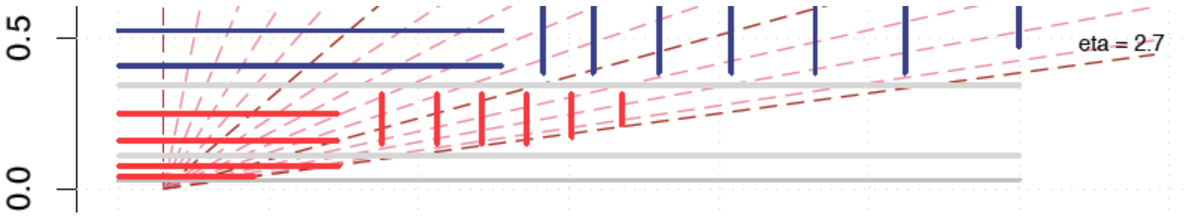
1 Introduction

2. Motivation

Traditionally tracking detectors in collider experiments have three geometrical parts: a barrel composed of cylindrical layers, and two endcaps composed of disks. The performance of the barrel layers is best in their central part, and decreases towards the ends of the layer where the tracks cross the cylindrical surface at shallow angles and the material "seen" by the tracks is amplified by the factor 1/sin(θ). This factor reaches the value of 7.5 at the limit of the acceptance of the pixel detector for the ATLAS upgrade (pseudo-rapidity of 2.7), and if we take into account the beam spot length the factor becomes 10 for tracks originating at z=0, and even 13 for tracks originating at the limit of the beam spot, for the first detection layer with a radius of 40 mm.

To limit the explosion of amount of traversed material in the forward region the length (and the angular acceptance) of the cylindrical layers is reduced, and the remaining acceptance is covered by disk-like layers. The ideal angle for the barrel-endcap transition from purely geometrical point of view is 45 degrees, or η=0.9



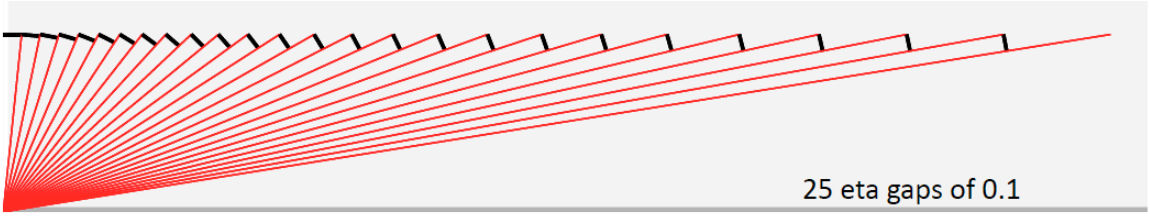
In practice the barrel-endcap transition is made at much larger polar angles, as illustrated by the picture of the proposed pixel detector layout for the ATLAS upgrade. There are several reasons for this:

- The difficulty to arrange, support, connect and cool rectangular pixel modules on small disks results in more material on the disk layers compared to cylindrical layers built from the same modules.
- Building a rigid barrel structure followed by disks forces the barrel layers to be of more or less the same length
- The end-of-stave cards, the electrical and cooling pipe connectors and routing of services result in a significant accumulation of material at the end of the barrel part, degrading the tracking performance in the transition region. A longer barrel extends the central region free from this material.
- The difficulty to place sensors on a disk at very small radii and very close to the barrel can result in a second barrel layer which covers the full angular acceptance, with the resulting material penalty.

These considerations result in a sub-optimal amount of traversed material and tracking performance, and incite us to look for a better layout for the future ATLAS pixel detector.

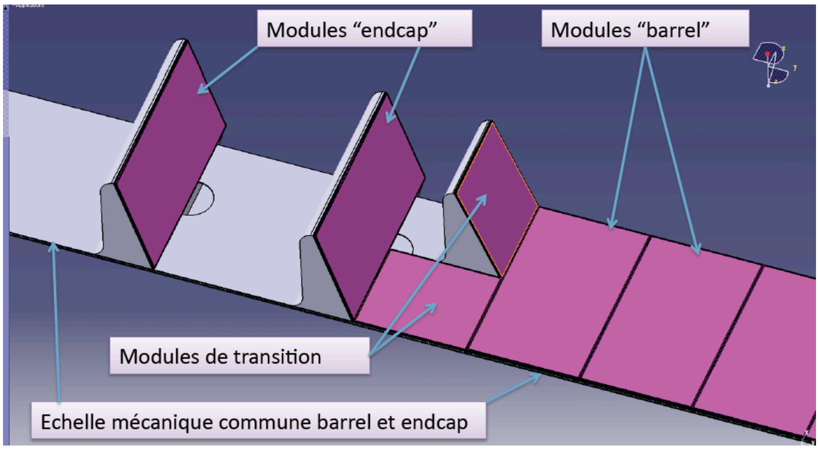
3. The alpine stave concept

The question of the ideal placement of sensors on a tracking layer is not new, and the theoretical solution for a hadronic collider is known:

