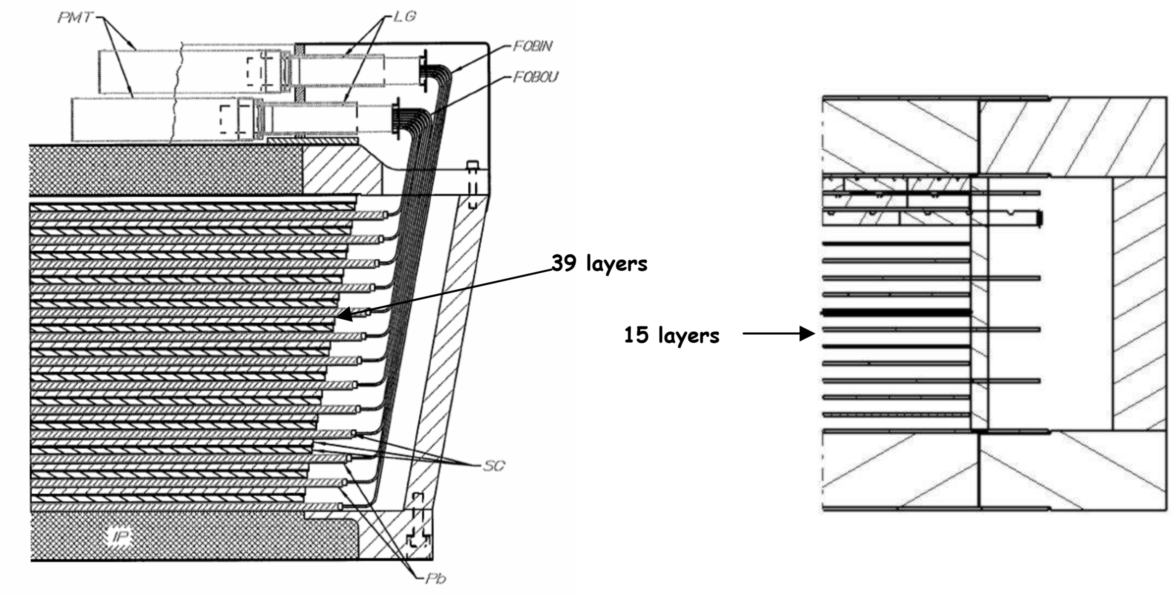

Figure 3:
Current EC (39 layers) ***(left hand side)***
New Preshower Calorimeter (15 layers) ***(right hand side)***

The detailed definition of the internal active components and their use will not be discussed as it is outwith the scope of this report.

2.3. The Forward Detector concept

The preshower is implemented in the forward carriage as shown in figure 4, in six sectors. Positions 1 to position 3 are calculated and vertical symmetry is used.

