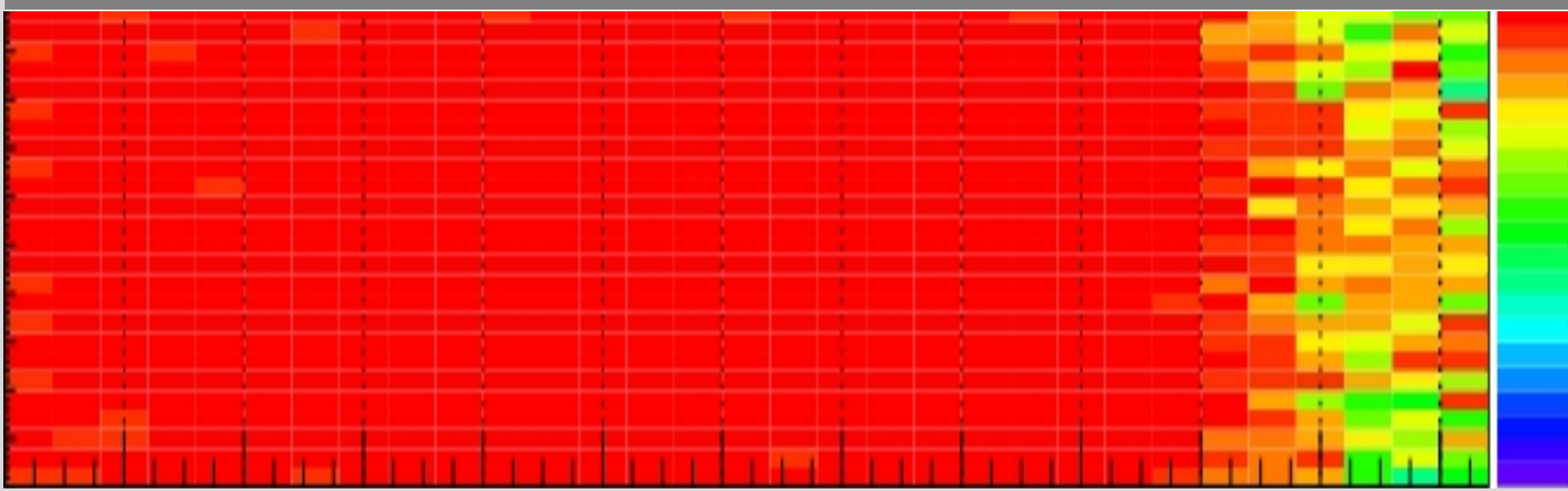
Investigation of hit efficiency of n-in-p pixels with different designs

Natascha Savić
M. Bomben*, A. Macchiolo, R. Nisius, S. Terzo
*LPNHE & UPD, Paris

26th RD50 Workshop, Santander
June 22nd-24th 2015

MAX-PLANCK-GESELLSCHAFT
Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)



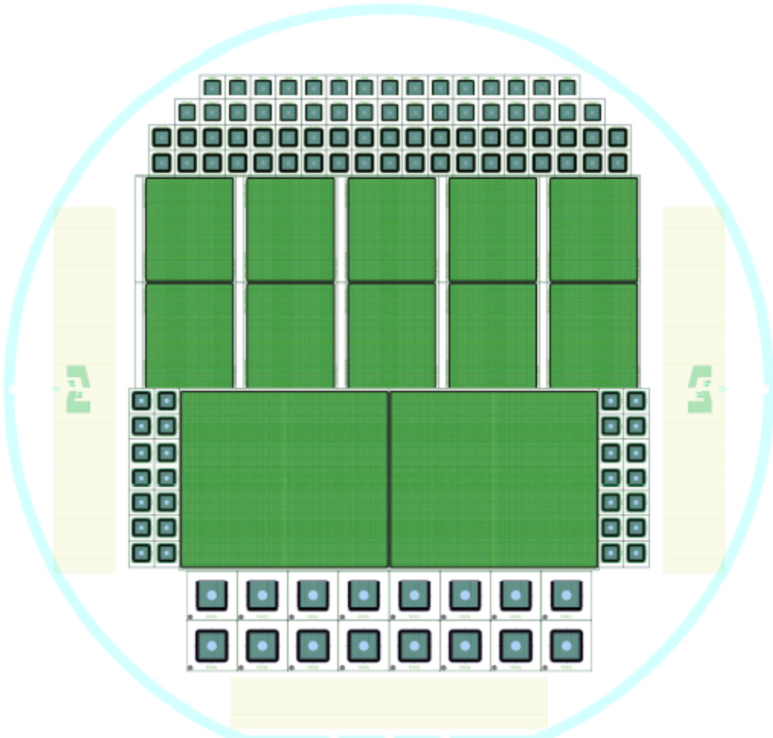
Overview

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

- **Test-beam studies with n-in-p planar pixels in (un-)irradiated modules**
  i. with different implementations of punch-through designs (including the design of Dortmund TU)
  ii. with 25x500 μm^2 pitch pixels with external punch-through structure (MPI design)
- **Laboratory studies at MPP with investigation of**
  i. charge collection with source scans
  ii. dependence of charge collection on temperature
- **Test-beam studies with n-in-p planar pixels**
  i. irradiated module at high Φ (80° incidence angle (η~2.4))

CIS3 Production

- First 6" production at CiS
- 6" wafers on p-type FZ material
- Thickness : 265 - 270 μm



- **CiS3** standard FE-I4 pitch with modified punch-through structures
  - Pixel size : 50x250 μm²
  - Pixel number : 80x336

- **CiS3** modified FE-I4 with 25 μm r-Φ pitch
  - Pixel size : 25x500 μm²
  - Pixel number : 40x672

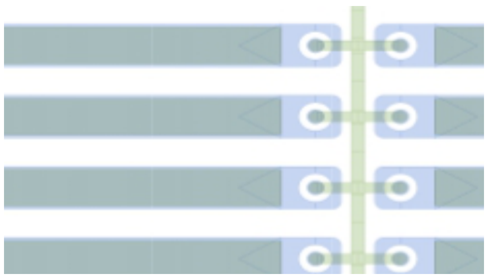
RD50 project: 2012/01

Different punch-through designs

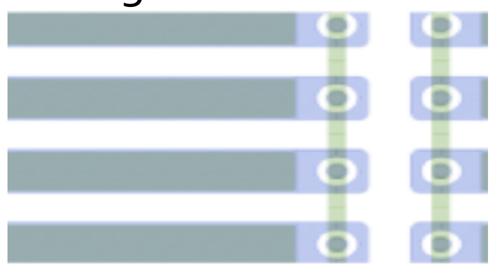
Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

