Qualification of a HV-MAPS produced by TSI

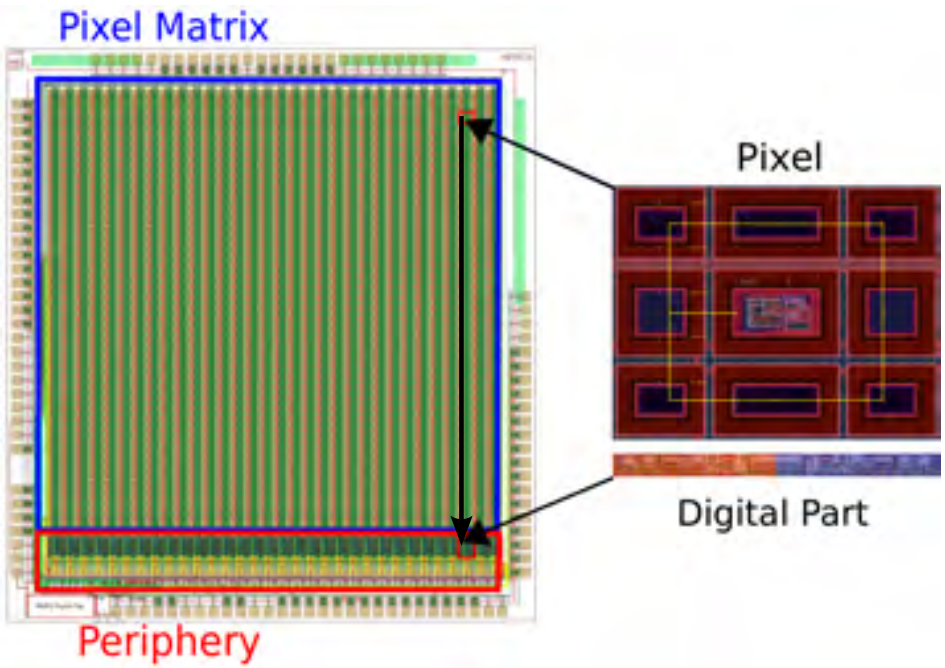
Christoph Blattgerste
for the Mu3e collaboration

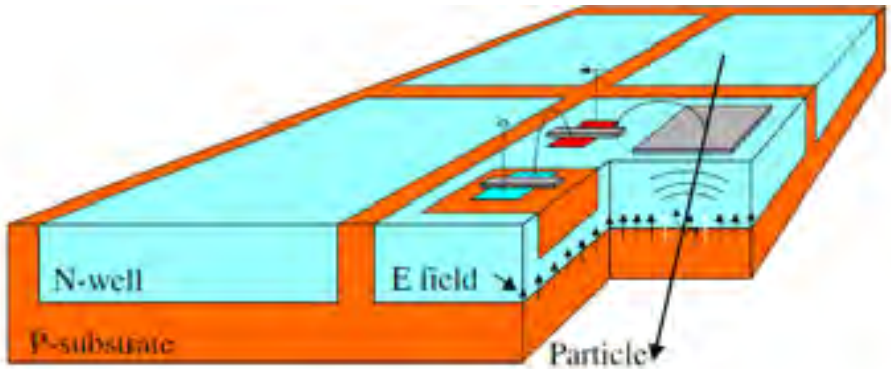
Heidelberg University

26.03.2019

MuPix7

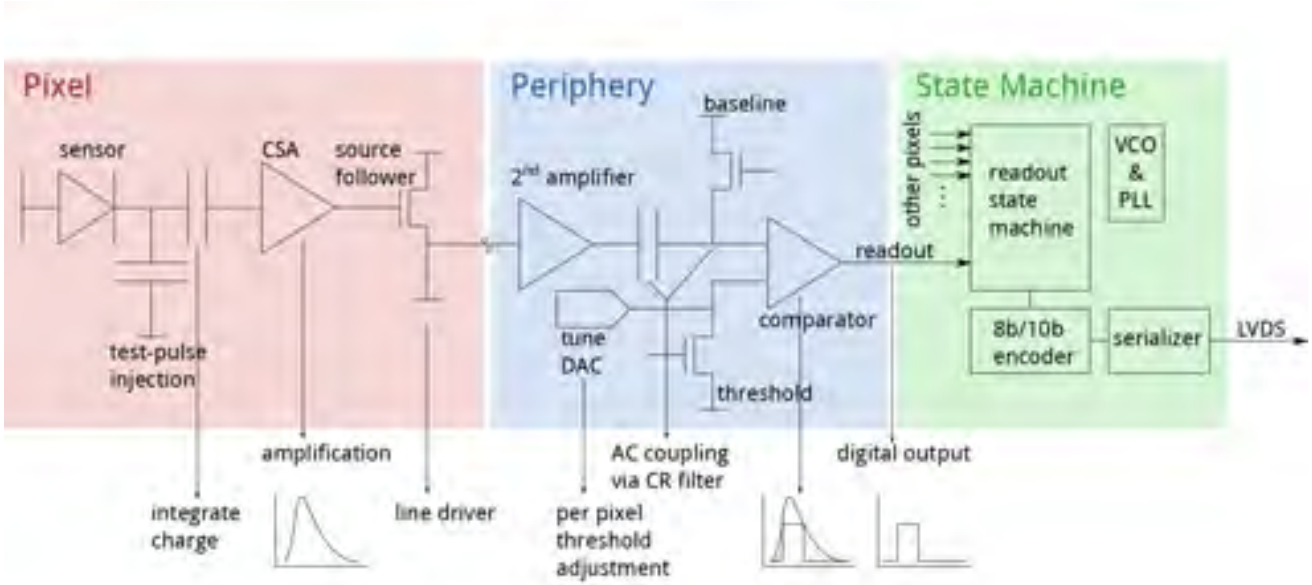
- MuPix7 is first fully monolithic HV-MAPS developed for Mu3e
- Well characterized prototype produced by AMS
- 40×32 pixels with a size of $103 \times 80\,\mu m$





Electronics

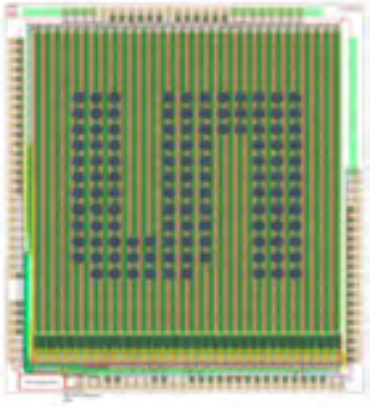
- Amplifier in each pixel
- Conversion analog $\leftrightarrow$ digital at comparator in periphery cell
- Digital electronics and state machine in periphery



Motivation

- AMS process no longer supported & delivery delays

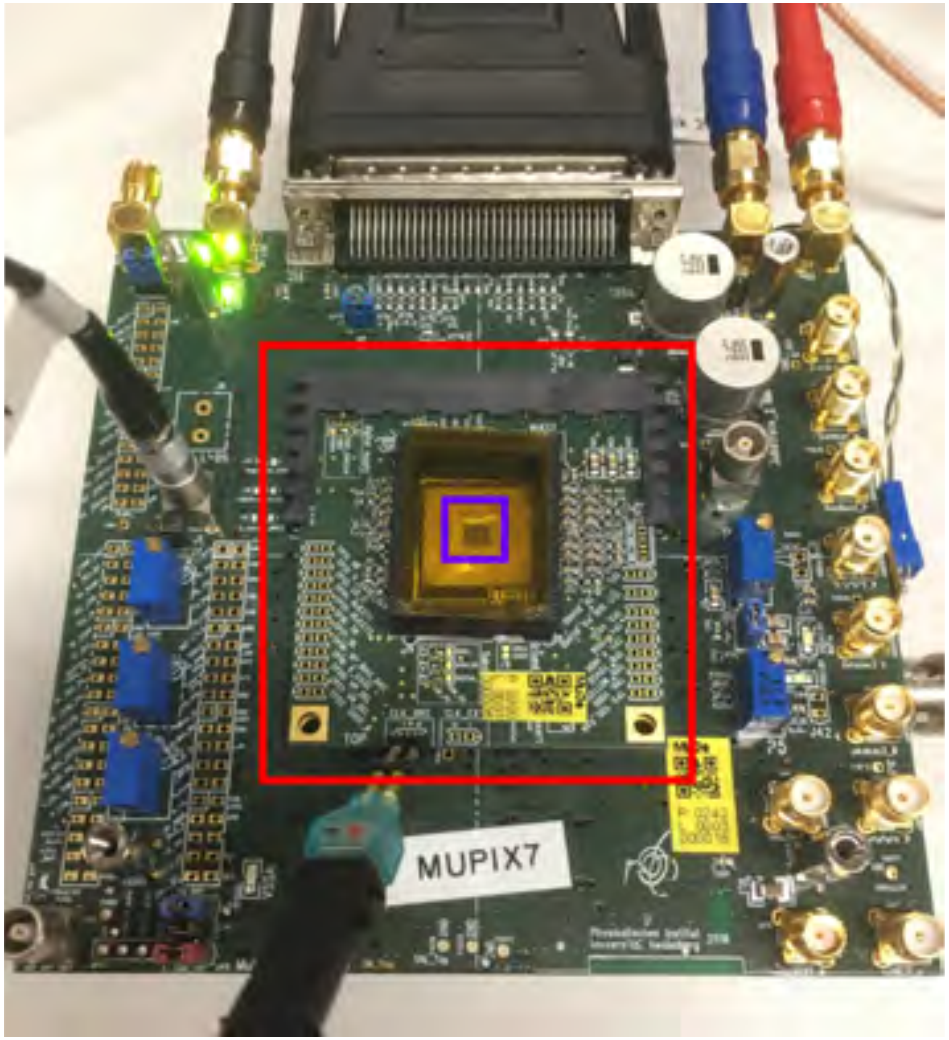
→ Change to TSI HV as manufacturing process?



