Executive summary on ELADs

Towards the optimal position resolution

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HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

PIER

DESY Strategy Fund

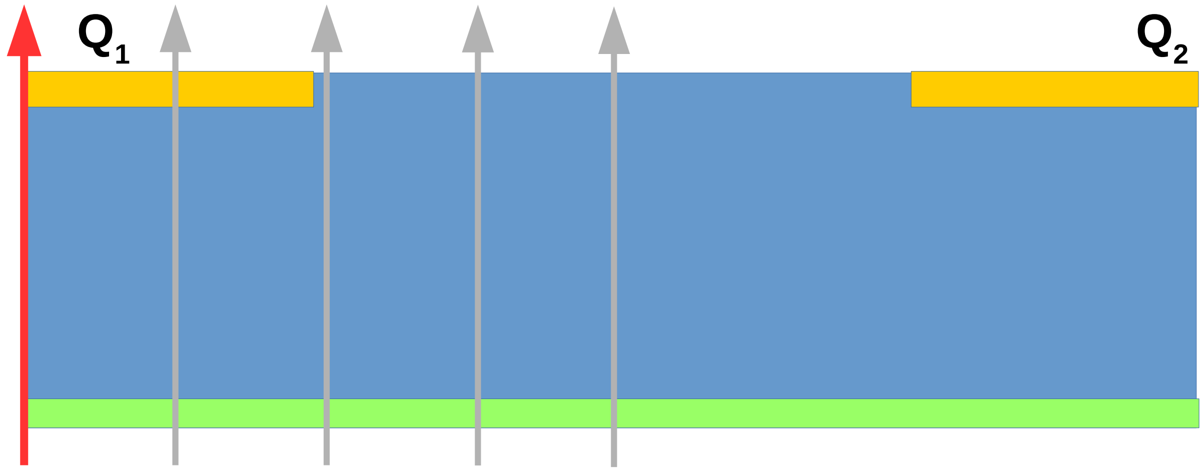
DSF project: Development of an enhanced lateral drift sensor

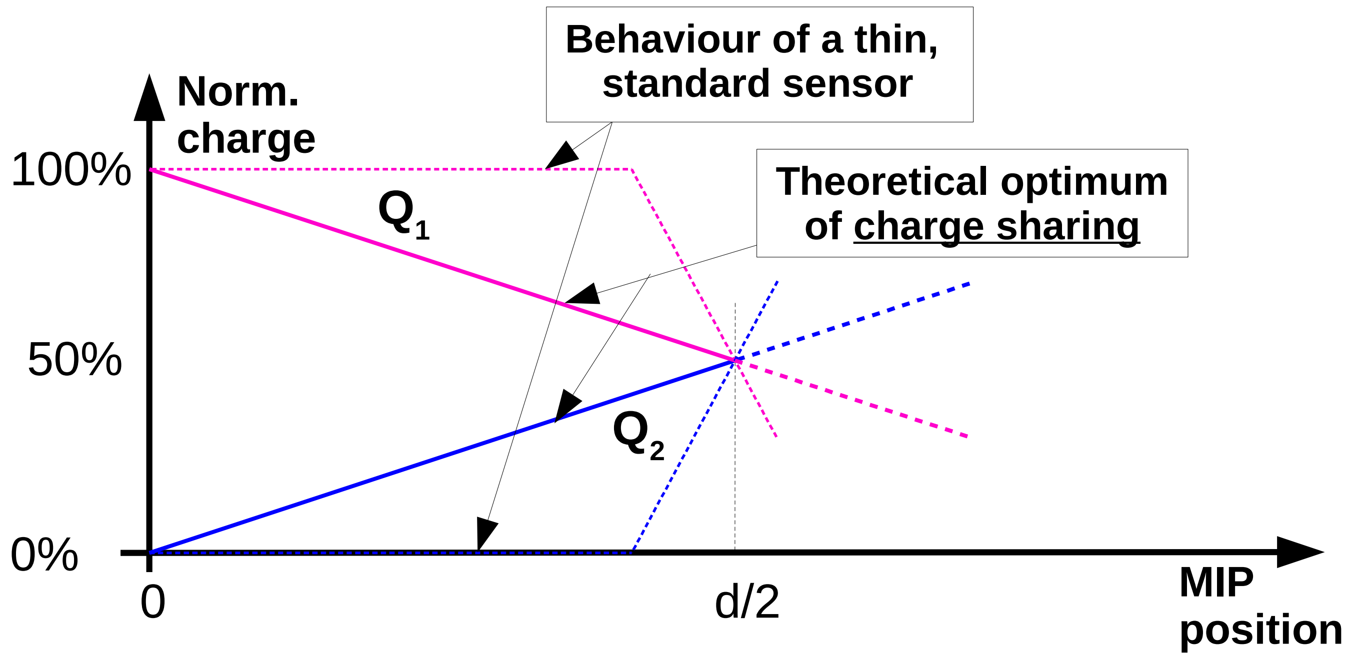
Project information

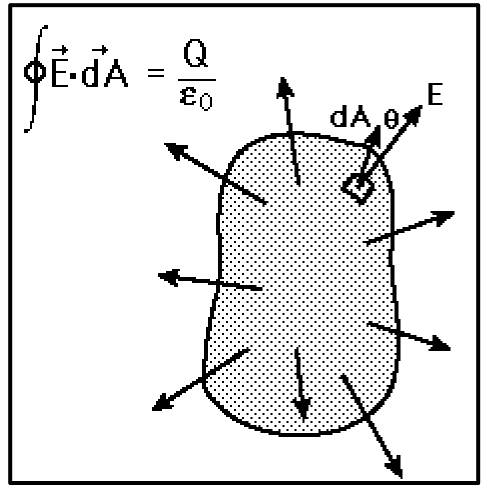
PI(s)	Hendrik Jansen (DESY/FH/CMS)
Role	Inventor, PI, supervisor
Starting date	01.03.2017

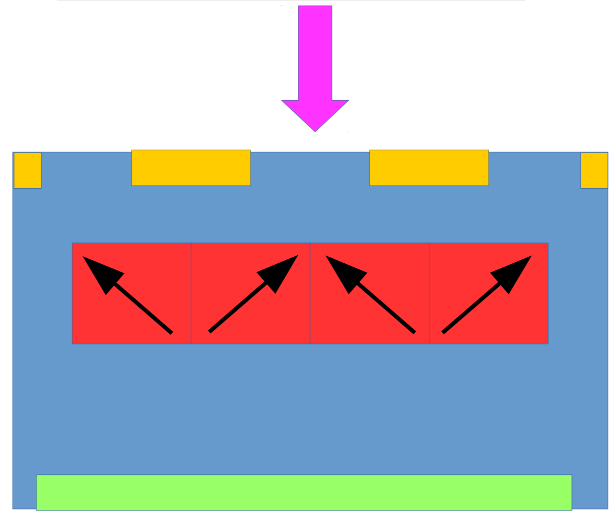
Position resolution revised

Free charges follow field lines
→ Exploit Maxwell's 1st eq.



