Valutazione di materiali ceramici sottili per circuiti ibridi per l'upgrade del tracciatore di LHCb

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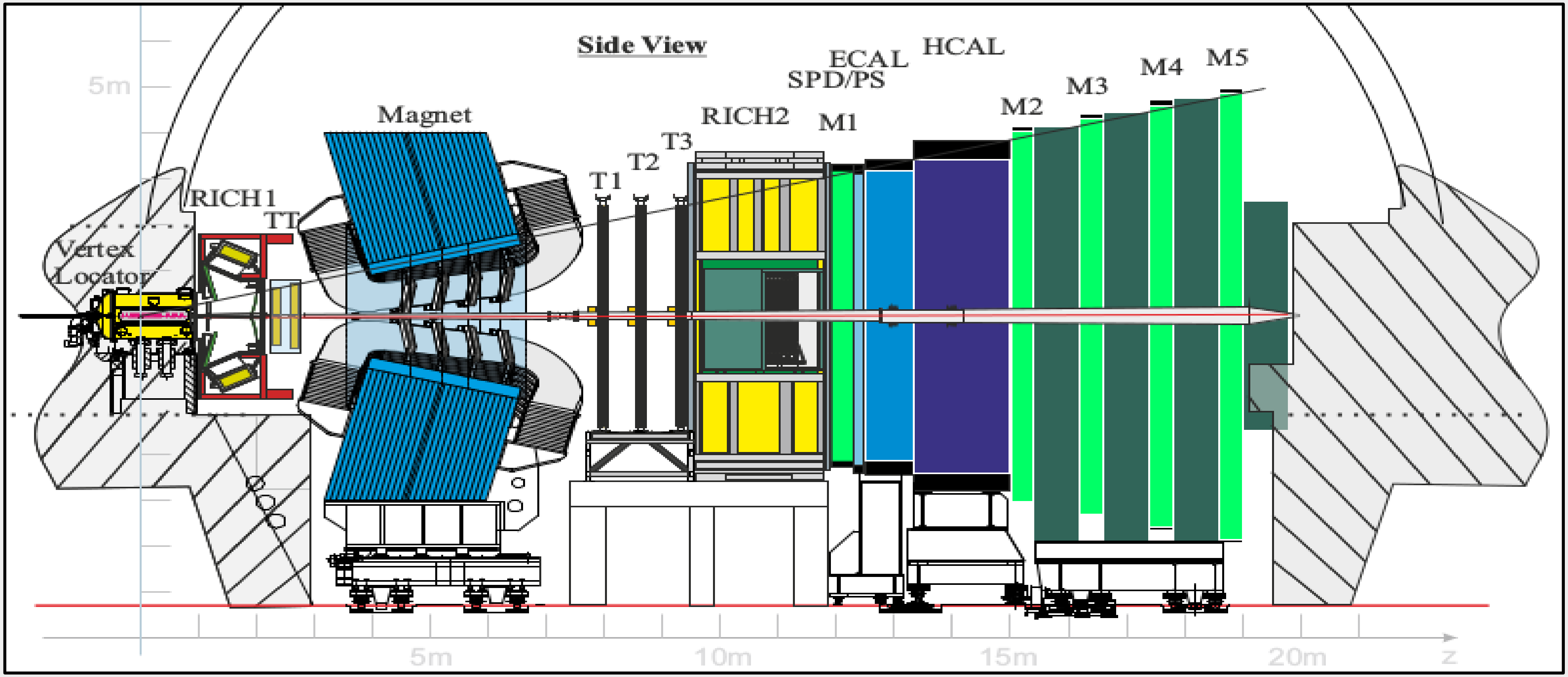
LHCb experiment

