Performance of CMOS sensors for a digital electromagnetic calorimeter

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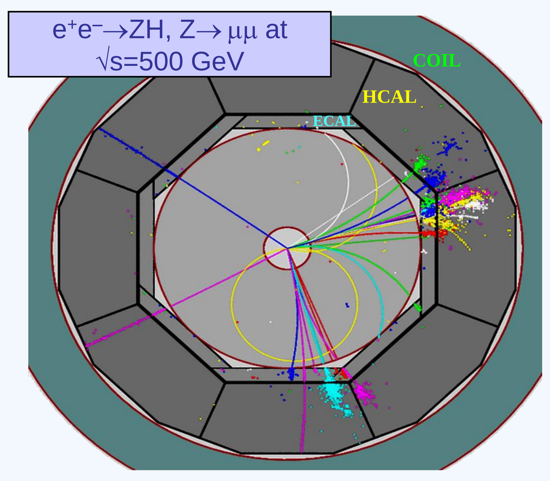
SPiDeR

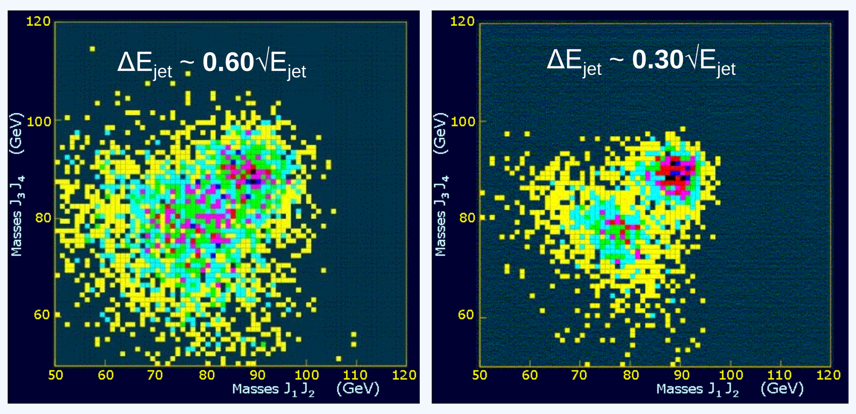
http://www.spider.ac.uk/

Motivation

The e+e- international linear collider (ILC)
•Planned CM energy in the range 500 GeV to 1 TeV
•Complements the physics programme of the LHC

Most ILC physics processes characterised by multi-jet final states
•The reconstruction of the invariant mass of two or more jets is critical (see right; from CALICE collaboration)
•Jet energy resolution major driver for detector design
•"Particle flow" widely accepted as good technique to achieve required performance