$\leftrightarrow$

- *AMS H18* and *TSI HV* based on same IBM HV process
- Identical design in 180 *nm* HV-CMOS
- Expect no significant differences between AMS/TSI beside statistical variations

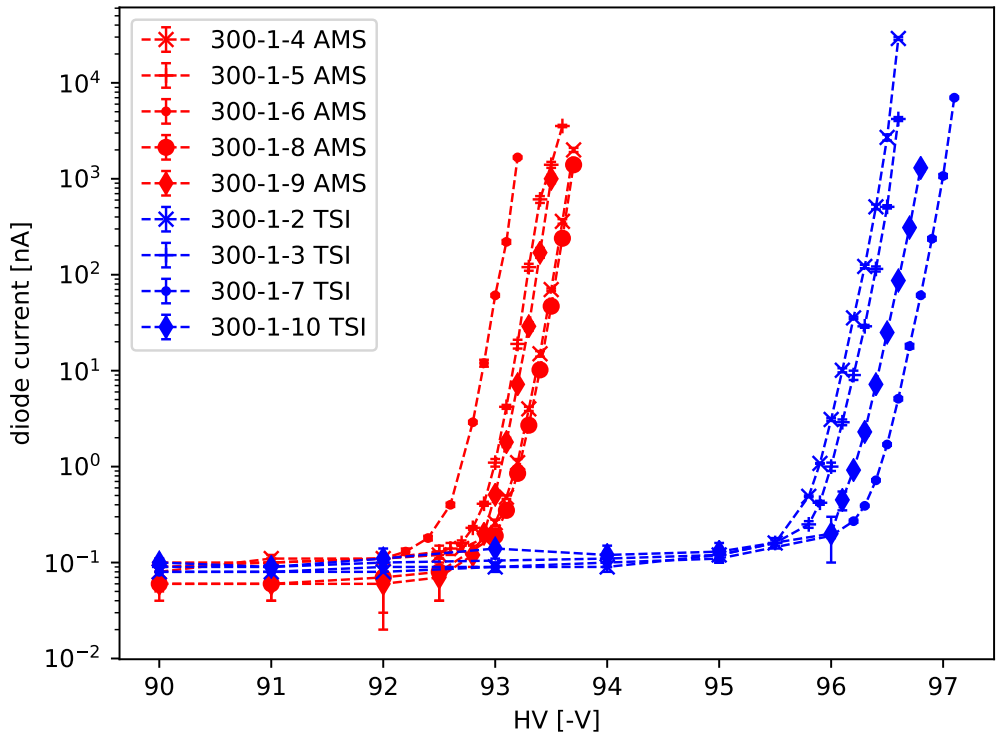
Setup



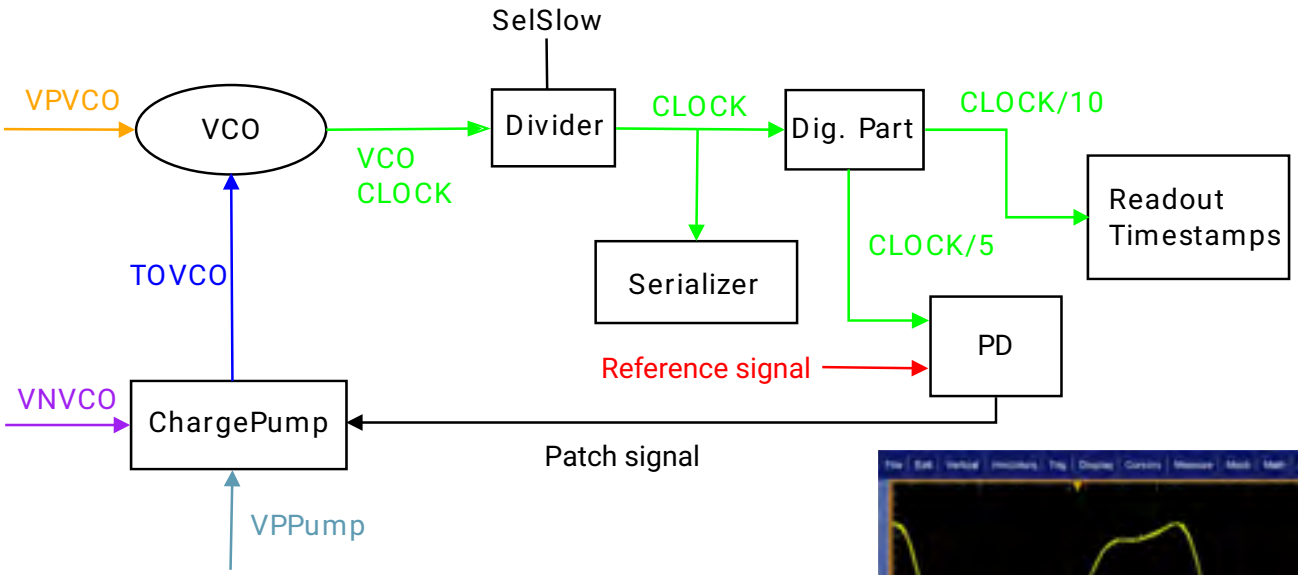
- MuPix7 sensors bonded on insert (5 AMS & 4 TSI)
- Mupix8 v2 PCB with MuPix7 insert (printed circuit board)
- Data readout via 8b/10b encoded LVDS signal with Stratix IV FPGA

Breakdown Voltage

- I-V-curve for reverse biased diodes
- Clear difference between foundries
- Higher breakdown allows for higher HV
- Hint for TSIs quality

