UT status report

Nicola Neri
on behalf of the Milano UT group

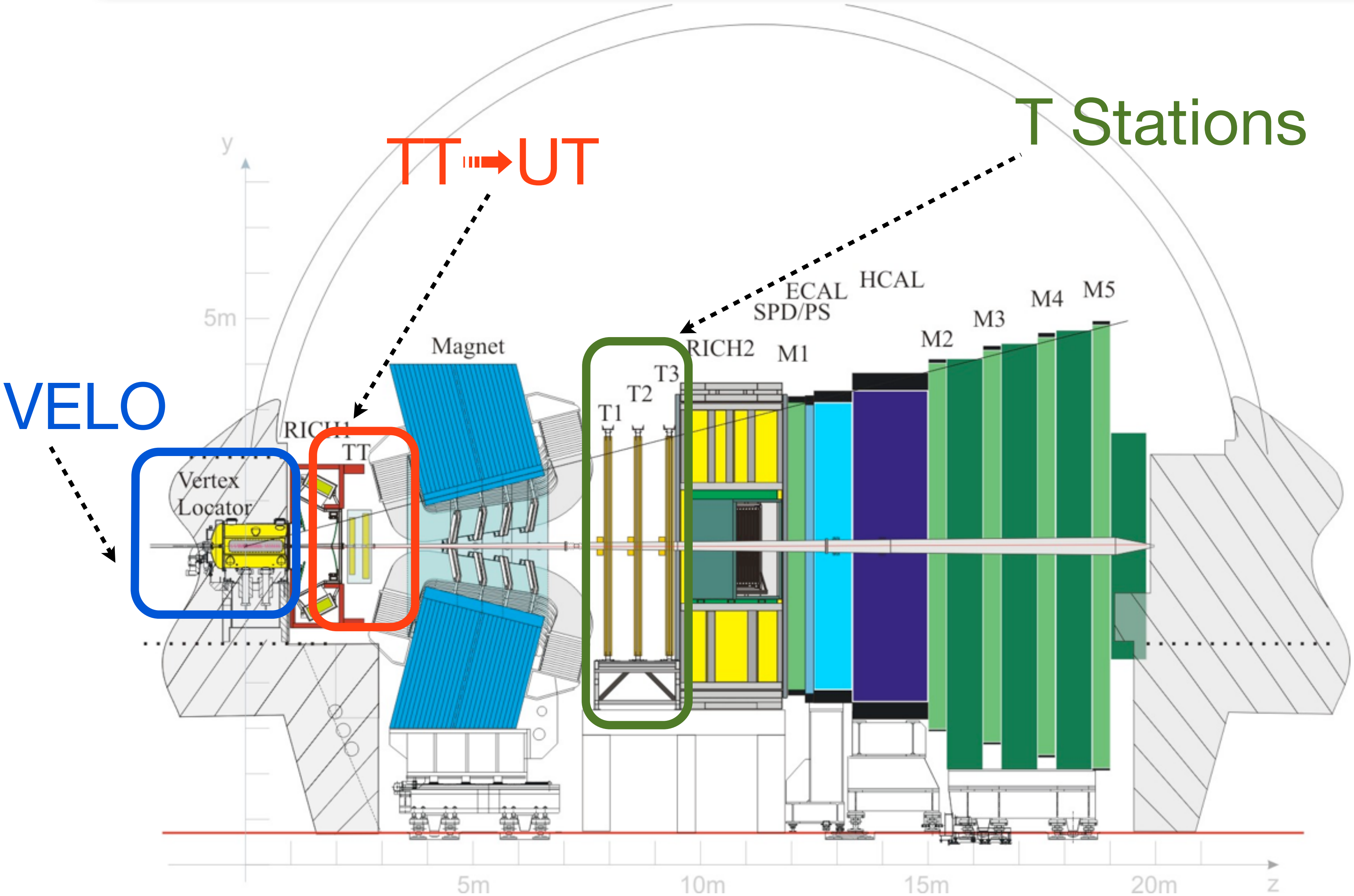
INFN - Sezione di Milano

13-14 Ottobre 2015 - LNF

Outline

- Overview of UT upgrade
- Activity in Milano
- Conclusions

LHCb detector

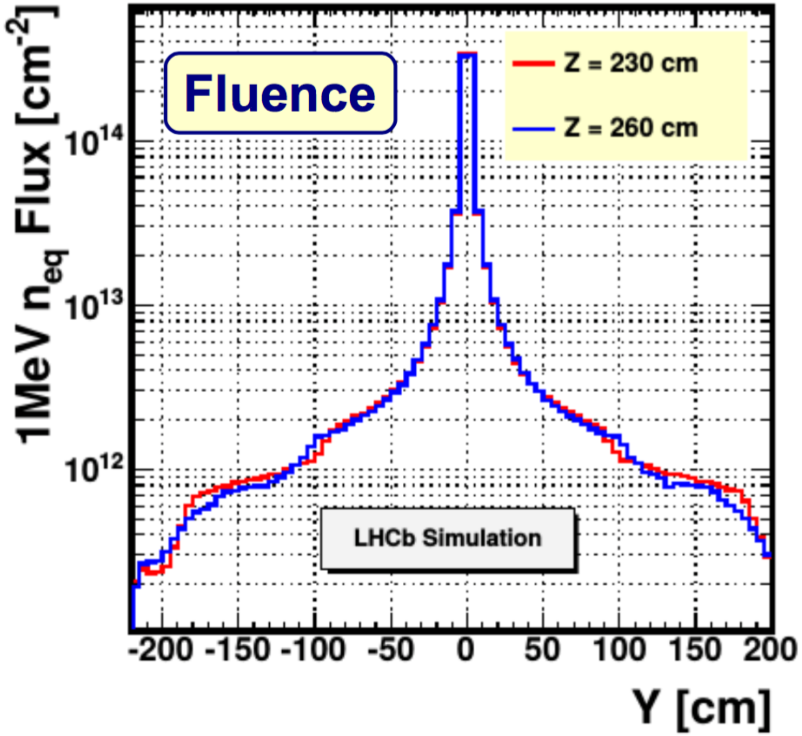


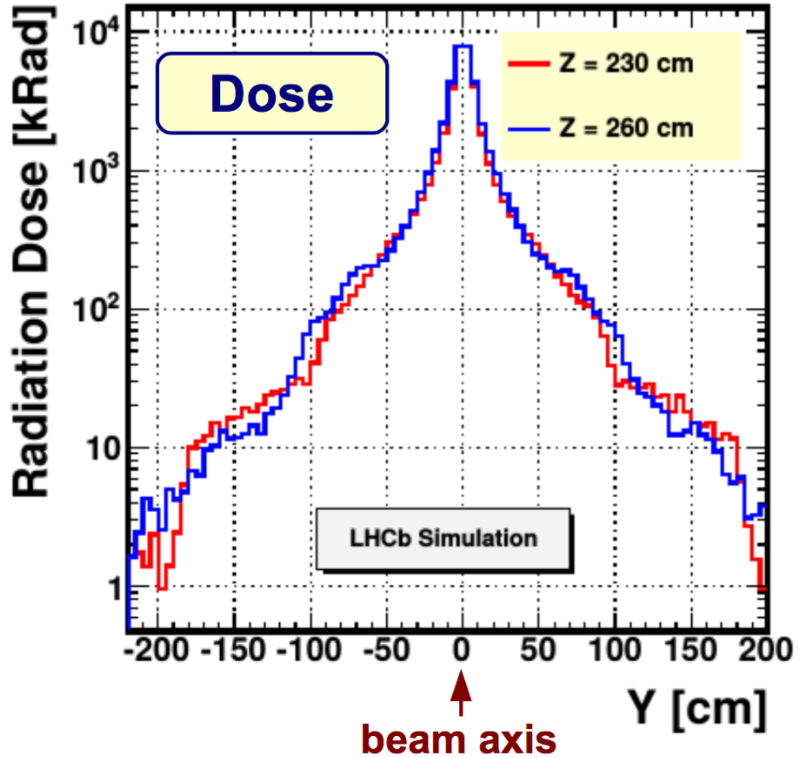
UT group

Motivations for UT upgrade

- Main motivations for TT replacement:
    - Beetle chip is not compatible with the 40 MHz readout: it is an integral part of the detector module
    - radiation hardness: particularly demanding for inner sensors (40 MRad max dose)
    - finer detector granularity: reduce the occupancy at high rates
    - Improved coverage at small polar angle: reduced beam pipe clearance, circular cut out of the sensors around the beam pipe
- Main changes and challenges in UT design:
    - readout electronics (ASICs + hybrids) in the active area: improves S/N but increases material budget and power dissipation
    - evaporative CO_2 cooling is required to operate the sensors at T=-5°C to reduce leakage current and prevent thermal runaway in presence of radiation damage

Fluence and dose





- **up to 5 × 10^{14} 1-MeV n_{eq}/cm^2**
- **up to 40 MRad**

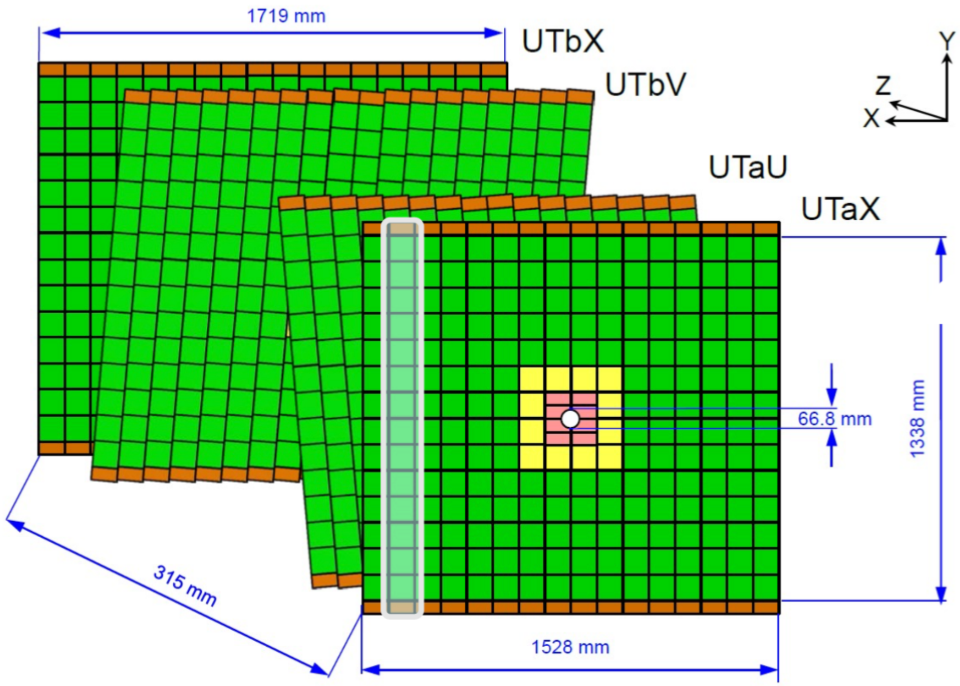
} **after 50 fb^{-1}** (including safety factor 2)

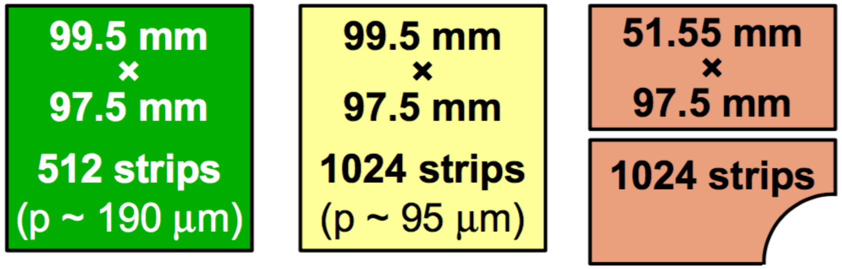
- **to mitigate effects of radiation damage:**
  - **keep sensors below – 5°C**
  - **n-in-p sensors in inner-most region** (p-in-n in outer region to save cost)

Layout

- **four detection layers**
  - 2 × vertical strips
  - +/– 5° stereo views

  } in light-tight, thermally insulating box
- **three silicon sensor geometries**
  - coarser granularity in outer region
  - finer granularity in inner region
- **silicon sensors and read-out chips mounted onto 130 cm long “staves”**
- **to avoid gaps in acceptance**
  - detectors on both sides of stave
  - adjacent staves overlapping
- **to minimize acceptance loss around LHC beam pipe**
  - inner-most sensors circular cut-outs

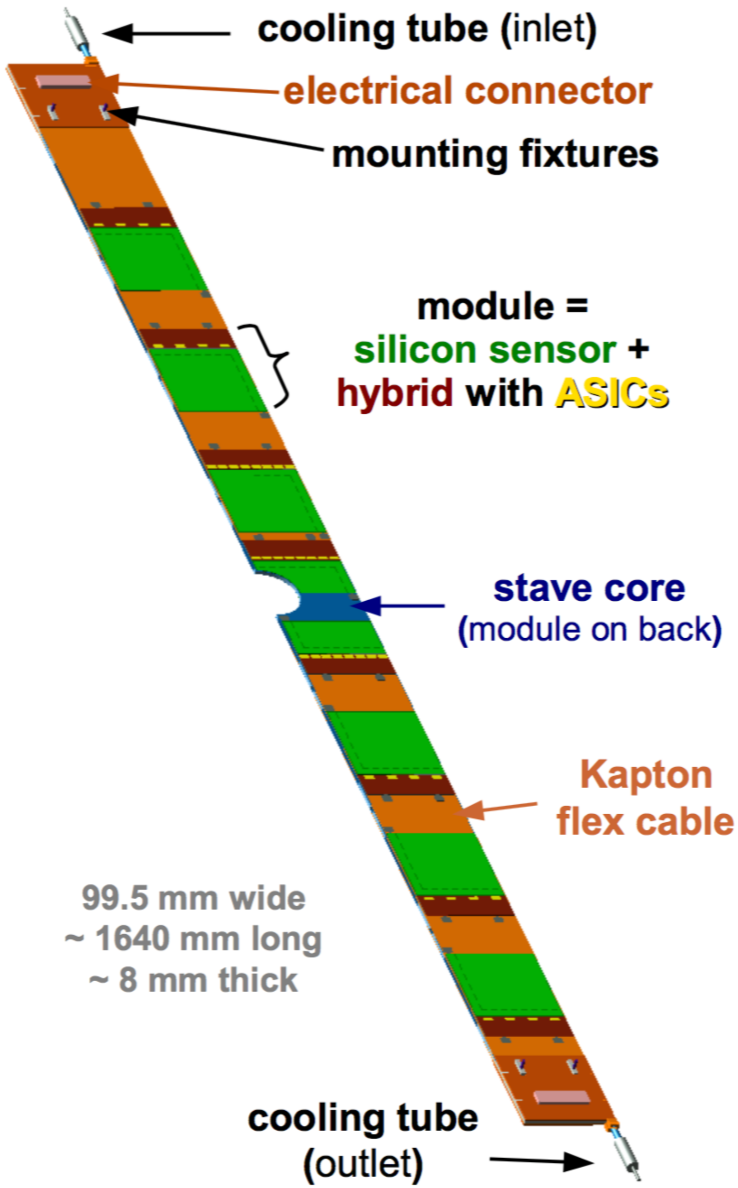




p-in-n **n-in-p**

Stave design

- **inspired by ATLAS stave concept**
  - detector modules mounted on both sides to provide full acceptance coverage
  - sensor + front-end hybrid + stiffener
- **precise positioning of detector modules**
  - rigid core consisting of sandwich structure
- **cooling of sensors and front-end electronics**
  - bi-phase CO_2 at ~ 30 bar as coolant
  - Titanium cooling pipe, 2 mm Ø
  - "snake design" to optimize heat path to ASICs
- **transport of signal readout, control signals, low voltage, bias voltage to detector modules**
  - Kapton flex cable mounted onto stave core, underneath detector modules



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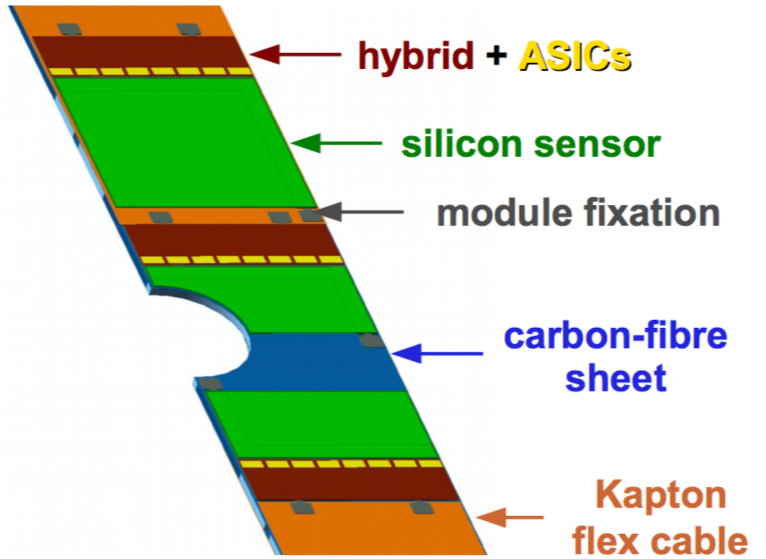
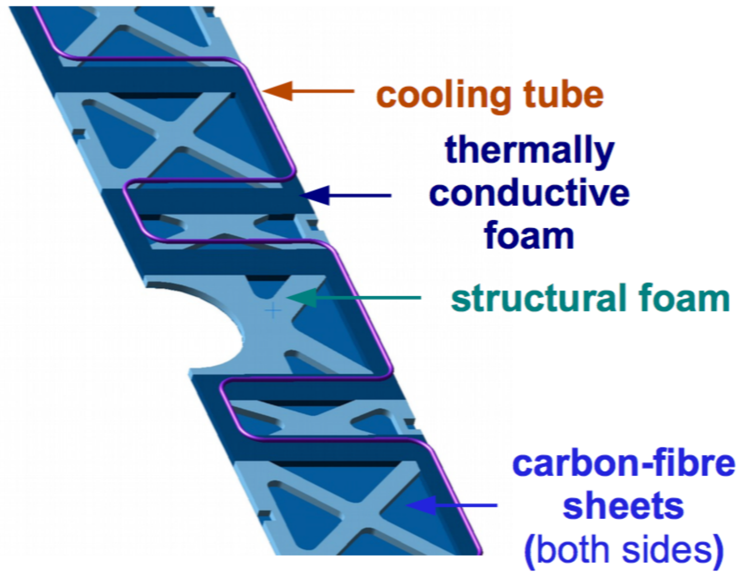


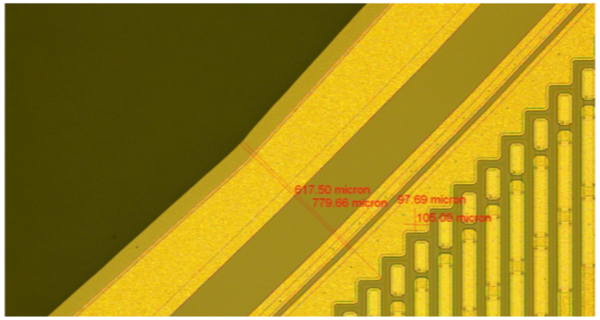


Silicon sensors

	Type A	Type B	Type C	Type D
Substrate Type	n (oxyg.)	p	p	p
Chip size x (⊥ strip) (cm)	9.75	9.75	9.75	9.75
Chip size y(‖ strip)(cm)	9.95	9.95	5.155	5.155
Thickness (μm)	250/320	250	250	250
Wafer resistivity	3-5 KΩcm	3-5 KΩcm	3-5 KΩcm	3-5 KΩcm
# of strips	512	1024	1024	1024
Interstrip C (pf)	5-35	5-35	5-20	5-20
Breakdown V (V)	>700	>700	>700	>700
Total number	1020(888)	55(48)	20(16)	20(16)