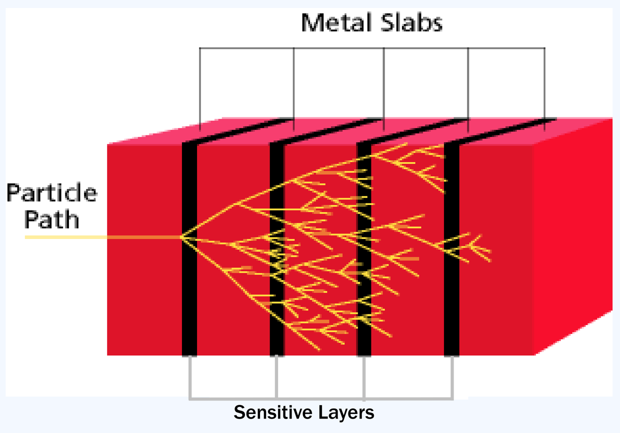


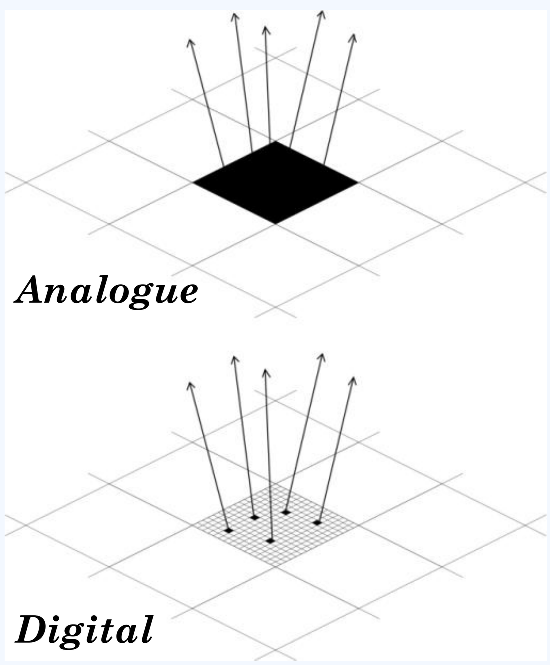


WW and ZZ separation for different jet energy resolutions shown left (from CALICE collaboration)
•Sets requirement around $\sigma_E/E = 30\%/\sqrt{E}$

Digital Electromagnetic Calorimetry

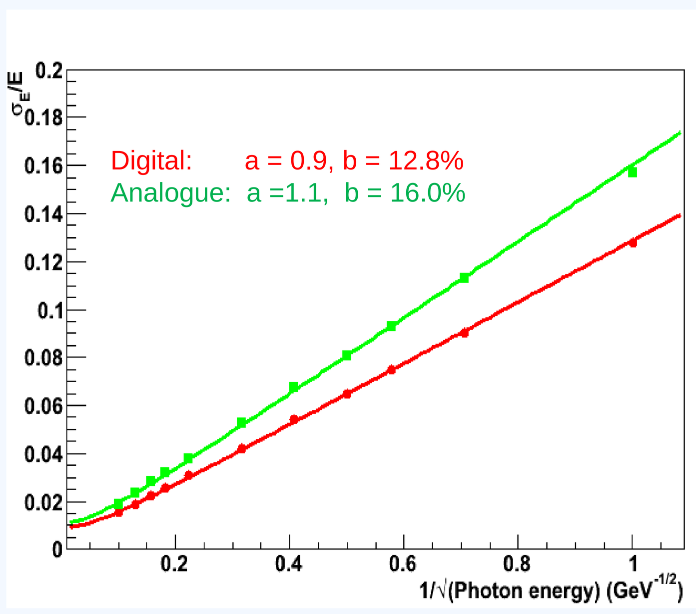
Electromagnetically interacting particle gives shower in dense material (see right)
•Usually, sampling calorimeter measures energy deposited in sensitive layers (analogue readout)
•Concept of digital calorimetry is to measure number of particles in sensitive layers instead





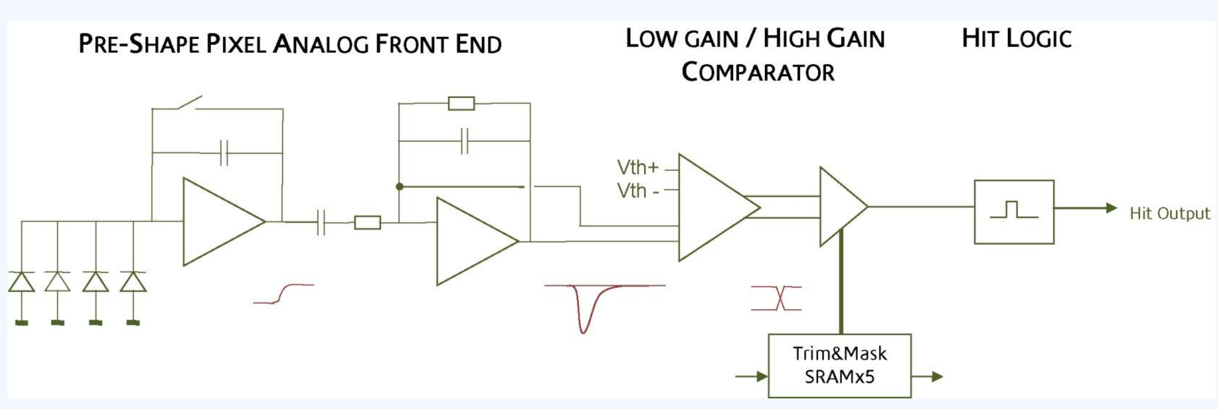
Counting particles eliminates resolution contribution from Landau fluctuations
•Closer to intrinsic stochastic shower variations
•Fine pixel granularity reduces probability of multiple particles per pixel (see left); allows digital pixel readout
•High granularity should also improve particle flow

