

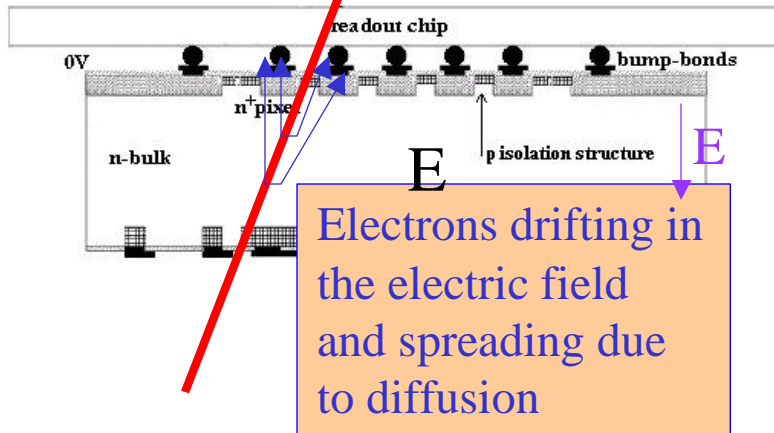
Spatial resolution predicted for the BTeV pixel sensor

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- Physics processes modeled in the simulation
- Some detailed studies
 - Effect of different thresholds
 - Advantages of analog readout
 - Sensitivity to digitization accuracy
- Reality check: a comparison with our test beam data

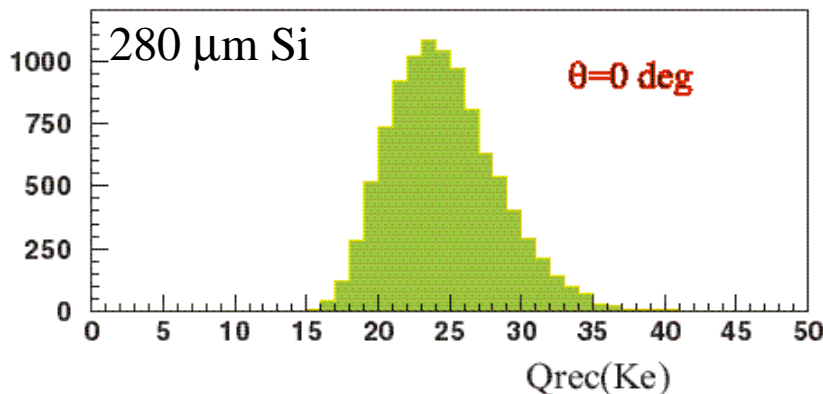
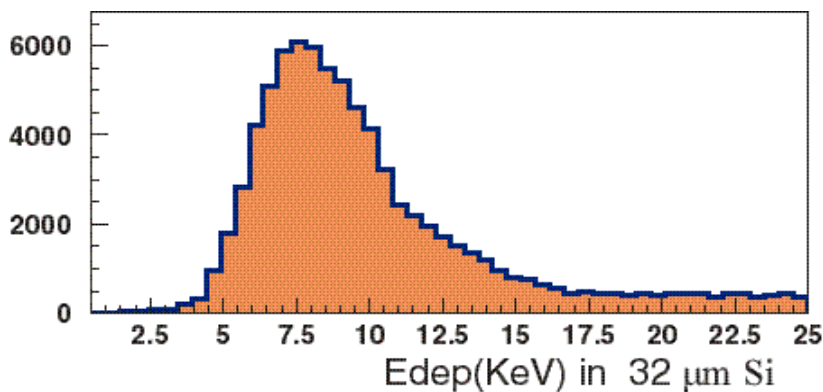
Physics processes modeled in the simulation

MIP crossing the sensor



- Energy deposition by charged track along its path length. Spread of the electron cloud due to **diffusion**.
- Drift in E corresponding to doping and bias voltage.
- $E \times B$ (our sensors will be in dipole field of 1.6 T).
- Realistic parameters of the **front end electronics** (noise, threshold, digitization accuracy).