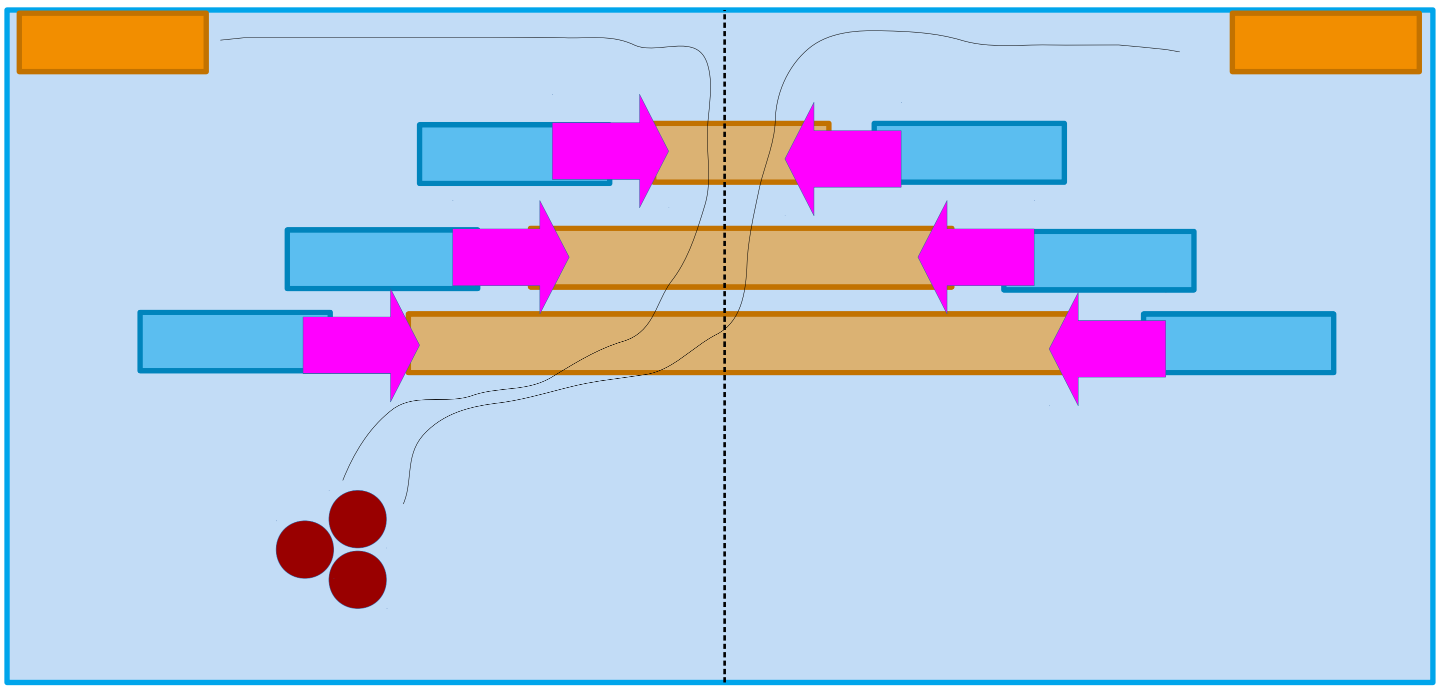






Concept of ELAD sensors

p-n-p (or n-p-n) structure creates lateral electric field



→ Charges drift towards unit cell boundary
→ Diffusion enables 'crossing of boundary'

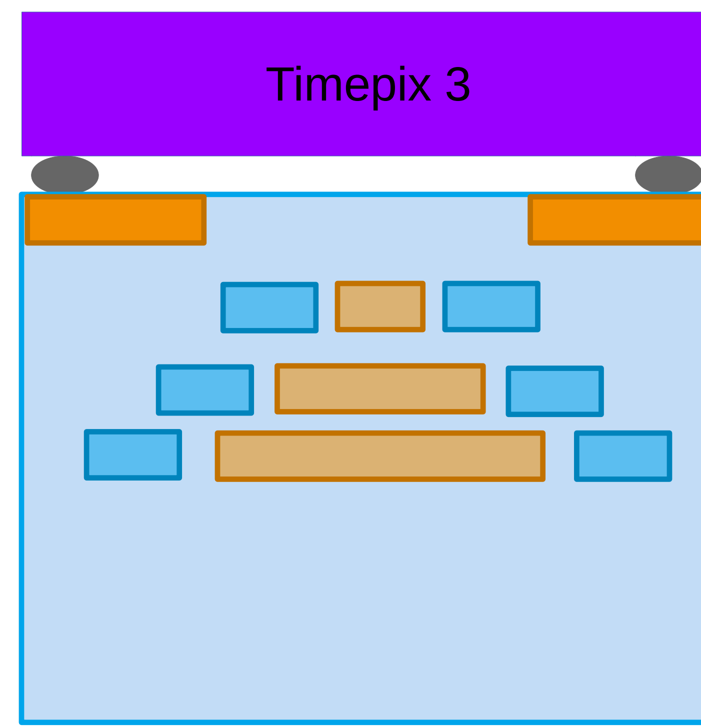
Patent granted:
H. Jansen, DE102015116270B4
H. Jansen, Nucl. Instr. Meth. A **831** 242 (2016)
A. Velyka, H. Jansen, TIPP 2017 proceedings

No one has done this before

… can we do it?

