INFN Istituto Nazionale di Fisica Nucleare
Sezione di Perugia

The Phase-1 upgrade of the CMS silicon pixel detector

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For the CMS collaboration

INFN Perugia

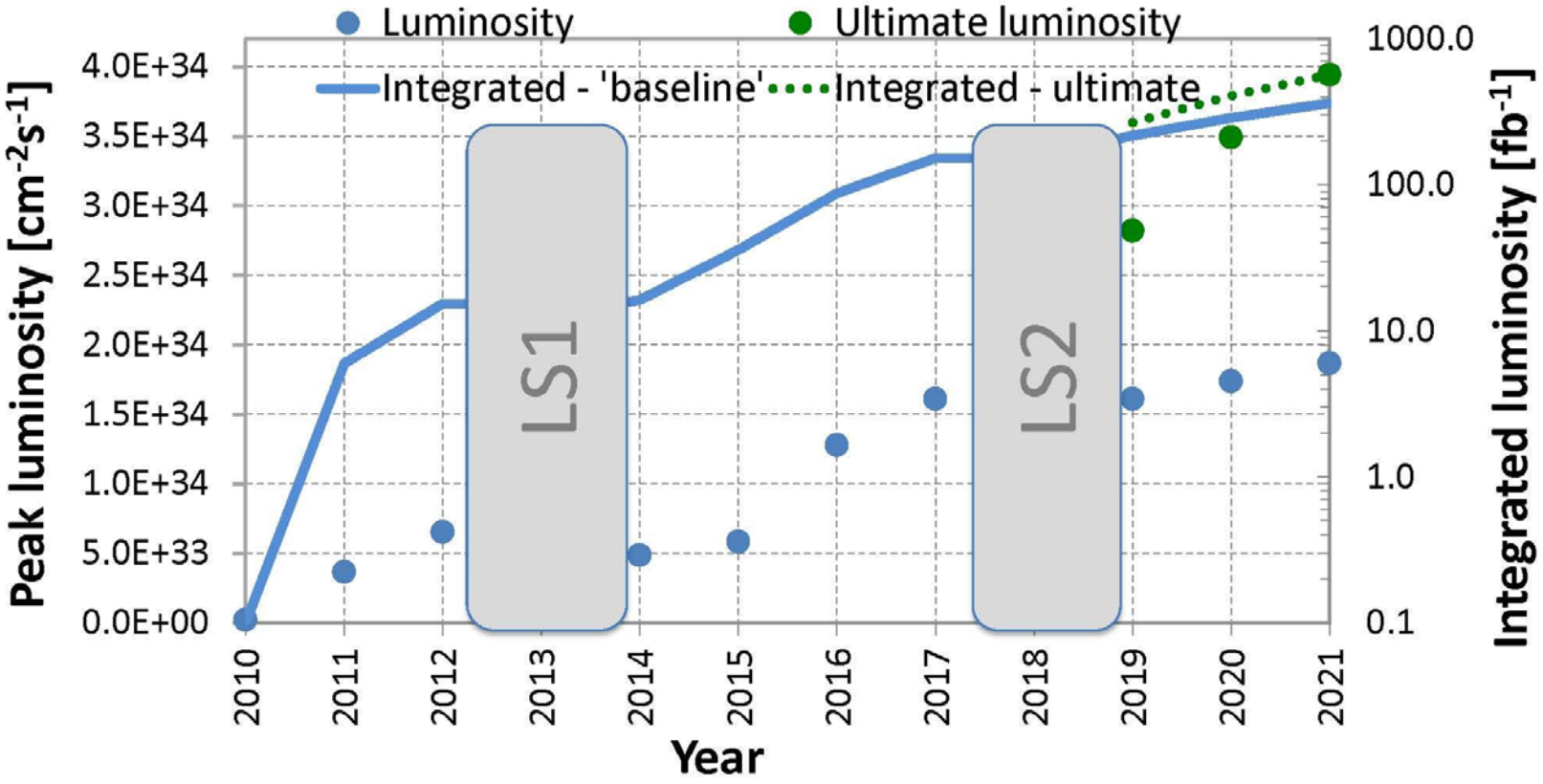
Summary

- The need for a phase-1 upgraded pixel detector
- The design of the new pixel detector
- The italian consortium for the production of the third layer of the detector

Why we will need a new pixel detector in 2017?

- Radiation damage:
  - We will reach by that date the radiation fluence of 1.2×10^{15} neq/cm^2 in the first layer when the detector will deteriorate its position resolution by a factor 2
- Keeping the pace of the LHC new performances
  - Present tracker was designed for 1×10^{34} Hz/cm^2 (25 ns bunch crossing) luminosity
  - Future performances after LS2 will be 2×10^{34} Hz/cm^2 (25 ns or 50 ns bunch crossing) luminosity
  - At the target luminosity pileup will reach a value of 50 (or even 100 for 50 ns b.c.) an increase in efficiency and a reduction of fake rates is needed

