Beam Test Report 2010: FORTIS TPAC

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for the SPiDeR collaboration
(slides from M. Stanitski, Pixel2010)

(Plus Eμ proposal)

Introduction

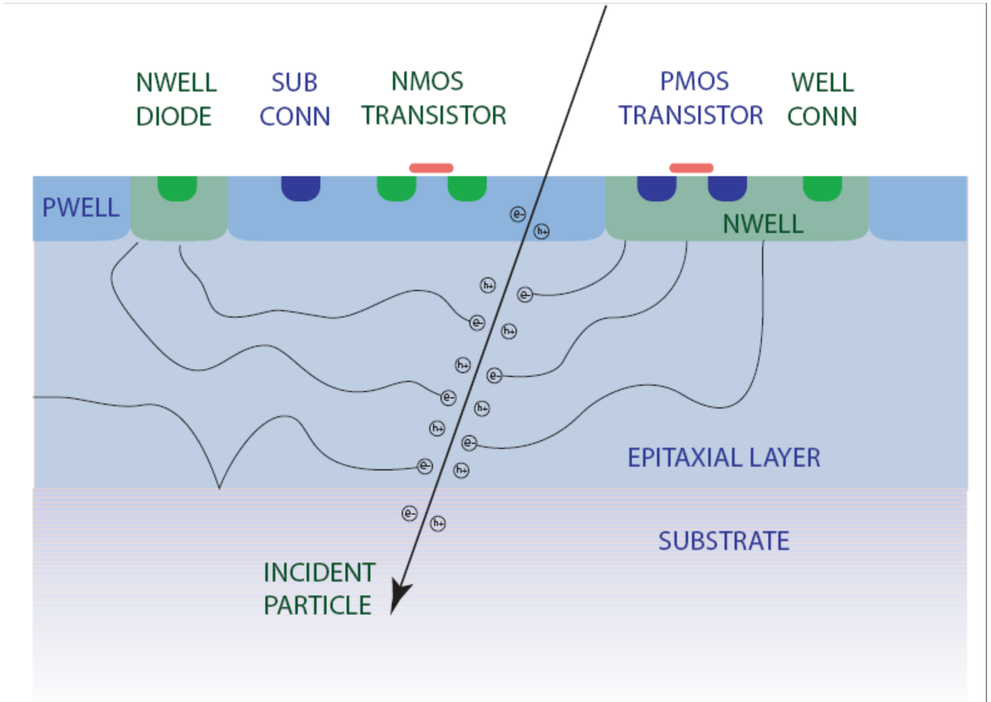
- SPiDeR = **S**ilicon **Pi**xel **De**tector **R**&D
- UK-centered Collaboration
  - generic CMOS Pixel R&D for future Colliders
  - Birmingham, Bristol, Imperial College, Oxford and RAL
  - recently Queen Mary College joined
- Develop CMOS Sensors to address requirements for future colliders
  - Granularity
  - Speed
  - Power
  - Material budget

The INMAPS Process

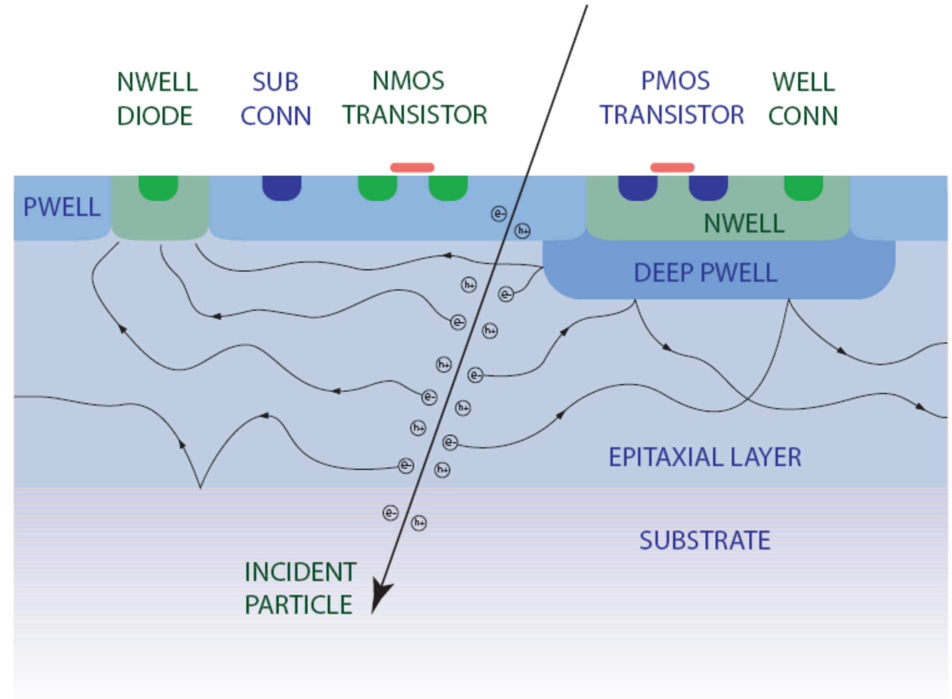
INMAPS features

- Standard CMOS Process
  - 180 nm
  - 6 metal layers
  - Precision passive components (R/C)
  - Low leakage diodes
  - 5/12/18 μm epitaxial layers
- Added features for INMAPS
  - Deep p-well
  - High resistivity epitaxial layer
  - 4T structures
  - Stitching

Deep p-well implants



Standard CMOS

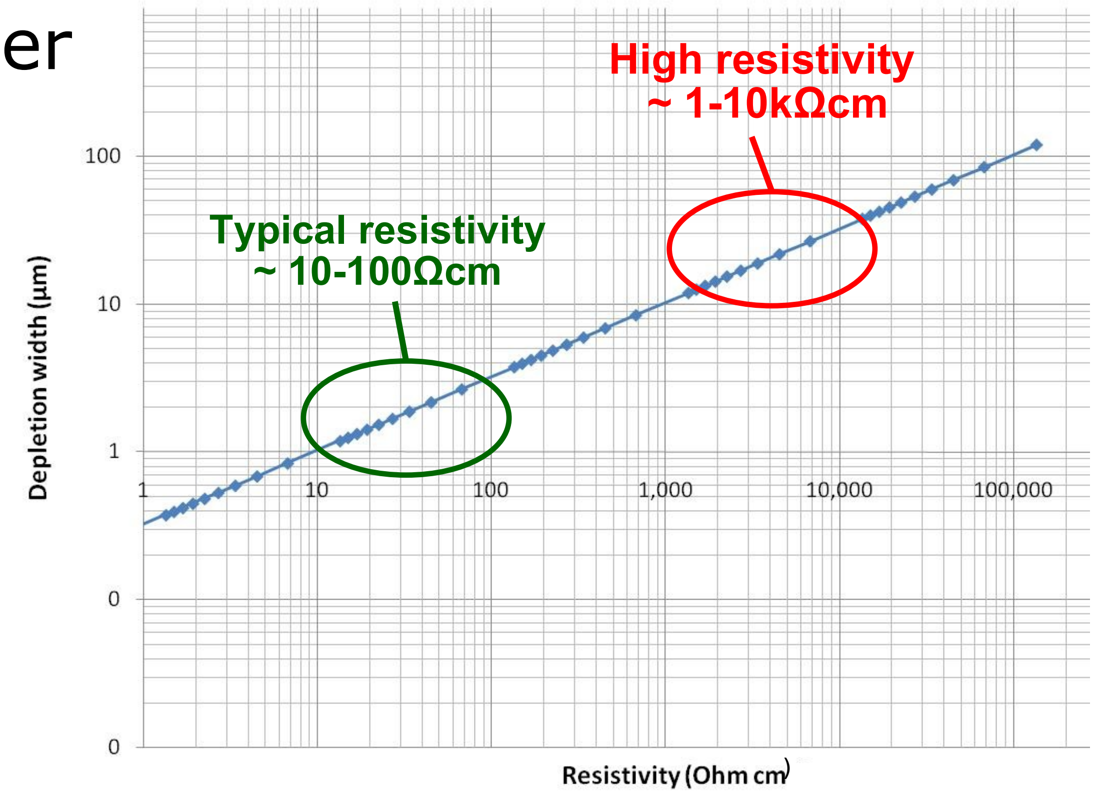


INMAPS

- Eliminate parasitic charge collection by PMOS
  - Allow full CMOS in-pixel electronics

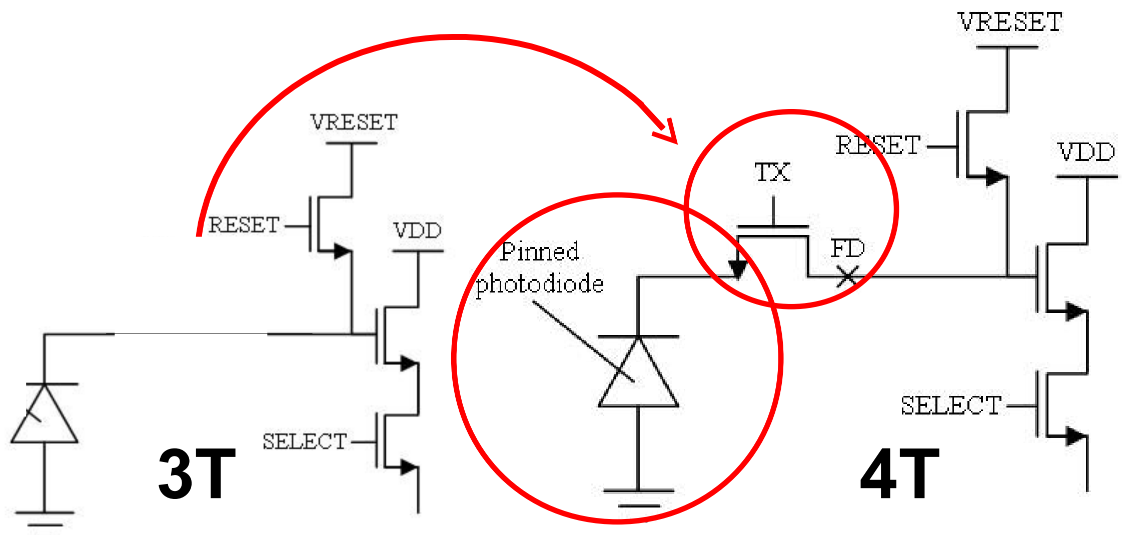
High resistivity Epi-layers

- Charge collection by diffusion in epitaxial layer
  - slow
  - radiation-soft
- INMAPS on high-res Epi
- Potential benefits
  - Faster charge collection
  - Reduced charge spread
  - Increased Radiation hardness



4T Pixels

- **3T MAPS**
  - Readout and charge collection area are the same
- **4T MAPS**
  - Readout and charge collection area are at different points
  - Charge transferred to floating diffusion
- Benefits
  - Low Noise & in-pixel CDS
  - High Gain



STFC Centre for Instrumentation funded Fortis 1.0/1.1 as a technology prototype (see later)

