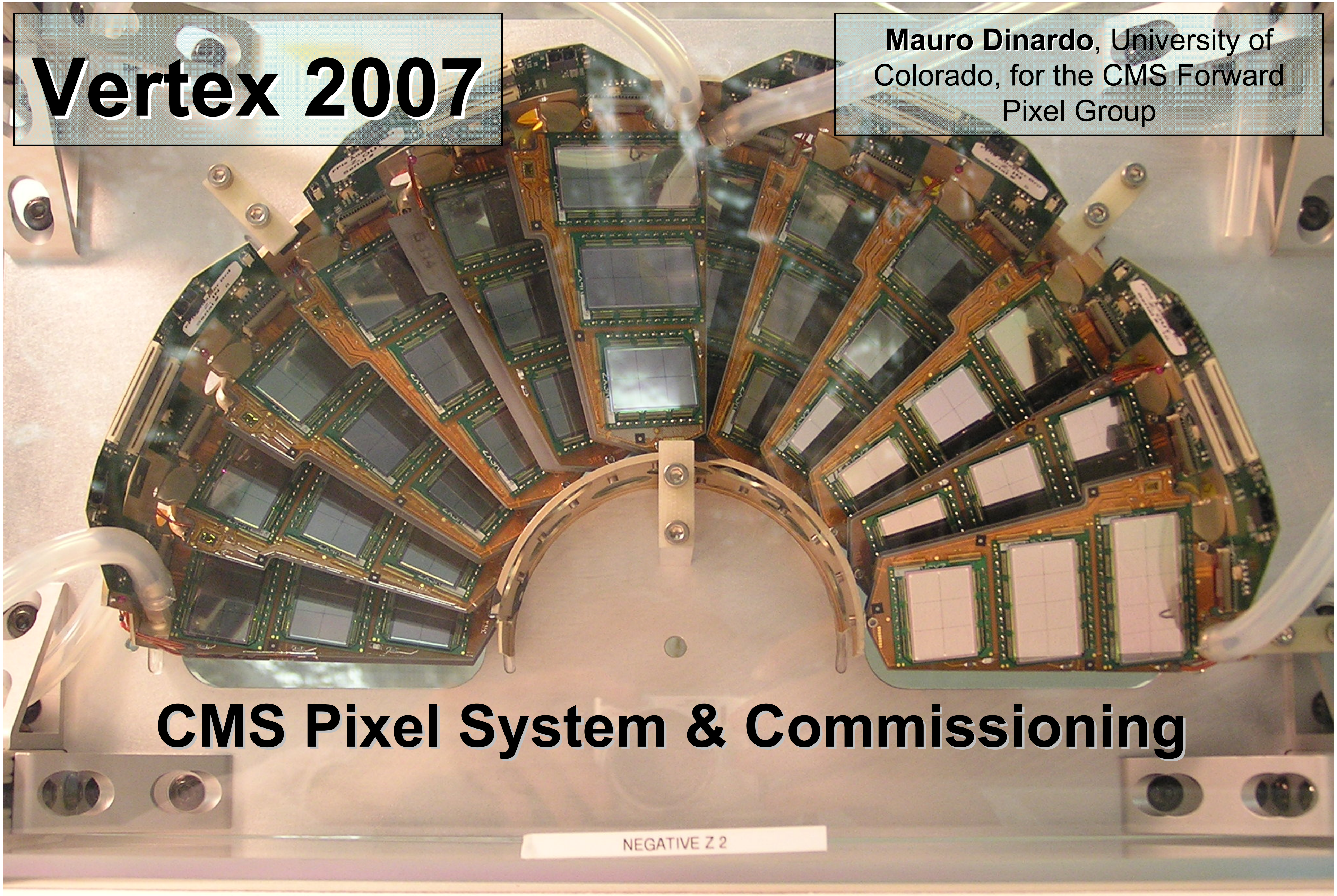
Vertex 2007

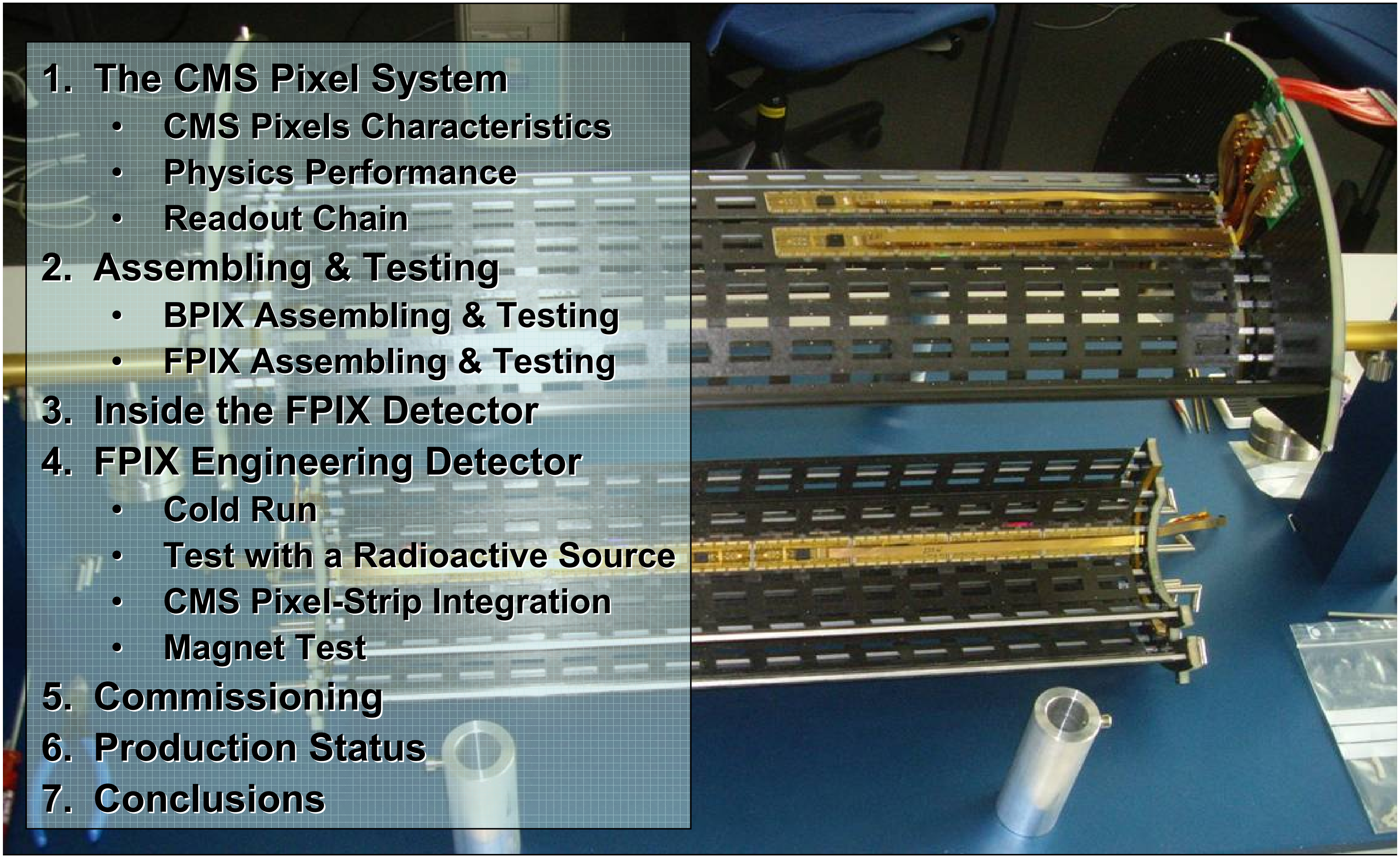
Mauro Dinardo, University of Colorado, for the CMS Forward Pixel Group

CMS Pixel System & Commissioning



09/24/2007

Outline

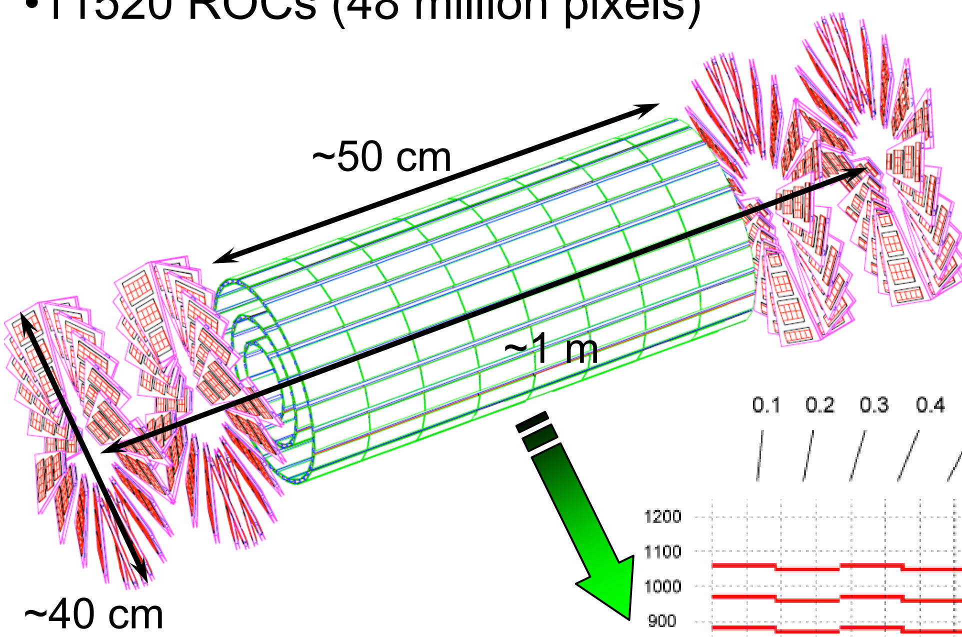


1. The CMS Pixel System
   - CMS Pixels Characteristics
   - Physics Performance
   - Readout Chain
2. Assembling & Testing
   - BPIX Assembling & Testing
   - FPIX Assembling & Testing
3. Inside the FPIX Detector
4. FPIX Engineering Detector
   - Cold Run
   - Test with a Radioactive Source
   - CMS Pixel-Strip Integration
   - Magnet Test
5. Commissioning
6. Production Status
7. Conclusions

The CMS Pixel System: Detector Geometry

Barrel Pixels

- 3 barrel layers at *r* of 4.3, 7.3 and 10.4 cm
- 11520 ROCs (48 million pixels)

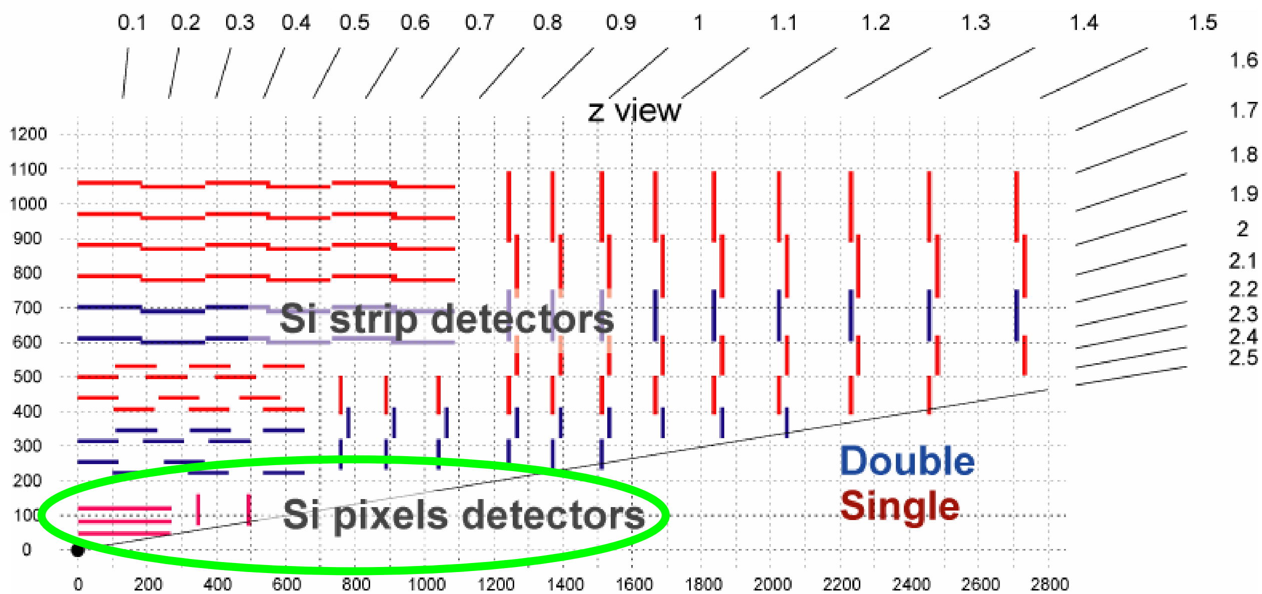


Forward Pixels

- 4 disks at *z* of ±35.5 and ±46.5 cm
- 4320 ROCs (18 million pixels)

The design allows for 3 pixel hits up to |η| of ~2.5, providing:

