WP4: Radiation Hard Semiconductor Detectors

- Status of activities -

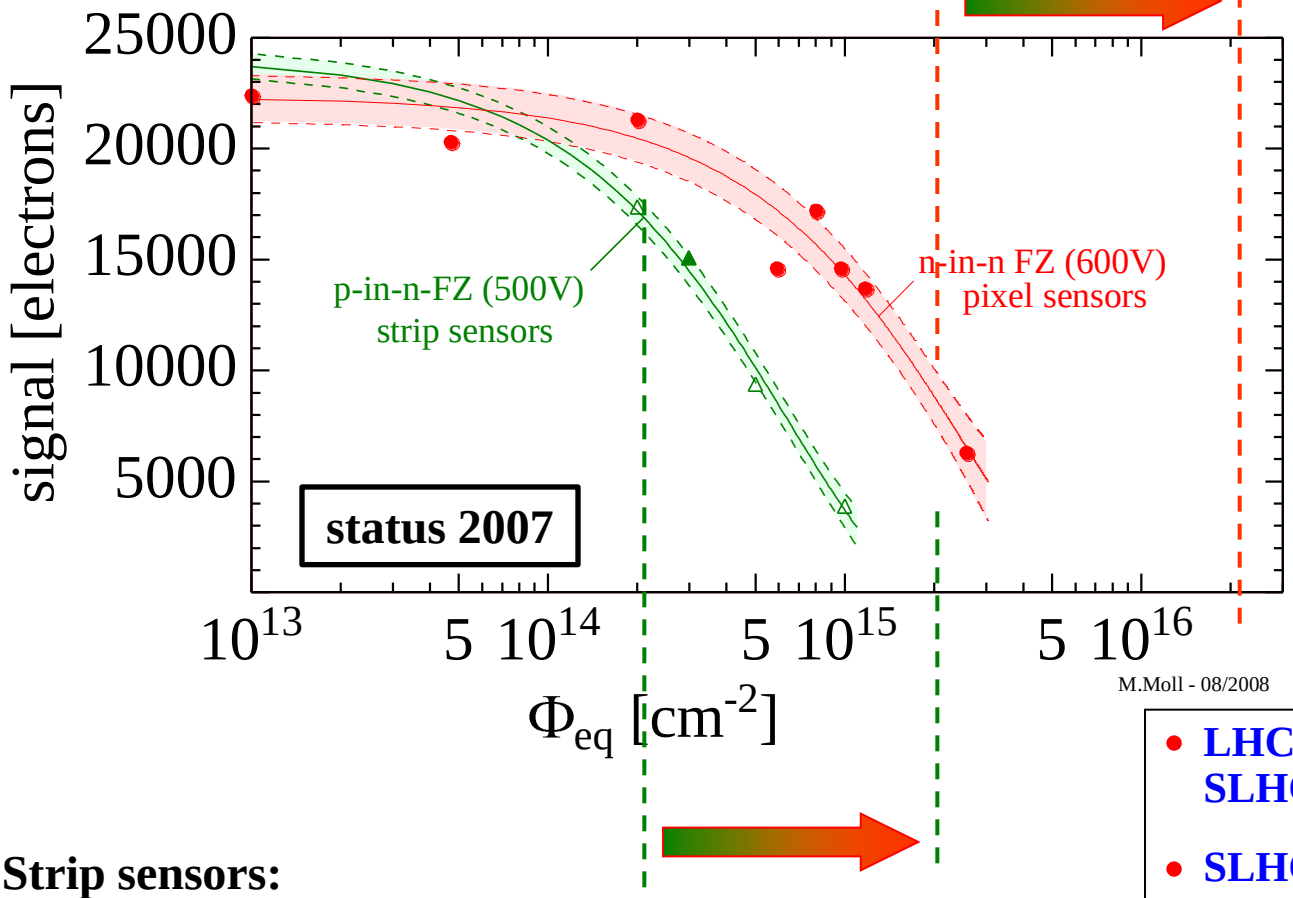
Michael Moll (PH-DT)

OUTLINE

- **WP4 – Challenge and Aim**
- **WP4 – Work program, organization and participants**
- **Status:**
  - **Pixel sensor evaluation/development** *(in collaboration with ATLAS)*
  - **Strip sensor evaluation/development** *(in collaboration with CMS)*
  - **Generic R&D** *(in collaboration with RD50)*
  - **Build up of infrastructure** *(common CERN infrastructure)*
- **Work plan for 2010/2011**

Challenge: Sensors for the sLHC Trackers

Pixel sensors:
max. cumulated fluence for LHC and sLHC



Note: Measured partly under different conditions! Lines to guide the eye (no modeling)!

