MALTA — Rad Hard Monolithic Pixel Sensors in Tower 180 nm for Tracking and Timing

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for the MALTA R&D Collaboration*

MALTA - MAPs for Collider Applications

- NIEL radiation hardness 3 x 10^{15} n_{eq}/cm^2
- TID radiation hardness >100 Mrad
- Pixel Pitch 36.4 x 36.4 μm^2
- 40 MHz bunch tagging
- Low voltage operation (6V to 55V)
- Sensor size ~20 x 20 mm^2
- Target ENC noise ~ 10 e-
- Minimal Threshold ~ 100 e-

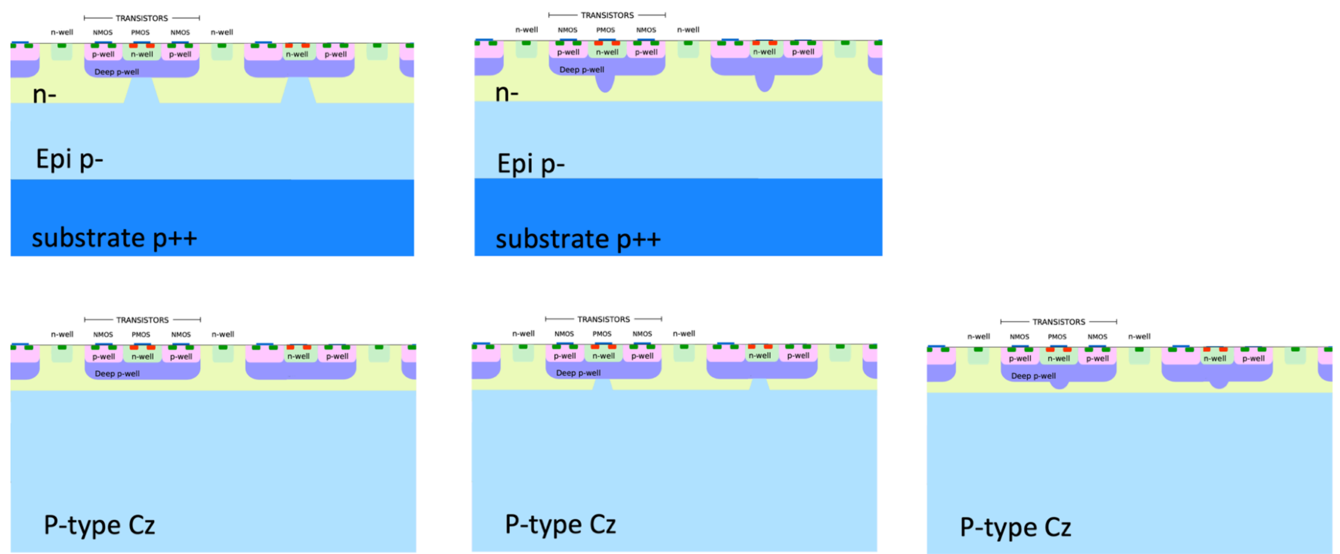
Optimised Readout Architecture

- Asynchronous readout architecture → high hit rate capability
- Data streaming for triggerless readout, track trigger formation
- Sensor-to-sensor high-speed signal transmission for modules

MALTA Sensor Performance & Parameters

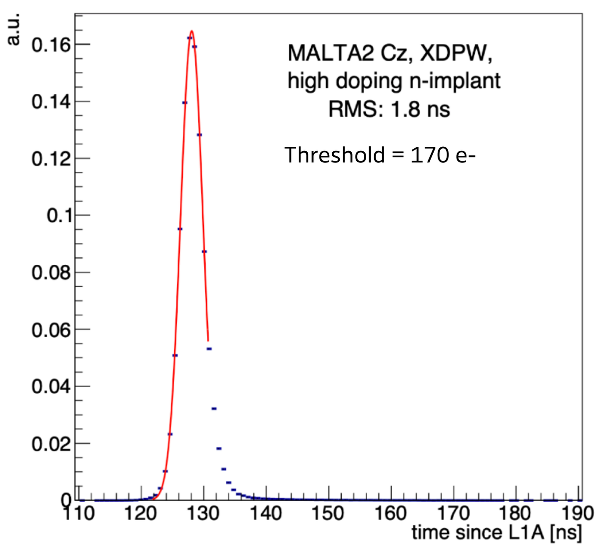
- Matrix size 512 x 512 pixel (MALTA1) or 512 x 224 pixel (MALTA2)
- Radiation-hard MALTA sensor implemented in high volume industrial 180 nm CMOS imaging process (Tower Semiconductor)
- Small 3 µm collection electrode, 3.5 µm spacing to electronics → small pixel input capacitance of 230 aF, low cross talk
- Optimisable sensor thickness—from 50 µm to 300 µm
- Low pixel analog power: <1 µW/pixel
- Full efficiency (>98%) 2 x 10^{15} n_{eq}/cm^2
- Time-resolution <2 ns
- Threshold after irradiation ~120 e-
- Optimised implant design for high charge collection speed, fast signal response and radiation hardness
- Produced on Epitaxial and Czochralski high-resistivity substrates

