IR Transparent Si microstrips

(alignment optimized Si sensors)

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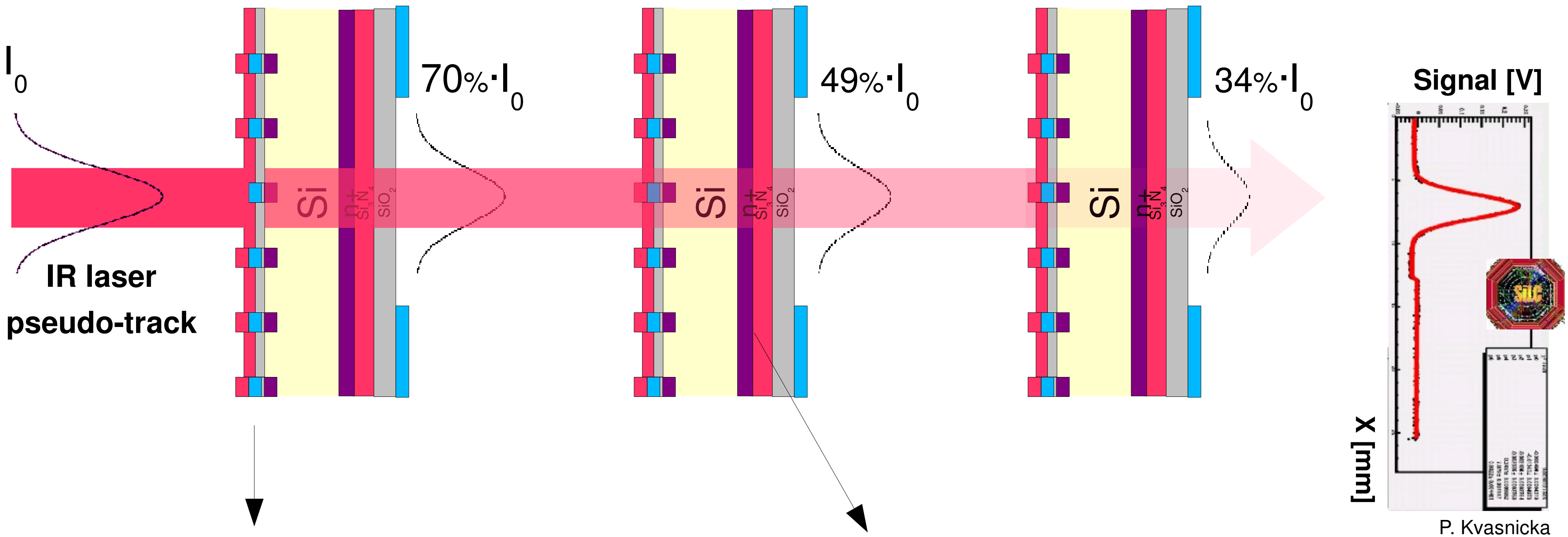
Giullio Pellegrini, Enric Cabruja

4th EUDET Annual Meeting — Geneva 19th Oct. 2009

IR track alignment

- Aim: align Si microstrip sensors using IR laser tracks



IR light is partially absorbed by Si

Φ~1 mm opening in Al allows beam-through

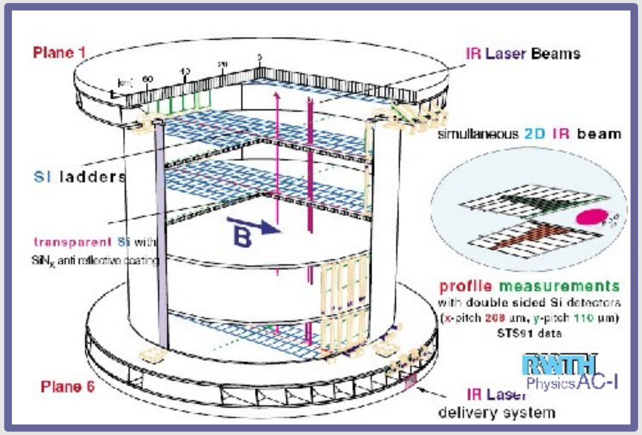
- Higher %T ⇒ simpler implementation of the system:

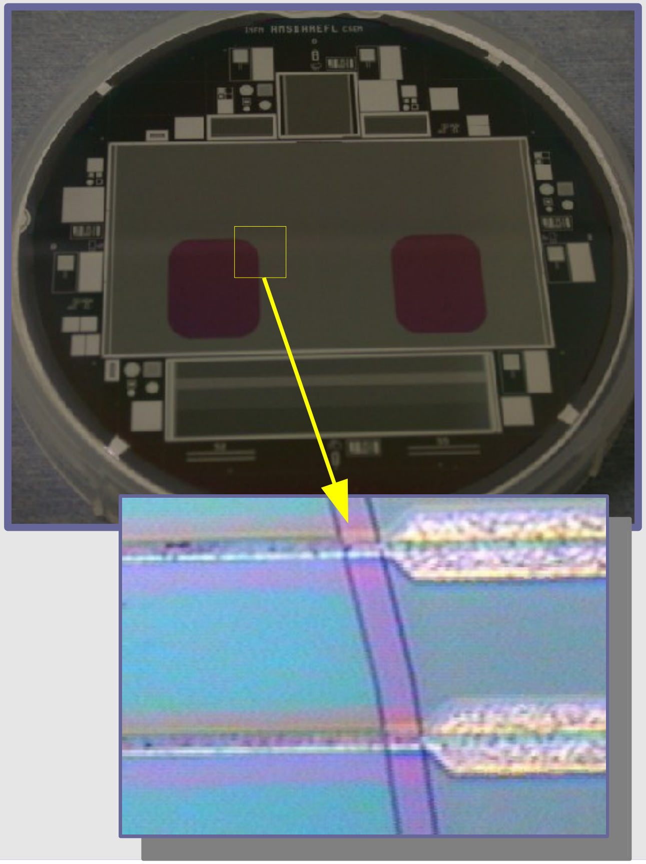
Transmittance	90%	80%	70%	60%	50%	40%
Traversed	30	15	10	7	5	4

- System features:
  - Laser intensity~200 MiPS ⇒ **sharing same DAQ as Si detector**
  - Silicon modules are directly monitored, **no external fiducial marks**

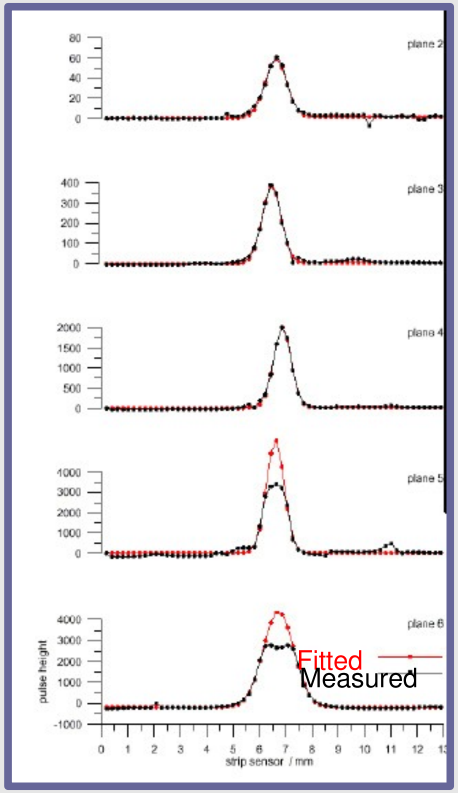
IFCA Instituto de Física de Cantabria

An idea that works …





Up to 4 ladders traversed



AMS-01 innovation (W. Wallraff)

λ = 1082 nm, 110 µm RO pitch

IR “pseudotracks”

1-2 µm accuracy obtained

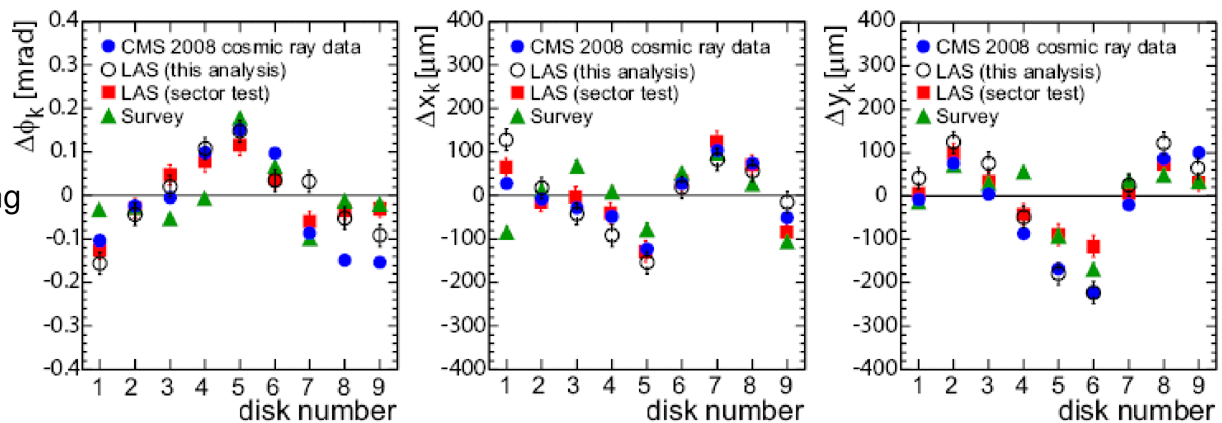
Transmittance~ 50%

CMS

TEC

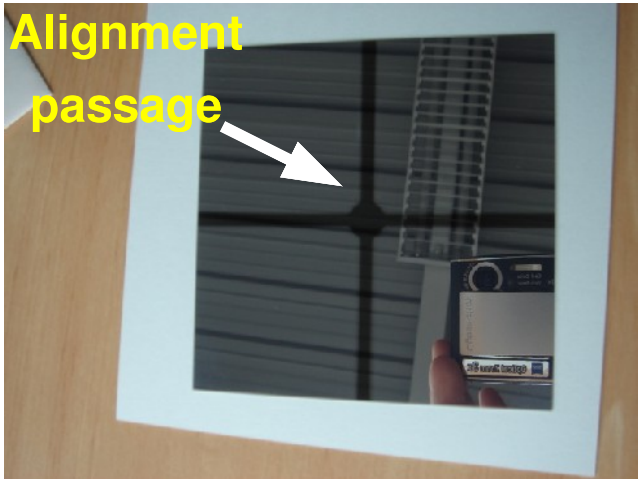
λ = 1075 nm

- Optimization of sensors not included from beginning of sensor design→**lower transmittance** ~20%
- Some sensors need to be operated in saturation
- 100 µm reconstruction error needed for L1 trigger

