Verbund 05H2018
R&D Detektoren (Tracking)

Kickoff Meeting
Heidelberg, February 13./14.

Plans in Heidelberg

HV-MAPS & Tracking Activities in Heidelberg

Mu3e Collaboration

- R&D for HV-MAPS pixel tracker
- development of fast tracking algorithms

ATLAS Collaboration

- involved in several track trigger projects
  (→ L1Track, HTT, FTK, triplet track trigger)
- CMOS sensors for ATLAS ITK upgrade → studies
- ATLASpix prototypes and demonstrators

Future Circular Collider (new!)

- triplet track trigger
- study of radiation tolerant pixel sensors and scalability to large areas

Mu3e Experiment

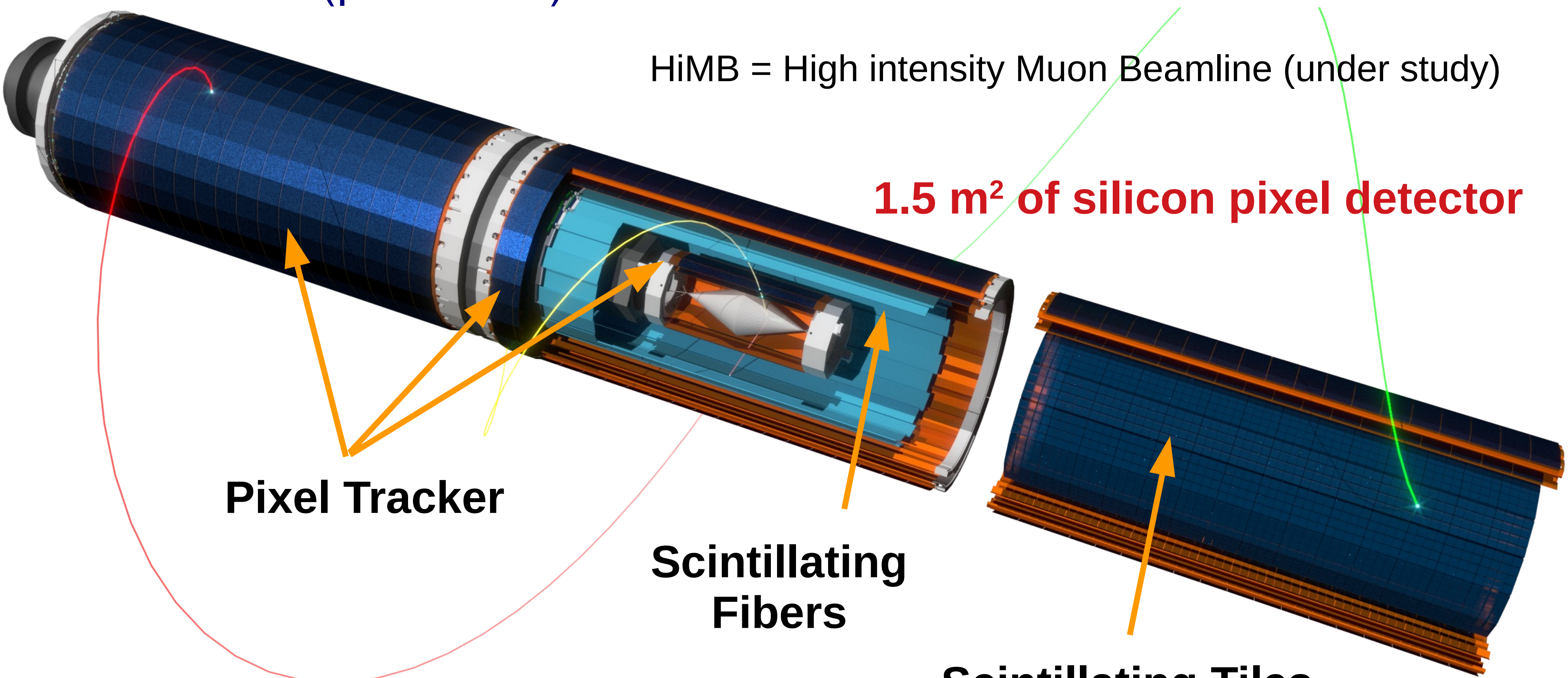
<u>Aiming for a sensitivity (SES)</u>   <u>requires:</u>

$BR(\mu \rightarrow e\,e\,e) < 2 \cdot 10^{-15}$ (phase I) → **10^8 muons/s (PiE5)**

$BR(\mu \rightarrow e\,e\,e) < 10^{-16}$ (phase II) → **$>10^9$ muons/s (HiMB)**

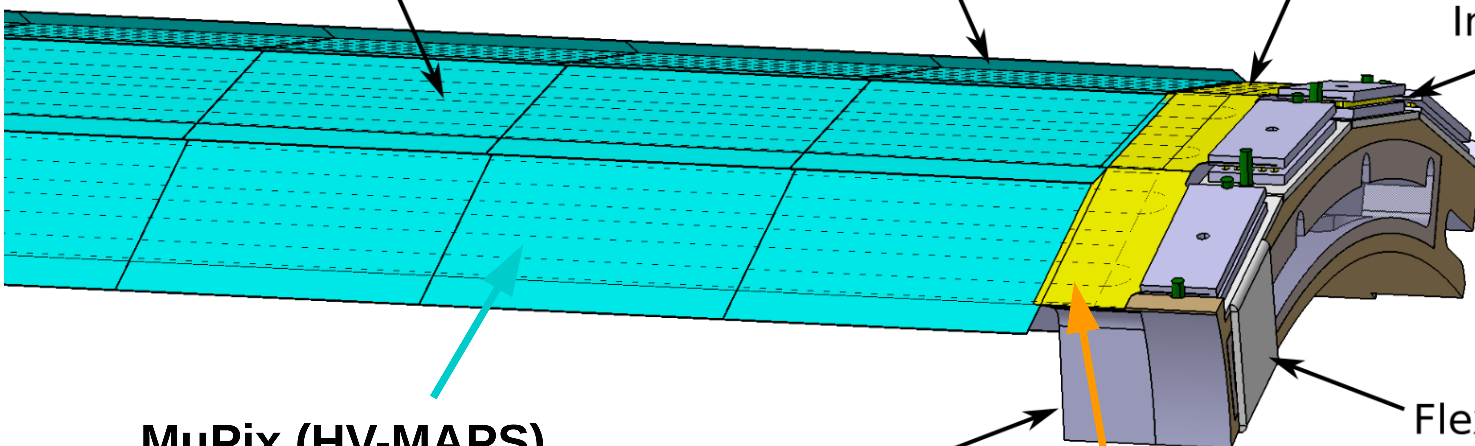
HiMB = High intensity Muon Beamline (under study)

1.5 m² of silicon pixel detector

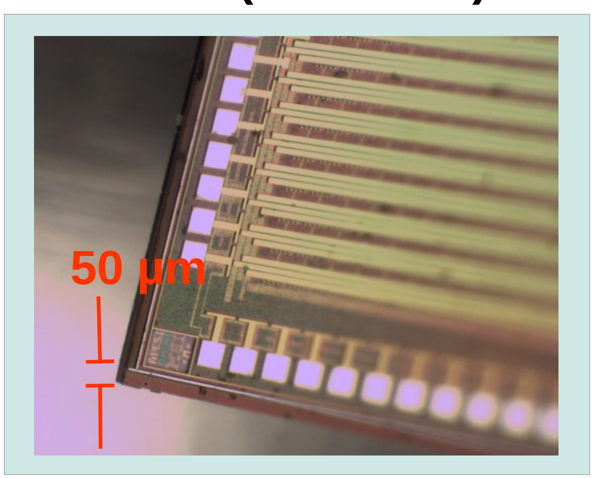


(Outer) Pixel Tracker Module

Ultra-thin pixel sensor modules with a radiation length of **X/X_0 = 1.15 per mil**

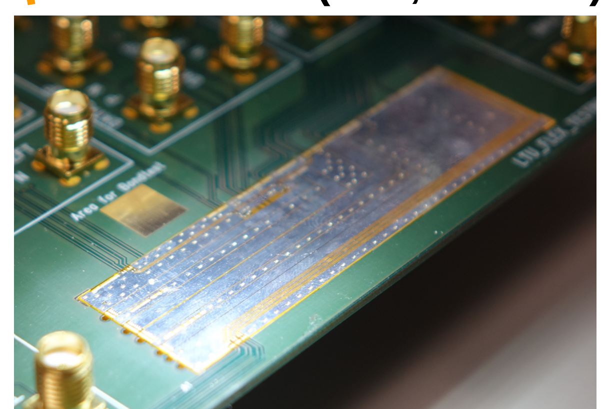


MuPix (HV-MAPS)

