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Upgrade plans for the CMS Pixel Detector

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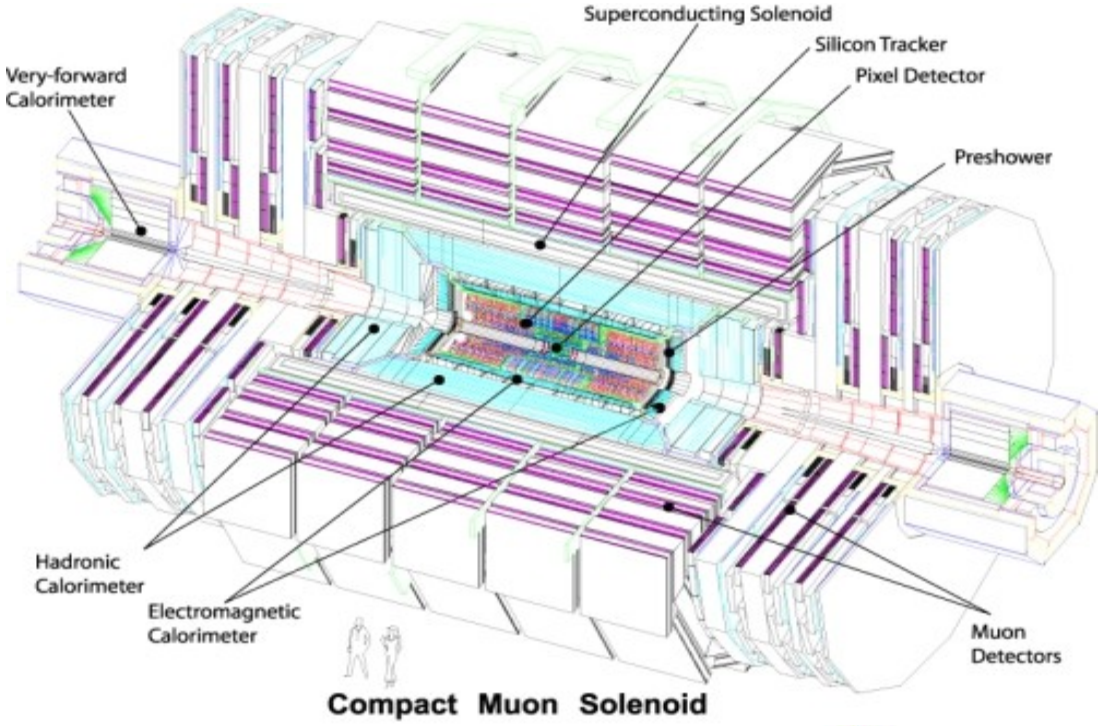
for the CMS Pixel Group

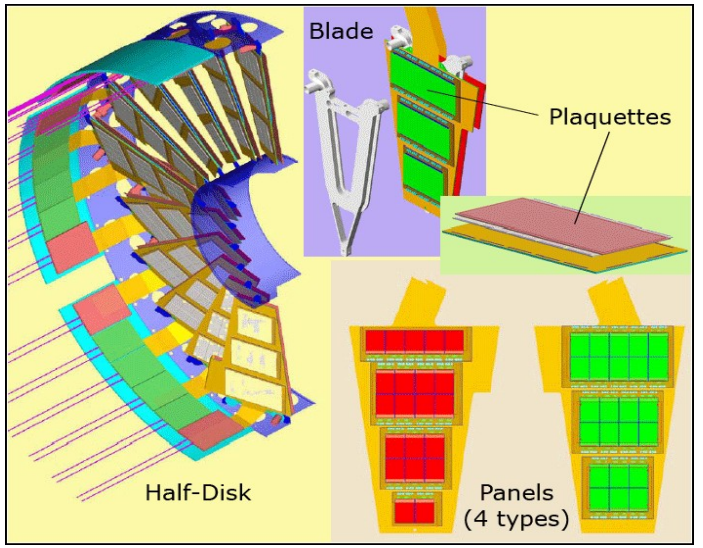
11th Pisa Meeting on advanced detectors

La Biodola 29 May 2009

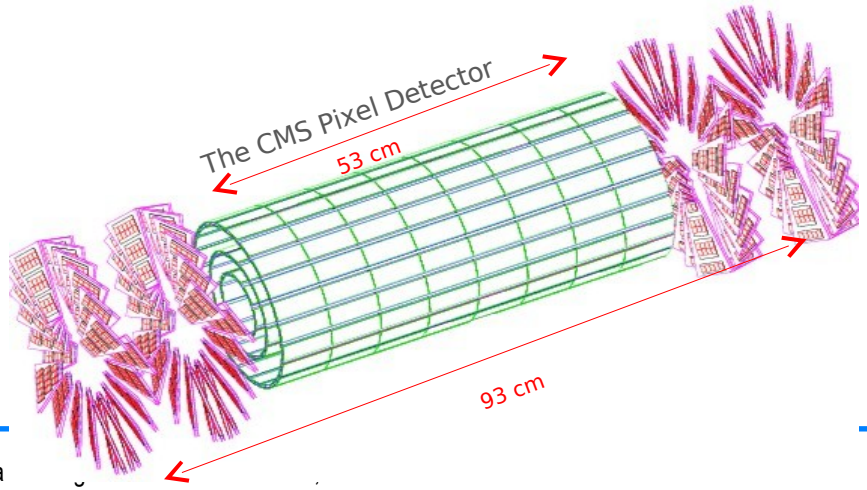
- Introduction
- new detector layout
- mechanics & cooling
- readout & electronics
- conclusions

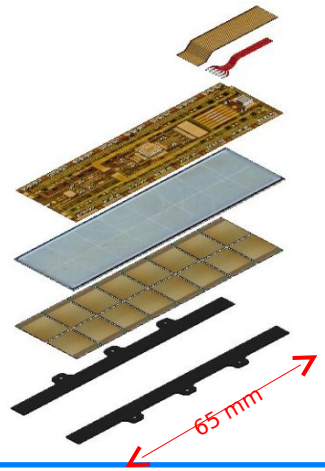
System overview (slide from G. Bolla)





Panels of the Forward Pixel Detector





Modules of the Barrel Pixel Detector

- Forward Pixel Detector (**FPix**) has two disks on each side at 34.5 cm and 46.5 cm
- FPix has 672 modules

- Barrel Pixel Detector (**BPix**) has 3 layers of radii 4.3 cm, 7.2 cm and 11.0 cm
- BPix has 768 modules

- Total of **~15,840 Readout Chips**

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Introduction

- Present CMS pixel detectors built for
  - Instantaneous luminosity up to 10^{34} $cm^{-2}s^{-1}$ (rate capability)
  - Integrated fluences up to 6 x10^{14} n_{eq}/cm^2 (sensor radiation damage)
- Motivations for a detector upgrade
  - inner layer(s) will eventually need replacement
    designed for 2 years of full LHC luminosity operation
  - Possible intermediate LHC upgrade beyond 10^{34} $cm^{-2}s^{-1}$ around 2014 (Phase 1)
  - Performance improvement
    - More layers for robust pattern recognition
    - Reduction of material in tracking region
    - Higher rate capability, reduce readout deadtime

Upgrade plan, boundary conditions

- Minimal disruption of data taking
  - Interface to CMS (DAQ, control)
- O(5) years time (present pixel >10 years)
  - Only modest modifications of the readout chip
- incremental upgrade
- Re-use existing services (power cables, readout fibers, cooling tubes)
  - 3 layers + 2 disks → 4 layers + 3 disks factor 1.6 increase of channels
  - Readout
    analog coded 40 MHz → digital coded 320 MHz
  - Power
    Modify existing supplies(CAEN), cable losses just acceptable
  - Cooling C_6F_{14} → CO_2
  - Endcap services already allocated for 3 disks