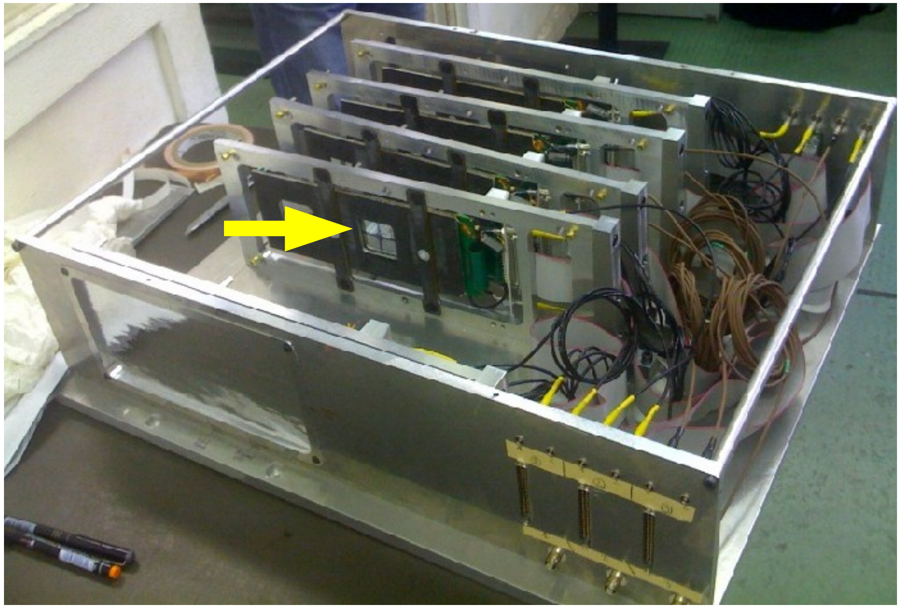


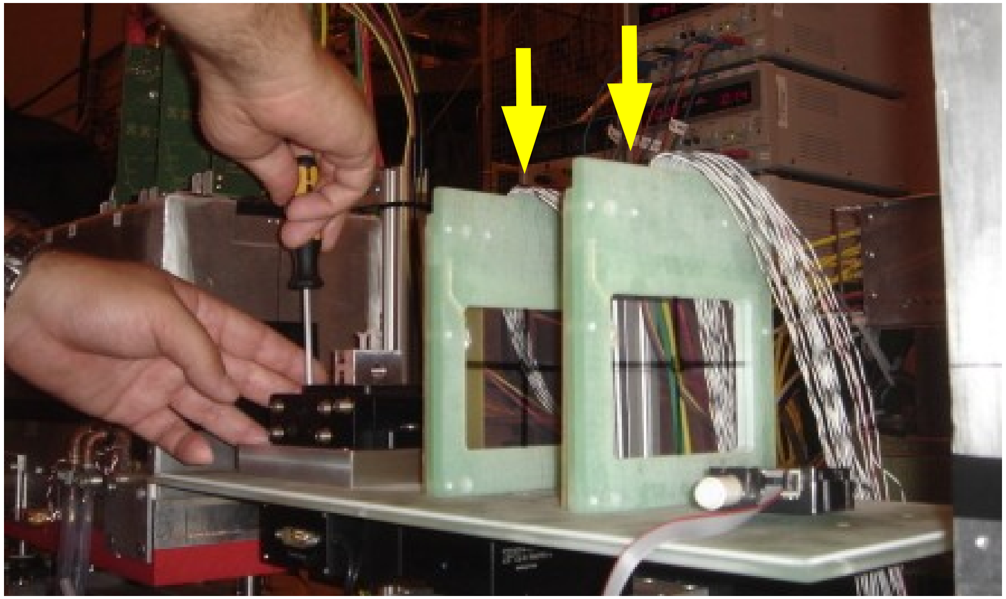
(CMS first paper at JINST !!)

SiLC HPK alignment sensors



Set of 5 sensors out of a batch of 30 sensors produced by HPK.





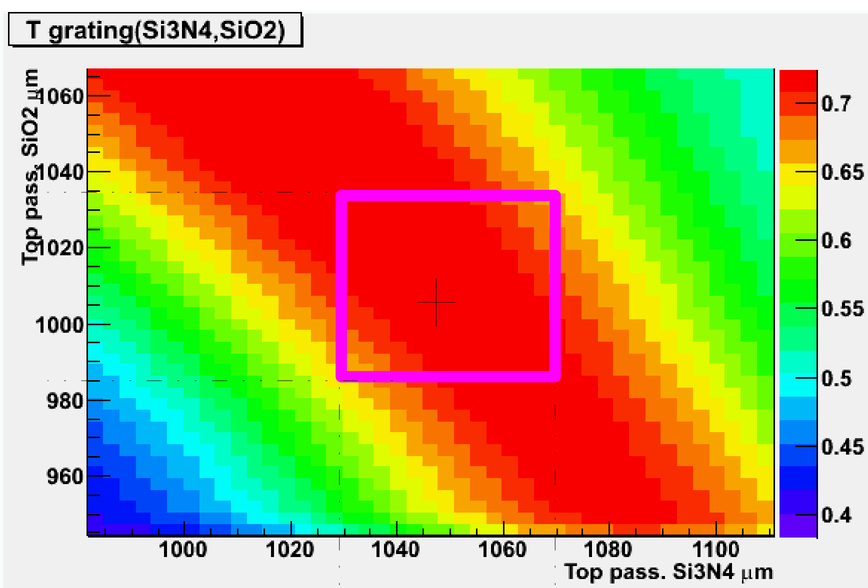
3 used for **SiLC alignment test beam prototype (Dec 08):** LPHNE's SiTr-130-88 chip

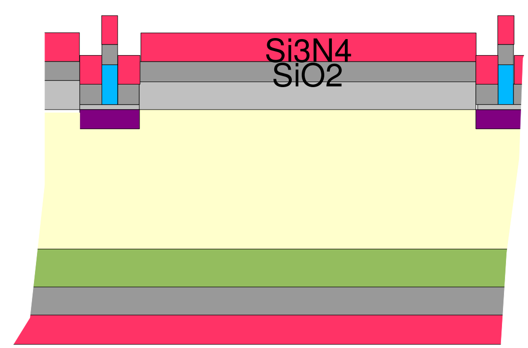
2 used for **SiLC test beam (Aug 09):** APV25 readout by HEPHY

Note: Using CMS sensor optical design T[λ=1060 nm] ~16%

Constraints for maximum %T

- Developed full simulation of light propagation through sensor multilayer. Diffraction by strips taken into account (first time such detailed simulation has been done). Details in Eudet-Memo-2008-37
- Transmittance depends mostly on pitch over strip width
- Idea to boost %T:
  1) Choose optimal layout (sw/pitch=10%)
  2) Use passivation (=SiO_2+Si_3N_4) as an AntiReflection Coating (ARC)
- Recipe for production process:
  Deposit each layer and measure its thickness (design thickness tolerance ≤5%)
  Correct last Si3N4 layer if needed, according to plots like:





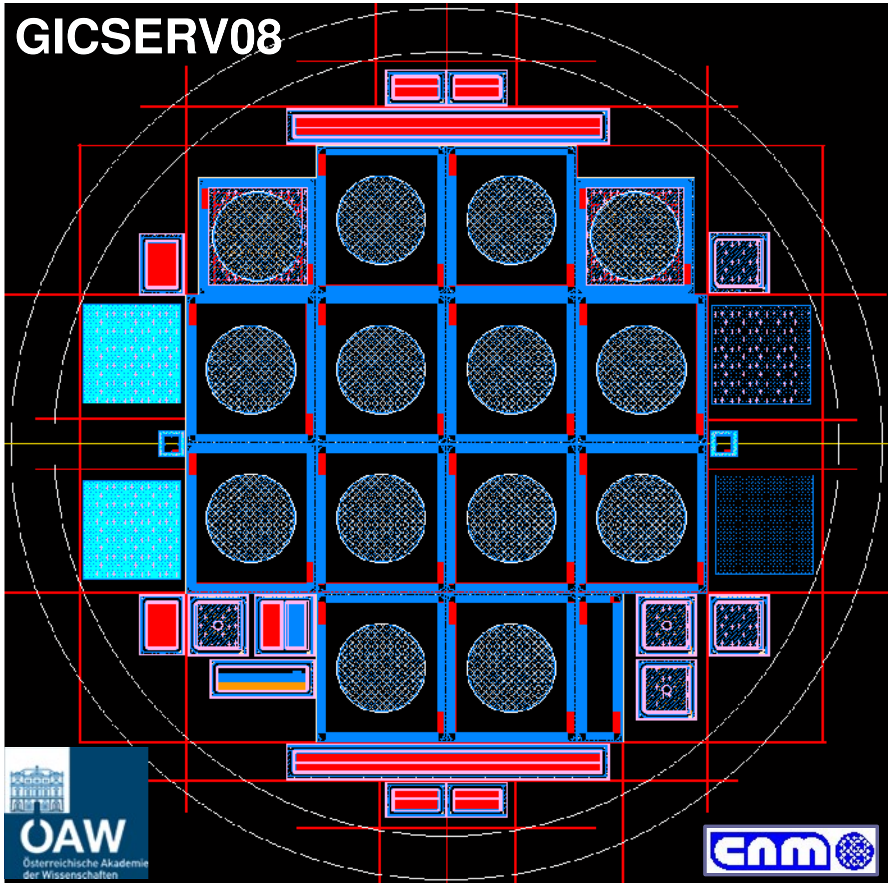
Si3N4	1046	X
SiO2	1006	Y
Al	950	
SiO2 (FO)	1000	
295 μm Si + implants		
SiO2	1020	
Si3N4	1005	

λ=1085 nm

CNM sensors (GICSERV08)

- Prototypes built by CNM-Barcelona (Spain)

- Aims:
  — Test %T vs multigeometry
  — Use optical test structures (continuous layers) to extract refraction index and control deposition
  — Test of electrical test structures



- 5+1 wafers
- 12 μstrip detectors per wafer (6 with intermediate strips, without metal contacts)
- 50 μm RO pitch (25 μm interm. strip)
- 256 RO strips
- 1.5 cm length varying strip width (3,5,10,15 μm)

- Mask designed by **D. Bassignana** (CNM)
- Electronic test structures designed by **M. Dragicevic** (Vienna) including:
  CAP TS AC, CAP TS DC, CMS Diode, MOS, GCD, Sheet
- Optical test structures available (Si, Si+p^+,SiO_2, SiO_2+passivation)

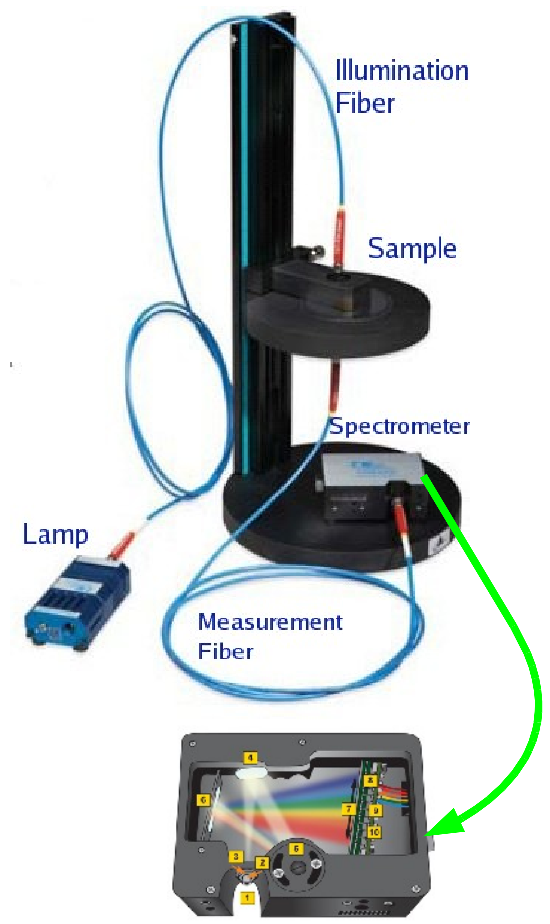
Production progress

- Production started on 11th of May 09
- All processes done until deposition of 1st passivation layer (end of July 09)
- Thickness of all layers measured after each deposition

