R&D in the FCAL Collaboration

Wolfgang Lange on behalf of the
FCAL Collaboration

Outline

- Status of the Collaboration
- Goals
- Activities
  - CLIC design studies
  - LumiCal prototype sensors & ASICs
  - BeamCal sensor R&D & readout ASIC
  - System test
  - Pair monitor design
  - CMS and FLASH diamond sensor applications
- Summary

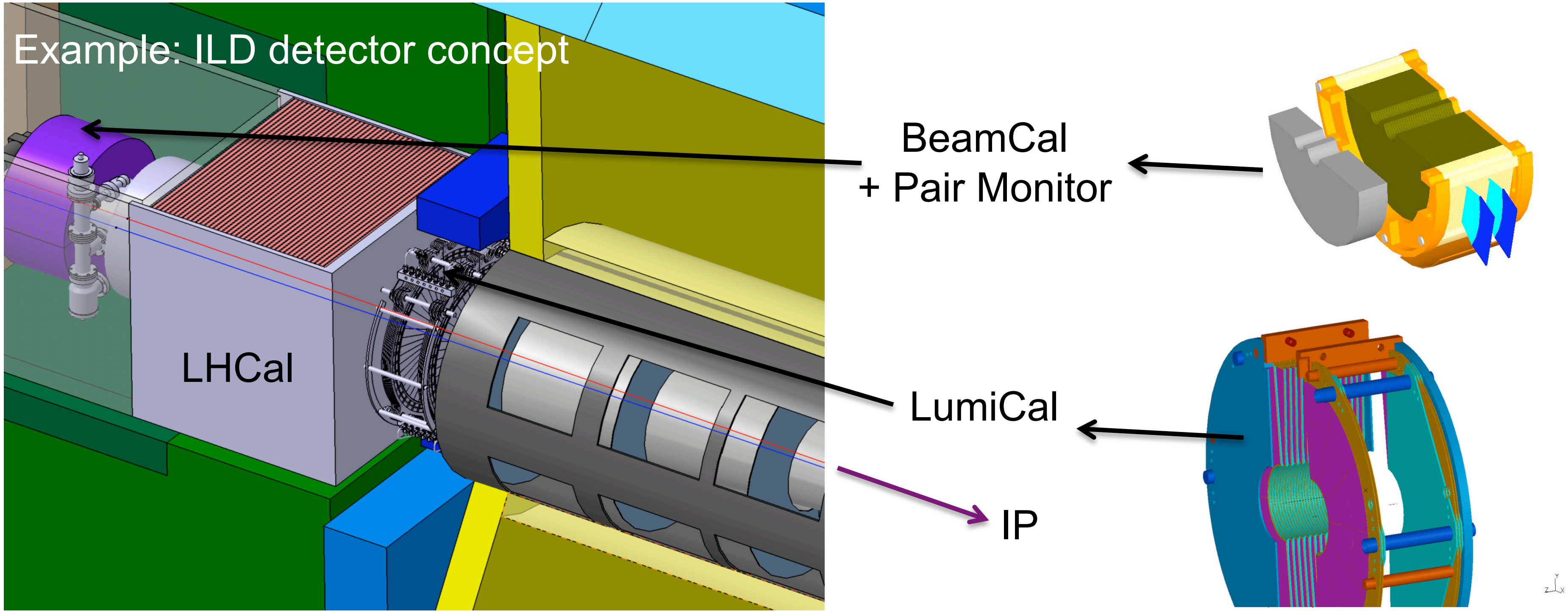
FCAL Collaboration

Labs involved (alphabetical order):

Argonne National Lab (calorimetry),
Bucharest IFIN-HH (simulation, doses and neutron flux),
CERN (CLIC detector design),
University of Colorado (simulation, BeamCal performance),
Cracow, Institute of Nuclear Physics (sensor design, position monitoring, LumiCal simulation),
Cracow University of Science and Technology (ASICs),
DESY Zeuthen (simulation, BeamCal design, sensors, fast feedback, test beams, irradiation),
JINR Dubna (GaAs sensors, simulation of BeamCal),
NCPHEP Minsk (test beam participation, GaAs sensor tests),
Royal Holloway College, London (fast feedback and beam background simulation),
Stanford University (ASIC design),
Tel Aviv University (LumiCal simulation and sensor test),
TU Dresden, IKP (data transmission planned),
Tuhoku University + KEK (Pair monitor),
Vinca Institute, Belgrade (simulation, physics background),
NEW:
UC Santa Cruz (sensor radiation hardness studies),
SLAC (simulations and background studies).

- Participation in *EUROTeV, EUDET, FP7 (MC-PAD, infrastructure), NoRHDIA, and INTAS* programmes

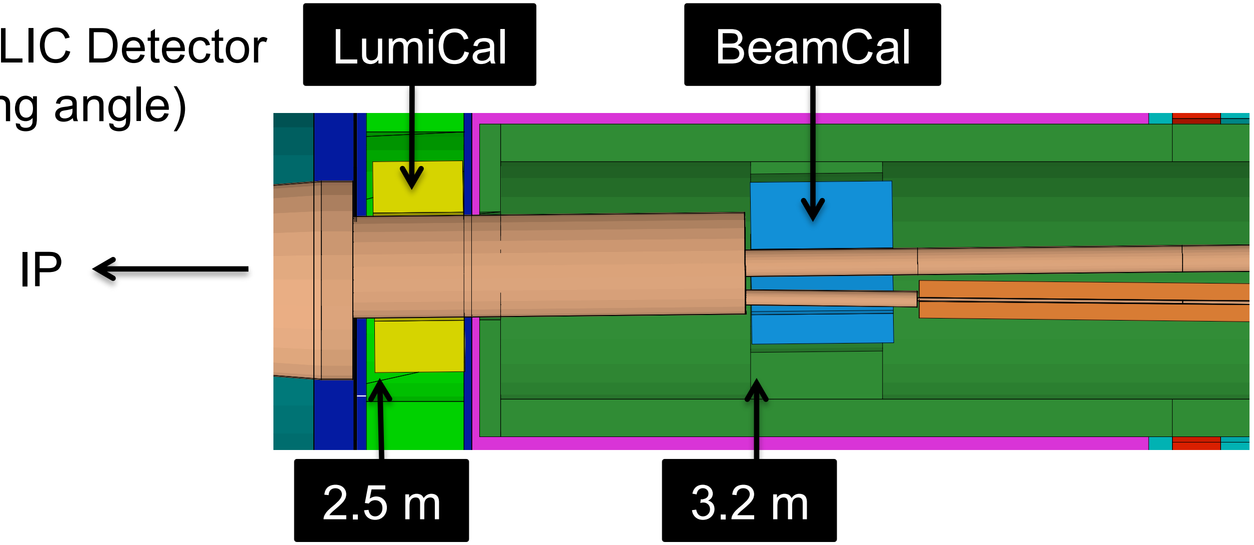
Goals



- Understanding physics (simulation etc) to optimize detector design for
  - precise luminosity measurement,
  - hermeticity (electron detection at low polar angles),
  - assisting beam tuning by fast feedback of BeamCal data to machine.
- Challenges: radiation hardness (BeamCal), high precision (LumiCal) and fast readout (both)