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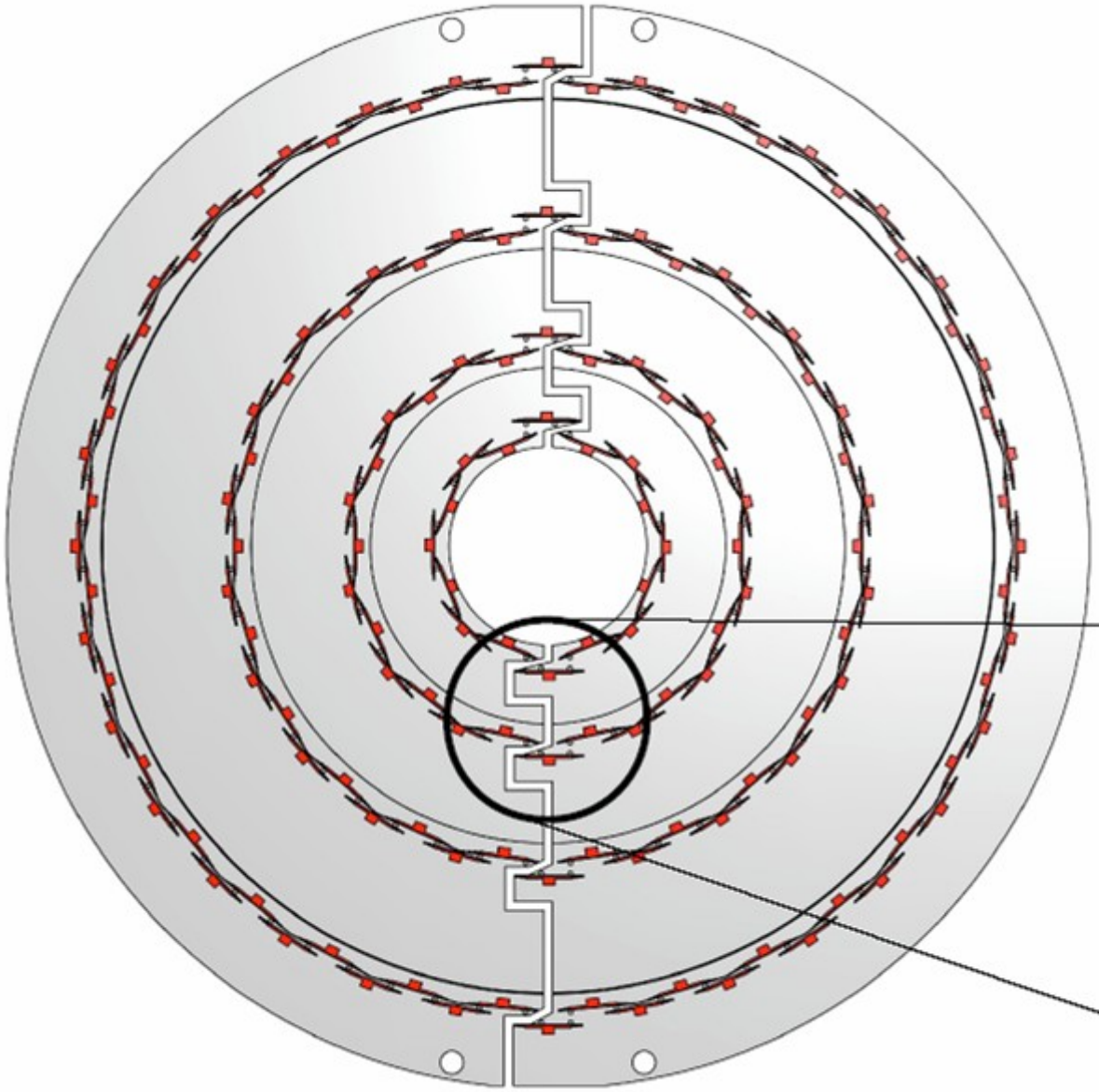
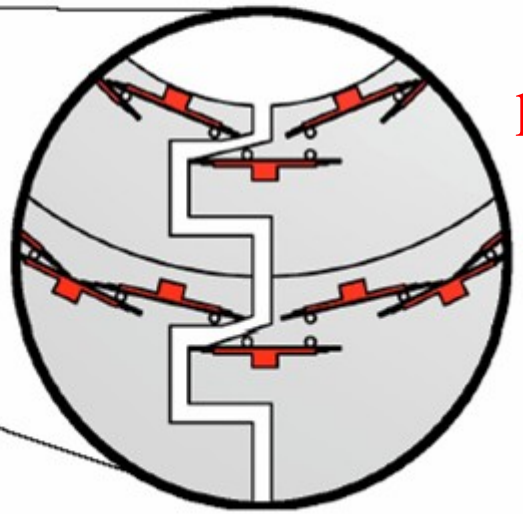
4 Layer barrel detector geometry

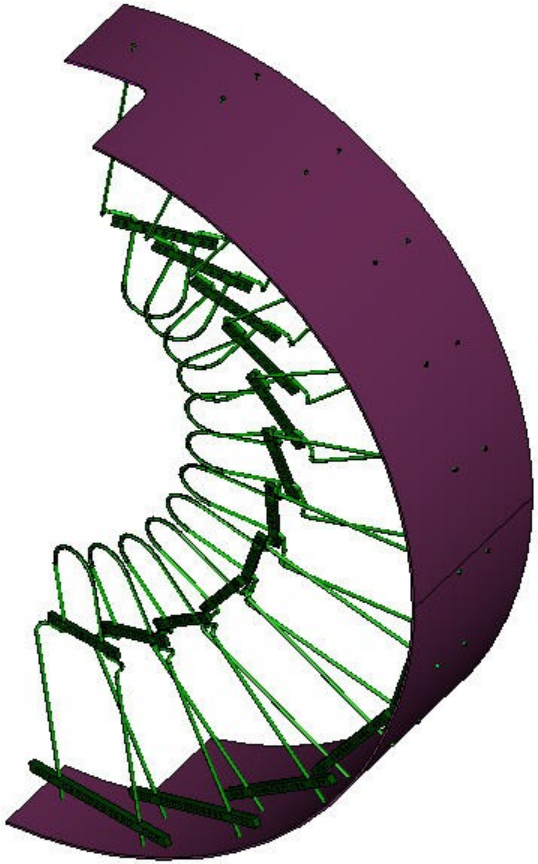


- Two identical half shells
- 1 type of fullmodule only
- Layer 1: R 39mm; 16 faces — 44 mm
- Layer 2: R 68mm; 28 faces — 72 mm
- Layer 3: R 109mm: 44 faces — 103mm
- Layer 4: R 160mm: 64 faces — -
- Clearance to beampipe 4mm

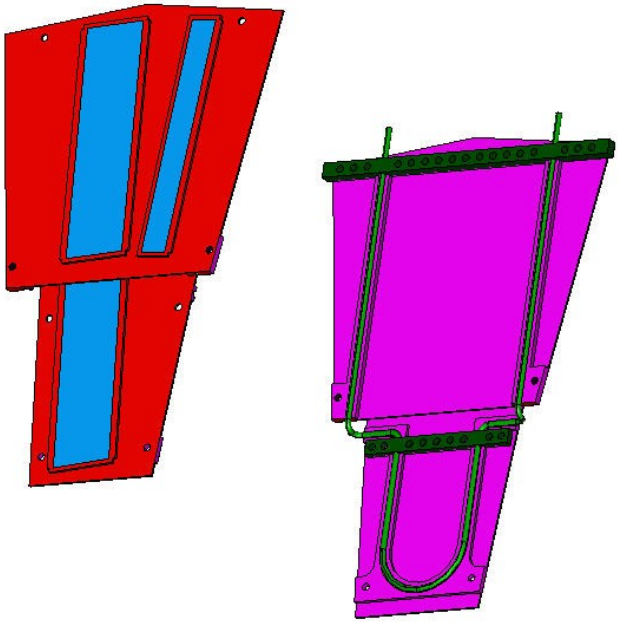


present x 1.6

3 Disk Pixel Endcap Geometry



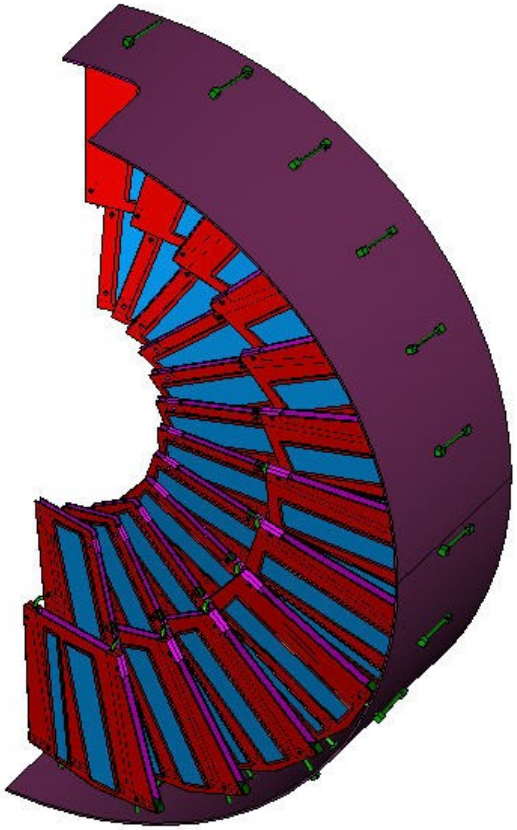
CO_2 cooling structure



Conceptual design of new blade with TPG substrate and cooling pipe

Total Quantity per half disk:

Outer: 2X8 : 24 modules, 384 ROCs
1X8 : 24 modules, 192 ROCs
Inner: 2X8: 24 modules, 384 ROCs