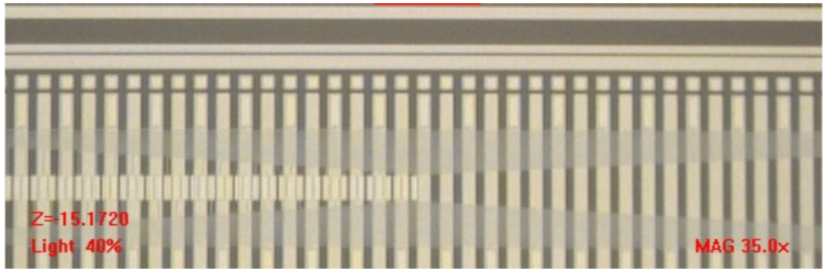
99.5 mm long	**99.5 mm long**	**51.55 mm long**	**51.55 mm long**
512 strips (p ~ 190 μm)	**1024 strips** (p ~ 95 μm)	**1024 strips** (p ~ 95 μm)	**1024 strips** (p ~ 95 μm)

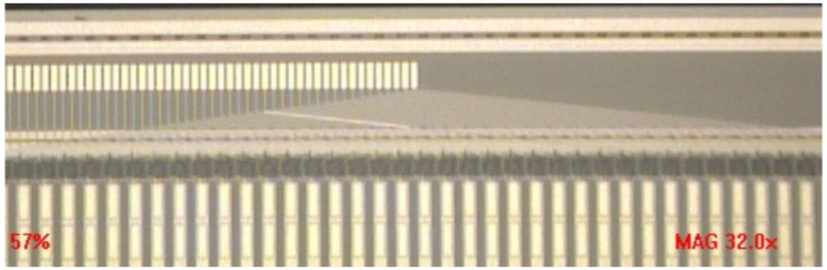
Silicon sensors



Circular cutouts (type D)

- **layout of guard rings close to cut-out**
  - charge collection efficiency, radiation hardness

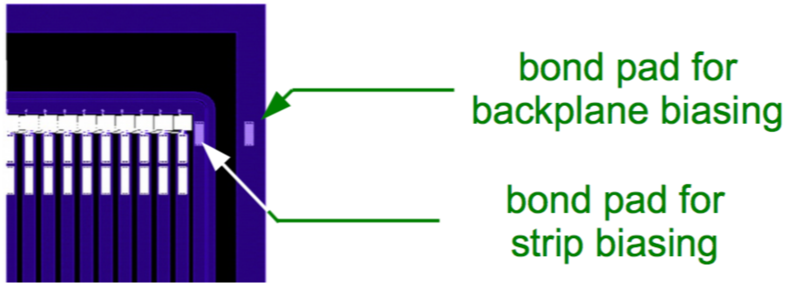




Embedded pitch adaptors (type A)

- **implemented as double-metal layer**
  - reduce dead material
  - save one row of wire bonds
- **two geometries under consideration**
  - cross talk
  - charge loss

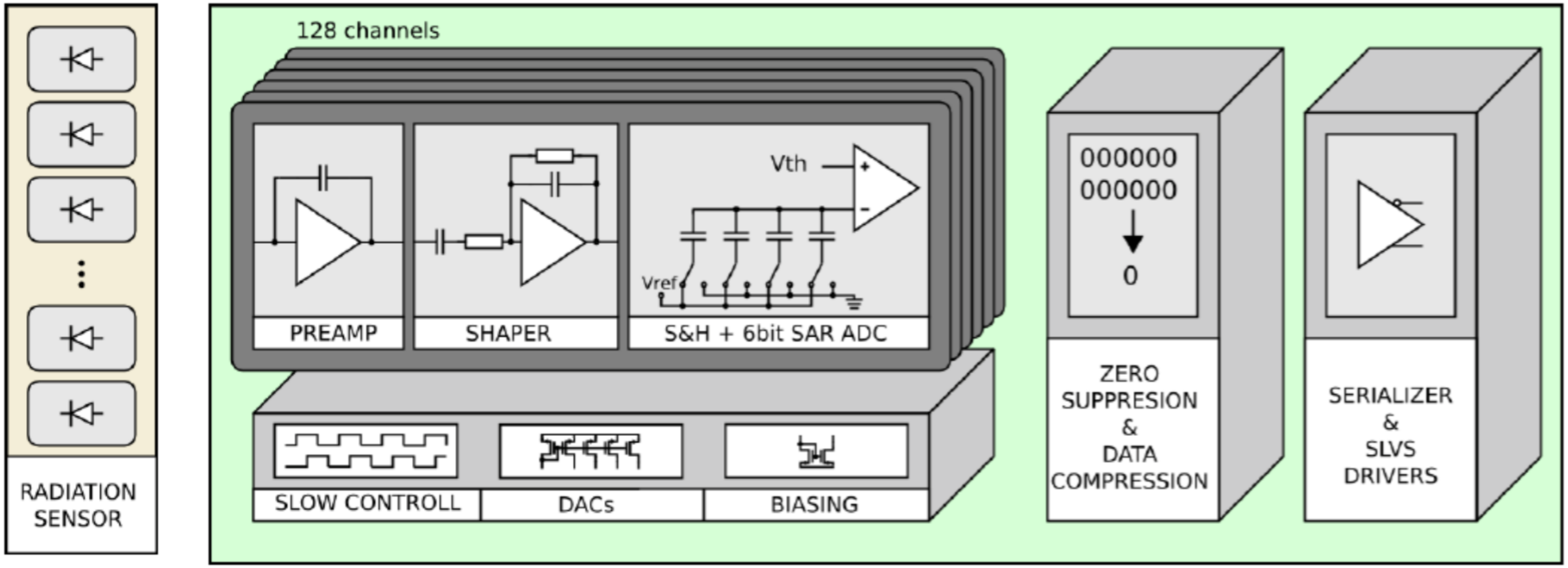
  } before and after irradiation
- **external pitch adaptor as backup**



Top-side biasing (all sensor types)

- **connection to backplane via active edge**
  - long-term performance, radiation hardness
- **modified module design allowing for direct contact to backplane as backup**

SALT readout chip



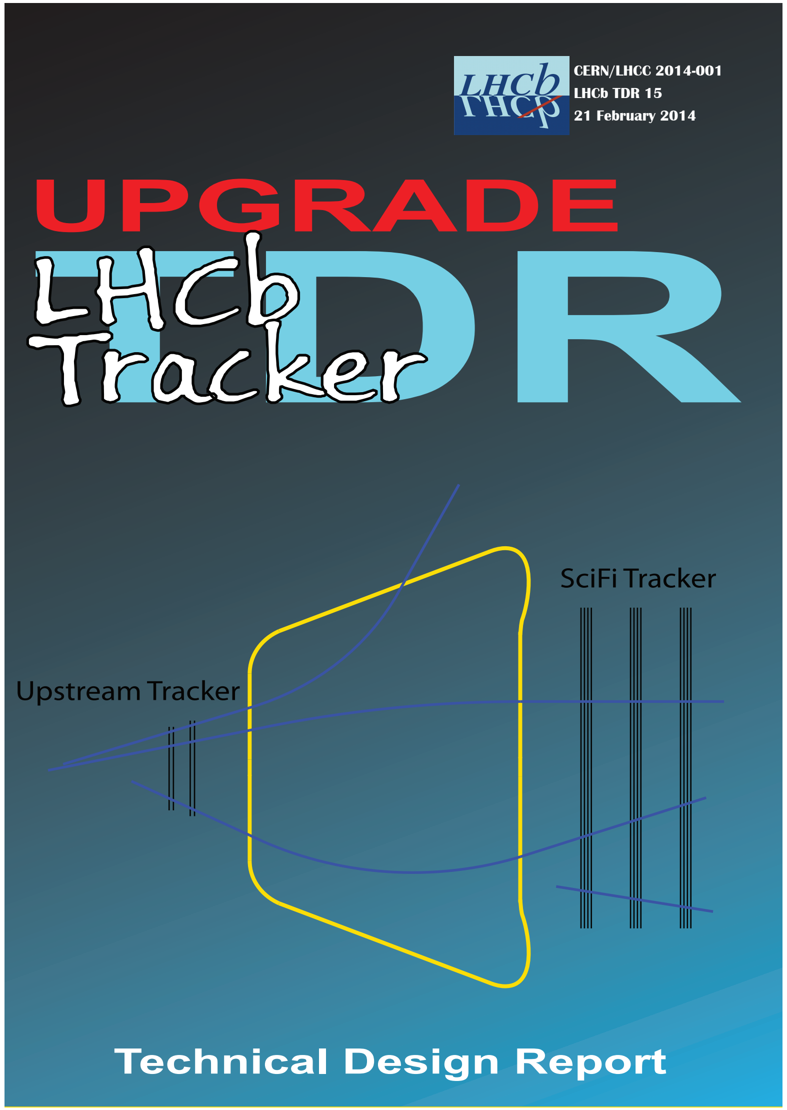
Custom development in radiation-hard 0.13 μm technology (IBM → TSCM)

- **128 channels: front–end amplifier → shaper → ADC → pedestal subtraction**
- **zero–suppression → data compression → serialisation**
- **SLVS output drivers: (up to) five e–port links**
- **first version of full 8–channel prototype in hand, tests ongoing**

INFN Milano activities

- Design and construction of:
  - flex cables
  - hybrid circuits for front-end electronics
- Design of CO_2 cooling system
  - Thermal and mechanical simulations of the UT stave
  - Cooling system prototype
- Test and characterisation of prototype silicon strip sensors
  - Test in laboratory
  - Test beam: developed new DAQ board and software for reconstruction and analysis of the data

LHCb Tracker TDR



- Authors of Tracker TDR

A. Abba[u], F. Caponio[u], M. Citterio, S. Coelli, A. Cusimano[u], J. Fu, A. Geraci[u], M. Lazzaroni[t], M. Monti, N. Neri, F. Palombo[t]
[25]*Sezione INFN di Milano, Milano, Italy*

- Responsibilities for UT upgrade
  - Sensor and Hybrids WG (M. Citterio co-convener)
  - Mechanics and Cooling WG (S. Coelli co-convener)
  - Integration with LHCb WG (N.Neri co-convener)
  - Editor of Tracking TDR (N. Neri "Mechanics and cooling" chapter)

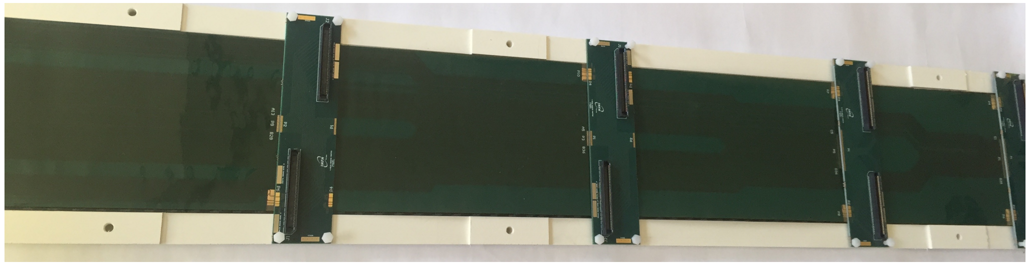
Data flex design

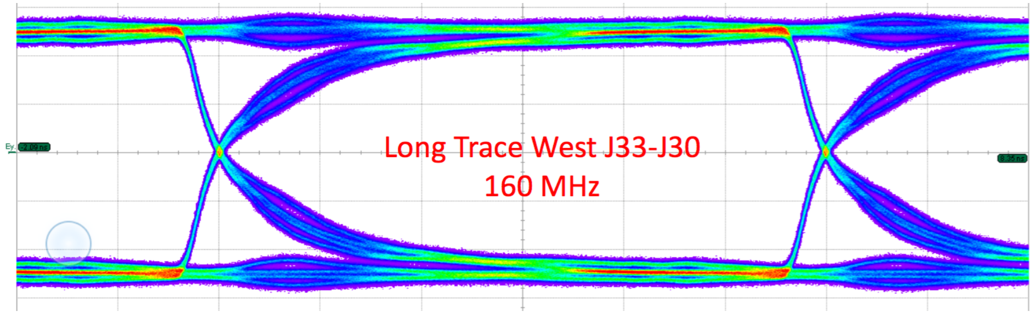
Mauro Citterio
Fabrizio Sabatini

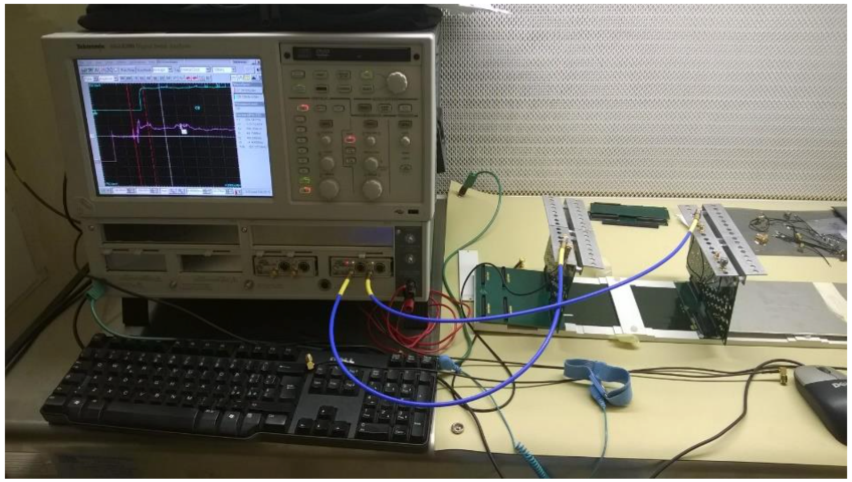
- Technological challenge:
  - data flex positioned under the silicon sensors in the active area: carrying power, ground and data lines
  - low material budget (~0.1% X_0): Kapton + Cu (Al) traces
  - thousands of traces, 80 cm long and 10 cm wide
  - low impedance, signal integrity
  - few manufacturers available

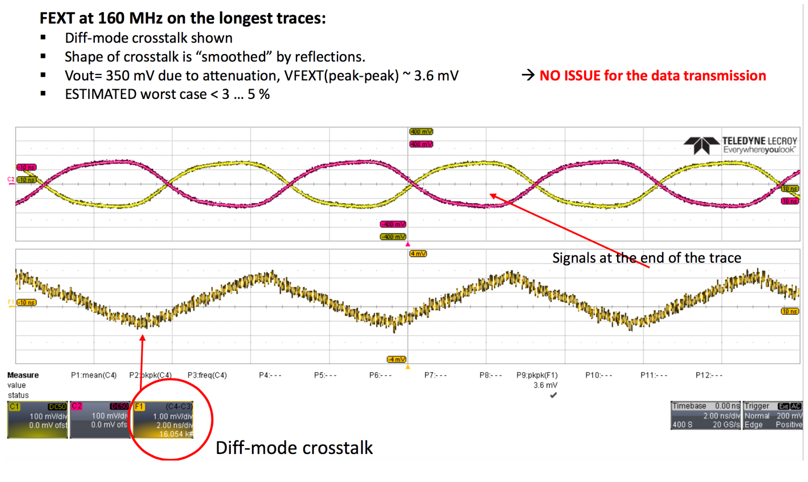
Data flex - 1st prototypes

- First generation data flex
  - produced at industry
  - good signal transmission, low cross-talk: design validated
  - but low yield in production





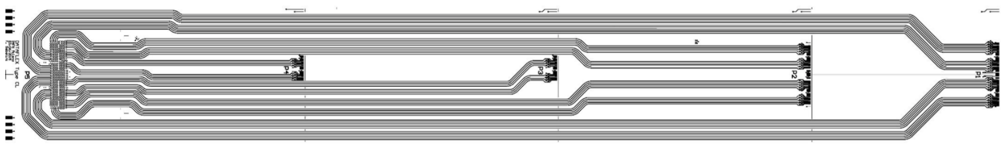




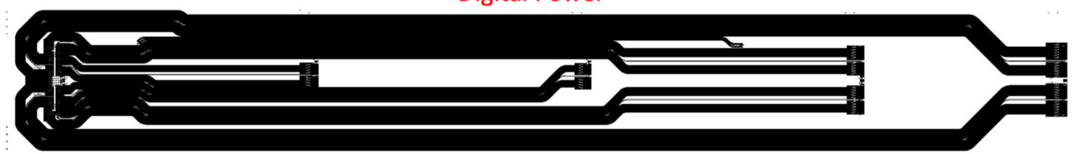
Data flex - 2nd prototypes

- Technology: full flex + stiffener design
- Improvements: better trace shapes and width, added HV traces, stack with 4 layers (2 data + 2 power lines), larger space between traces
- CERN workshop is the baseline production facility. Received few samples in these days, starting the test
  - Contacts with other manufacturers: Altaflex (USA) visit company on Nov 6th. Also contacts with ViaSystem (USA), and Flexible Technology (UK)