50x250 µm² pixel pitch

Standard punch-through



Bias line over punch-through dot



Bias line over center of pixel implant

individual p-t

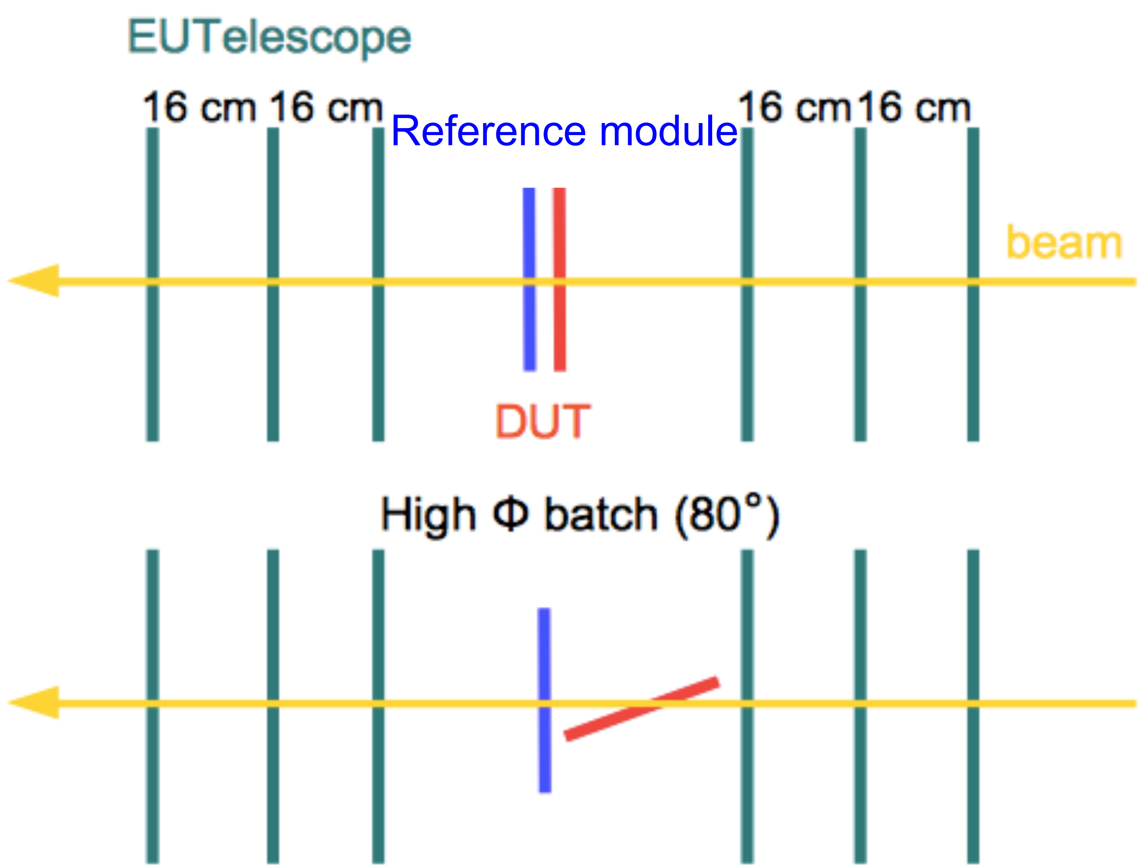
25x500 µm² pixel pitch

Common punch-through

combined p-t

Test-beam studies of different module designs

- Test-beam set up sketch

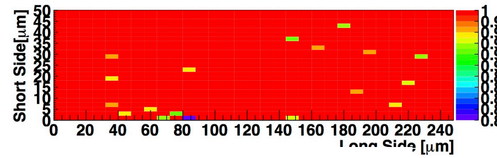


Data analysis sequence

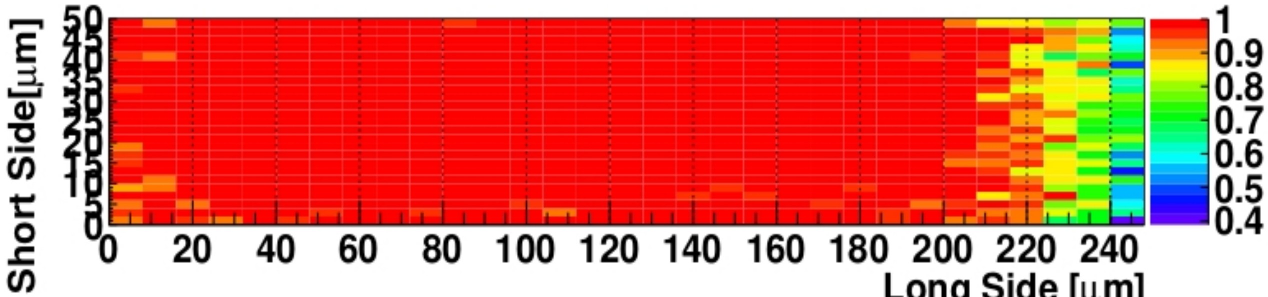
- Test-beam at DESY with 4 GeV electrons
- Track reconstruction done by EUTelescope
- Track analysis done with Tbmon2

Different punch-through designs- in-pixel hit efficiency

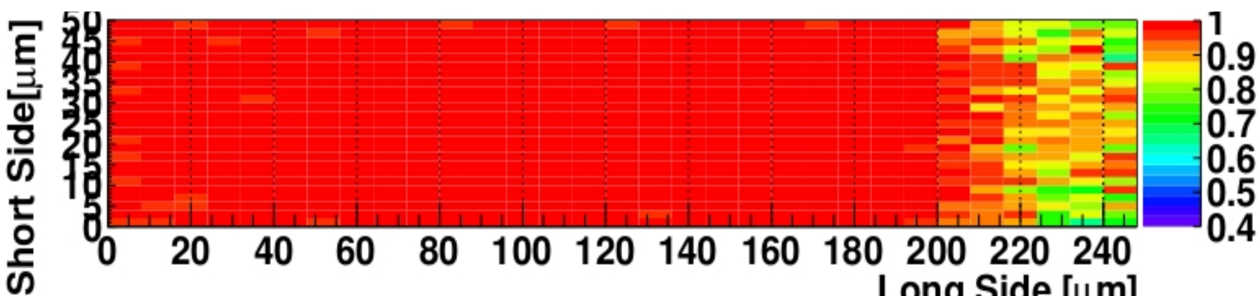
- **Irradiated at 3e15 n_{eq}/cm^2, V=700 V**



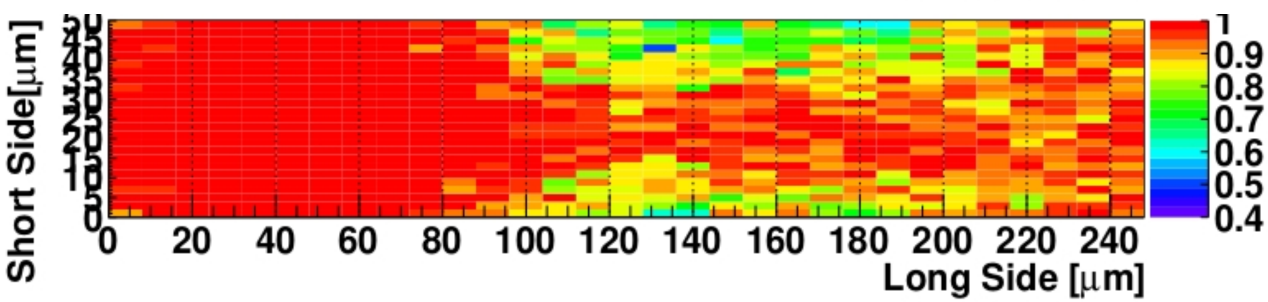
<- For comparison: hit efficiency map of the same module, but unirradiated



Standard punch-through



Bias line over punch-through dot

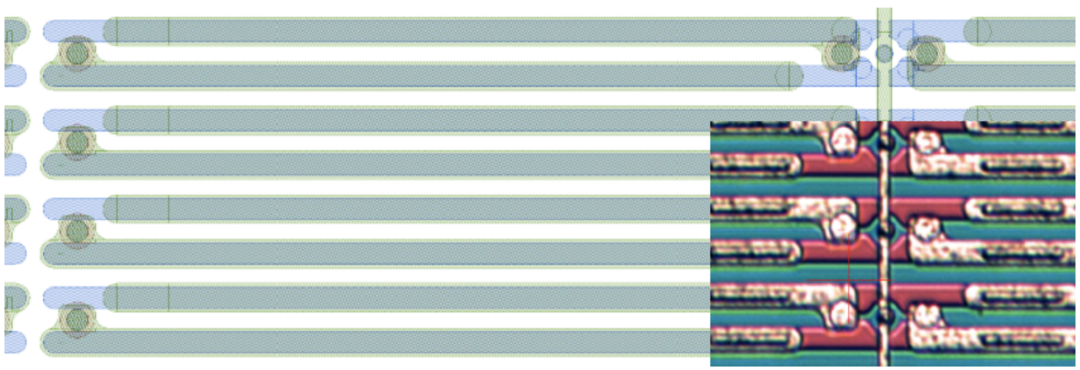


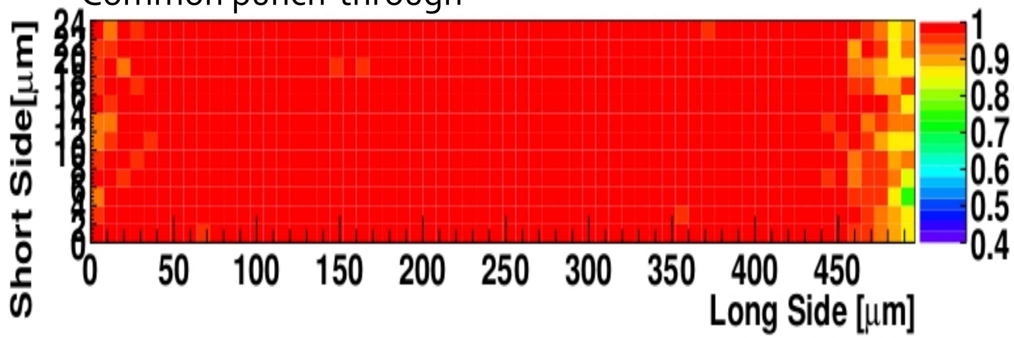
Bias line over center of pixel implant

Third design less efficient due to horizontal bias rail between pixels

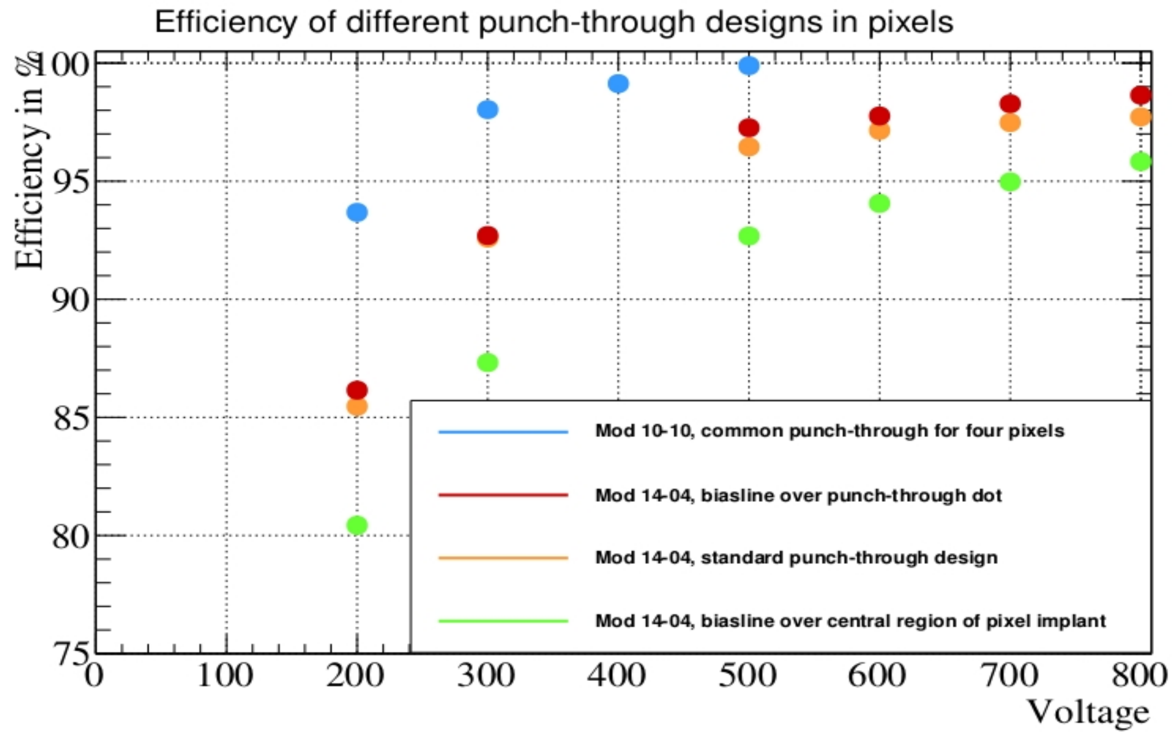
Novel punch-through design for 25x500 µm pitch