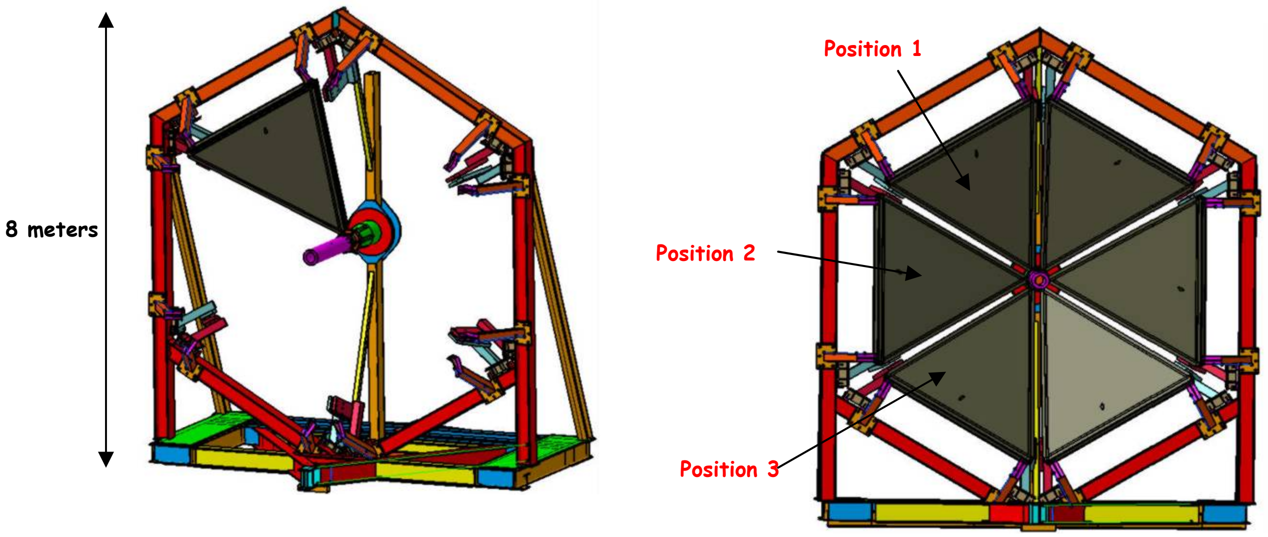

Figure 4: The forward carriage and positions of the preshower

3. Finite element analysis of the Preshower Calorimeter

The analysis of the mechanical behaviour of the preshower is performed with the SAMCEF software package. The geometry is fully redesigned in surface elements, and meshed in shell finite elements. The material and thicknesses followed by the boundary conditions and loads are applied in the model.

3.1. General aspects

The geometry of the preshower is based on the solid step file provided by Jefferson Laboratory and read with Catia. The design principle is presented in figure 5. It shows that the 15 layers of scintillators and lead are stacked together in a box with aluminium sides and one front and back sandwich panel.

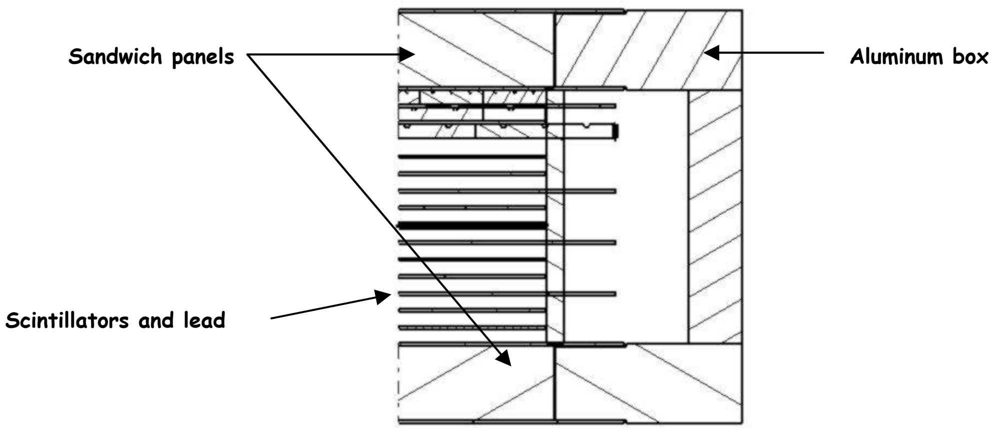

Figure 5: Layout of the preshower

As the preshower has larger sizes than the thickness of the plates, shell elements are used to mesh the structure and so minimize the number of nodes. The geometry is therefore redesigned inside Catia with surface shapes. This geometry is transferred via a step file to the SAMCEF modeller.

The preshower coordinate system is placed parallel to the structural axis of the geometry and then only gravity is rotated for each one of the 3 positions. The geometrical origin is placed at the top of the triangle.

The structure is meshed with shell elements of type “mindlin”. This element is a thick shell with transverse shear deformability. The meshed structure comprised of 2138 elements is illustrated in figure 6.

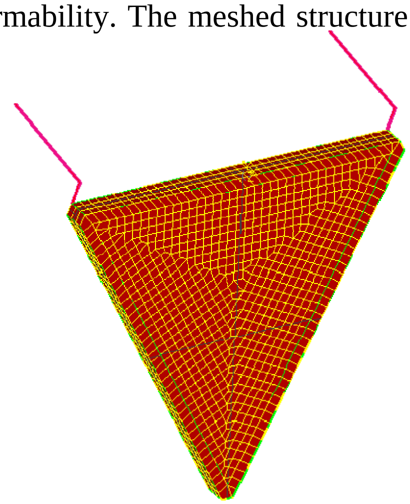

Figure 6: The mesh model of the preshower composed of 2138 elements (with 175 volumes)

3.2. Aluminium box and fixing points

The aluminium box is meshed with 1963 elements on its neutral fiber. The aluminium material parameters are listed in table 1.

The preshower is fixed to the forward carriage by 2 support beams made of stainless steel (parameters listed in table 1) and the profile of the beam is approximated by a square tube of 200x200x15 mm.

3.3. Scintillators and lead

The 15 layers of scintillators and lead are modelled by a volume with a slack rigidity which has been approximated at a conservative 150 MPa. This value is hard to estimate due to the large number of slats stacked and pressed together. However it permits the reproduction of the load as one hydrostatic pressure spread over the aluminium box using contact elements, as illustrated in figure 7.