FZ Silicon
Strip and Pixel Sensors

- n-in-n (FZ), 285µm, 600V, 23 GeV p
- p-in-n (FZ), 300µm, 500V, 23GeV p
- p-in-n (FZ), 300µm, 500V, neutrons

References:

[1] p/n-FZ, 300µm, (-30°C, 25ns), strip [Casse 2008]
[2] n/n-FZ, 285µm, (-10°C, 40ns), pixel [Rohe et al. 2005]

M.Moll - 08/2008

"sLHC" = 3000fb^{-1}

Strip sensors:
max. cumulated fluence for LHC and sLHC

- **LHC detectors would fail in SLHC due to radiation damage**
- **SLHC will need more radiation tolerant tracking detector concepts!**

Work program and structure of WP 4

WP4 is organized around 4 partly overlapping projects

- **1. Development and evaluation of pixel sensor concepts**
  in framework of ATLAS Pixel Upgrade projects (H.Pernegger)
  - Evaluation of rad. tolerant sensors for innermost pixel layers in view of IBL and sLHC pixel:
    Pixel technologies: Silicon planar sensors, Silicon 3D sensors, Diamond sensors
  - Support in organizing and running of testbeam and irradiation campaigns for the ATLAS pixel community.

- **2. Development and evaluation of sensor concepts for CMS upgrade**
  in framework of CMS Tracker upgrade projects (A.Peisert (since 2010), M.Mannelli (before))
  - Sensor R&D program with HPK (Hamamatsu) to evaluate sensors based on various silicon **sensor materials: FZ, MCZ and EPI silicon of n- and p-type** and **different thickness**
  - Part of prg. for preproduction, qualification and large scale production of CMS phase II upgrade

- **3. Generic R&D on radiation tolerance of silicon sensors**
  in framework of RD50 project (M.Moll)
  - Generic R&D on understanding of radiation damage in silicon

- **4. Build up of test equipment & infrastructure for PH common use** (M.Moll)
  - Equipment: Probestations for CV/IV measurements of sensors
  - TCT/ β-source test system in climate controlled container
  - Offer services as part of PH Departmental Silicon Facility

WP4 – Participants

Challenge: make WP4 a common activity with long term profit for CERN-PH

ATLAS

CMS

RD50

PH-DT ssd support to all CERN Experiments

Coordinator: Michael Moll (PH-DT)

Project 1 (ATLAS - Pixel):

- **WP4-Fellow: Alessandro La Rosa; WP4-PhD: Christian Gallrapp**
- **Daniel Dobos, Heinz Pernegger,** *(B.di Girolamo, F.Dittus)*

Project 2 (CMS - Tracker):

- **A.Peisert, M.Mannelli, S.Mersi, student Joyeeta Sinha (4 months), Georg Auzinger (PhD),** *(Duccio Abbaneo)*
- **Technical support** *(1.3 FTE: J.F. Pernot, J.P. Chatelain, E. Albert, H. Postema, A. Tsirou, I. Ahmed)*

Note: Tech support also given to Project 3&4

Project 3 & 4 (RD50 & ssd test equipment):

- **WP4-Fellows: Manuel Fahrer , Irena Dolenc**
- **M.Moll, N.Pacifico** (MCPAD ESR), **E.Castillo Sanchez** (Trainee)
- **R.Fortin, DT-FSU** (Technical support)

Note: Participation also in Project 2

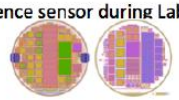
Observers (presently no active role)

- **LHCb : Paula Collins**
- **ALICE : Petra Riedler**
- **TOTEM: Gennaro Ruggiero**

ATLAS Pixel R&D

- **Interest**: performance evaluation of different sensors type for LHC phase 1 (in particular ATLAS IBL) and phase 2 upgrade with LHC and SLHC electronics (characterization before & after irradiation)
- **Available device for characterization:**