Expansion into CLIC Design Studies

Example of CLIC Detector
(larger crossing angle)

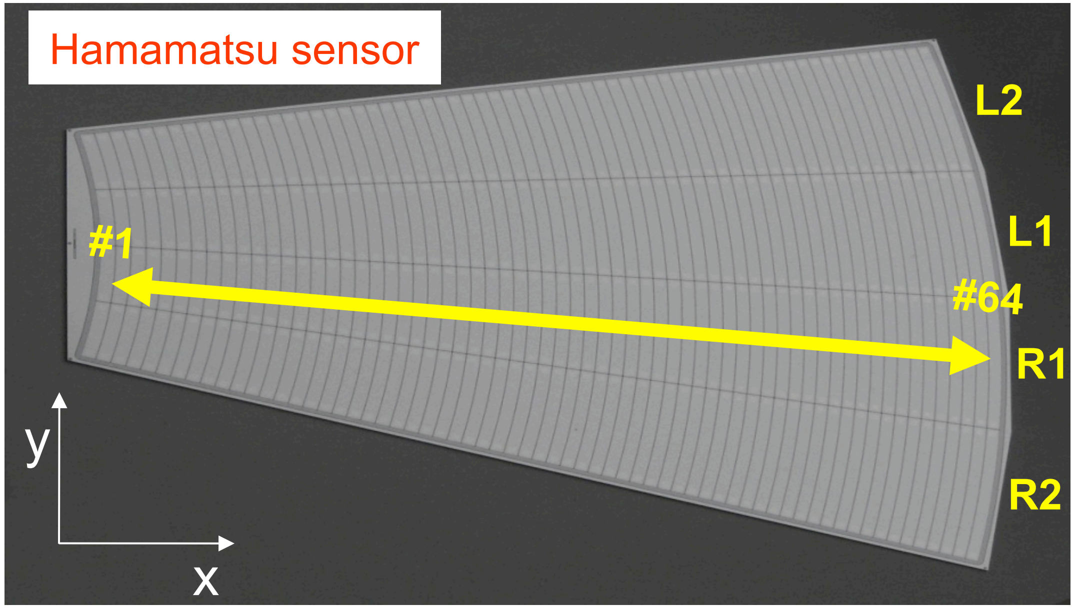


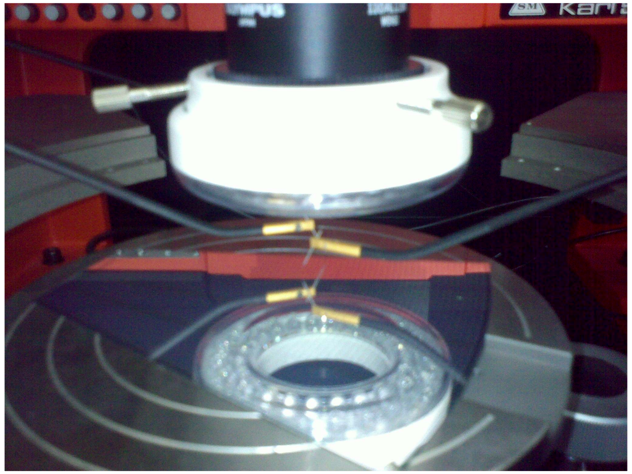
Similar task ➔ similar design ➔ similar methods

- Collaboration with Linear Collider Detector Group @ CERN, CERN joined FCAL
  - application of already developed simulation tools (FCAL)
  - exchange of students
- Optimization of detector design for a luminosity measurement with an accuracy of $\leq 10^{-2}$

LumiCal Sensors (1)

- LumiCal: low irradiation load → silicon-tungsten sampling calorimeter
  - ✓ Design (optimized geometry for luminosity measurement)
  - ✓ Hamamatsu sensor prototypes (6”, p in n, DC-coupled)
    - Measurements in Cracow, Zeuthen, Tel Aviv (cross calibration)

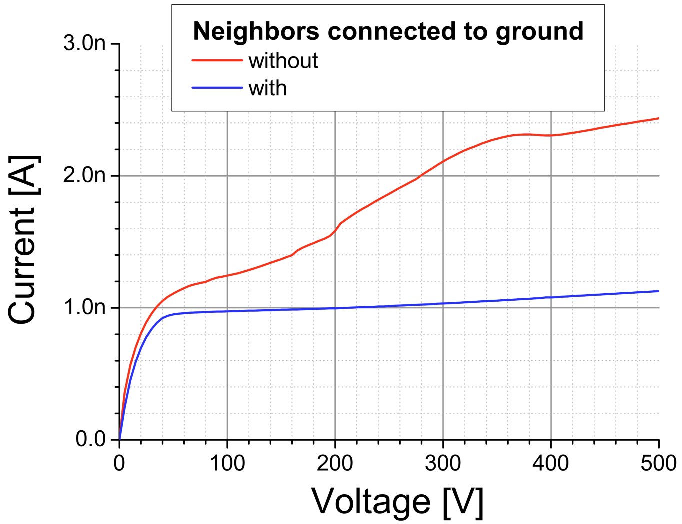




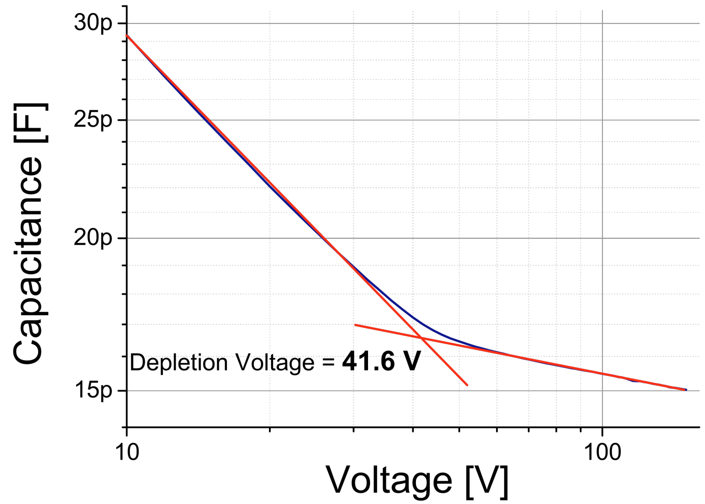
Sensor at probe station

LumiCal Sensors (2)

- Measurements in Cracow, Zeuthen, Tel Aviv (cross calibration)