Simulation of electron-hole creation



- Charge track path length, divided into ~ 30 μm slices
- E_{dep} in each slice fluctuates according to experimental straggling distribution (Bichsel, Rev. Mod. Phys. 60, (1988) 3.)
- Resultant charge distribution has FWHM ~ 10 Ke
- Tail truncated (δ rays ignored)

Hypotheses and caveats

- The algorithm implemented is quite general
- Most of the results will use parameters tuned to the proposed BTeV experiment:
 - Pixel cell 50x400 μm
 - Analog readout with 1 flash ADC/cell
 - Peaking times of the order of 100 ns (\Rightarrow we can assume full charge collection)
 - Collected charge carriers are electrons (n^+np^+ sensors)

What we did not include so far

- Non-Gaussian tails due to δ rays
- Effects of possible lateral **E** field distortion
- Time dependent effects due to the electron current pulse shape
- Capacitive coupling effects between pixels

Charge spreading due to diffusion

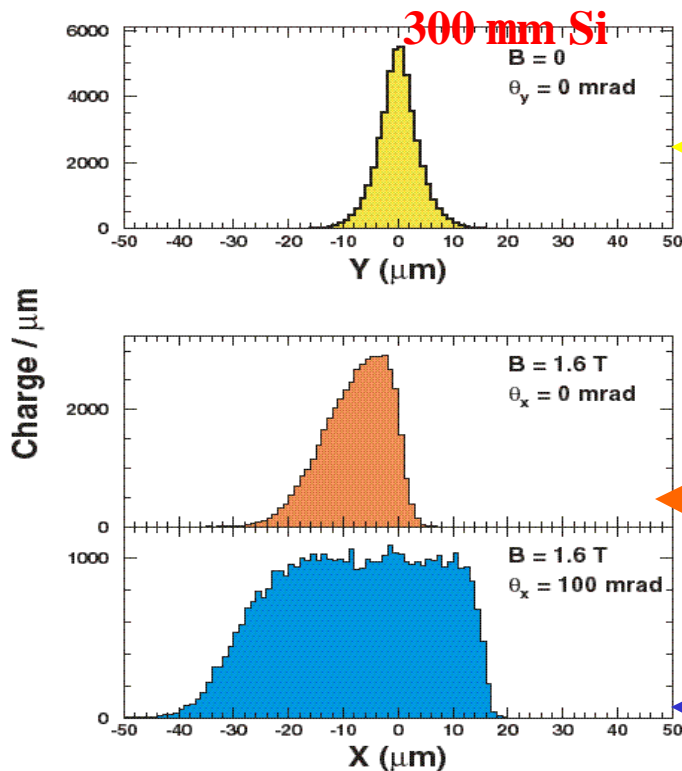
- The diffusion coefficient is associated to the carrier mobility through:

$$D_e = \frac{kT}{q} m_e$$

- We assumed $m_e = 1450 \text{cm}^2/\text{Vs} \Rightarrow$

$$\langle \sqrt{\Delta r^2} \rangle = \sqrt{2D\Delta t} \approx 12 \mu\text{m}$$

Charge spreading due to diffusion and its interplay with the magnetic field



- Lateral spread due to diffusion
- Interplay between B field and diffusion
 - At normal incidence
 - For an angled track