  - **ATLAS Planar**
    - N-in-N from Pixel production (used as reference sensor during Lab, irrad. and beam tests)
    - N-in-N and N-in-P from CiS (expected soon)

  - **ATLAS 3D-Si**
    - Double side double type column from FBK-irst
    - Passing-Through-Column (FE-I3 compatible) from FBK-irst (end spring)
    - Passing-Through-Column from Common floor-plan (from all vendors) (FE-I3 and FE-I4)(expected in early summer)

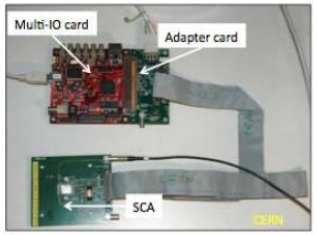
    

  - **ATLAS Diamond**
    - 1x Irradiated scCVD (single-chip / FE-I3)
    - 3x unirrad. and 1x irrad. pCVD (full module)
    - 3x scCVD (single-chip / FE-I3) under test (lab 161)
    - 2x pCVD (single-chip / FE-I4) in Bonn for metallization

- **ATLAS FE-Ix Experimental set up:**

ATLAS – TurboDAQ (FE-I3)
TPLL and TPCC
VME based



ATLAS – USBPix (FE-I3 and FE-I4 chips)
USB based

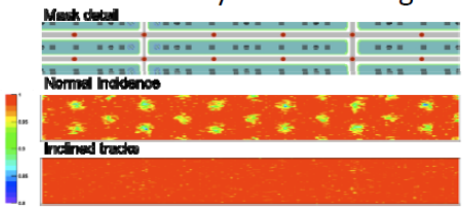
Setups available in Lab 161-01-24

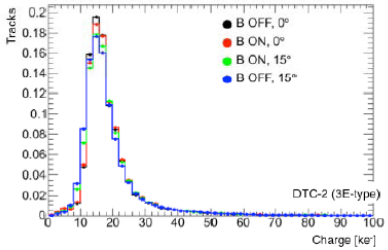
- **Activities:**
  - Lab measurements (electrical test, threshold & noise and response to radioactive source tests)
  - Test beam at CERN SPS (hit eff., pulse high distribution, charge sharing and residual distr.)
  - Common irradiation at CERN PS
  - Post-irrad. validation (Electrical & Lab characterization + Test beam measurements)

Alessandro La Rosa, Heinz Pernegger

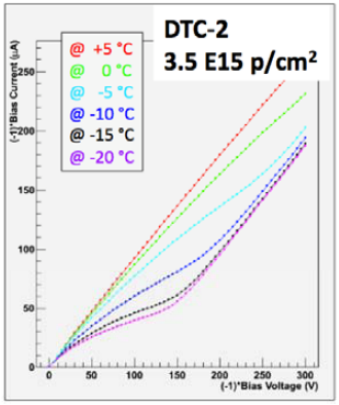
Some results

- **Silicon (FBK: 3D-Si, dtc type)**
  - **Lab measurements**
    - IV study shows a breakdown about 70 V
    - Sr90 source test → good CCE and less charge sharing than planar
  - **Testbeam measurements**
    - DUTs tested w/ & w/out 1.6T magnetic field and at 0° and 15° of beam angle of incidence
    - Hit efficiency and Pulse high dist.



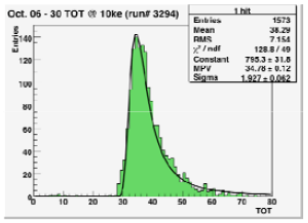


  - **Irradiation**
    - First test after 3.5 e15 p/cm^2 → Behavior in agreement with theory:
      - Low temperature low current
      - Damage rate: α(1.24 e15 n_{eq}/cm^2)=4 e-17 and α (2.17 e15e15 n_{eq}/cm^2) = 5 e-17



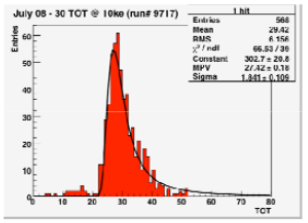
- **Diamond**
  - Lower capacitance → Lower Th (fact. 2) & Noise but ~50% of collected signal
  - "invisible" if compared w/ bare FE
  - Before & after irrad study

BEFORE irradiation



MPV=35

AFTER irrad (7 e14 p/cm^2)