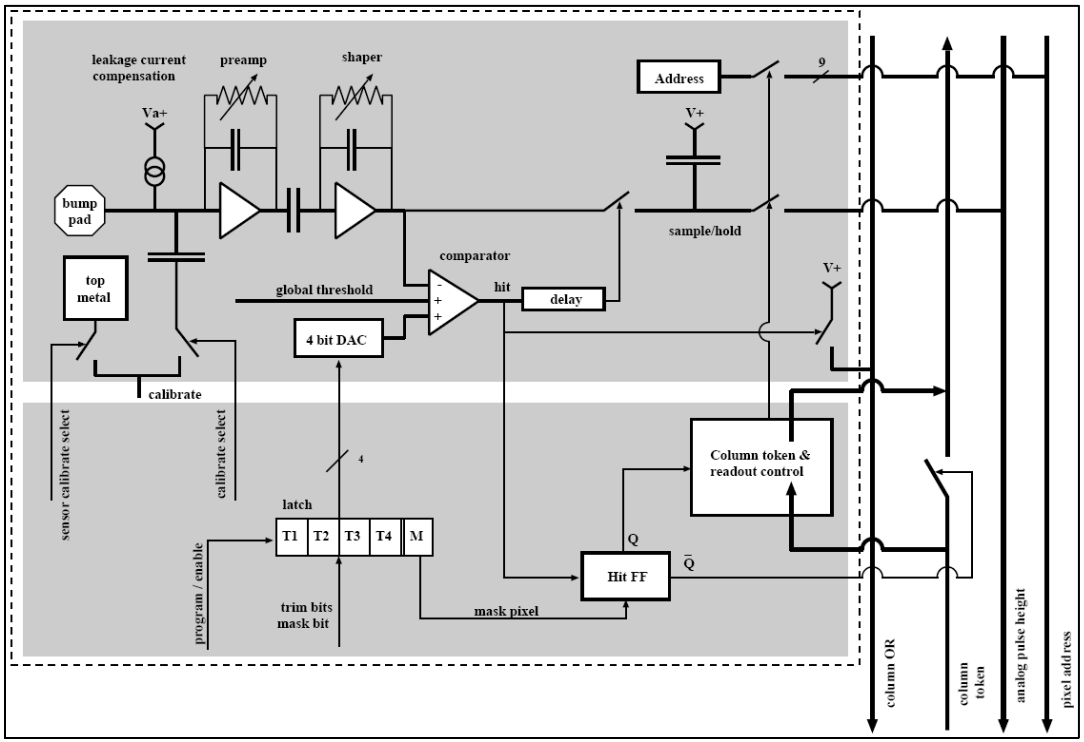
1. Seeds for pattern recognition
2. Precision vertexing near the IP
3. Fast tracking and vertexing in High-Level Trigger using only pixel info.

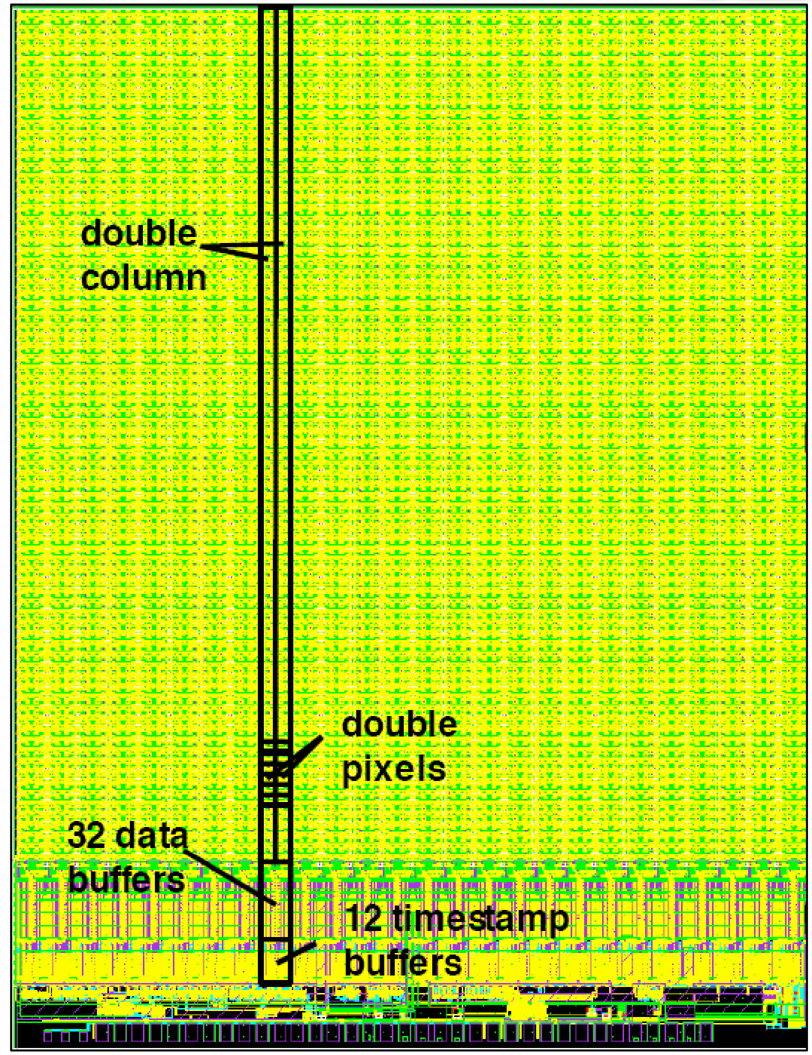


Layout of the CMS tracker

The CMS Pixel System: Readout Chip

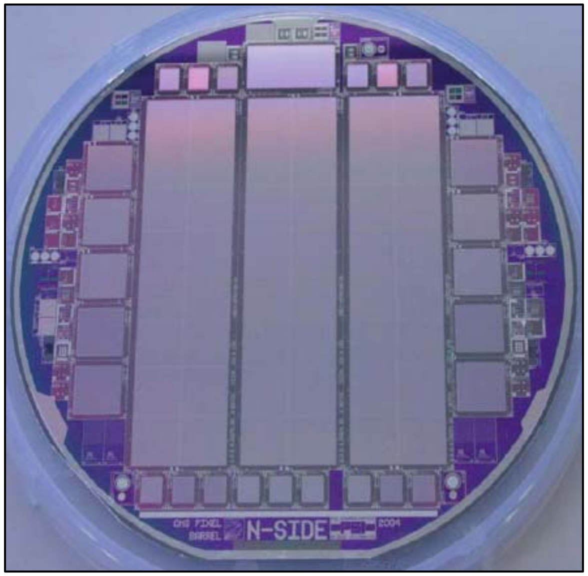
- 0.25μm IBM CMOS radiation tolerant
- 100x150 μm² pixel cell size:
  - ✓Maximum occupancy ~0.033% at full LHC luminosity
- 52x80 cells organized in double columns
- 32 data and 12 time stamp buffers
- Readout of position and pulse height is encoded on 6 analog levels

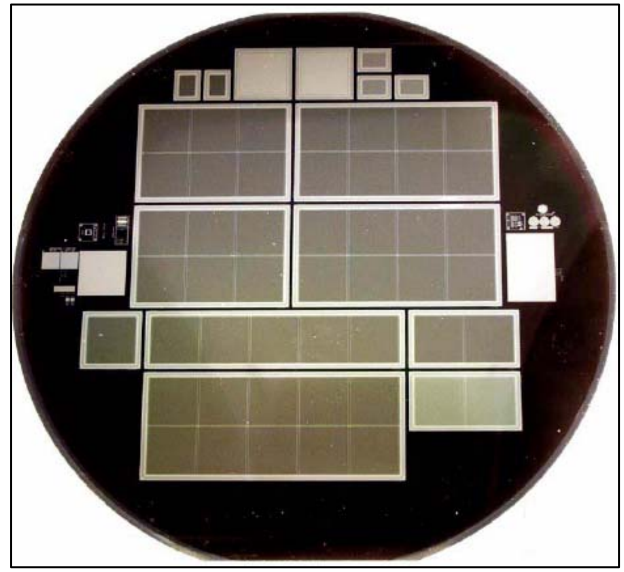




Schematic view of a pixel unit cell

The CMS Pixel System: Sensors





Barrel Pixels (BPIX)

- bulk width: ~270 μm
- *n*-in-*n* with p-spray isolation (from CIS)
- bump bonded to the ROCs in house at PSI using In

Forward Pixels (FPIX)

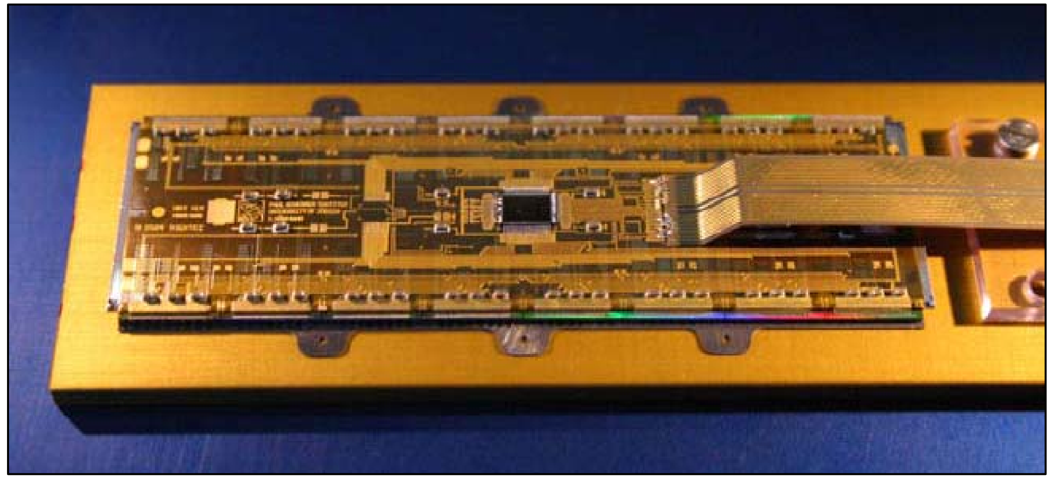
- bulk width: ~270 μm
- *n*-in-*n* with partially open p-stop isolation (from SINTEF)
- bump bonded to the ROCs at two vendors (RTI and IZM) using PbSn

Sensors have been irradiated up to a proton fluence of ~$1.6 \cdot 10^{15}$ particles/cm^2 (= 46 Mrad = 3 years of CMS at full LHC luminosity for the innermost layer of the barrel):

- Breakdown voltage well above 600 V (without localized noisy regions)
- Total collected charge: >60%
- Particle detection efficiency: > 99% (above the goal of the TDR)

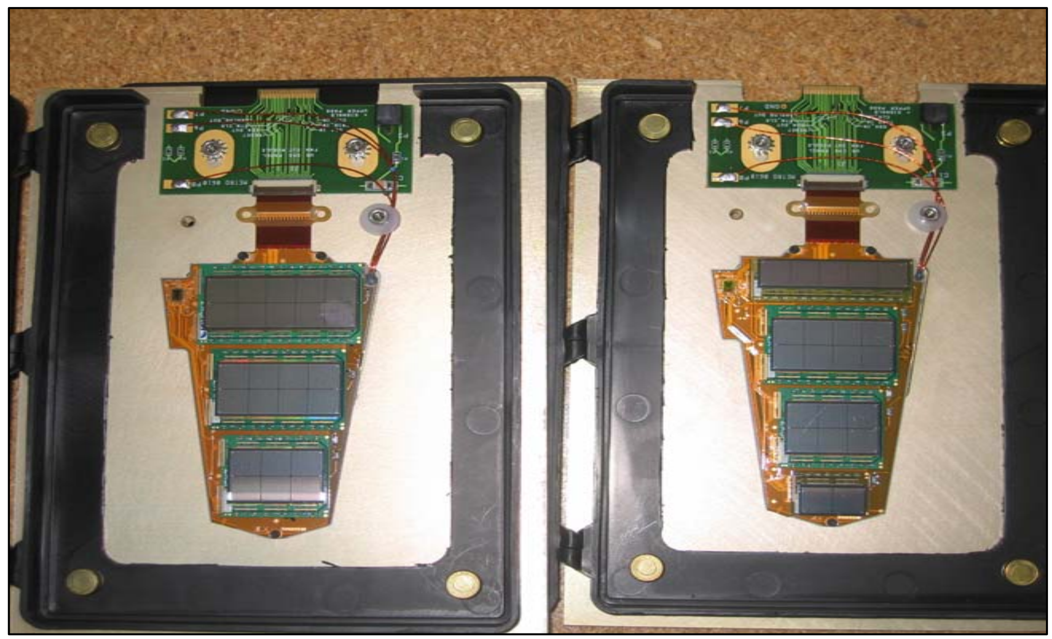
The CMS Pixel System: Modules

Two different types of BPIX modules:
•full module (16 ROCs)
•half module (8 ROCs)



Five different types of FPIX modules with 2,5,6,8,10 ROCs

Modules mounted on two different types of panels:
•4 module panel
•3 module panel

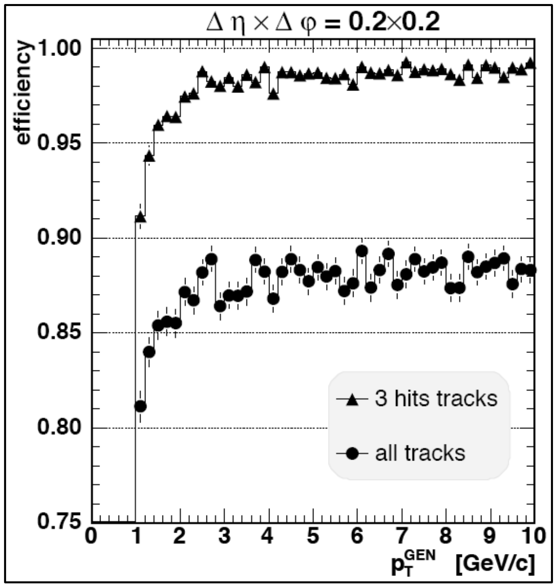


The CMS Pixel System: Physics Performance

BPIX : in ***rφ*** the resolution is improved thanks to the large Lorentz angle (cluster size ~2); in ***z*** the cluster size is 1 – 7 depending on the incident angle

