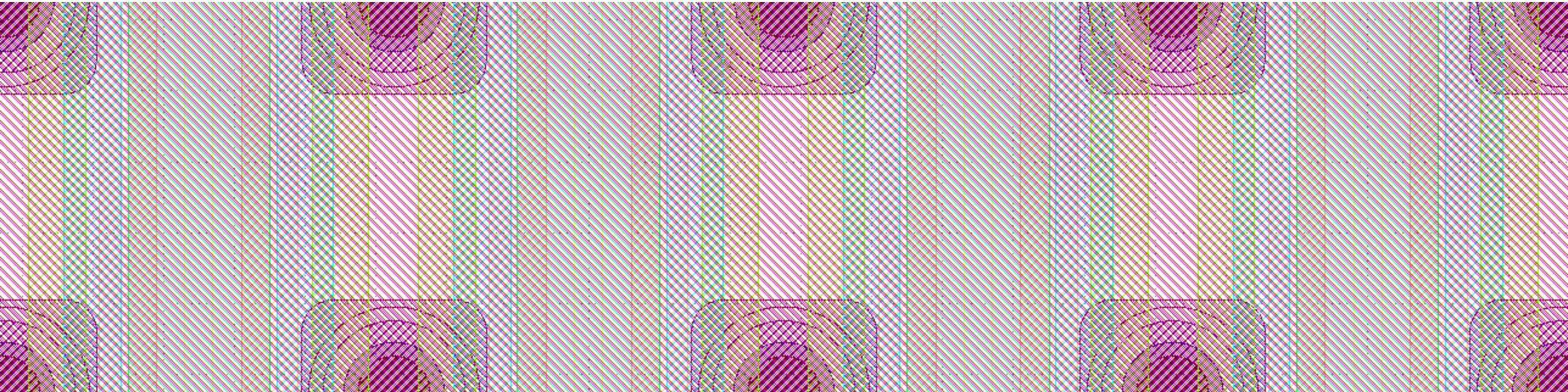


Update on ELAD sensor development

Towards the optimal position resolution



Hendrik Jansen, Simon Spannagel, Anastasiia Velyka

HELMHOLTZ

RESEARCH FOR
GRAND CHALLENGES

■ PIER ■

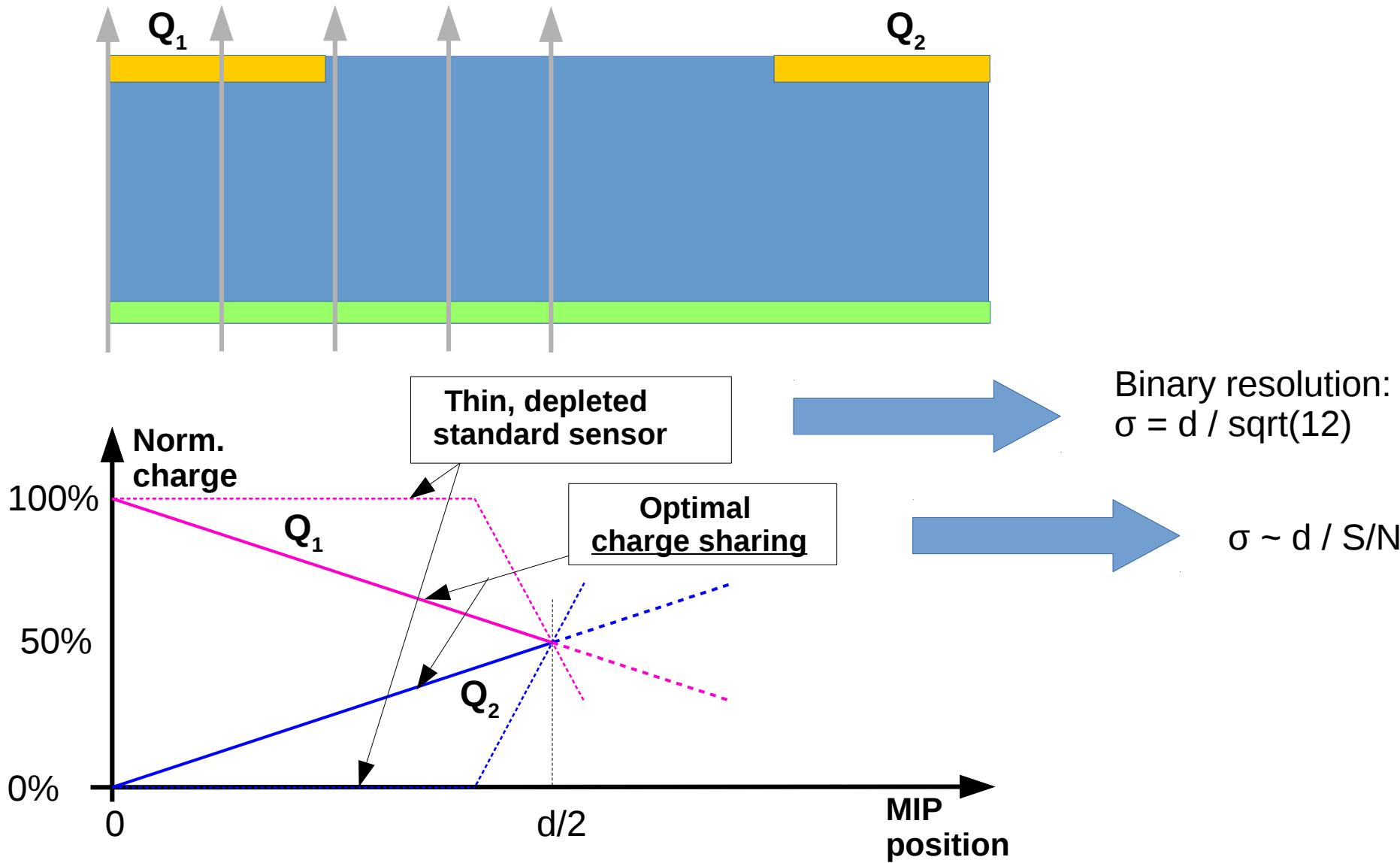
DESY Strategy Fund



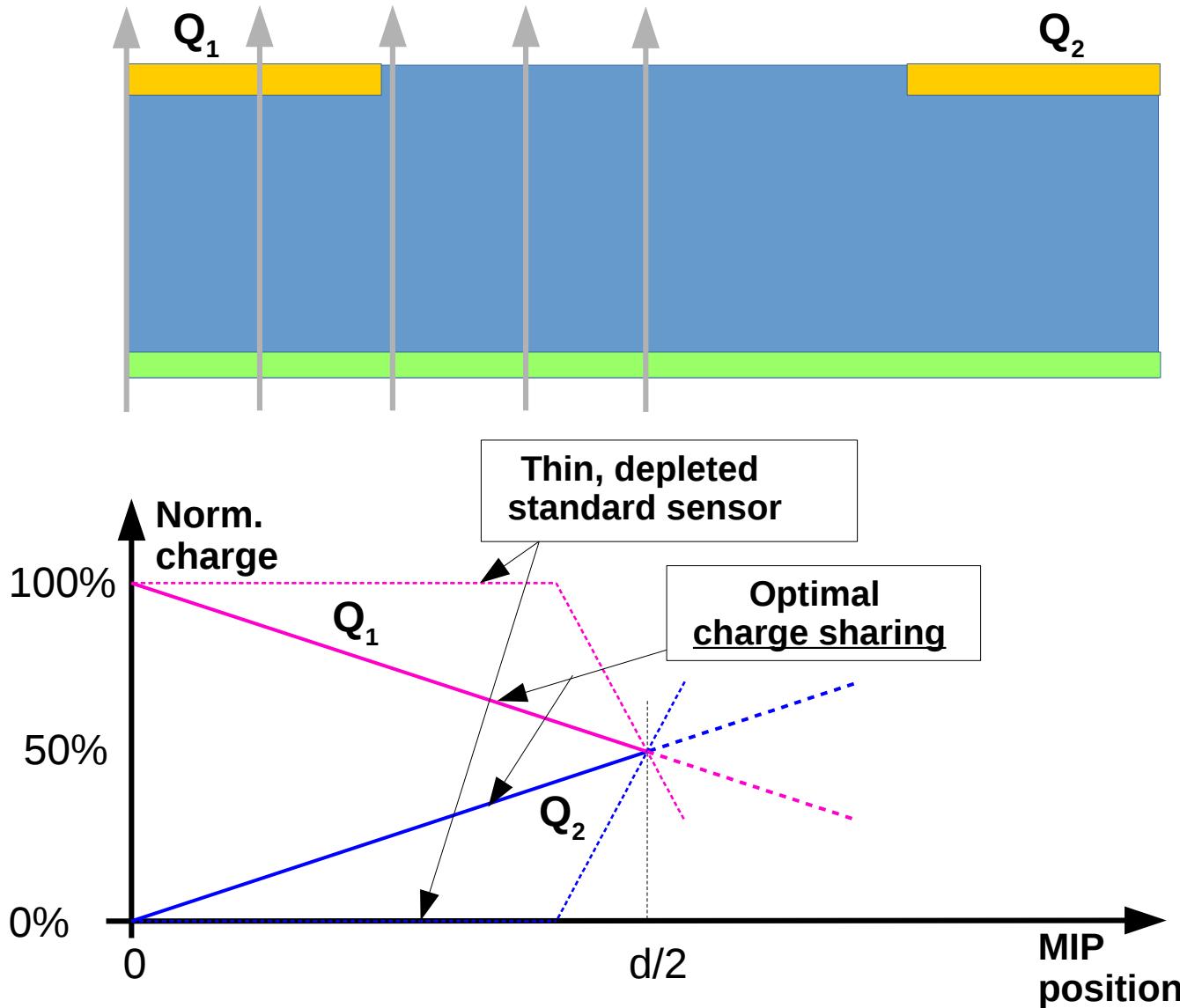
Forschungsinstitut
für Mikrosensorik GmbH



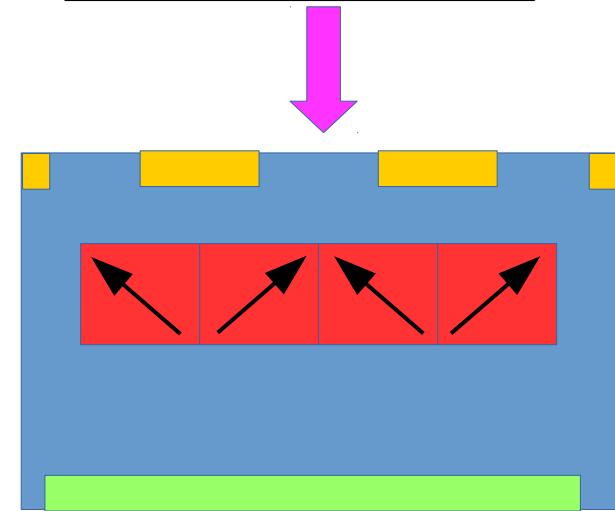
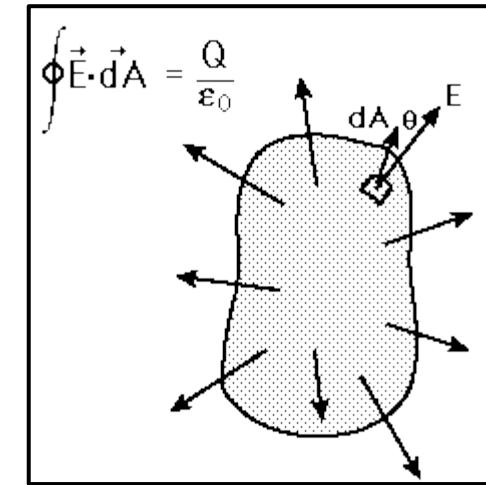
Position resolution revised