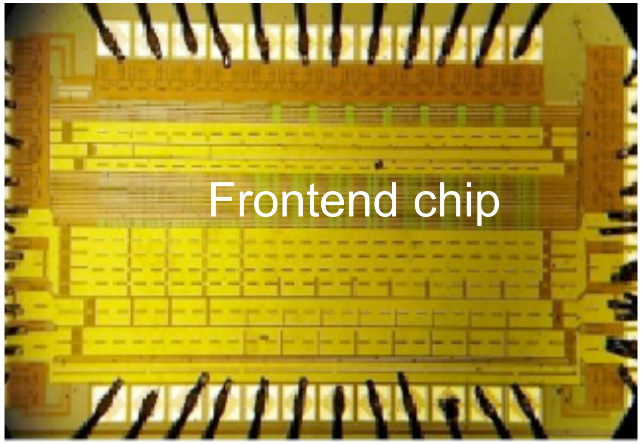
I/V Measurement (One Pad)

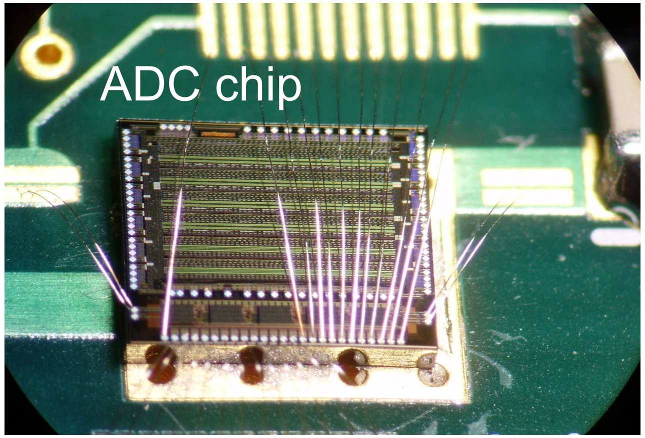


C/V Measurement (One Pad)

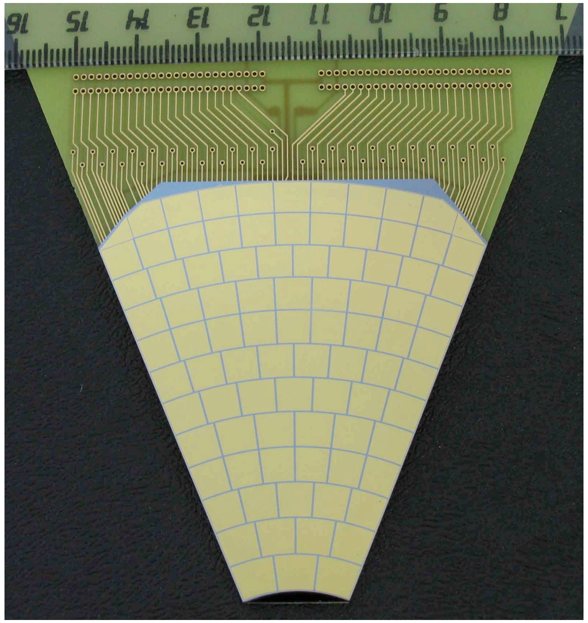
LumiCal Readout

- Frontend readout prototype chip developed at UST Cracow, manufactured in a MPW run
- Measured (preliminary results) in Cracow and Zeuthen:
  - Noise ≈ 300 e^- (+ 28 e^-/pF), gain ≈ 35 mV/fC
- Frontend chip will be used for testbeam measurements of a sensor plane
- ADC prototype chip developed at UST Cracow, manufactured in a MPW run
- Currently being measured in Cracow:
  - Resolution 10 bit,
    S/N ≥ 58 dB up to 25 MHz ➔ proof of principle (pipelined ADC)



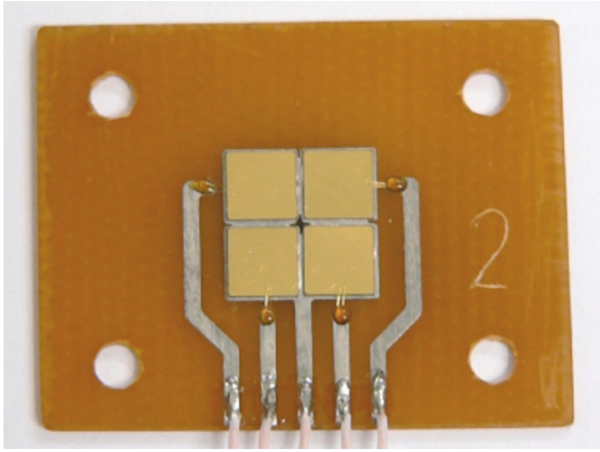


BeamCal Sensors - GaAs



GaAs sensor intensively measured and irradiated (see previous PRC reports)

3 lots with different doping manufactured and irradiated: differences in behaviour observed…



- For electromagnetic irradiation semi-insulating GaAs remains operational up to 1.5 MGy
- GaAs is a candidate for areas with less intense irradiation, to be compared with rad-hard silicon
- Sensor manufacturing via JINR Dubna

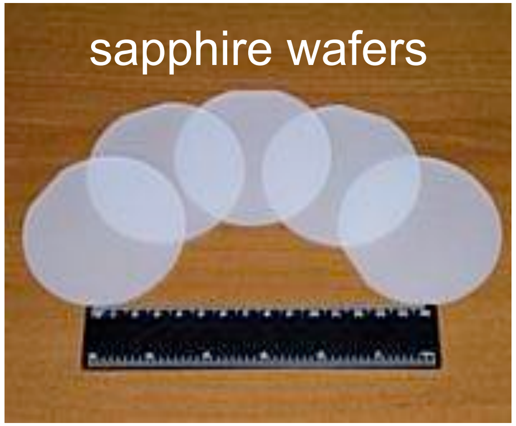
BeamCal Sensors - Sapphire

Sapphire (Al_2O_3) as sensor material:

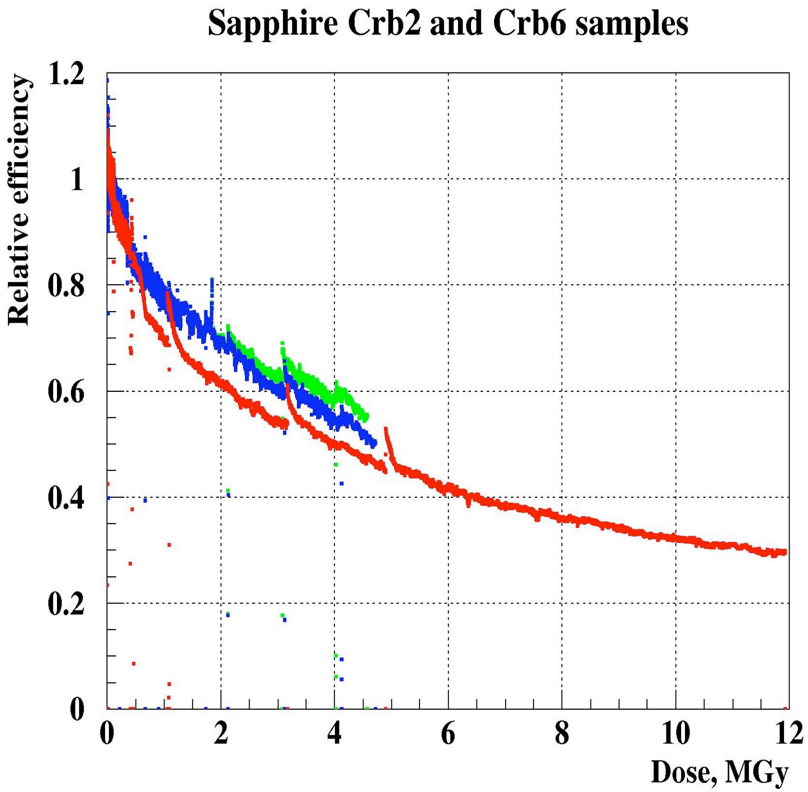
- Band gap: 9.9 eV (diamond: 5.5 eV, Si: 1.12 eV)
- Single crystal samples 1x1 cm^2
- cut 001 (crystal orientation)
- wafer size up to 300 mm
- metallization 50/50/200 nm Al/Ti/Au