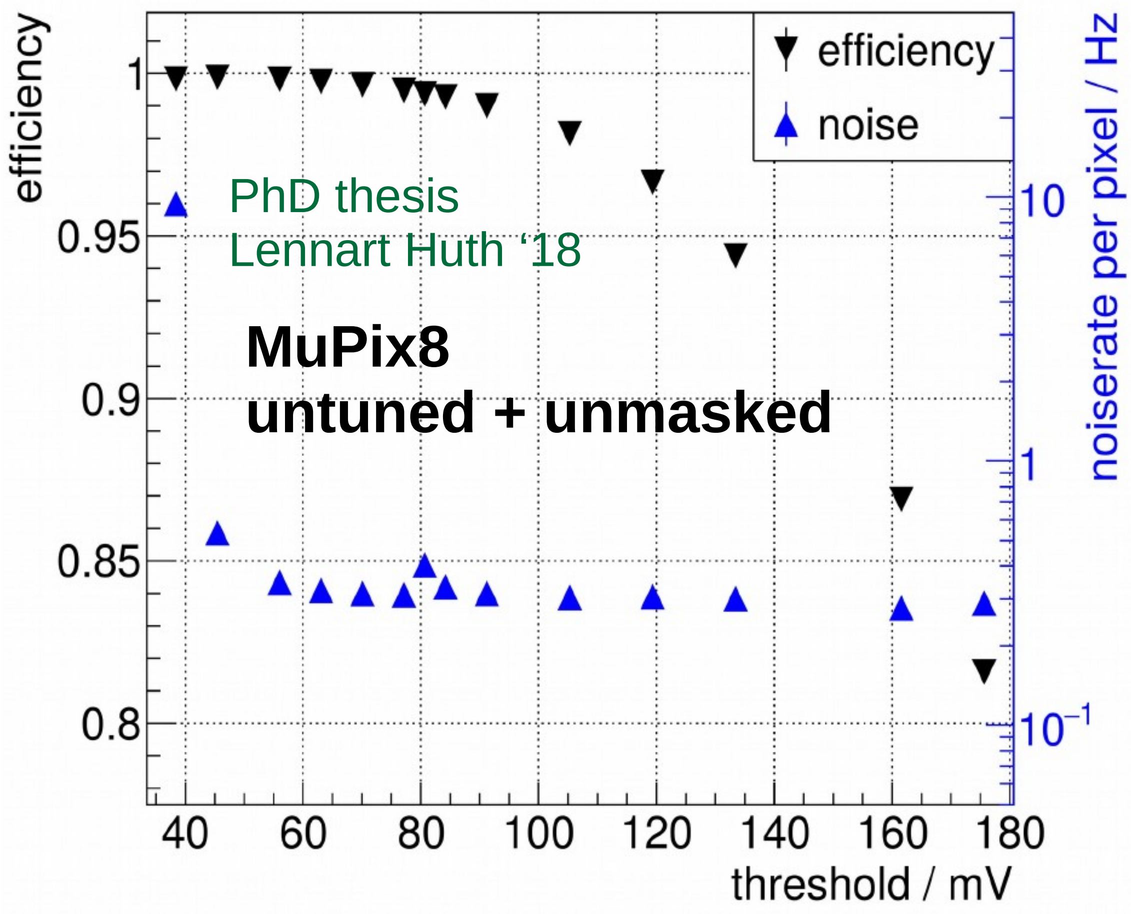


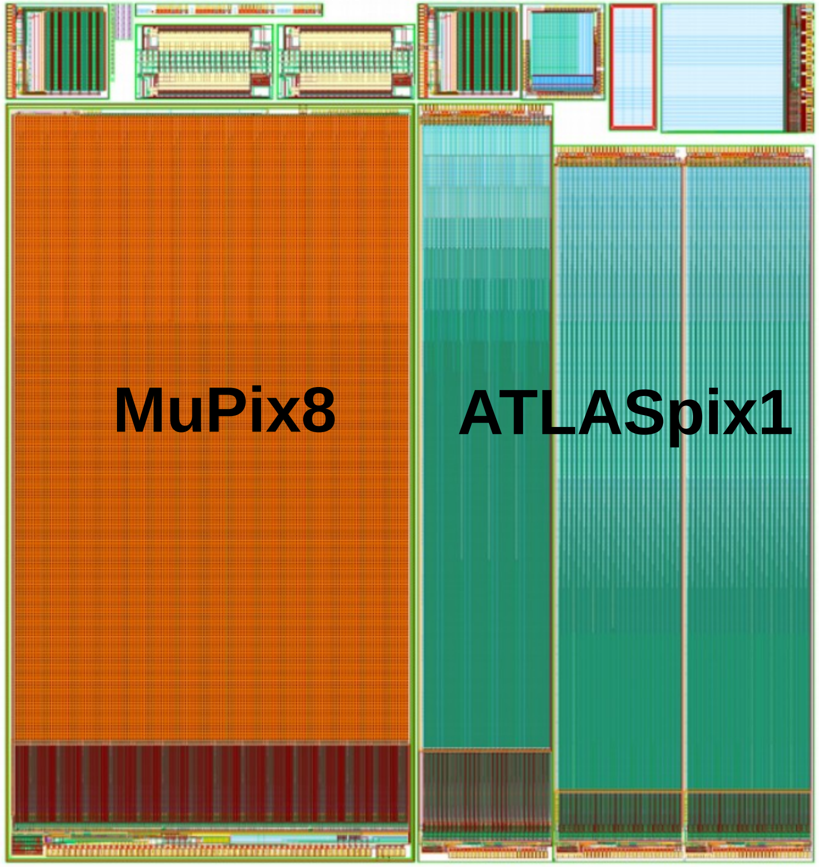
Monolithic pixel sensor in
180 nm HV-CMOS

High Density Interconnect (< 100 µm)
(LTU, Ukraine)



