Universität Zürich[UZH]
Physik-Institut

Phase 1 Upgrade of the CMS Pixel Detector

Lea Caminada (University of Zurich)
on behalf of the CMS collaboration

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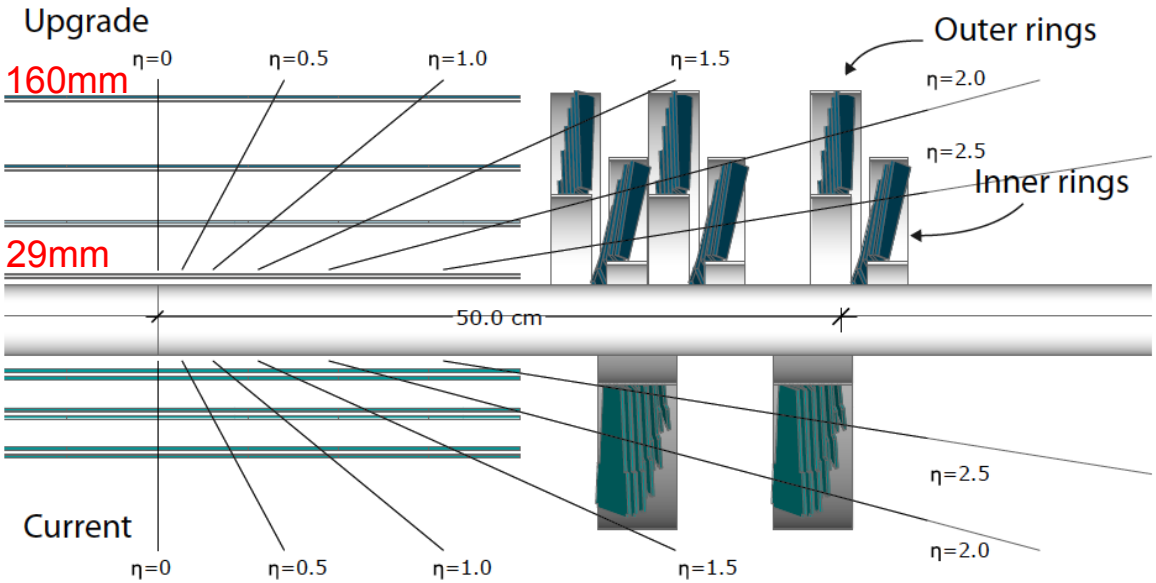
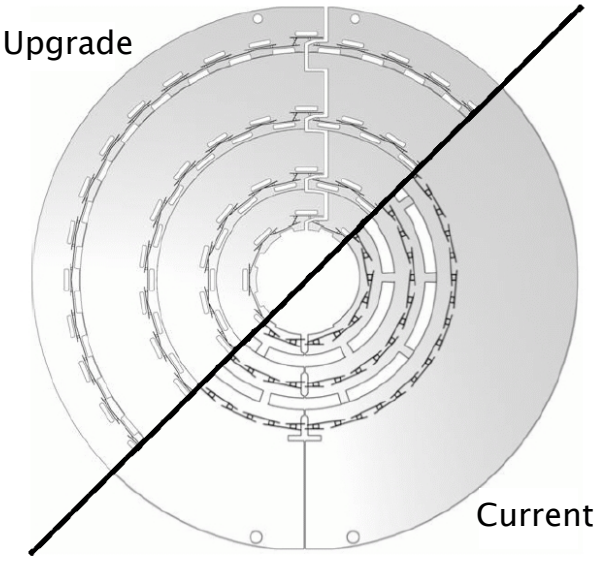
Phase 1 Pixel Detector Overview

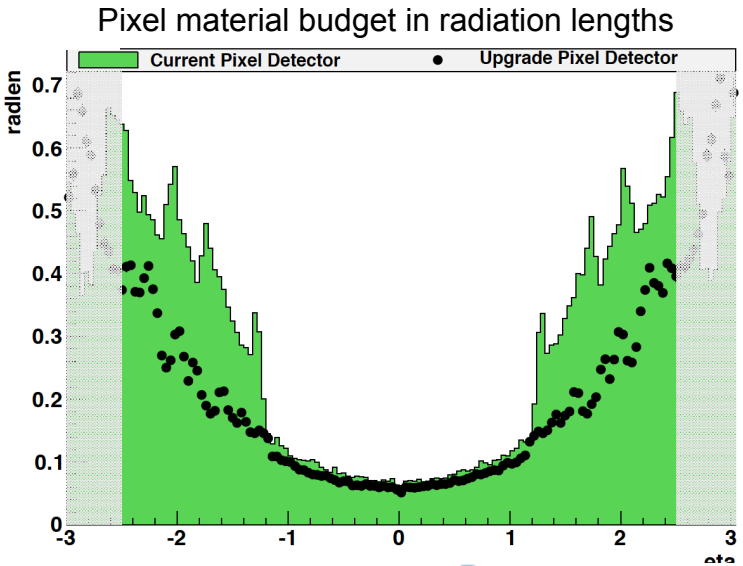
- CMS pixel detector has shown excellent performance during data-taking
- But performance will degrade with higher luminosity → need replacement to cope with luminosities up to $2x10^{34}$ $cm^{-2}s^{-1}$
- Main improvements:
  - Additional pixel barrel layer and endcap disk
  - Innermost layer closer to the interaction point
  - Significantly less material
  - Faster front-end electronics to reduce dead-time
- To be installed in extended winter shutdown 2016/17