operated as leakage current monitor…

- Charge collection efficiency few %
- still ~30 % of initial value after 12 MGy
- promising candidate for large depositions



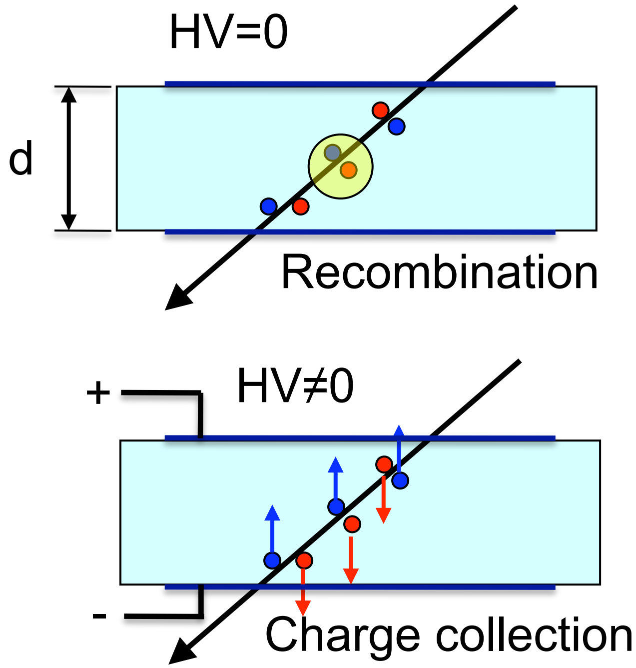
Drawback:
Slow signals



Diamond Sensors – Polarization (1)

- Poly- and single crystalline diamond sensors were intensively investigated (see also previous reports)
- Recent measurements especially on polarization effects in sCVD

Measurements show a larger degradation in signal yield after irradiation: why?

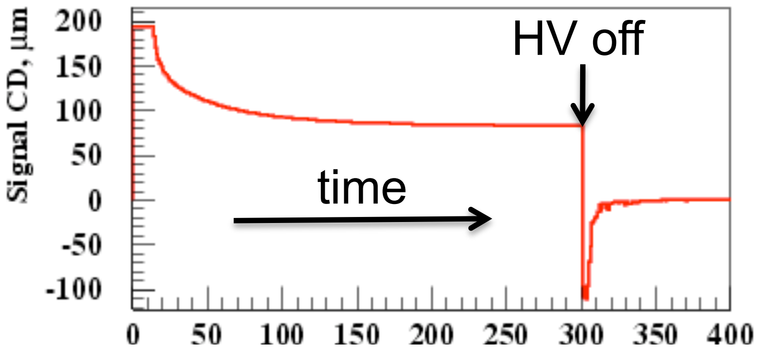


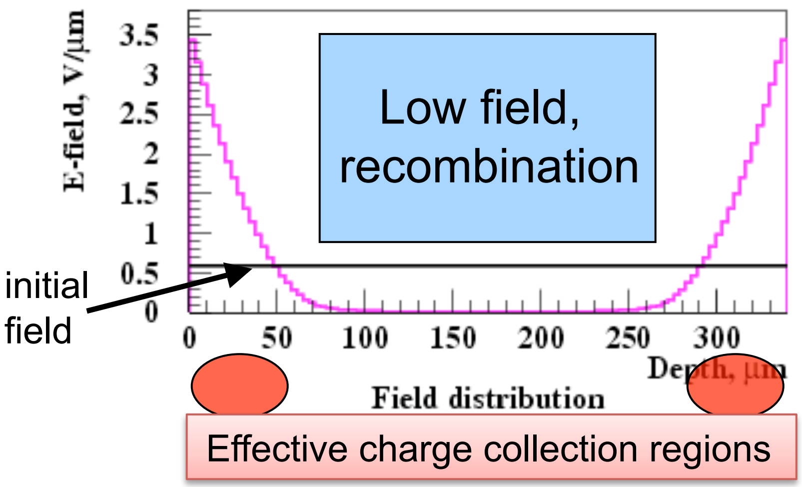
- Charge Collection Efficiency (CCE) depends on electric field (below saturation)…
- Radiation causes local damages of the lattice structure.
- Local damages (traps) are able to capture free charge carriers and release them after some time.
- Tried to understand the damage behaviour:

Drift Diffusion Model:
Trapping of collected charge carriers creates an internal field which super-imposes the external field.

Diamond Sensors – Polarization (2)

Observation: signal changes polarity when bias voltage (external field) is removed.



