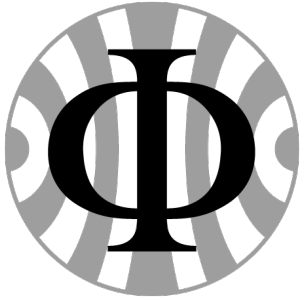
On the Path to Module Integration with the HV-MAPS prototype MuPix9

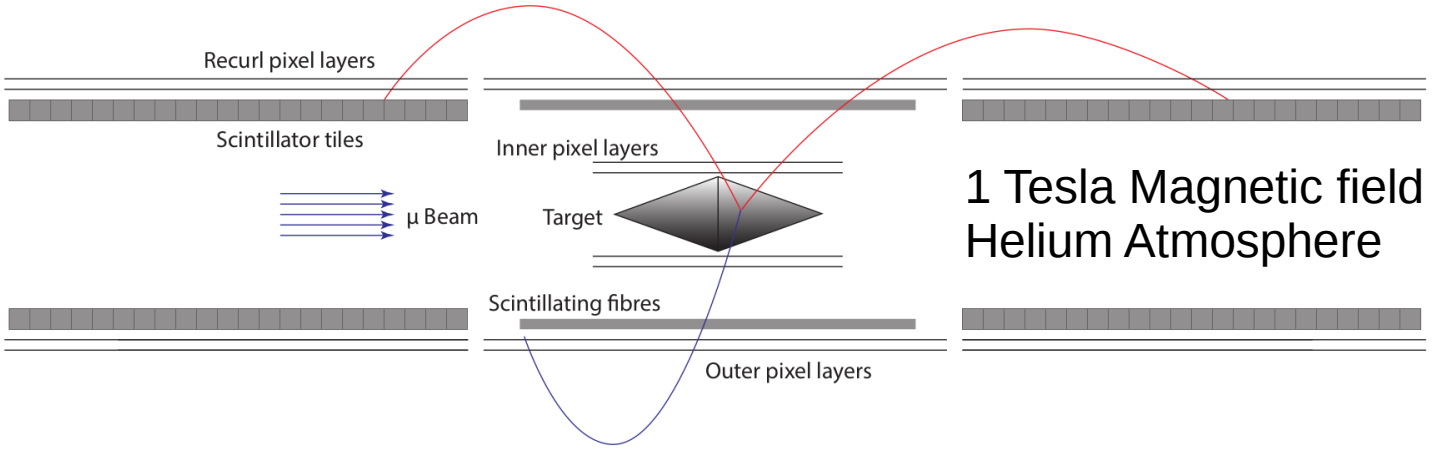


Heiko Augustin*, Alena Weber and Ivan Perić for the Mu3e Collaboration

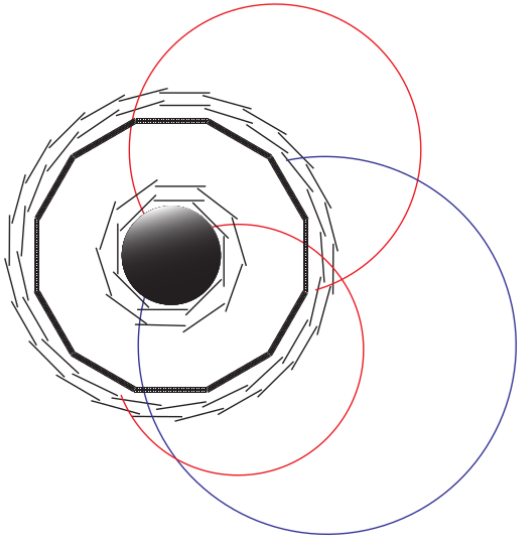
DPG Spring conference 2019 – Aachen

26.03.2019

The Mu3e Detector



1 Tesla Magnetic field
Helium Atmosphere



- Search for $\mu^+ \rightarrow e^+e^-e^+$
- 10^9 decays per second
- $p_{max} = m_\mu/2$

➔ Multiple Coulomb Scattering

- Good vertex and time resolution (100 μm & 500 ps)
- Good momentum resolution (0.5 MeV)

The Mu3e Detector

Pixel detector requirements:

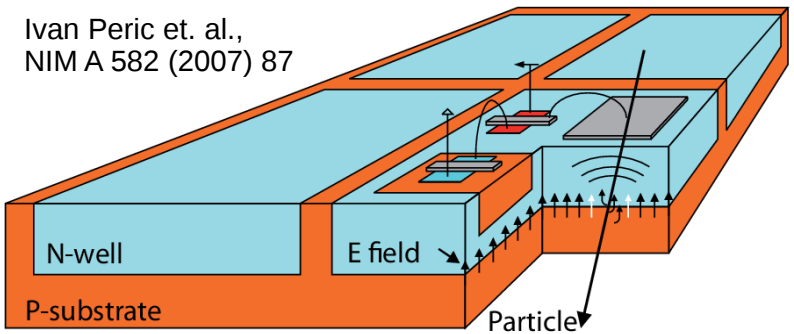
Pixel Size	Time Resolution	Material Budget	Efficiency
80 x 80 μm^2	< 20 ns	0.1% X_0/layer	> 99 %

- Search for $\mu^+ \rightarrow e^+e^-e^+$
- 10^9 decays per second
- $p_{max} = m_\mu/2$

➔ Multiple Coulomb Scattering

- Good vertex and time resolution (100 µm & 500 ps)
- Good momentum resolution (0.5 MeV)

High Voltage - Monolitic Active Pixel Sensors



- Low ohmic substrates (10-200 Ωcm)
- High voltage > 100V
- Deep N-well diode
- ~ 30 µm depletion
- Charge collection via drift

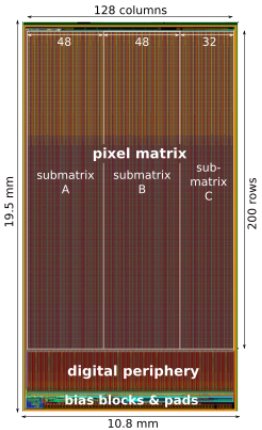
- In-pixel electronics
- Monolithic design:
  Detection and Readout
  combined in one chip
- Commercially available processes:
  AMS 180nm
  TSI 180nm
- Chips are thinned to 50 µm