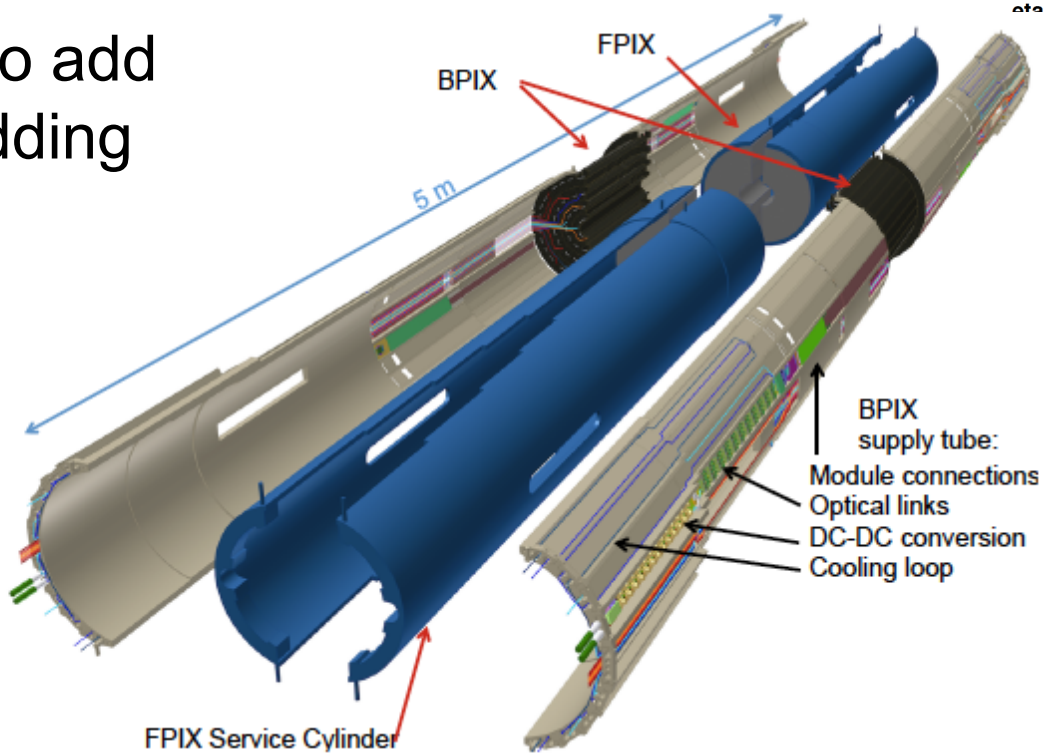




Upgrade Pixel System

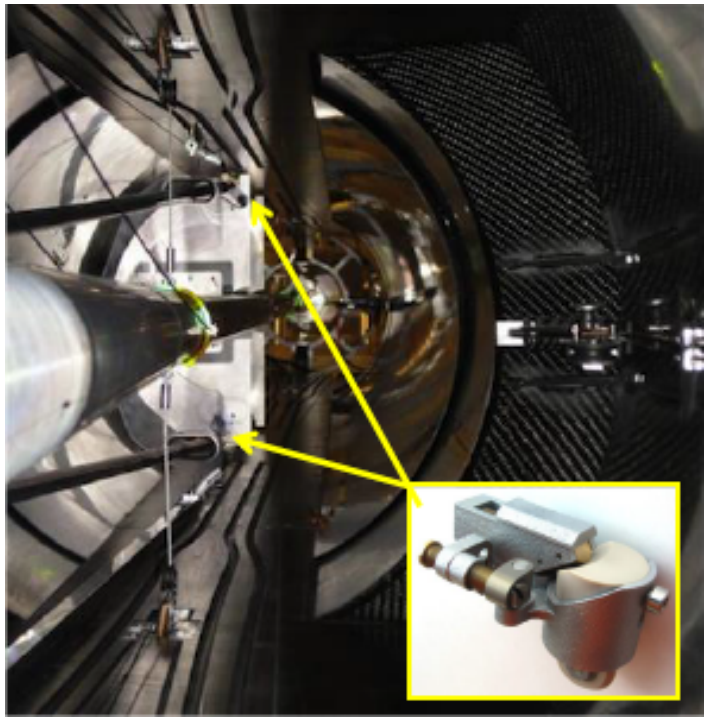
- Barrel (BPIX) and forward (FPIX) pixel detectors connected to service half cylinders
- Upgrade system has to fit in same mechanical envelope → strong constraints on new services
- Optimized design allows to add additional layer without adding material:
  - lightweight mechanics and CO_2 cooling
  - Connectors and auxiliary electronics moved to higher eta

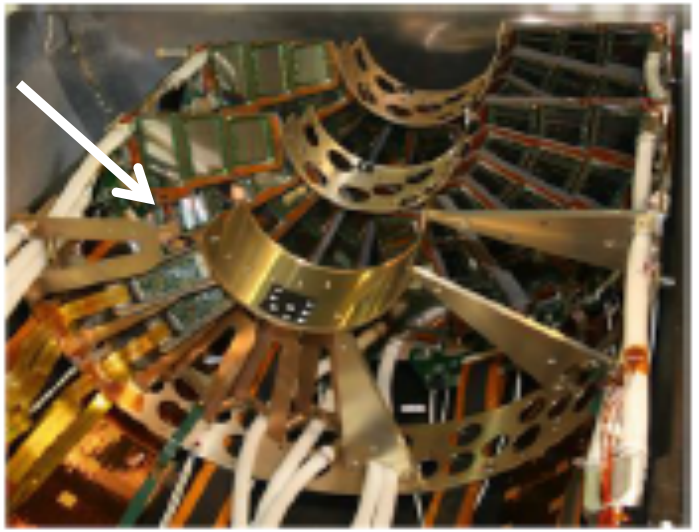




P5 Activities during LHC Shutdown

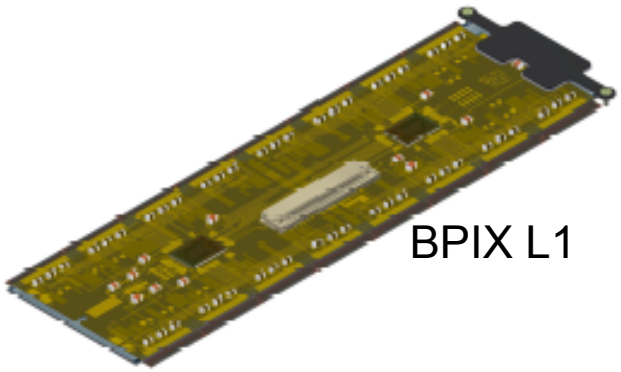
- New AlBeMet® beam pipe with smaller diameter (45mm) installed
- Performed trial installation of BPIX and FPIX mockups around beam pipe
  - Moves on wheels in curved rails
  - Adjustable wheels to insert half shells away from beam pipe and only close when in final position
- Installed pilot system consisting of 8 modules on FPIX disks:
  - Includes full readout system and DC-DC powering option
  - Goal is to gain operational experience with the new system in real LHC conditions → see Bora Akgun's talk

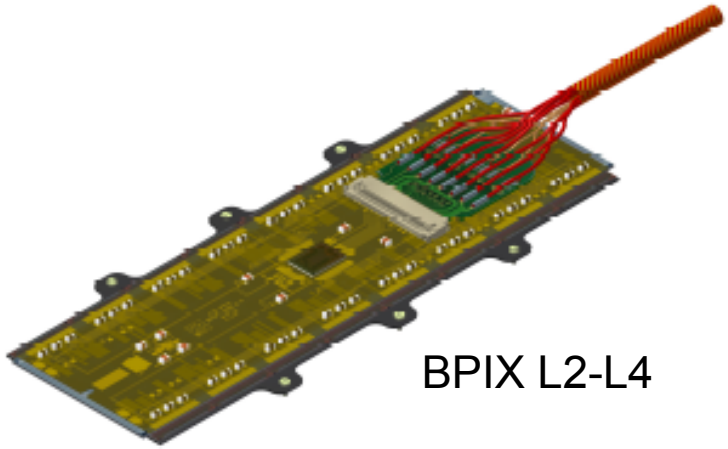


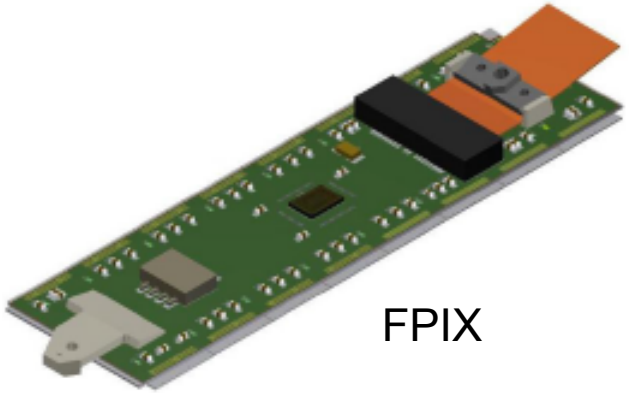


Pixel Detector Modules

- Similar module design as in current detector: sensor and pixel size unchanged
  - 280um n-in-n planar silicon sensor
  - 100x150um pixels
  - 16 ROCs per module
  - Token Bit Manager (TBM) chip controls module readout, wire-bonded to high-density interconnect flex print (HDI)
- Readout of pixel pulse-height information
- New ROC design with digital readout and higher rate capability
- Module readout with 400 Mbit/sec transmission link speed
  - 1 link for FPIX and BPIX L3-4
  - 2/4 links for BPIX L2/L1

