CO2 Cooling

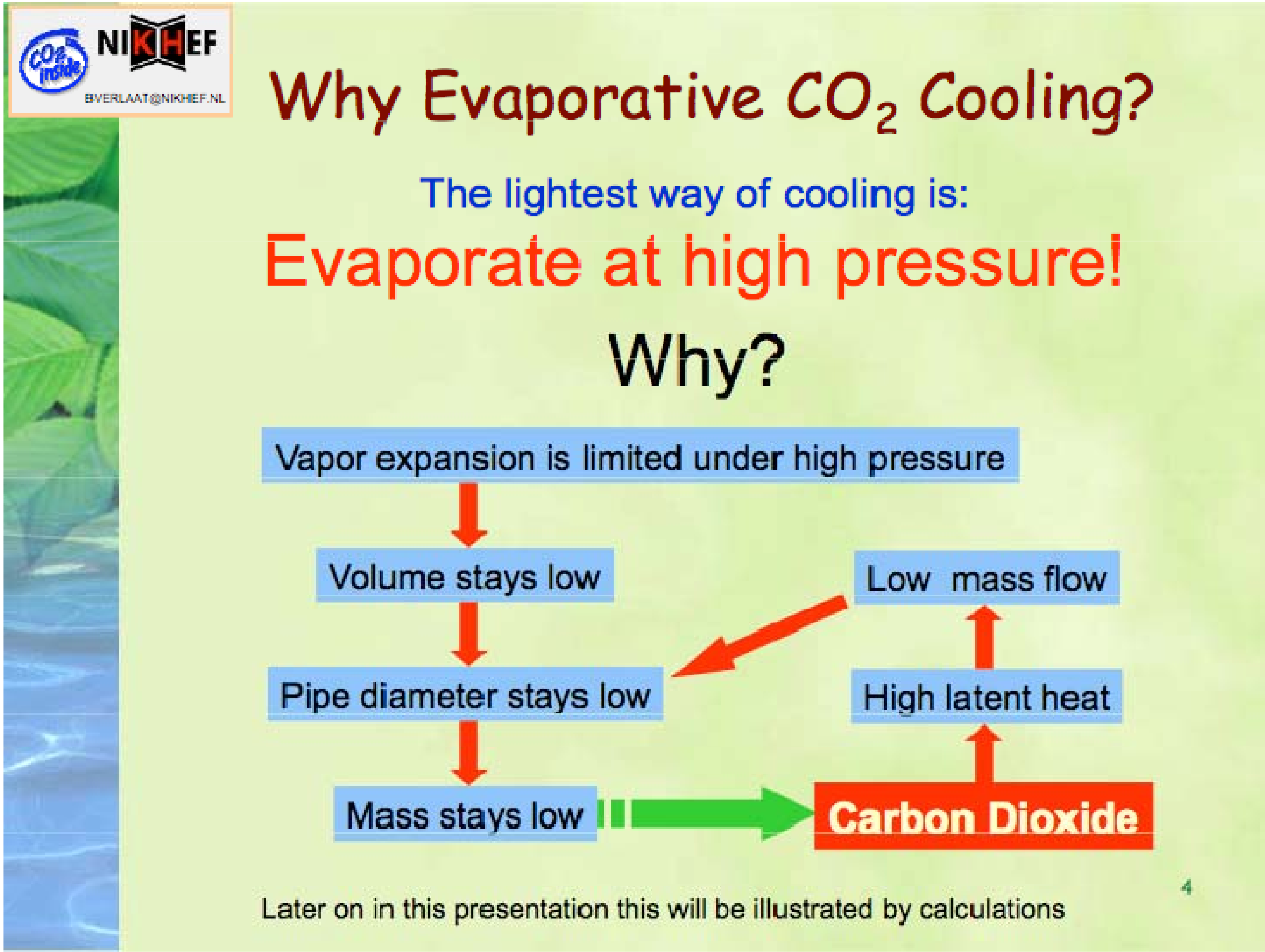
For the CMS Pixel detector

Advantages

- LHCB has chosen CO2, with the following arguments:
- Radiation hard
- Has excellent thermodynamic properties for micro-channels.
- Low dT/dP
- Low mass
- Low liquid/vapour density ratio
- Low viscosity
- High latent heat
- High heat transfer coefficient

Pressure advantage

- Intuitively, higher pressures seem a disadvantage but:
- Gas flow at higher pressures needs smaller pipe diameters
- Pressure drops due to flow become less significant, allowing smaller pipes
- Small pipes can easily support the required pressures


NIKHEF
BVERLAAT@NIKHEF.NL
Why Evaporative CO_2 Cooling?
The lightest way of cooling is:
Evaporate at high pressure!
Why?
Vapor expansion is limited under high pressure
Volume stays low
Pipe diameter stays low
Mass stays low
Low mass flow
High latent heat
Carbon Dioxide
4
Later on in this presentation this will be illustrated by calculations

Pressure values

- At 20 degrees C – two phase at 57 bar
- At -12 degrees C – two phase at 25 bar
  – Corresponds to detector operation
- At +5 degrees C – two phase at 40 bar
  – Corresponds to detector storage using the standard chilled water to cool the reservoir.

