Alignment of Silicon tracking systems: R&D and first EUDET prototype

IFCA SiLC (a.o.):
Jordi Duarte, Marcos Fernández,
Javier González, Sven Heinemeyer,
Richard Jaramillo, Amparo López,
Celso Martínez, David Moya,
Alberto Ruiz, Ivan Vila

Presented by:
Marcos Fernández García

Supported by the FP6-Infrastructure I3 European Project EuDET

3rd EUDET Annual meeting (Amsterdam) – 6-8 Oct 2008

Objectives

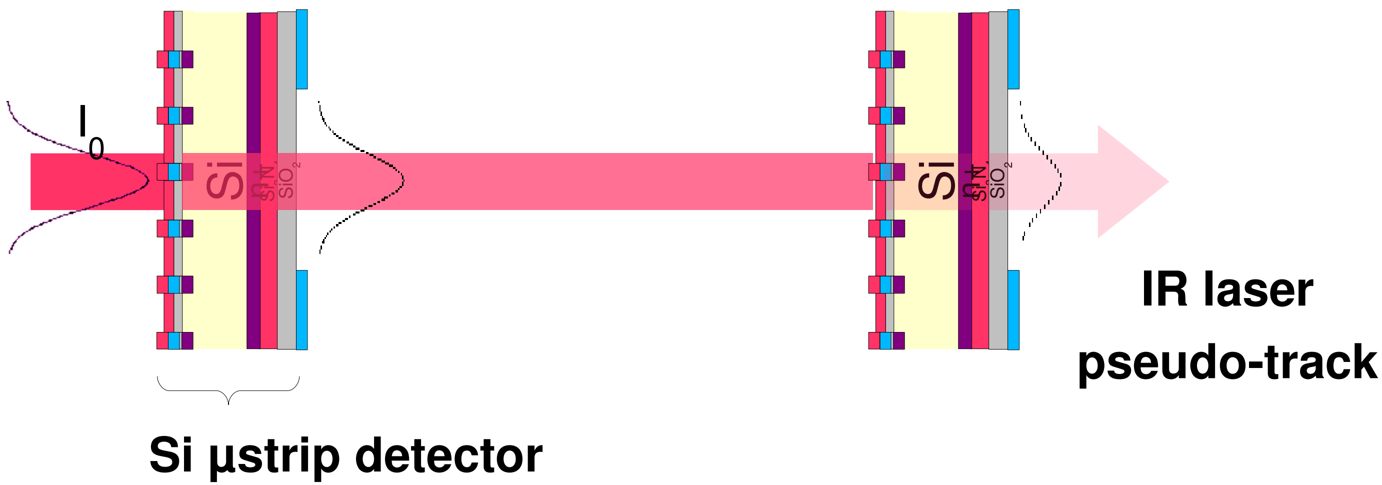
The main goal of SITRA within the EUDET project is to develop and install a test beam infrastructure based on silicon tracking detectors.

The **role of IFCA** within the SITRA task **is to beam-test a prototype of the alignment system** to work out the alignment challenges, the distortions handling and calibrations for the overall tracking system. The alignment prototype will be **based on a system developed for LHC**, using laser beam and Si sensors to measure the detector position with high precision.
(from EUDET Annex 1 documentation, pg. 45)

Instituto de Física de Cantabria

Laser alignment

Proposed alignment method for Si microstrips is a track alignment where particle tracks are replaced by laser tracks. Laser gaussian beam is spatially reconstructed.



- This is possible because...

  IR light is partially absorbed by Si.

  Back electrode (opaque material) removed only in the window where the laser goes through (Al free line of sight through layers of Si)

- Advantages

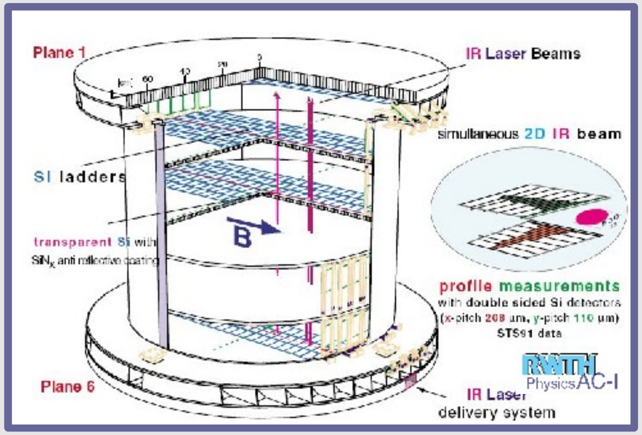
  Laser~200 MIPS ⇒ sharing same DAQ as Si detector

  Silicon modules are directly monitored, no external fiducial marks

  No extra material added

  System can be easily accommodated to any tracker design

An idea that works …



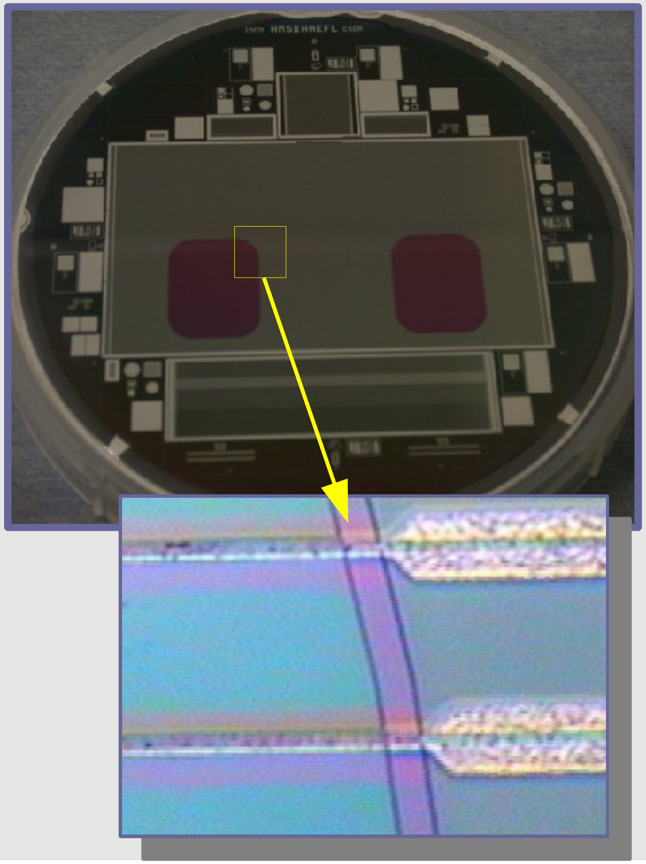
AMS-01 innovation (W. Wallraff)

λ = 1082 nm

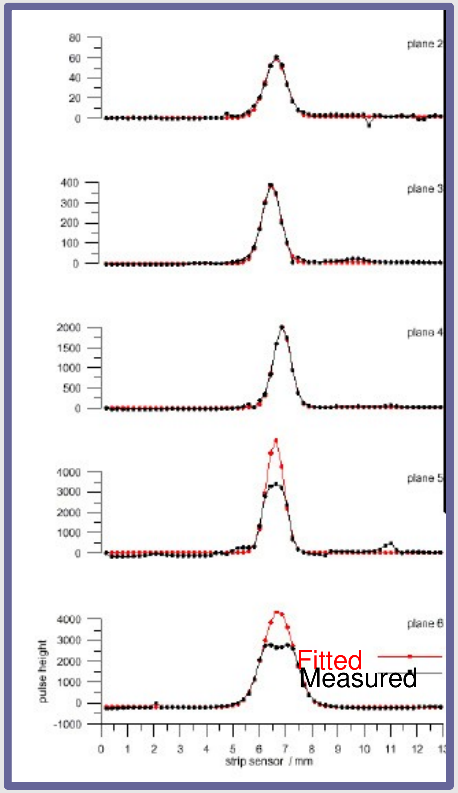
IR "pseudotracks"