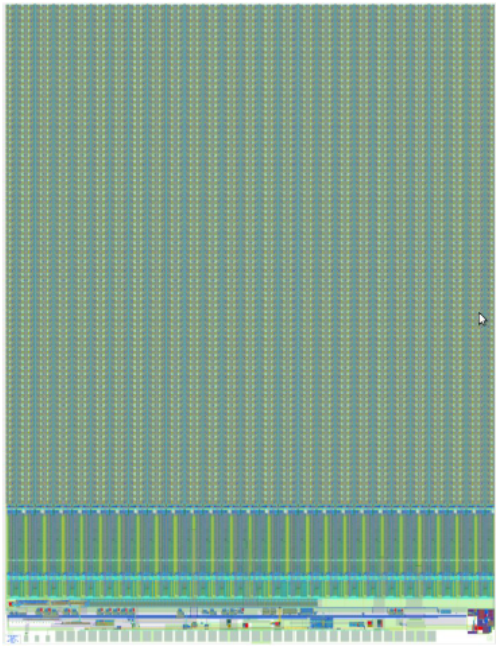

BPIX L1

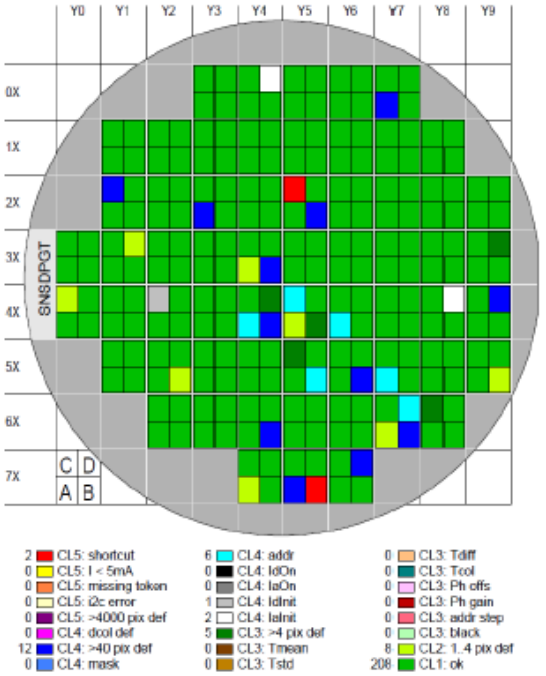

BPIX L2-L4


FPIX

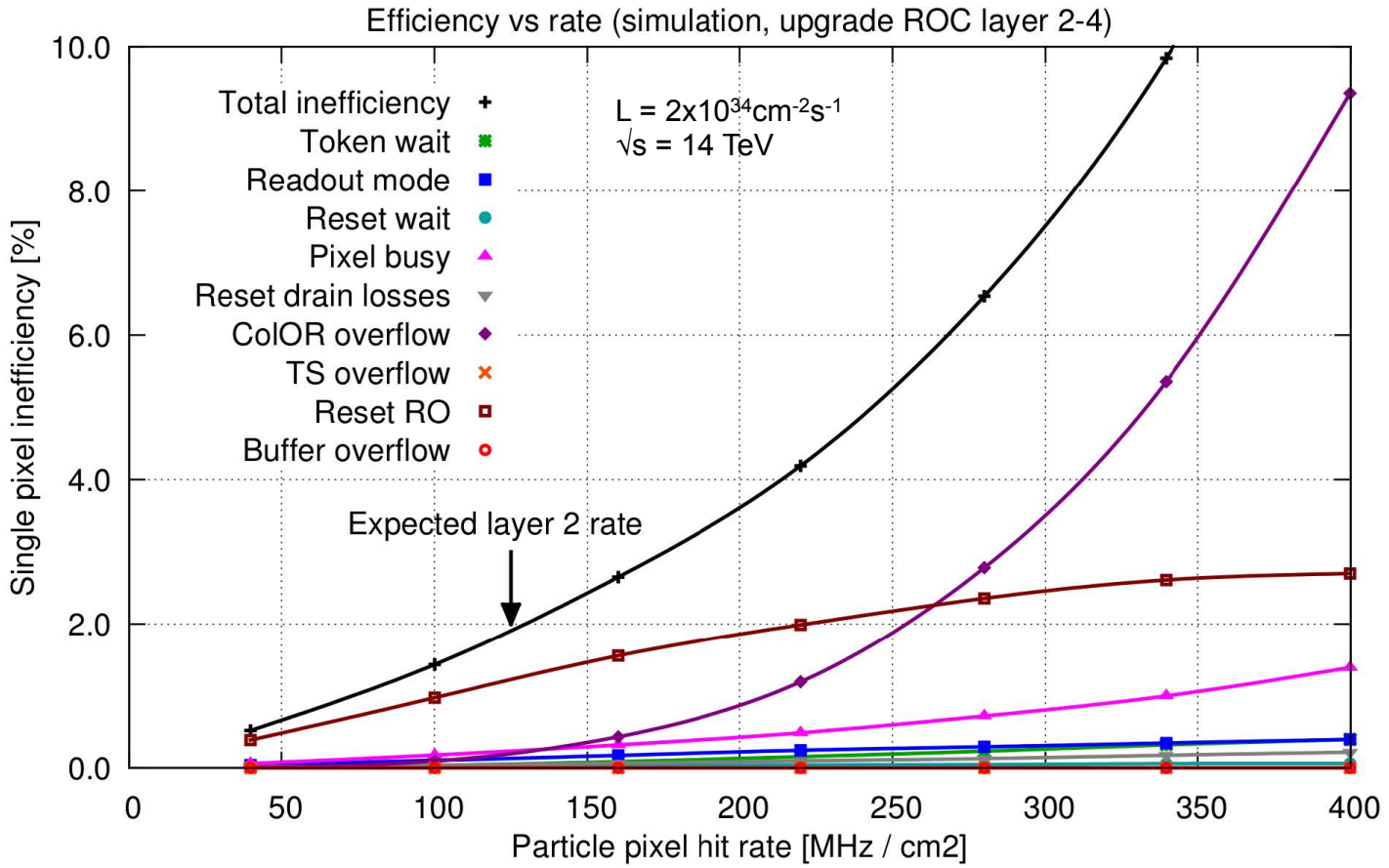
PSI46dig Readout Chip

- 250nm CMOS ASIC
  - 80x52 pixels
- New features
  - Digital readout (8-bit ADC)
  - Higher rate capability
  - Higher radiation tolerance
  - Lower threshold operation (~1600e)
- Same readout architecture as well tested PSI46 (column-drain)
- Wafer yield > 89% (determined based on first batches)
- 240 wafers needed for full production are mostly delivered and currently being tested at PSI and FNAL





PSI46dig Rate Capability

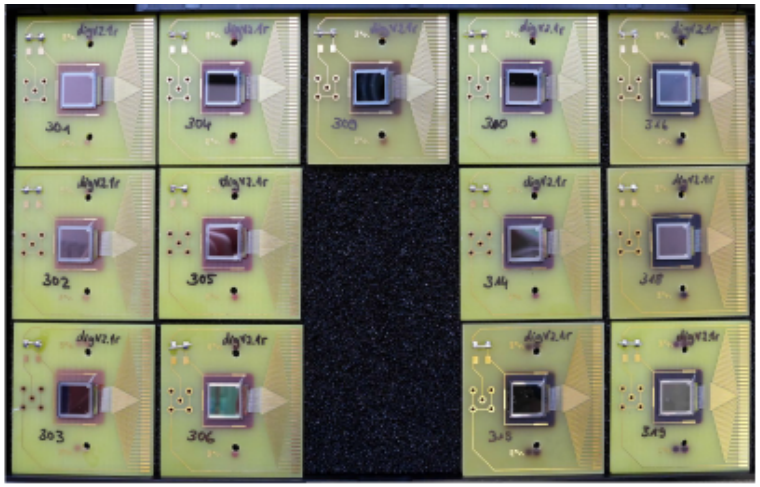


- Tolerable losses (<2%) in BPIX L2-4 and FPIX
- Extrapolation to L1 hit rates (up to 580 MHz/cm^2) → leading loss mechanism (ColOR overflow) > 30%
- Dedicated L1 chip design in preparation

