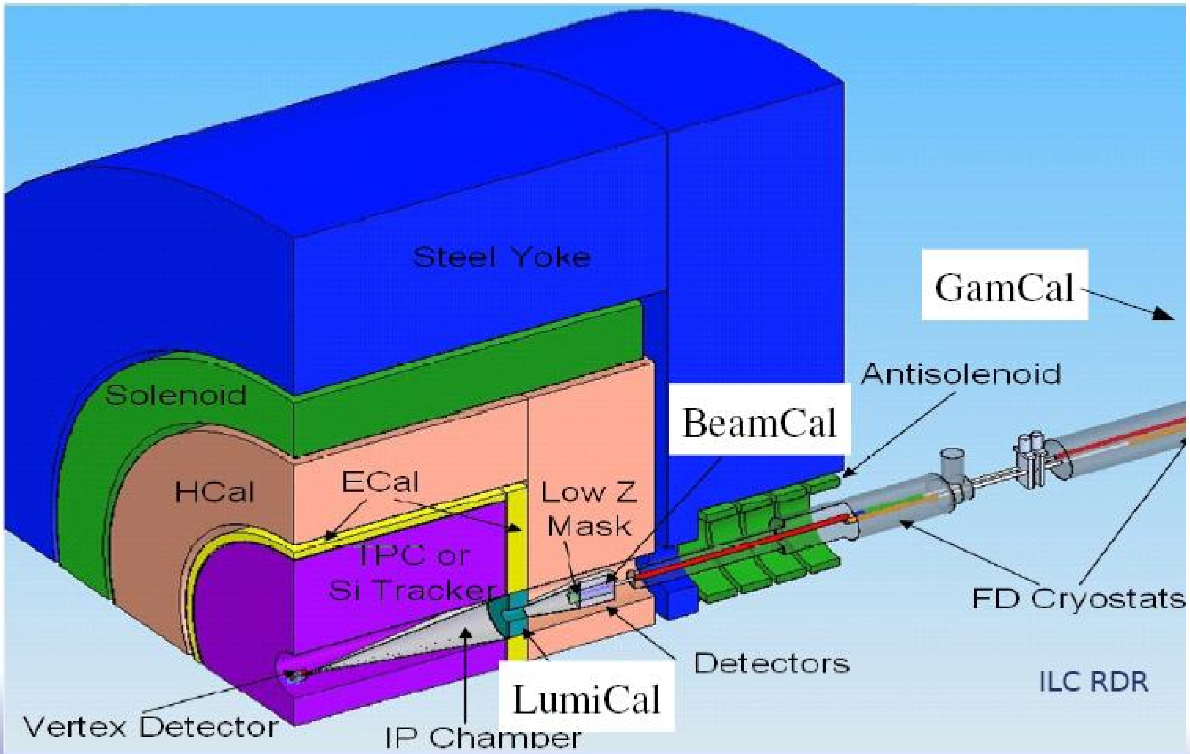
Fcal sensors & electronics

Alternatives and investigations

Forward Region Design



FCAL Collaboration

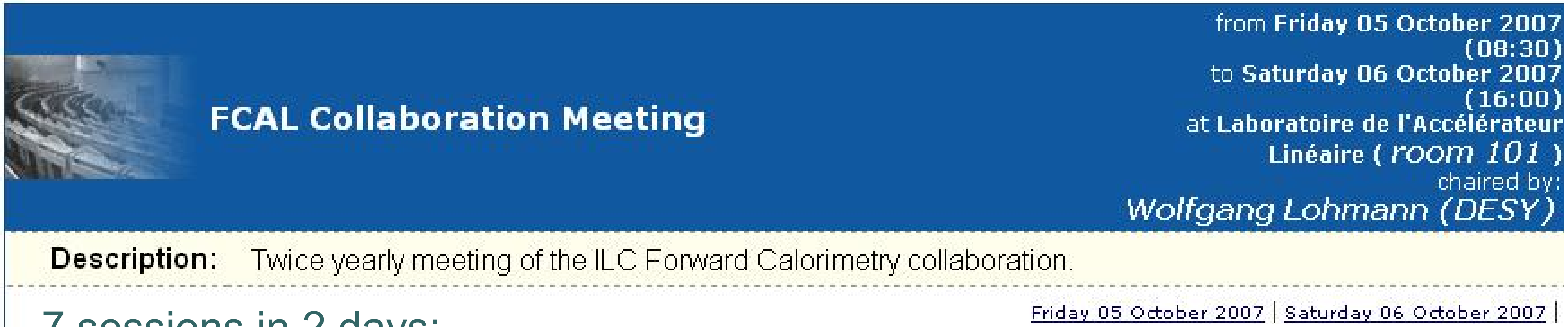
14 partners from 10 countries

- Academy of Science, Prague
- AGH University of Science & Technology, Krakow
- Brookhaven National Lab, Upton
- DESY
- Institute of Nuclear Physics, PAS, Krakow
- Joint Institute Nuclear Research, Dubna
- Laboratoire de l Accélérateur Linéaire, Orsay
- National Center of Particle & HEP, Minsk
- Royal Holloway University, London
- Tel Aviv University
- University of Colorado, Boulder
- VINCA Inst. of Nuclear Sciences, Belgrade
- Yale University, New Haven

- Cooperation with SLAC

Supported by:
- EUROTeV
- EUDET
- NoRHDIA
- INTAS
- DOE
- ISF
- Fital

Abdenour LOUNIS



FCAL Collaboration Meeting

from **Friday 05 October 2007 (08:30)**
to **Saturday 06 October 2007 (16:00)**
at **Laboratoire de l'Accélérateur Linéaire** (*room 101*)
chaired by:
Wolfgang Lohmann (DESY)

Description: Twice yearly meeting of the ILC Forward Calorimetry collaboration.

Friday 05 October 2007 | Saturday 06 October 2007 |

7 sessions in 2 days:

1-Introduction session 1: Physics and Beam diagnostic using beamcal
2- Session 2 : integration, vacuum issues

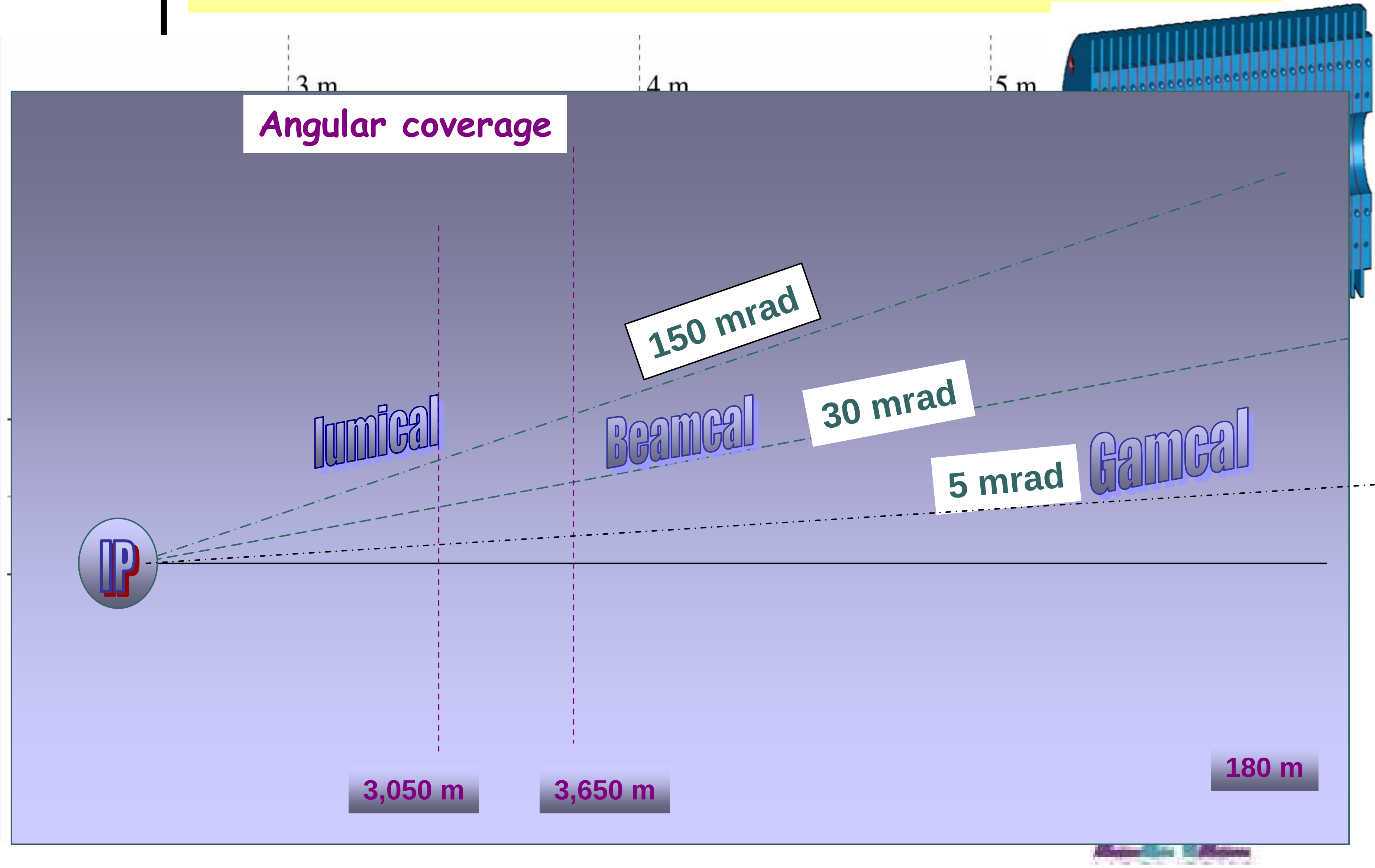
3- Session 3 : Lumical and Beamcal issues
4- session 4: FCAL Electronics and readout