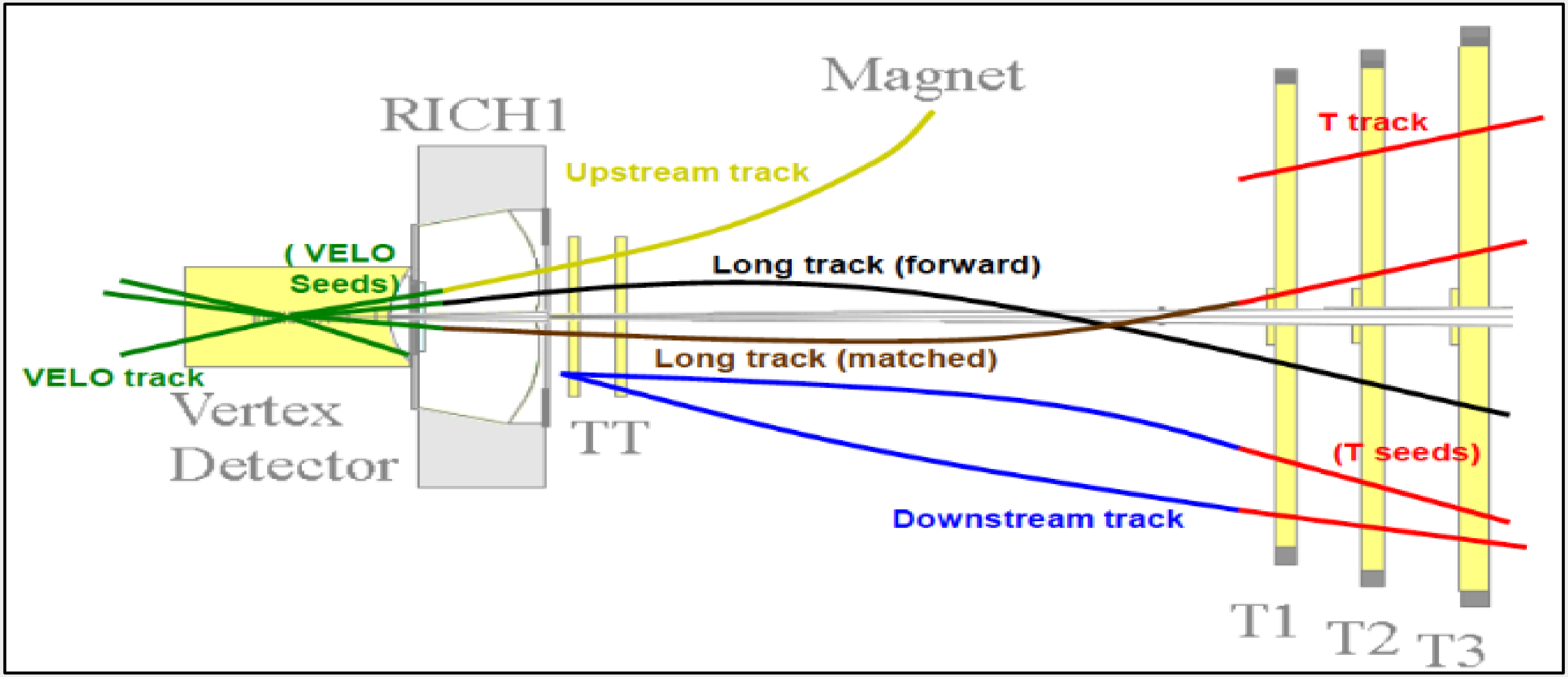


Forward spectrometer experiment at the LHC for studies of CP violation and rare decays of b hadrons

Excellent results already achieved:

→ few results in tensions with Standard Model (e.g.: b->sl$^+$l$^-$ transitions, tauonic B → D*τν decays)
→ first observation of rare $B_s^0 \to \mu^+\mu^-$ decay productions
→ discovery of tetraquark and pentaquark
→ obtained world best measurements in heavy flavour physics

LHCb tracking system



Vertex Locator → measures particle tracjectories near the proton-proton interaction point

Tracker Turicensis (to be upgrade with Upstream Tracker) → placed upstream of the magnet

T-Stations → measures particle interactions downstream of the magnet

LHCb Upgrade

Precision measurements of LHCb are **limited by statistical error**

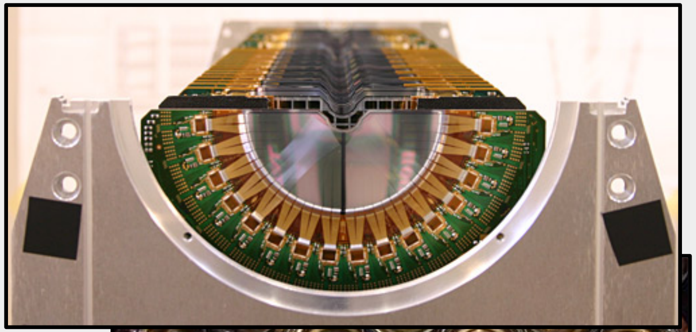
Much **higher statistics** needed

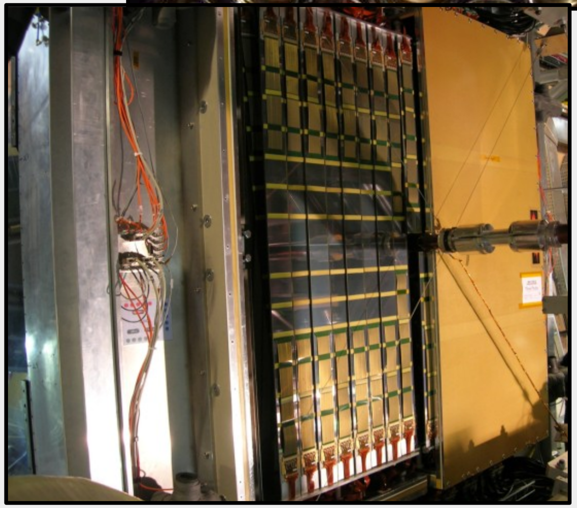
Need to upgrade the detector to cope with **high particle rates**