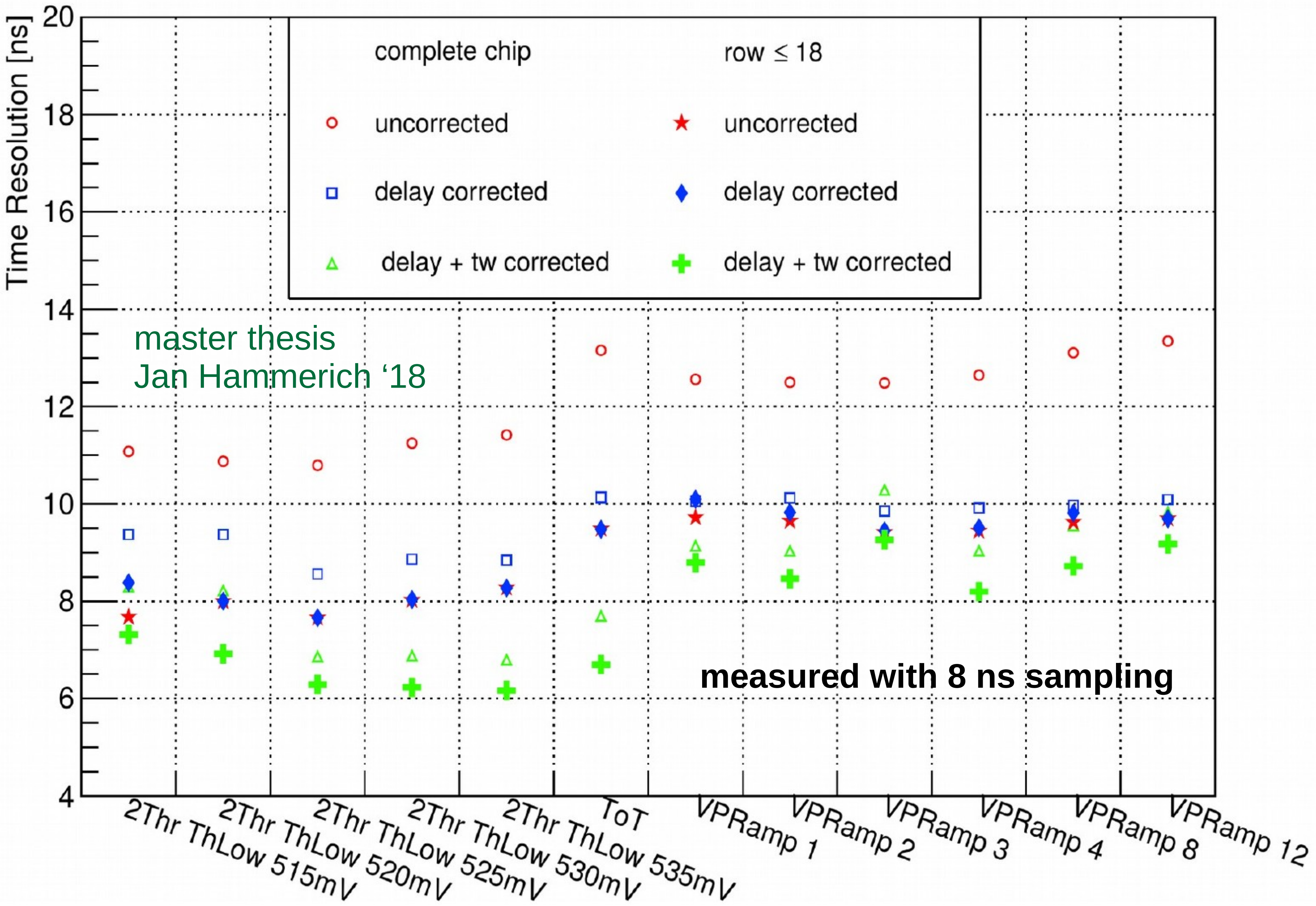
Recent Mupix Results





substrate resistivity is 80 Ohm·cm

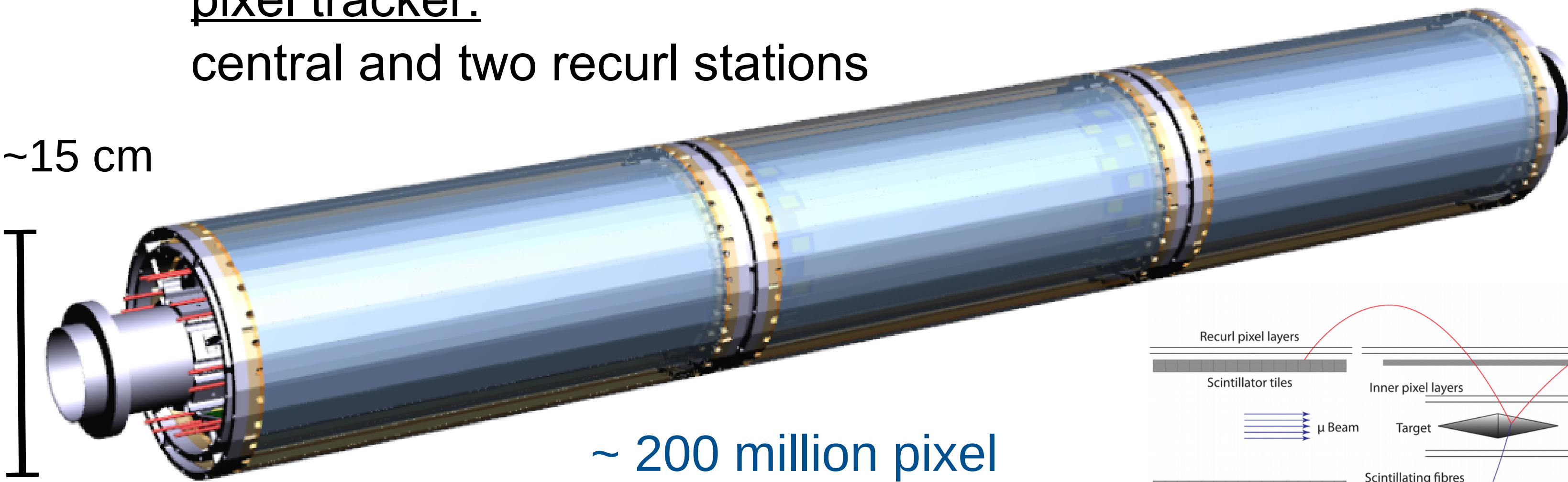
Time Resolution with Mupix8



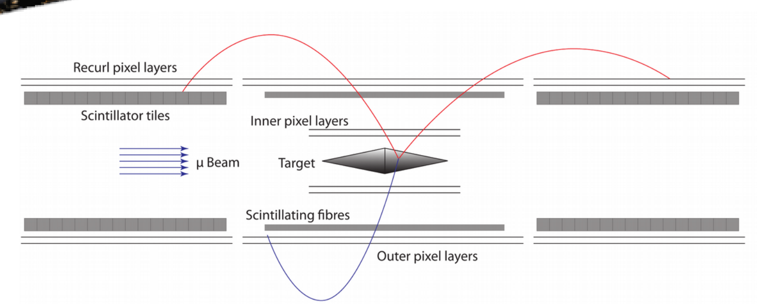
Pixel Detector + Helium Gas Cooling

pixel tracker:
central and two recurl stations

~15 cm



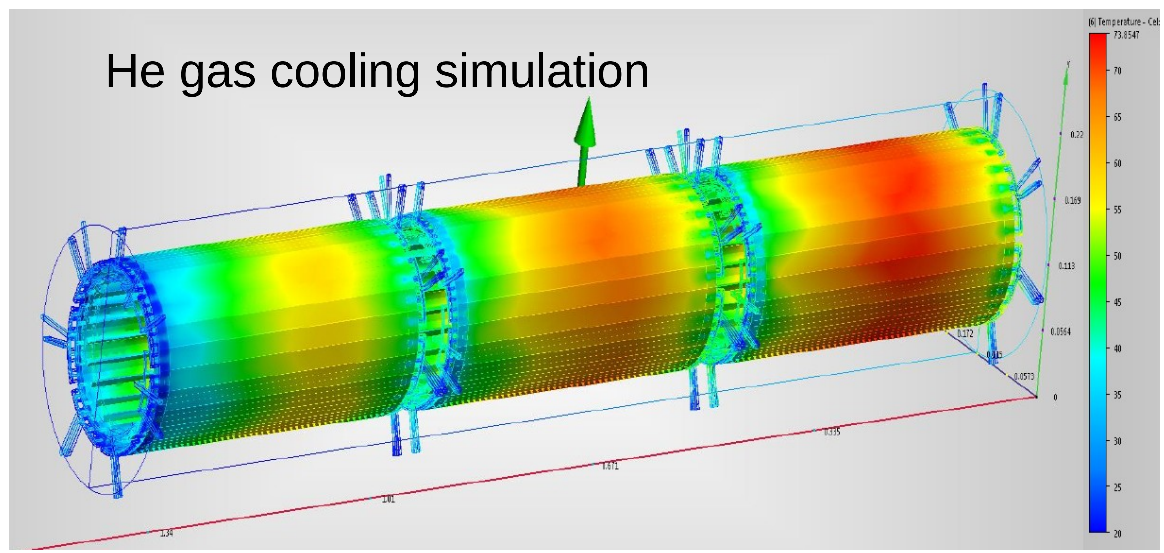
~ 200 million pixel



He gas cooling concept

→ temperatures 20-50 °C

→ no extra material in
active volume!



Mu3e Status and Plans for Phase I

- Superconduction solenoid produced by Cryogenic (London)
- Delivery expected in summer 2019
- Detector construction will start in 2019/20

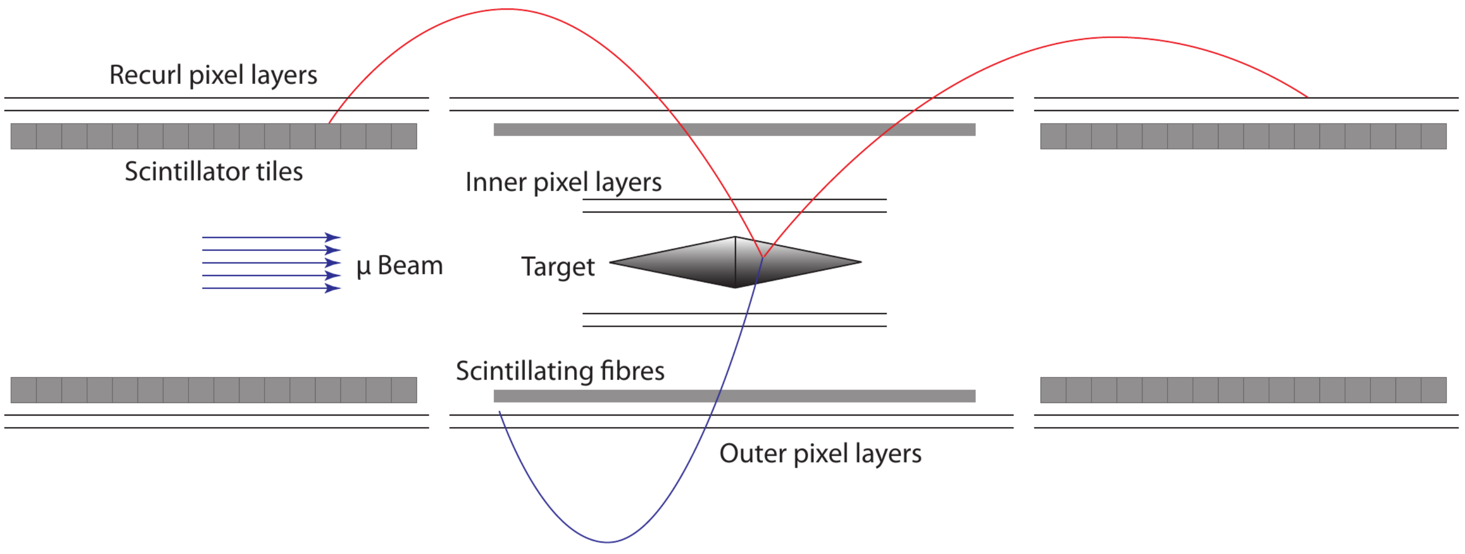
Specification of Mupix10 (final)

	Requirements	MuPix 7	MuPix 8	MuPix 9	MuPix 10 expected
		designed/measured			
pixel size [µm^2]	80×80	103×80	81×80	81×80	80×80
sensor size [mm^2]	20×23	3.8×4.1	10.7×19.5	4.5×3.5	20×23
active area [mm^2]	20×20	3.8×2.8	10.3×16.0	$X \times Y$	20×20
active area [mm^2]	380	10.6	166	6.2	400
sensor thinned to thickness [µm]	50	50, 63, 75	63, 100	-	50
LVDS links	$3+1$	1	$3+1$	$1+1$	$3+1$
maximum bandwidth [Gbit/s]	3.75	1.6	6.4	3.2	6.4
timestamp clock [MHz]	≥ 50	62.5	125	125	125
RMS of spatial resolution [µm]	≤ 50	≤ 30	≤ 30	not meas.	≤ 30
power consumption [mW/cm^2]	≤ 350	$\approx 300^\dagger$	$250-300$	not meas.	≈ 250
time resolution [ns]	≤ 20	≈ 14	$\approx 13\ (6^*)$	≈ 9	$\approx 10\ (5^*)$
efficiency at 20 Hz noise [%]	≥ 99	99.9	99.9	not meas.	≥ 99.5
noise rate at 99 % efficiency [Hz/pix]	≤ 20	< 10	< 1	< 1	< 1
#charge amplifiers	no spec.	2	1	1	1
charge (pulse) measurement	no spec.	-	6 bit	6 bit	6 bit
ring transistors (irradiation tolerant)	no spec.	no	yes	yes	yes
substrate resistance [Ω cm]	no spec.	≈ 20	$\approx 20, 80, 200$	≈ 20	≈ 80