Saturday

1- Beamcal and Lumical Mechanics
2- Background estimations and algorithms
3- Discussion and closeout session

http://ilcagenda.linearcollider.org/conferenceDisplay.py?confId=2285

Geometry and position



BeamCal: W-sensor Sandwich

BeamCal: $5 < \theta < 28$ mrad

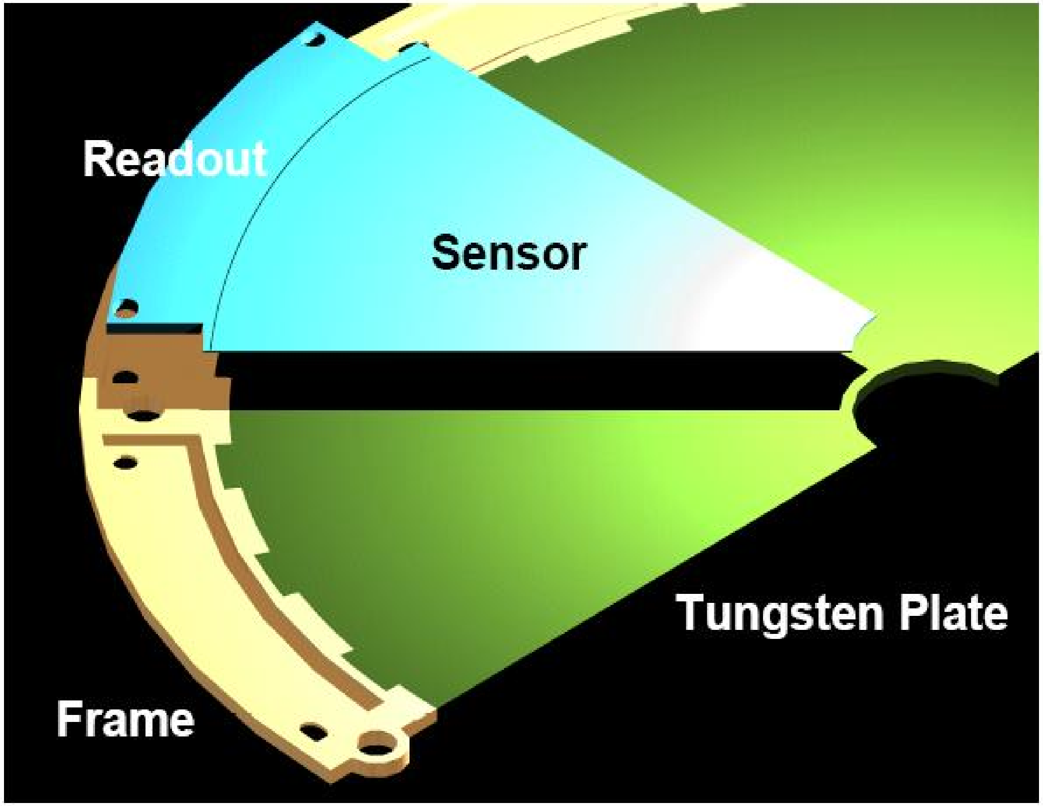
Length = 30 X_0

(3.5mm W + .5mm senso

Molière radius= 1 cm

Space for electronics

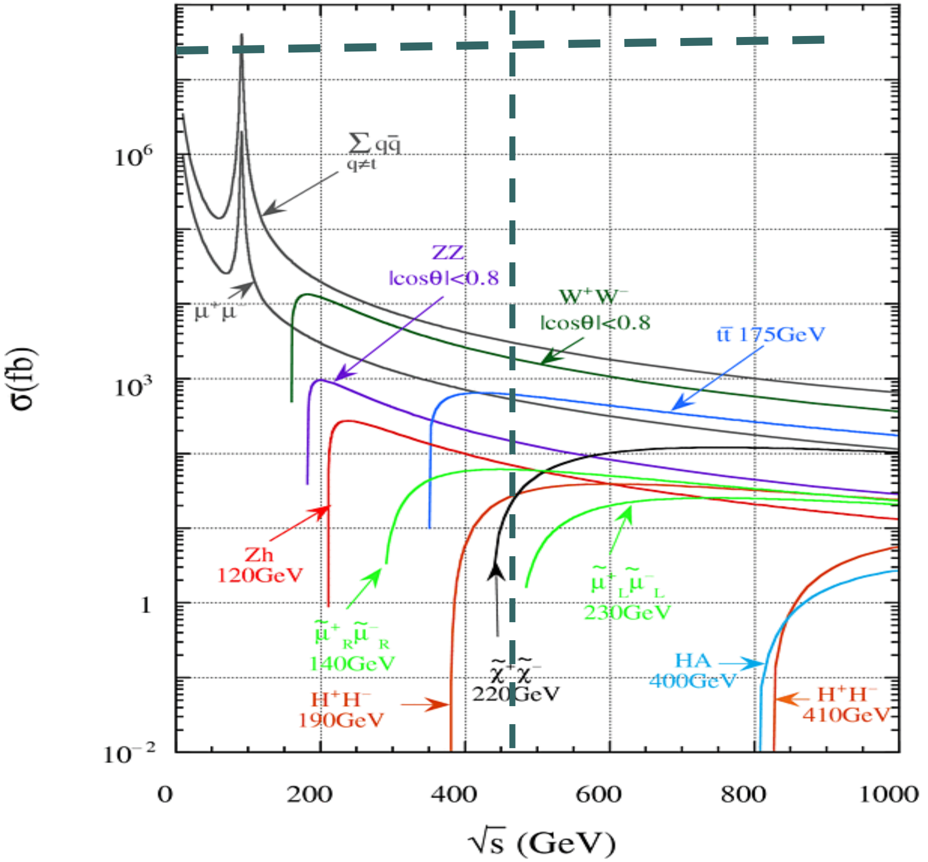
Sensor and R/O Hybrid



Pad size : ½ RMoliere

The BeamCal detector

- **purpose:**
  - Detection of electrons/photons at low angle
  - Beam diagnostics from beamstrahlung electrons/positron pairs
  - Shielding of Inner Detector
  - **Extend the sensitive region to lowest polar angles (hermeticity)**



Two photon cross section

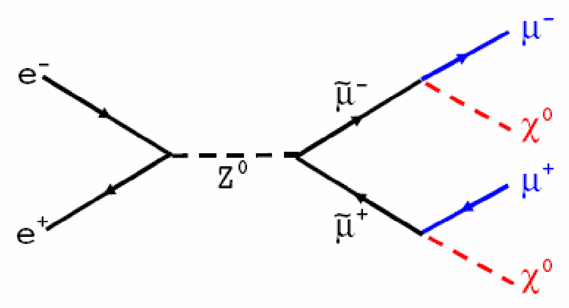
Background
10^5 times higher than SUSY Cross section

The BeamCal detector

- Two photon events is the most serious background in many physics searchs (Beyond SM)

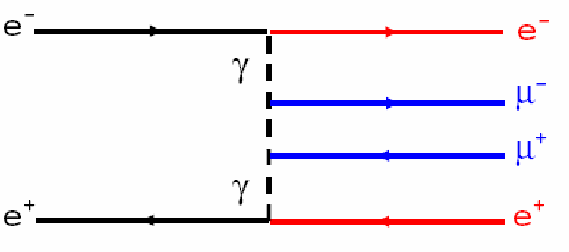
(missing energy and missing momentum)

  - Very important feature of beamcal is to separate high energy electron with P~P beam and pile up of low energy beamstrahlung pairs



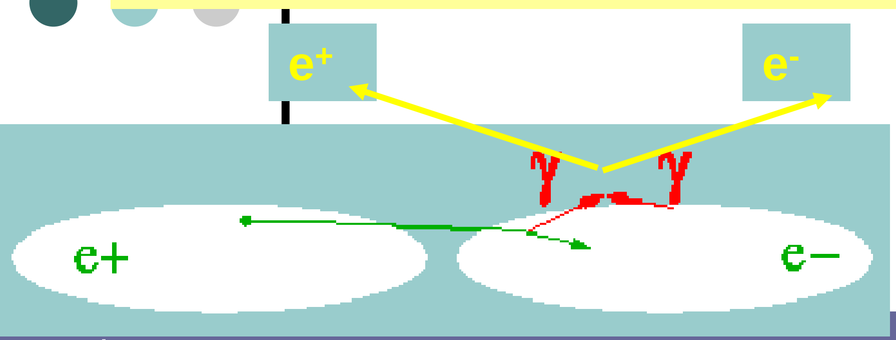
Example of Physics signal

SUSY : smuon production
And missing energy

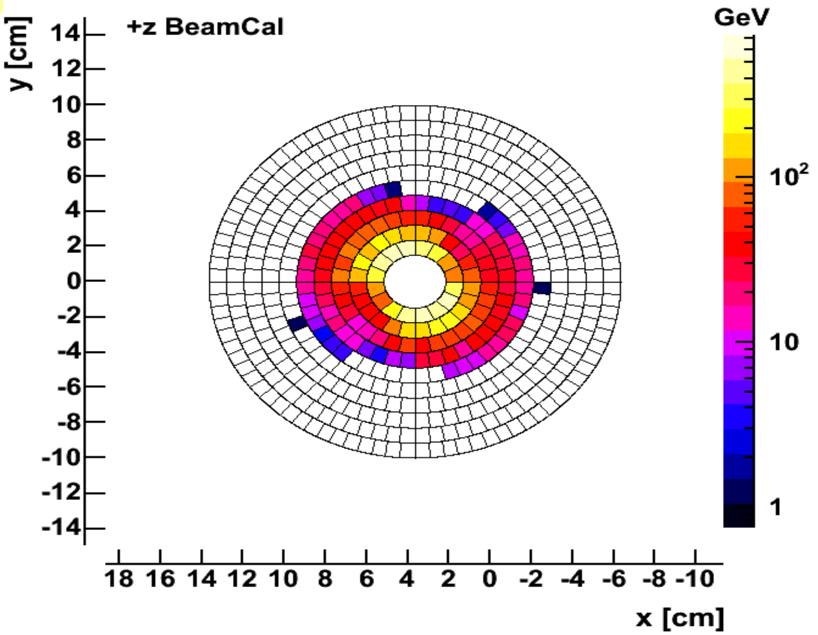


Background signal : 2 photons events may fake signal « in case of electron escape »

Beamstrahlung: Photons and e^+e^- pairs E deposit and Irradiation



e^+e^- pairs from beamstrahlung are deflected into the BeamCal



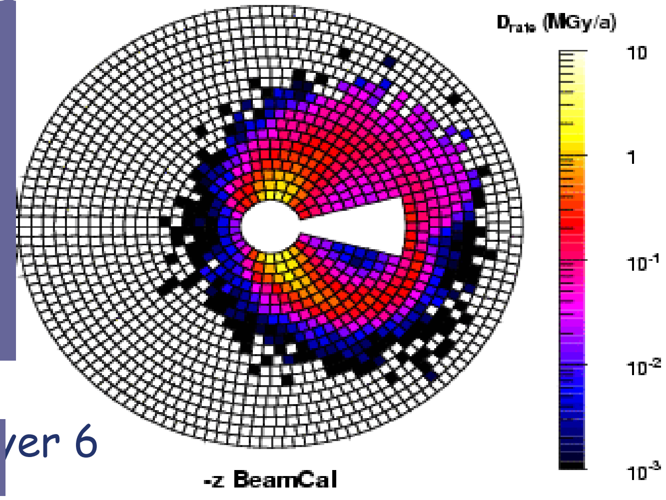
- **High energy deposition**

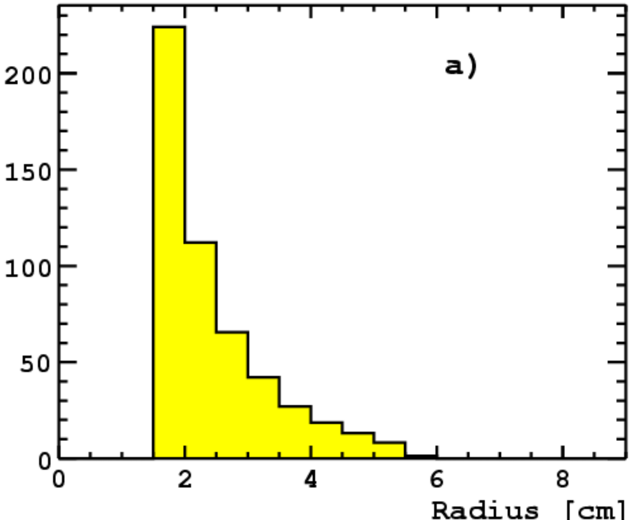
(inner layers of the beamcal)