Expected **increase of signal yield** at least one order of magnitude

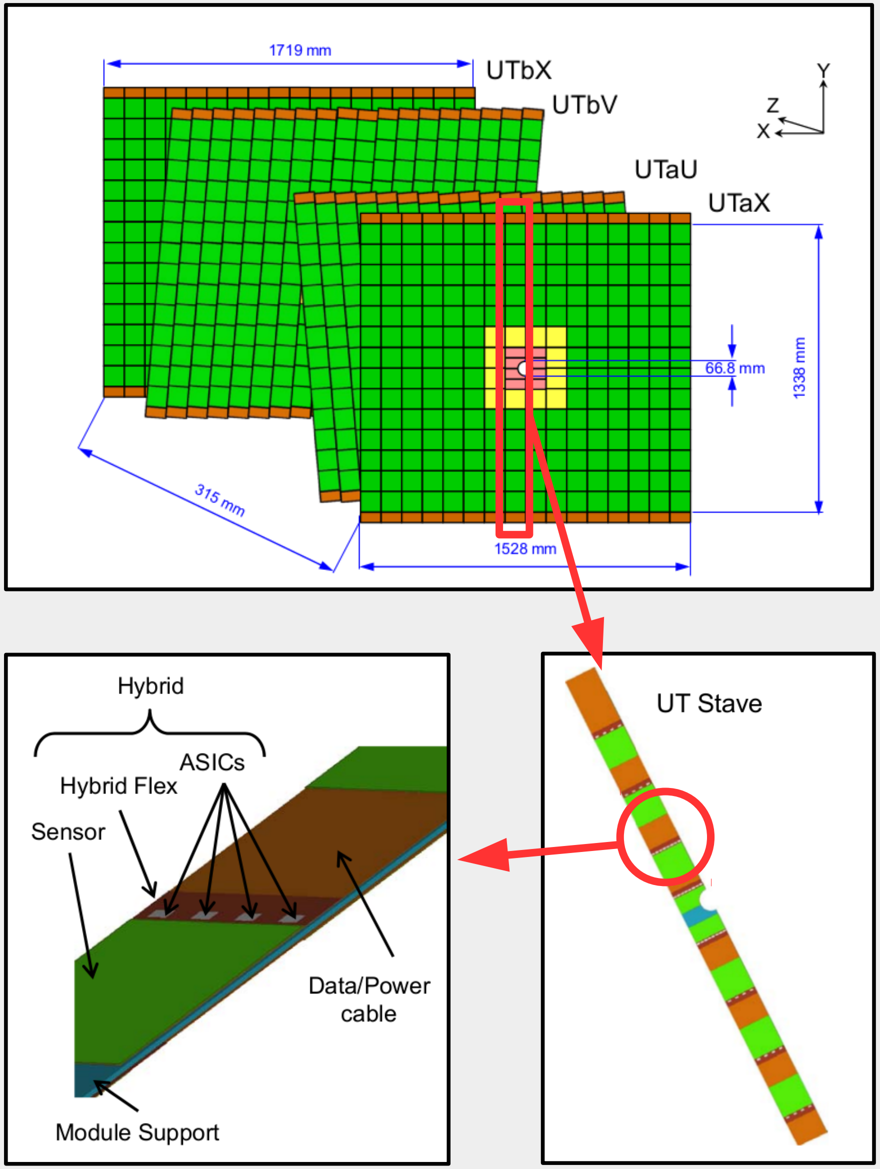
New detectors, new read-out electronics, new trigger scheme

Read out the entire event at each bunch crossing, **every 25ns**
(not possible at the moment)





Upstream Tracker upgrade



Upgrade of the **silicon strip tracker** positioned upstream of the magnet

Crucial detector of the LHCb tracking system

UT conceptual design:

→ **4 planes** of silicon strip sensors

→ Finer granularity near the beam pipe

→ Overlap between sensors to **avoid gaps in acceptance**

→ radiation-hard silicon sensors to **resist to high radiation dose** (up to 40MRad)

→ **New front-end electronics** for 40MHz read-out scheme

Main Challenges in UT design

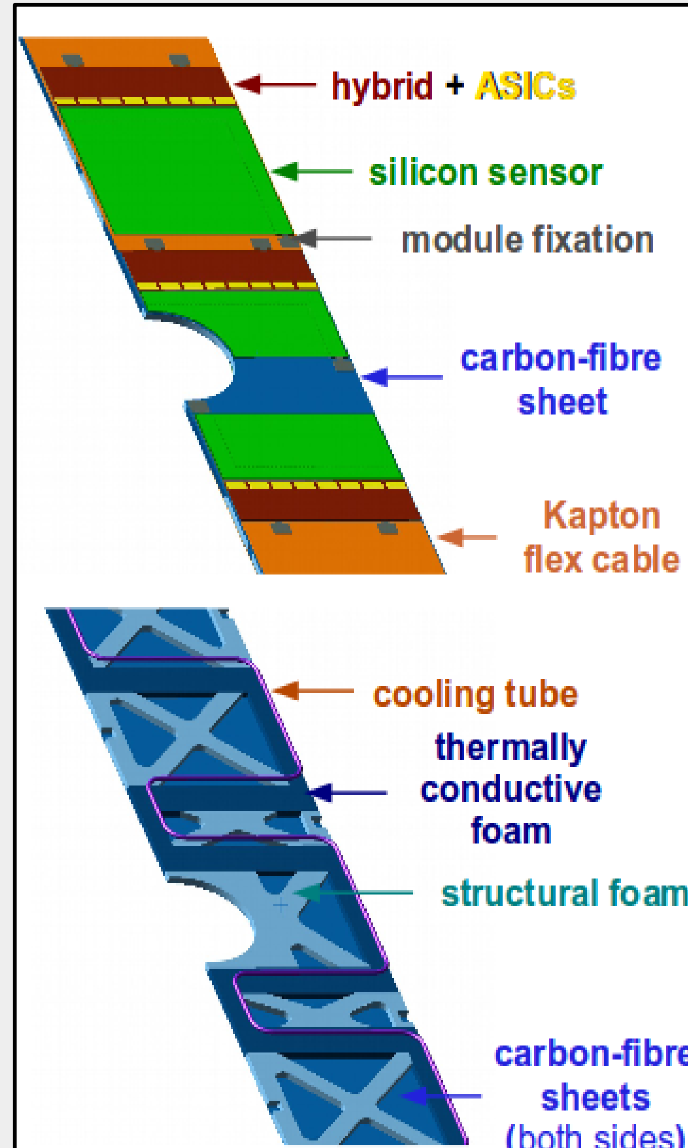
High efficiency detector → high signal over noise (~20)