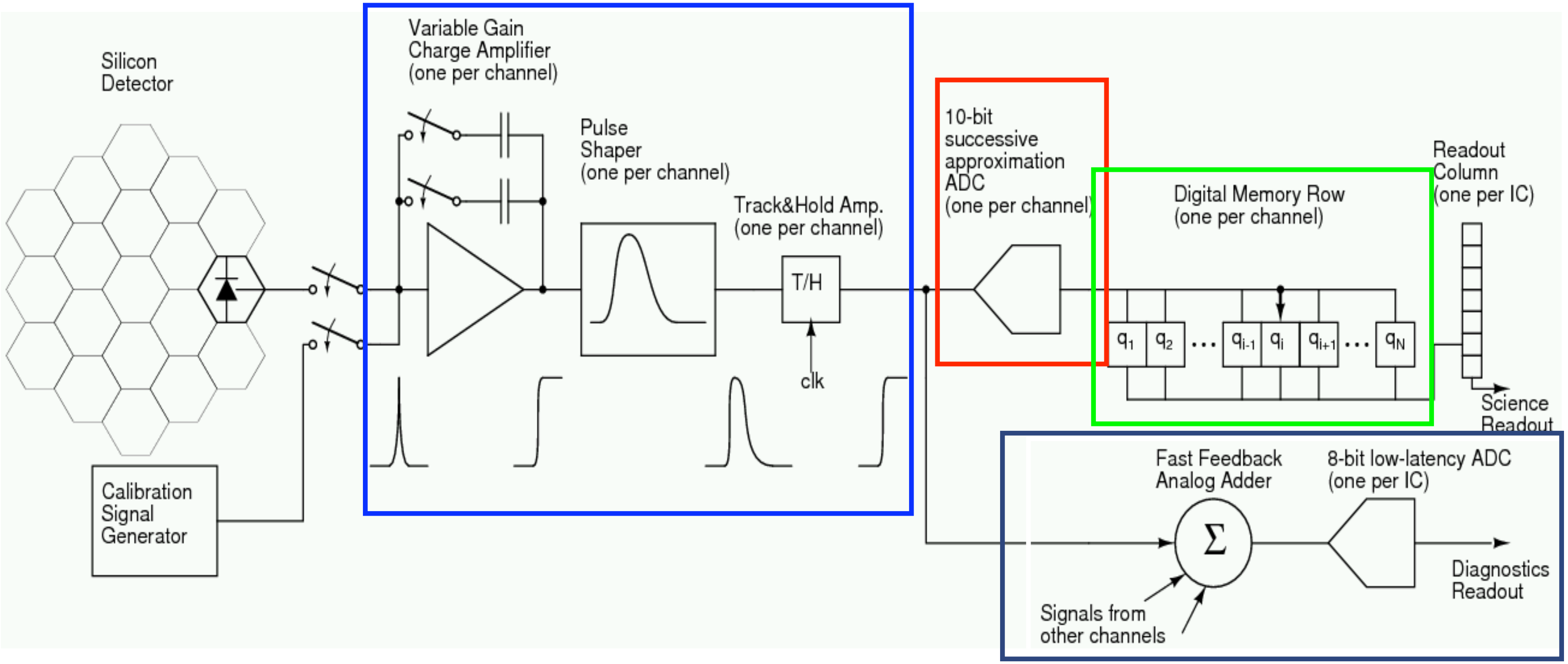


Model:

- Asymmetry is introduced by the applied electric field
- Asymmetric trap filling according to charge carrier density
- Space charge (non filled traps) created in the bulk of the detector
- Compensation of the external field by space charge ←→ Polarization
- After removal of the external field (HV off) the internal field only remains and signal polarity is inverted

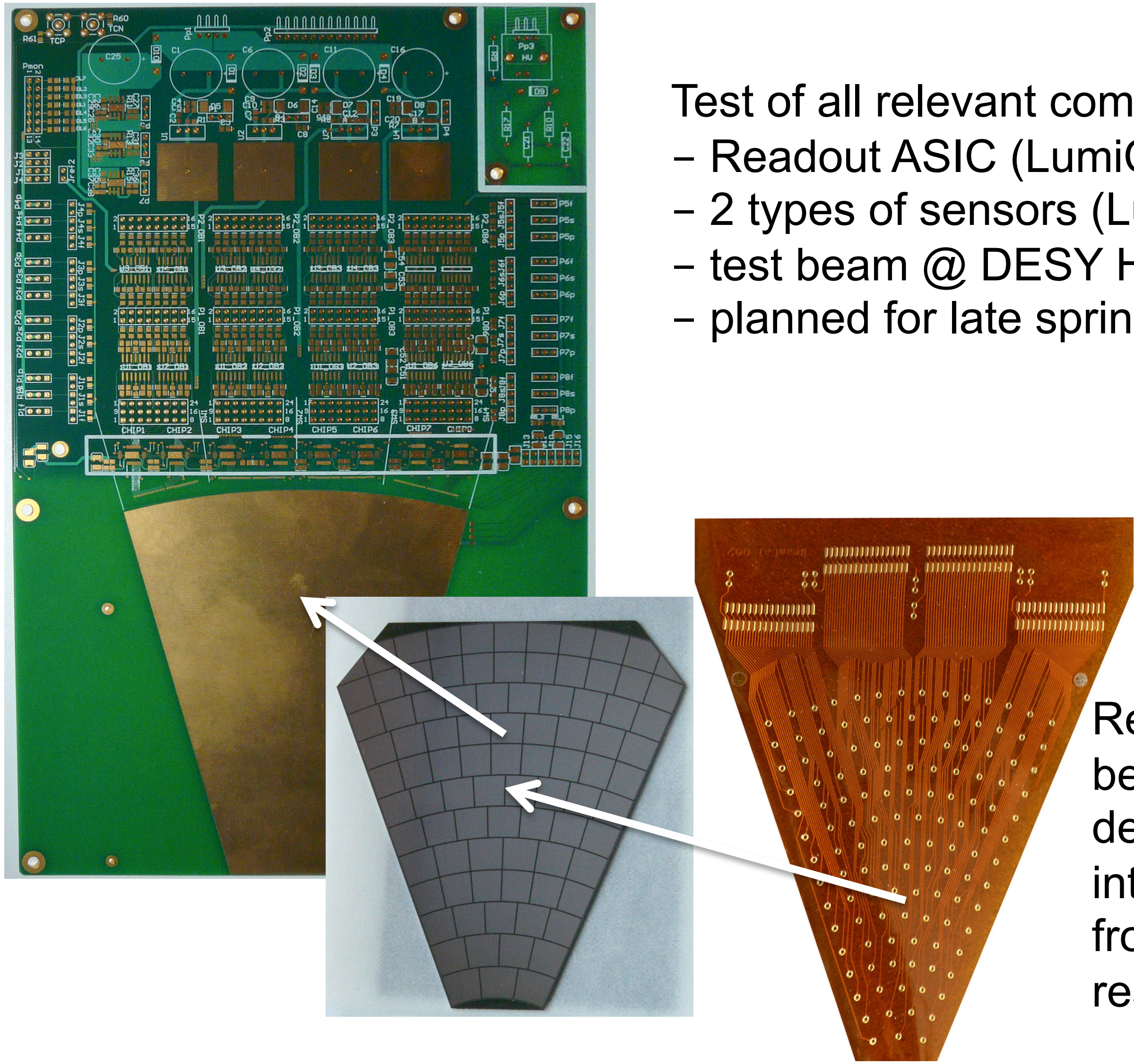
Therefore now measurements: biasing the sensor with alternating polarity

BeamCal Readout ASIC



- Design at Stanford University (KPIX technology)
- readout between bunch trains (‘science readout’)
- prepared for fast feedback (diagnostics readout to machine)
- prototypes expected in 2010