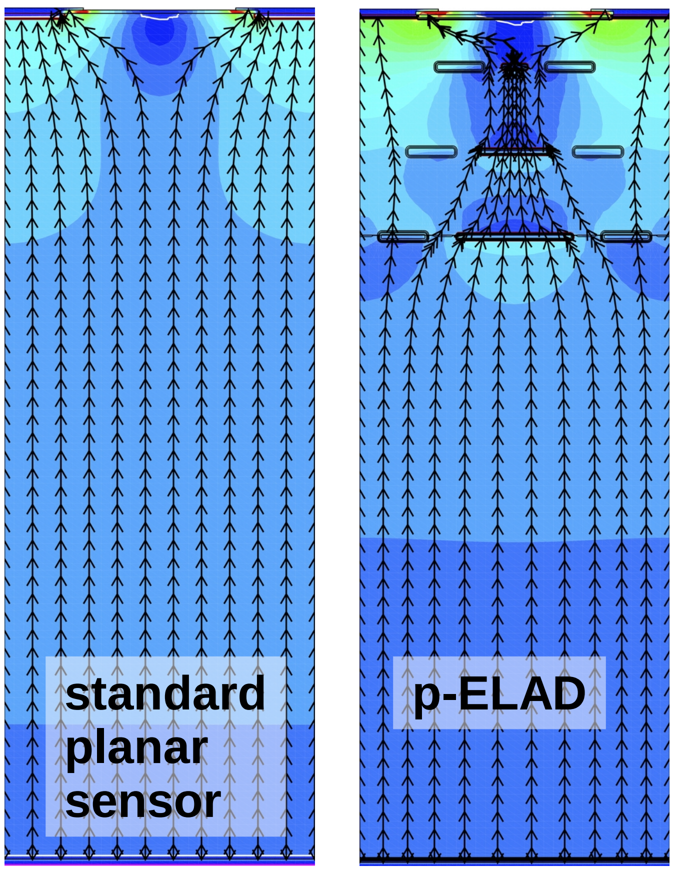
Goal: Produce a *functional prototype*

- Extensive **device (static + transient) simulation**
  → Find 'good' parameters for an ELAD sensor
- **Detector simulation** for performance benchmarking
  → AllPix squared
- **Process simulations** to study process features
  → alternate implantation and epitaxial growth
- **Develop process** for bulk engineering
  → Test structures, full wafers
- **Standard read-out implants and thinning**
- **Flip chipping** with TimePix3 ASIC
- **Testbeam and lab characterisation** at DESY/CERN



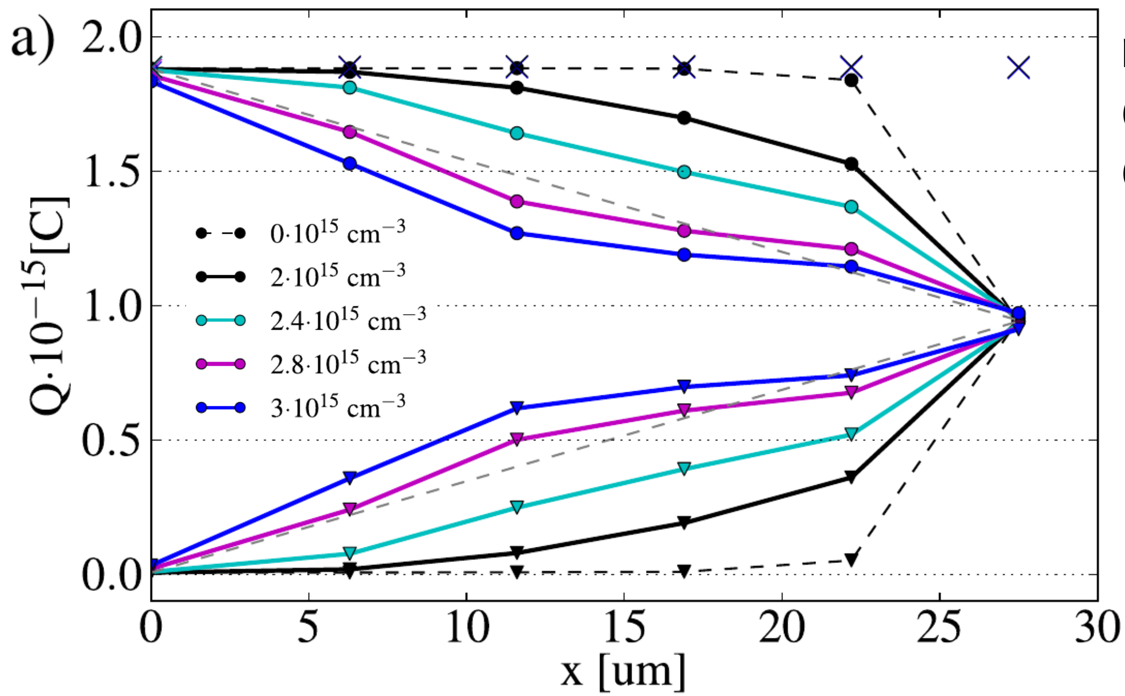
TCAD simulations

Buried implants create lateral electric field



Total electric field

Scan charge sharing a.f.o. MIP position



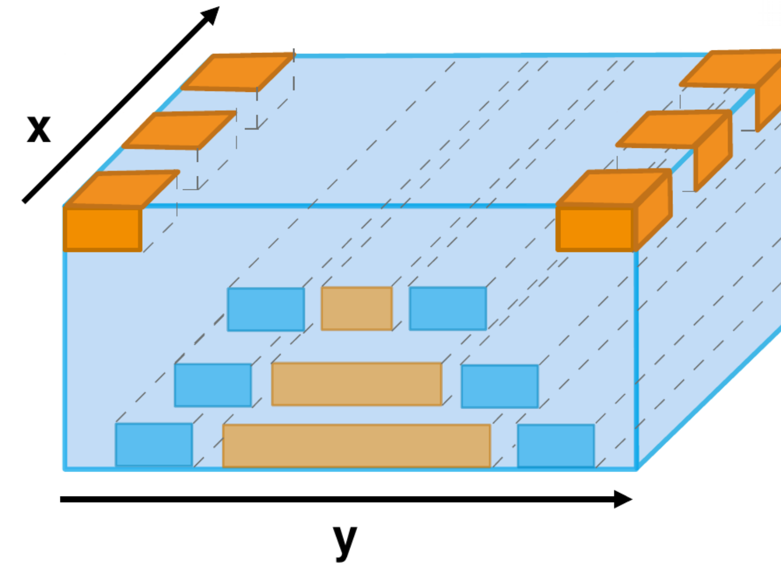
n-ELAD
@ 280 V
@ 150 µm

→ ELAD design allows to tune charge sharing
→ No charge loss (no low-field areas)
→ Close to theoretical optimum