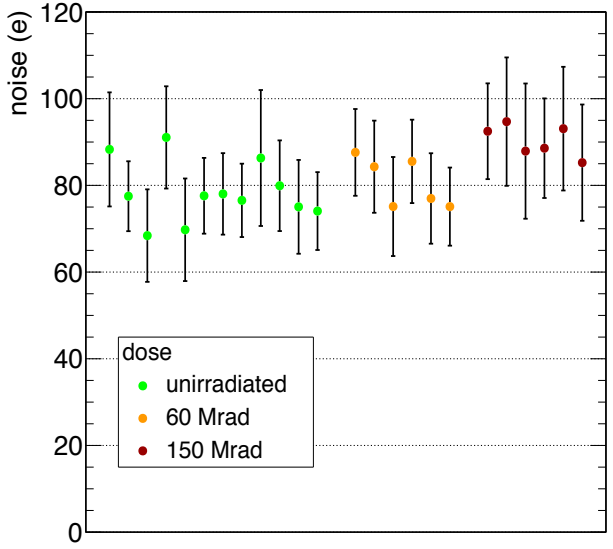
Radiation Hardness

- Expected dose of 120 Mrad for L1, decreases quickly with radius
- ROC and single chip modules irradiated to doses exceeding nominal L1 dose using 23 MeV proton beam at Karlsruhe
- ROC shows excellent performance even after highest doses

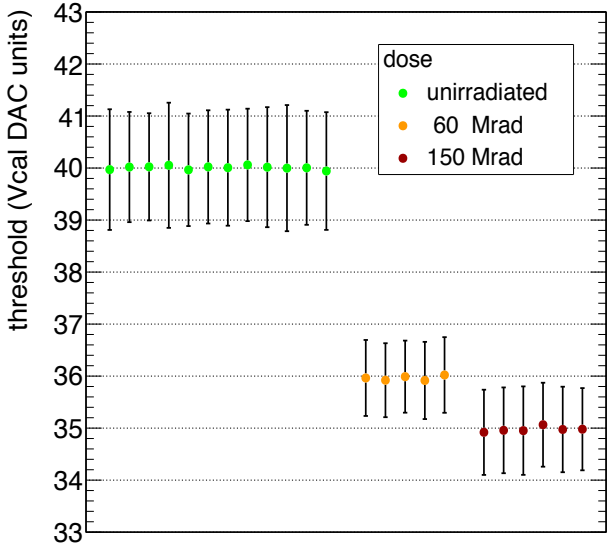
PSI46digv2.1respin

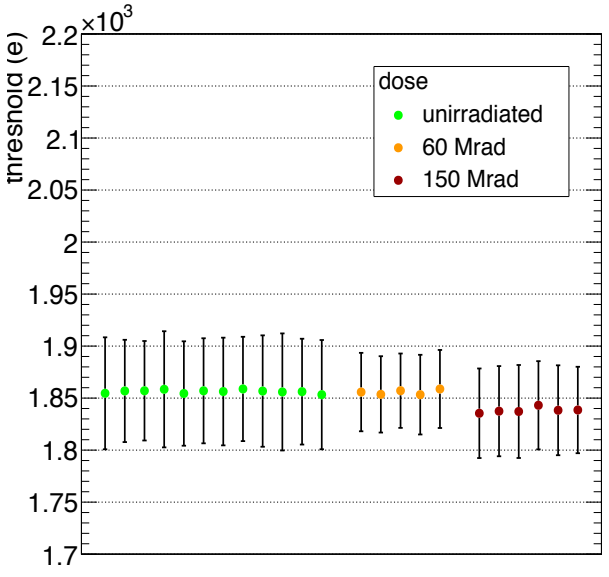


Noise



Threshold





Module Production

- Module production and testing done in different centers
- Components for module production (sensors, ROC, TBM, HDI) mostly delivered and distributed to production centers
- All centers produced good number of pre-series modules during last year
- Production for final system is now ramping up
- Aim to finish production for L2-L4 and disks early 2016
- L1 module production in summer 2016

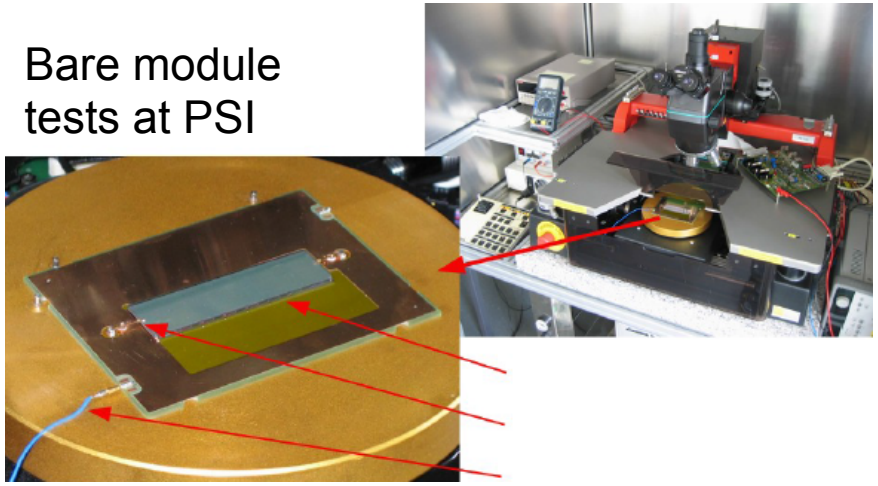
Task	Place	2015									
		Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Module production											
Layer 4	KIT/Aachen	20	70	130	190	265	325	385			
	Desy/UH	20	60	100	140	180	220	260	300	340	380
Layer 3	CERN	40	80	120	160	200	236				
	INFN		39	65	78	111	150	186	251	260	
Layer 2	CH	20	80	140	200	260	300				

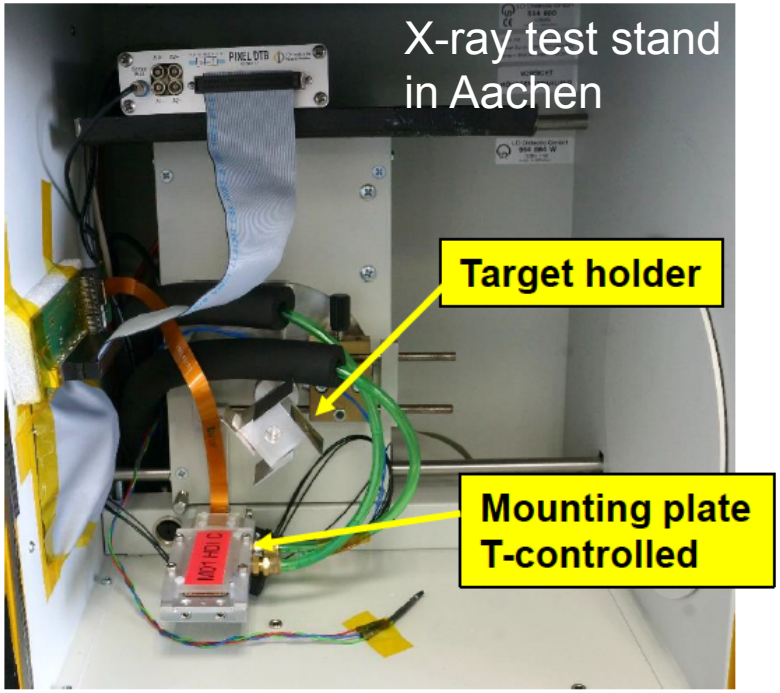
Module Testing

- Bare-module tests to test sensors and ROCs right after bump-bonding
  - IV curves, ID/IA, basic functionality, bump-bonds
- Full module tests and qualification according to well-defined and exercised procedure
  - IV curves
  - ROC, TBM and pixel functionality
  - Thermal cycling
  - High-rate x-ray tests
  - x-ray calibration
  - 7h per module