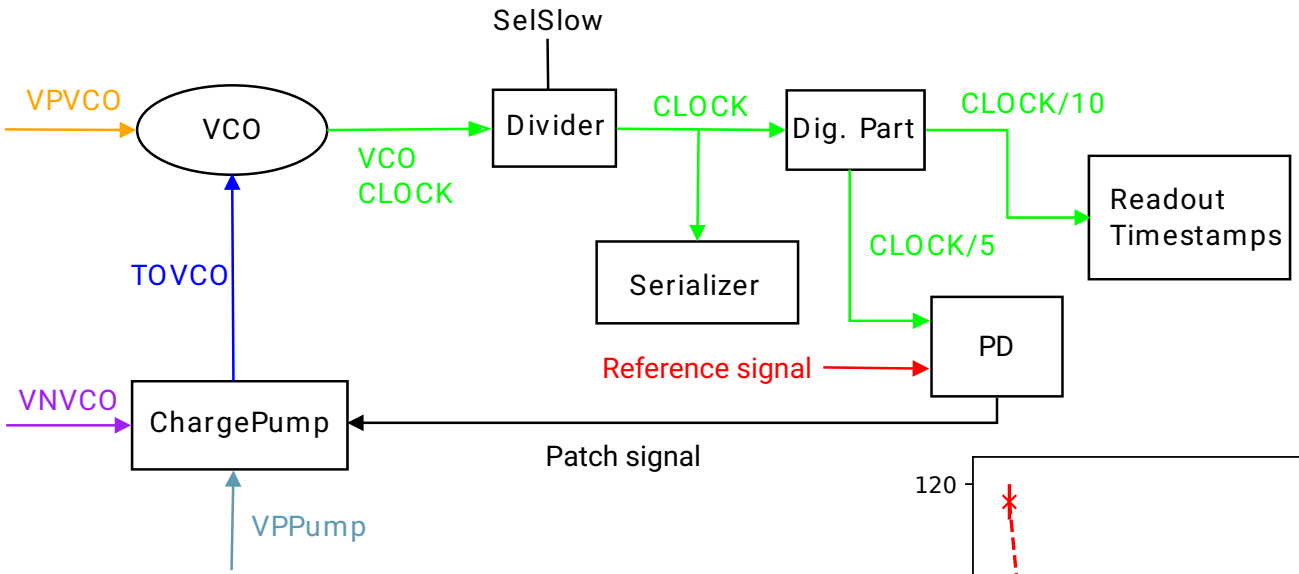


VCO scan

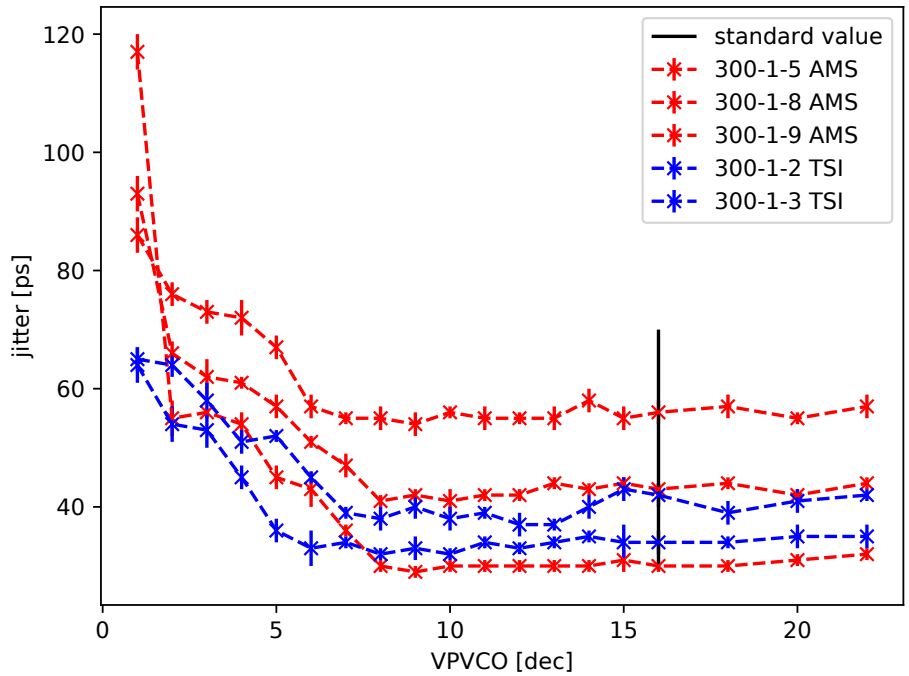


- Same shape for TSI and AMS
- TSI slightly less jitter (not significant)
- same DAC value suitable for TSI chips

VCO scan

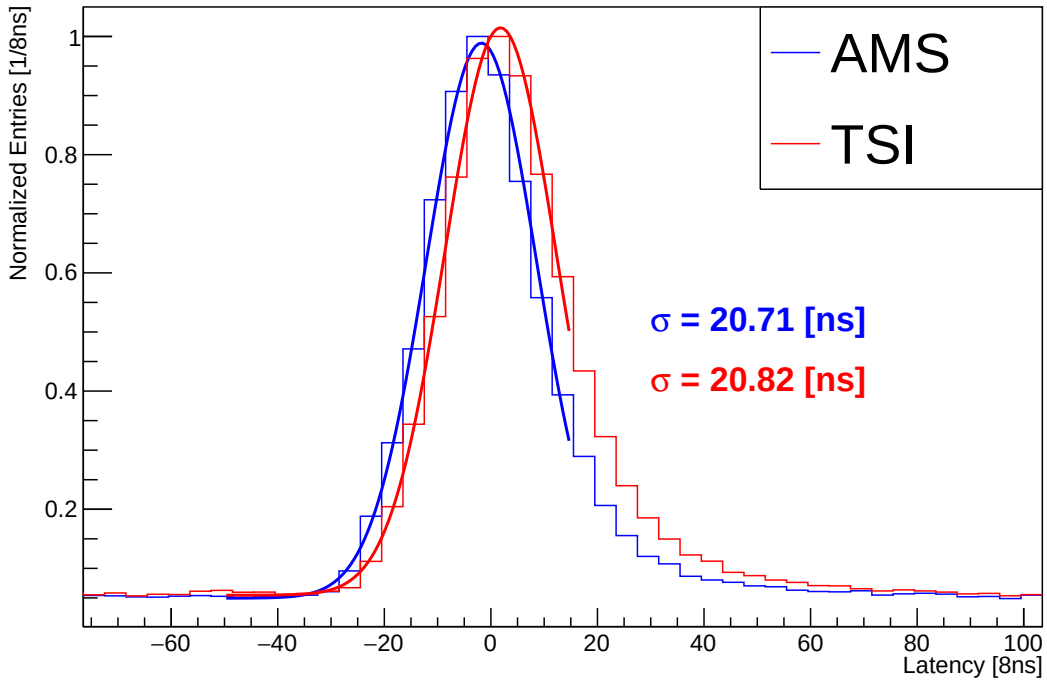


- Same shape for TSI and AMS
- TSI slightly less jitter (not significant)
- same DAC value suitable for TSI chips



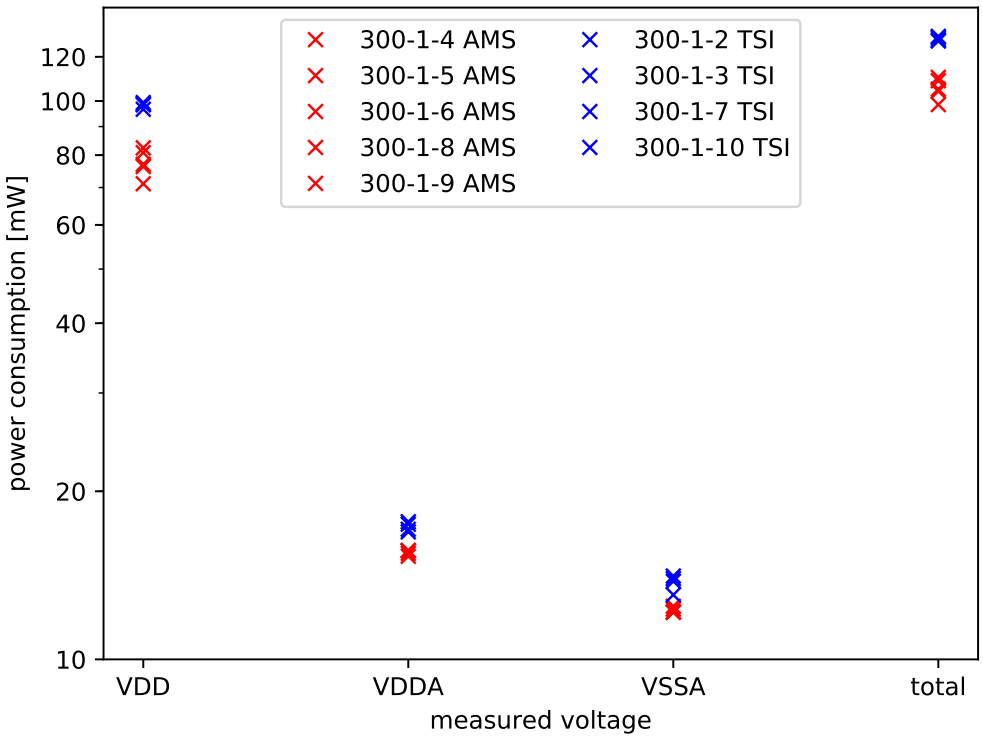
Time resolution

- Latency: Hit TS - Trigger TS
- No significant difference
- Right tail due to time-walk



