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MoTiC: a Monolithic Pixel Detector with Timing

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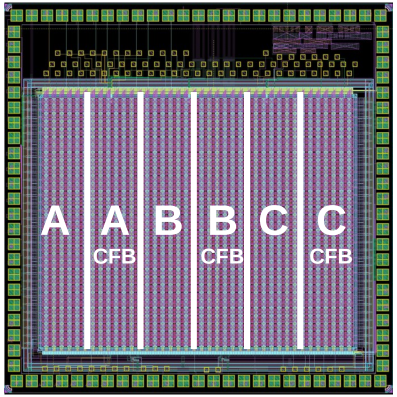
Introduction

- The PSI High Energy Physics group in collaboration with ETHZ has a generic R&D program for DMAPS since 2019
- Different technologies are being evaluated
- Goal: position sensitive particle detectors featuring timing
- Aiming for
  - Spatial resolution < 10µm
  - Timing resolution < 1ns
- Possible applications at PSI in-house experiments

MoTiC: Monolitic Timing Chip

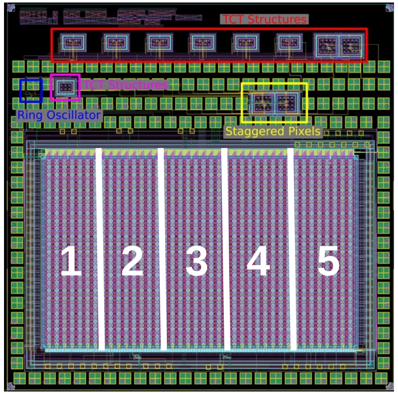
- Modified LFoundry 110nm process
- Full frame readout with external trigger
- In-pixel discriminators
- 1 TDC shared by 4 pixel
- Sensing elements designed by ARCADIA
- Small electrodes with small capacitance
- Back-side processing for guard rings and metal contacts
- Depletion from back-side
- Thickness: 48, 100, 200µm

Same sensor
6 different amplifiers
80 columns, 64 rows
50 x 50µm^2



MoTiC A

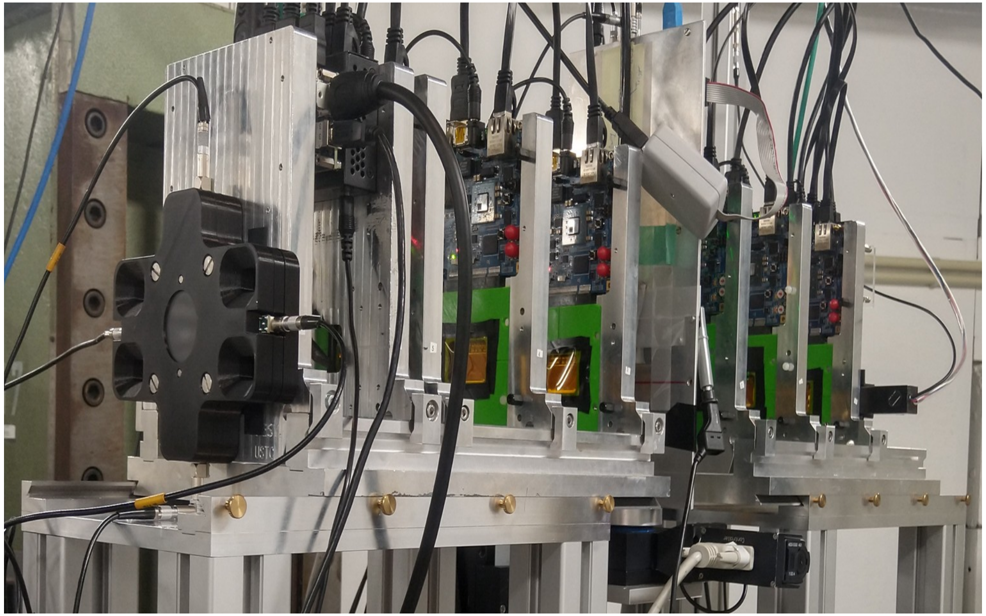
Same amplifier (C)
5 different sensors
80 columns, 48 rows
50 x 50µm^2

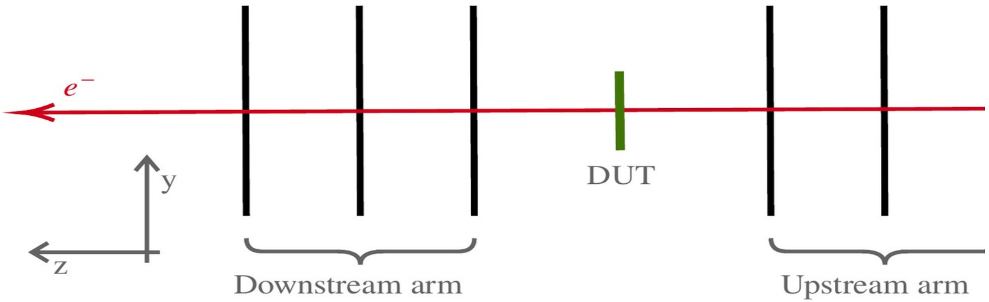


MoTiC B

Beam Test at DESY II

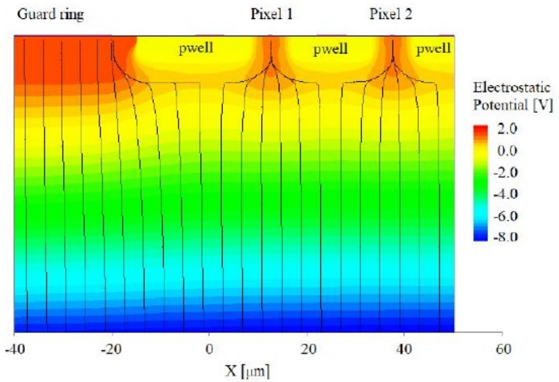
- Adenium Telescope
  - 6 planes of Alpide sensors
  - 29.24µm x 26.88µm pixels
  - 50µm thick
  - Spatial resolution < 5µm
- Non-irradiated samples
- 4GeV electrons
- Room temperature
- Offline Threshold: 8 x RMS
- Analysed using (modified) Corryvreckan
- Some further analysis in Python





Cluster Size

- Larger than 1 at vertical incidence
  - Also seen in TCT measurements
  - Confirmed by ARCADIA simulations
- Low electric field below the p-wells
  → longer charge collection time
  → higher probability of diffusion
- MoTiC B has relatively low-gain preamplifier
  → many pixels don't reach the threshold
  → smaller cluster size



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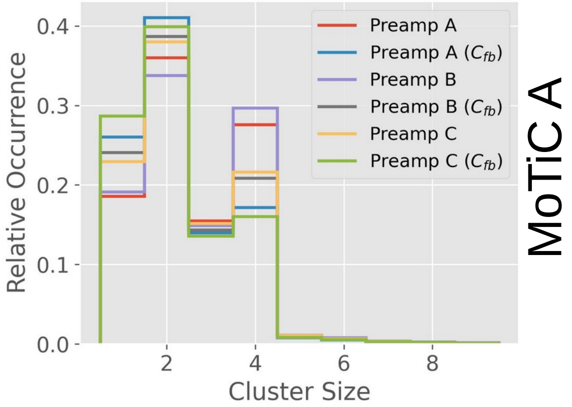