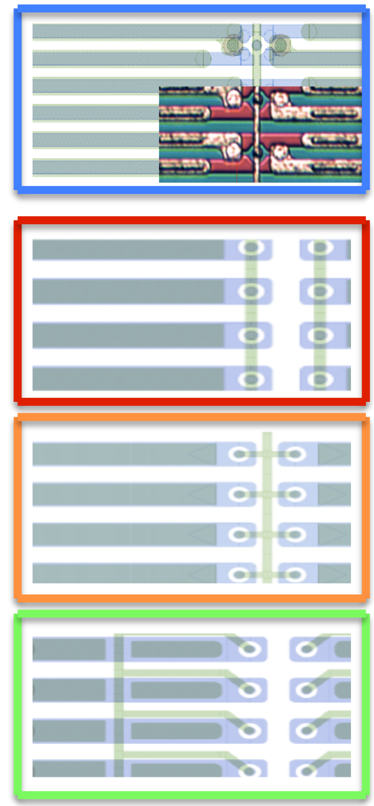
- In-pixel hit efficieny of irradiated CiS3 at 3e15 n_{eq}/cm^2 at V=500 V
- Module with common punch through structure for 4 pixels
- Efficiency obtained at 500 V : **99.38 ± 0.02 %**





Efficiencies after irradiation

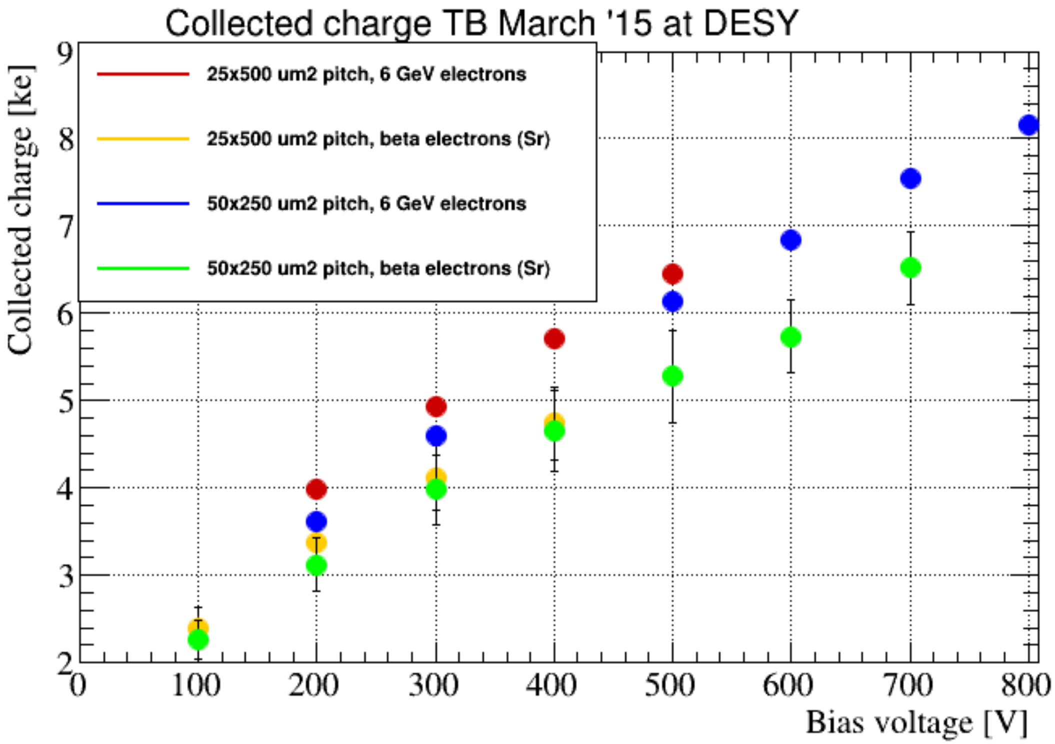


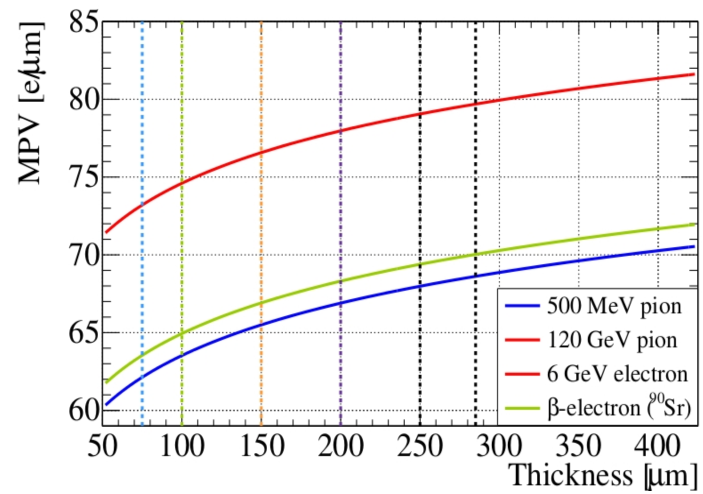


- Efficiencies of different punch-through designs at 500 V :
  1. Bias line over punch-through dot : **97.25 ± 0.06 %**
  2. Standard punch-through : **96.45 ± 0.05 %**
  3. Bias line over center of pixel implant : **92.67 ± 0.09 %**
  4. * New external p-t : common punch-through for four pixels : ***99.38 ± 0.02 %***

Total efficiency of all structures (unirradiated module)
99.86 ± 0.01 %

Charge collection source scan & test-beam





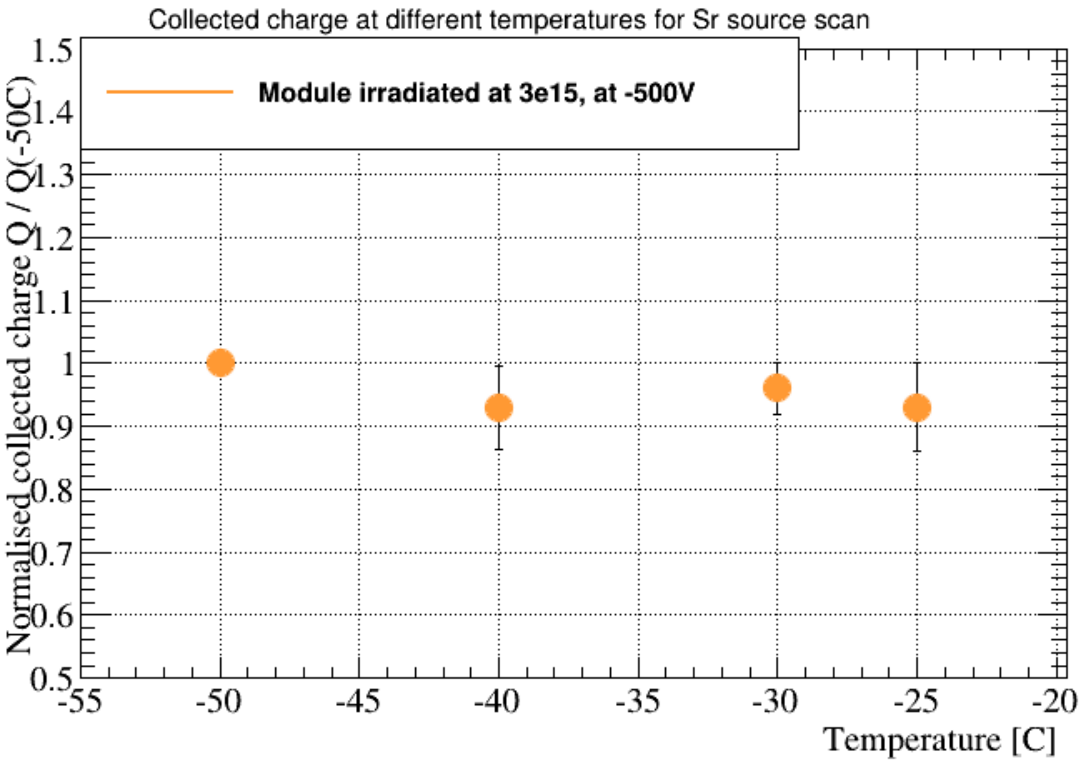
S. Terzo: Dependence of the MPV of collected charge per µm on the thickness of the sensor for different energies

- Collected charge for 25x500 µm² and 50x250 µm² pitch sensor
  1. For E = 2.280 MeV β-electrons from the ^{90}Sr decay chain (yellow and green line)
  2. For electrons with GeV as delivered by DESY facility (red and blue line)

Charge at different temperatures

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

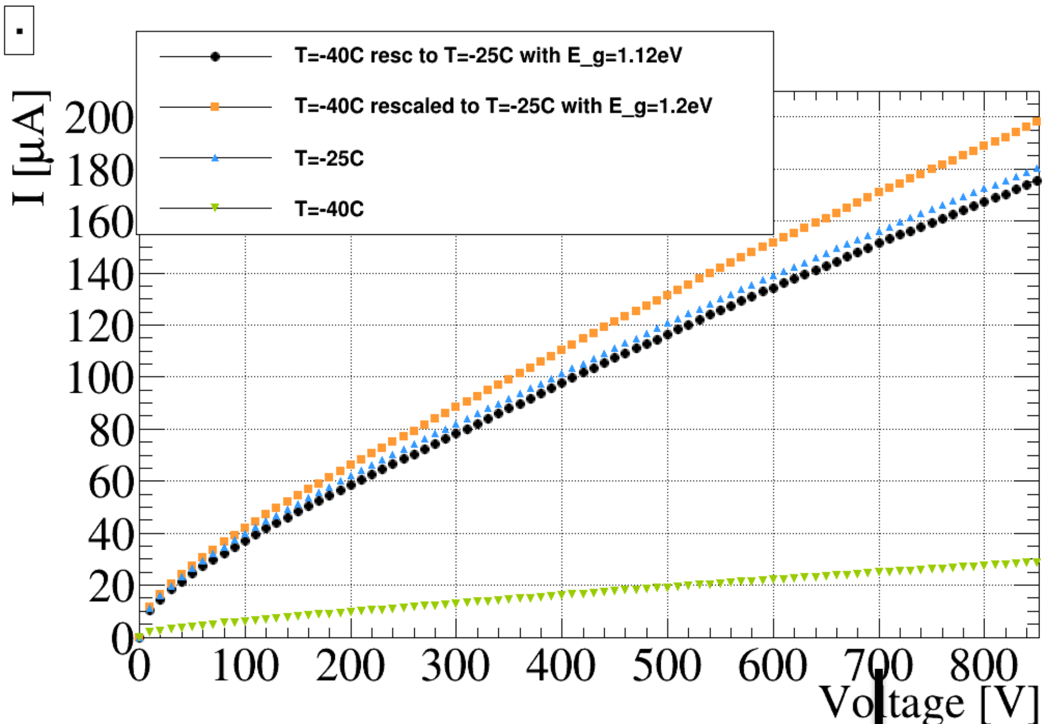
- Charge collection of one module irradiated at a fluence of 3e15 n_{eq}/cm^2 at KIT and at temperatures of -50°C, -40°C, -30°C and -25°C (module retuned for each temperature step)
- Charge collection with Strontium source scan at a voltage of 500 V