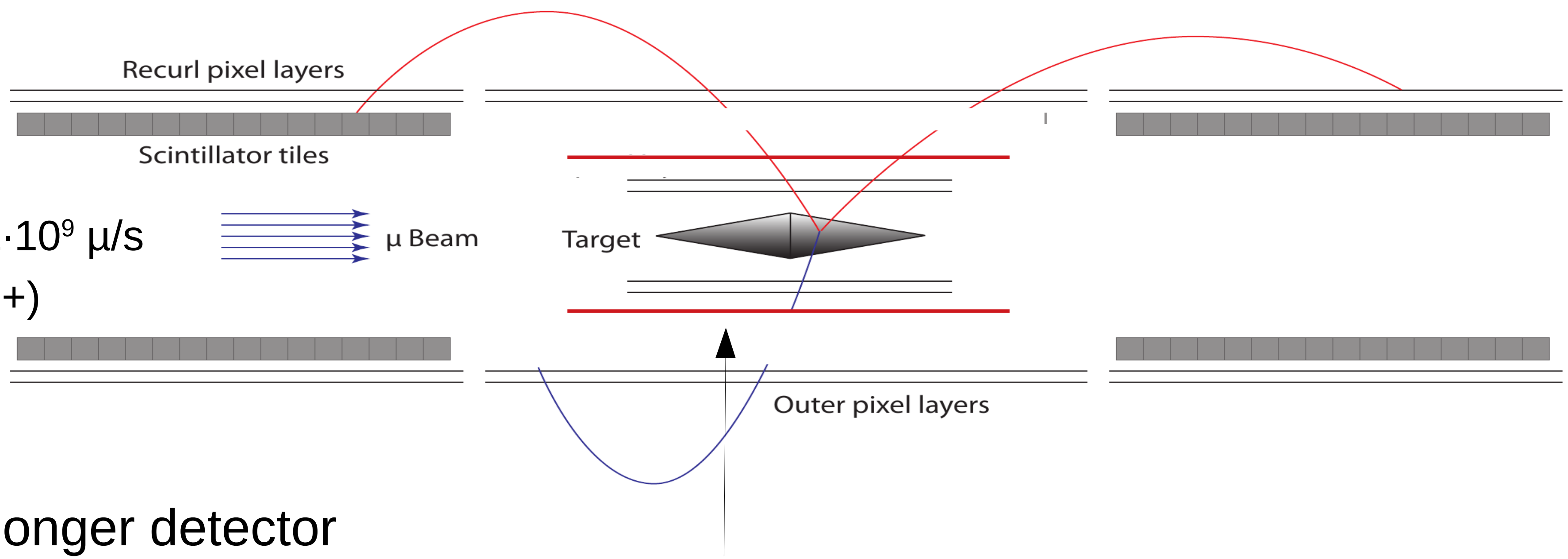
preliminary

Mu3e Phase II

Phase I: 10^8 μ/s



Phase II: $2 \cdot 10^9$ μ/s
(year 2025+)

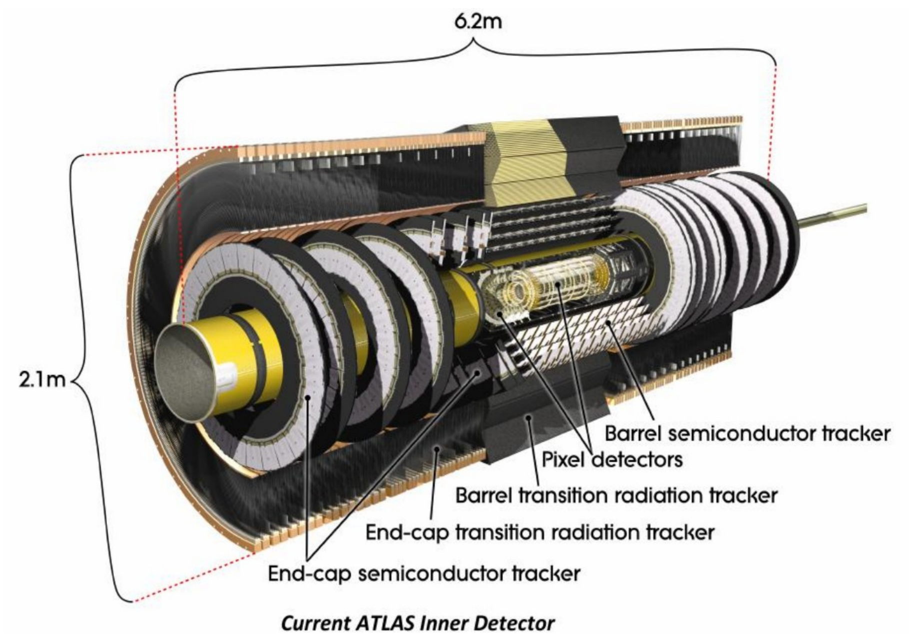


- longer detector
- replace scintillating fibers by ultra-fast pixel (~100ps)

HV-MAPS Project

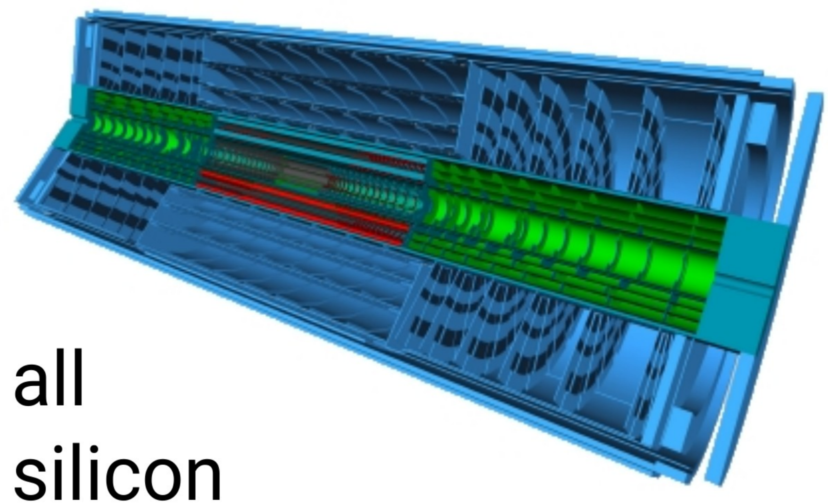
- 2015-2018: BMBF funding for HV-MAPS ~ 360k€ (together Ivan Peric, KIT)
- Goal: “Generic” R&D for HV-MAPS
- characterisation of HV-MAPS prototypes in the lab and using test beams (e.g. 2018: 8 weeks)
- several irradiation campaigns for ATLASpix (and Mupix7)
- later R&D for ATLASpix demonstrator chip (→PhD topic of Adrian Herkert)
- TCAD simulations of HV-MAPS (→PhD topic of Anni Meneses)
- study of new track trigger concepts based on monolithic pixel sensors (→PhD topic of Tamasi Kar)

ATLAS High Luminosity Tracker (ITK)



Current ATLAS Inner Detector

→



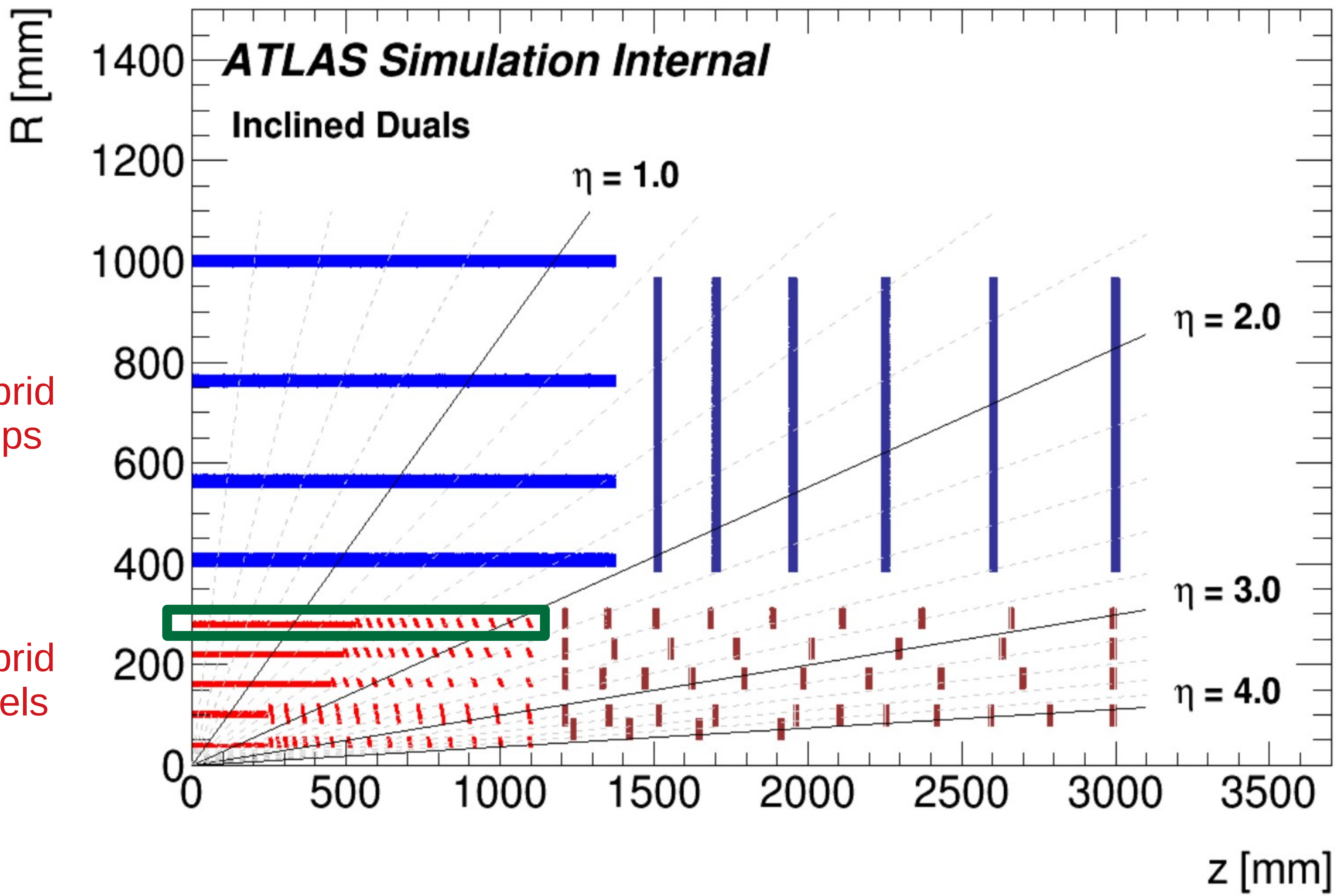
all silicon

- increase luminosity to 5-7·10^{34} $cm^{-2}s^{-1}$
- high pile-up (<μ> ≈ 200)
  - → higher data rates
  - → more radiation damage