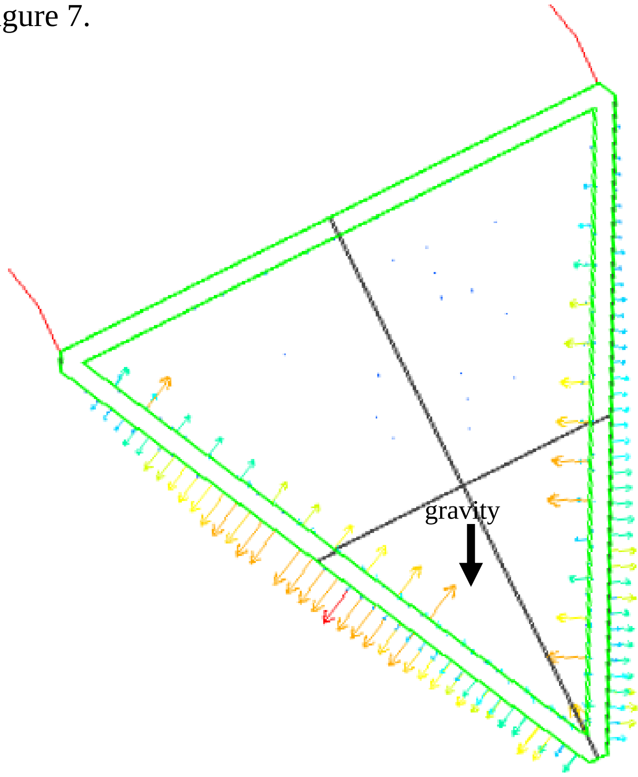

Figure 7: Load transfer from the scintillators and lead layers to the sides of the box

3.4. Front and back panel

The preshower is composed on the front and back face by sandwich composite panels based on a glued metal-foam-metal structure. The metal is a 2 mm plate of stainless steel and the foam is polyurethane core material of 50 mm thickness (FR-3700-15) [3] (see parameters listed in table 1).

After discussion with the Jefferson Laboratory engineers, these panels must have a local deformation lower than 0.5 mm/m. This value can be obtained with reasonable manufacturing using calibrated thick foams and taking care in the gluing process. The overall planarity must be better than 2 mm/m to avoid stress on the scintillators. This value must be achieved at the manufacturing level and kept during the mounting and functioning of the preshower. This data is the deformation limit taken for this analysis.

The critical aspect of a sandwich composite structure [4] is the internal stress assessment, and is decomposed in 2 typical components as illustrated in figure 8: the tensile stress σ_x, in the skins, and the internal shear stress τ_{xz}, in the core material. They are compared to the strength limits given in table 1.

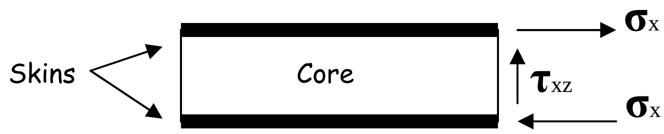

Figure 8: Stress decomposition in a sandwich composite panel

3.5. Material and thickness

Below all parameters used for the FEA analysis, are summarized.

Material	Bicron	Lead	Aluminium	Stainless steel	Polyurethane FR-3700
Thickness (mm)	10	2.2	38 and 54	2	50
Density (Kg/m^3)	1032	11250	2700	7850	240
Young modulus (MPa)	2700	18000	70000	200000	140
Shear modulus (MPa)	Not used	Not used	Not used	Not used	34
Tensile strength (MPa)	Not used	Not used	120	200	4
Shear strength (MPa)	Not used	Not used	Not used	Not used	3,3

Table 1: Material parameters used in the simulation and for the analysis

3.6. Boundary conditions and loads

The preshower is screwed to the forward carriage which is assumed to be rigid. This kind of fixing is modelled by clamping the extreme corners (two upper feet and the bottom points of the triangular box).

In a further analysis, the fixing points will have to be modelled in more detail. But as shown in the results, the level of stress is so low that it doesn't need a more detailed geometry definition in the current model.

The load applied on the structure in this linear static analysis is the gravity due to the dead load. This is applied to the total mass of the preshower which is around 5530 Kg.

4. Results of the static analysis

4.1. Displacements

The displacement values are measured for each position.

Position 1:
0.74 mm of maximal deflection located on the front panel as shown in figure 9. The bending of the support beams in position 1 is estimated to be around 0.5 mm.

Position 2:
1.3 mm of maximal deflection located on the top corner of the preshower as shown in figure 10.

Position 3:
Opposite values of the position 1 and load applied on the back panel.