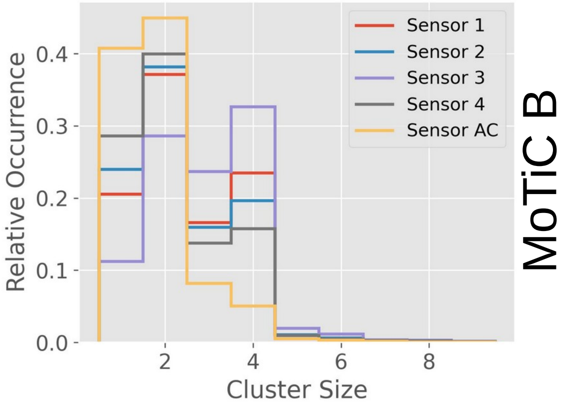

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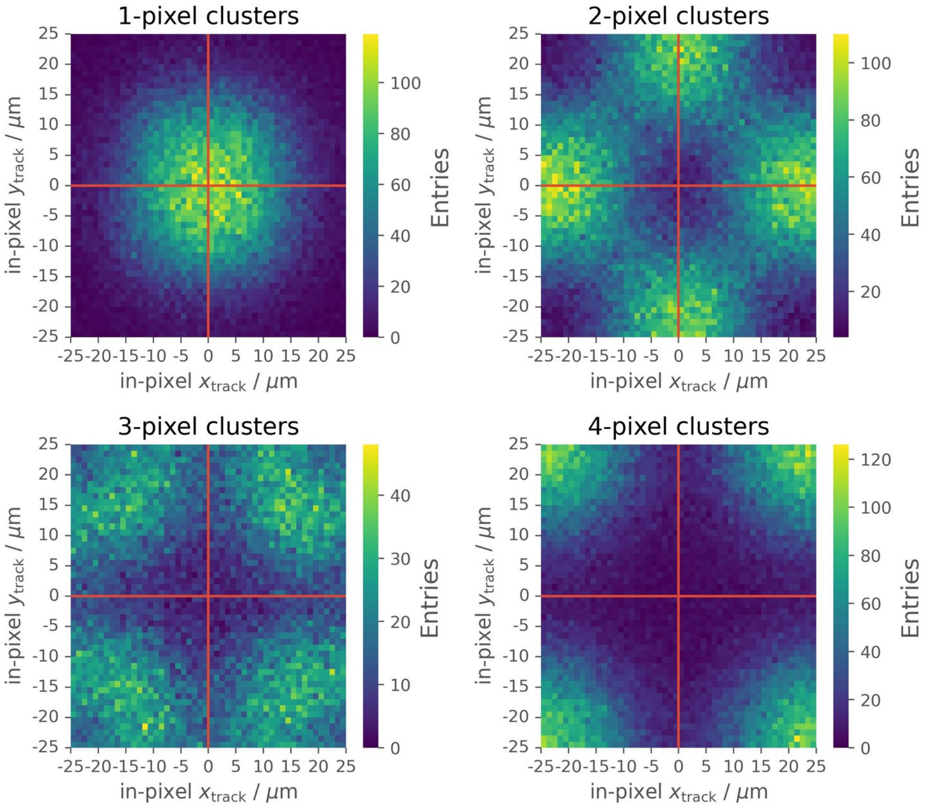
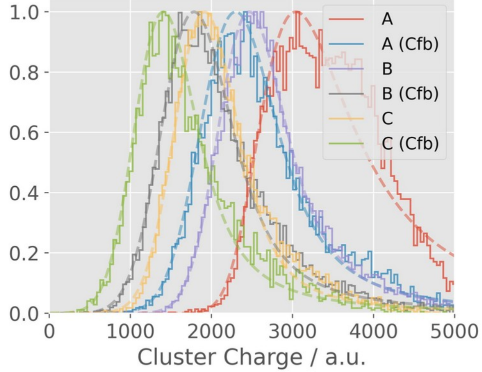


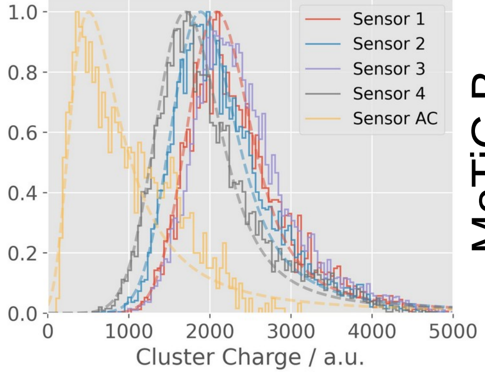
MoTiC A

Cluster Charge

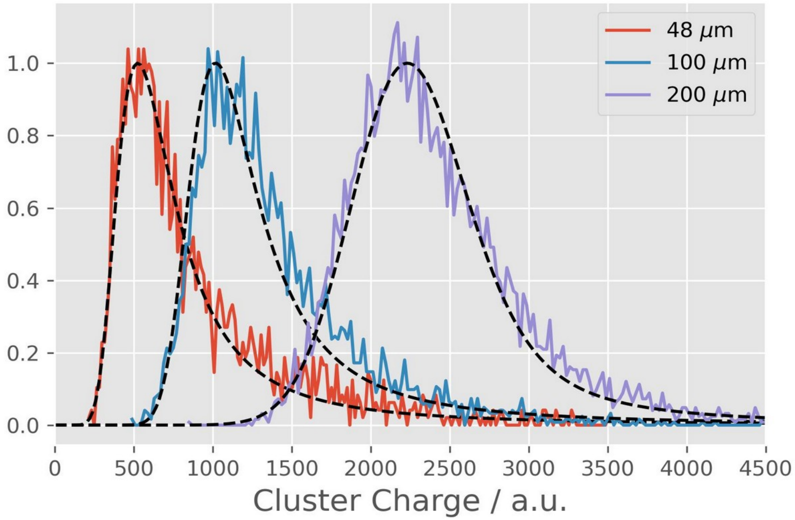
- Pulse-height distribution distorted in MoTiC
  - Saturation of high-gain amplifiers
  - Flat response for small amounts of charge
- Only 4-pixel clusters considered
- Amplifiers with additional feedback capacitor have lower pulse heights
- Preamlifier AC has a lower gain by a factor of ~3 due to large input capacitance
- Charge scales linearly with thickness
  - Thickness ratios: 1 : 2.08 : 4.17
  - Most probable values: 1 : 1.93 : 4.25

