Forward Calorimeters for the ILC

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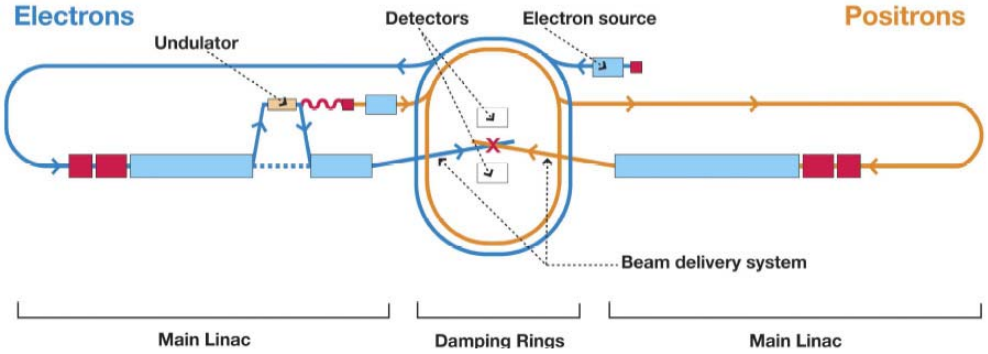
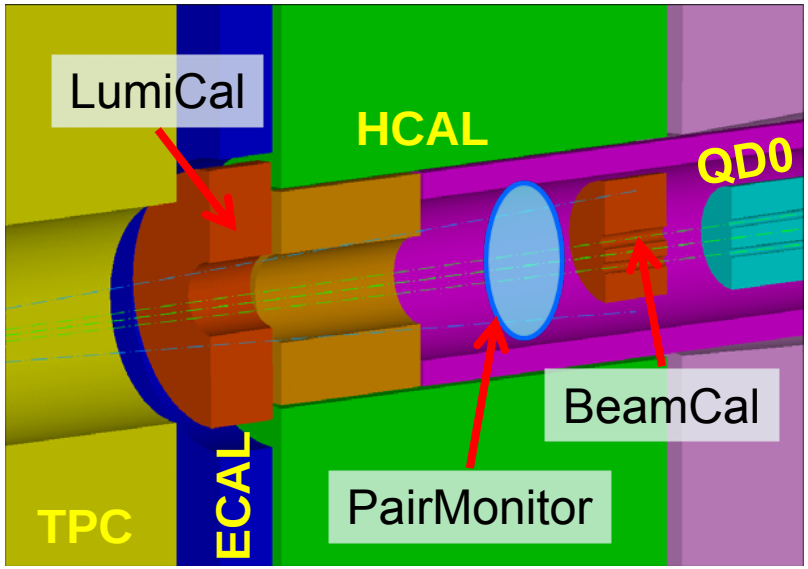
- FCAL Challenges at ILC
- Sub-Detectors and Ongoing R&D
- Outlook

2nd Helmholtz Alliance Detector Workshop
DESY
March 2009

Forward Calorimeters at the ILC



500 GeV centre-of-mass energy
Luminosity 2×10^{34} cm^{-2} s^{-1}
Polarization e- 80% e+ 30% (60%)
Beam σ_x~600 nm σ_y~6 nm σ_z~300 μm

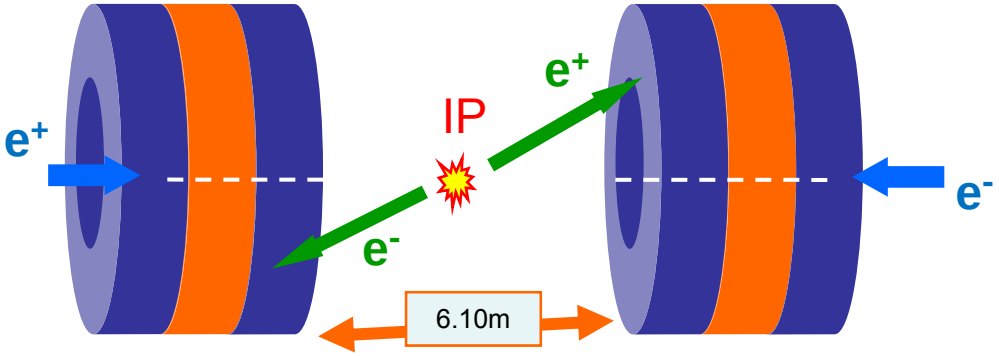


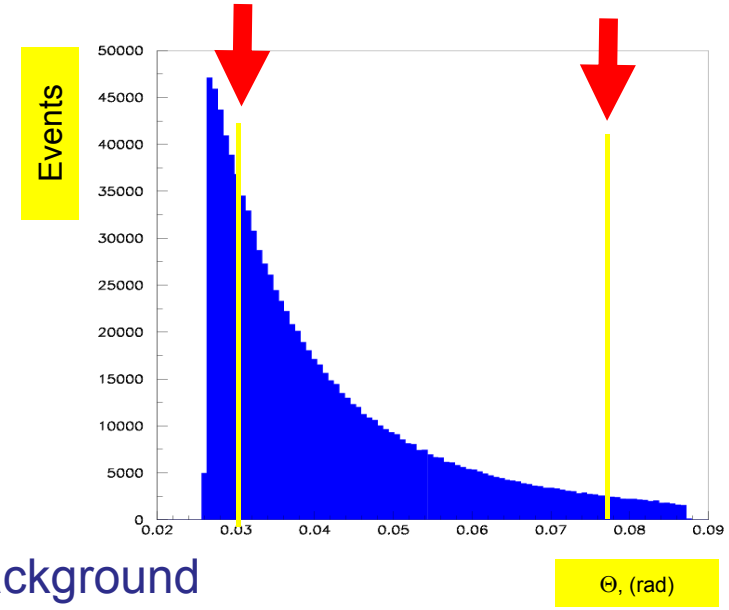
- 4 main very-forward detectors:

- LumiCal at 44-155 mrad
  → luminosity measurement ($\Delta L/L \sim 10^{-3}$-10^{-4})
- BeamCal at 5-45 mrad
  → fast beam diagnostics & feedback
  → electron veto
- Pair Monitor (1st layer of BeamCal)
  → beam parameter determination by measuring e^+e^- from beam-beam interactions
- GamCal at 100m distance to IP
  → beam diagnostics with beamstrahlung photons

LumiCal

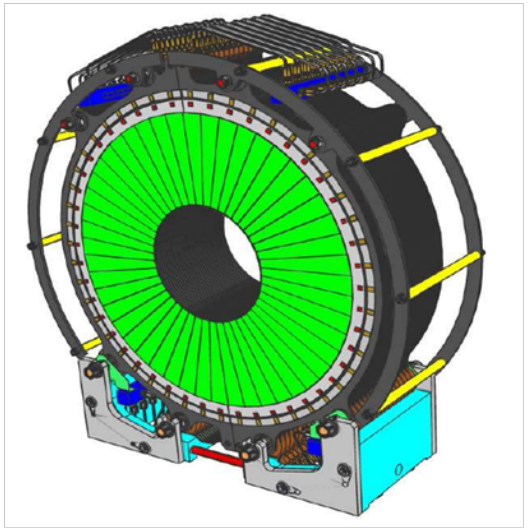
- Luminosity measurement using Bhabha events $e^+e^- \rightarrow e^+e^-$ like at LEP: $L \sim N/\sigma_{theory}$
- Cross-section ~ θ^{-3} → precise fiducial volume and small angular bias





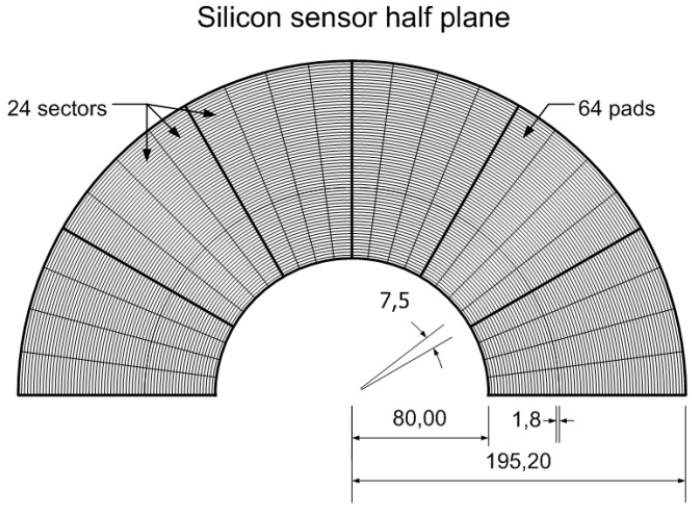
- Compact calorimeter → small Moliere radius
- Well measured energy scale ~ 0.1%

  → reduce radiative events and two-photon background



- W/Si sandwich calorimeter with 30 layers
- 3 mm tungsten absorbers
- 300 µm Si sensors
- 64 radial and 48 azimuthal divisions

LumiCal Sensors

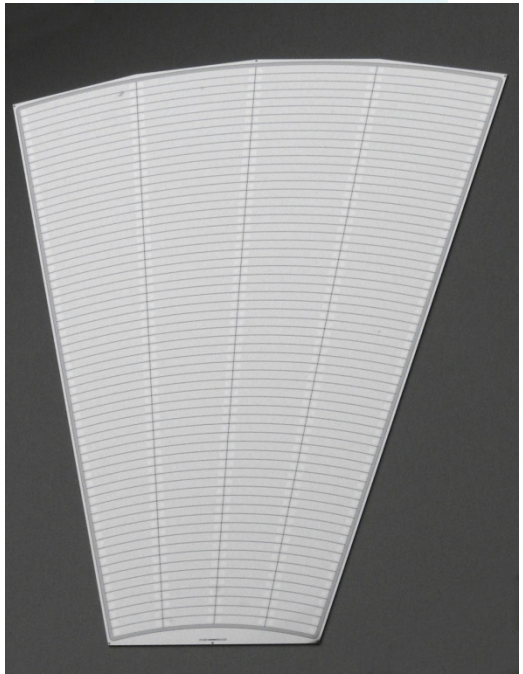


- n-type silicon, p+ strips, n+ backplane
- 320 µm thickness ±15 µm
- Strip pitch: 1.8 mm
- Strip p+ width: 1.6 mm
- Strip Al width: 1.7 mm

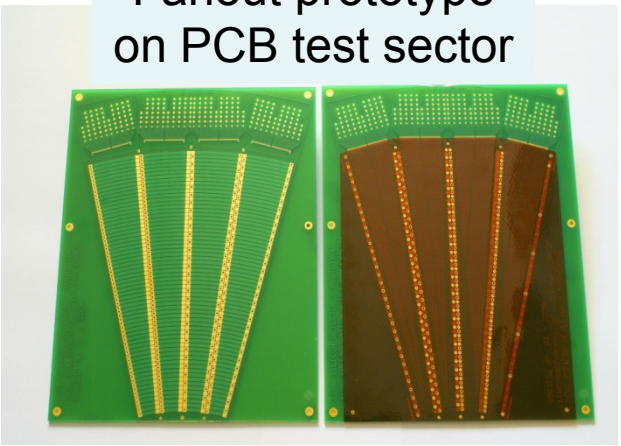
- Prototype produced by Hamamatsu arrived in March
- Measurement of the sensor characteristics started