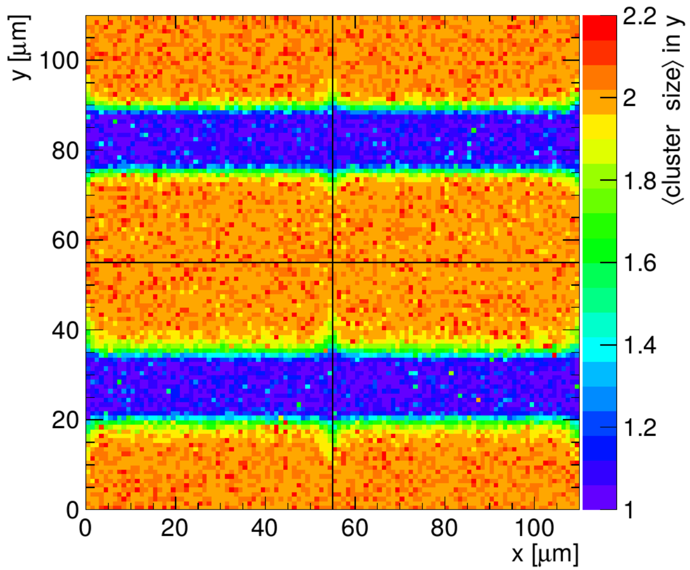
Detector simulation – AllPix^2

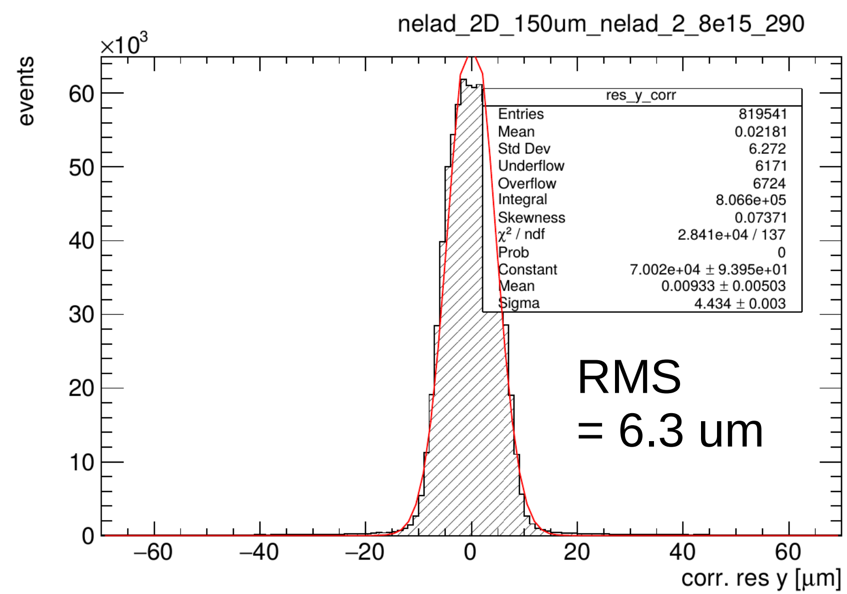
Study impact of deep implants on spatial resolution
→ Final step of the optimisation scheme

AllPix^2: generic detector simulation framework
→ Monte Carlo particles from Geant4
→ Charge deposition
→ Charge drift/diffusion (import TCAD E-field)
→ Digitizer



cluster size in y

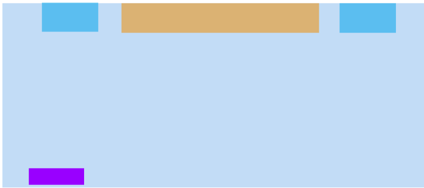




Result
- Large CS2 region
- Improvement:
~2.4 vs bin. res.

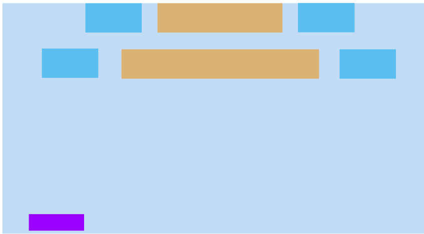
Process development / Project status

Process not available, started R&D at ISE, Freiburg



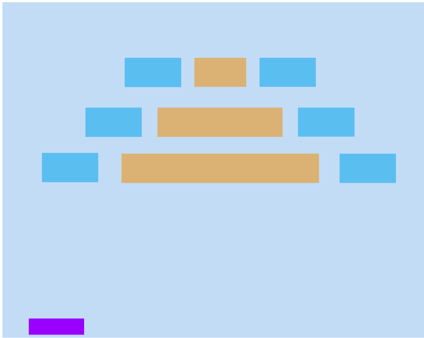
→ After 1y, ISE announced to not be able to pursue process R&D

Consultation with FMD (`Forschungsfabrik Mikroelektronik Deutschland')



→ Network of Fraunhofer Institutes for microelectronics
→ Signed contract beginning of June
→ Process development on-going

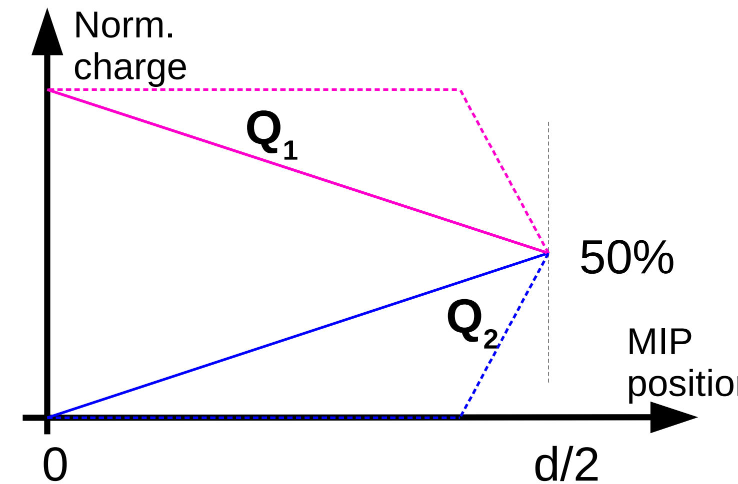
Expected result

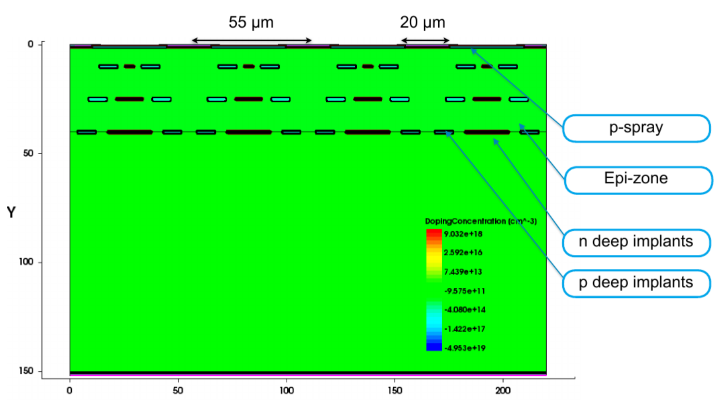


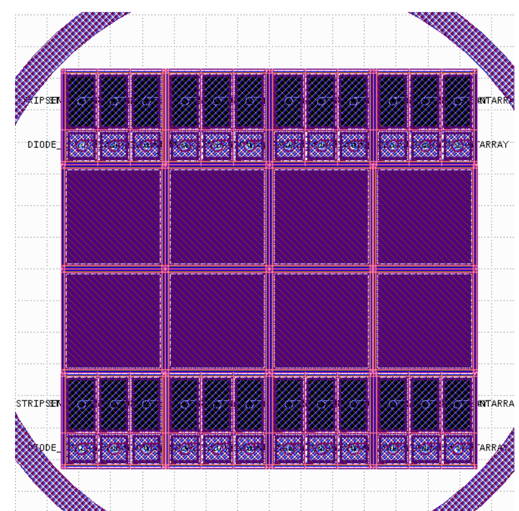
→ "Buried implant process"
→ 200 mm wafer
→ Total price ~40k for 25 wafers with complete ELAD structure (3 layers)