→ **Collected charge does not vary with temperature**

Power dissipation studies I-
leakage current scaling with T

- Leakage current of bare sensors placed onto a cold chuck in a probe station
- Example of irradiated CiS sensor at **5e15 n_{eq}/cm²**, **200 µm thick**, annealed for 4 days



Leakage current rescaled to T= -25°C by using

$$\frac{I_2(T_2)}{I_1(T_1)} = \left(\frac{T_2}{T_1}\right)^2 \exp\left(-\frac{E_g}{2k_b}\frac{(T_1 - T_2)}{T_1 \cdot T_2}\right)$$

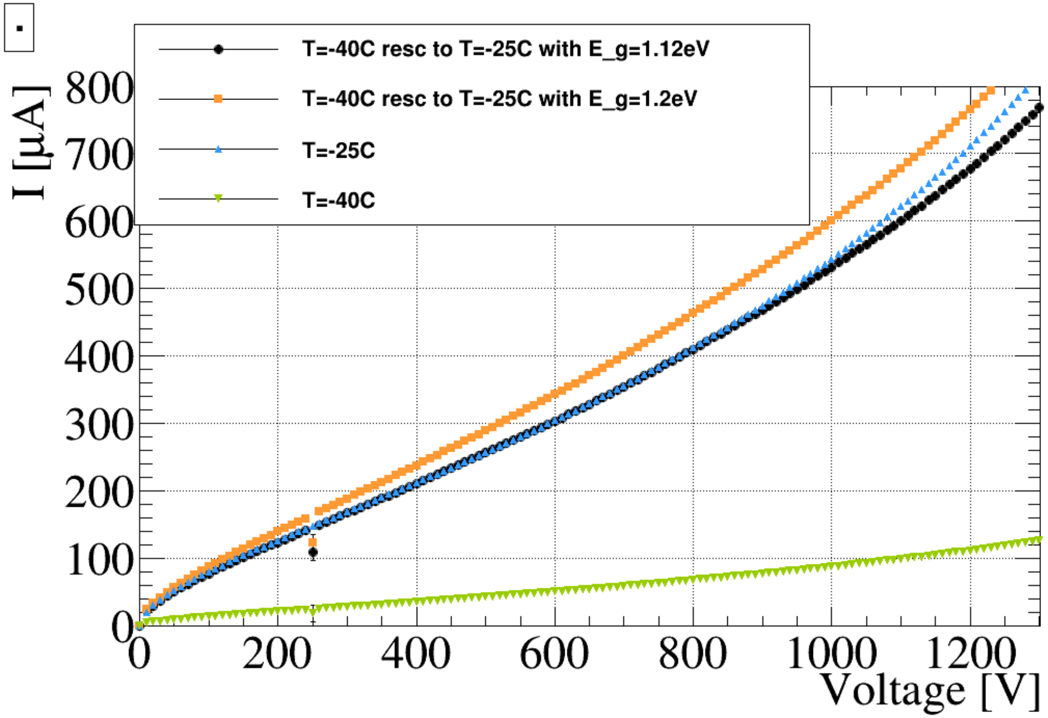
Measurements in better agreement with

E_g= 1.12 eV!

Power dissipation : 31 mW/cm²

Power dissipation studies I- leakage current scaling with T

- Example of irradiated CiS sensor at **1.3e16 n_{eq}/cm^2**, **200 µm thick**, annealed for 6 days

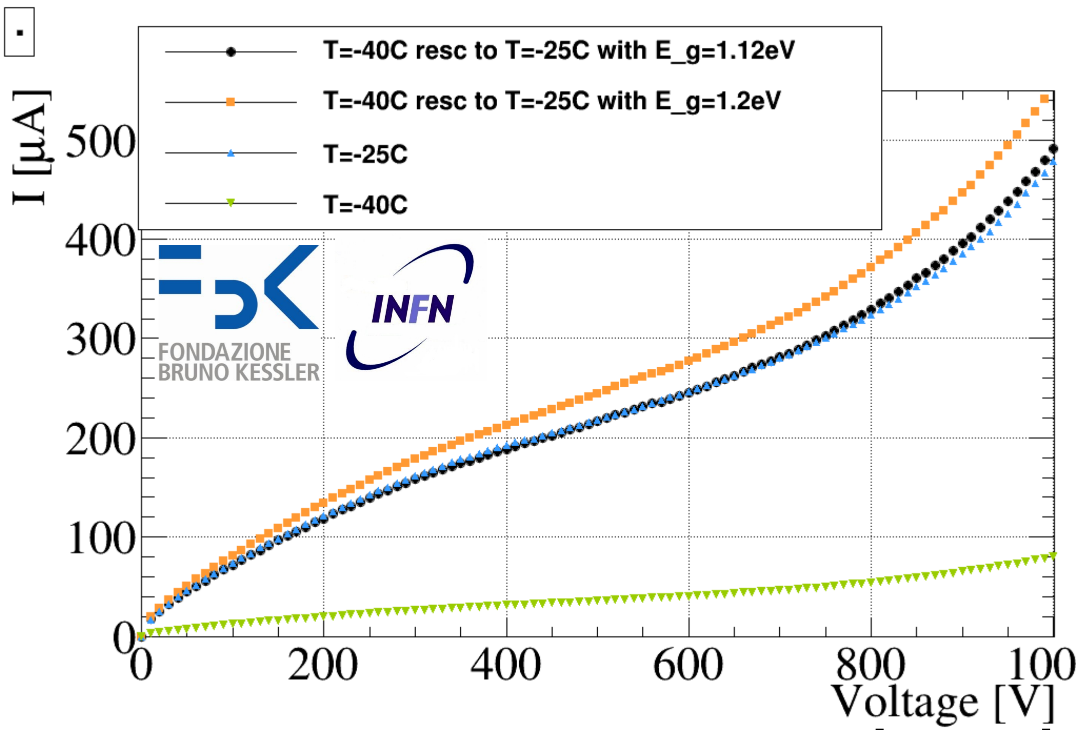


→ Difference in power dissipation depending on fluence

Power dissipation : 93 mW/cm^2 150 mW/cm^2

Power dissipation studies II-
leakage current scaling with T

- Example of irradiated FBK sensor at **1e16 n_{eq}/cm^2**, **100 µm thick**, annealed for 2 days *(thanks to FBK and IFN groups for supplying the sensor and for useful discussion)*



→ **At highest fluences there is not a significant difference in leakage current comparing 100 µm to 200 µm sensors**

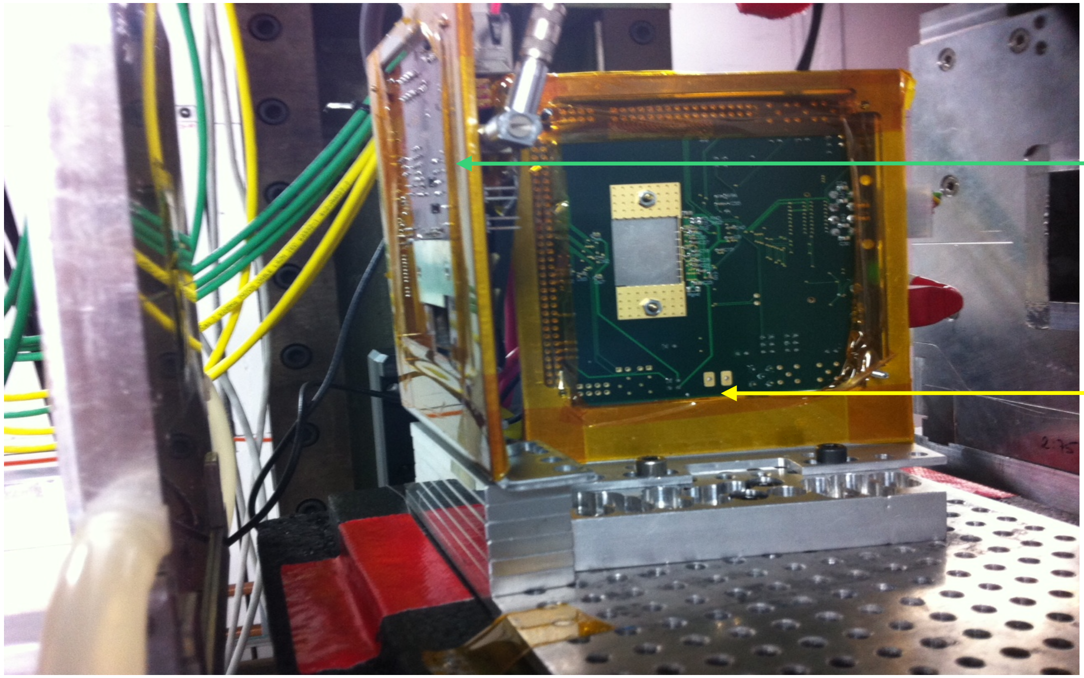
→ **Higher hit efficiency is expected for smaller thicknesses at lower voltages**