Luminosity forecast



Radiation damage

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Layer 1: 1 MGy

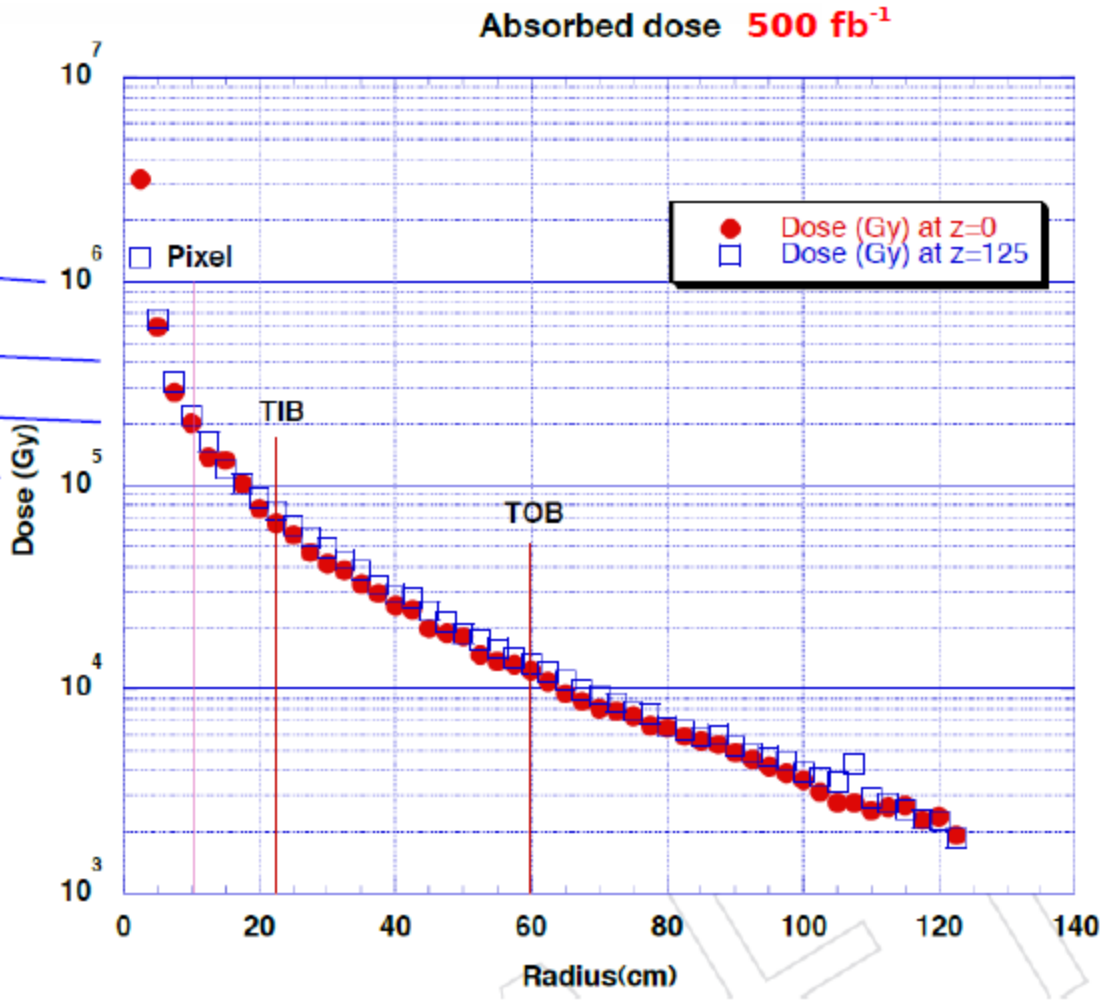
Layer 2: 400 kGy

Layer 3: 200 kGy

Layer 4: 150 kGy

100 kGy = 10 MRad

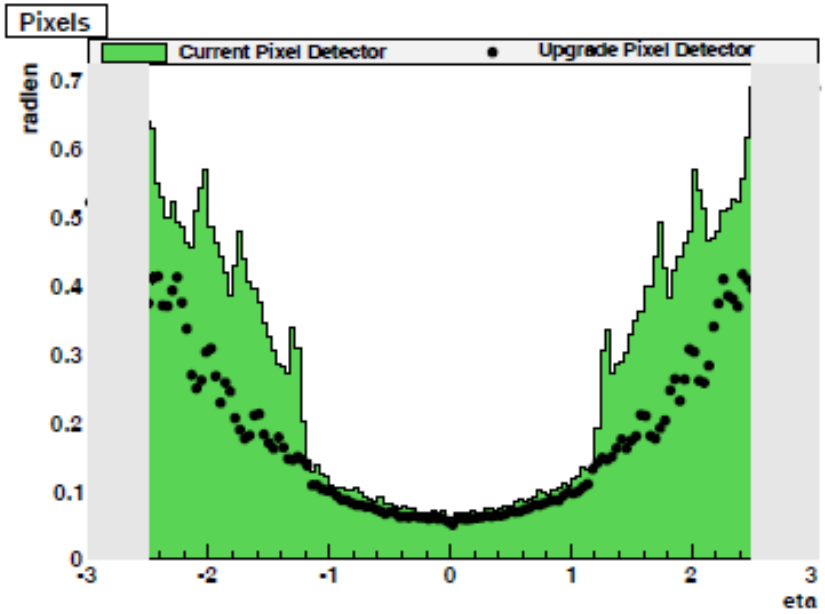
Fluence:
3 10^{13}/cm^2 mips
≃ 1 MRad

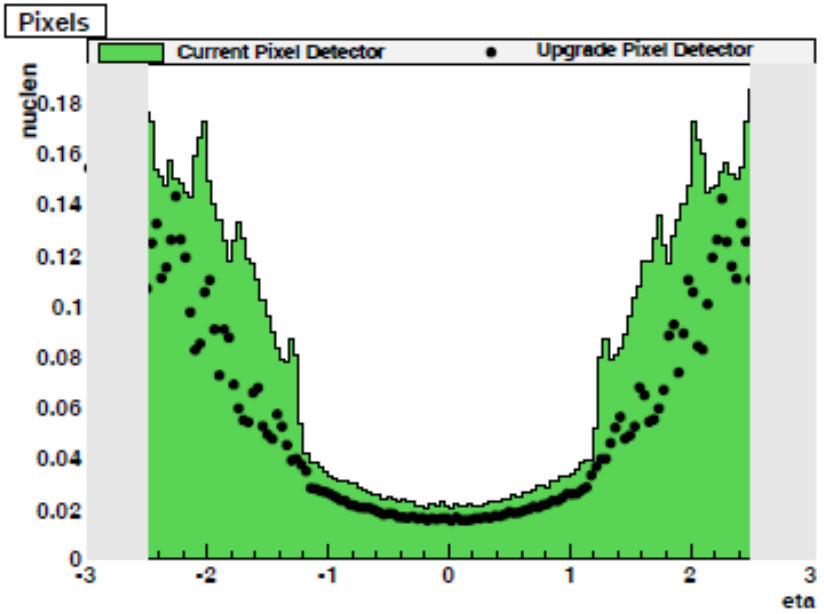


Data loss performance comparison

Detector	Radius (cm)	% Data loss for ($cm^{-2}s^{-1}$ @ ns) 1×10^{34} @ 25	2×10^{34} @ 25	2×10^{34} @ 50
Current detector				
BPIX1	4.4	4.0	16.0	50.0
BPIX2	7.3	1.5	5.8	18.2
BPIX3	10.2	0.7	3.0	9.3
FPIX1 and 2		0.7	3.0	9.3
Upgrade detector				
BPIX1	3.0	1.19	2.38	4.76
BPIX2	6.8	0.23	0.46	0.93
BPIX3	10.2	0.09	0.18	0.36
BPIX4	16.0	0.04	0.08	0.17
FPIX1–3		0.09	0.18	0.36

Material budget reduction



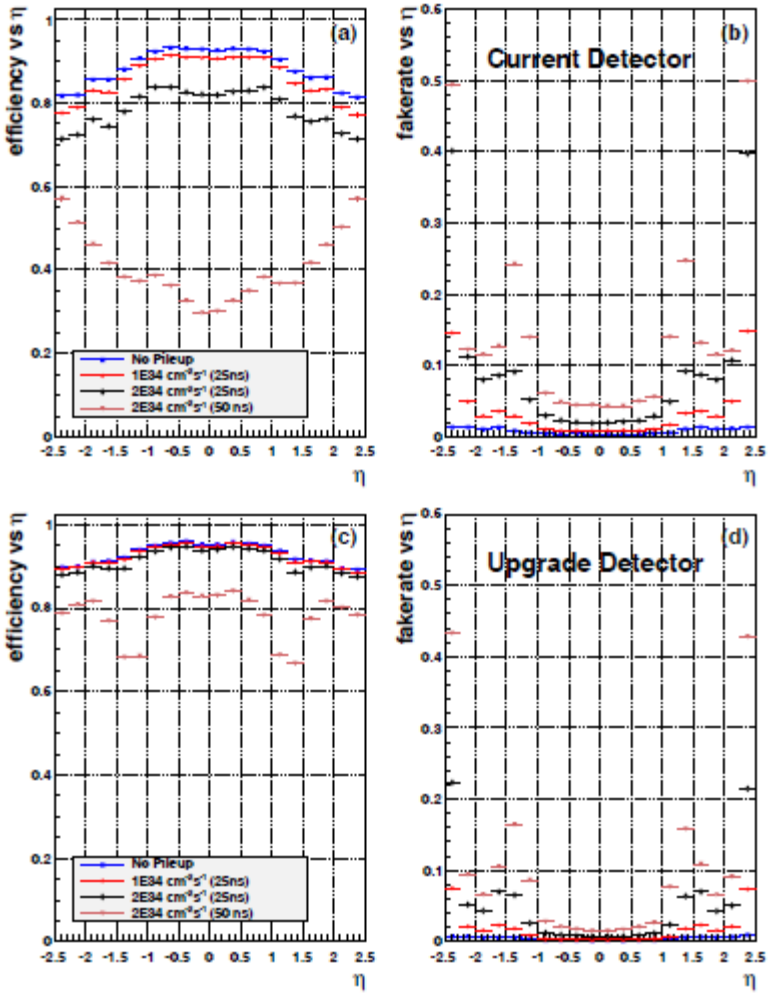


Tracking efficiency and fake rate (definitions)