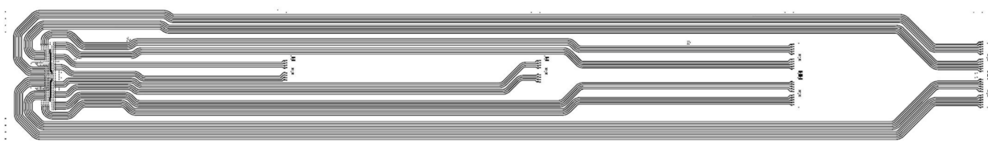
Top Layer



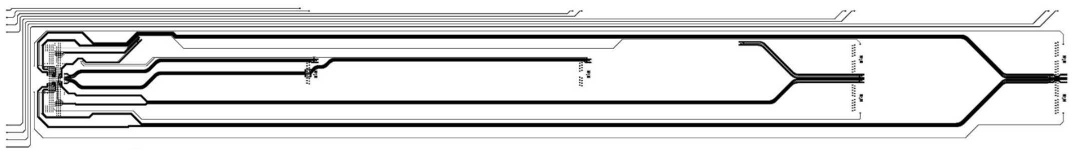
Digital Power



Inner Layer



Analog Power + HV

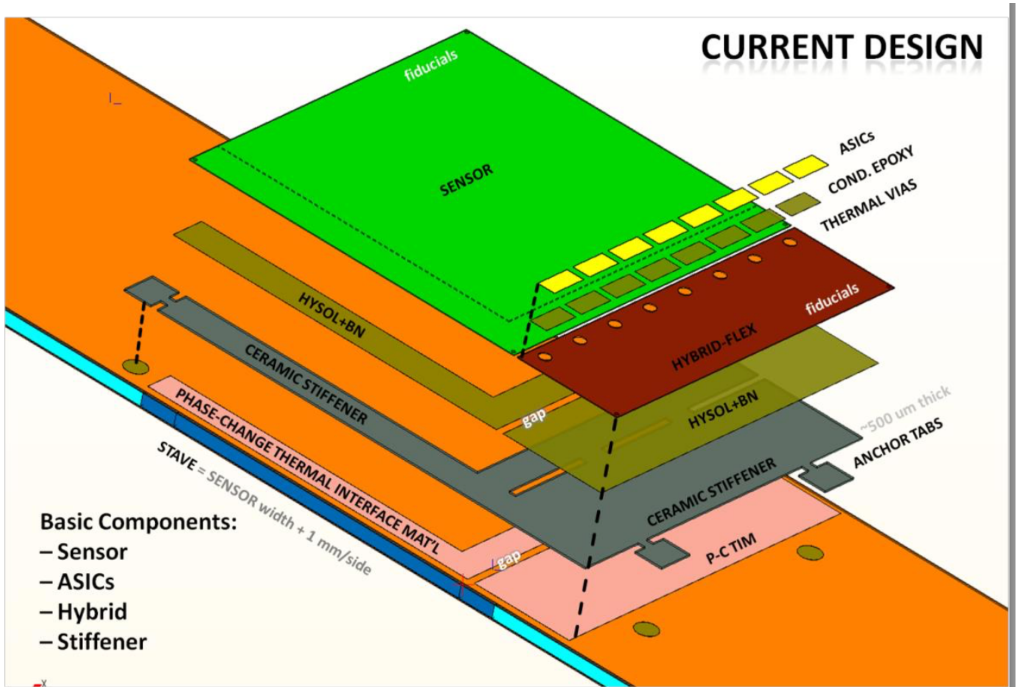


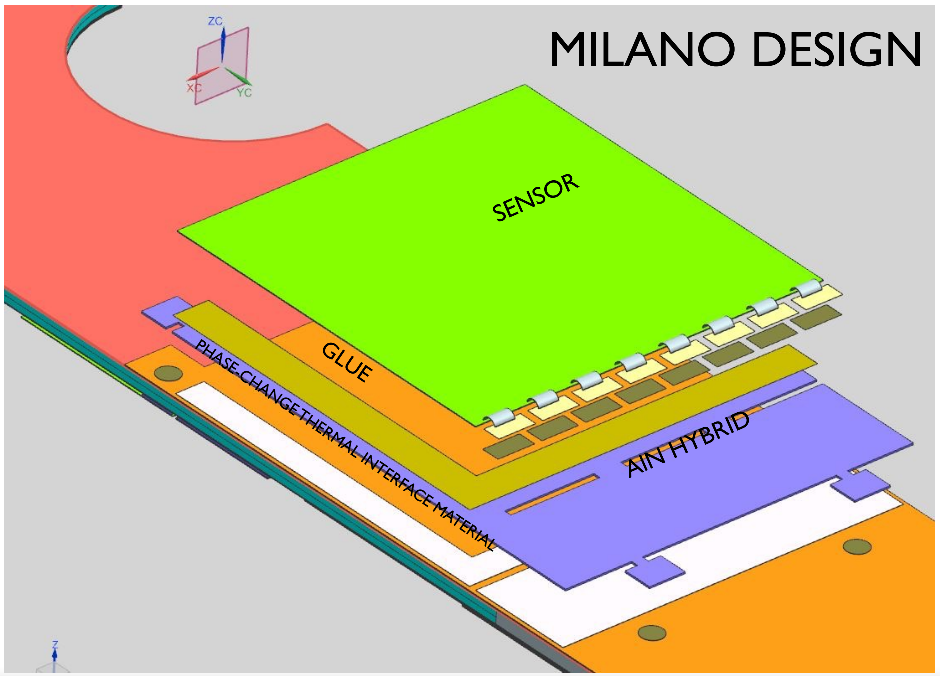
Module design

- Low material budget and operations at T=-5 ºC set stringent requirements on module design
- Efficient heat dissipation and electrical insulation for sensor and FEE
- Use of ceramic material: excellent thermal conductivity and electrical insulation

Mauro Citterio
Fabrizio Sabatini

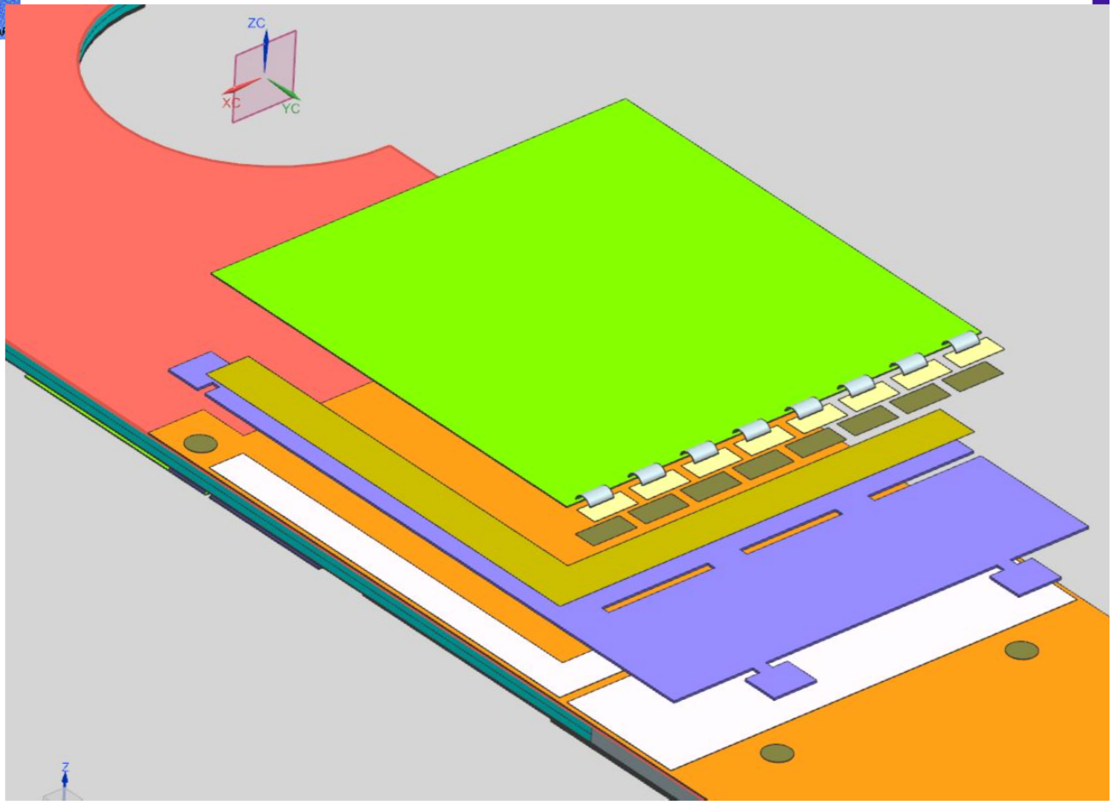
Nicola Neri
Marco Petruzzo





Milano proposal for ceramic hybrid

New Ceramic Hybrid Design

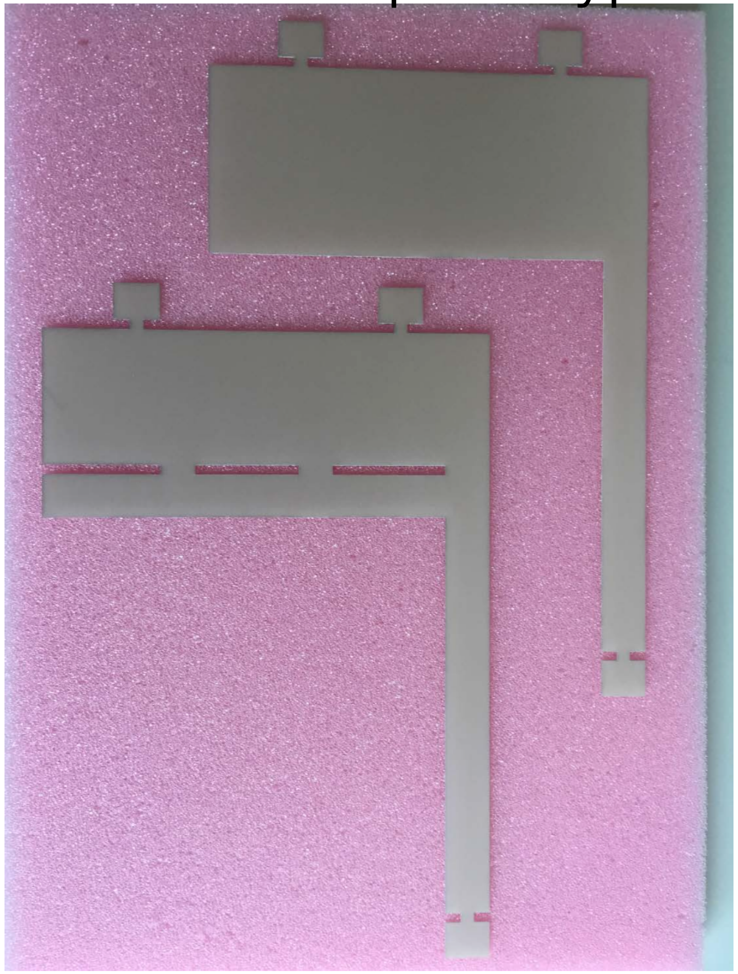


With respect to v5 hybrid solution: no thermal vias, no hybrid flex, no epoxy layer
Pro: improved thermal conductivity and cooling efficiency
Simplified construction and mounting of the stave

8/05/2015 Mauro Citterio - UT Workshop May 2015

Thick-film technology for electronic circuitry
Aurel produced AlN hybrids for BaBar SVT

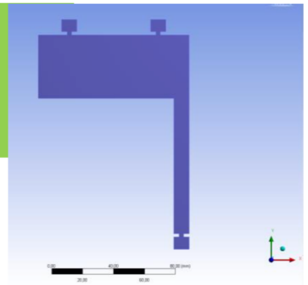
Mechanical prototypes

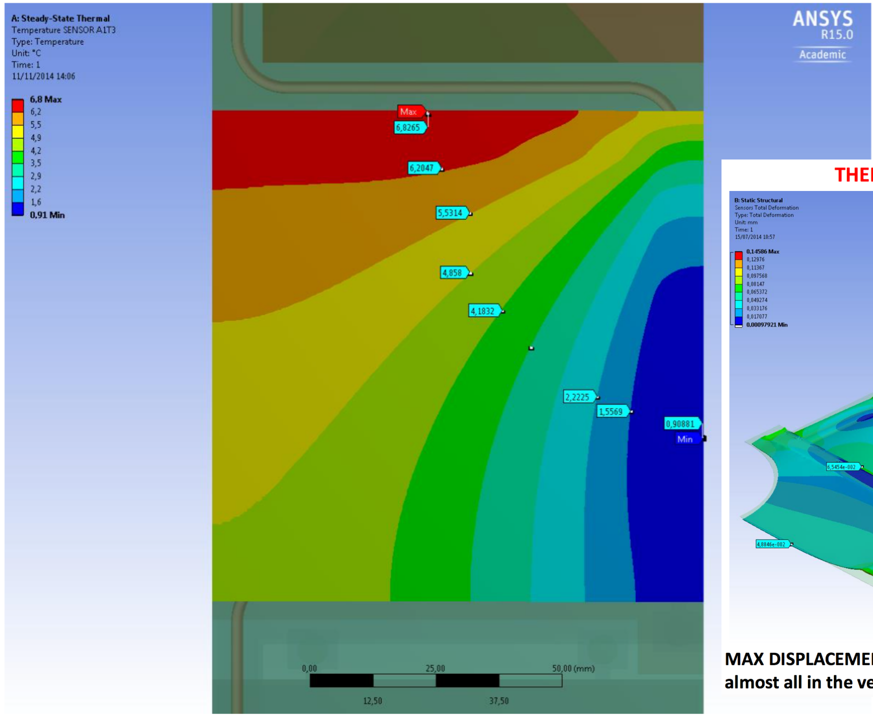


250 um thick AlN substrate

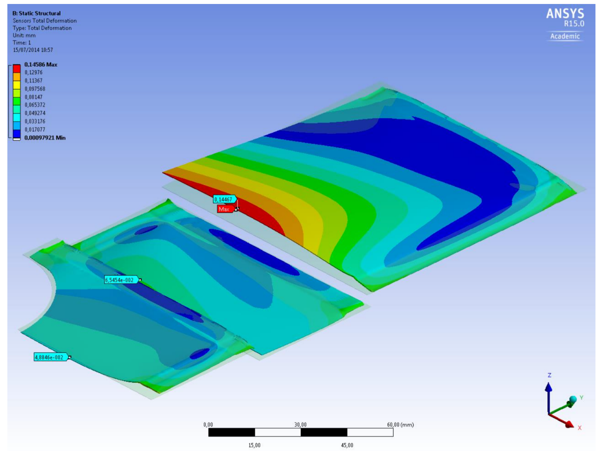
Thermal & Mechanical simulations

Material AlN (Aluminum Nitride)
thermal conductivity k = 180/180/180;
ceramic thickness = 0.250 mm





THERMALLY INDUCED DEFORMATION



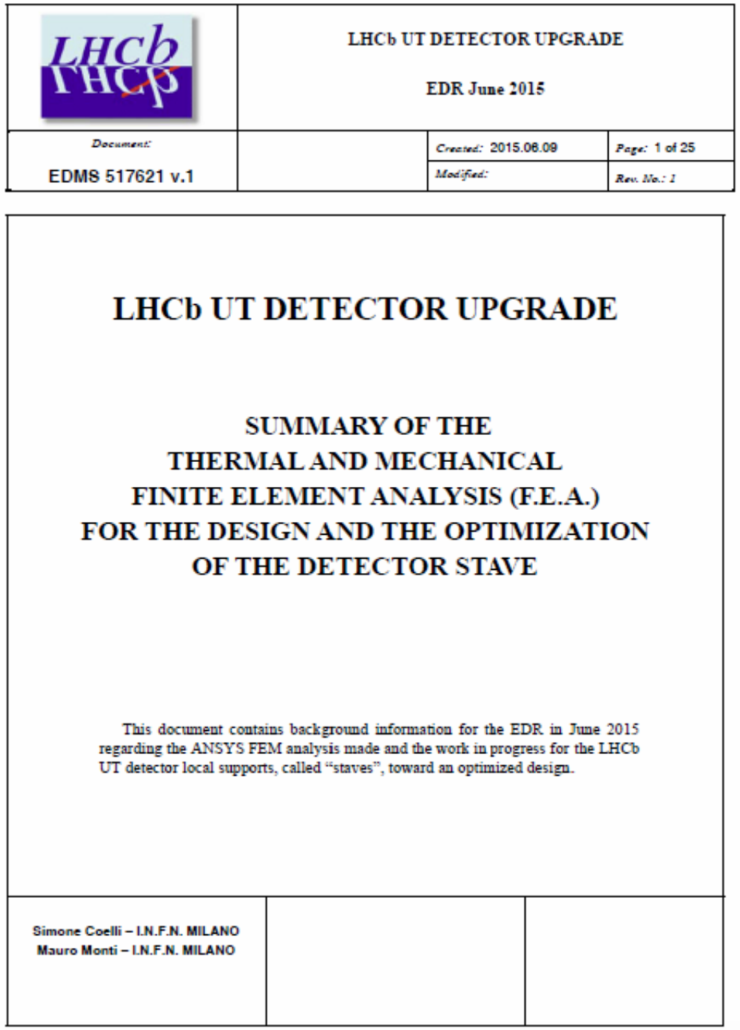
MAX DISPLACEMENT IN THE SENSOR A1.T3: 150 µm
almost all in the vertical direction Z axis, out of sensor plane

SENSOR A1.T3
MAX DELTA T = 5.9 °C

39

T_{max} (sensor) < T (CO_2) + 7°C	✔
ΔT (sensor) < 6°C	✔
T (ASIC) < T (CO_2) + 23°C	✔

Simone Coelli
Mauro Monti



LHCb UT DETECTOR UPGRADE

EDR June 2015

Document: EDMS 517621 v.1

Created: 2015.06.09

Modified:

Page: 1 of 25

Rev. No.: 1

LHCb UT DETECTOR UPGRADE

SUMMARY OF THE
THERMAL AND MECHANICAL
FINITE ELEMENT ANALYSIS (F.E.A.)
FOR THE DESIGN AND THE OPTIMIZATION
OF THE DETECTOR STAVE

This document contains background information for the EDR in June 2015 regarding the ANSYS FEM analysis made and the work in progress for the LHCb UT detector local supports, called "staves", toward an optimized design.

Simone Coelli – I.N.F.N. MILANO
Mauro Monti – I.N.F.N. MILANO

$C0_2$ cooling setup in Milano

Opened cold box

Dummy stave with heaters +temperature sensors

Mock-up stave with titanium cooling tubes in snake pipe configuration

Cooling system measurement of T, P of CO_2 fluid

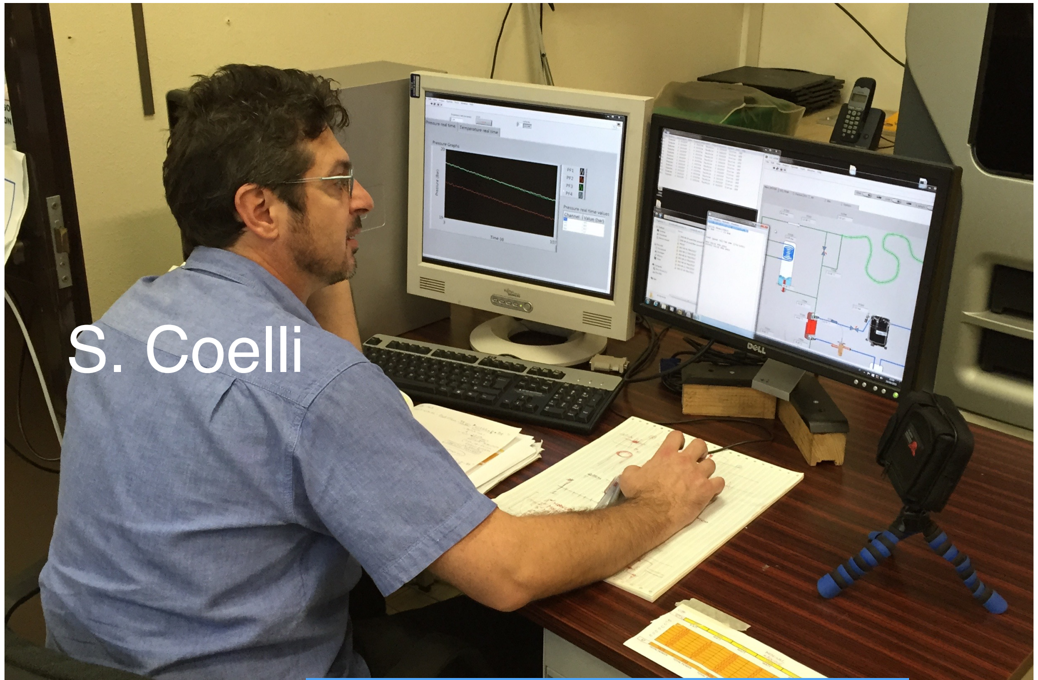
TRACI v 2-Phase Accumulator Controlled Loop system from CERN.