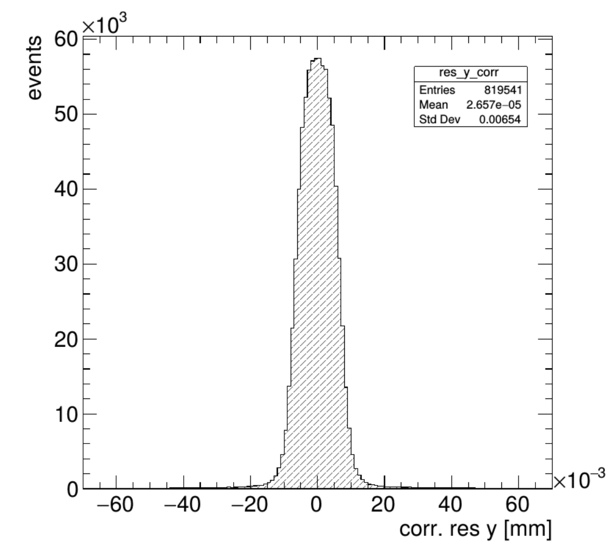
Conclusion

- **Technologically challenging project**
  (no one tried this before in HEP)
- Try to reach **theoretical optimum** of position resolution
- **Interesting technology** for future HEP detectors
  reached RMS residual of 6.5 um @ 55 um pitch
- **Bulk engineering opens new possibilities** in sensor design
- Process soon, prototypes beginning 2020







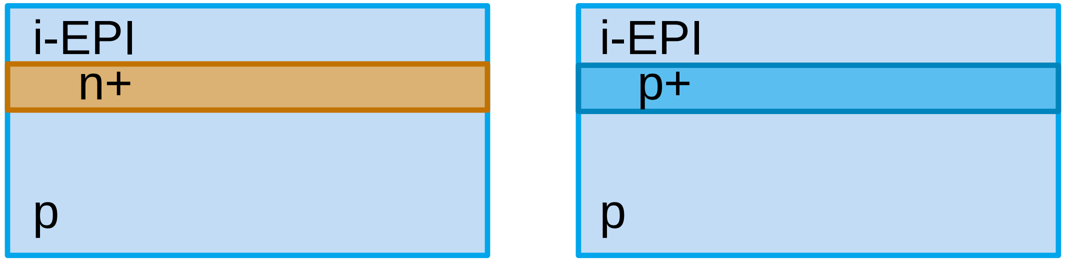


Backup

Process development

FMD (`Forschungsfabrik Mikroelektronik Deutschland')
→ Network of Fraunhofer Institutes involved in microelectronics
→ Very open to R&D projects

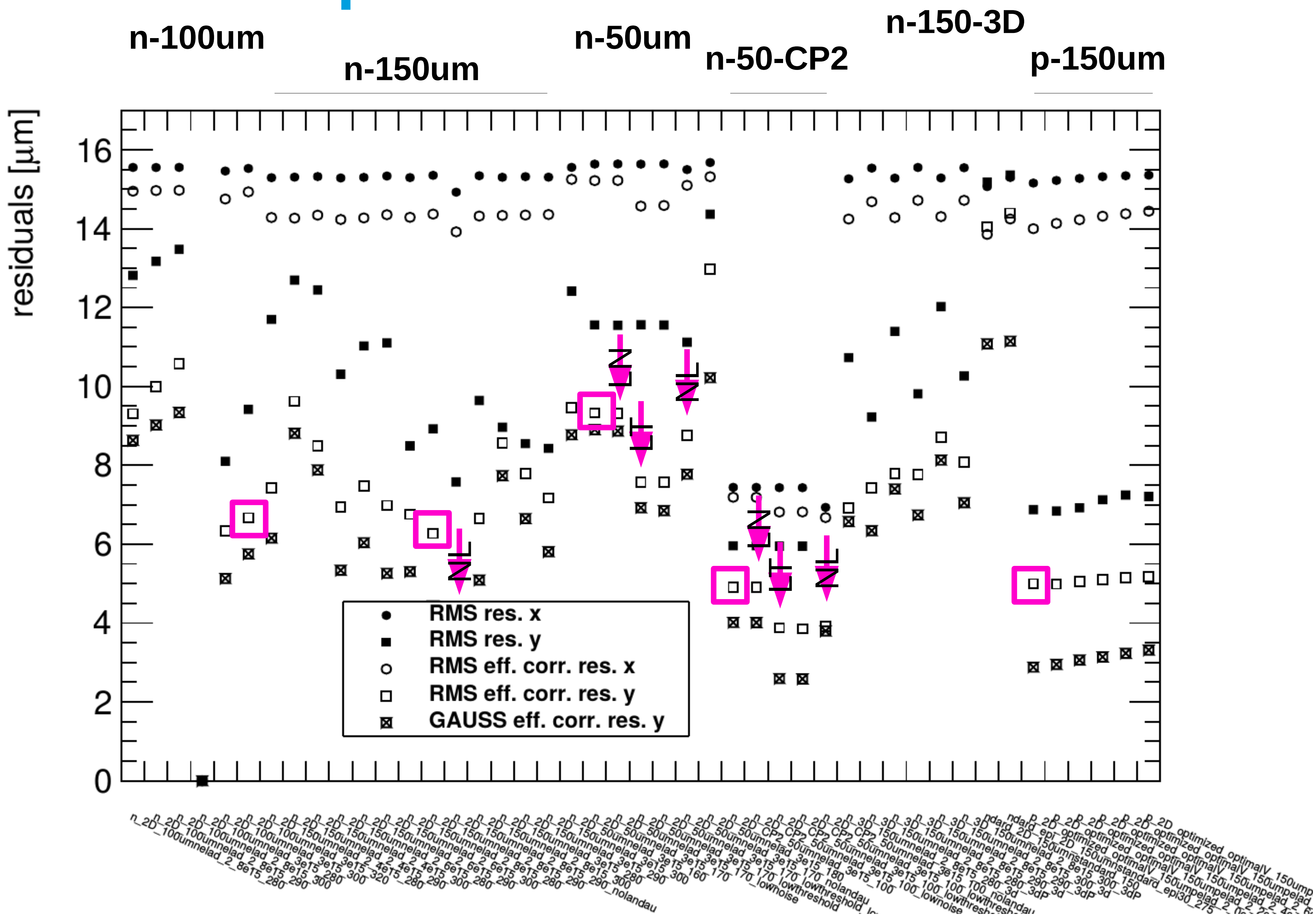
Received contract for 'pre-studies', **already signed**
- 200 mm wafer, p-type, 5kOhmcm
- Implant unstructured p(n) on p-substrate through oxide
- RTA or oven annealing
- intrinsic EPI (slightly p), 15 um
- oven for temperature budget mimicking
- SRP and SIMS for depth analysis