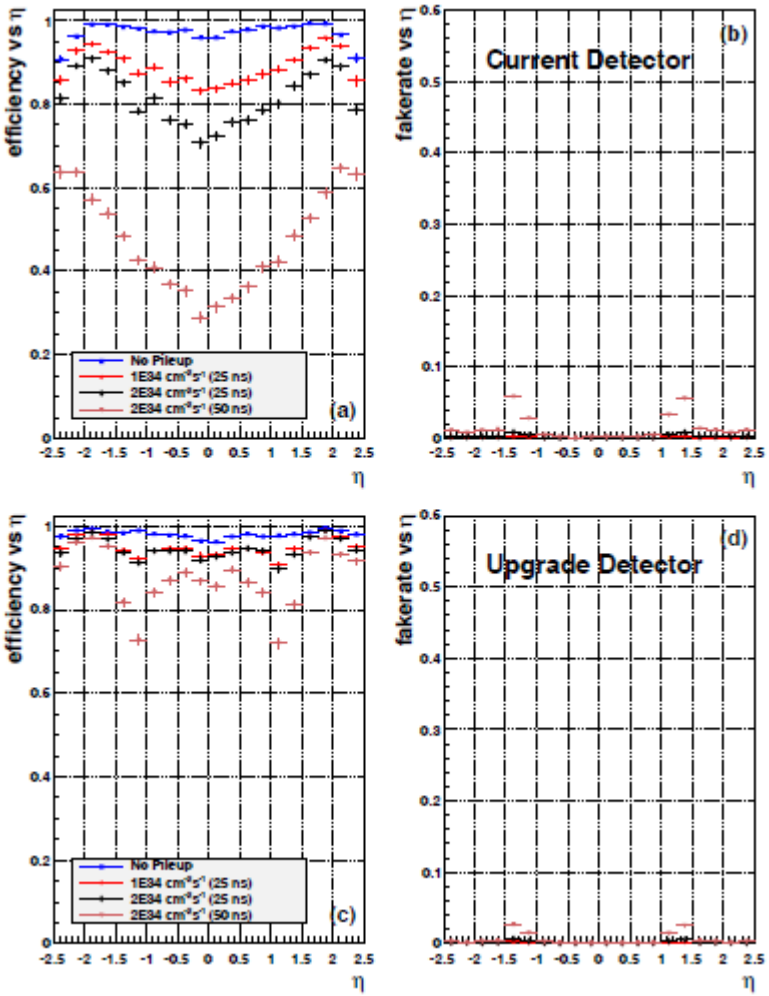
$$\text{Tracking efficiency} = \frac{\text{Number of truth tracks matched to reconstructed tracks}}{\text{Number of truth tracks}}$$

$$\text{Track fake rate} = \frac{\text{Number of reconstructed tracks not matched to truth tracks}}{\text{Number of reconstructed tracks}}$$

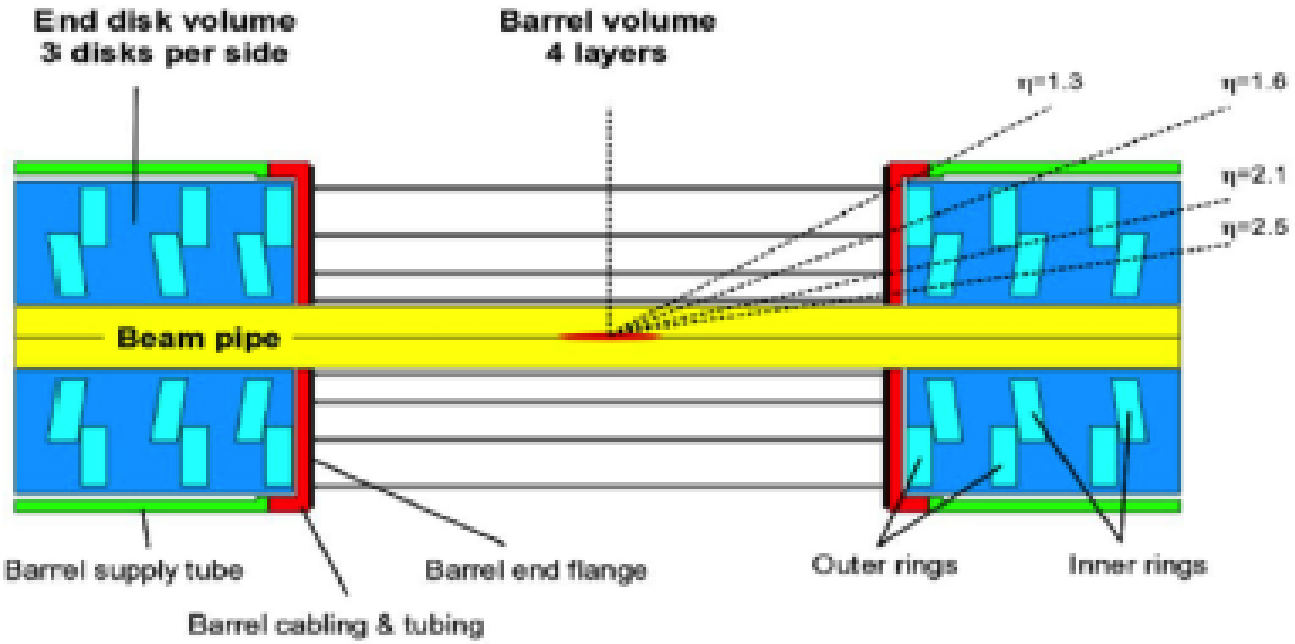
Tracking efficiency and fake rate (t tbar)



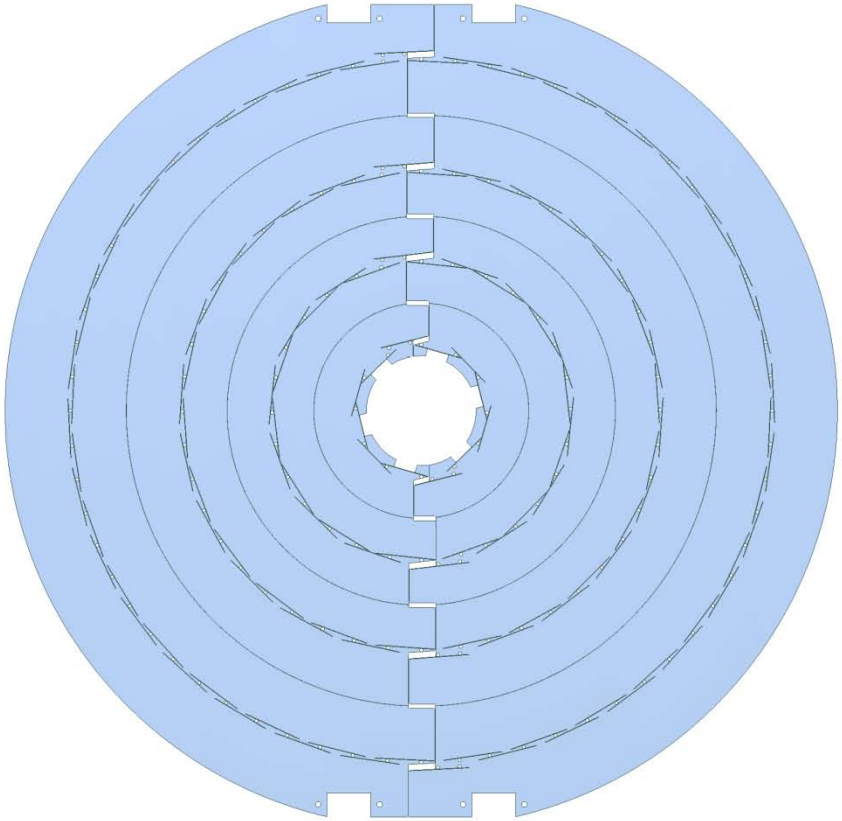
Tracking efficiency and fake rate (2 muons)



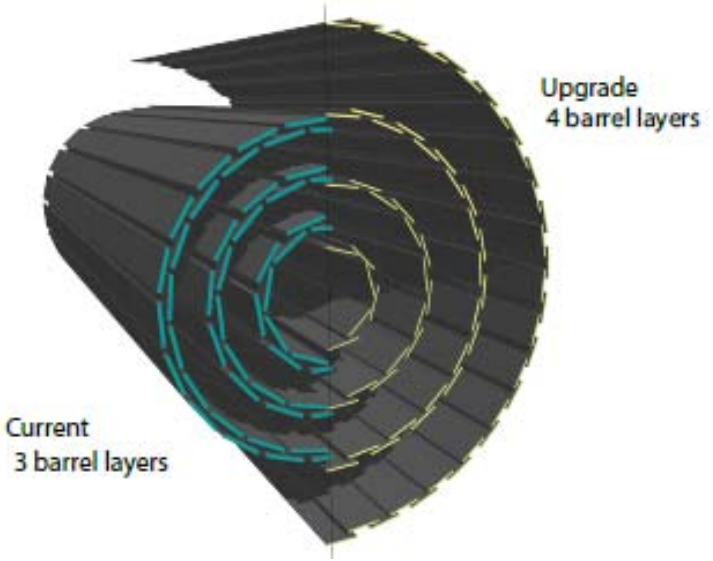
Structure of the new detector (Fpix and Bpix)