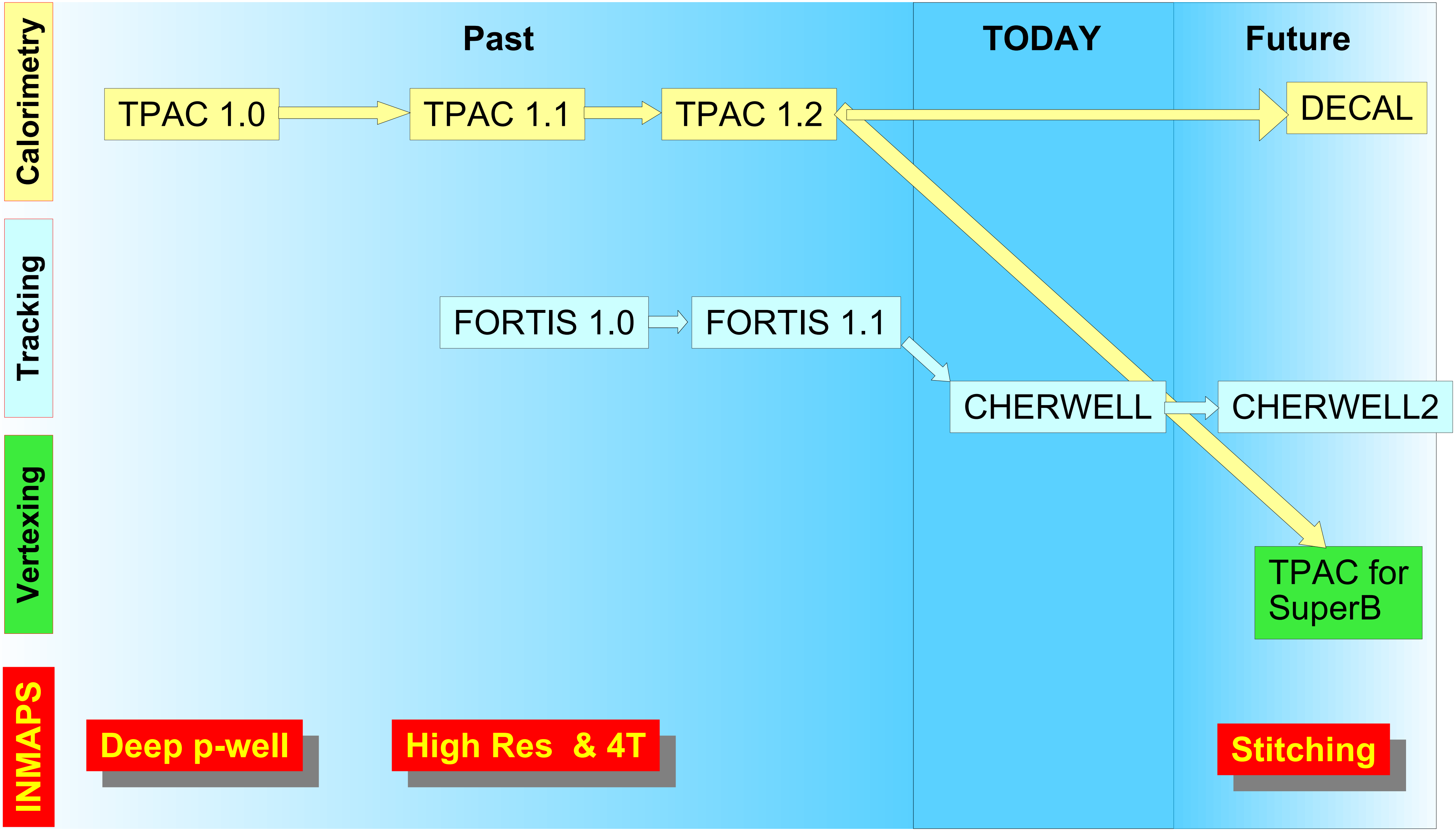
Stitched Sensors

- Standard CMOS limited to ~ 2.5 x 2.5 cm^2
- Technique relatively new to CMOS
  - Stitching offered by some foundries
  - Allows wafer-scale sensors
- Example Sensor
  - LAS (For imaging)
  - Designed at RAL
  - 5.4x5.4 cm^2

SPiDeR

Sensors & Results

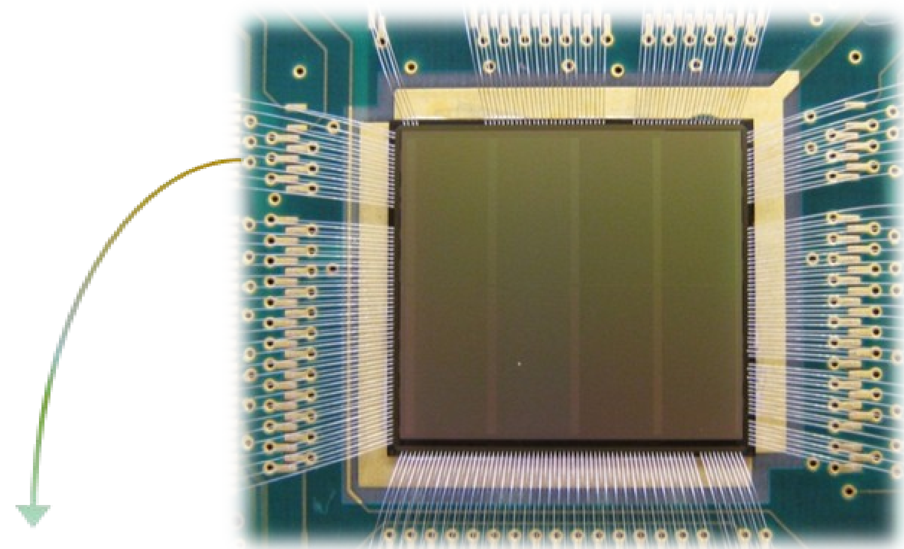
Sensor Overview

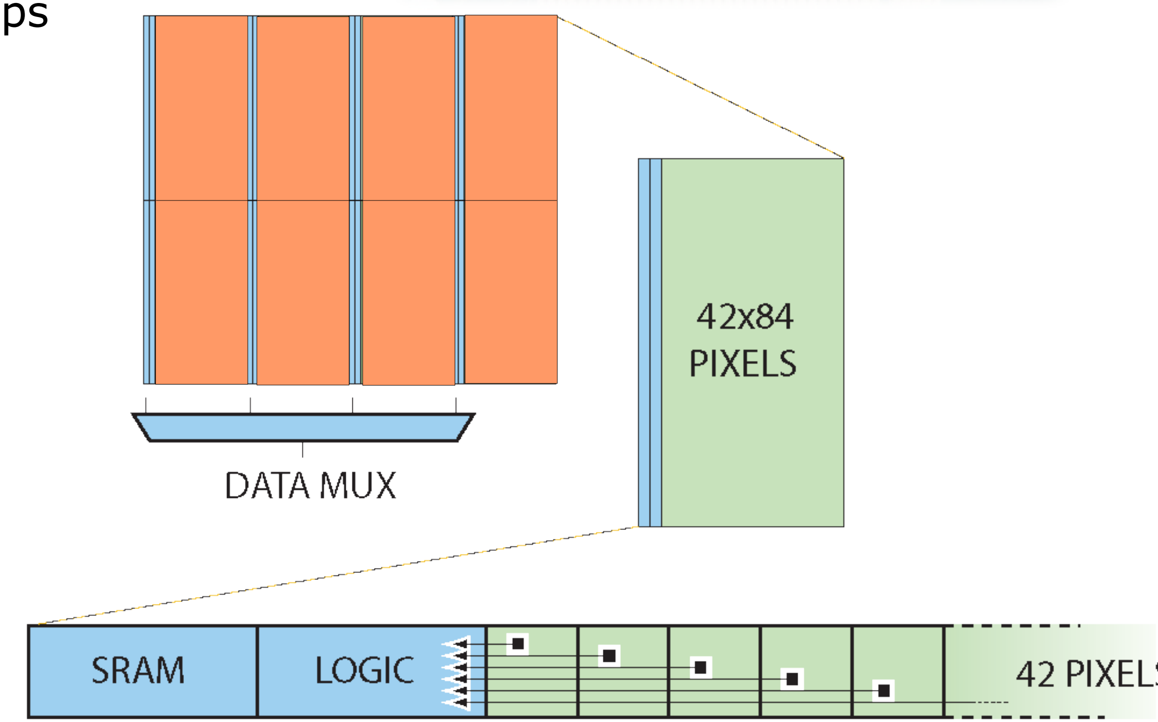


SPiDeR

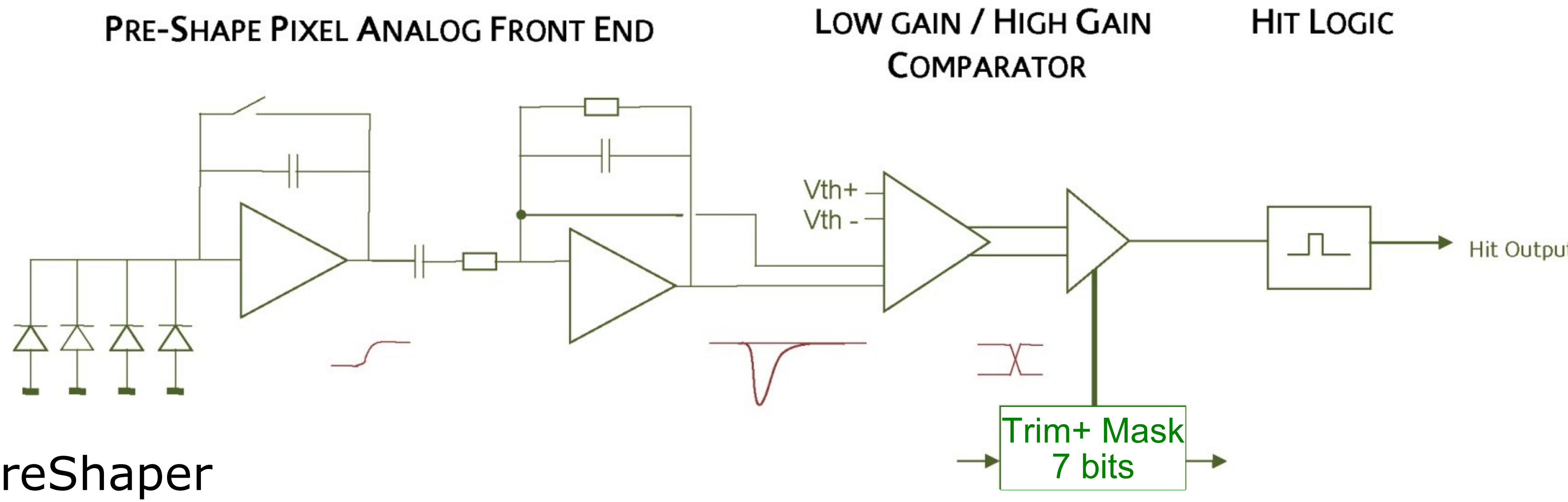
The TPAC 1.2 Sensor

- 8.2 million transistors
  - 28224 pixels , 50 x 50 μm
- Sensitive area 79.4 mm^2
  - of which 11.1% “dead” (logic)
- Four columns of logic + SRAM
  - Logic columns serve 42 pixels
  - Record hit locations & timestamps
  - Sparsification on chip
- Data readout
  - Slow (<5Mhz)
  - 30 bit parallel data output
- Developed for
  - Digital ECAL as Particle Counter