MPV=27 (79% of unirrad)

CMS SLHC Tracker
- Thin Sensor R&D with HPK -

Project is integral part of CMS Tracker upgrade

WP4 participation in Phase I:

- **coordination of project: F.Hartmann**
  M .Mannelli (HPK contact)
  A. Peisert (coord meas. at CERN)
- **irradiation of sensors**
- **characterization of sensors**
  (… requires still set up of some specific equipment at CERN)

Outline plan:

- **Phase I: Targeted R&D**
  - **Establish required sensors characteristics & basic specifications**
  - **Single Source R&D with HPK agreed with CERN, together with framework for Market Survey & Procurements for Phase II & Phase III**
- **Phase II: Preproduction and Qualification**
  - **Finalize detailed specifications and QA protocols**
  - **Qualify for large scale production**
- **Phase III: Large Scale Production**

Input: Marcello Mannelli

Status of HPK Thin Sensor R&D Order

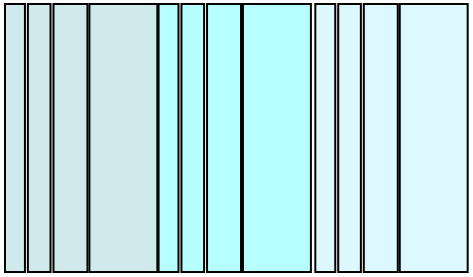
- **Aim: Identify technology for tracker upgrade**
- **Delivery of sensors expected in June 2010**
  - **Different silicon material, different technologies**

substrate type & Active Thickness	FZ 200um carrier	MCZ 200um thinning	FZ 100um carrier	epi 100um	epi 75um	FZ 300um	Total
P-on-N Production	6	6	6	6	6	6	36
N-on-P Production p-spray	6	6	6	6	6	6	36
N-on-P Production p-stop	6	6	6	6	6	6	36
2'nd metal production P-on-N	6						6
2'nd metal production N-on-P p-stop	6						6
2'nd metal production N-on-P p-spray	6						6
Total	36	18	18	18	18	18	126

- **Evaluate**
  - **Geometry**
  - **Radiation hardness and annealing behavior**

Status of HPK Thin Sensor R&D Order

- **Each wafer contains ~ 30 different sensors and test structures**
- **Massive irradiation and test campaign organized**
- **CERN will participate in evaluation of**
  - **A) multi-geometry strip and pixel detectors *(A.Peisert et al.)***



3 regions, 4 groups of 32 strips in each region
pitch 70 μm, 80 μm, 240 μm, 120 μm
different width/pitch in each region
~3 cm long strips

Electrical tests: IV, CV, $C_{interstrip}$, $R_{interstrip}$, $C_{coupling}$

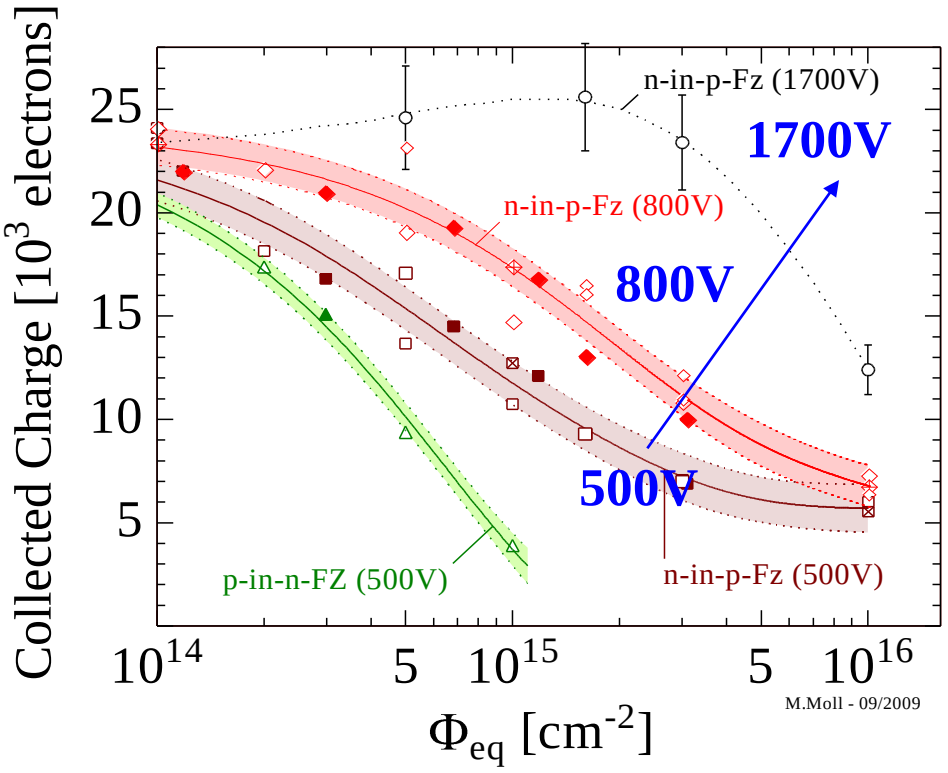
Cosmic rack and x-y table for measurements with a source:
CCE, noise, position resolution