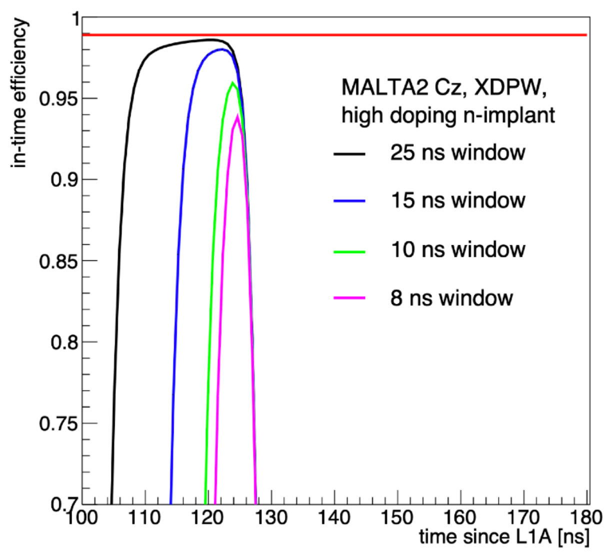
MALTA Sensor Variants



MALTA pixel and substrate variants:
Sensors produced with several field-shaping options in high-resistivity Epi or Czochralski

Timing Studies

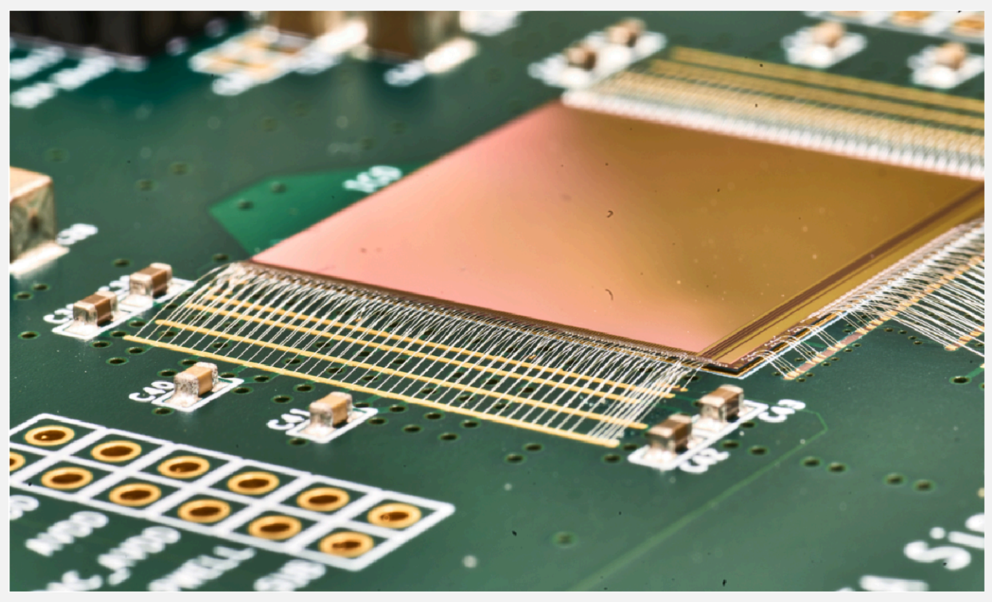




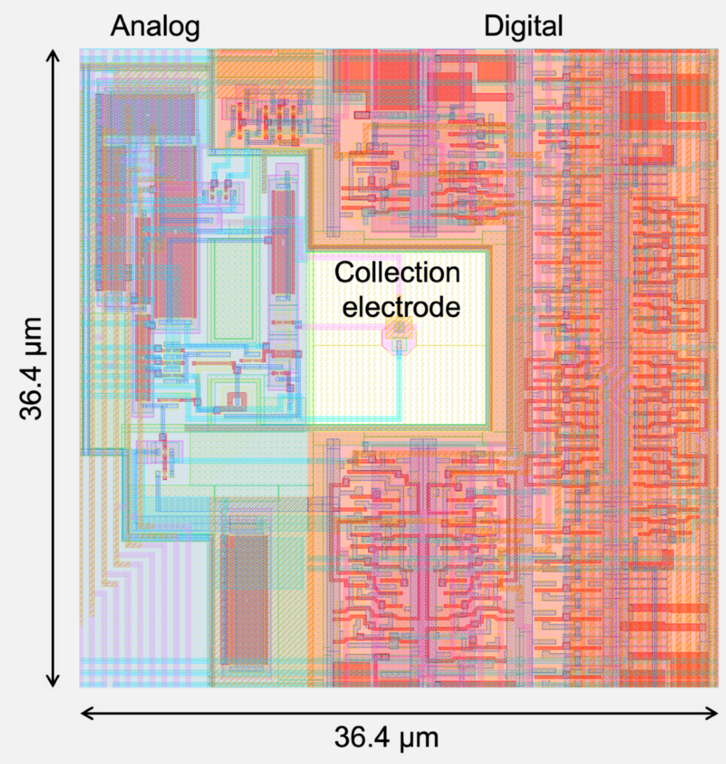
Timing Resolution σ_t ~ 1.7 ns, from
- Electronics jitter, Time-walk
- Charge collection effects
- Scintillator jitter (~0.5 ns)
- FPGA readout jitter (~0.9 ns)

Charge Collection Within Window
- Timing = leading hit wrt scintillator
- 90% of hits collected within 8 ns
- 98% of hits collected within 25 ns
- 95% within 25 ns @ 3 x 10^{15} n_{eq}/cm^2

