Diamond Sensors for sLHC Tracker Upgrades

- The physics case
- Pixel upgrade boundary conditions
- Diamond pixel module prototypes
- A diamond vertexing system

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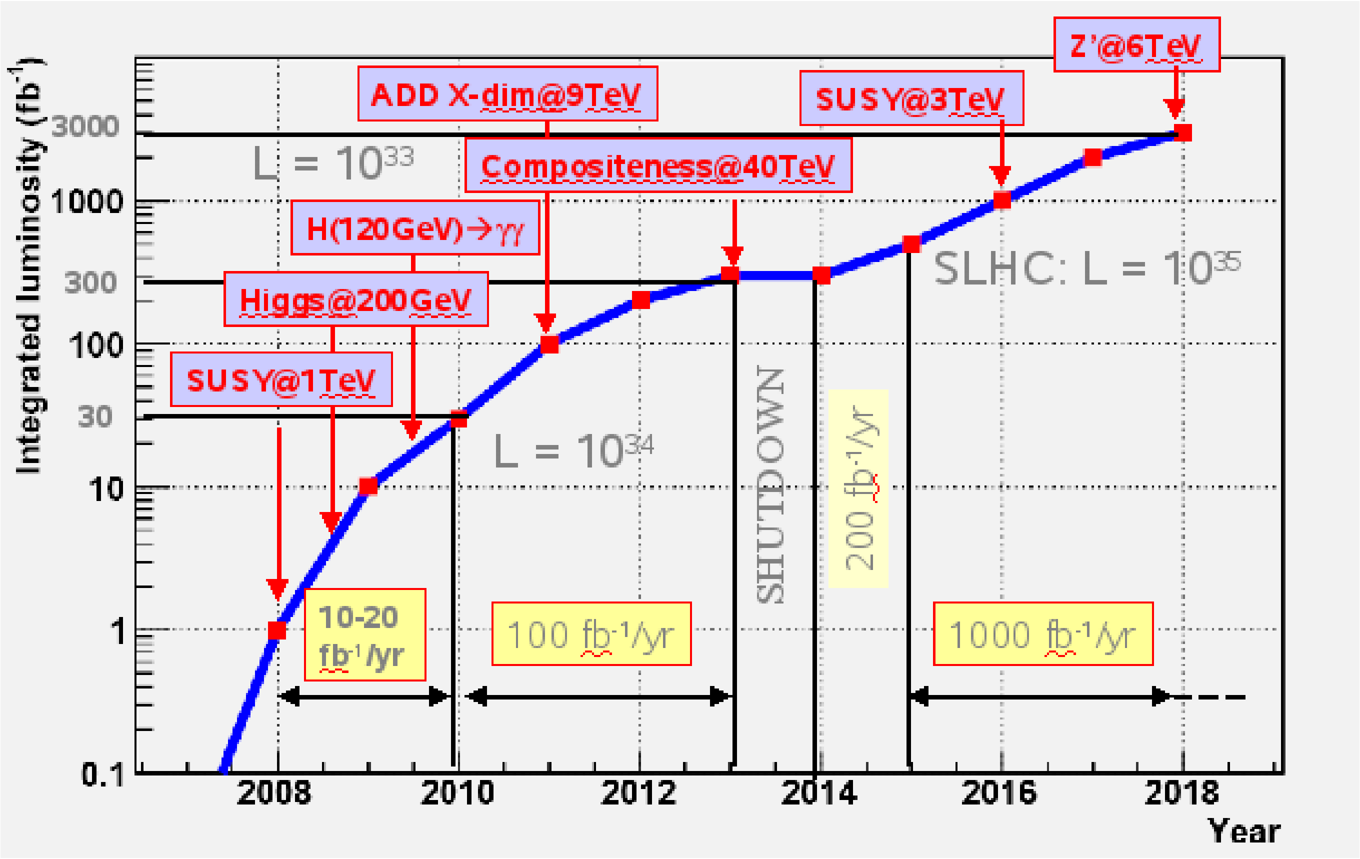
Vertex07, September 25, 2007

Physics Motivation

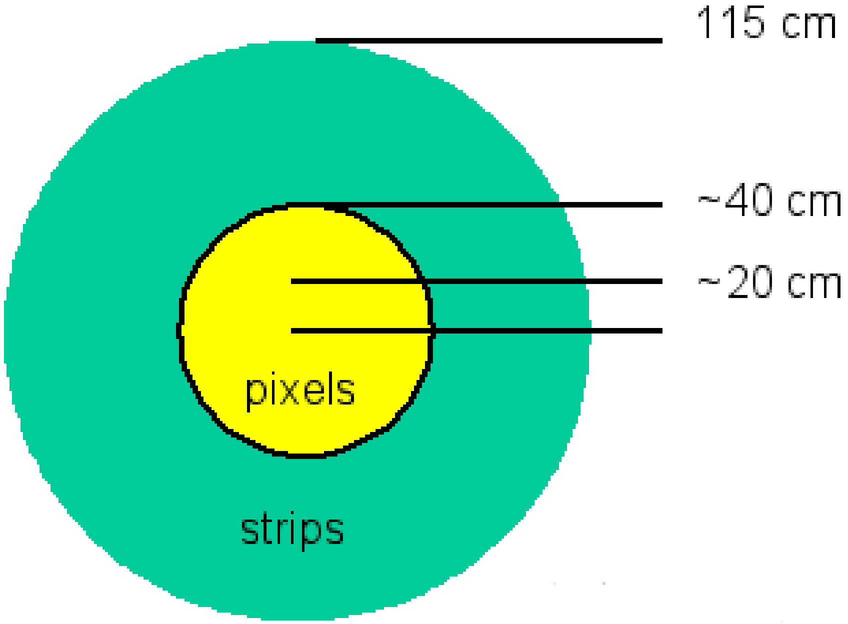
- Have begun to study $\mathcal{L} = 10^{35}$ cm^{-2}s^{-1} luminosity



- Tracker main victim of this luminosity (Occupancy, radiation dose)
- Move all layers out in radius – what about smallest radii?