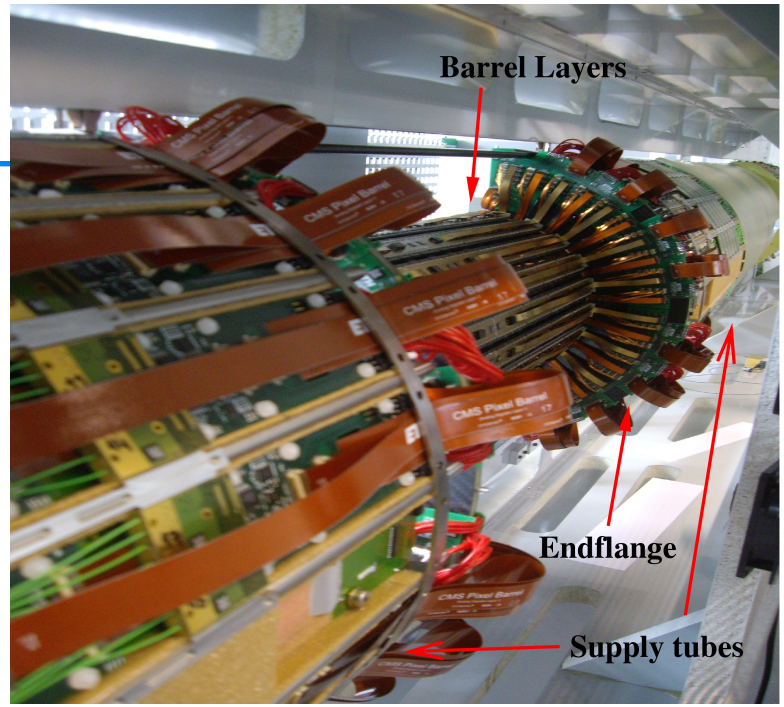
2->3 disks

larger area per disk

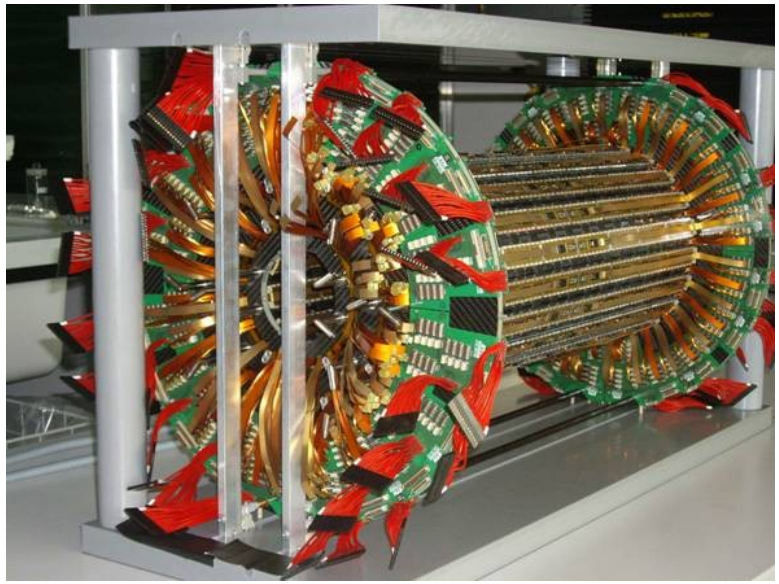
present x 1.8

Material reduction

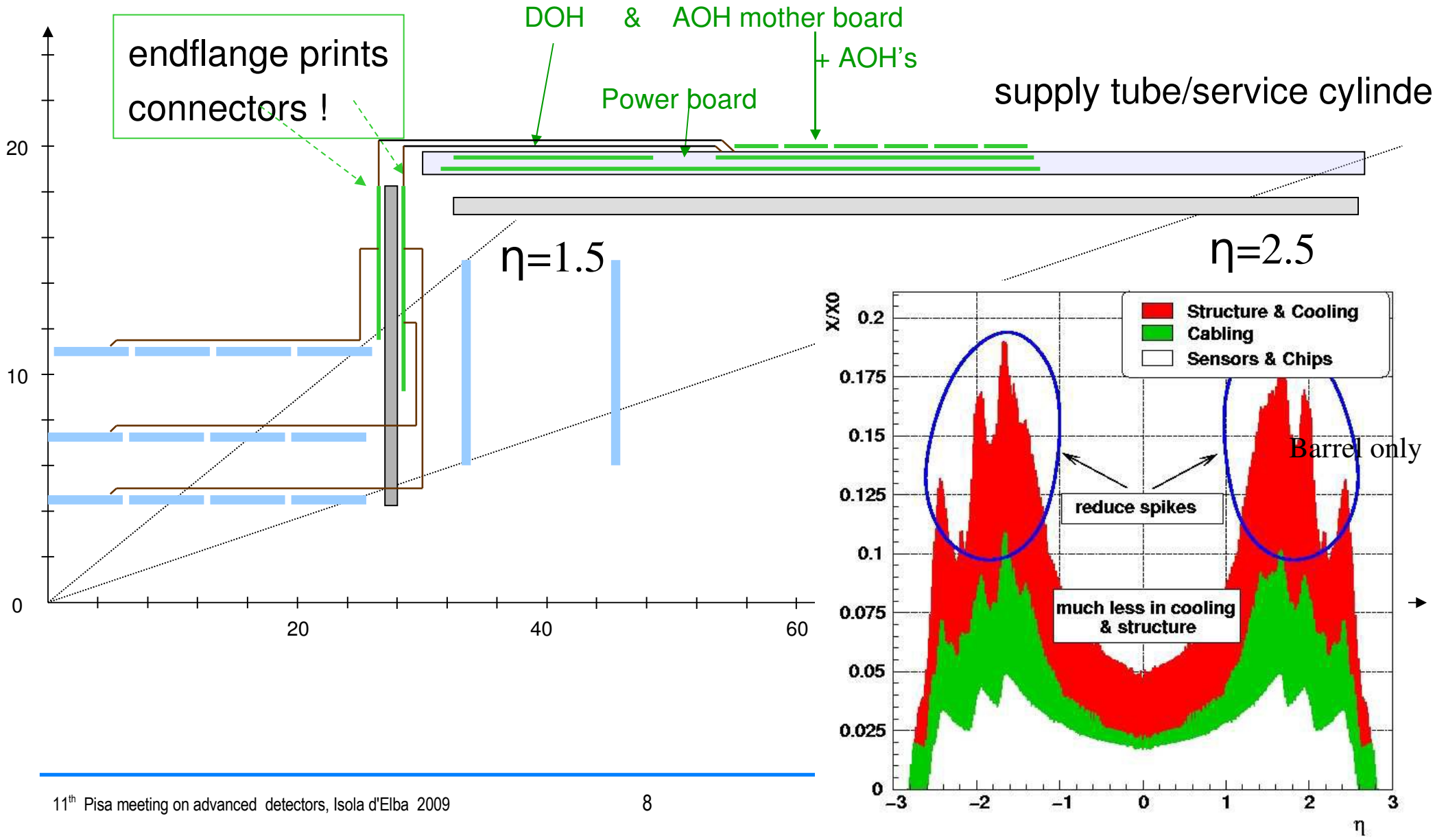
Present CMS pixel: 2 % X0 per layer
~ 1/3 sensor + chips
~ 2/3 cooling, mechanics, cables
bulkheads inside tracker acceptance



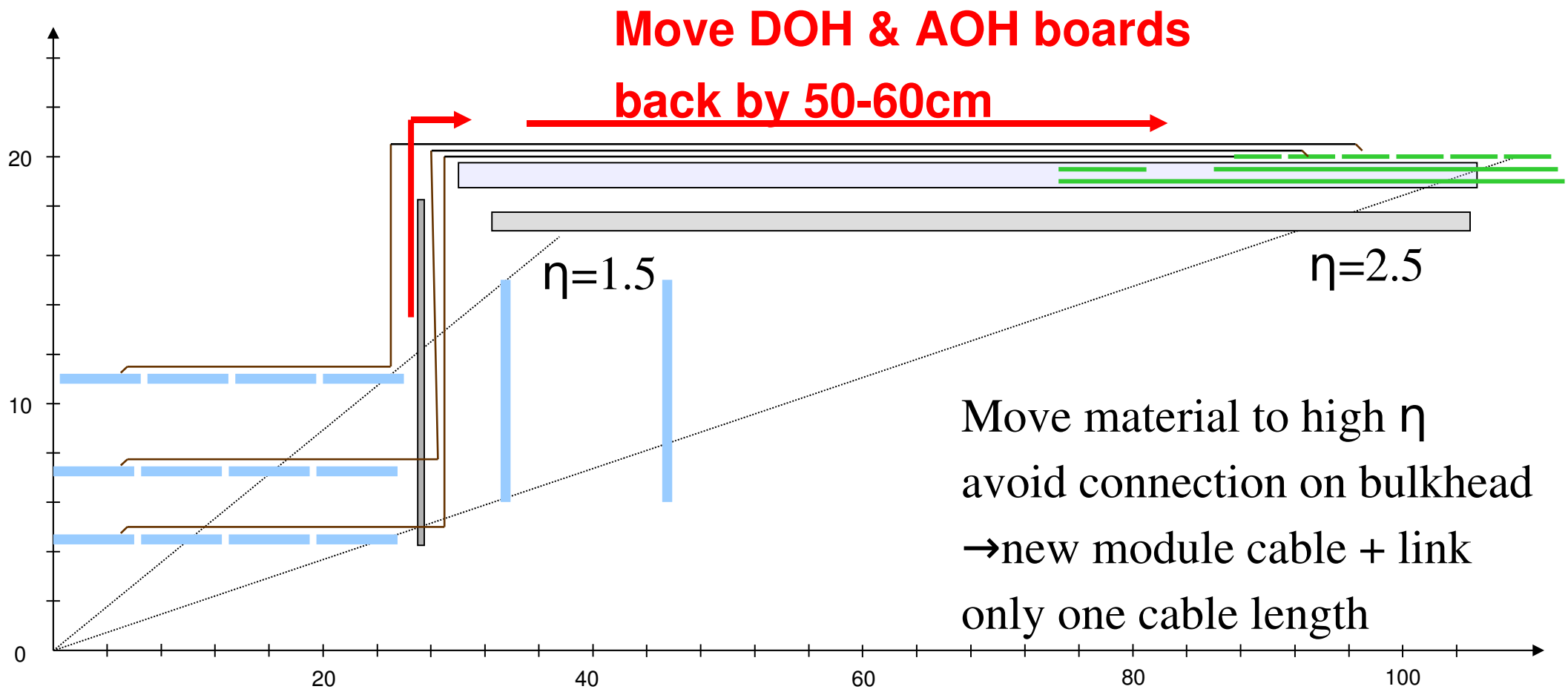
Material reduction
- move material out in z/η
- avoid connectors
- reduce module material