MoTiC A



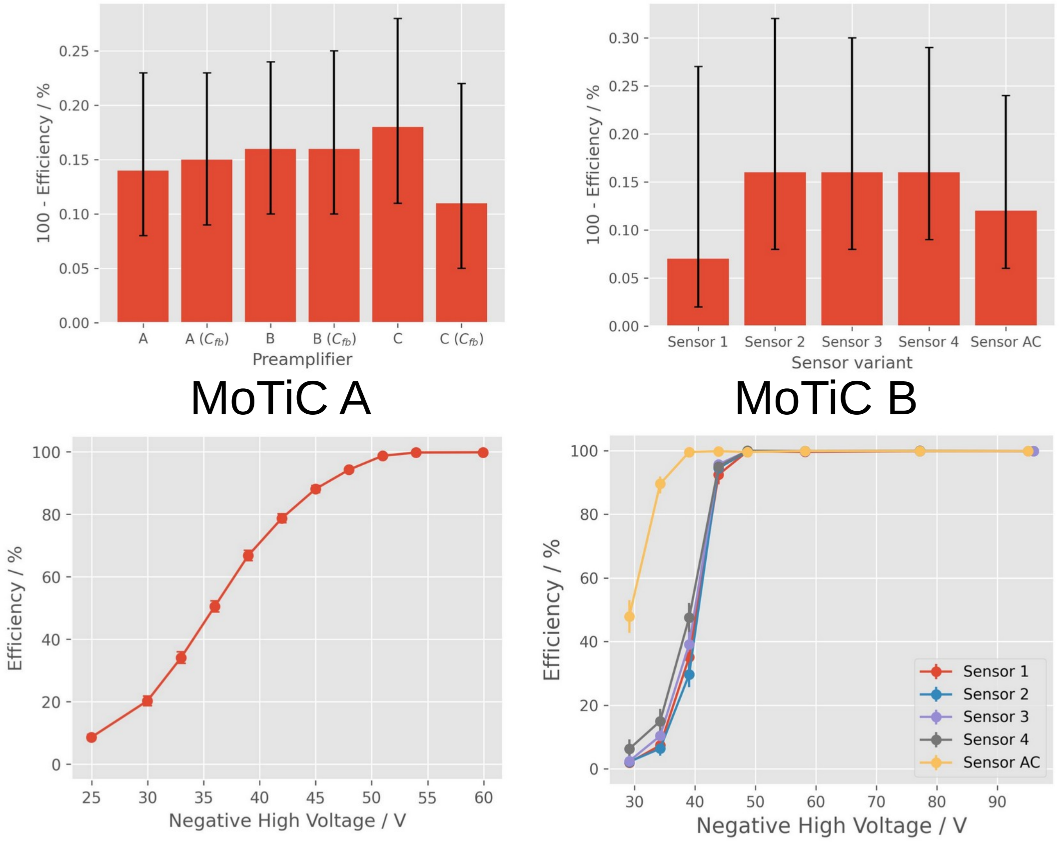


MoTiC B



Hit Efficiency

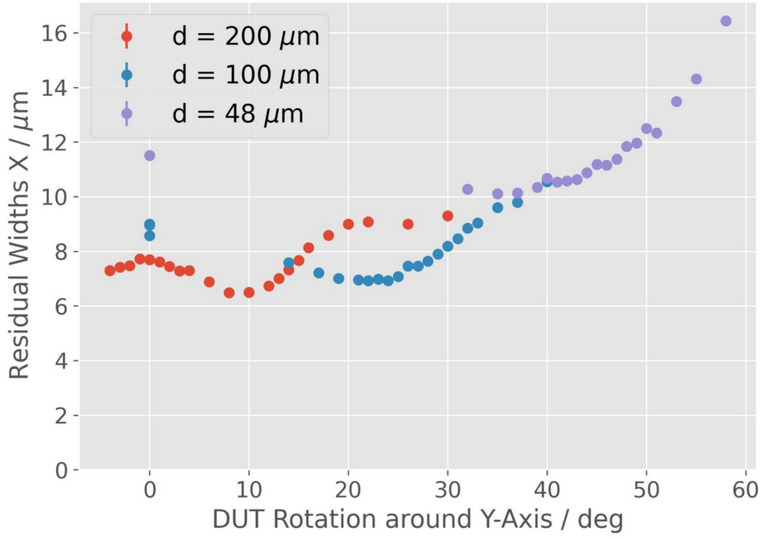
- $$\varepsilon = \frac{N_{\text{assoc.clusters}}}{N_{\text{tracks}}}$$
- Offline threshold
- Hit efficiency > 99.8%
- MoTiC A
  - 200 µm thick
  - Max. efficiency at V_{bias} > ~55V
- MoTiC B
  - Max. efficiency at V_{bias} > ~50V
  - AC variant efficient at V_{bias} > ~40V

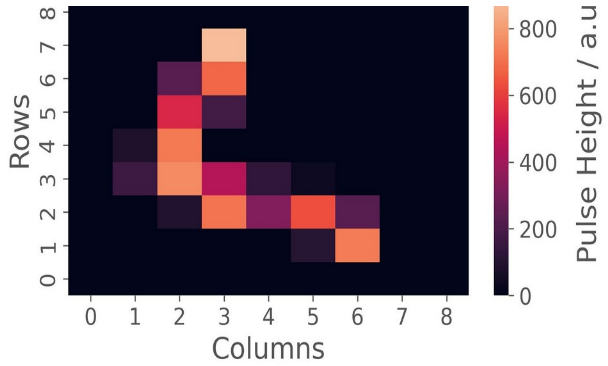


Spatial Resolution

- $\sigma_{hit} = \sqrt{RMS_{trc}^2 - \sigma_{TEL}^2}$
- Center of Gravity
- Truncated RMS of DUT residuals
  - Discard values outside ±6 RMS
- Resolution at vertical incidence better than resolution of binary readout (14.4µm)
- Optimal angle differs from arctan(pitch/thickness)
- Best resolution: **4.8µm** for the 200µm thick sensor

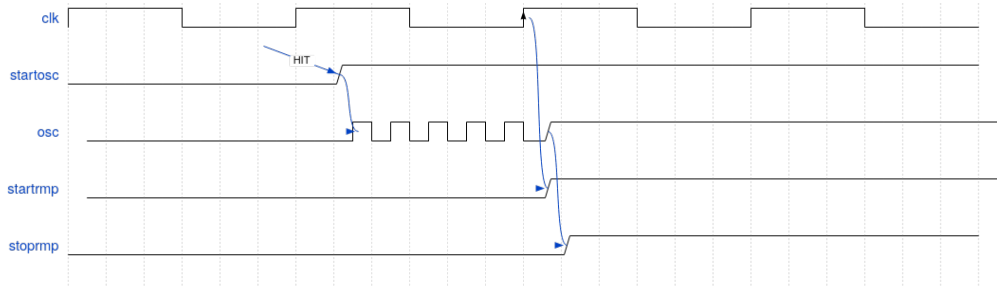
Type	t / µm	Angle / deg	$\sigma_{residual}$ / µm	σ_{tel} / µm	σ_{DUT} / µm
MoTiCv1 A	200	0	7.7 ± 0.1	4.4 ± 0.5	6.3 ± 0.4
MoTiCv1 A	200	8	6.5 ± 0.1	4.4 ± 0.5	4.8 ± 0.5
MoTiCv1 A	100	0	9.0 ± 0.1	4.4 ± 0.5	7.9 ± 0.3
MoTiCv1 A	100	21	6.9 ± 0.1	4.4 ± 0.5	5.3 ± 0.4
MoTiCv1 A	48	0	11.5 ± 0.1	5.0 ± 0.5	10.4 ± 0.3
MoTiCv1 A	48	37	10.1 ± 0.1	5.0 ± 0.5	8.8 ± 0.3

