Performance study of cluster splitting CCD (Marty's CCD)

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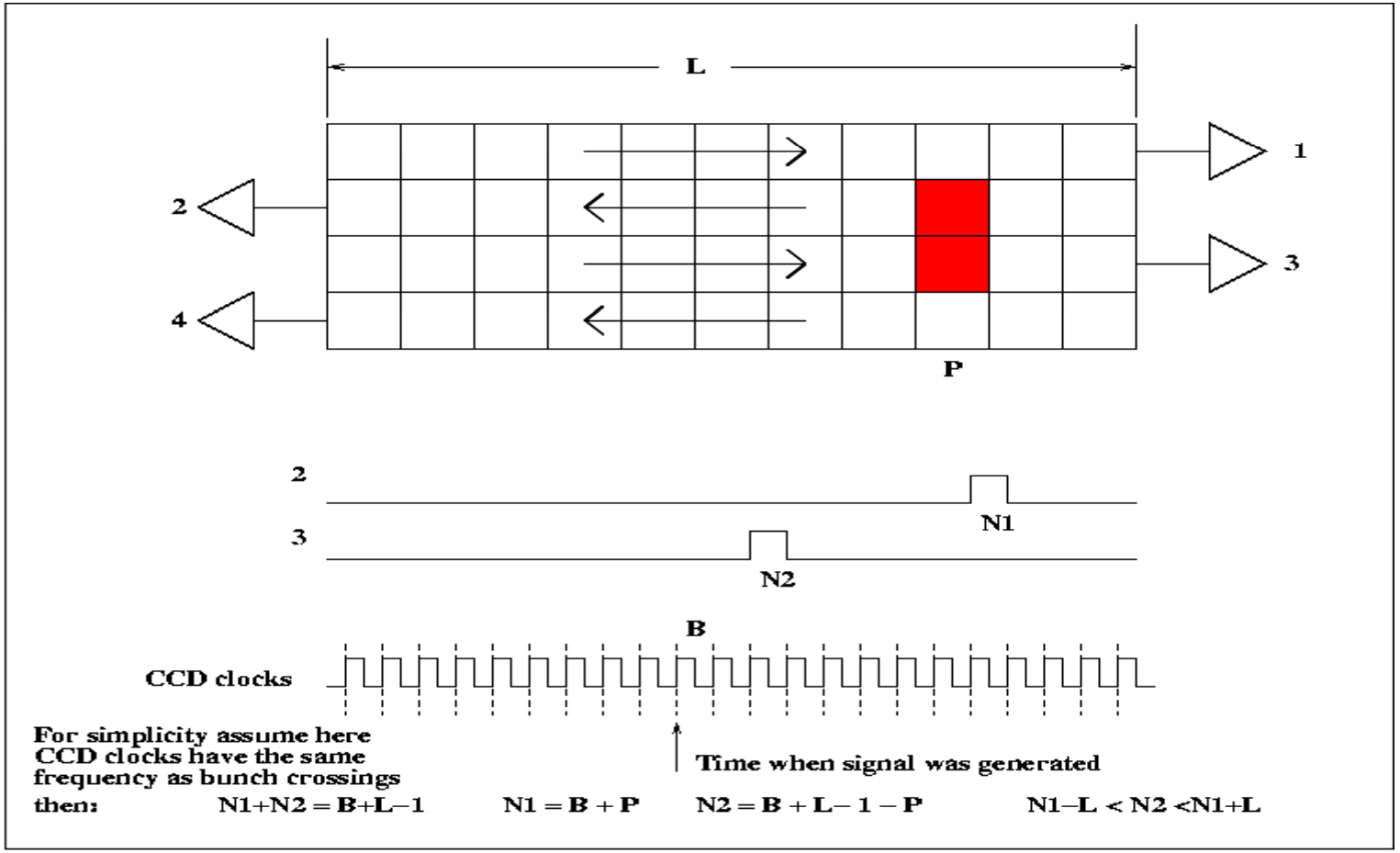
Topics

- 1. What is this ? Pros and cons.
- 2. What and how was simulated
- 3. One column clusters effects
- 4. Accepted background density
- 5. Hit reconstruction efficiency
- 6. How to improve efficiency
- 7. Conclusions