Position resolution revised

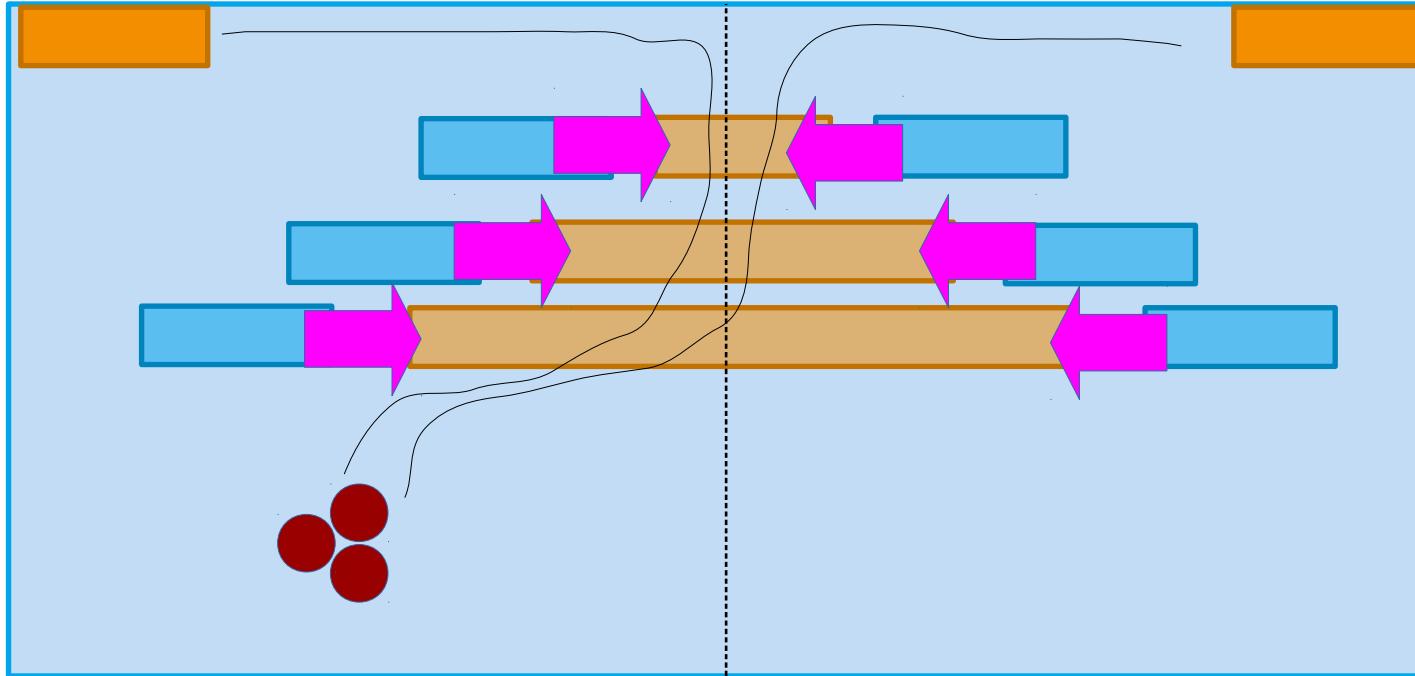


Free charges follow field lines
→ Exploit Maxwell's 1st eq.



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’

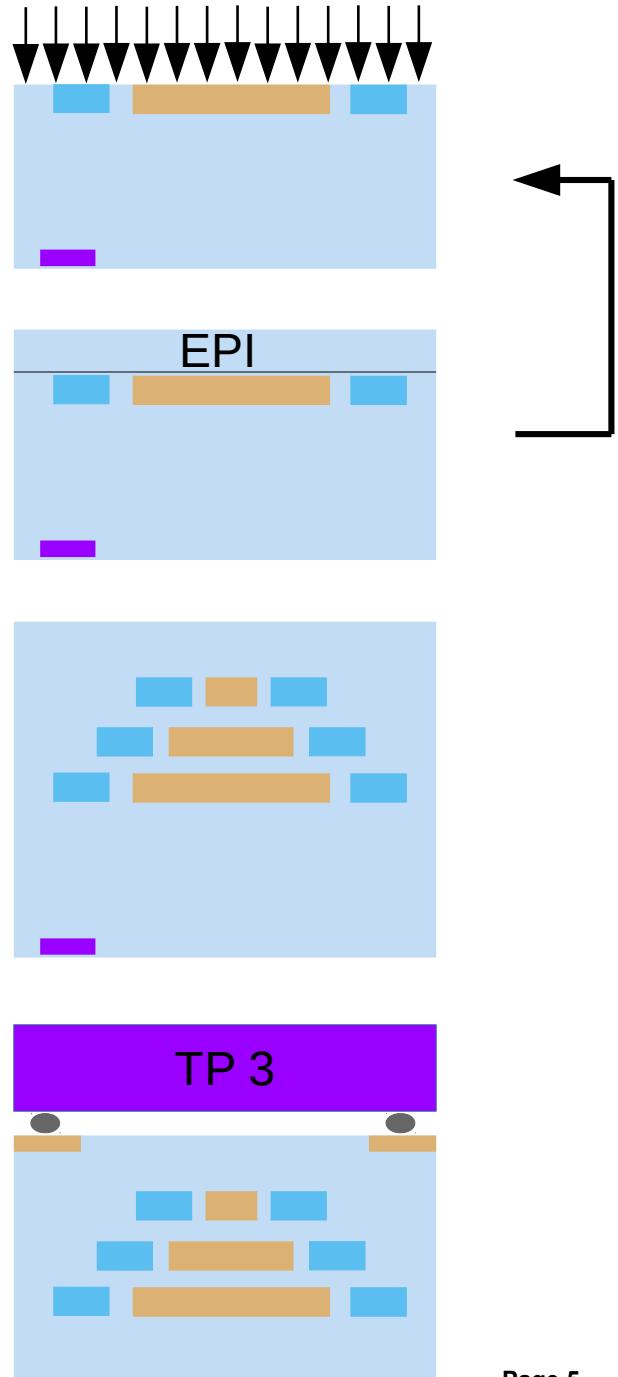
Patent granted:
H. Jansen, DE102015116270B4
H. Jansen, Nucl. Instr. Meth. A 831 242 (2016)
A. Velyka, H. Jansen, TIPP 2017 proceedings

No one has done this before

... can we do it?

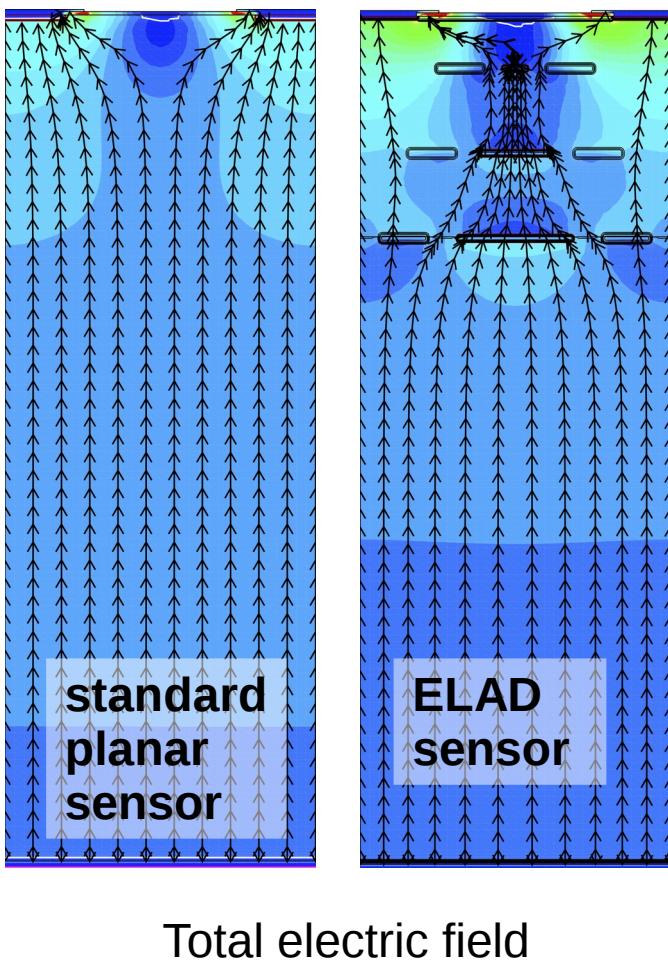
Goal: Produce a *functional prototype*

- 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

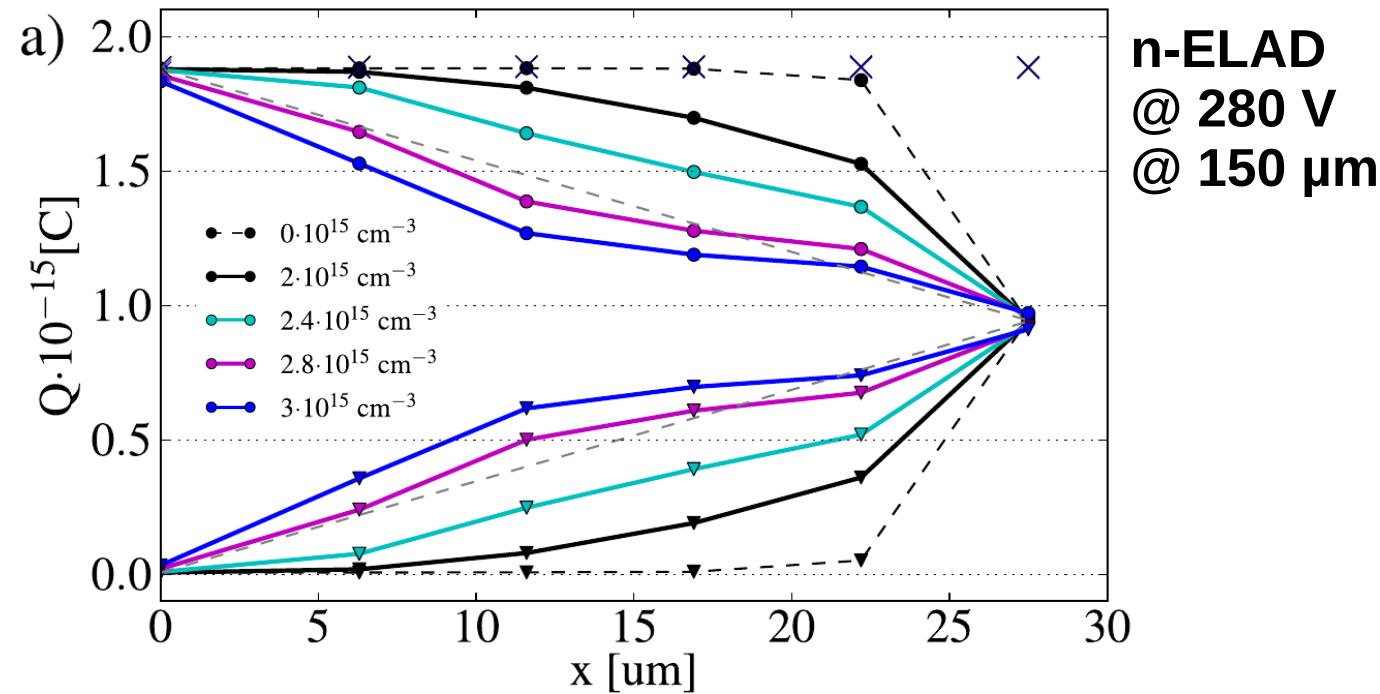


TCAD simulations

Buried implants create lateral electric field



Scan charge sharing a.f.o. MIP position



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

Detector simulation – AllPix²



Study impact of buried implants on the spatial resolution

→ Final step of the optimisation scheme after TCAD

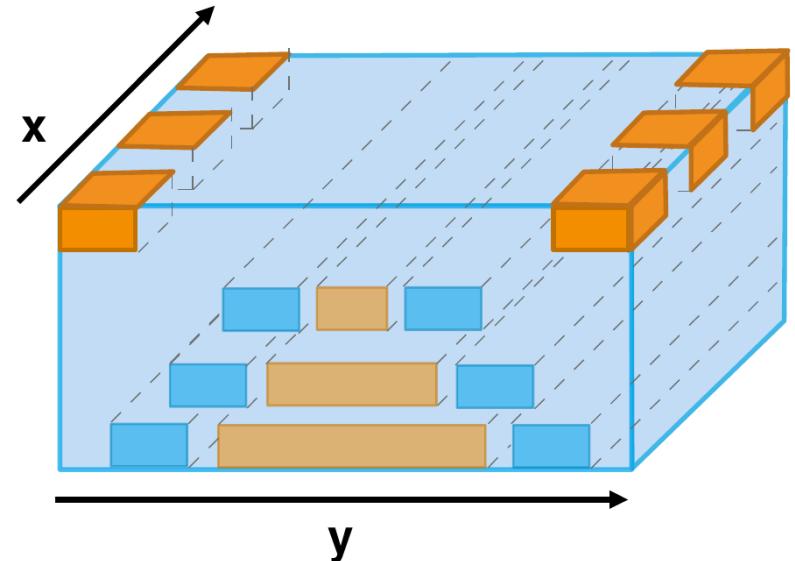
AllPix²: generic detector simulation framework