FPIX : a tilted (turbine) geometry of 20° was chosen to improve the resolution in ***r*** thanks to the Lorentz effect and in ***rφ*** thanks to the non-zero incident angle (average cluster size ~2)

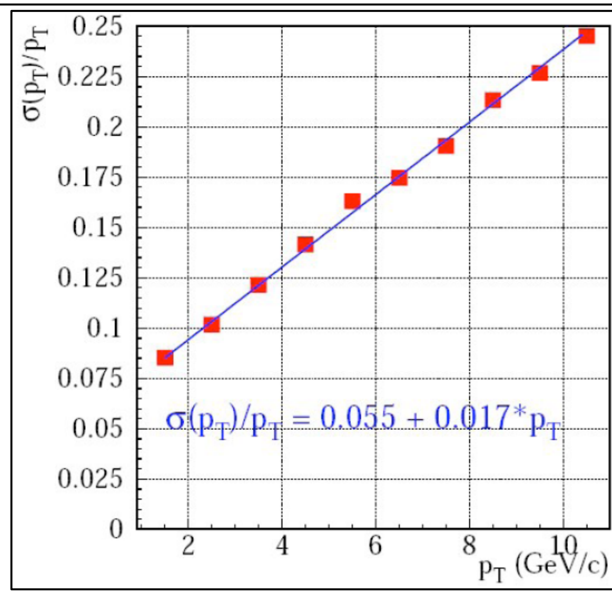
Efficiency of Track Reconstruction Using Pixels Only



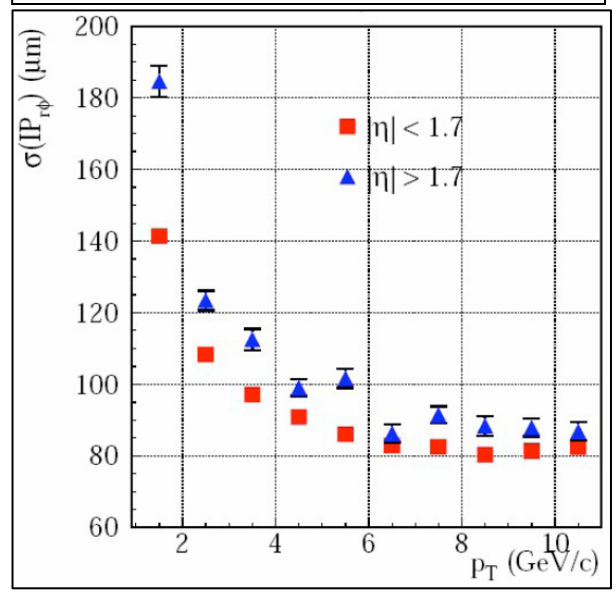
~90% of the triplets corresponds to real tracks
(Luminosity = 10^{34} cm^{-2}s^{-1})

Resolutions Using Pixels Only

Transverse Momentum Resolution

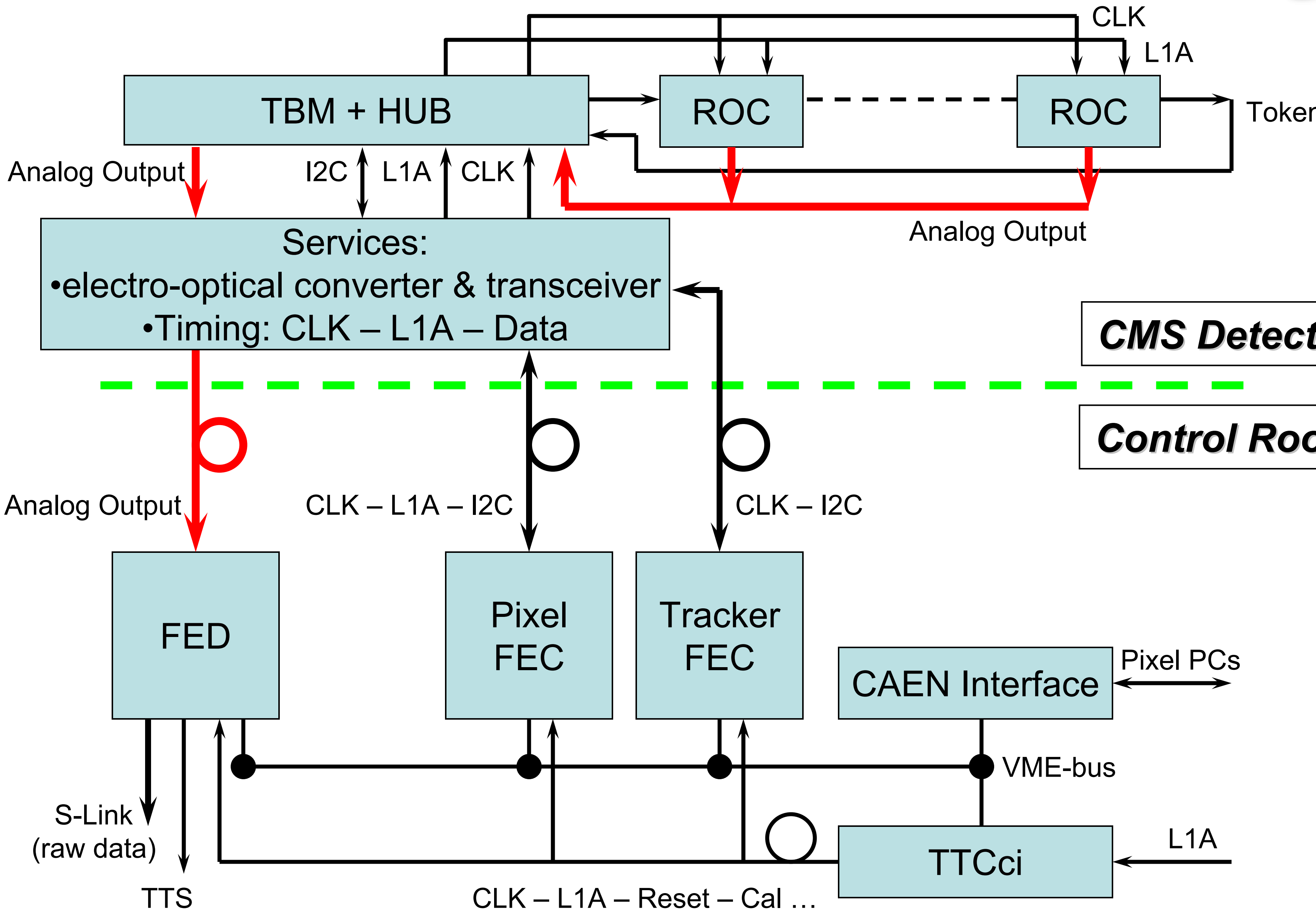


Impact Parameter Resolution



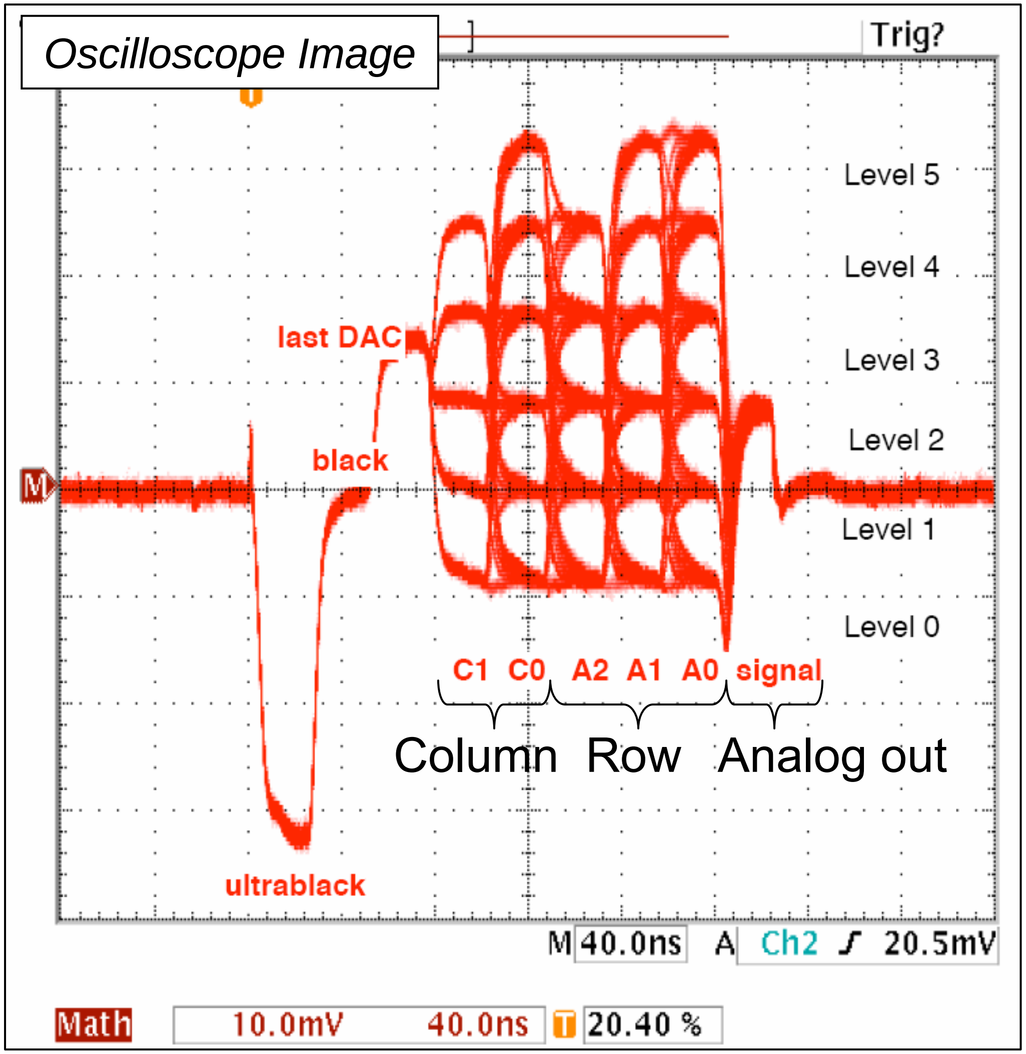
The pixel-only track finder is extremely fast and therefore can be employed in the first stages of the High-Level Trigger

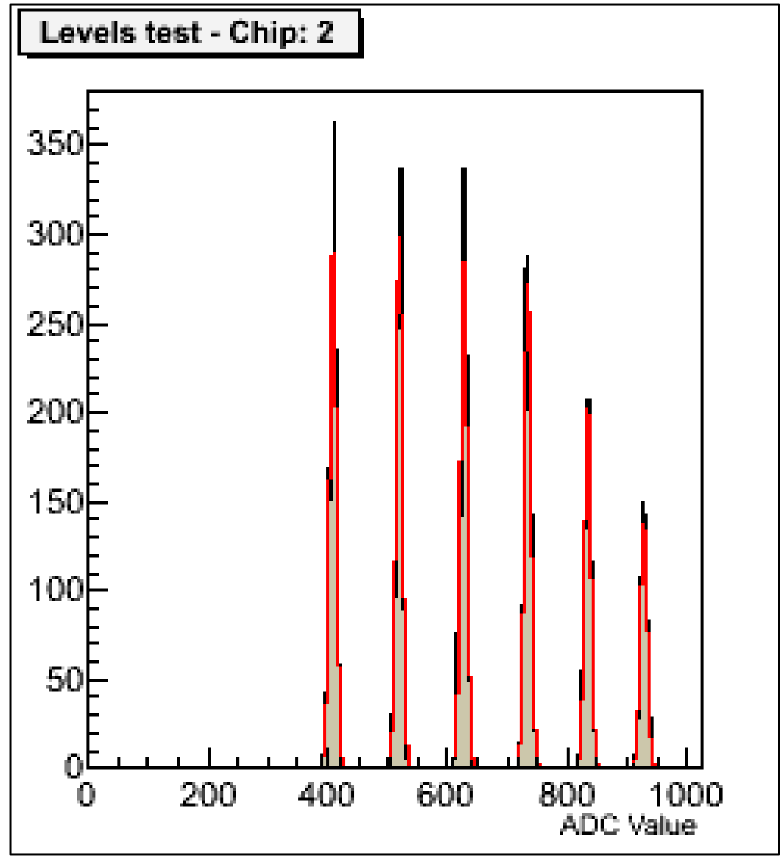
The CMS Pixel System: Readout Chain



The CMS Pixel System: Analog Readout

The output of the ROCs is analog → Front End Digitizer performs a 10 bit digitization