→ Allows understanding of buried implants
and qualification for possible ELAD run

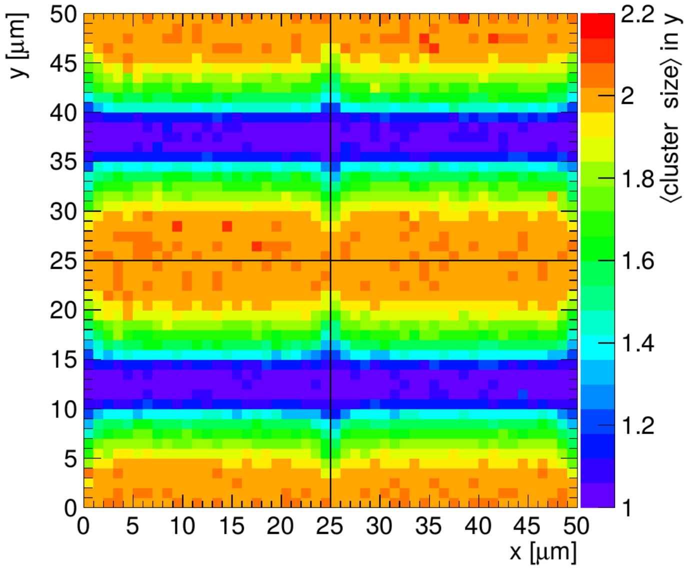
→ **Results expected in 6 to 8 weeks**

Grand comparison



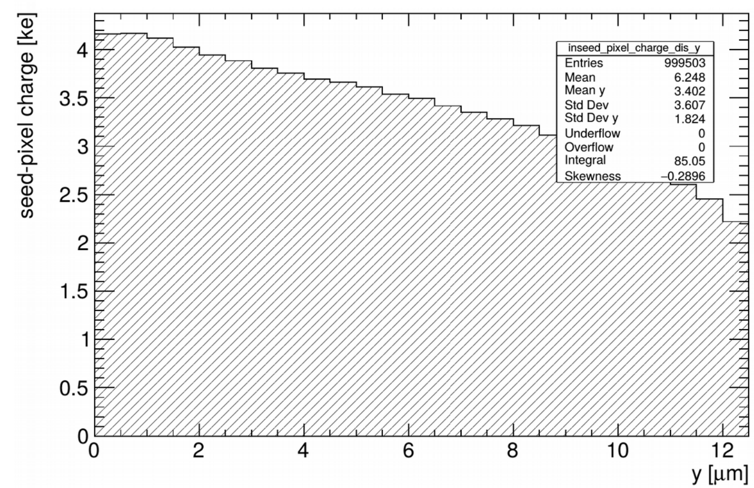
n-ELAD, CP2, 3.0e15, 100 V, 50 um, LT

cluster size in y

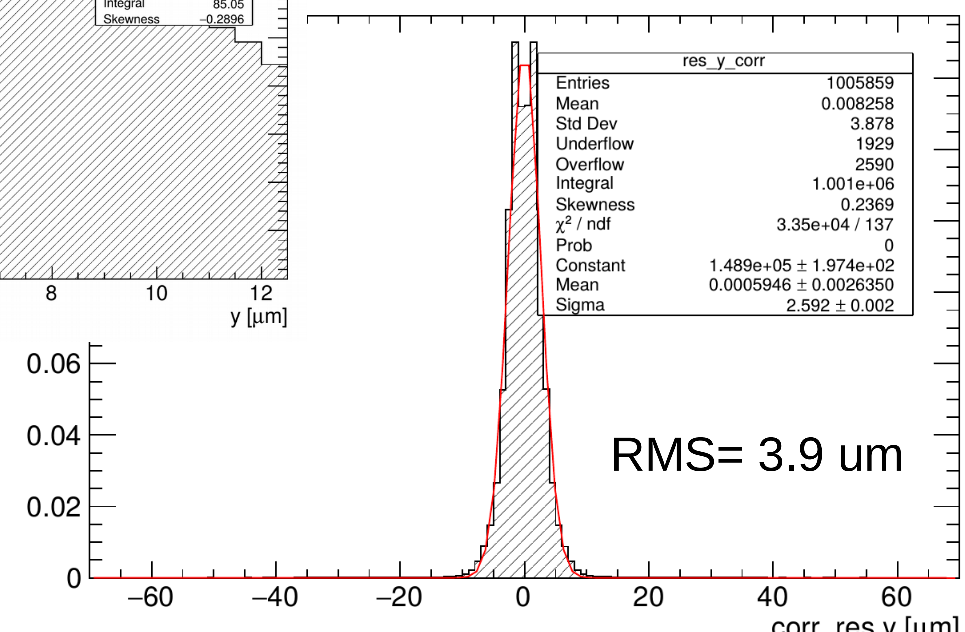


Assumes threshold of 350e (before 700e)