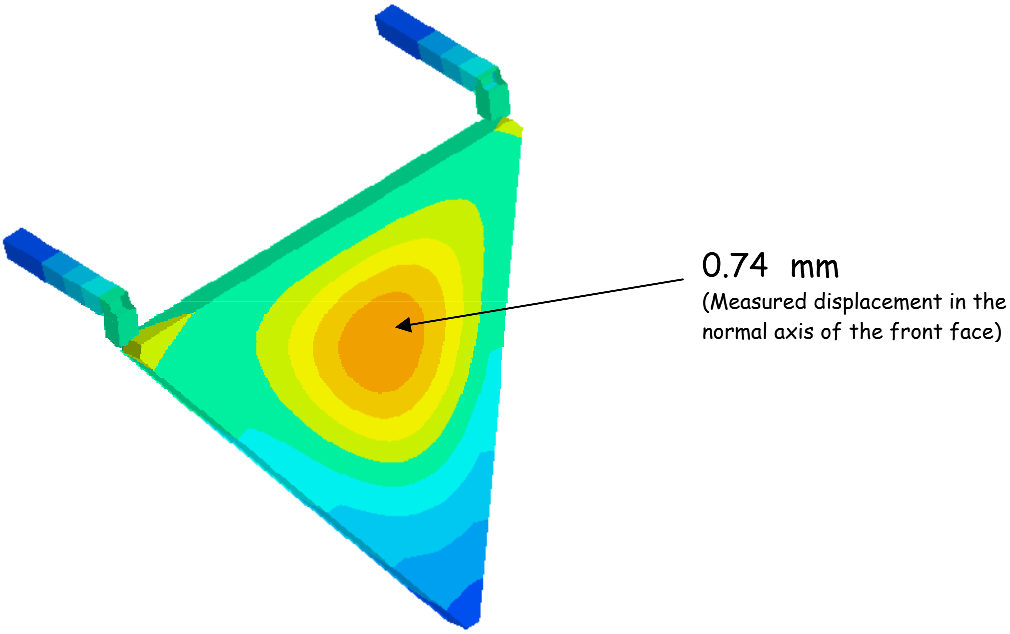

Figure 9: Maximum deflection of the front panel in position 1

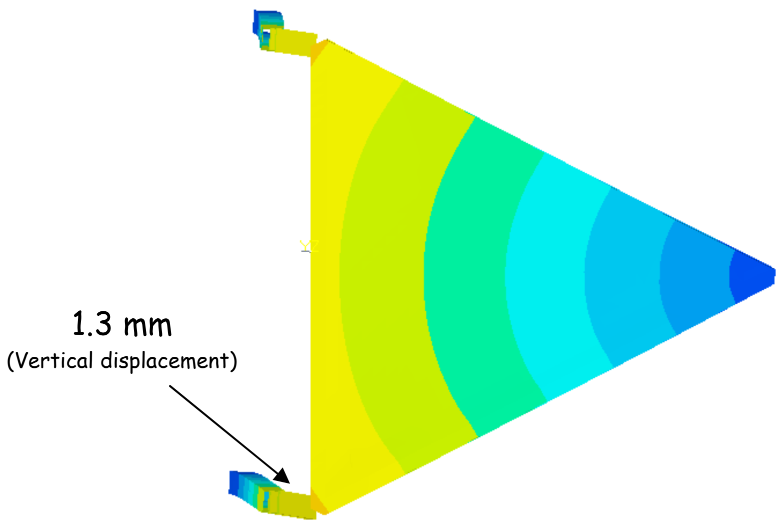

Figure 10: Maximum deflection of the preshower in position 2

The deflection of the front panel is under the limit of 2 mm specified in the §3.4.
The deformations of the box are negligible compared to the big size of the detector.

4.2. Stresses

The maximum stresses in each position are measured.

Position 1:
For the front panel, the maximum tensile stress $\boldsymbol{\sigma}_x$ is 5.4 MPa and the internal shear stress $\boldsymbol{\tau}_{xz}$ is 0.014 MPa. Figure 11 shows the location of the measure.
The stress on the clamped foot is around 24 MPa.

Position 2:
In this position the panels are not loaded perpendicularly to their face but link the aluminium box sides. The tensile stress $\boldsymbol{\sigma}_x$ is 4.66 MPa but the internal shear stress $\boldsymbol{\tau}_{xz}$ is negligible with 0.004 MPa.
The stress on the clamped foot is higher with 41 MPa as shown in figure 12.

Position 3:
The results are exactly the same as position 1 but in opposite direction.