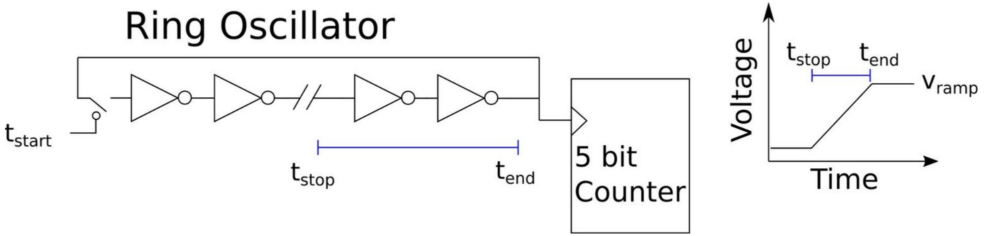


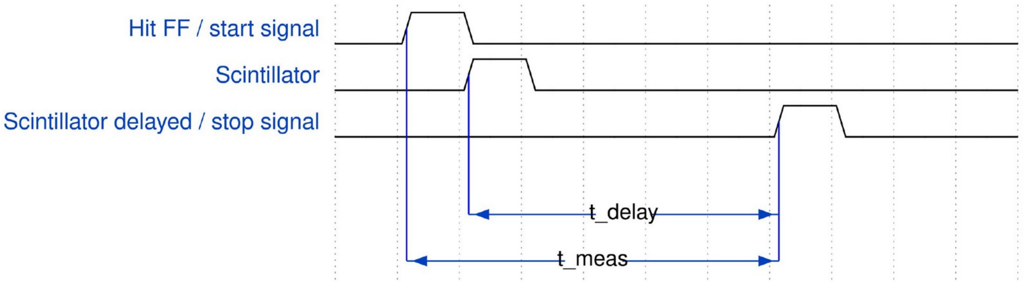


Time Measurements - ATDC

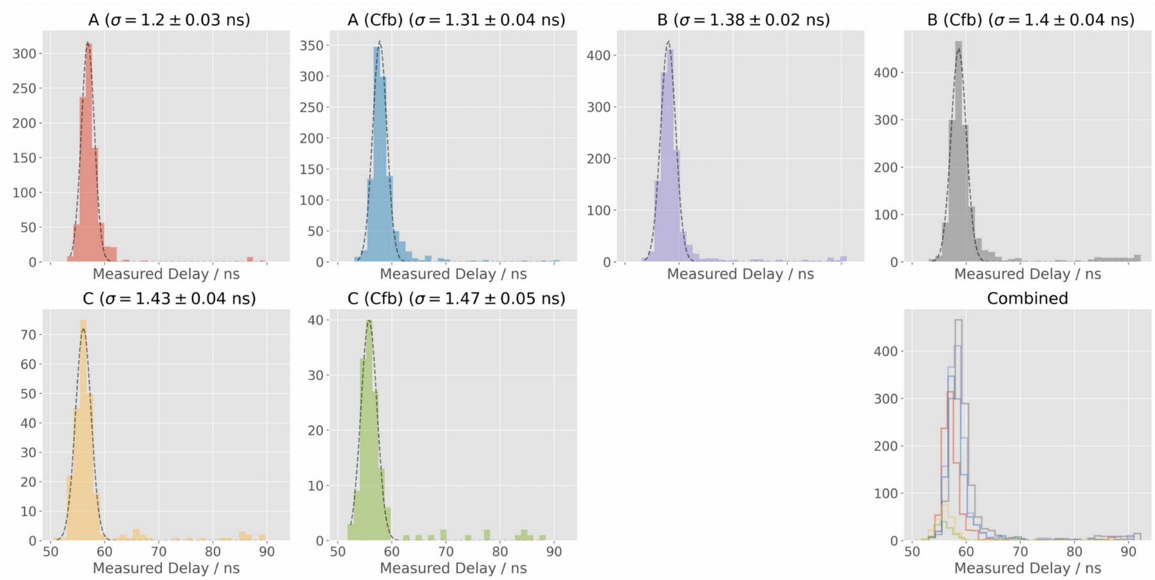
- Every 4 pixels share a TDC
- $t_{TDC} = (cnt_{OSC} \times \tau_{OSC}) - t_{ramp}$
- Timing resolution
  - 10 ps test structure
  - 40 ps in pixel
- No clock at test beam
- Hit FF used as start
- Signal from a dedicated fast trigger system used as stop
  - Coincide of 2 dual readout scintillators
  - Jitter less than 200ps



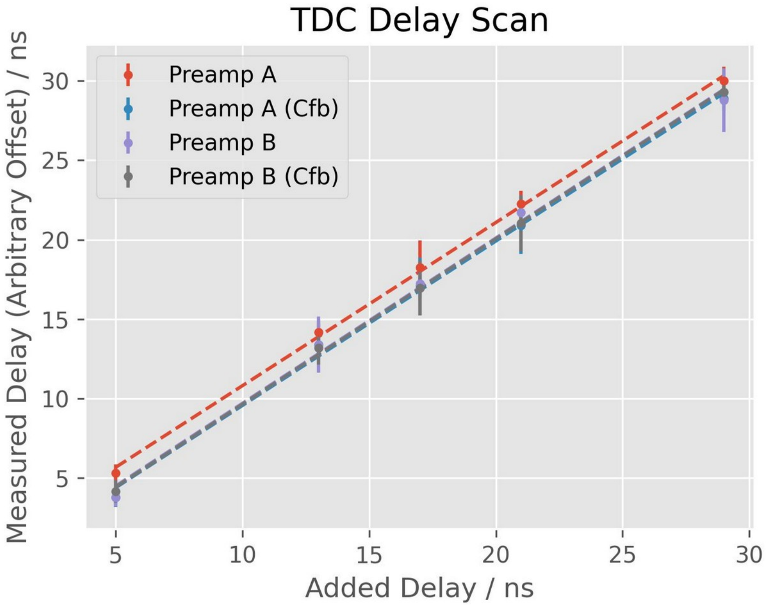




Time Measurements



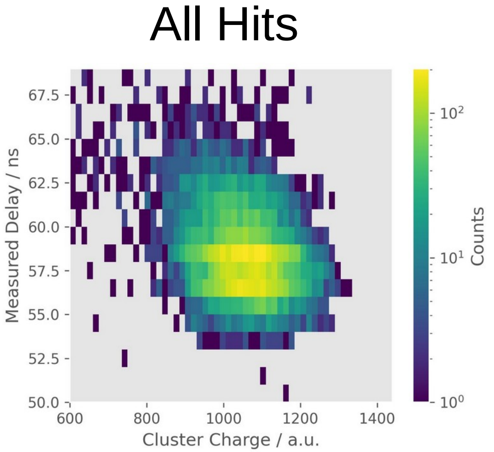
Preamplifier	Time resolution / ns
A	1.20 ± 0.03
A (C_{fb})	1.31 ± 0.04
B	1.38 ± 0.02
B (C_{fb})	1.4 ± 0.04
C	1.43 ± 0.04
C (C_{fb})	1.47 ± 0.05

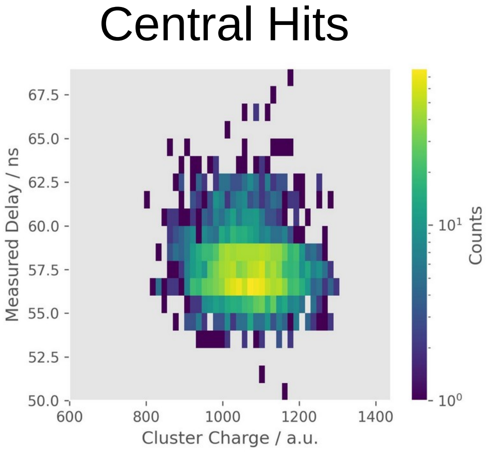


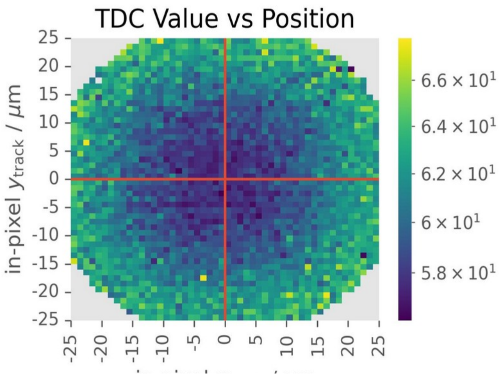
Preamplifier	Slope / ns/ns
A	1.04 ± 0.02
A (C_{fb})	1.04 ± 0.03
B	1.04 ± 0.04
B (C_{fb})	1.04 ± 0.02