The Road Map to the Mu3e Pixel Chip

MuPix7

First
fully monolithic
prototype

MuPix8

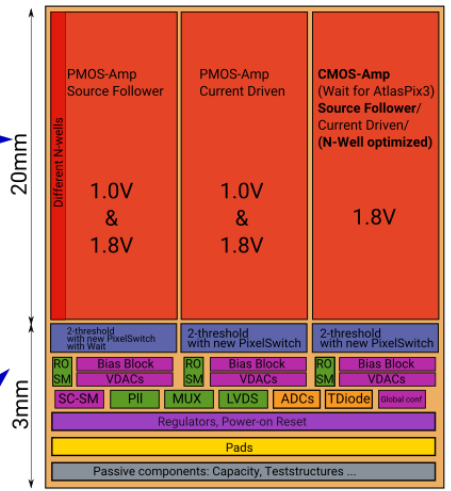


Scalability

MuPix9

Detector Integration

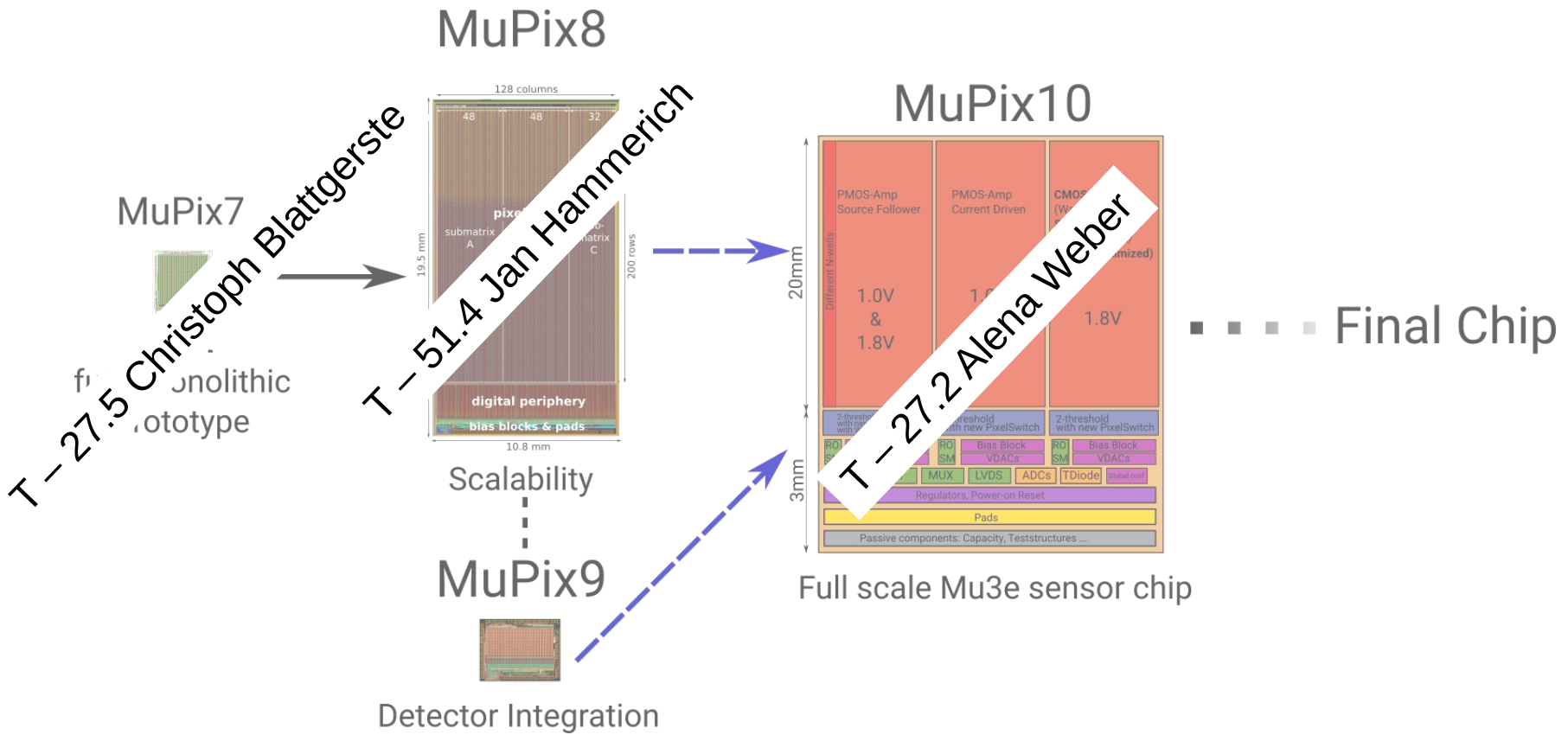
MuPix10



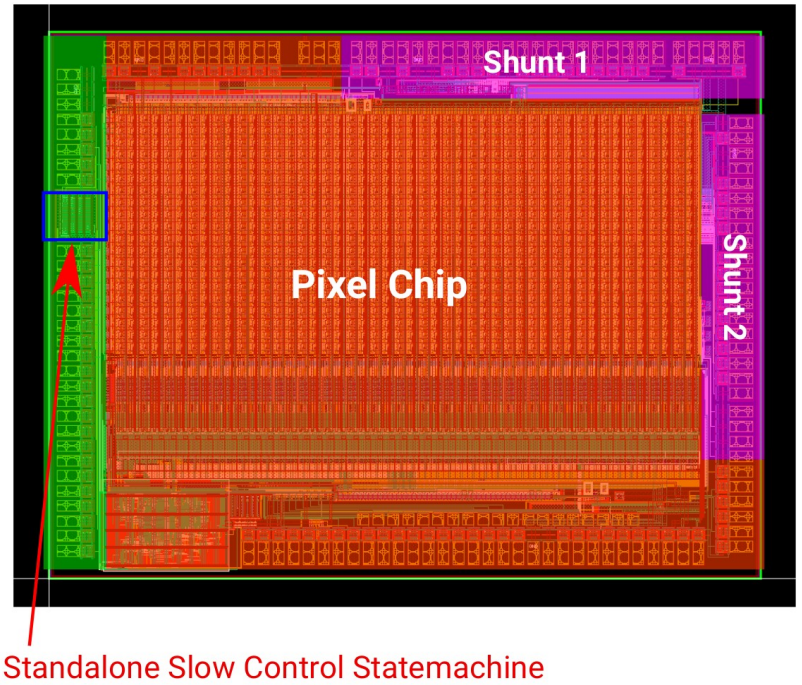
Full scale Mu3e sensor chip

Final Chip

The Road Map to the Mu3e Pixel Chip

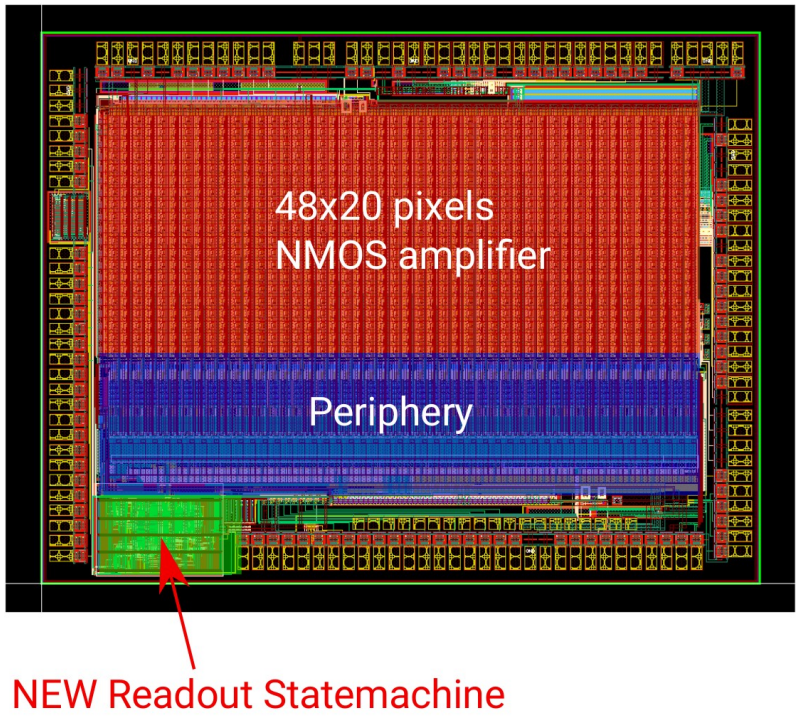


The MuPix9 Chip



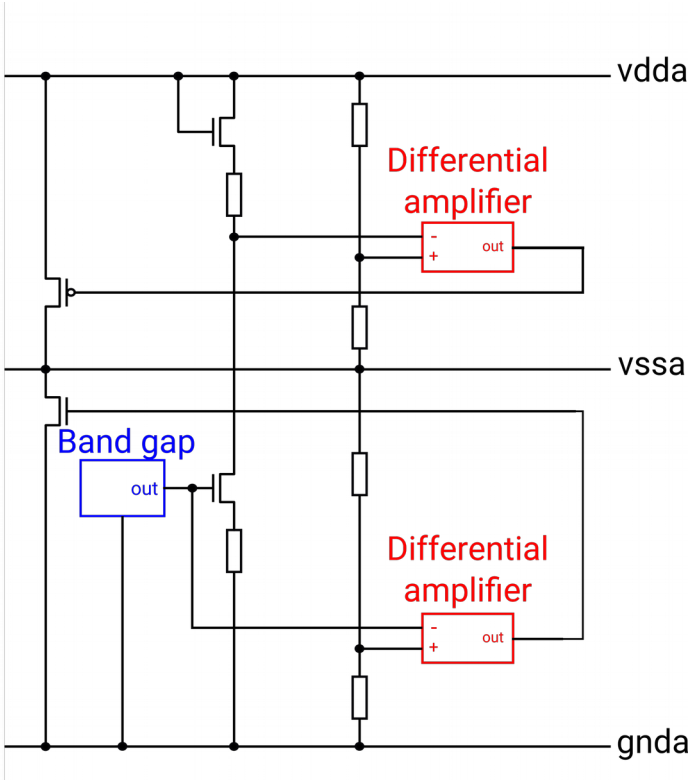