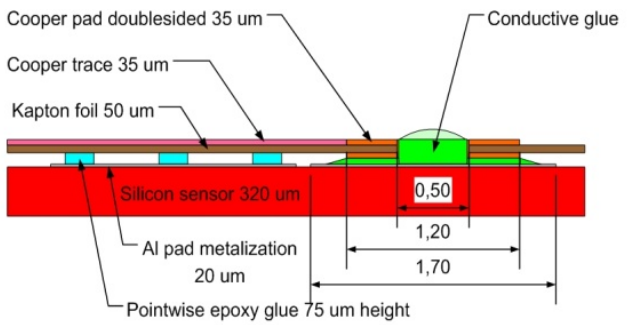
- In parallel: development of the fanout

First Prototype



Fanout prototype on PCB test sector

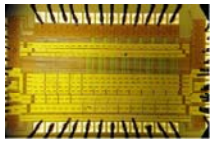


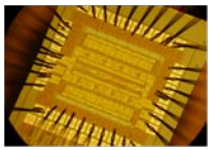


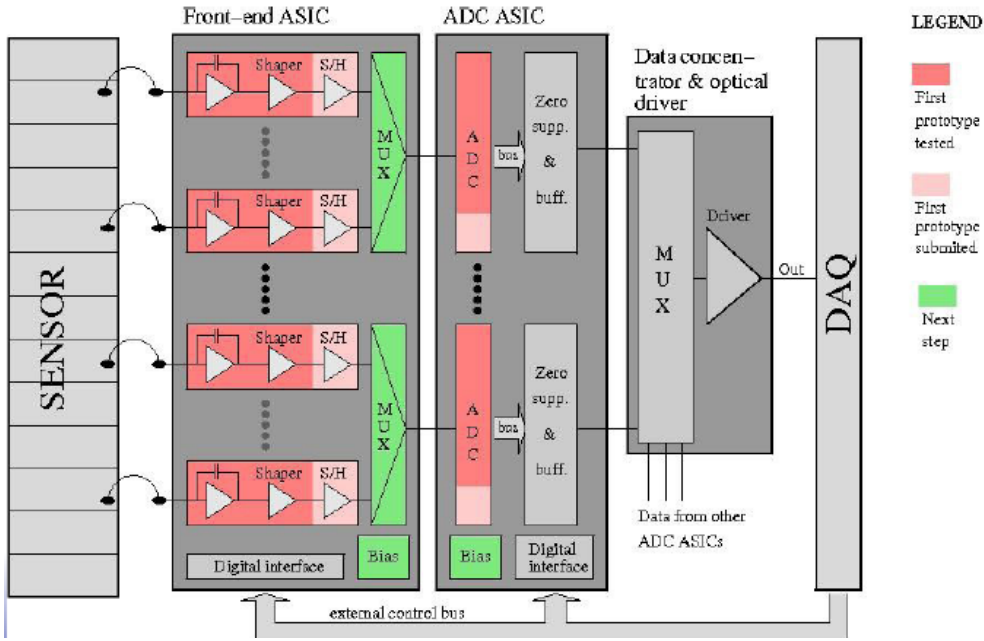
Bump bonding

LumiCal Front-end

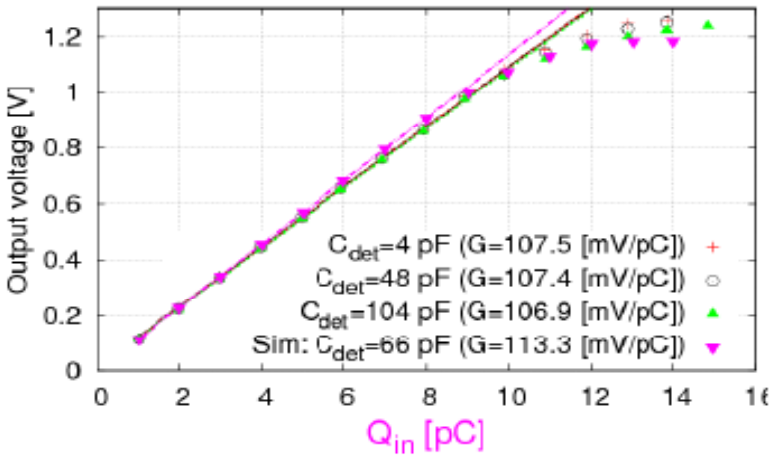
- 200000 readout channels
- R&D goal: ~1000 channels (now: a few)
- 0.35 µm CMOS ASICs
- first frontend and ADC prototypes tested
- Pre-amp, pole zero cancellation, shaper
- Active MOS and passive R feedback with similar results in physics mode
- 10-bit pipelined ADC 1.5 bit/stage



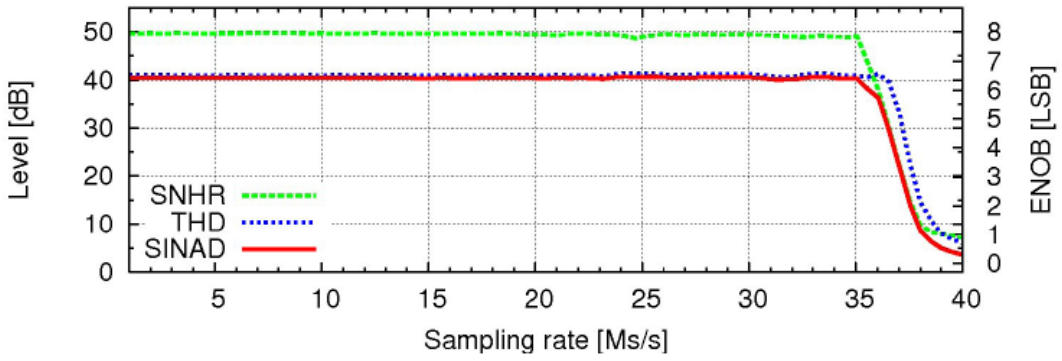




Physics mode



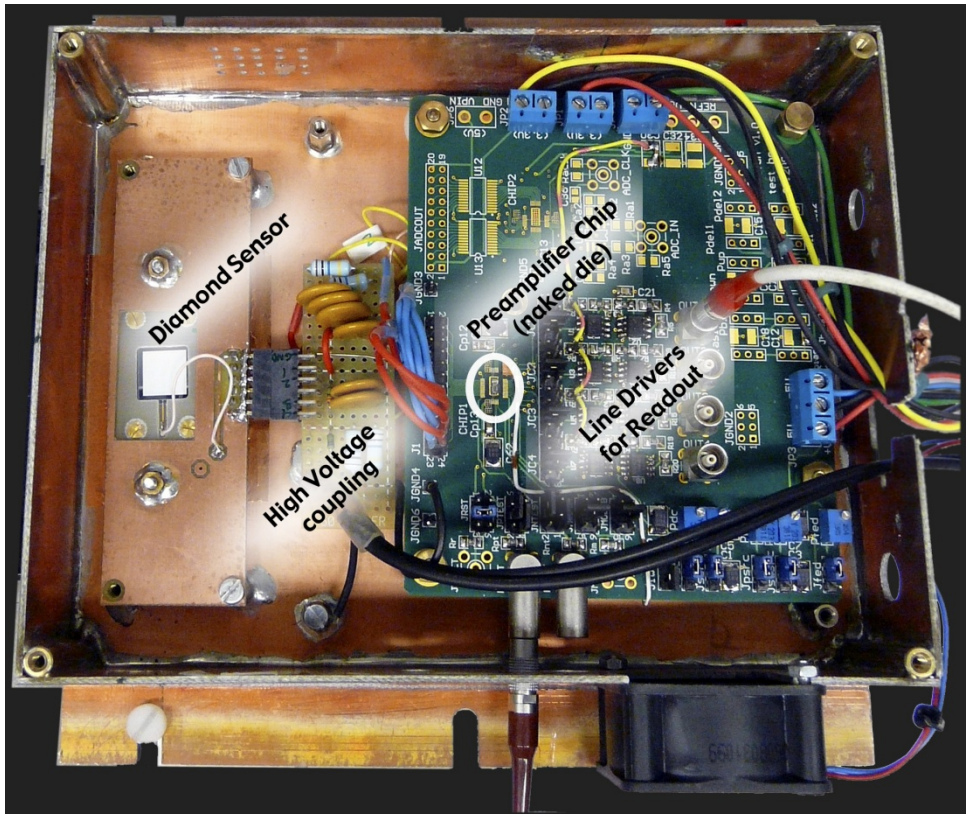
gain test results with different detector capacitance



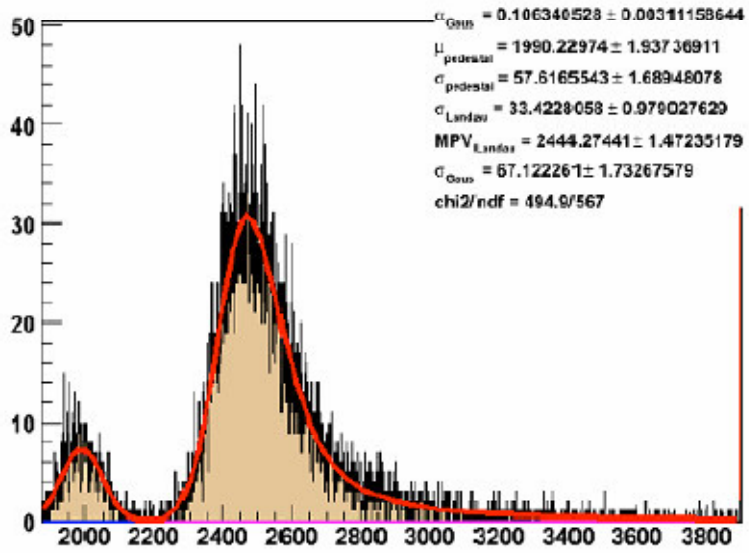
ADC dynamic performance
→ more work needed (stage nonlinearities)

LumiCal Front-end

- First successful test of the analog front-end with a single-pad sensor

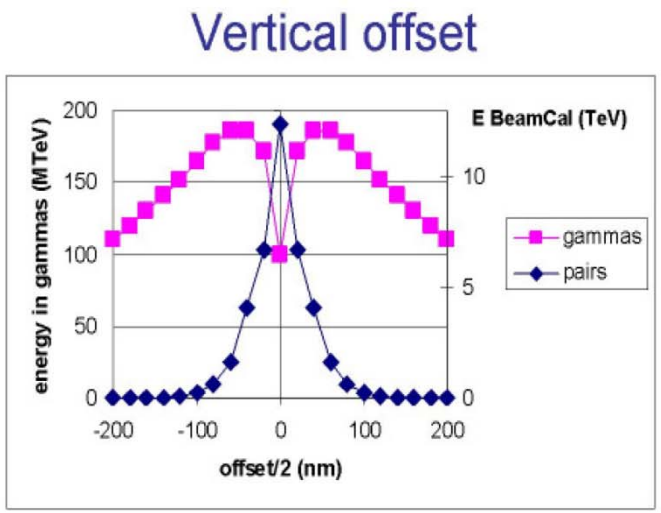


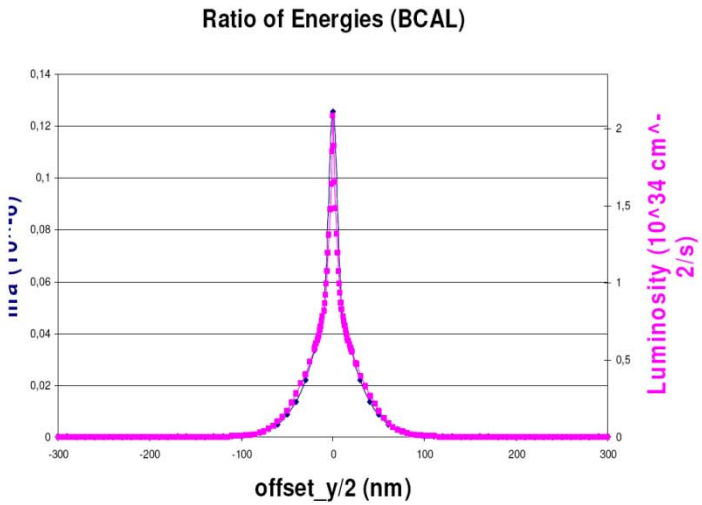
Si detector, MOS preamp.