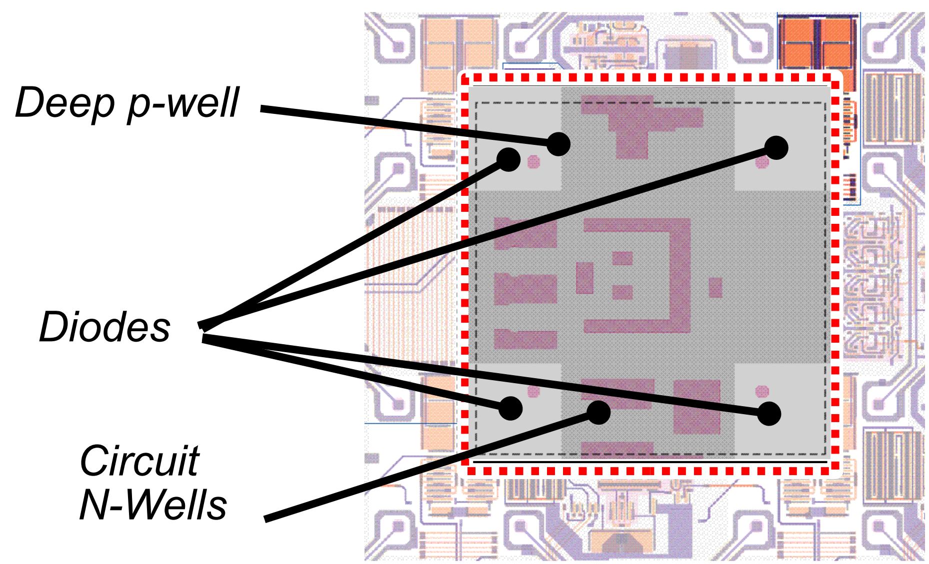




TPAC Architecture Details

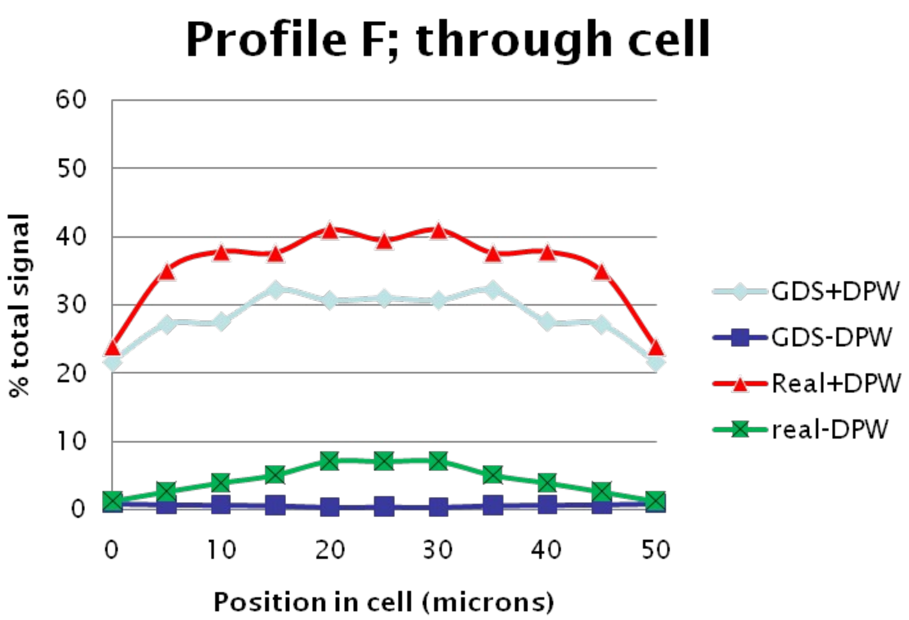


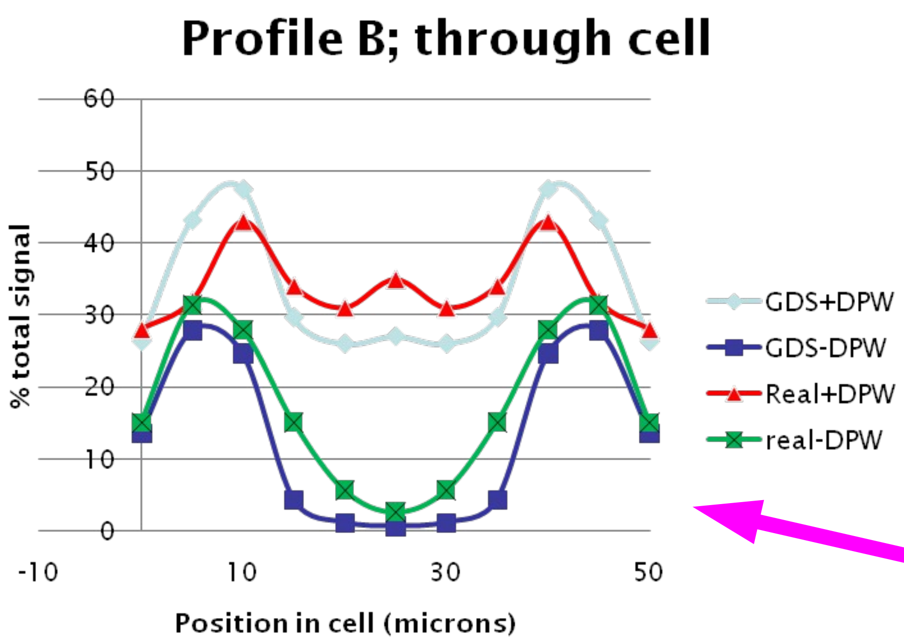
- PreShaper
  - 4 diodes
  - 1 resistor (4 MΩ)
  - Configuration SRAM & Mask
  - Comparator trim (6 bits)
- Predicted Performance
  - Gain 94 μV/e
  - Noise 23 e^-
  - Power 8.9 μW

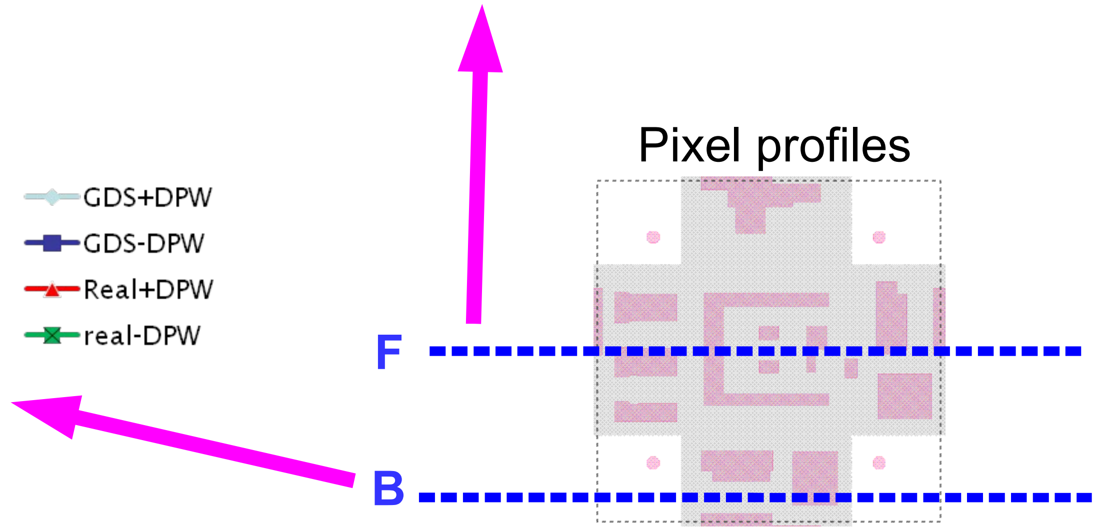


TPAC 1.X Results

- Using ^{55}Fe sources and IR lasers
  - Using the test pixels (analog output)
  - IR laser shows impact of deep p-well implant