- Monte Carlo particles from Geant4
- Charge deposition
- Charge drift/diffusion (import TCAD E-field)
- Digitizer

Today:

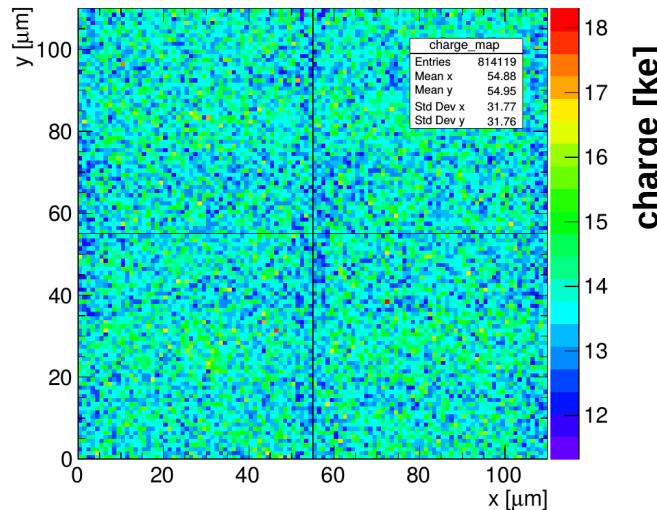
- p-ELAD: one data point @ 150 µm
- n-ELAD: various parameters

Update on process development



ELAD, 150 um thick

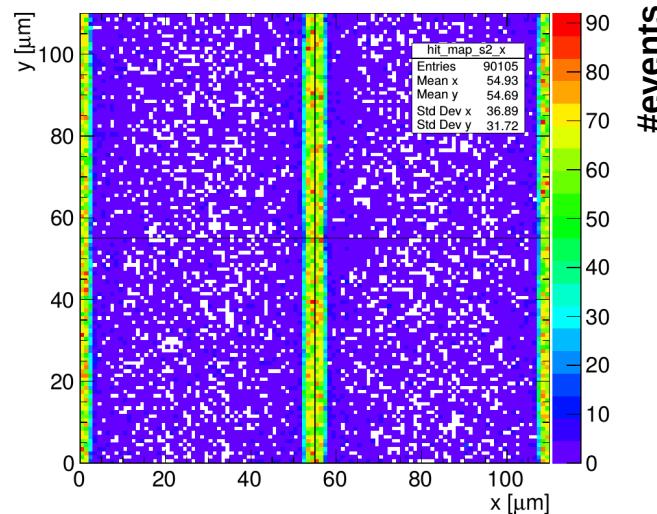
**Cluster CHARGE
in x/y**



signal > threshold

→ Little loss
in corners

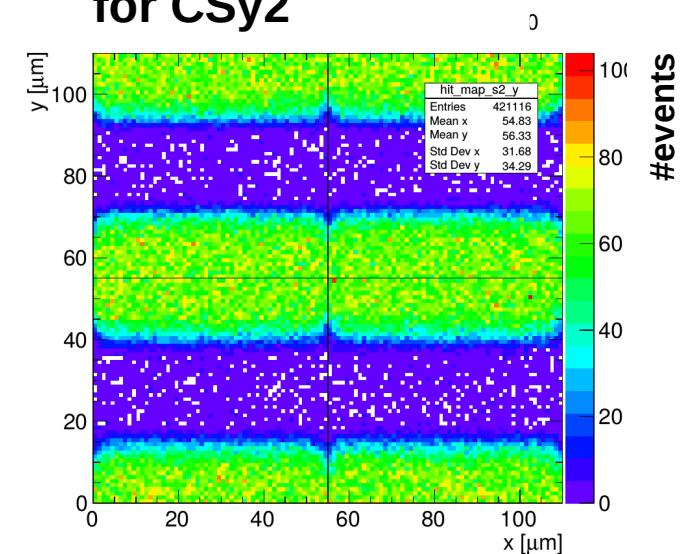
**#events in x/y
for CSx2**



Sharing in x over
~ 3 um

→ mostly CS1

**#events in x/y
for CSy2**



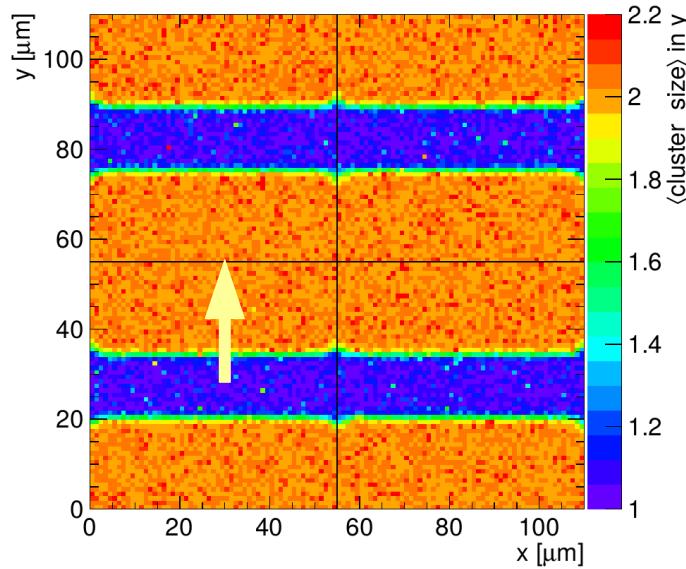
Sharing in y over
~ 20 um

→ U_{bias} and n_{bi} dependent
→ >50% CSy2

p-ELAD: $n_{bi} = 2e15\text{cm}^{-3}$, 150 um thick

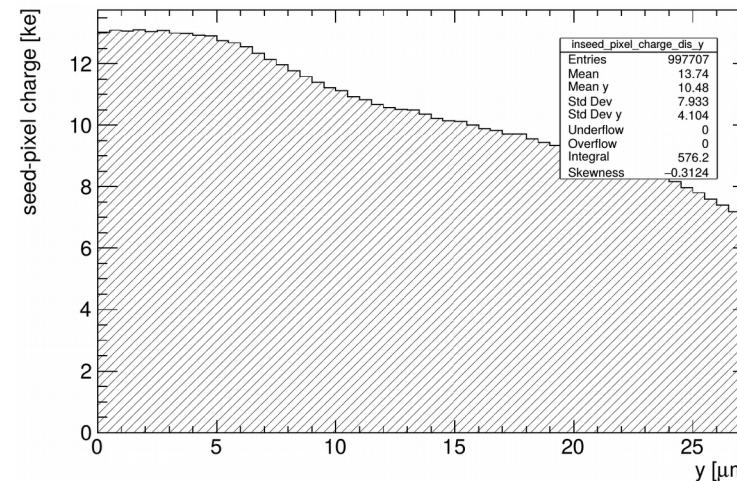


cluster size in y

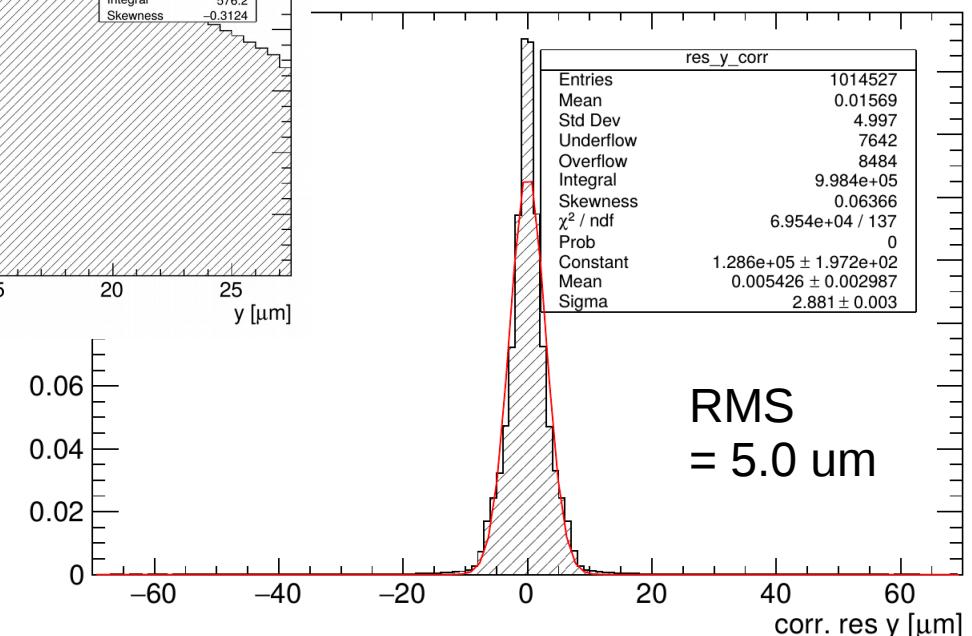


Assumes 700e threshold, TP3 footprint

In-seed charge distribution



corrected res. in y



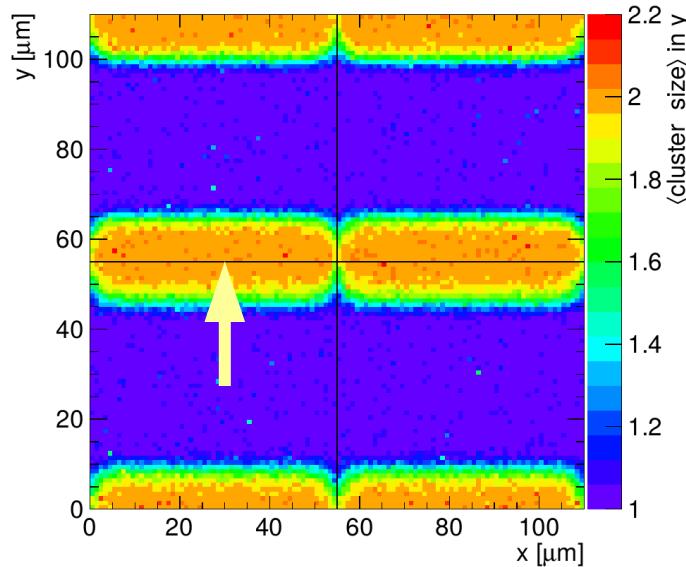
Result

- Favourable aspect ratio (thick/pitch ~ 3)
- Large CSy2 region (fraction $> 80\%$!)
- Improvement ~ 3 vs binary resolution