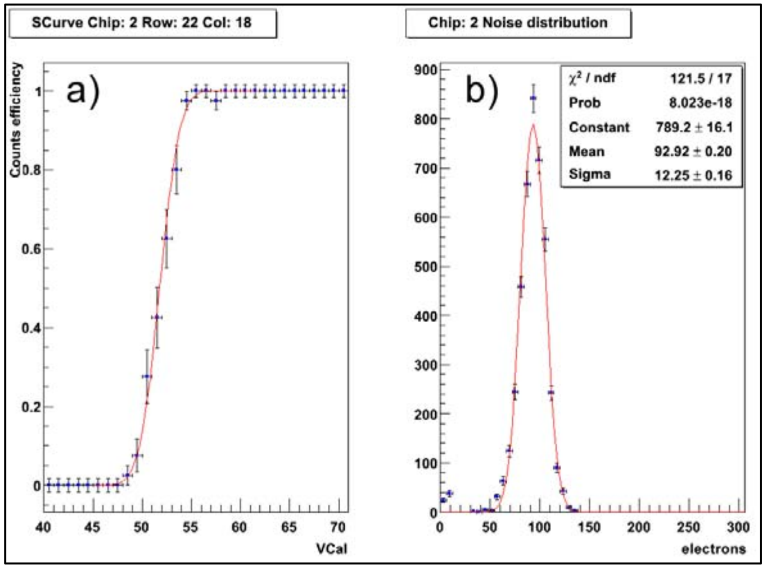


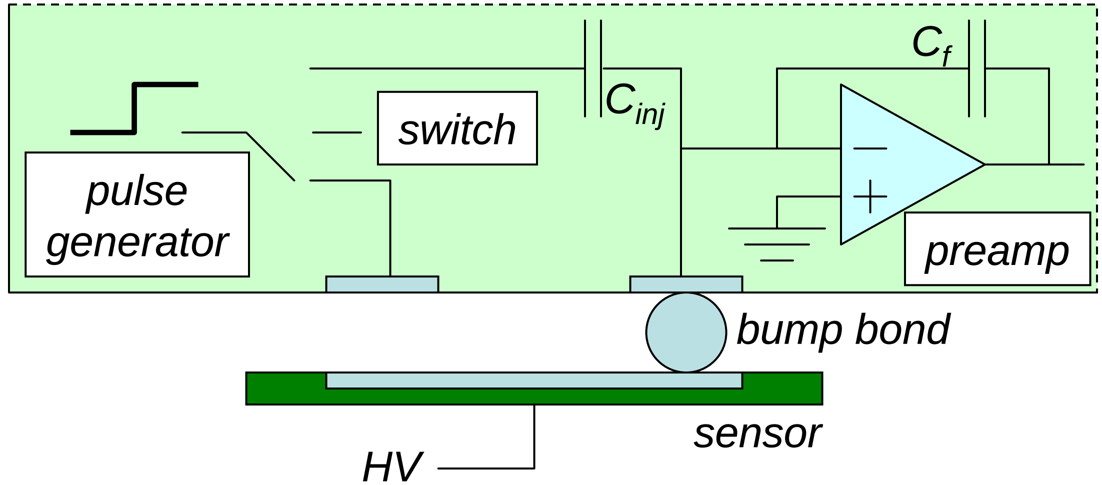
- Level separation: ~110 ADC
- Level broadening: ~4 ADC

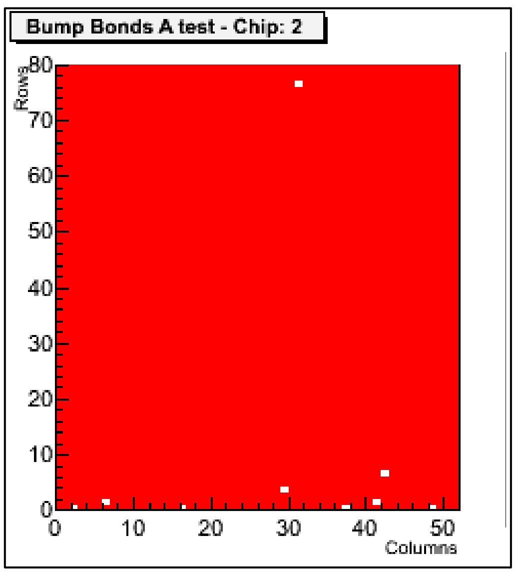
Level separation ~28σ

Module Testing

We test the performance of the modules at each assembly step







Noise distribution on a chip (at the input of the preamplifier as measured by a Threshold-curve):

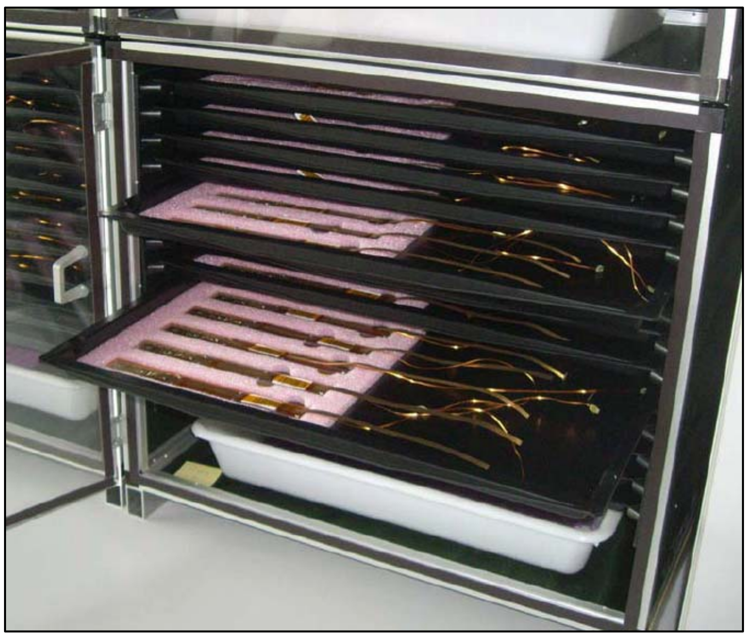
- **μ_N ~100 e^-**
- **σ_N ~12 e^-**

Signal size (MIP): ~22000 e^-

“Bump-bonds” test:

maps all the bad bump-bonds of the ROCs by comparing the response of the cell to different methods of charge injection

BPIX Module Assembling and Testing



Production rate:

4 full modules/day

+

2 half modules/day

or

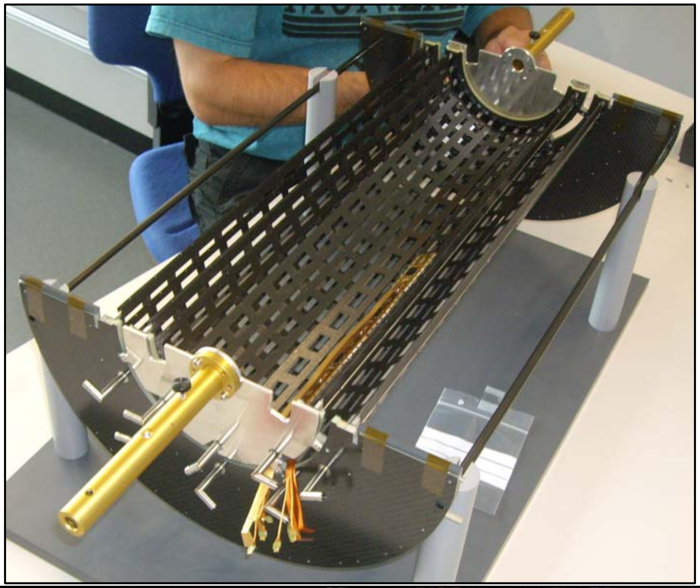
6 full modules/day

Testing

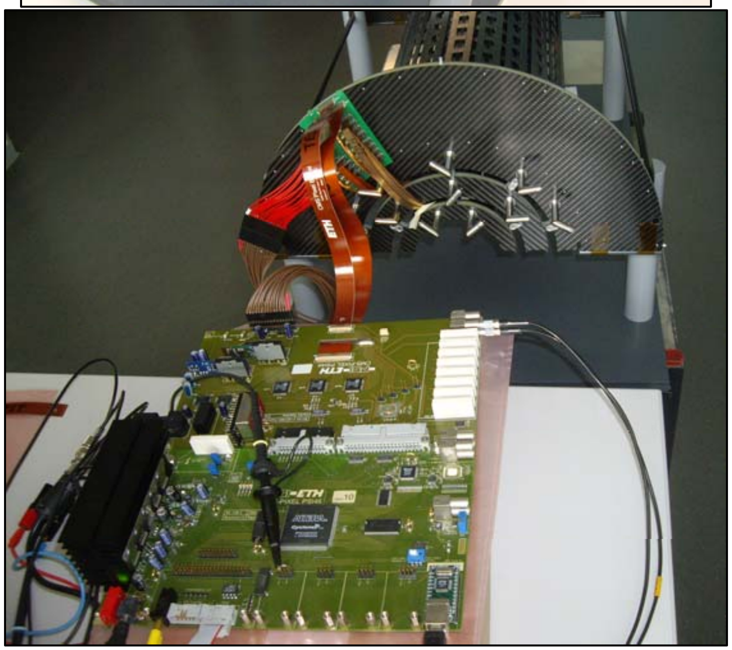
Modules stored in dry boxes ready to be mounted on the carbon fiber support structure (after module production is complete)

Needed for the 3 layers: 672 full modules + 96 half modules

BPIX Module Assembling and Testing



First module mounted on the engineering BPIX detector

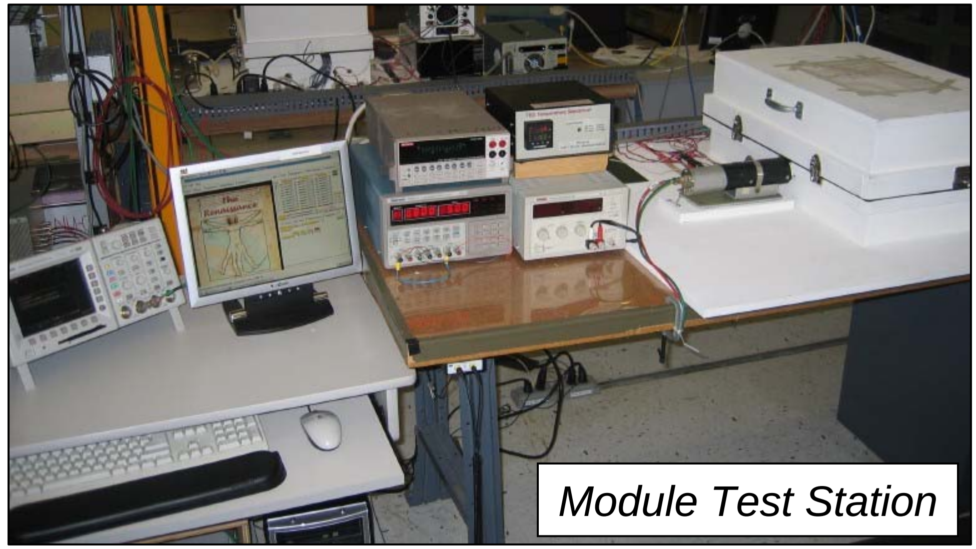


Stand alone test system for group of 12 modules

- It's very convenient for sector testing after mounting
- It replaces FEC, FED and power system

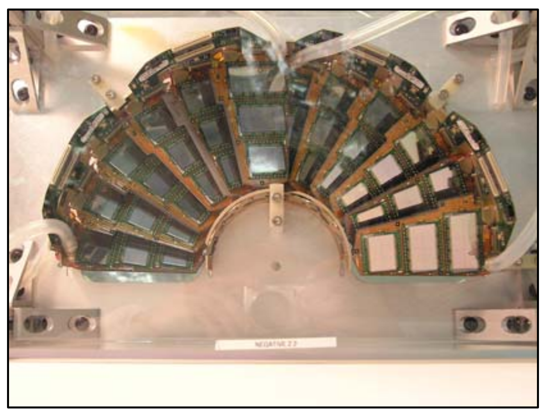
FPIX Module Assembling and Testing

1. Modules are assembled and quickly tested at Purdue University at a production rate of 6 modules/day
2. They are shipped to FNAL and then visually inspected
3. The modules then undergo a two-day thermal cycling process consisting of ten cycles between +20 and -15°C
4. Since the detector will operate at cold temperatures to minimize the effects of radiation damage, modules undergo detailed characterization at -15°C



Module Test Station

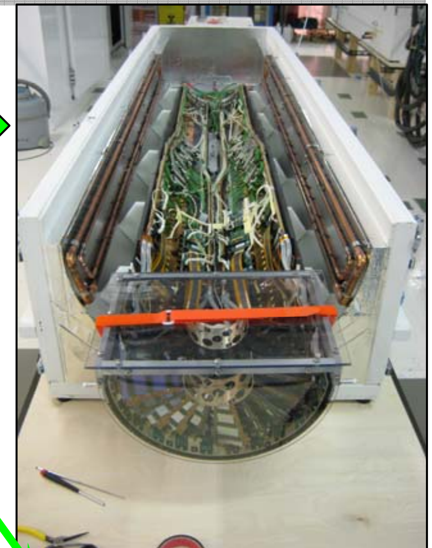
Two half disks are mounted in the half service cylinder to be tested with the final DAQ electronics, before being shipped to CERN for commissioning