ATALS CMOS project

hybrid strips

hybrid pixels



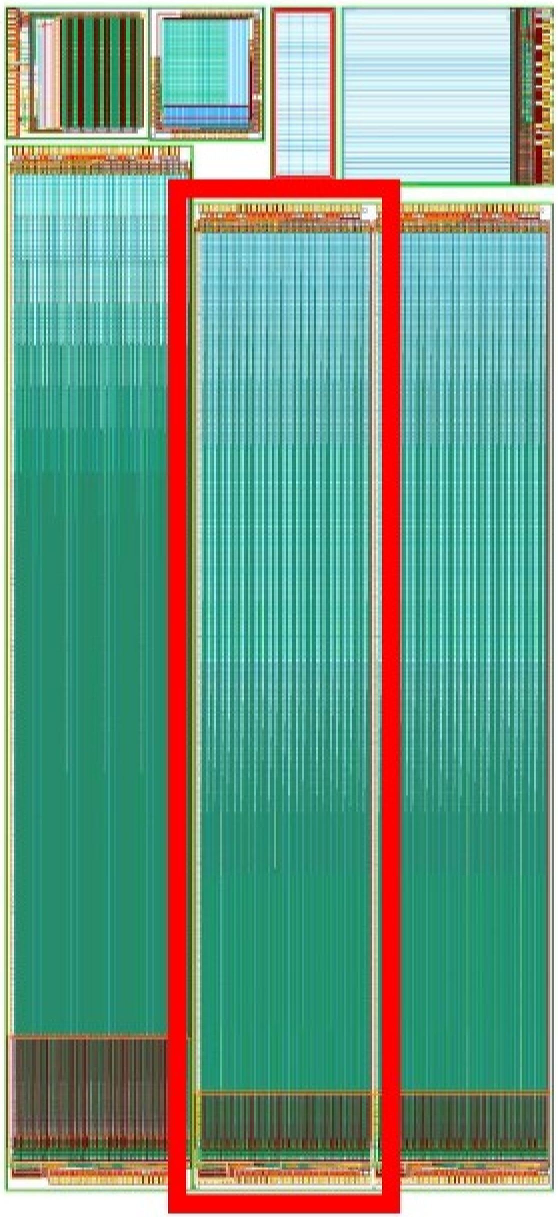
CMOS group proposal: replace **hybrid** pixels in **outer (fifth) pixel barrel layer** with **monolithic** CMOS sensors → our preference **HV-MAPS**