10^5 e^+e^- pairs depositing

up to 10 TeV/bunch crossing

- **~ 100 MRad per year**



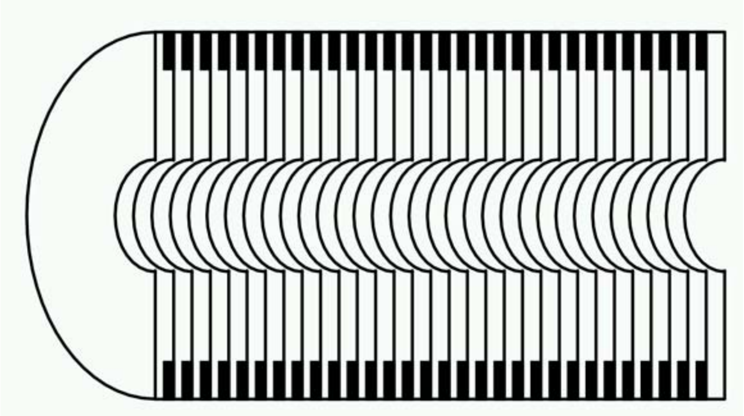


- **response within μs**

Challenging Project

To built a High Precision device, High occupancy, High radiation level and Fast electronic readout ➔ innovation in design techniques

Recall



BeamCal structure

- 2 end caps ×
- 30 Silicon – Tungsten sandwiched layers per cap ×
- 1512 channels per layer
- Total channel count: **90,720**
- At 32 channels per chip, this implies **2836 chips**

Sensor options

- Silicon radiation Hard
- GaAs
- Diamond pCVD , ScCVD

Look for best performances in terms of :

Signal yield
stability , long-term behavior
charge collection efficiency
charge collection distance
radiation hardness
Easy industrial procurement
budget

Basics

Assuming a parallel plate detector of thickness λ and E the applied field

Charge collection distance : CCD

Average drift distance = $\delta = (\mu_e + \mu_h) . \tau . E$

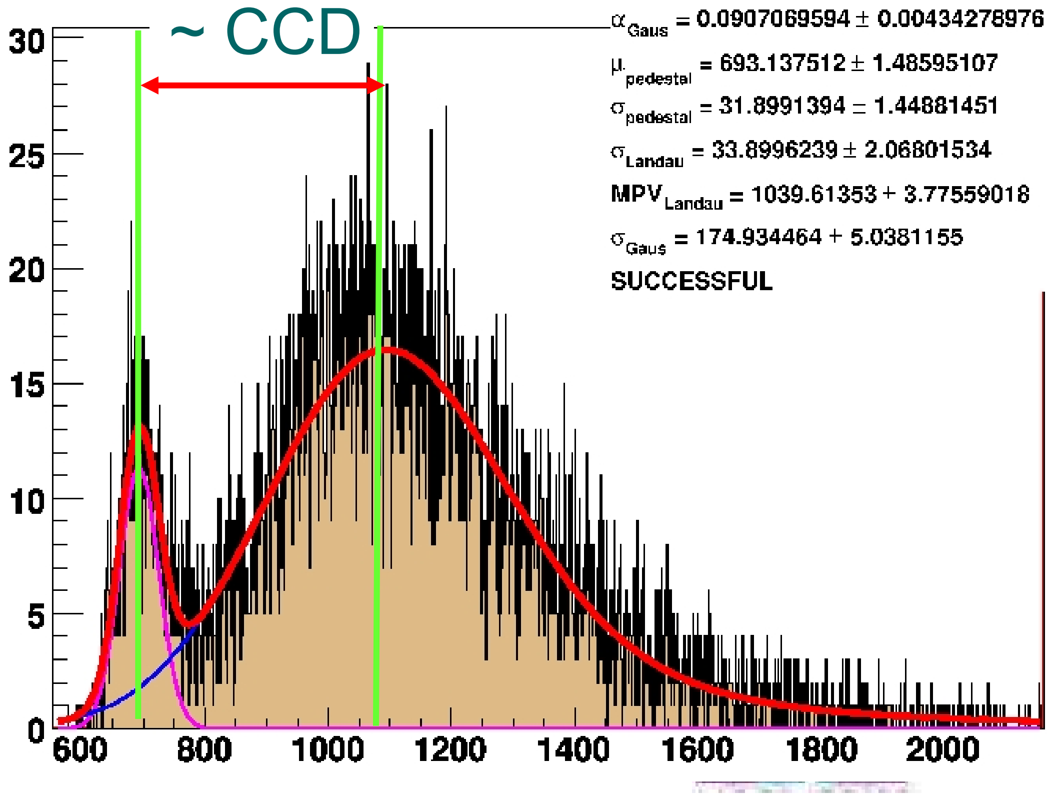
μ_e = electron mobility

μ_h = hole mobility

τ = mobility weighted lifetime o

Efficiency η is the ratio of the tc
to the total charge Q_0 generated

δ and η limited by τ (presence of
➔ Gives hints and information a



* K. Hetch, Z. Phys. 77(1932)235

Gallium Arsenide

Compound structure

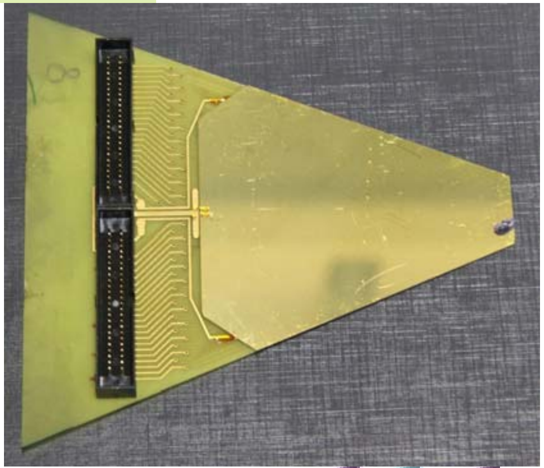
Band Gap at 300K : 1.424 eV
M^*_e = 0,067 me
M^*_h = 0.45 me
μ_e= 9200 $cm^2/(V.s)$
μ_h=400 $cm^2/(V.s)$

The choice of GaAs over silicon is dictated by its radiation hardness

Advantages over silicon :

- **Higher electron saturated velocity and higher electron mobility**
- **Working at high frequency (250 GHz)**
- **Lower noise level at high frequency**
- **High breakdown level**
- **no type inversion observed**

JINR Tomsk

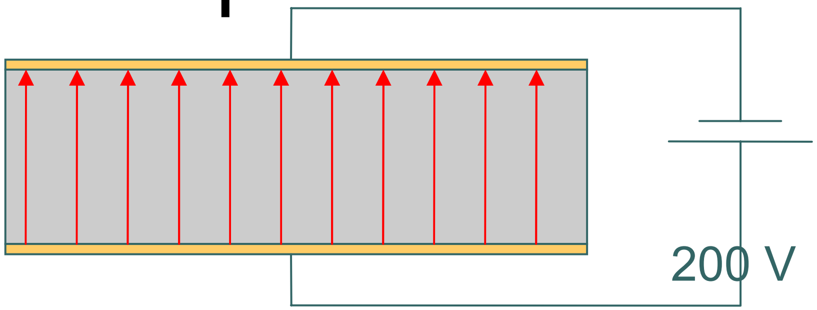


Silicon advantages:

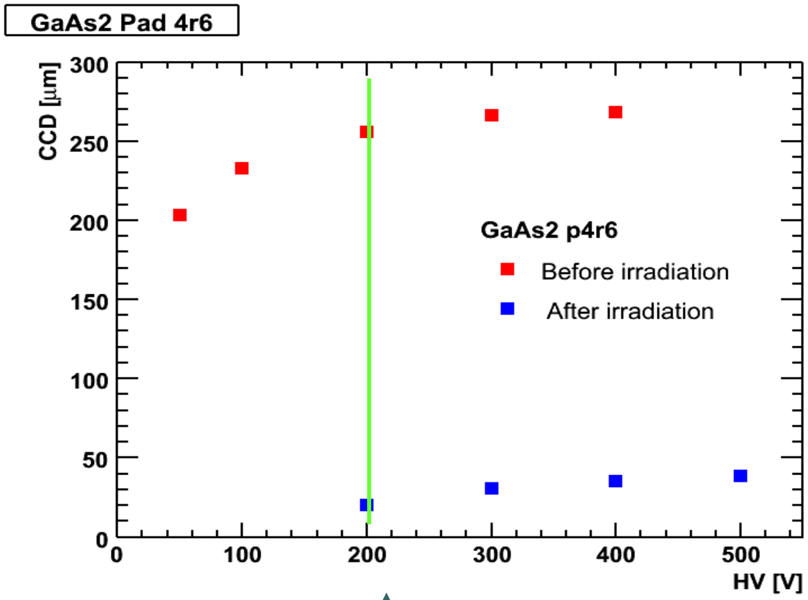
- **Abundant and cheap process**
- **Allow fabrication of (2X) larger wafer (~300 mm)**
- **Presence of SiO2 as insulator**