Simulation indicates significant resolution improvement in principle (see right)
•Exact value sensitive to core shower density; not measured at high granularity
•Resolution needs to be demonstrated in practice



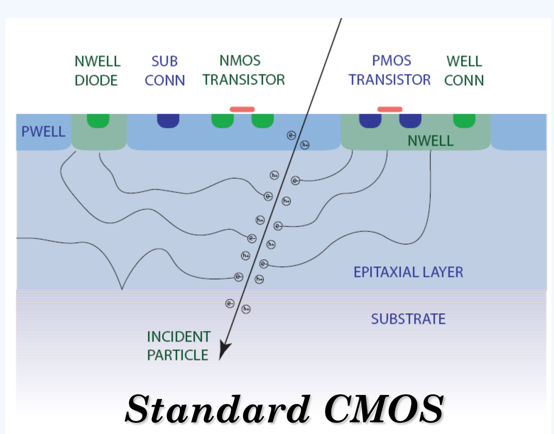
TPAC 1.2 Sensor

The TPAC (Tera-Pixel Active Calorimeter) sensor V1.2 is a study sensor to investigate aspects of digital electromagnetic calorimetry

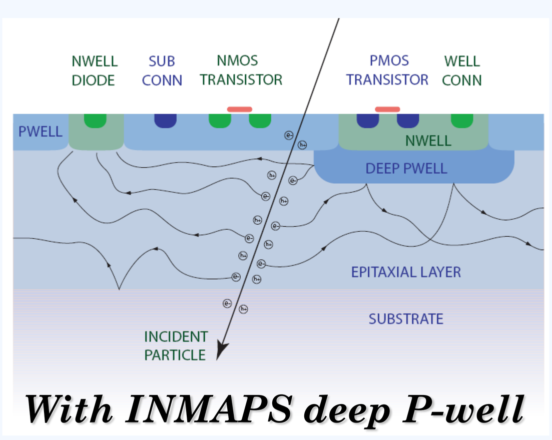


•Four signal diodes per pixel for efficient charge collection
•Shaping preamplifier, comparator and individual trim circuit in every pixel (see left)
•Timing and readout architecture compatible with ILC beam structure

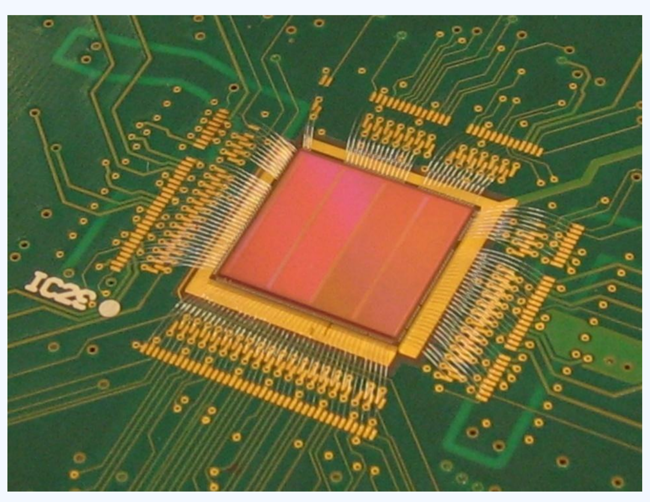
Fabricated in "INMAPS" process; enhanced features beyond standard CMOS
• Deep P-well to prevent signal absorption in circuit N-wells (see right); allows use of full CMOS (NMOS and PMOS) in pixel
•High-resistivity epitaxial layer for faster signal collection