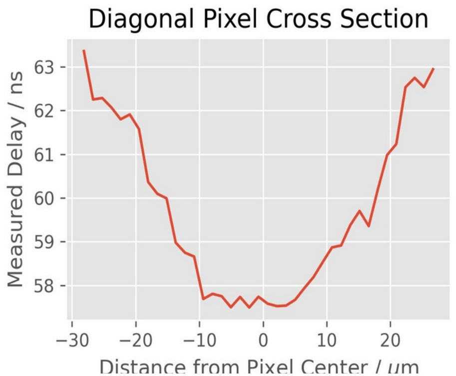
Drift Time Measurements

- MoTiC A
- 1-pixel clusters
- Consider only a radius of 10µm → no timewalk
- Pulse height > 800 ADC
- ~ 5ns drift time from corners
- Compatible with ARCADIA simulations and measurements









Summary

- A DMAPS prototype chip using modified LFoundry 110nm process has been developed
- Comprises different amplifier and sensor designs
- Charactrized using partilce beams
  - Hit efficiency > 99.8%
  - Spatial resolution < 5µm
  - Coarse timing resolution < 1.2ns

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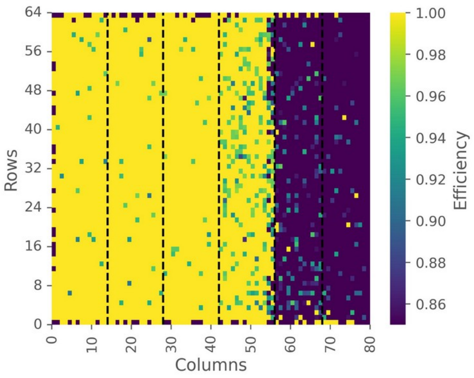
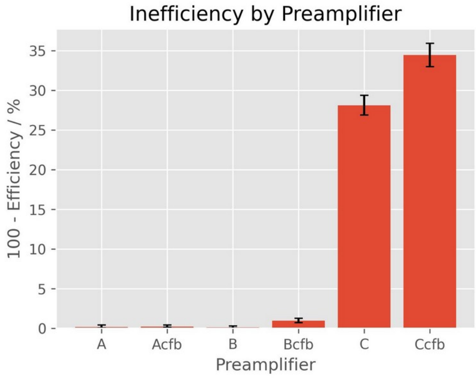
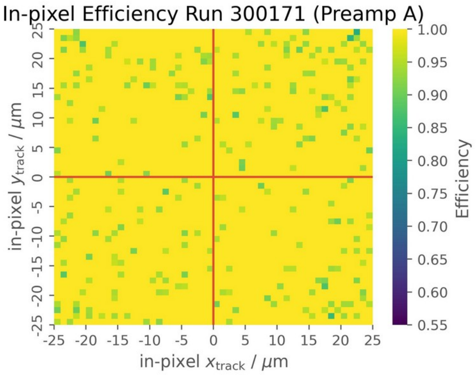
Backup Slides

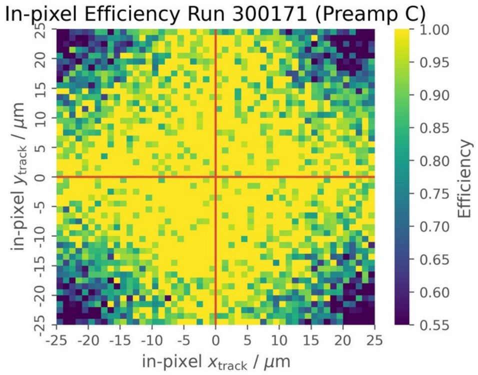
Hit In/Efficiencies – Online Threshold

- Online threshold
- Readout can trigger comparator
- Varying gain leads in different effecitve threshold
- Results in much higher inefficiency in preamplifier C
- Efficiencies:
  - A, A(Cfb) and B > 99.7%
  - B(Cfb) > 99%





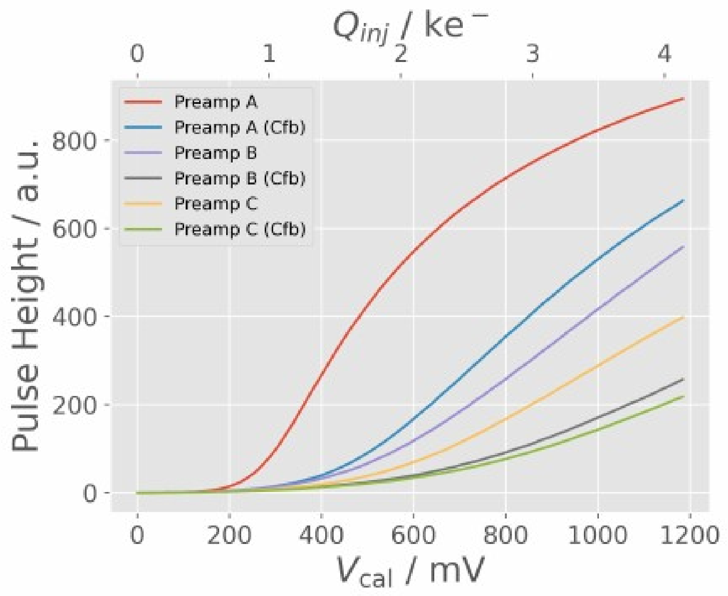




Pulse Height / Online Threshold

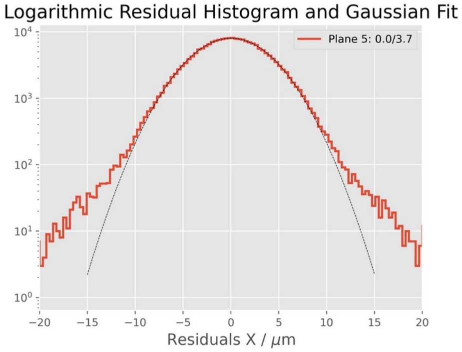
Table 6.1.: Thresholds applied in runs with online threshold. The thresholds in terms of V_{cal} and an approximate conversion to electrons are also shown.