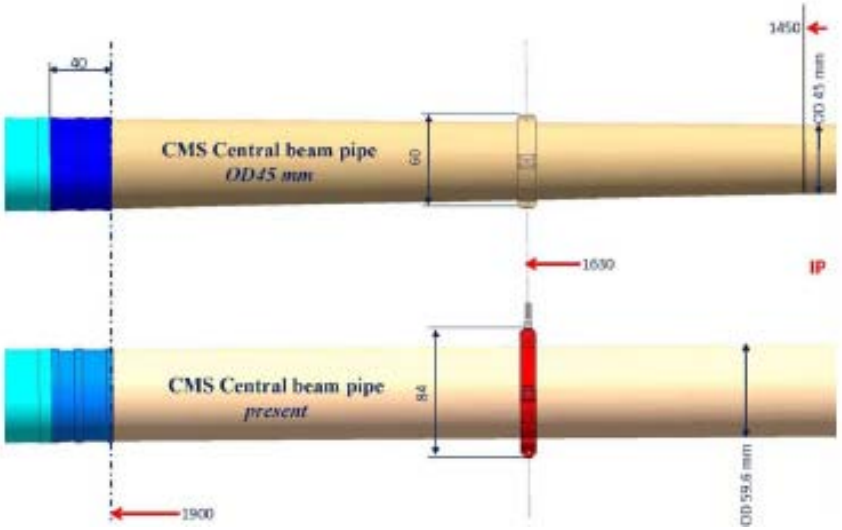
Bpix structure and modularity

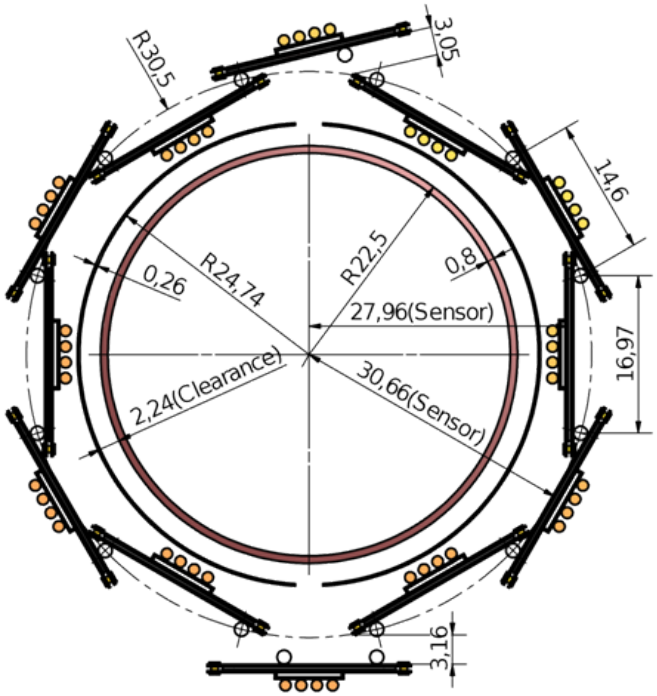


layer	radius	facets	modules
4	160 mm	64	512
3	109 mm	44	352
2	68 mm	28	224
1	30 mm	12	96
(1*)	(39 mm)	(16)	(128)
			1184