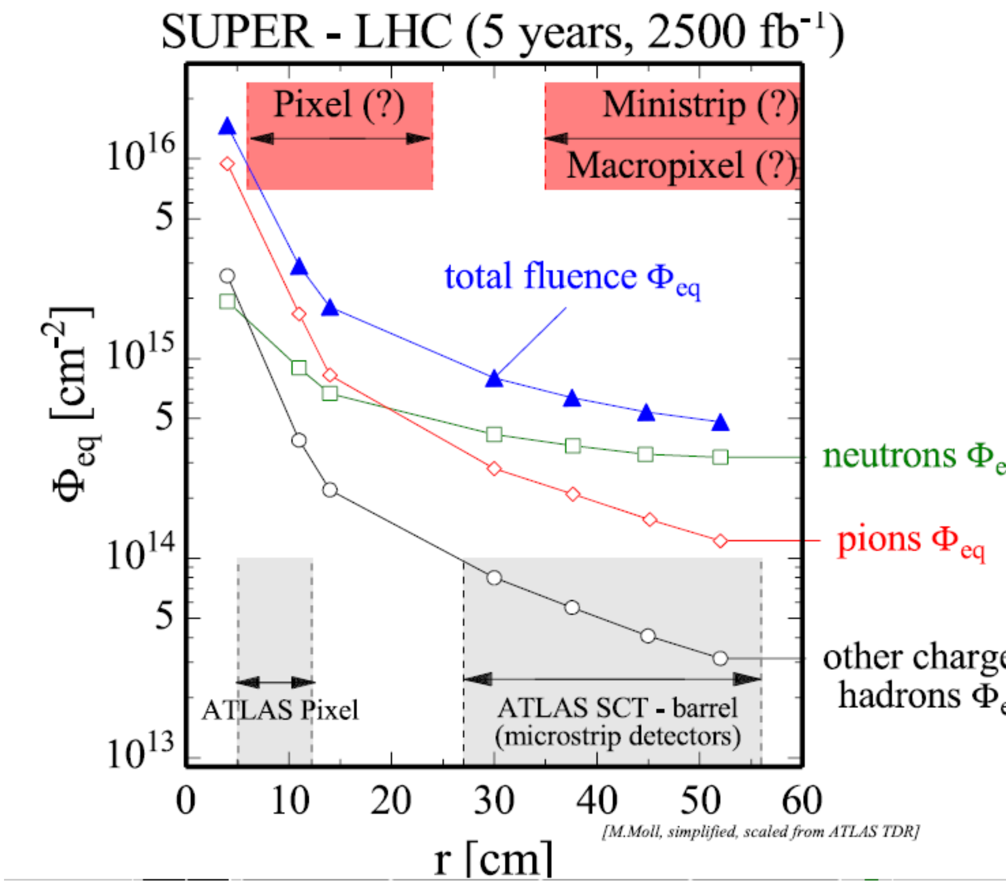
Schematic sLHC Tracker Upgrade

ID volume



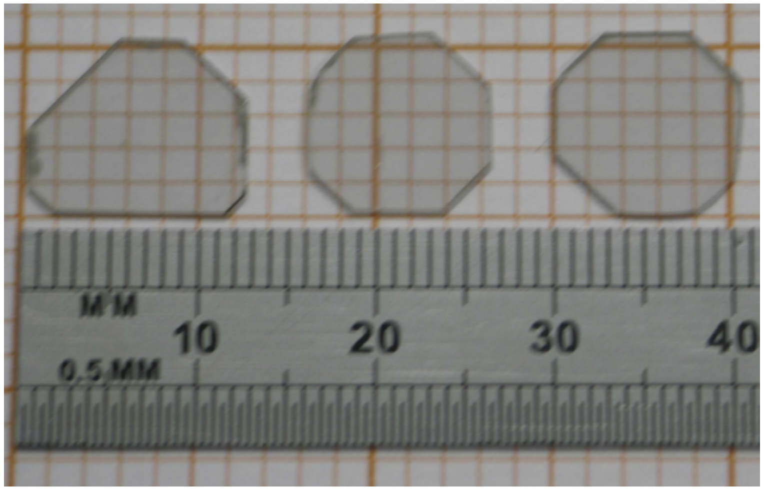
- Data rates 10x higher
- Move division between Pixels and strips from 15 to 45 cm to cope with occupancy and radiation
- In ATLAS the TRT must be replaced

- Radiation dose 10^{16} at r= 4 cm



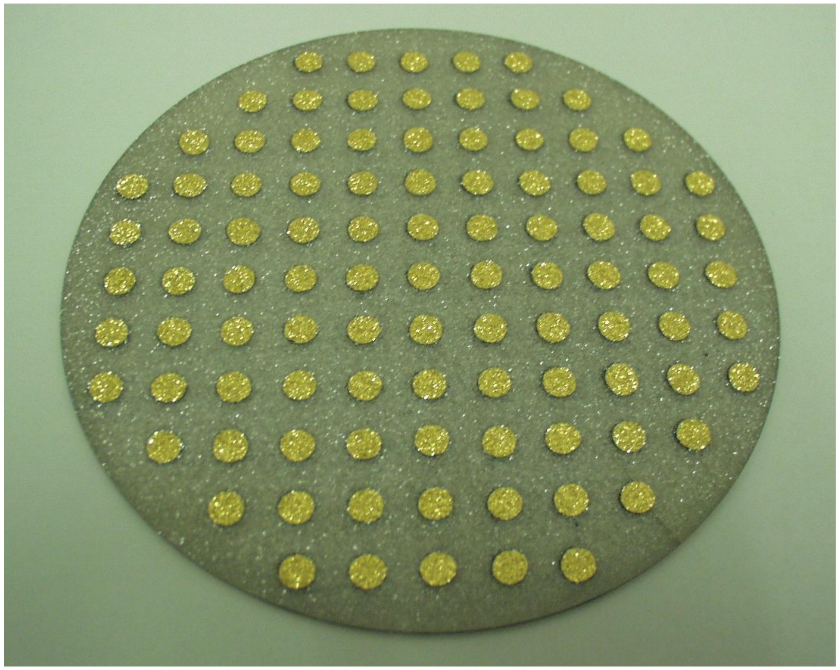
[M.Moll, simplified, scaled from ATLAS TDR]

Examples of CVD Diamond Material



scCVD samples

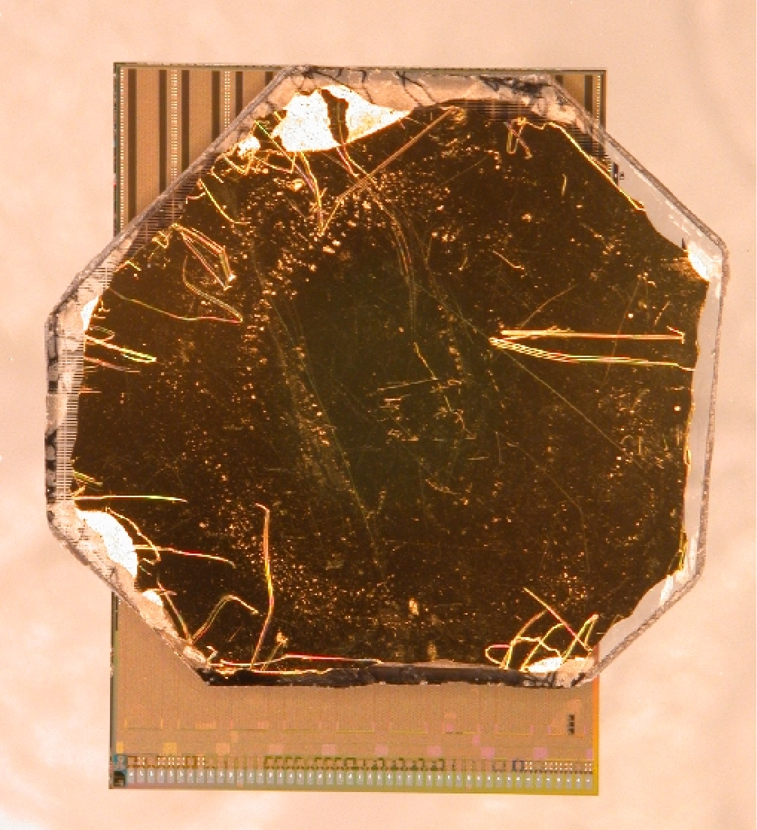
(Courtesy Element6)

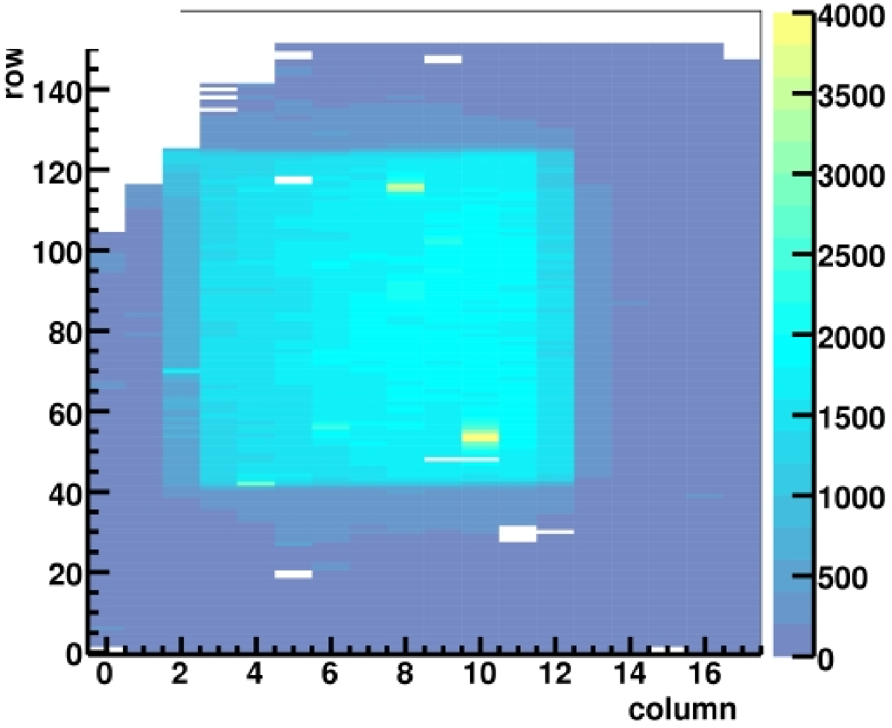


- pCVD diamond wafer
- Dots are on 1 cm grid

- High quality pCVD wafers grown 12 cm in diameter
- Best material from wafers grown up to 2 mm thick