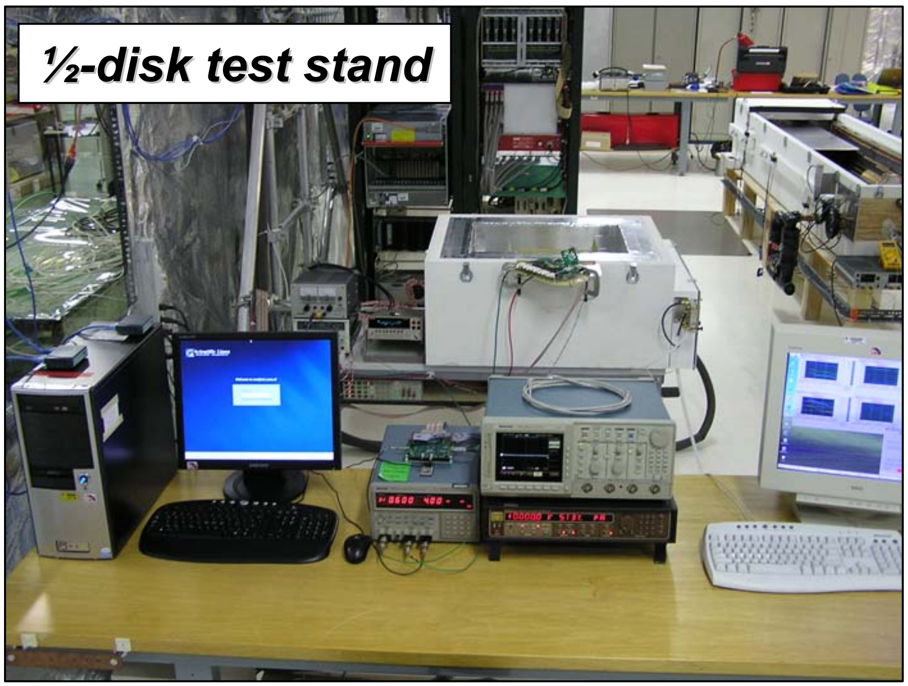
Modules are mounted on the half disks

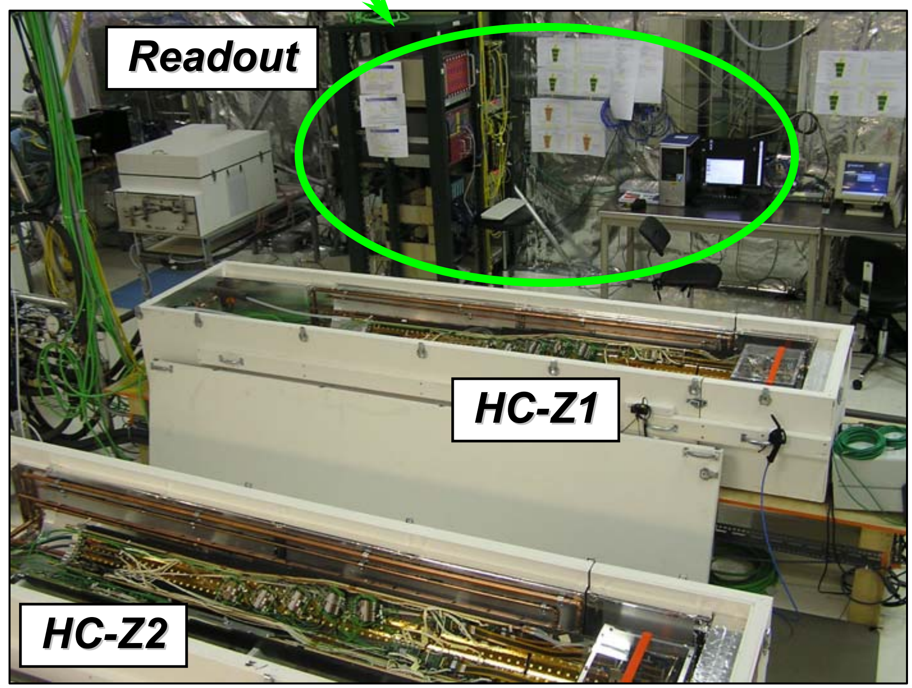
FPIX Commissioning at CERN

The ½-disks and the ½-service cylinder are reassembled at the CERN Pixel clean room

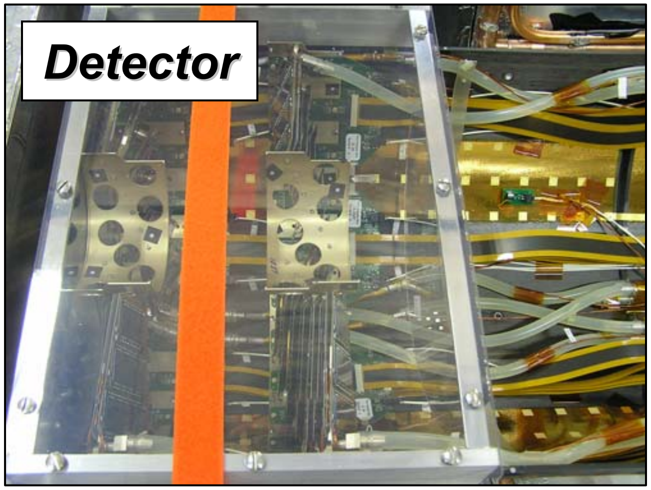


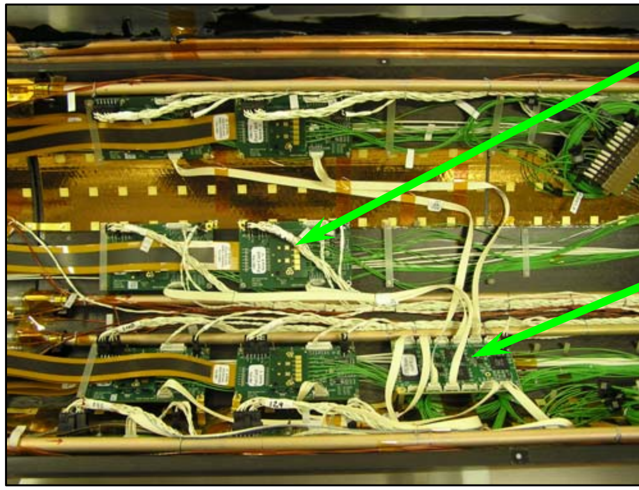
- An experiment-like readout system is implemented to commission the detector
- **An engineering FPIX detector was also built to pioneer all of the assembly and testing procedures**





Inside the FPIX Detector





Portcard:
- *Electro-optical converters & transceiver*
- *Timing: CLK – L1A – Data*

Communication & Control Unit:
- *Handle data to/from portcards*

All data (digital & analog) are carried by optical fibers

Hit information from each panel (~10^5 channels) is carried by one fiber thanks to multiplexing and zero suppression on chip → **~190 fibers for ~18 M channels**

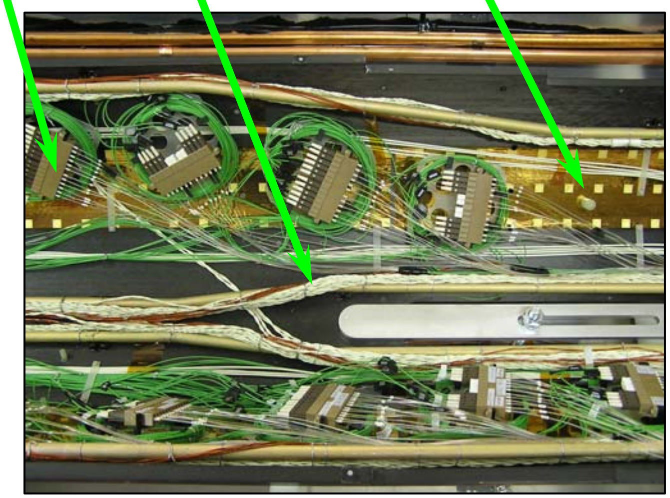
Strip-tracker (no zero suppression on chip): one fiber carries 256 channels → **~38000 fibers for ~9.6 M channels**

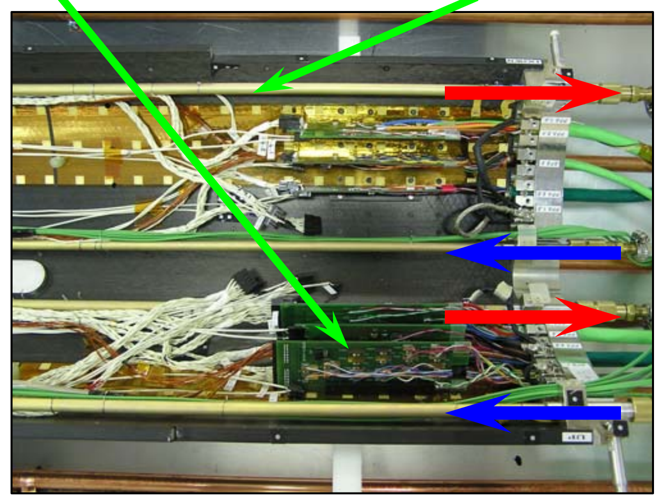
Gnd strip

Power cables

Power filter boards

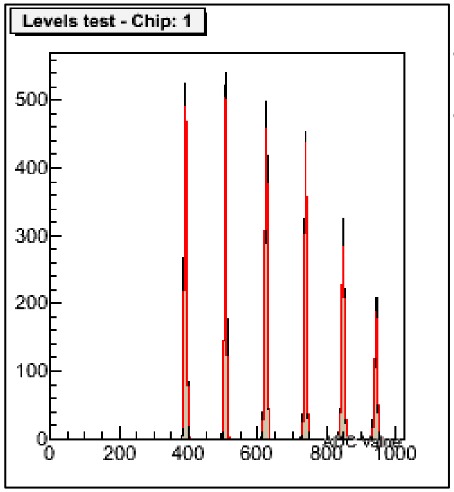
Cooling lines





Engineering FPIX Detector: Cold Run

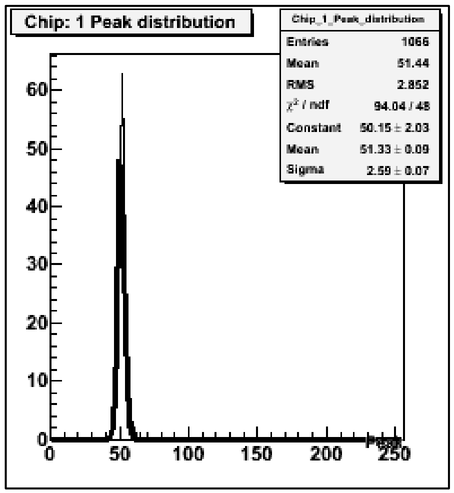
Measurements performed at **+20°C**

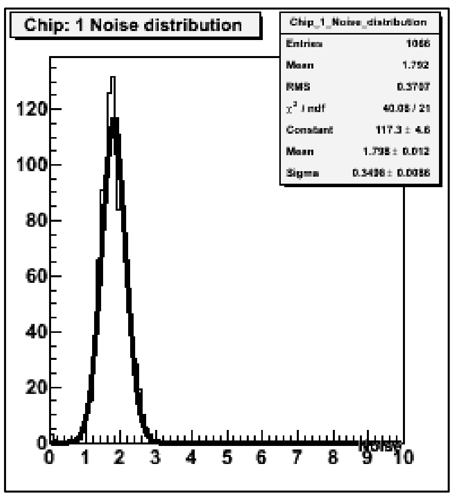


- Level separation: ~110
- Level broadening: ~3.3

Level separation = 33σ

Threshold dispersion: ~156 e⁻



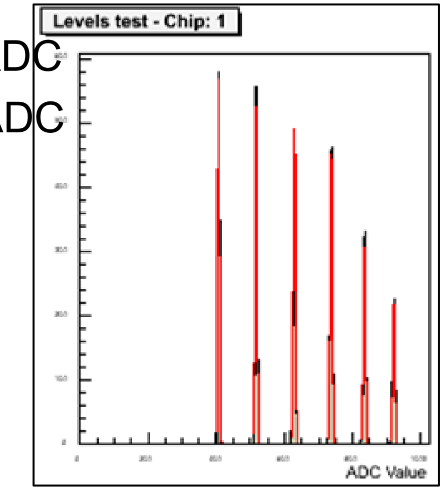


Noise: ~108 e⁻

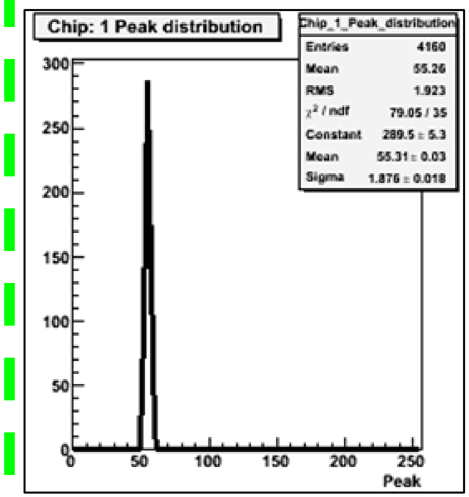
Measurements performed at **-10°C**

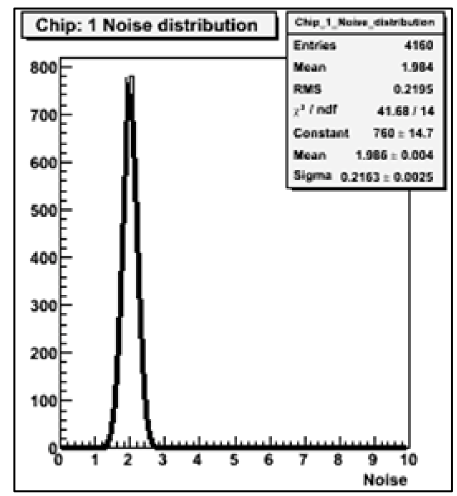
- Level separation: ~110 ADC
- Level broadening: ~2.9 ADC