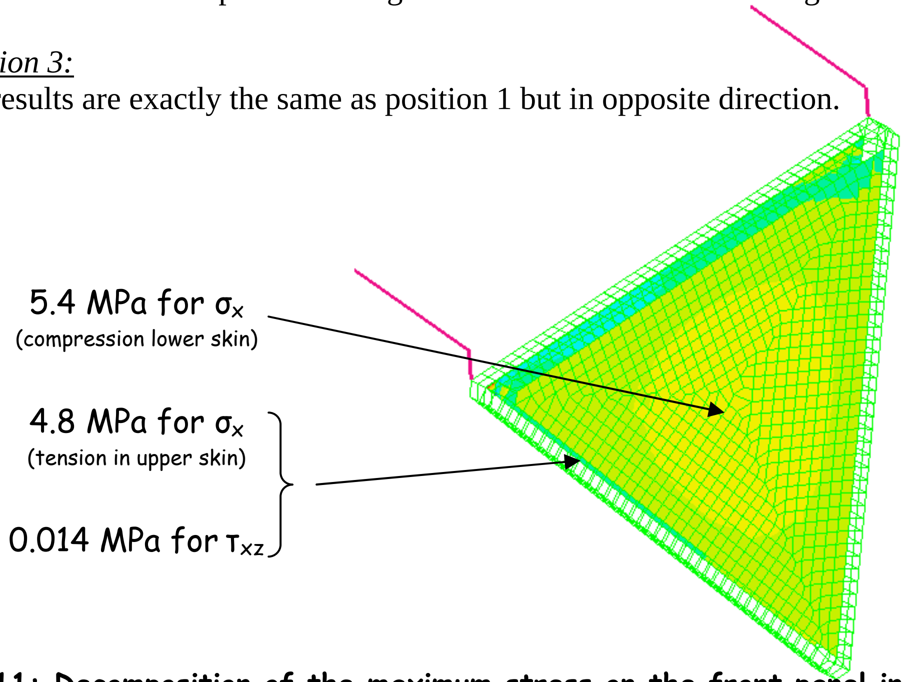

Figure 11: Decomposition of the maximum stress on the front panel in position 1

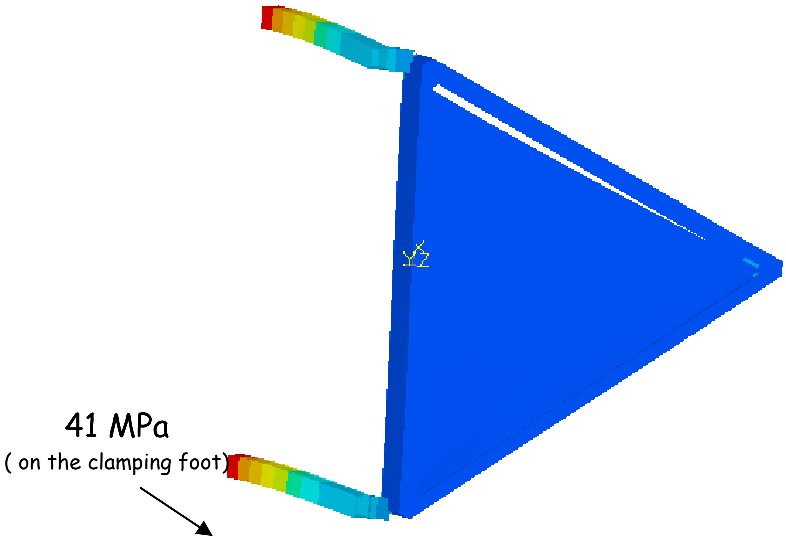

Figure 12: Maximum stress in position 2

No stresses are above the strengths listed in table 1, which show a stable behaviour of the structure.

Remarks:

1- The boundary of the sandwich panels are glued and screwed to the aluminium frames. The internal shear stress inside the gluing is estimated around 1.3 MPa (with an interface length of 30 mm), well within the limiting criteria of usual gluing which is around 15 MPa.
2- The horizontal mounting position calculation shows low values of displacements and stresses under the condition that special tools are used to handle the preshower.

5. Conclusion

The static analysis shows that the preliminary design of the preshower is adequate and stable.

References

[1] http://www.jlab.org/Hall-B/clas12/
[2] M. Amarian et al., NIM A 460, 239 (2001)
[3] General Plastic data sheet for the polyurethane foam FR-3700
http://www.generalplastics.com/products/idatasheets.php?pfoamname=FR-3700
[4] Matériaux composites, Daniel Gay, Hermes Lavoisier, ISBN 2-7462-1098-3