Single Crystal Pixel Demonstrator Results

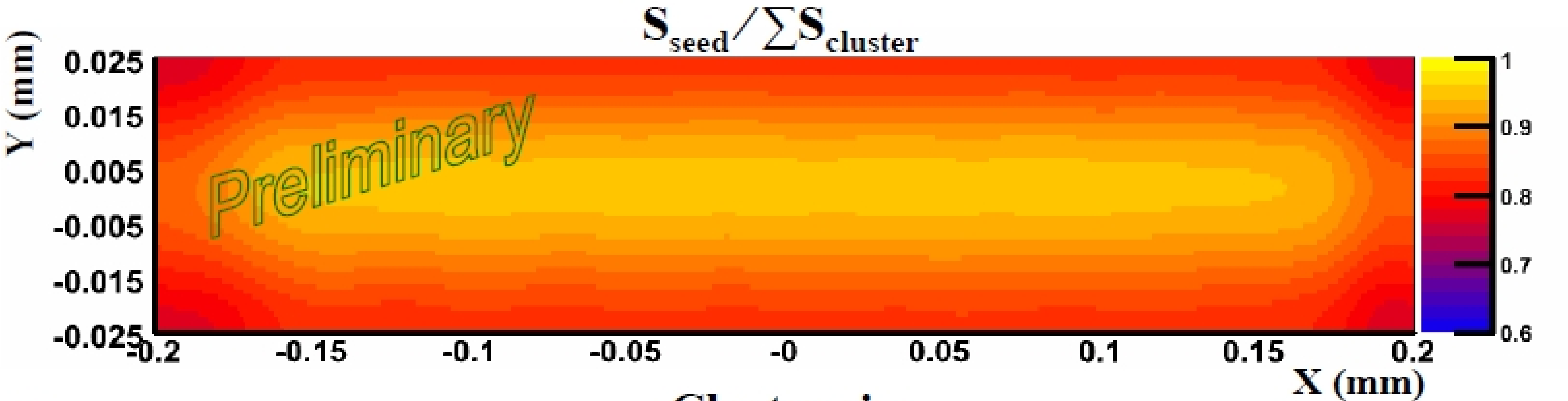




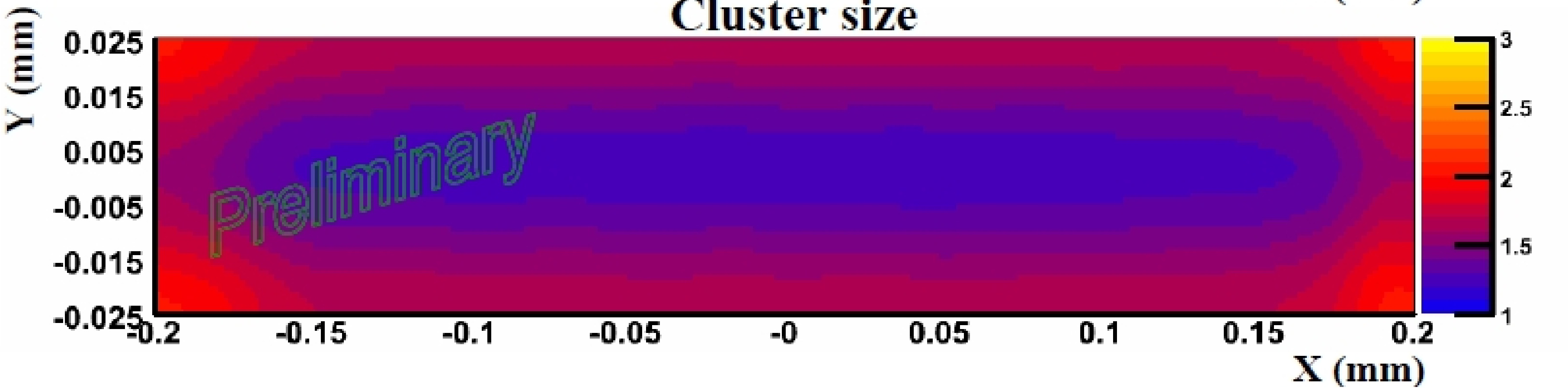
- Single crystal, single-chip `ATLAS` pixel prototype
- Testbeam track distribution

Pixel Charge Sharing in Diamond

- Study the charge sharing between pixels in diamond



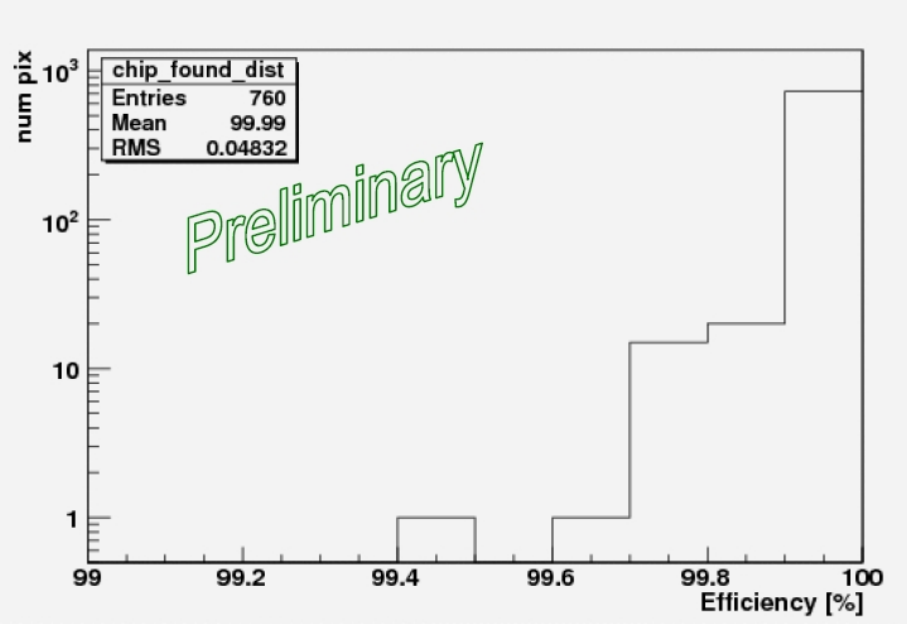
$S_{seed}/\sum S_{cluster}$

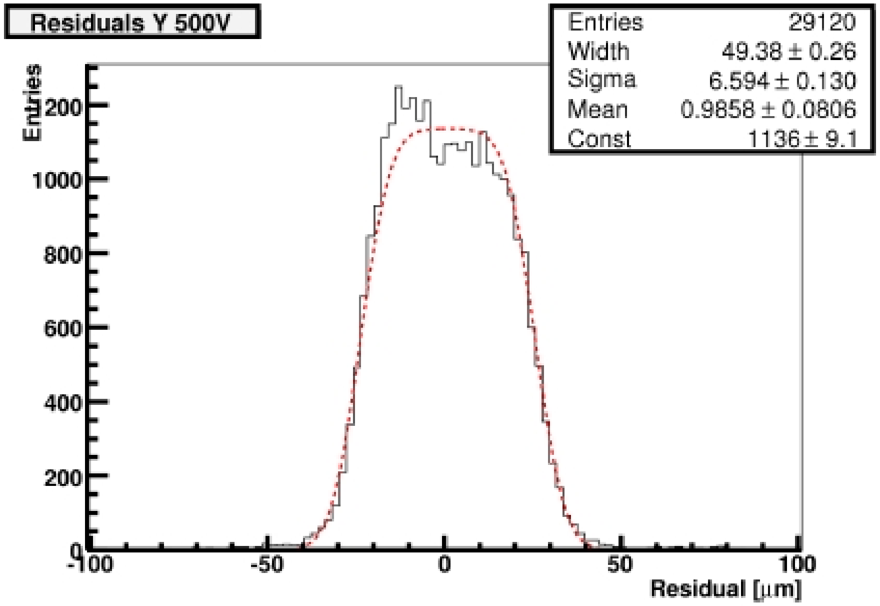


Cluster size

- Most of the charge ends up on single pixels
- Should anticipate similar performance in silicon after irradiations

Pixel Efficiency and Position Resolution





- Identify and remove problem pixels
  - 6/800 have bad electronics
- Remainder show $\varepsilon > 99.9\%$