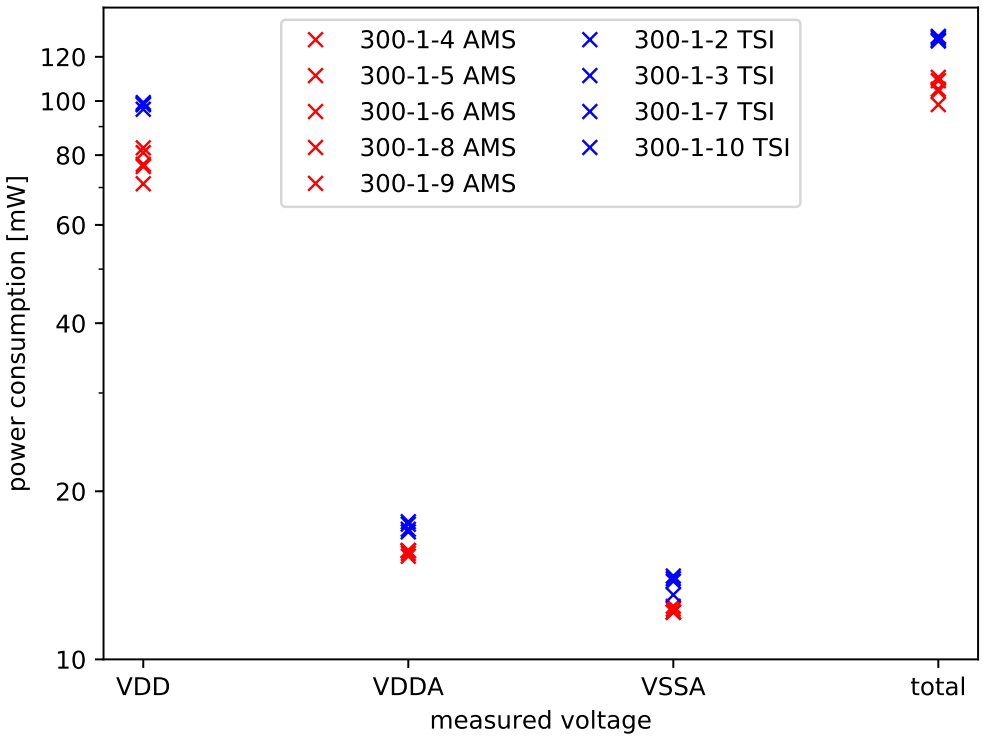
Power consumption

- *VDD*: digital part
- *VDDA*, *VSSA*: analog pixels
- Most power for digital part
- Big variances for *VDD*



Power consumption

- TSI *VDD* about 25% higher than AMS
- TSI *VDDA*, *VSSA* about 10% higher than AMS
- TSI has higher power consumption overall



Power consumption for important DACs

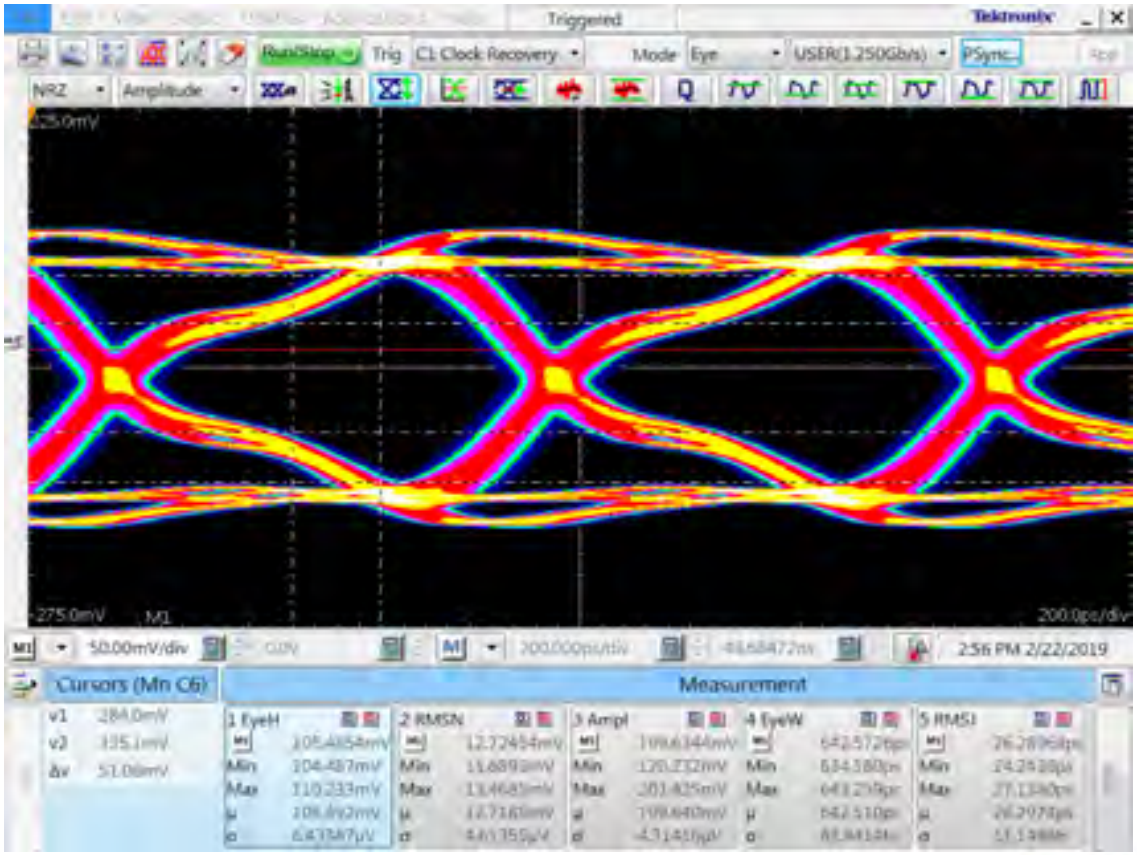
DAC	current (AMS) [mA]	current (TSI) [mA]	TSI/AMS
VN2	3.9	4.4	1.13
VNLVDS	8.0	19.1	2.39
VPComp	3.8	4.4	1.16
VPDac	11.5	12.4	1.08

Power consumption for important DACs

DAC	current (AMS) [mA]	current (TSI) [mA]	TSI/AMS
VN2	3.9	4.4	1.13
VNLVDS	8.0	19.1	2.39
VPComp	3.8	4.4	1.16
VPDac	11.5	12.4	1.08

LVDS output

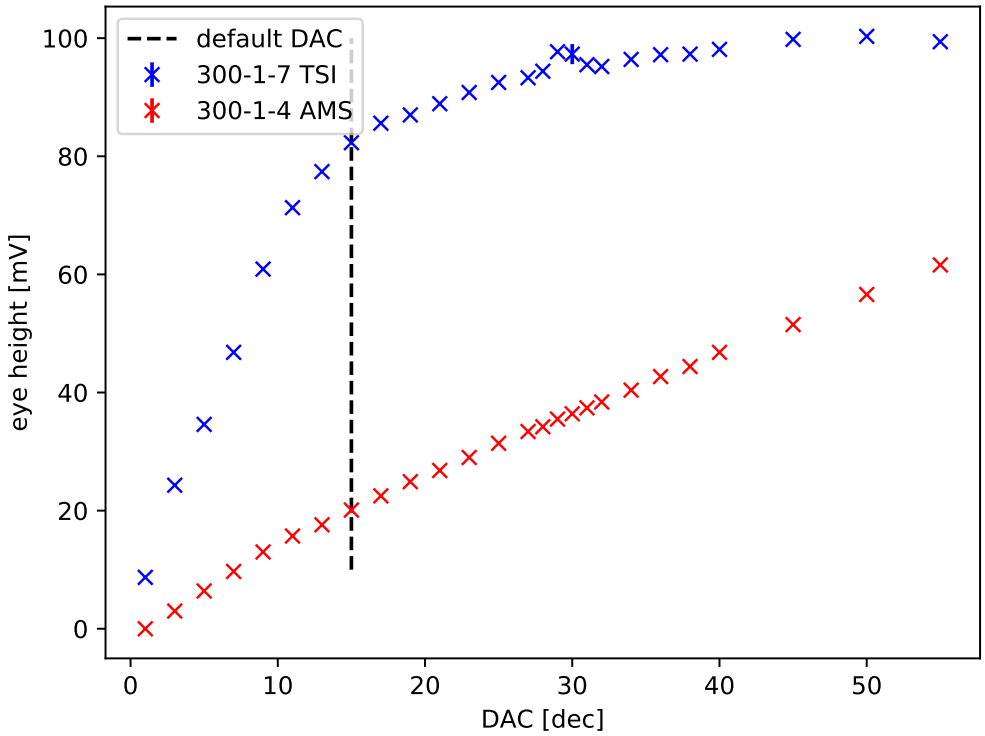
- Need for high resolution spectrum analyzer
- “Eye” as overlap of differential signals
- VNLVDS affects eye height only
- eye height measured correctly