Measurement of CO_2 mass flow

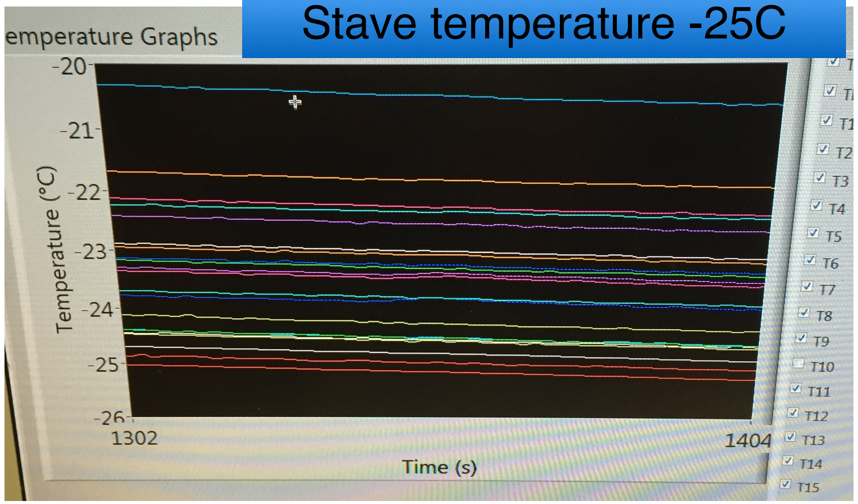
Simone Coelli
Andrea Capsoni
Carlo Gesmundo
Andrea Merli
Ennio Viscione

UT stave cooling test

“Control room” for CO_2 cooling system



Stave temperature -25C

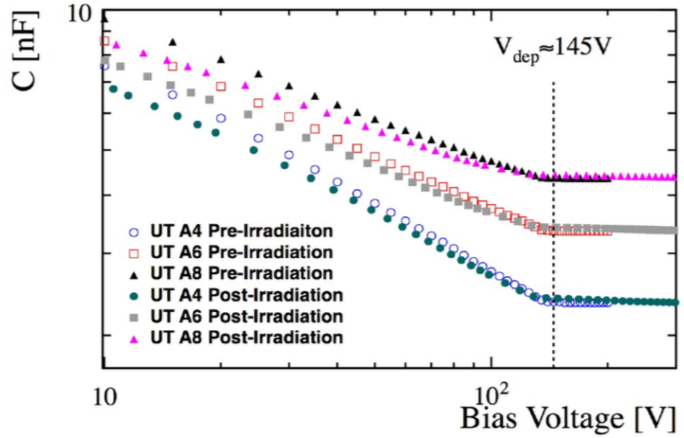


TRACI CO_2 system

Test beam activity

First prototypes from Micron and HPK

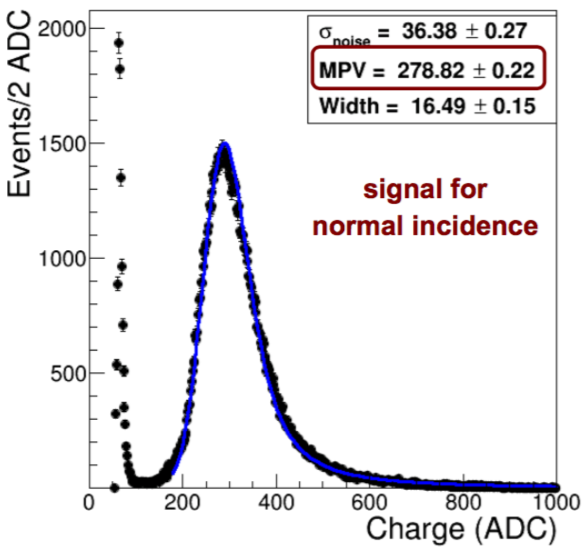
- **not yet final thickness and technology**
- **irradiation with 24 GeV p at CERN irrad facility**
    - up to 3.2 × 10^{13}/cm^2 (type A), 7.4 × 10^{14}/cm^2 (type D)
- **test beam campaign using 180 GeV p at CERN**
    - VELOpix beam telescope (→ 3 μm resolution)
    - Beetle readout chip for detectors under test
- **analyses underway**

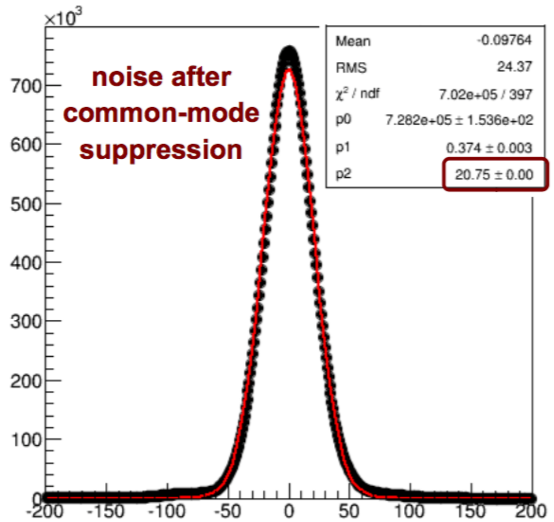


S/N ~ 13.4

okay for 200 μm thick sensors and Beetle noise performance

- **expect new set of prototype sensors with final specs by the end of 2015**





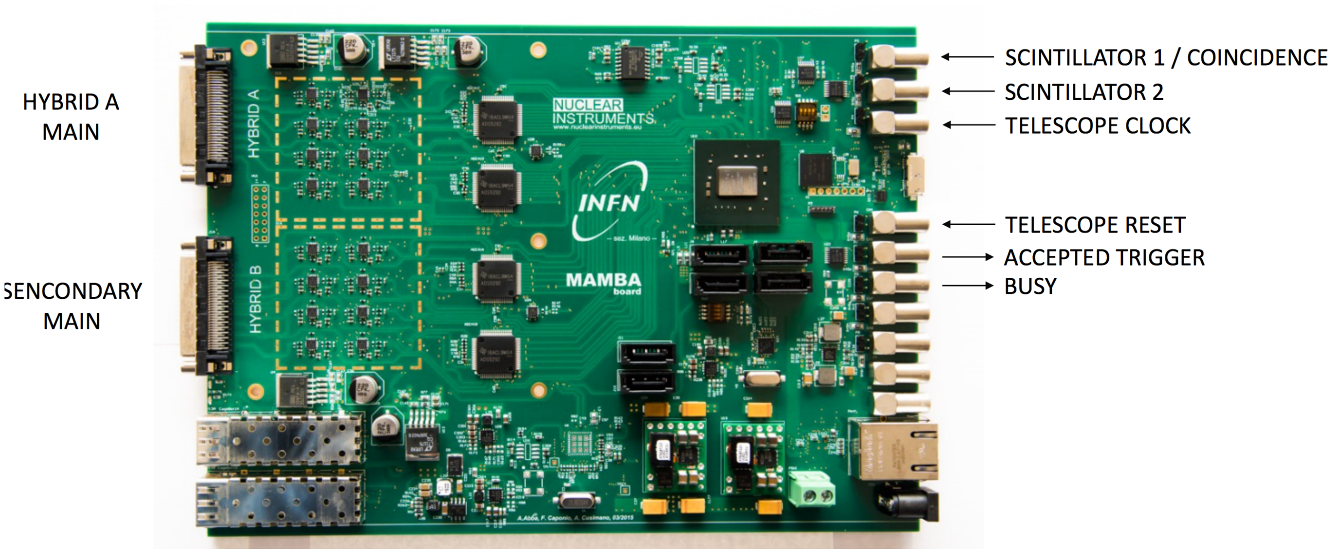
Milano contributions

- New DAQ system for testbeam
- Online software and GUI
- Offline reconstruction and simulation software
- Silicon strip sensor telescope

New DAQ system

Andrea Abba,
Francesco Caponio

- Developed in Milano a new DAQ system for testbeam:
  - 100x DAQ rate wrt previous Alibava system
  - improved trigger scheme and track matching (time stamp info for DUT hit-Telescope track matching)
  - online software: GUI, Beetle chip configuration, monitoring



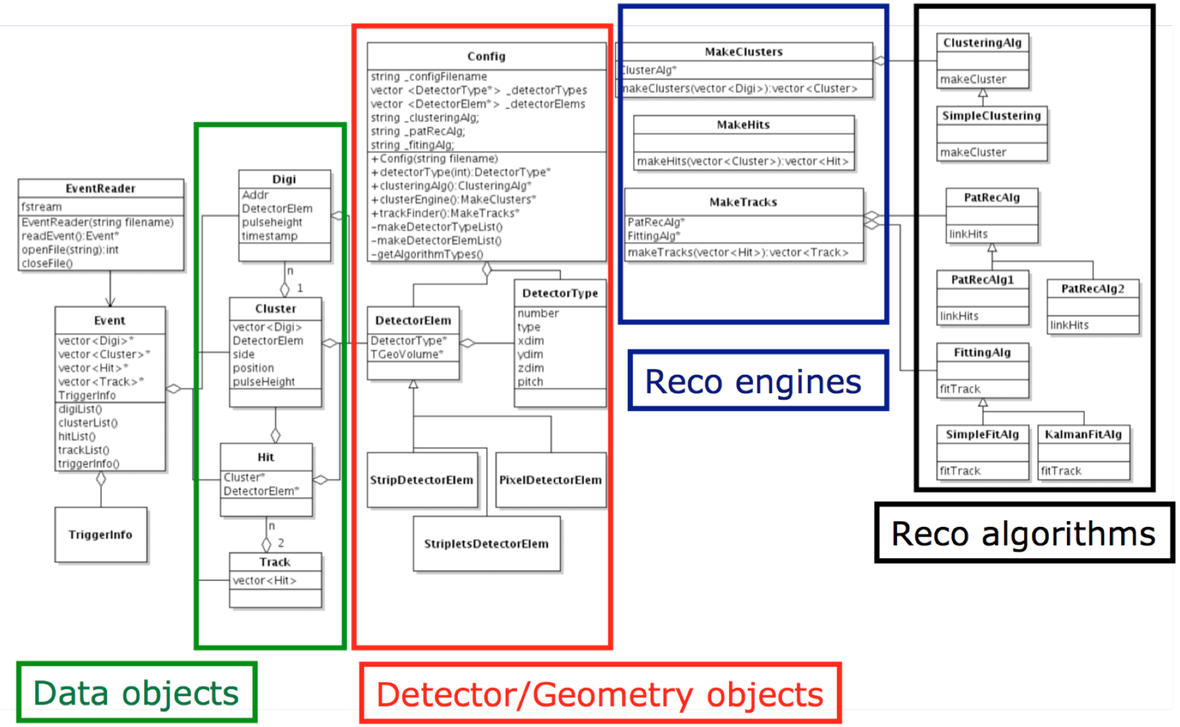
DAQ system performed very well in July and October testbeam and was acknowledged by the UT collaboration

synergy with Retina CSN5 experiment

Offline software

- Software package (Sbt) for track reconstruction and analysis of testbeam data
- Data analysis

Nicola Neri
Marco Petruzzo
Jinlin Fu
Biplab Dey



LHCb-PUB-2015-015
May 30, 2015

Testbeam studies of pre-prototype silicon strip sensors for the LHCb UT upgrade project

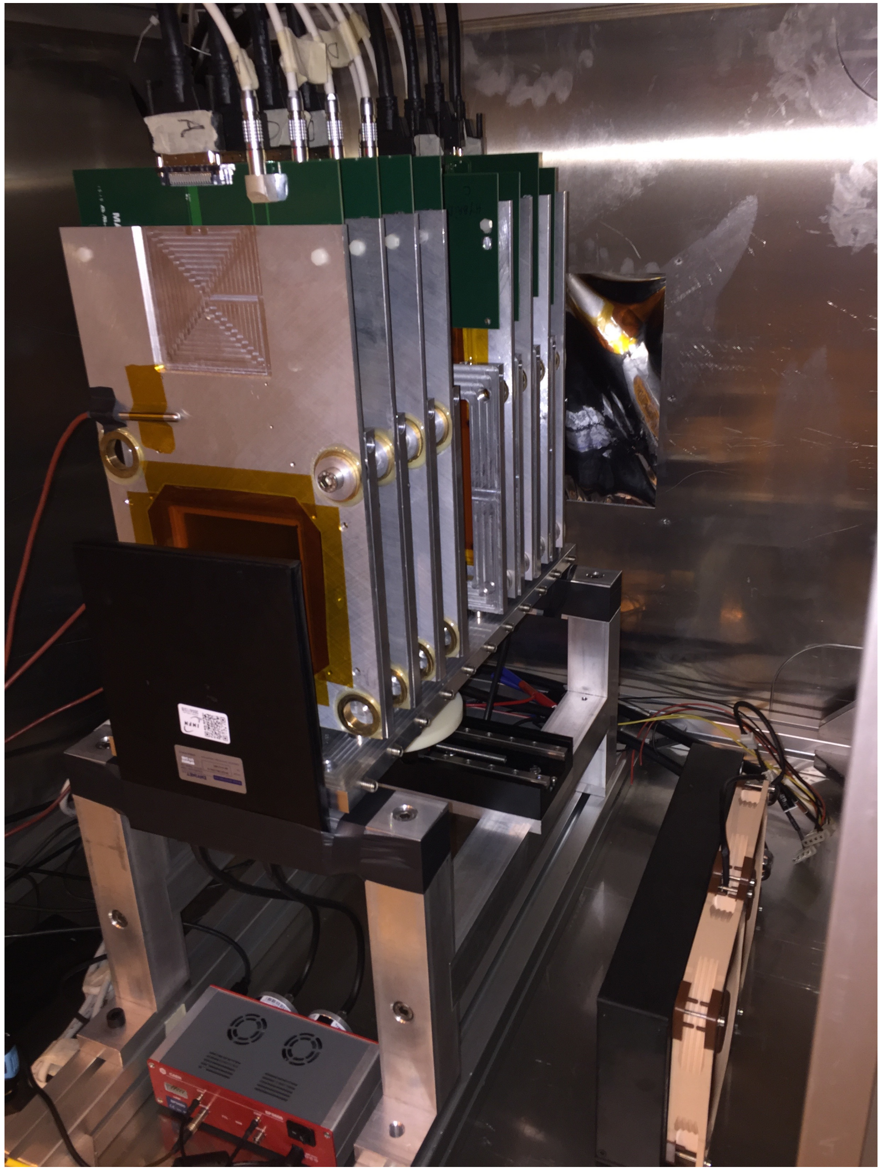
A. Abba[1], M. Artuso[2], S. Blusk[2,6], T. Britton [2], A. Davis[3], A. Dendek[4], B. Dey[5], S. Ely[2], T. Evans[7], J. Fu[1], P. Gandini[2], F. Lionetto[5], P. Manning[2], B. Meadows[3], R. Mountain[2], N. Neri[1], M. Petruzzo[1], M. Pikies[4], T. Skwarnicki[2], T. Szumlak[4], J. C. Wang[2]

[1] *Instituto Nazionale di Fisica Nucleare - Sezione di Milano, Italy*
[2] *Syracuse University, Syracuse, NY USA*

arXiv:1506.00229 **Accepted, NIM A**

“Retina” telescope

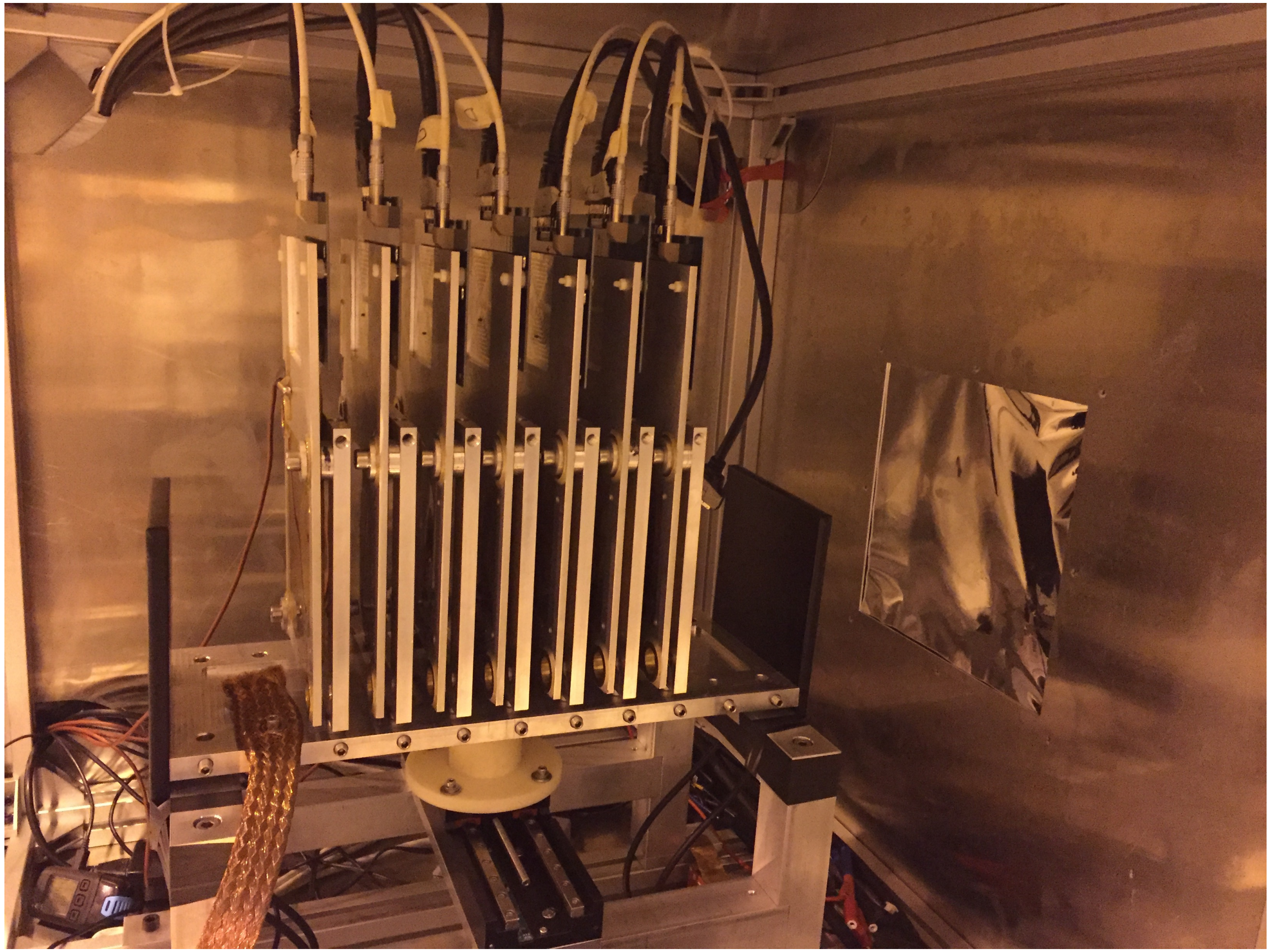
- Built in Milano a telescope based on TT silicon strip sensors and Beetle chip readout
- Artificial retina algorithm for real time tracking implemented in custom Mamba DAQ board (CSN5 project)
- First prototype of embedded real time tracking system based on retina algorithm



October 2015 testbeam

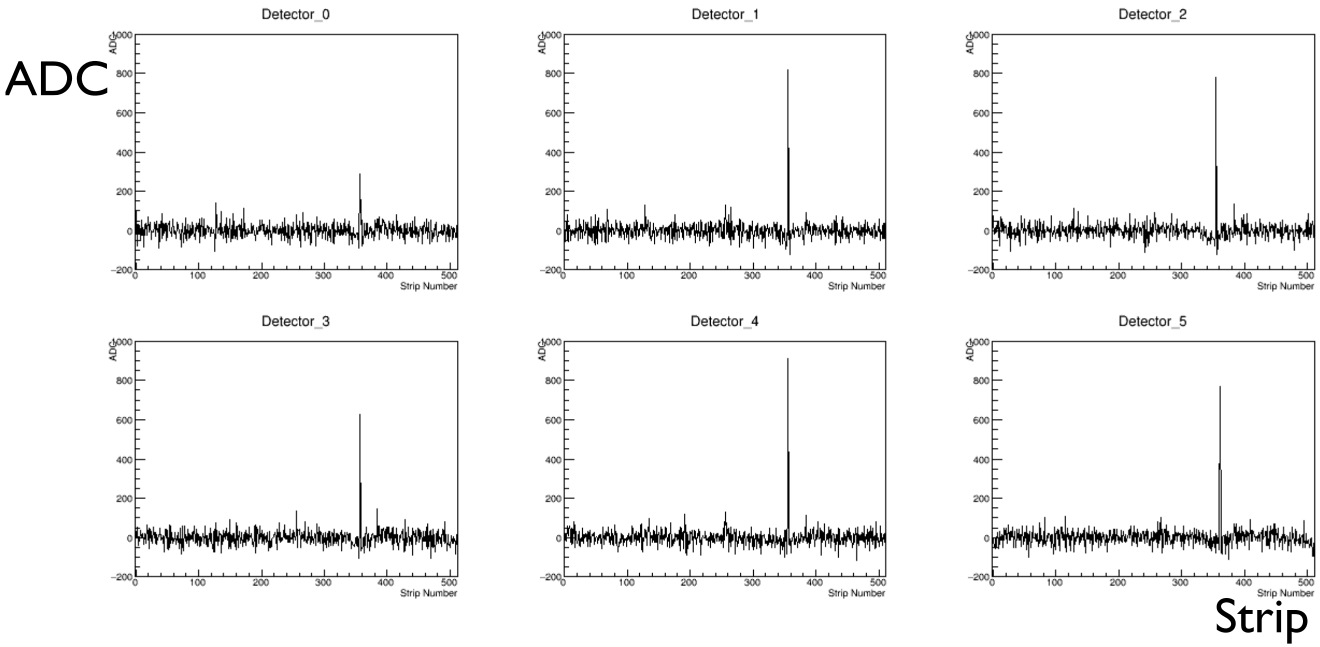
Telescope on beam at CERN:

- test of real time tracking performance: “retina response”
- test of UT DAQ system (can test also UT sensors in the future)



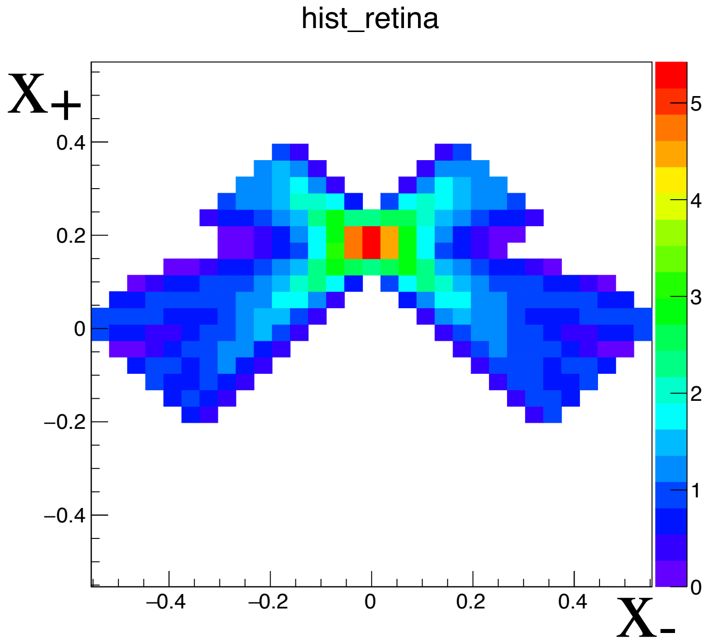
First look at data

Marco Petruzzo
Andrea Merli

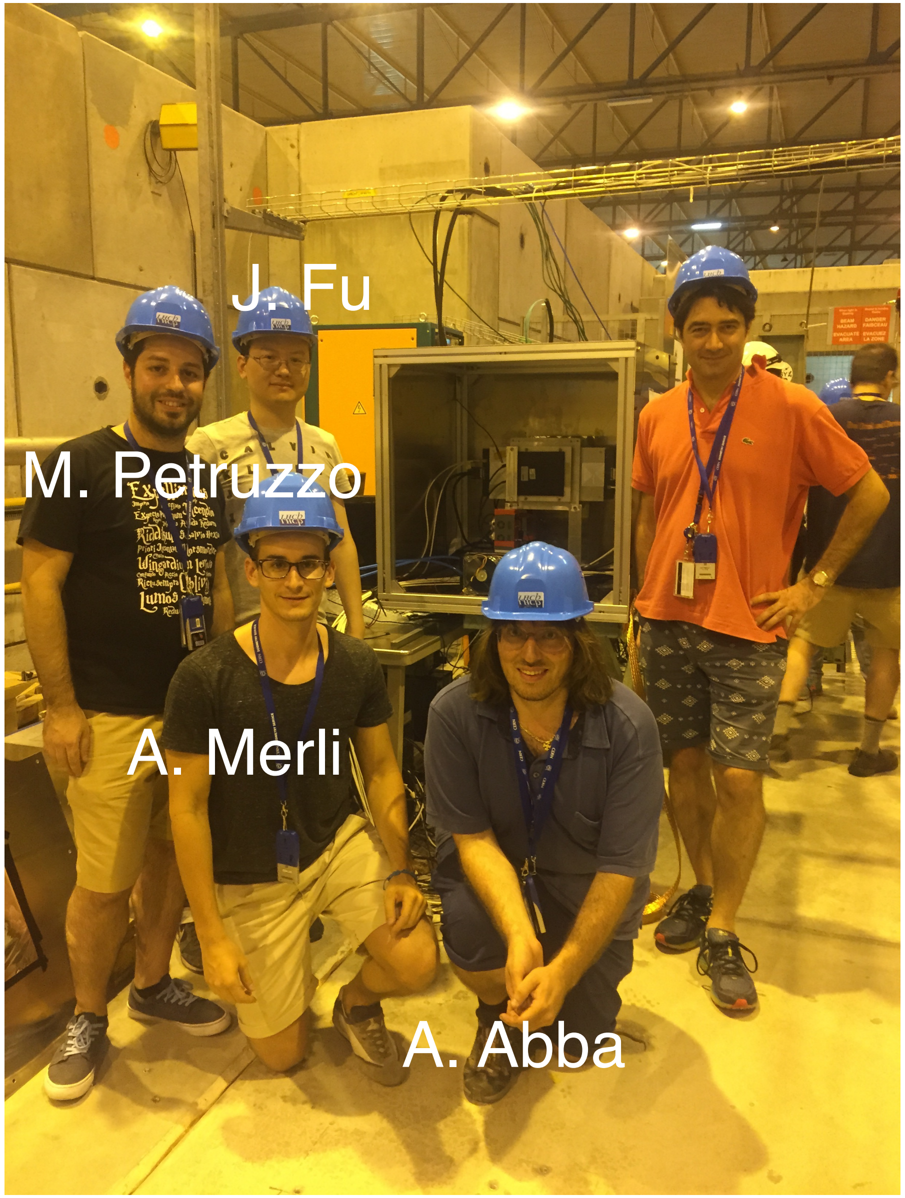


- Track hits on telescope detectors

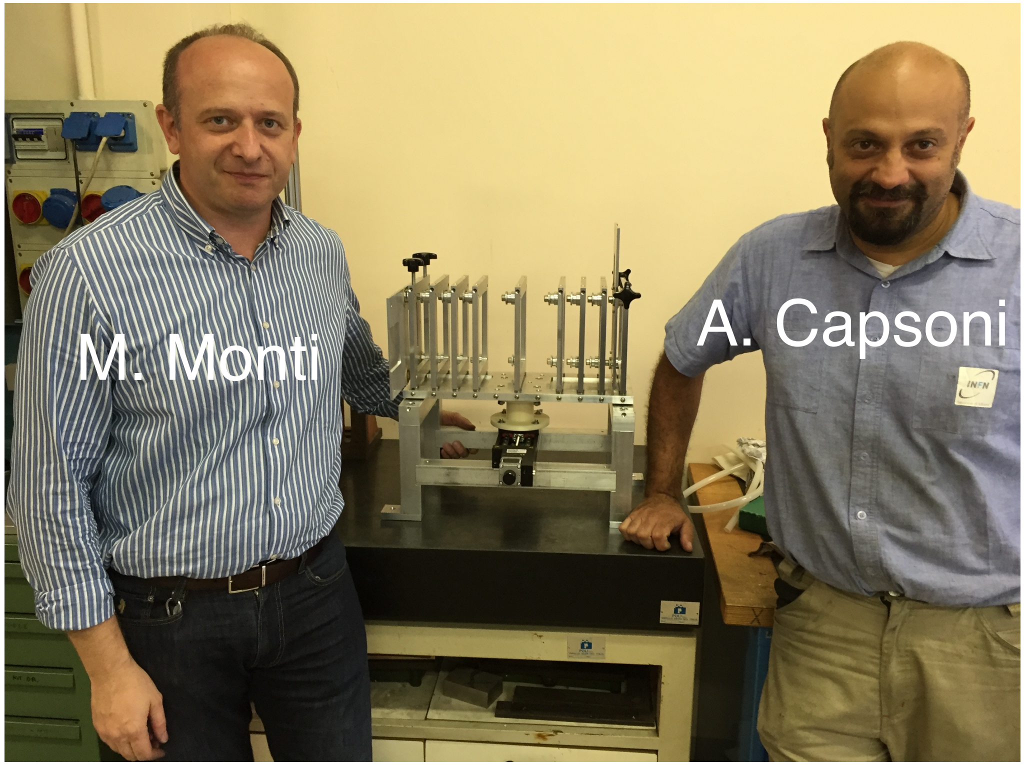
- Real track seen by the “Retina” fast track finding system
- Online tracking: Mamba board returns track parameters in real time



Testbeam crew



Mechanical workshop



For mechanics also:
Simone Coelli
Ennio Viscione
Fabrizio Alberti

Summary

Summary

- R&D to demonstrate the viability of proposed key design solutions
  - silicon detector with embedded pitch adaptor, top-side biasing and circular cutout
  - new rad-hard front-end SALT chip
  - ceramic hybrid circuit
- Gradual transition to production phase in 2016-2017 to be ready for installation in mid 2019
- Milano group is effectively contributing to the UT project:
  - Flex cables design and production. 2nd generation flex cables produced at CERN
  - Milano AlN based hybrid solution. Aurel will produce first prototypes soon
  - Design of the CO_2 system architecture. Setup for cooling system test in Milano
  - Contribution to testbeam: DAQ system, reconstruction software, silicon telescope

Backup slides

Tesi di laurea

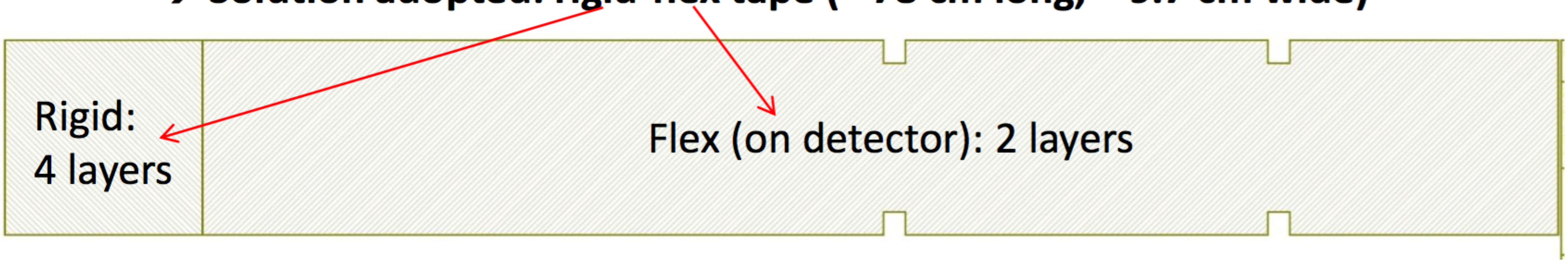
- M. Petruzzo, “First Prototype of a Tracking System with Artificial Retina for Fast Track Finding”, October 2014 - now PhD student UniMi
- E. Spadaro Norella, “Analisi dei dati del test su fascio di prototipi di rivelatori al silicio a strip per l’upgrade dell’ esperimento LHCb”, March 2015 (laurea triennale)
- A. Merli, “Search for CP violation using T-odd correlations in $\Lambda^0_b \to ph^-h^+h^-$ and $\Xi_b^0 \to ph^-h^+h^-$ decays (h = K, π)”, April 2015 - borsista neolaureato INFN- now PhD student UniMi
- D. Marangotto, “Study of $\Lambda^0_b \to p h^- \mu^+ \mu^-$ decays”, ongoing
- D. Terzi, “Studies for an embedded tracking system using precise space and time information of the hit”, ongoing

Contributions at conferences

- N. Neri, “First Prototype of a Tracking System with Artificial Retina for Fast Track Finding”, IEEE Nuclear Science Symposium, Seattle, USA (November 2014)
- N. Neri, “First prototype of a silicon tracker with artificial retina”, TREDI 2015, Trento (February 2015)
- N.Neri, “First results of the silicon telescope using an artificial retina for fast track finding”, ANIMMA2015, Lisboa, Portugal (April 2015)
- J. Fu, “Ricerca di violazione di CP attraverso osservabili T-dispari in decadimenti di mesoni con charm”, IFAE 2015, Roma (April 2015)
- N. Neri, “Production and decay of heavy flavour baryons”, FPCP2015, Nagoya, Japan (May 2015)
- M. Petruzzo, “Real time tracking with a silicon telescope prototype using the “artificial retina” algorithm”, Pisa Meeting 2015 (May 2015)
- B. Dey, “Recent Results from LHCb”, SSI 2015, SLAC, (August 2015)
- A. Merli, “Ricerca di violazione di CP nei decadimenti $\Lambda_b \rightarrow p h^- h^+ h^+$ con h=K,π a LHCb”, SIF 2015, Roma (September 2015)
- B. Dey, “Experimental prospects in b->sll”, Novel aspects of b to s transitions: investigating new channels, Marseille (October 2015)

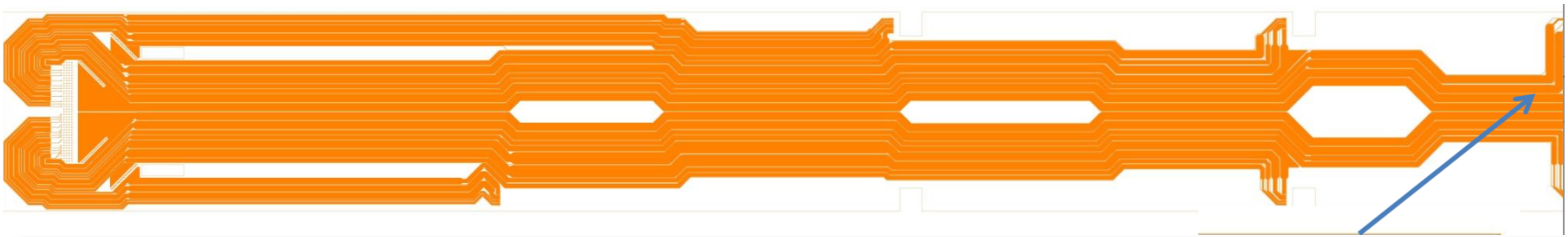
Data flex design 1st generation

→ **Solution adopted: rigid-flex tape (~ 78 cm long, ~ 9.7 cm wide)**

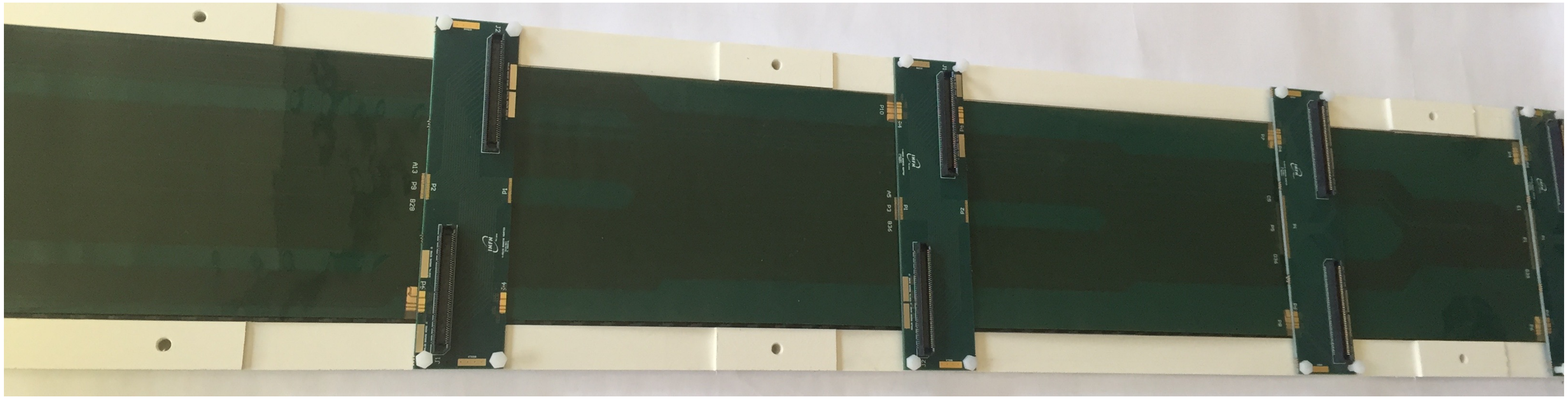


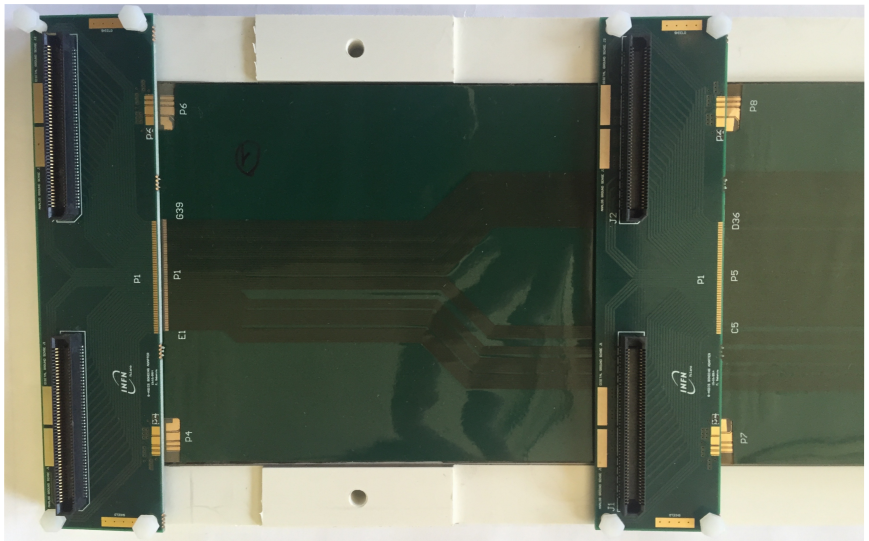
Top Layer: signal traces microstrips

Bottom layer: "large" power traces



Prototypes 1st generation





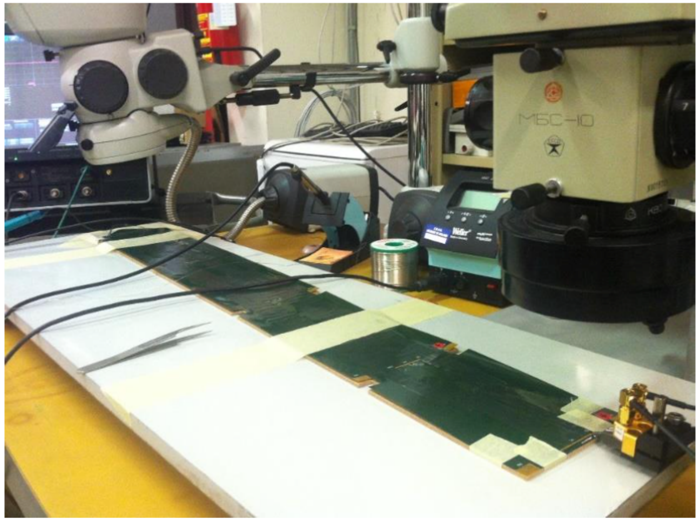
- Nov14 2014, received first data-flex prototypes by Fineline.
- Long traces ~80cm. Difficult to manufacture: short and open on signal traces
- Relatively low yield ~50%. About 2 months delayed delivery