Existing Supply pipes

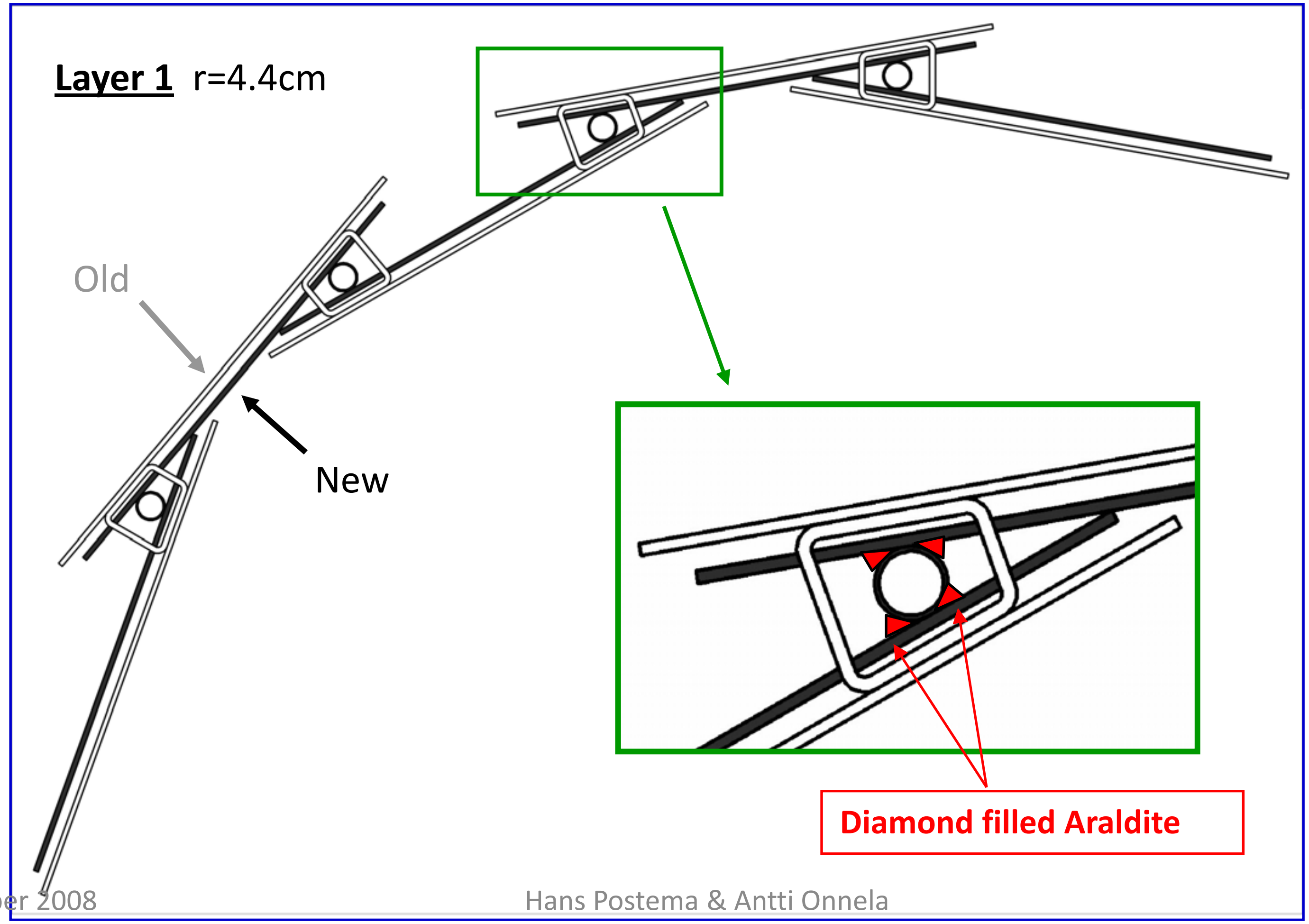
- It is virtually impossible to replace the existing tracker supply lines
- The installed pipes reach the elastic limit at approximately 150 bar (measured at CERN)
- Operation at 40 bar seems feasible