Characterization of ATLASpix1

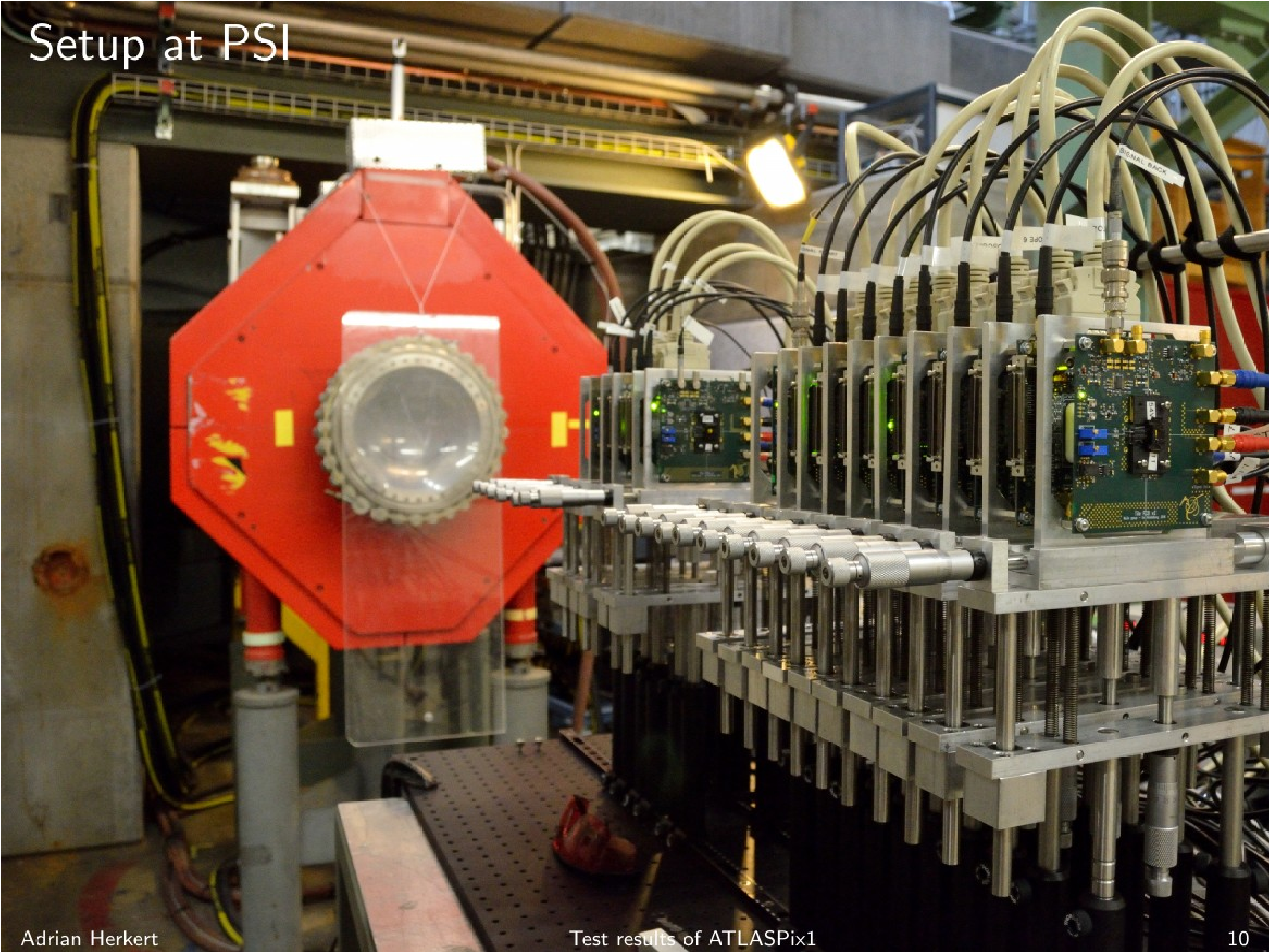
- 25 x 400 pixel
- 130 x 40 µm^2

$\rightarrow$ 3.25 x 16 mm^2 active area

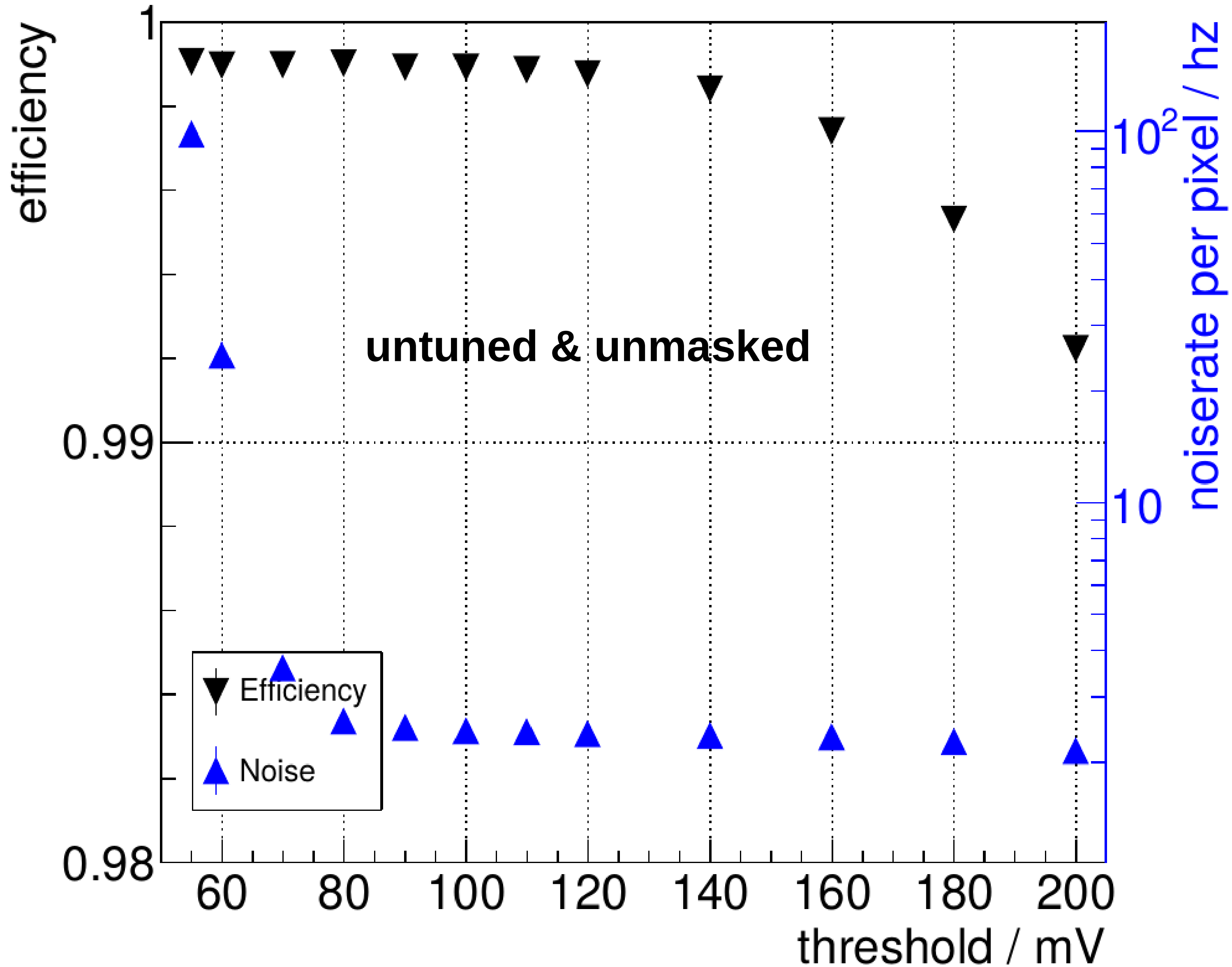
- Amplifier and comparator in pixel
- 10 bit hit timestamp
- 6 bit ToT information
- 3 tune bits
  (not used so far)
- 1 masking bit
- Column drain readout



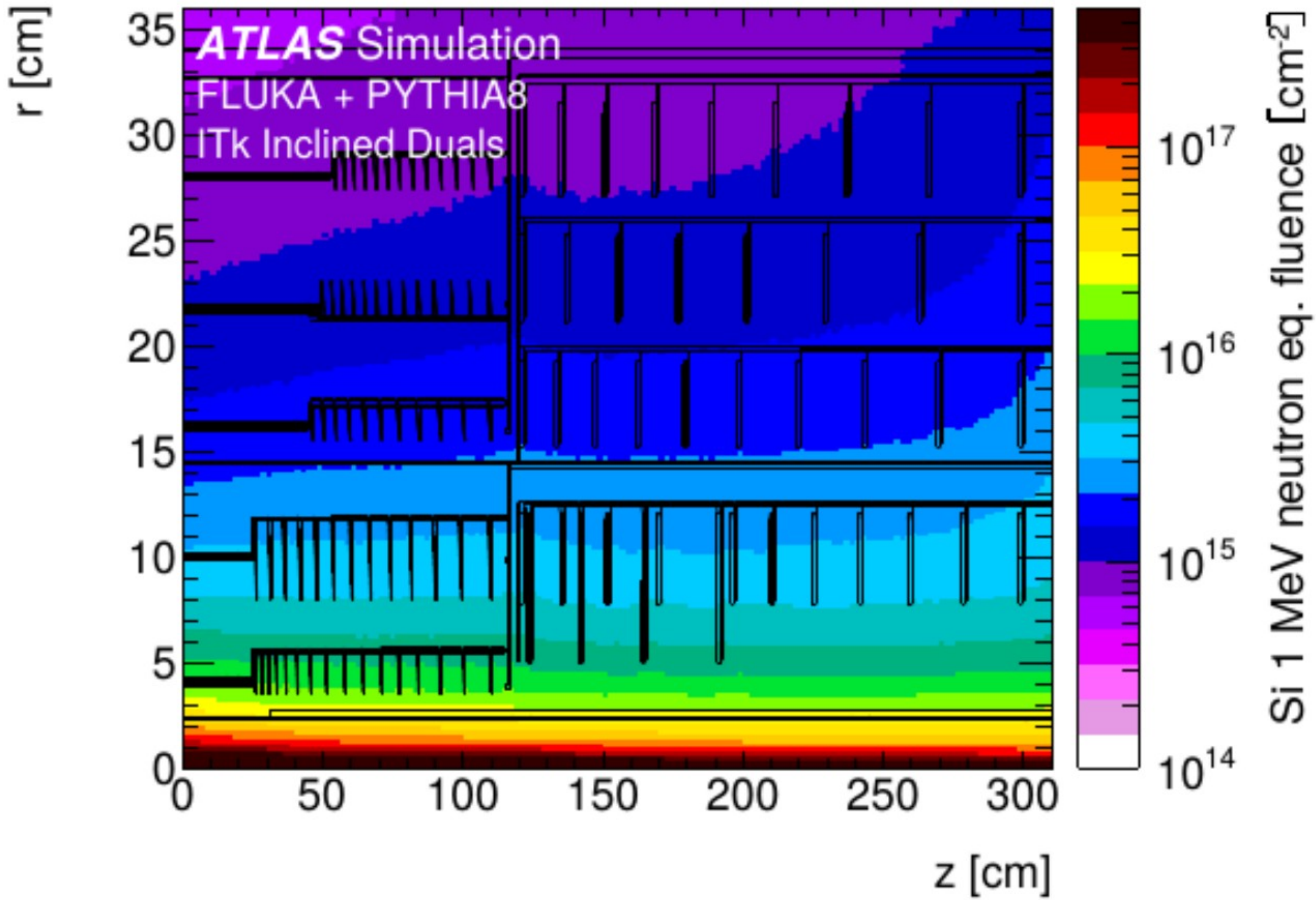
Setup at PSI



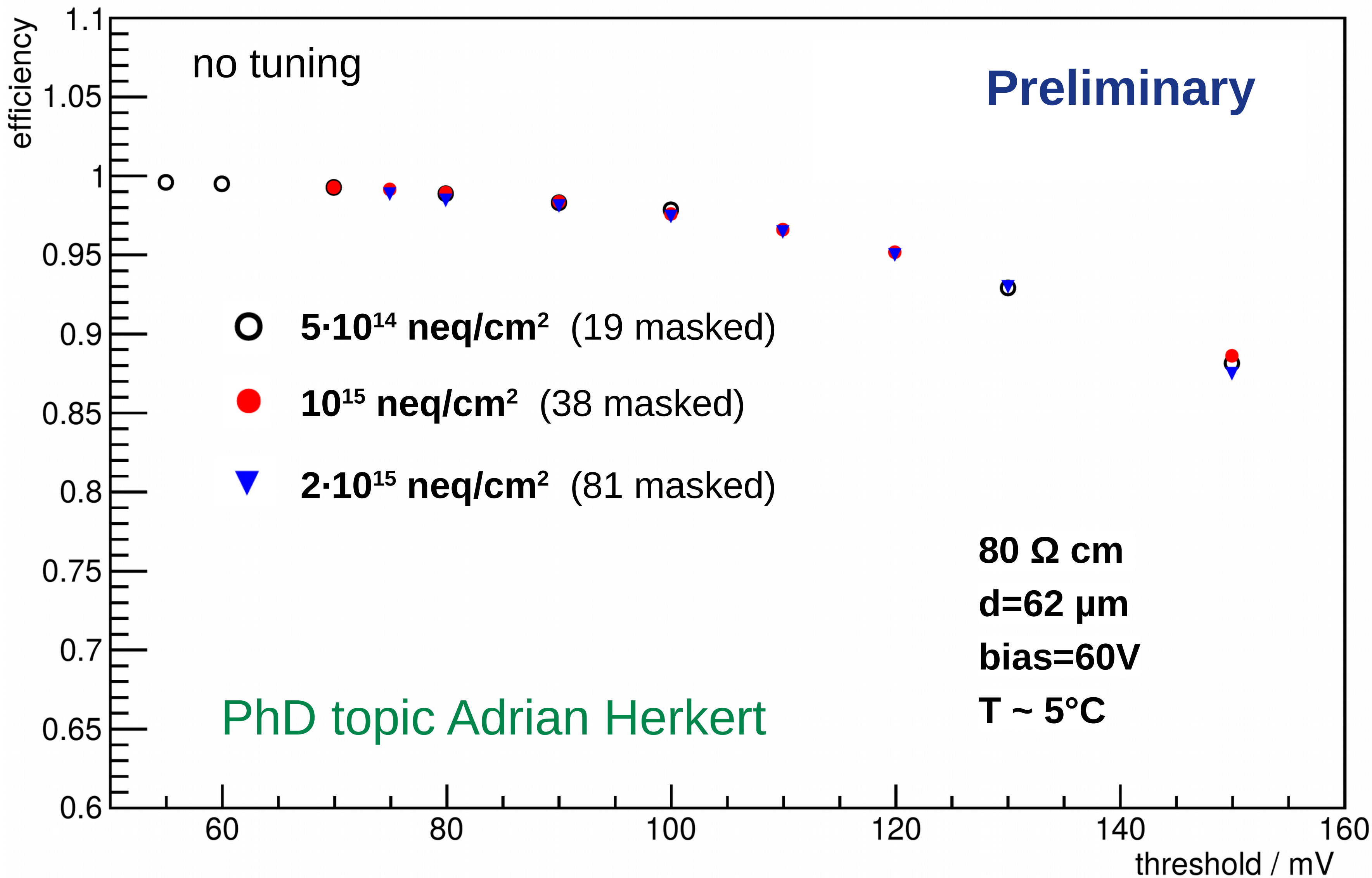
ATLASpix Performance



ITK fluence map



Neutron Irradiated 80 Ωcm Sensors @ 60V



- efficiency (charge collection) does not depend on fluence!