  - **B) pad diode test structures *(M.Moll et al.)***
    - CV, IV, CCE measurements, annealing studies
- **Setups for measurements have to be ready in June**

RD50 – Radiation hard semiconductor devices for very high luminosity colliders

RD50

- **RD50 collaboration: 47 Institutions with 250 members**
- **WP4 involvement in management of collaboration** *(M.Moll co-spokesperson)*
- **CERN (WP4) R&D focused on RD50 key questions:**
  - **p-type silicon and its annealing behavior (*'base line option'* for ATLAS Tracker upgrade)**
  - **charge multiplication in highly irradiated sensors**
  - **radiation tolerance of p-in-n Magnetic Czochralski silicon sensors**



FZ Silicon Strip Sensors

- n-in-p (FZ), 300µm, 500V, 23GeV p [1]
- n-in-p (FZ), 300µm, 500V, neutrons [1,2]
- n-in-p (FZ), 300µm, 500V, 26MeV p [1]
- n-in-p (FZ), 300µm, 800V, 23GeV p [1]
- n-in-p (FZ), 300µm, 800V, neutrons [1,2]
- n-in-p (FZ), 300µm, 1700V, neutrons [2]
- p-in-n (FZ), 300µm, 500V, 23GeV p [1]
- p-in-n (FZ), 300µm, 500V, neutrons [1]

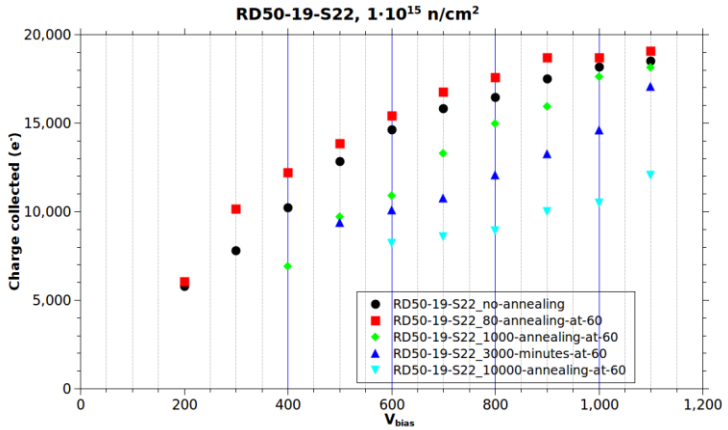
References:

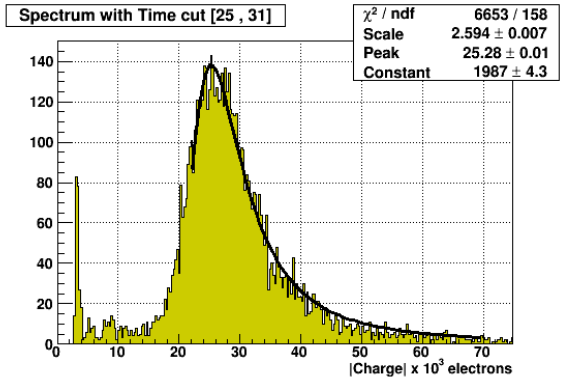
[1] G.Casse, VERTEX 2008
(p/n-FZ, 300µm, (-30°C, 25ns)

[2] I.Mandic et al., NIMA 603 (2009) 263
(p-FZ, 300µm, -20°C to -40°C, 25ns)