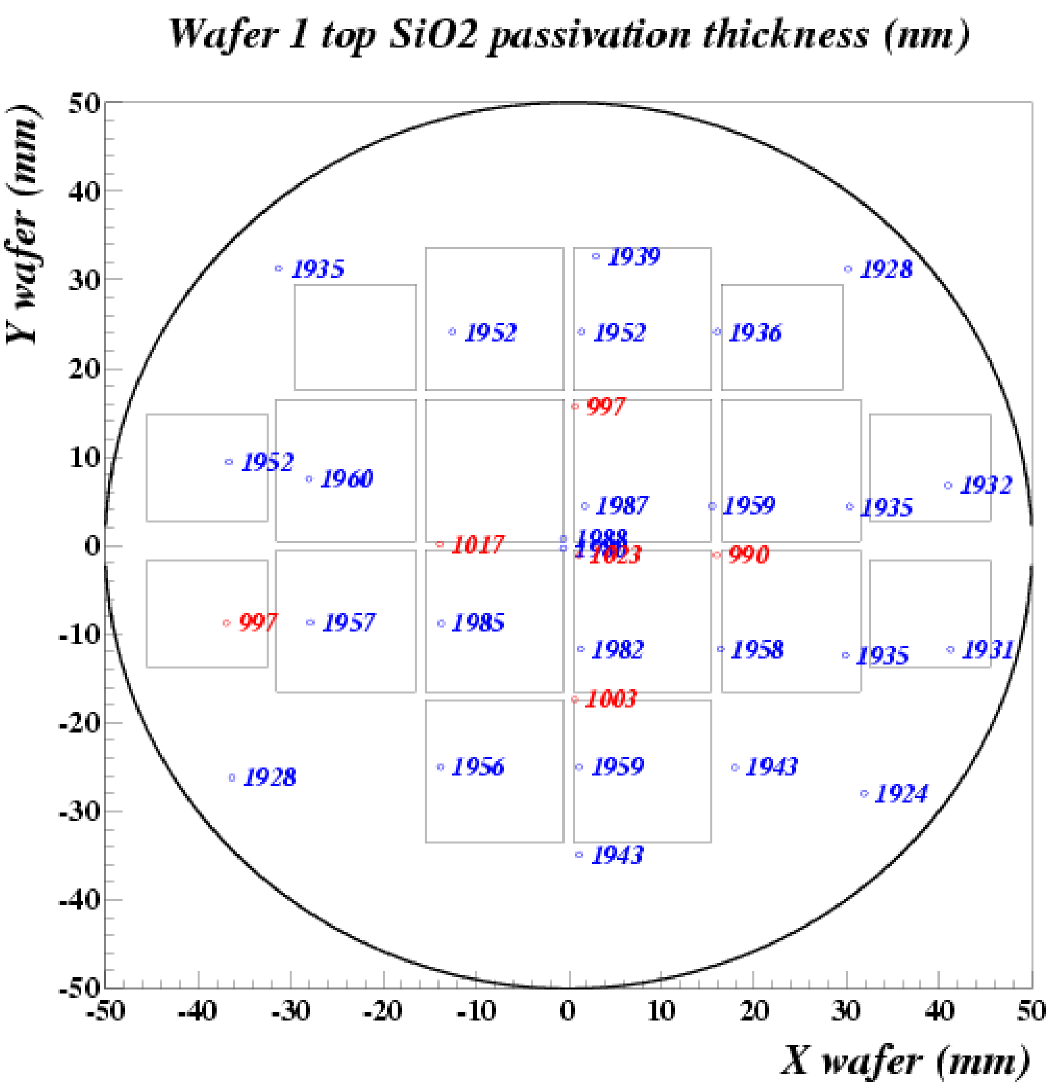
- For the 1st batch, we decided to hold the production just before deposition of the last passivation layer. Like this we can measure the wafer at an intermediate step

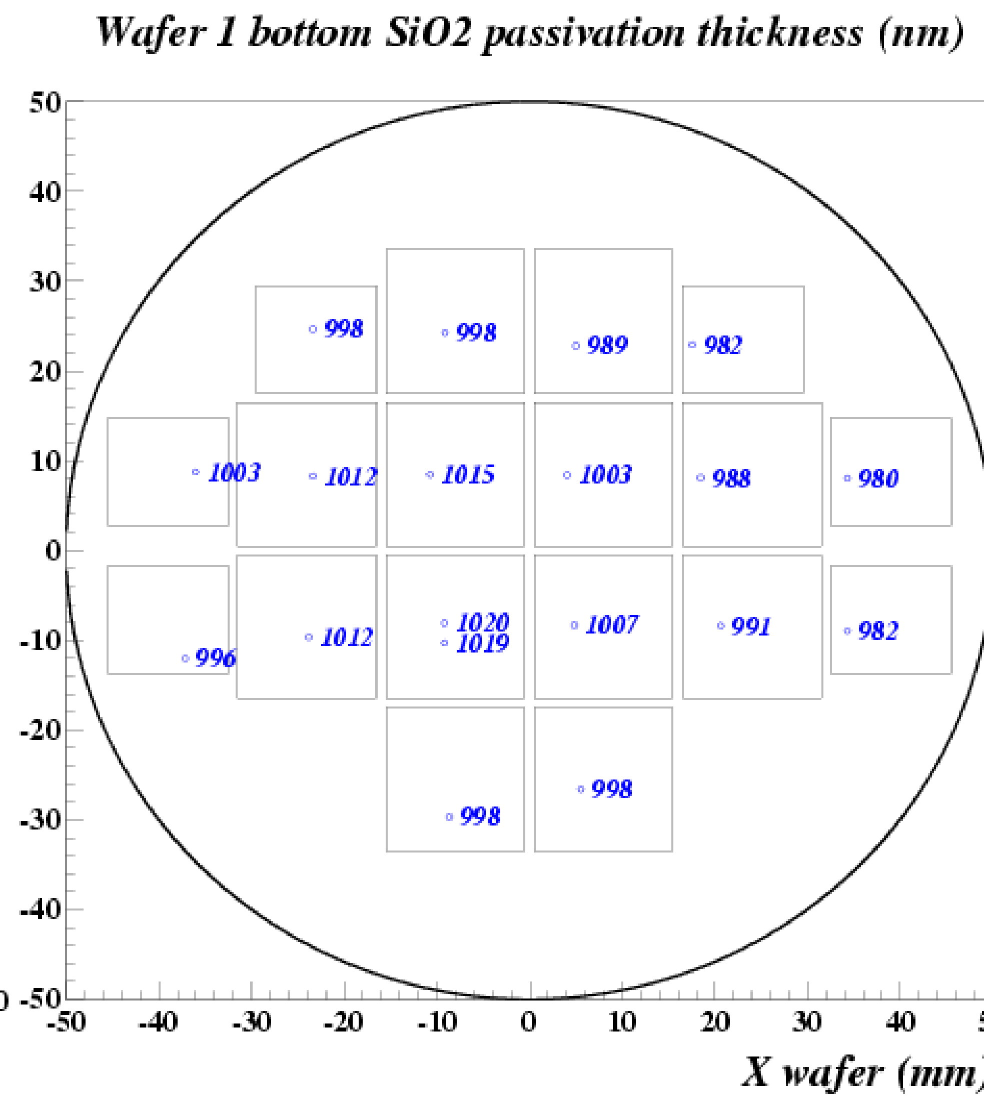
- Optical measurements were taken by end of July
  - — Test structures (no internal structure)
  - — Sensors (strips ⇒ diffraction)

- NIR spectrophotometer used for Optical measurements
  - — %T : Measures spectrum with sample in/out
  - — %R: Comparison against calibrated reflector



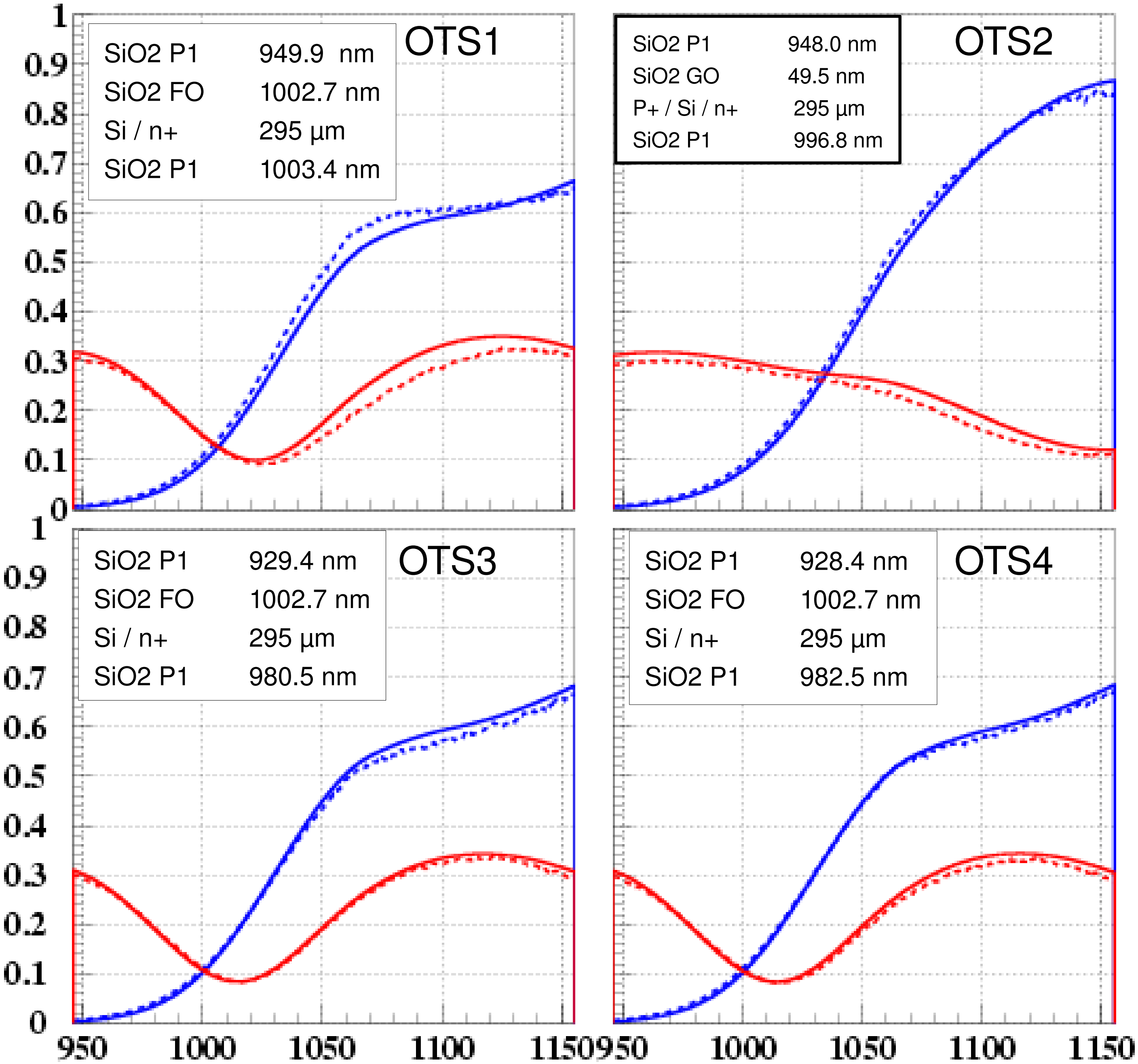
Top and bottom SiO2 passivation thickness measurements





- Aluminum (not shown) also measured
- All materials within requested 5% tolerance thickness

WAFER 1: Measured optical test structures vs simulated



- Test structures simulated (no fit involved)
- n^+ and p^+ taken optically identical to Si
- 1st result: Transmittance of Si can be increased by ~30% with just 2 layers of 1 µm SiO2
- **New parametrization** for SiO2 refr. index used !!!