Summary of Efficiencies after Irradiation

- no tuning of pixels;   ≤ 81/10000 pixel masked

Efficiency$_{40\ Hz}$	**sub-strate**	**thick-ness**	**bias voltage (#masked pixel)**			
fluence (neq/cm²)	**(Ω cm)**	**(µm)**	**60 V**	**70/75 V**	**80/85 V**	**90/95 V**
n 2e15	**80**	**62**	**98.5% (81)**	**98.4% (81)**	**98.6% (81)**	
n 1e15	**80**	**62**	**99.3% (38)**		**99.5% (38)**	**99.5% (39)**
n 5e14	**80**	**62**	**99.5% (19)**			
n 2e15	**200**	**100**	**96.5% (55)**		**98.7% (60)**	**98.7% (55)**
n 1e15	**200**	**100/725**	**98.7% (18)**	**99.4%**	**99.5%**	**99.4%**
n 5e14	**200**	**100**	**99.2% (14)**			
p 5e14 (50 MRad)	**200**	**100**	**≥ 99.6% (9)**	**≥ 99.7% (9)**	**≥ 99.9% (9)**	
p 1e14 (10 MRad biased)	**200**	**725**	**≥ 99.7%**			

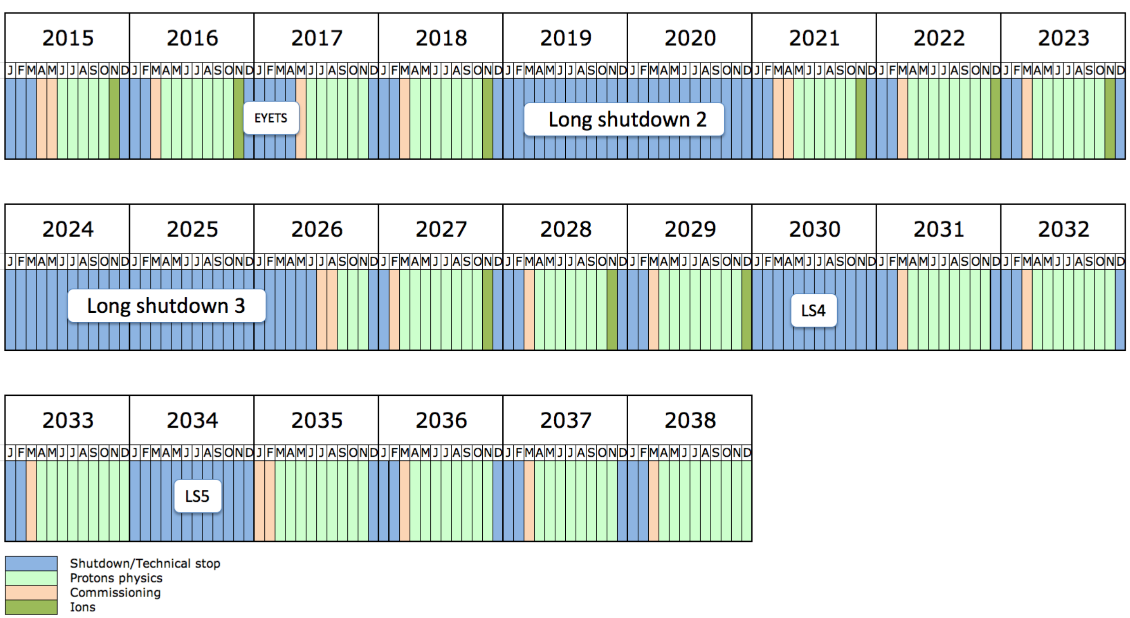
≥ means that the 40 Hz/pixel noise limit was not reached

HD-Plans for ATLAS ITK

- Contribute further to ATLASpix demonstrator → production readiness
- Could also help in characterization of prototype modules

Then turn to future projects

- ATLAS vertex detector in CMOS?
- High Energy LHC (HE-LHC), FCC → higher radiation ($10^{16\text{-}17}$)