Low material budget → thin and compact materials (250µm thickness)

High precision detector → high granularity (90-180µm pitch)
→ high number of channels (~500K)
→ complex read-out electronics

Resistant to radiation → need to operate at -5° to reduce the effects of radiation damage

Effiecient cooling system → evaporative CO_2 system
→ cooling tubes under the electronics
→ capable to operate until -30°C



Ceramic materials for applications to silicon sensors

Ceramic materials provide:

→ high **thermal conductivity** (~150 W/(m.K))

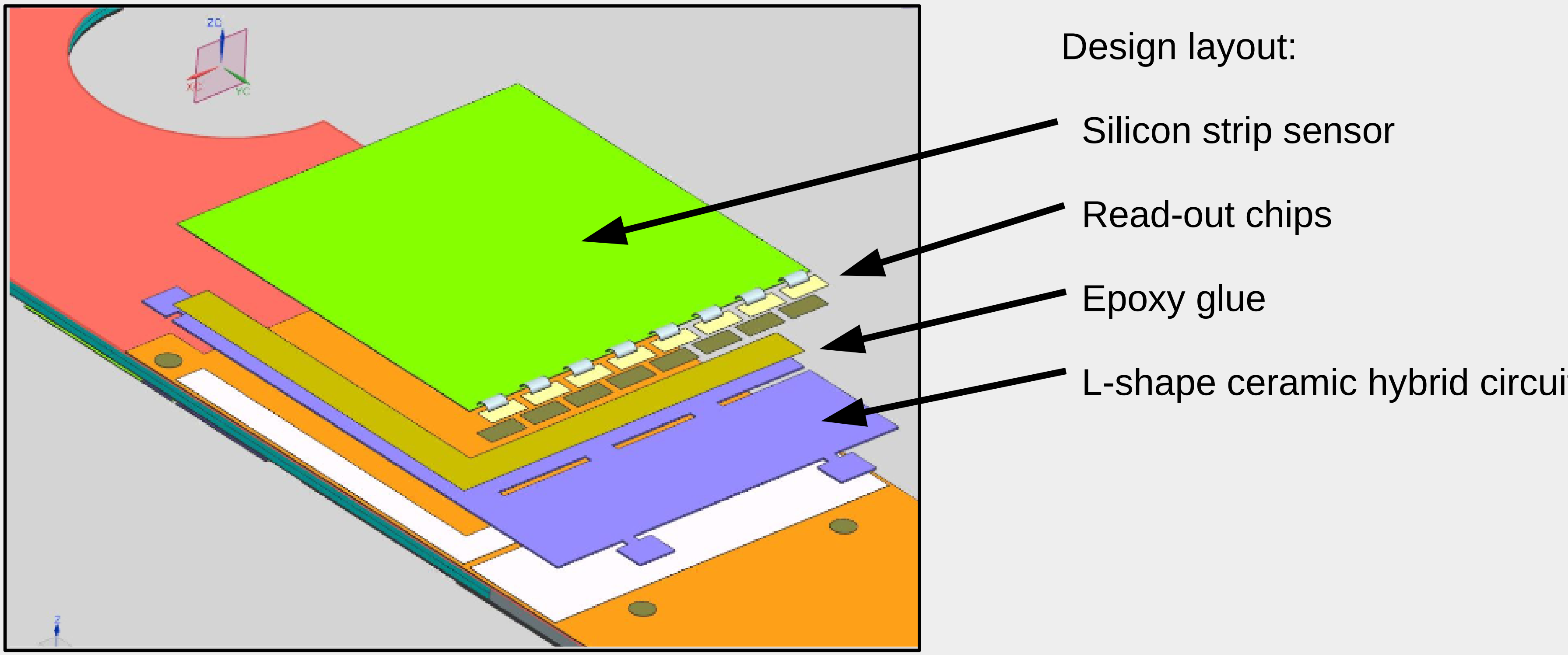
→ **precise mechanical** layout (~ O(10μm))

→ excellent **electrical insulation**
(dieletric strength ~17KV/mm)

→ excellent **resistance to radiation** (up to 40MRad)

These features are very interesting for **applications in detector construction**

Ceramic hybrid circuit for UT sensor modules



Innovative solution, based on **advanced ceramic** materials allows compact module design :