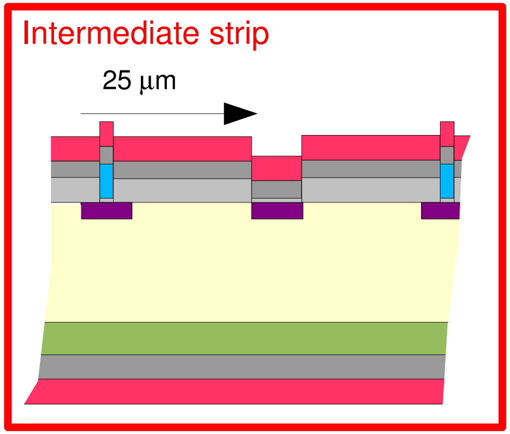
Photometric measurements of transparent microstrip detectors prior to last Si_3N_4 deposition

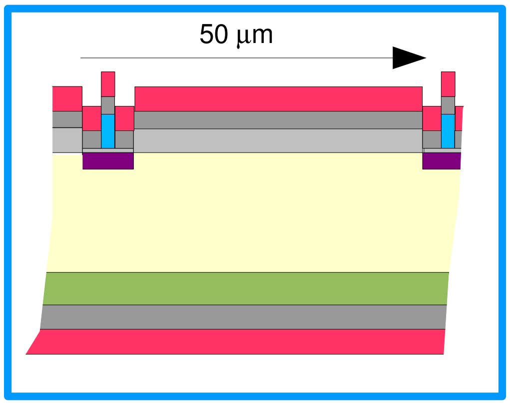
This is a control measurement before completion of sensor

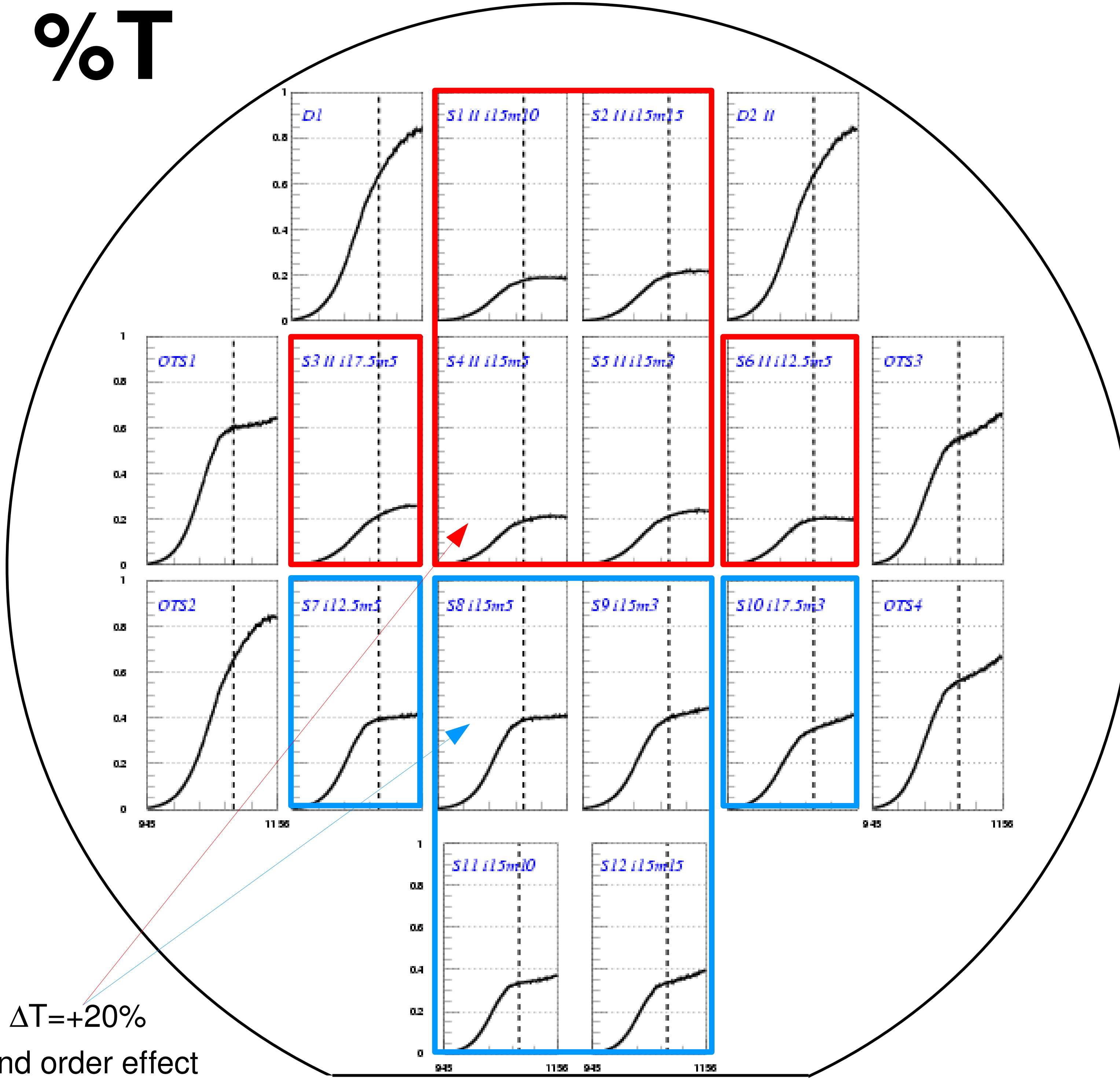
Last passivation layer(s) top and bottom Si_3N_4 determine overall transmittance

Wafer 1:: %T

measured



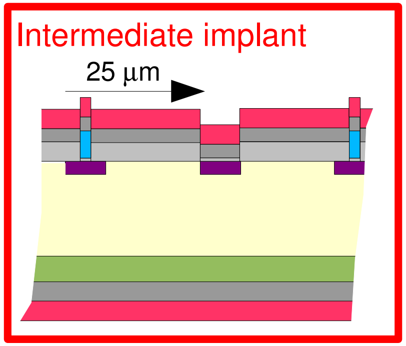


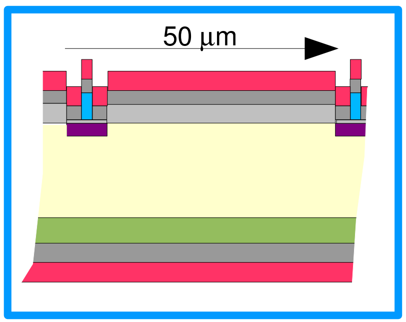


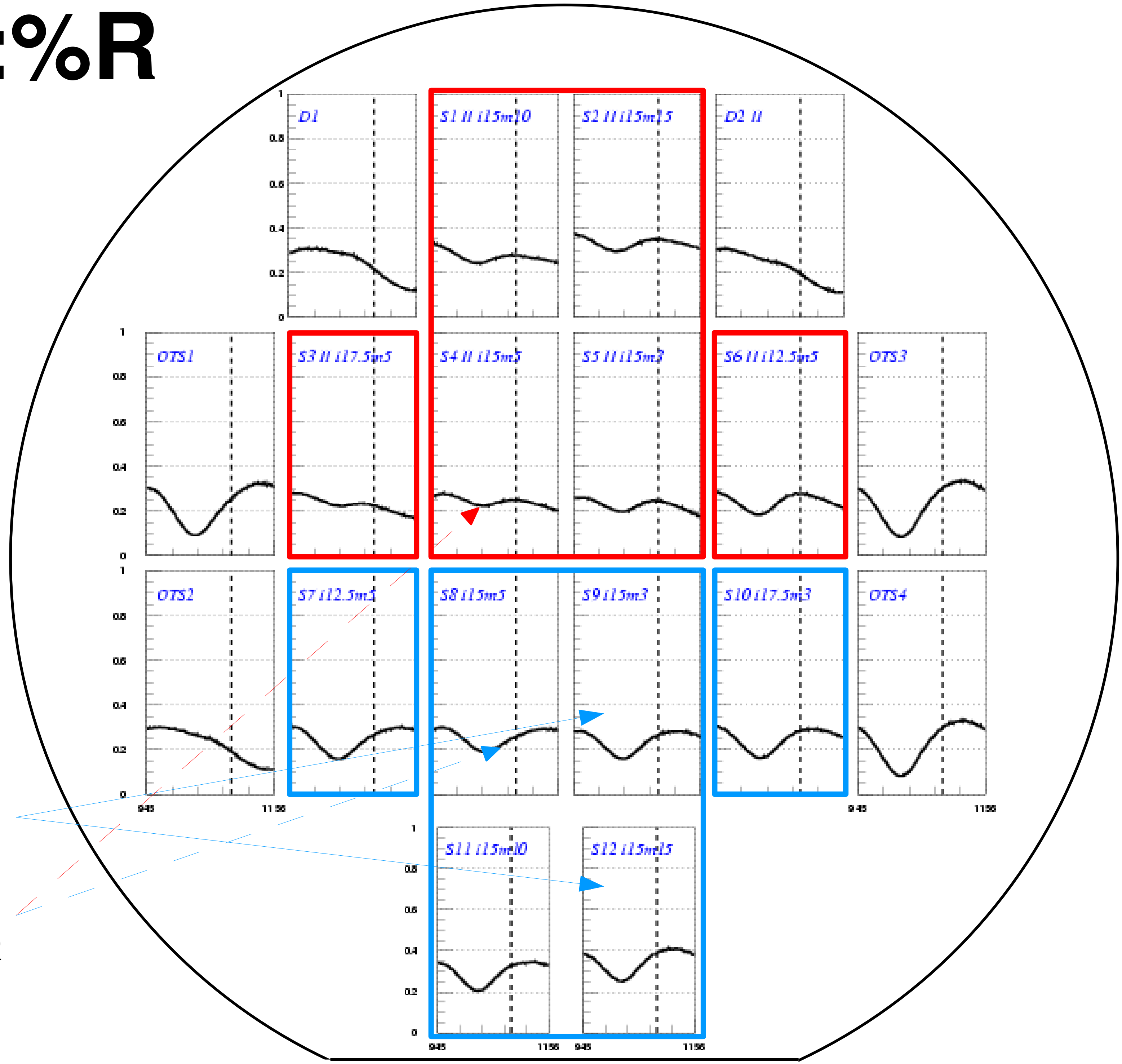
- T~70-80% test structures
- No intermediate implant ⇒ ΔT=+20%
- Metal width [3-5] μm: second order effect
- Metal width >10 μm: ΔT≤-5%

Wafer 1::%R

measured







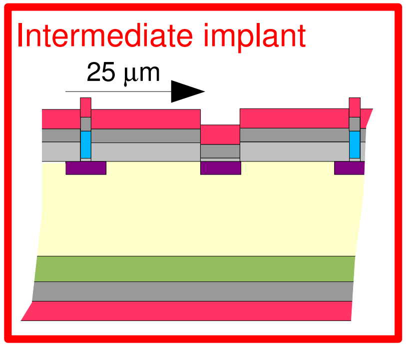
- Metal width has higher influence in reflectance: ΔR=10% between [3-15] µm

- Removal of intermediate implant does not reduce %R

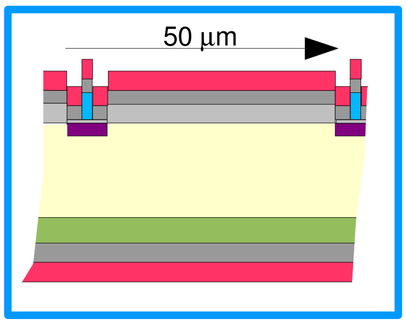
- **⇒ %R linked to Al width while %T related to uniformity**