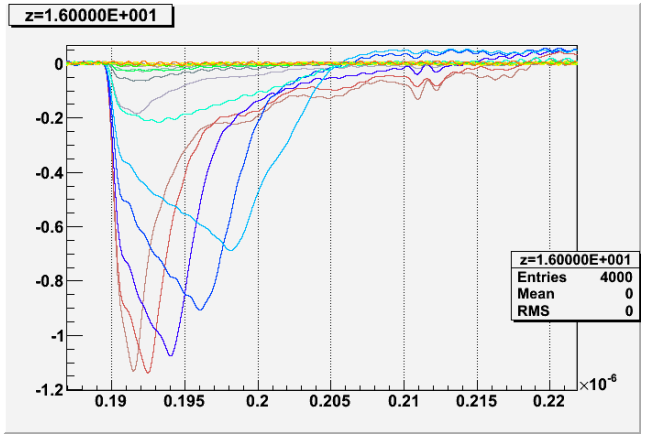
Characterization of irradiated ministrip sensors

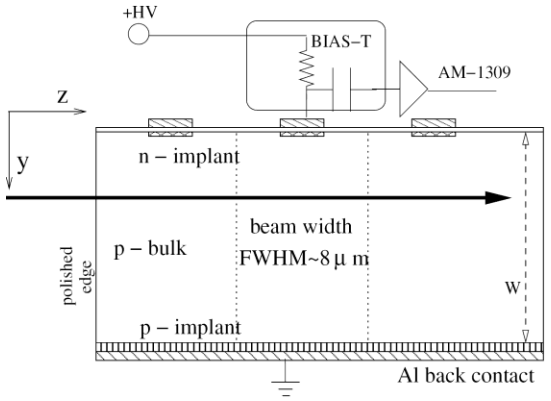
- **Annealing study on irradiated MCZ silicon strip sensors**
  - **CCE with beta source and LHCb Beetle chip based DAQ (ALIBAVA)**





- **Characterization of charge transport inside irradiated sensors**
  - **Edge TCT (Transient Charge Technique) with infrared picosecond laser**





Status: Build up of test equipment

Solid State Detector Lab (SSD) in bldg.28 (attached to Silicon Facility – 186)

- **'Refurbishment' of ssd characterization tools**
  - **Probe station for CV/IV measurements** (4" chuck in dark box, CV/IV up to 1000V)
  - **CCE with Sr^{90} source** (one channel, μs shaping, cooling)
  - ***Status*: Done**, *including centralized data storage and database*
- **New TCT(Transient Charge Technique)/CCE setup in bldg.28**
  - ***Status*: Done, see next slide** *(cooling needs to be improved to reach -40ºC)*
- **New edge TCT system in bldg.28**
  - ***Status*: first measurements done, needs further work**

ATLAS Pixel laboratory (bldg. 161)

- **Pixel test stations in Bat 161 for sensor + FE chip measurments**
  - ***Status*: Fully operational**; *With source and electronic calibration in climate chamber*