- AMS aH18 (MPW)
- 20 Ωcm substrate
- Test of new NMOS in-pixel amplifier
- Test of serial powering infrastructure:
  shunt regulator
- Slow control statemachine

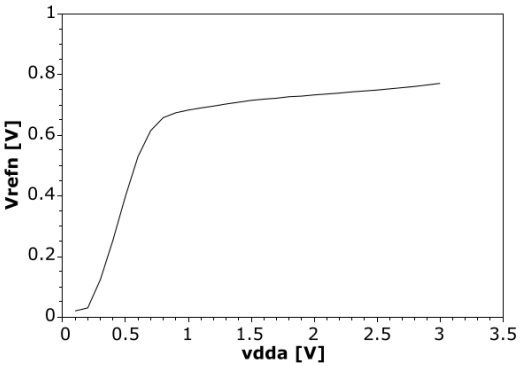
The MuPix9 Chip

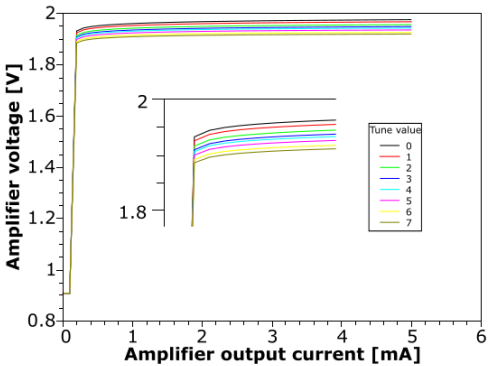


- AMS aH18 (MPW)
- 20 Ωcm substrate
- Test of new NMOS in-pixel amplifier
- Test of serial powering infrastructure:
  shunt regulator
- Slow control statemachine