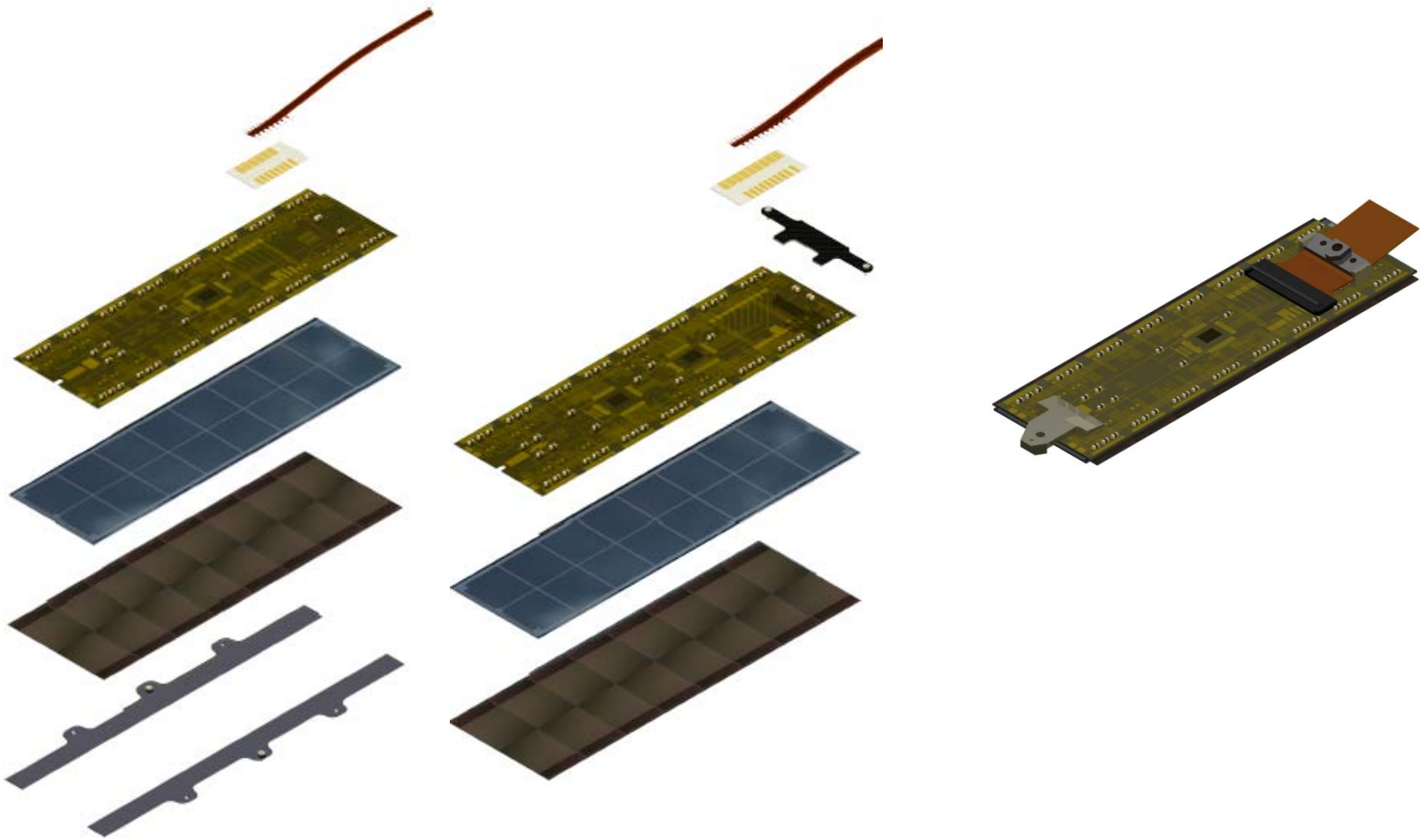
New and old beam pipe and first layer





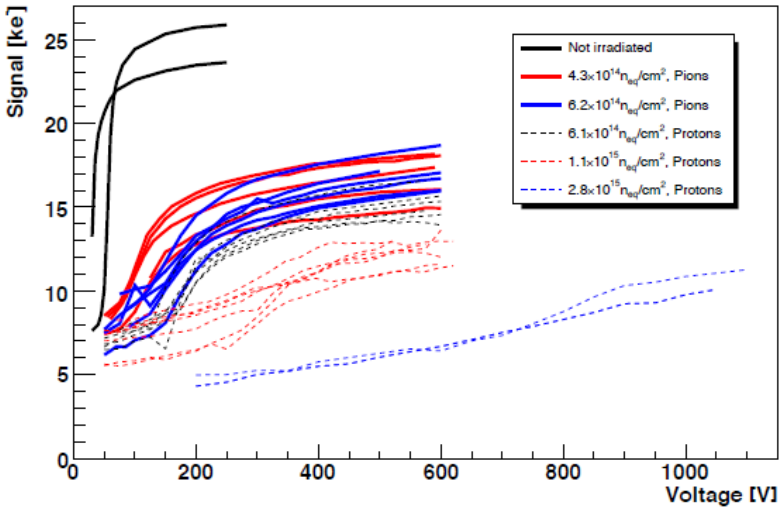
Carbon fiber structure

Detector+ FE modules



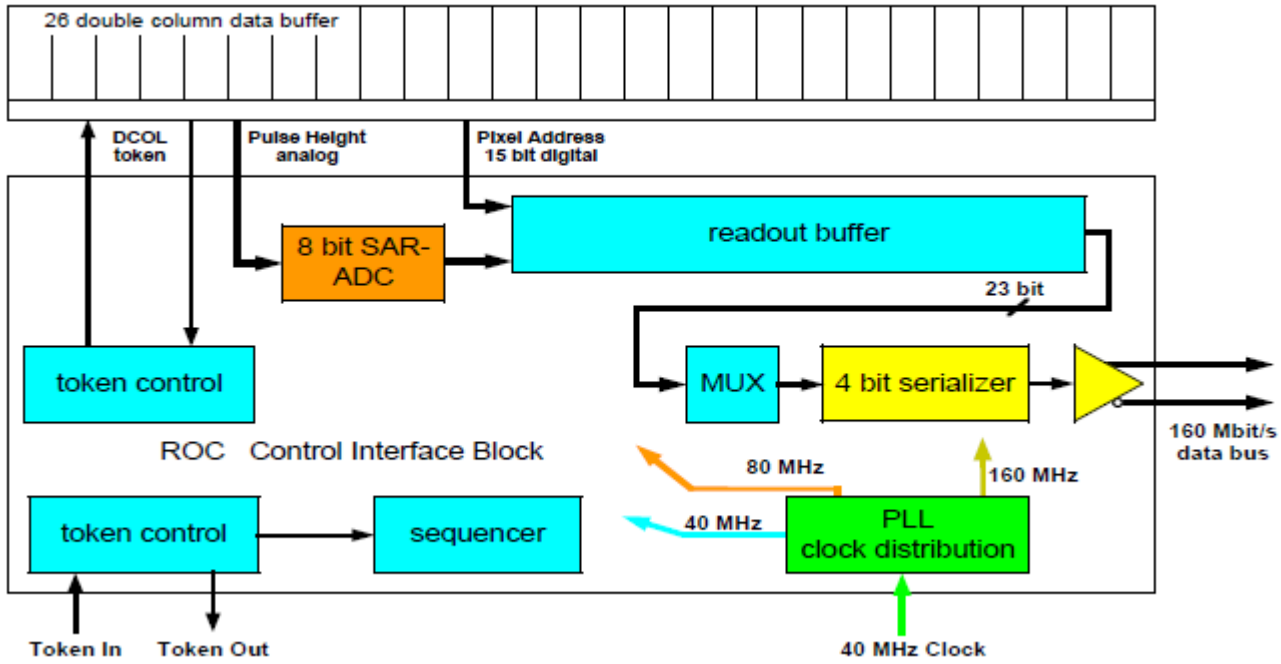
The Sensor

- 16.2 x 64.8 mm^2 lateral dimensions 285±5 μm thickness
- Pixel size: 100 x 150 μm^2 (66560 pixels)
- Substrate: Diffusion oxigenated float zone (n-doped) 3.7 kΩcm resistivity (fully depleted at 55 V)



The digital ROC

- No modification in the technology (250 nm)
- Few modifications in the analog part
- Main modifications in the digital part



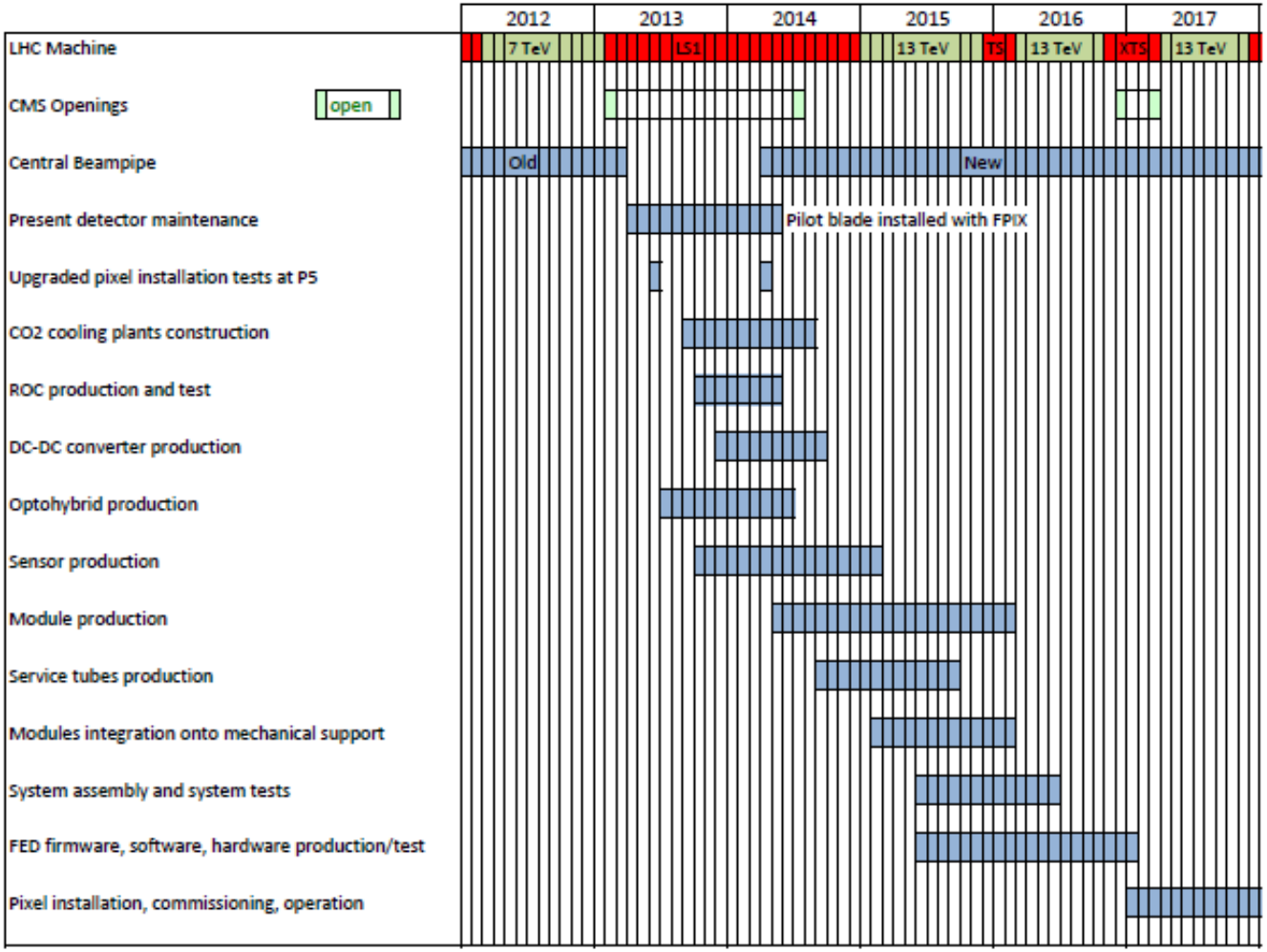
Performance comparison between the old analog and the new digital ROC

	PSI46V2	PSI46DIG
ROC size	7.9 mm x 9.8 mm	7.9 mm x 10.2 mm
Pixel size	100 μm x 150 μm	100 μm x 150 μm
Smallest radius	4.3cm	2.9cm
Settable DACs / registers	26 / 2	19 / 2
Power Up condition	not defined	default values
pixel charge readout	analog	digitized, 8bit
Readout speed	40 MHz	160 Mbit/s
Time stamp Buffer size	12	24
Data Buffer size	32	80
Output Buffer FIFO	no	yes
Double column Speed	20 MHz	20 MHz (40 MHz)
Metal layers	5	6
Leakage current compensation	yes	no
in-time threshold	3500 e	$<$ 2000 e
PLL	no	yes
Data loss at max Operating flux	$\sim$3.8% at 120 MHz/cm^2	1.6% at 150 MHz/cm^2 ($\sim$3% at 580 MHz/cm^2)