n-ELAD: $n_{bi} = 3e15$, 50 um thick

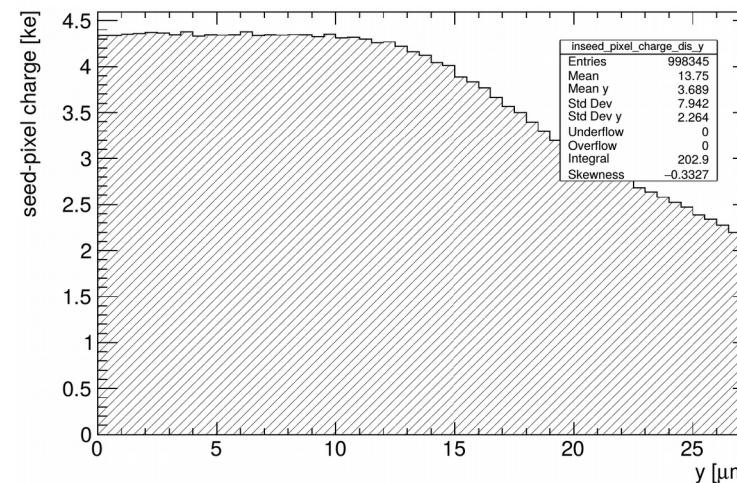


cluster size in y

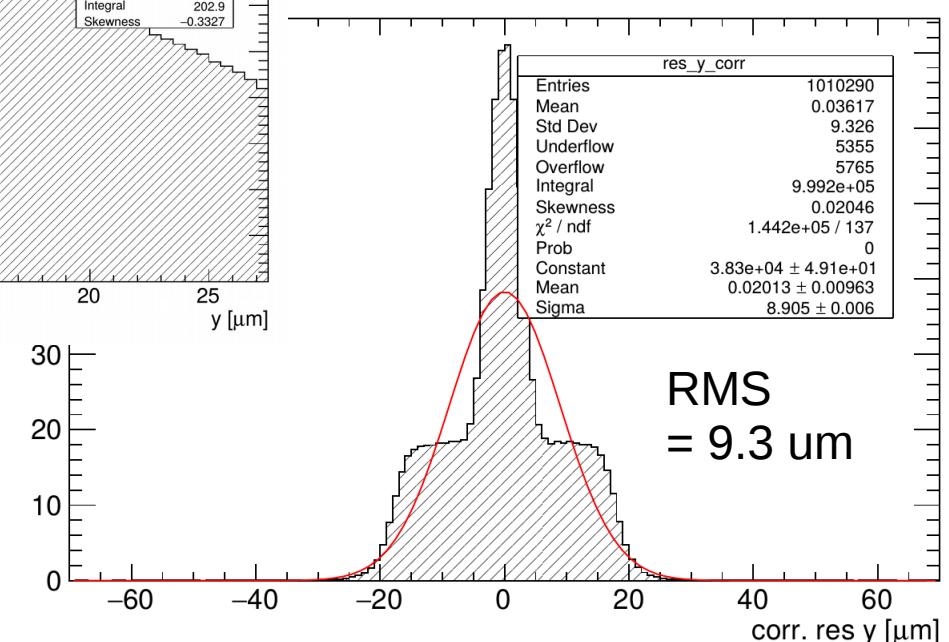


Assumes 700e threshold, TP3 footprint

In-seed charge distribution



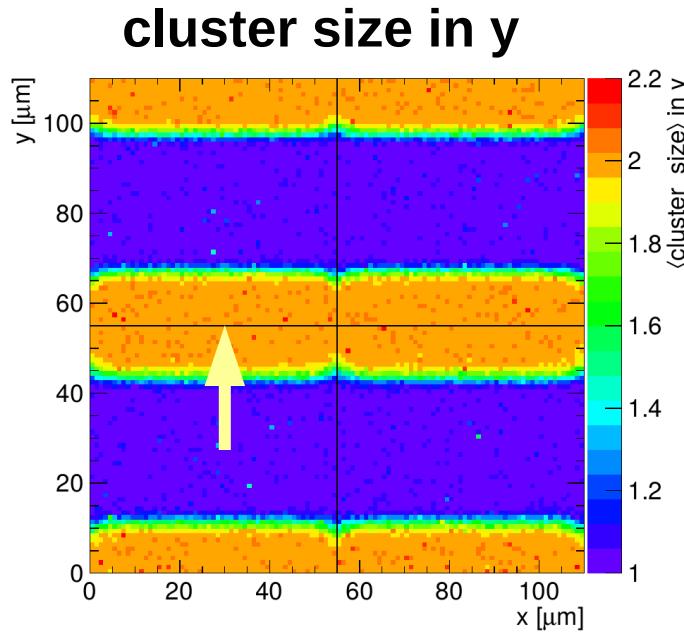
corrected res. in y



Challenge:

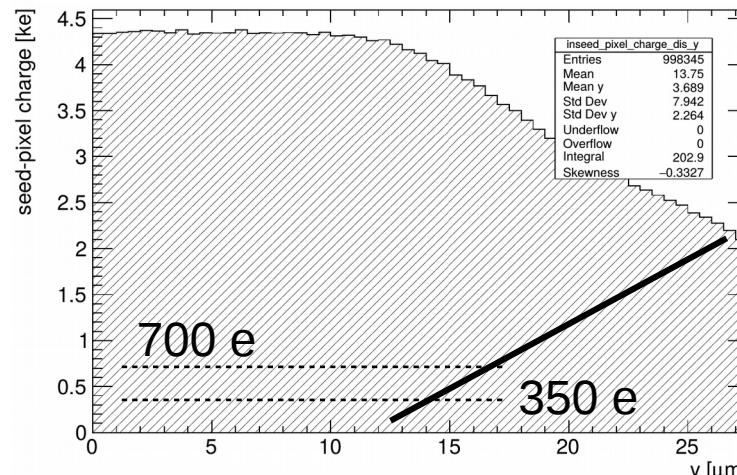
- Signal / Threshold suffers factor 3
- Unfavourable aspect ratio
- Short drift length → higher n_{bi}
→ Increase bias voltage for depletion

Make a wish: Low Threshold TP3

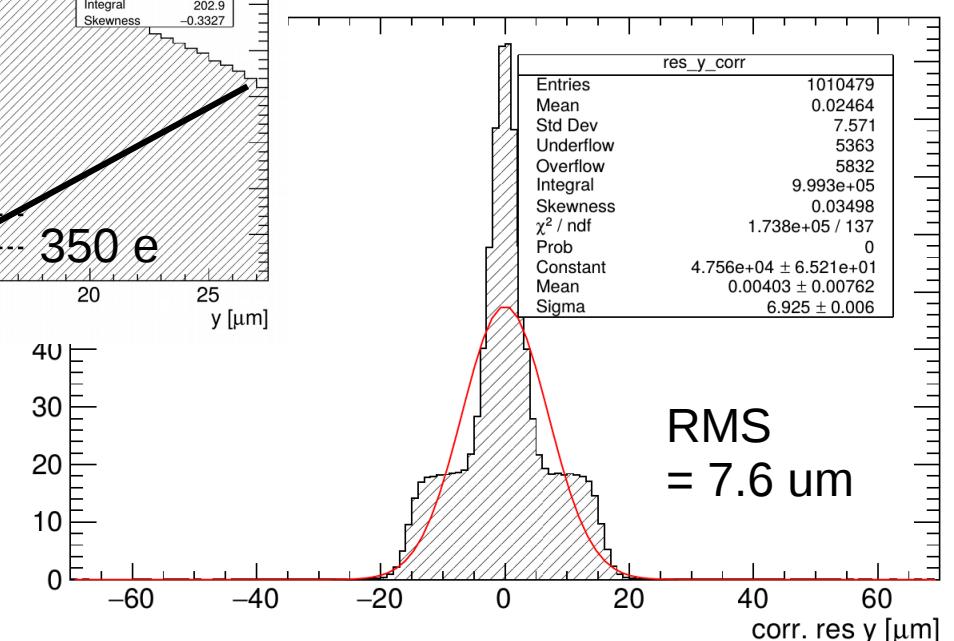


Assumes 350e threshold

In-seed charge distribution



corrected res. in y



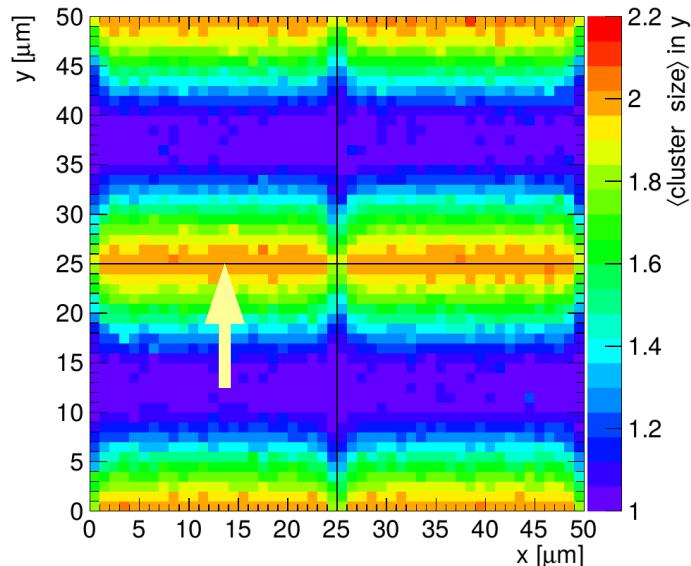
Result

- Lower threshold helps
- But still large CSy1 region

n-ELAD: CP2, $n_{bi} = 3e15$, 50 um thick

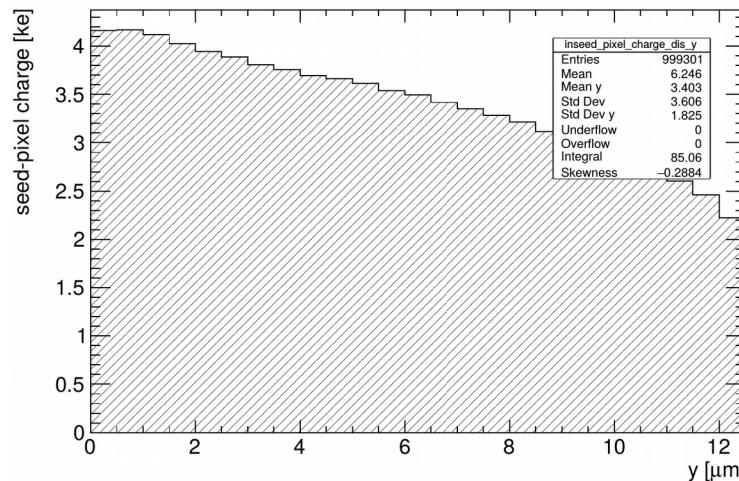


cluster size in y

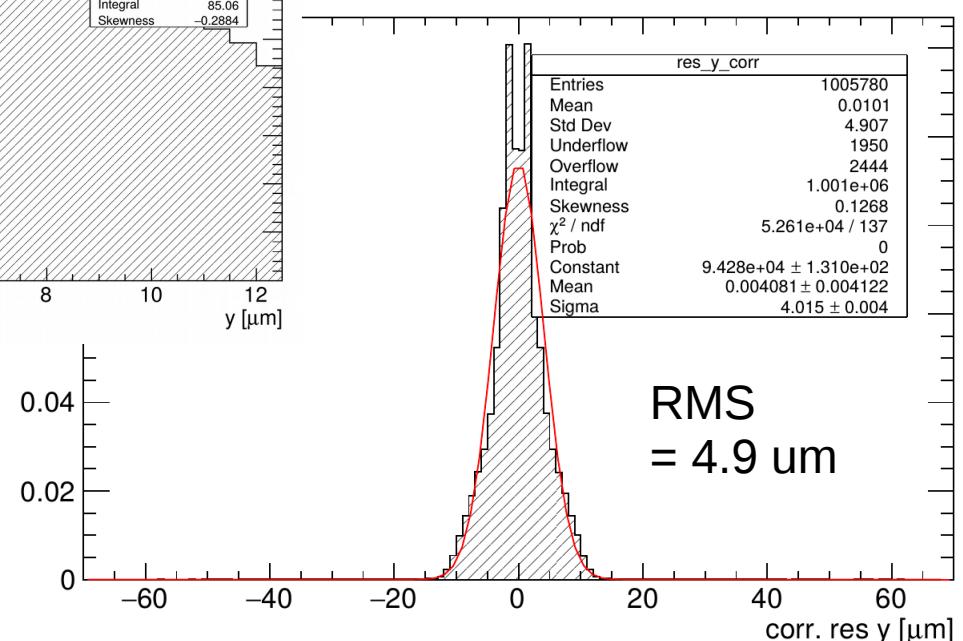


Assumes 700e threshold
Assumes higher resistivity EPI
Optimised geometry of buried implants