Shunt-Regulator

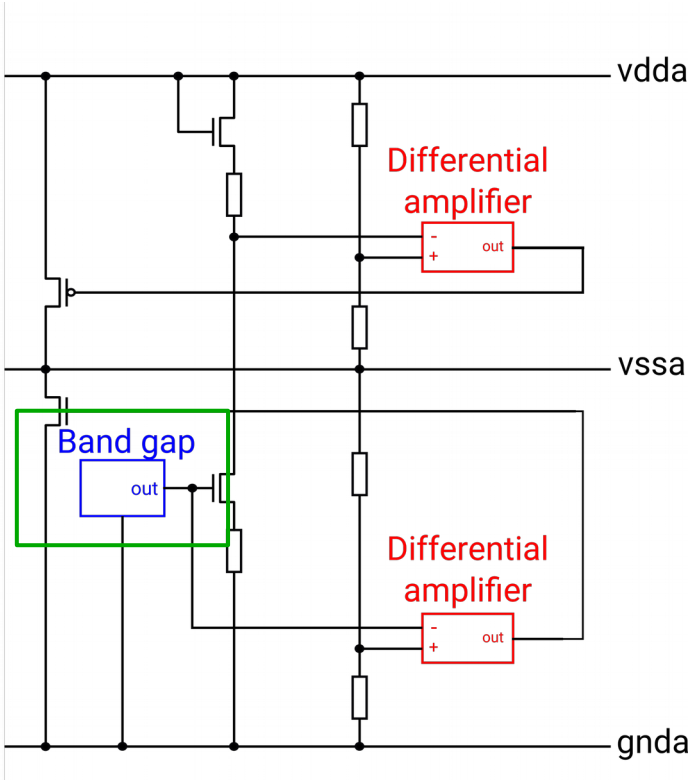


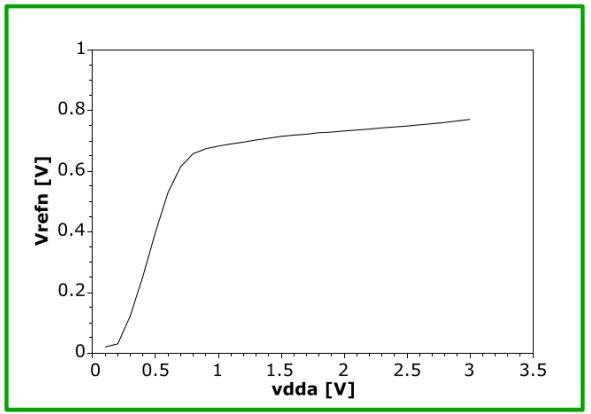


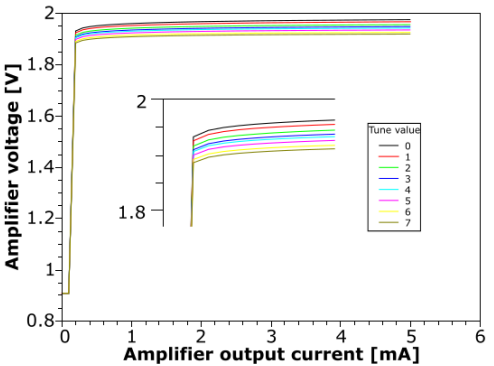


- Bandgap and differential amplifer are functional
- PMOS shunt transistor is not working
- A new fully re-worked version is submitted

Shunt-Regulator

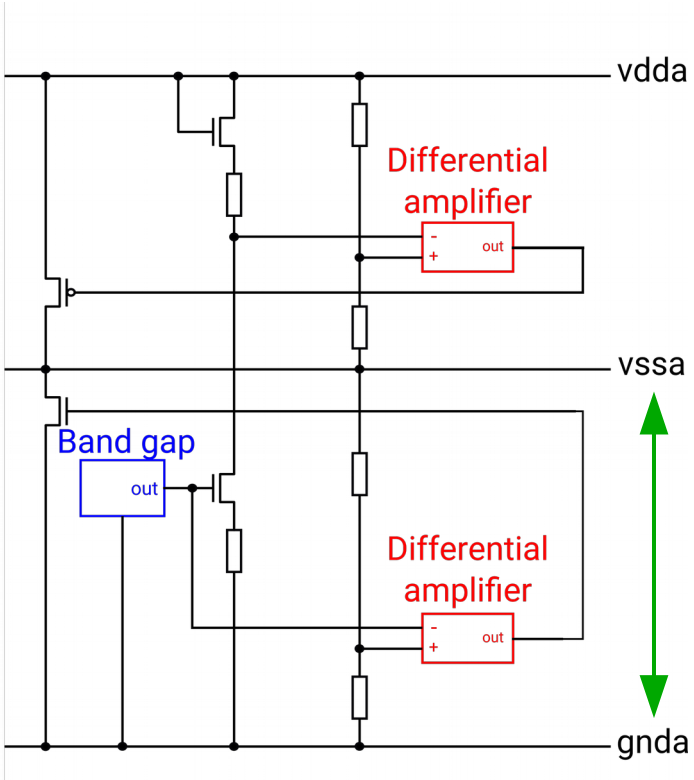


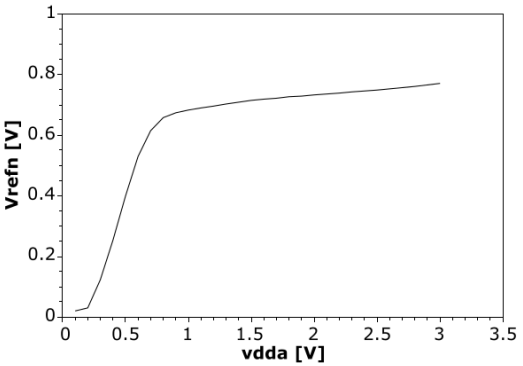


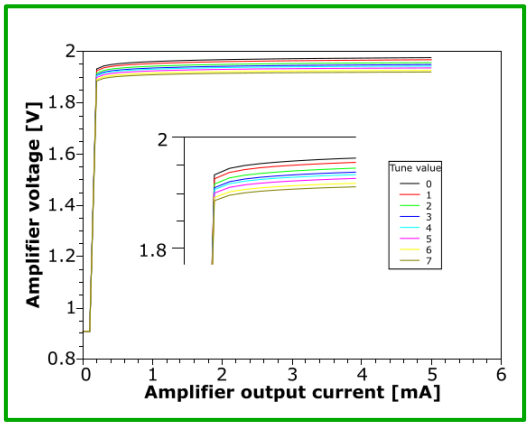


- Bandgap and differential amplifer are functional
- PMOS shunt transistor is not working
- A new fully re-worked version is submitted