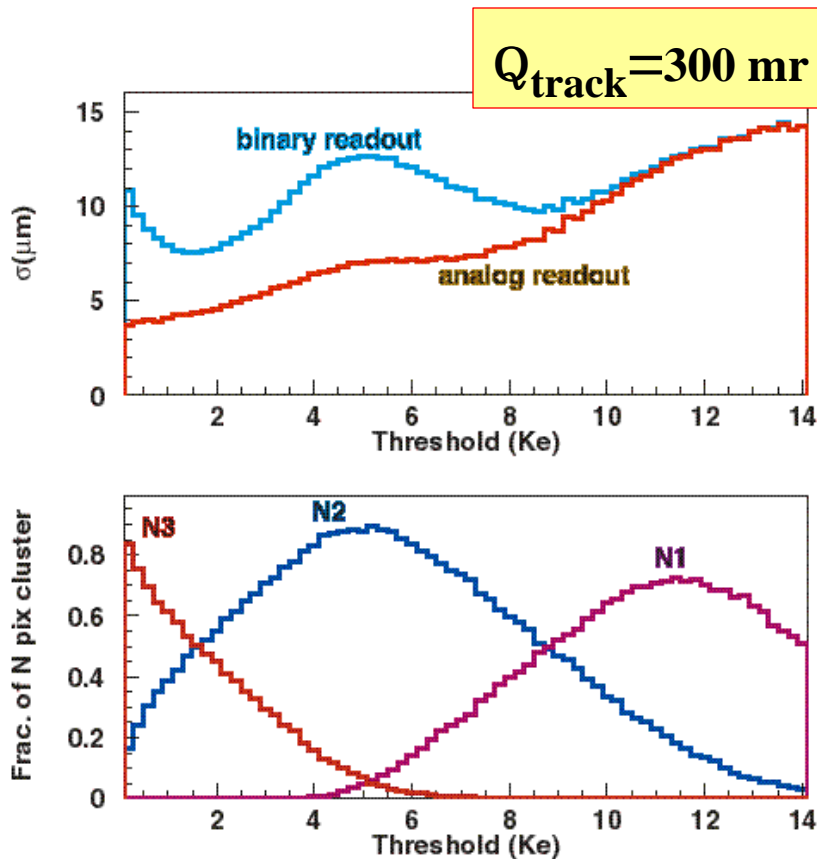
Simulation of front end electronics

- Key elements
 - intrinsic noise (expected to be very small throughout the detector lifetime for **fpix2**)
 - discriminator threshold
 - digitization accuracy for analog readout

Advantages of analog readout

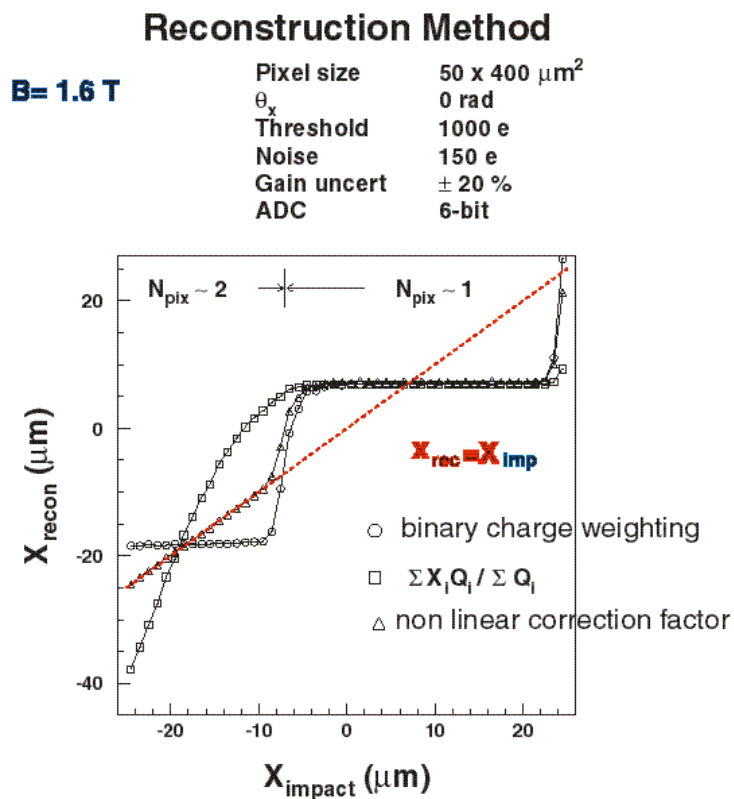
- Analog readout improves spatial resolution using charge weighting, and allows more effective monitoring of sensor and readout chip performance.
- Effectiveness depends upon **electronic noise**, **threshold** and **digitization accuracy**.
- Interplay between these effects will be discussed