Produced by Siberian Institue of Technology

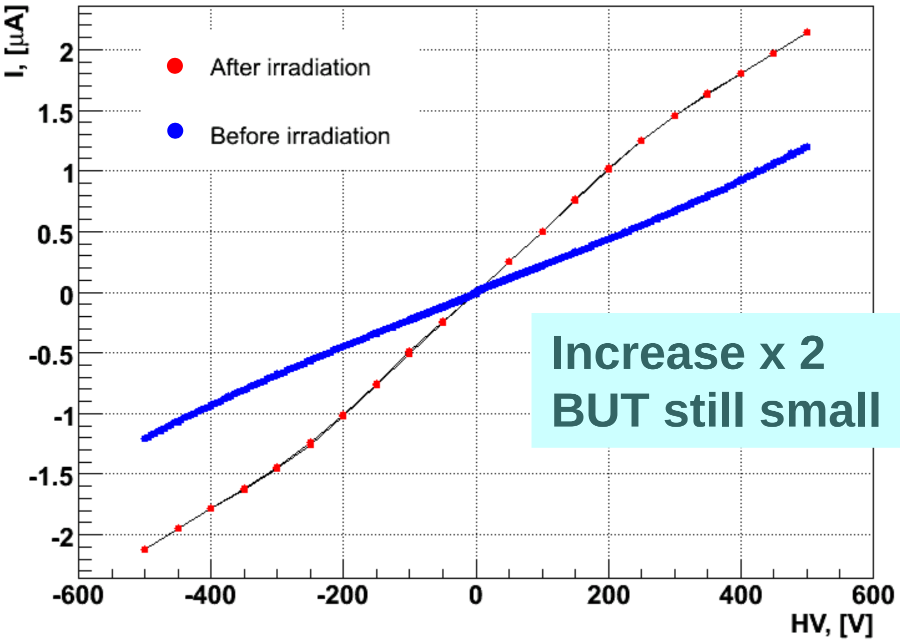
AsGa results



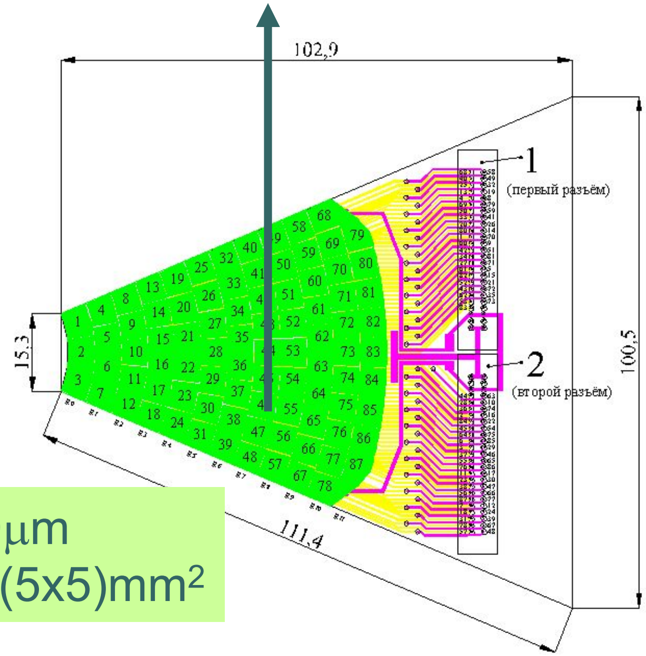
CCD decrease



GaAs2 Pad 4r6



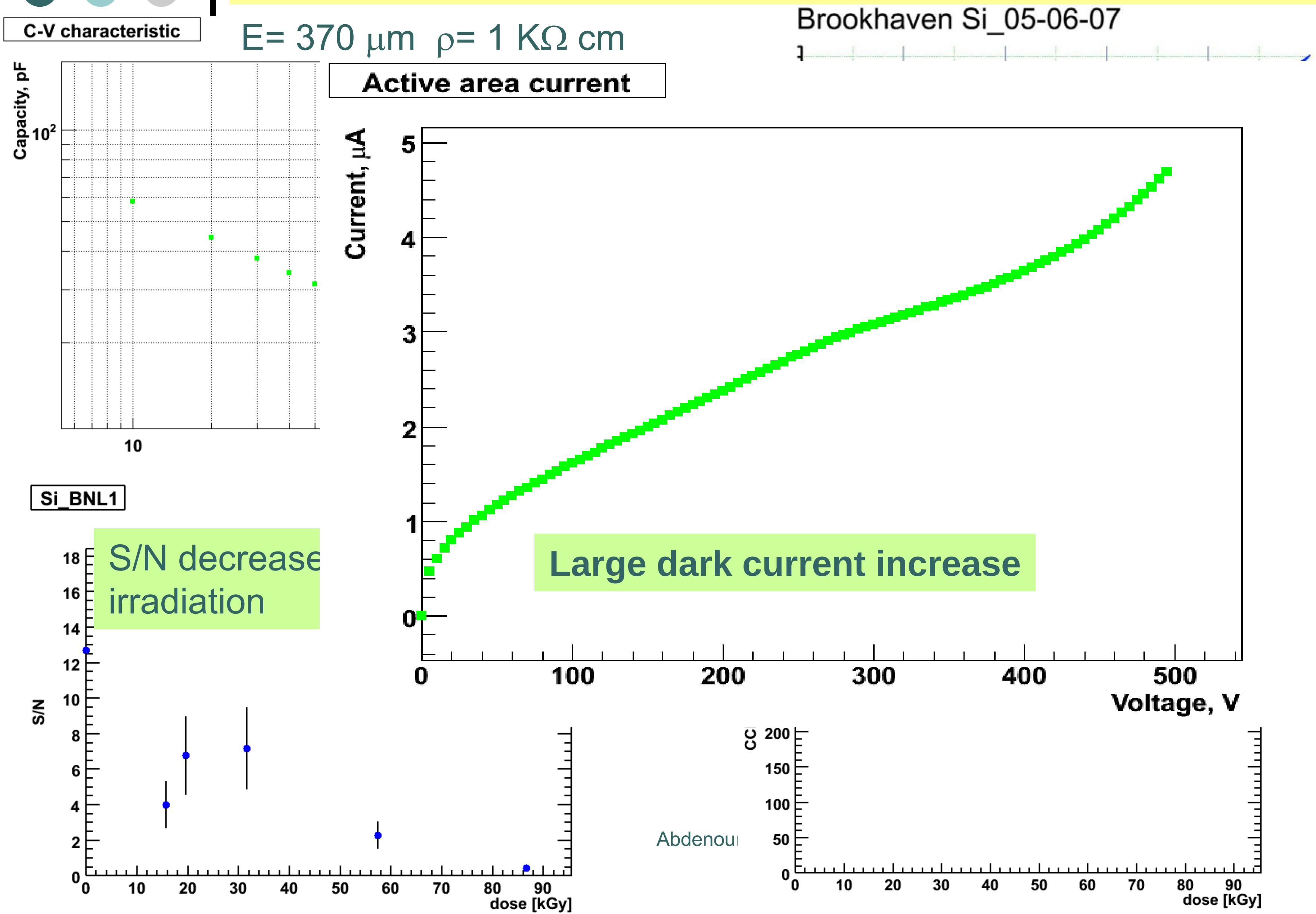
Increase x 2
BUT still small



e=50µm
85 x (5x5)mm^2

Rad Hard silicon (BNL) – n type McZ silicon,

E= 370 µm ρ= 1 KΩ cm



S/N decrease irradiation

Large dark current increase

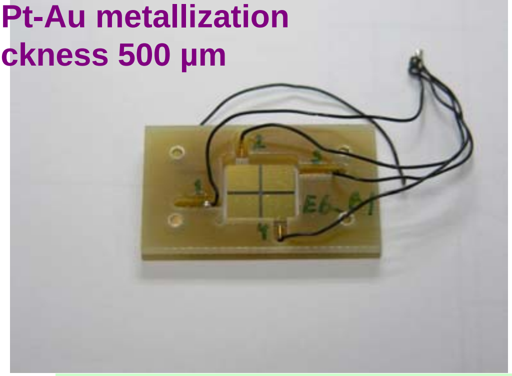
Abdenou

Diamond sensors

- Higher mobility ~30% e^- et 60% holes // better than si
- Low dielectric constant ε =5.7
- Thermal conductivity* 900-2320 W/m.^{0}K

(air = 0.025 water = 0.6 silicon = 149)

Available manufacturers E6 and Fraunhofer (IAF)
PcvD 1x1 cm^2 and thickness 200-900 μm
ScvD 5x5 mm^2 and 340 μm

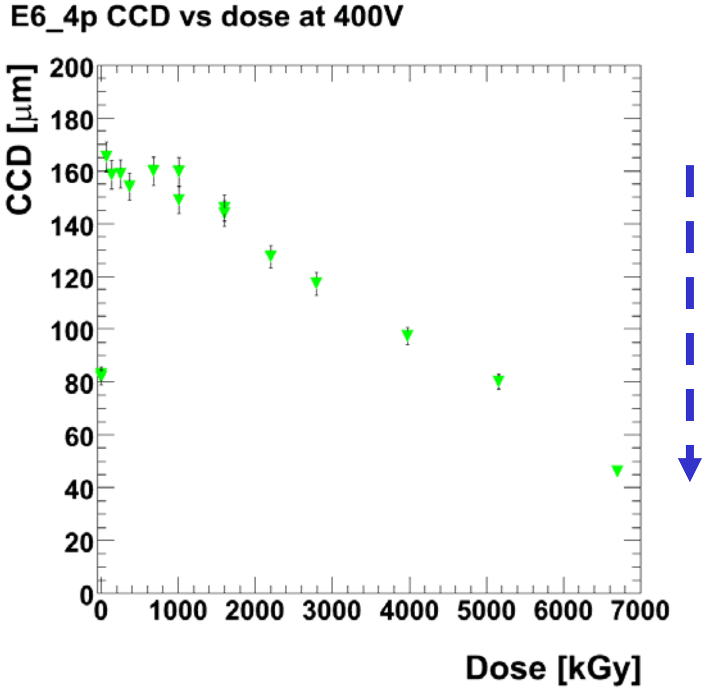


pCVD diamonds
active area 10x10 mm2,
Ti-Pt-Au metallization
thickness 500 µm

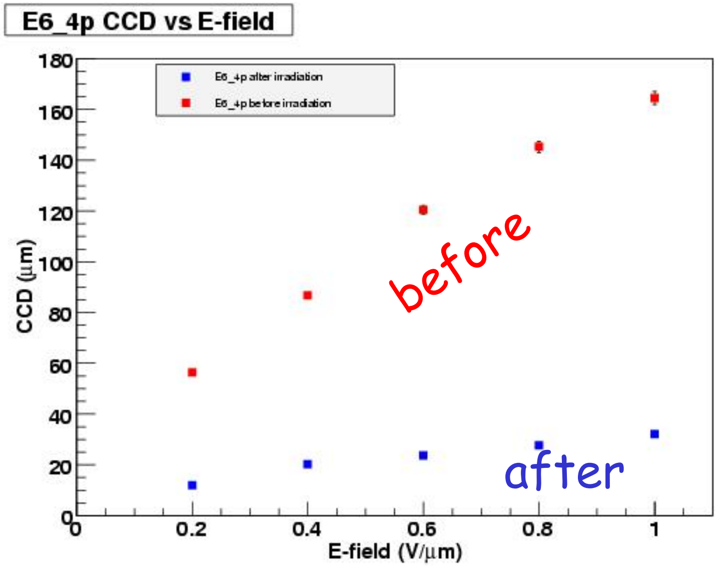
scCVD diamond
area 5x5 mm2, thickness 340 µm,
metallization Ø3mm