LVDS scan

- Significant difference AMS/TSI
- higher "eye" for TSI chips

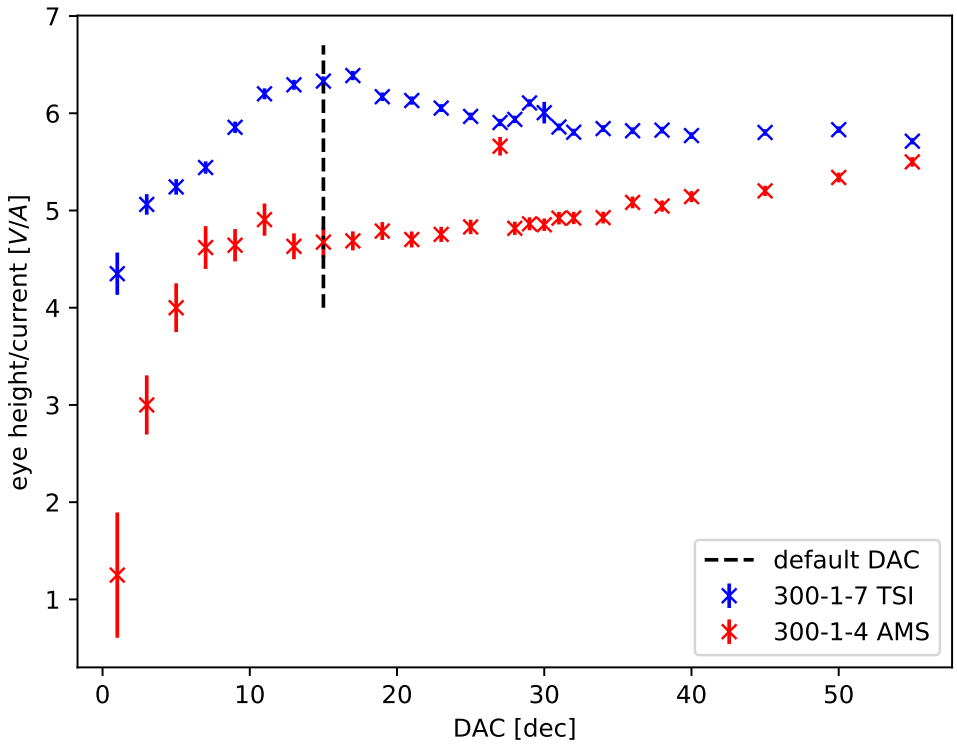
$\rightarrow$ 4$\times$ better signal quality for TSI



LVDS power consumption

- Significant difference AMS/TSI
- better signal quality for TSI needs higher power

→ TSI generates higher signal for same power



Summary

comparison

Area	AMS	TSI
Breakdown	$HV_{AMS} \approx 93\,V$	$HV_{TSI} \approx 96\,V$
PLL	$\mu_{AMS} \approx 42.0\,ns$	$\mu_{AMS} \approx 35.0\,ns$
Time res.	$\sigma_{AMS} \approx 20.7\,ns$	$\sigma_{TSI} \approx 20.8\,ns$
Power	$P_{AMS} \approx 105\,mW$	$P_{TSI} \approx 129\,mW$
LVDS	$VNLVDS_{AMS} = 15$	$VNLVDS_{TSI} = 2$

Summary

comparison

Area	AMS	TSI
Breakdown	$HV_{AMS} \approx 93\,V$	$HV_{TSI} \approx 96\,V$
PLL	$\mu_{AMS} \approx 42.0\,ns$	$\mu_{AMS} \approx 35.0\,ns$
Time res.	$\sigma_{AMS} \approx 20.7\,ns$	$\sigma_{TSI} \approx 20.8\,ns$
Power	$P_{AMS} \approx 105\,mW$	$P_{TSI} \approx 129\,mW$
LVDS	$VNLVDS_{AMS} = 15$	$VNLVDS_{TSI} = 2$

results

Difference only in power consumption
$\rightarrow$ solvable with lower DAC VNLVDS for TSI chips

Outlook

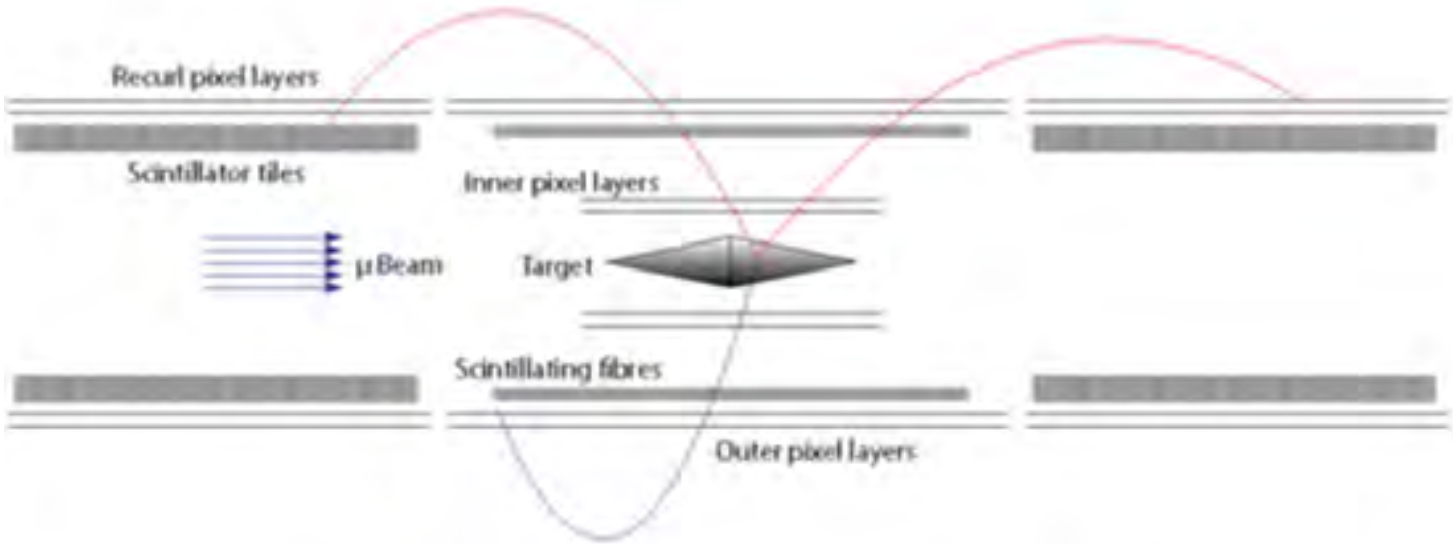
future measurements

- Signal-to-noise (SNR)
- Efficiency measurements from test-beam
- Evaluation of irradiated chips