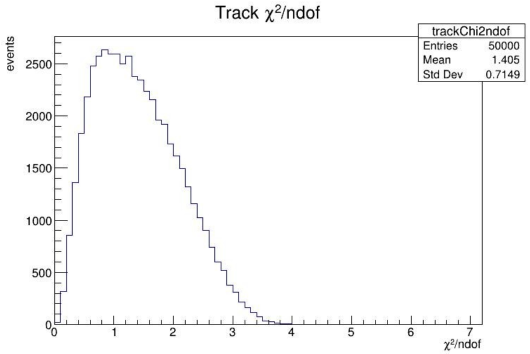
Preamplifier	Threshold / mV	V_{cal} Threshold / mV	Threshold / e^-
A	804	530	1800
A (Cfb)	804	904	3100
B	785	704	2400
B (Cfb)	785	1118	3900
C	757	>1200	>4100
C (Cfb)	757	>1200	>4100

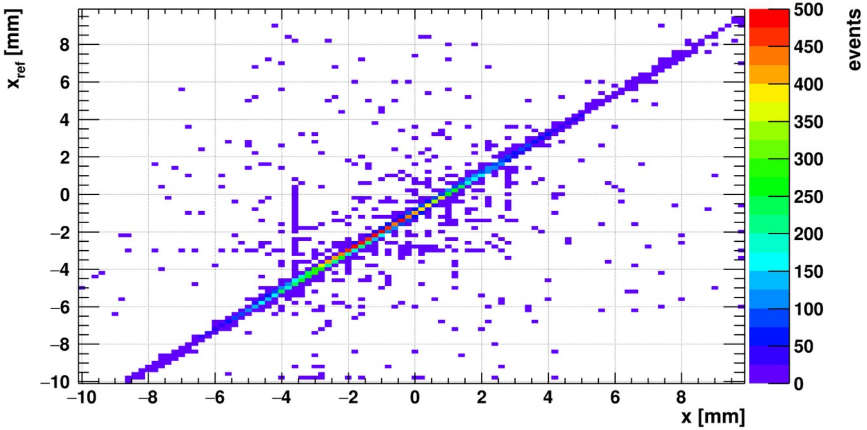


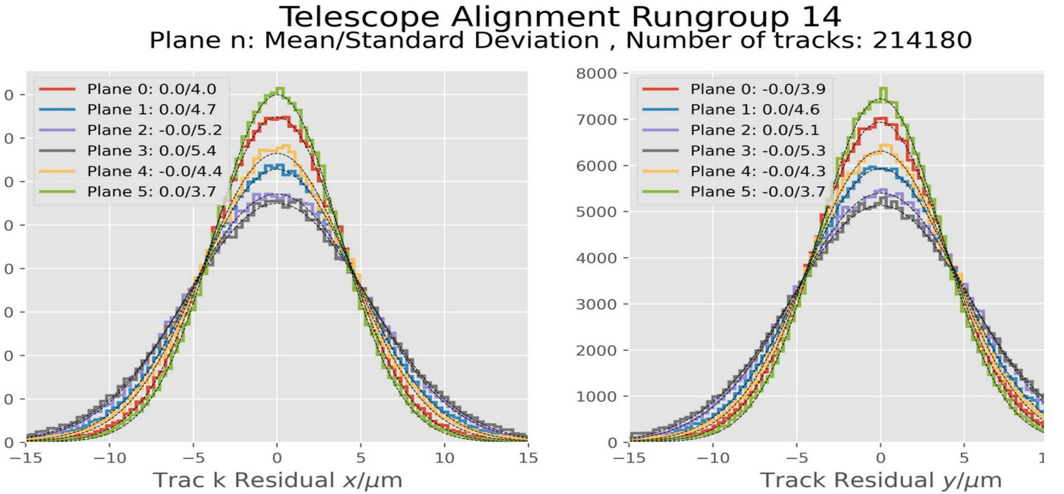
Telescope Alignment

- Using General Broken Lines (GBL)
- Itterative with χ2 and spatial cut down to pixel pitch
- Tails from delta electrons
- Z-position measred with hand, optimized by scan