System test of components

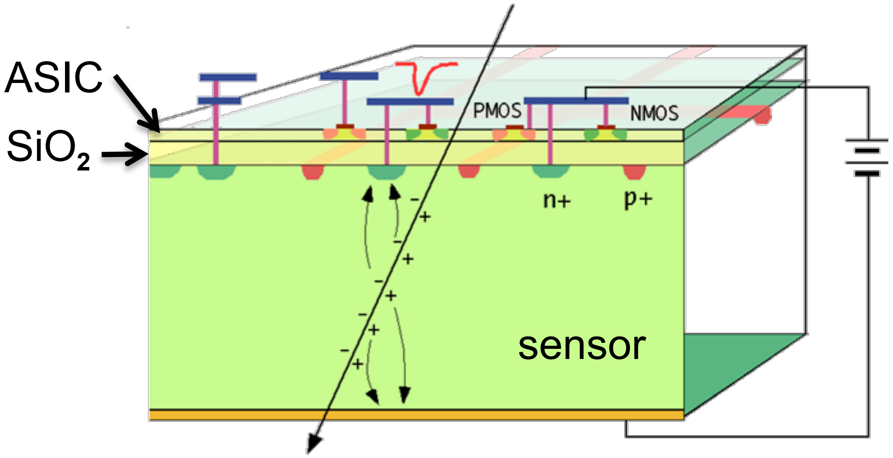


Test of all relevant components:

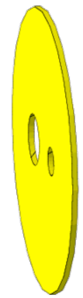
- Readout ASIC (LumiCal)
- 2 types of sensors (LumiCal Si, BeamCal GaAs)
- test beam @ DESY HH using EUDET telescope
- planned for late spring 2010

Required thin gap (≤ 0.5 mm) between absorber layers demands sophisticated interconnection technology from sensor pads to readout electronics…

Pair Monitor Design



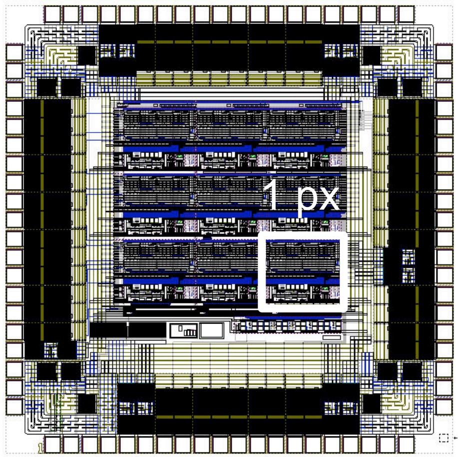
- Pixel size: 400 x 400 μm^2
- Radius: 10 cm
- Total number of pixels: **~200,000**



→ Monolithic construction allows the elimination of the bump-bonding process.

- First step: design of a readout prototype ASIC for 3x3 pixels:
- digital readout (preamp, discriminator, counter)

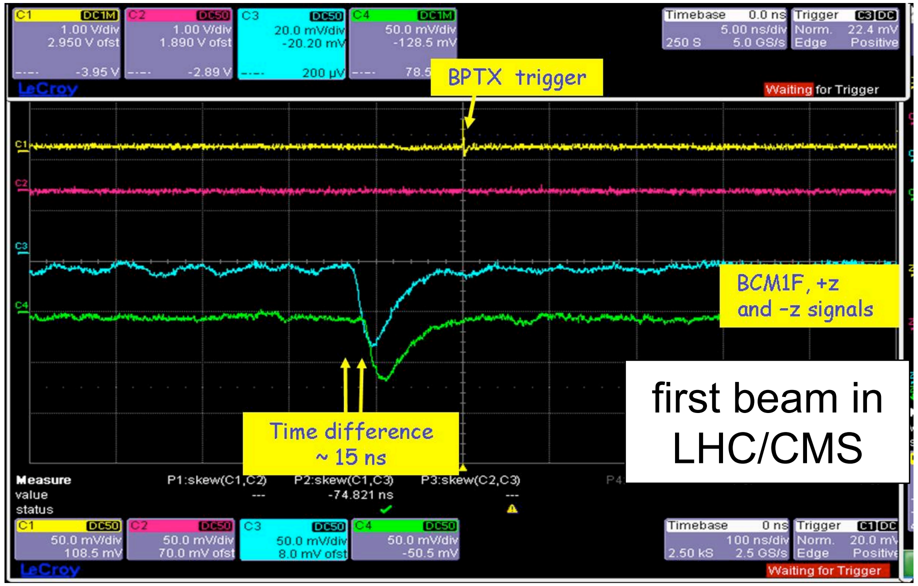
- manufactured chip (CMOS 0.2 μm, SOI technology)
- performance measurements:
  - gain: ~ 17 mV/fC
  - noise: ~ 260 e$^-$ (+ 130 e$^-$/pF) @ signals ~ 20000 e$^-$

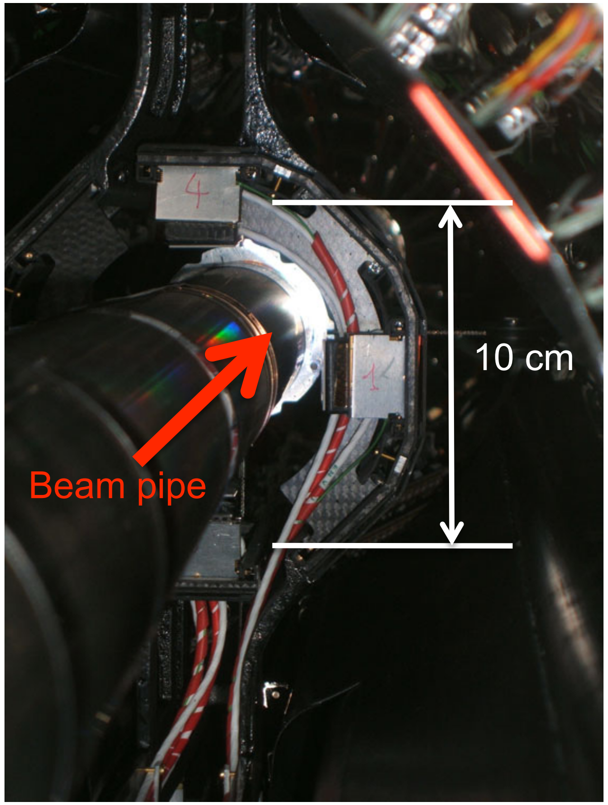


CMS Beam Condition Monitor (1)

- transfer of acquired 'know how' -

- CMS: Beam and Radiation Monitoring System (see also CMS report to PRC)
  1) Characterization of pCVD diamonds (for BCM2)
  2) Commissioning and operation of BCM1F
     - at z = ± 1.8 m, r = ~5 cm, 4 modules / plane
     - data from first LHC runs in September 2008