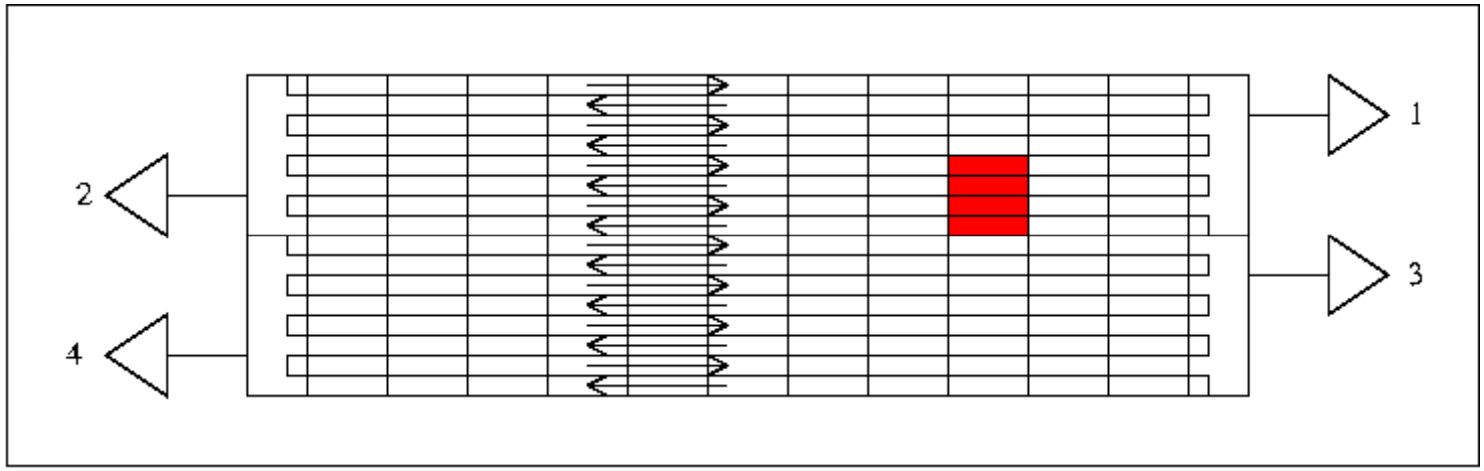
What is this


L
1
2
3
4
P
2
3
N1
N2
B
CCD clocks
For simplicity assume here
CCD clocks have the same
frequency as bunch crossings
Time when signal was generated
then:
N1+N2 = B+L−1
N1 = B + P
N2 = B + L− 1 − P
N1−L < N2 <N1+L

Marty's idea

- Shift charge in neighboring columns in opposite directions. If signal from one track appears in more than 1 column it will allow to calculate time of the signal.
- This works well when not many hits are observed in neighboring pair of columns. To achieve this use short columns (for example, not along CCD length, but across)
- Another condition for it to work – majority of hits should span more than 1 column

How to have better charge sharing



We can make narrow channels in which charge is moving, and provide clocks to move charge in neighboring channels in opposite directions. To reduce number of electronics channels, we can combine charge from few channels at the ends of the column

Pros and Cons

- Pros:
  - It uses already existing CCD technology. No fancy features, like 45 nm process required. It can be done today.
  - It reduces background hits density observed in physics event to acceptuble level with moderate clock frequency (in most cases 3MHz would work) compare to 50 MHz for column parallel CCD
- Cons:
  - Needs cryostat (though room temperature operation is also possible for special types CCD)
  - Radiation hardness is a concern, as for any CCD
  - Diffusion is essential. So CCD can’t be depleted. But that limits image clocks frequency, so 10 MHz may be problematic. Though it does not appear needed.

What and how was simulated

- I have used my existing FullCCDSimulation package to simulate charge diffusion and all effects of pixel signals digitization. This package was announced at Paris (2004). It was verified by comparison with VXD3 data.
- Package was modified to add algorithm of processing opposite direction readouts.
- Also, electronics noise hit generation was included.
- Overlay of events from different bunch crossings with corresponding time stamps was implemented
- Combining of the charge from narrow channels was not implemented so far. I simulated narrow channels by assuming they have separate readout channels. For background rejection study it may be conservative approach.