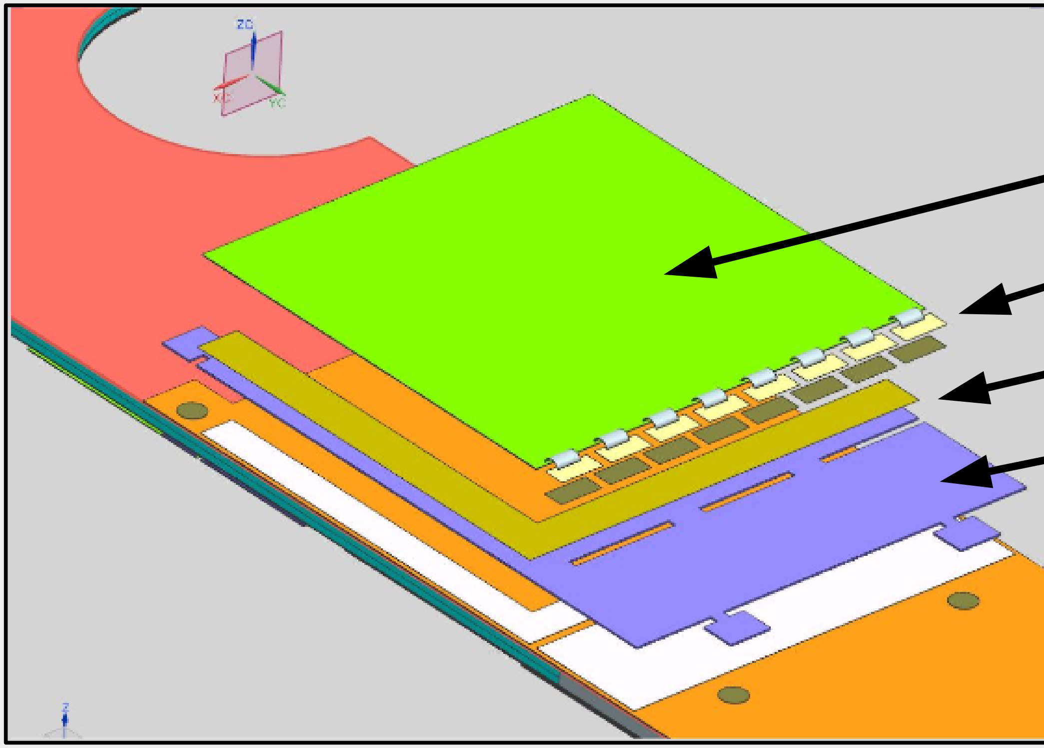
→ **Mechanical support** for sensor and front-end chips

→ Efficient **thermal bridge** between cooling system and sensor

→ **Electronic circuitry** for read-out system

→ **Low material** budget using reduced ceramic thickness

Ceramic hybrid circuit for UT sensor modules



Design layout:

- Silicon strip sensor
- Read-out chips
- Epoxy glue
- L-shape ceramic hybrid circuit

Different ceramic materials under investigation:

→ **Aluminum Nitride**: **standard** ceramic for electronic circuits
well assessed technology

→ **Pyrolitc Boron Nitride:** better mechanical properties
non standard material for electronic circuitry
R&D is required

Thermal simulations

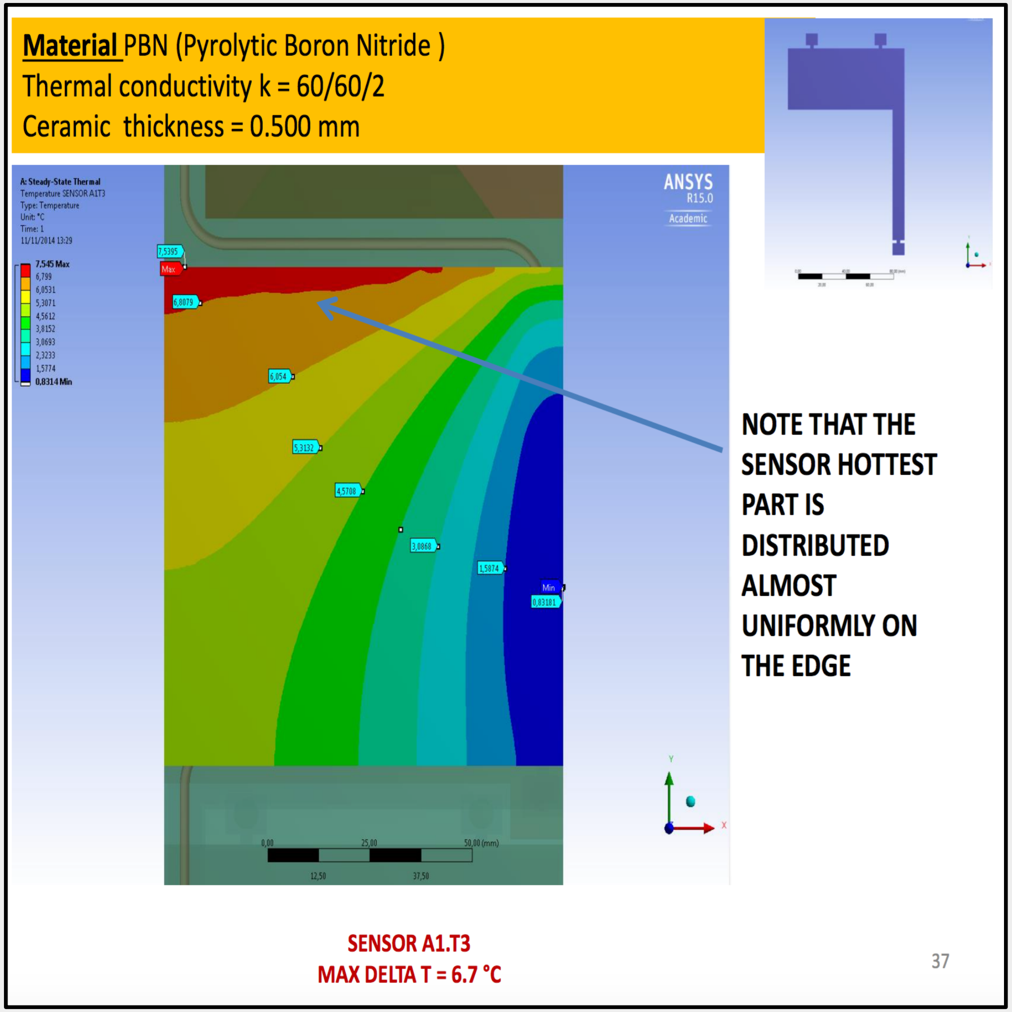
Thermal simulation to evaluate the **heat distribution** over the sensors:

→ Red region is near the read-out chip

→ Blue region is above the cooling pipe

→ **AlN and PBN simulated**

→ **Both show similar behaviour**

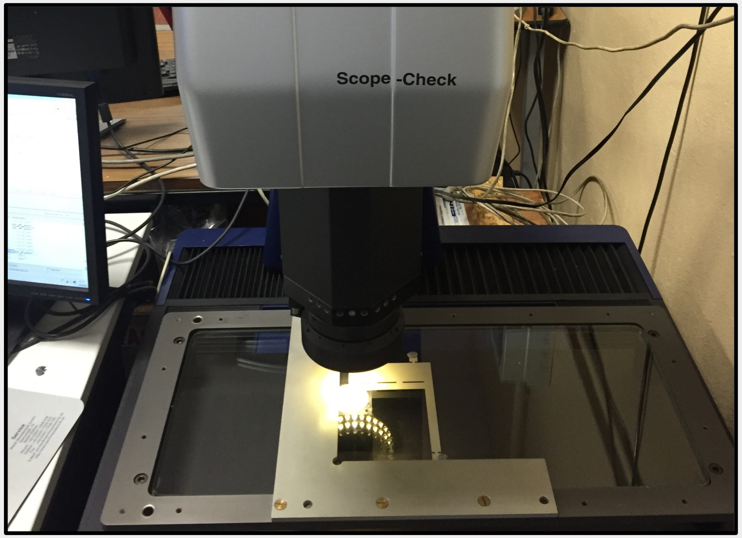


Thermomechanical simulations show **~100um deformation** along the plane axis:

→ sensor is glued along to sides only

→ **does not represent a problem**

Mechanical measurements on ceramic mechanical prototypes



Optical metrological measurements, performed on mechanical prototypes:

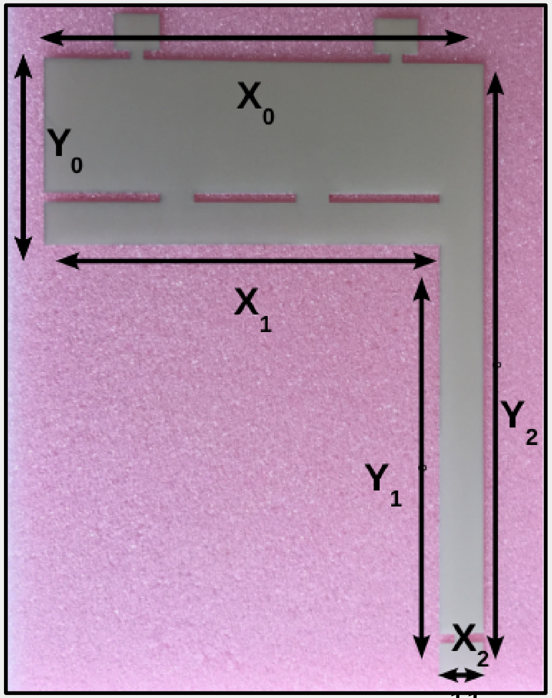
- at **ambient** temperature (20°C)
- at **nominal working** temperature (-5°C)

Planarity measurements:

- Measure **vertical coordinate** as a function of the position on the ceramic suface

Good mechanical properties:

- **No evident deformations** of the system (<10μm)