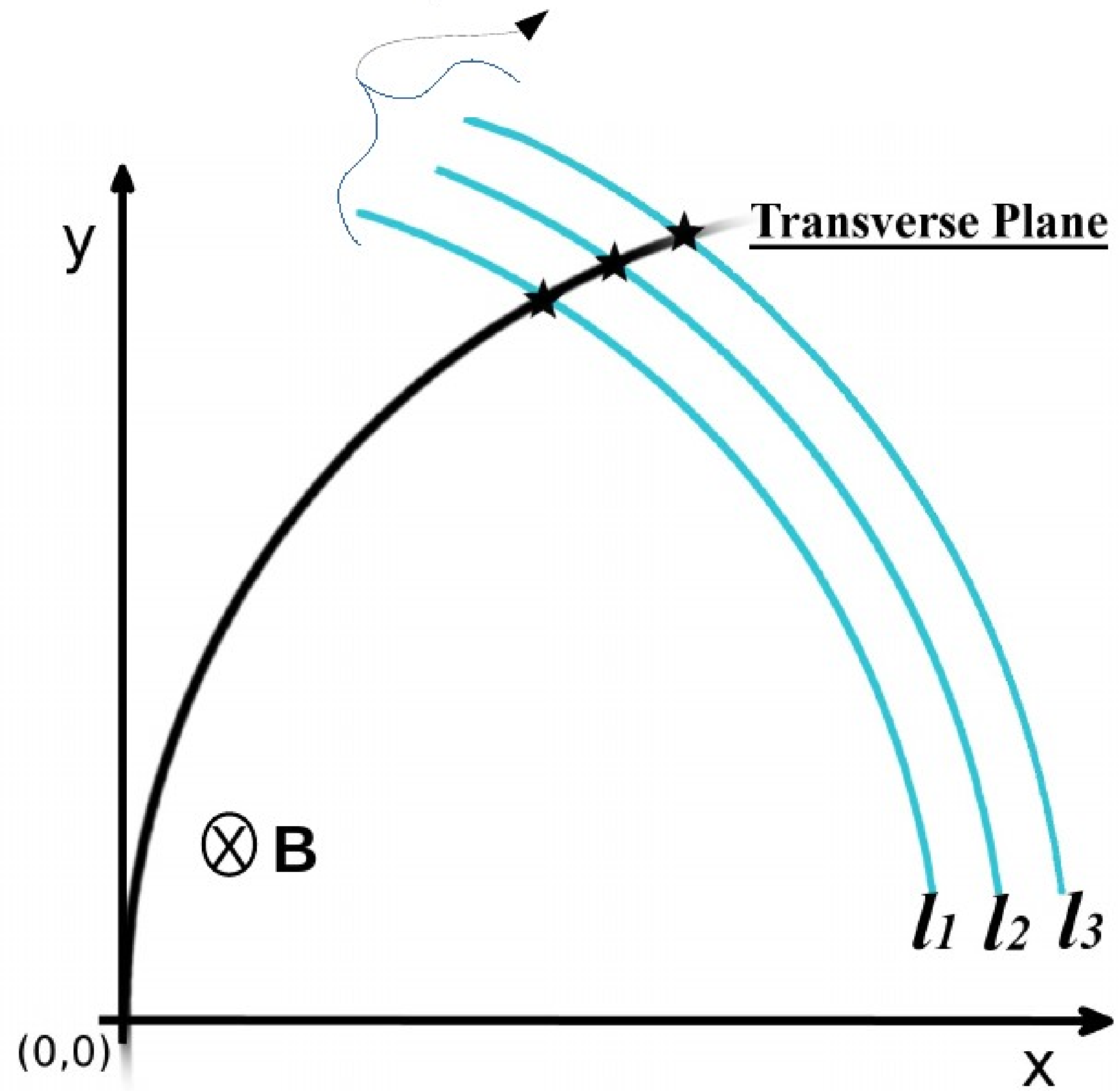
New Ideas

Triplet Track Trigger : Concept

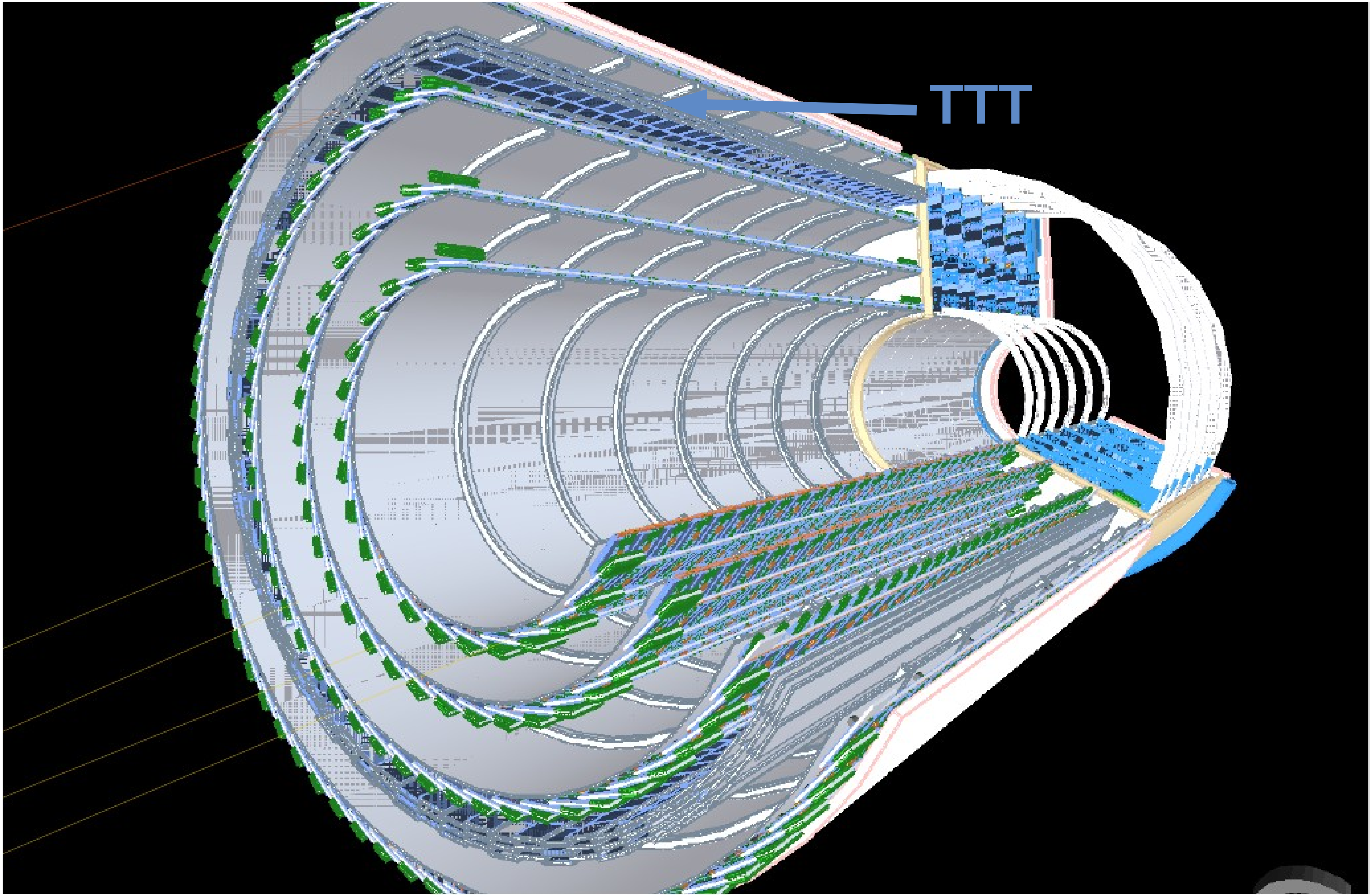
- Three closely stacked detector layers at large radii → Triplet
- Uniform magnetic field B along the axis of the detector layers (Z axis)
- Particle propagates in a helical trajectory in B
- Circular trajectory (X – Y plane)

Why large radii?
→ Large lever arm → $\frac{\sigma_{pt}}{p_t} \propto \frac{1}{L}$

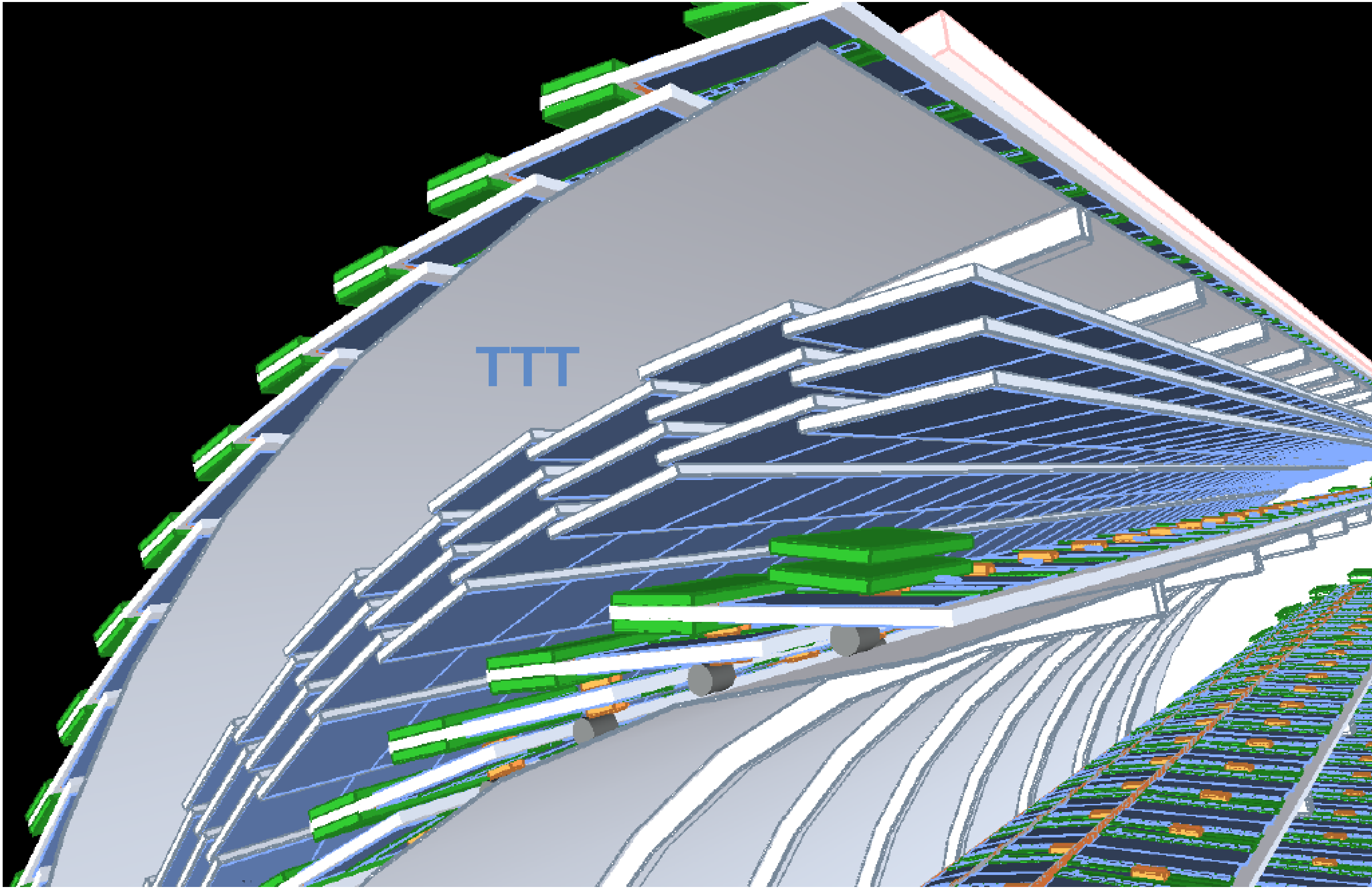
PhD topic Tamasi Kar



ATLAS with TTT



ATLAS with TTT

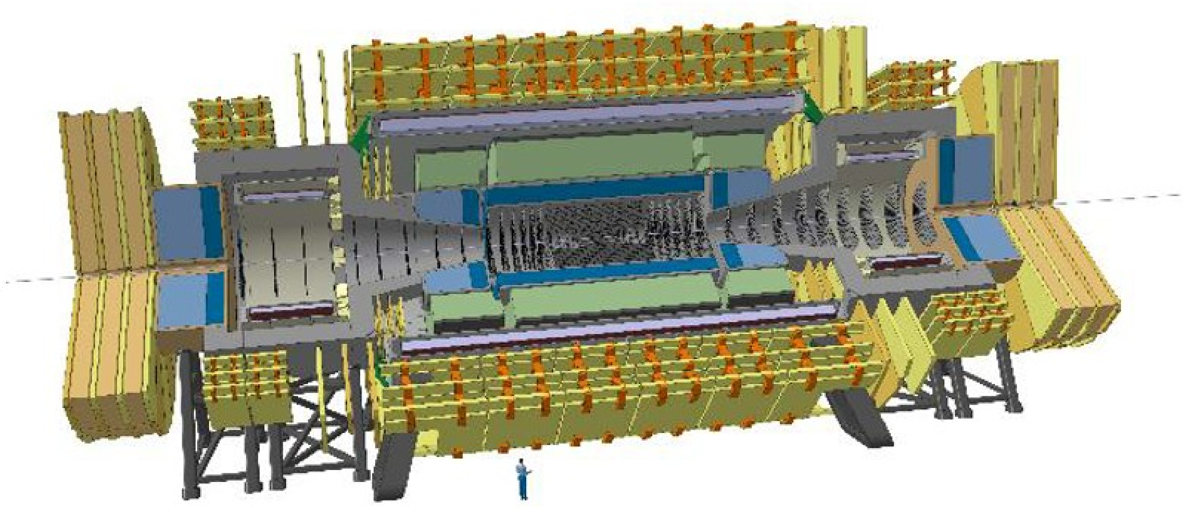


Triplet Track Trigger for FCC-hh

Results obtained so far from fast and detailed simulations are very promising!

- Significant reduction of pile-up possible on trigger level
- Requires fast and radiation hard CMOS sensor

Similar studies have been started for a possible FCC-hh detector!



Summary

Heidelberg is devoted to the development of new tracking

- detectors (sensors)
- concepts
- fast reconstruction methods (trigger)

Tracking detectors (pixel sensors) are essential for future particle physics projects to fulfill requirements on:

- precision (spatial&timing resolution)
- rate capabilities
- radiation hardness

Synergies might also be expected from some applications

- beam telescopes
- radiation therapy, …

Currently, we consider HV-MAPS as the most promising technology (concept) for many future projects