→ **To be confirmed with beam tests of pixel modules irradiated at this fluence**

Power dissipation : 75 mW/cm^2 147 mW/cm^2

Testbeam studies of tracking at high Φ

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)



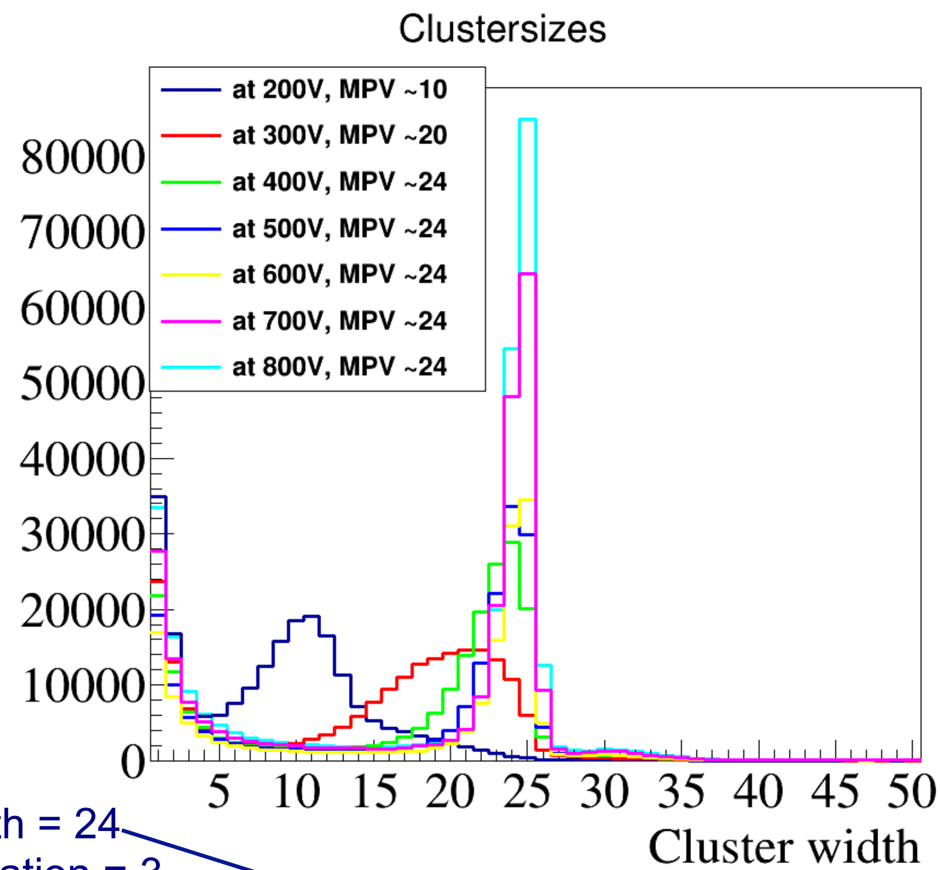
Not irradiated reference module

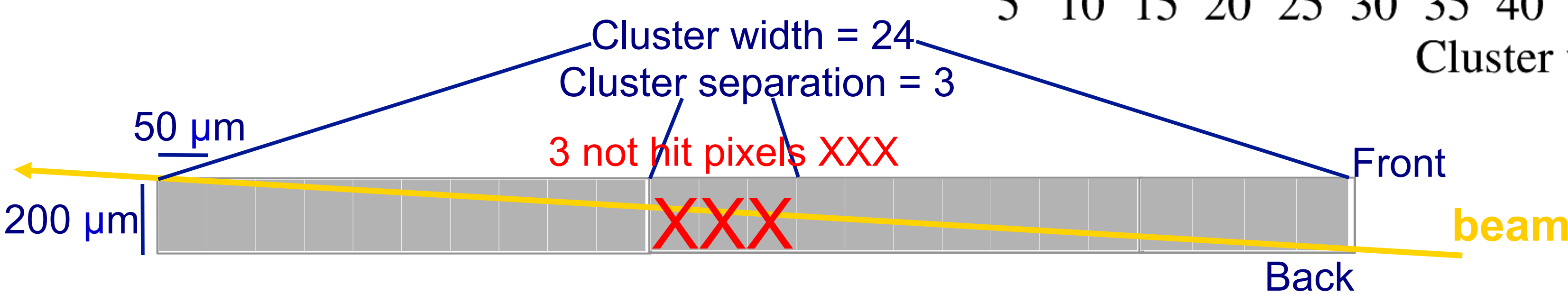
Irradiated DUT, 200 µm thick

- High Φ set-up with an n-in-p FE-I4 module at high Φ (80°), irradiated at 2e15 n_{eq}/cm^2 at KIT and a reference plane, perpendicular to the beam
- Alignment was unsuccessful -> no tracking information available from EUTelescope

Distribution of cluster widths

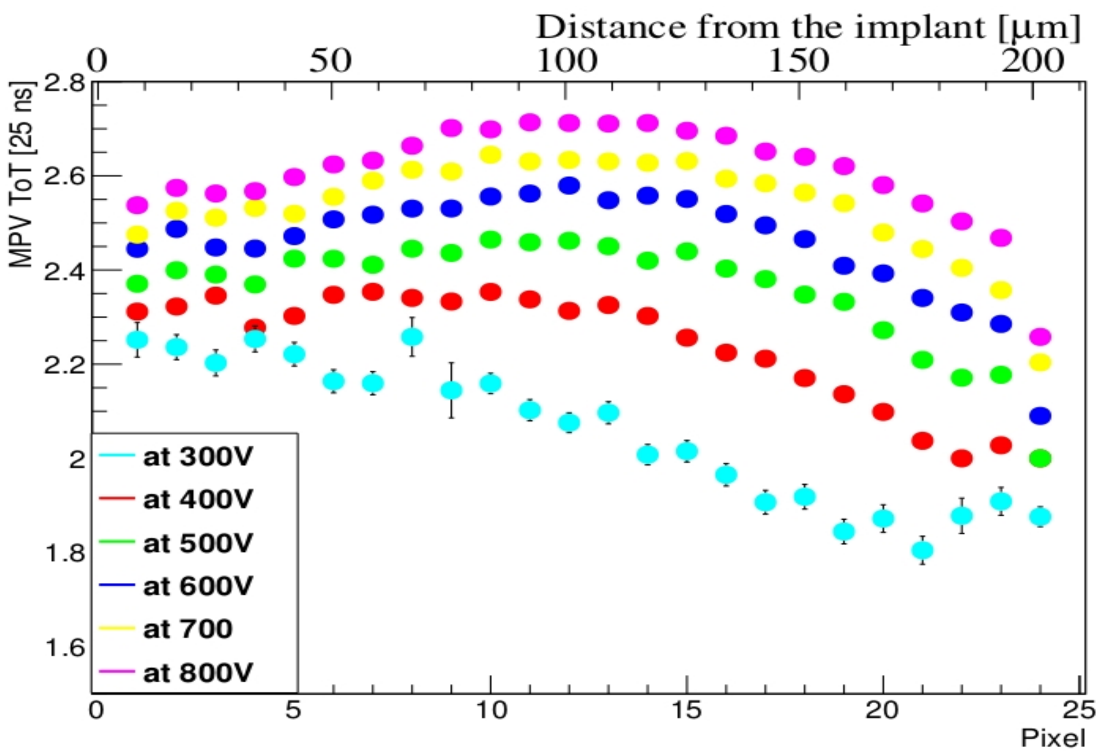
- Cluster width distribution at 200 V to 800 V
- Expected cluster width from geometry ~ 24
- Geometry :
  200 µm thickness,
  50x250 µm² pitch,
  placed at 80° in r-phi

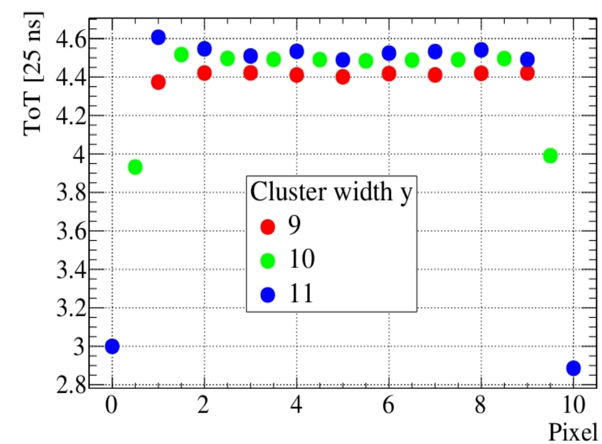




Charge collection at high Φ

- Charge collection vs pixel number and depth at 300 V up to 800 V for a cluster width of 24
- Tuning of CiS2 module : threshold 1000 e, 6 ToT @ 4 ke





S. Terzo: Charge collection vs pixel number of an unirradiated 100 μm thick VTT module for three different cluster widths

Front

Back

Beam is entering from the sensor backside (right to left)

Introduction

- 2D TCAD simulation of an n-on-p detector, 200 μm thick, irradiated with fluence = 2 x 10^{15} n_{eq}/cm^2, T = 253.15 K
- Configuration: hi-ϕ, with tracks impinging at 10° wrt the pixel surface
- 3 pixels (pitch 50 μm) are simulated – as done in the past studies*
- radiation damage model tested: Petasecca (Perugia model)**
- 6 bias points: 300, 400, 500, 600, 700 & 800 V in data & simulation
  - In addition 100 & 200 V for simulation only
- Observables:

➢ Electric field

➢ Ramo potential

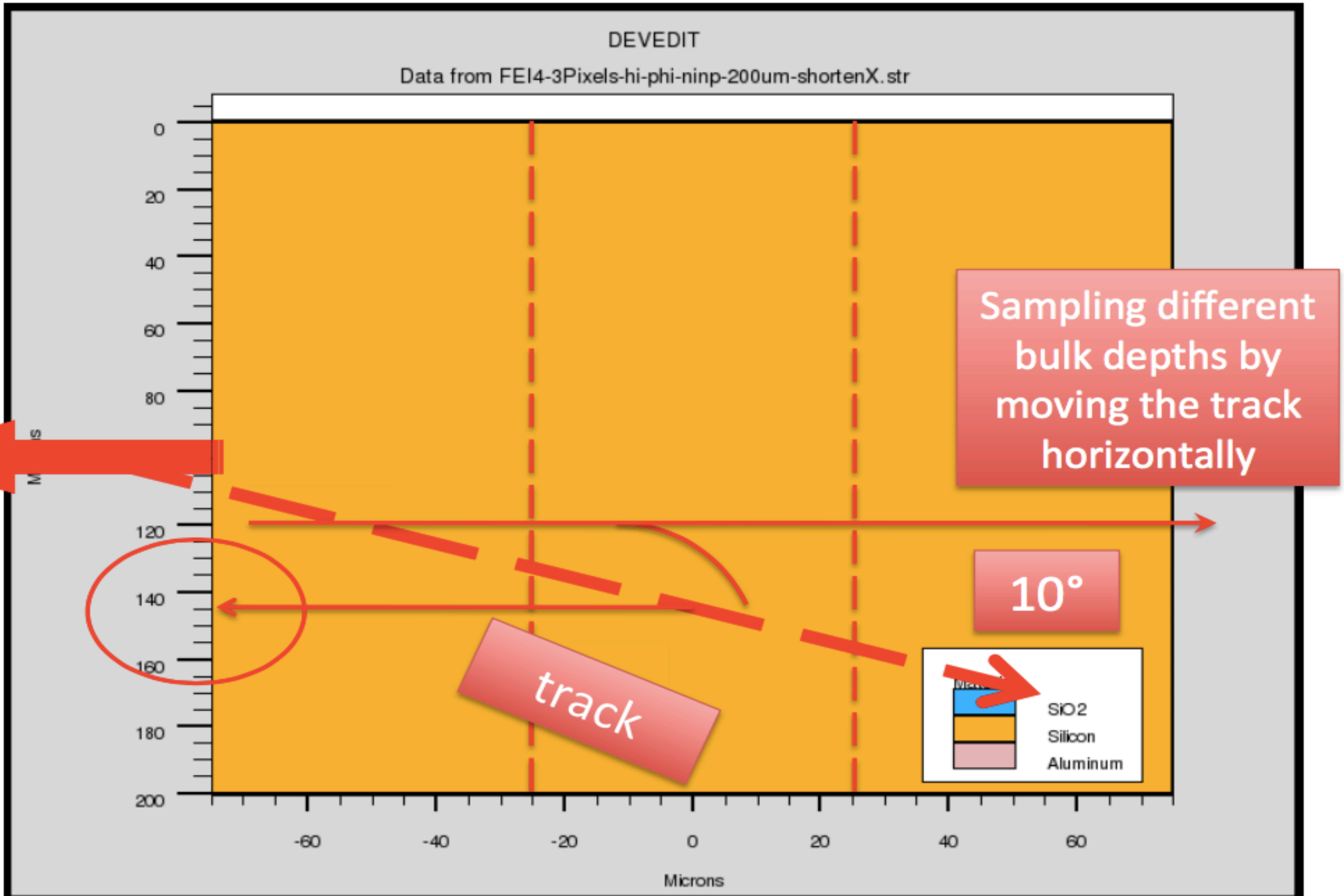
➢ Collected charge

*See M. Bomben @ 25th RD50 workshop

**Petasecca, M. et al, Nuclear Science, IEEE Transactions on , vol.53, no.5, pp.2971-2976, Oct. 2006

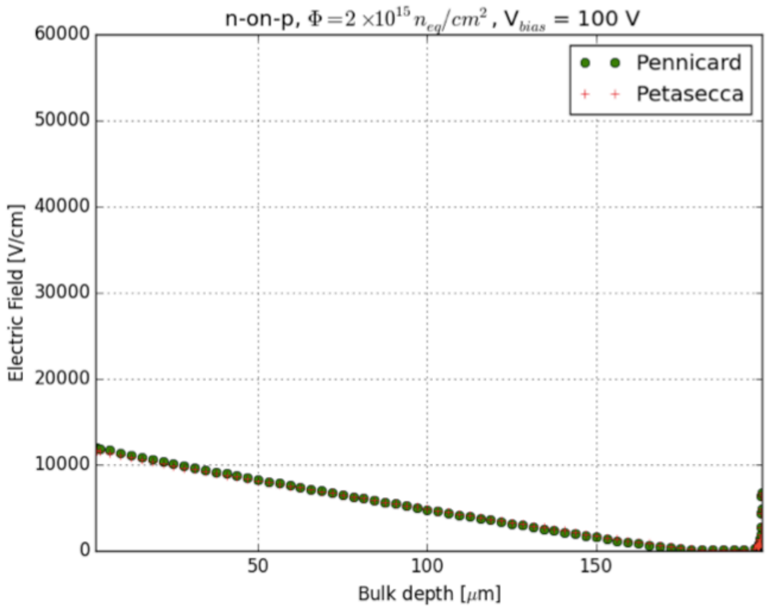
M. Bomben - TCAD simulations

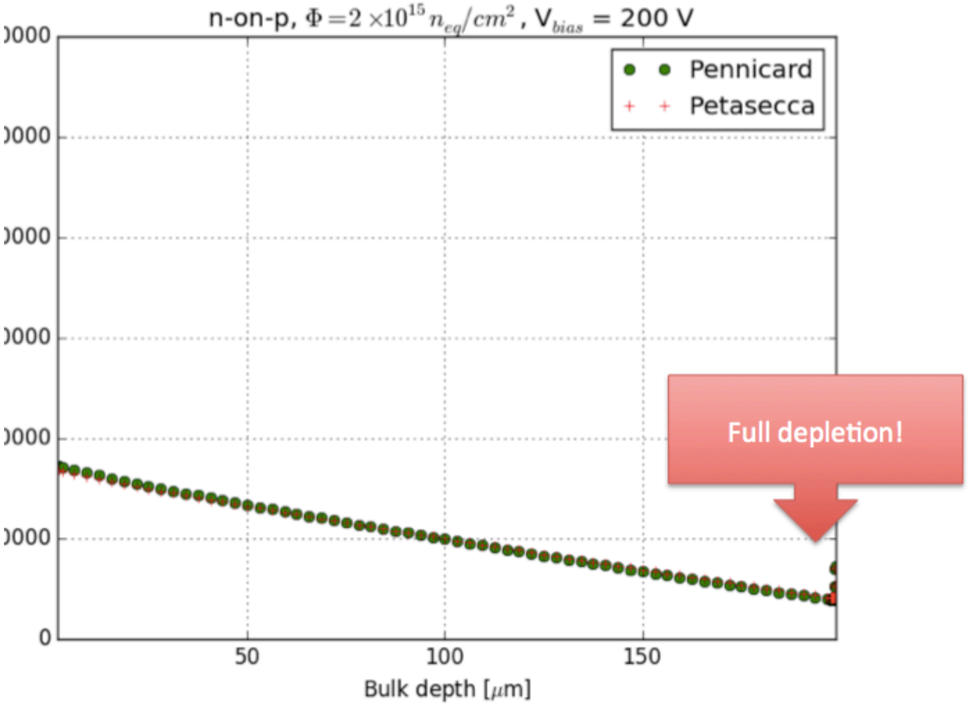
Simulated structure



M. Bomben - TCAD simulations

Electric field – 100 V – 200 V

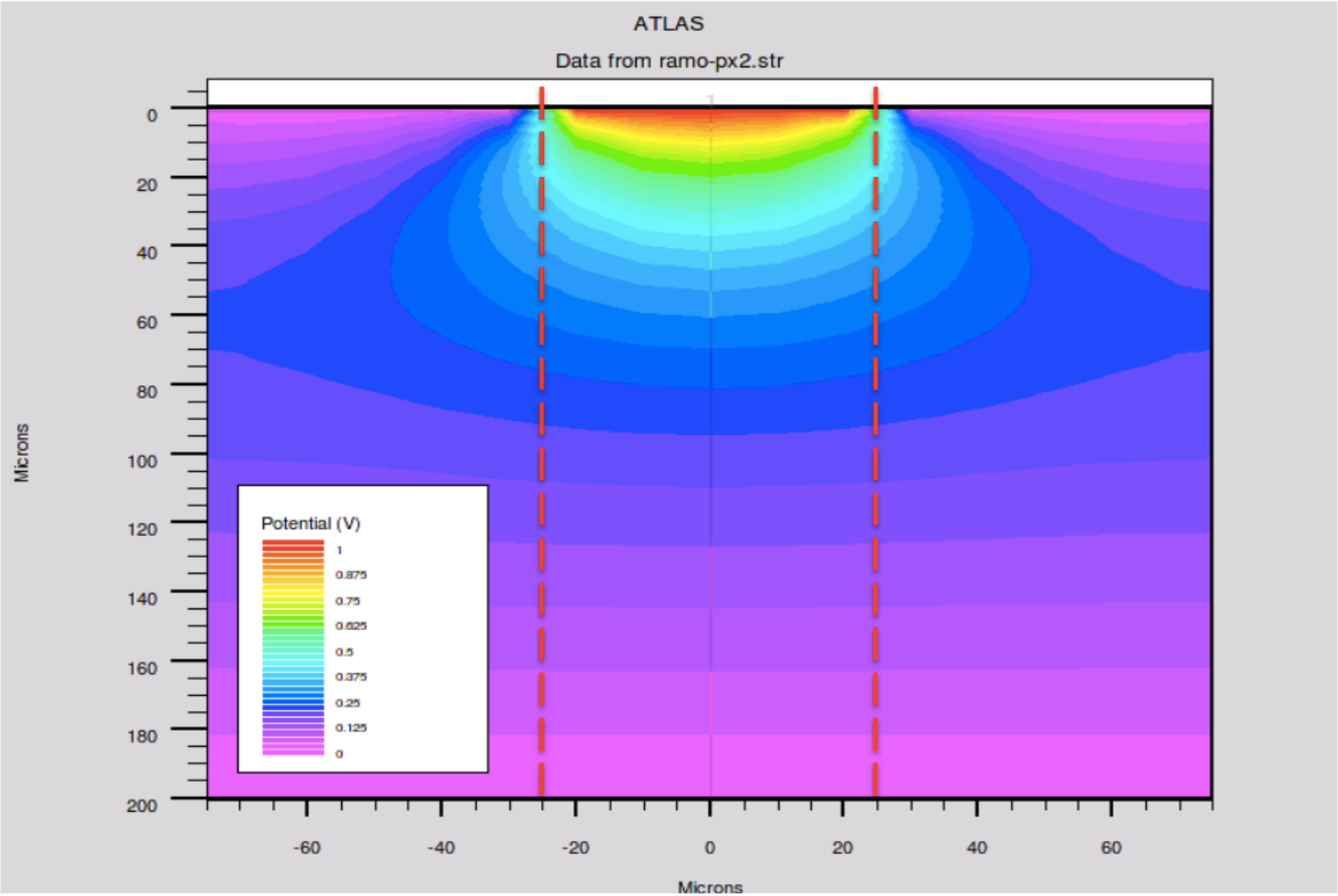




Simulation: sensor depleted at 200 V
Data suggest higher depletion voltages around 500 V