What and how was simulated - more

- I assumed that background hits are generated by particles with random and uniform distribution of dip angle.
- As the efficiency of hit reconstruction depends on dip angle, I calculated average efficiency based on some general angle distribution of tracks in physics event
- I assumed column direction perpendicular to Z.

Simulation parameters

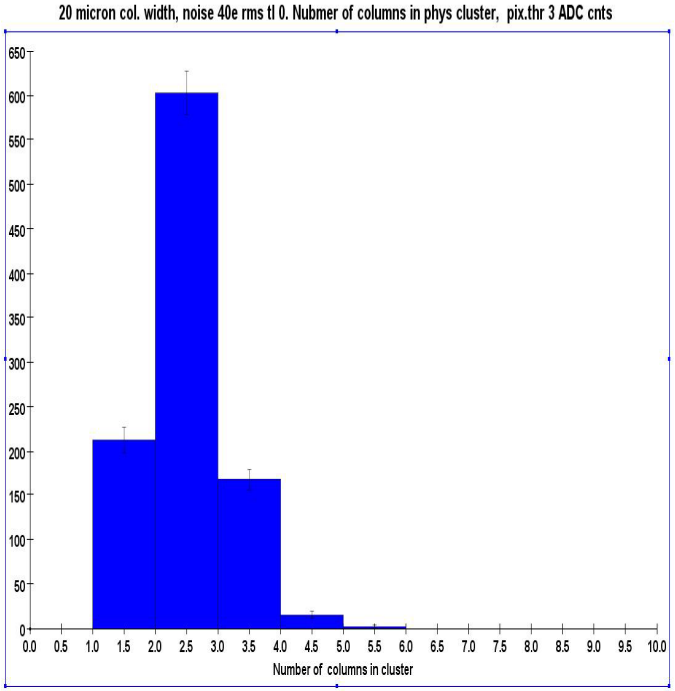
- I simulated 3 different column widths: 20μ , 10μ, 5μ.
- I used 3 different single pixel thresholds 4,5 and 6 ADC counts. Note that signal from min ionizing particle had most probable value of about 40 ADC counts.
- I used 3 different image clock speeds: 3MHz, 6MHz and 12 MHz
- I generated background hit densities 0.01,0.02, 0.03, 0.06, 0.12, 0.2 and 0.3 hits/mm^2/bunch
- I used rather aggressive electronics noise level of 40 e charge rms
- I used column length 500 pixels
- Even with rather low noise level, number of electronics noise hits exceeding threshold 4 was about 4 hits per 500 pixels.

Effect of single column hits

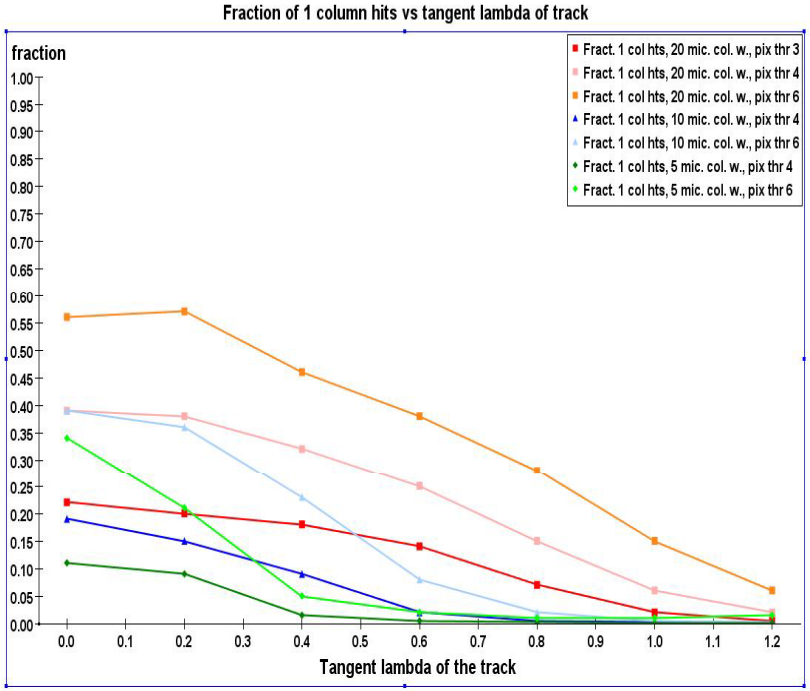
- Such hits can't be assigned time. So they are assumed valid for any event within full column readout time from the time they appear on the output. That increases their contribution into attached to physics event background by factor of hundreds compare to two-column hits.
- But that is not the major impact. The most important effect is, that if physics event hit is limited to only one column, but some another hit (from background or electronics noise) appeared within timeframe consistent for combining hits in neighboring column, it will lead to wrong time assignment for our physics hit, so it will be thought as not belonging to given event, giving hit recognition inefficiency.