Present detector layout



Reduce material in tracker accpetance

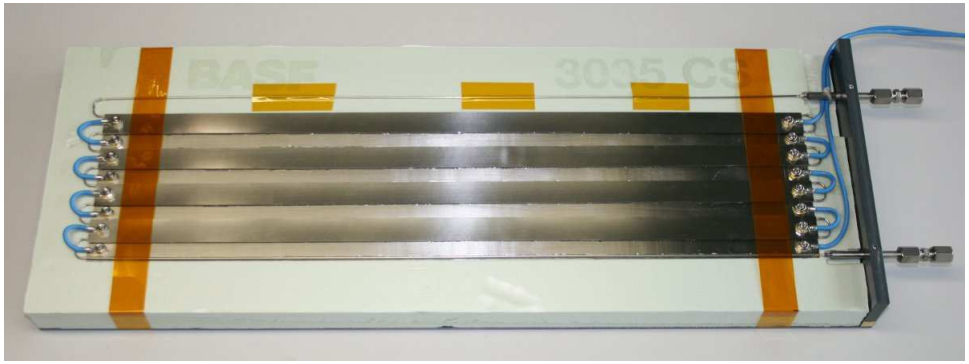


CO2 cooling

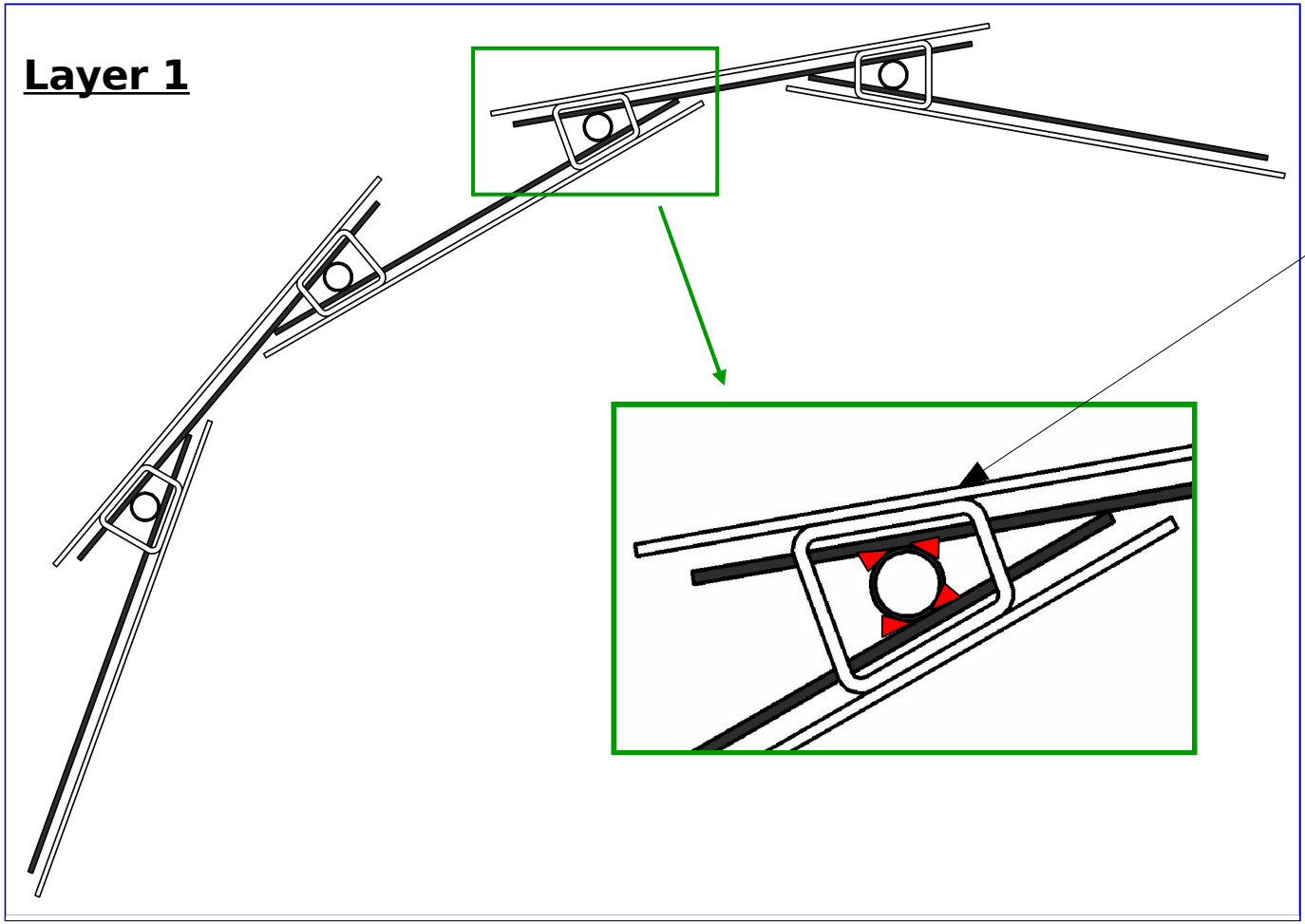
Evaporative cooling with CO2,
saturated mixture of gas and liquid

- Promising for HEP
- Makes use of the high latent heat
  - Less flow, smaller diameter pipes
  - Material savings in pipe and coolant
- CO2: low mass, rad-hard,..
- relatively high pressures
  - 25 bar at -12 C
  - 57 bar at 20 C
  - no problem for small diameter tubes
  - ok for existing services with some safety precautions for "warm operation"

- CMS pixel upgrade
- 1.5 mm diameter tubes
- 50 um wall thickness
- tests underway at CERN, Lyon
- serial cooling, 5 m loop (½ of layer1)
  140 W, 1g/s ΔT 3.7 C , ΔP 2.5 bar