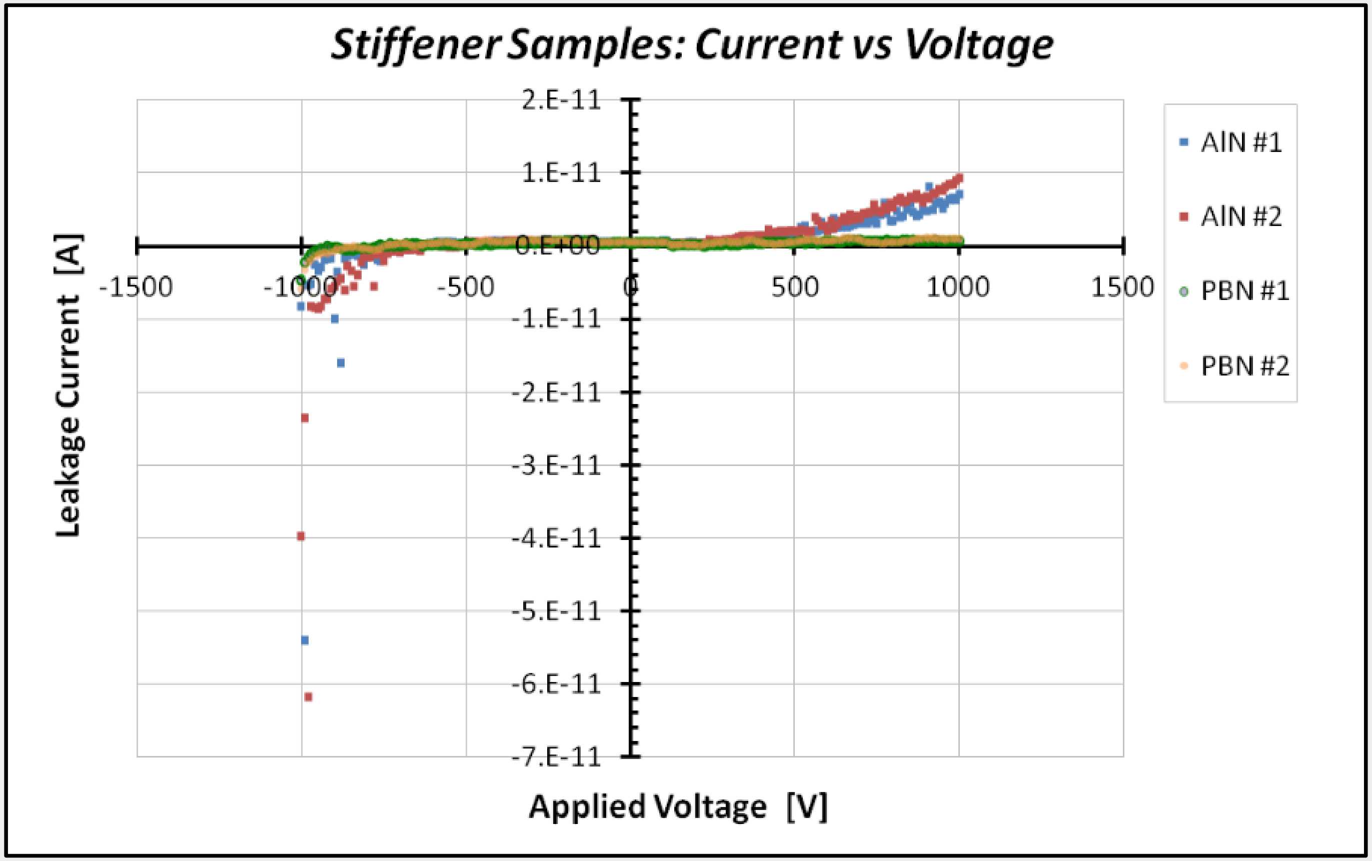
Irradiation test of Aluminun Nitride and Pyrolitc Boron Nitride ceramic

Tests on different prototypes :

→ Samples **irradiated at 40MRad** with ^{60}Co γ-rays

→ **Extremely low** leakage currents (<10pA at 500 V)

→ **Both prototypes satisfy** electrical insulation requirements



Thick-film technology for electronic circuitry on ceramic

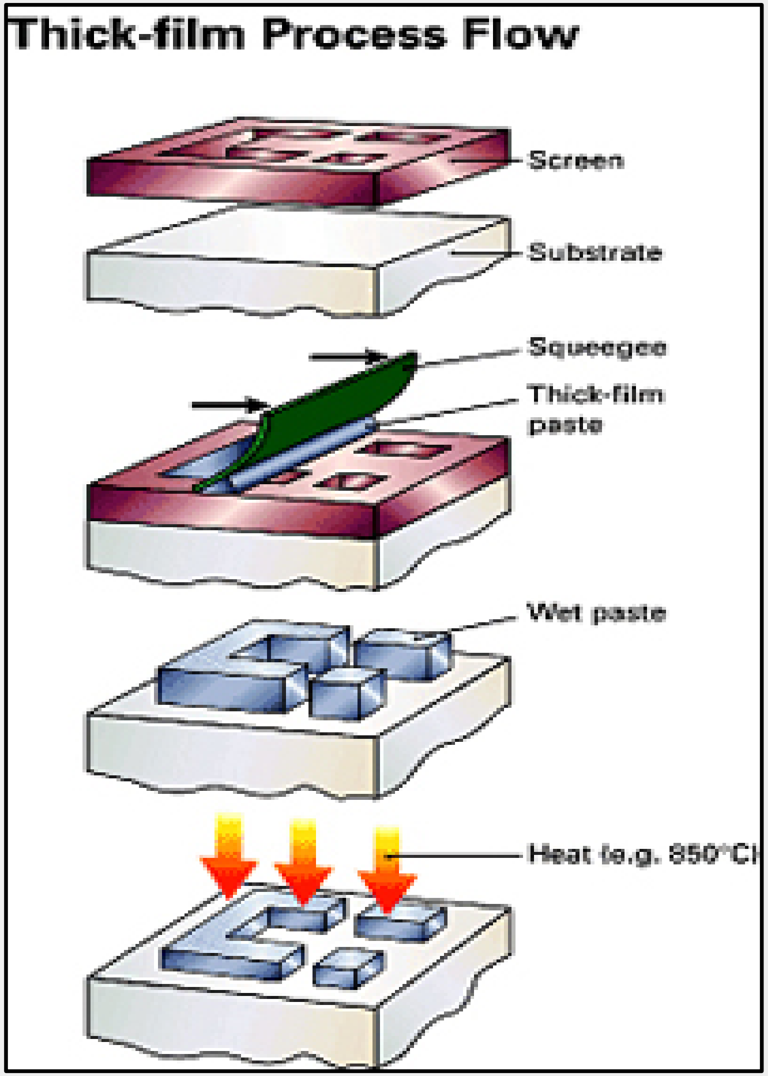
Implementation of **electronic circuitry** on ceramic is possible using the **“thick-film” technology**

