The large-scale CO$_2$ cooling systems for ATLAS and CMS upgrades: design and operational aspects

FORUM ON TRACKING DETECTOR MECHANICS – JUNE 2019
CORNELL UNIVERSITY – ITHACA
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The ATLAS and CMS Phase 2 upgrades

Major upgrades in ATLAS and CMS silicon detectors during LS3

ATLAS:
- New tracker + HGTD: \( \approx 300 \text{kW} \)

CMS
- New tracker + barrel timing layer: \( \approx 200 \text{kW} \)
- New endcap calorimeter + endcap timing layer: \( \approx 330 \text{kW} \)

Both systems cooled by CO\(_2\)
- Large cooling power
- Lower temperature request
  - Down to -40\(^\circ\)C for ATLAS PIXEL

\( \Rightarrow \) New era for CO\(_2\) cooling!
The ATLAS and CMS Phase 2 upgrades CO$_2$ cooling systems

Details in B. Verlaat’s talk

My talk

CO$_2$ Primary cooling station

On surface CO$_2$ storage

CO$_2$ plants

Concentric transfer lines

UX-15 Experimental cavern

USA-15 Service cavern

USA-15 shaft

CO$_2$ plants

Concentric transfer lines
# Detector specifications

## ATLAS NUMBERS

<table>
<thead>
<tr>
<th>ATLAS ITk cooling</th>
<th>Evaporation T at the detector exit</th>
<th>Heat load of detector</th>
<th>Ambient pick up</th>
<th>Preheaters</th>
<th>Heat per cooling unit</th>
<th>Cooling units</th>
<th>Plant type (Qty heads)</th>
<th>Max power/planet</th>
<th>Detector distribution lines</th>
<th>Average power per distribution line</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pixel End Cap (PEC)</td>
<td>-40</td>
<td>32.6</td>
<td>3.26</td>
<td>3</td>
<td>56</td>
<td>2</td>
<td>6</td>
<td>69</td>
<td>12</td>
<td>6</td>
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<tr>
<td>Pixel Barrel (POB)</td>
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<td>59.6</td>
<td>5.96</td>
<td>8</td>
<td>33</td>
<td>1</td>
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<td>34</td>
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<td>6</td>
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<tr>
<td>Pixel inner system (PX)</td>
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<td>27.0</td>
<td>2.7</td>
<td>3</td>
<td>62</td>
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<td>2</td>
<td>69</td>
<td>7</td>
<td>8</td>
</tr>
<tr>
<td>Strip End Cap (SEC)</td>
<td>-38</td>
<td>38.8</td>
<td>3.9</td>
<td>4</td>
<td>62</td>
<td>2</td>
<td>2</td>
<td>69</td>
<td>7</td>
<td>8</td>
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<tr>
<td>Strip barrel (SBR)</td>
<td>-38</td>
<td>62.4</td>
<td>6.24</td>
<td>8</td>
<td>32</td>
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<td>1</td>
<td>34</td>
<td>3</td>
<td>8</td>
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<tr>
<td>HGTD</td>
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<td>4</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>206</td>
<td>24</td>
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<tr>
<td>Spare plant</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td>245.4</td>
<td>24.54</td>
<td>6</td>
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</tbody>
</table>