Shunt-Regulator

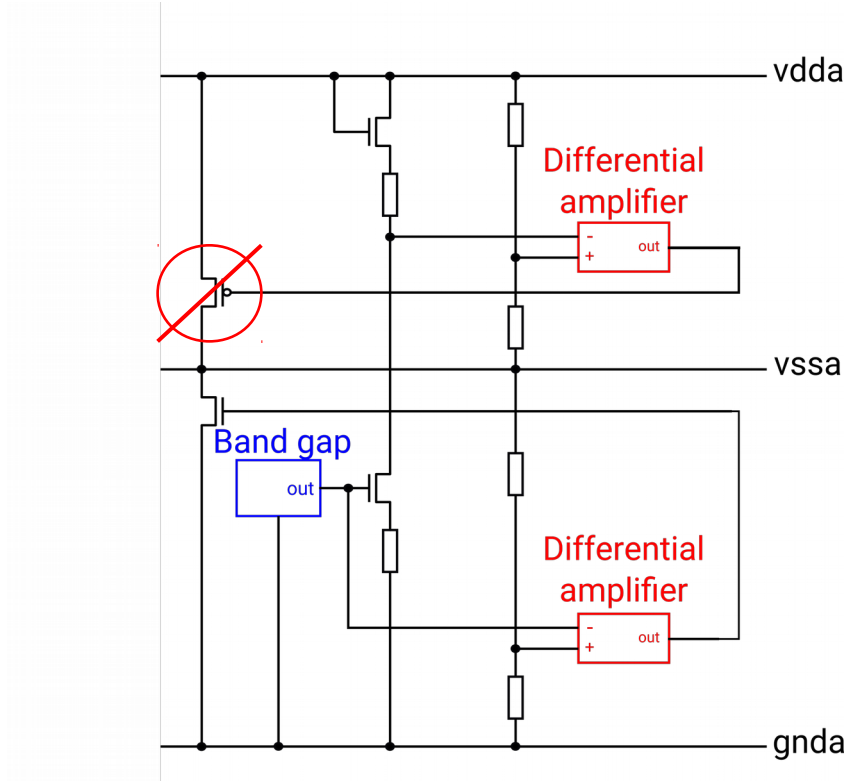


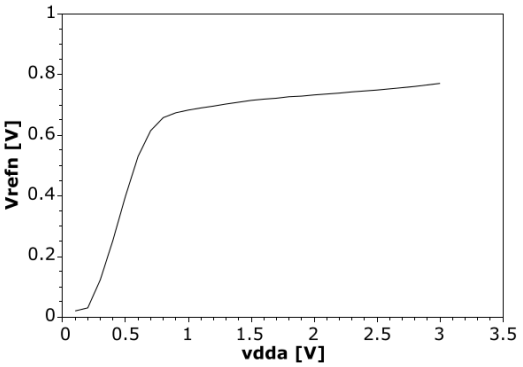


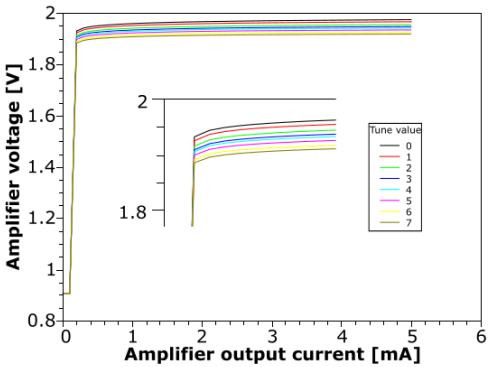


- Bandgap and differential amplifer are functional
- PMOS shunt transistor is not working
- A new fully re-worked version is submitted