CMS pixel detector with CO2 cooling

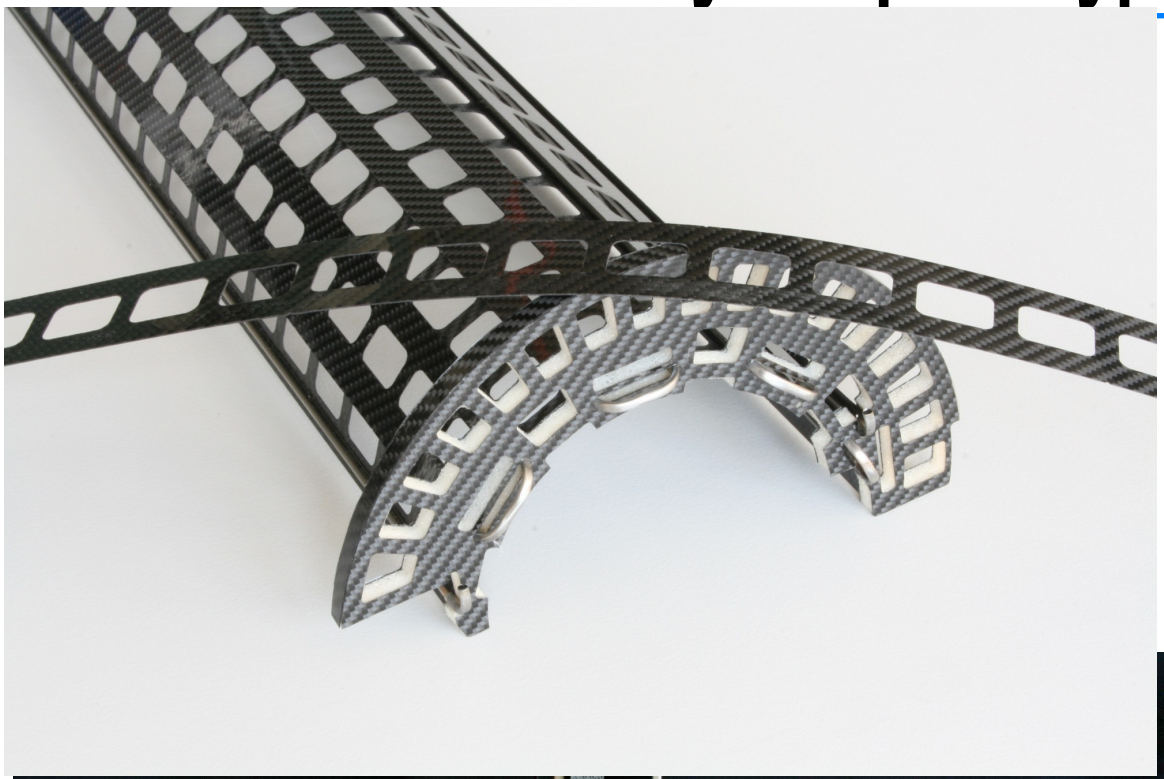


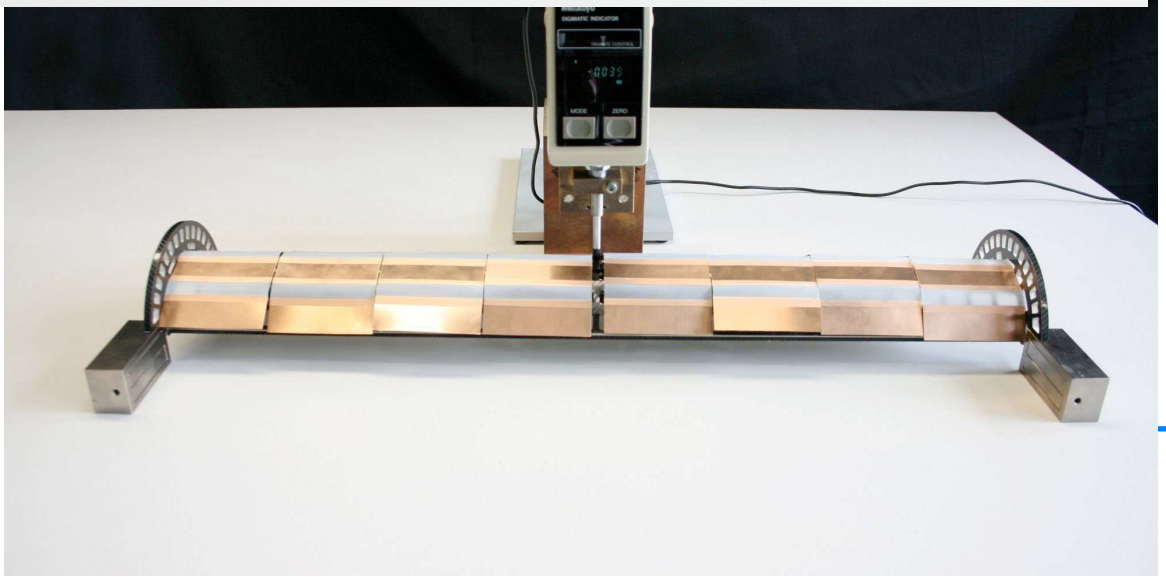
Smaller tubes
300 um Al
→50 um steel

C6F14 1.7 g/cm^3
CO2 1.0 g/cm^3

serial cooling,
no manifolds

Barrel Layer 1 prototype mechanics





200 um carbon fiber
·1.5 mm/50 um tubes
·1.8mm/100 um bends
·4 mm Airex foam (bulkhead)

single loop, pressure tested to 100 bar
total weight 42 g + 7 g CO2
deflection with load 40 um

central region:
1/3 of original material
(per layer, < 50% w/ 4th layer)
bulkhead region:
huge reduction
(no connectors / manifolds)
factor 2-3 reduction planned for disks
(US CMS)

Material reduction: Modules

One twisted pair cable (instead of power cable + kapton signal cable)

- 6 x 250 um power + 12 x 125 um ctrl/data
- 1.2 m long

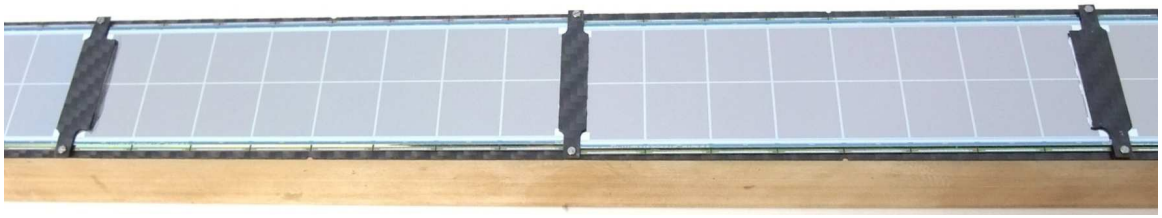
smaller size SMD capacitors

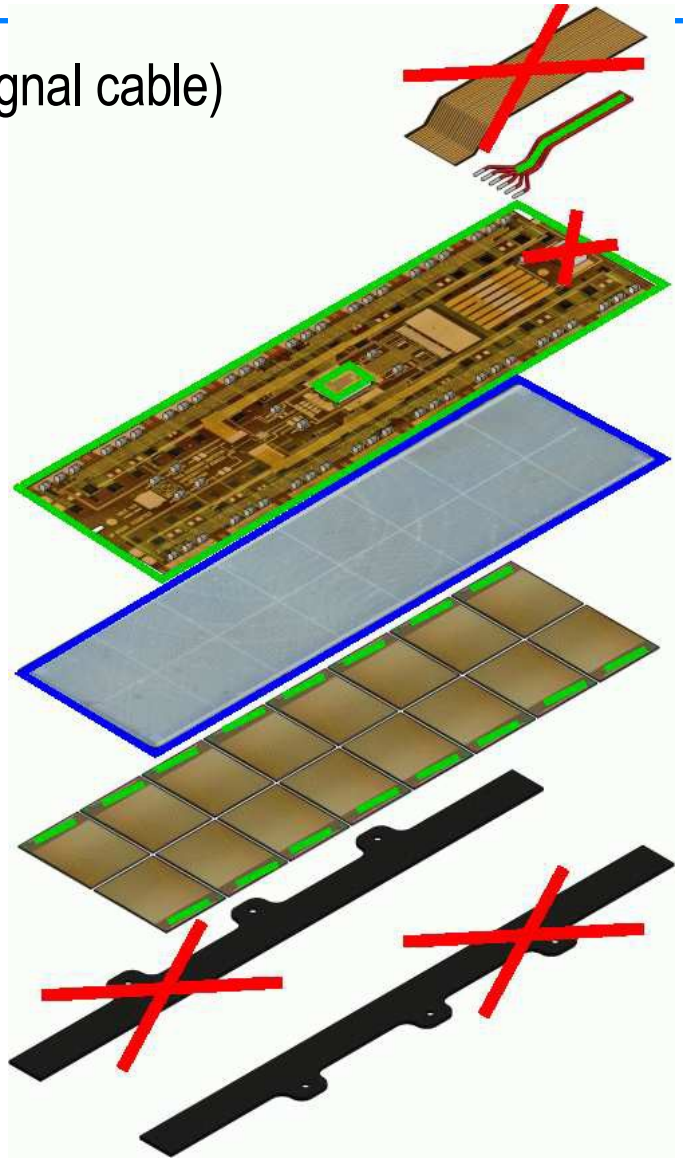
readout chip thickness 175 um →75 um

smaller mounting screws

no base-strips (SiN)