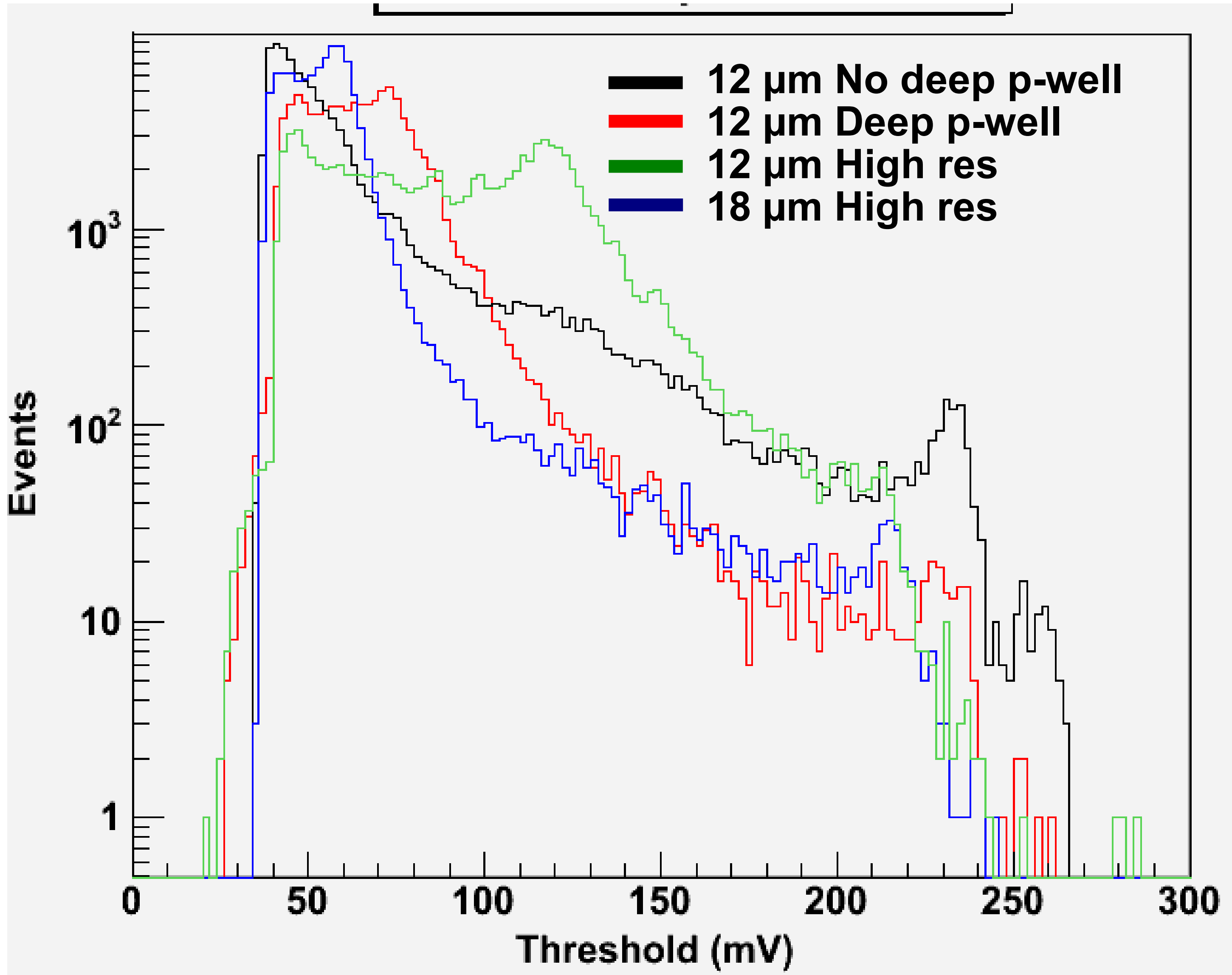






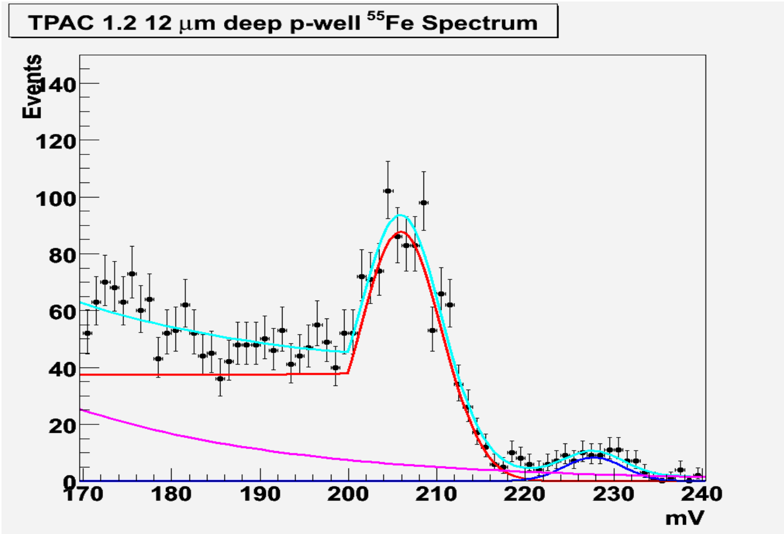
^{55}Fe Spectrum with TPAC 1.2

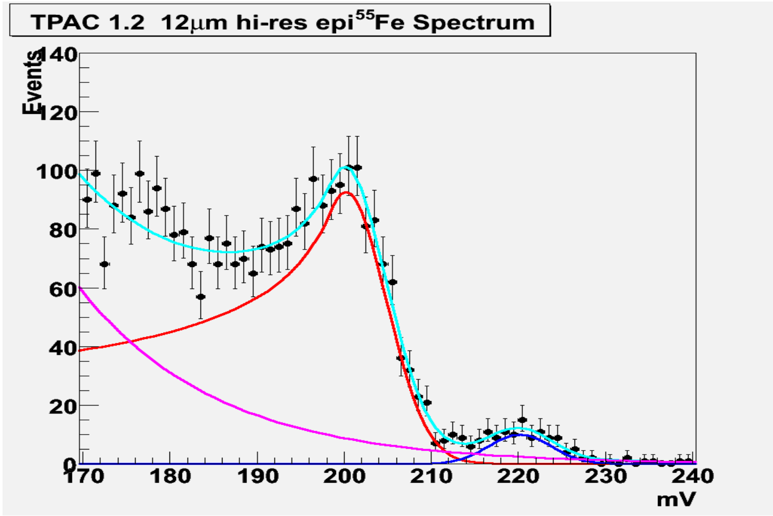
- Using test-pixels with analog out
- Powerful ^{55}Fe source
- Take 100k samples per sensor



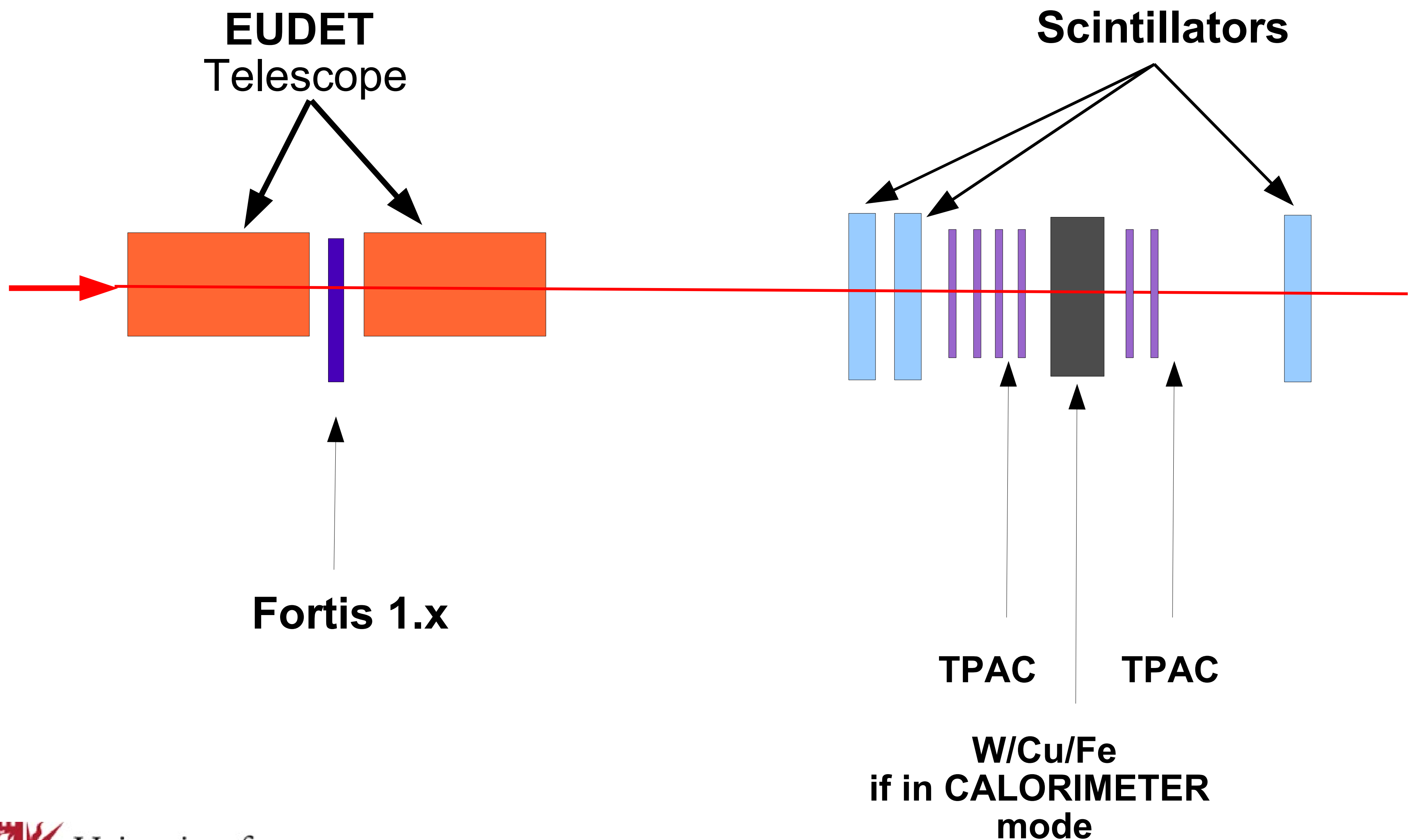
^{55}Fe Spectrum with TPAC 1.2

- ^{55}Fe source
  - Deep p-well
  - High -res
- Separation of K_α and K_β
- Hi-res sensor works





Common Testbeam setup



TPAC 1.2 Testbeam at DESY

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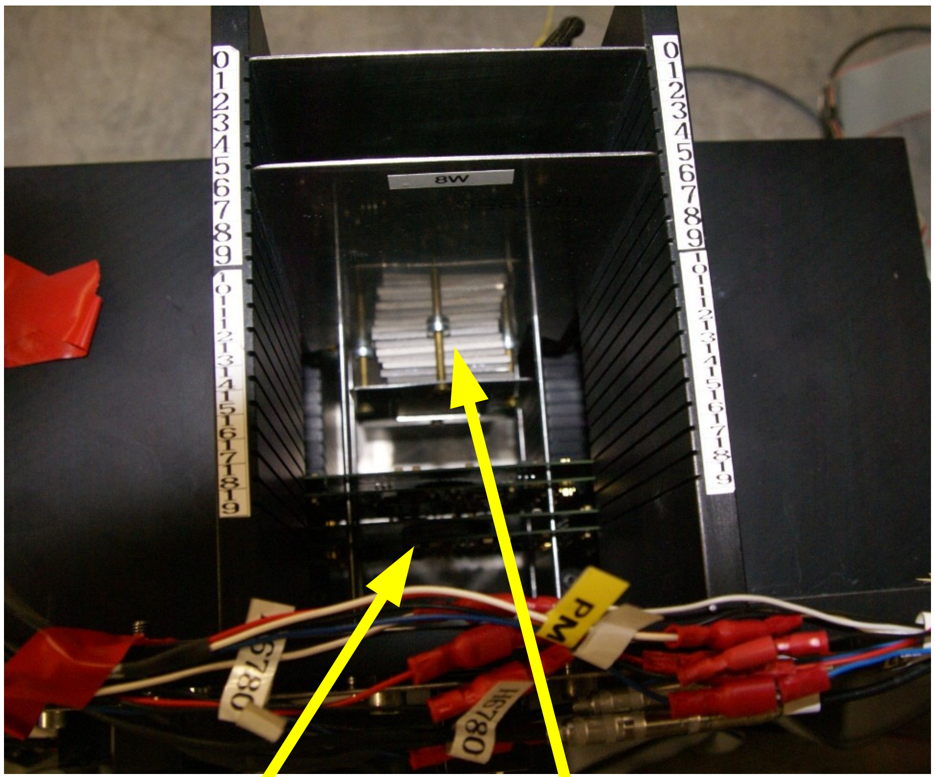
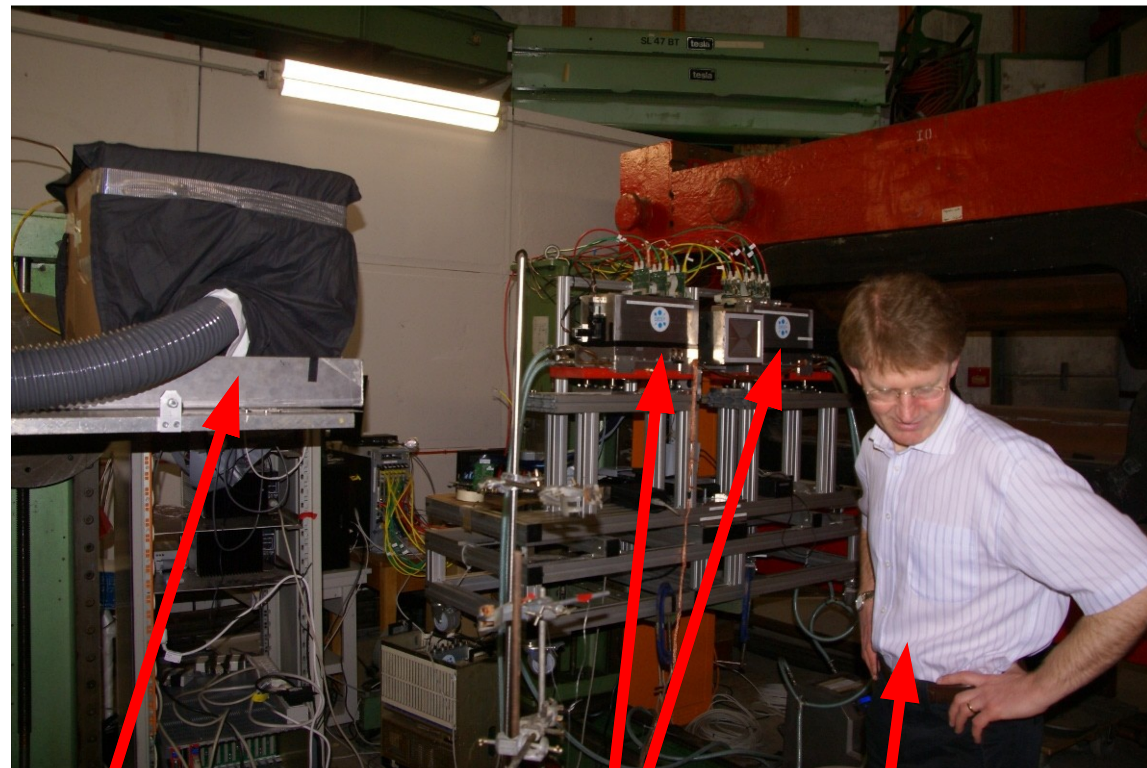