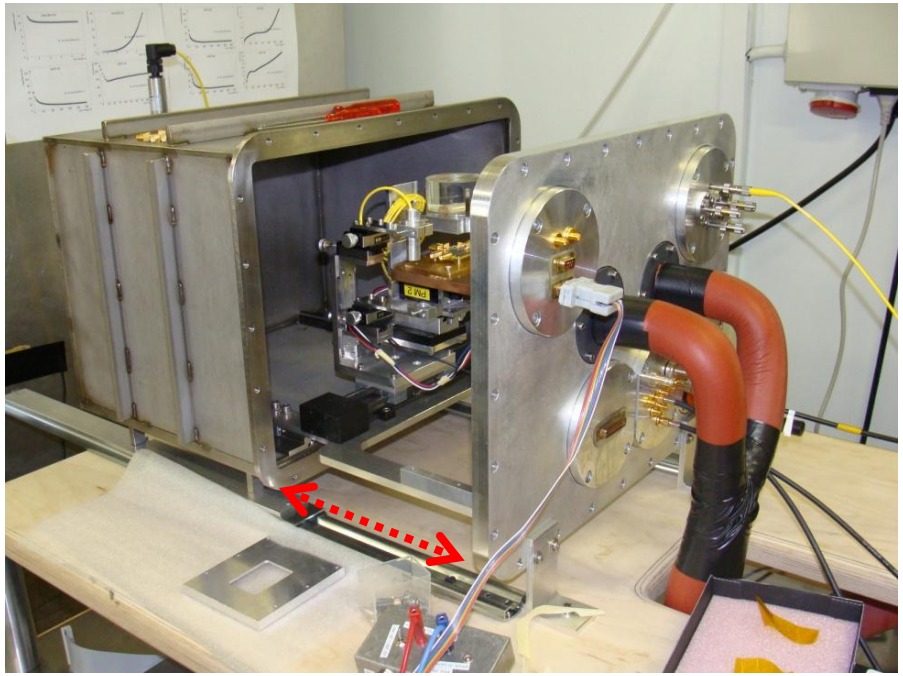
Silicon Facility – bldg 186

- **New 4 inch probe station with cold chuck for CV/IV measurements**
  - ***Status*: Almost ready,** *delay due to work load of technicians in other projects*
- **Cold box installation for measuring CMS multistrip geometry sensors**
  - ***Status*: Will be ready in June for arrival of first HPK sensors**

Example: New TCT/CCE/CV/IV setup

Characterization methods

- **TCT (Transient Charge Technique)**
  - strip and pad sensors, multichannel
  - lasers illumination on both sides of sample
  - red + infrared laser (ps pulses)
- **CCE (Charge collection efficiency)**
  - Sr^{90} source
  - Scintillator based trigger
- **CV / IV**
  - CV with frequency up to 1 MHz



Mechanics & Cooling

- **Cooled with silicon oil**
  - vacuum or dry air atmosphere
  - Temperatures down to below -25°C
    (down to -40° C with peltier booster)
- **Movable with linear motor stage**
  - laser and source
    can be scanned over DUT
- **Modular system with flanshes**
  - allows for easy mounting of additional feedthroughts

Sample mounting & Electronics

- **SMA connectors (HF)**
  - 2.5 GHz oscilloscope (epool)
- **Sample boards (support PCB)**
  - detectors to be bonded
  - good thermal & HF properties
- **Amplification**
  - Fast commercial amplifiers
  - ALIBAVA system for strip sensor CCE
    - based on LHCb Beetle Chip
    - 25ns shaping time, 128 channels

Link between WP4 and Experiments

IBL project and WP projects

Comment from Heinz Pernegger:

- **Two major areas of contributions for ATLAS IBL and sLHC upgrade**
  - **IBL Pixel Sensor Development interrelates with WP project on sensors**
  - **IBL Integration and stave studies interrelates with WP project on cooling (CO_2)**
- **People currently involved:**
  - **D. Dobos, F. Dittus, C. Gallrapp, A. La Rosa, H. Pernegger**
  - **M. Capeans, A. Catinaccio**
  - **Work carried out in close cooperation between PH-ADE, PH-ADO and PH-DT**
- **Pixel Sensor Development for IBL and sLHC**
  - **Planar, 3D silicon and CVD diamond pixel sensors**
    - Studies of irradiated pixel detectors in Lab
  - **Major responsibility for Irradiation and Testbeams**
    - Coordinator for IBL and 3D irradiation (A. La Rosa)
  - **We have setup and operate facility for pixel tests in Bat 161 which is used by whole collaboration**
- **Significant contribution to the ongoing IBL module development program:**
  - **Module prototype program (tests of sensor-chip assemblies)**
  - **Tests of new FEI4 pixel chip for IBL (module test analysis, DAQ)**
  - **Major partners: Bonn, Ohio, Genova/Trento, Dortmund**

Link between WP4 and Experiments
WP4 and ATLAS pixel sensor R&D

Comment from Heinz Pernegger:

The cooperation between WP4 and ATLAS pixel sensor development has been very successful and beneficial for both

- **The generic sensor development benefit strongly from experiment developments (e.g. availability of pixel electronics)**
- **For ATLAS, in particular the IBL, it allowed to support the development and evaluation of pixel sensors of different technologies**