In-seed charge distribution



corrected res. in y



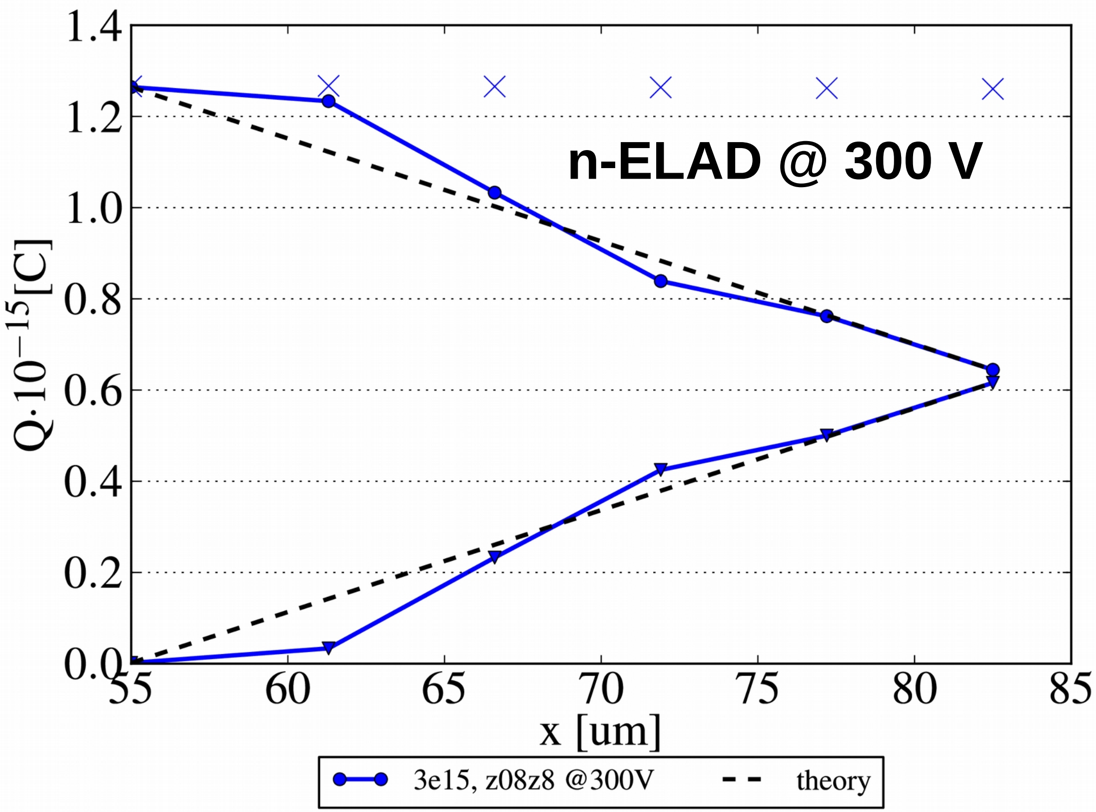
Result

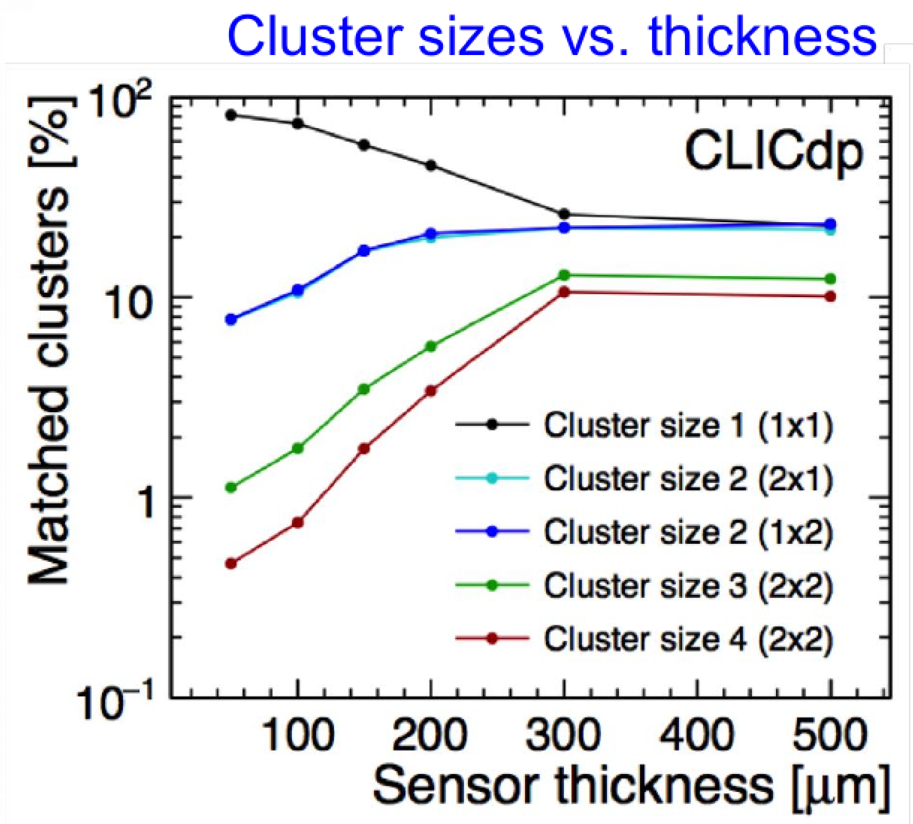
- **Impact of LT especially when sharing!**
- **Again larger fraction of CSy2 region**
- **Improvement ~1.25 vs nominal threshold**
- **residual width of CSy1 = 4.1 um**

TCAD simulations – η function

for 100 µm thickness

Now optimising towards thinner sensors





[D. Dannheim]

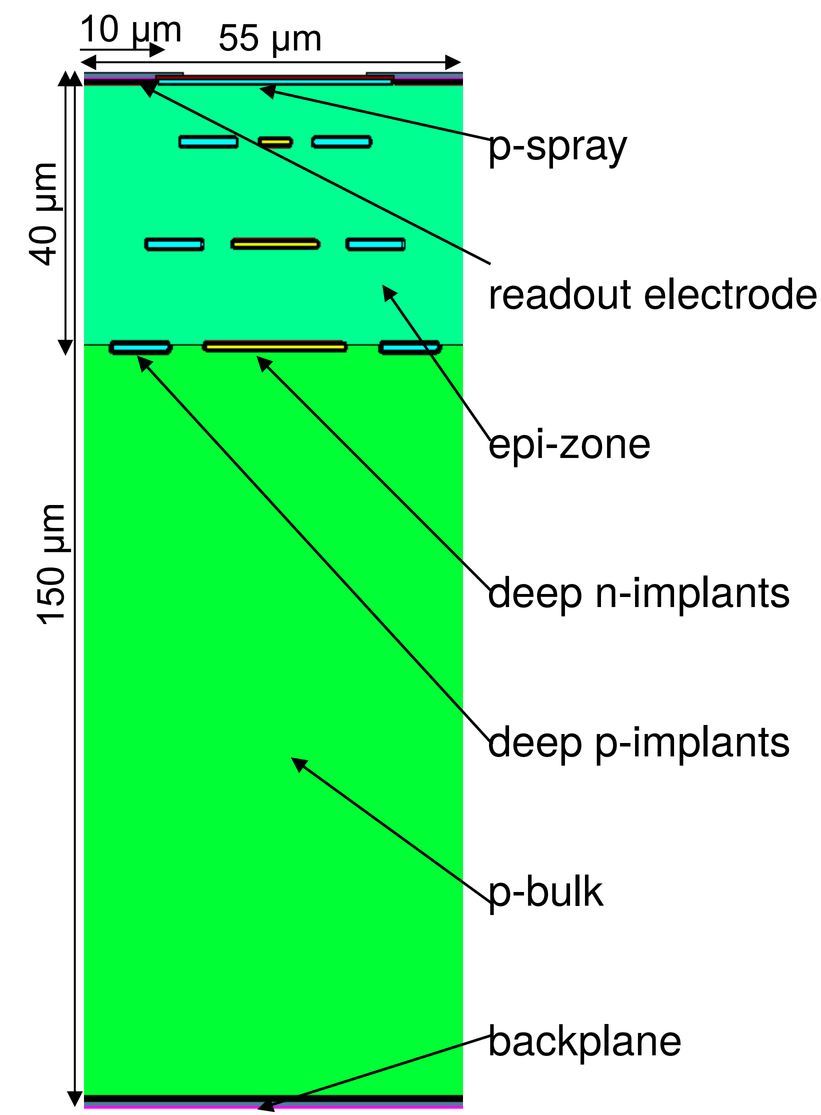
→ Next step: include also 50 µm

TCAD simulations - Geometry

- **deep p- and n-implants** deep in the sensor bulk
- first and second layer epitaxial part
- **TimePix3 footprint**
  squared pixel with pitch 55 µm
  r/o implant size 20 - 30 µm
- Total thickness 50 - 150 µm
- Epi thickness 40 µm
  Epi quality ~1e14 cm^{-3}