4 TPAC sensors

Tungsten slab

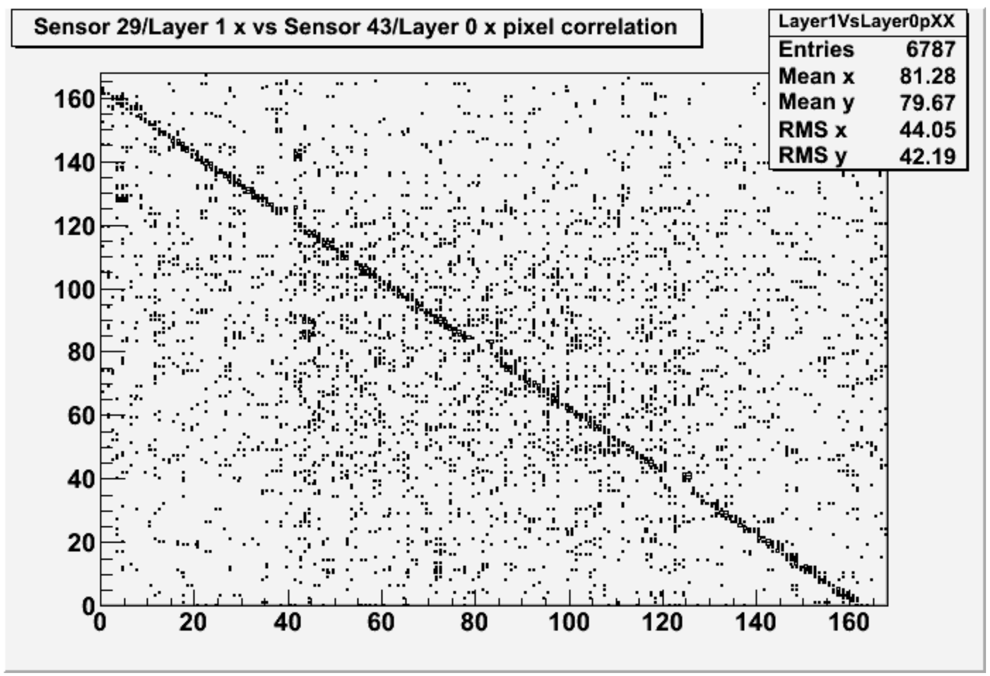
TPAC stack

EUDET Telescope

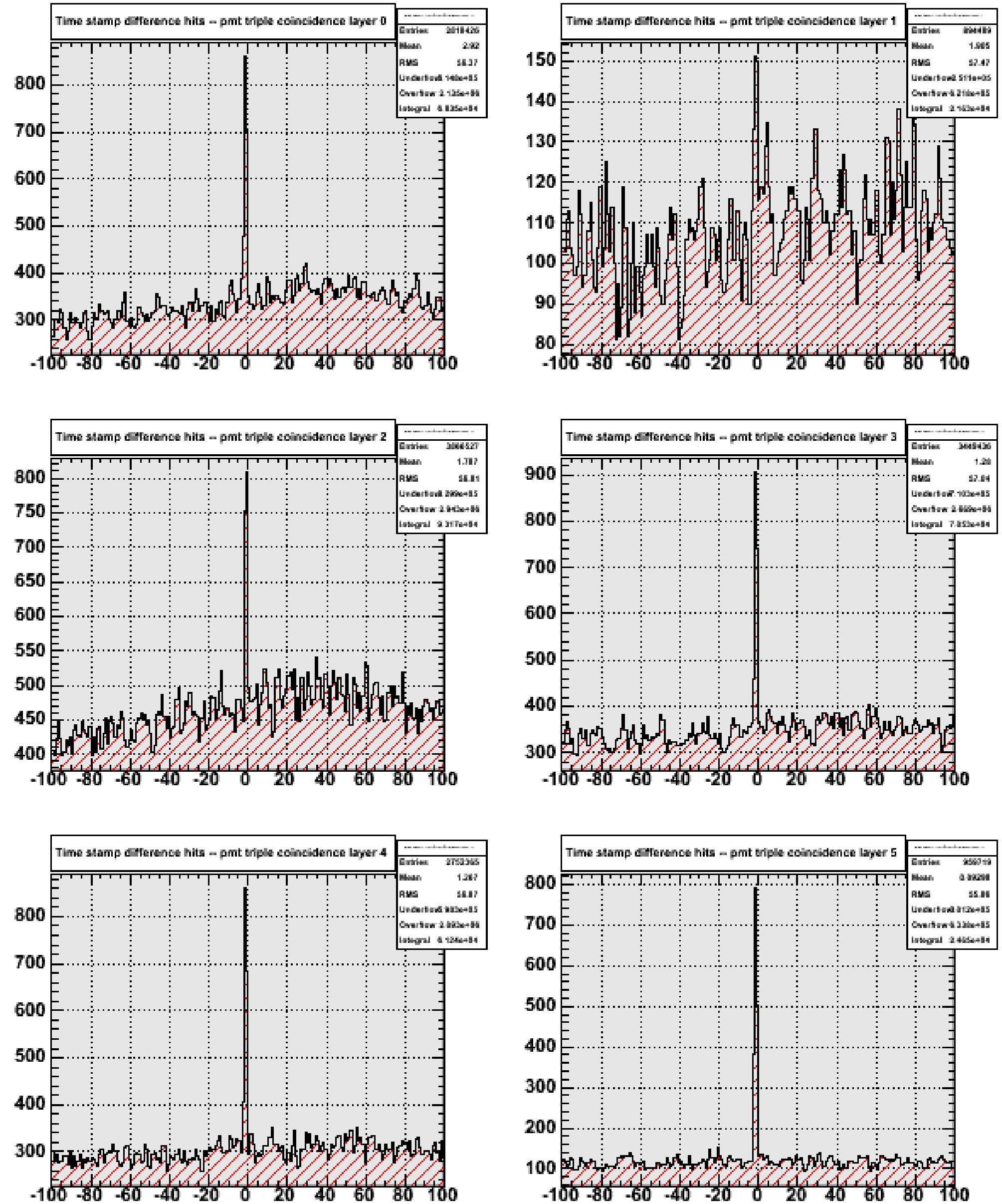
Nigel

TPAC 1.2 Testbeam

- Online plots
- 6 sensors (1 non deep p-well)



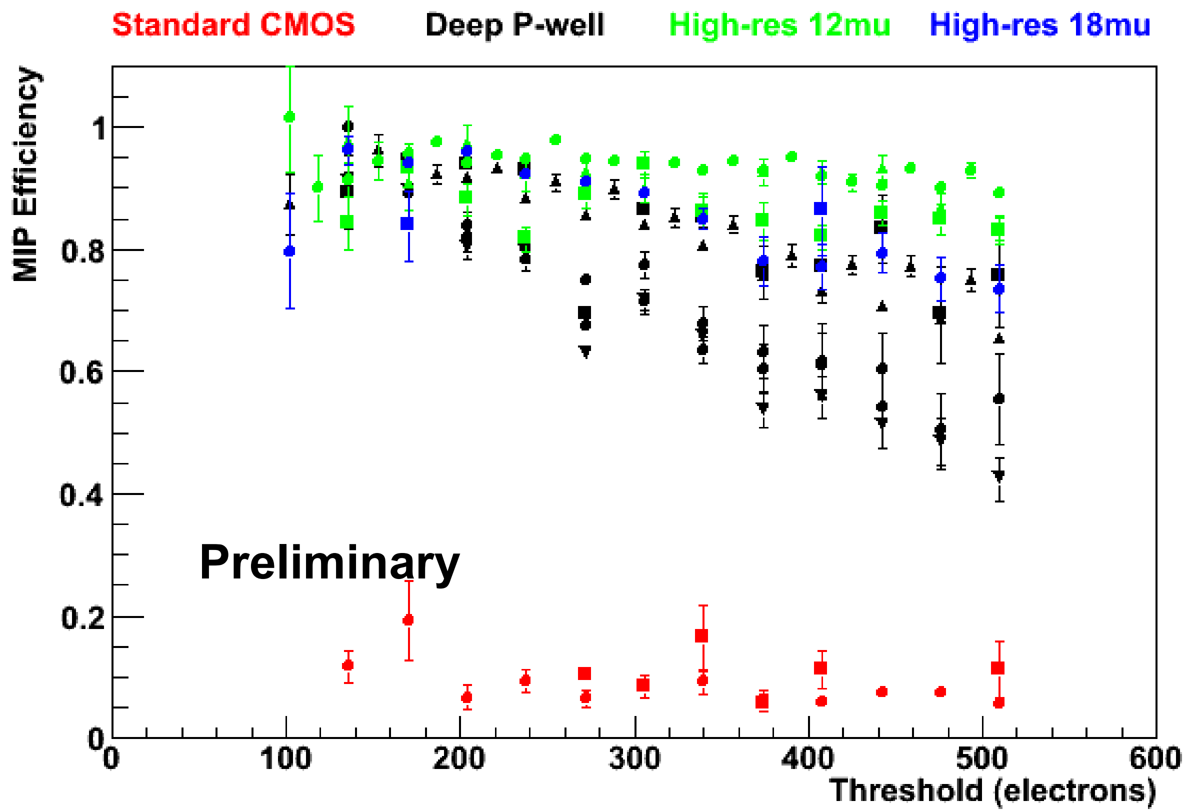
X-X correlation plot for two layers (back-to-back)



Hits in time with Scintillator hits

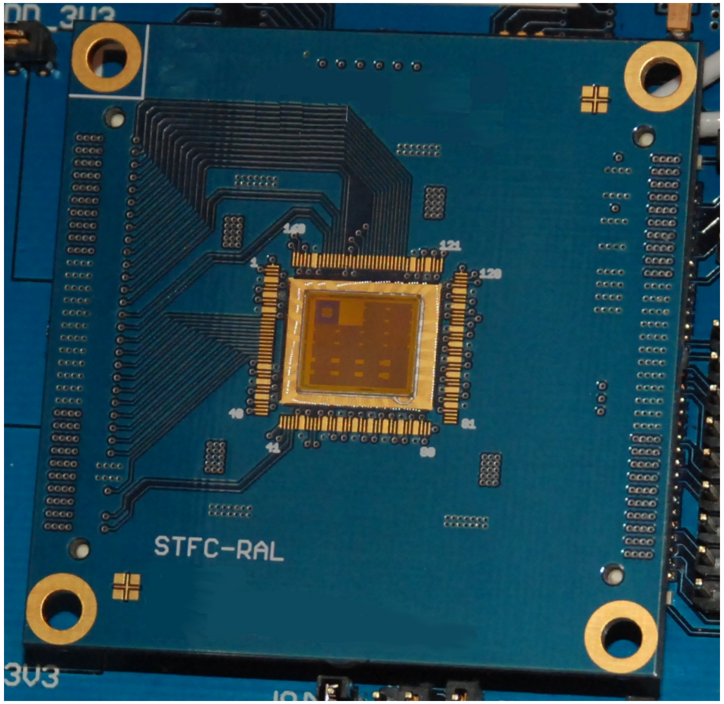
TPAC Testbeam Results

- No absorbers
- Due to use of in-pixel PMOS transistors, standard CMOS sensors have low efficiency
- Deep P-well shields N-wells and raises efficiency by factor ~5
- Adding high-resistivity epitaxial layer makes further improvement with resulting efficiency close to 100%