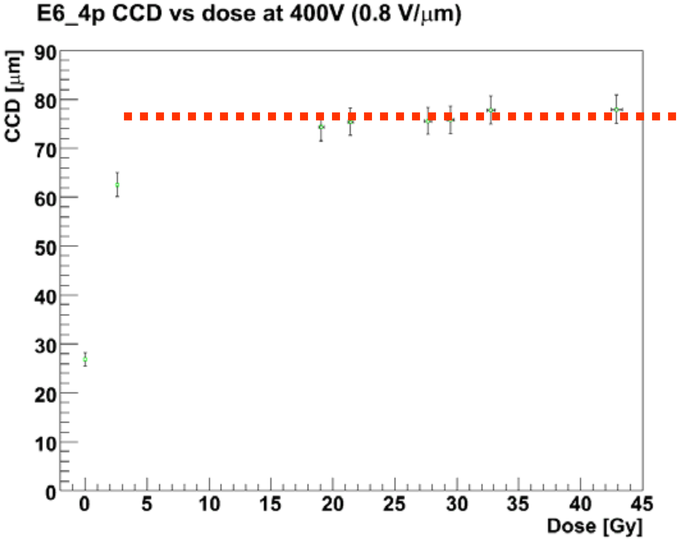
* It is defined as the quantity of heat, ΔQ, transmitted during time Δt through a thickness L, in a direction normal to a surface of area A, due to a temperature difference ΔT, under steady state conditions and when the heat transfer is dependent only on the temperature gradient

Diamond from E6



75% drop for 700 MRad

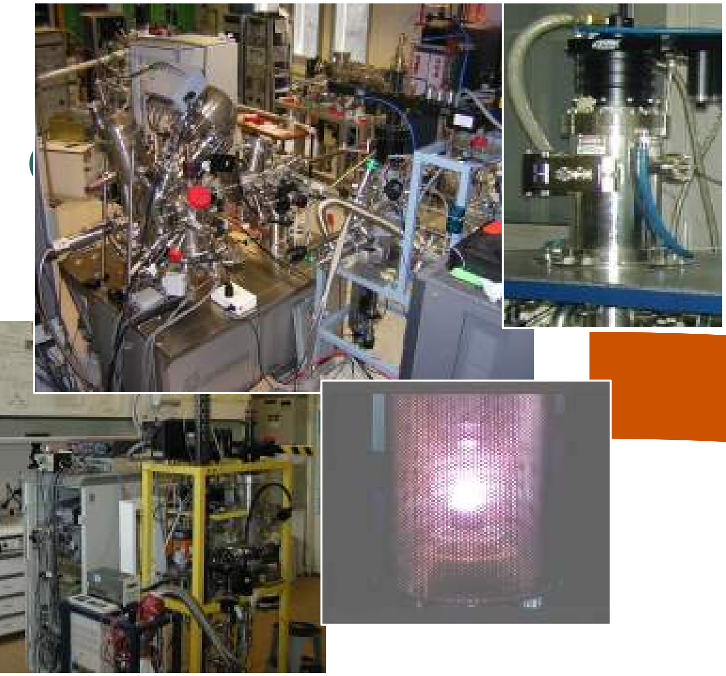




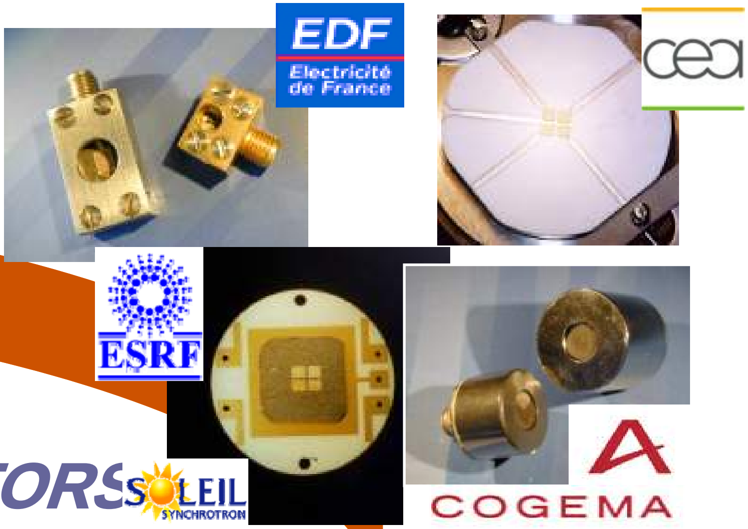
80 μm

Abd

Diamond at Saclay



PROCESS



DETECTORS and SENSORS

APPLICATIONS

Electronique

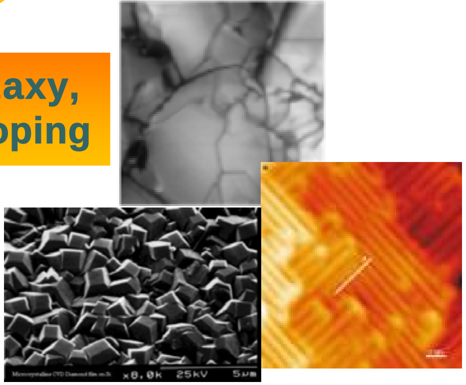
Extreme environments

Interfaces

Bio fonctionnalisation

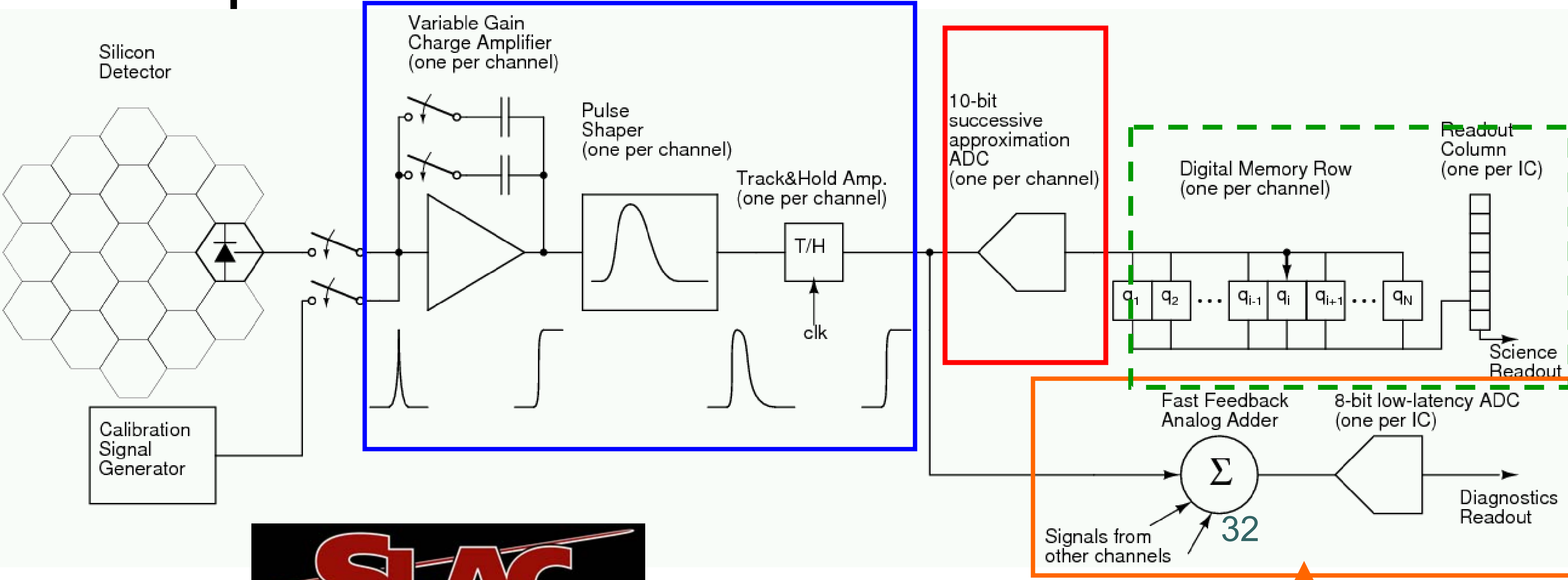
Sensors and transducers

R&D on épitaxy,
Single crystal growth, doping



Abdenour LOUNIS

BeamCal electronics



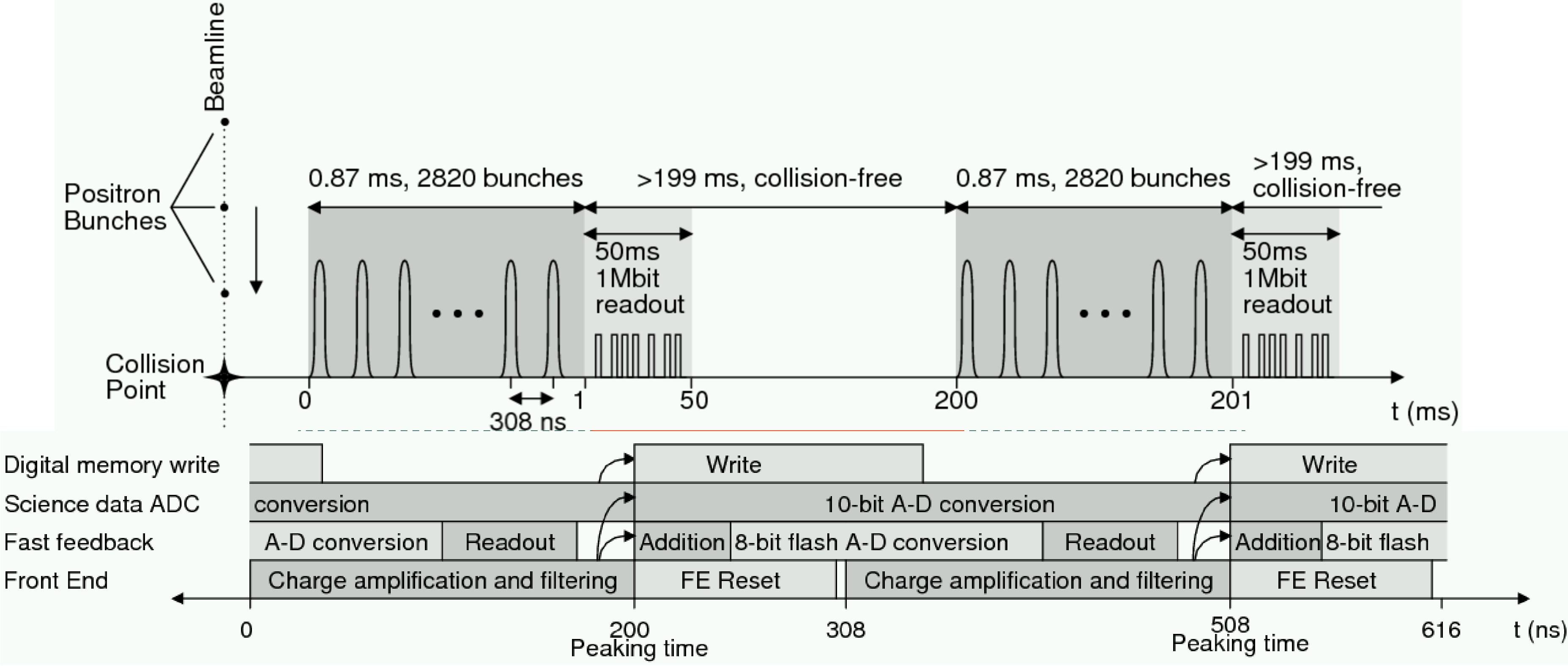
Fast feedback

R/O after each BX

- **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**

BeamCal electronics

Timing diagram: between pulse trains



100000 electronics channels

Summary

Sensors :

- GaAs tested and showed increasing leakage current
- Both poly- and single crystalline CVD diamond sensors stood the absorbed doses of several MGy
- Values of CCD after irradiation being less than that before,

More work to be done

- Understand the mechanism of damage
- Clarify the dependence of CCD on dose, dose rate
- Discuss with manufacturers the possibility to provide more radiation hard samples in future.