So, how many single column hits ?

It depends on column width, track angle and single pixel threshold

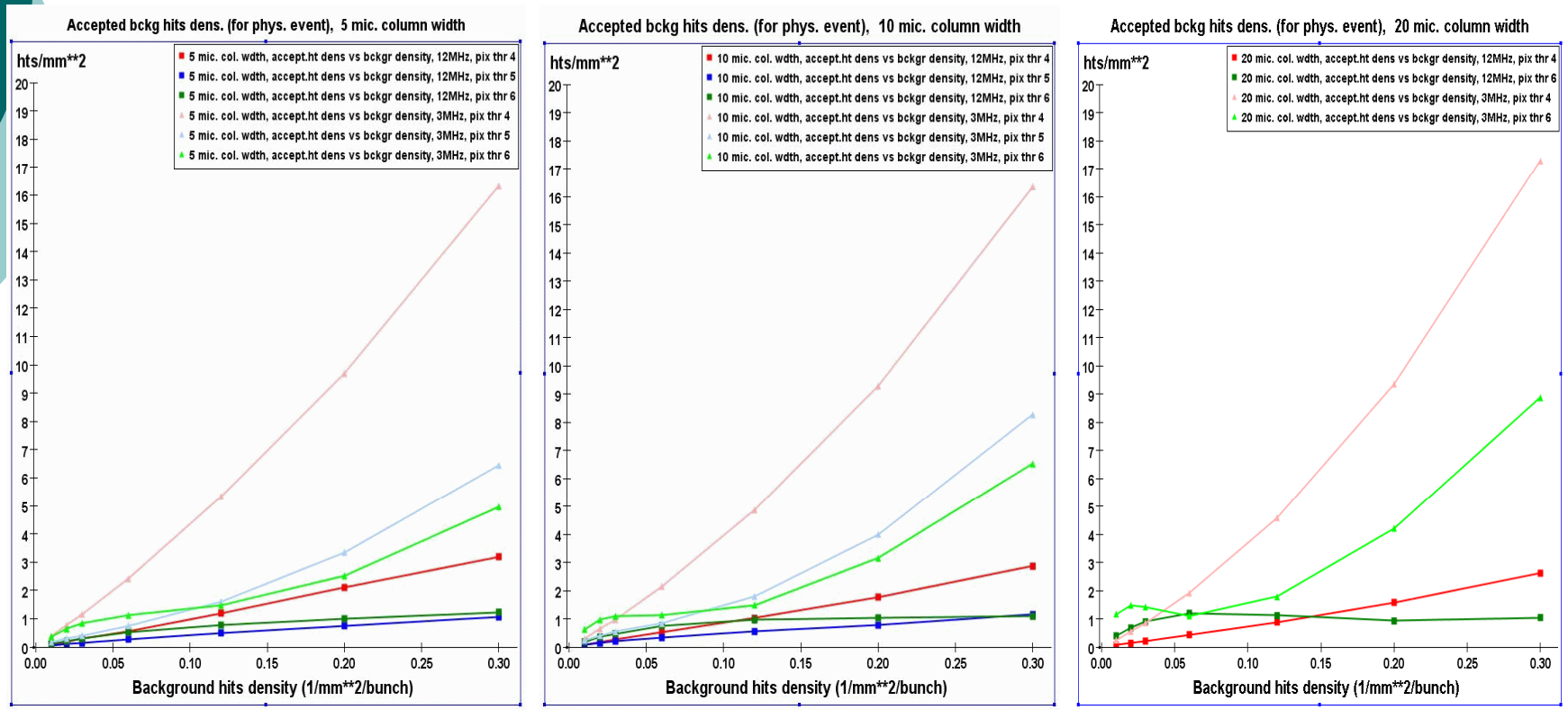


Example of number of column distribution. 20μ columns, but very low (3 ADC cnts) pixel thr.