- Safety aspects need to be studied

Modified Mechanics for CO_2 Cooling

Cooling pipes stainless steel. Diameter d = 1.50 mm and wall thickness t = 50 μicrons

$$p_{\max} = 2 \cdot \varepsilon_{yield} \cdot \left(\frac{t}{d}\right)$$ → p_{max} = 275 bar safety factor 3 → **p_{op} = 90bar**



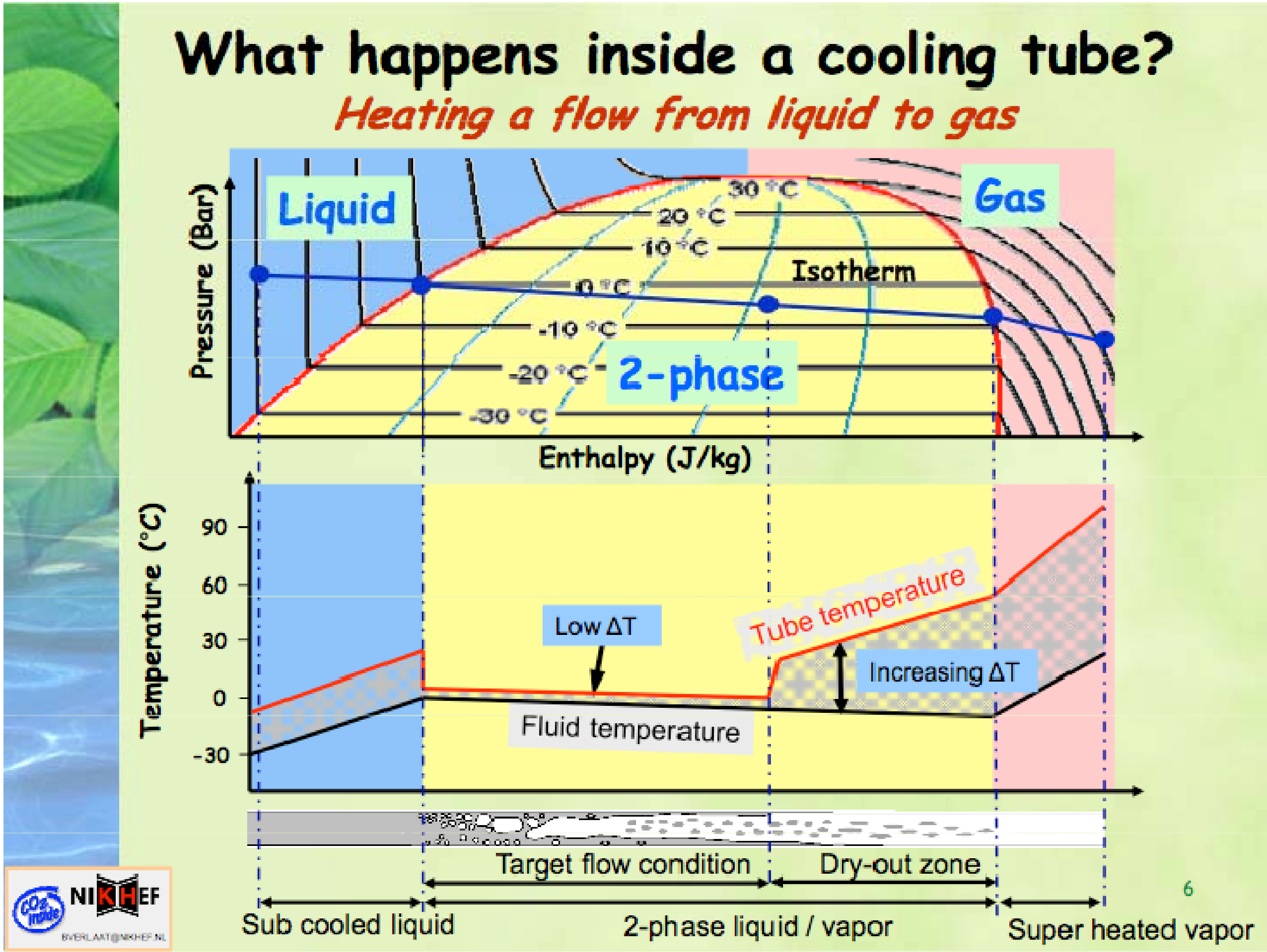
Modified Mechanics for CO_2 Cooling (2)

• Biphase CO_2 cooling allows long cooling loops (~2-3m) with very small diameter pipes (~ 1mm) for thermal loads of ~ 100 W

• Present C_6F_{14} monophase has parallel cooling pipes with manifold and large crosssection silicon hoses for feed and drain in front of FPIX tracking region.