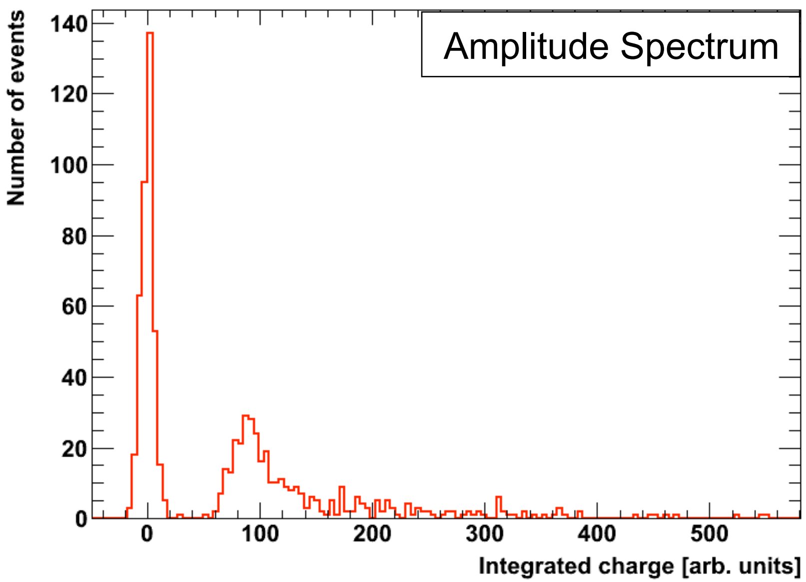


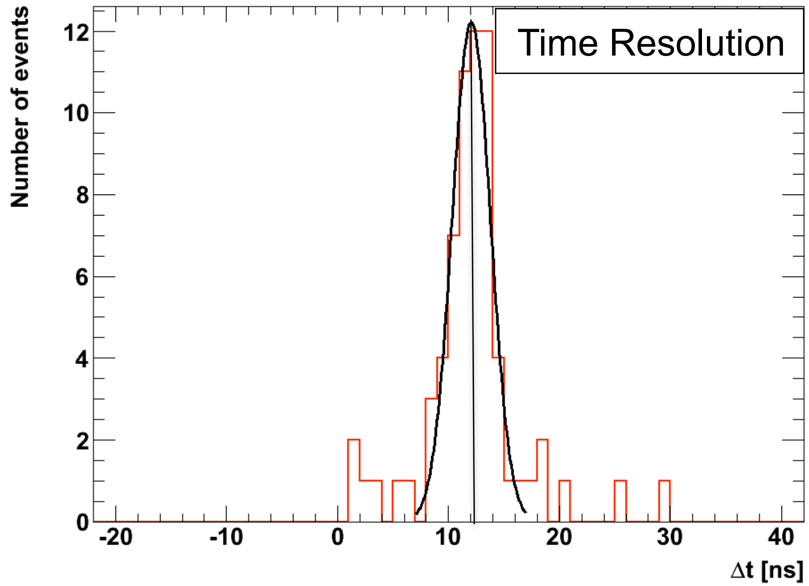


CMS Beam Condition Monitor (2)

- transfer of acquired 'know how' -

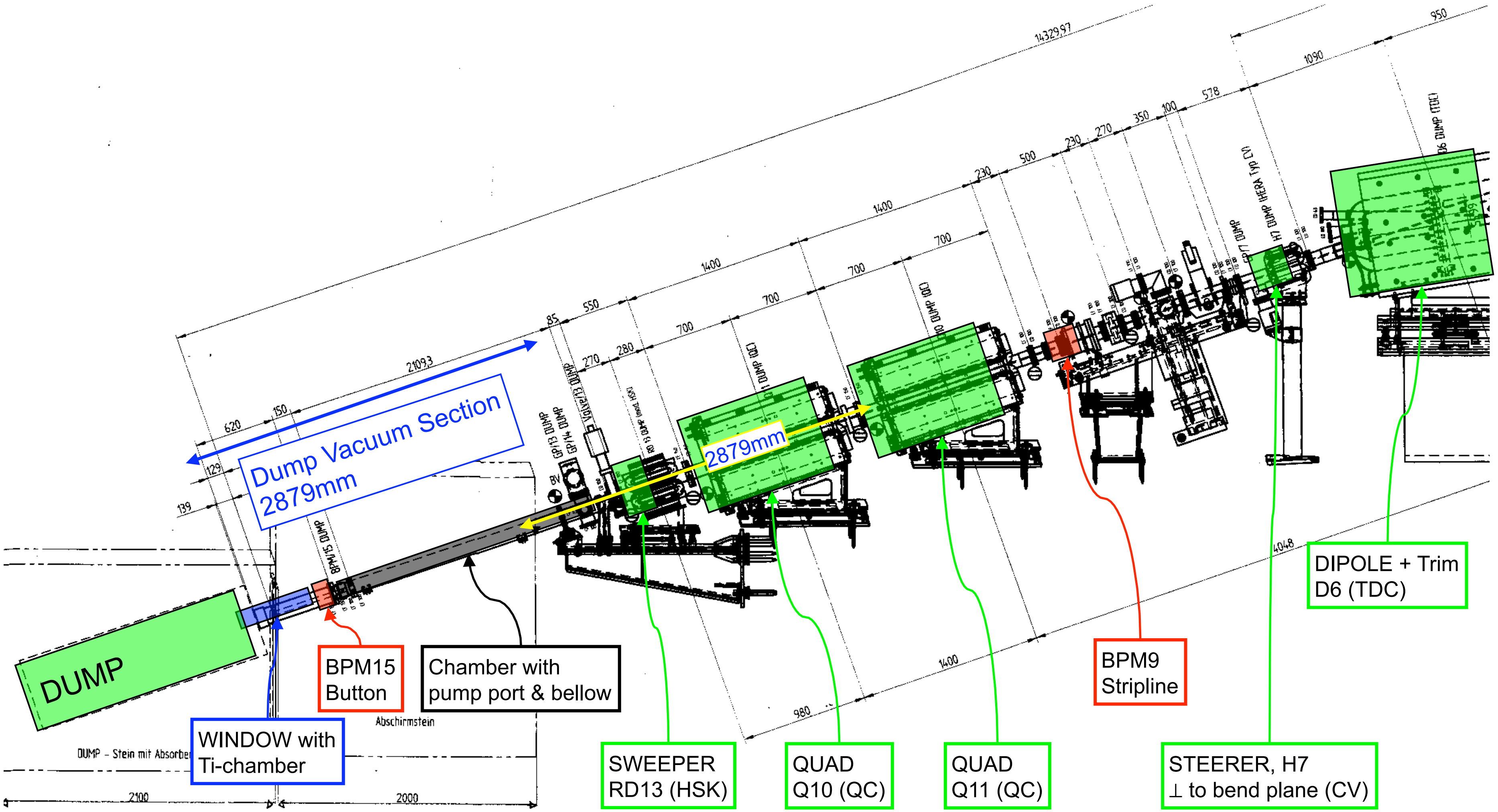
- BCM1F data
  - Landau/Gauss shaped amplitude spectrum: S/N > 12
  - Time resolution of signal peak values (ADC) < 2 ns (halo particles)
  - Readout will deliver spectra (ADC) and rates (TDC, counters)