- Single pixel clusters dominate
- See edges of pixel with $\sigma \approx 7\mu$m

Pixel Diamond Prototype Results

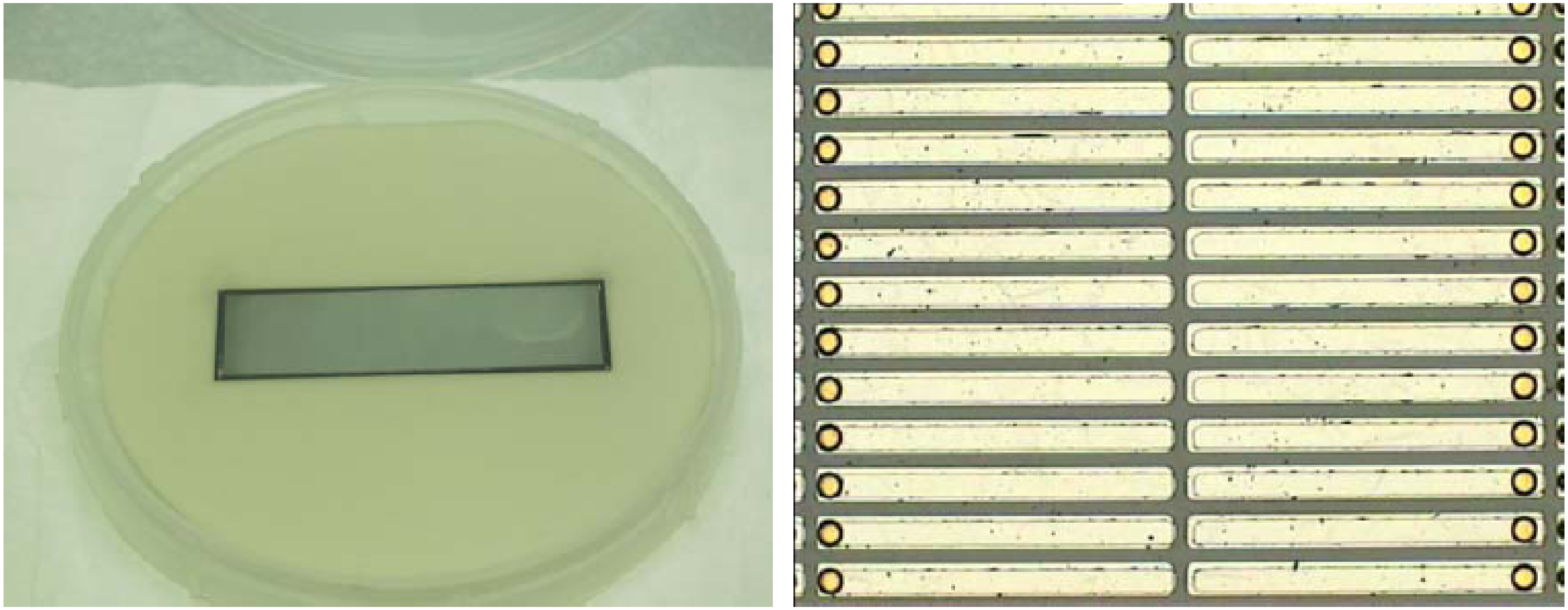


Figure 5: (a) Photograph of the ATLAS pixel diamond mounted in the carrier ready for bump bonding. (b) Zoom view of the pixel pattern after the under-bump metal is deposited.

Diamond Pixel Module

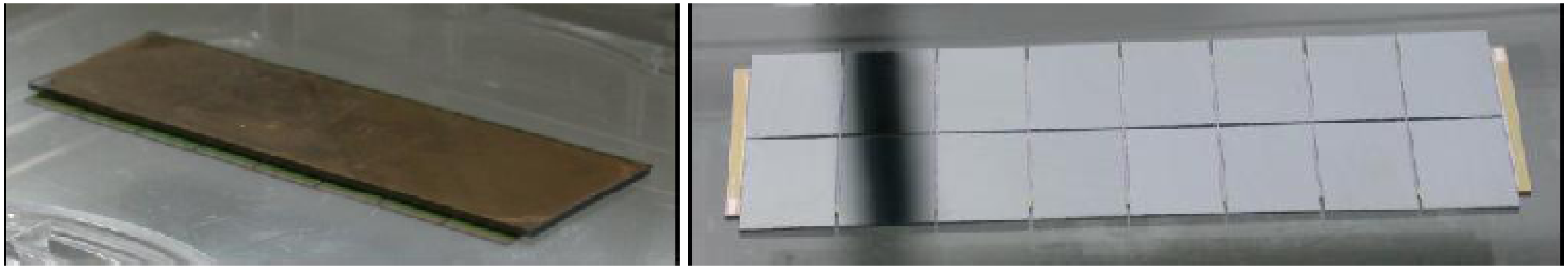


Figure 6: Photograph of the detector side (a) and electronics side (b) of the final ATLAS pixel module.

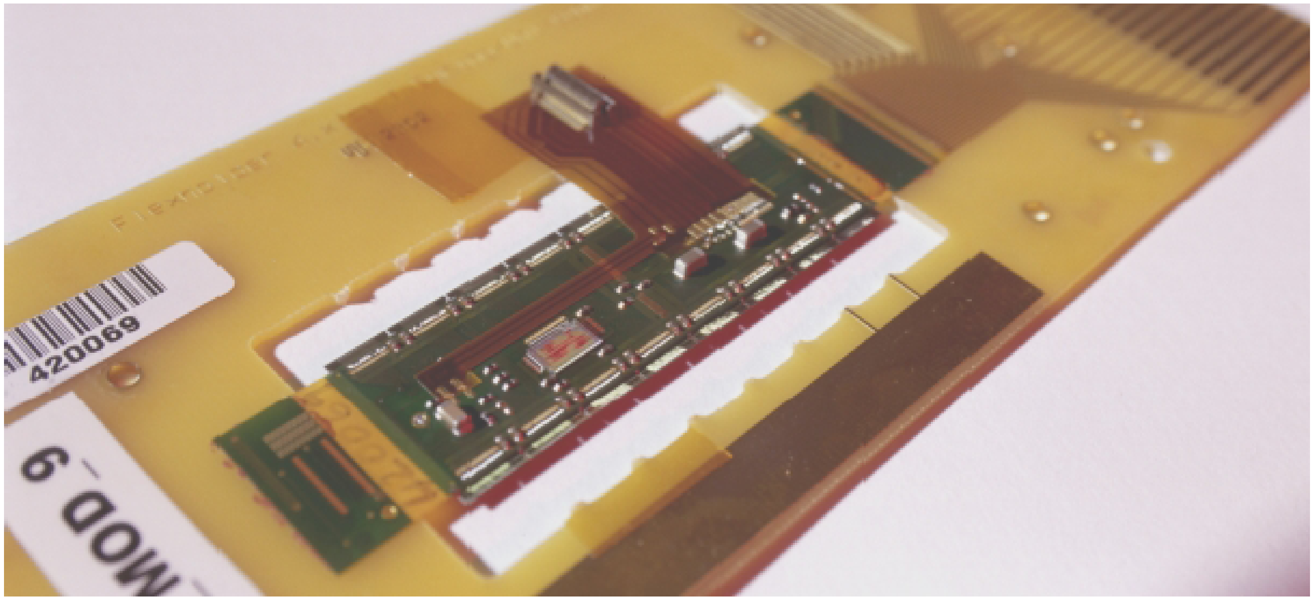


Figure 7: Photograph of the fully dressed diamond ATLAS Pixel Module ready for test.

