Introduction

- ALICE: experiment at CERN LHC.
- ITS Upgrade Project: replace Inner Tracker System.
  - Goal: design & implementation of new cooling system.

**PROJECT SCHEDULE**

2012-2014 **R&D phase**

- **2012**: Study technology proposals.
- **2013**: Selection of technologies. Qualification studies.
- **2014**: Final design and validation. Integration & final testing.

2015-2018 **Construction and Installation**

5/8/2013

M. Gómez Marzoa
Introduction

Inner Tracker System (ITS): two-barrel, 7-layer structure

INNER BARREL (3 layers)

OUTER BARREL (4 layers)

ONLY ONE EXTREMITY ACCESSIBLE!
Charged and neutral particles cross pixel modules, leaving:

1. **Ionizing current**: signal
2. **Non-ionizing current**: radiation damage → energy loss

**Detector module**: STAVE

**Inner Barrel geometrical constraints.**

**Full ITS sectional view.**
Introducción

Stave mechanical/cooling design:

1. **Power dissipation** = \( f(\text{pixel technology, electronics, read-out, ...}) \)
2. Operational **temperature** and uniformity.
3. **Minimize material budget:** critical in detector design.

\[
\frac{x}{X_0} 100[\%]
\]

\[
X_0 = \frac{716.4 \cdot A}{Z(Z + 1) \ln \frac{287}{\sqrt{Z}} \rho} [cm]
\]

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Inner Barrel</th>
<th>Outer Barrel</th>
</tr>
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<tbody>
<tr>
<td>Power density to dissipate ([W , cm^{-2}])</td>
<td>( \approx 0.40 )</td>
<td>( \approx 0.40 )</td>
</tr>
<tr>
<td>Total material budget per layer ([% of X_0])</td>
<td>( \leq 0.30 )</td>
<td>( \leq 0.80 )</td>
</tr>
<tr>
<td>Operation temperature ([^\circ C])</td>
<td>(&lt; 30 ) (dew point: 13(^{\circ}C))</td>
<td>( \approx 10 )</td>
</tr>
<tr>
<td>Pixel max. temperature non-uniformity ([K])</td>
<td>( \approx 10 )</td>
<td></td>
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Project Objectives

Innovative Lightweight Cooling Systems for the Upgrade of the Inner Tracker System (ITS) of the ALICE Experiment at CERN

- Study, develop, qualify and integrate ITS Upgrade cooling system.
- R&D on minimal material budget detector cooling technologies.
  - High-conductivity, light-weight materials.
  - Plastic piping for cooling.
  - Impact of material budget fluctuation of a two-phase flow.
- Provide ALICE ITS Upgrade with a lightweight cooling system as project final deliverable.
# State of the Art

## Cooling systems in high-energy particle detectors

<table>
<thead>
<tr>
<th>System</th>
<th>Solution</th>
<th>Detector</th>
<th>Limitations</th>
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<tbody>
<tr>
<td><strong>Air Cooling</strong></td>
<td>High-conductive structure as cooling ducts</td>
<td>STAR</td>
<td>Low power dissipation</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td>Vibrations</td>
</tr>
<tr>
<td><strong>Single-phase liquid cooling</strong></td>
<td>Cooling pipe + carbon foam</td>
<td>IBL Outer layers Present ITS outer layers</td>
<td>$\uparrow x/X_0$ Leakless (water)</td>
</tr>
<tr>
<td></td>
<td>Polyimide microchannels</td>
<td>ITS Upgrade</td>
<td>$\uparrow \Delta p$</td>
</tr>
<tr>
<td><strong>Two-phase flow cooling</strong></td>
<td>Channel</td>
<td>ATLAS I. Det.</td>
<td>Flow distribution</td>
</tr>
<tr>
<td></td>
<td>Channel CO$_2$</td>
<td>ATLAS/CMS Upgrades</td>
<td>Low temperatures</td>
</tr>
<tr>
<td></td>
<td>Heat pipes</td>
<td>ATLAS Pixel (proposal)</td>
<td>Integration $\uparrow x/X_0$</td>
</tr>
<tr>
<td></td>
<td>Si microchannels</td>
<td>ITS Upgrade</td>
<td>$\uparrow x/X_0$ Stave integration</td>
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</tbody>
</table>
# State of the Art

## Cooling technologies/materials

<table>
<thead>
<tr>
<th>Technology</th>
<th>Examples</th>
<th>Applications</th>
<th>Innovative features</th>
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<tbody>
<tr>
<td>High-conductivity materials</td>
<td>Carbon fiber, Graphite foils, Graphite foam</td>
<td>Thermal spreader</td>
<td>- Mechanical &amp; thermal features</td>
</tr>
<tr>
<td>Small-scale plastic tubing</td>
<td>Polyimide, PEEK</td>
<td>Medical industry</td>
<td>- Erosion/aging, Cooling capabilities, Radioactive environments</td>
</tr>
<tr>
<td>Connectors/filters</td>
<td>Integration issues</td>
<td></td>
<td>- One end accessible, Out of detector area, Flow distribution</td>
</tr>
</tbody>
</table>
Inner Barrel Cooling proposals:

1. Air Cooling: CFD
   a) Layer-by-layer air cooling.
   b) Impinging jet proposal (w/ Univ. St. Petersburg).

2. Ultra Low-Mass Cooling Systems:
   a) Wound-truss structure.
   b) Wound-truss structure with high-conductivity plate.
      i. Cooling tubes over plate.
      ii. Cooling from stave extremities.
R&D phase

Inner Barrel Cooling proposals:

1. Air Cooling: CFD
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2. Ultra Low-Mass Cooling Systems:
   a) Wound-truss structure.
   b) Wound-truss structure w/ high-conductivity plate.
      i. Cooling tubes over plate.
      ii. Cooling from stave extremities.