Backup slides

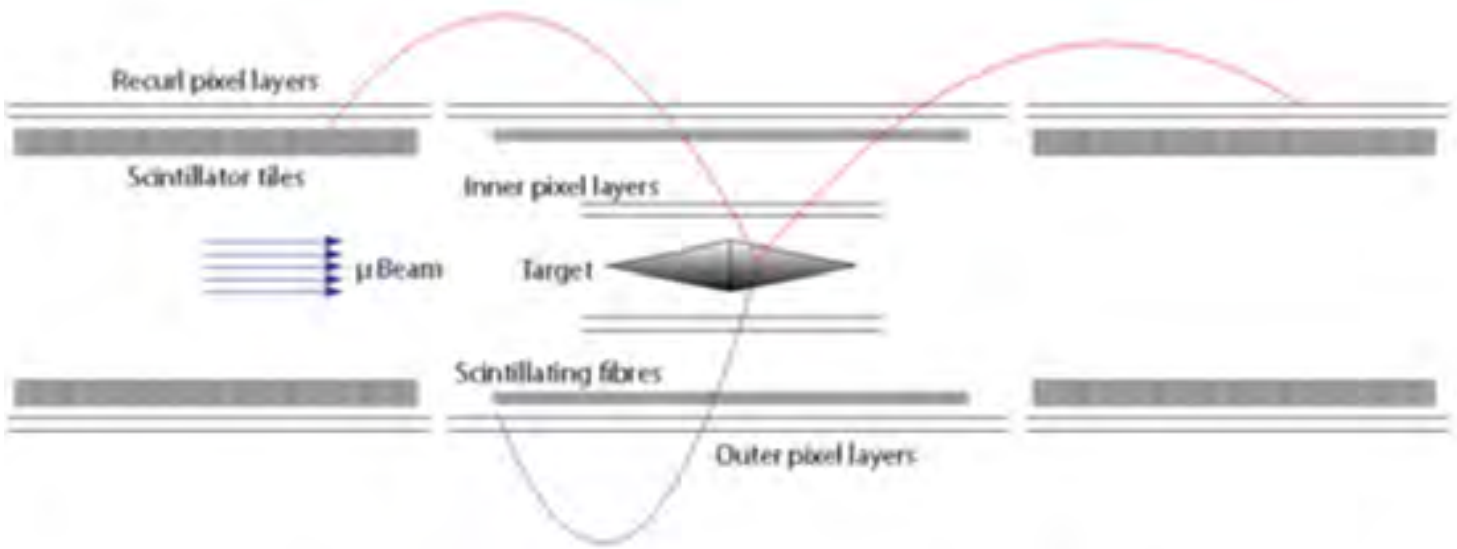
Mu3e

- Search for decay $\mu^+ \to e^+e^-e^+ \to$ cLFV
- Exclude other decays e.g. $\mu^+ \to e^+e^-e^+\nu_e\nu_\mu$
- $\sum \vec{p} = 0 \quad \& \quad \sum m_\mu c^2$
- multiple layers with recurl $\to$ vertex/momentum resolution



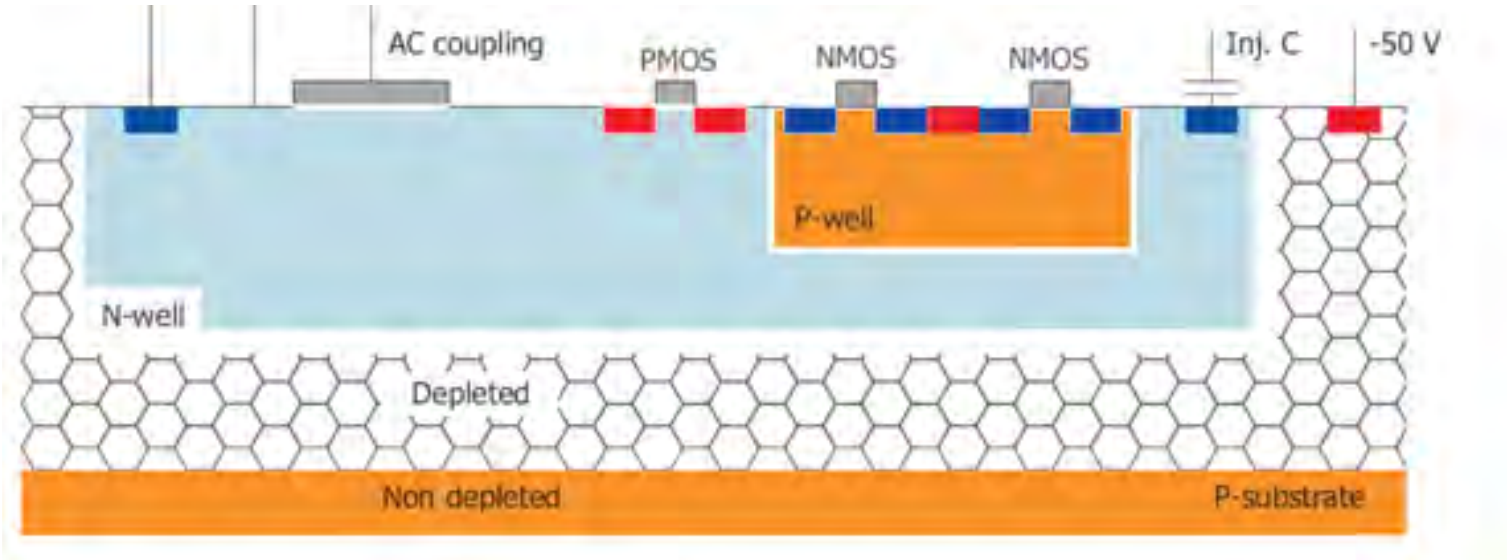
Detector

- Pixel layers provide good vertex resolution
- Scintillating fibers & tiles with precise timing resolution
- Recurl through applied magnetic field $\rightarrow$ momentum measurement



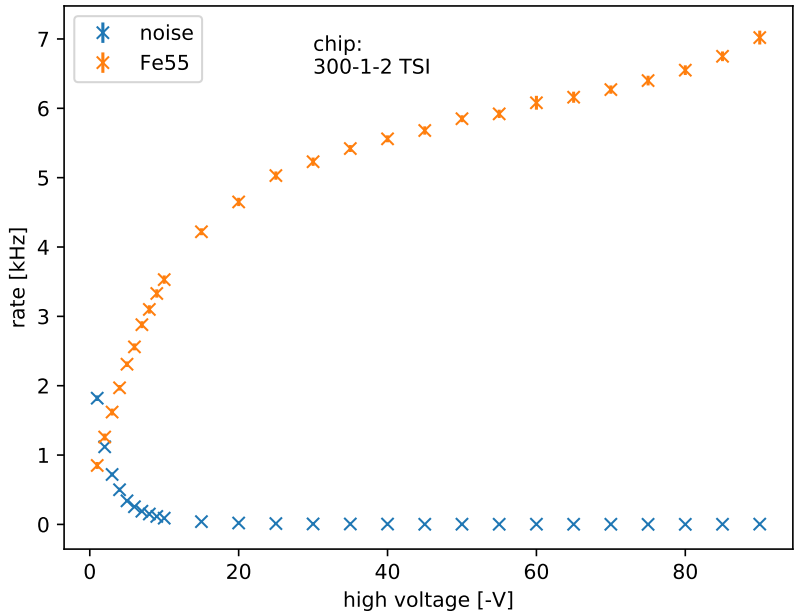
Diodes profile

- larger depletion zone for stronger electric field
- depletion over whole diodes profile



HV scan

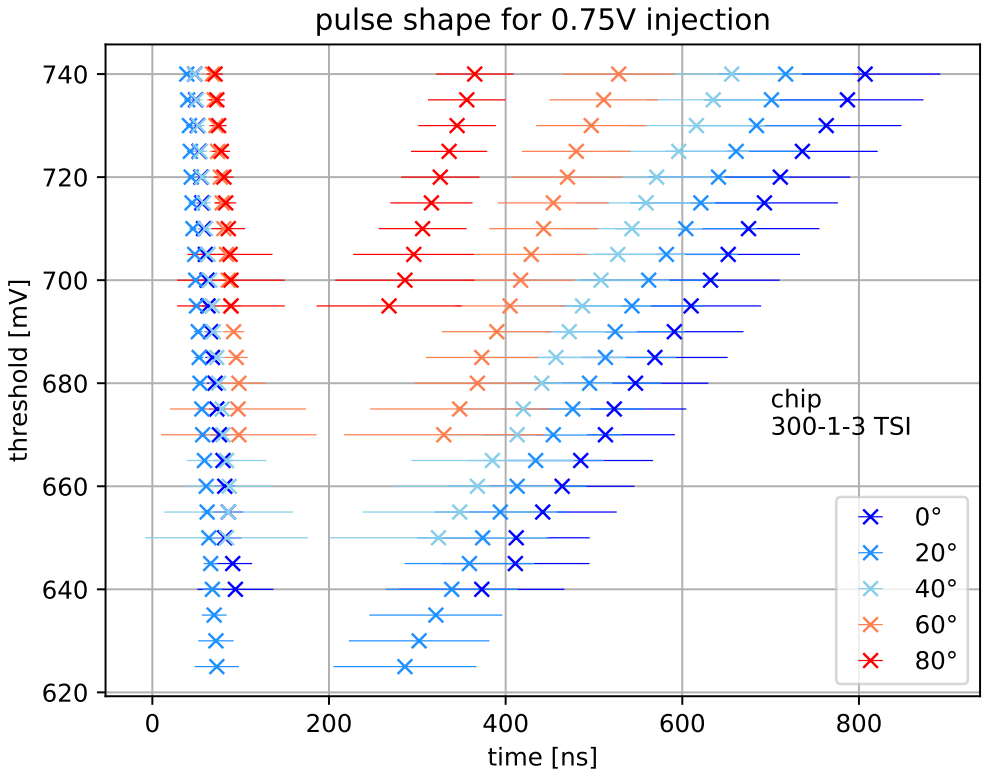
- scan HV applied to each pixel
- higher HV $\rightarrow$ more hits
- higher HV $\rightarrow$ less noise