Testbeam Beam Profile

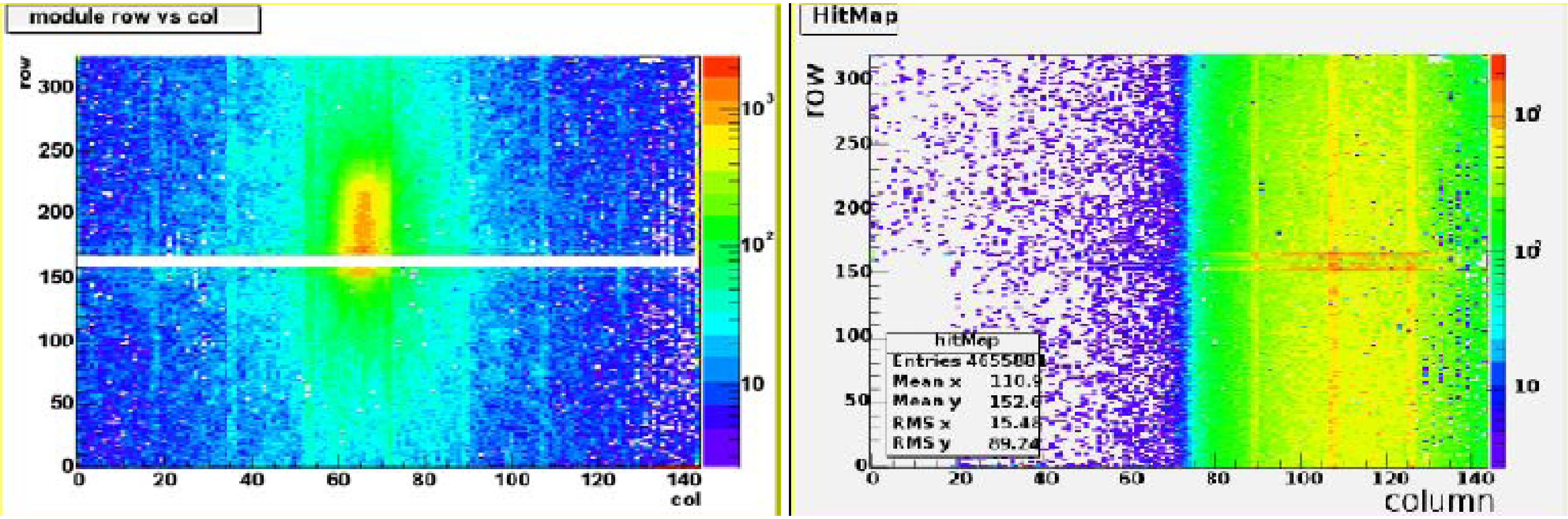


Figure 8: ATLAS pixel module hitmaps in the (a) 180 GeV pion beam at CERN and (b) the 4-6 GeV electron beam at DESY. At DESY, with telescope tracking, one observes the edge of the scintillator trigger and that the ganged pixel region has been resolved.

Diamond Pixel Hit Resolution

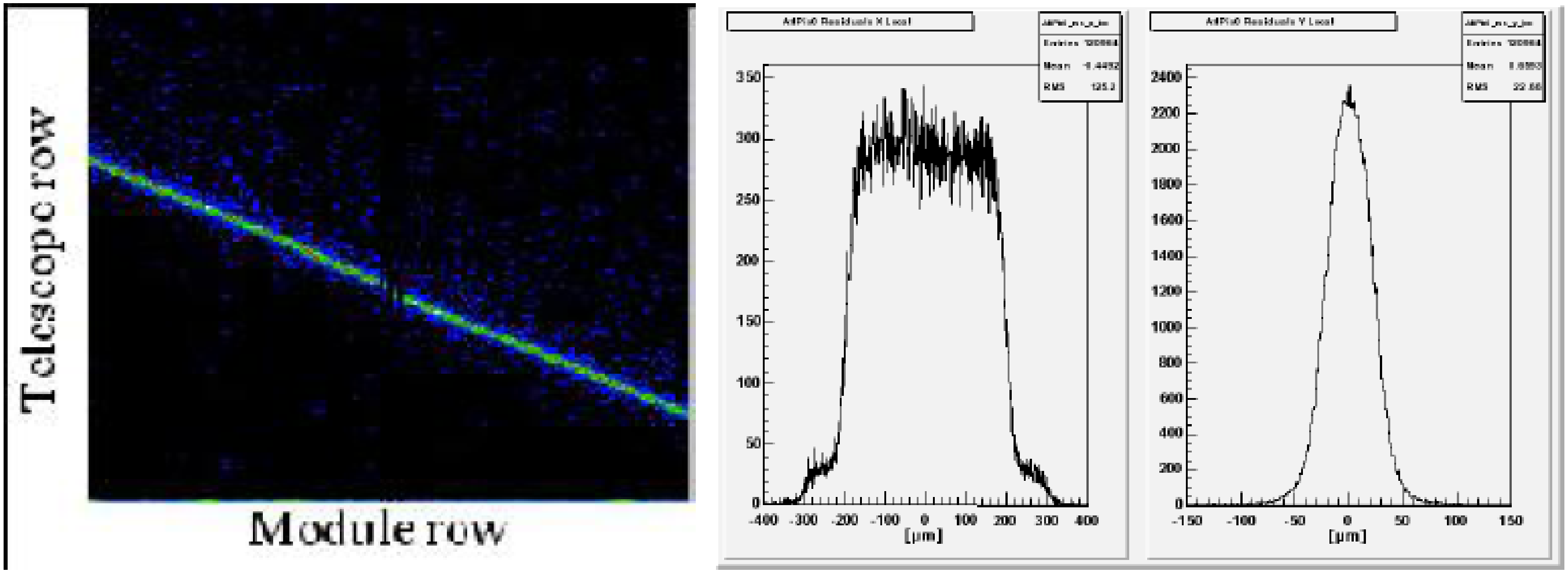
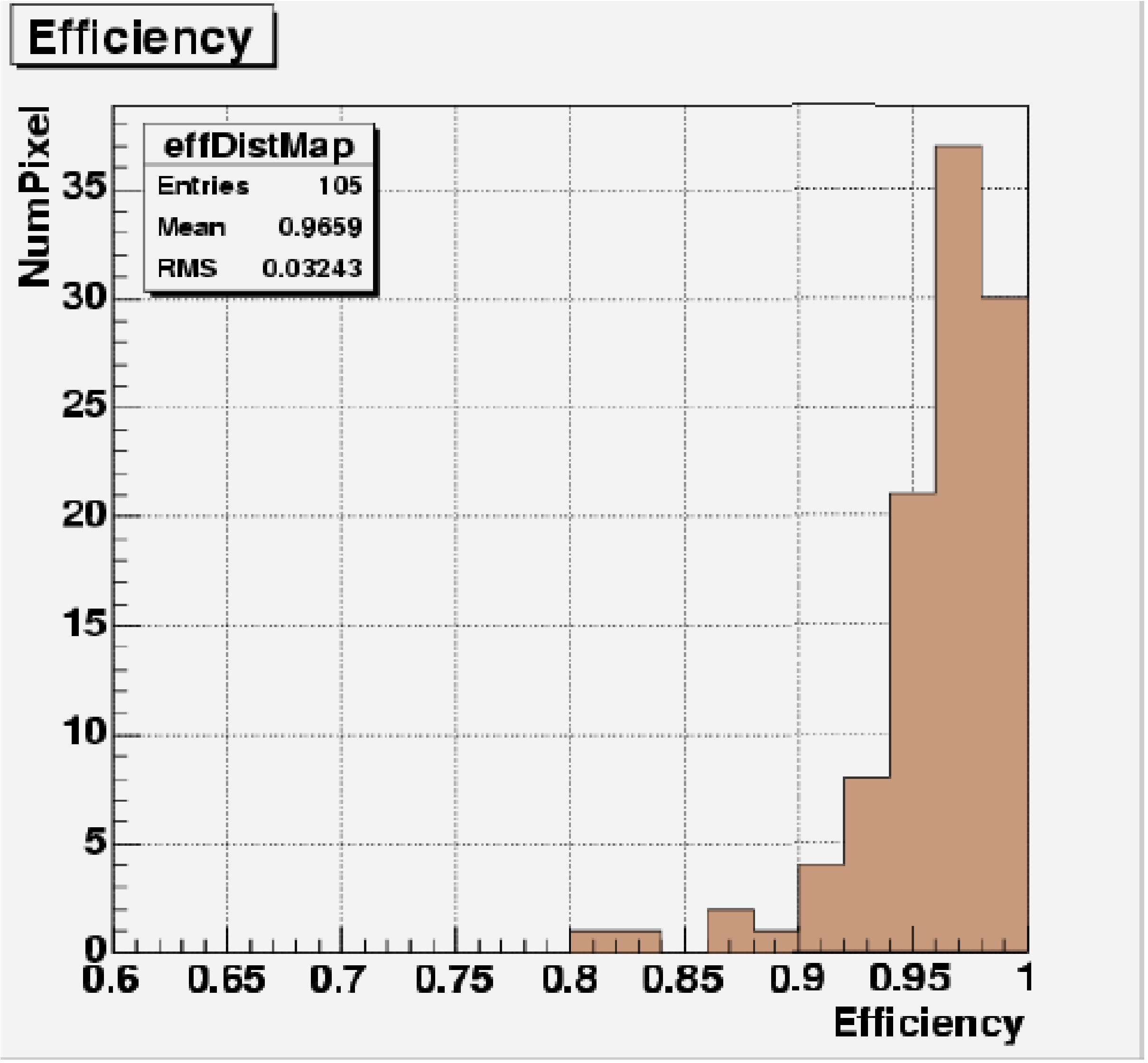


Figure 10: (a) ATLAS pixel module correlation with the tracking telescope. (b) Pixel module spatial resolution in the testbeam at DESY. The contribution from multiple scattering dominates the resolution and has not been unfolded.