Specific support made possible through WP & Atlas cooperation on sensors

- **Participation in sensor prototyping runs and manufacturing of evaluation prototypes**
  - **3D sensor development at FBK-irst for double sided and active-edge 3D sensors, optimization of design charge collection and noise performance**
  - **Planar sensor development for new n-n planar sensors at CIS with slim edges and improved radiation hardness**
  - **pCVD and scCVD diamond sensors for charge collection studies and diamond pixel module tests**
  - **Pixel bump-bonding to sensors at IZM**
- **Infrastructure**
  - **Update and improvement of sensor characterization lab in Bat 161**
  - **acquisition and further development of new readout electronics**
- **Support of personnel**
  - **Currently support one fellow (A. La Rosa) and one doctoral student (C. Gallrapp) through WP funds.**

WP4 and CMS Tracker upgrade

Comment from Duccio Abbaneo:

CMS silicon sensors R&D relies on WP4 and collaboration with the group of M. Moll

- **Results from RD50 are the basis of the R&D program**
- **Access to DSF facilities and expertise**
- **CERN financial contribution to the project comes from WP4 funds**

As soon as CMS has developed a well-structured R&D project, WP4 resources have been made available to the project (with a fair share with the other experiments). Without that, CERN participation in the project would not have been possible.

Thanks to this policy, WP4 resources are being used in the most effective way, without any barrier between "generic R&D" and "detector-specific R&D".

In few words: fully useful WP, managed in an exemplary way.

Budget 2010

Budget allocation 2010: 340 KCHF

CET: 155KCHF from 2009 commitment on 34004 not balanced yet !

Splitting on activities in 2010:

- ATLAS activities 65 KCHF
- CMS activities 65 KCHF
- RD50 activities 65 KCHF
- Infrastructure (common setups) 65 KCHF
- PhD student, FSU, Fellow, epool, travel, others 80 KCHF

Manpower – Students/Fellows

On WP budgets (2008-2012):

- 1 PhD (WP4-budget)
- 1 Trainee (WP4-budget)
- 3 Fellows (WP-global)

Details:

Some commitment for 2012

WP4-topic	Postion	2008												2009												2010												2011												2012											
		1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12
Eduardo DEL Castillo Sanchez	Trainee																																																												
Christian Gallrap	PhD																																																											
Manuel Fahrer	Fellow																												+ 6 months																															
Alessandro La Rosa	Fellow																												+ 6 months						+ 6 months																									
Irena Dolenc	Fellow																																																										

All students/Fellows in WP4:

Postion	WP4-topic	budget	Name	Supervisor	Begin	Comment
Trainee	RD50	WP4	Eduardo DEL Castillo Sanchez	Moll	1.10.09	(2years)
Student	CMS	CMS	Joyeeta Sinha	Peisert	1.4.10	(4months)
PhD	RD50	Austrian PhD	Katharina Kaska	Moll	1.4.07	
PhD	RD50/CMS	MCPAD	Nicola Pacifico	Moll	1.1.09	
PhD	ATLAS	WP4	Christian Gallrap	Pernegger	1.1.10	
PhD	CMS	CMS	Georg Auzinger	Abbaneo	1.9.10	
Fellow	Setups/CMS	WP4	Manuel Fahrer	Moll	1.3.08	
Fellow	ATLAS	WP4	Alessandro La Rosa	Pernegger	1.4.08	
Fellow	RD50/CMS	WP4	Irena Dolenc	Moll	1.4.10	
Fellow	CMS (50%)	CMS	Stefano Mersi	Abbaneo	1.3.08?	

Workplan for next 12 months

- **Workplan "ATLAS pixels":**
  - Test of sensor assemblies with new FEI4 chip (for IBL and sLHC)
  - Characterization of irradiated sensors (planar, 3D and diamond)
  - Organize and support common irradiations and test beams for ATLAS Pixel community
  - Performance studies of pixel sensors for phase I upgrade (IBL)
- **Workplan "sensors for CMS"**
  - Participate in CMS work on HPK sensor characterization before & after irradiation with main focus on multistrip stuctures and diodes/ministrip sensors
- **Workplan on activities in framework of RD50**
  - Submission of detector production runs at Micron (2010)
  - Detailed studies on reverse annealing in p-type silicon strip sensors
  - Sensor characterizations with new infrastructure (fast/multi and edge TCT, Alibava)
  - Start project on simulation of irradiated silicon sensors using commercial software
- **Workplan on common infrastructure at CERN**
  - Produce second setup for CCE measurements with LHCb Beetle chip (ALIBAVA)
  - Finalization of cold chuck system for CV/IV measurements