Standard CMOS



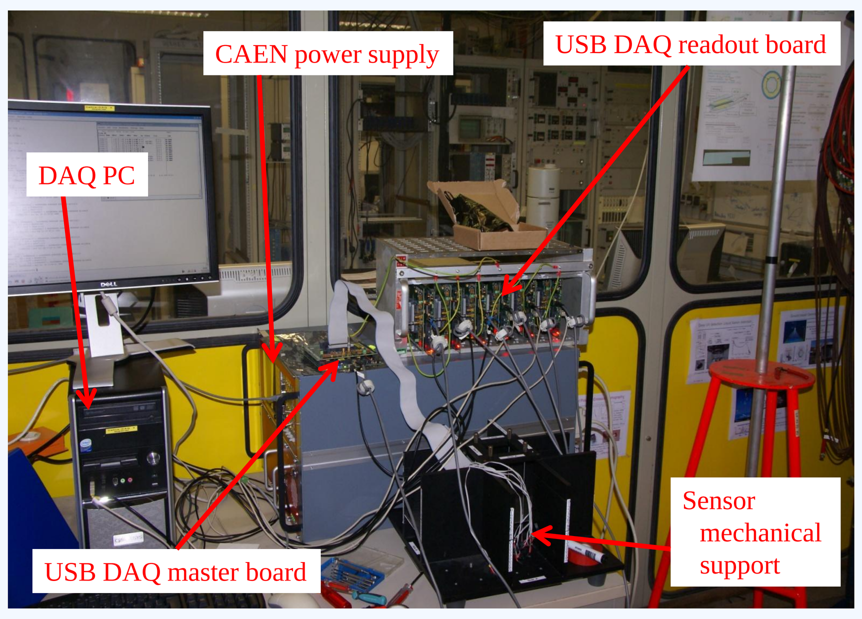
With INMAPS deep P-well



TPAC 1.2 fabricated in 0.18μm INMAPS CMOS
•50μm pixel pitch on a 1cm² sensor (see left)
•168×168 pixel array, 28k pixels total

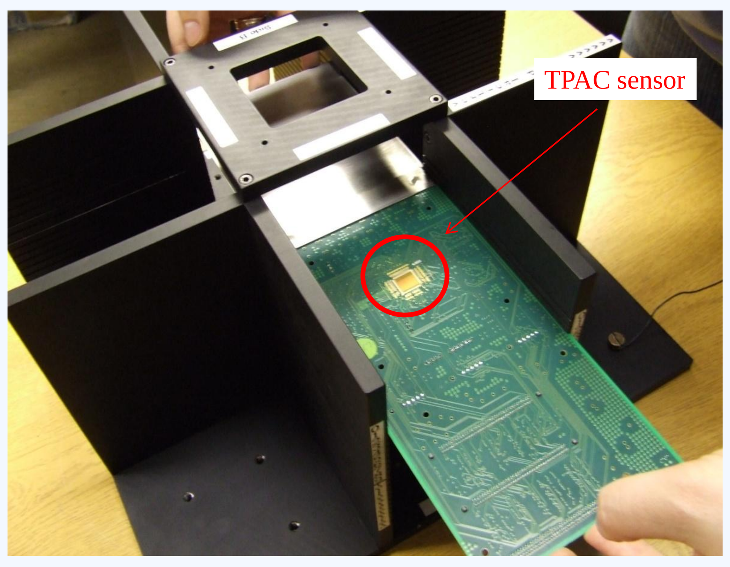
Total of four variants of sensors made, including with and without INMAPS enhancements
•Standard CMOS process
•INMAPS deep P-well enhancement
•INMAPS deep P-well and high-resistivity epitaxial layer, with standard (12μm) and thicker (18μm) layer depth