Sensitivity to different front end electronics thresholds



- Noise and digitization resolution effects neglected
- **Slow degradation** of the resolution for **relatively low thresholds** and analog readout

Optimization of position reconstruction algorithm—small θ



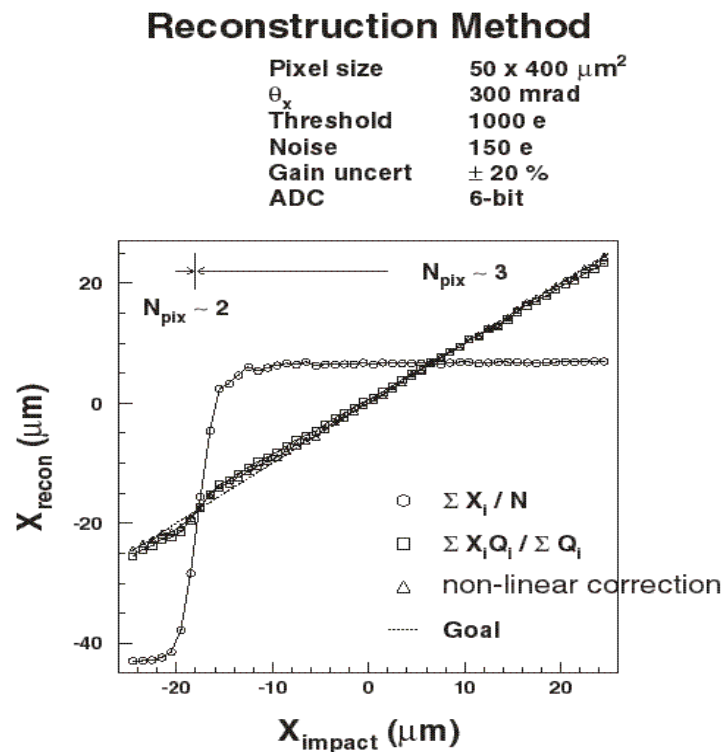
Analog information can be used to interpolate between pixel centers

Non-linear nature of diffusion requires a correction factor

$$f(x_{\text{rec}}, \theta)$$

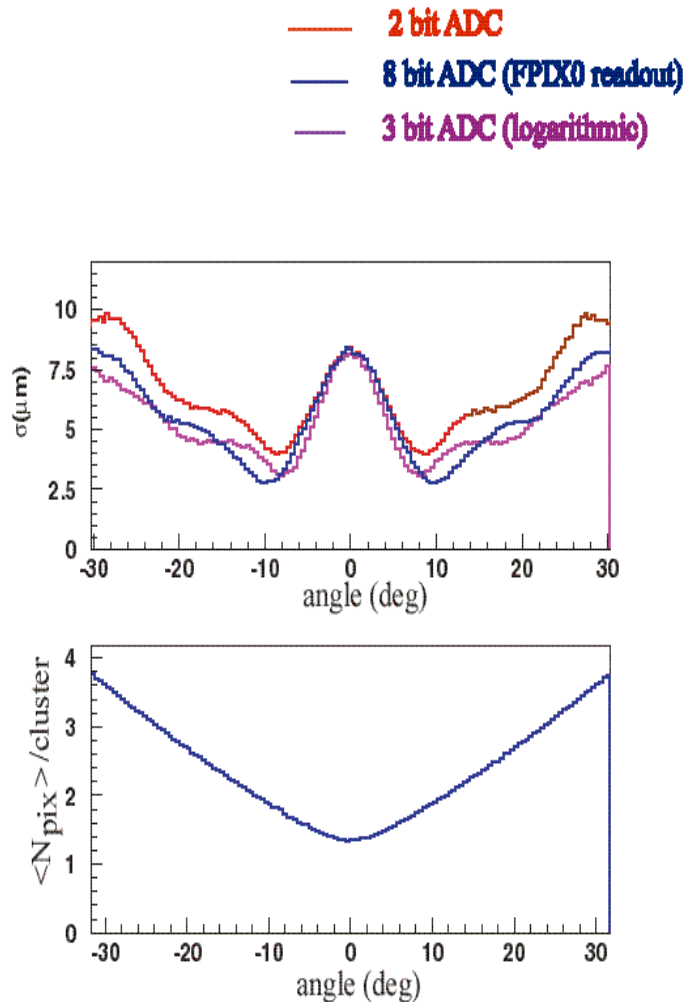
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Optimization of the position resolution – medium θ