Electronics : beginning of the process, first prototypes under tests

(charge amplifier and filter) – next year for complete circuit realisation

Beamcal : Matters for contribution et open issues

- Sensors :

→ Exploit new developments in rad hard (oxygenated) silicon

→ Diamond : exploit scientific know-how of next door neighboors (CEA)

→ To provide pure thin diamond sensors (very low noise electronics to be designed for this purpose)

→ Synergy LHC studies and SLHC (irradiation, fine granularity)

- Electronics (one group only for Beamcal electronics)

→ Possible effort here for alternative design to the analog front-end (actual design is made on 0,18 μm CMOS technology)

→ SiGe for analog part is one of the technology adapted for such harsh environment (SLHC) ?

Subtle design for minimal power dissipation

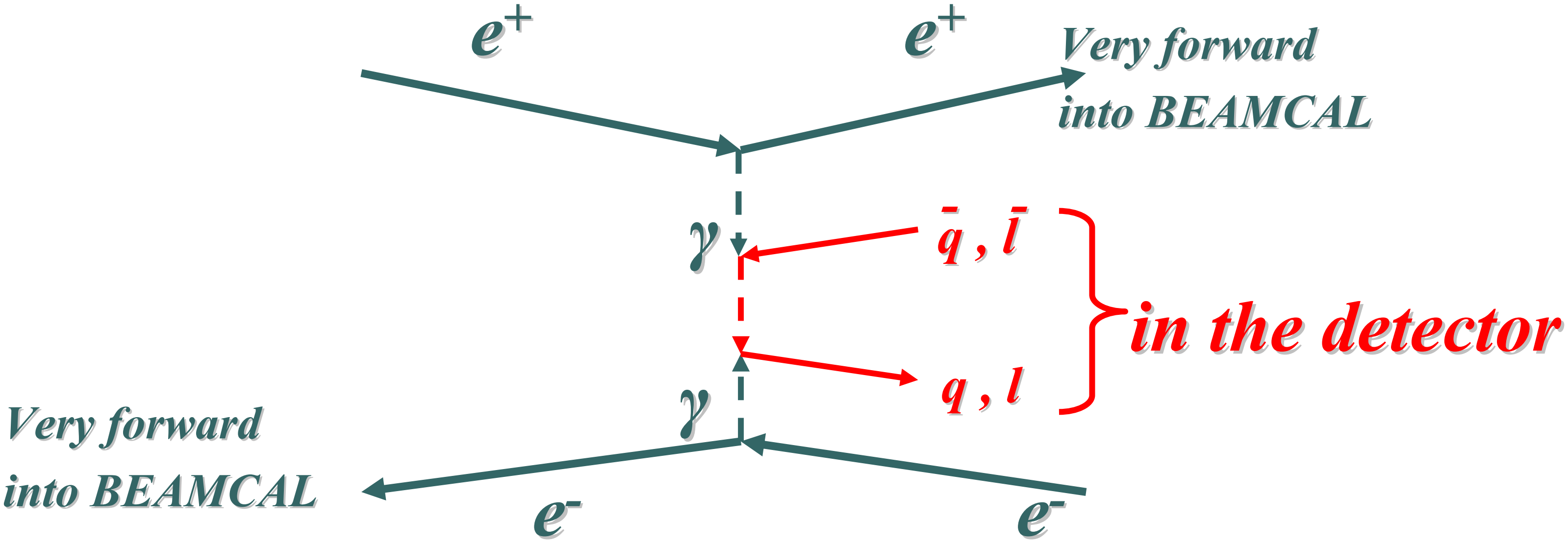
→ One could exploit its expertise in ADC design

END

All good ideas …
Suggestions …
participations
Commitments …
are warmly encouraged

Additional slides

2 Photon Process

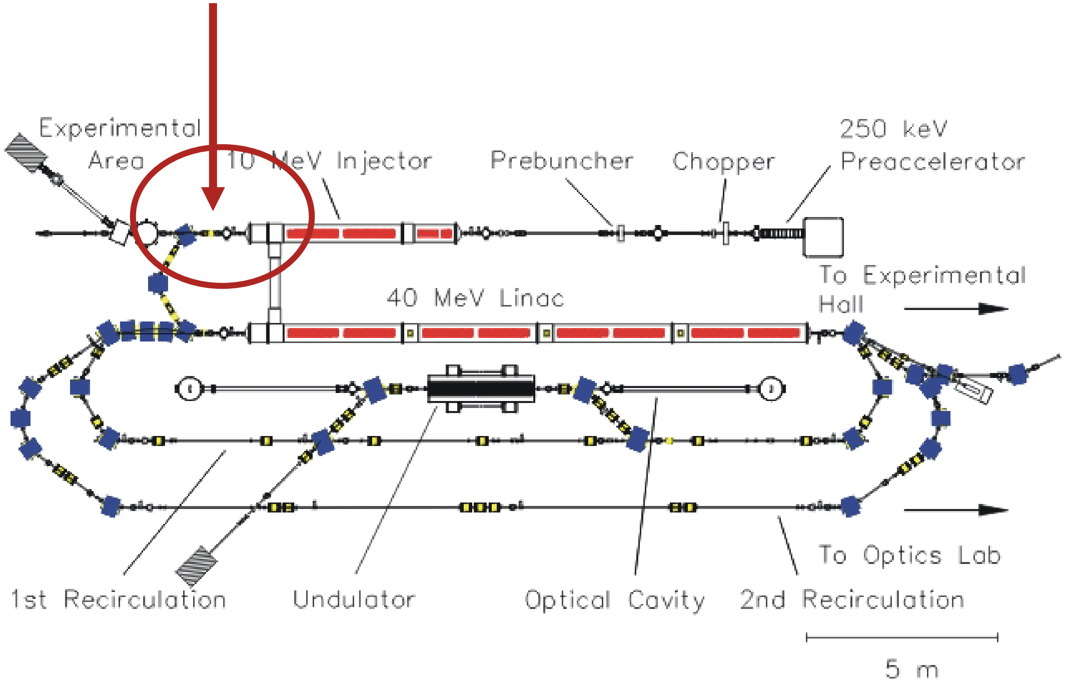


Very forward
into BEAMCAL

in the detector

Very forward
into BEAMCAL

TEST BEAM @ S-DALINAC



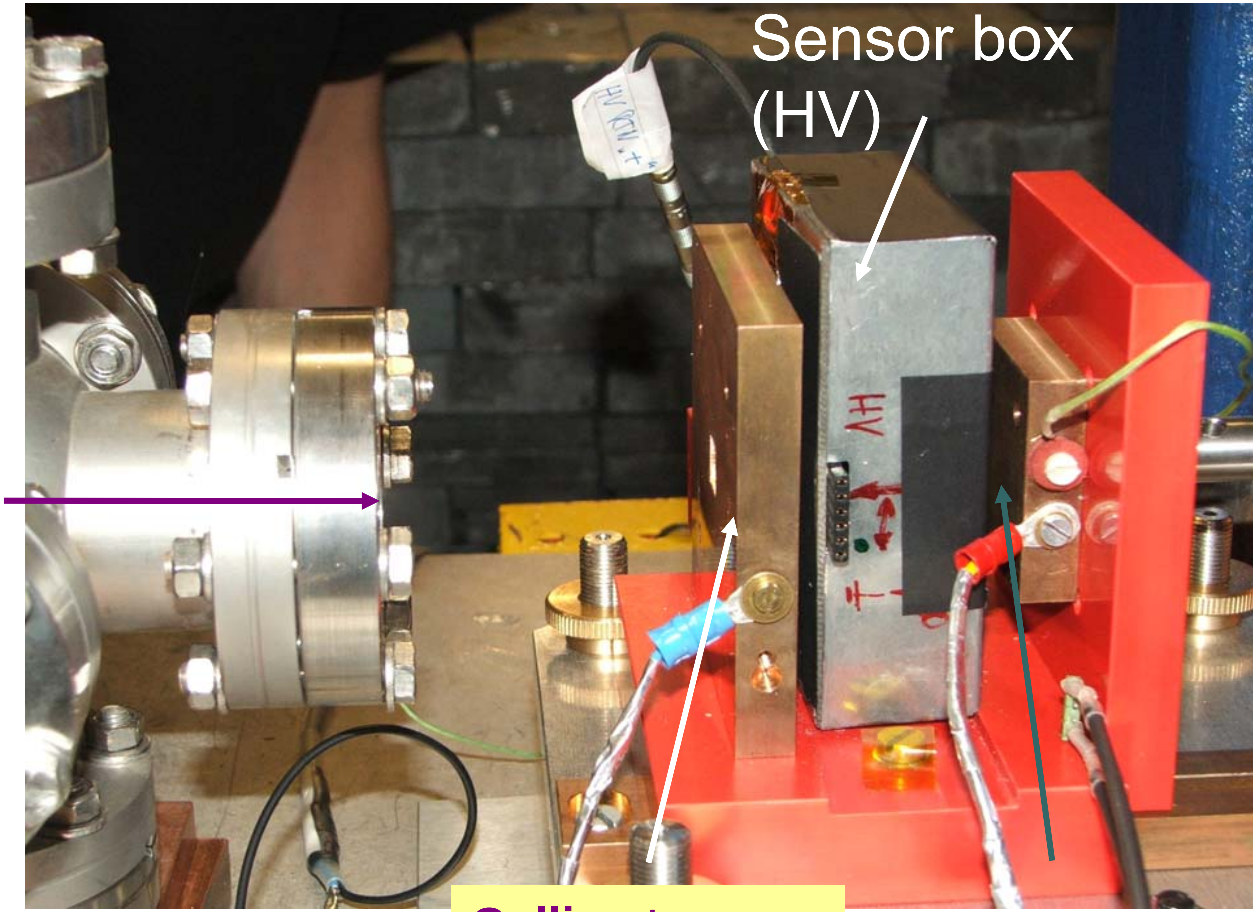
Superconducting **DA**rmstadt **LIN**ear **AC**celerator
Institut für Kernphysik, TU Darmstadt