Pixel Module Efficiency

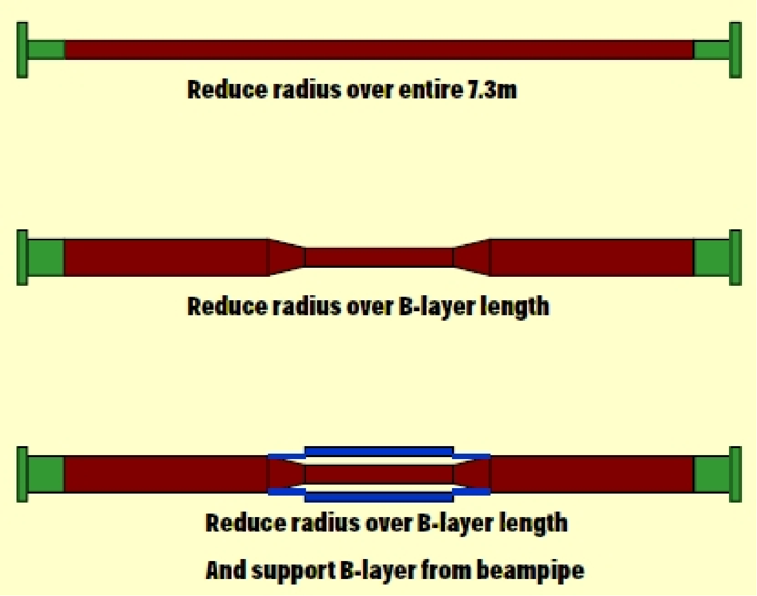


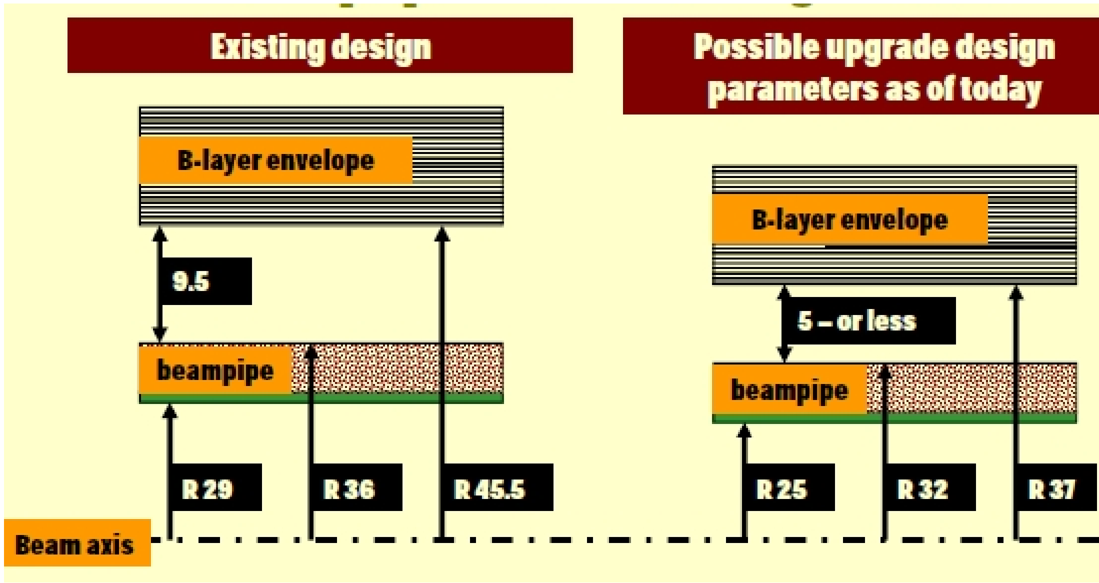
Diamond in the ATLAS b-layer Replacement

- Proceed in stages: Replace b-layer first
- Doesn't demand ultimate radiation tolerance
- Thermo-mechanical advantages of diamond more interesting
  - Spread heat load from readout chips (used in other experiments)
  - Can make the modules very thin
  - Put cooling only at module ends
  - 0.2% X_0 sensor, 0.15% X_0 readout chip, Cooling/support 0.5% X_0?
    - All together less than 1.0% X_0
- b-layer replacement will have about 100 modules

Beampipe “Upgrade”