- When angle spreads the charge among several pixels, charge division becomes linear and effect of correction negligible
- Limitations of binary readout more evident

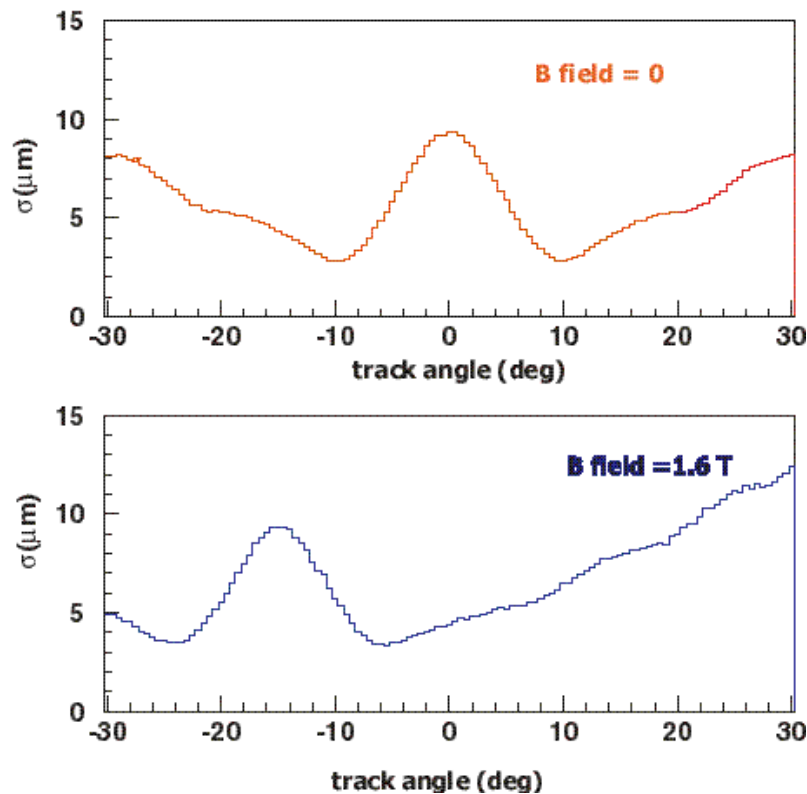
Sensitivity to digitization resolution



- 3 bit ADC with thresholds scaling in \ln ratio has a performance comparable to an 8 bit ADC