CERN and DESY Beam Tests

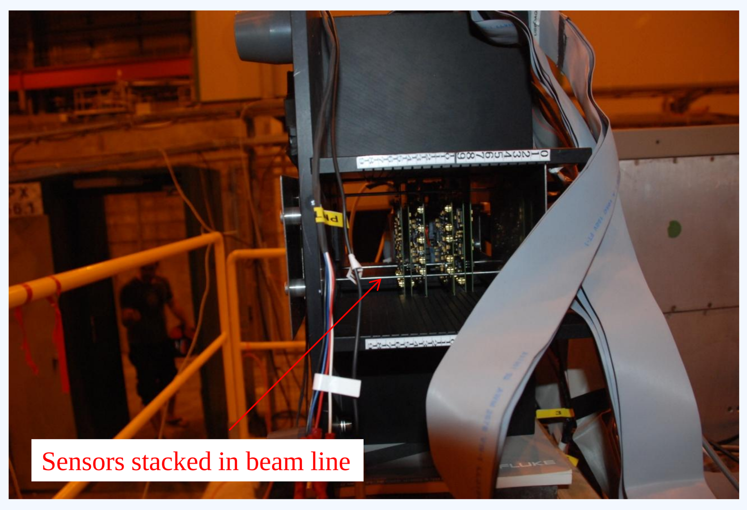


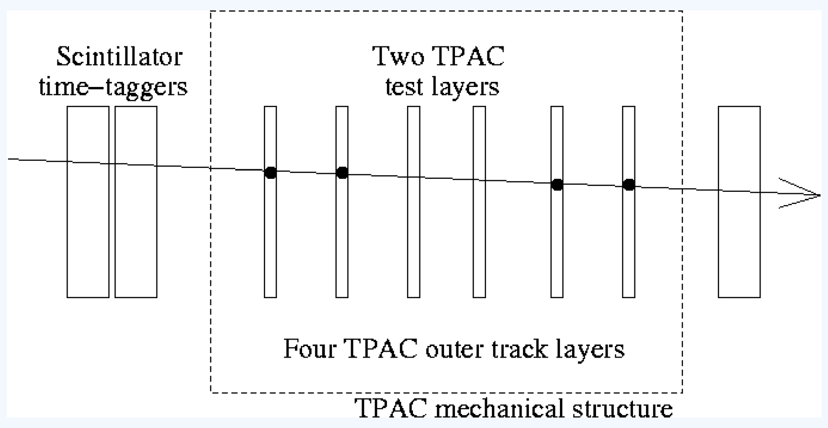
TPAC 1.2 sensors tested in beam at CERN (Aug 2009) and DESY (March 2010)
•All four sensor variants tested in beam
•120GeV pion beams at CERN
•1-5GeV electron beams at DESY

Custom-designed DAQ system (see left)
•ILC-like timing and readout
•USB-based interface to Linux PCs



Custom mechanical sensor support (left and below) allows up to six sensors to be stacked at precise positions relative to each other in beam