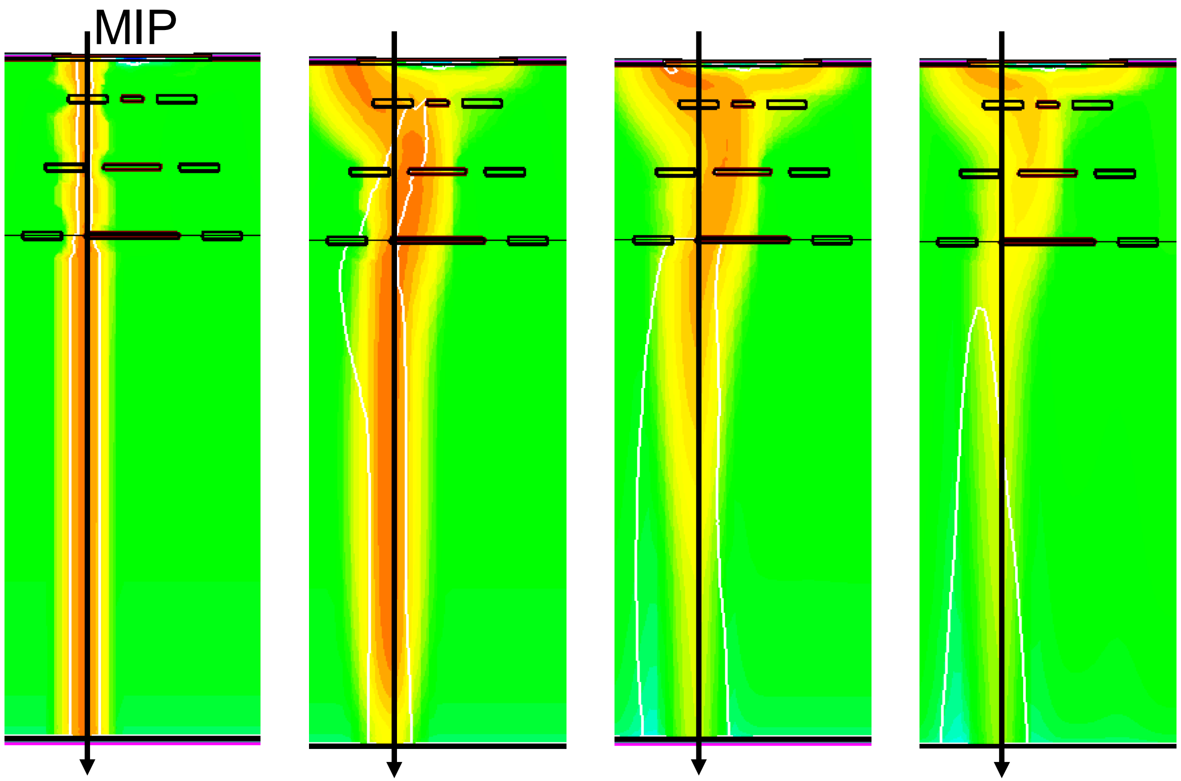
p-substrate, p-EPI, p-n-p structure
→ p-ELAD

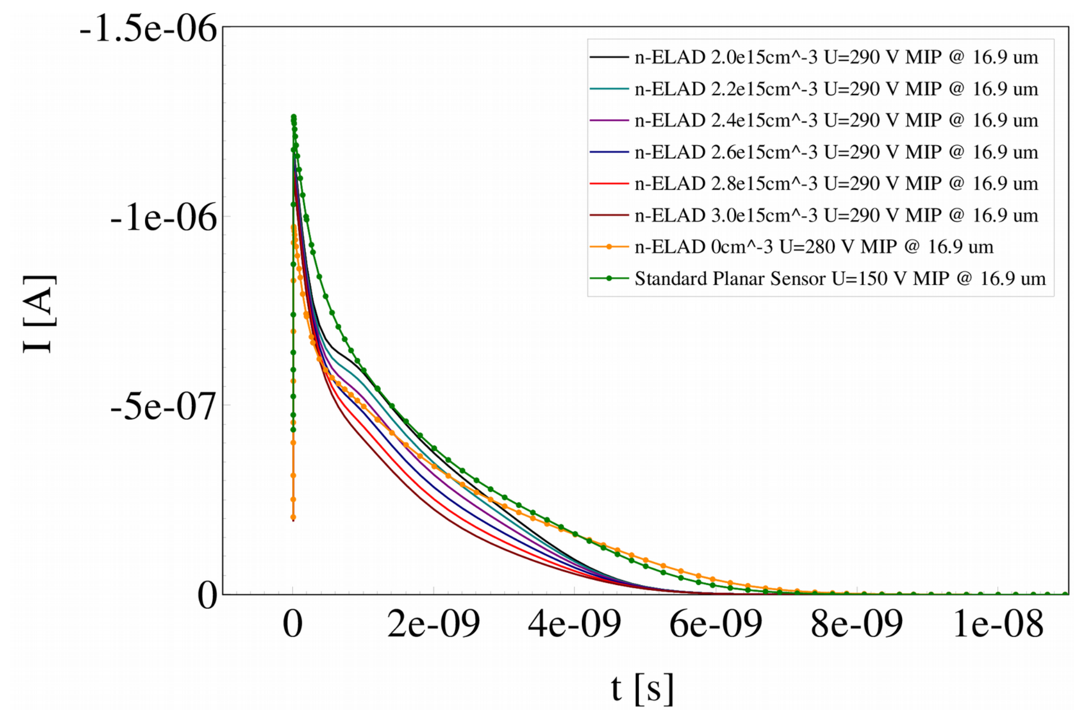
n-substrate, n-EPI, n-p-n structure
→ n-ELAD



TCAD simulations – MIP transient

Unlike standard planar sensors, ELAD shows charge sharing





→ Charge beneath deep implants detours towards unit cell boarder

→ Active charge sharing!