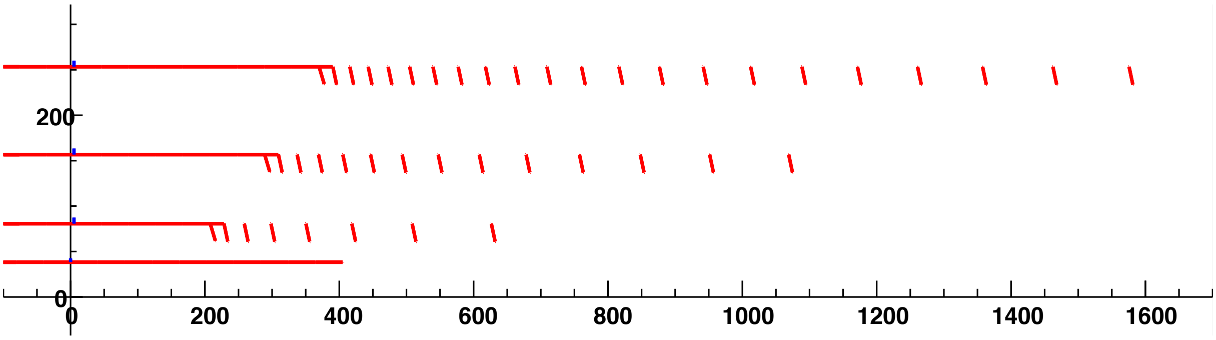


The sensors should ideally be crossed perpendicularly by track coming from the center of the beam spot, their centers should be placed on a cylindrical surface, and the distance between sensors should be adjusted to guarantee hermeticity. This arrangement cannot be easily realized in three dimensions using rectangular sensors, and it ignores the problems of mechanical support, cooling and connectivity of the modules, which explains why it has never been built. But it can serve as an inspiration for a layout.

The solution proposed in this note is based on the technologies used in the IBL project.

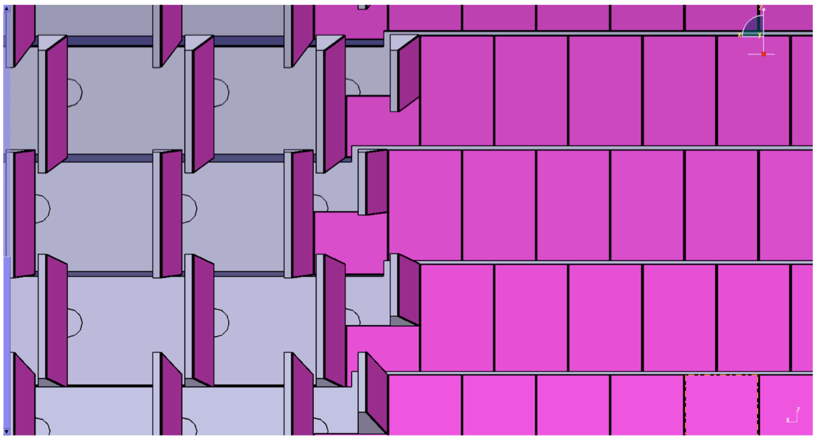


The pixel modules are placed on a mechanical support, or "stave", made from carbon fiber laminates surrounding a low-density carbon foam, with integrated titanium cooling pipes. The originality of the proposal is in the placement of some of the modules on small blocks of carbon foam at a large angle to the stave plane, giving them the desired orientation. With this type of stave we can approximate the ideal orientation of modules:



The innermost layer is the only one that cannot benefit from this type of stave, since it is placed as close as possible to the beam pipe, and there is no space for endcap modules protruding inwards from the stave plane. Outward-protruding rectangular modules would not result in a hermetic layer. The barrel-endcap transition point can be chosen independently, and therefore optimally, for each layer, to minimize the traversed material.