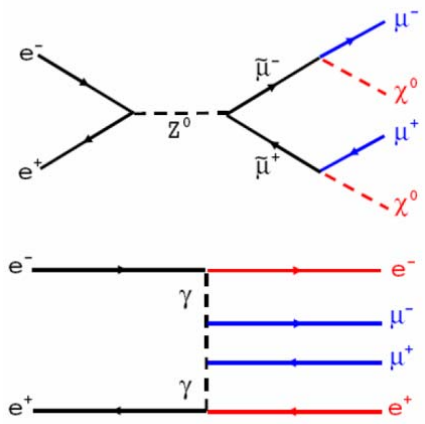
BeamCal Physics

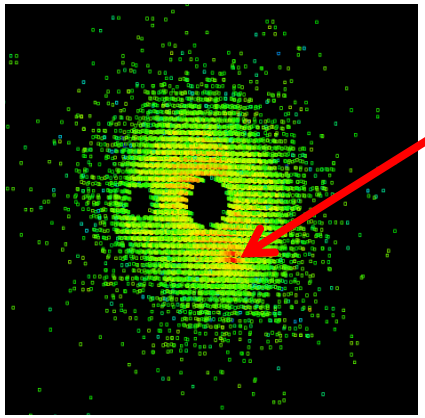
- Luminosity can be optimised by measuring e^+e^- pairs (BeamCal/Pair Monitor) and beamstrahlung photons (GamCal) → fast readout and feedback loop
- Example:



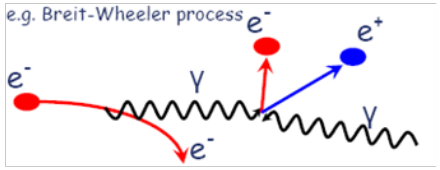


- BeamCal shall tag forward electrons from two-photon processes as background to SUSY:



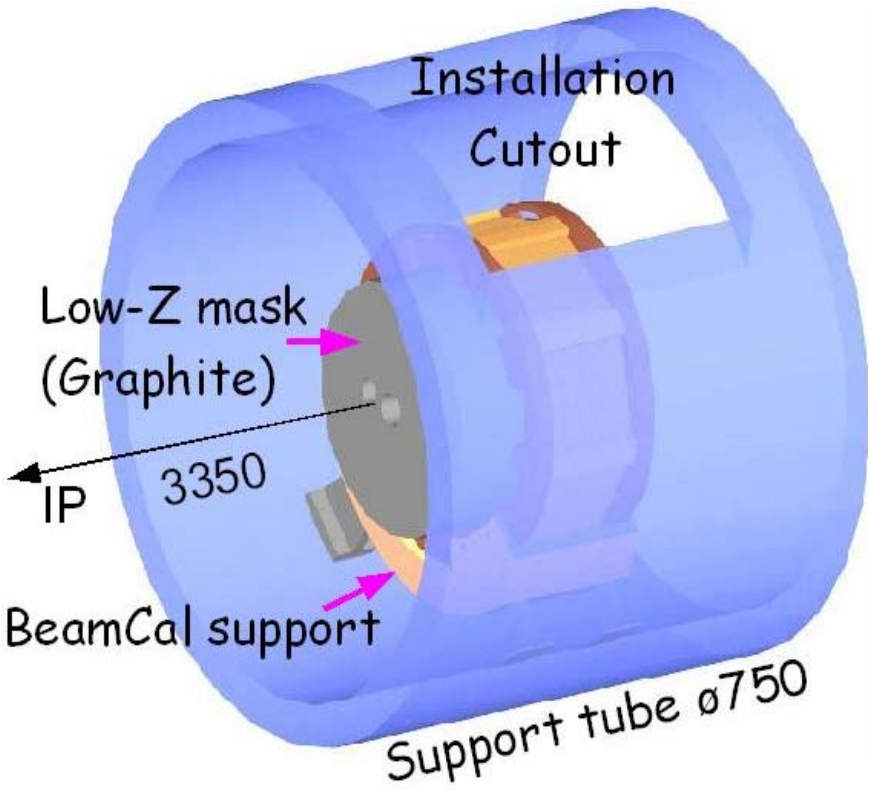


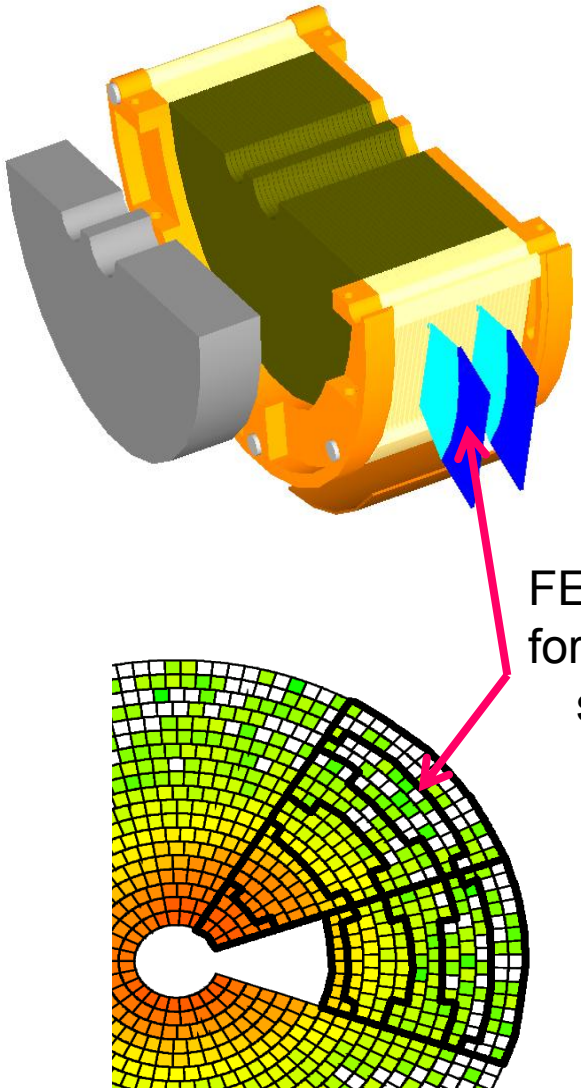
Identify single electron in background of 10^4 beamstrahlung pairs



→ high radiation dose 10 MGy/a

BeamCal Design





- W sandwich calorimeter with 30 layers
- 3 mm tungsten absorbers
- 8 radial sectors with 1280 channels each

BeamCal Sensor Materials

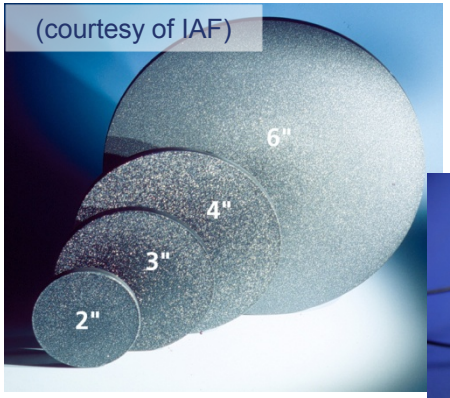
- pCVD diamonds:
- radiation hardness under investigation (e.g. LHC beam monitors, pixel detectors)

- GaAs:
- semi-insulating GaAs, doped with Sn and compensated by Cr

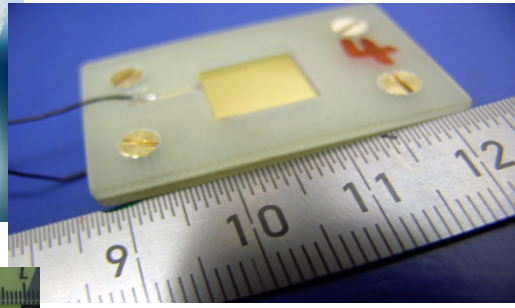
- SC CVD diamonds:
- available in sizes of mm^2

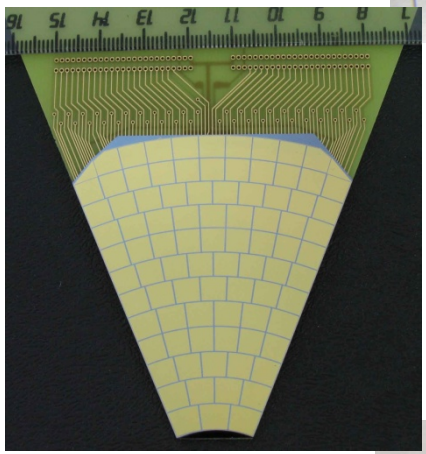
- Sapphire (Al_2O_3) and Quartz (SiO_2)