Pixel and Sensor Test Layout

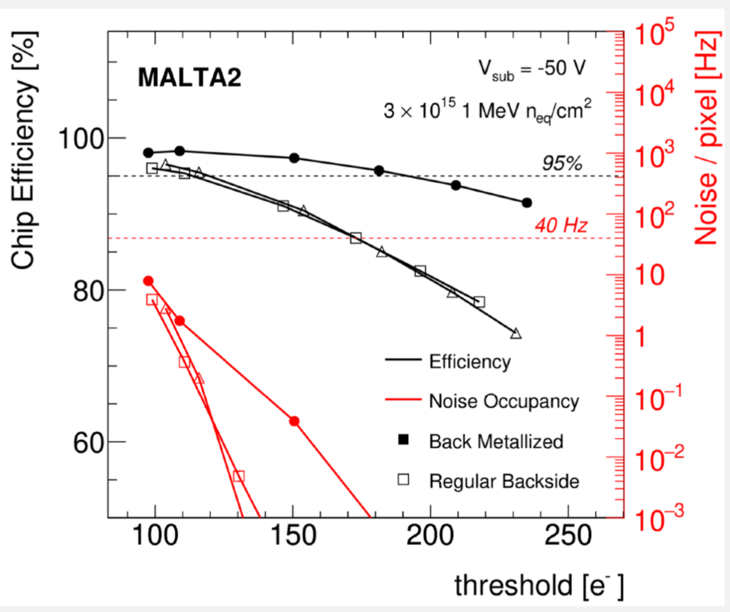


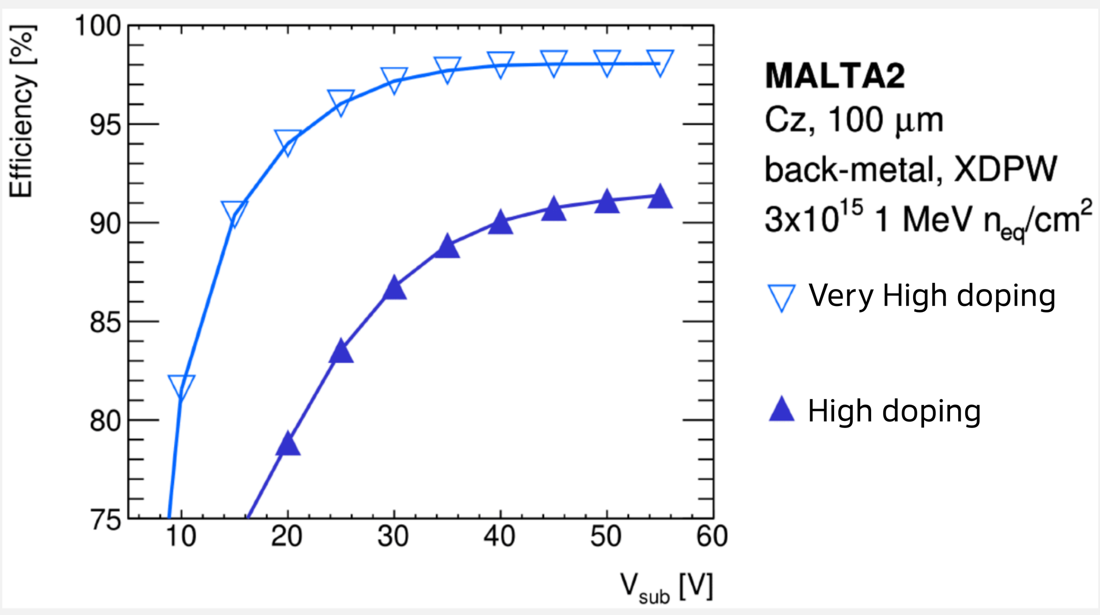
MALTA Test Setup:
Fast FPGA-based readout, custom firmware, PC board for sensors



MALTA Pixel:
Separate analog and digital sections (mirrored)