\Rightarrow Our front end electronics is optimized for BTeV needs

Magnetic field effects

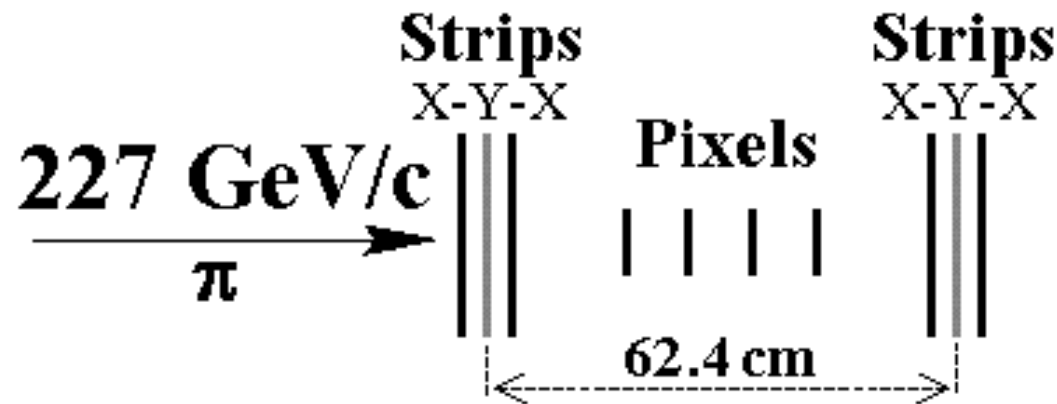


- Si thickness assumed $280 \mu\text{m}$
- Magnetic field induces a shift of about 17 deg in the charge orientation in the bend plane

Reality check: a comparison with test beam data

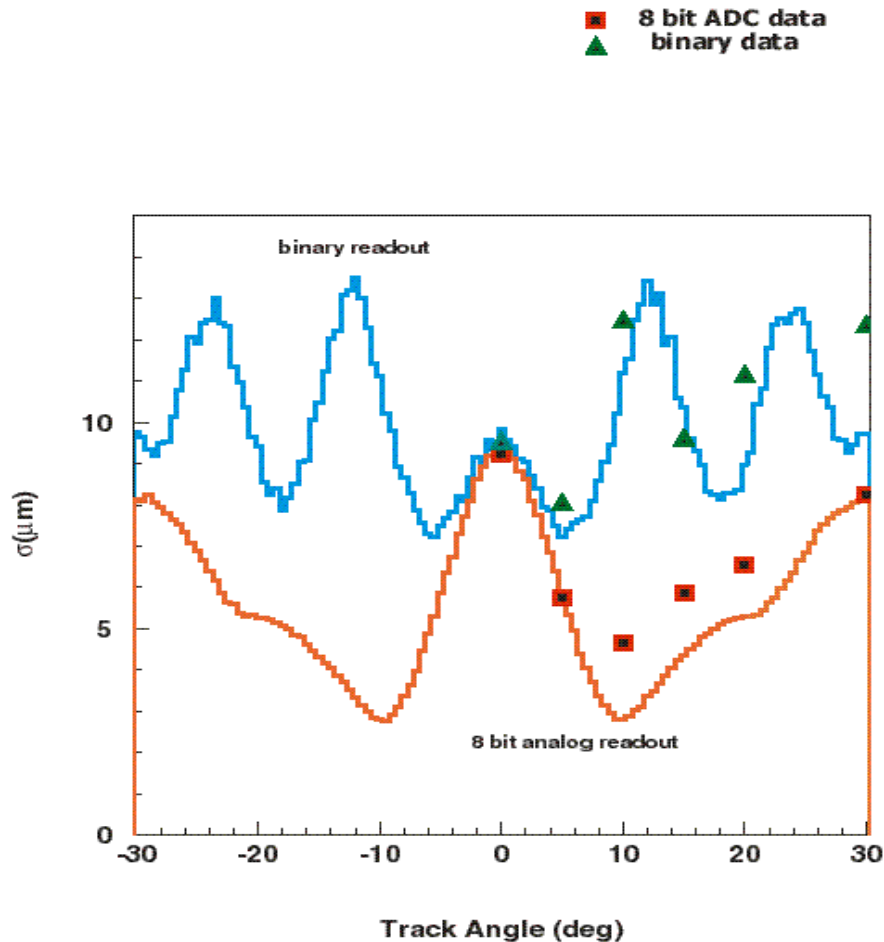
- The BTeV pixel group has recently collected an impressive amount of beam test data on n^+np^+ sensors bump bonded to two different front end devices (see G. Chiodini's talk)
- We can perform a direct comparison of the resolution predicted from this simulation and experimental data with various experimental parameters (bias, track angle, digitization resolution..)