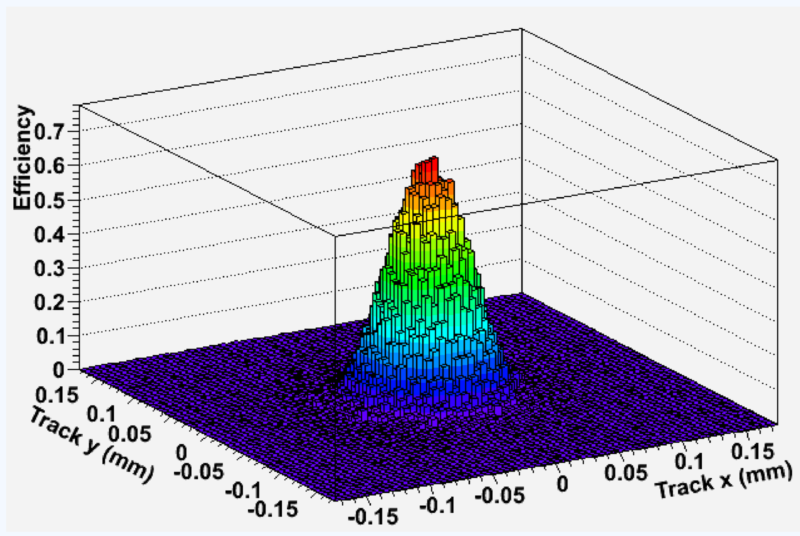




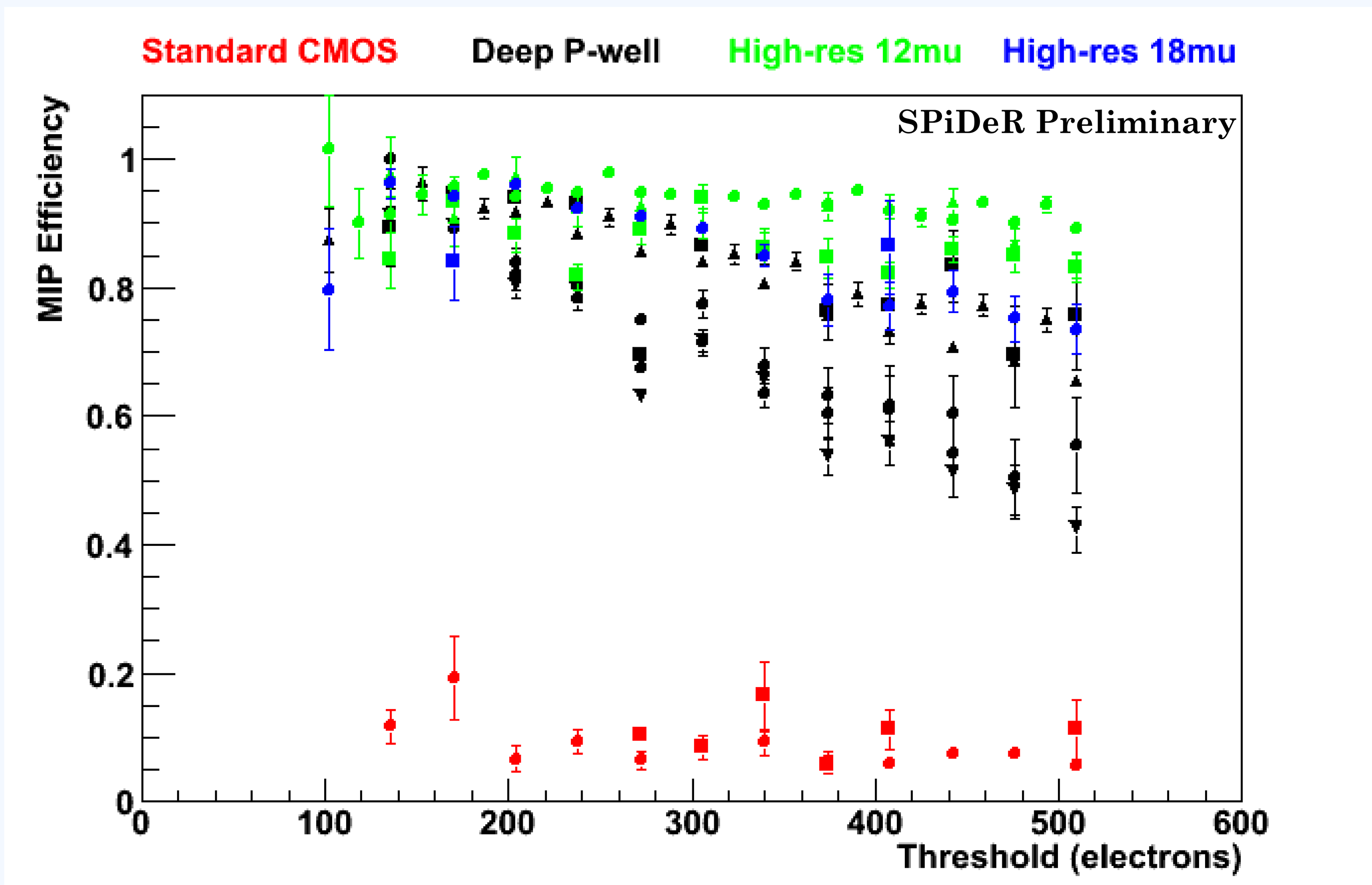
MIP leaves average signal of ~1200 electrons in a 12μm epitaxial layer
•Measure MIP efficiency as a function of digital readout threshold using tracks formed in sensors of other layers

Beam Test Results

Project tracks to individual sensors
•Check for sensor hits as a function of position relative to pixel centre to find probability of hit (see right)
•Determine MIP efficiency by fitting distribution of hit probability to a flat top function, convoluted with a Gaussian to allow for track resolution



MIP efficiency per pixel for both CERN and DESY data measured for all four sensor variants (see below)
•Due to use of in-pixel PMOS transistors, standard CMOS sensors have low efficiency
•Deep P-well cuts off N-well signal absorption and raises efficiency by factor ~5
•Adding high-resistivity epitaxial layer makes further improvement with resulting efficiency close to 100%



Very significant improvement in efficiency found using INMAPS enhanced features compared to standard CMOS process, allowing use of in-pixel PMOS components