In-seed charge distribution



corrected res. in y



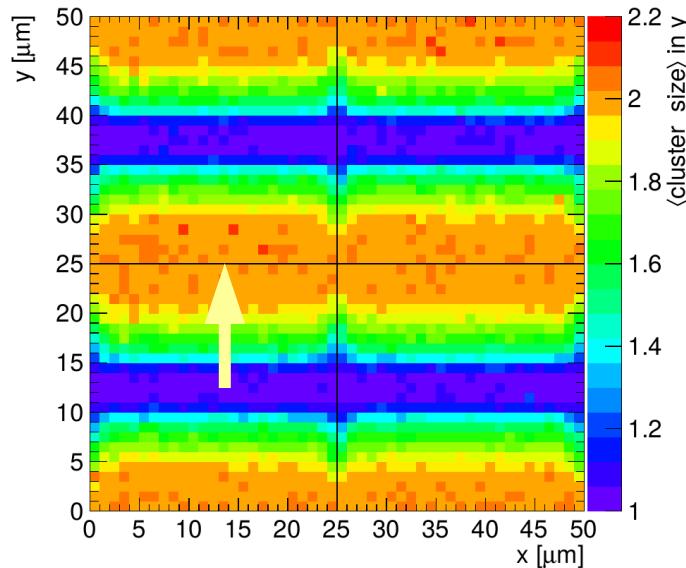
Result

- More favourable aspect ratio
- Larger fraction CSy2 region
- Improvement ~2 vs TP3 footprint

Wishing again ... low threshold CP2

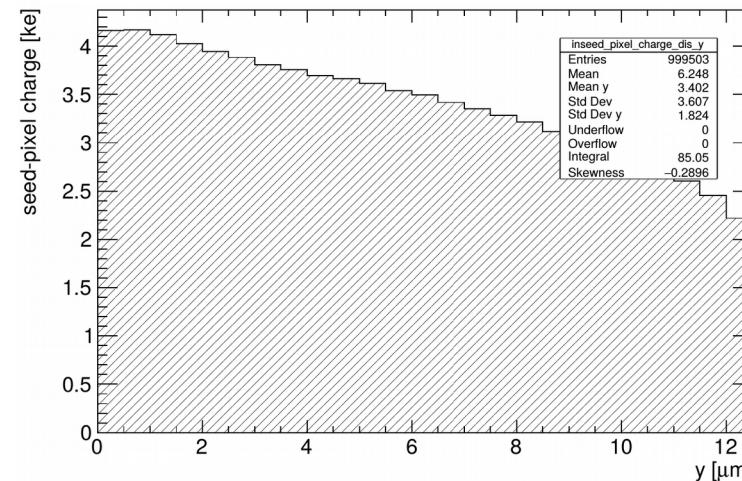


cluster size in y

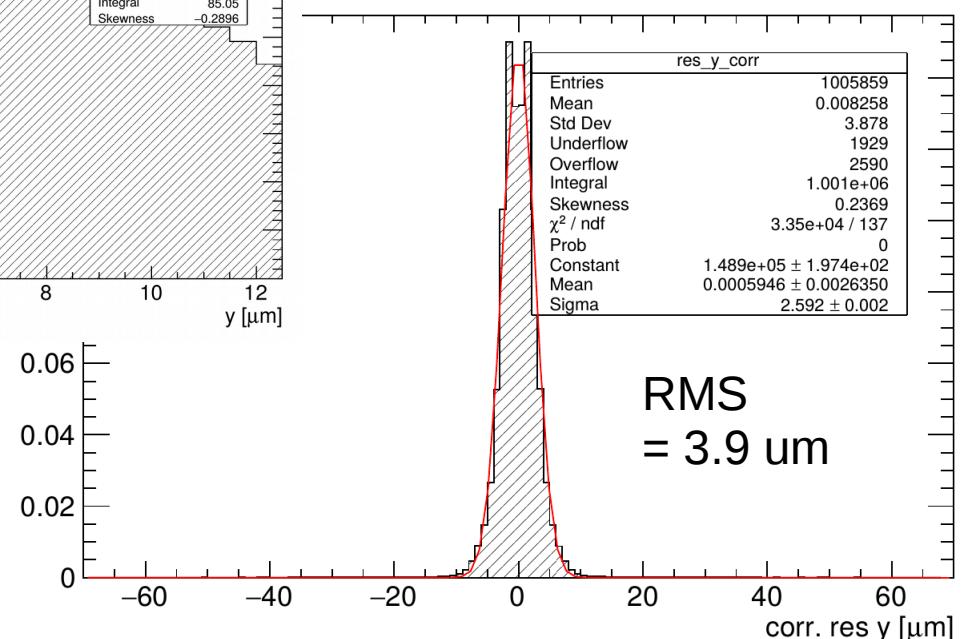


Assumes threshold of 350e

In-seed charge distribution



corrected res. in y



Result

- Impact of LT especially when sharing!
- Residual width of CSy1 = 4.1 μm

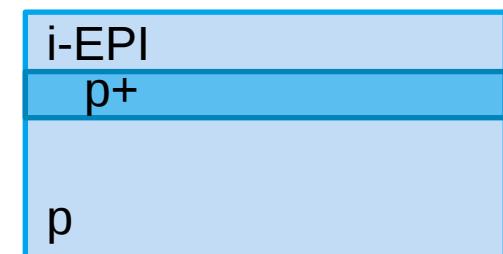
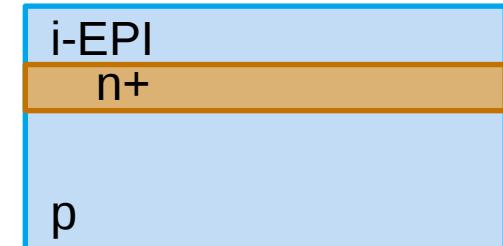
Process development

Consultation with FMD (`Forschungsfabrik Mikroelektronik Deutschland')

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

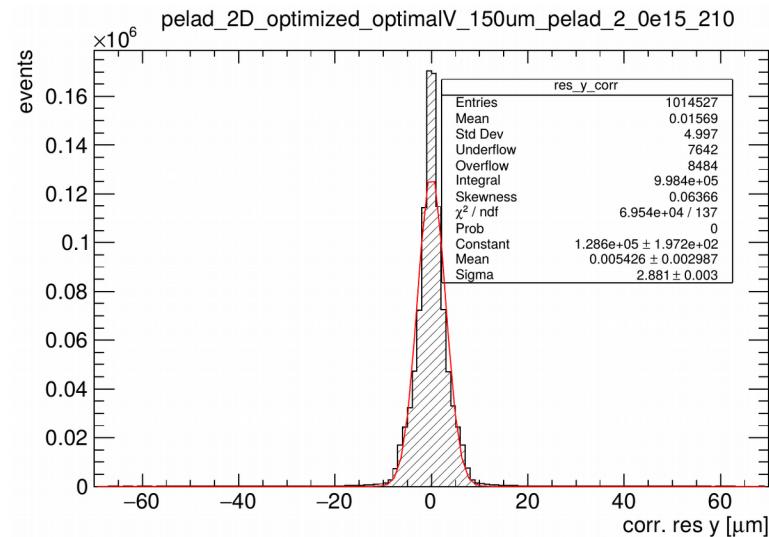
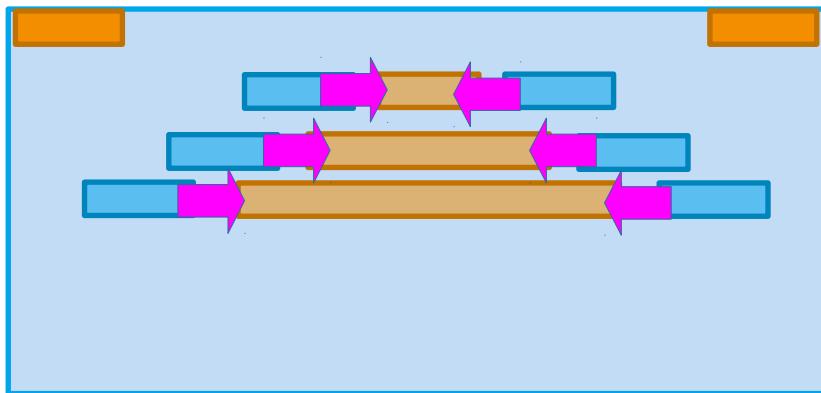
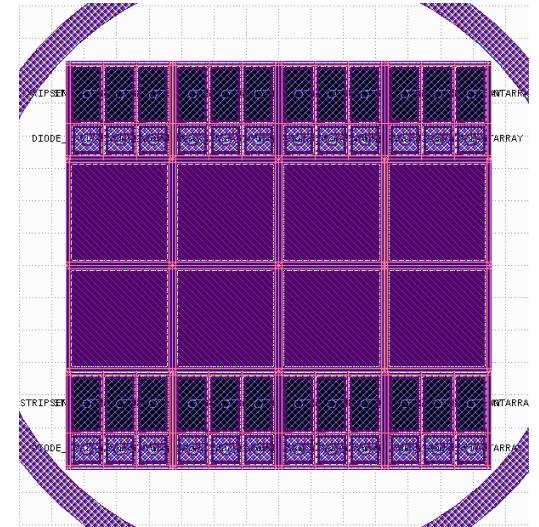
Pre-studies include

- 200 mm wafer, p-type, 5kOhmcm
- Implant unstructured p(n) on p-substrate through oxide
- RTA (oven) annealing
- Intrinsic EPI (slightly p), 15 um (← **THIS WEEK**)
- Mimick total EPI temperature budget with oven
- SRP and SIMS for depth analysis
 - “Buried implant process”