almost factor ~ 2 material reduction





Electronics(1) : Readout

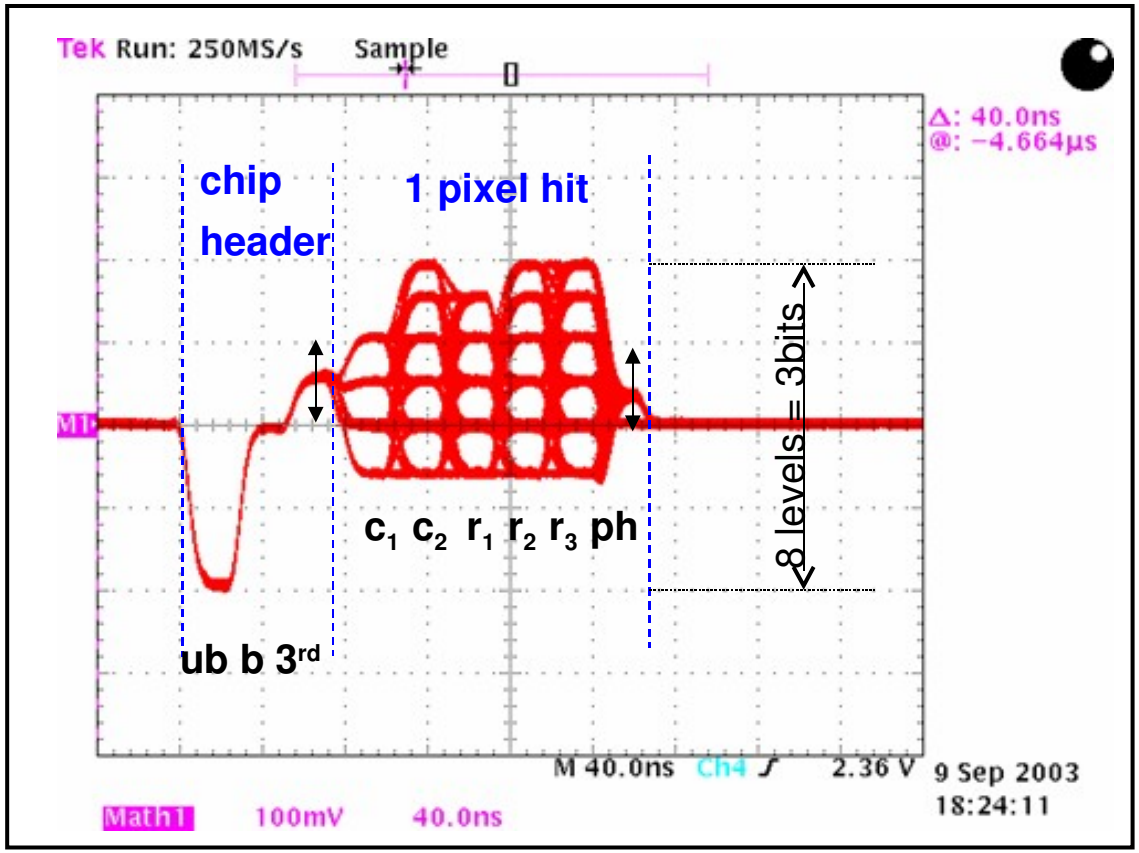
Need to double readout bandwidth

present pixel uses 40 MHz analog optical link, equivalent to ~100 Mbit/s →

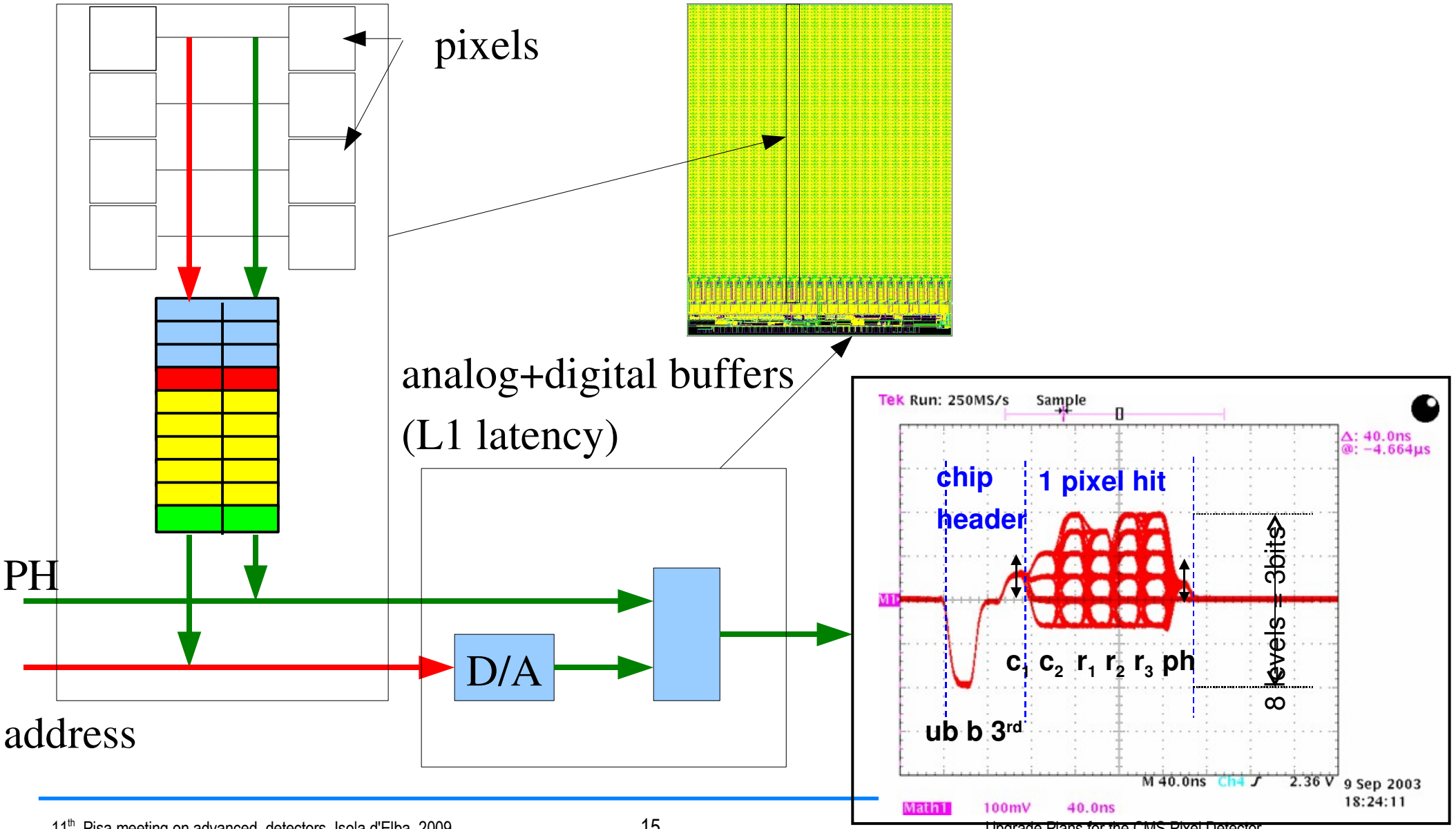
2 fibers / module (layer 1+2),
1 fiber/module in layer 3 (lower rates)

upgrade:

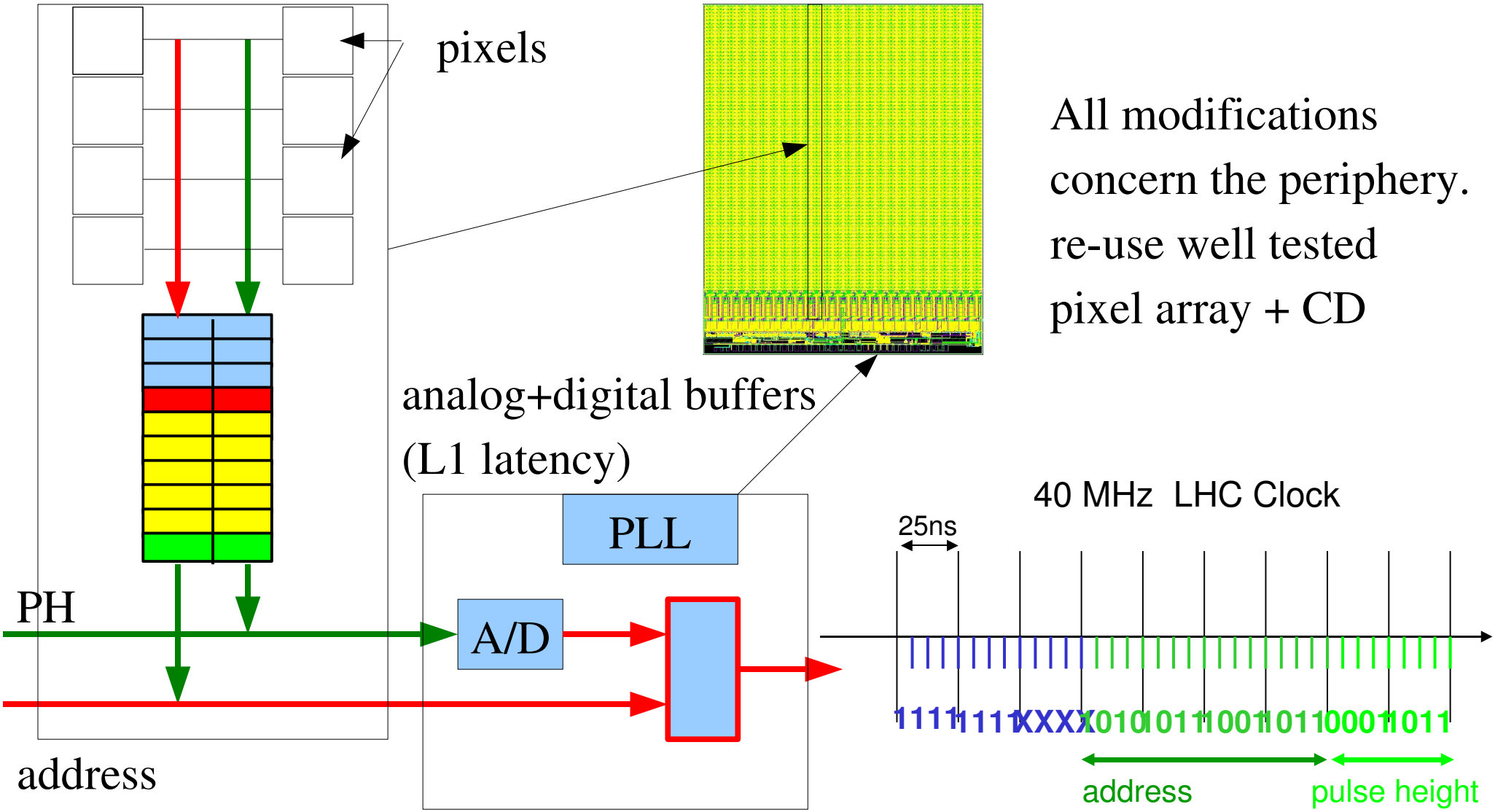
- one fiber per module in all layers
  frees fibers for Layer 4
  use 320 Mbit/s digital link
- Possible with rather small modifications of
  - readout chip
  - TBM (module controller)
  - FED (optical receiver)



readout chip modification : present detector



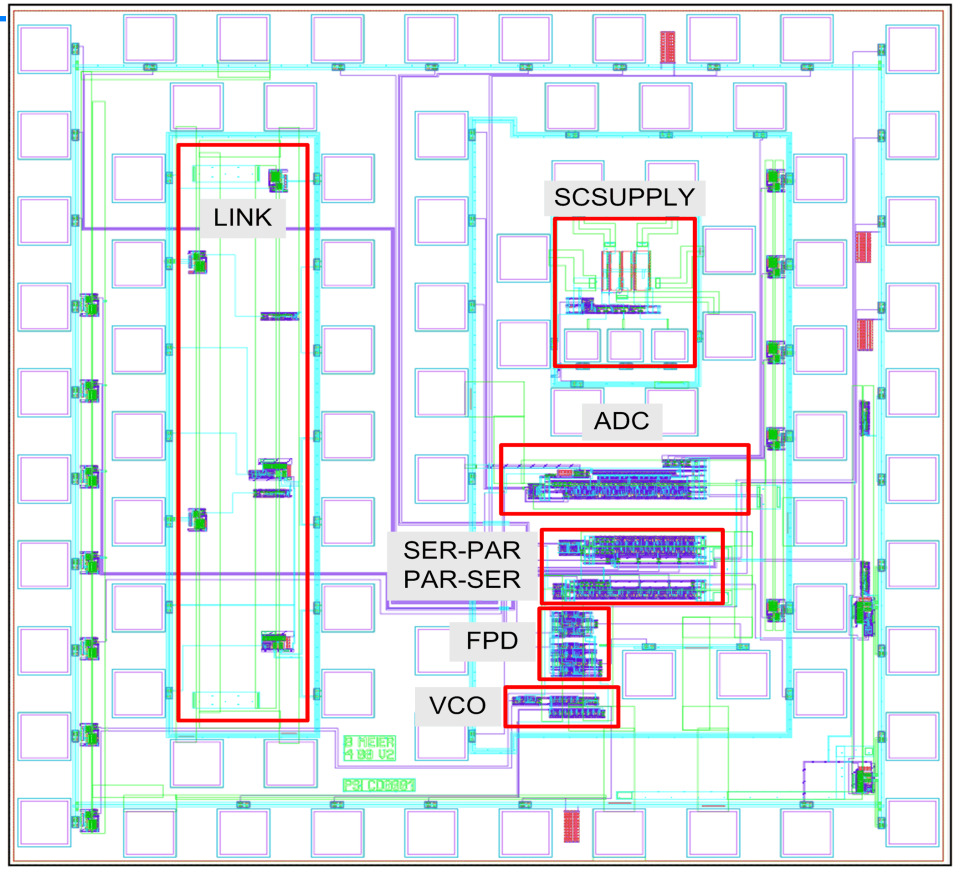
readout chip modification: digital readout