CVD: Chemical Vapor Deposition

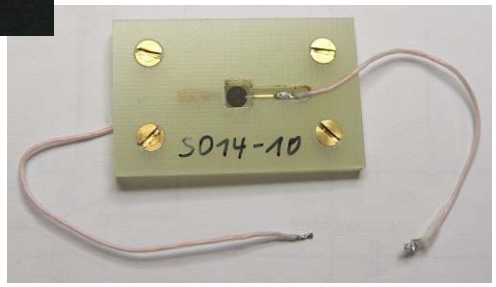


polycrystalline CVD diamond





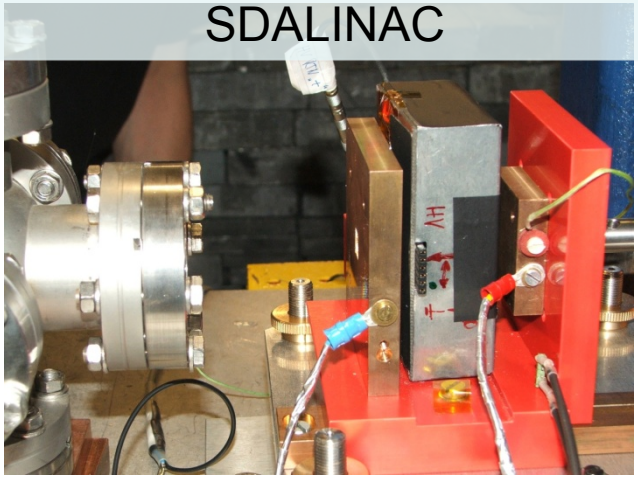
GaAs



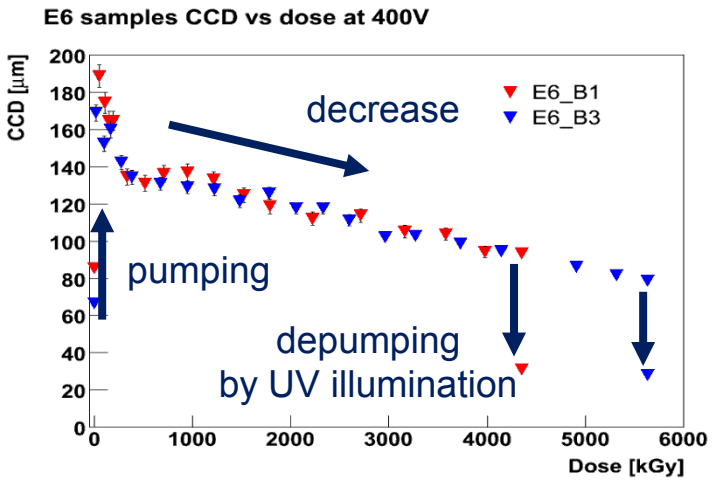
Single crystal CVD diamond

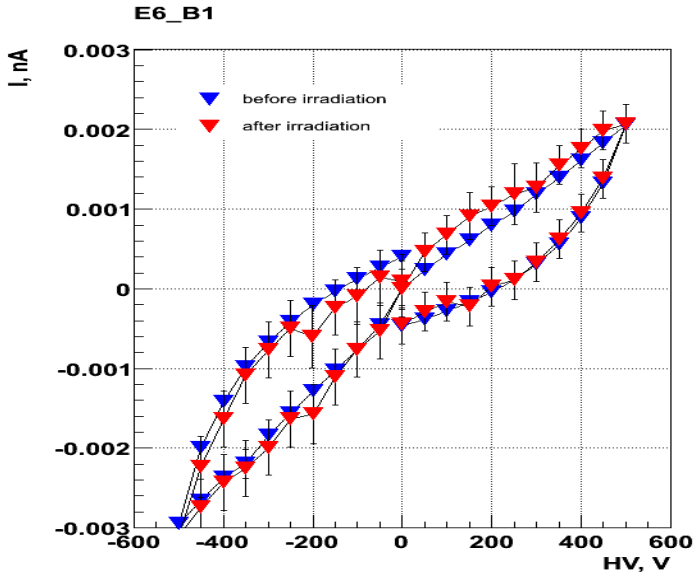
BeamCal Sensors

Irradiation tests at TU Darmstadt SDALINAC



Charge Collection Depth vs. dose for pCVD diamond

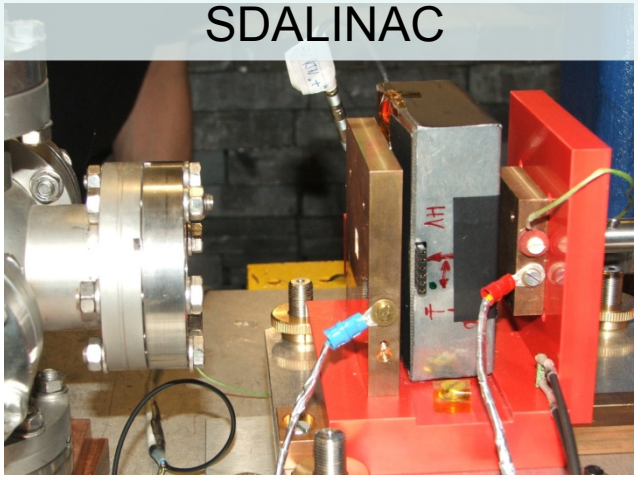




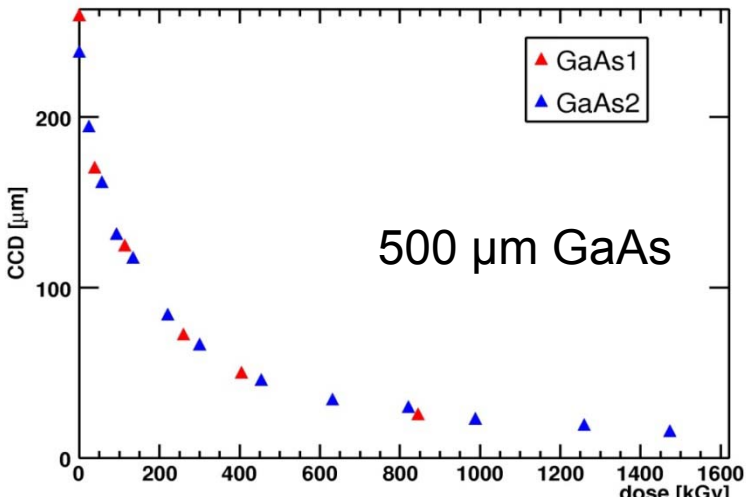
No increase of leakage current (at room temperature)

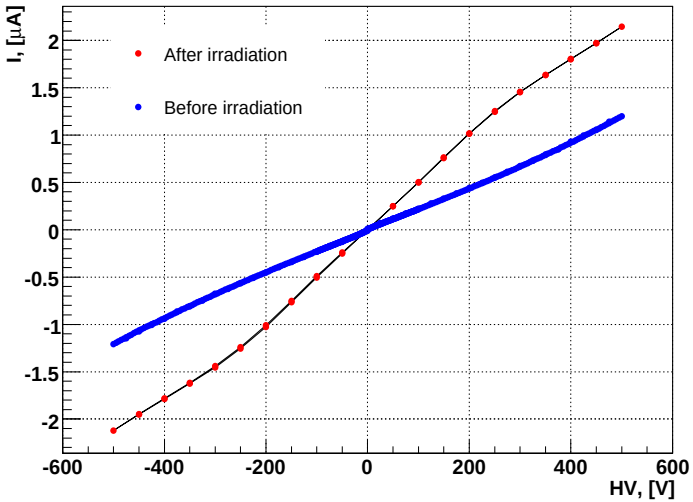
BeamCal Sensors

Irradiation tests at TU Darmstadt SDALINAC



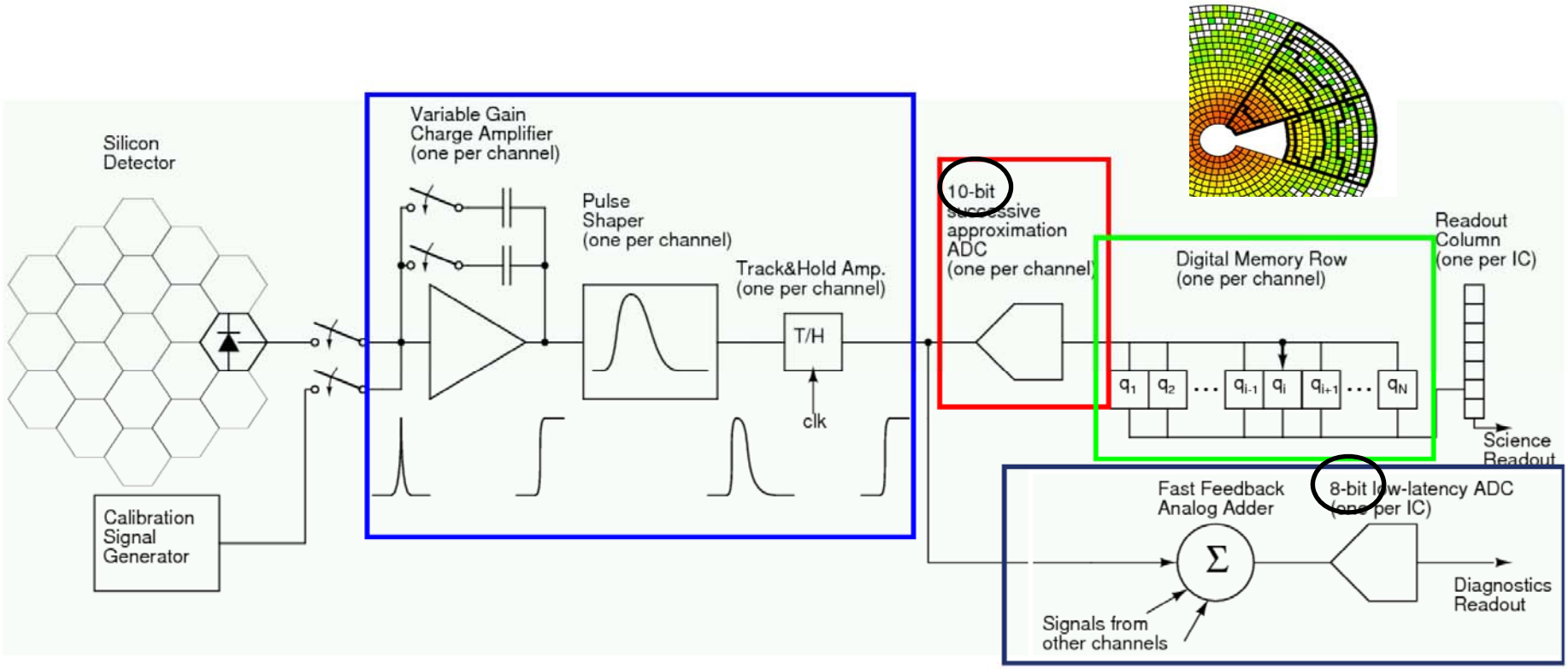
Charge Collection Depth vs. dose for GaAs





Acceptable increase of leakage current

BeamCal Front-End

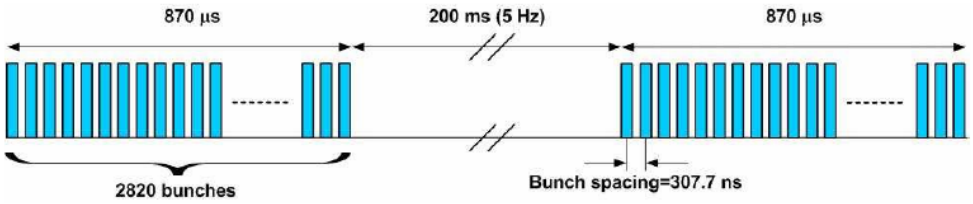


- Dual-gain front-end electronics: charge amplifier, pulse shaper and T/H circuit
- Successive approximation ADC, one per channel
- Digital memory, 2820 (10 bits + parity) words per channel
- Analog addition of 32 channel outputs for fast feedback; low-latency ADC