Wafer 1

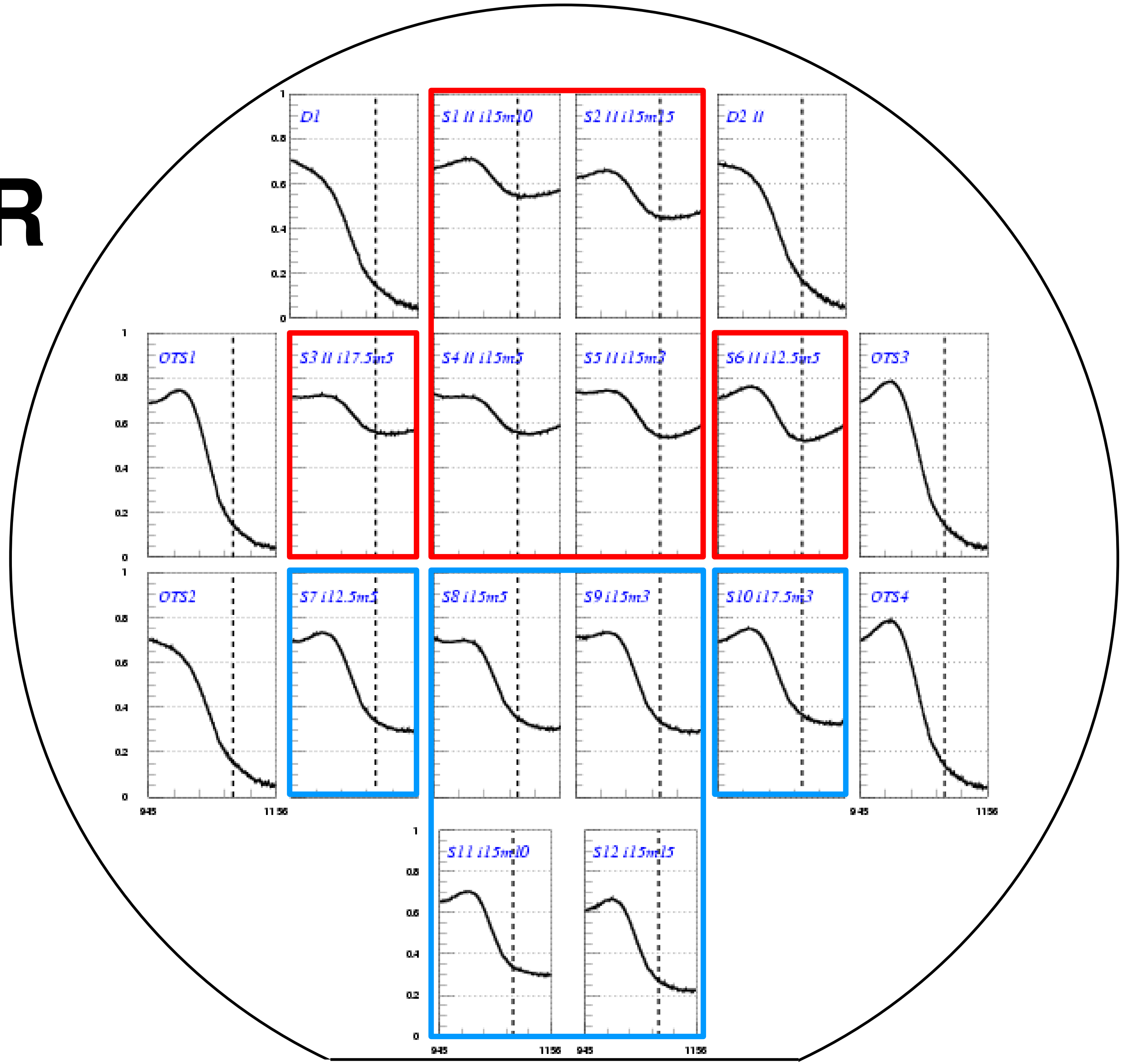
%A=1-T-R



Intermediate implant
25 µm



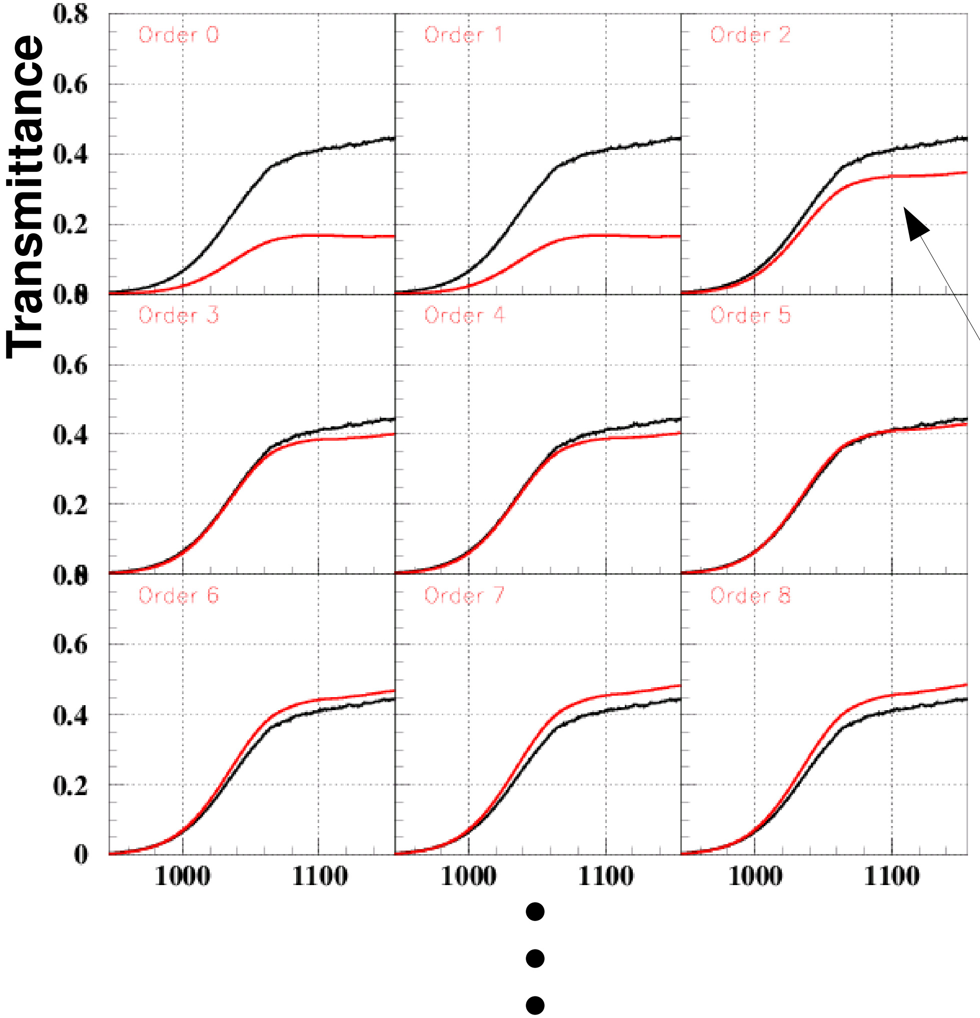
50 µm

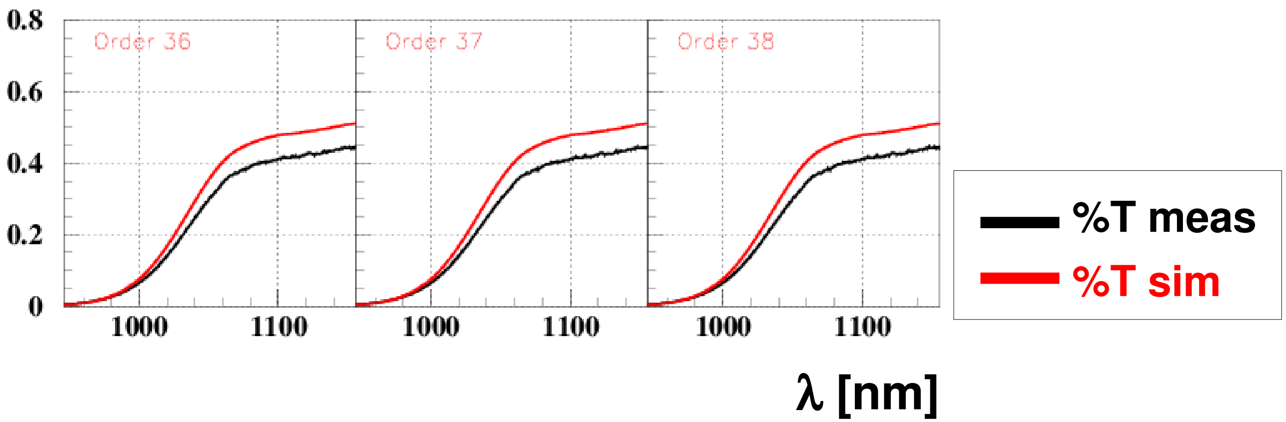


D1
S1 II i15m10
S2 II i15m15
D2 II
OTS1
S3 II i17.5m5
S4 II i15m5
S5 II i15m3
S6 II i12.5m5
OTS3
OTS2
S7 i12.5m5
S8 i15m5
S9 i15m3
S10 i17.5m3
OTS4
S11 i15m10
S12 i15m15
0
0.2
0.4
0.6
0.8
1
945
1156

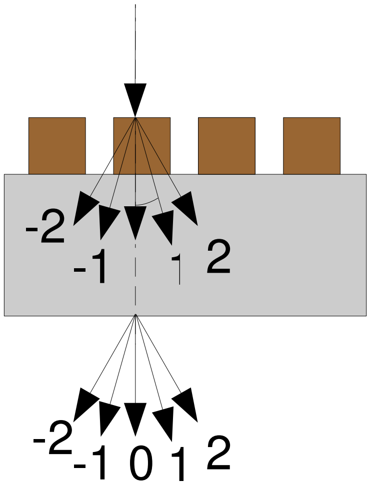
WAFER 1: Measured sensor vs simulated

- Implant width=15 μm
  Metal width=3 μm
  No intermediate implant



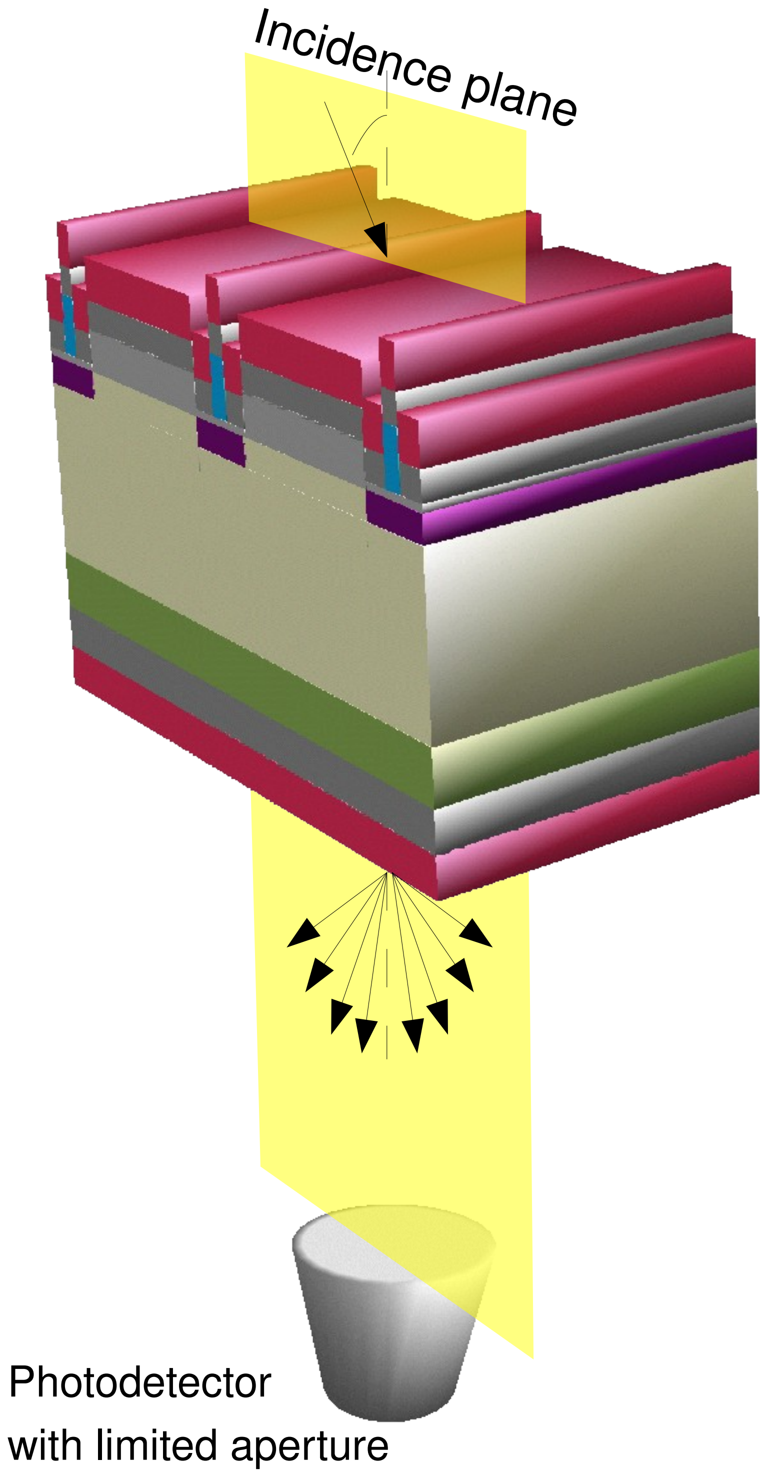


- Diffraction orders:



- Plots show cummulative %T distribution up to 38 diffraction orders. For example: T[2]=T[order 0]+T[o=±1]+T[o=±2]

- Our calculation overestimates %T. Why? (see next page)



Diffraction: Far field calculation

Geometrical acceptance problem.