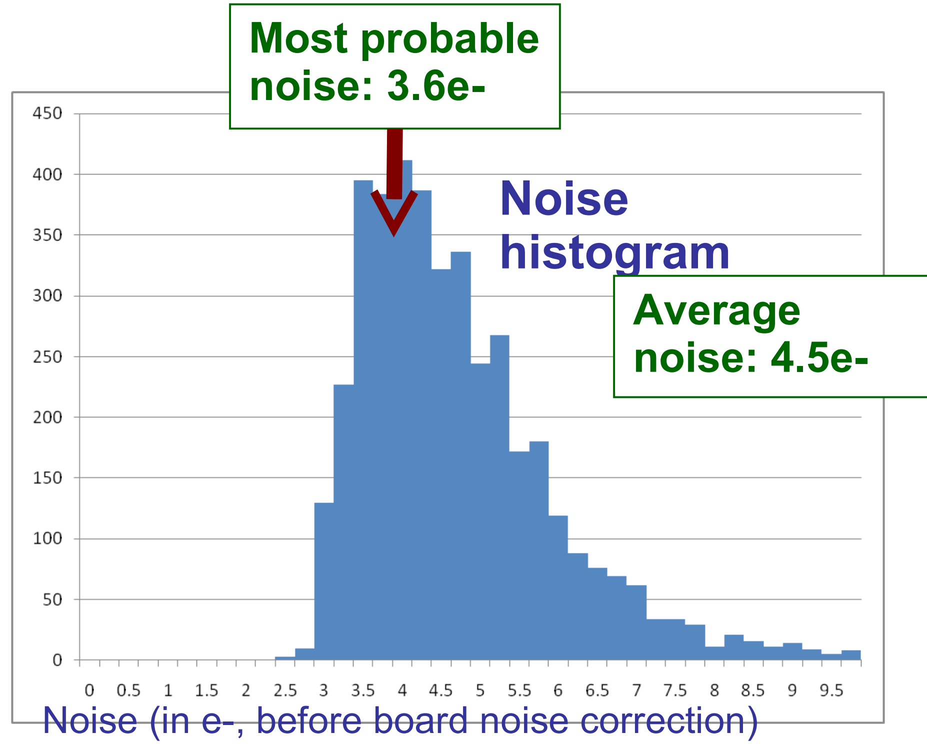
Fortis

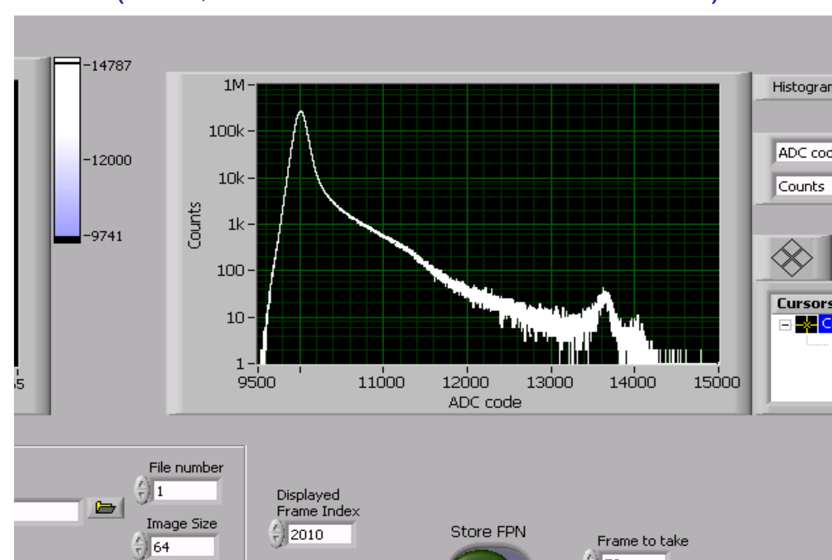
- Test sensor to evaluate 4T for tracking/vertexing
  - Simple readout architecture
  - Analog output
- 12/13 variants of pixels for Fortis 1.0/1.1
  - Size of source follower
  - size of the collecting diode
  - Pitch (6- 45 µm)
  - Combined diodes at floating diffusion node
- Made also on high-res substrate



Results with Fortis 1.x

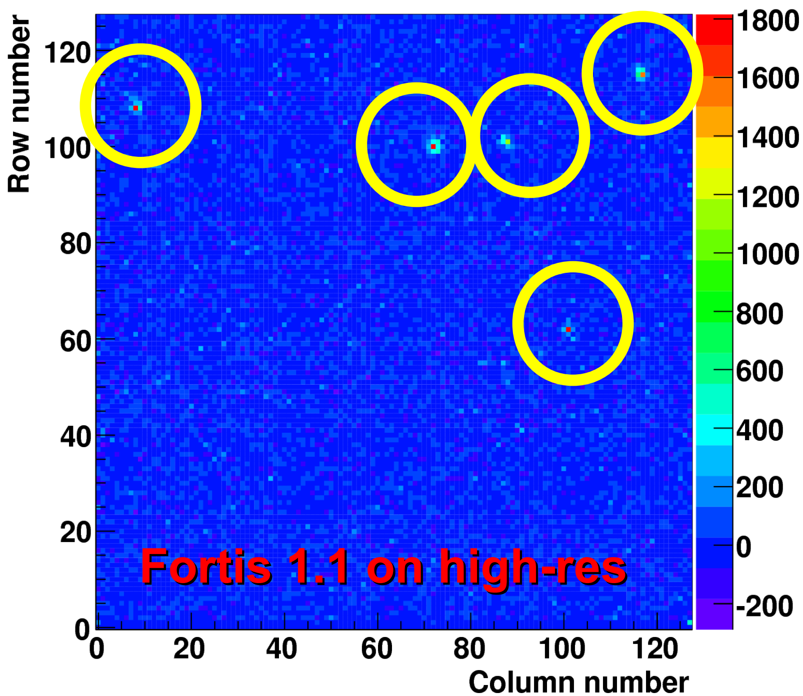
- Noise Measurements
- Photon Transfer Curve technique
  - Average noise: 4.5 e^-
  - Gain 65 μV/e^-
- ^{55}Fe source:
  - Gain 56 μV/e^-
  - Noise 7.7 e^- using all pixels