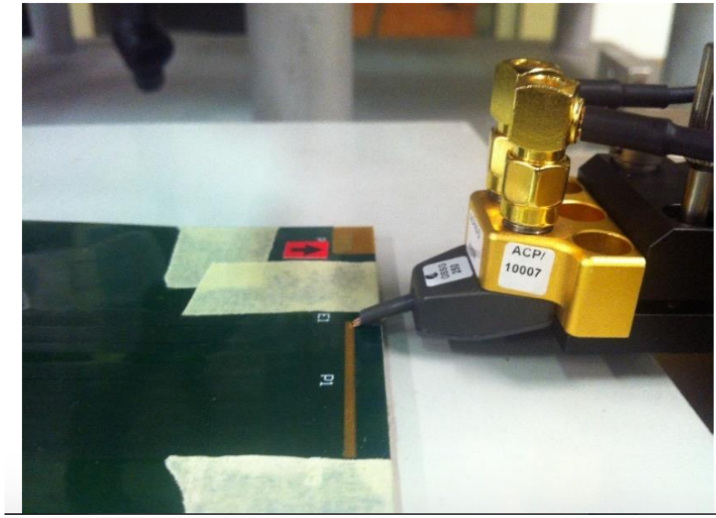
Flex cables testing

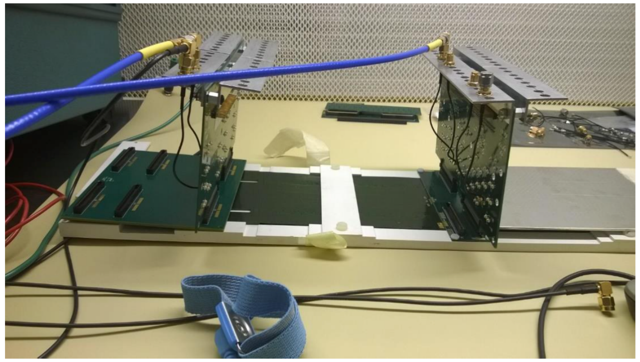
First manual tests with probes

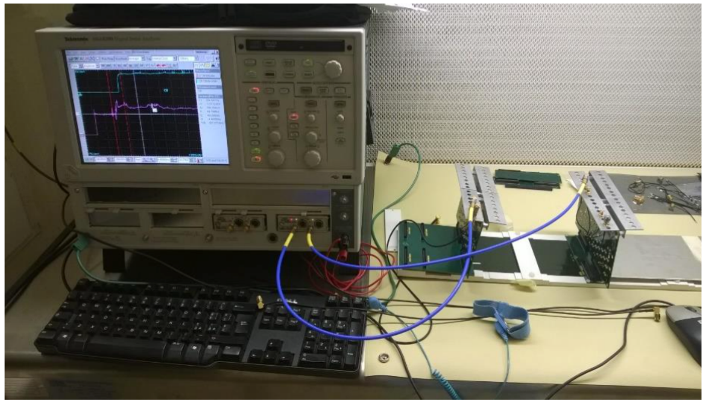
Test setup using adapter cards

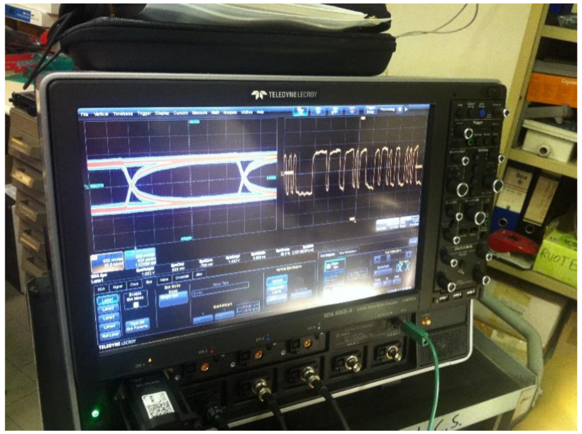
Mauro Citterio
Fabrizio Sabatini
Marco Petruzzo
Biplab Dey
Fabrizio Alberti
Ennio Viscione







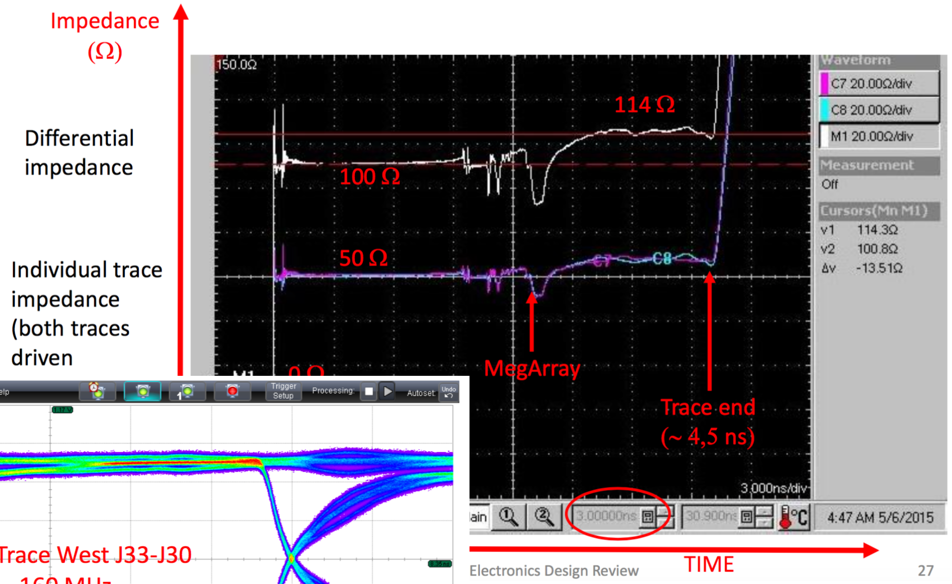


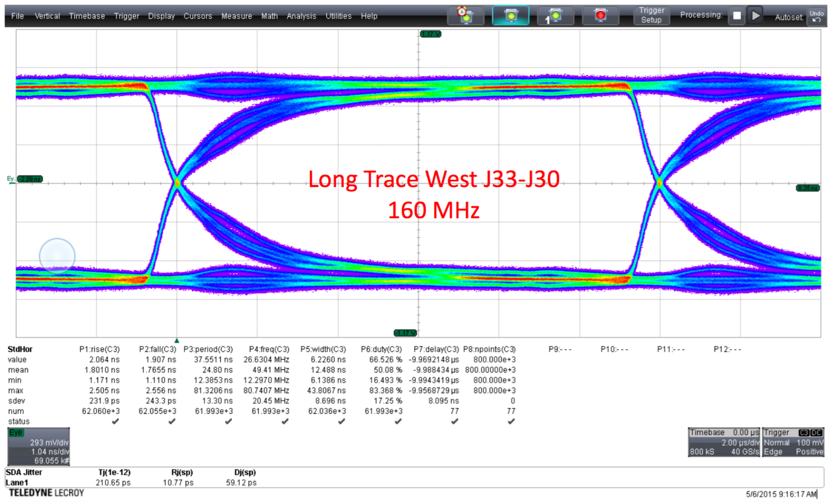


Flex cable prototype test

- Transmission test up to 330 MHz with high frequency probe and pseudo random signal, TDR measurements, resistance and impedance measurements

- Quality tests are OK: data-flex design validated





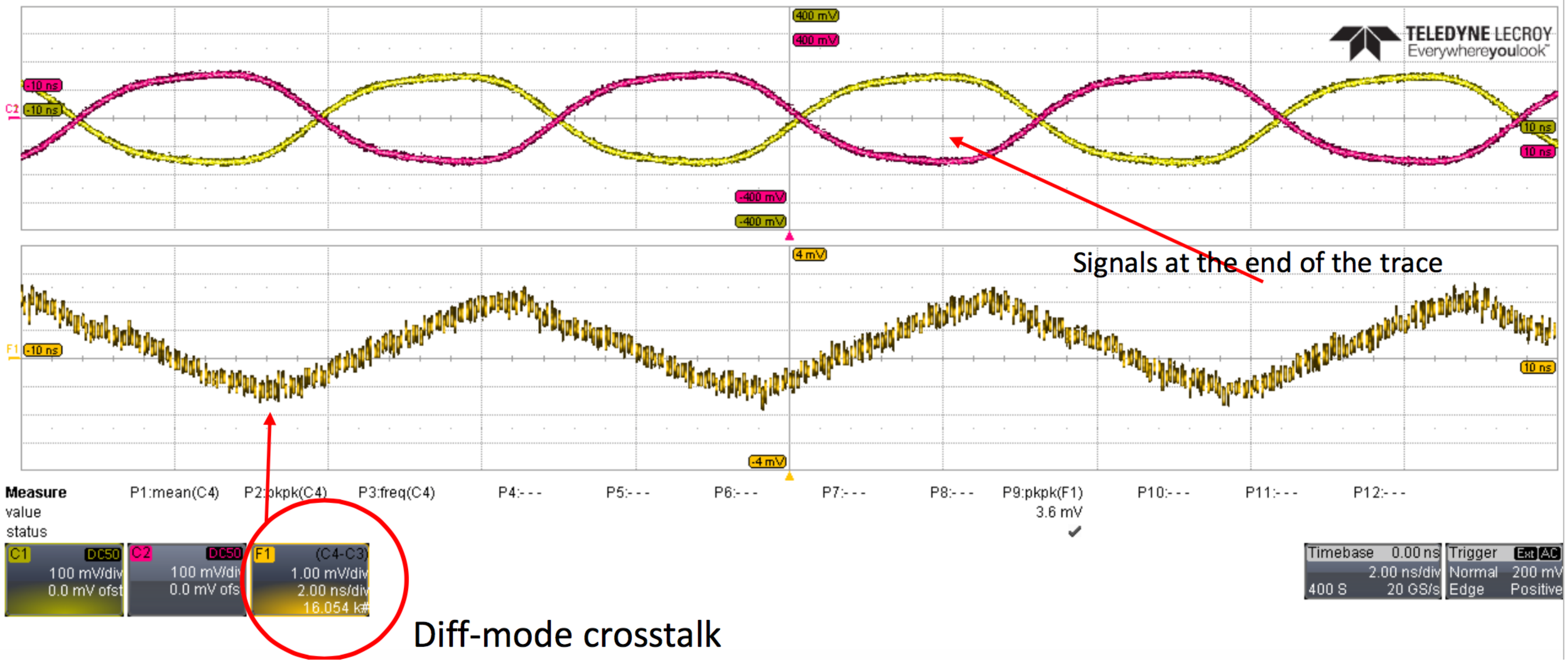
Cross-talk measurements

FEXT at 160 MHz on the longest traces:

- Diff-mode crosstalk shown
- Shape of crosstalk is “smoothed” by reflections.
- Vout= 350 mV due to attenuation, VFEXT(peak-peak) ~ 3.6 mV
- ESTIMATED worst case < 3 … 5 %

Low cross-talk

→ **NO ISSUE for the data transmission**



Diff-mode crosstalk

EDR: feedback from reviewers

- “The work done to study signal propagation in the present flexes was extremely impressive. We were happy that the new design will address many of the impedance discontinuities found. The flex rigid technology used in the present tape restricts the number of potential vendors, and pushes up the price. The decision to use flex technology with a stiffening piece would seem to be appropriate”
- Data flex PRR scheduled for June 2016
  - production starts July 2016
  - production ends August 2017

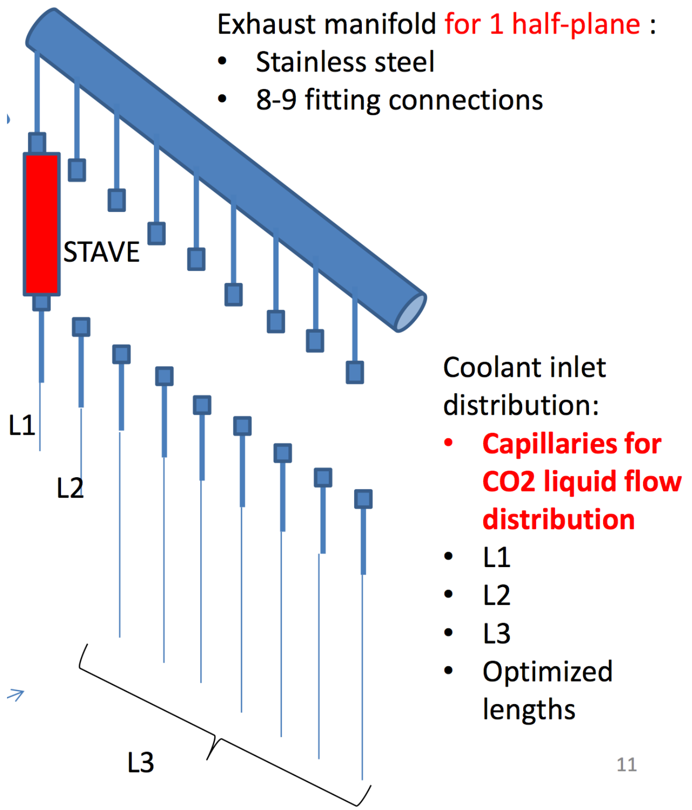
EDR: feedback from reviewers

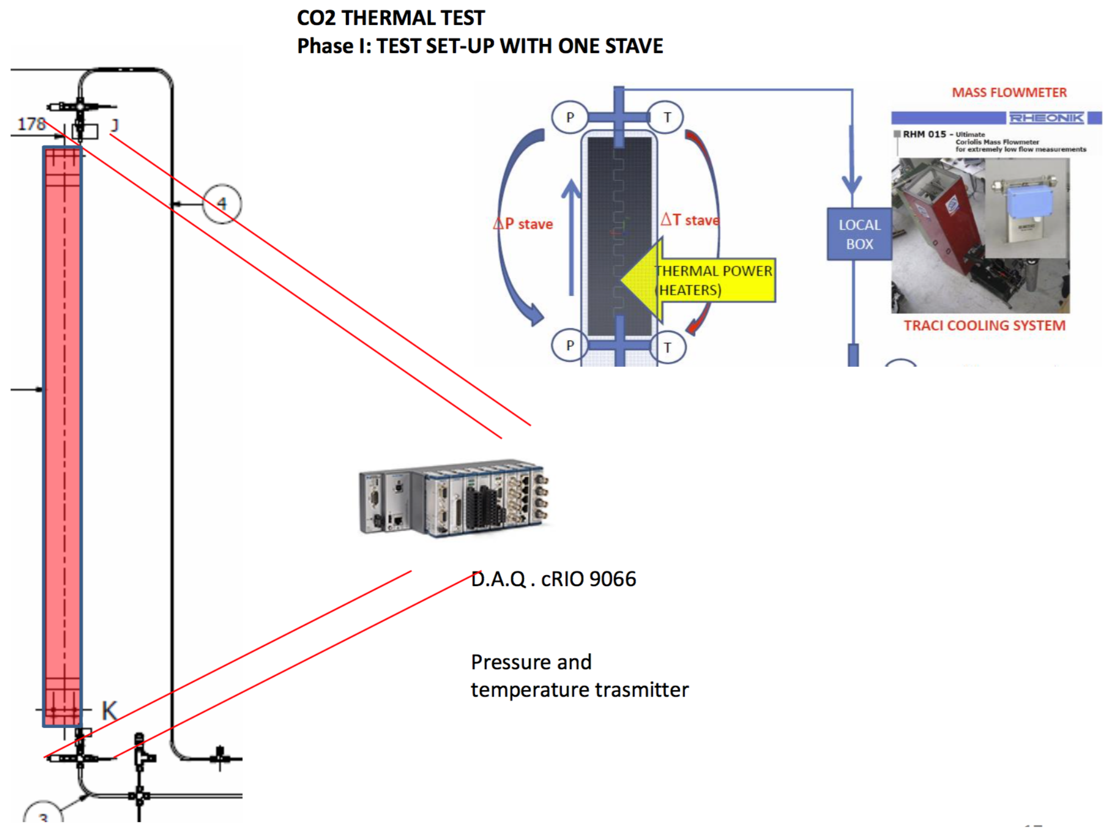
- "We were pleased that information on the hybrid was presented, despite its omission from the formal agenda." Hybrid schedule determined by SALT chip. Few months delay.
- Hybrid R&D in 2015 (SALT 8 channel) and in 2016 (SALT 128 channel)
  - EDR Sept 2016
  - PRR Dec 2016
  - Production starts Jan 2017, ends May 2018

Design of the CO_2 cooling system

Simone Coelli
Carlo Gesmundo

- Participation to the development of TRACI cooling system in collaboration with CERN
- Crucial contribution to the design and test of the UT CO_2 cooling system