Due to limited size of the sensing optics, not all radiation is captured ⇒ Update simulation to account for this effect (work in progress)

Summary

- IR tracks useful to align selected sensors. Higher %T needed to simplify system
- We are after a simple production process that can be easily implemented by large scale producer
  - Passivation=ARC
  - Layers deposited to 5% thickness tolerance
- 5+1 wafers with multigeometry sensors produced. Production stopped (foreseen) for control
  - New SiO2 parametrization was needed
- Deposition tolerance at CNM is remarkable. Better than 5% in almost all layers
- Measurements of %T and %R were done
  - Simulated continuous optical test structures very close to measurements
  - Working on full sensor simulation

BACKUP

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).

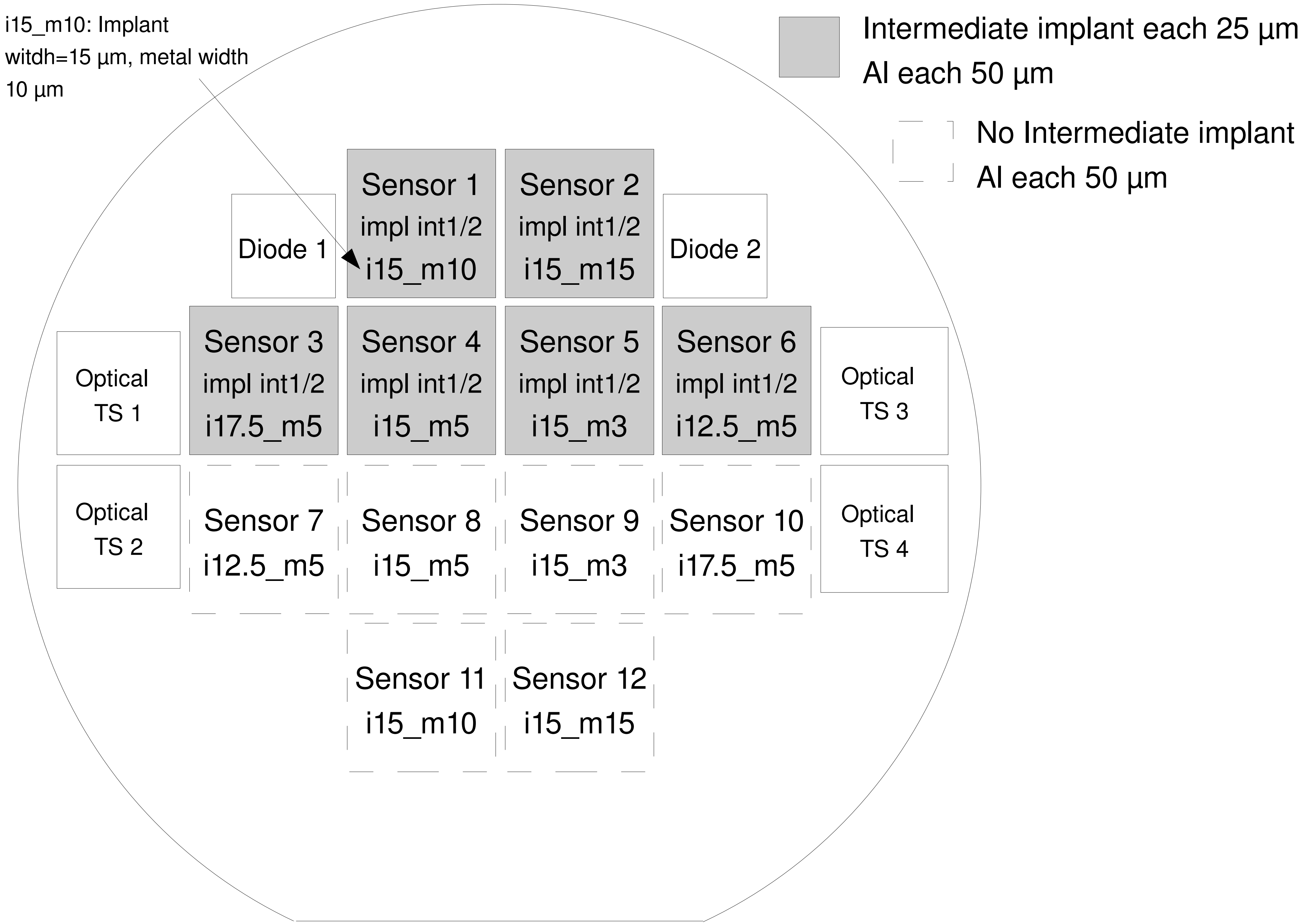
Moreover there are **5 associated institutions**:
IMB-CNM/CSIC in Barcelona (Spain)
Moscow State University and Obninsk State University (Russia)
IFIC/CSIC and University of Valencia (Spain)
HEPHY Vienna, Austria.

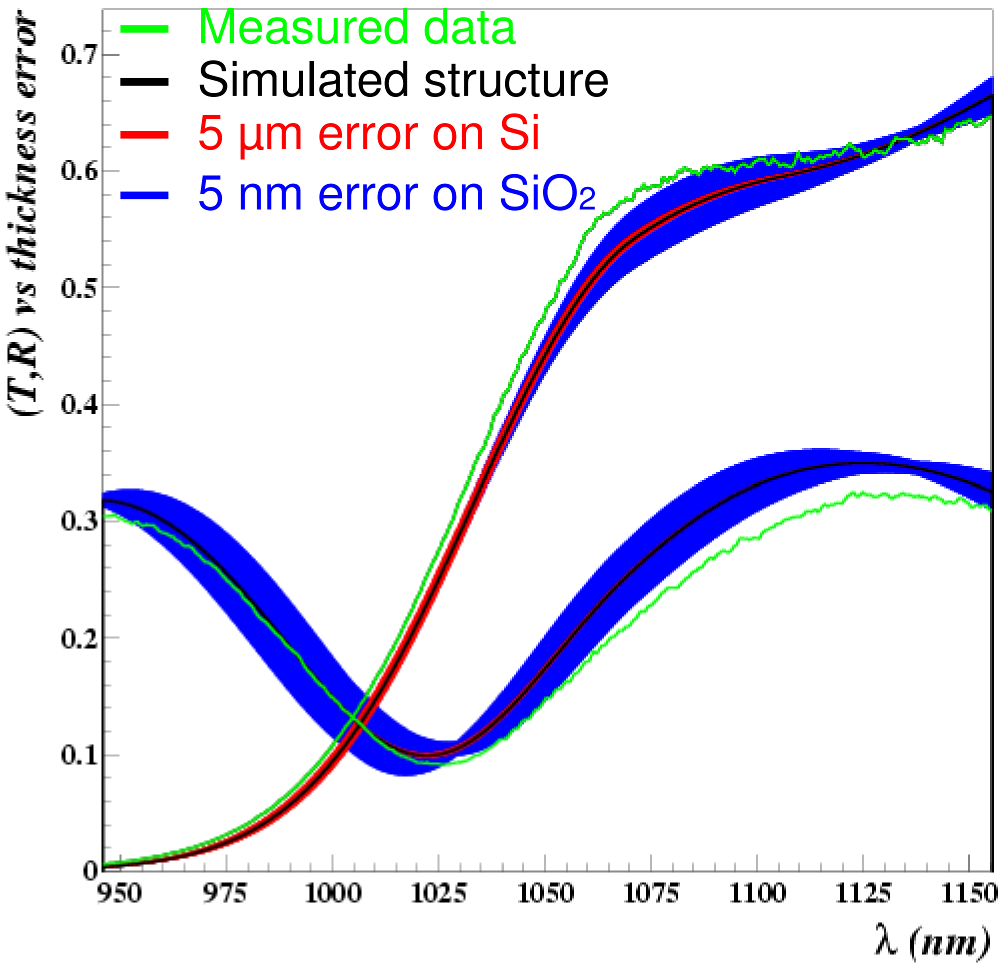
These institutes, together with many other form the the SiLC (Silicon for the Linear Collider) collaboration, which is a **generic R&D collaboration** to develop the next generation of large area Silicon Detectors for the ILC. It applies to all detector concepts and gathers teams from all proto-collaborations.

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

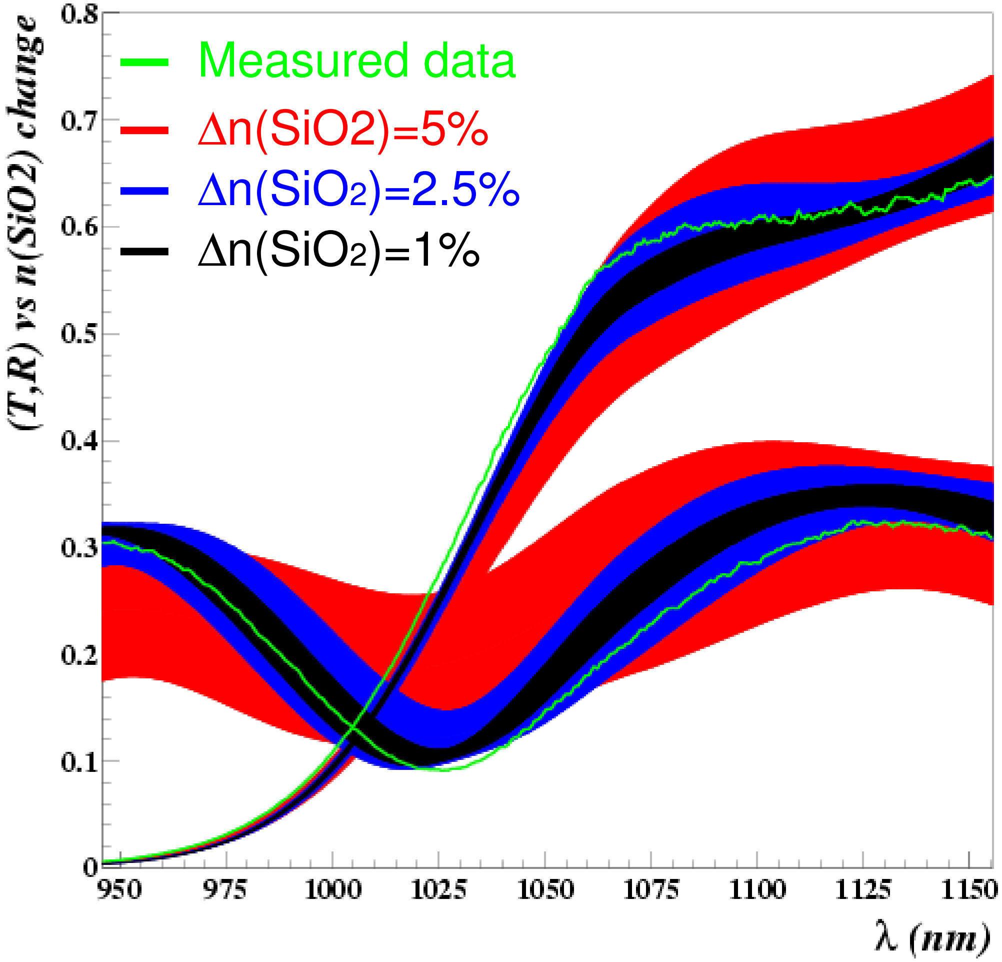

i15_m10: Implant witdh=15 µm, metal width 10 µm
Intermediate implant each 25 µm
Al each 50 µm
No Intermediate implant
Al each 50 µm
Diode 1
Sensor 1 impl int1/2 i15_m10
Sensor 2 impl int1/2 i15_m15
Diode 2
Optical TS 1
Sensor 3 impl int1/2 i17.5_m5
Sensor 4 impl int1/2 i15_m5
Sensor 5 impl int1/2 i15_m3
Sensor 6 impl int1/2 i12.5_m5
Optical TS 3
Optical TS 2
Sensor 7 i12.5_m5
Sensor 8 i15_m5
Sensor 9 i15_m3
Sensor 10 i17.5_m5
Optical TS 4
Sensor 11 i15_m10
Sensor 12 i15_m15



Can observed difference be due to thickness measurement error?