Using the injector line of the S-DALINAC:

10 ± 0.015 MeV and possible beam currents from ***1nA to 50µA***

Beam tests setup

Beam area:



Sensor box (HV)

Beam exit window

Collimator (I_{Coll})

Some material propreties

Property	Si	Diamond	Diamond
Material Quality	Cz, FZ, epi	Polycrystalline	single crystal
E_g [eV]	1.12	5.5	5.5
$E_{breakdown}$ [V/cm]	$3 \cdot 10^5$	10^7	10^7
μ_e [cm^2/Vs]	1450	1800	>1800
μ_h [cm^2/Vs]	450	1200	>1200
v_{sat} [cm/s]	$0.8 \cdot 10^7$	$2.2 \cdot 10^7$	$2.2 \cdot 10^7$
Z	14	6	6
ε_r	11.9	5.7	5.7
e-h energy [eV]	3.6	13	13
Density [g/cm3]	2.33	3.515	3.515
Displacem. [eV]	13-20	43	43
e-h/µm for mips	89	36	36
Max initial ccd [µm]	>500	280	550
Max wafer ϕ tested	6”	6”	6mm
Producer	Several	Element-Six	Element-Six

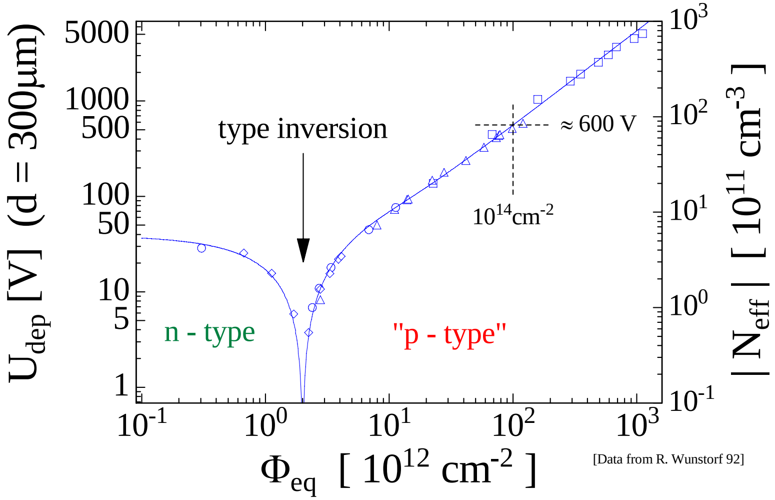
Bandgap
(<<Leakage)

Capacity

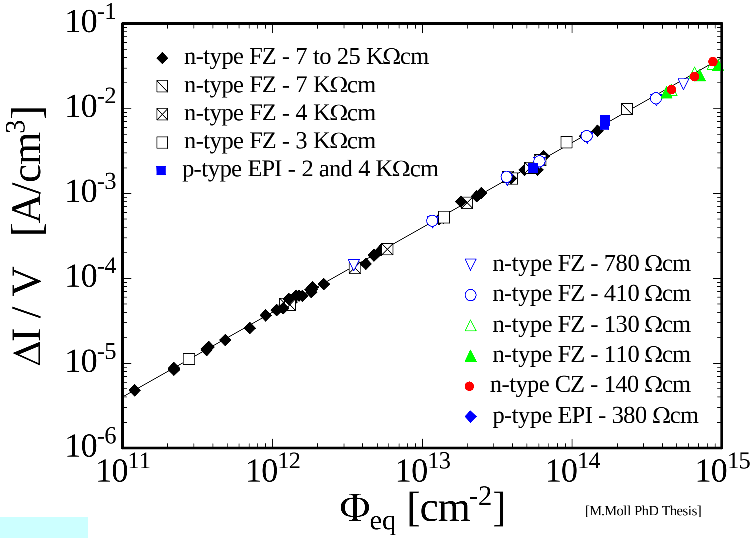
Displacement

Signal : 36e/µm

basics

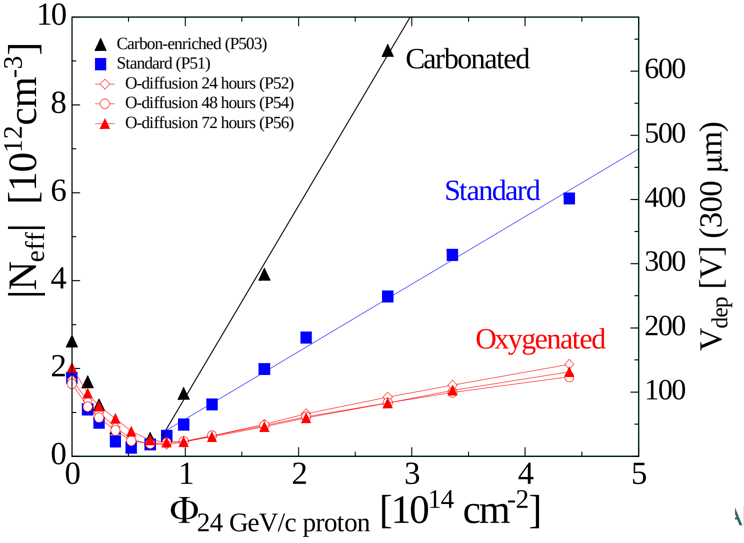


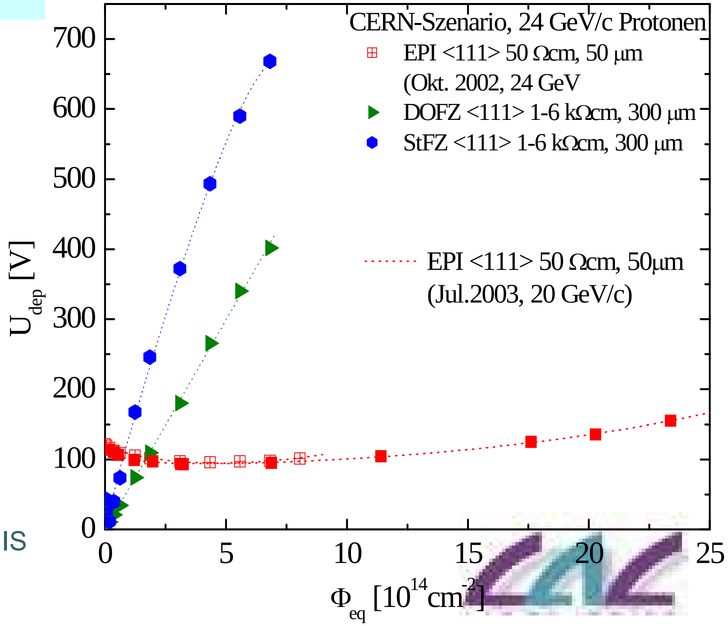
[Data from R. Wunstorf 92]



[M.Moll PhD Thesis]

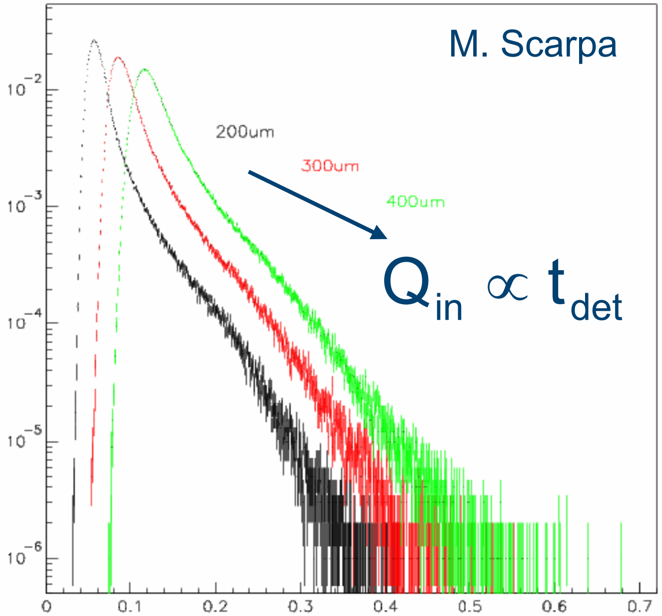
Progress made by RD50- Last developments





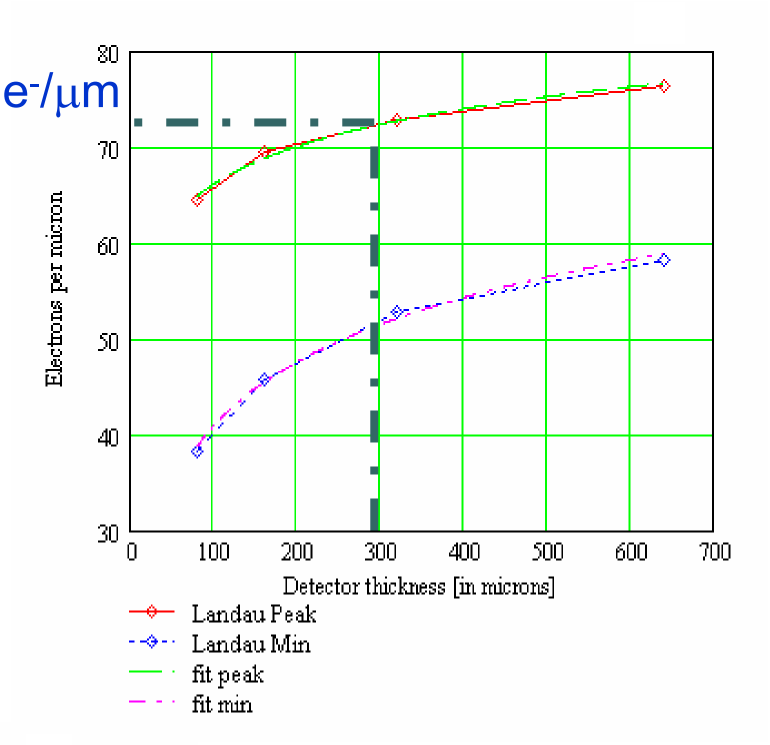
Front End electronics status

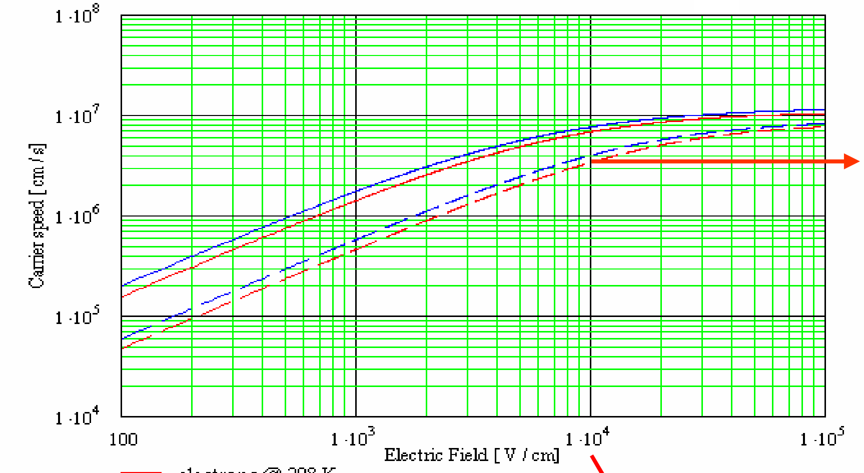
Silicon devices



Energy Deposited (MeV)