- Have been offered the opportunity to reconsider beampipe envelope

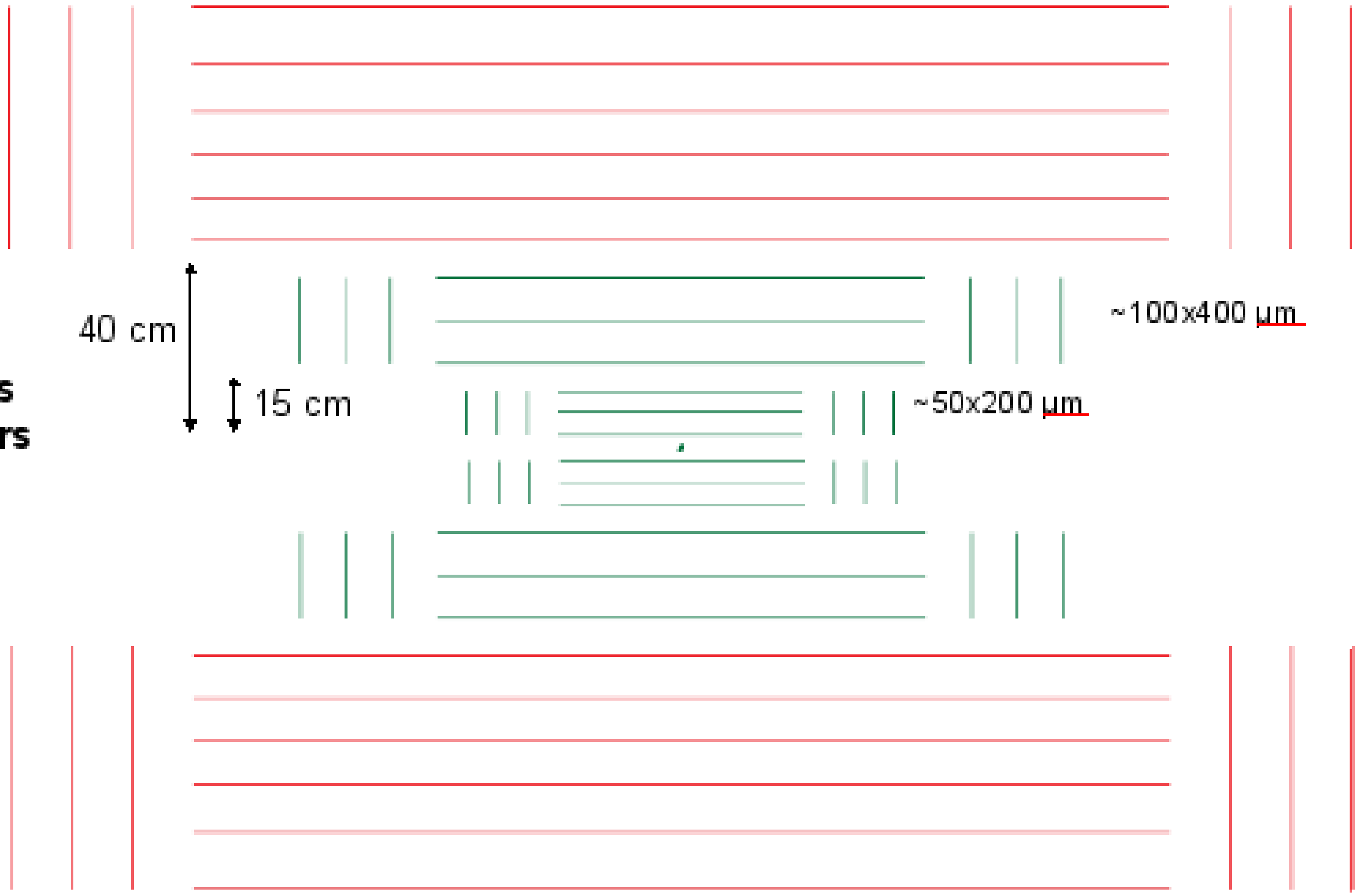




- Mount on the beampipe
- Insert b-layer inside current layers

- Early operational experience will inform choice of revised dimensions

Possible sLHC Tracker Layout



Strips
6 layers

Pixels
6 layers

40 cm

15 cm

~100x400 μm

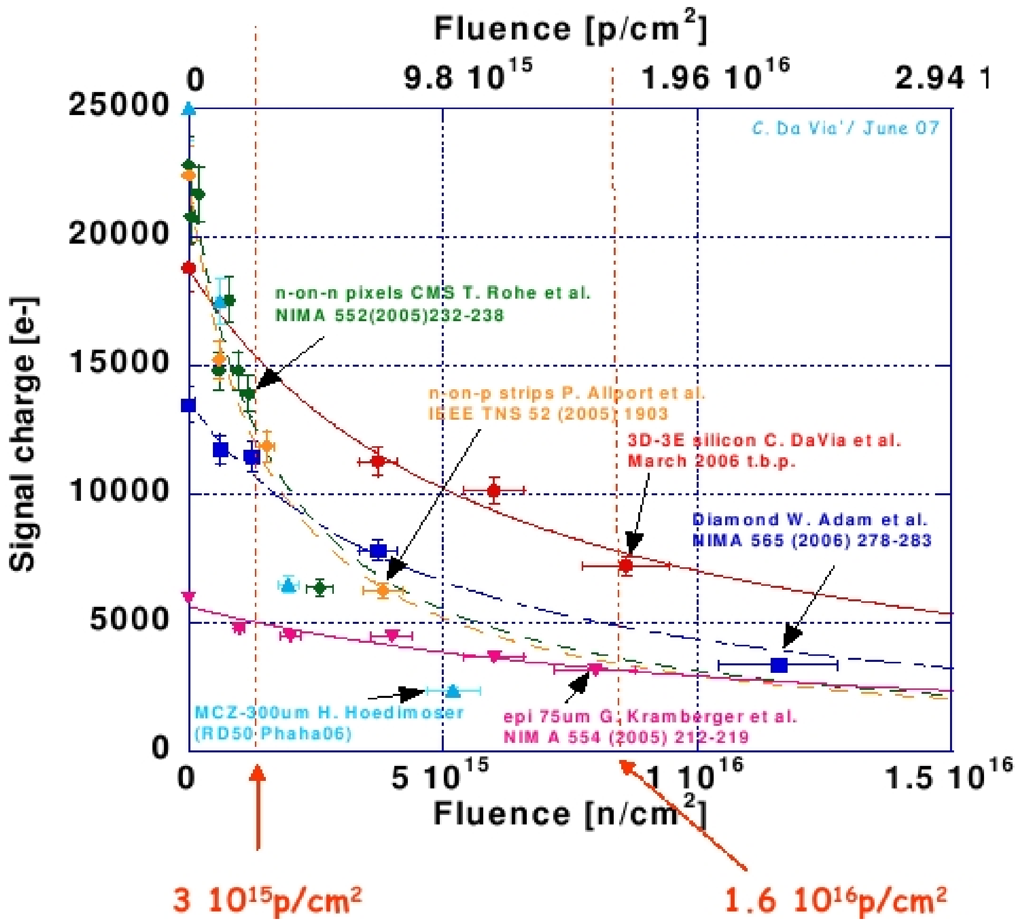
~50x200 μm

Inner Pixel Layer Dimensions

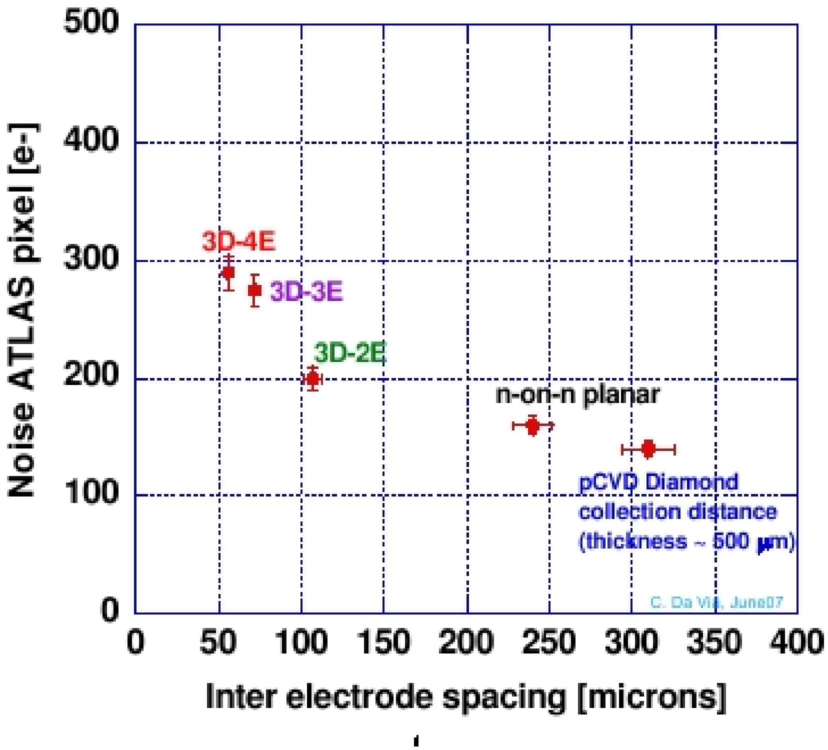
Layer	Radius (cm)	Length (cm)	Area (m^2)	Modules
Barrel-1	4	100	0.25	126
Barrel-2	8	100	0.50	252
Barrel-3	12	100	0.75	378
Disks 1-3			0.27	140
Total			1.77	896

- Roughly 1/3 of the current pixel system
- Reduce readout pitch ($50 \times 250\ \mu m^2$) $\Rightarrow$ roughly same channel count