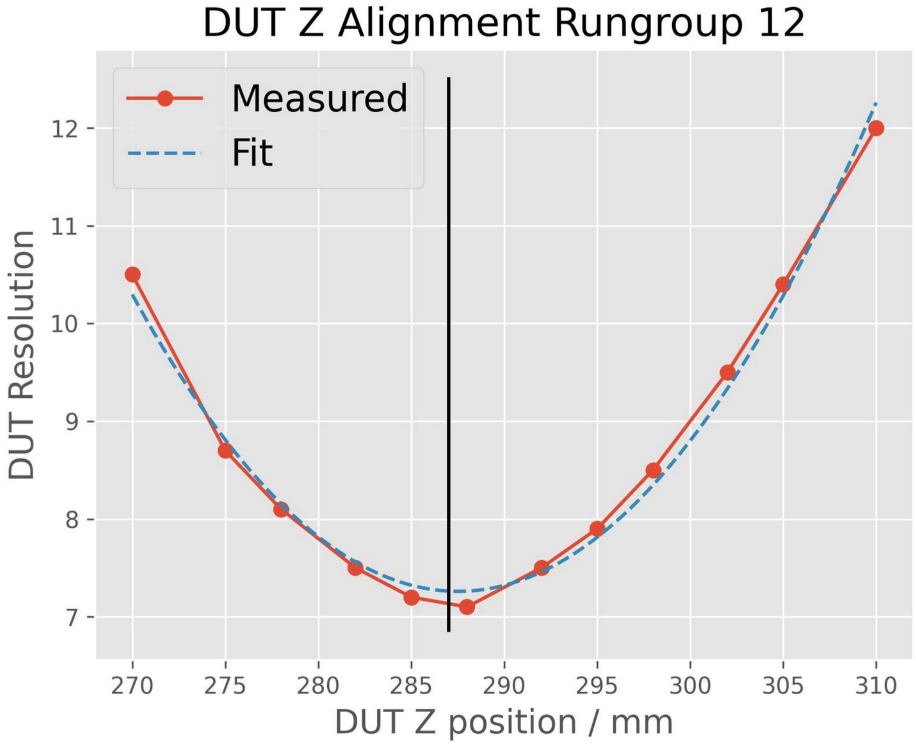


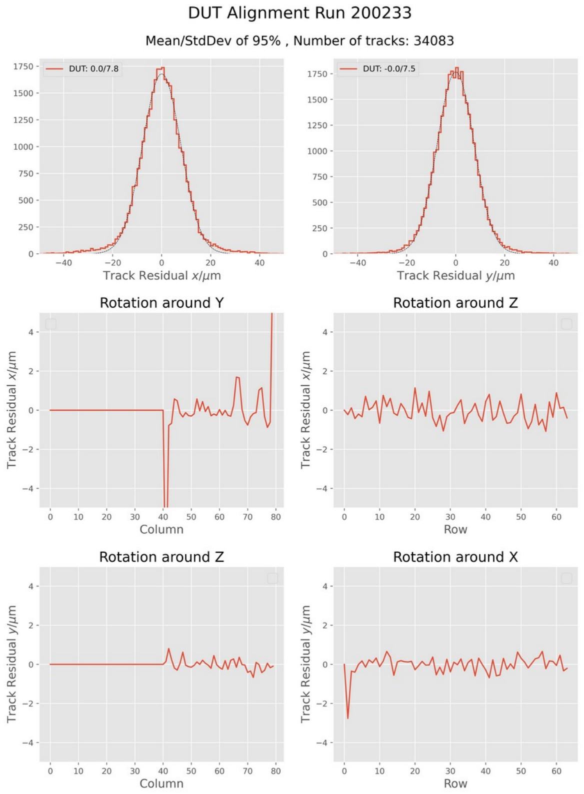






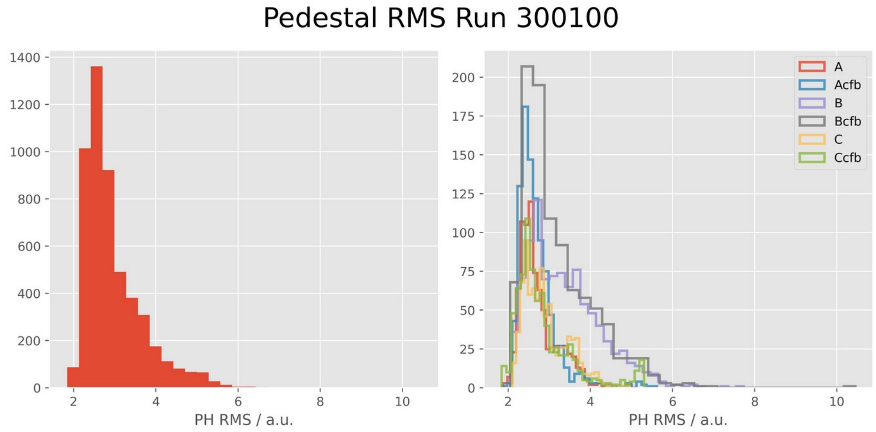
DUT Alignment

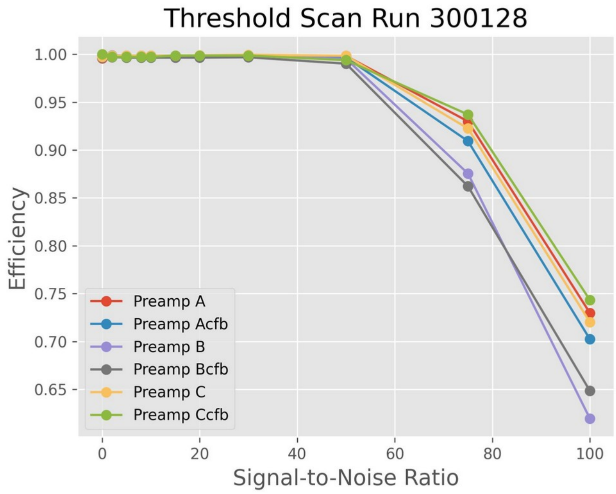




DUT Hit Discrimination

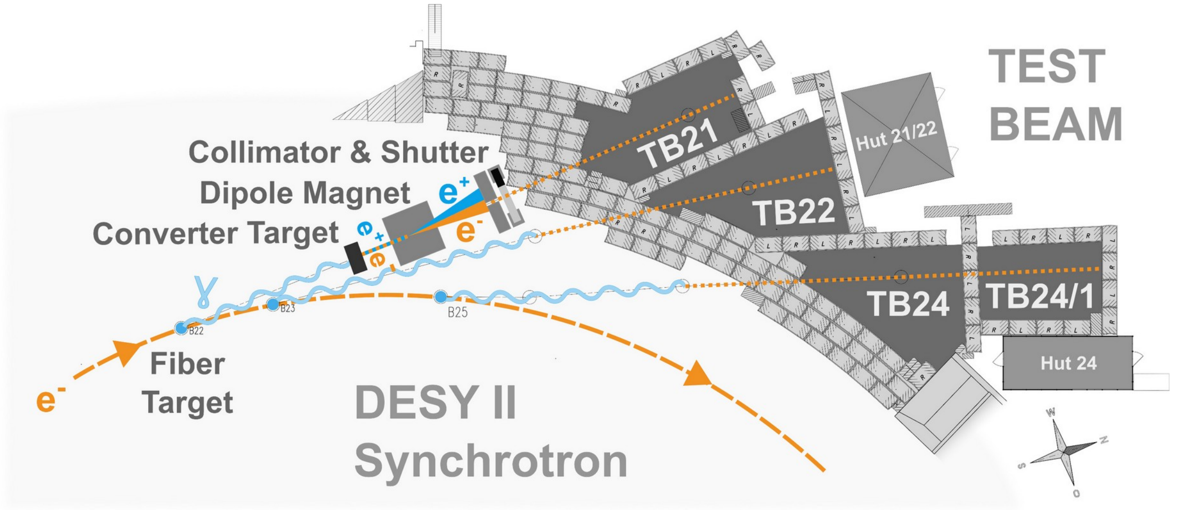
- Online threshold has to be high due to problem during readout
- Used offline threshold
- All the pixels are read for each trigger
- Pedestal calculated for each pixel
- 8 x RMS offline threshold, calculated per pixel
- A few hundred electrons electrons

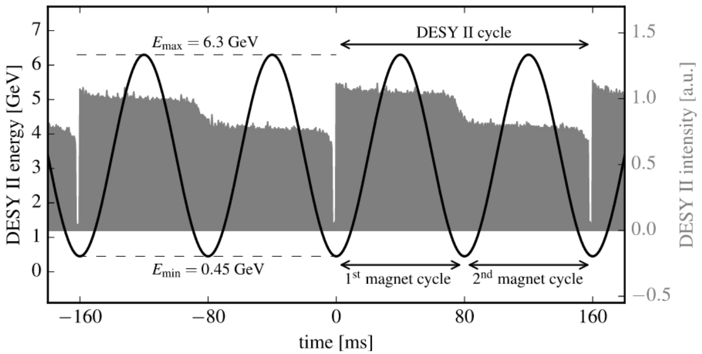


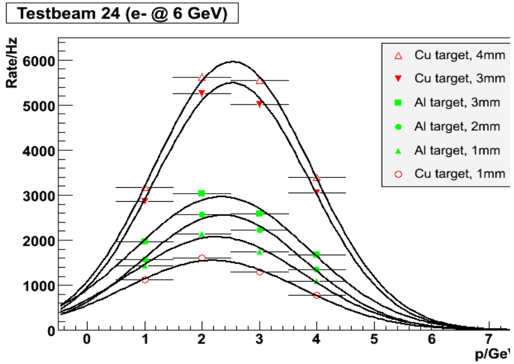


DESY II

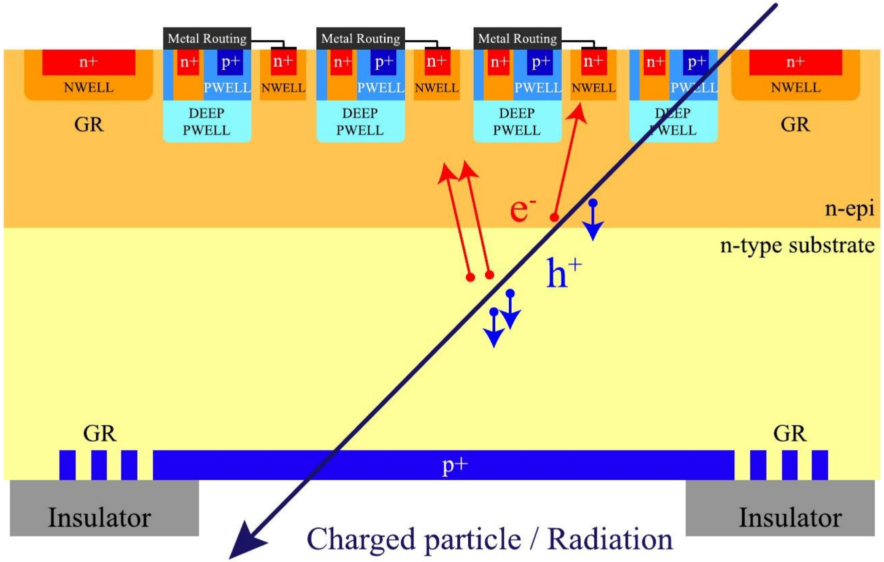
- Electron / positron beam
- Circumference: 292.8 m
- Energy cycle: 12.5 Hz (50 Hz /4)
- Revolution frequency: 1 MHz
- Bunch length: 30 ps
- Energy: 1 to 6 GeV
- Divergence: 1 mrad
- Primary particles hit a carbon fiber, generates bremsstrahlung photons
- A metallic target converts the photons t electrons/positrons
- Magnet current selects the beam momentum