Pulse shape

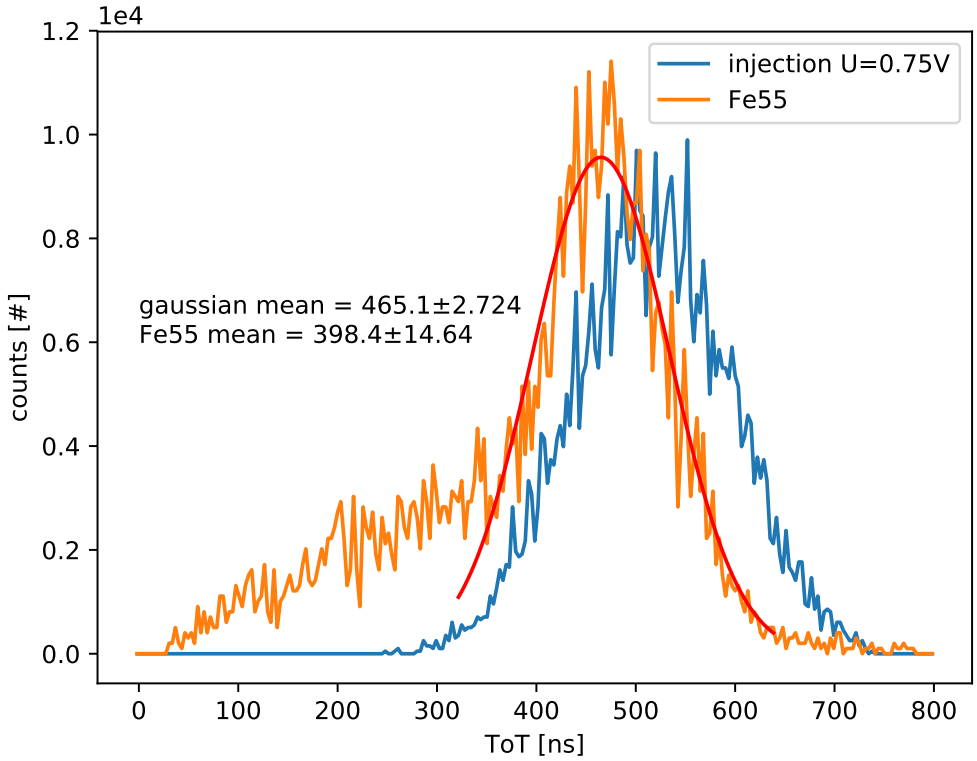
- Detector temperatures
  $T_{min} = 0°C$,
  $T_{max} = 70°C$
- Pulse shape changes with temperature
- Measurements show temperature dependency

→ DAC settings concerned for different temperatures



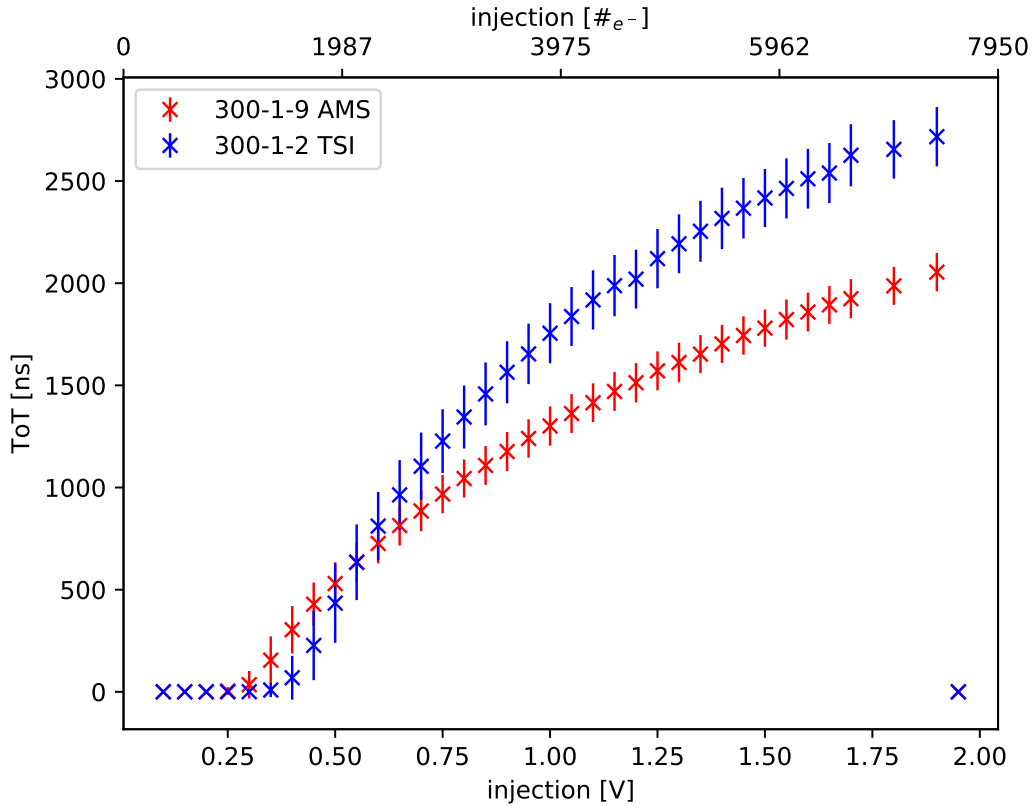
Injection

- quantify injection and source
- injection histogram is gaussian
- Fe55 histogram is gaussian with left tail
- tail caused by hits between pixel cells



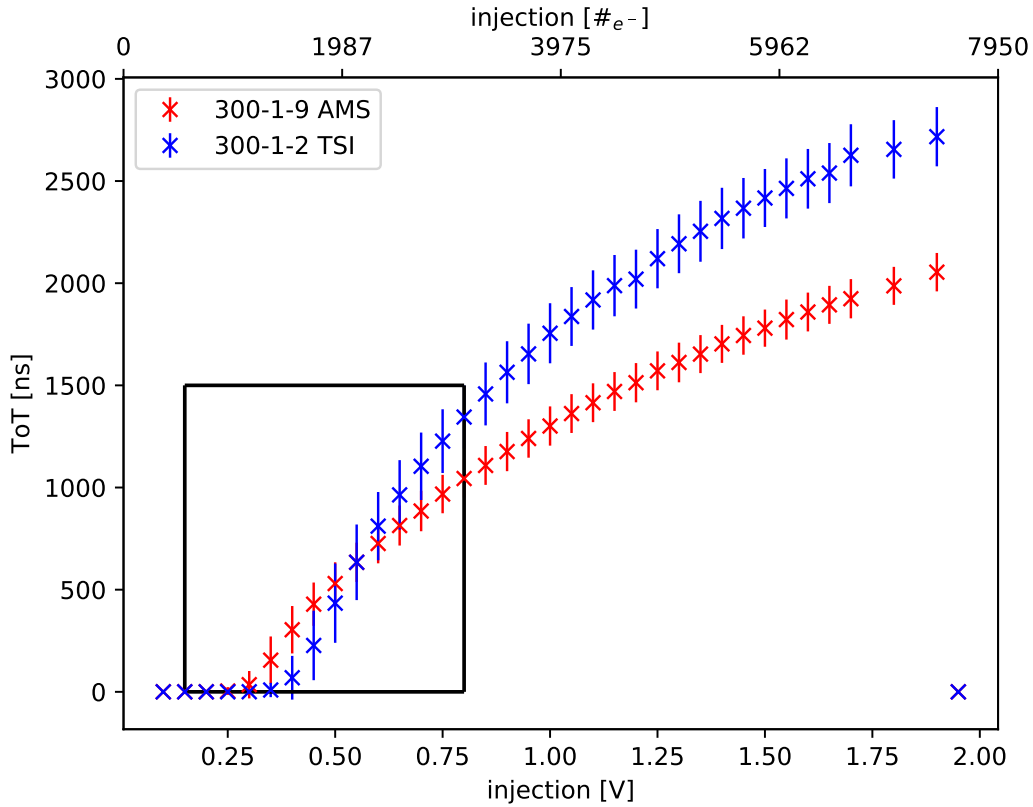
Injection

- varying injection creates different pulse heights
- readout electronics saturate for higher voltages