→ see John Stupak's talk

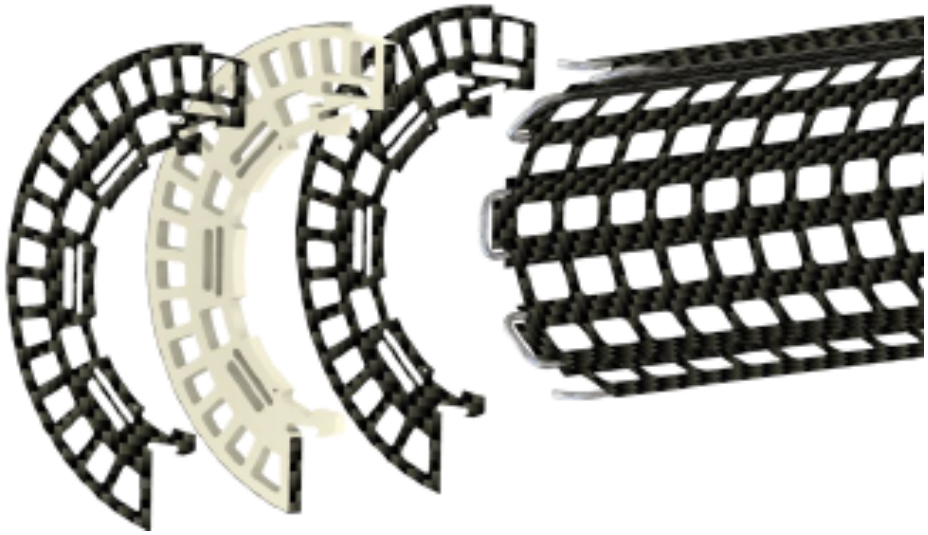
Bare module tests at PSI

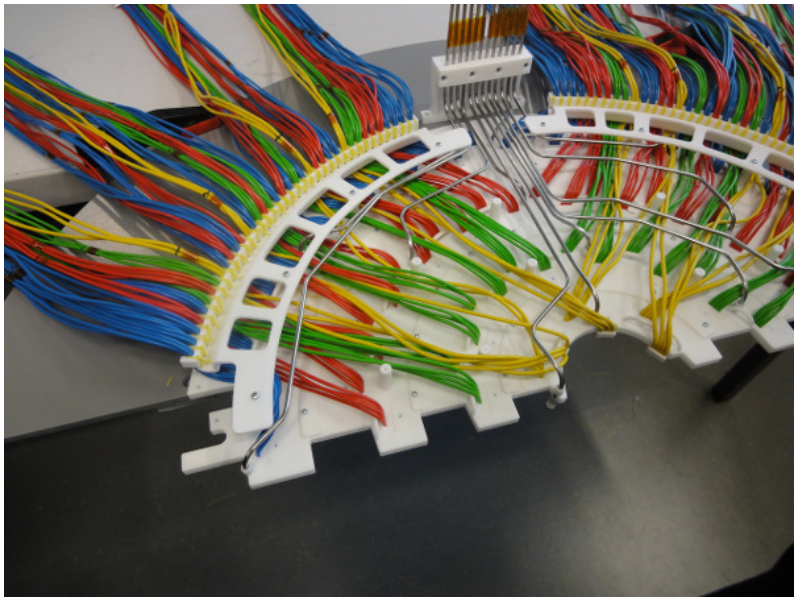




BPIX Mechanics and Cabling

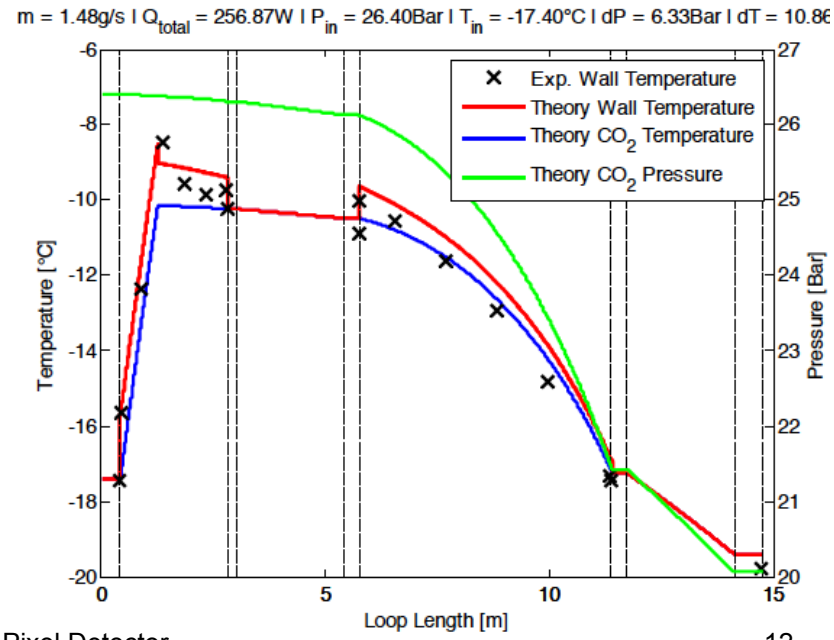
- Lightweight mechanics made from CFRP/Airex foam compound
- Cooling tubes are the backbone of the structure
- BPIX modules have 1m long twisted-pair cables → routing of cables at detector endflange non-trivial
- Built 3D printed cabling mockup to develop cabling procedure and exercise with real geometry
  - First radial routing of L2-4 cables, L1 cables at the end





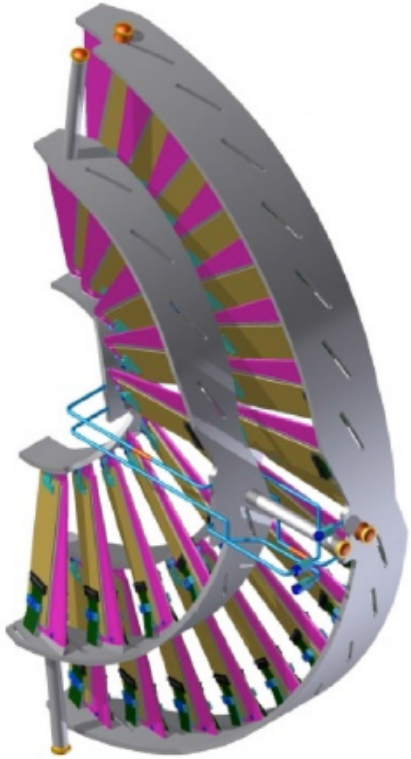
Cooling

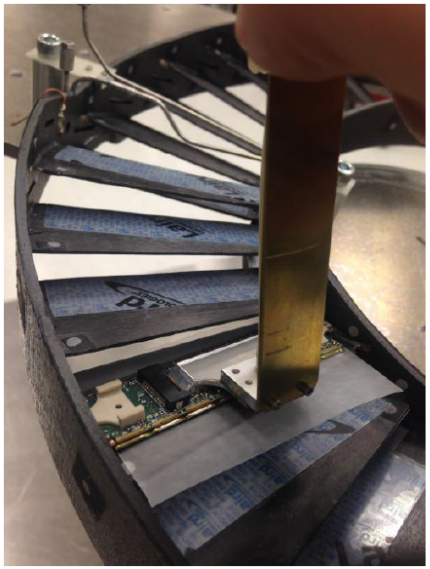
- 2-phase CO_2 cooling
  - T= -20^{0}C with the option to go lower
- Thin stainless steel cooling tubes in active region
  - 1.6 mm inner diameter
  - 50um wall thickness
- BPIX cooling tubes run along service cylinder and detector
- Prototypes built and being tested at CERN CO_2 plant
- CO_2 plant at CMS experimental area installed and commissioned during LS1

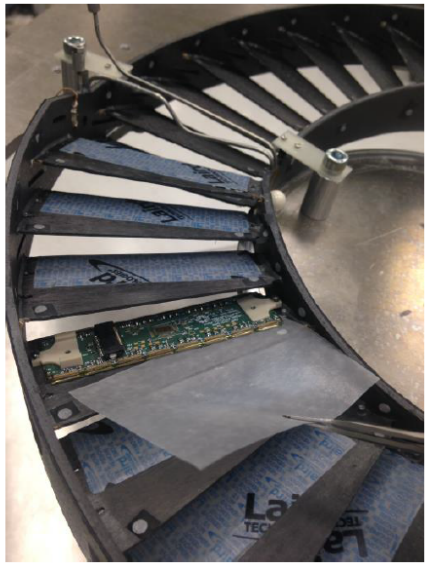


FPIX Mechanics and Cooling

- Half disk consists of one inner and one outer blade assembly
- Cooling loops embedded in graphite ring
- Thermal Pyrolytic Graphite (TPG) blades transport heat to ring
- Prototypes produced and module mounting procedure is being exercised