Radiation Tolerance Comparison



NB: 3D Silicon at 2 V/μm, Diamond at 1 V/μm

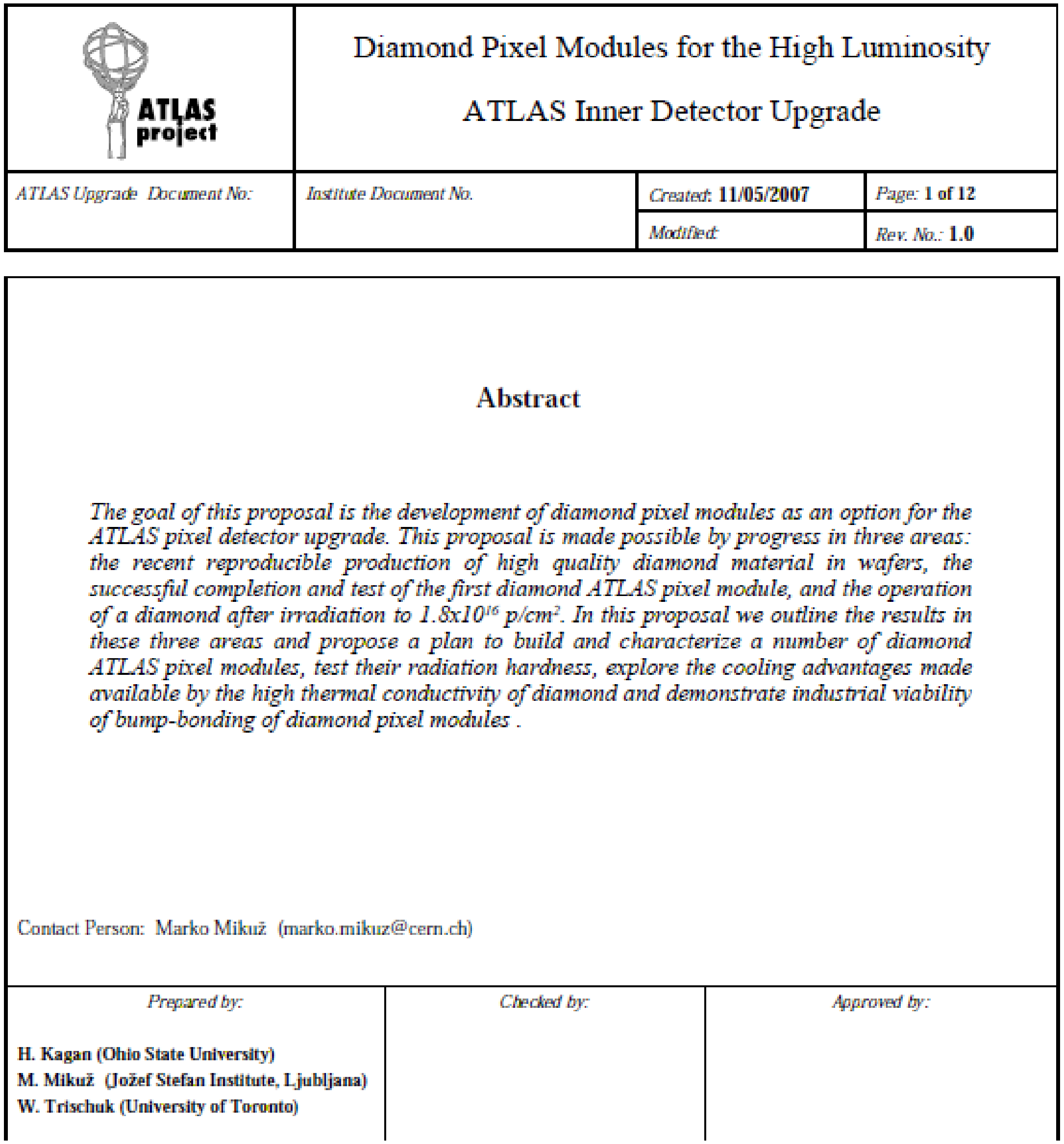


(Comparisons: Phil Allport
ATLAS-Week, Glasgow, 2007)

- Diamond offers
  - a proven signal at 10^{16} p/cm^2
  - 30-50% lower noise/threshold
- n-on-n silicon is a b-layer backup

ATLAS Diamond Pixel Sensor EOI

- Submitted May 2007
- Institutions:
  - Bonn
  - Carleton
  - CERN
  - Ljubljana
  - Ohio State
  - Toronto
- Expect feedback in Fall 2007



ATLAS project

Diamond Pixel Modules for the High Luminosity

ATLAS Inner Detector Upgrade

ATLAS Upgrade Document No:	*Institute Document No.*	*Created:* **11/05/2007**	*Page:* **1 of 12**
		Modified:	*Rev. No.:* **1.0**

Abstract

The goal of this proposal is the development of diamond pixel modules as an option for the ATLAS pixel detector upgrade. This proposal is made possible by progress in three areas: the recent reproducible production of high quality diamond material in wafers, the successful completion and test of the first diamond ATLAS pixel module, and the operation of a diamond after irradiation to 1.8×10^{16} p/cm^2. In this proposal we outline the results in these three areas and propose a plan to build and characterize a number of diamond ATLAS pixel modules, test their radiation hardness, explore the cooling advantages made available by the high thermal conductivity of diamond and demonstrate industrial viability of bump-bonding of diamond pixel modules .

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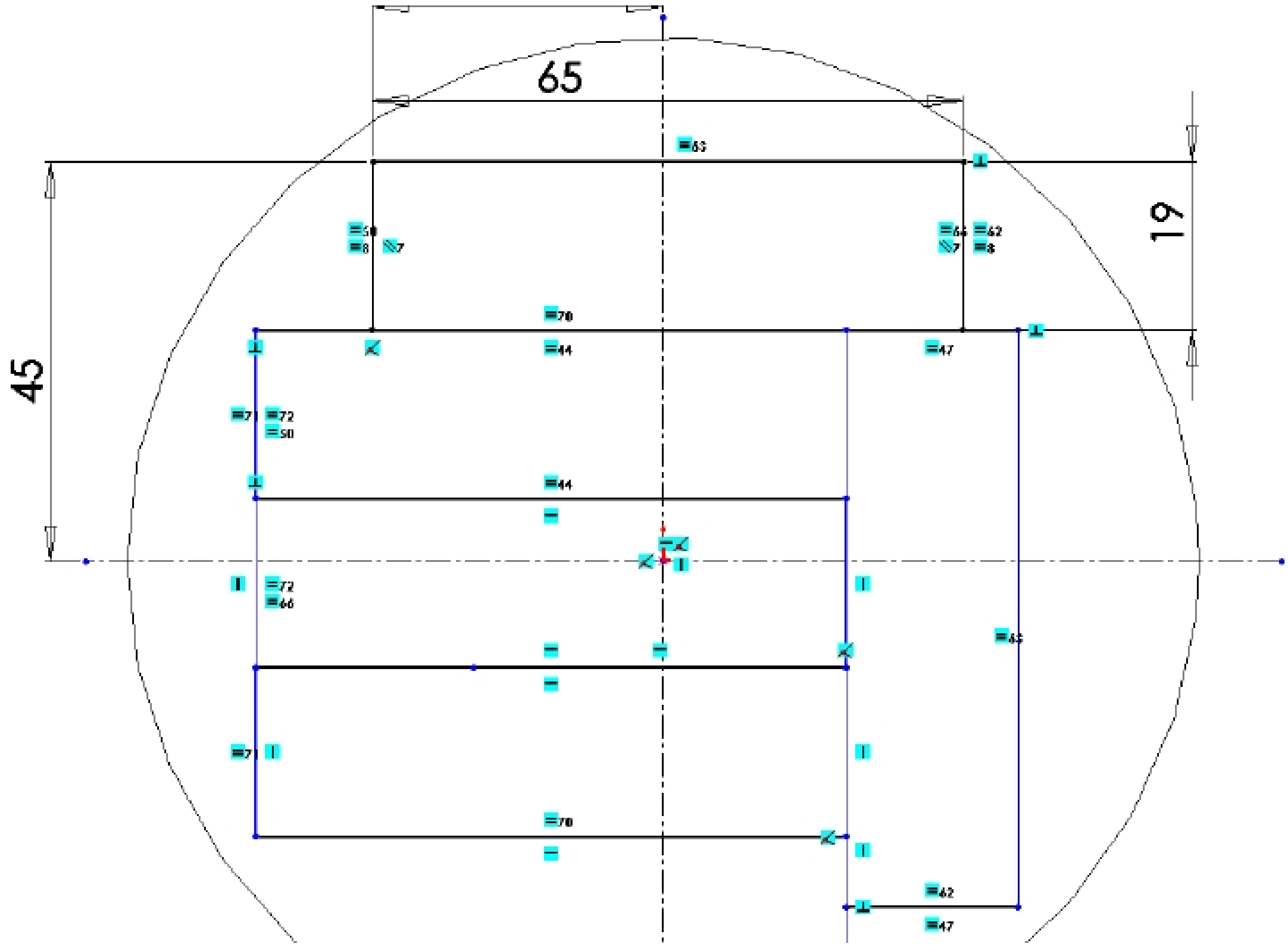
Cost Considerations

- Current Pixel Detector:
  - Current sensors cost 0.6 MCHF/m^2
  - VLSI readout chips cost 1.7 MCHF/m^2
  - Bump bonding costs 2.6 MCHF/m^2
  - Rest of services/mechanics 4 MCHF
- Sensor cost is a consideration
- Cost/feasibility of bump-bonding is more important

Diamond Sensor Wafer Pattern



- Giving input to diamond suppliers on part count and delivery rate
- Expect budgetary quotations in 2008 to inform sensor cost estimates

Summary

- Performing irradiations of first module now
- Assembling second full pixel module in Fall 2007
- Developing industrial metalisation and bump-bonding solution
- Place diamond purchase and bump-bonding contracts in early 2008
- Designing thinner mechanical support/cooling schemes
  - to take advantage of thermo-mechanical properties of diamond

Diamond sensors are a serious alternative for radiation hard trackers