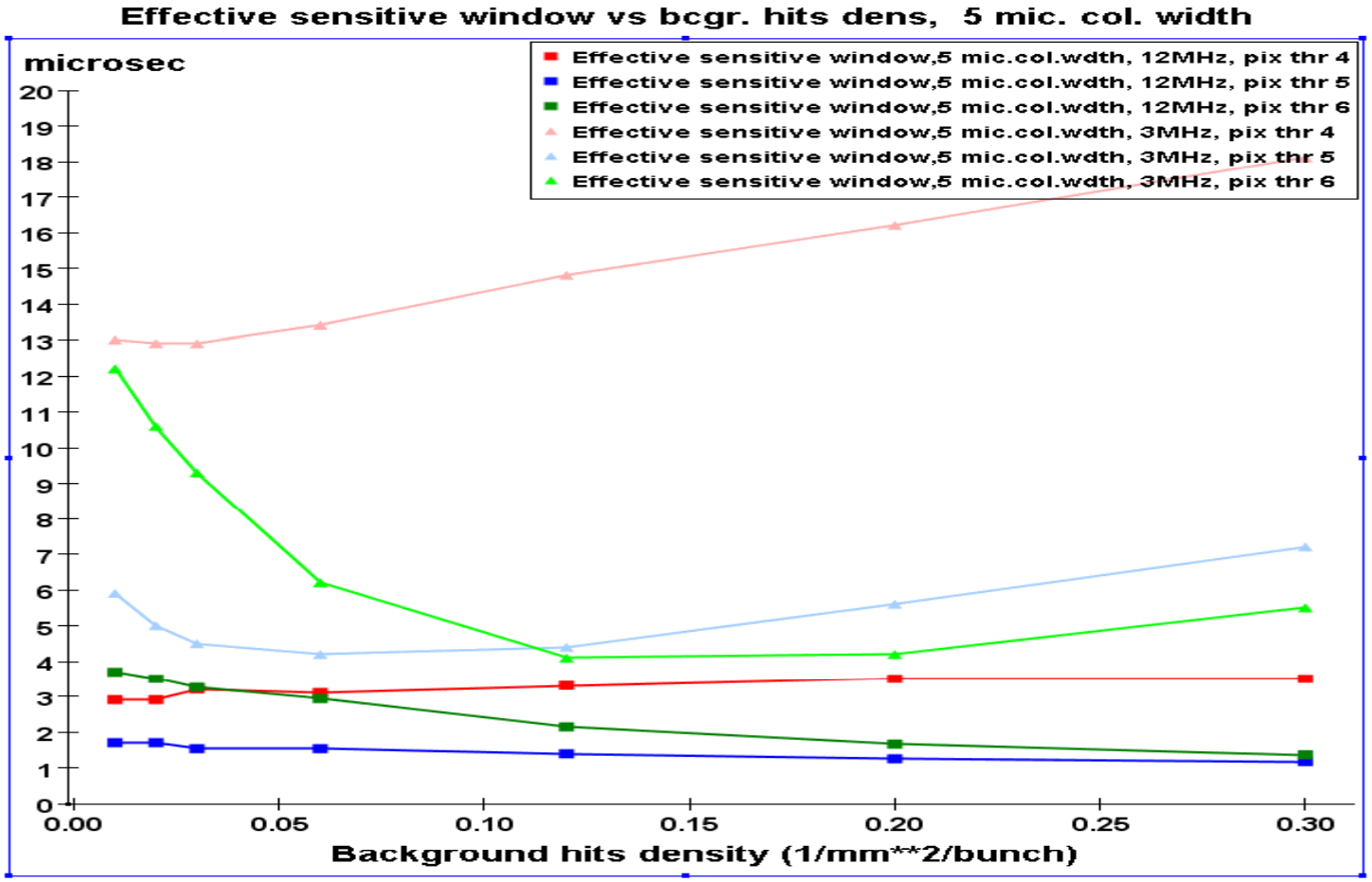
Fraction of single column hits vs track tangent lambda for different parameters