Conclusion

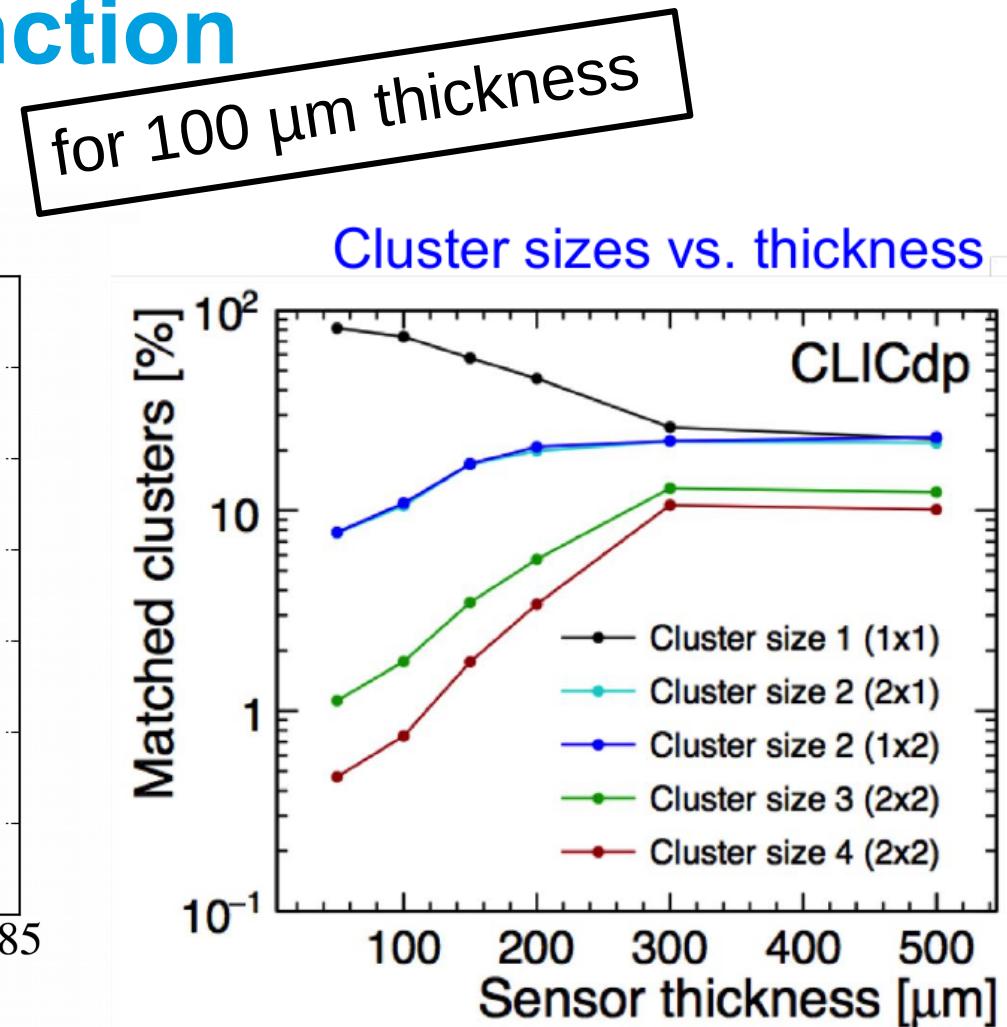
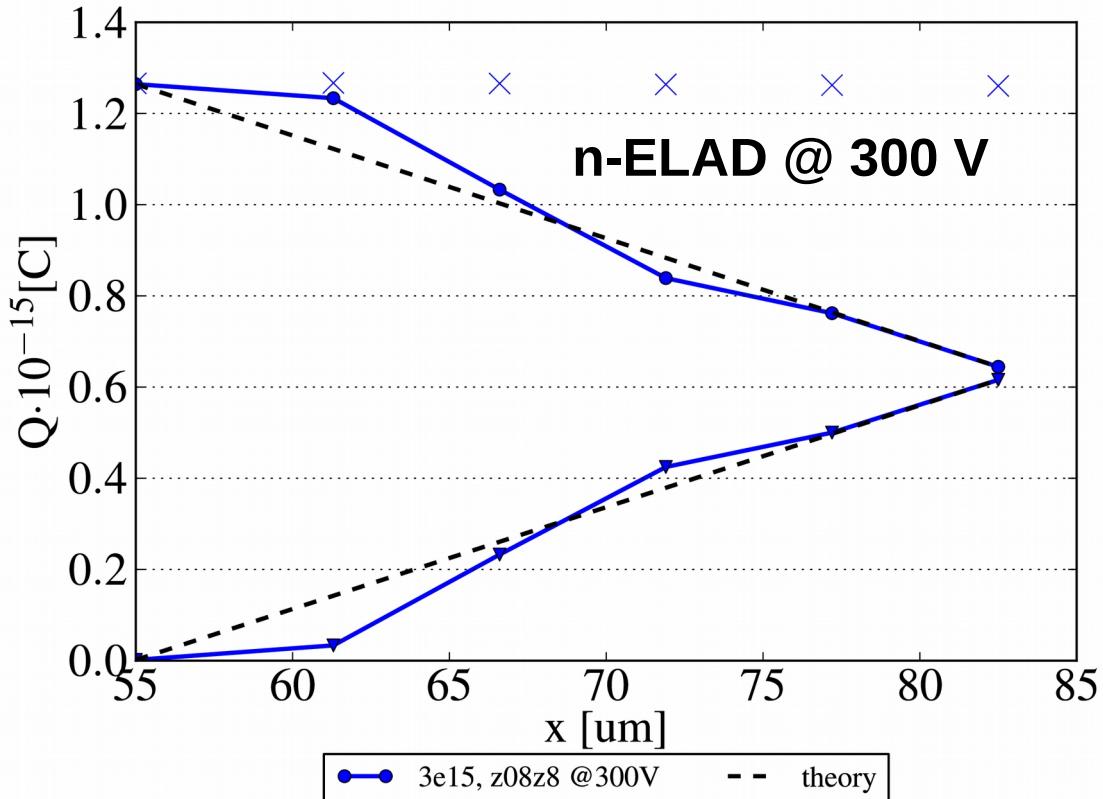
- **Technologically challenging project** aiming to reach the **theoretical optimum** of position resolution
- **Interesting technology** for future HEP detectors:
RMS residual of 5.0 μm @ 55 μm pitch
- **Bulk engineering opens new possibilities** in sensor design
- **Low threshold ASICs** for charge sharing detectors
- **Process soon, prototypes beginning 2020**



Backup

TCAD simulations – η function

Now optimising towards thinner sensors

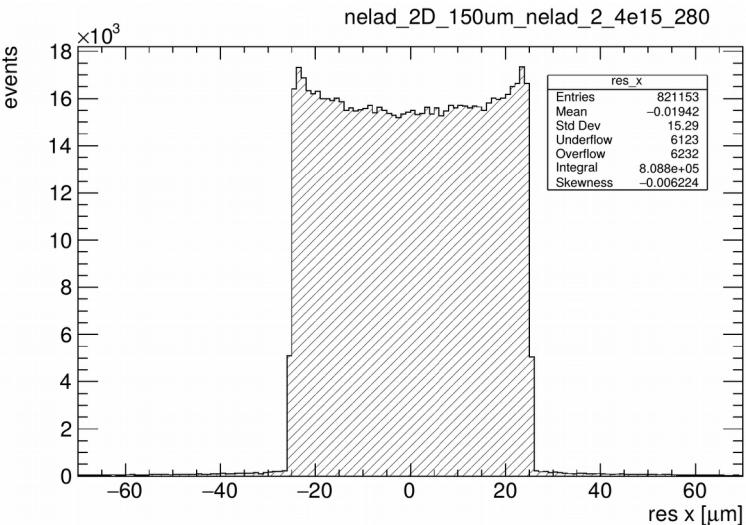


→ Next step: include also 50 μm

[D. Dannheim]

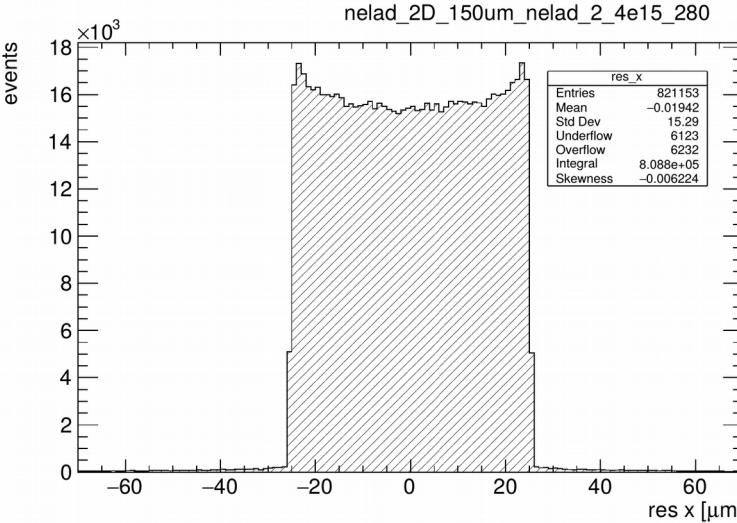
Eta correction

CoG

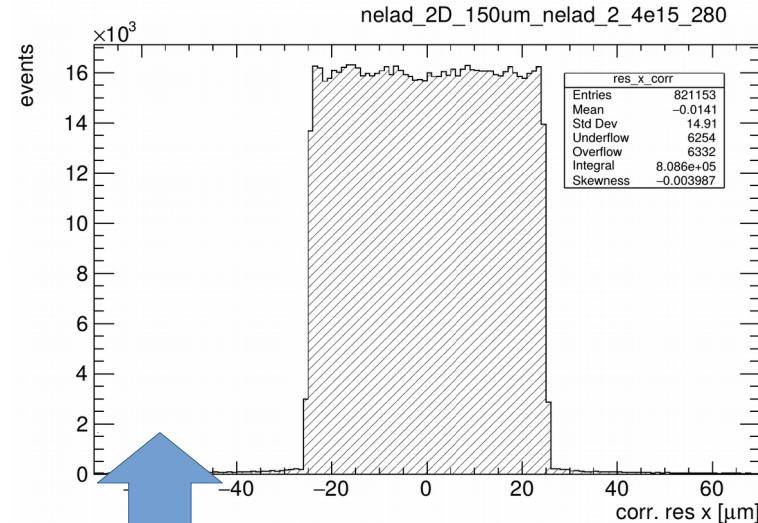


Eta correction

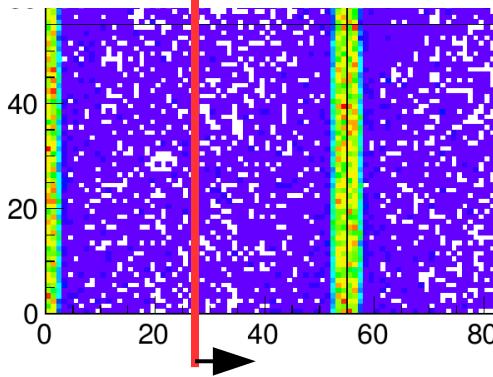
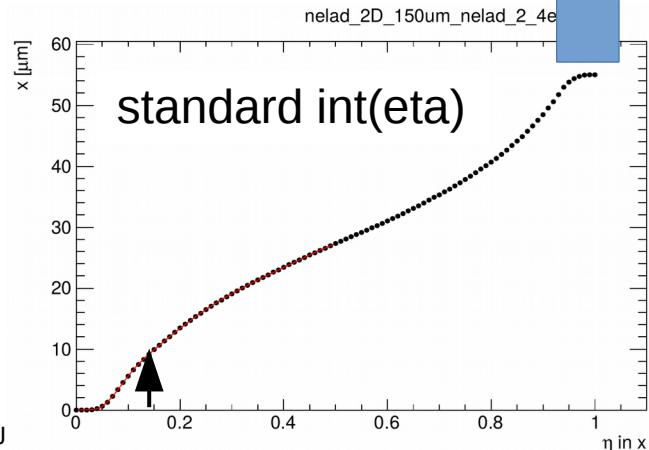
CoG