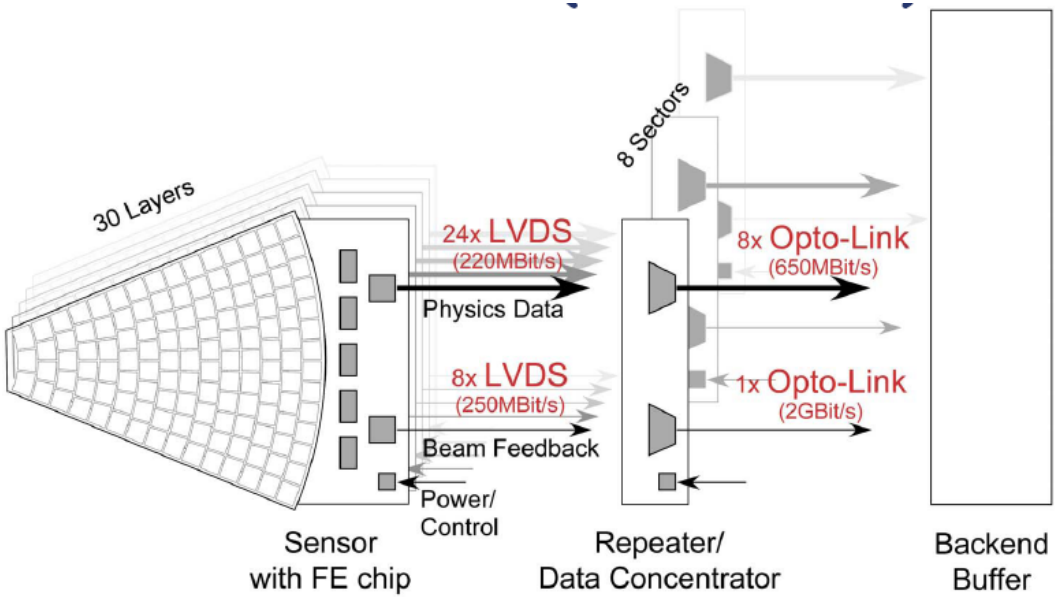
Prototype in 0.18-μm TSMC CMOS technology

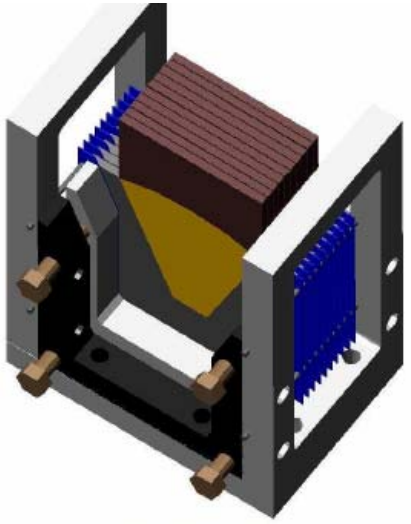
BeamCal Read-Out

- physics data of 130 MB per bunch train: buffered and read out in 200 ms gap
  - 5 GB/s per sector for 8 sectors with 30 layers each
- beam feedback data: fast readout at 3 MHz with 2 GB/s per sector



- different frontends are being discussed - connected to readout

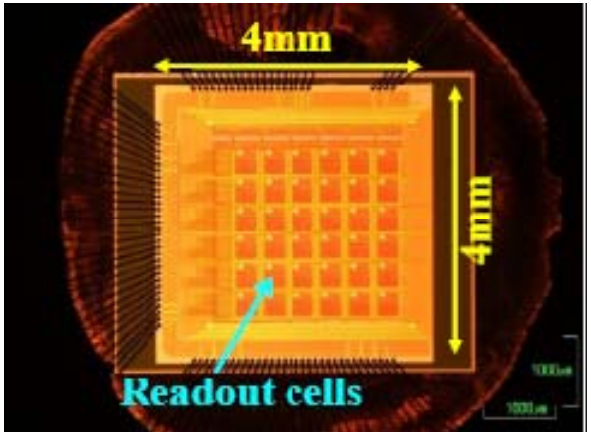


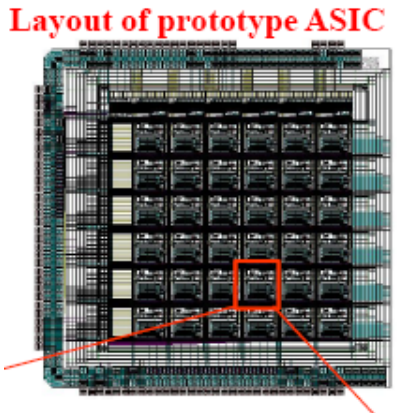


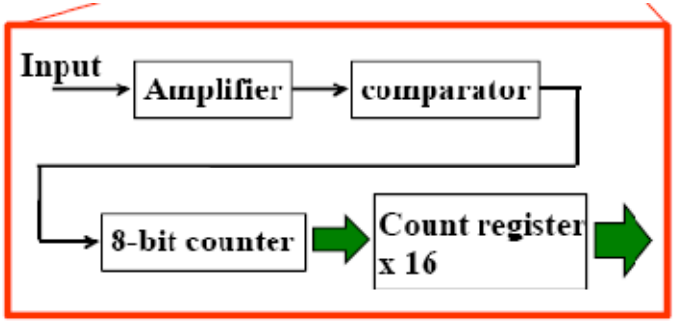
- prototype test with 1 sector 10 layers foreseen in 2012

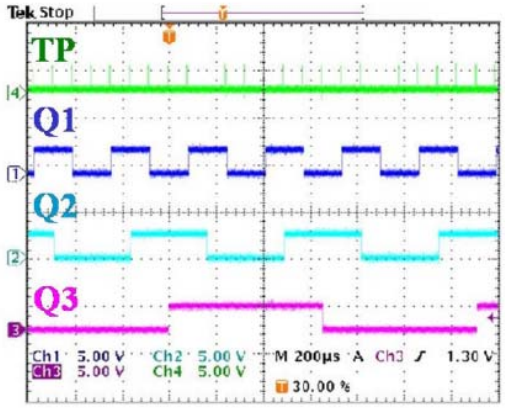
Pair-Monitor Front-End

- ASIC for the pair monitor
- .25 µm TSMC technology
- number of pixels: 36
- Pixel size: 400 x 400 µm^2
- Prototype produced and tested



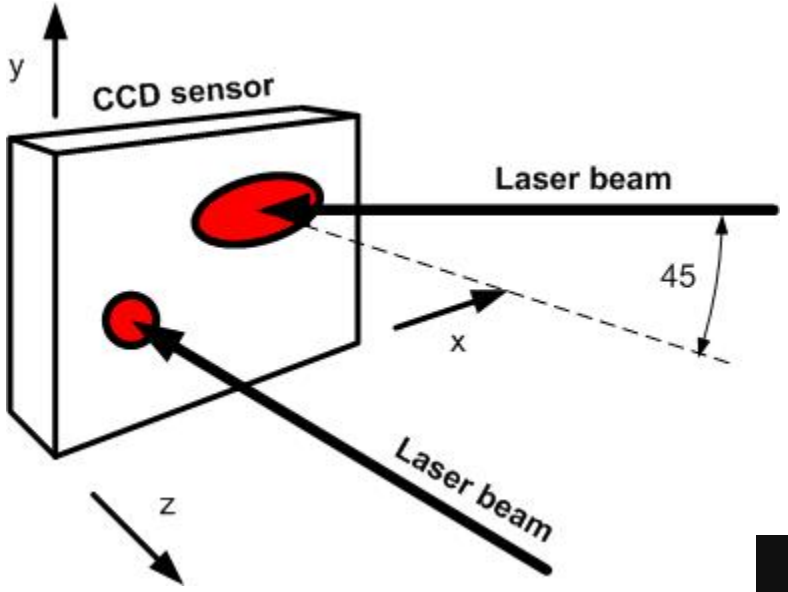


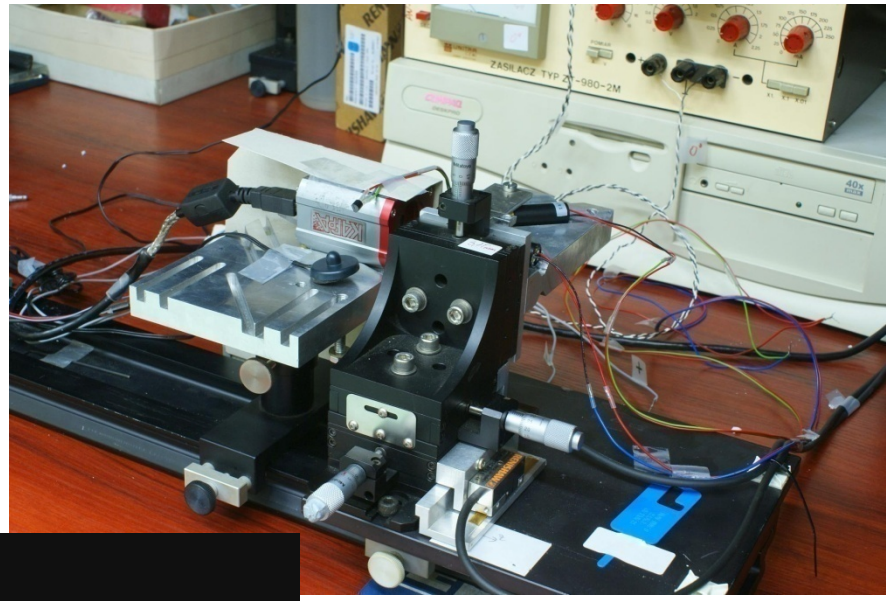


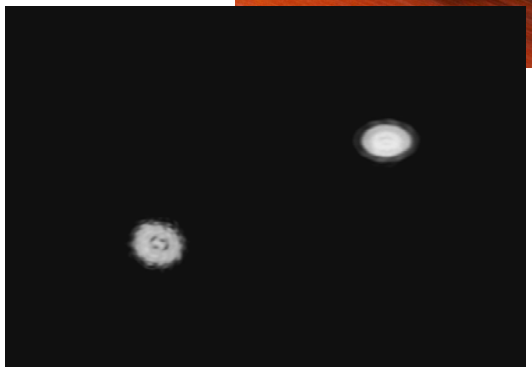


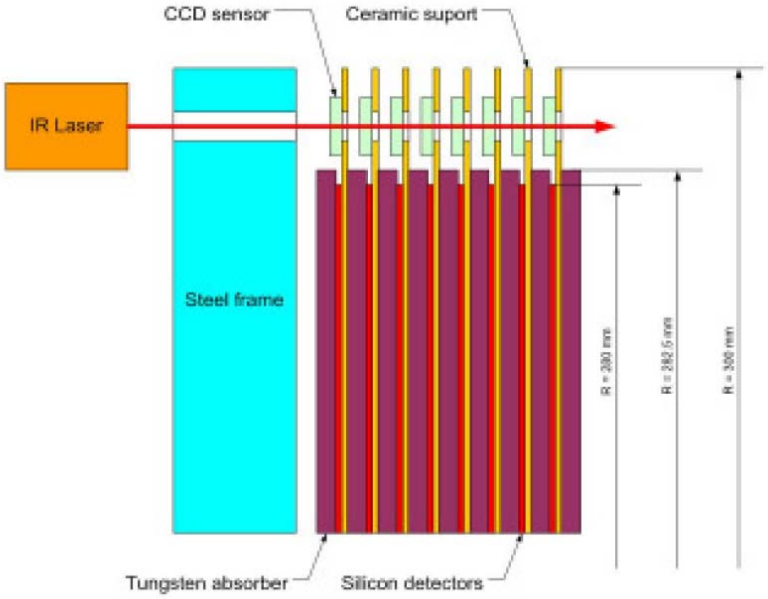
- Pair monitor will use Silicon-on-Insulator technology in next step
- prototype 2009