Level separation = 38σ



Threshold dispersion: ~114 e⁻

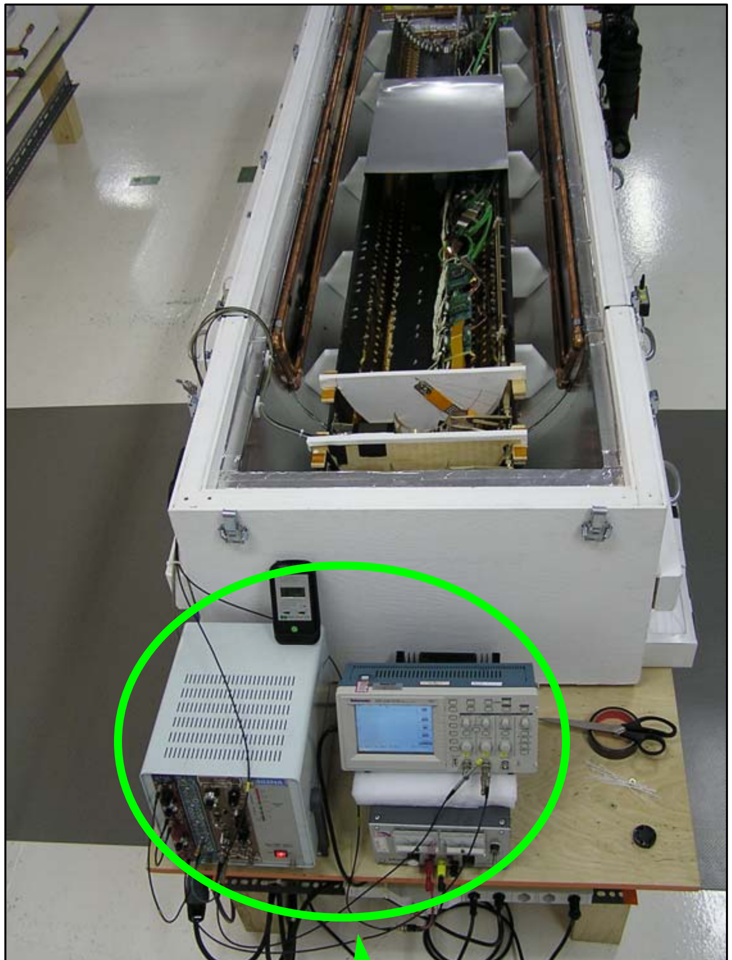


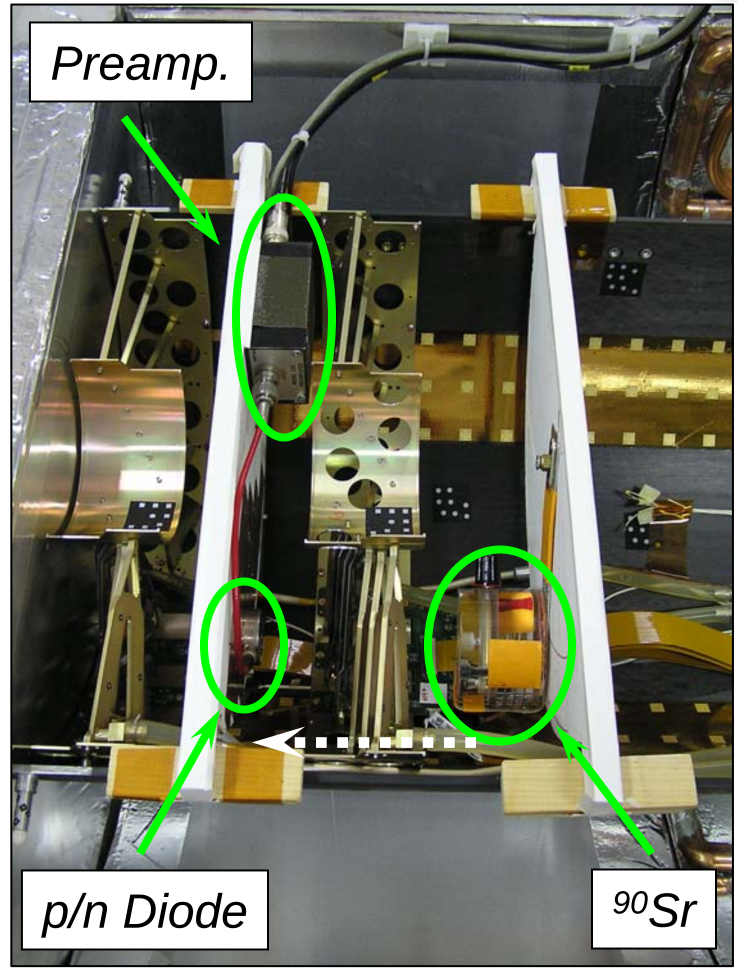


Noise: ~120 e⁻

30°C doesn't affect performance

Particles in the Engineering FPIX Detector

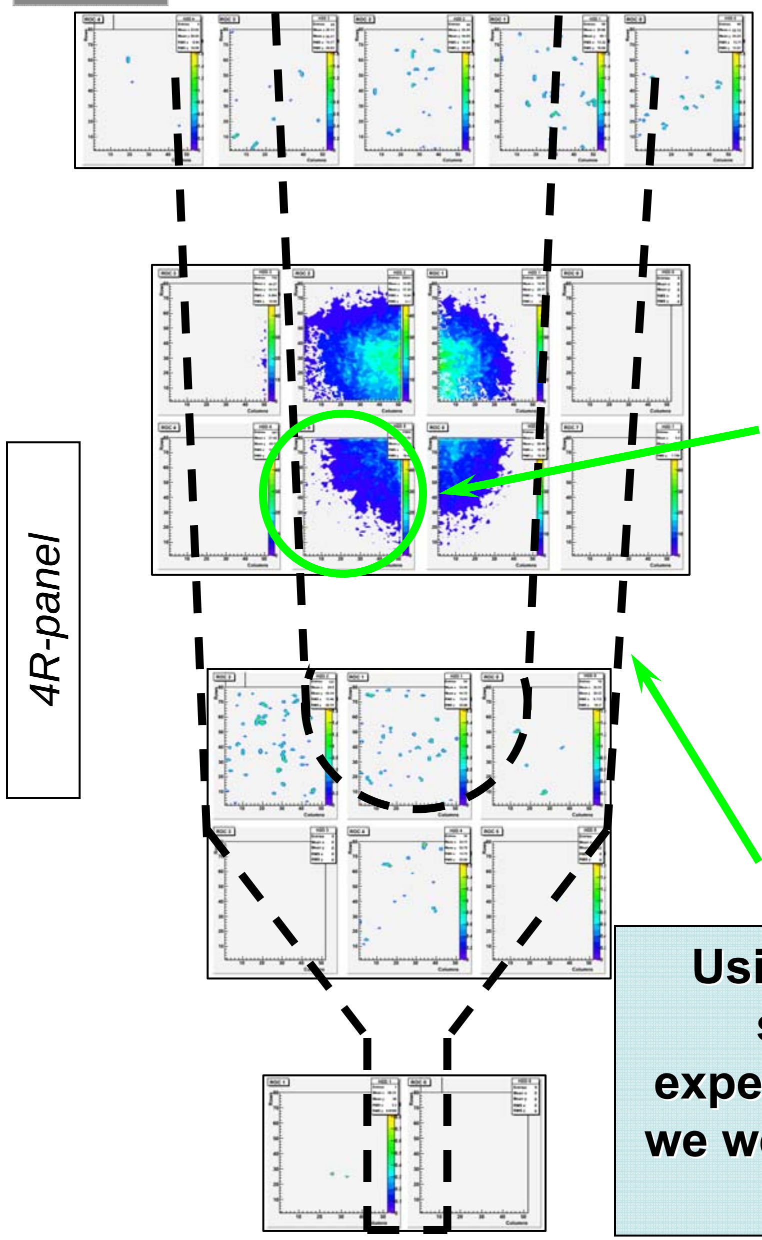


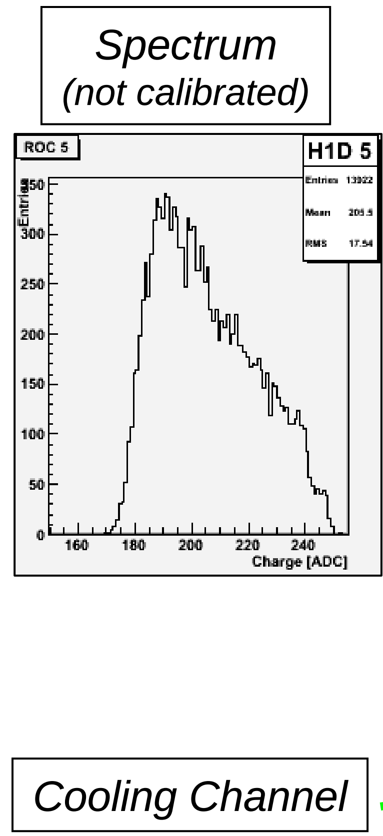


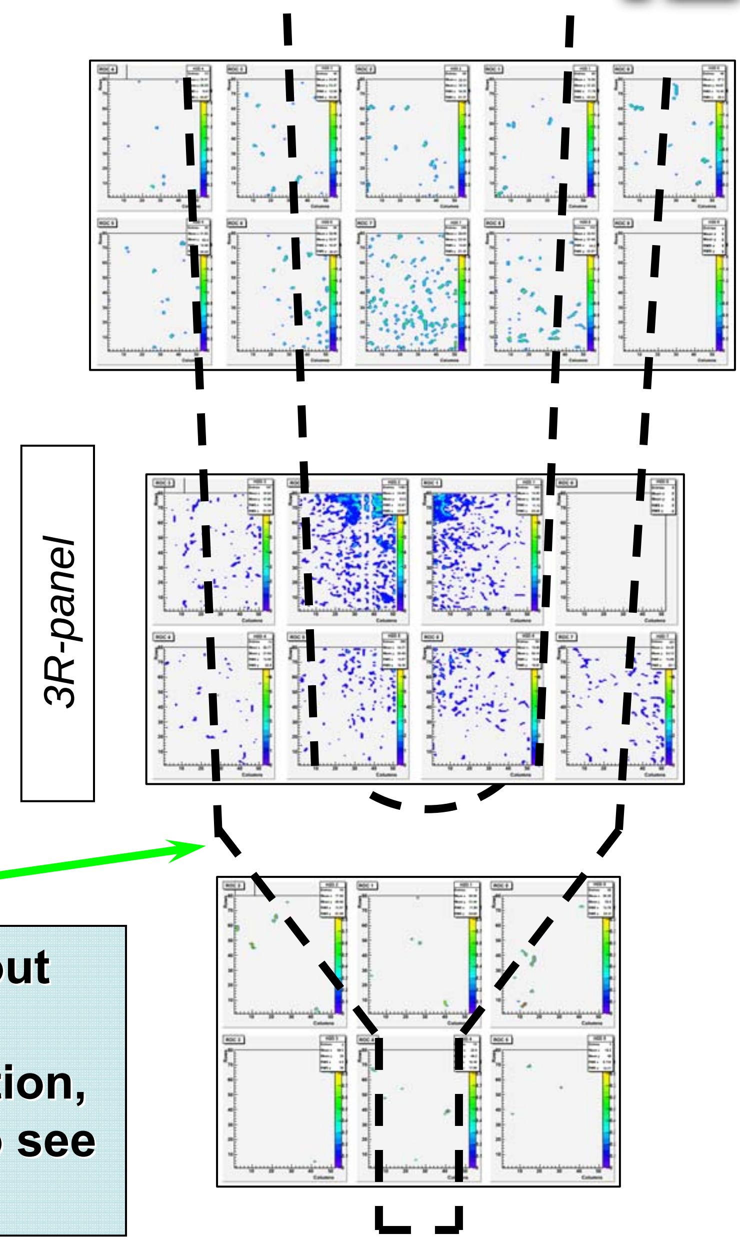
power supplies + amplifiers & shapers + discriminators + timing unit

- Radioactive source of ^{90}Sr of 1 mCi
- The system was triggered by means of a p/n diode (trigger rate ~100 Hz)