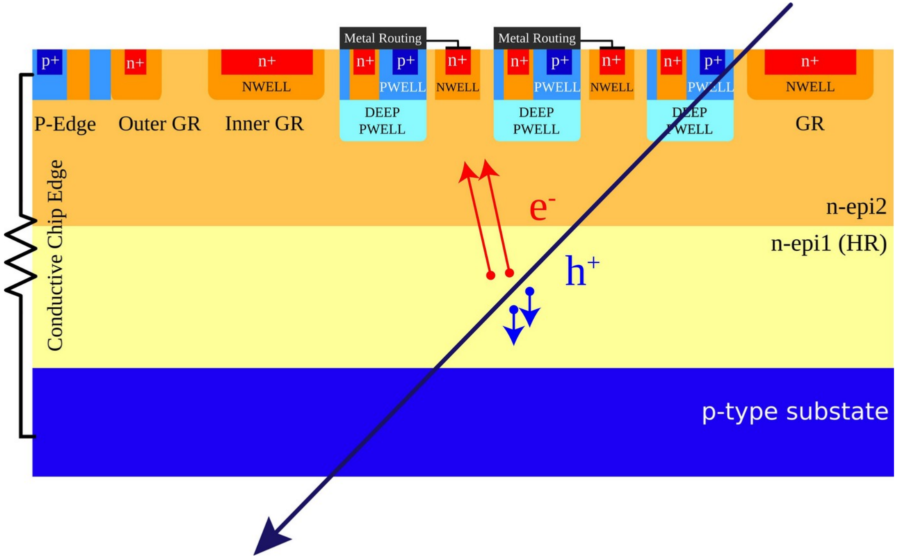




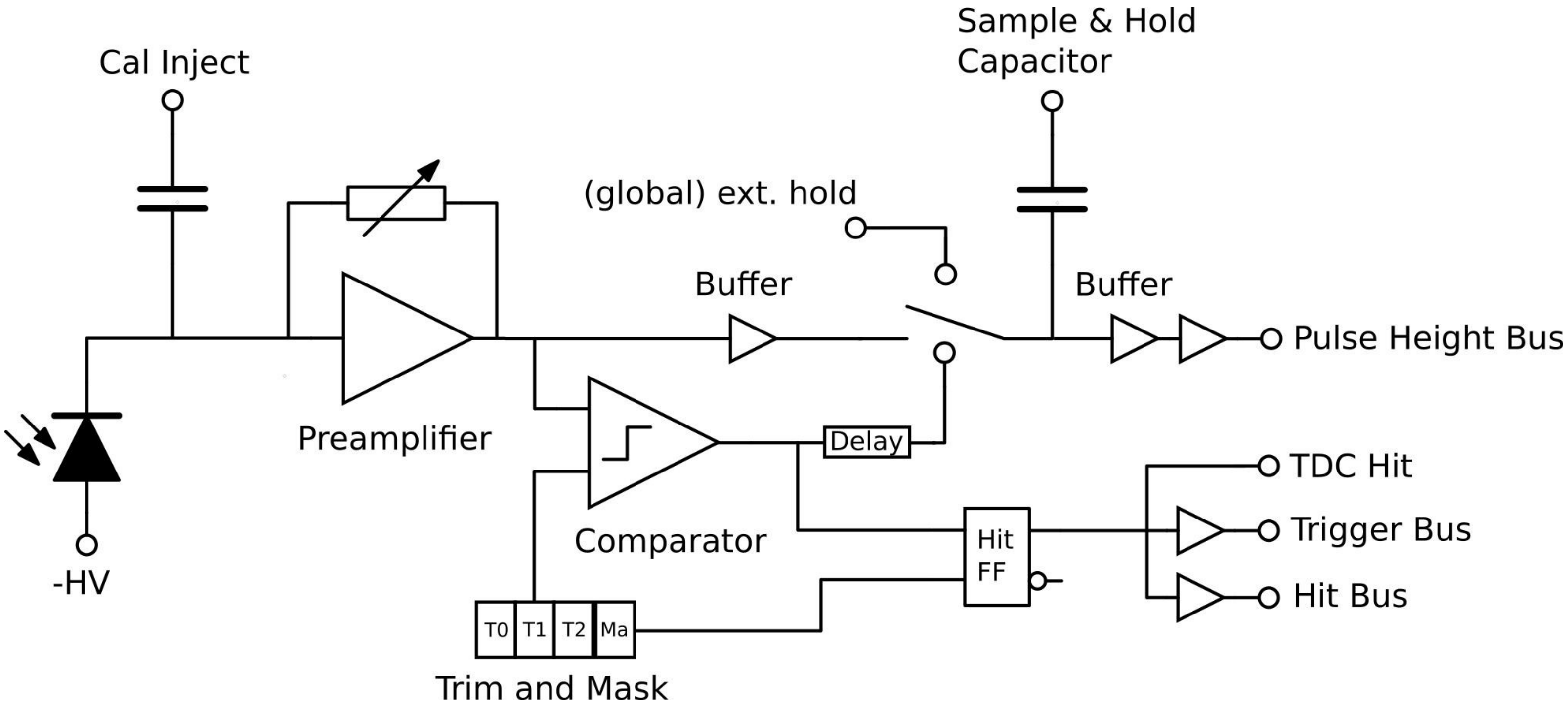


LF110 Process Overview

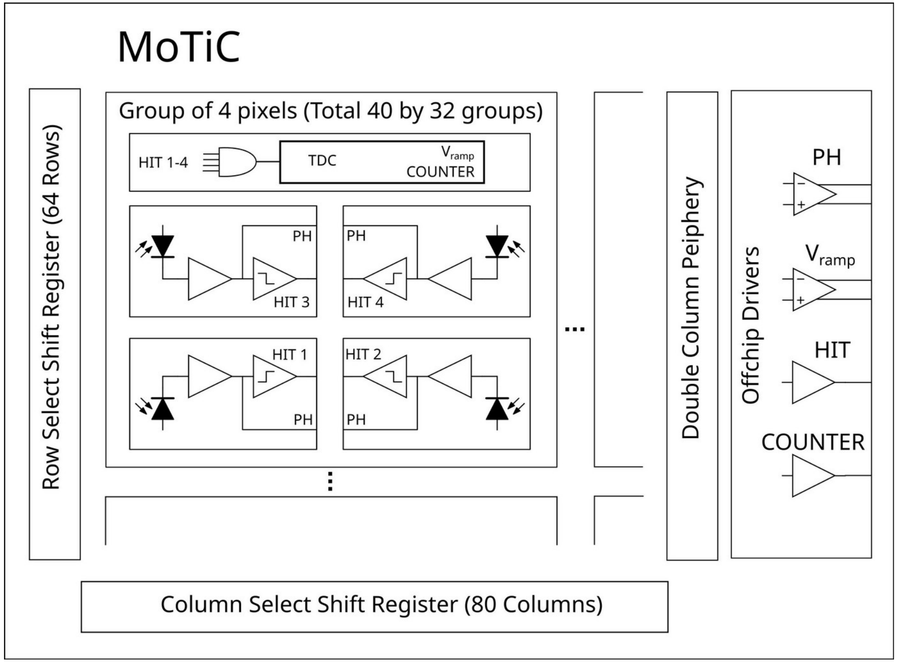




Pixel Schematic



MoTiC A Overview



Preamplifier Schematics