Laser Alignment System









- Over short distances accuracies reached:
- Displacements in x-y plane: ± 0.5 μm
- Displacements in z direction: ± 1.5 μm

Summary and Outlook

- FCAL R&D is actively pursued
- In Germany mainly at DESY: sensors and readout
- Letter Of Intend for the ILD is being prepared
- Interesting work is ongoing

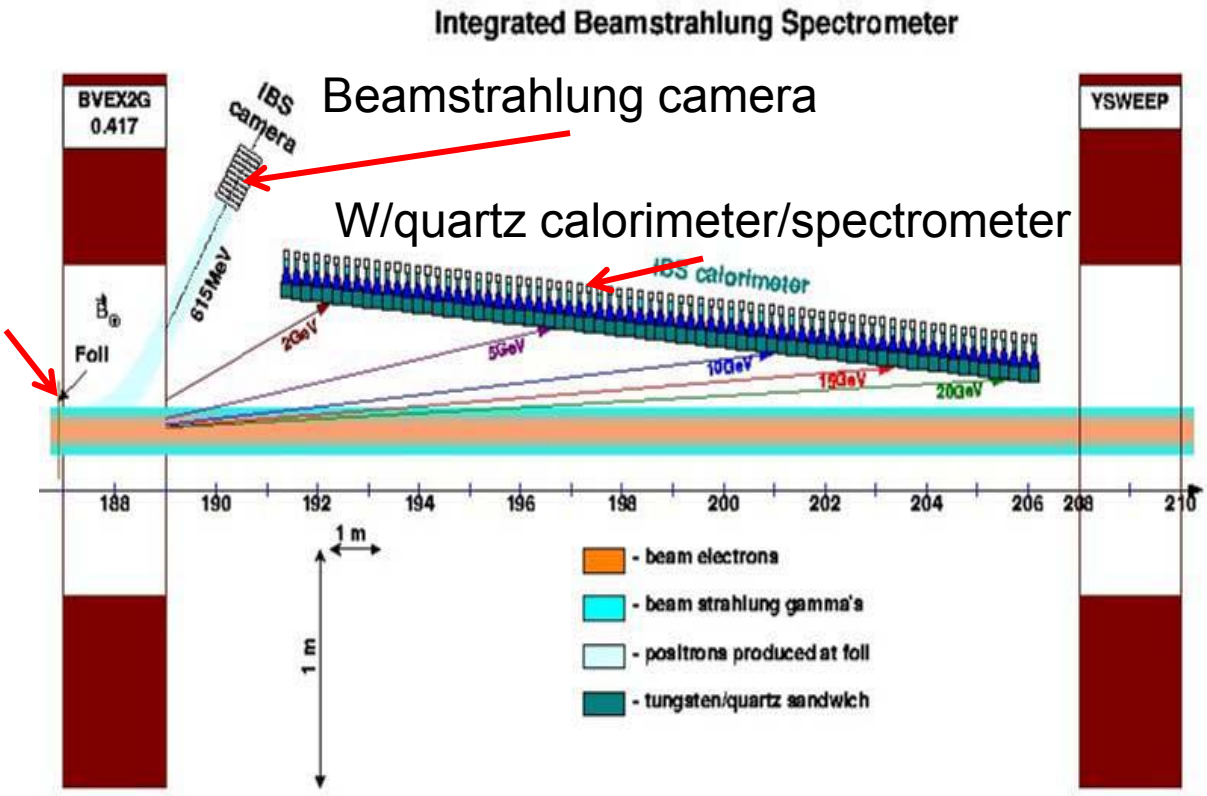
- thank's to the members of the FCAL collaboration for material and slides

Backup

GamCal Design

- Beam parameters can be measured more precisely if beam photon energy is measured → uncertainties on σ_z, Δx, ε_x, … reduced by a factor of ~2
- GamCal at ~100m from IP

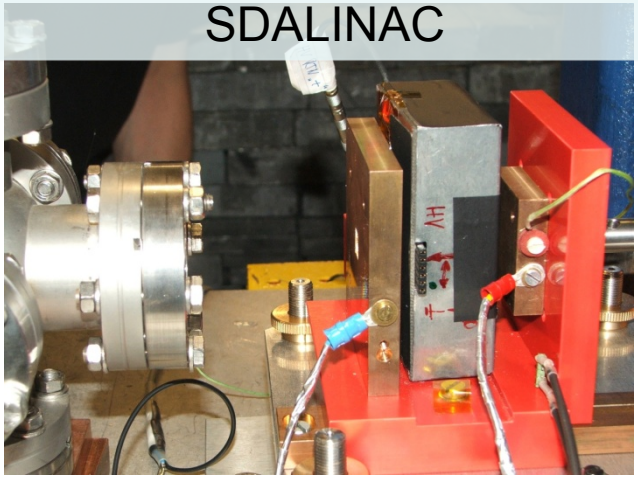
thin foil (diamond) induces $\gamma_{beam} \rightarrow e^+e^-$



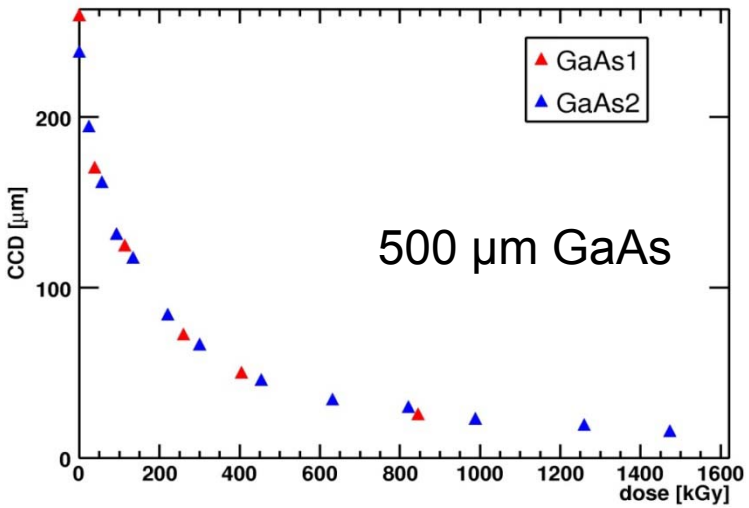
- Still in design phase → more MC simulations needed

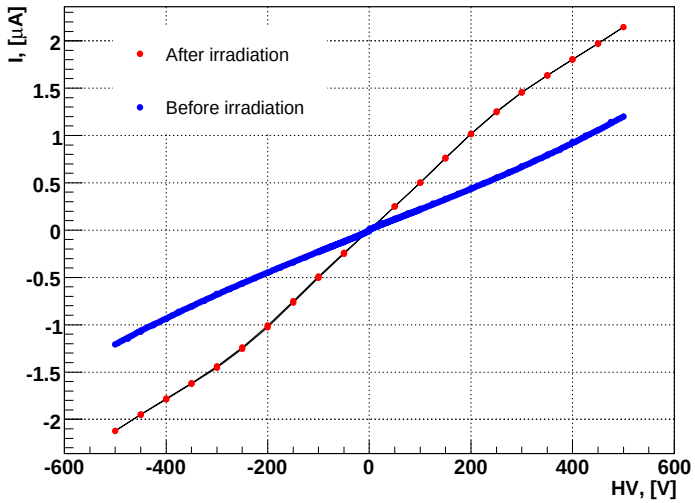
BeamCal Sensors

Irradiation tests at TU Darmstadt SDALINAC

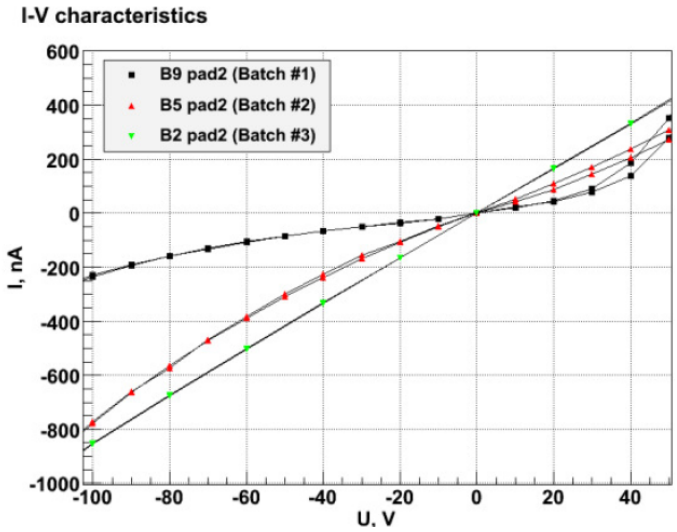


Charge Collection Depth vs. dose for GaAs





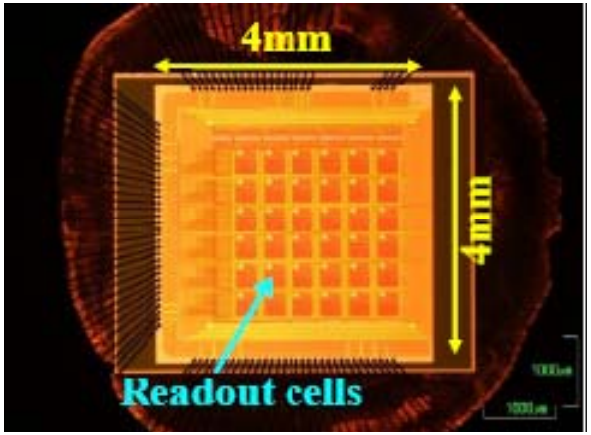
Acceptable increase of leakage current

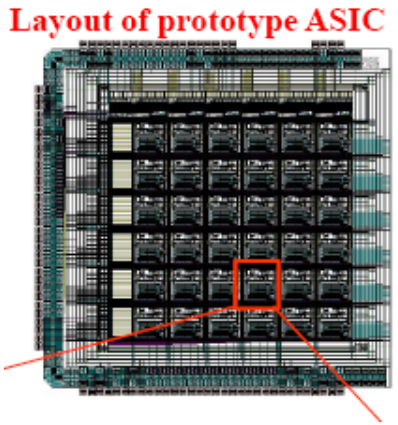


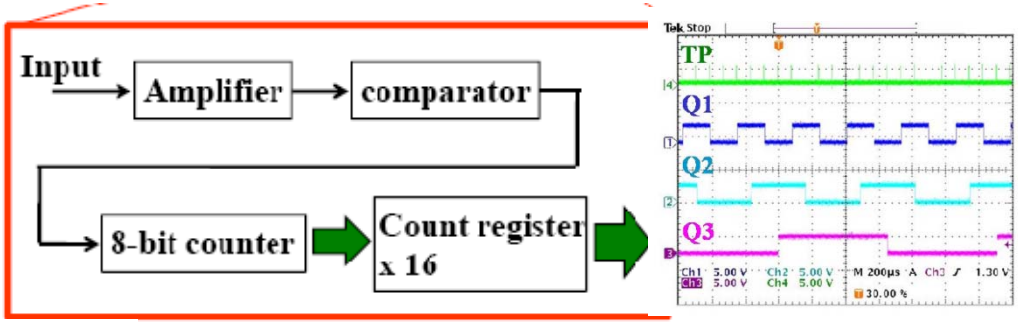
Current increases with Cr concentration
CCEfficiency decreases