• New CO_2 allows serialized pipes without pressure drop problems and therefore reduces resident cooling liquid by large factor.

• Density of liquid CO_2 is ~ 1.03 g/cm^3 compared to 1.76 g/cm^3 of C_6F_{14}


What happens inside a cooling tube?
Heating a flow from liquid to gas
Liquid
Gas
2-phase
Isotherm
30 °C
20 °C
10 °C
0 °C
-10 °C
-20 °C
-30 °C
Pressure (Bar)
Enthalpy (J/kg)
Temperature (°C)
90
60
30
0
-30
Low ΔT
Tube temperature
Increasing ΔT
Fluid temperature
Target flow condition
Dry-out zone
Sub cooled liquid
2-phase liquid / vapor
Super heated vapor
6

New cooling pipe

- Estimates by Bart Verlaat from NIKHEF allow for a 5.5 m long cooling pipe with a diameter of 1.5 mm
- This avoids all the manifolding in the detector
- The calculated pressure drop along the 5.5 m is 2 bar giving a dT of 3 degrees C
- But calculating 2-phase flow in small tubes is known to be very difficult

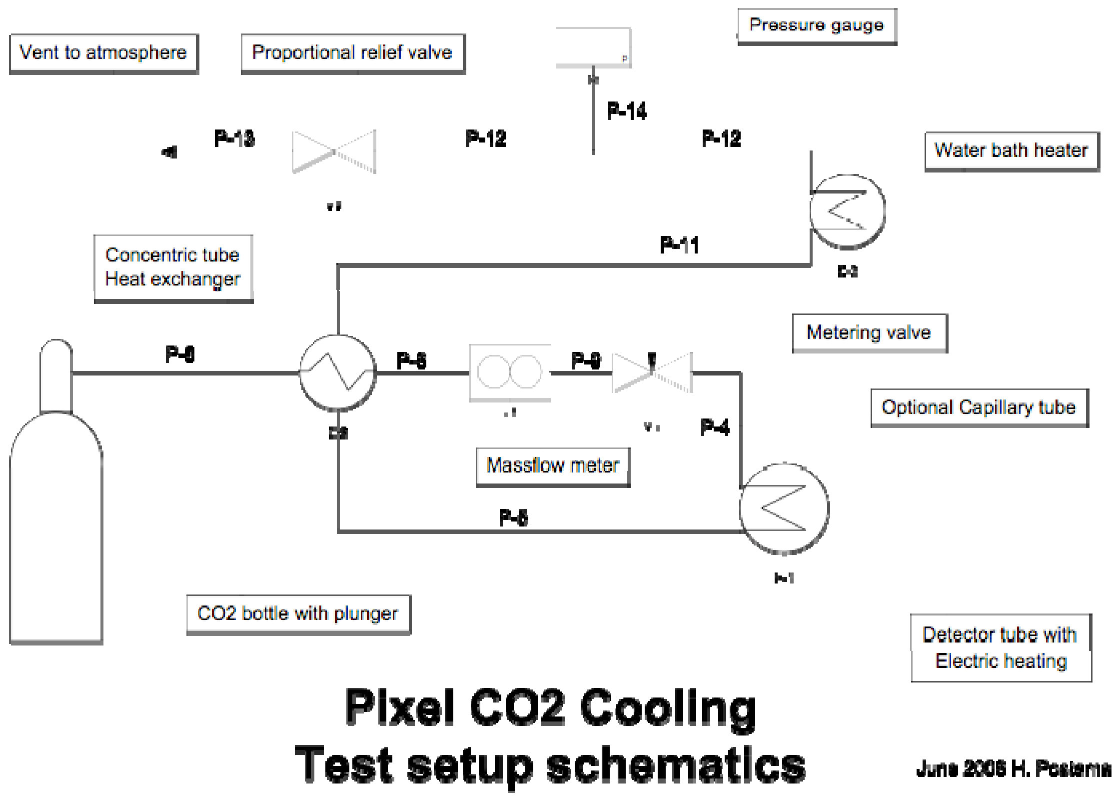
R & D

- At present everything indicates that this cooling method is feasible
- A simple test setup can increase the confidence level and can show that the concept is correct
- More sophisticated research is important to assure a full understanding of the system and optimize the design details as well as the operating parameters

Next steps

- Aachen as well as Lyon seem very interested in starting conceptual design verification test (see next slide)
- CERN Cryolab has already started to work on a test setup for high precision measurements and a full characterization of CO2 flow in small tubes

Design verification



Acknowledgements

- Several slides in this presentation are borrowed from:
  - CO2 cooling for HEP experiments – Bart Verlaat – TWEPP-2008
  - Pixel detector CO2 cooling – Roland Horisberger