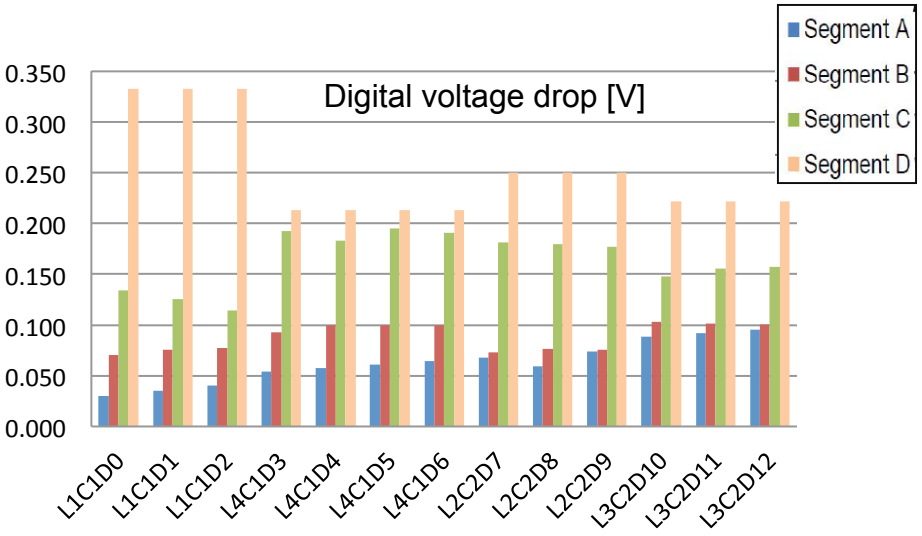
Power System

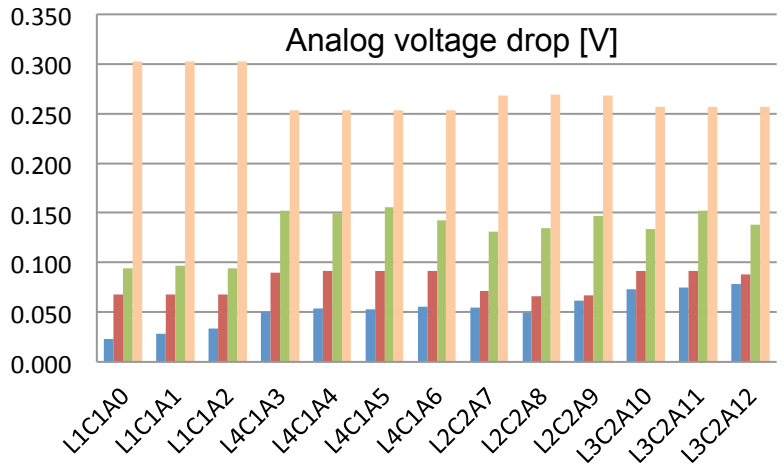
- Upgrade pixel detector has 1.9x more channels than current detector, but need to reuse same power cables
- Use DCDC converters near the detector (10V→3V/2.4V) with 80% efficiency
- Total of 1184 converters

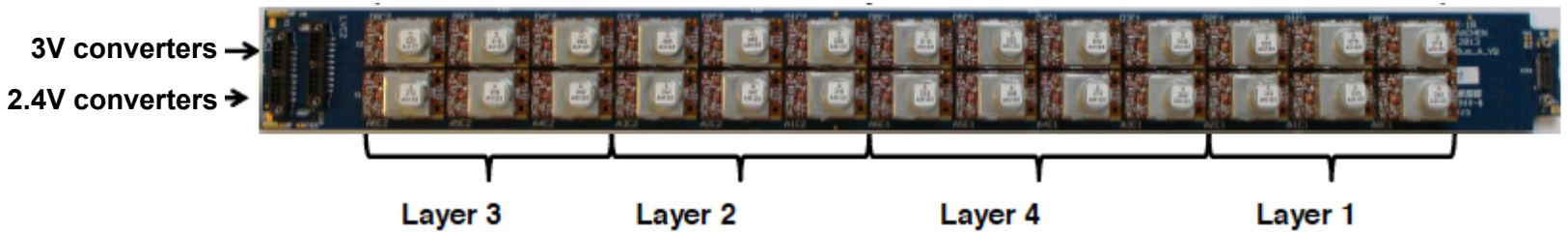
Currents per module

	ID [A]	IA[A]
L1	1.32	0.38
L2	0.71	0.38
L3	0.61	0.38
L4	0.58	0.38

VD = 2.4 V, VA = 1.6 V

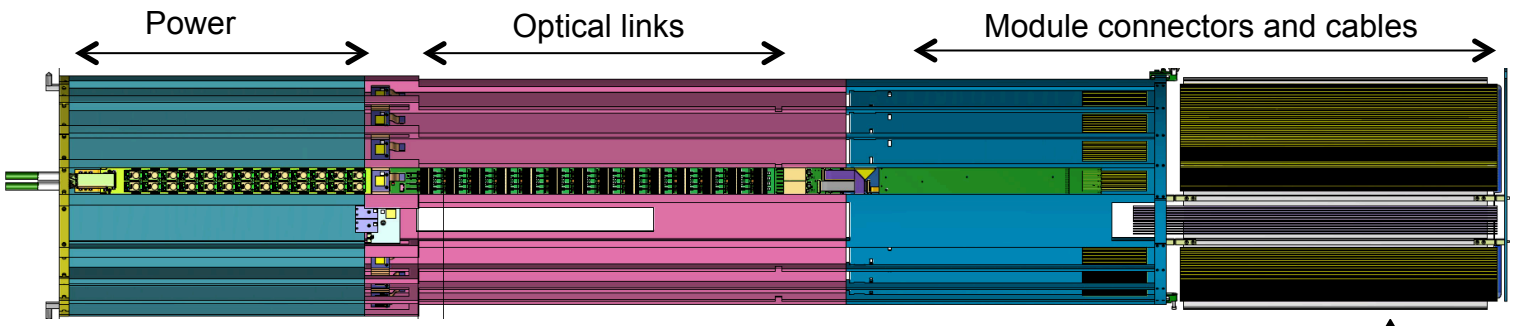


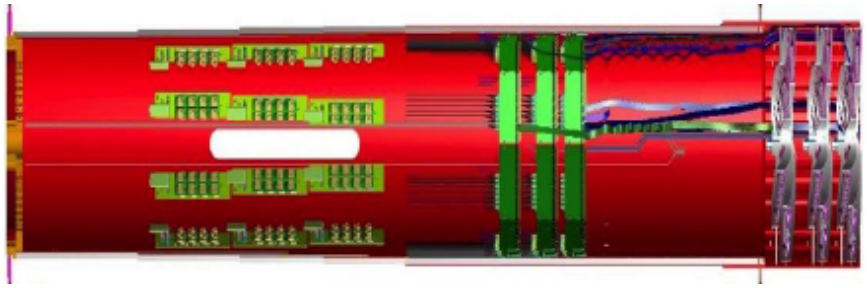




Service Cylinders

- Service cylinder houses power, readout electronics with optical converters and cooling lines
  - New design of optical links – Pixel Opto Hybrid (POH) with 4 or 7 TOSAs
- Mechanical structure made from layers of carbon fiber composite
- Readout and power boards and components will be assembled and tested on service cylinder before connection with detector