Density of accepted backgrounds

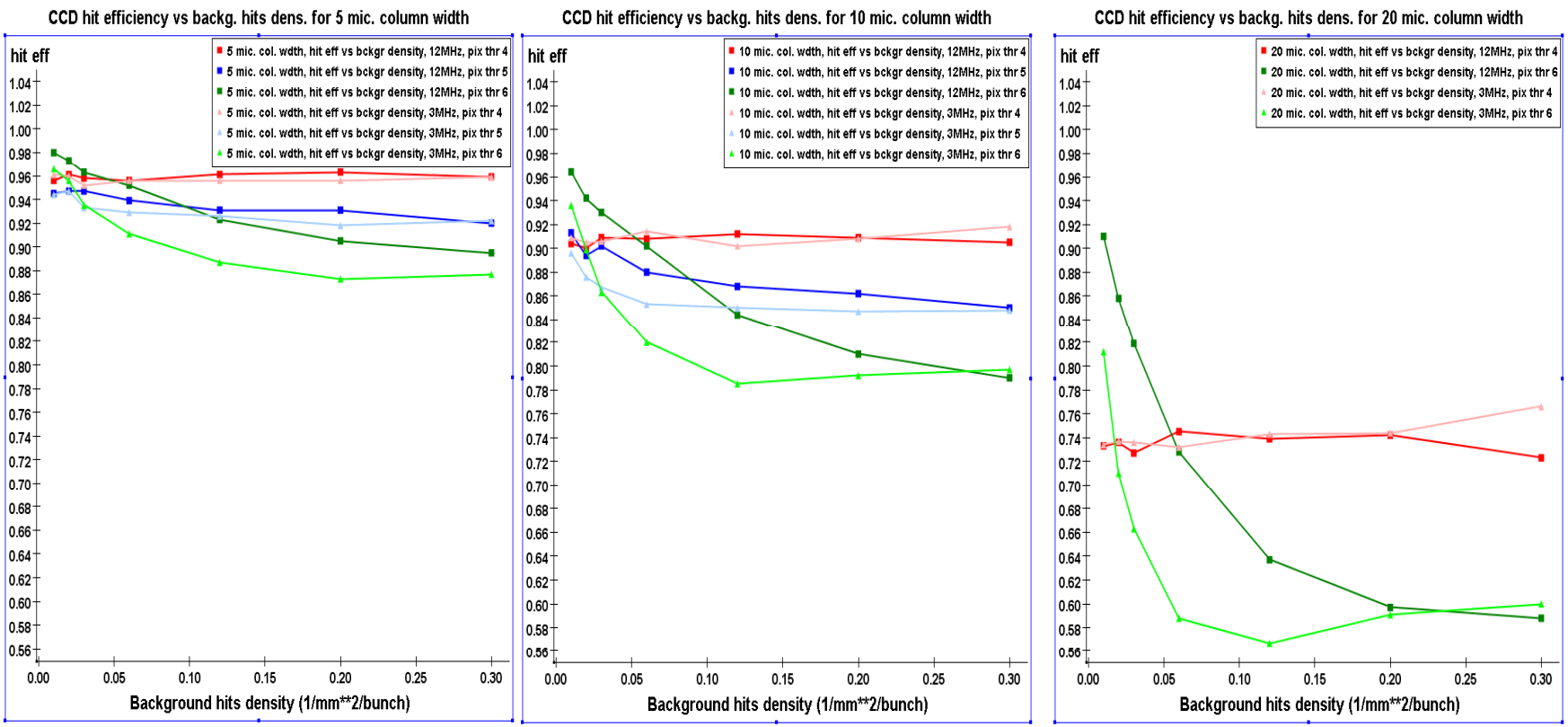


These plots for different column widths are almost indistinguishable. That means, that effect of single column hits on assigned hits density is minimal. This is mainly because of presence of electronics noise hits