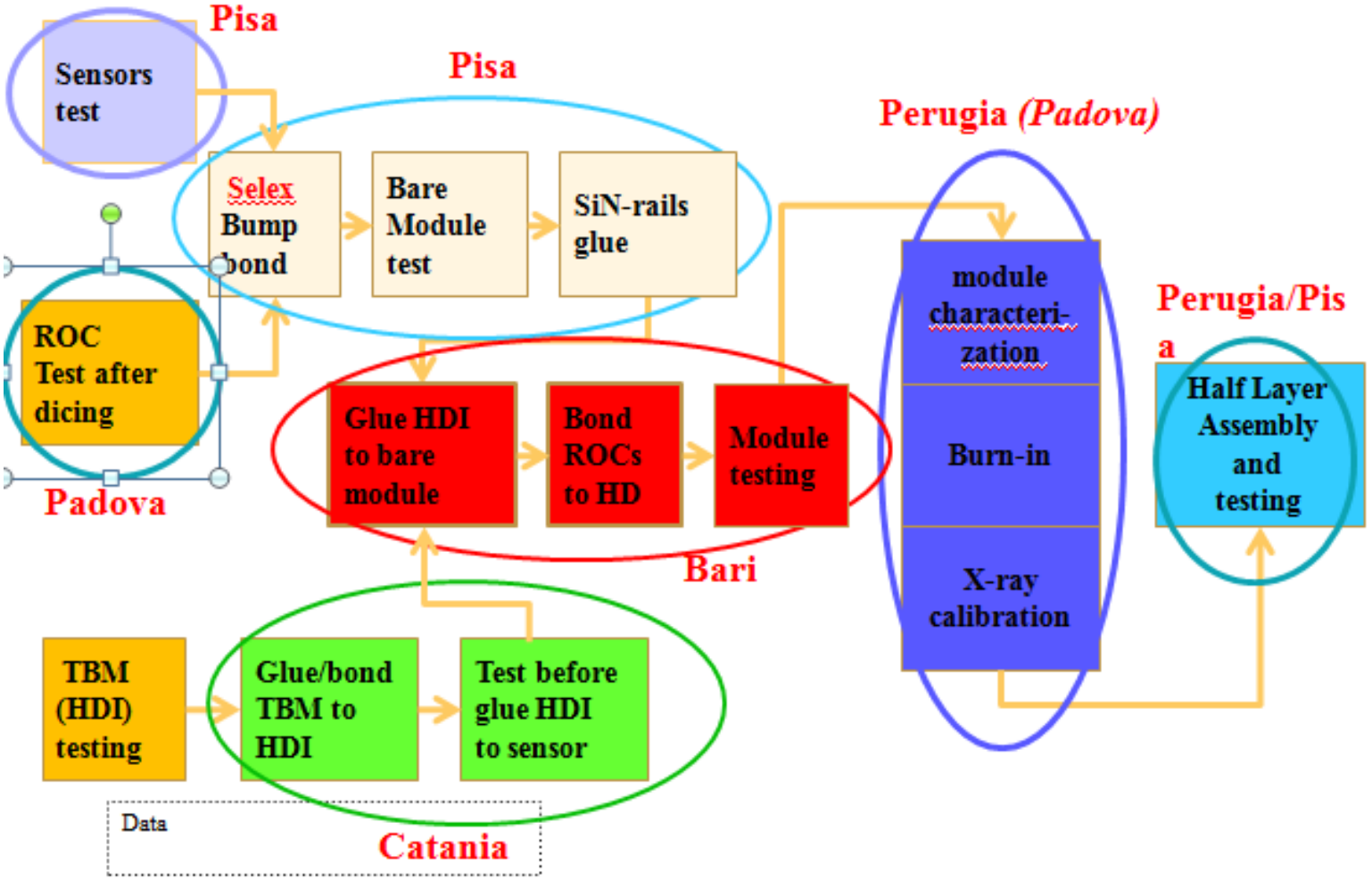
Additional new features of the phase-1 upgraded pixel detector

- New TBM
- New CO_2 cooling system
- New power distribution system
- New optohybrid

The production schedule

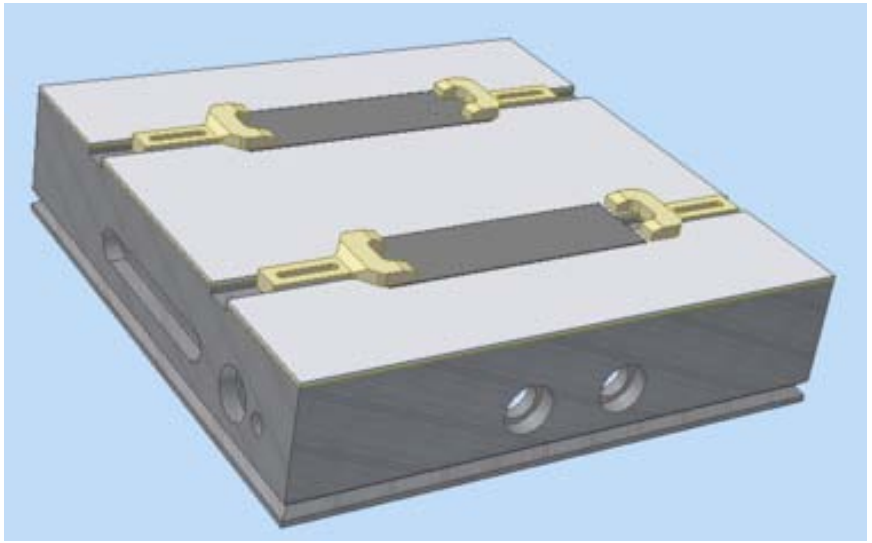


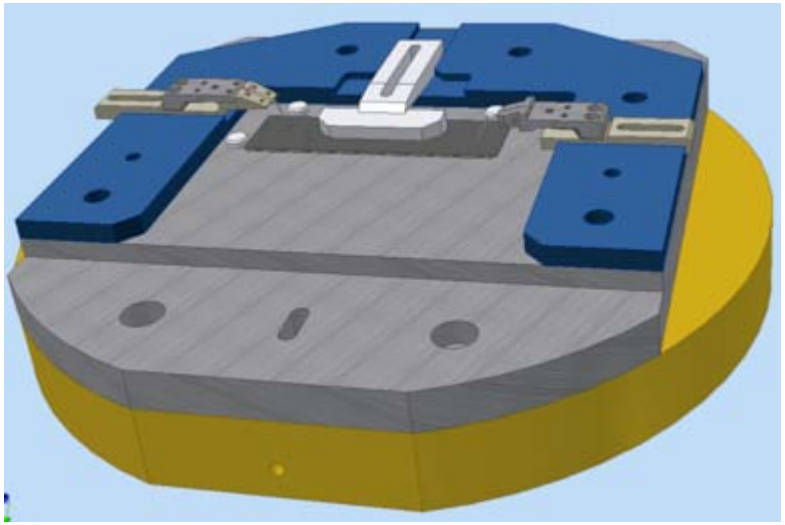
The italian consortium



Activities in Pisa

- Pixel sensor on wafer test.
- Diced sensors and test bare module electrical test
- Shear and pull test of Bump Bonded chip