The 3D positioning of staves must provide sufficient overlaps in phi for the barrel part while avoiding conflicts between neighboring staves. To avoid conflicts between the endcap blocks the neighboring staves are shifted by about 10.3 mm (half of the length of a single readout chip module).

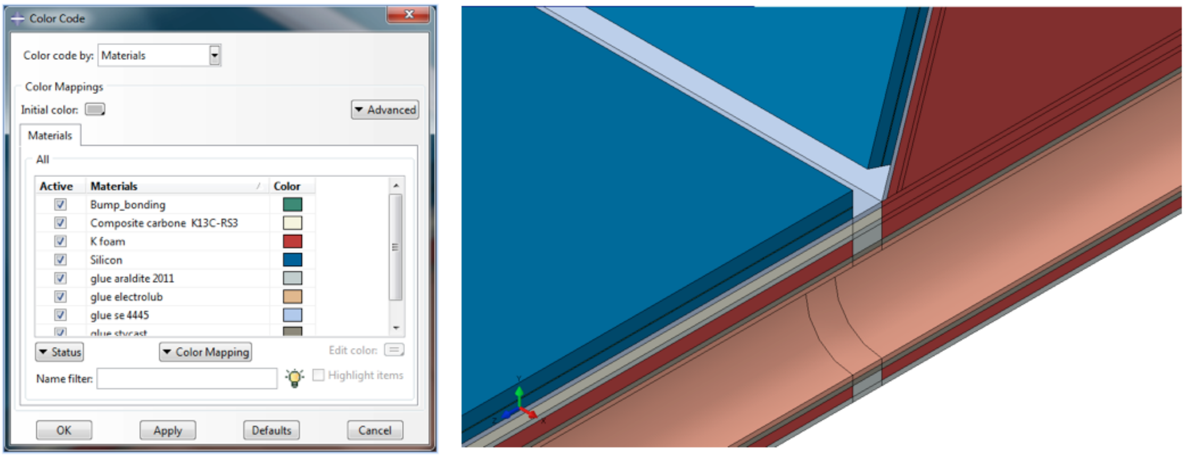


To avoid a conflict between the endcap module of one stave and the stave core of the next stave the stave core width is reduced on one side in the endcap region. The transition region, made of one barrel and one endcap modules of half width, is needed to avoid loss of hermeticity in the area of the last barrel module, where the stave width cannot be reduced. An alternative solution to this conflict would be to shift the first endcap module to one side, at the price of a small geometrical inefficiency.

3. Thermal performance

While the barrel part of the stave is similar in structure to the IBL stave (just doubling the width and adding a second cooling pipe), and therefore should have similar thermal performance, the endcap blocks are a radical departure from the IBL design and their thermal performance needs to be proven.

The Alpine Stave has been simulated in FEL (Abacus) with the same type of model and level of detail as the IBL stave, as shown in the figure below.



Color code by: Materials

Color Mappings

Initial color:

Materials

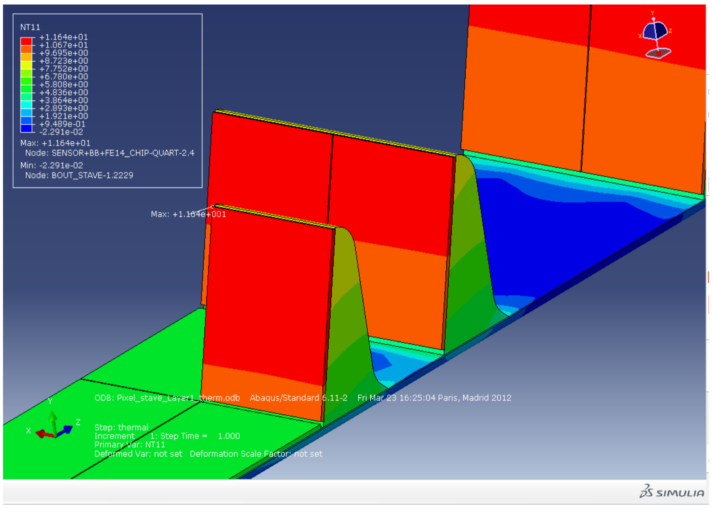
All

Active	Materials	Color
☑	Bump_bonding	🟩
☑	Composite carbone K13C-RS3	⬜
☑	K foam	🟥
☑	Silicon	🟦
☑	glue araldite 2011	⬜
☑	glue electrolub	🟧
☑	glue se 4445	🟦
☑	glue stycast	🟫