Another way to present accepted background density – effective sensitive window

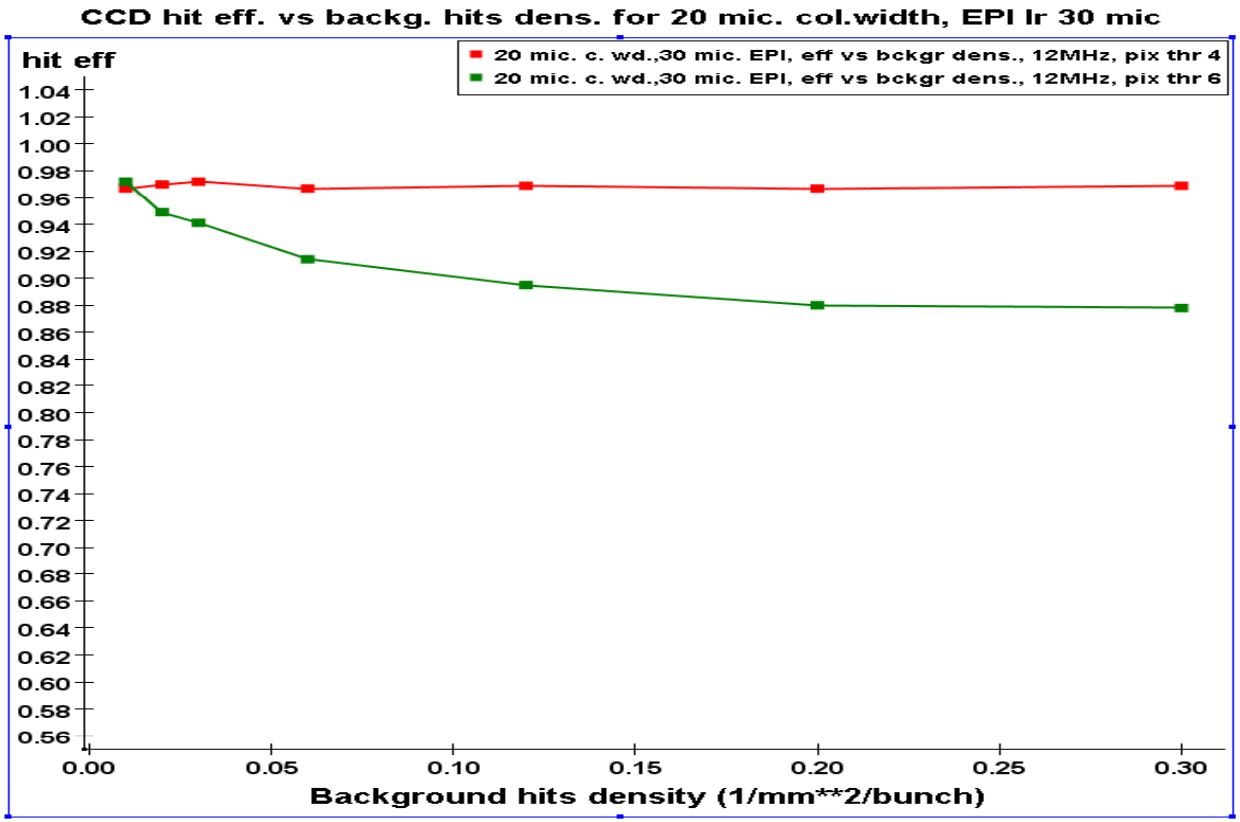


Hit Recognition Efficiency



Efficiency of physics hit recognition vs backgrounds density for different column widths. Not pretty !

How to improve efficiency ?



Increasing EPI layer thickness dramatically improve efficiency!

Conclusions

- Idea certainly works !
- The accepted background hits number is comfortable almost for any design parameters even with background level 10 times higher current estimates and slow (3MHz) readout.
- Major problem is in achieving high hit recognition efficiency. For this either narrower column widths, or thicker epitaxial layer thickness is needed