Particles in the Engineering FPIX Detector

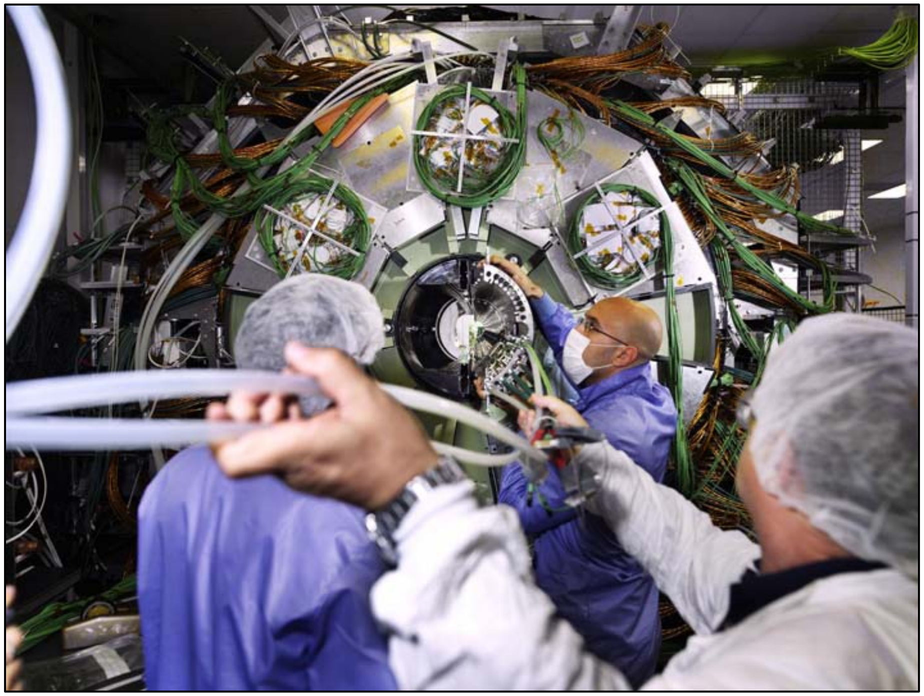




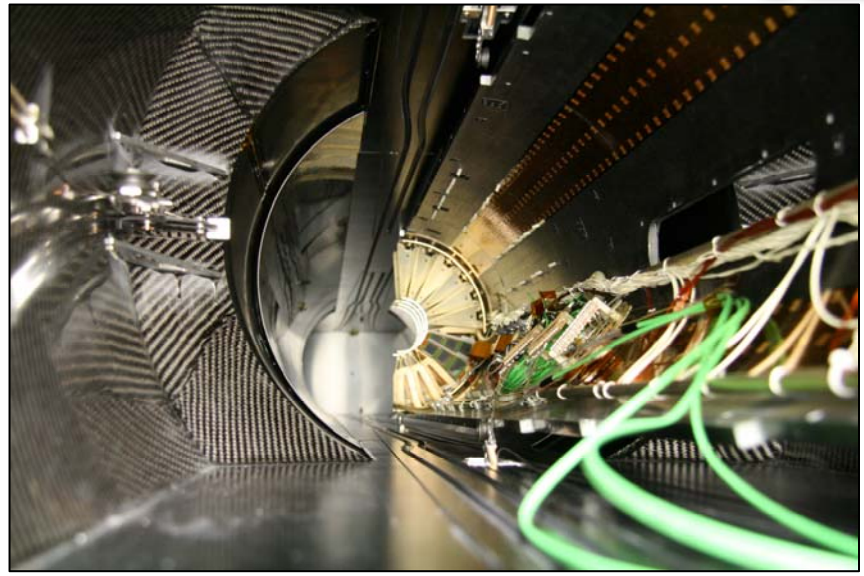


Using the final readout system and in an experiment-like condition, we were clearly able to see particles …

CMS Pixel-Strip Integration



Insertion into the strip tracker
(200 m^2 of Silicon detectors)

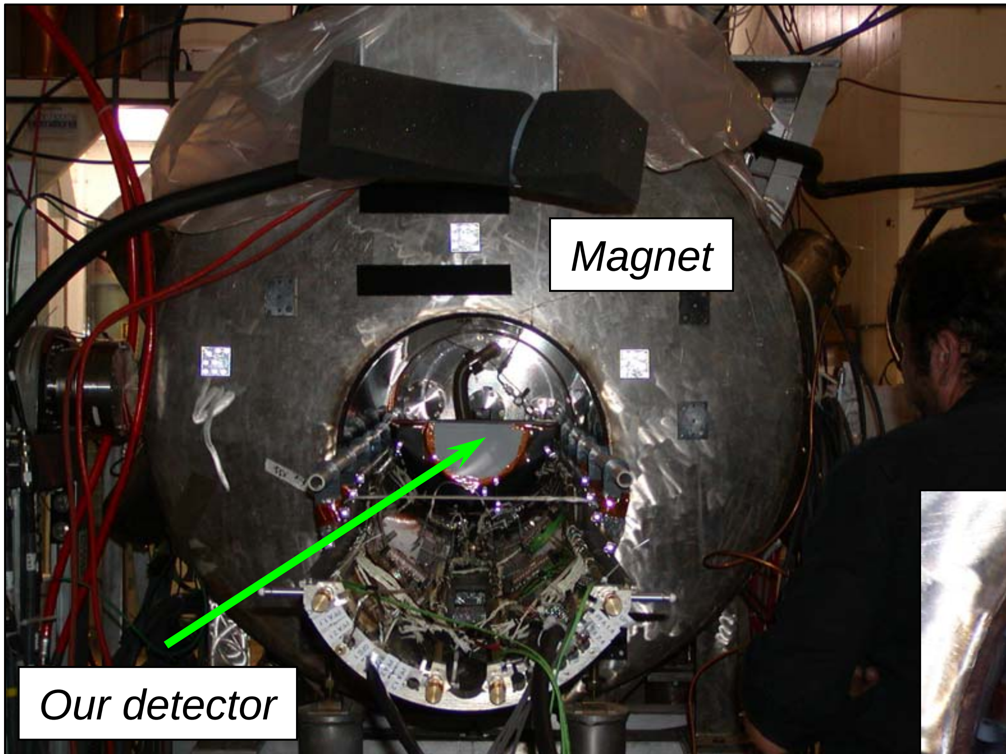


Engineering FPIX detector

Condition 1: Pixels ungrounded; Microstrips OFF
Condition 2: Pixels ungrounded; Microstrips ON
Condition 3: Pixels grounded; Microstrips ON

Chip #	Parameters	Condition 1	Condition 2	Condition 3
Chip 0	Threshold dispersion	120 e$^-$	114 e$^-$	114 e$^-$
	Noise	138 e$^-$	132 e$^-$	132 e$^-$
Chip1	Threshold dispersion	156 e$^-$	162 e$^-$	168 e$^-$
	Noise	108 e$^-$	108 e$^-$	114 e$^-$

FPIX Magnet Test

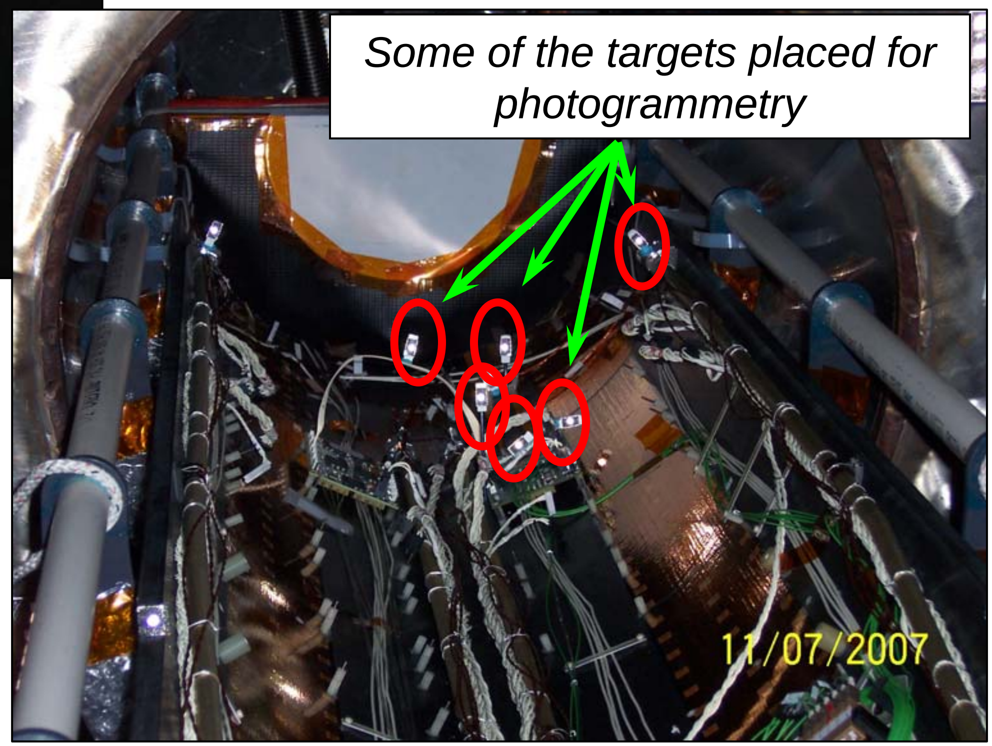


We wanted to test the behavior of the electronics and mechanics in a 4 Tesla magnetic field, in particular:

✓Monitor possible movements due to B-field ramp-up and ramp-down

✓Test wire-bonds at different trigger frequencies (CDF-effect)

✓Measure general performance (noise, gain, etc…)



The detector performed as expected and no movements were detected

CERN FPIX Commissioning: Strategy

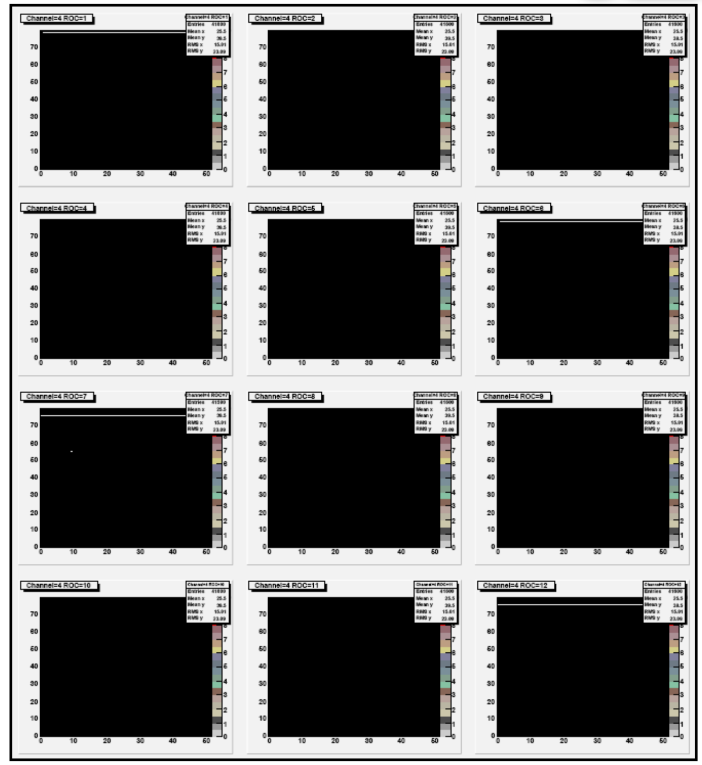
- **Sequence of tests:**
  - ✓Pixel Alive; Gain-curves; Threshold-curves

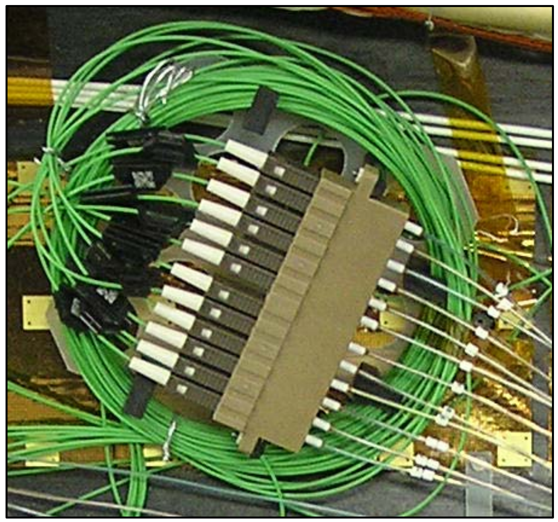
- **Checks:**
  - ✓ROC currents; Sensor leakage currents
  - ✓Intensity of the signal after opto-receiver on the FED → discover bad/dirty fiber connections

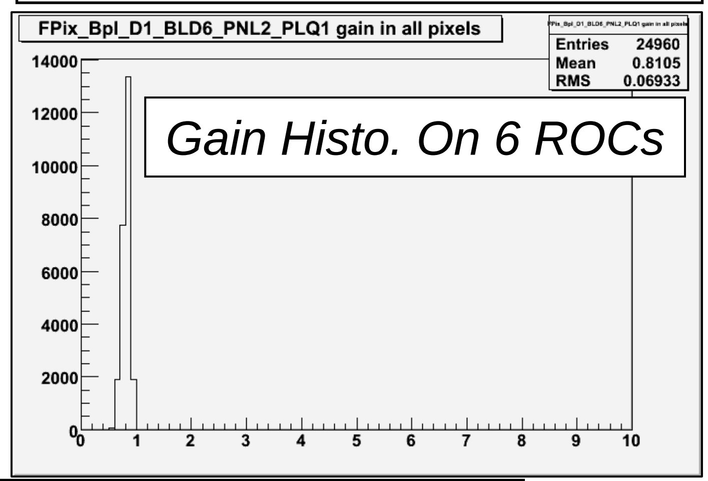
- **Map temperature sensors for the Detector Control System**