No (as long as measurement error < 5 nm)

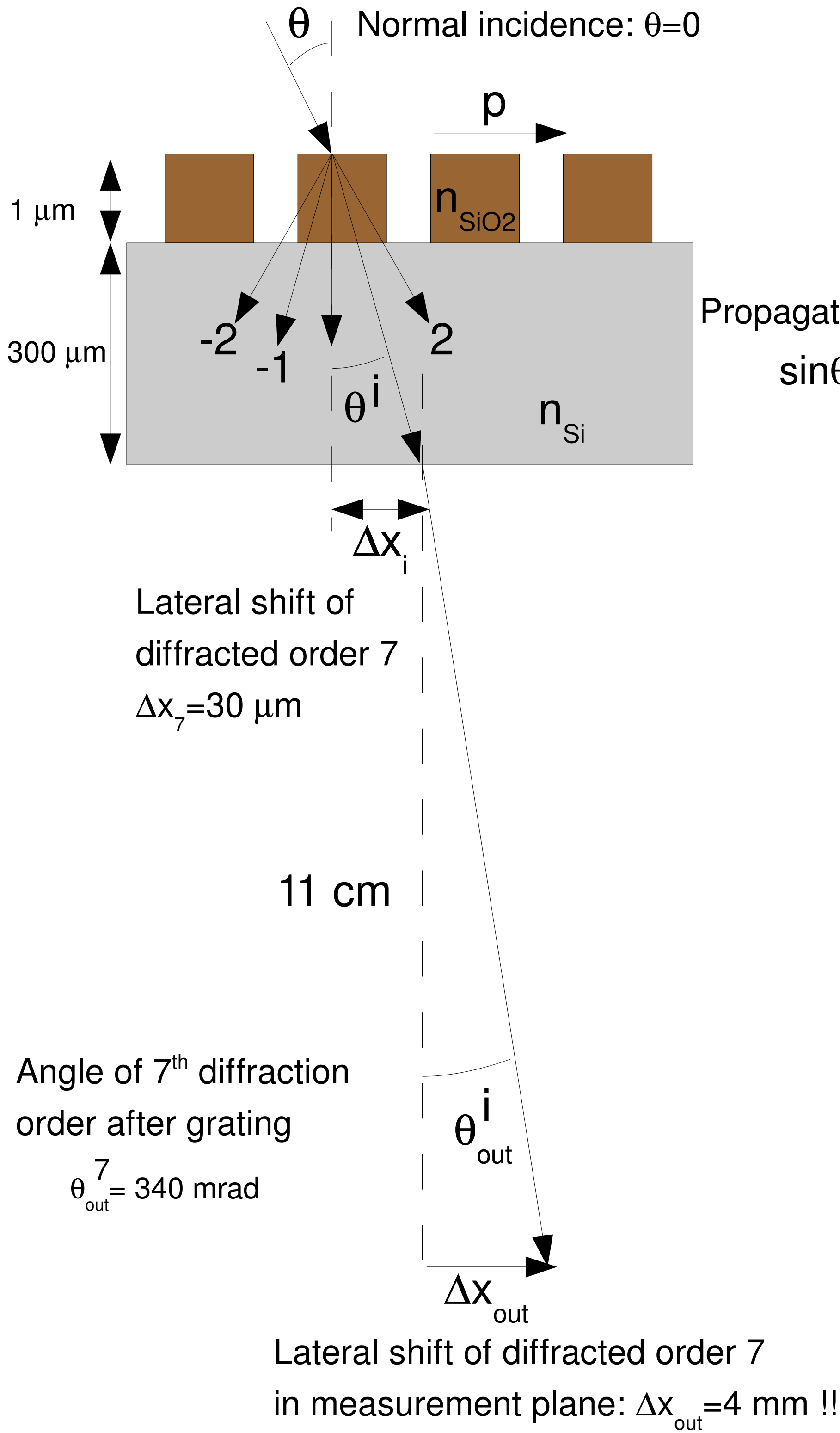
Observed that 5 nm error on SiO_2 influences much more than 5 µm error on Si



Can observed difference be due to refraction index scaling?

Maybe...

(if we allow $n(SiO_2)$ change of 2.5%)



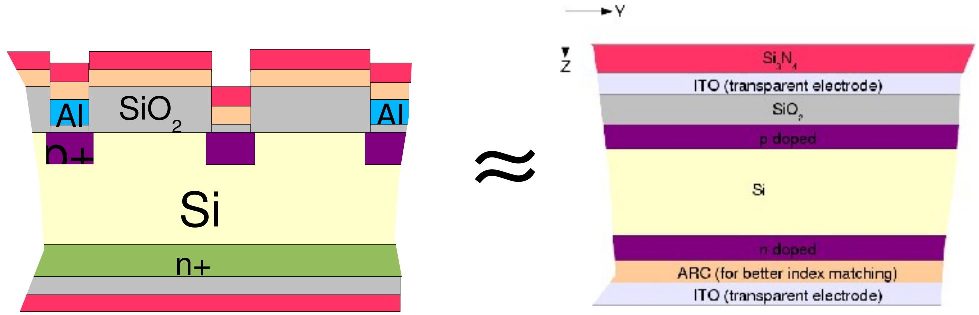
Propagation angle of diffraction order i: θ_i

$$\sin\theta_i = \sin\theta + i\,\lambda/(n_{SiO2}p)$$

<u>Notes:</u>

- First diffraction order falls 5.3 mm away from normal
- We have a 1.5 mm diameter pinhole at the measurement plane

Simulation of planeparallel structures



- **Simple simulation**: **multiple reflections** ⇒ interferences ⇒ Calculation of (T,R)

  — Refraction index either tabulated or modeled using dispersion relations

  $$n(\lambda),k(\lambda),d_i \Rightarrow \mathbf{T}_{\mathbf{calc}}, \mathbf{R}_{\mathbf{calc}} = f[\,n(\lambda),k(\lambda),d_i\,]$$

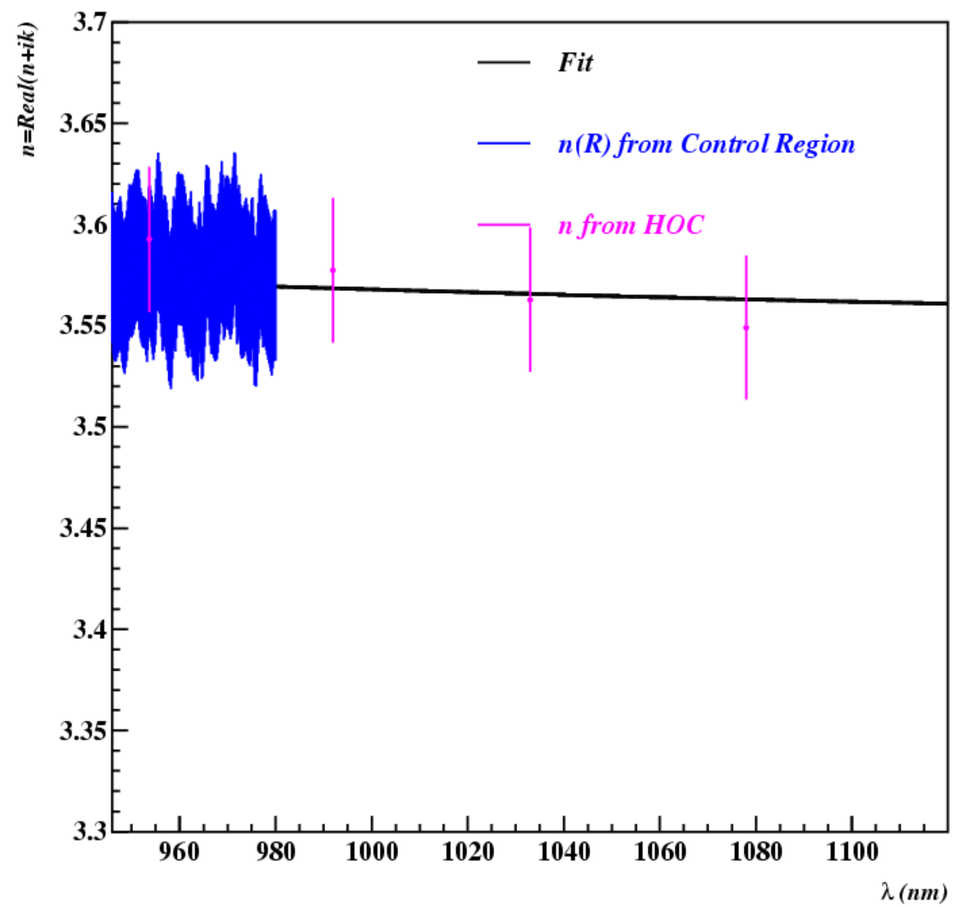
  (i=1...Number of layers)

  — Or solve the **inverse problem**:

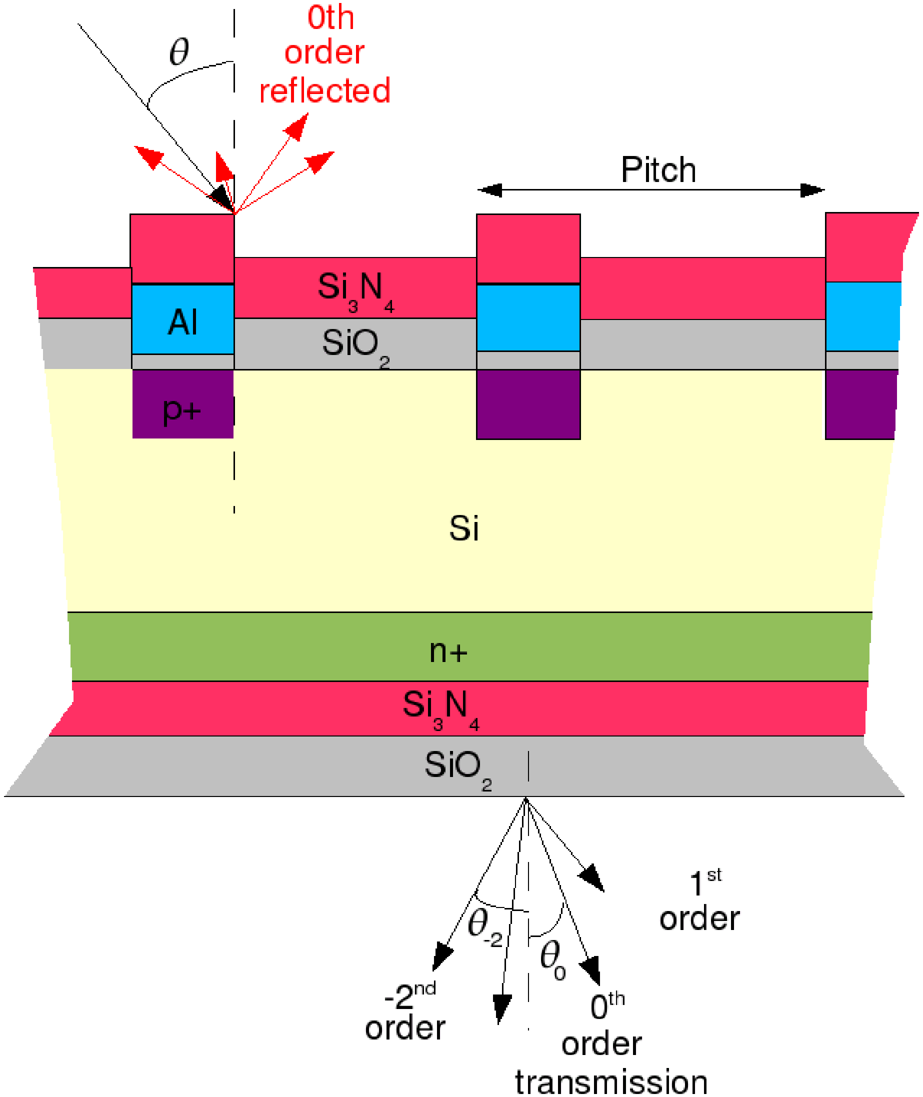
  $$\mathbf{T}_{\mathbf{meas}}, \mathbf{R}_{\mathbf{meas}} = f[\,n(\lambda),k(\lambda),d_i\,] \Rightarrow n(\lambda),k(\lambda),d_i$$

  using non-linear least squares fit

- **Inverse method** used to characterize material <u>samples from CNM</u>



Full optical simulation



- Microstrip layer is not continuous.