Radiation Hardness

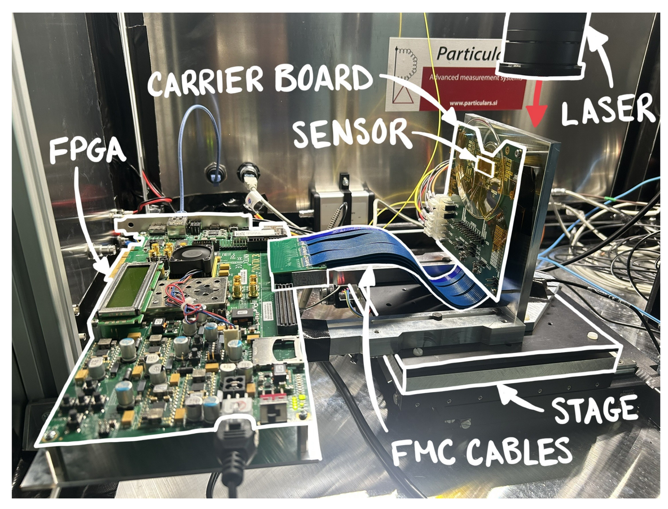


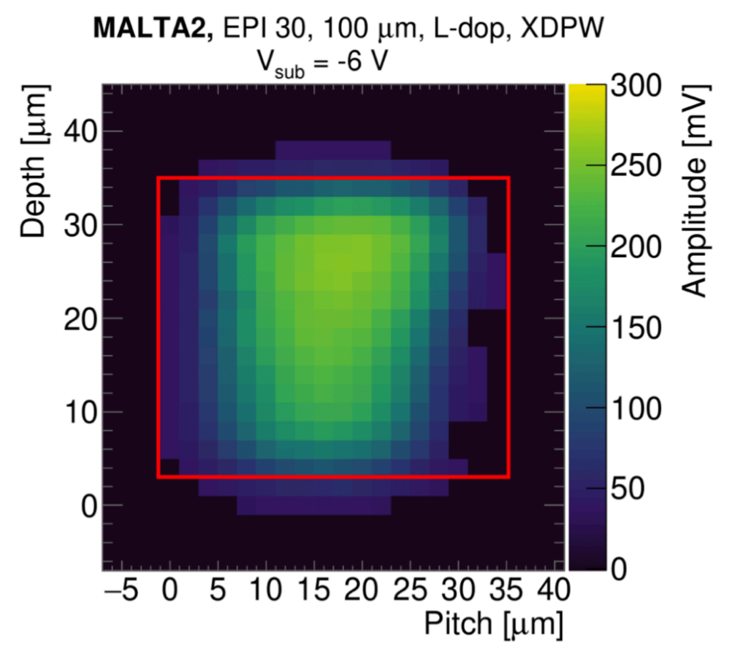


Excellent efficiency after 3 x 10^{15} n_{eq}/cm^2
- -30 V bias on VH-doped sensors
- Backside metallisation for eff. biasing
- Small noise occupancy

Very High Doping
- With ~70% higher doping on continuous n-layer
- > 95% efficiency up to 3 x 10^{15} n_{eq}/cm^2