Shunt-Regulator

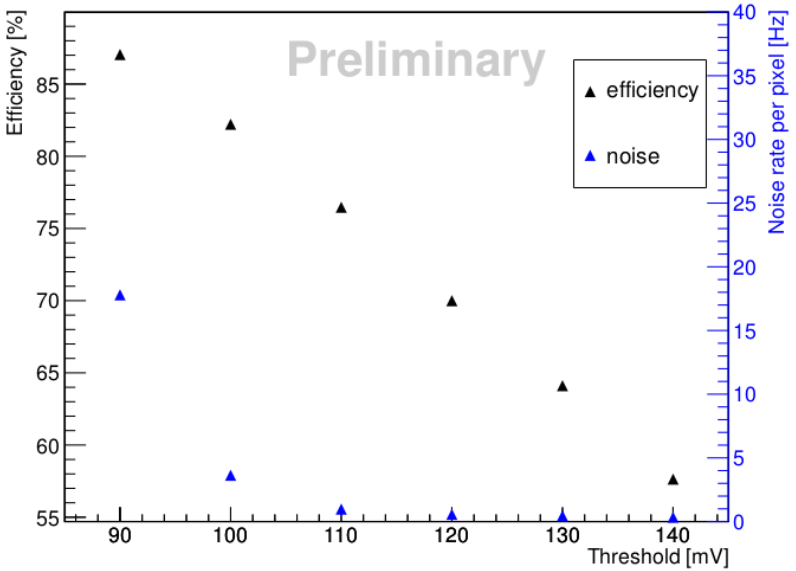






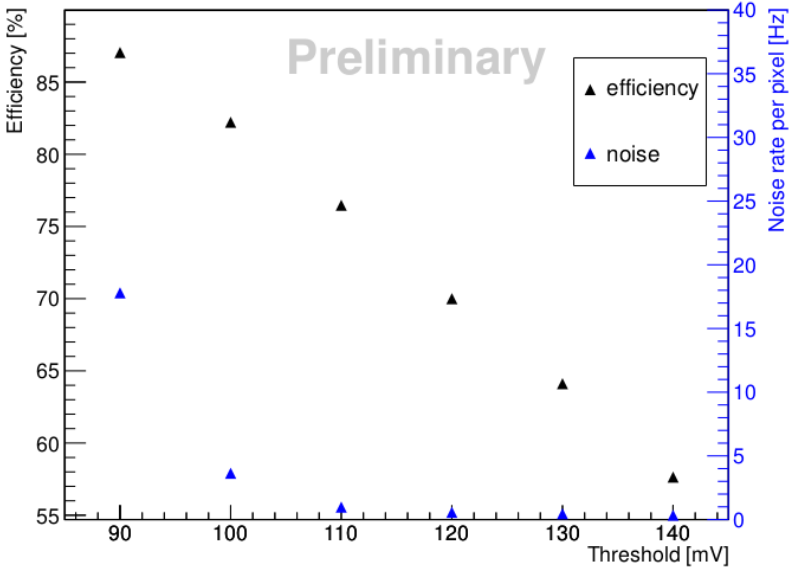
- Bandgap and differential amplifer are functional
- PMOS shunt transistor is not working
- A new fully re-worked version is submitted

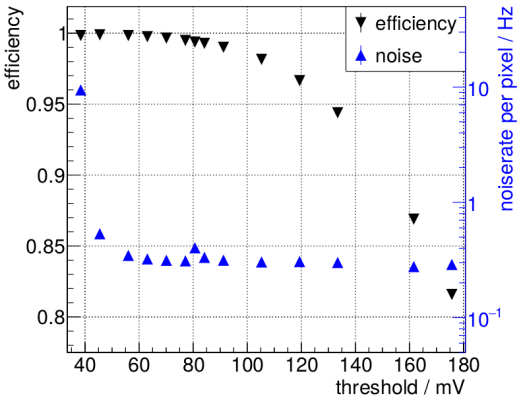
MuPix9 – Pixel Matrix



- Pixel matrix is fully functional
- Breakdown at -60V reverse bias (design -120 V)
- Performance out-of-the-box:
  Time resolution: σ < 9 ns
  Efficiency: ~86 %

MuPix9 – NMOS amplifier



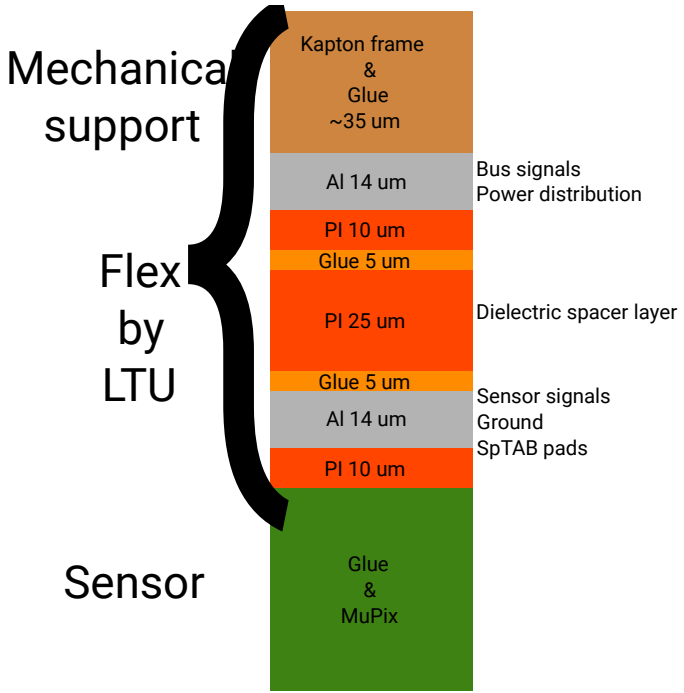


MuPix8
PMOS Amplifer
80 Ωcm

- Efficiency reduced by resistivity 80 → 20 Ωcm
- Limited by noise

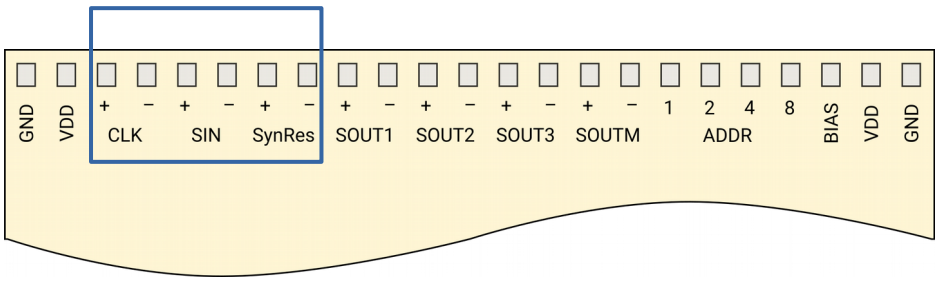
➔ PMOS amplifier is preferred

MuPix9 - Requirements for Module Integration

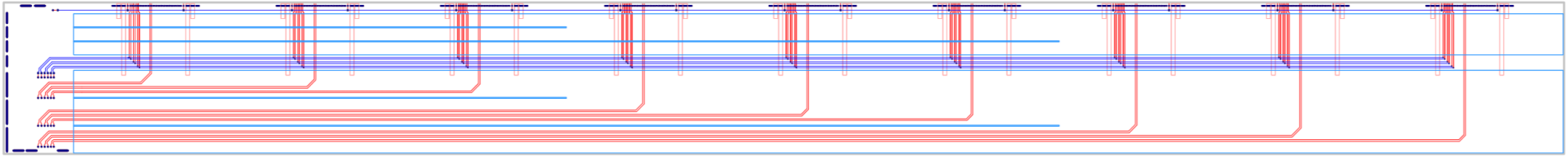


- Ultra-low material design (0.1% X_0)
- Powering, configuration and readout via a 2 layer aluminum flexprint
- Up to 9 chips per flexprint
- Power distribution is challenging → minimisation of per chip signals