Activities in Padova

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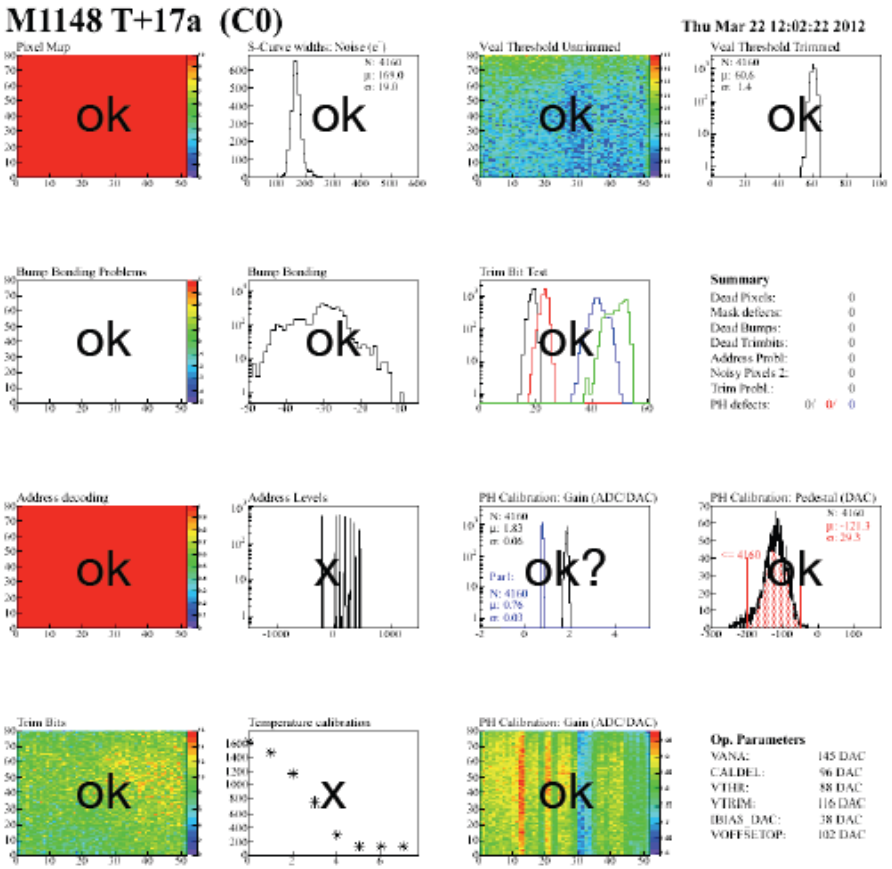
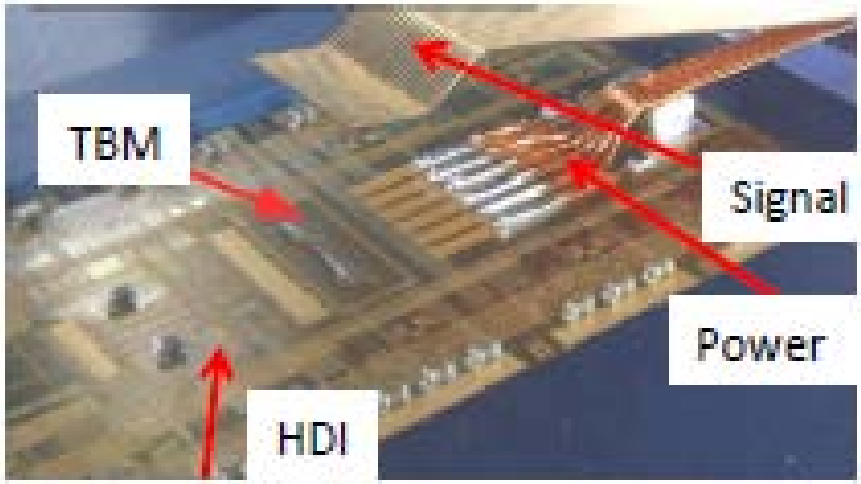
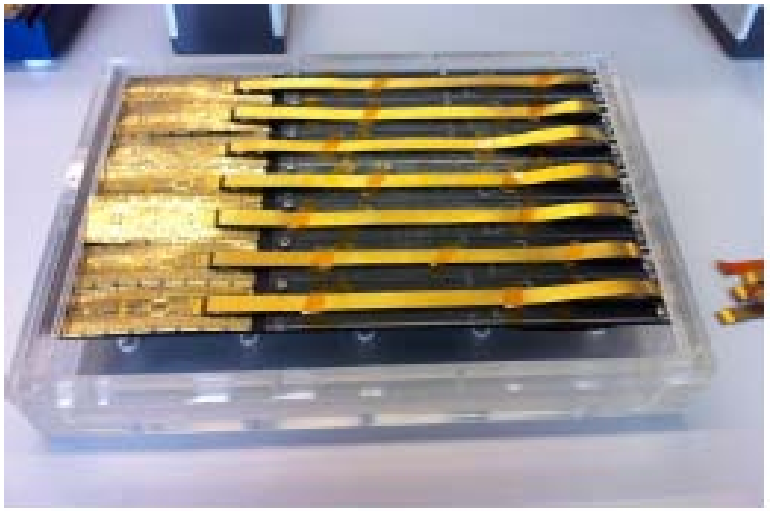
- Electrical test of ROC



Activities in Catania

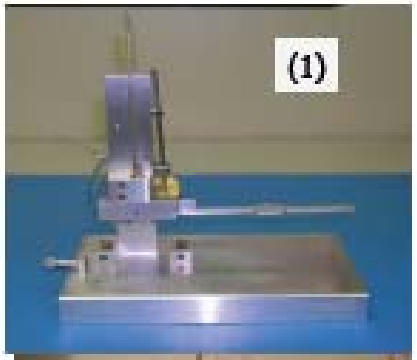
- Quality test of "bare" HDI
- TBM bonding on HDI
- Cable assembly of HDI
- Final electrical test of HDI
- Production of transportation boxes

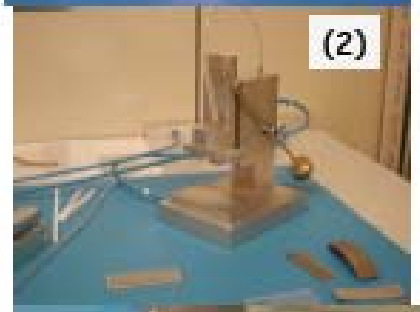


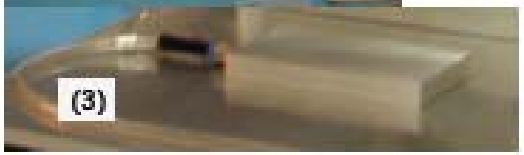


Acivities in Bari

- Assembly of HDI with bare module
- Preliminar test







Sensor module to HDI gluing

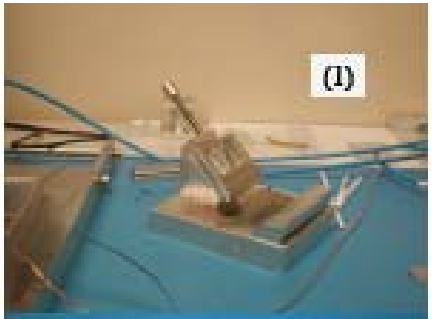
Glue applicator

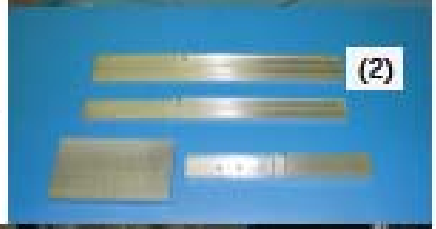
Vacuum chuck

Module to HDI under-fill

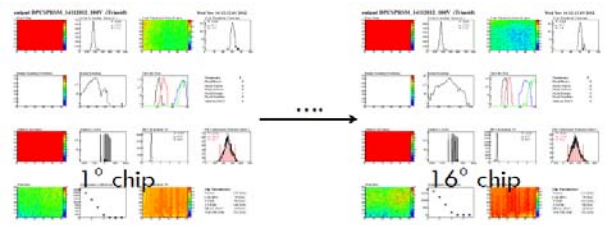
Handles

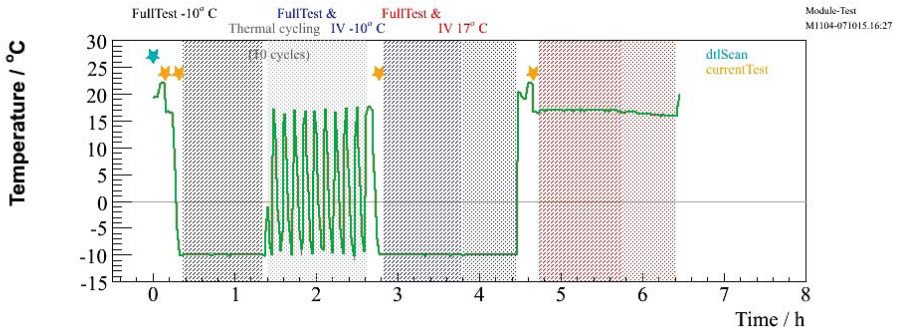
Prototype of assembly station
-optical survey
-Jig aligner