Total heat: 245.4, Total heads: 6

## CMS NUMBERS

<table>
<thead>
<tr>
<th>CMS phase II upgrade</th>
<th>Evaporation T at the detector exit</th>
<th>Heat load of detector</th>
<th>Ambient pick up</th>
<th>Preheaters</th>
<th>Heat per cooling unit</th>
<th>Cooling units</th>
<th>Plant type (Qty heads)</th>
<th>Max power/planet</th>
<th>Detector distribution lines</th>
<th>Average power per distribution line</th>
</tr>
</thead>
<tbody>
<tr>
<td>OT</td>
<td>-35</td>
<td>105</td>
<td>0.5</td>
<td>8</td>
<td>77</td>
<td>2</td>
<td>3</td>
<td>103</td>
<td>26</td>
<td>46</td>
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<tr>
<td>IT</td>
<td>-35</td>
<td>37</td>
<td>0.5</td>
<td>3</td>
<td>46</td>
<td>1</td>
<td>2</td>
<td>69</td>
<td>22</td>
<td>24</td>
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<td>BTL</td>
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<td>38.5</td>
<td>6.5</td>
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<td>105</td>
<td>1</td>
<td>3</td>
<td>131</td>
<td>26</td>
<td>4</td>
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<tr>
<td>CE +z TOP</td>
<td>-35</td>
<td>57.5</td>
<td>3.5</td>
<td>1.25</td>
<td>105</td>
<td>1</td>
<td>3</td>
<td>131</td>
<td>26</td>
<td>4</td>
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<tr>
<td>ETL +z</td>
<td>-35</td>
<td>40</td>
<td>1</td>
<td>1.5</td>
<td>105</td>
<td>1</td>
<td>3</td>
<td>131</td>
<td>26</td>
<td>4</td>
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<tr>
<td>CE -z TOP</td>
<td>-35</td>
<td>57.5</td>
<td>3.5</td>
<td>1.25</td>
<td>105</td>
<td>1</td>
<td>3</td>
<td>131</td>
<td>26</td>
<td>4</td>
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<tr>
<td>ETL -z</td>
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<td>40</td>
<td>1</td>
<td>1.5</td>
<td>105</td>
<td>1</td>
<td>3</td>
<td>131</td>
<td>26</td>
<td>4</td>
</tr>
<tr>
<td>CE -z/+z BOTTOM</td>
<td>-35</td>
<td>115</td>
<td>7</td>
<td>2.5</td>
<td>62</td>
<td>2</td>
<td>2</td>
<td>87</td>
<td>25</td>
<td>24</td>
</tr>
<tr>
<td>Spare plant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>490.5</td>
<td>23.5</td>
<td>20.2</td>
</tr>
</tbody>
</table>

Total heat: 490.5, Total heads: 7
Cooling plant specifications

24/7 365d/Y operation

Full redundancy
  - No interruption of cooling in case of problem or for maintenance

Space and integrations constraints in both ATLAS and CMS underground facilities
  - Limited number of cooling plants

Large detector power loads
  - Large cooling plants
Redundancy approach – the common rail concept

Normal operation:

Each cooling plant connected to its own transfer line
  - Distribute flow to its own manifold

Temperature setpoint regulated by local accumulator

Each cooling plant can run at different temperature setpoint

Spare cooling plant running cold liquid in bypass over a common rail
  - Spare plant has pressure reference to the surface storage
  - Kept ready to immediately take over in case of need

Spare plant runs cold over the common rail for direct kick-in
Redundancy approach – the common rail concept

Back-up operation:

In case of problem or for maintenance reasons spare cooling plant takes over

Automatically piloted valves ensure fast switch over

Temperature setpoint regulated by local accumulator of replaced plant

In case spare plant is needed by several “users”, a common temperature setpoint needs to be agreed

Spare plant replaces any of the other units, which can be dismounted for maintenance or repair.
Maintenance requirements

One single (small...) team maintaining both systems
  - Currently 8 people operation team

Limit the amount of spare parts
  - Cost and space

Standardized maintenance procedures

Standardized units in both experiments
Specifications summary

Detector requirements
  - Power and granularity

Integration constraints
  - Number and size of cooling plants

M&O
  - Standardized approach

Design requirements and guidelines
  - Unique design
  - Modular design
Cooling plant design

- Hydraulic head
  - Stroke adjustment
  
- Gear box

- Electric motor

- Flow control box (dry-air box or mono block)

- Pump heads in individual foam boxes

- Strong support frame (pump weigh 2873 kg)

<table>
<thead>
<tr>
<th>Plant Module Type</th>
<th>Stroke Adjustment</th>
<th>Electric Motor</th>
<th>Gear Box</th>
<th>Hydraulic Head</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triple head</td>
<td>2500</td>
<td>103/131 kW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dual head</td>
<td>1900</td>
<td>69/87 kW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Single head</td>
<td>1300</td>
<td>34/44 kW</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total weight of 3H plant module about 5t
Component selection – Pump