standard eta correction



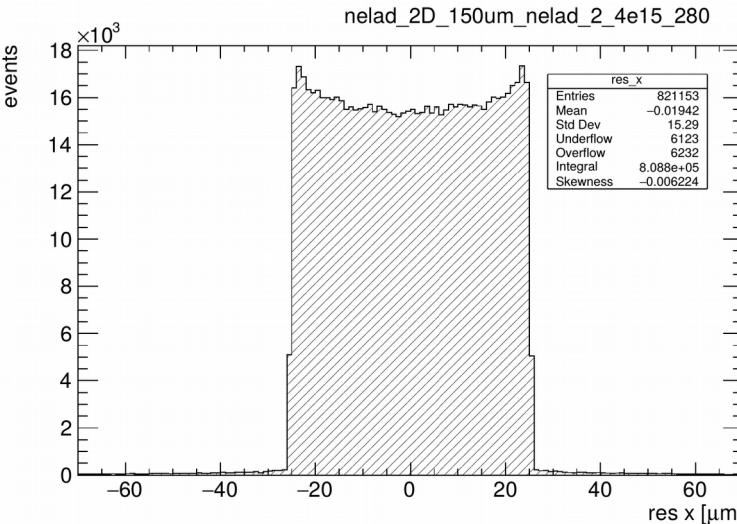
Correction
from seed
centre



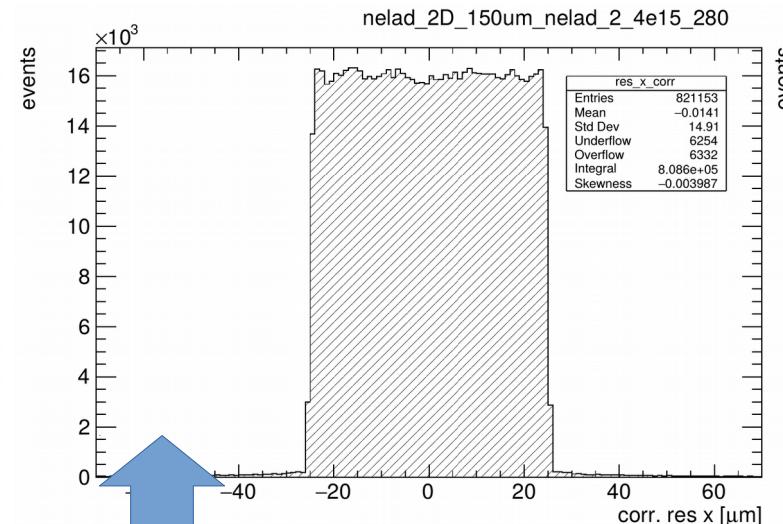
Eta correction



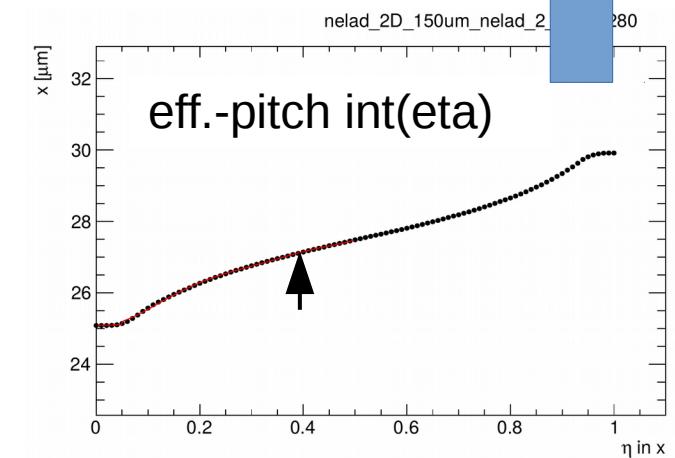
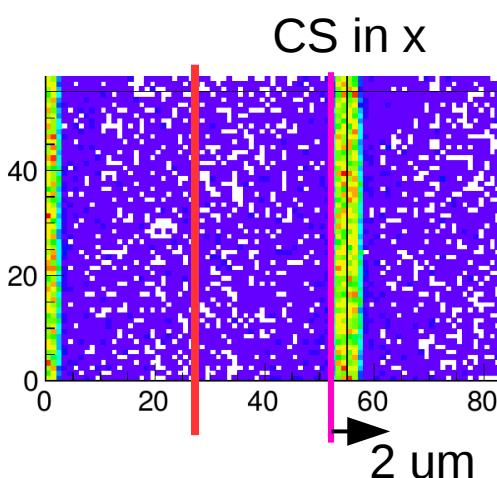
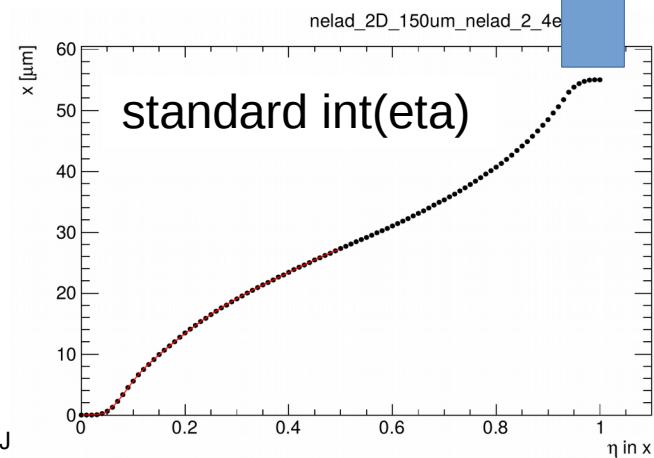
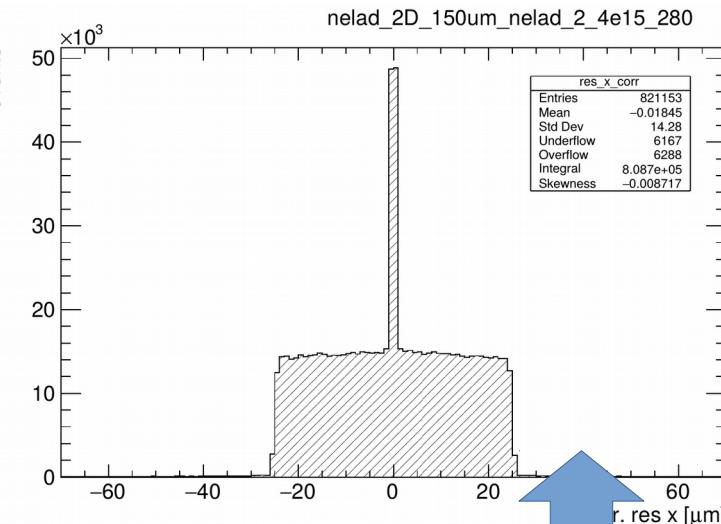
CoG



standard eta correction

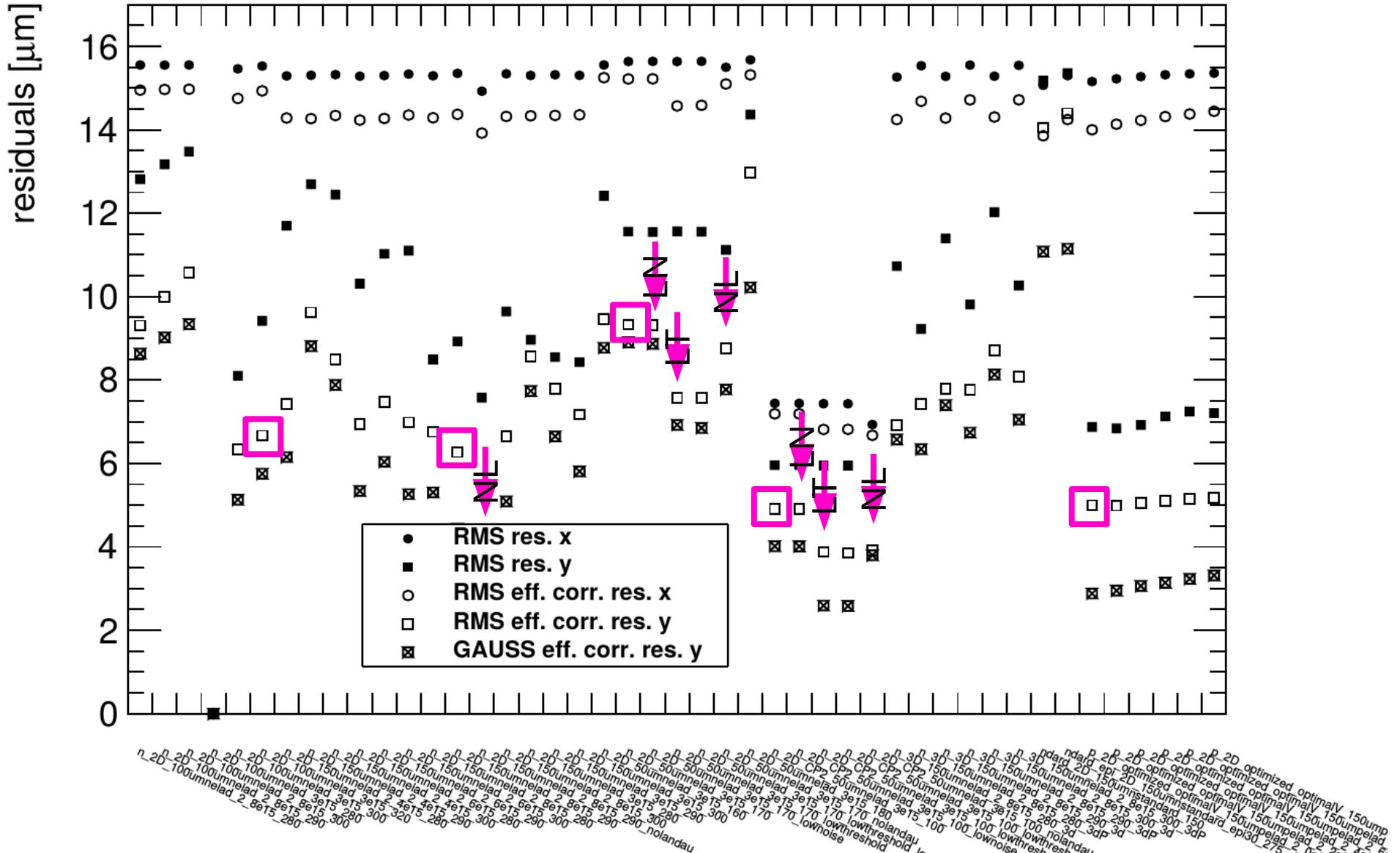


eff.-pitch eta correction



Grand comparison

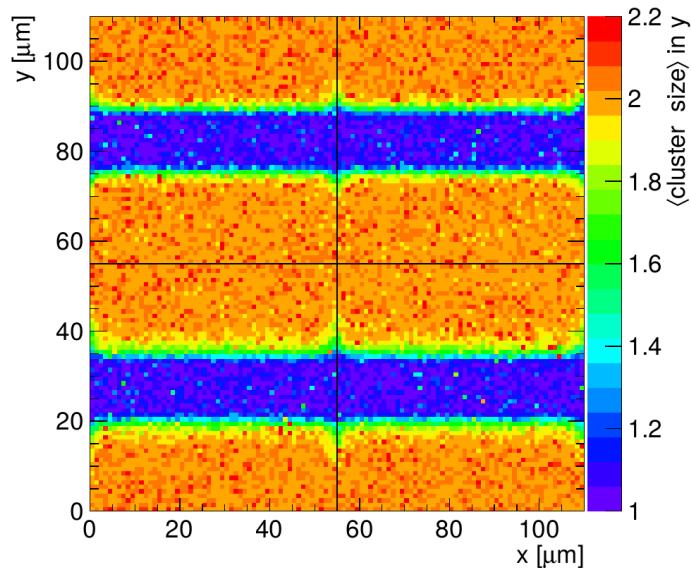
n-100um n-150um n-50um n-50-CP2 n-150-3D p-150um