Name filter:

Fig. XX A dtailed view of the barrel-endcap transition with the choice of materials used in the FEL model. The stave is cut longitudinally along the middle of the cooling pipe. [FIXME old image, no face plate in endcap]

The results of the thermal simulations are very encouraging:



```
Max: +1.164e+01
 Node: SENSOR+BB+FE14_CHIP-QUART-2.4
Min: -2.291e-02
 Node: BOUT_STAVE-1.2229
```

```
ODB: Pixel_stave_Layer1_therm.odb    Abaqus/Standard 6.11-2    Fri Mar 23 16:25:04 Paris, Madrid 2012

Step: thermal
Increment      1: Step Time =    1.000
Primary Var: NT11
Deformed Var: not set   Deformation Scale Factor: not set
```

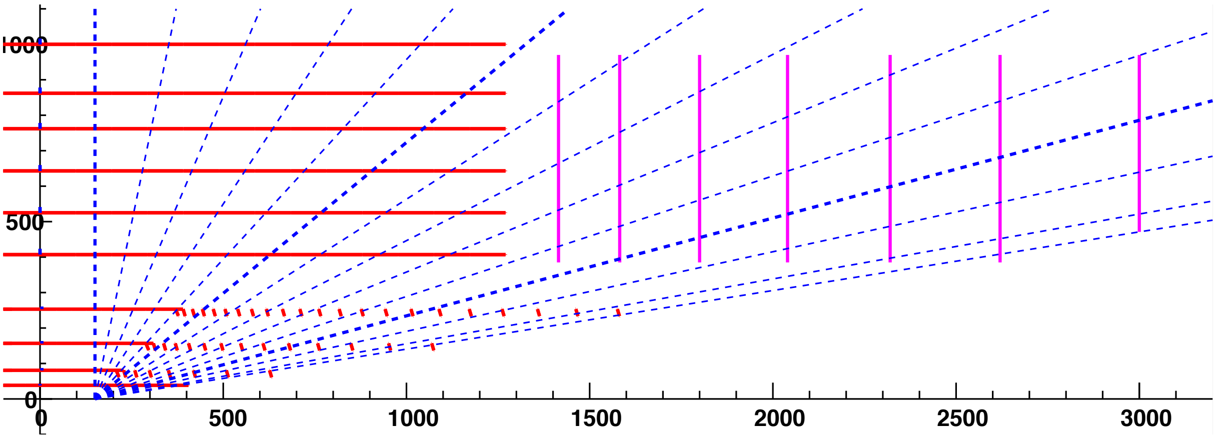
The temperature difference between the inner wall of the cooling pipe and the hottest point of the endcap modules is below 12 degrees, with materials identical to the IBL, including a faceplate in the endcap block. The temperature difference between the hottest point of a barrel module and an endcap module is about 4 degrees. If the endcap faceplate is removed (assuming one can control the penetration of the thermal grease in the foam in this case), the temperature difference between barrel and endcap modules vanishes.

The endcap block shape and thickness have been optimized to some extent, but there is a large field of further optimizations to explore. The most obvious to explore is modification of the endcap faceplate: in the barrel part (and the endcap stave core part) the faceplate is needed to provide mechanical rigidity, but this is not the case for the endcap blocks. Therefore the carbon fiber laminate could be replaced in this region with thinner and/or much better thermo conducting materials. Alternatively, a solution could be found for the excessive penetration of the thermal grease in the foam in the absence of a faceplate. But even with the proven and tested IBL materials and assembly technology the thermal performance of the endcap blocks is adequate for keeping the modules safely away from thermal runaway.

4. Pixel detector layout for the LOI

A layout based on Alpine staves, or “Alpine layout”, can be adapted in principle to any layer radii. However, the length of the last layer, which is roughly seven times it’s radius for the studied acceptance, can become very large, and a single mechanical support for the entire length becomes unreasonable. The actual stave length limit depends on the details of the mechanical structure.

The pixel detector layout described below is adapted to the parameters of the LOI Pixel layout, namely the inner and outer radii of the barrel parts of the Alpine staves coincide with the radii of the corresponding barrel layers in the LOI layout.



The number of sensors per stave (for the barrel and the endcap parts) is derived from the acceptance requirements in order to provide hermetic coverage.