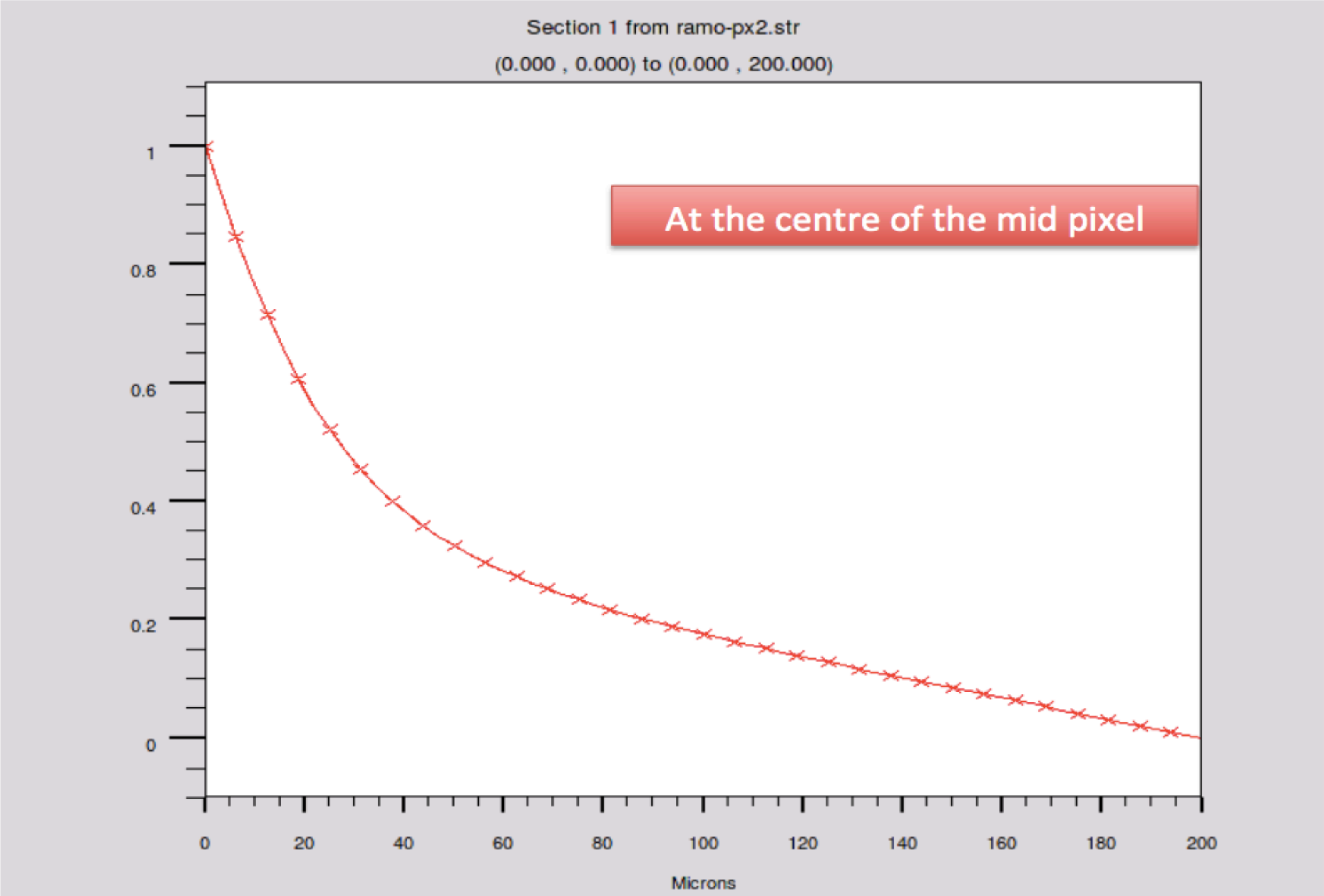
M. Bomben - TCAD simulations

Ramo potential - map



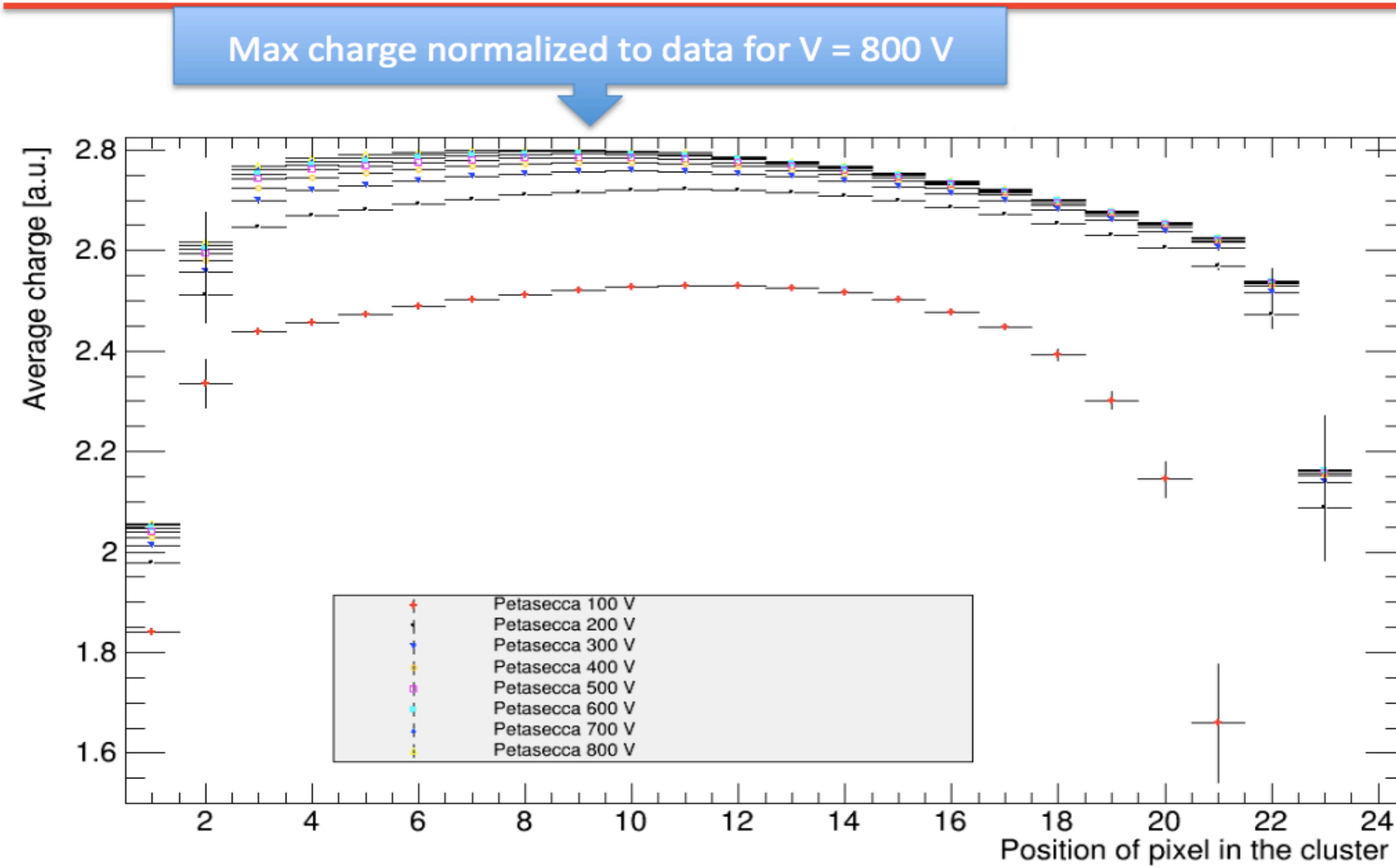
M. Bomben - TCAD simulations

Ramo potential – along the bulk depth



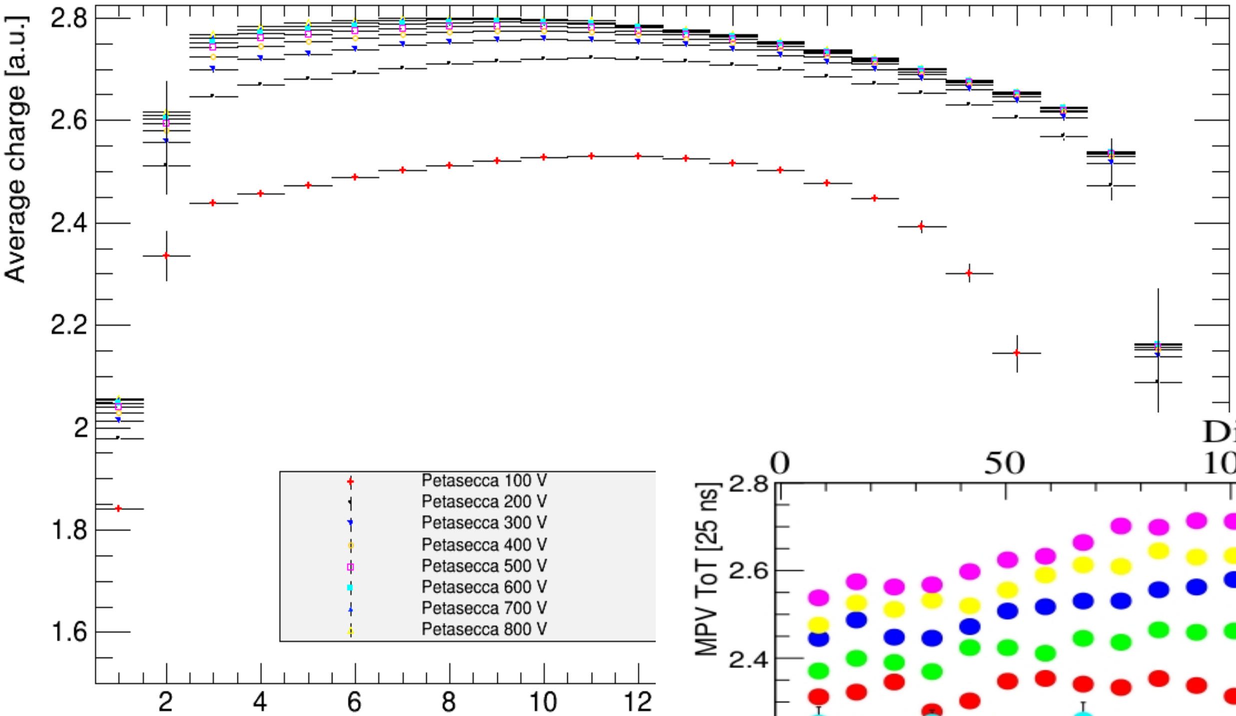
M. Bomben - TCAD simulations

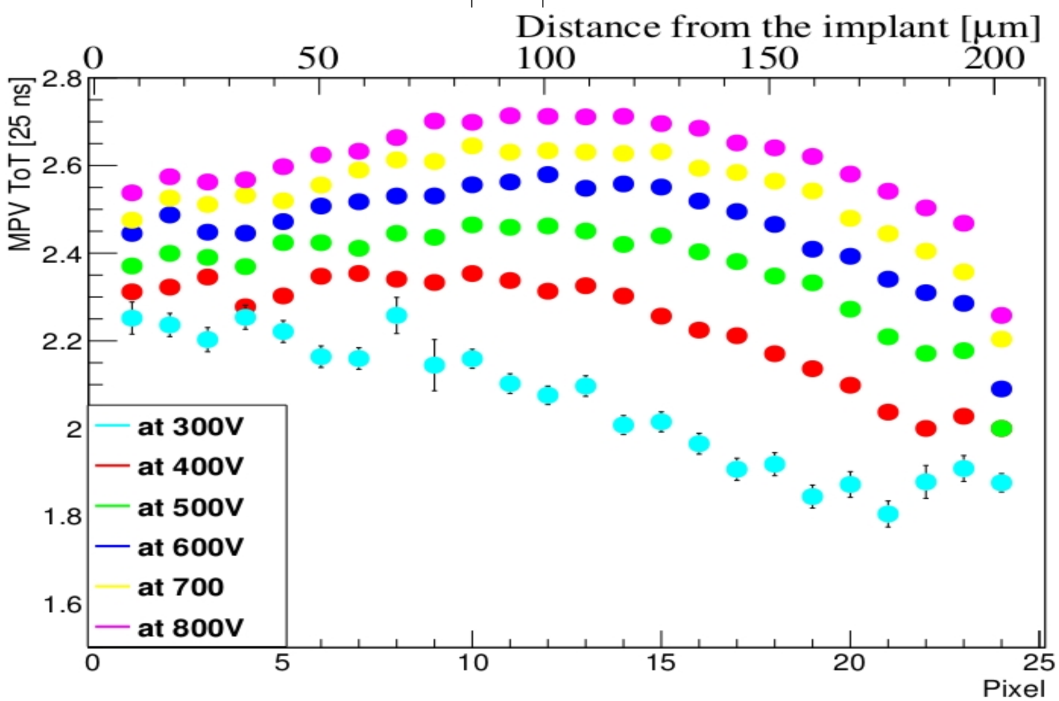
Petasecca - Charge collection profile



M. Bomben - TCAD simulations

Comparison simulation to data





Petasecca simulation of collected charge in qualitative agreement with data

Summary and Outlook

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

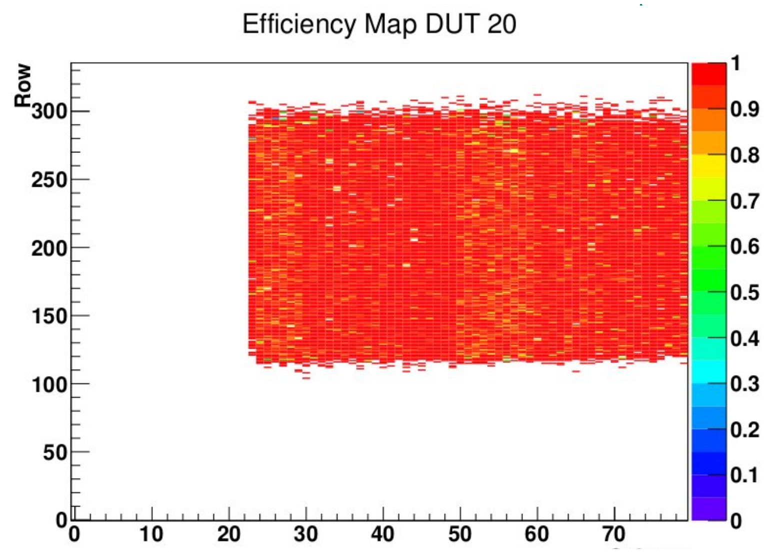
- Laboratory studies
- No dependency of collected charge on temperature
- Lower power dissipation for thinner sensors
- Testbeam studies
- Different punch-through designs show different efficiencies :
  - Improved hit efficiency with respect to the standard design especially for the external punch-through (99.4% at 3e15 n_{eq}/cm^2 !)
- Grazing angle technique employed to study charge collection properties of irradiated modules at different depths
  - TCAD simulations show similar behaviour compared to data