72 e⁻/μm





Hole speed: 34 μm/ns

E_{field} =200 V on a 200 μm thick detector

Basics

Charge collection efficiency

Limitations →

- **partial depletion**
- **deep trapping sites**
- **type inversion**

Collected charge:

$$Q = Q_o \cdot \varepsilon_{\mathrm{dep}} \cdot \varepsilon_{trap}$$

$$\varepsilon_{dep} = \frac{d}{W}$$

$$\varepsilon_{trap} = e^{-\frac{\tau_c}{\tau_t}}$$

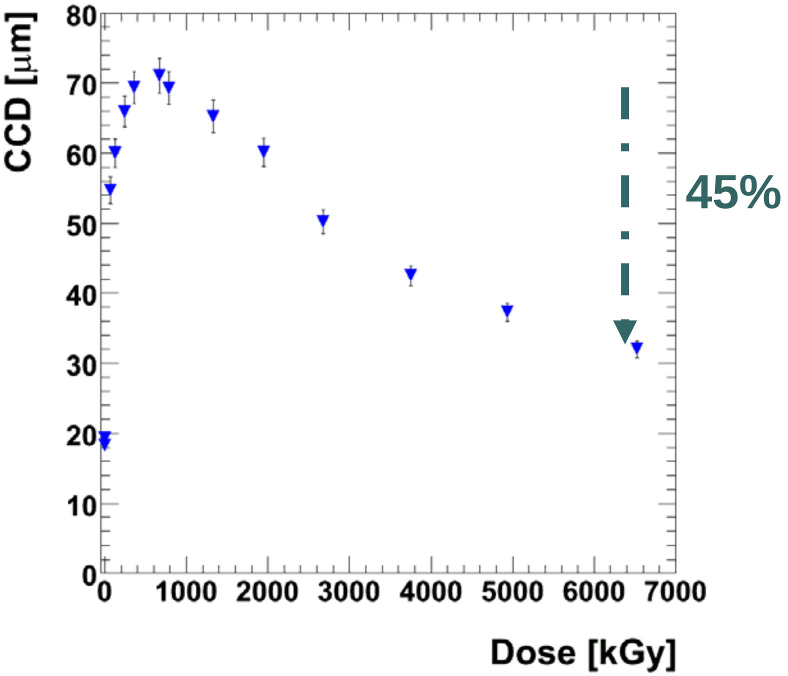
W: total thickness
d: Active thickness
τ_c : Collection time
τ_t : trapping time

τ_t trapping time increase with fluence *

* krasel et al. (RD50) NIM A541(2005)189

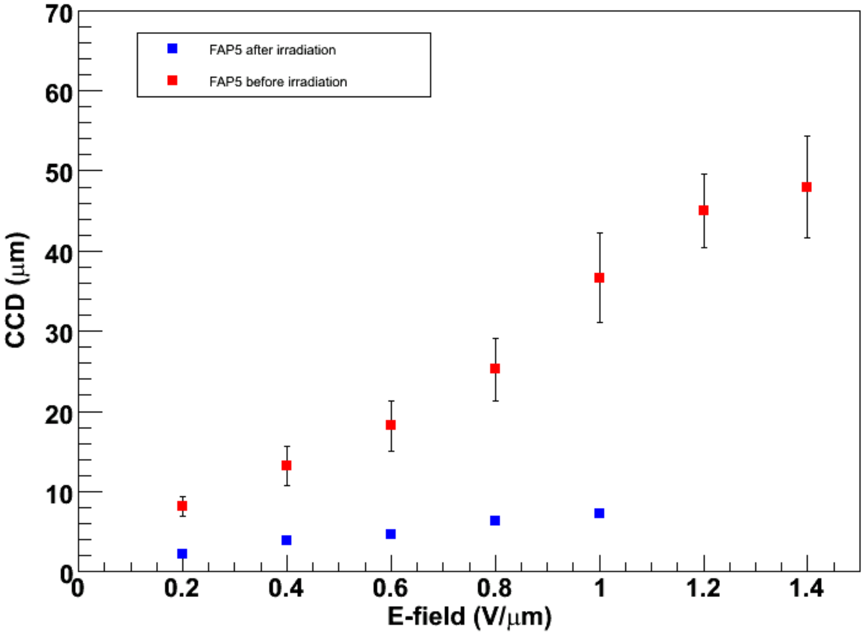
FAP

FAP5 CCD vs dose at 400V

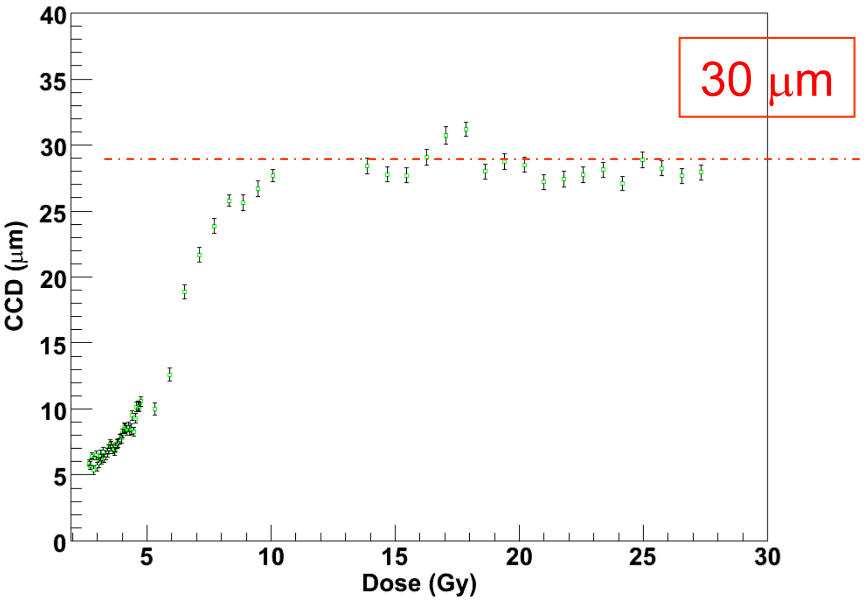


45%

FAP 5 CCD vs E-field



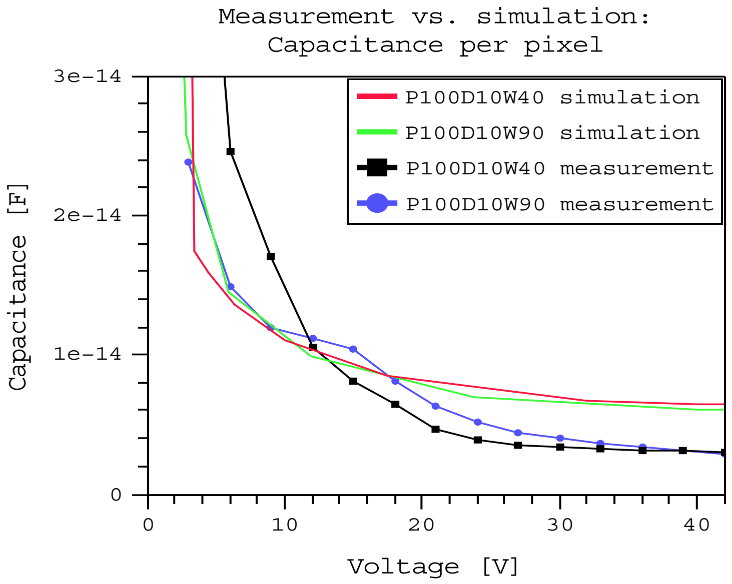
FAP5 CCD vs dose at 0.8V/µm

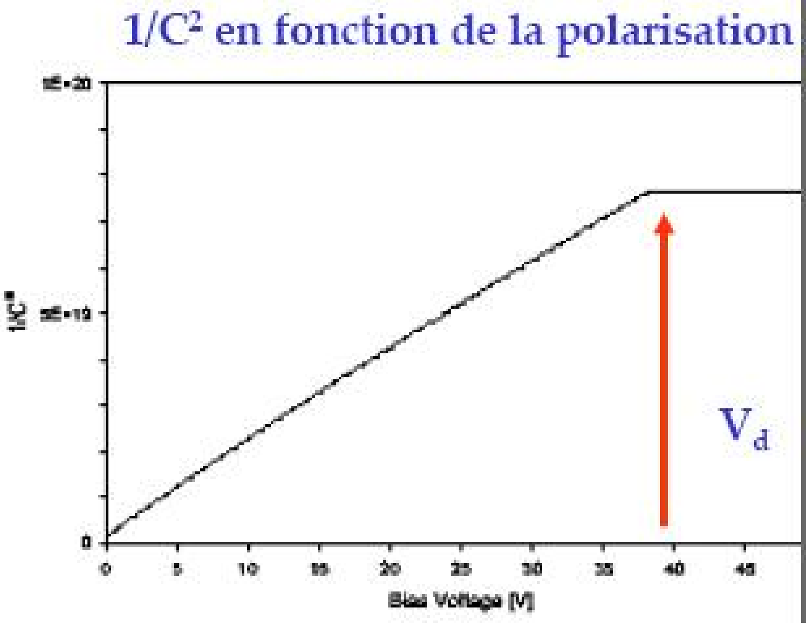


30 µm

Abd

$$C = A\sqrt{\frac{\varepsilon}{2\rho\mu V_b}} \;=\!=\!=\!=\!>\; C \propto \frac{1}{\sqrt{V_b}}\,.$$





Abdenour LOUNIS