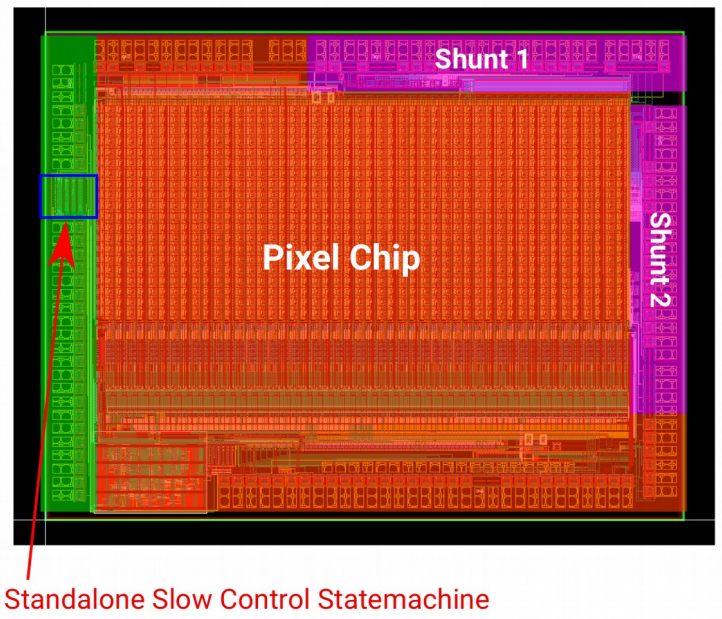
Flexprint Constraints



- 12 differential lines per flexprint
- Use bus for common signals
- ➔ 1 differential bus for slow control (SIN)
- ✖ MuPix8 shift register requires 5 inputs

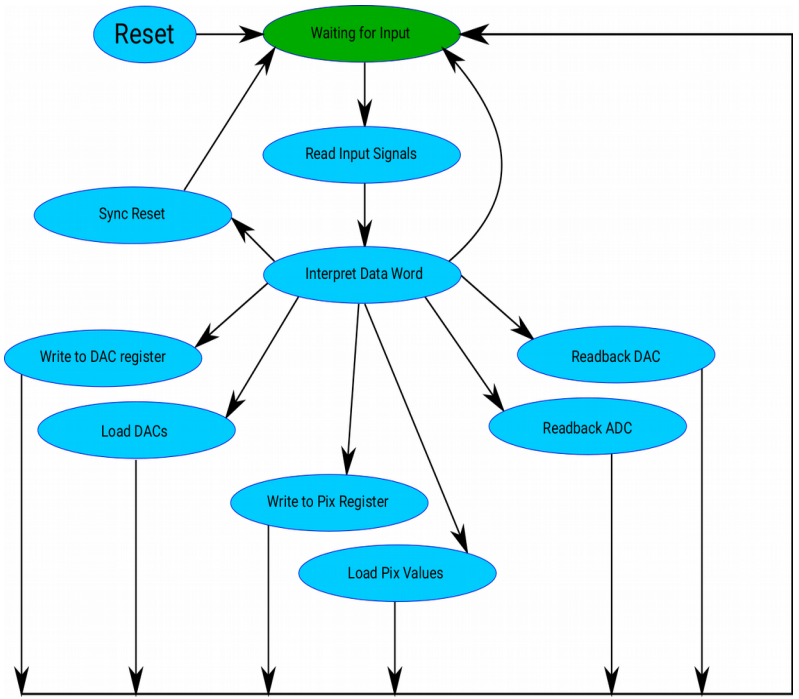


MuPix9 - Slow Control Statemachine

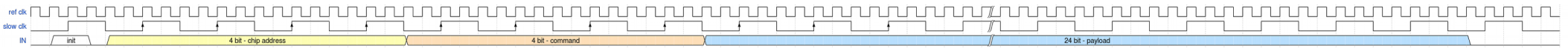


- Synthesized verilog code
- I²C like protocol
- Slow control data parser
- 32 bit data words:
  4 bit chip address (bus)
  4 bit command
  24 bit payload

MuPix9 - Slow Control Statemachine

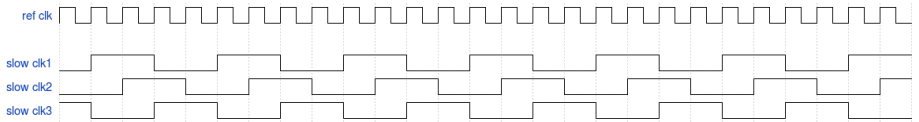


- Synthesized verilog code
- I²C like protocol
- Slow control data parser
- 32 bit data words:
  4 bit chip address (bus)
  4 bit command
  24 bit payload
- Broadcast: synchronous reset

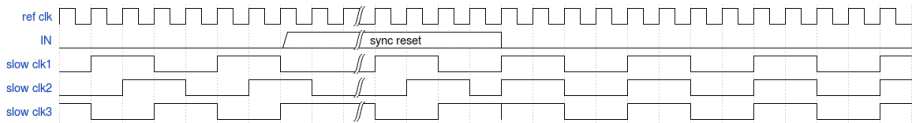


MuPix9 – Synchronous Reset

Power up

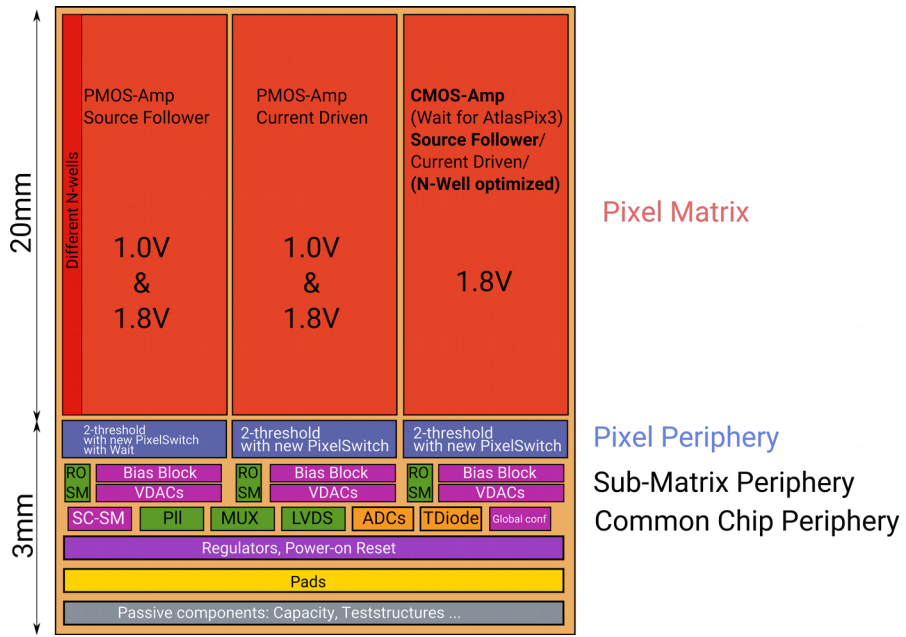


Synchronous reset



- Phase of the state machine clock undefined on power up
- Synchronisation to control FPGA
- Synchronisation of all chips on the bus
- ✔ Successfully tested in the lab