- **Run the entire system at +15°C and -10°C**

Pixel Alive





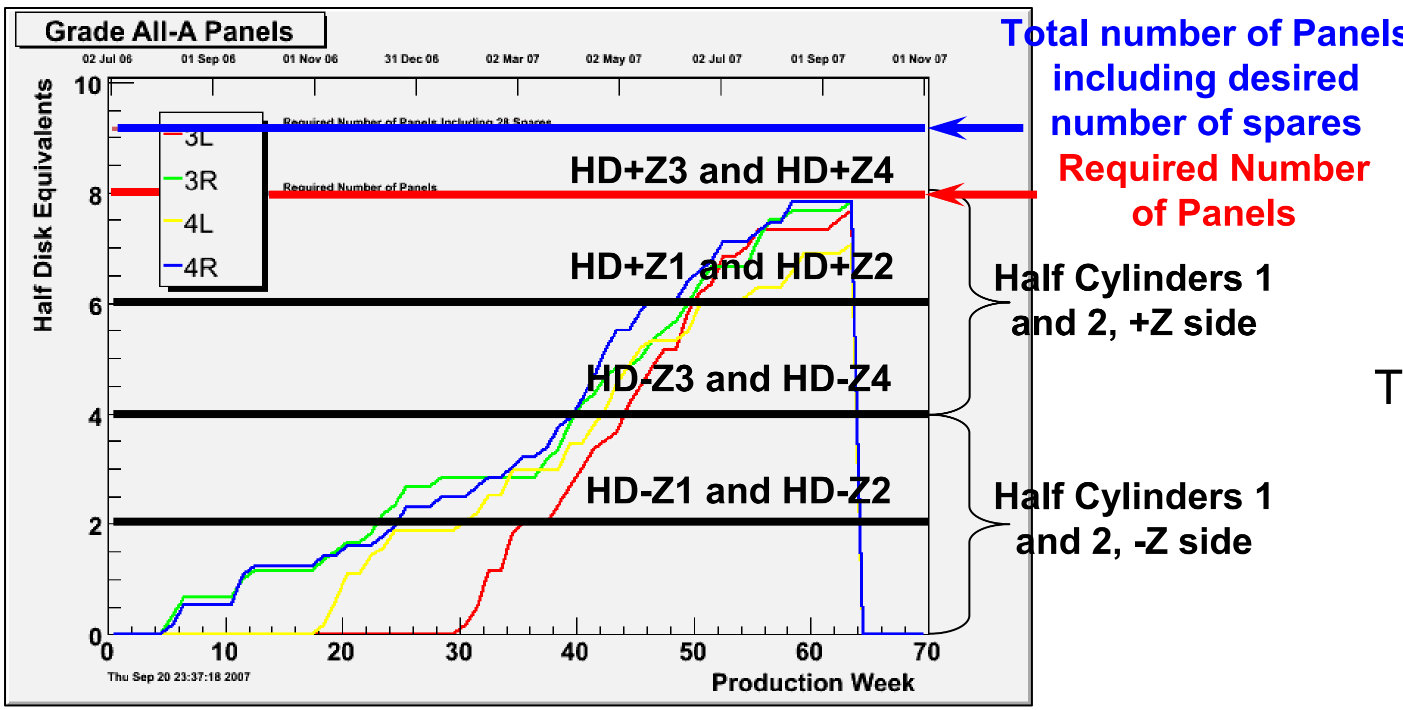


Gain Histo. On 6 ROCs

Barrel Pixels

- ➢Engineering detector is almost ready (transport from PSI to CMS will occur 1 week prior to installation)
- ➢Production detector assembly on support structure will start soon (expect to mount all modules in 30 working days):
  - •First half-shell will be done in middle of November, with contingency
  - •Second one in early January, with lots of contingency

Forward Pixels



50% of the forward pixel detector is currently being commissioned at CERN

The remaining 50% will be shipped from Fermilab to CERN between September and November

The other components, services and VME boards are ready

Conclusions

- Sensors and ROCs perform as expected after high doses of radiation

- The pixel production is running smoothly and, to achieve the best quality, extensive tests are performed at every stage of the assembly

- In the past months we had some important tests:
  - ✓Run the whole engineering detector, with the final readout system, at -10°C
  - ✓Run the whole engineering detector, with the final readout system, in the final experiment-like condition with a radioactive source
  - ✓Integration of the engineering detector with the silicon strip tracker
  - ✓Test in a 4T magnetic field a fully instrumented sector

- The commissioning of the CMS Pixels system is ongoing at CERN and PSI for FPIX and BPIX respectively → software tools are being developed and debugged

The CMS Pixel system will be ready early next year for installation

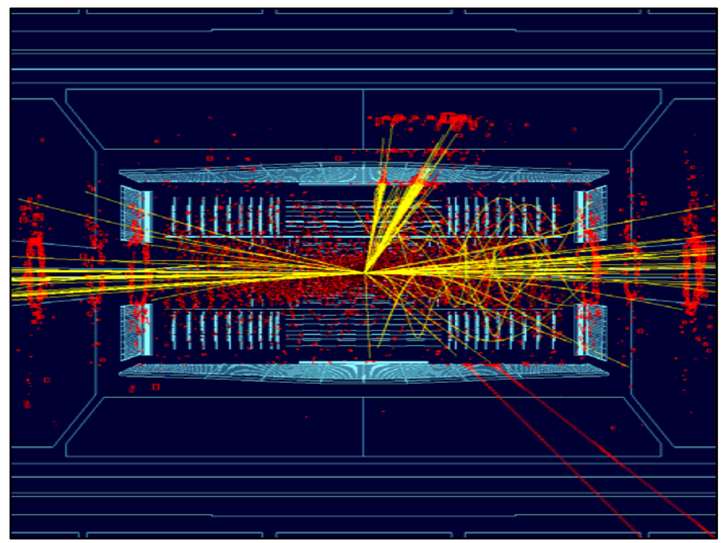
Backup Slides

The CMS Pixel System: LHC Environment

Accelerator/CMS Characteristics	Related Aspects of the Design of the Pixel System
Bunch spacing: 25 ns	*Shaping Time – S/N Ratio – ROC Internal Buffers Depth*
CMS L1A trigger latency: ~3.2 μs	
Density of produced particles (4.3 cm from the beam): $4*10^7$ paticles/(cm^2 s)	*Pixel Size*
Nominal luminosity: 10^{34} particles/(cm^2 s)	
Minimum bias: ~25	
Radiation dose (4.3 cm from beam): $6*10^{14}$ particles/(cm^2 y) (~16 Mrad/y)	*Sensor Type & Radiation Hardness Chip*

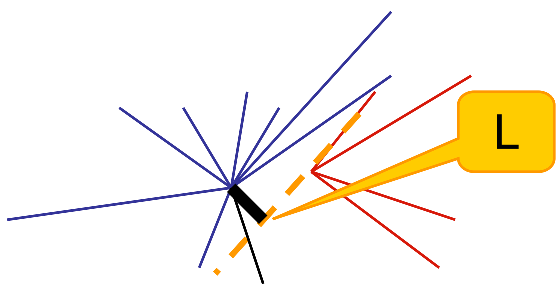
Other Important Aspects for the Design

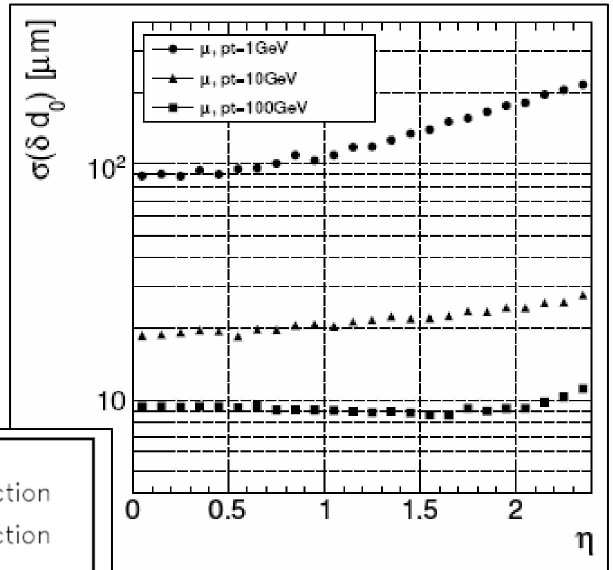
✓choice between analog or digital readout
✓area needed to accommodate the individual pixel electronics
✓dependence of the pixel capacitance on the pixel geometry
✓power density of the pixel array
✓expected sensitive detector thickness
✓total available signal charge
✓Lorentz drift angle of the charge
✓mean track incident angle

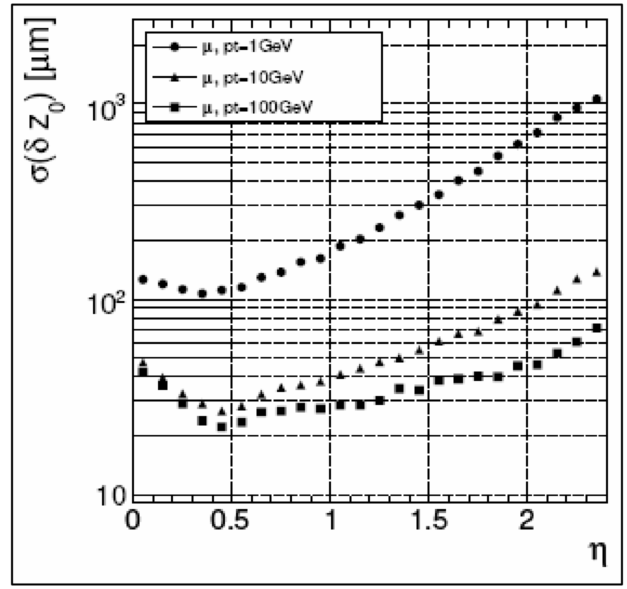


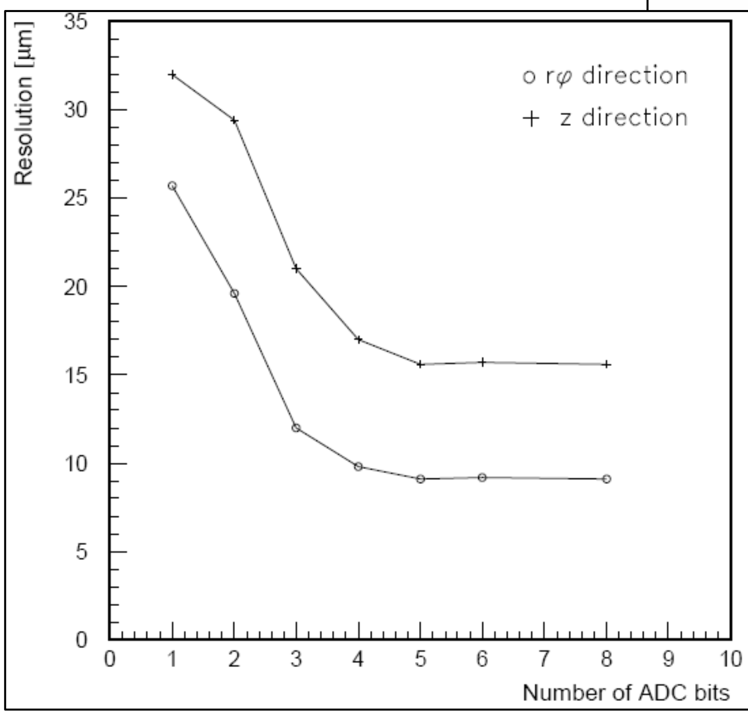
The CMS Pixel System: Physics Performance

Impact Parameter Resolution









Grade A Modules

Bad pixels:

< 20 pixels incorrectly decoded per ROC

< 20 dead pixels (in Pixel Alive) per ROC

< 40 bad Bump Bond A per ROC

No pixel fail mask bit

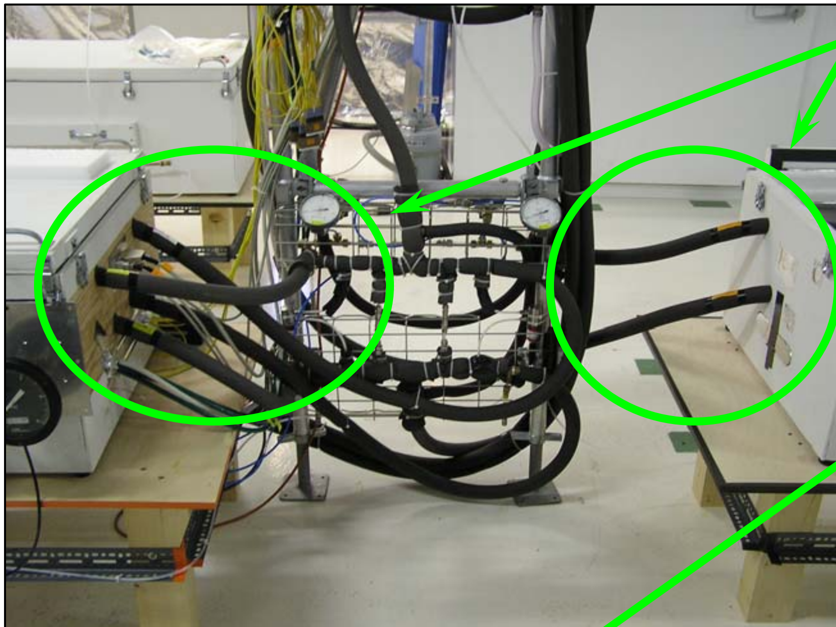
Total bad pixels (Bump Bond A not included) < 20

Noise: mean threshold between 2700e and 4200e. Threshold width below 200e. Mean noise below 150e. Noise width below 30e. Fewer than 100 pixels outside 4σ in threshold. Fewer than 50 pixels above 4σ in noise.

Gain: width of gain intercept less than 4 ADC counts. Width of gain slope less than 0.3 (in ADC/VCal). Fewer than 50 pixels outside 4σ in slope and intercept.

Sensor leakage current: current at 250 V below limit (1x2 – 11 nA; 1x5 – 23 nA; 2x3 – 24 nA; 2x4 – 26 nA; 2x5 – 37 nA). Current at 300 V over current at 250 V less than 2. Maximum voltage above 500 V.

CERN FPIX Commissioning: DCS



2 separate cooling systems (production detector & engineering detector) equipped with:

a. relief valves
b. mechanical and electrical differential pressure gauges
c. temperature and humidity sensors
d. dry air line

b. and **c.** are controlled by a Programmable Logic Controller system with interlock capabilities using the same components as in the final experiment