If \( q' \sim 0.1 \text{ W cm}^{-2} \)

Complex, risky, high air velocity through jet holes
R&D phase

ULTRA-LOW-MASS COOLING SYSTEMS

- **MATERIALS**: lowest material budget + integrity
  - **Structure**:
    - Carbon fiber (K13D2U, K1100): \( \lambda \) up to 1000 W m\(^{-1}\) K\(^{-1}\)
    - Graphite foil (30µm thick): \( \lambda > 1000 \) W m\(^{-1}\) K\(^{-1}\)
  - **Tubes**: Polyimide, PEEK (↓ wall thickness).

Analytical/CFD studies
Experimental tests
Optimization of 2 geometries
R&D phase

ULTRA-LOW-MASS COOLING SYSTEMS

**P1:** Wound-truss structure.

- $w=1.4 \text{ g}$
- Global $\frac{x}{X_0}=0.32\%$
- K13D2U-2k fibre width: 1.5mm
- Fibre winding angle: 23deg

Transversal section:
- Pipe (ID 1.450mm)
- Graphite sleeve (30μm)
- K13D2U-2k fibre (70μm)
- Silicon dummy (50μm)
- Glue (~ 100μm)
- Kapton® heater

**P2:** Wound-truss structure with high-conductivity plate.

- $w=1.7 \text{ g}$
- Global $\frac{x}{X_0}=0.36\%$
- M60J Truss filament diameter: 300μm

Top structure:
- Carbon fleece (20μm)
- Graphite foil (30μm)
- Cooling pipe (ID 1.450mm)
- Plate: K13D2U CF (70μm)
- Carbon fleece (20μm)
- Glue (~100μm)
- Kapton® heater
R&D phase

ULTRA-LOW-MASS COOLING SYSTEMS

- Prototype manufacturing and testing:
  - Mechanical tests.
  - **Thermal tests**: real performance of prototypes.

<table>
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<tr>
<th>Fluid</th>
<th>Advantages</th>
<th>Limitations</th>
</tr>
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<tbody>
<tr>
<td>Single-phase water</td>
<td>Radiation hard Loop simplicity</td>
<td>Conductive: leak-less system Liquid: ↑ refrigerant x/X₀</td>
</tr>
<tr>
<td>Two-phase C₄F₁₀</td>
<td>Radiation hard Dielectric Vapor: ↓ refrigerant x/X₀ Cooling at constant T</td>
<td>More complex loop Distribution (340 staves ITS)</td>
</tr>
</tbody>
</table>

- 2 experimental loops to test 2 different concepts.
R&D phase

ULTRA-LOW-MASS COOLING SYSTEMS: EXP. SETUP

- Fast and simple way to assess prototype performance.
- Tested several prototype configurations with the 2 refrigerants.
R&D phase

ULTRA-LOW-MASS COOLING SYSTEMS: RESULTS

1. Little difference when cooling with water or $C_4F_{10}$ (Fig. 1a)
2. Prototype performance not subject to flow rate/mass flux (Fig. 1)
3. Plate proto (P2) outperforms wound-truss stave (P1) (Fig. 1, 2)

**Fig. 1:** Difference max. temperature in heater-mean fluid temperature for P1 (a) and P2 (b).

**Fig. 2:** Results with $C_4F_{10}$: $G=250 \text{ kg m}^{-2} \text{ s}^{-1}$, $q'=0.3 \text{ W cm}^{-2}$
Current state of the work

1. Studied and tested several stave configurations, including:
   - Plate with squeezed pipes
   - No-pipes stave + cooling from extremities (low power only).

2. Made new proposal adhering to the requirements \( P2 \).
   - **Material budget:** to be reduced
     - Two-phase flow/reduce pipe size
     - Thin plate: \textbf{K1100-X} \((\lambda > 1000 \text{ W m}^{-1} \text{ K}^{-1})\)

3. **Outer Layers:** similar concept
   - Same power dissipation expected.
   - Layers 30 mm wide (2 x 15 mm).
   - 850-1500 mm long.
Future steps

1. Polyimide piping: robust and suitable under radioactivity.
   - **Erosion tests:** facility under construction (water).
   - Measurements before/after: wall thickness, ε, SEM...
   - Water analysis (suspensions)

2. Pipe integration:
   - Avoiding connectors (pipe bend)
   - Prevent pipe kinking/buckling: embed reinforcing coil/braid

3. Refrigerant: $\text{C}_4\text{F}_{10}$ availability?
   - **Alternative:** R236fa (HFC)
   - Radiation impact?

(top) Single-pipe stave concept
(centre) Polyimide/Pebax® tube bend
(bottom) Composite polyimide+coil PTFE/Pebax®
Innovative Lightweight Cooling Systems for the Upgrade of the Inner Tracker System (ITS) of the ALICE Experiment at CERN

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Manuel GÓMEZ MARZOÁ

In collaboration with the ALICE ITS Upgrade Project