- Interferences alone do not describe measured spectra. Needed to account for **diffraction**

- Fresnel and Fraunhoffer approximations for diffraction not applicable here, because some layers are transparent..

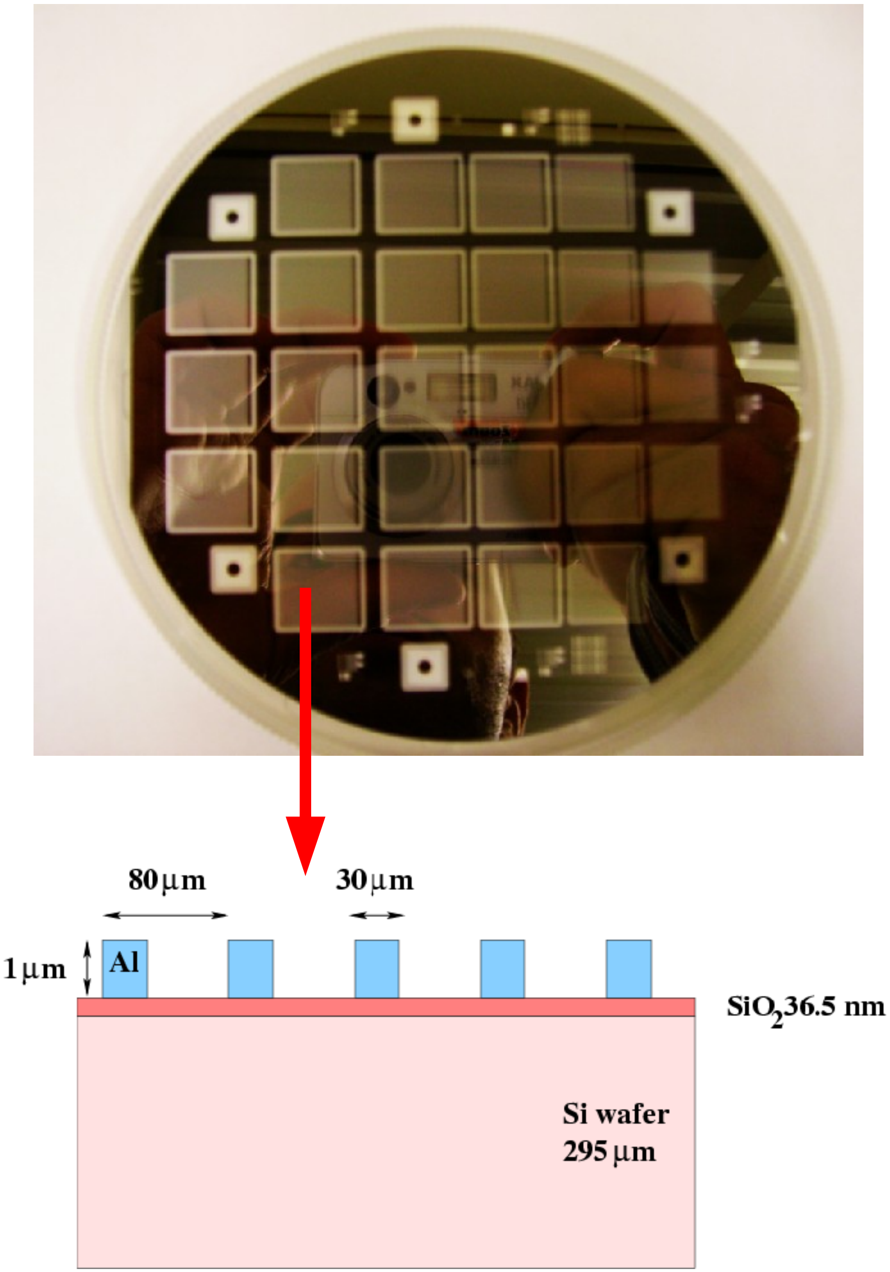
Then:

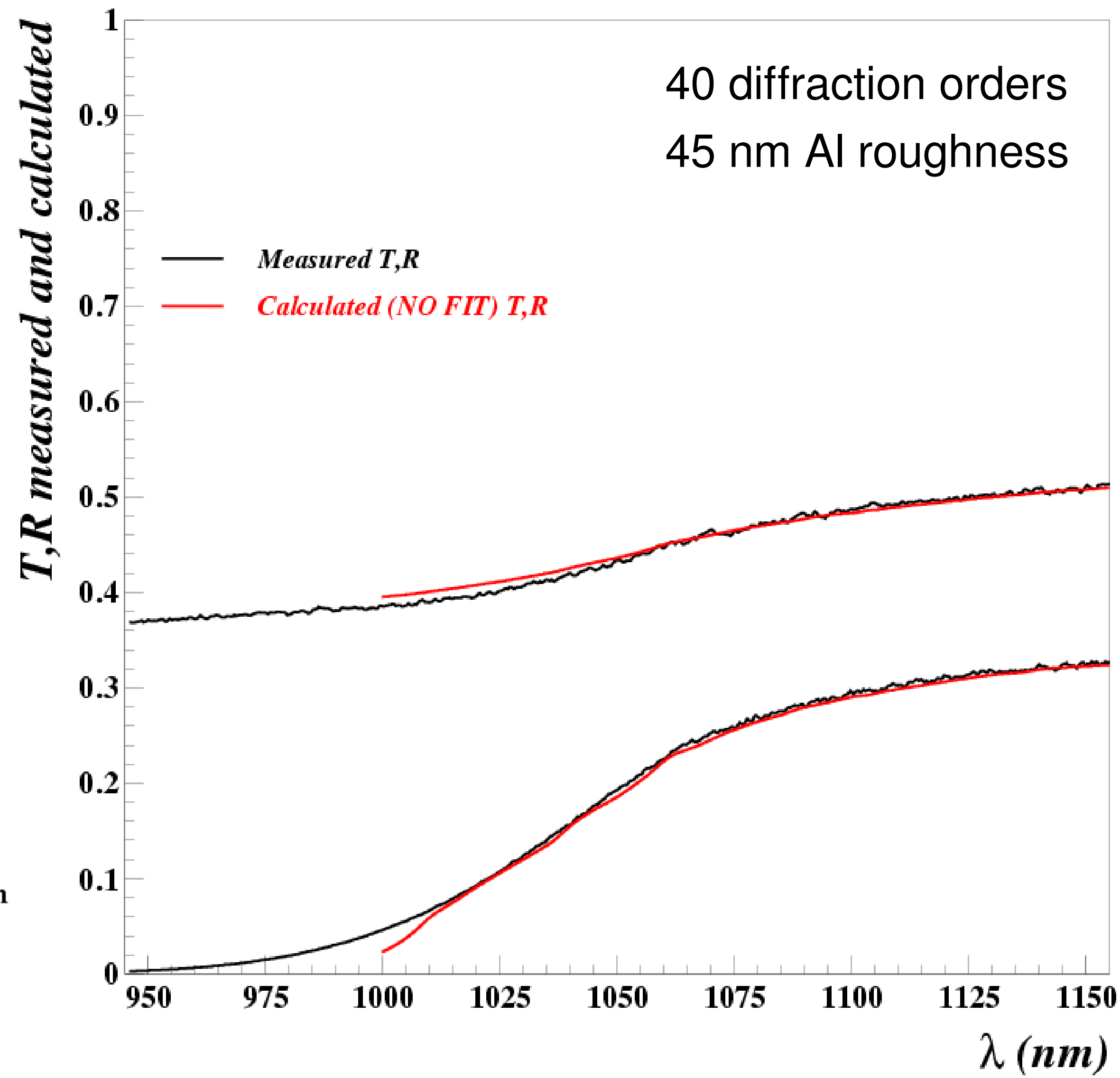
- Solve **Maxwell** equations **rigorously**

- Using **RCWA method** (see EUDET-memo-2008-37):
  — Fields expressed as Fourier expansions
  — RODIS software for diffraction efficiency at any order.

Measurement of CNM diffraction sample

- CNM produced a simple wafer to test the simulation, using GICSERV07 access.





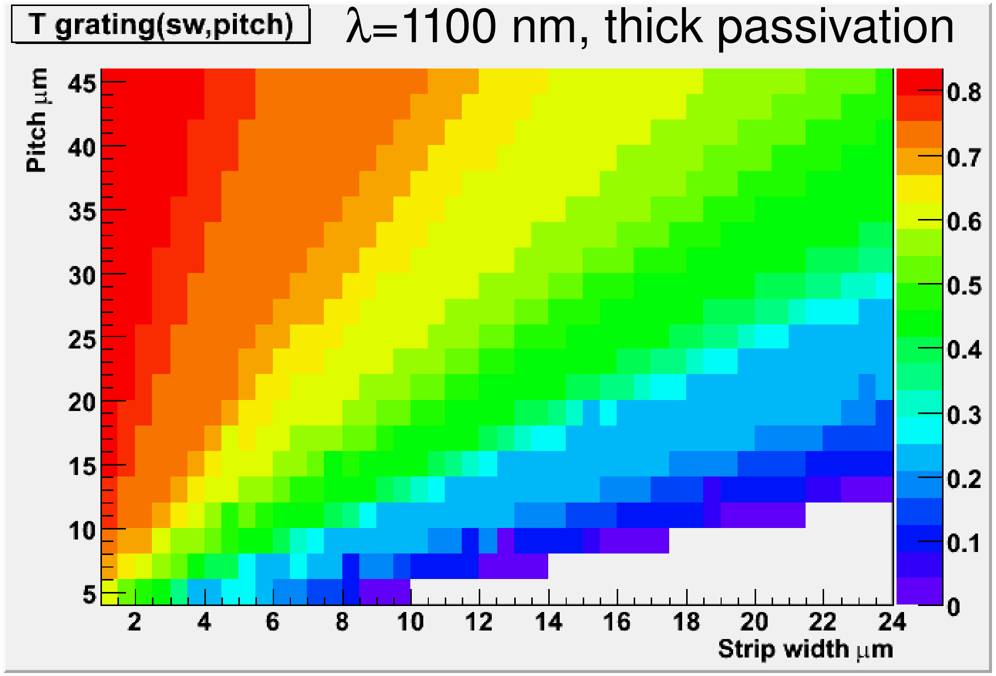
Optimization constraints

— Study done at **2** different **wavelengths**:

1) Readily available IR laser wavelength **λ=1085 nm**
2) longer (exotic) wavelength **λ=1100 nm** (higher transmittance of Si).

— Fixed readout **pitch** (SiLC baseline+Beetle chip) is **50 μm**. One intermediate strip

What is the best strip width?



— For fixed pitch:

Wider electrode width ⇒ smaller %T

— Bigger pitch ⇒ higher %T

— **We will produce sensors of different strip widths** to test it

— Field oxide is a key parameter for CNM:

Field Oxide thickness= 1 μm
Al thickness= 950 nm

— **Repeatability** on the deposited thickness of a material **is a percentage of its thickness**. So the thicker the material is, the worse accuracy on thickness achieved