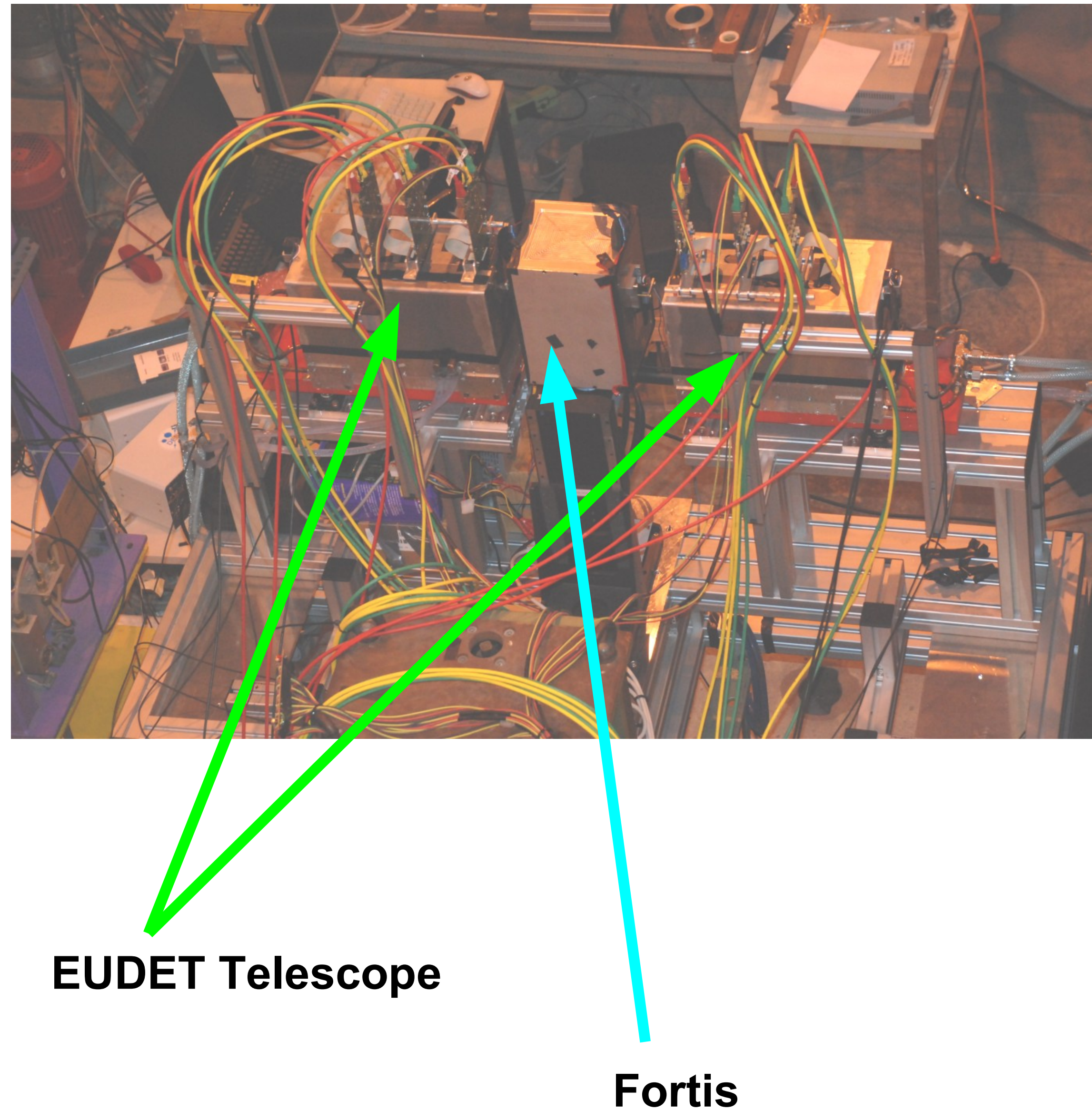




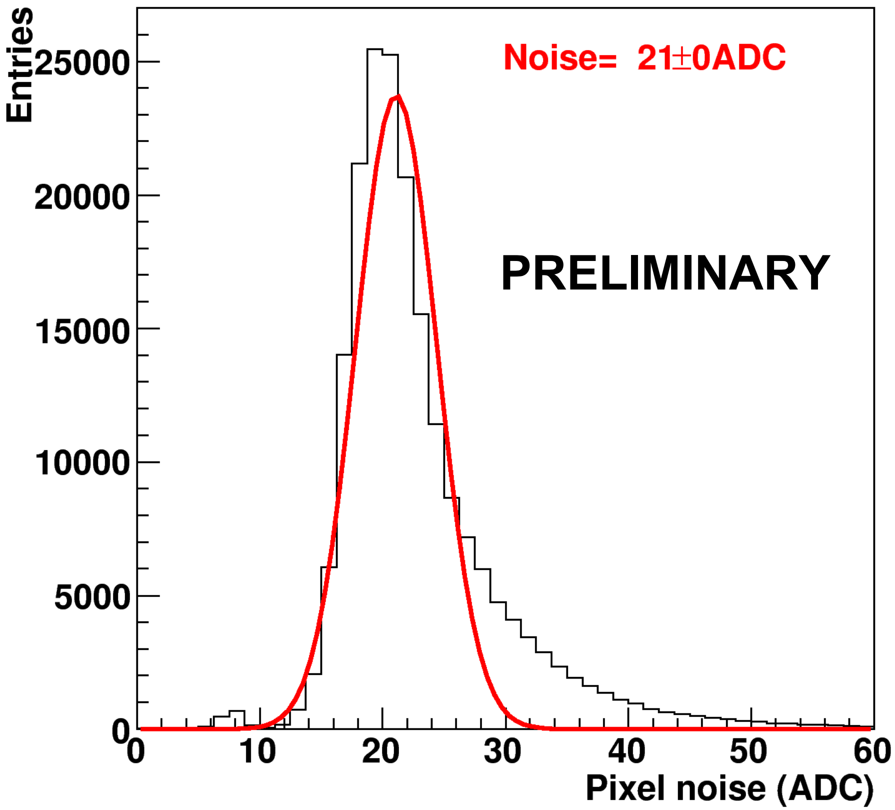
Testbeam at CERN

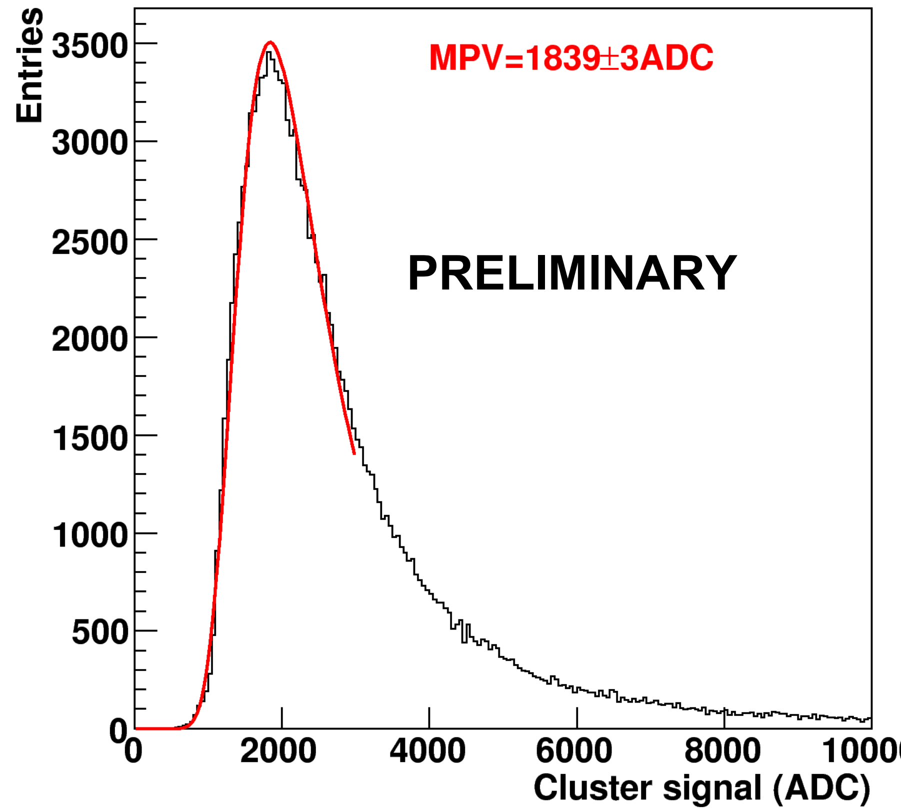
- Test at CERN SPS in June 2010
  - 120 GeV Pions
- Taking advantage of EUDET telescope





First Fortis Test beam results

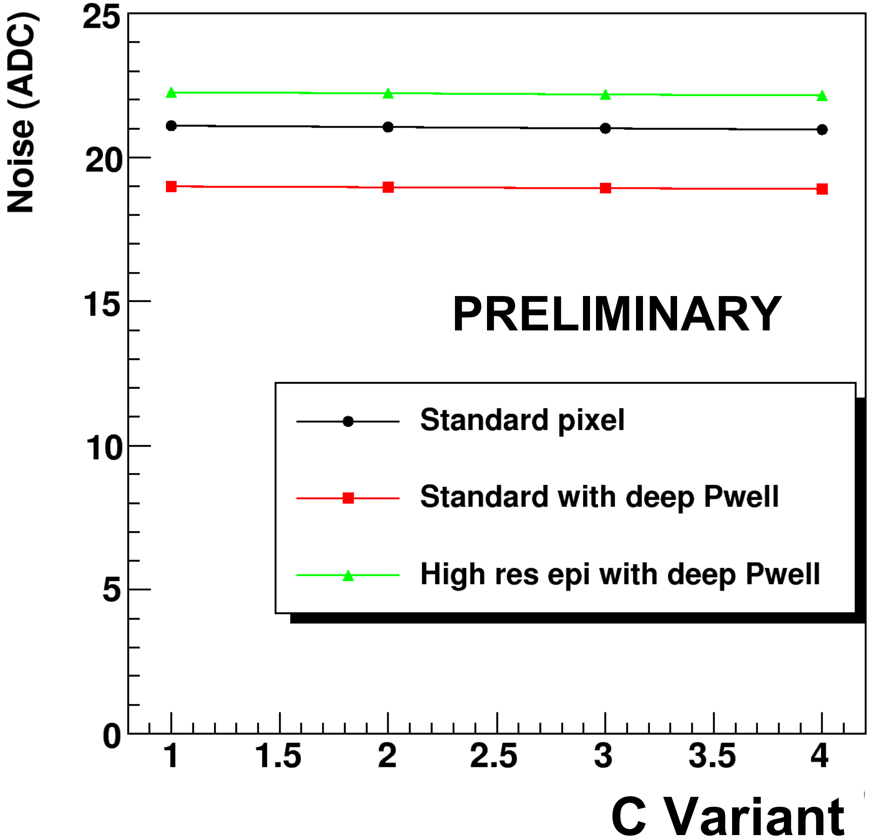


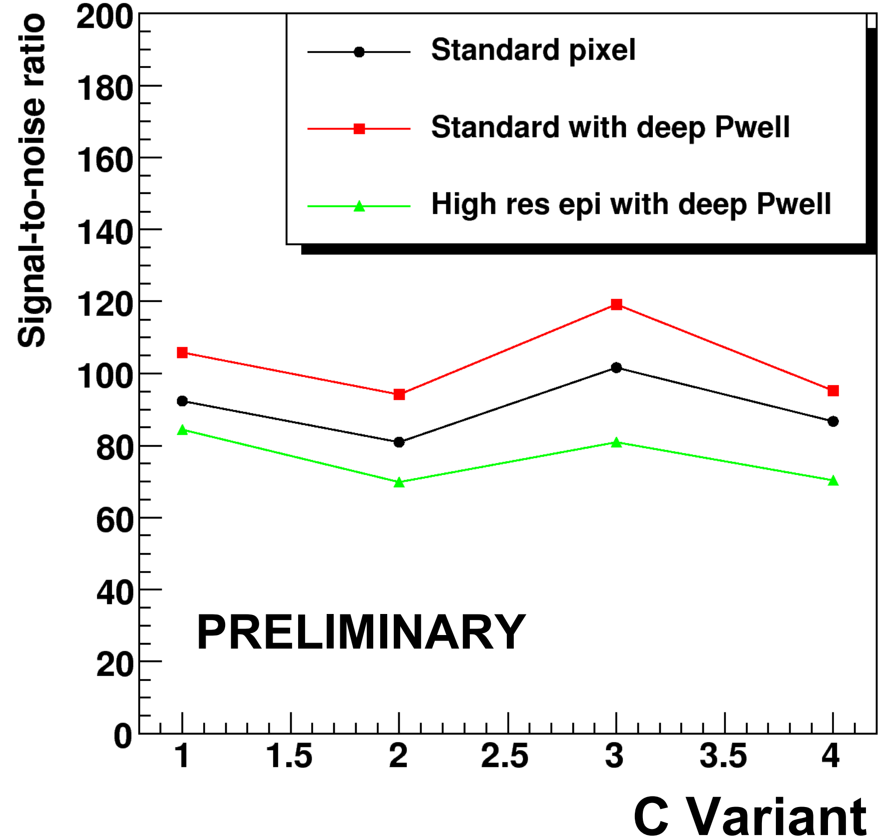


Standard CMOS C1 variant

C variants have 15 µm pitch and different source follower transistor variants

Cont'd





Pixel Variants C1-C4

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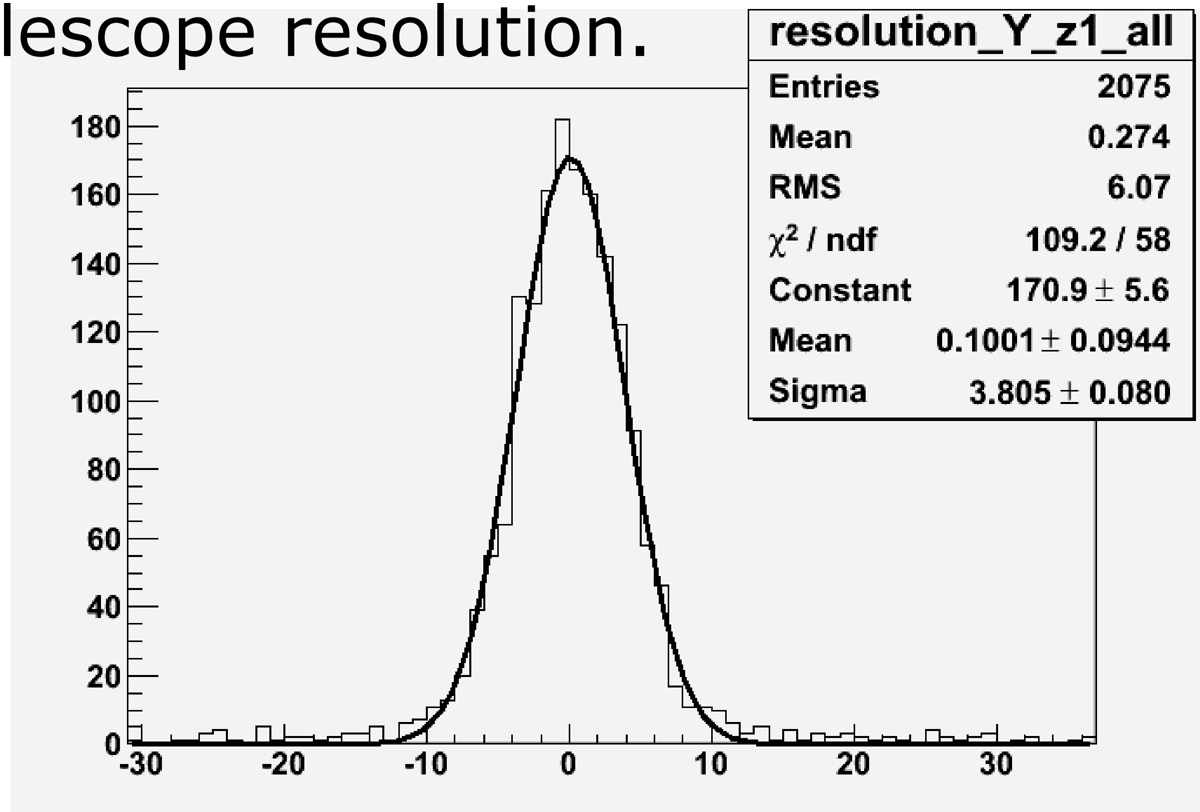
Cont'd

- Residual to track in “y” direction.
- Includes effect telescope resolution.