Specs:
- Liquid CO$_2$
- Large flows: 1000 – 1500 g/s
- High pressure: up to 100 bar
- Low temperature: -50°C min

Market survey and call for tender at CERN in 2018
- Contract awarded to LEWA pumps
  - Historical CO$_2$ pump supplier

First pump to be delivered at CERN in the coming weeks
- Validation of the design on a prototype cooling plant (DEMO) at CERN
Component selection – Pump

Multiple heads LDG membrane pump
  ○ Configurable with 1, 2 or 3 heads
Up to 1500g/s in 3H configuration
Large dimensions
  ○ ≈1.5m x 2.5m x 3m...
  ○ ≈3t...
Main component of the system
  ○ Driving the design of the system

<table>
<thead>
<tr>
<th>Pump configuration</th>
<th>Flow rate 100% stroke [kg/s]</th>
<th>Flow rate 70% stroke [kg/s]</th>
<th>By-pass &amp; storage flow %</th>
<th>Flow rate 100% stroke [kg/s]</th>
<th>Flow rate 70% stroke [kg/s]</th>
<th>Max power -35 °C, 33 % VQ [kW]</th>
<th>Nominal power -35 °C, 33 % VQ [kW]</th>
<th>Max power -35 °C, 42 % VQ [kW]</th>
<th>Nominal power -35 °C, 42 % VQ [kW]</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 heads</td>
<td>1,58</td>
<td>1,11</td>
<td>10%</td>
<td>1,42</td>
<td>1,00</td>
<td>147</td>
<td>103</td>
<td>187</td>
<td>131</td>
</tr>
<tr>
<td>2 heads</td>
<td>1,05</td>
<td>0,74</td>
<td>10%</td>
<td>0,95</td>
<td>0,66</td>
<td>98</td>
<td>69</td>
<td>125</td>
<td>87</td>
</tr>
<tr>
<td>1 head</td>
<td>0,53</td>
<td>0,37</td>
<td>10%</td>
<td>0,47</td>
<td>0,33</td>
<td>49</td>
<td>34</td>
<td>62</td>
<td>44</td>
</tr>
</tbody>
</table>
Component selection – Flanges and fittings

Below 1” pipe size

- Swagelok VCR type is the baseline
  - Metal to metal seal
  - Known, proven reliability, compact, ”cheap” and easy to procure
Component selection – Flanges and fittings

Above 1” pipe size

- ANSI flanges available but too large for our application
- NORSOK standard describes more compact flanges
  - Used in oil&gas industry
  - Metal to metal seal
  - Used at high pressure and cryogenic temperatures (LNG, -160°C)
  - Up to 60% space and 82% weight savings
- Full range available with several models from 1” up to 48”...
Component selection – Valves below 1”

Below 1”:
- Swagelok (CMS Pixel)
  - No cryogenic extension but cold operation compatible actuators
  - From ¼” to 1”, shut-off, 3-way, regulation
  - VCR connection
- Rotarex (ATLAS IBL, LHCb MAUVE)
  - Cryogenic extension
  - From ¼” to 1”, shut-off
    - Discussion started for up to 2”
  - VCR compatible connection

Regulation:
- CAREL (everywhere !!)
  - Full range of size and Cv
  - Very compact
Component selection – Valves above 1”

Not too many candidates which fulfil our requirements...

AE Valves (Emerson group)
- High pressure
- Low temperature (LNG application)
- Full range of actuation available
- Size up to 42”...
The DEMO project

Construction of 2 prototype cooling plants
  - First module (3H) before end of 2019
  - Second module (1H) in 2020

Validate all components

Validate common rail concept, operation and maintenance procedures

DEMO integration proposal in Lab 153
Integration studies

ATLAS: 1x3H, 5x2H, 1x1H, 6 accumulators, 1 crane, false floor

CMS: 5x3H, 3x2H, 7 accumulators, 1 crane, false floor

=> Very challenging projects!
Conclusions

Combination of all specifications and constraints lead to a unique modular design for the cooling plants

Large pipe sizes above 1” require new components

All cooling plants aspects (technical and operational) will be debugged with the DEMO project well ahead of installation underground

Integration studies are challenging, but work is on-going and progressing very well
Thank you!