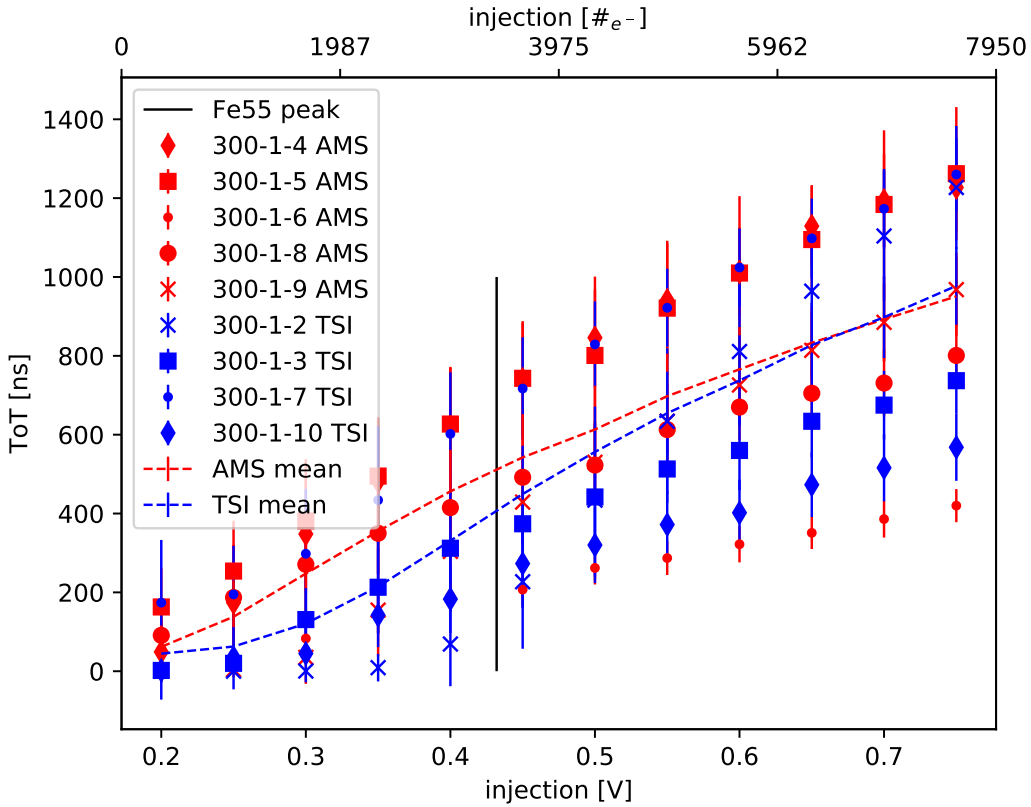
Injection

- varying injection creates different pulse heights
- readout electronics saturate for higher voltages



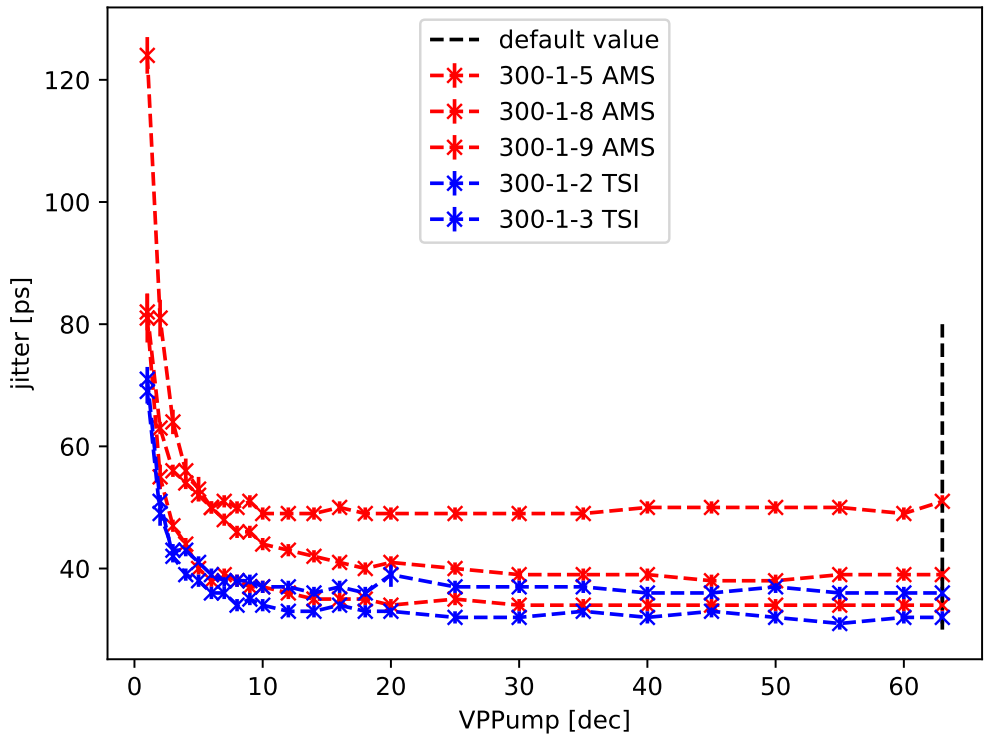
Injection

- difference due to statistical variations
- different absolute values unimportant



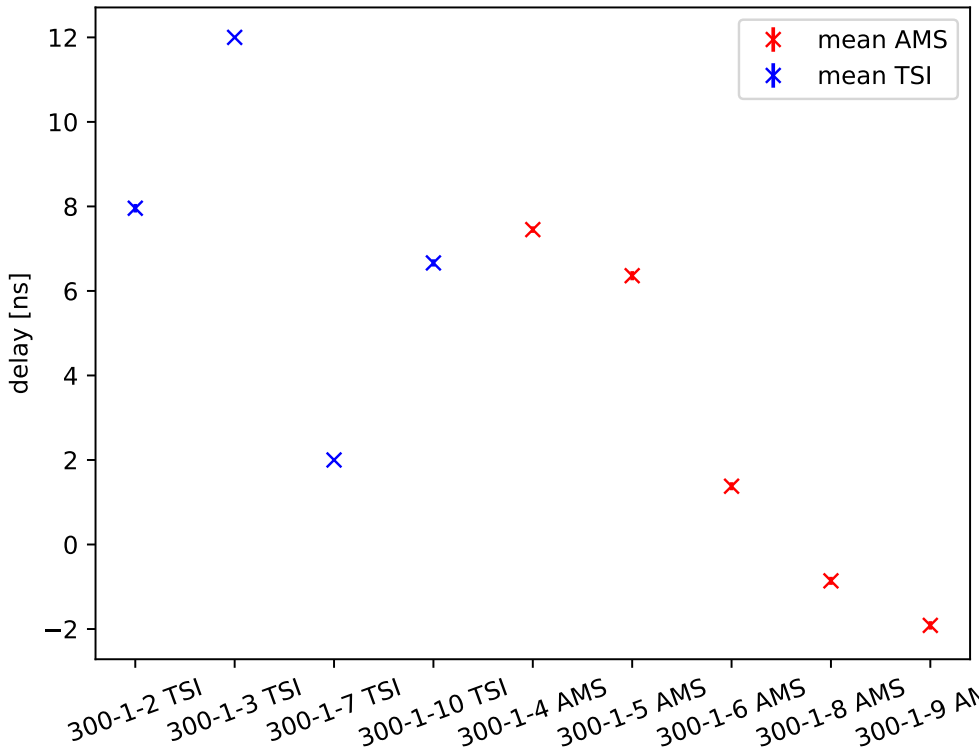
VPPump scan

- exponential shape
- same for TSI and AMS
- TSI slightly less jitter (not significant)
- DAC value are suitable



Time resolution

- Low delay
- High time resolution
- AMS chips perform better
- no significant differences



Time resolution

- Low delay
- High time resolution
- AMS chips perform better
- no significant differences