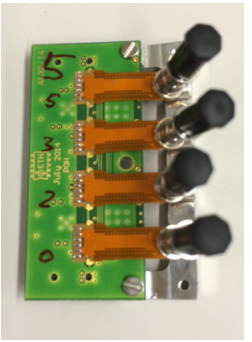




BPIX Supply Tube

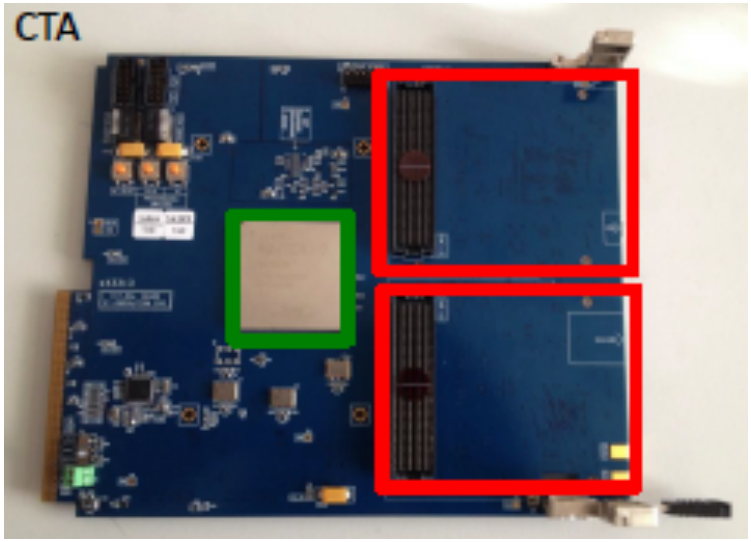
FPIX Service Cylinder

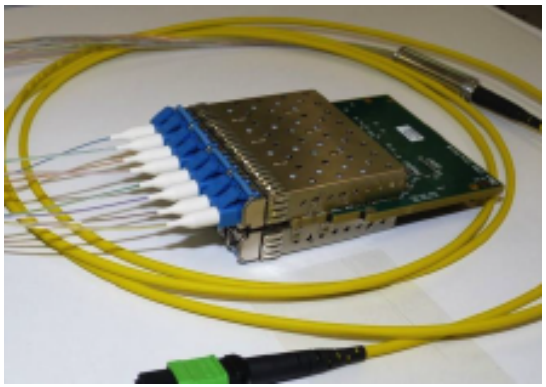
POH



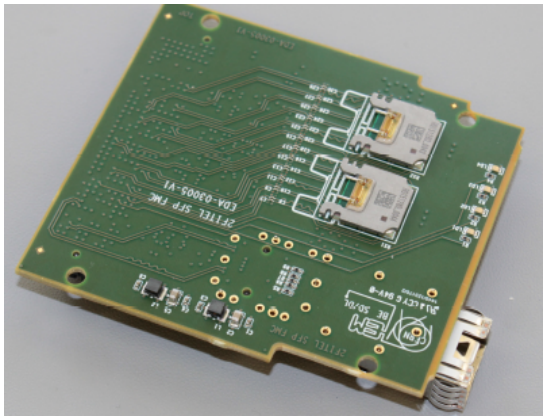
Phase 1 Pixel DAQ

- VME-based DAQ of current pixel detector will be replaced by uTCA system
- High-speed signal links up to 10 Gbits/sec
- uTCA DAQ modules:
  - 56 FED (front-end driver)
  - 2 TK-FEC (detector slow control)
  - 10 PIX-FEC (detector control)
  - 6 AMC13 (clock and trigger distribution)
- Hardware development well advanced and prototype available for demonstrator systems
  - AMC with 2 mezzanine cards with optical components
- Firmware development ongoing