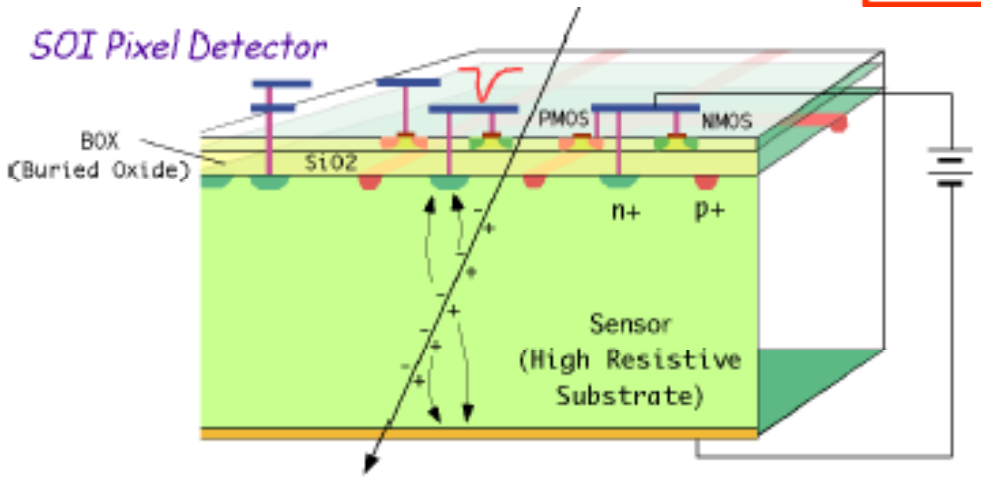
Pair-Monitor Front-End

- ASIC for the pair monitor
- .25 µm TSMC technology
- number of pixels: 36
- Pixel size: 400 x 400 µm^2
- Bump bonding to a sensor
- Prototype produced and tested





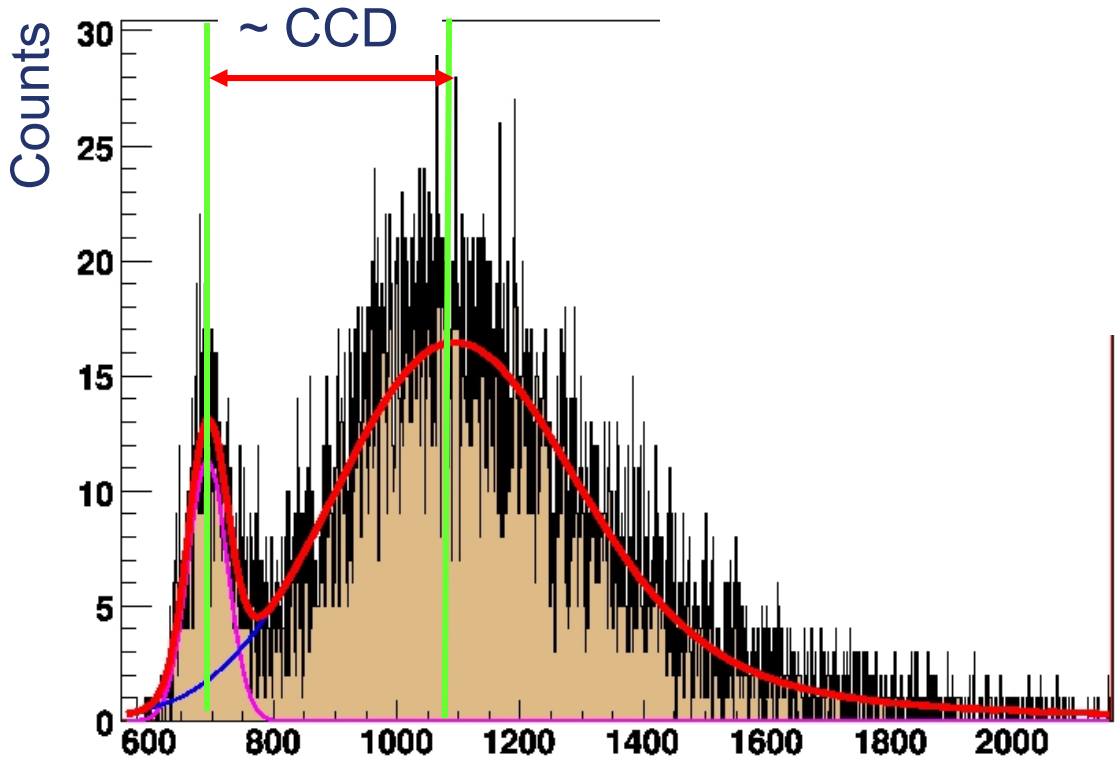




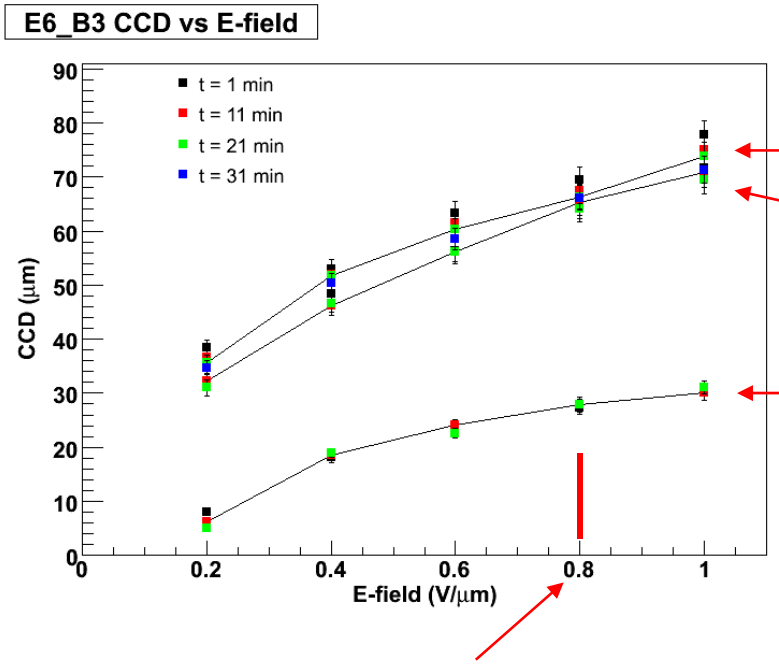
- Pair monitor will use Silicon-on-Insulator technology in next step
- prototype 2009

CCD Measurement

CCD = *Charge Collection Distance*
= mean drift distance of the charge carriers
= charge collection efficiency x thickness (assuming 36 ionized e-h pairs per µm)



CCD Behaviour after Irradiation

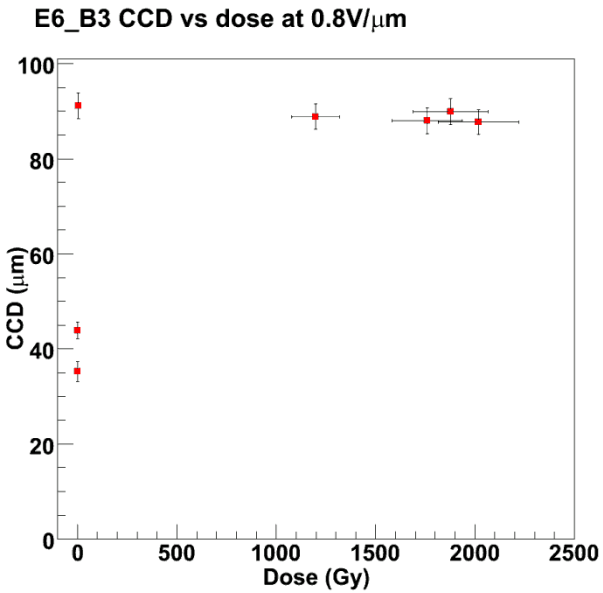


Before irradiation

After irradiation before UV illumination

After irradiation, UV illuminated

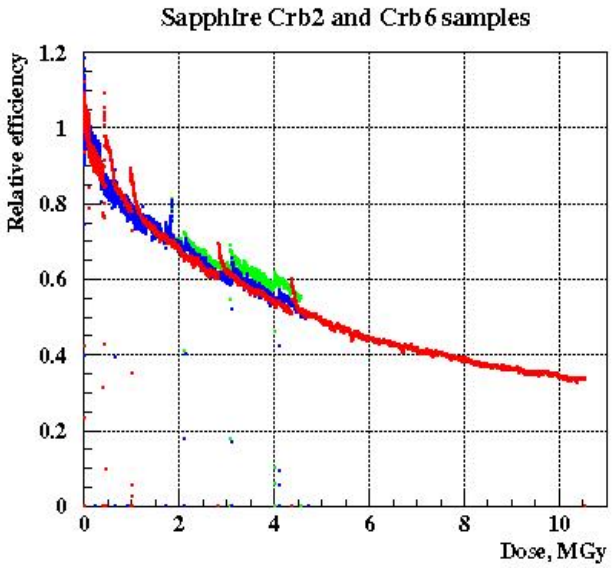
Value used at testbeam

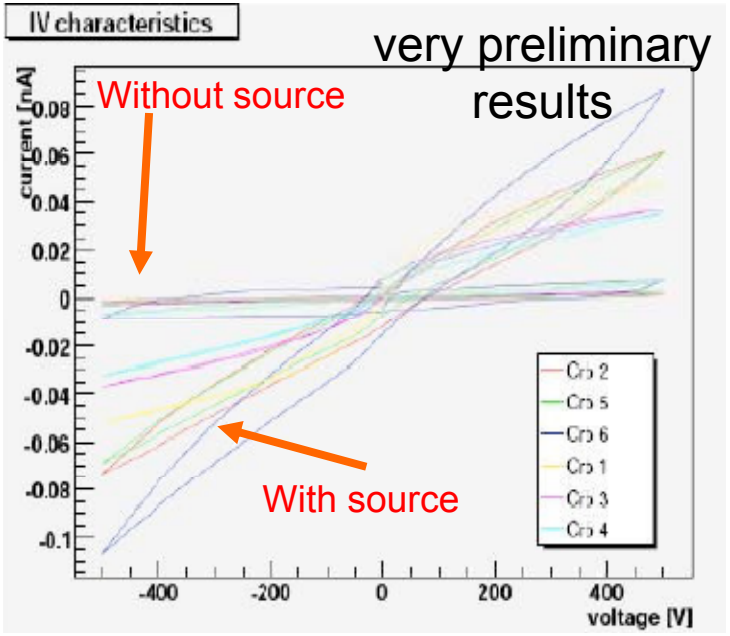


BeamCal Sapphire and Quartz Sensors

Single crystal sapphire

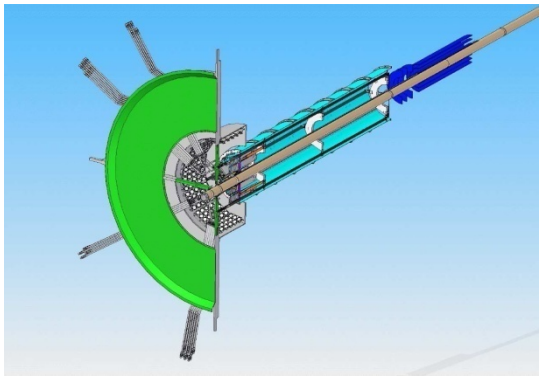
- CCE is a few %
- At a dose of ~12 MGy the signal current dropped to 30 % of its initial value
- 12 MGy ~ 10^{17} e^-/cm^2