    - Repeat simulation with new Perugia model
  - Repeat the measurement at CERN-SPS with less scattering

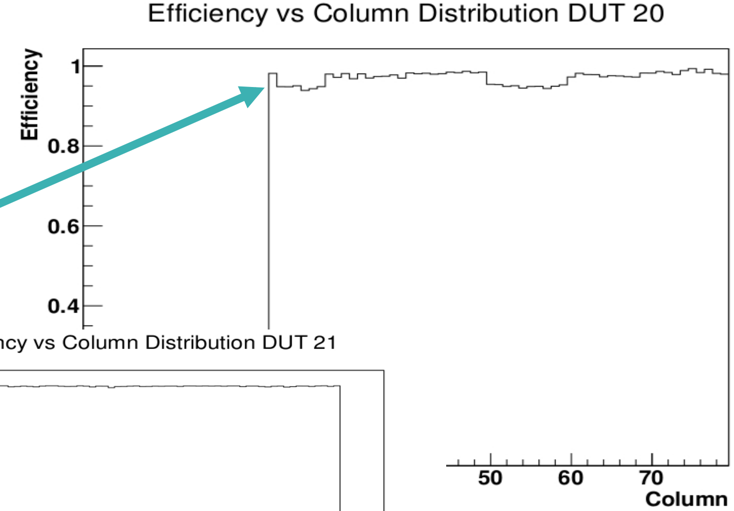
Thank you for your attention!

Back-up

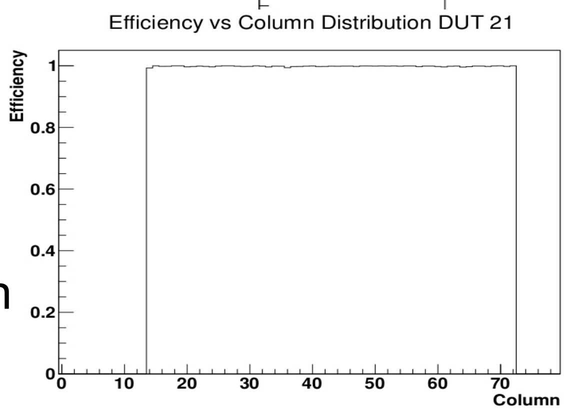
Hit efficiency map of different punch-through structures

- Sensor with 3 different punch-through designs (every ten columns):
  - C30-40 : standard
  - C40-50 : bias line over punch-through dot
  - C50-60 : bias line over center of pixel implant
- Differing efficiencies depending on punch-through structure





For comparison: hit efficiency vs column of the same module, but unirradiated ->



P-bulk: irradiation models

In red boxes: models differences

Petasecca p-bulk

"Numerical Simulation of Radiation Damage Effects in p-Type and n-Type FZ Silicon Detectors," Petasecca, M. et al, Nuclear Science, IEEE Transactions on , vol.53, no.5, pp.2971-2976, Oct. 2006,

Type	Energy (eV)	Defect	$\sigma_e(\mathrm{cm}^2)$	$\sigma_h(\mathrm{cm}^2)$	$\eta(\mathrm{cm}^{-1})$
Acceptor	E_C -0.42	VV	2.0×10^{-15}	2.0×10^{-14}	1.613
Acceptor	E_C -0.46	VVV	5.0×10^{-15}	5.0×10^{-14}	0.9
Donor	E_V +0.36	C_iO_i	2.5×10^{-14}	2.5×10^{-15}	0.9