- Good efficiency even in the pixel corners

Depletion Studies: Edge TCT

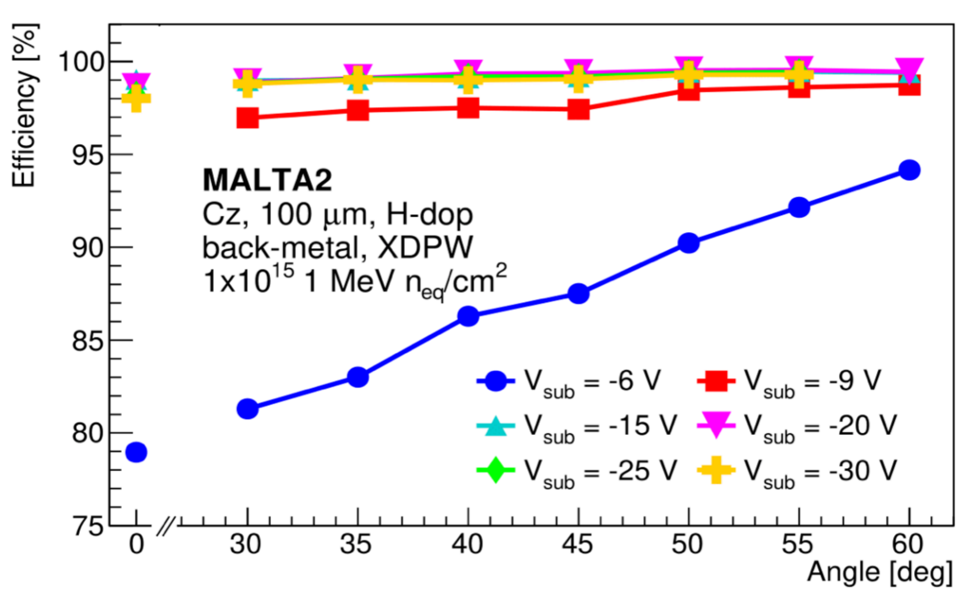


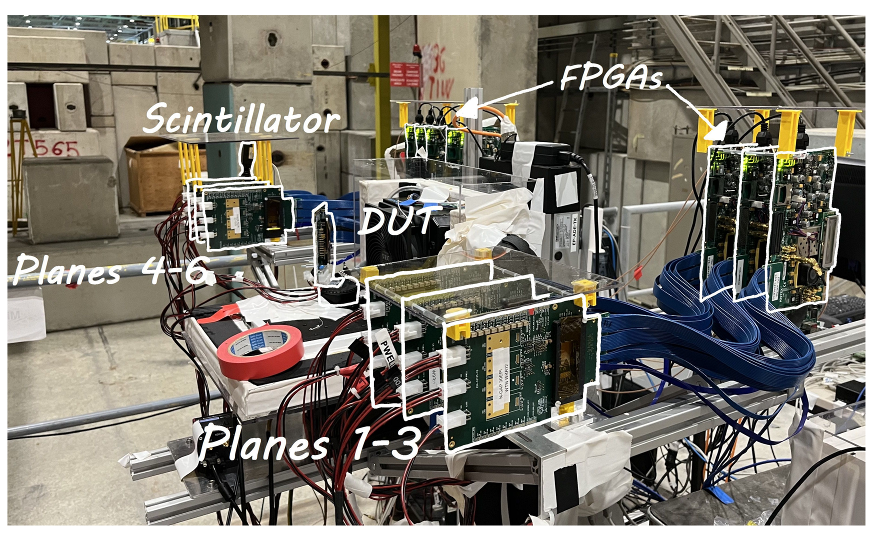


Edge TCT Setup @ DESY+HU
- IR pulsed laser, 1064 nm wavelength
- 4 µm beam width at focus
- Sensor edge polish + PCB cut out
- Charge injection in special analog pixels
- Scan in 2 axes w/ ~0.2 µm precision