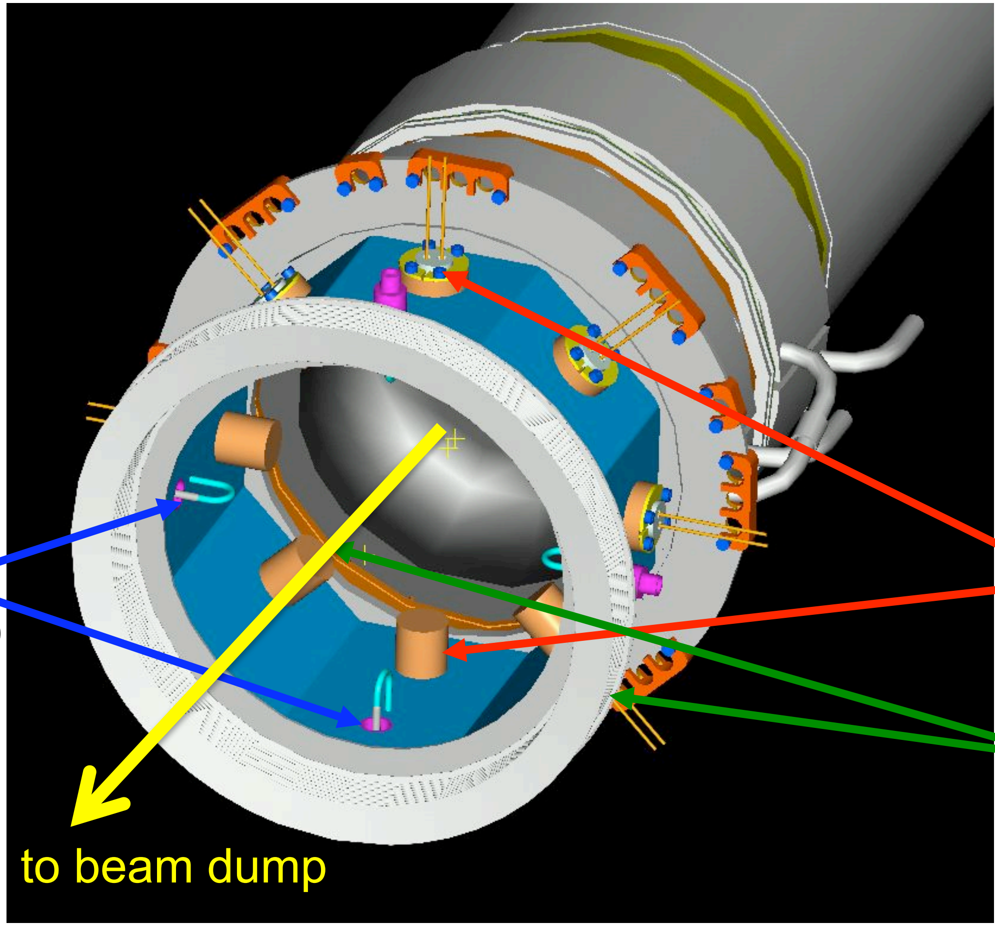


FLASH Beam Condition Monitor:

- transfer of acquired 'know how' -

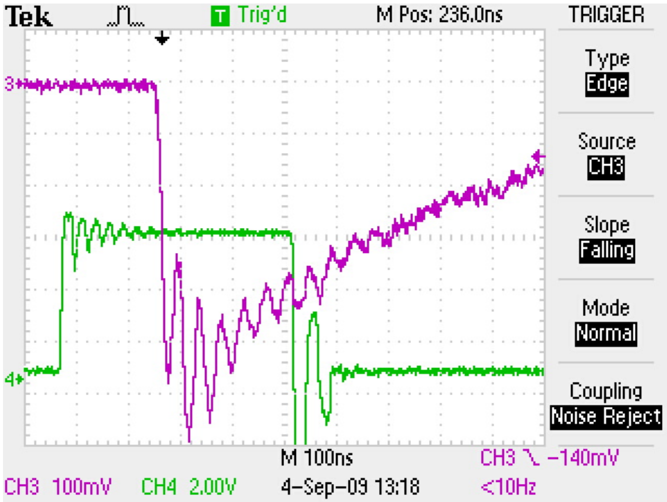


FLASH - Assembly



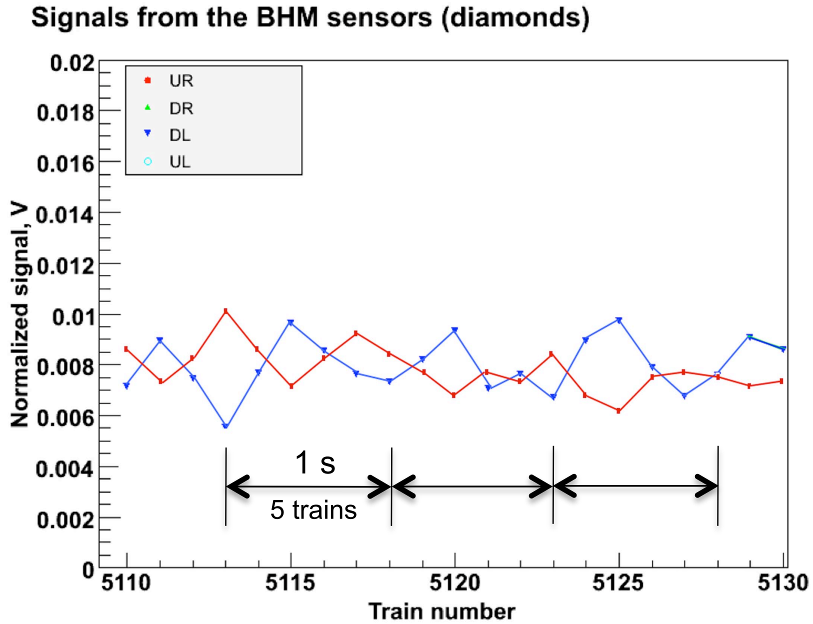
FLASH – Preliminary Results

signal (diamond), 9 mA run



magenta: diamond signal
green: bunch trigger

Signals 'up right' and 'down left' for a swept beam (T ~ 1 s)



bunch train repetition rate: 5 s^{-1}

Summary

- Successful work since last report
- Forward instrumentation for linear colliders 'bundled' under FCAL's roof: ILC as well as CLIC
  - Contribution to CLIC 'Conceptual Design Report' (2010)
  - Contribution to ILD 'Detailed Baseline Design' (2012)
- Detailed understanding of physics and instrumentation improves
- Sensor technology improves: test beam 2010
- ASIC design ongoing (LumiCal frontend and 10 bit ADC, BeamCal r/o chip)
- Outspin and knowledge transfer into other fields
- Development of radiation hard sensors expanding into sLHC
- Papers and presentations (most recent)
  - BCM1F (NIM), LumiCal frontend (NIM), 4 contributions to IEEE NSS (2008 and 2009), 2 contributions to TWEPP (2008 and 2009)
  - 1 PhD thesis, 4 Diploma theses

Acknowledgement

Thank you for your attention!

Spare Slides

Pair Monitor

The Pair Monitor (situated in front of BeamCal) is a silicon pixel detector. It measures the beam profile at the IP, using the distribution of the pair background from Beam Strahlung:

Identical charges with respect to the 'facing' beam are scattered with a large angle. Scattered particles represent information on beam shape.