1-2 µm accuracy obtained

Transmittance~ 50%

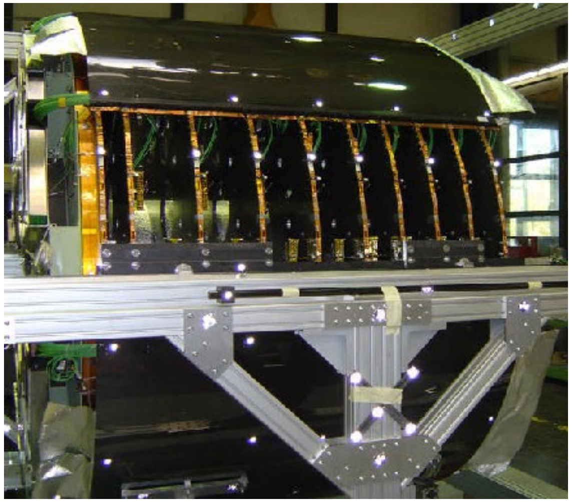


Up to 4 ladders traversed



CMS

TEC



λ = 1075 nm

- Optimization of sensors not included from beginning of sensor design ⇒ **lower transmittance** achieved~20%
- 180 deg **beam splitters** in the middle of the tracker produce back to back beams measured by modules
- Laser spot reconstructed with **10 µm resolution** (1^{st} sensor)

9 TEC disks (18 petals) reconstructed using 2 beams with 50 µm accuracy (100 µm required in CMS)

R&D lines

IFCA participates in 2 R&D lines within the SITRA alignment subtask:

1. **Produce** an integrated Alignment prototype as part of the SiTRA tracker prototype

   Keeping AMS/CMS-like sensor design with removed aluminum back-metalization in a 1 cm diameter window.

2. **R&D** on IR-transparent microstrip sensors

   Aim is to increase transmittance to the sensor to IR light.

Integrated alignment prototype

Standard module

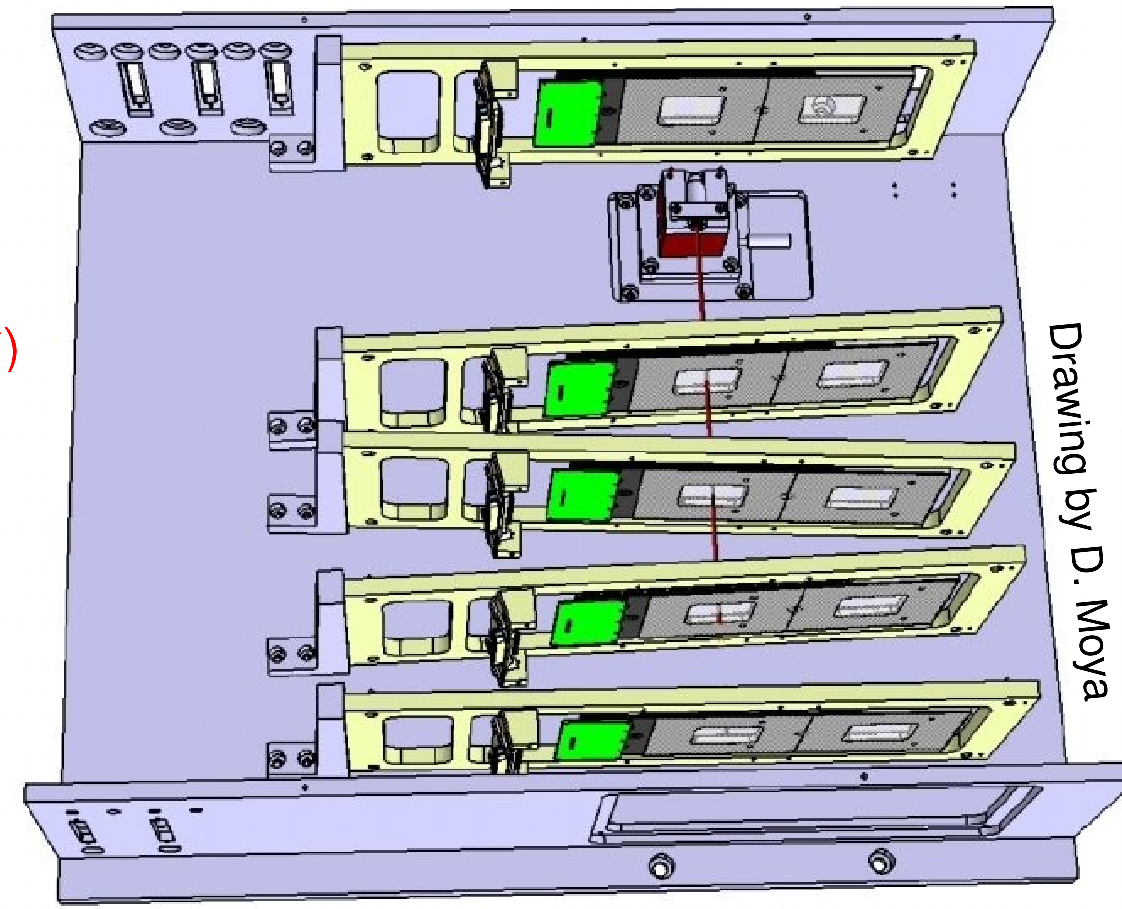
Laser colimator

Alignment module(*)

Alignment module

Alignment module

Standard module



Drawing by D. Moya

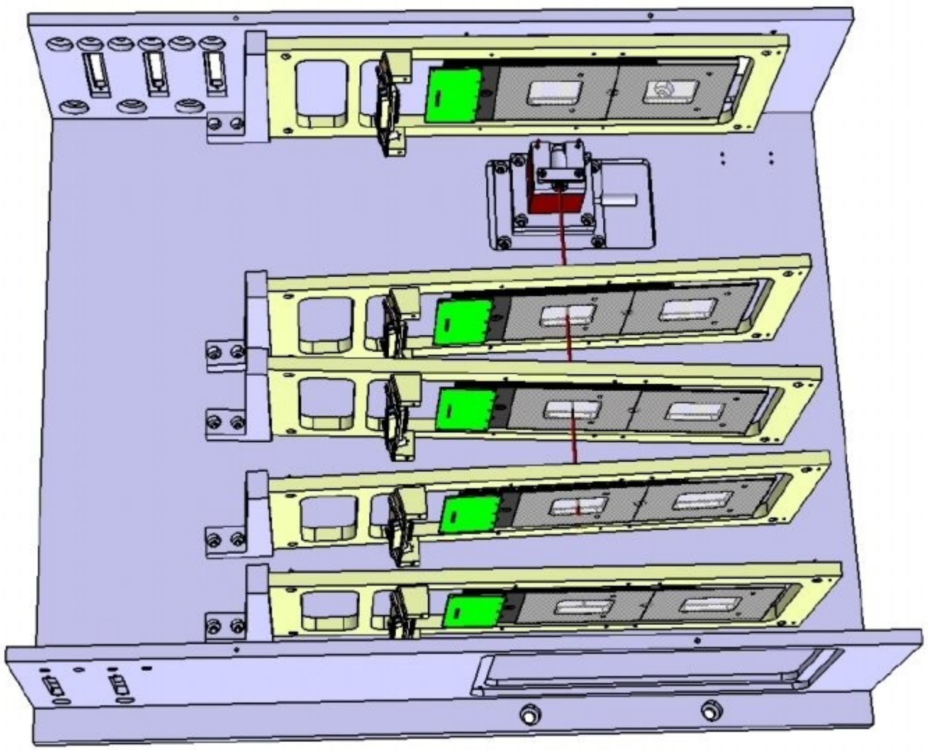
Goal:

3 inner modules can be aligned with particle tracks or with laser tracks ⇒ proof of principle

Inner module can be slightly “pushed/pulled”, comparison of reconstruction accuracy

(*) P.S. Alignment modules are rotated to avoid backward reflected beam traveling beam (avoids interferences beam-beam)

Responsibilities



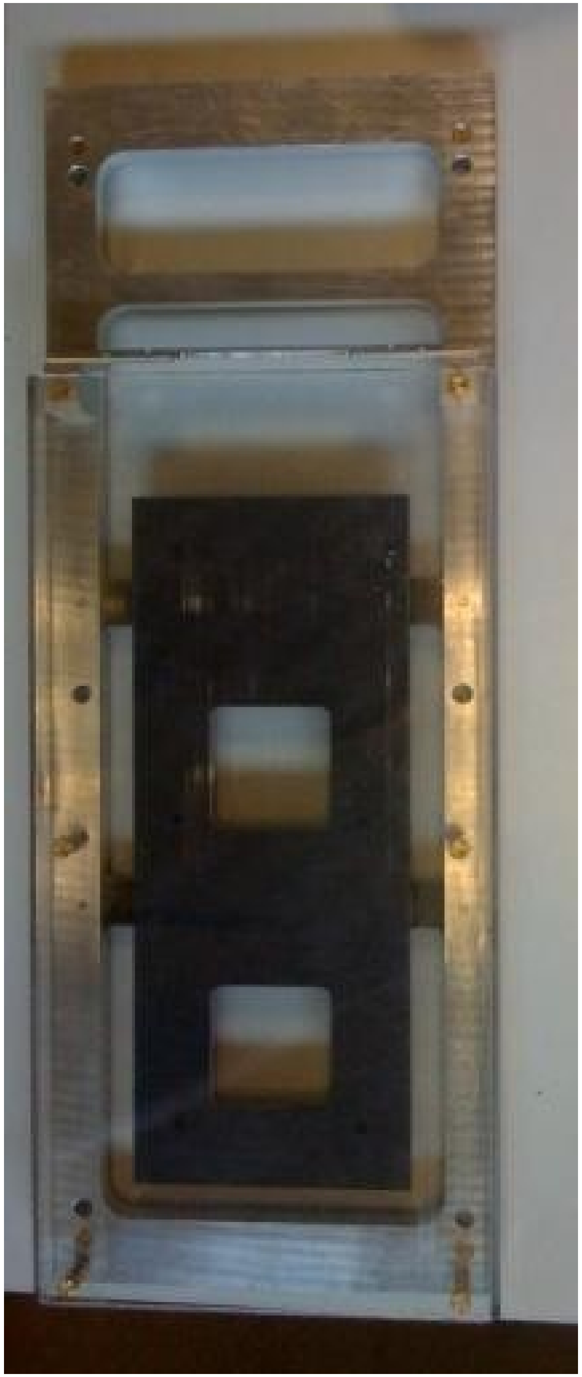
Mechanical design:	IFCA+LPNHEP
Optics:	IFCA
Faraday cage construction:	DESY
Sensors:	Hamamatsu
Module framing & mounting:	LPNHEP (†)
Bonding:	CERN (*)
Module pre-tests:	LPNHEP
FE & DAQ electr. & sw:	LPNHEP
Particle beam test:	ALL

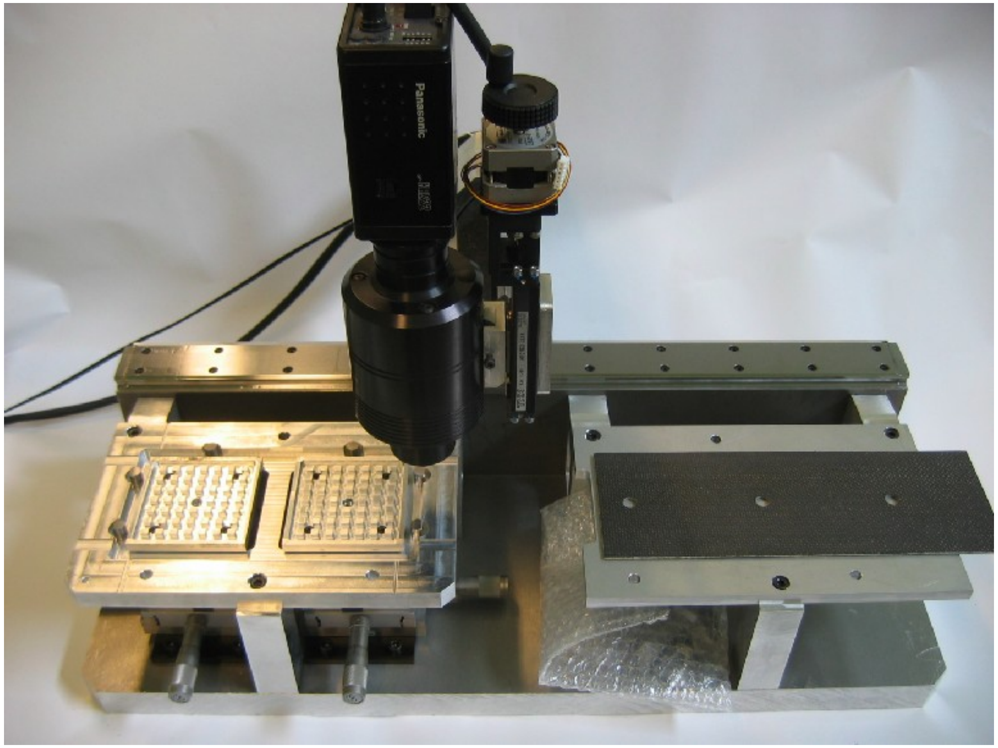
Further details: A. Charpy's talk (LPNHEP)

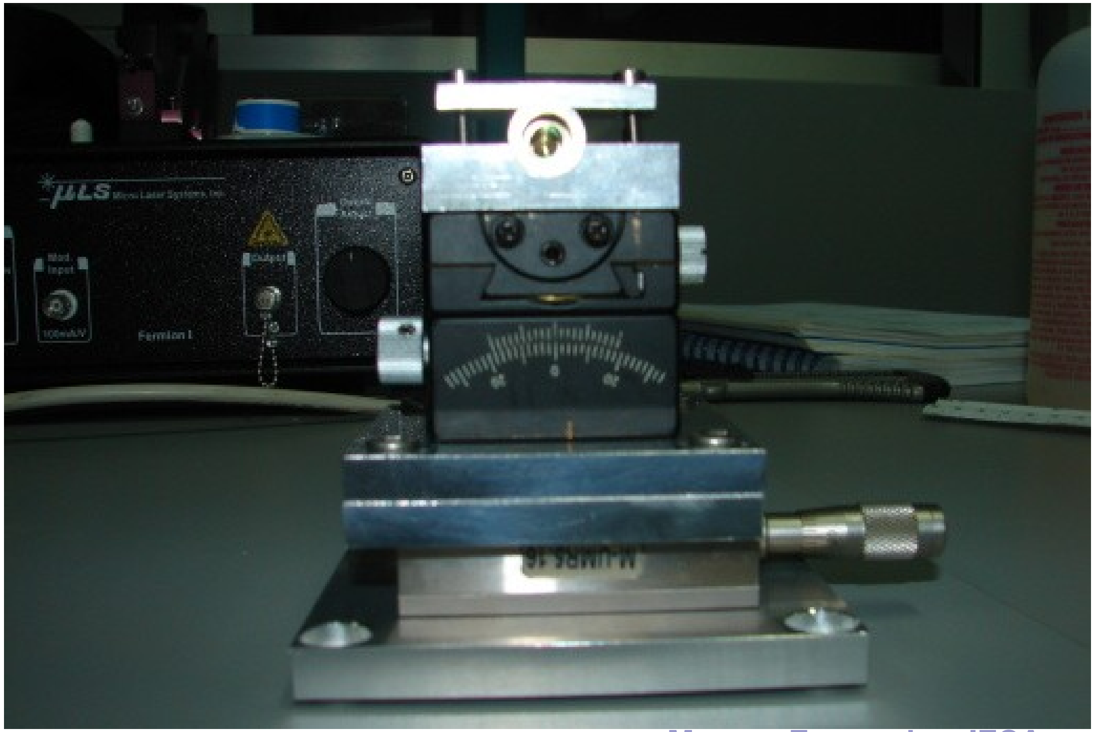
Thanks to:

(†) Paris' mechanical workshop

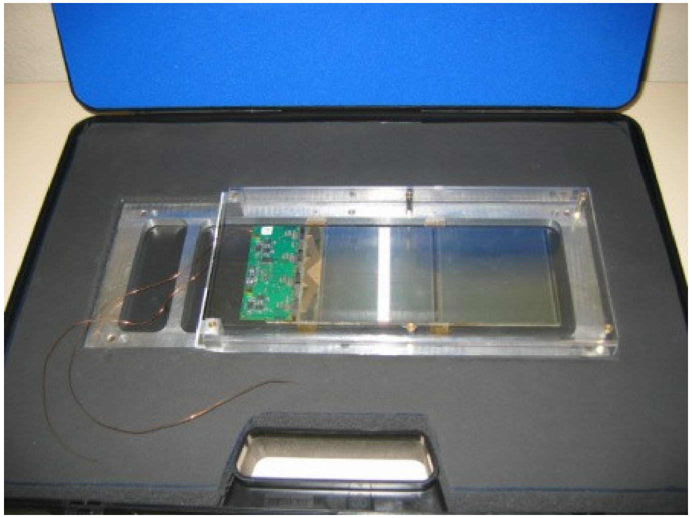
(*) CERN bond lab [Ian McGill]




Panasonic


μLS
Fermion I

Status

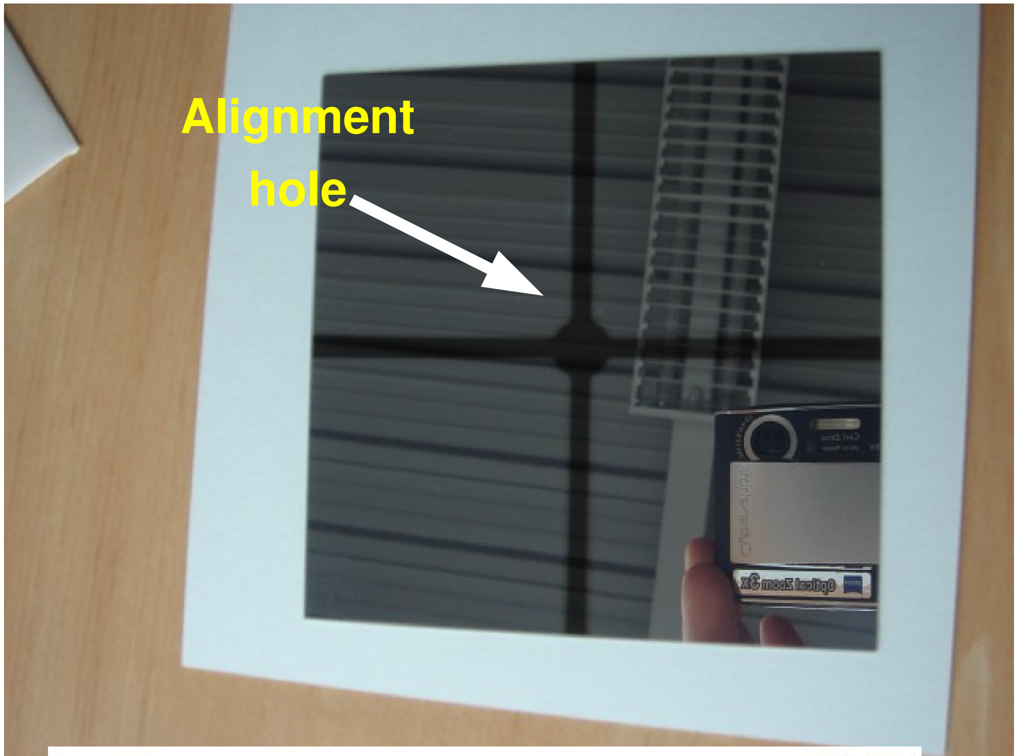


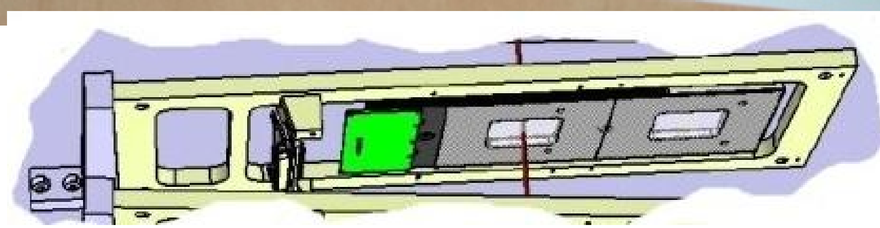
- Three alignment sensors optically tested using a spectrometer
- First glued module traveling today from Paris to CERN and back for tests
- Rest of modules will be assembled in 2 days/module
- All modules ready by ~Oct 18th
- Test beam formerly scheduled at SPS H6 120 GeV hadrons has been canceled due to early shutdown of SPS. Now we will be testing the detectors at PS, as parasitics of ALICE-FARICH (1st-11th of November)

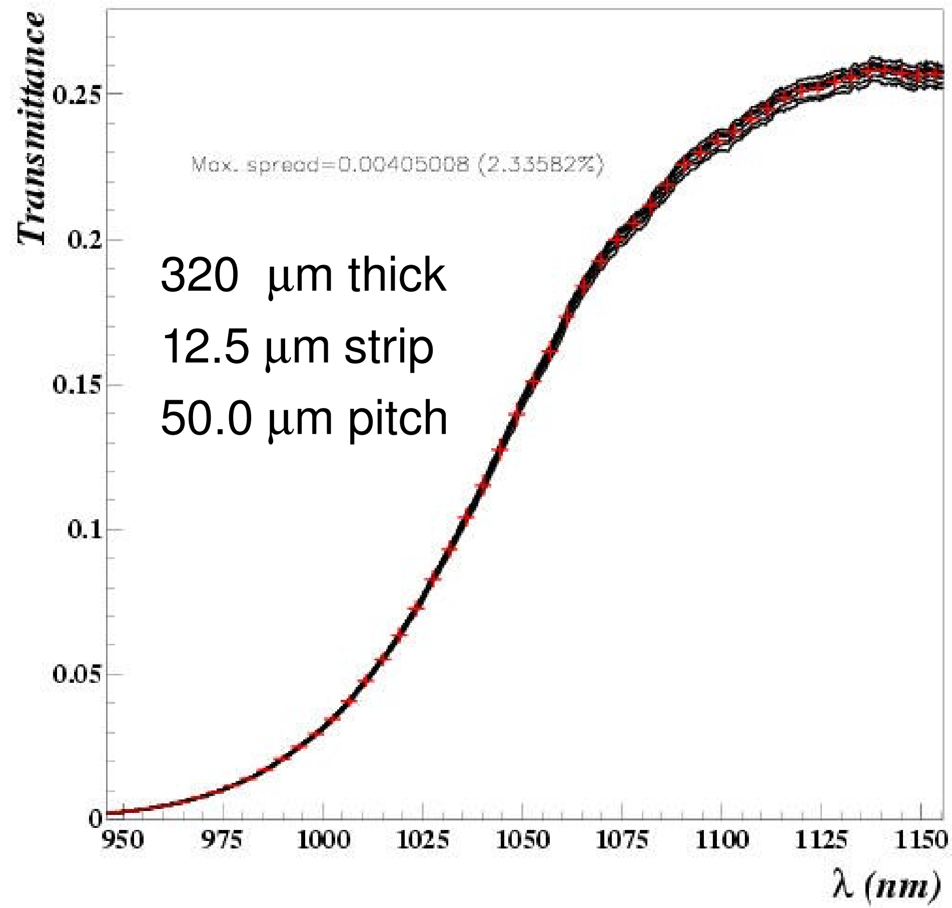
DAQ:

ADC readout from VA chips	... done
FPGA boards VHDL programming	... close to completion
GUI	... done
On line analysis suite	... done
Off-line analysis suite	... done

Sensor optical characterization







Measuring transmittance and reflectance to IR light using a spectrometer: T[λ=1060 nm] ~ 16%

Low transmittance of the sensors was expected. We did not ask for any modification to HPK sensors. This value agrees with CMS measured values of uncoated sensors.

Further optical tests of the sensors will be done at alignment lab in IFCA-Santander, after completion of the test beam...

Optical characterization at IFCA

Linearity (comparison of reconstructed position of a fixed laser spot scanned over the sensor vs displacement of motors) will be studied using a 3D motion table.

The table is in turn calibrated using an interferometer giving accuraccy of ~1 μm

Deflection (=deviation wrt incident direction) of the beam after traversing one module can be measured using a long granite bench and a laser.

R&D lines

There are 2 two R&D lines within the SITRA alignment subtask:

1. **Produce** an integrated Alignment prototype as part of the SiTRA tracker prototype

   Keeping AMS/CMS-like sensor design with removed aluminum back-metalization in a 1 cm diameter window.

2. **R&D** on IR-transparent microstrip sensors

   Aim is to increase transmittance to the sensor to IR light (20% of maximum transmittance is not too much...)

CNM SiLC (a.o.):
Manuel Lozano, Giullio Pellegrini,
Daniela Bassignana, Enric Cabruja

R&D on IR transparent μstrips

• Parallel R&D line that we initiated **together with CNM-Barcelona**

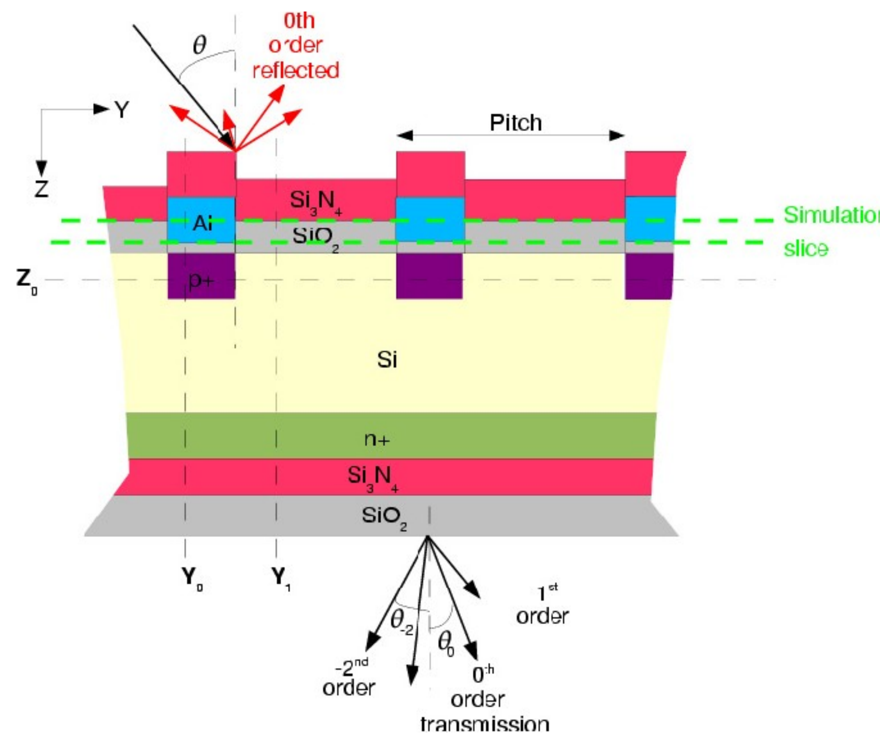
• The goal is to increase the optical transmittance of Silicon microstrips detectors to IR light, without making fundamental changes to the sensor.

How?

We have developed a **realistic simulation** of the passage of light through a detector, **including interferential** effects due to multiple reflections at the interfaces **and diffraction** due to the patterned strips. Not such level of detail found in AMS or CMS works before.

Identified **key parameters** contributing to the %T of the detector

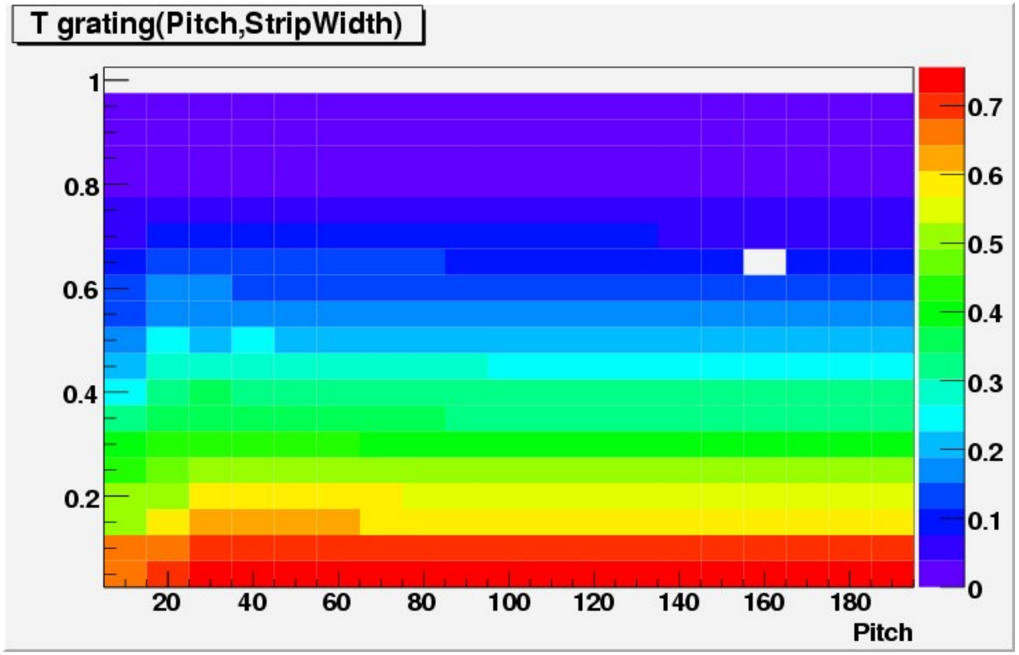
Stack of materials is then **optimized** for maximum and robust %T



Maximization of transmittance

• We found that most critical parameter is the width/pitch ratio. Intuitively, the less Al, the more transmittance. Good compromise: **strip_width = 10% · Pitch**

• T(pitch,strip_width), with strip_width expressed as percentage of the pitch
Using Al strips:

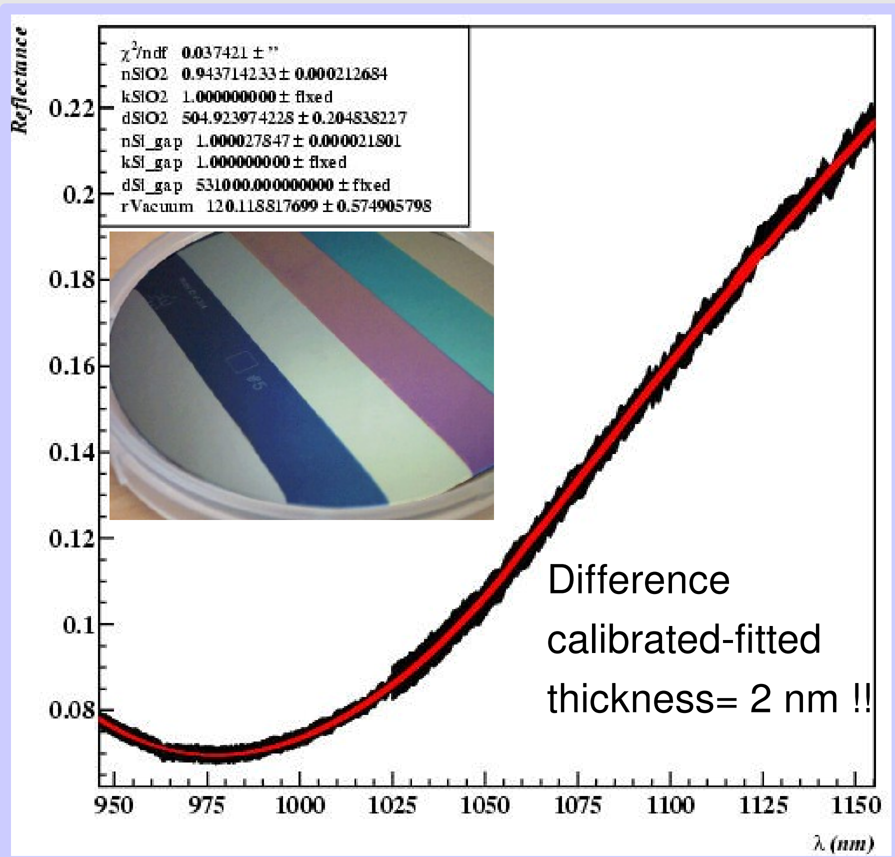


• A further thickness optimization of the multilayer leads to few % increase of transmittance
However, %T has to be maximized such that it is robust against small changes of layer thickness (fabrication tolerance).

Validation of simulation

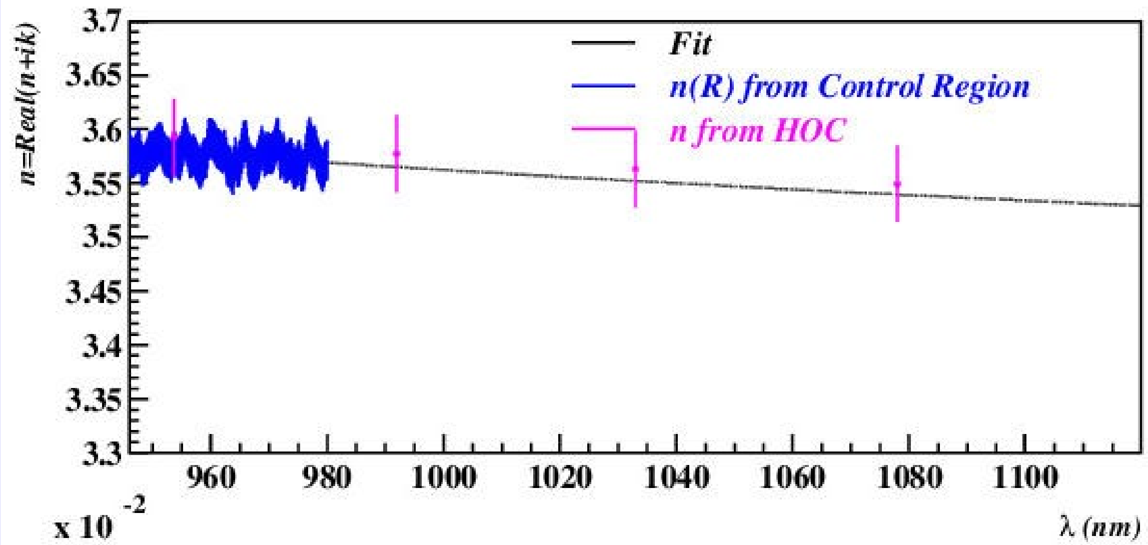
Firstly, continuous layers [no strips=easier] have been reproduced

This part of the simulation has been validated using a calibrated reference wafer



Another example:

Calculated refraction index of a Si wafer compared against tabulated Si data



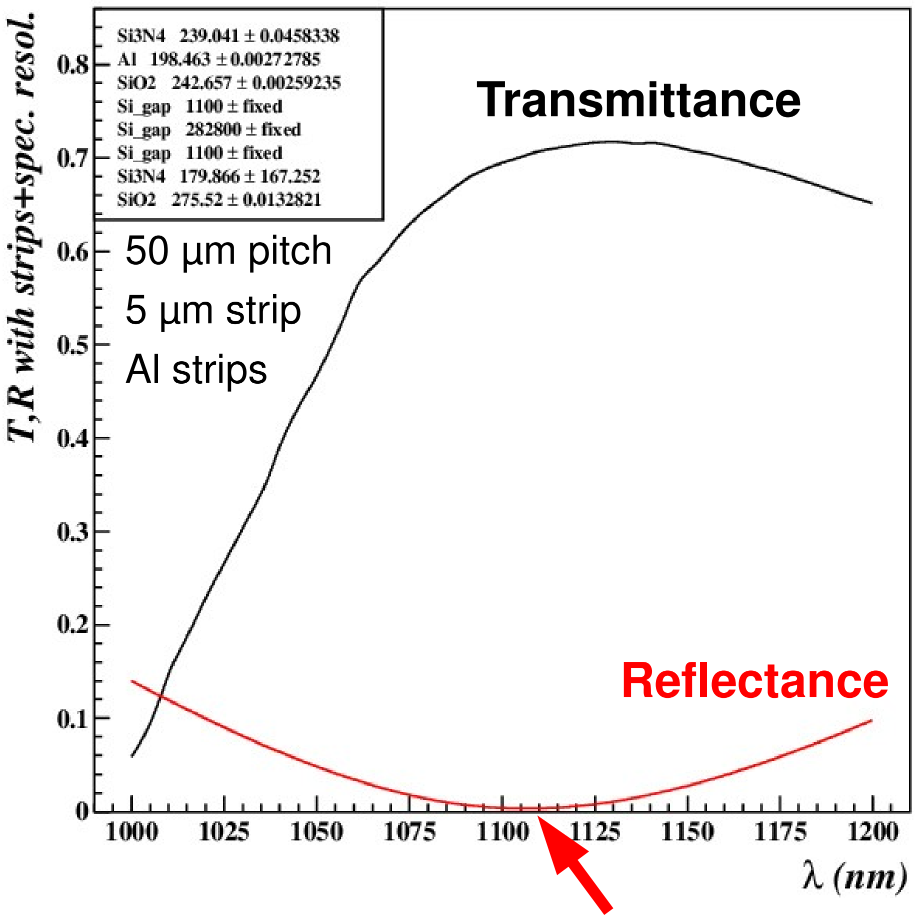
Si wafer + sample materials provided by CNM

Material **refraction indexes** are the input needed for the simulation of the full sensor stack.

Validation of patterned layers simulation

Simulation with strips. Not yet validated. This work is ongoing.