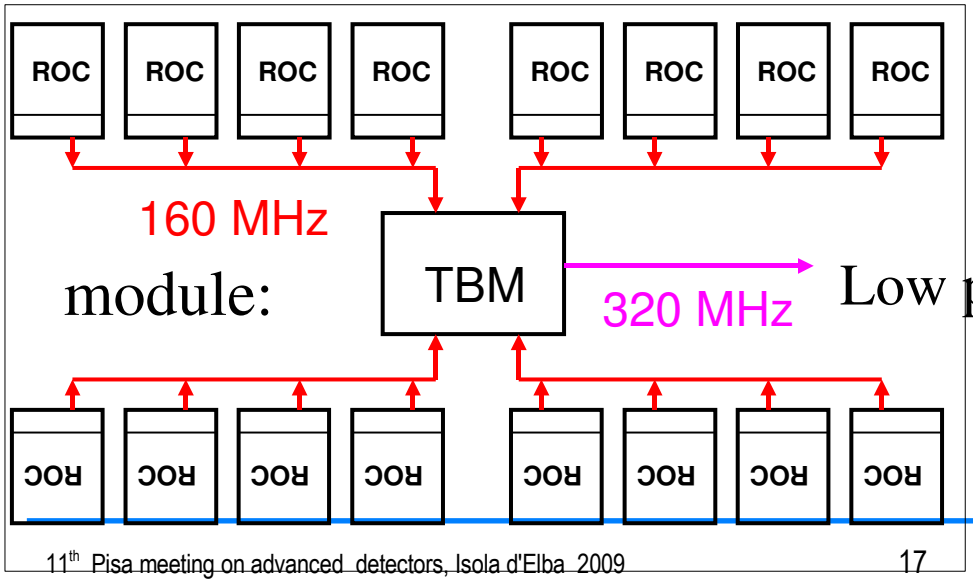


All modifications concern the periphery. re-use well tested pixel array + CD

Readout chip modifications

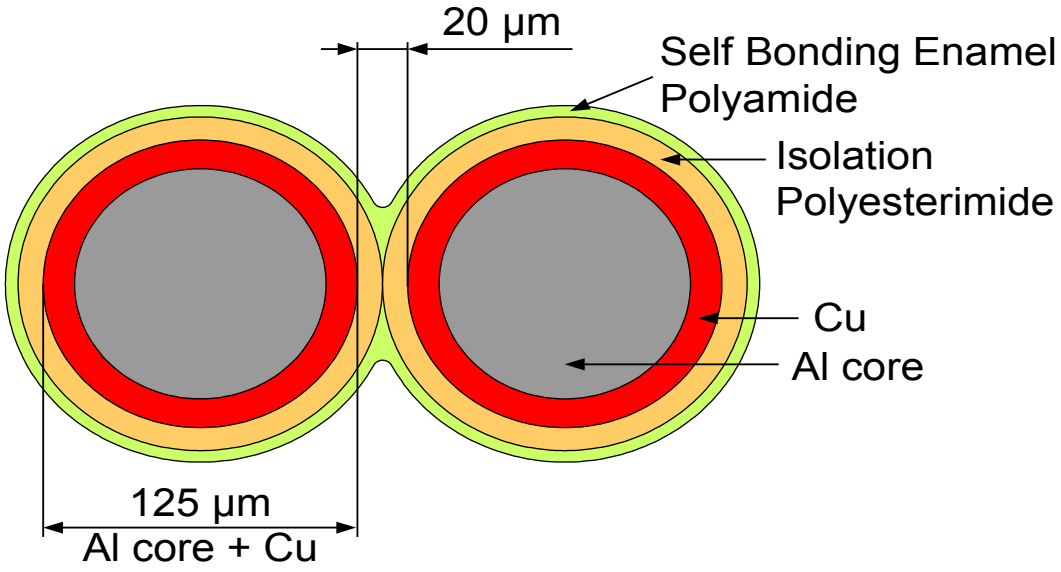
- first prototypes of PLL and ADC designed and tested in 0.25 um technology
- 8 bit successive approximation ADC
- 8 cycles conversion time (@160 MHz)
- converts during transmission of address
- improved versions resubmitted in 2009

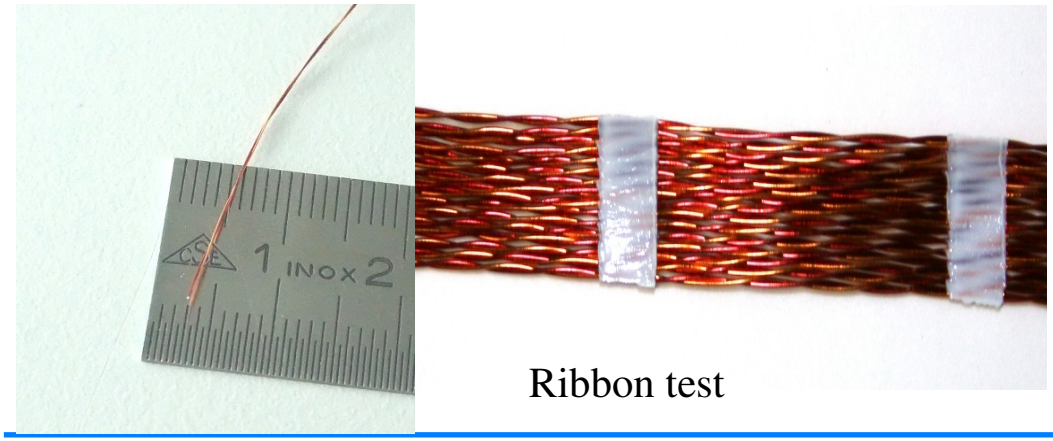




Micro Twisted Pair Cable / low power link

cross section





Ribbon test

twisted pair self bonding wire

- 125 µm wire diameter (4um Cu)

Electrical characteristics:

- Impedance: 50 Ohms diff. (low)
- v = 2/3 c_0 (5 ns/m)
- C = 100 pF/m, L=250 nH/m

Low power link

- Differential driver/receiver
- Low swing: 20 mV diff.
- Low power: 1.2 mW per link
- Prototype ok to 160 MHz
- Improved version submitted

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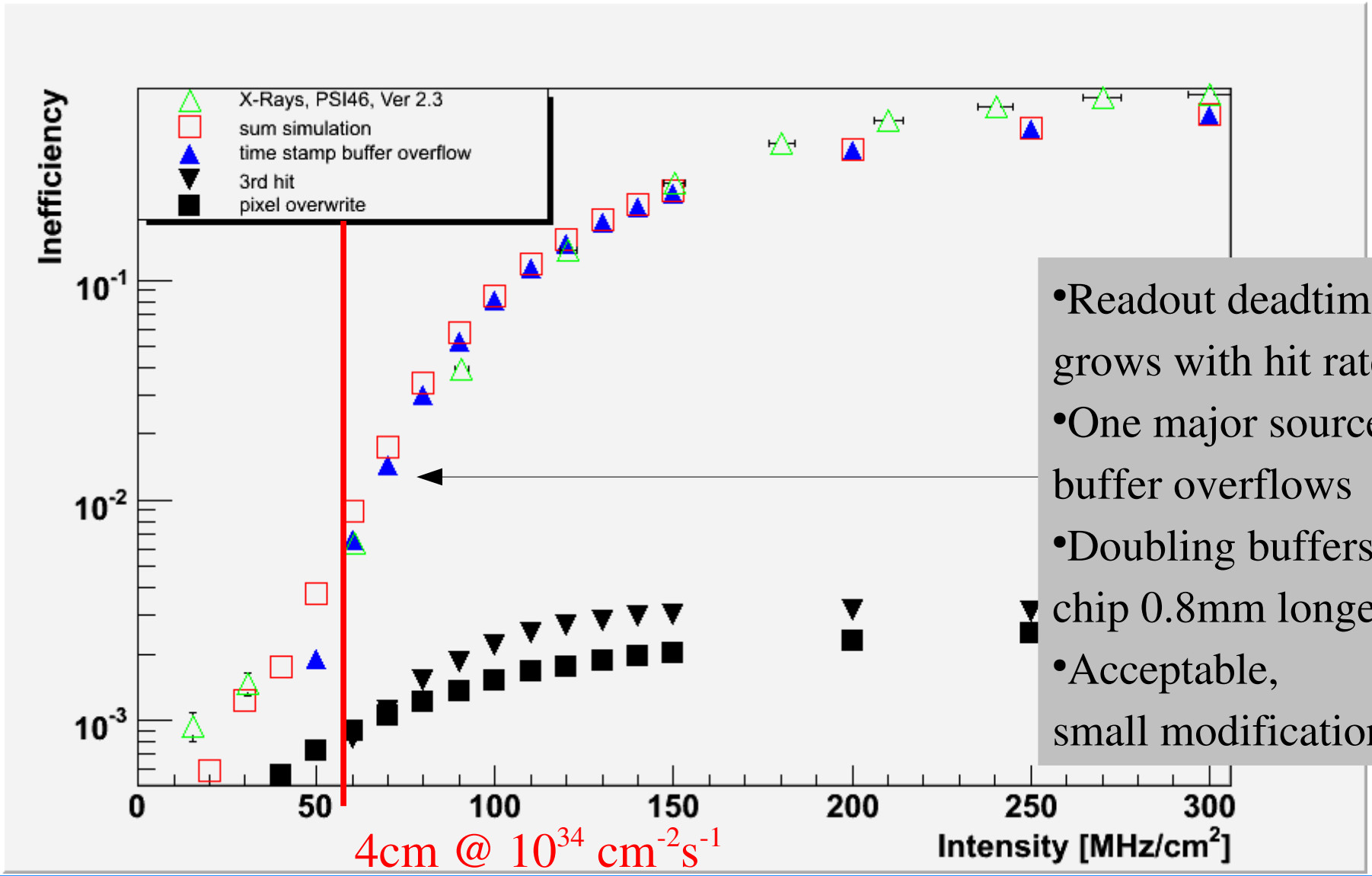
Electronics(2): Readout chip data losses