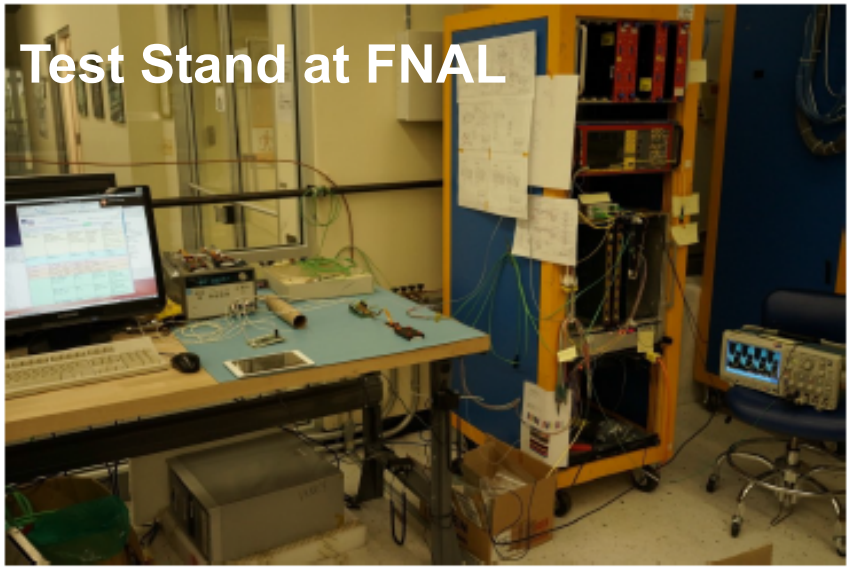
FEC-FMC

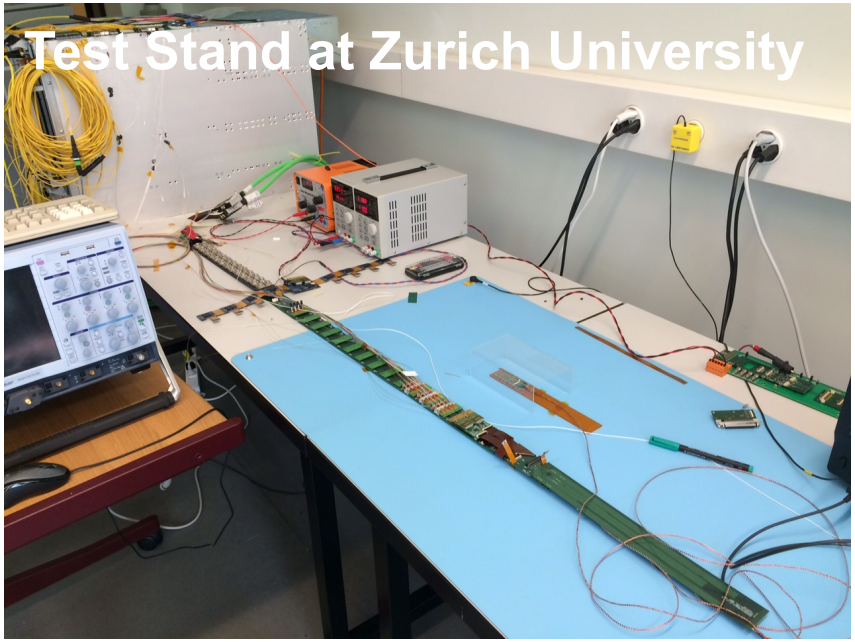


FED-FMC

System Test Stands

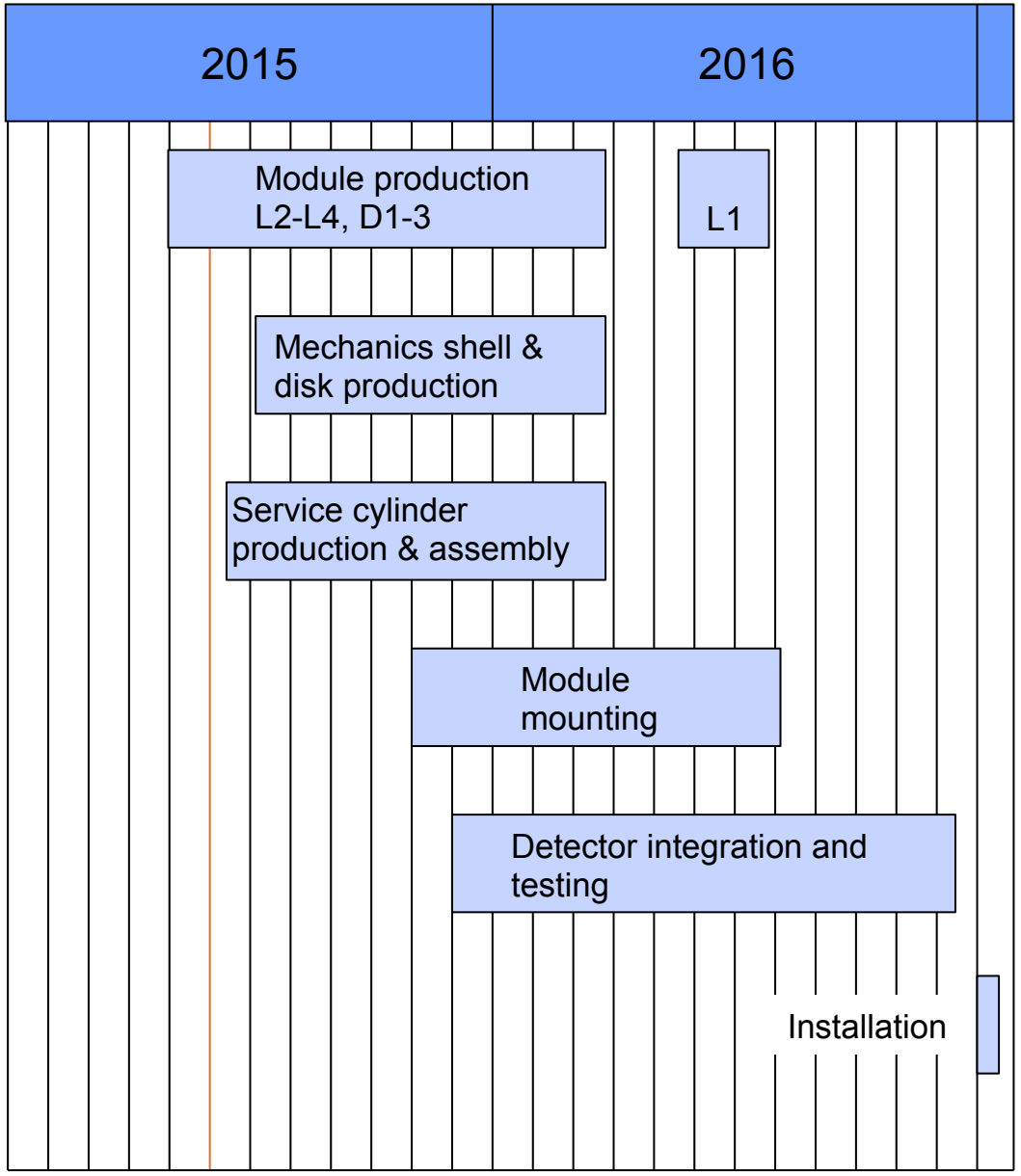
- System tests of BPIX and FPIX to gain experience in operating the system
- Test all components prior to full production
- Establish test and calibration procedures
- Exercise transition from VME to uTCA DAQ





Towards the Installation

- 2015 devoted to production of modules, electronic boards, detector mechanics and cooling
- Module mounting starts in fall 2015 for FPIX, spring 2016 for BPIX
- Assembly of service cylinders proceeds in parallel
- Integration and testing of detector and service tubes in 2016
  - 4 FPIX half cylinders
  - 2 BPIX halves
- Installation in January 2017

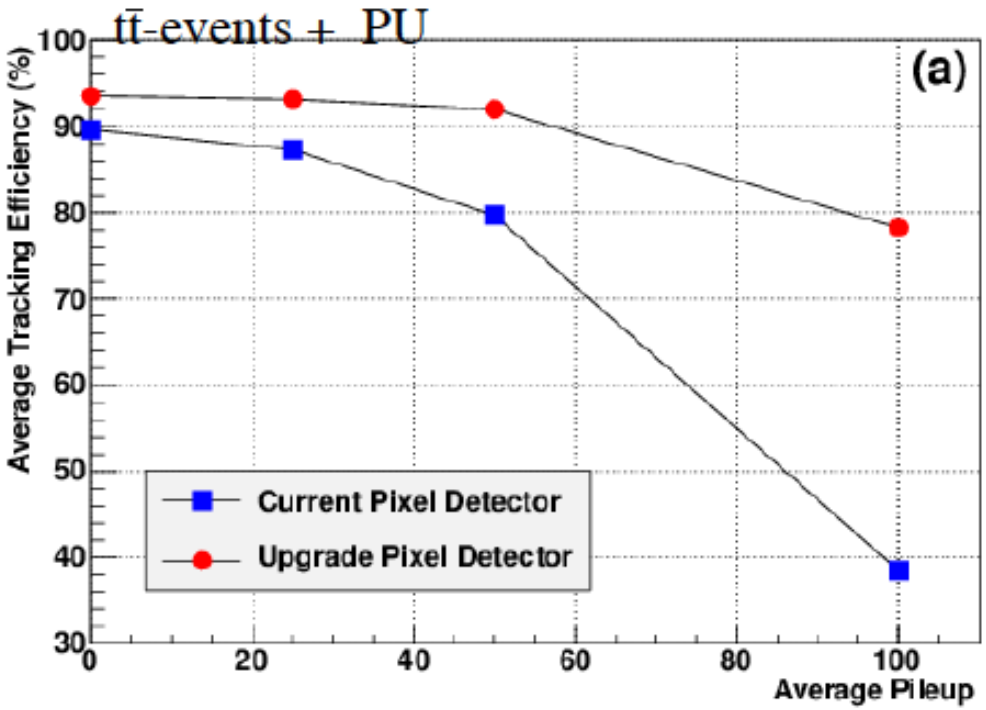


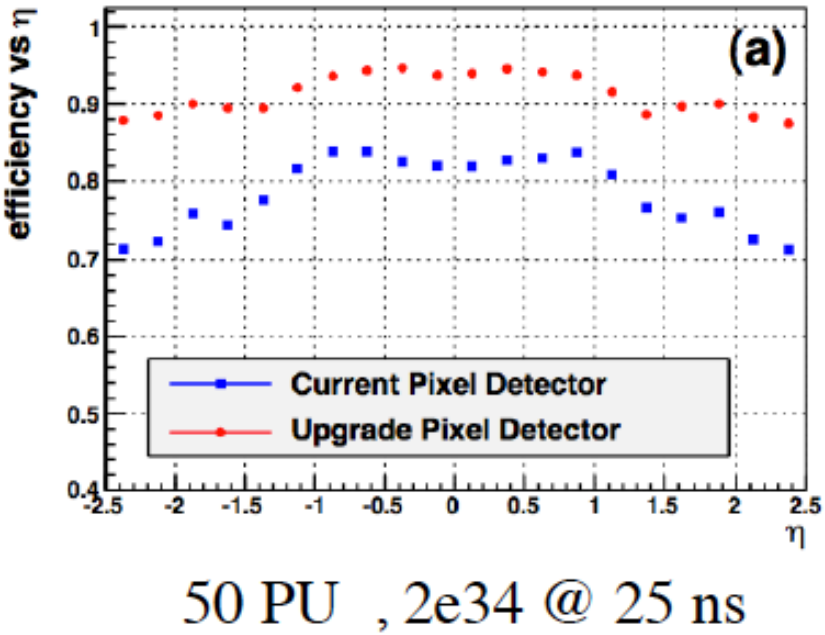
Summary

- Current CMS pixel detector will be replaced by Phase 1 CMS pixel system during extended LHC winter shutdown 2016/2017
- Phase 1 system features additional barrel layer and end cap disks, reduced material budget and improved rate capability and lower threshold operation
- Fabrication of module components mostly completed → now entering module production phase
- Prototypes of all final components (power, readout electronics, modules) available and being tested in system tests
- Pilot system installed and integrated within CMS DAQ

Backup

Tracking Efficiency





- Clear improvement at target instantaneous luminosity, can tolerate higher pileup