ETCT scan of MALTA2
- MALTA2 with 30 µm Epitaxial layer
- Red box = approximate pixel location
- Pitch FWHM @ -6V: 23.6 ± 0.2 µm
- Depth FWHM @ -6V: 30.2 ± 0.2 µm

Grazing Angle Studies: CERN SPS Testbeam

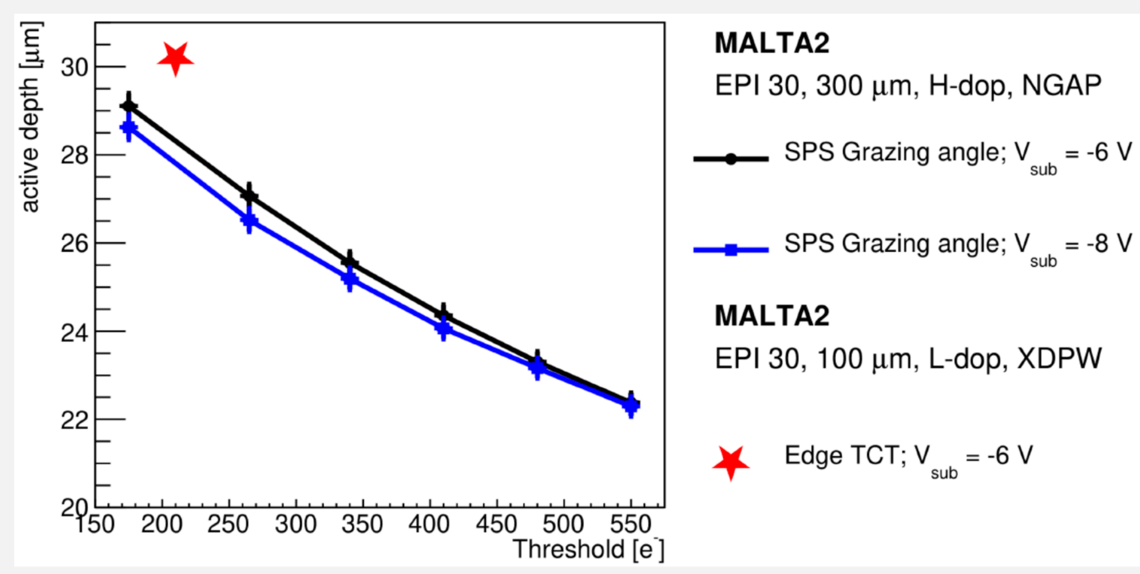




Inclined MALTA2 sensors @ SPS
- Studied inclined 1 x 10^{15} n eq/cm² irradiated sensor
- MALTA2 Czochralski sensor from -6 V to -30 V
- Demonstrated increased efficiency and cluster size
- Recover efficiency at low bias for irradiated samples

MALTA Telescope @ CERN SPS
- 6 tracking planes, <5 µm spatial resolution
- Scintillator for timing
- Cold box: up to 2 DUTs + rotational stage
- Flexible triggering, online monitoring

Depletion Studies: Summary



Grazing Angle + Edge TCT Comparison
- Active depth measured by two separate methods
- SPS threshold: pixel discriminator, Edge TCT threshold: oscilloscope trigger
- Almost no change in active depth vs. bias
- Grazing Angle vs. eTCT results match at low threshold

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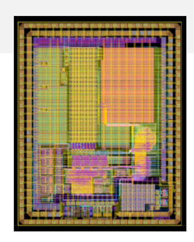
[1] https://ade-pixel-group.web.cern.ch/PublicPlots
[2] MALTA Telescope: EPJC 83 (2023) 7, 581
[3] MALTA2 Czochralski: EPJC 84 (2024) 251
[4] MALTA2 Depletion Depth: NIMA 1063 (2024)

Coming Soon: MALTA3



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