- Readout deadtime grows with hit rate
- One major source: buffer overflows
- Doubling buffers makes chip 0.8mm longer
- Acceptable, small modification

Readout Modifications: pxFED

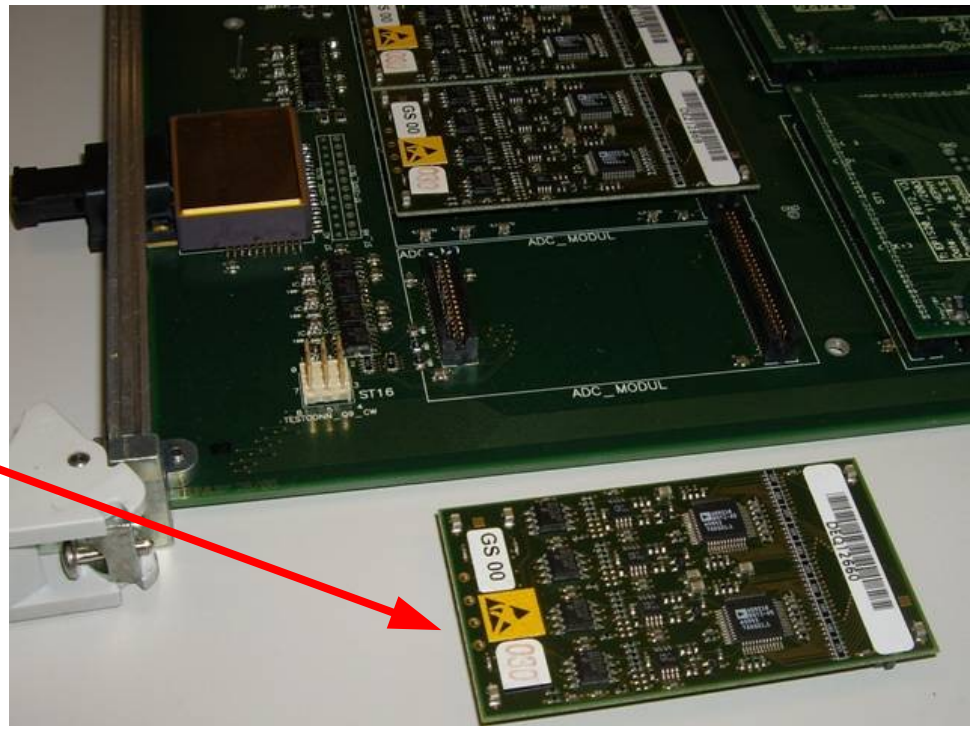
FED

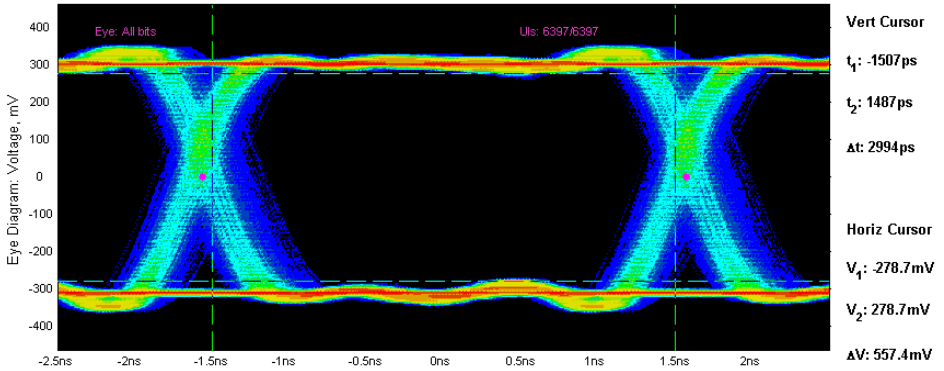
- Converts optical/electrical
- Decodes analog levels
- Sends data to CMS DAQ
- Optical receiver +ADC on daughter cards
- 24 channels / 9U VME module

Replace daughter cards

- digital receiver
- De-serializer

(HEPHY, Vienna)





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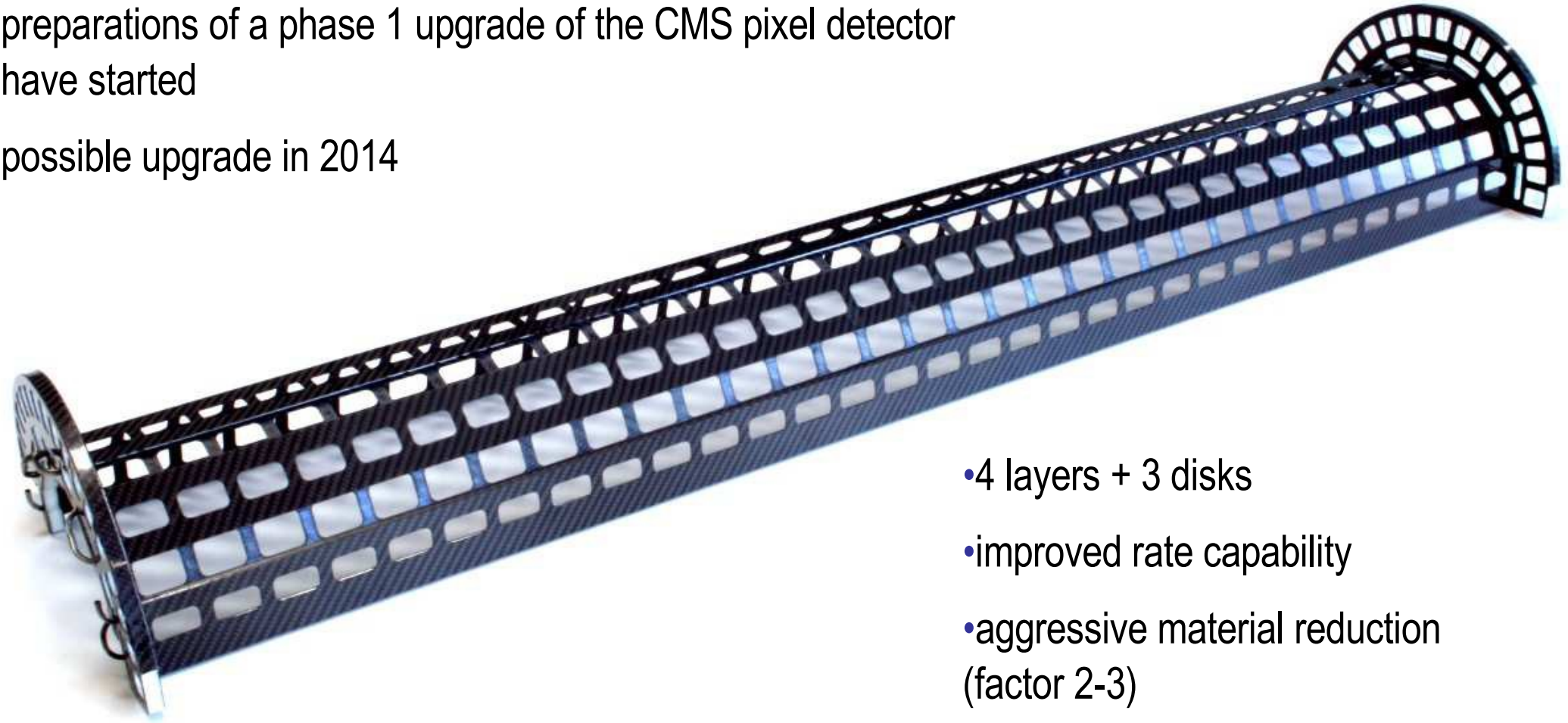
Summary

existing cms pixel detector will need (partial) replacement after a couple of years of full LHC luminosity

preparations of a phase 1 upgrade of the CMS pixel detector have started

possible upgrade in 2014



- 4 layers + 3 disks
- improved rate capability
- aggressive material reduction (factor 2-3)