A quick reminder on our test beam set-up



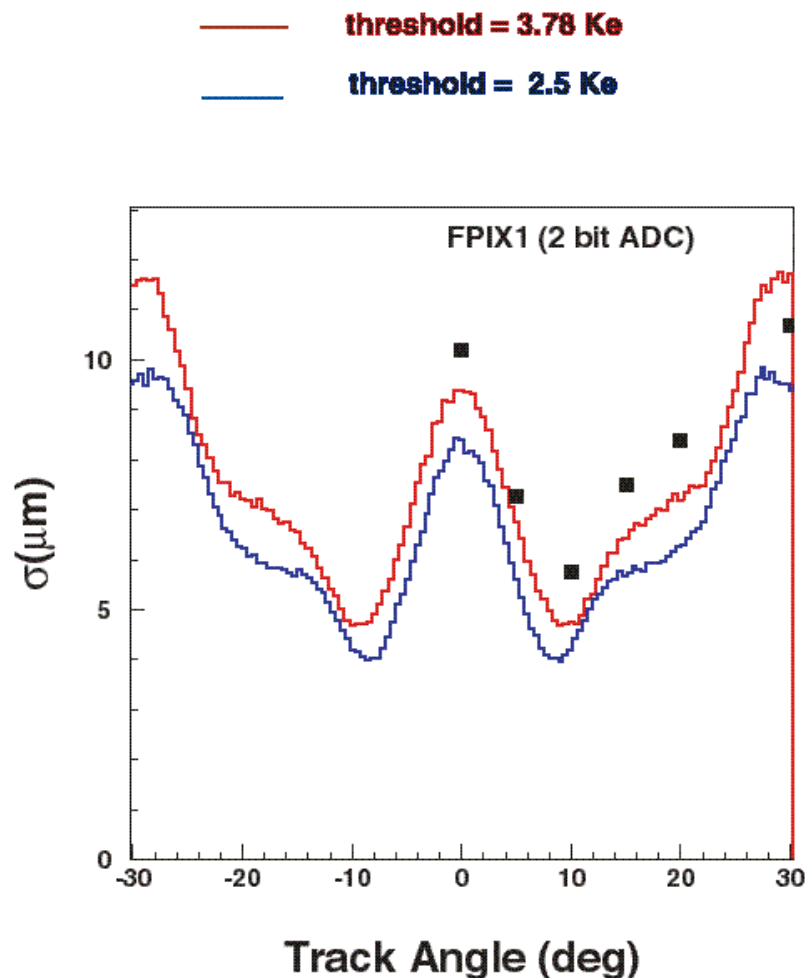
- 5 pixel planes tested (n^+np^+ sensors, with p-stop and p-spray insulation)
- We learned a lot of things, here I will focus on the measured resolution for two different front end electronics devices: FPIX0 (analog output connected to external 8 bit ADC) and FPIX1 (2 bit on chip FADC).

Comparison of FPIXO data with the predicted spatial resolution



- Input parameters:
 - 280 mm thick detector (n^+n^+) with p-stop interpixel implantation
 - Average threshold 2.5 Ke
 - 8 bit ADC external to the chip
- Same data analyzed with only binary interpolation and with analog interpolation with non-linear correction

Comparison of FPIX1 data with simulation



- Input parameters:
 - 280 mm thick detector (n^+np^+) with p-stop interpixel insulation
 - Average threshold 3.78 Ke
 - 2 bit on chip FADC
- We show also the predictions with 2.5 Ke threshold to disentangle effect of higher threshold from effects of coarser digitization

Conclusions

- The simulation tool developed gives results in good agreement with test beam data and allow us to tune the sensor and front end electronics parameters for optimum performance
- It is quite general: can be used for other applications
- A more detailed study of the effects neglected (δ rays, imperfect knowledge of s-curve correction etc.) and may lead to a more complete understanding of the test beam data.