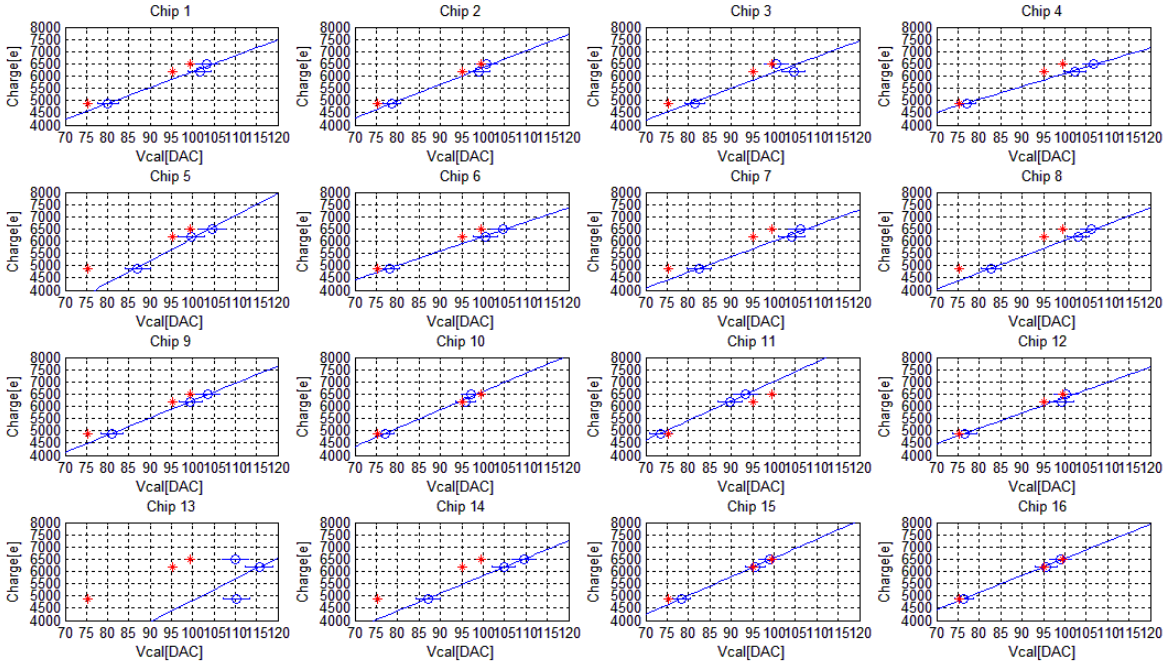


Activities in Perugia (preliminar test and thermal cycling)





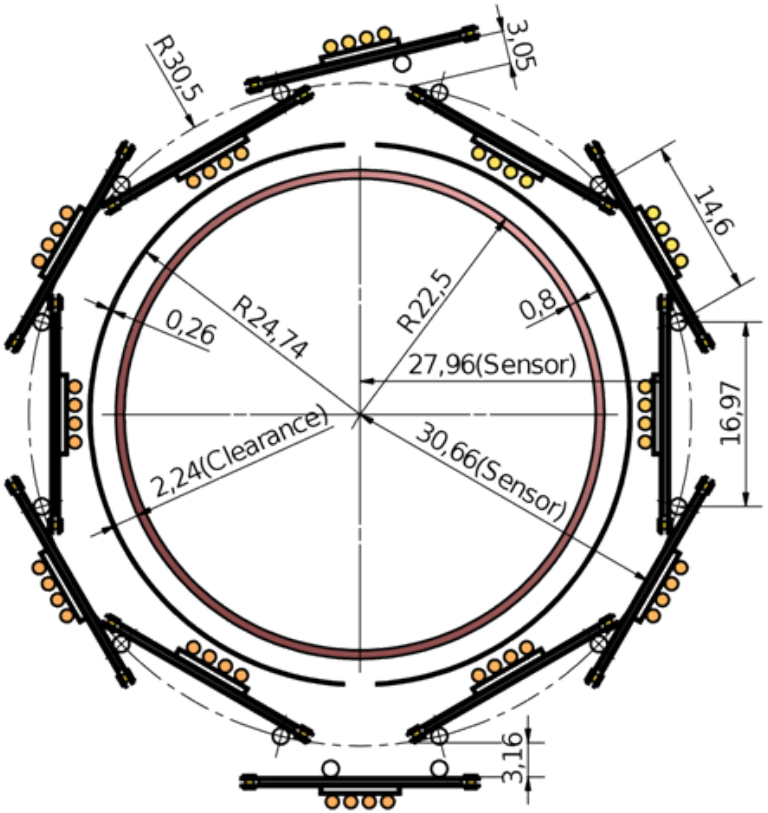
Activities in Perugia (X-ray calibration)



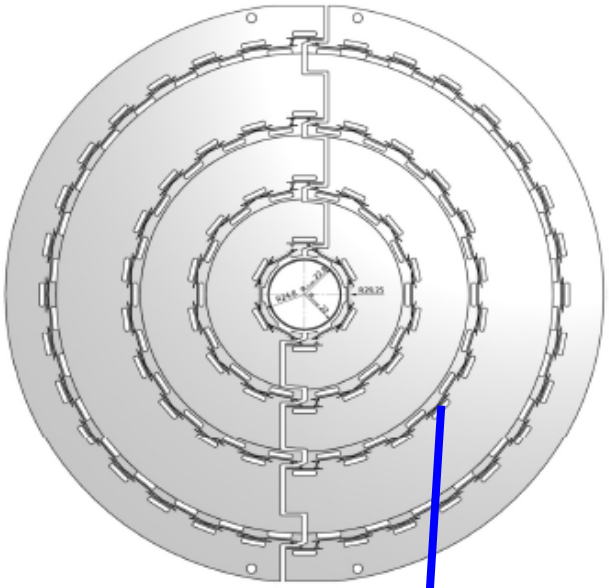
Final goal: being ready for early 2017

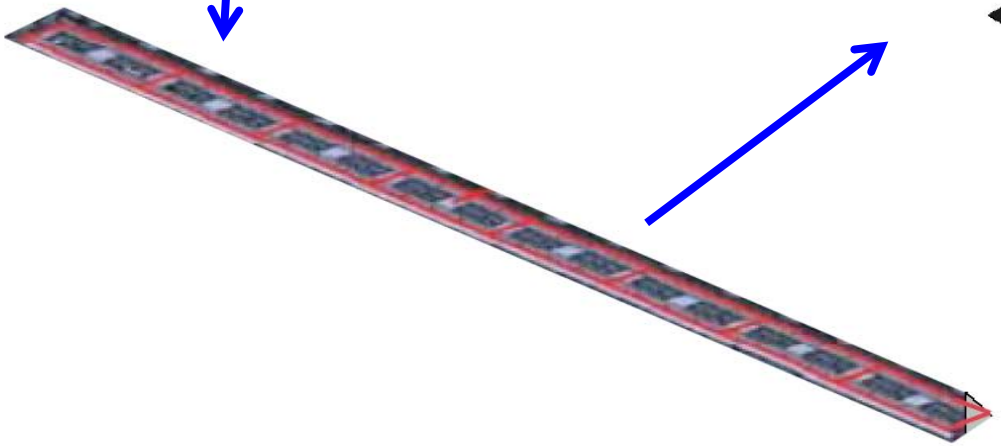
Spare slides

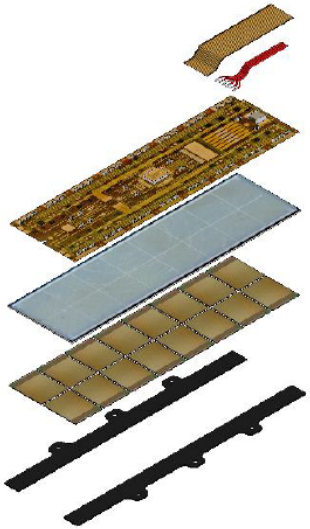
Layout of layer 1



Structure extra







Cables:
signal&power

HDI print

Si sensor

16 ROCs

Base strips:
Si_3N_4

Analog part of the digital ROC