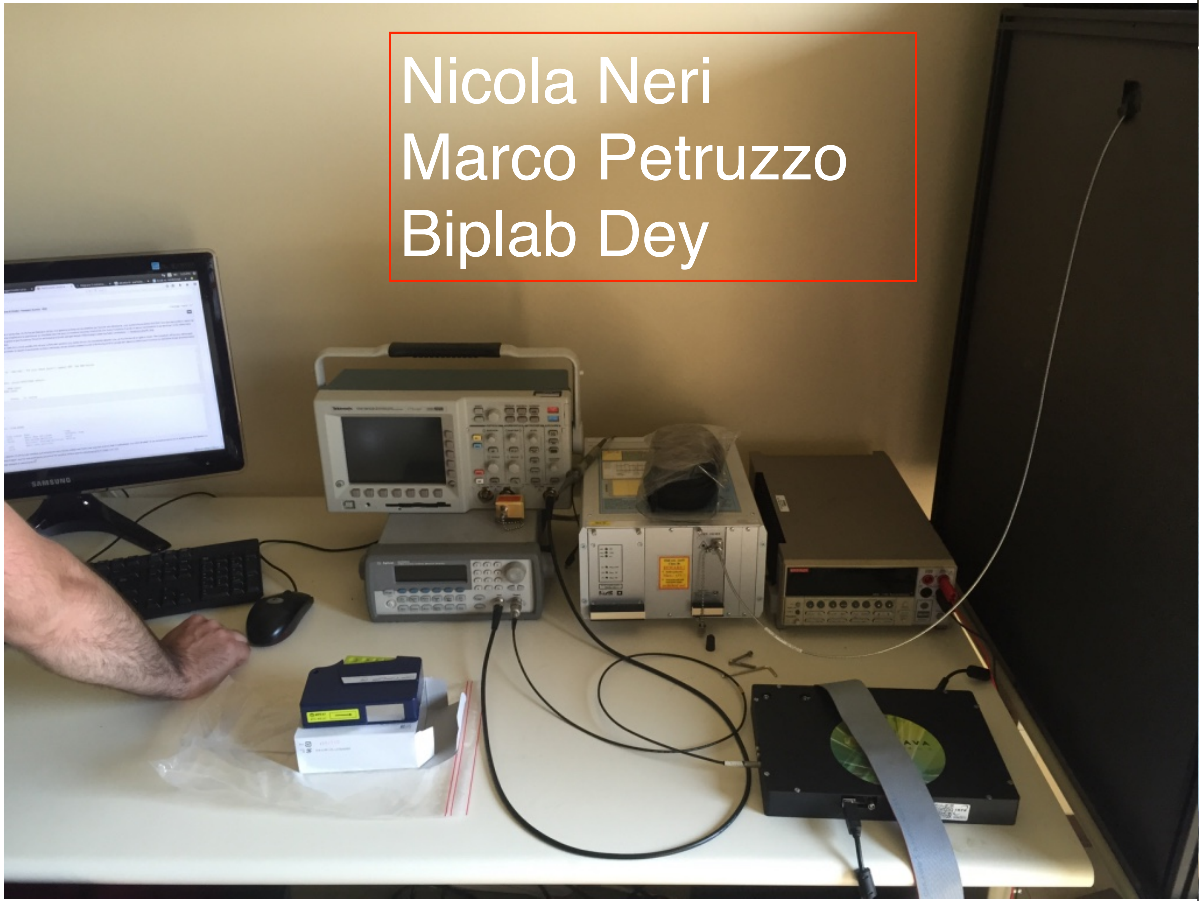


EDR: feedback from reviewers

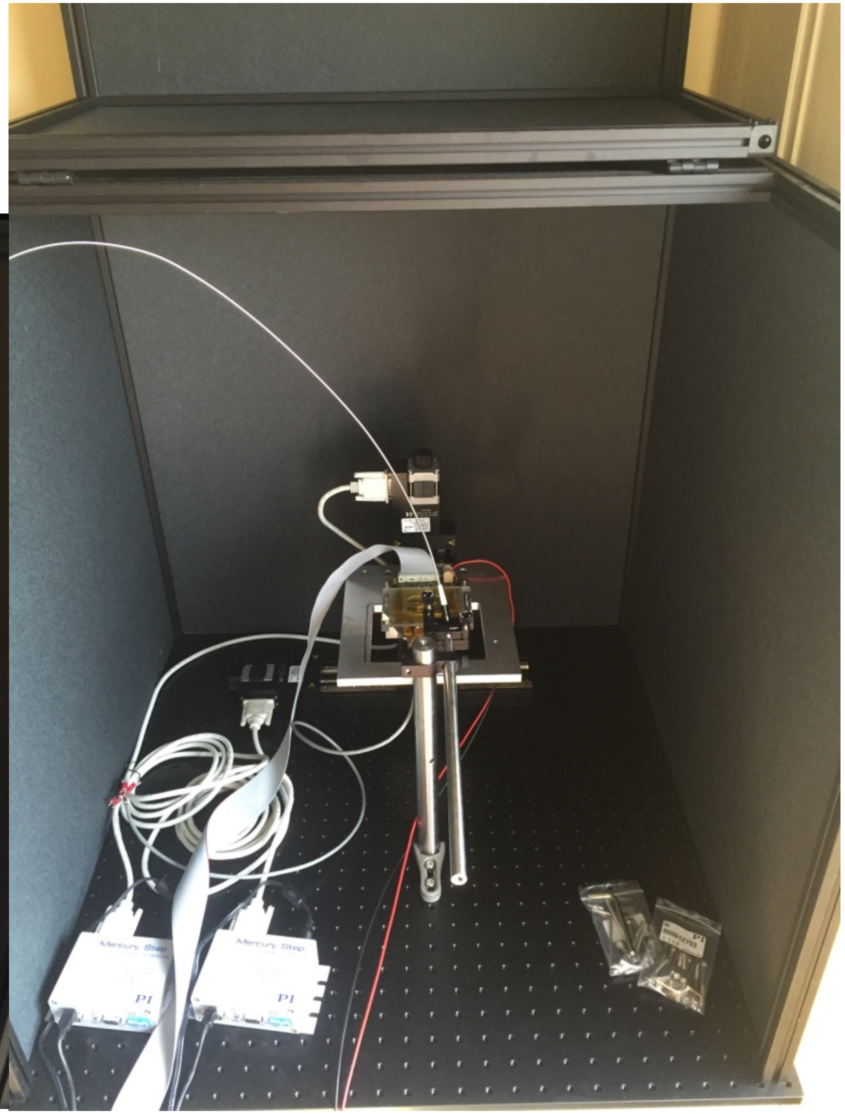
- "The UT stave design appears generally correct. The snake-pipe geometry allows efficient cooling of the modules, and with the use of two-phase CO_2 as coolant the targeted -5C max temperature on the sensors is well achievable"
- Stave thermal and mechanical simulation, CO_2 tests, Simone Coelli.
  - "According to the studies the ΔT's between cooling pipe and sensor highest temperature are found to be about max 5 C. This is fine as needing to achieve -5C as the max temperature on sensors, and with CO_2 cooling can go to sufficiently low coolant temperatures (-30C)."
- Cooling system production January 2017

Prototype sensor testing

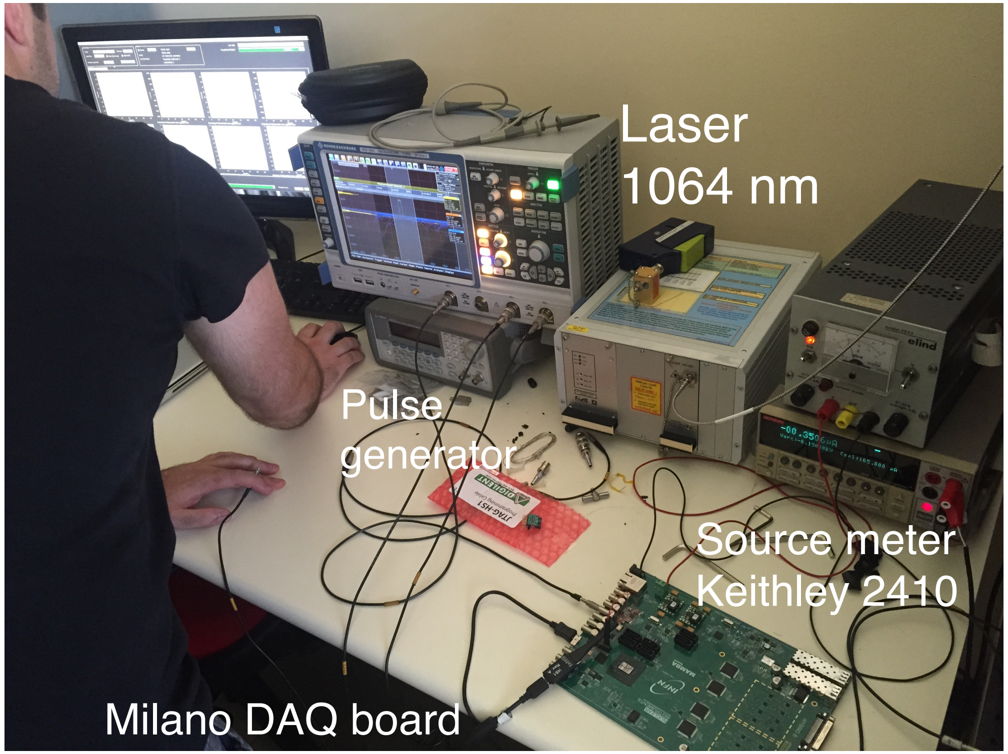
- Test detector modules using 1064 nm laser with 10 μm spot size and radioactive sources
- The setup is ready and will be used as soon as safety procedures will be implemented

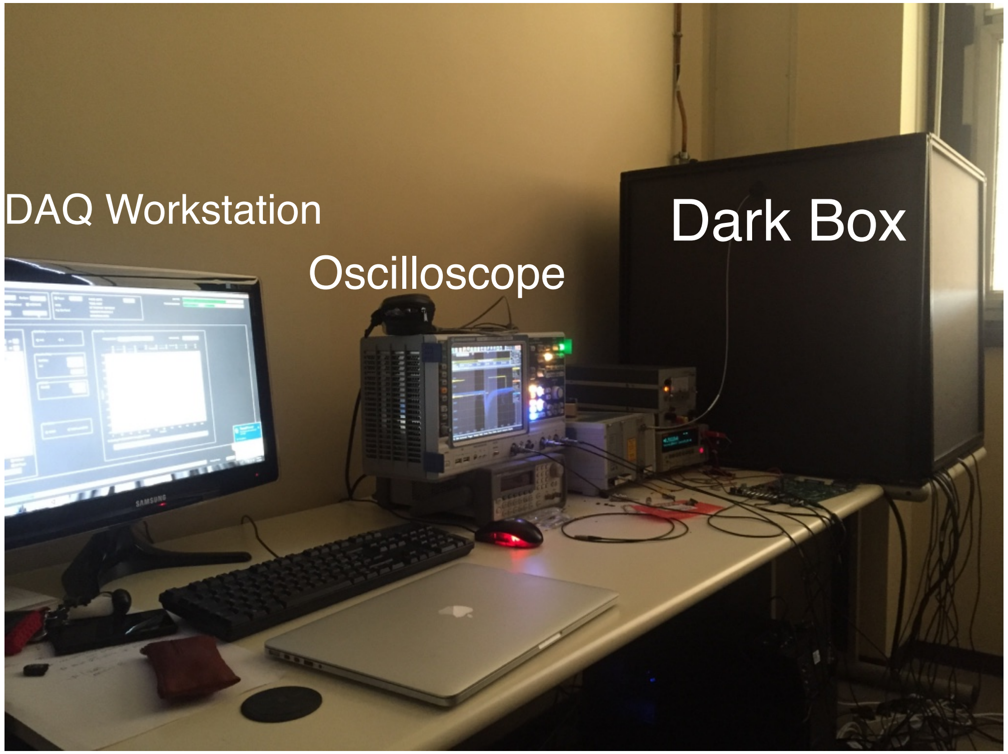


Dark Box with automatic positioning system

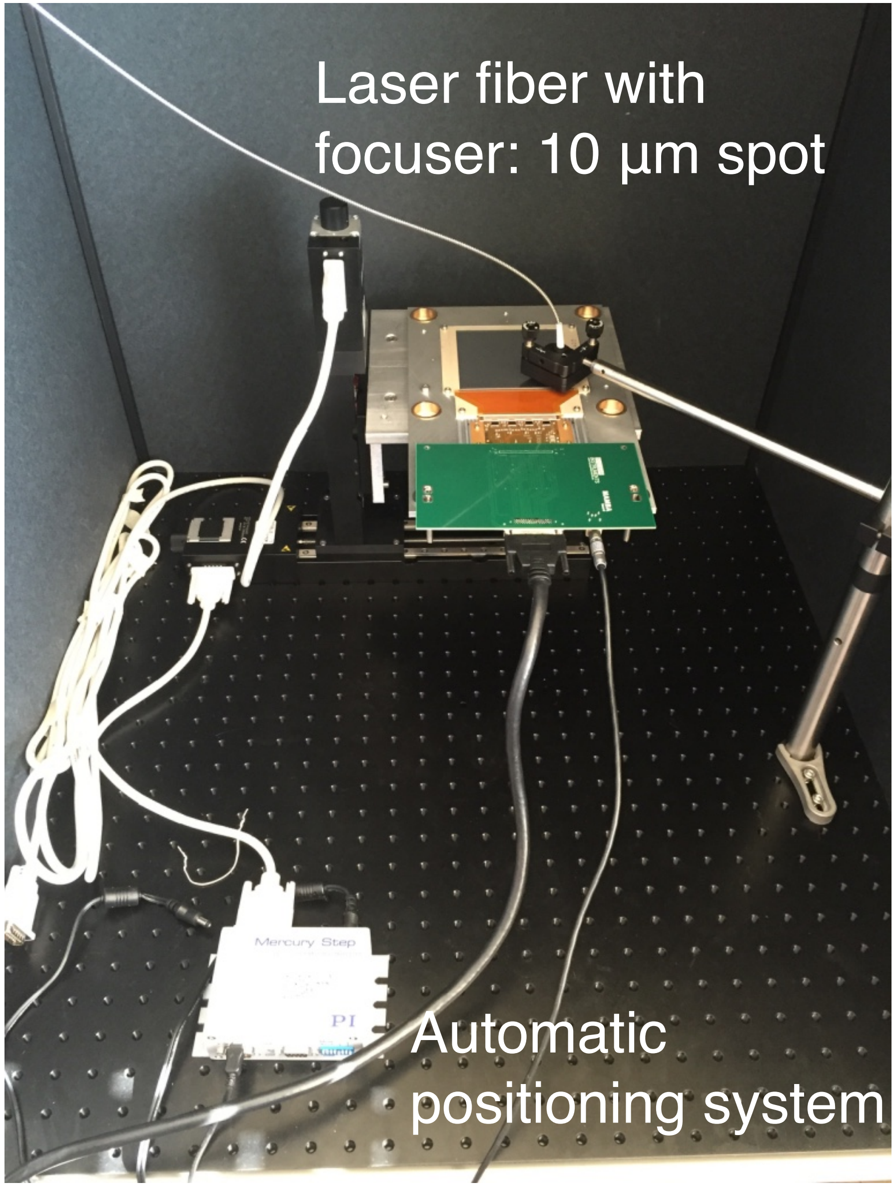


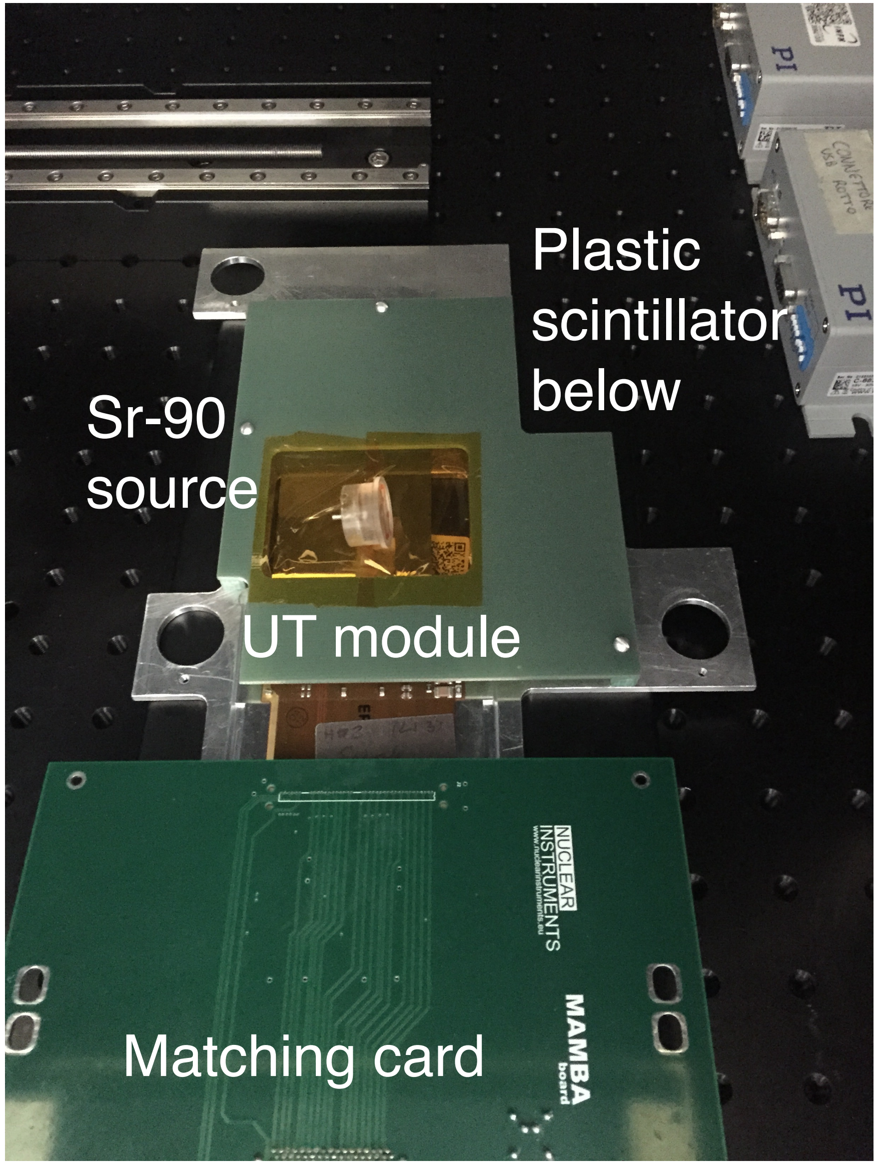
Test setup in Milano





Sensor test


Laser fiber with
focuser: 10 μm spot
Automatic
positioning system


Plastic
scintillator
below
Sr-90
source
UT module
Matching card

Sr-90 signal - UT sensor

Hamamatsu sensor

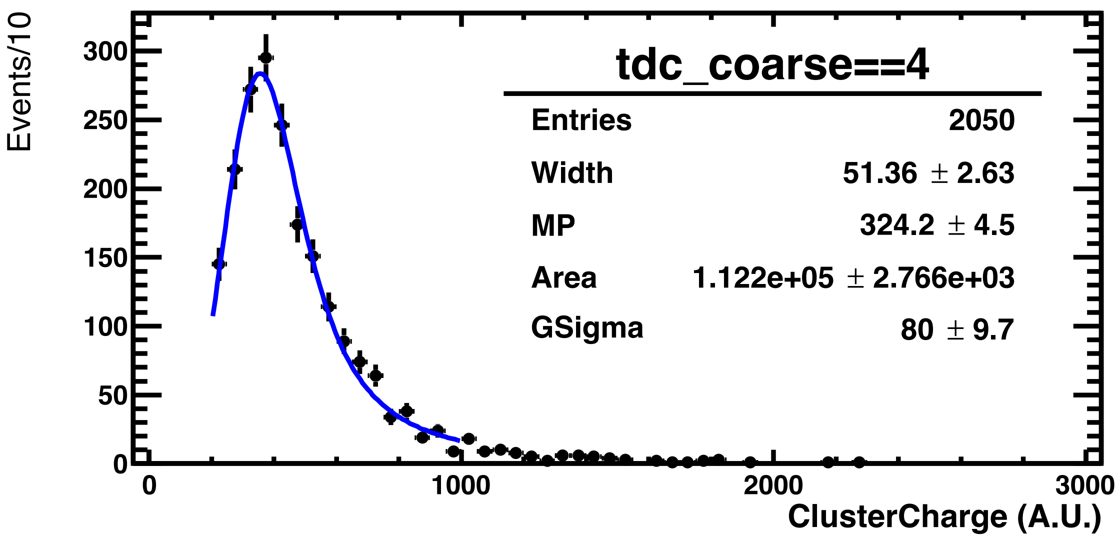
200 μm thick, 180 μm pitch, n-in-p

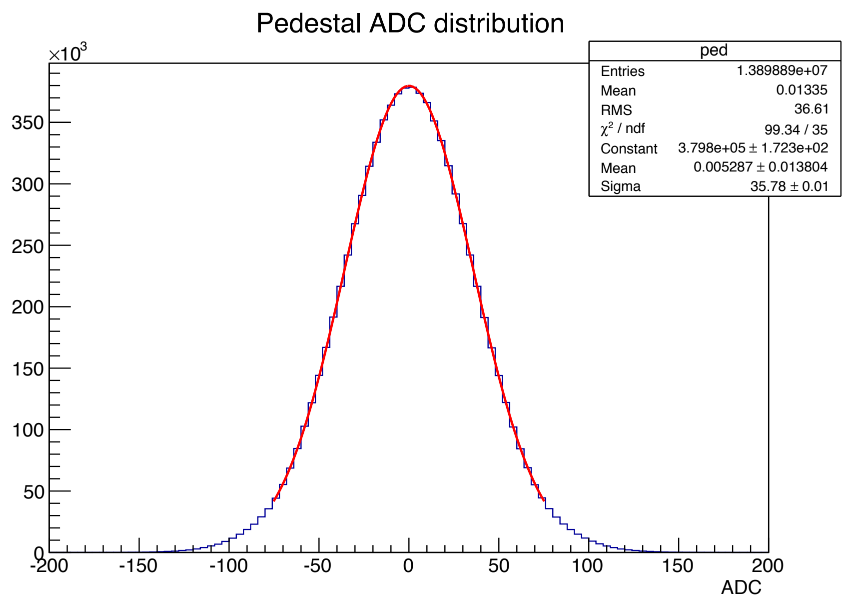
Gain ADC = 10 dB

S/N ~ 324/37=9

MPV ~ 14.440 e (PDG)