n-ELAD, 2.8e15, 290 V, 150 um

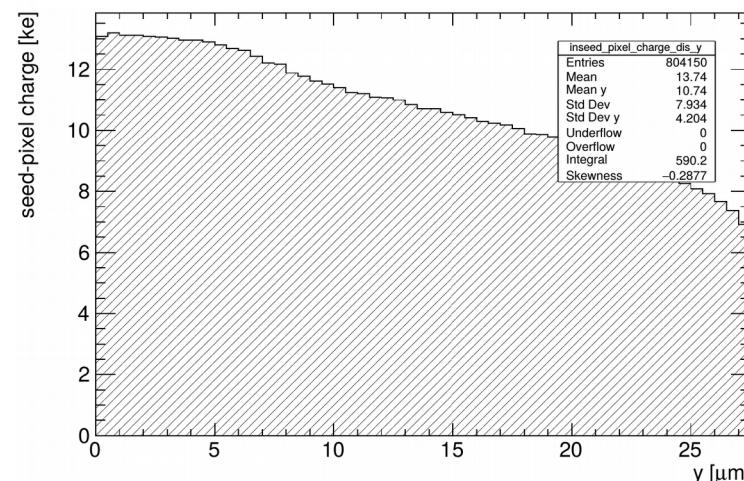


cluster size in y

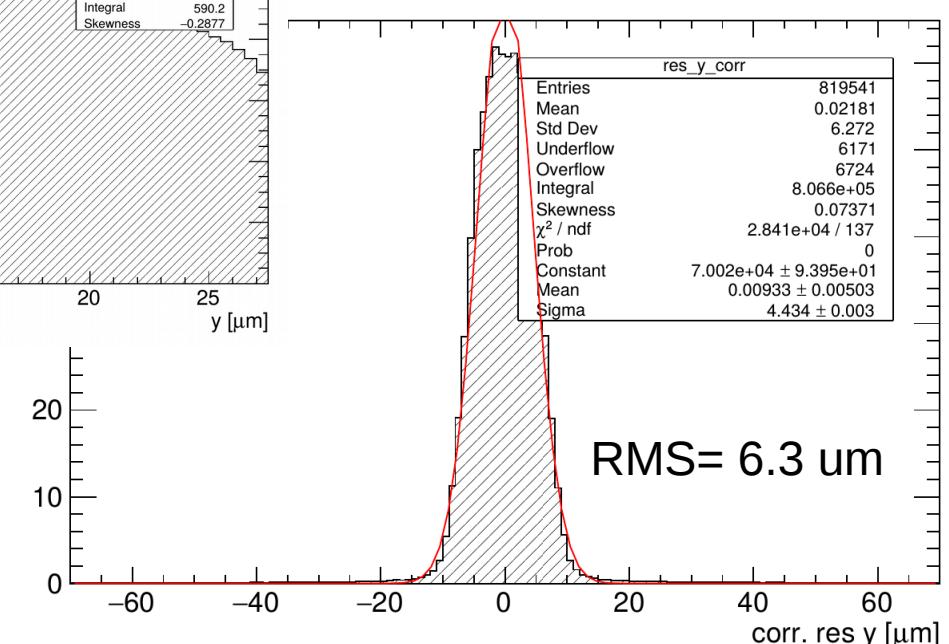


Assumes 700e threshold, TP3 footprint

In-seed charge distribution



corrected res. in y



Result

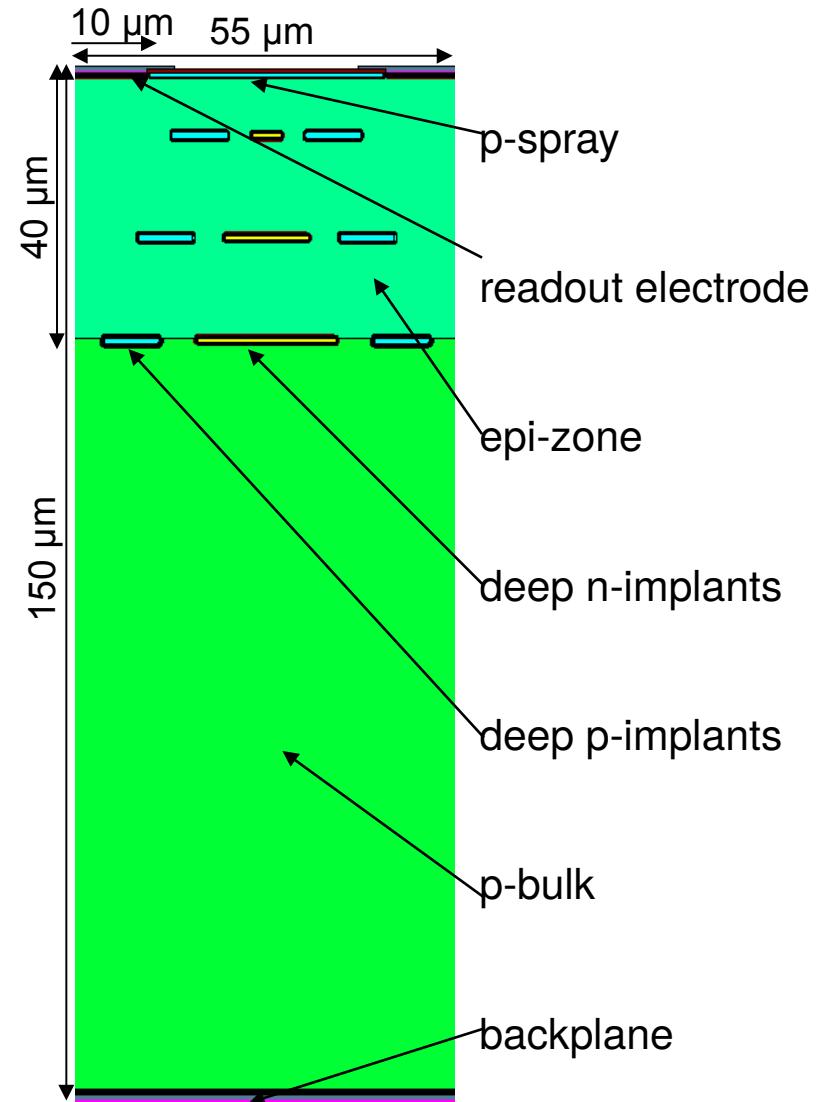
- Favourable aspect ratio (thick/pitch ~ 3)
- Large CSy2 region
- Improvement ~2.4 vs standard sensor

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 $55 \mu\text{m}$
r/o implant size $20 - 30 \mu\text{m}$
- Total thickness $50 - 150 \mu\text{m}$
- Epi thickness $40 \mu\text{m}$
Epi quality $\sim 1\text{e}14 \text{ cm}^{-3}$

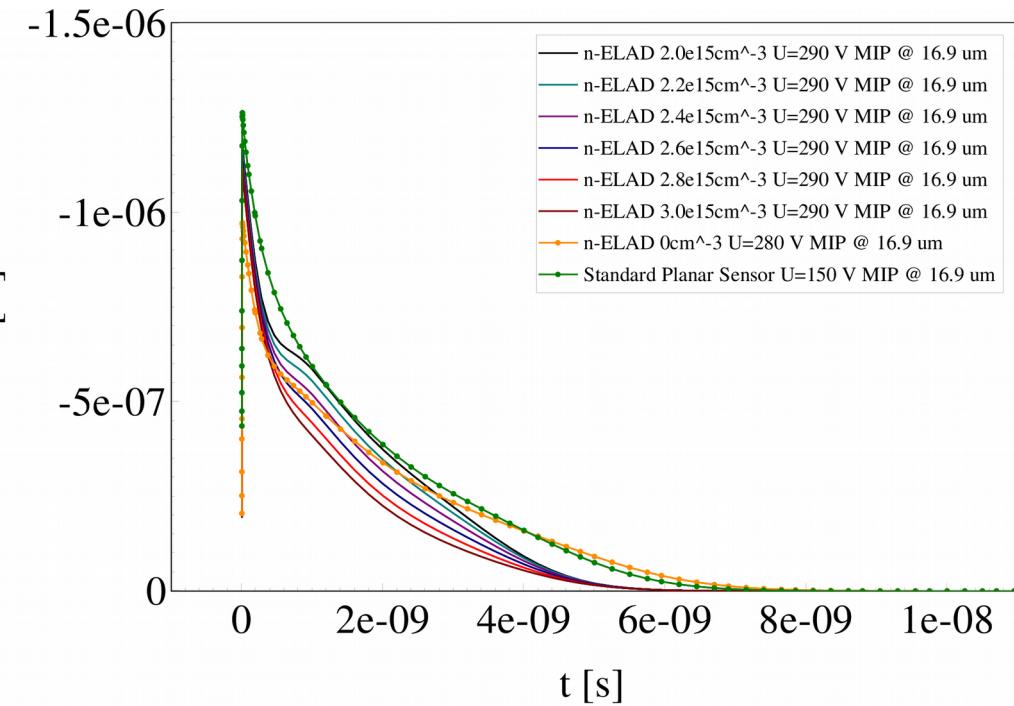
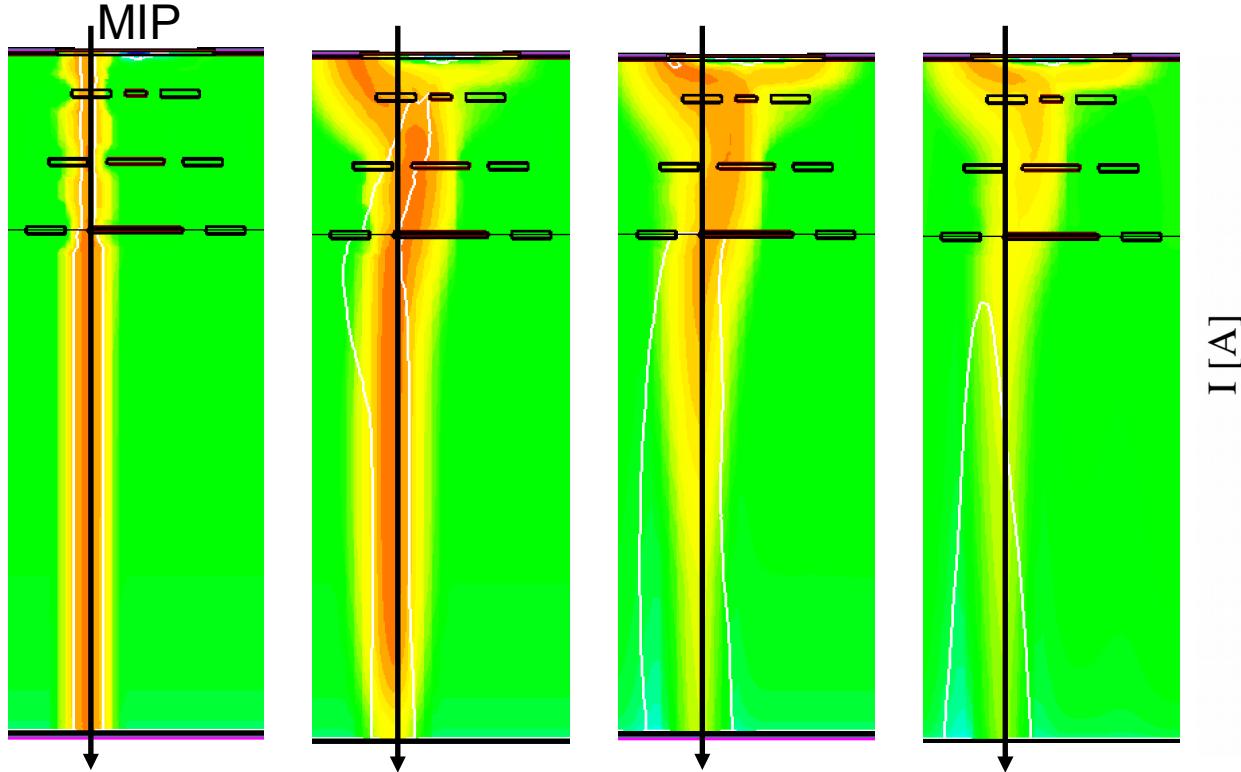
p-substrate, p-EPI, p-n-p structure
→ p-ELAD

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 borderer
- Active charge sharing!