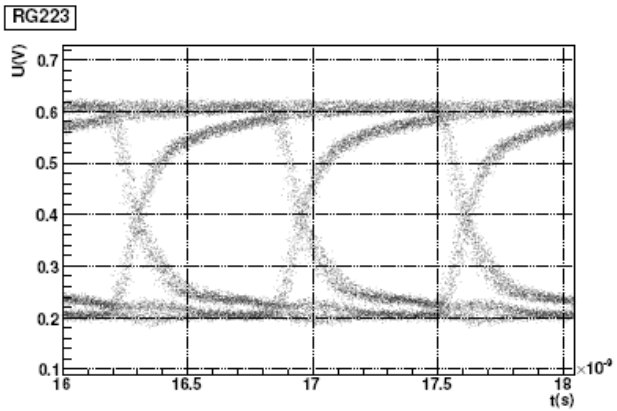


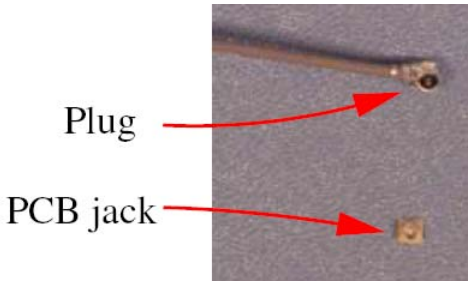


Synergy With SLHC: RadHard Serial Links

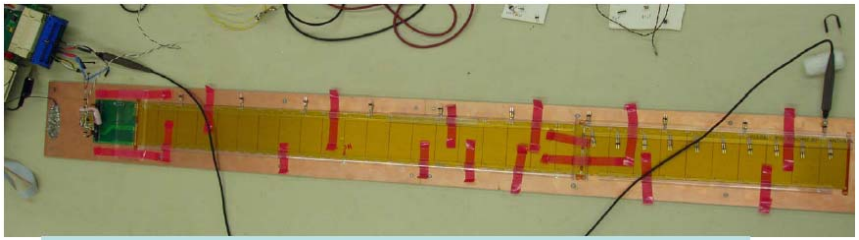
- Coax cables from FE to optical links with ~1.5 Gb/s (SLAC)

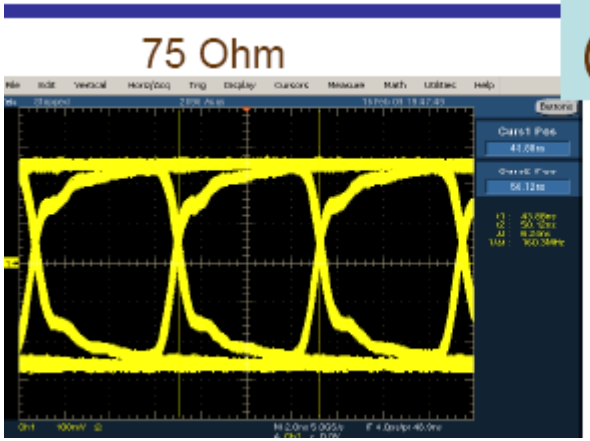






- Flex cables (SLAC,Oxford,UCSC)

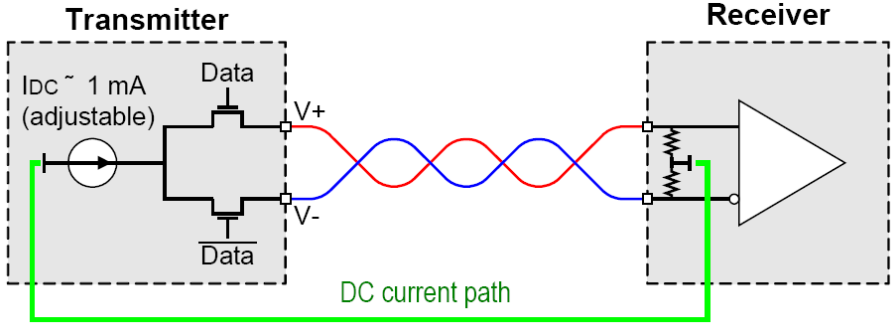




@160 MHz

C = 0 pF

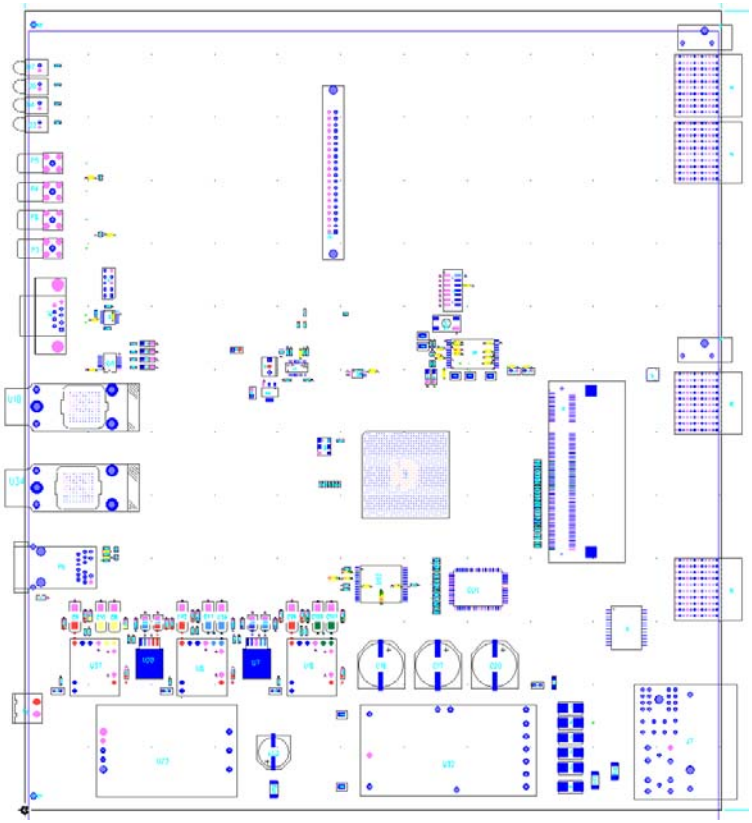
- Low-power twisted pair cable with ~160 Mb/s (PSI): LVDS → LCDS



Synergy With SLHC: ATCA Technology

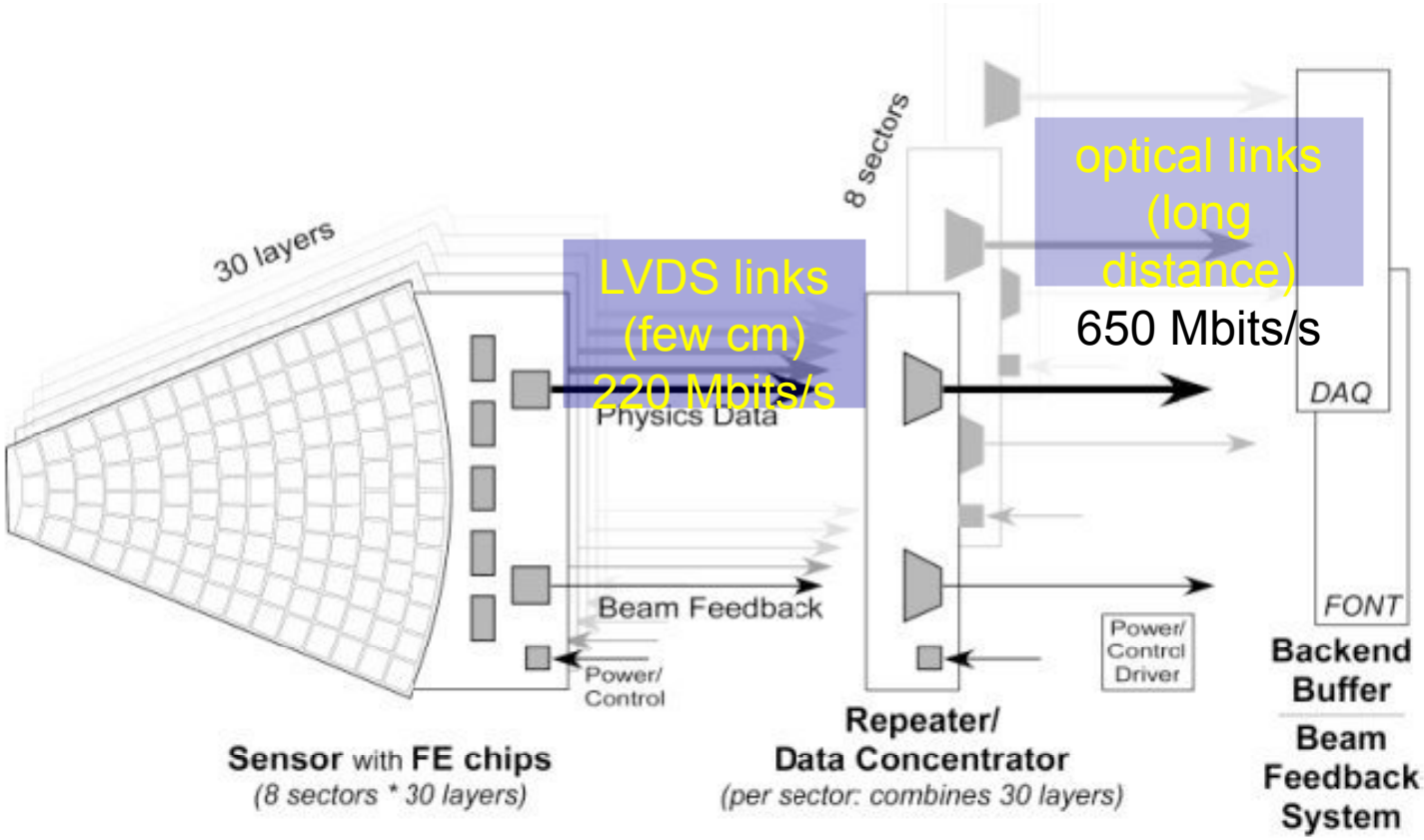
- ATCA shelf systems are used at DESY in XFEL control systems
- Planned to be used in ATLAS trigger/readout at SLHC

ATCA ReadOutDriver prototype



TU Dresden: LumiCal Readout

- current plans: LumiCal readout system requirements and design in 2009
  → from ADC to data-concentrator to optics to ?
- in 2010: prototyping based on new ATLAS prototype readout?



- more thoughts needed ...