Summary and Outlook

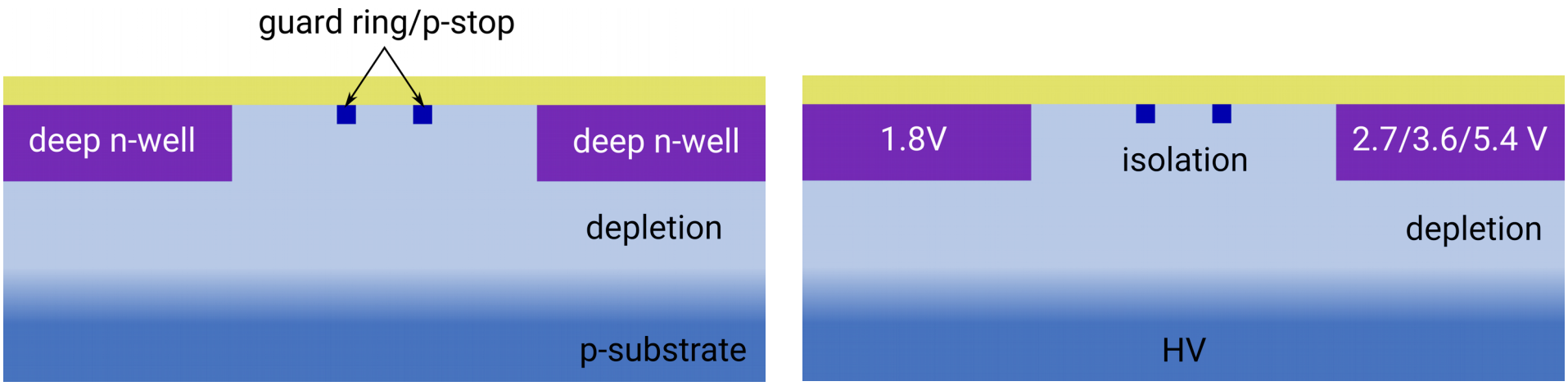


- First step towards module integration
- MuPix9 is in the lab
- ➔ Focus on slow control
- Expansion of the MuPix9 slow control interface:
  - 64 bit input
  - more broadcast commands
- ➔ Crucial input for MuPix10

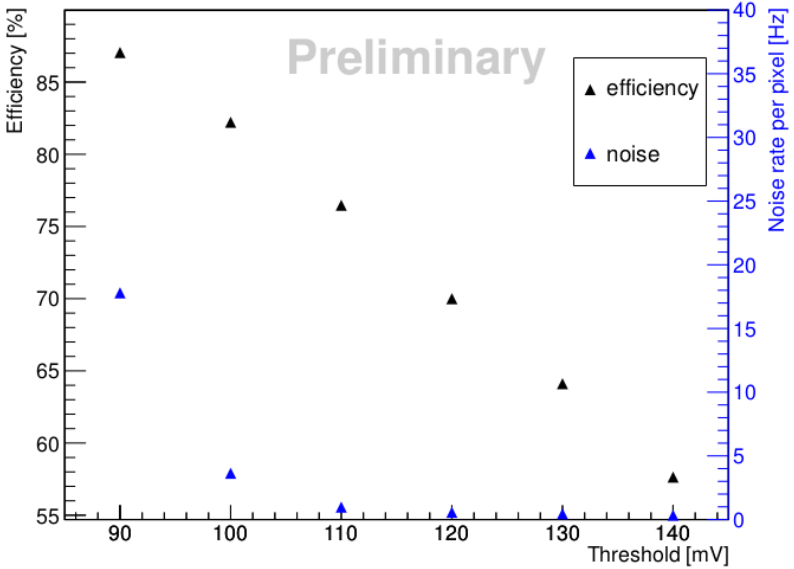
Thank you!

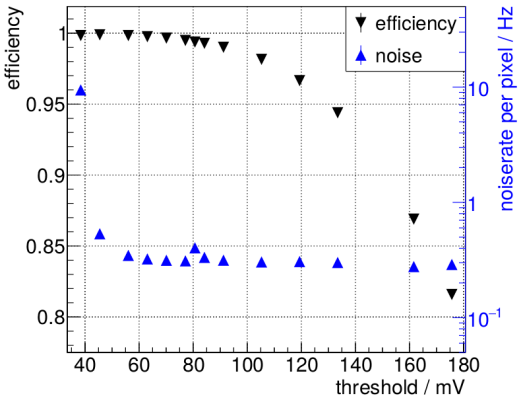
Questions?

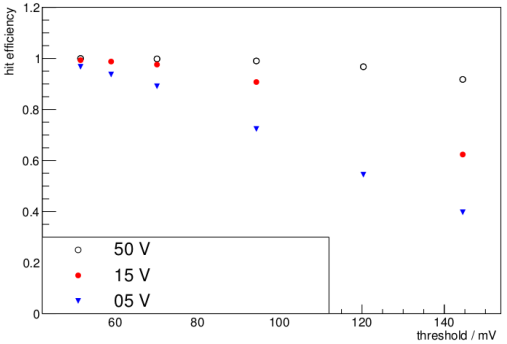
On-chip Power Domains



MuPix9 – NMOS amplifier







- Efficiency reduced by resistivity 20 to 80 Ωcm
- Limited by noise
- ➔ PMOS amplifier is prefered