PRELIMINARY

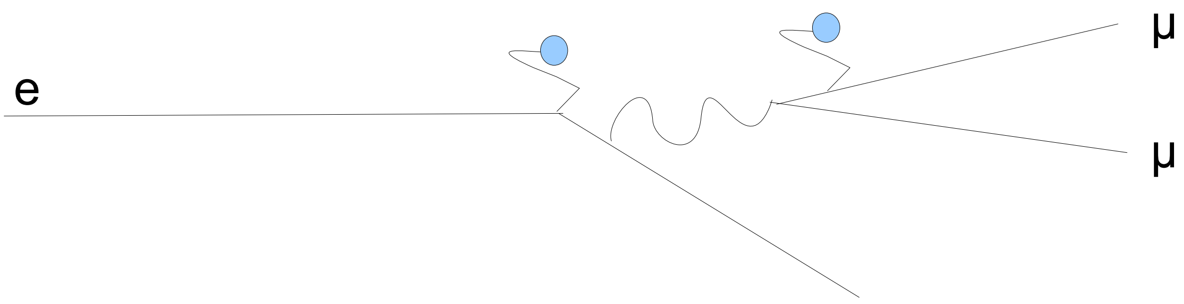


Pixel Variants C1-C4

$e \rightarrow \mu\mu$ (Emu)

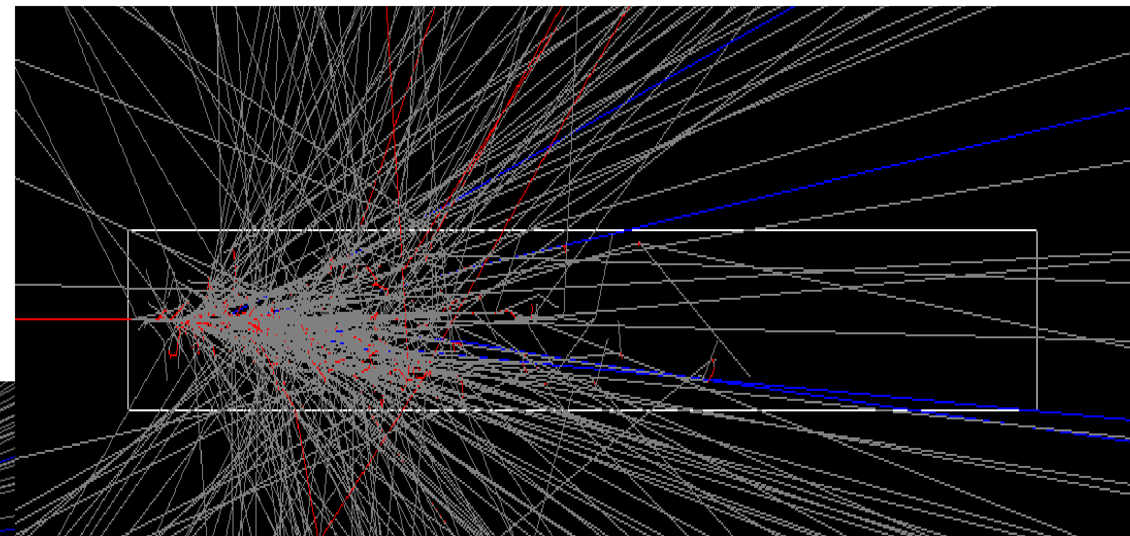
Proposal for $e \rightarrow \mu\mu$ Measurement

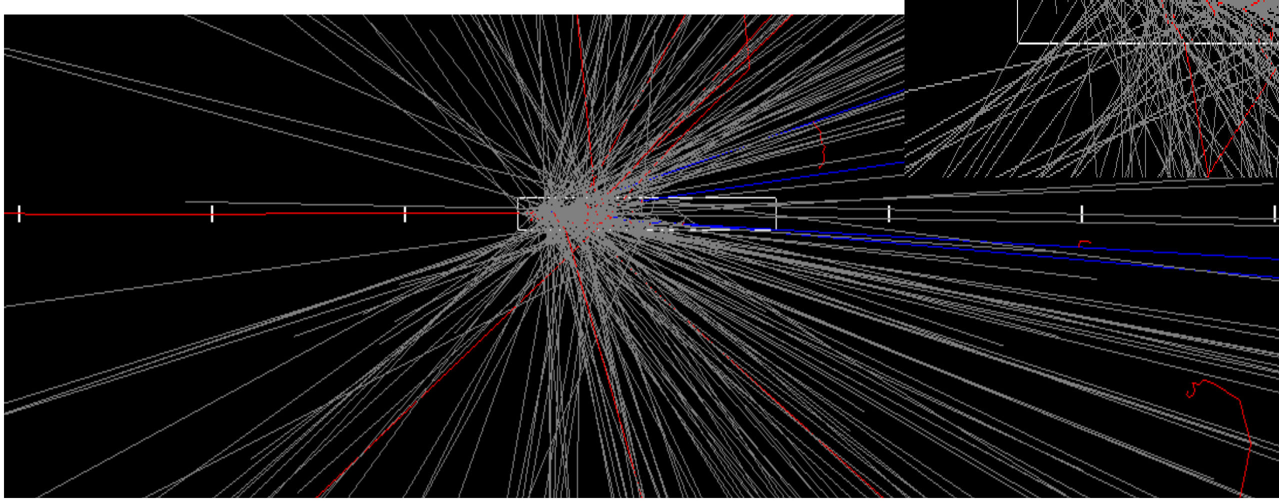
- Muon pair production in electromagnetic showers at TeV has been investigated
  - e.g. V.A.Kudryatsev and O.G.Ryazhskaya. Il Nuovo Cimento C, 21 (1998) 119.
- Propose to make a measurement at GeV scales
  - Near threshold.
  - Match against G4 cross-sections
  - Will be challenging. Initial simulations indicate a few pairs from one week's running (at most)



Proposal for e→μμ Measurement

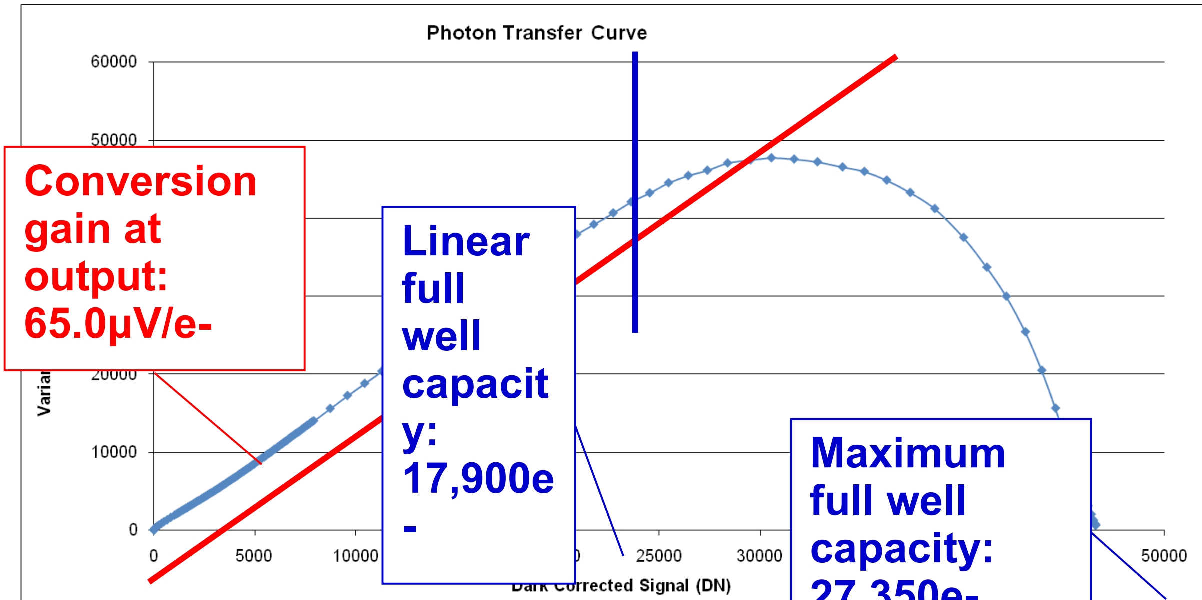
- Yield @ 5GeV ~ 10^{-9} muon pairs per 5GeV e^-
- Standard spacing upstream, target, close spacing downstream (acceptance)
- P peaks at ~100MeV





Fortis Photon transfer curve

A photon transfer curve is a plot of the dark-corrected signal obtained from an image sensor against the noise for that signal. It is obtained via one of two methods; an intensity sweep, where the integration time is fixed and the light level/temperature is varied, or via an integration sweep, where the light level/temperature is fixed and the integration time is varied.
At least two identical images are required for each step to obtain the PTC and the mean signal and variance are taken from these two frames. The subtraction of the two frames to calculate the variance removes fixed pattern noise, leaving only read noise (which is the noise of interest for an image sensor) and shot noise. Shot noise scales with the square root of the signal, giving a characteristic 0.5 gradient when plotted on a log-log plot, and is the basis of the photon transfer curve.
Many parameters can be extracted from a photon transfer curve to give the basic characteristics of an image sensor. The noise is taken from the y-intercept of the graph (i.e. the noise for 0 signal). The gain is taken from the x-intercept of the best t line taken from the plot, which if plotted on a log-log scale, should give the characteristic gradient of 0.5. The linear full well capacity is taken from the peak in the photon transfer curve. This is where the noise begins to reduce as the variation in signal is dampened as no more signal can be collected. The maximum full well capacity is taken as the maximum signal level which is plotted on the graph.
If an integration sweep was performed, the dark current can be obtained from the gradient of the dark signal level plotted against the integration time. A result for the PTC [9] from the best pixel variant for FORTIS 1.0 is shown in Figure 6. This pixel had a very low noise of 5.8 e, and a high conversion gain of 61.4 V/e▯, demonstrating the benets of the 4T pixel architect



Conversion gain at output: 65.0μV/e-

Linear full well capacity: 17,900e-

Maximum full well capacity: 27,350e-

Linear dynamic range: 4,970

Maximum dynamic range: 7,597