A **mask** is used to apply **conductive or dieletric pastes** on the substrate to produce the desired layout

The **mask is removed by evaporation** at 50-200°C

The **paste is fixed to the substrate** by heating at higher temperatures (~800 °C)

The process is **repeated for multiple layers**



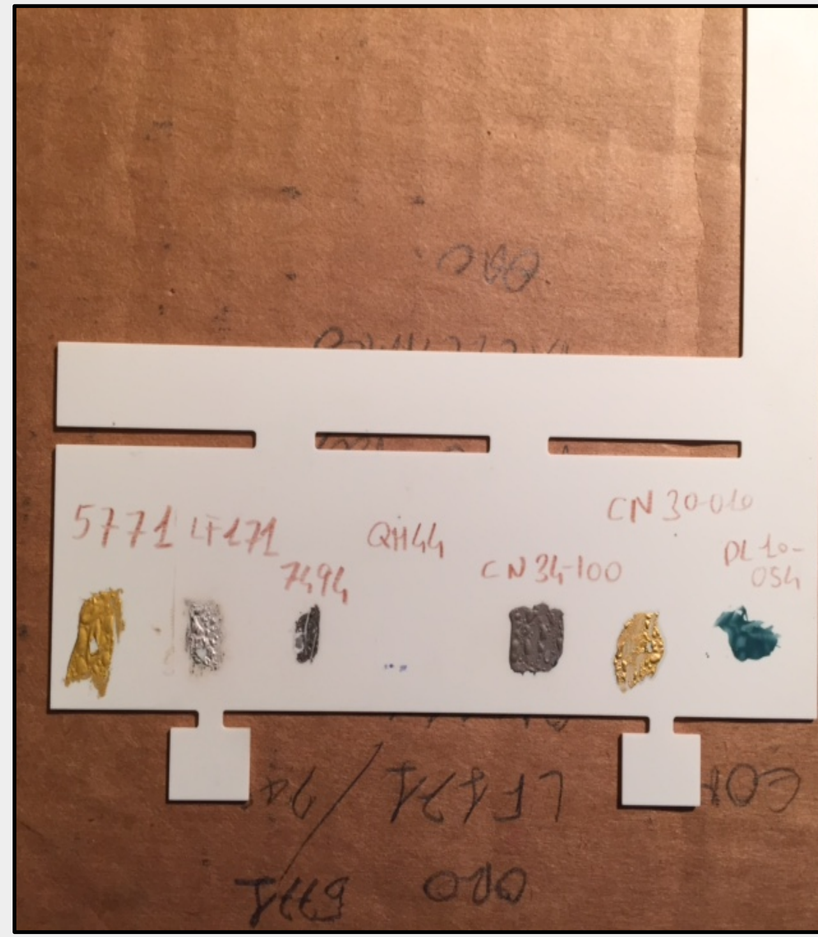
Test of thick-film technology on Pyrolitc Boron Nitride

Production of **electronic circuitry on Pyrolitc Boron Nitride** is not a standard industrial process

Altough, Pyrolitc Boron Nitride shows **better mechanical** and **radiation-hardness properties**

Different kind of **pastes are under investigation** to **verify the feasibility** of the hybrid circuit construction on this ceramic

At the moment **none of the tested pastes satisfies** the requirements



Future work and conclusions

This work is part of a **large effort for the upcoming LHCb upgrade** that will improve the data taking capibilities and it is **crucial to complete the scientific program** of the experiment

Preliminary results show that **ceramic hybrid circuit is a viable solution for the UT sensor modules**

Next steps:

Design of the first hybrid circuit, **production of a prototype** and **characterization**

→ Test of **thermomechanical properties**

→ **Characterization after proton irradiation** at 40MRad (@ IRRAD, CERN) :

→ **Integration** with silicon sensor and read-out electronics

→ **Validation of the prototype** results and approval for construction

→ **Large scale production** for application in the LHCb experiment

Thanks!