Example of predictions:



Typical AntiReflection Coating signature

Optimized for maximum %T, thin layers

No thickness tolerance studied yet

Maximum %T for a realistic sensor of 70%

Samples of **known** strip detectors without back Al provided by CNM ⇒ validation

We expect to have a transparent design with strips ready by the end of this month

Conclusions

• The role of IFCA within the SITRA task is to beamtest a prototype of the alignment system

• Proposed alignment strategy is based in already existing CMS and AMS systems: IR laser tracks shot across layers

• A prototype following these guidelines is currently being built. Beam test will take place 1st of Nov at CERN PS. IFCA has made the design of the FC and the optical characterization of the sensors. The FC is built at DESY. Module mounting and tests done by LPNHE.

• Typical microstrip sensor transmittance to IR light is below 20%.
The higher transmittance ⇒ the more detectors can be aligned with a single beam

• We proposed a second R&D line with the goal of reaching high transmittance values of ≥70%. With a good choice of thicknesses, a simple reduction of the strip witdth to 10% of the pitch provides a dramatic increase of %T.

• Optimization of the current design is done in 2 steps:

1) a simulation of continuous planeparallel layers is used to extract the refraction indexes of the materials. This simulation has been validated

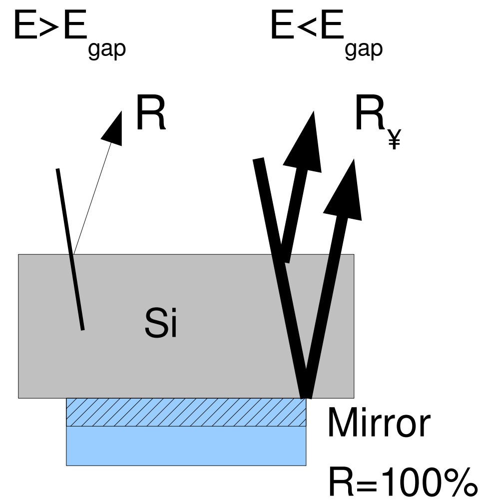
2) The refraction indexes are fed into a more complex simulation which takes into account diffraction by the strips.

• A robust sensor design will be settled by the end of this month and production of a 1st version will take place at CNM before the end of this year

BACKUP

Calculating n

- The real part of the refractive index can be calculated easily. Due to Si high absorption for E>E_{gap} and due to the thickness of the wafer, the photons do not reach the bottom surface
- Checked with a **mirror** on the Si wafer

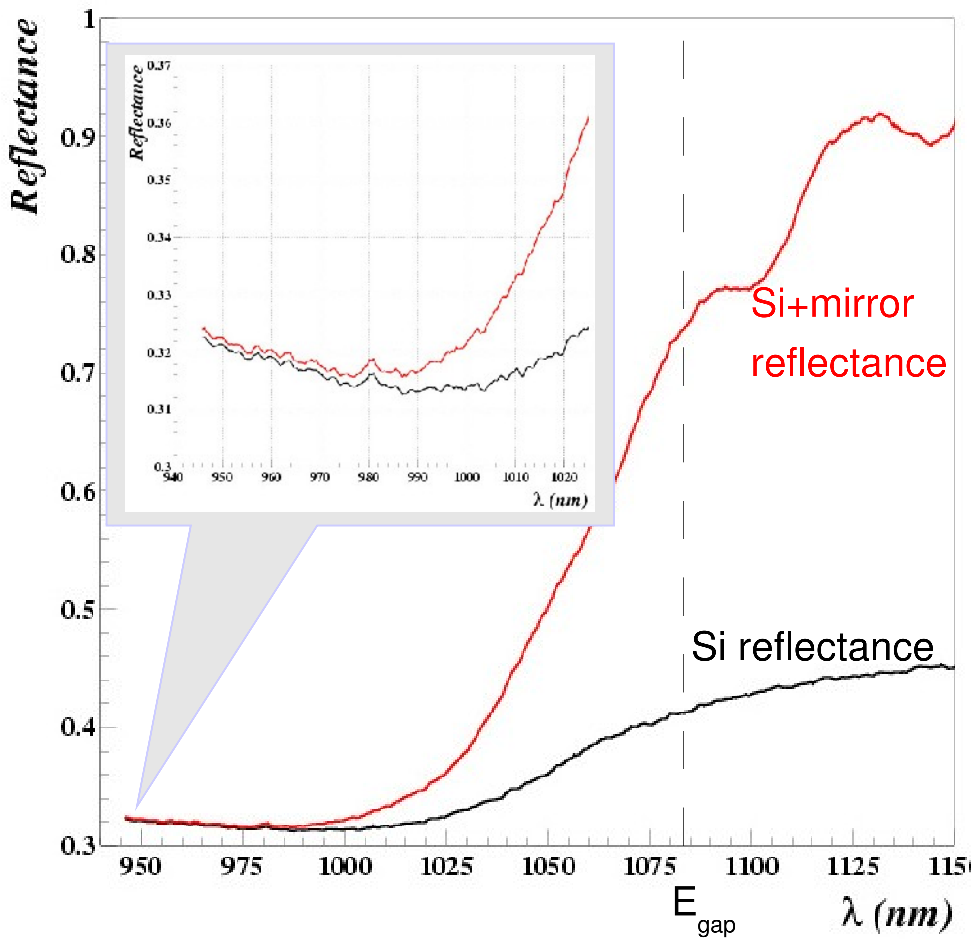


$$R=\frac{(n-1)^2+k^2}{(n+1)^2+k^2}\approx\frac{(n-1)^2}{(n+1)^2}$$

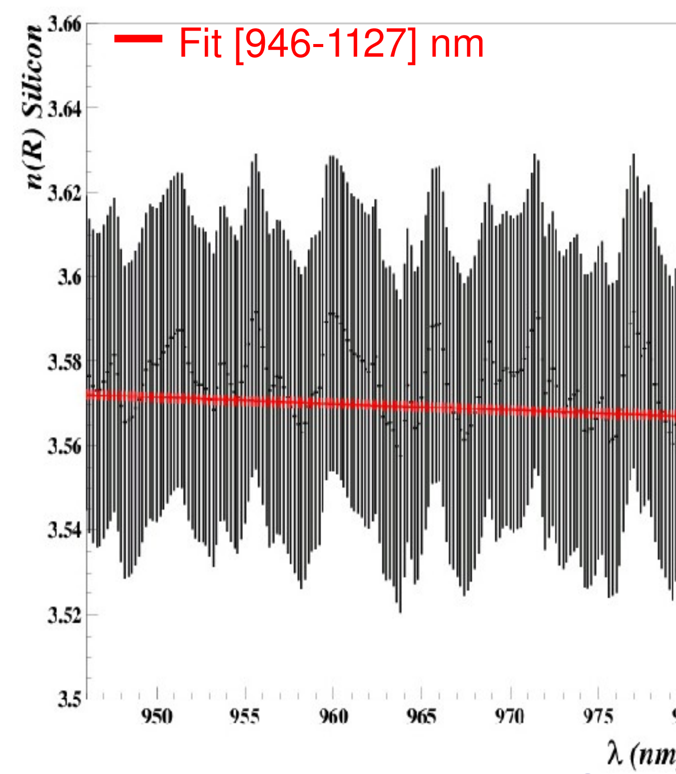
$(n\sim3.5, k\sim10^{-3})$

Independent of thickness and k

$$\sigma_n=\frac{\sigma_R}{\frac{\delta R}{\delta n}}=\sigma_R\frac{(n+1)^3}{4(n-1)}\approx10\,\sigma_R$$

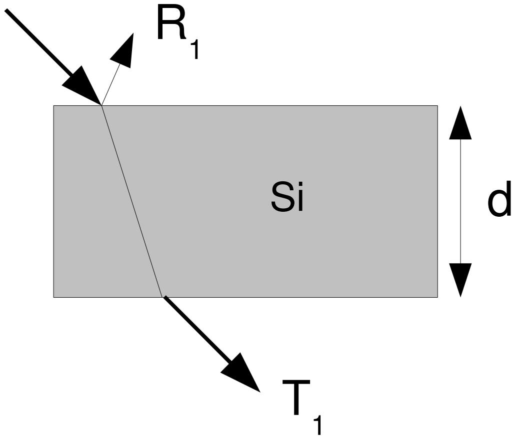


n(R) can be calculted using above formula:

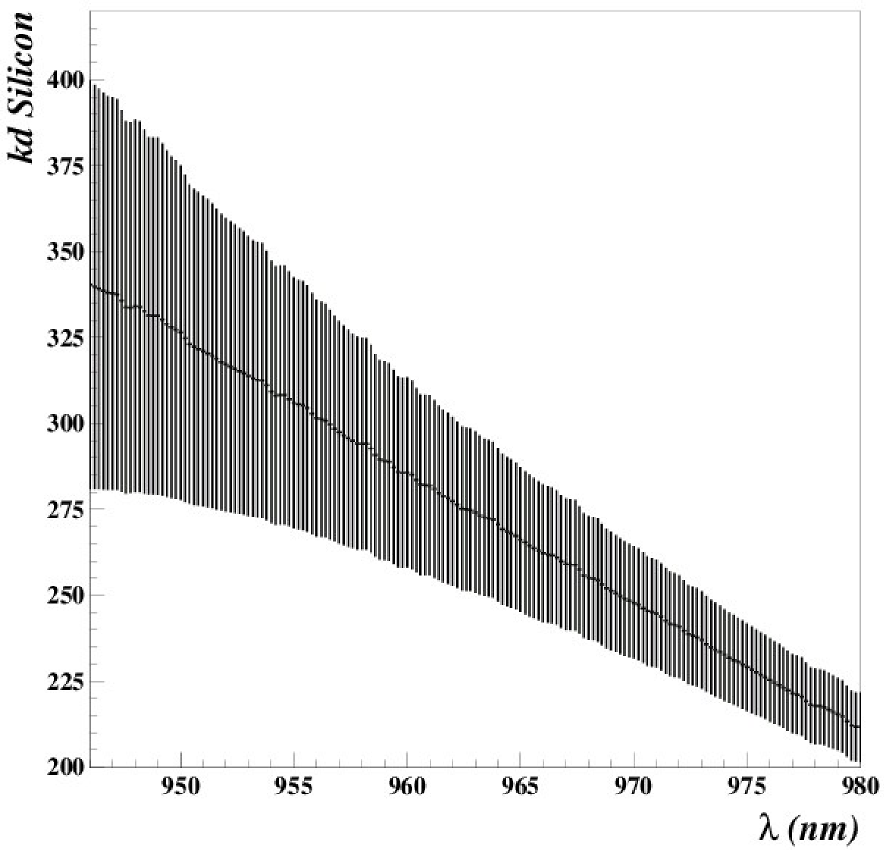


Calculating kd

• We can find kd analytically from the 1st transmitted beam (T_1), as a function of λ and R_1 (calculated before)



$$kd = \frac{\lambda}{4\pi} \ln\left(\frac{(1-R_1)^2}{T_1}\right)$$



Example of kd calculated from λ<980 nm

After multiple beams are reflected kd cannot be easily computed.

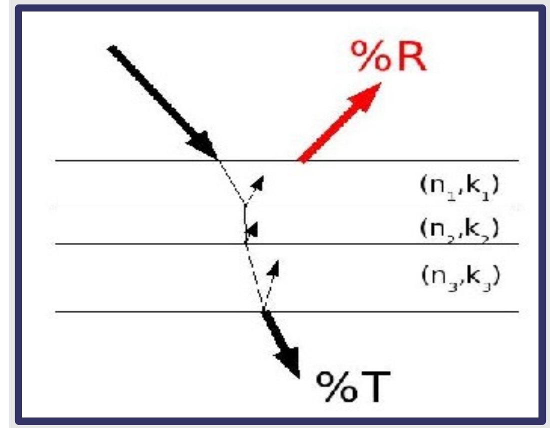
"k" always appears multiplied by "d". Correlation=1

Best is to measure "d$\pm\sigma_d$" independently and use this information in the global fit as a constraint

Alignment bench for beam deflection measurements. Deflections of order μrad can be measured as displacements of μm in meters

Cont. layers, sensor simulation

- The sensor is modeled as a multilayer media. Simulation features:
  - – Interferential effects due to multiple reflections are considered
  - – Absorption effects are included
  - – Refraction index (n,k) is a function of l
  - – Typical deposition thicknesses considered
  - – Deposition tolerances are included Þ We simulate realistic designs
  - – Laser spectral width is assumed (±2.5 x 2 nm)



T+R+A = 1

- Simulation particularities:
  - – Multilayers are left/right borderless
  - – Effect of aluminum electrodes is not included yet
  - – Energy going to secondary and higher order maxima (grid effect) is included

Transmittance	90%	80%	70%	60%	50%	40%
Traversed	30	15	10	7	5	4

- Aim is to achieve a transmittance as high as possible with moderate absorption (>3%)

Compromise of IFCA within the SITRA task

SIXTH FRAMEWORK PROGRAMME

Structuring the European Research Area Specific Programme

RESEARCH INFRASTRUCTURES ACTION

Contract for an

INTEGRATING ACTIVITY

implemented as

INTEGRATED INFRASTRUCTURE INITIATIVE (*I3*)

Annex I - "Description of Work"

Project acronym: EUDET

Project full title: Detector R&D towards the International Linear Collider

<u>(JRA2) Objectives and expected impact</u>, pg 42:

[...] development of prototypes structures, which can be used to test new tracking systems, and the provision of a **broad range of services needed to further develop and test Si-based tracking devices**.

<u>(JRA2) Si Tracking work description,</u> pg. 45:

The main issues **to be addressed** in these developments **and to be tested at the test beam** set-up are:

[...]

• A **prototype of the alignment system** to work out the alignment challenges, the distortions handling and calibrations for the overall tracking system. The alignment prototype will be **based on a system developed for LHC**, using laser beam and Si sensors to measure the detector position with high precision.

Framework and objectives

SITRA is one of the tasks of the Joint Research Activitiy JRA2 of EUDET.

There are **4 participating institutes** in the project:

- HIP University of Helsinki (Finland)
- LPNHE, UPMC and IN2P3/CNRS (France),
- Charles University in Prague (Czech Republic)
- IFCA-CSIC and University of Cantabria (Spain).

Moreover there are **5 associated institutions**:

- IMB-CNM/CSIC in Barcelona (Spain)
- Moscow State University and Obninsk State University (Russia)
- IFIC/CSIC and University of Valencia (Spain)
- HEPHY Vienna, Austria.

These institutes, together with many other form the the SiLC (Silicon for the Linear Collider) collaboration, which is a **generic R&D collaboration** to develop the next generation of large area Silicon Detectors for the ILC. It applies to all detector concepts and gathers teams from all proto-collaborations.

The main goal of SITRA within the EUDET project is to develop and install a test beam infrastructure based on silicon tracking detectors.

The **role of IFCA** within the SITRA task **is to beam-test a prototype of the alignment system** to work out the alignment challenges, the distortions handling and calibrations for the overall tracking system. The alignment prototype will be **based on a system developed for LHC**, using laser beam and Si sensors to measure the detector position with high precision.
(from EUDET Annex 1 documentation, pg. 45)


SIXTH FRAMEWORK PROGRAMME

Structuring the European Research Area Specific Programme

RESEARCH INFRASTRUCTURES ACTION

Contract for an

INTEGRATING ACTIVITY

implemented as

INTEGRATED INFRASTRUCTURE INITIATIVE (*I3*)

Annex I - "Description of Work"

Project acronym: EUDET

Project full title: Detector R&D towards the International Linear Collider