1 ADC ~ 45±5 e

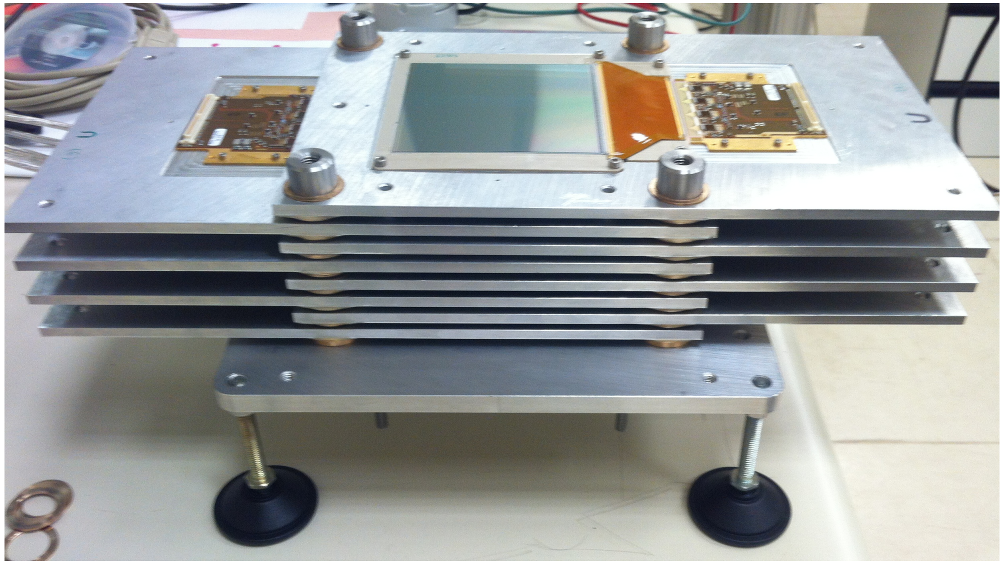




Silicon sensor telescope

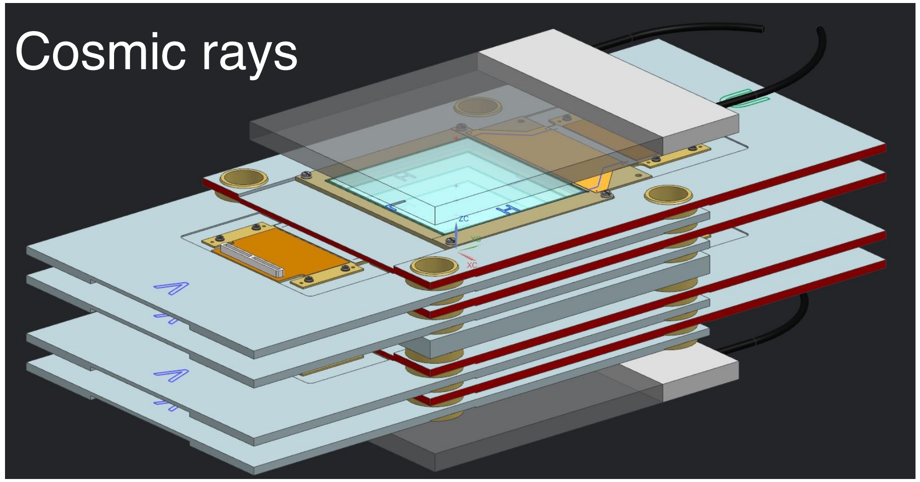
Nicola Neri (System design, simulations)
Marco Petruzzo

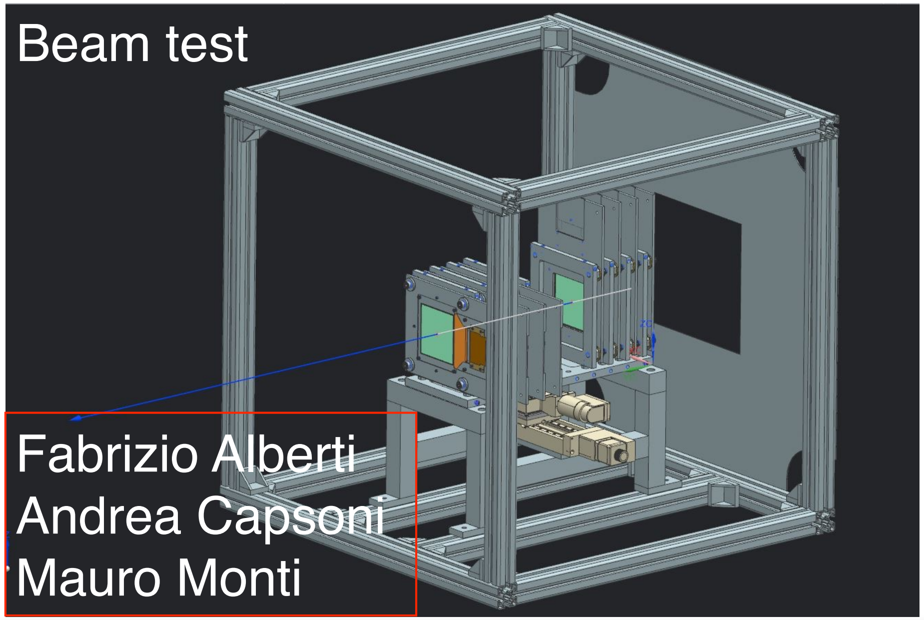
Simone Coelli (Mechanics)
Mauro Monti



- Built in Milano a prototype for "artificial retina" for fast track finding. CSN5 experiment

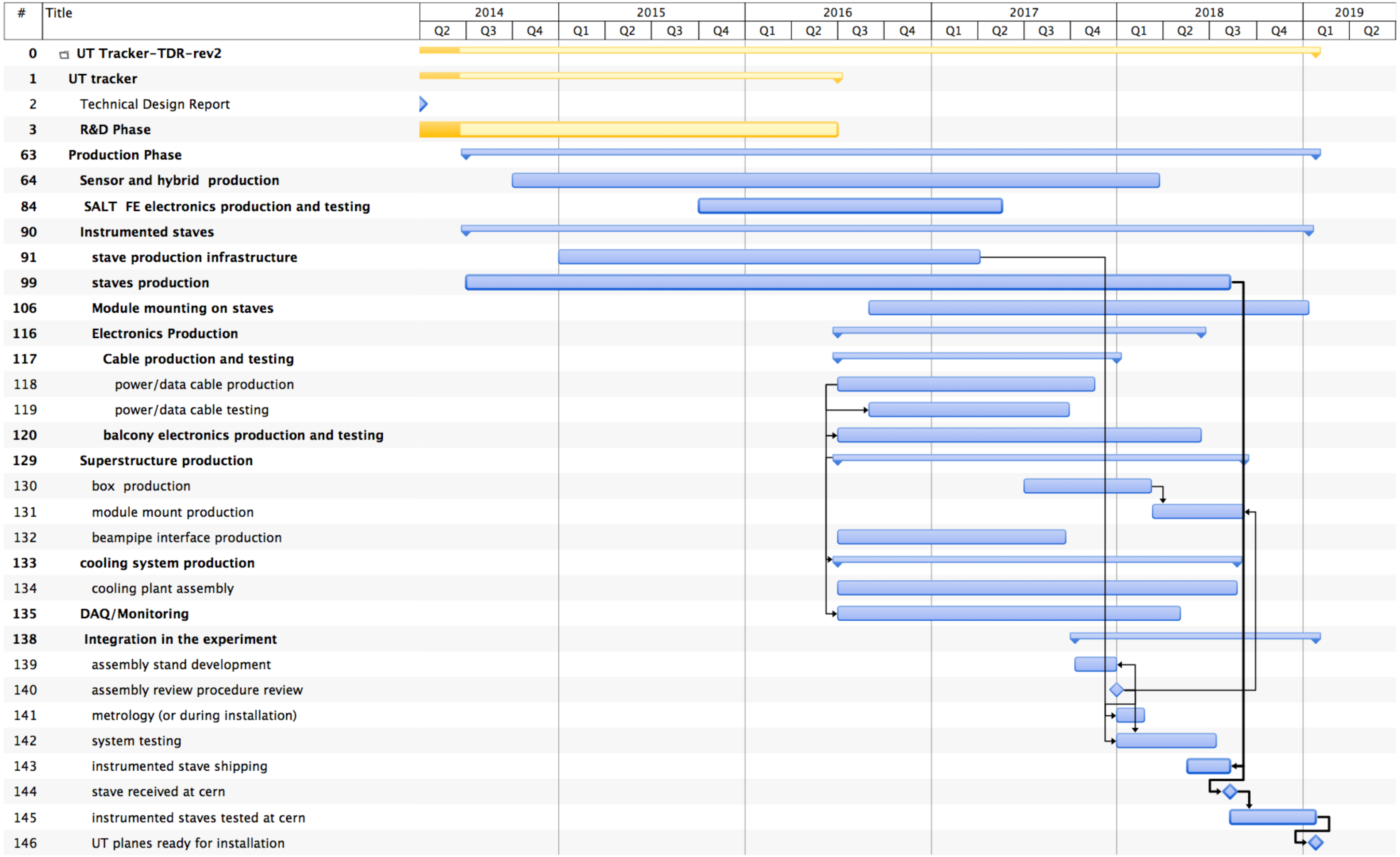
- Used also as fiducial tracking system for UT prototype detector test





UT upgrade project

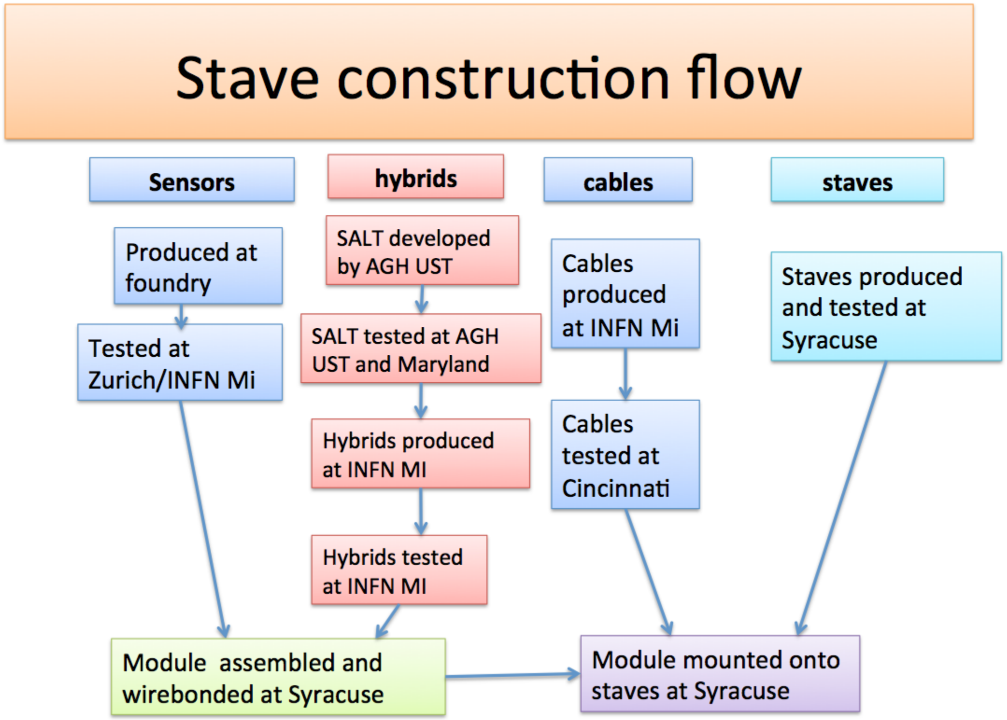
Project timeline



- Installation in Q_1 2019

Project sharing of responsibilities

Sensor and hybrid module	INFN Milano, Syracuse
SALT	AGH-UST
Electronics	INFN Milano, Maryland, Syracuse
DAQ, ECS & TFC	Maryland, Syracuse, Zurich
Mechanics and Cooling	CERN, Cincinnati, INFN Milano, Syracuse
Integration and Testing	All Institutes
Integration in LHCb	CERN, INFN Milano, Syracuse, University of Zurich
Software	All Institutes

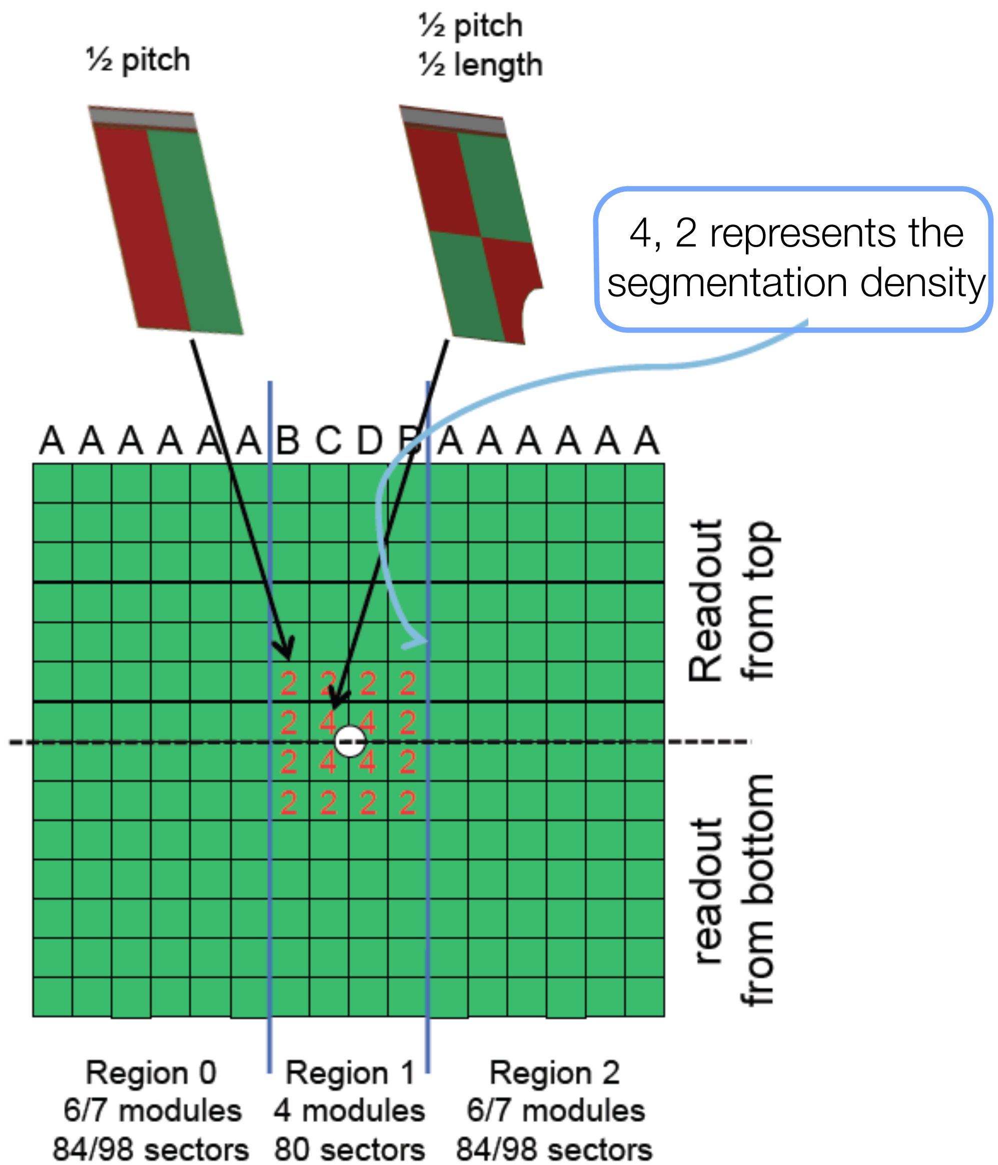


Project cost

Work Package	Cost (kCHF)
Si sensors and hybrids	2700
SALT ASICs	1300
Cables	160
PEPI Electronics	620
DAQ & HV/LV	780
Staves& Hybridisation	510
Infrastructure	130
Cooling	300
Total	**6500**

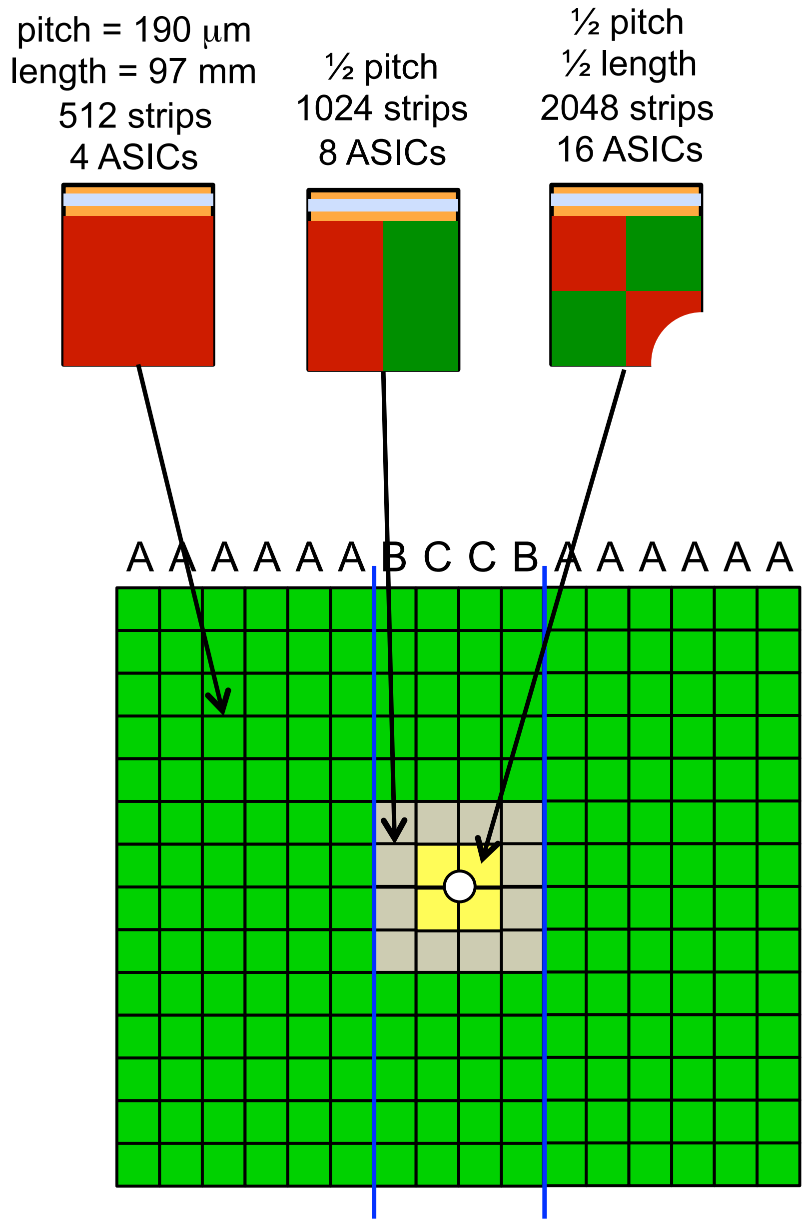
Silicon sensors and segmentation

- Rad hard detectors, maximum radiation ~40 MRad at the inner region
- sensor operated at T=-5 °C to prevent thermal runaway at the inner region
- sensor dimensions about 10 x 10 cm^2
- sensor thickness about 250 μm
- ~180 μm strip pitch. 90 μm pitch at inner region where the particle flux is higher



UT granularity and occupancy

- Occupancies in the UT are ~1% in the inner region and below 0.1% in the outer region with $L=2 \cdot 10^{33} cm^{-2} s^{-1}$
- Baseline detector has finer granularity near the beampipe. Having a poorer Y granularity in the central sensors, the ghost rate of VELO-UT tracks increases significantly



Material budget

- Multiple scattering dominates the momentum resolution at LHCb⇒ minimize material budget of tracking system
- Current design achieves ~1% X_0 per plane
- New design of the beampipe jacket: use of aerogel as thermal insulator. Significant reduction of material budget at η~4.5-5.0.

Material budget vs η for current TT and two different UT stave solutions