Unorthodox Musings toward True 3-D Readout for a Multi-kton LAr TPC

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Perspective – 1

"The two current designs are <u>good enough</u>"

- Is the scientific reach "maximized" ?
- What about unplanned discovery potential?
- Has due diligence been exercised ?

– "The time for new or better ideas is over"

Perspective – 2

"A design with small pixels might be better"

- Does a pixelized TPC provide better physics?
- Is a pixelized design technically possible?
- Can a pixelized design be demonstrated timely?
- Is a pixelized design affordable?

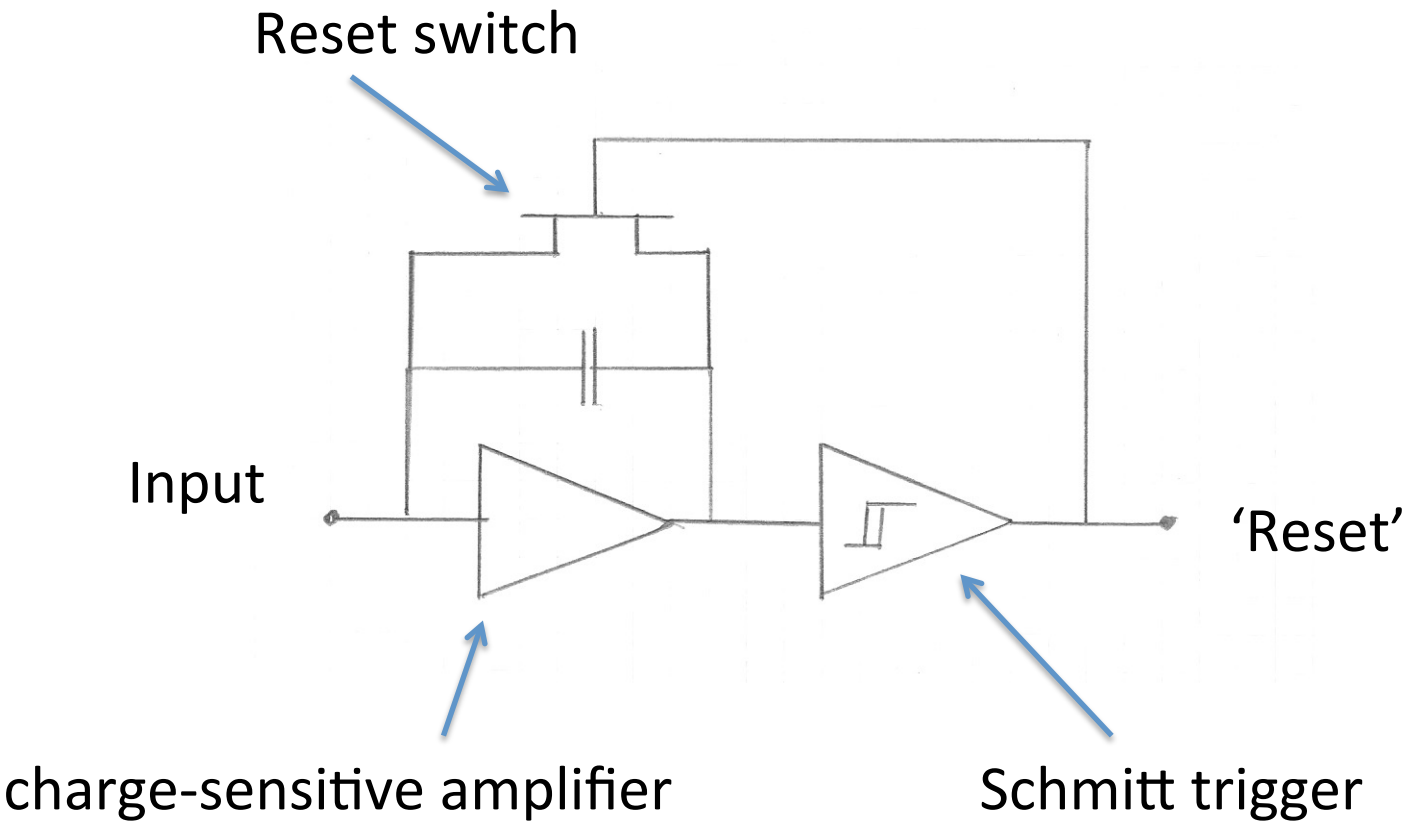
– "There isn't time enough to do it right, but there will always be time to do it over."

Starting points

- electronics must be embedded in LAr…
- simplest possible system concept…
- power dissipation must be ‘low’…
- follow the principle of “least action”

Must think out of the box ! (perhaps over the cliff…)

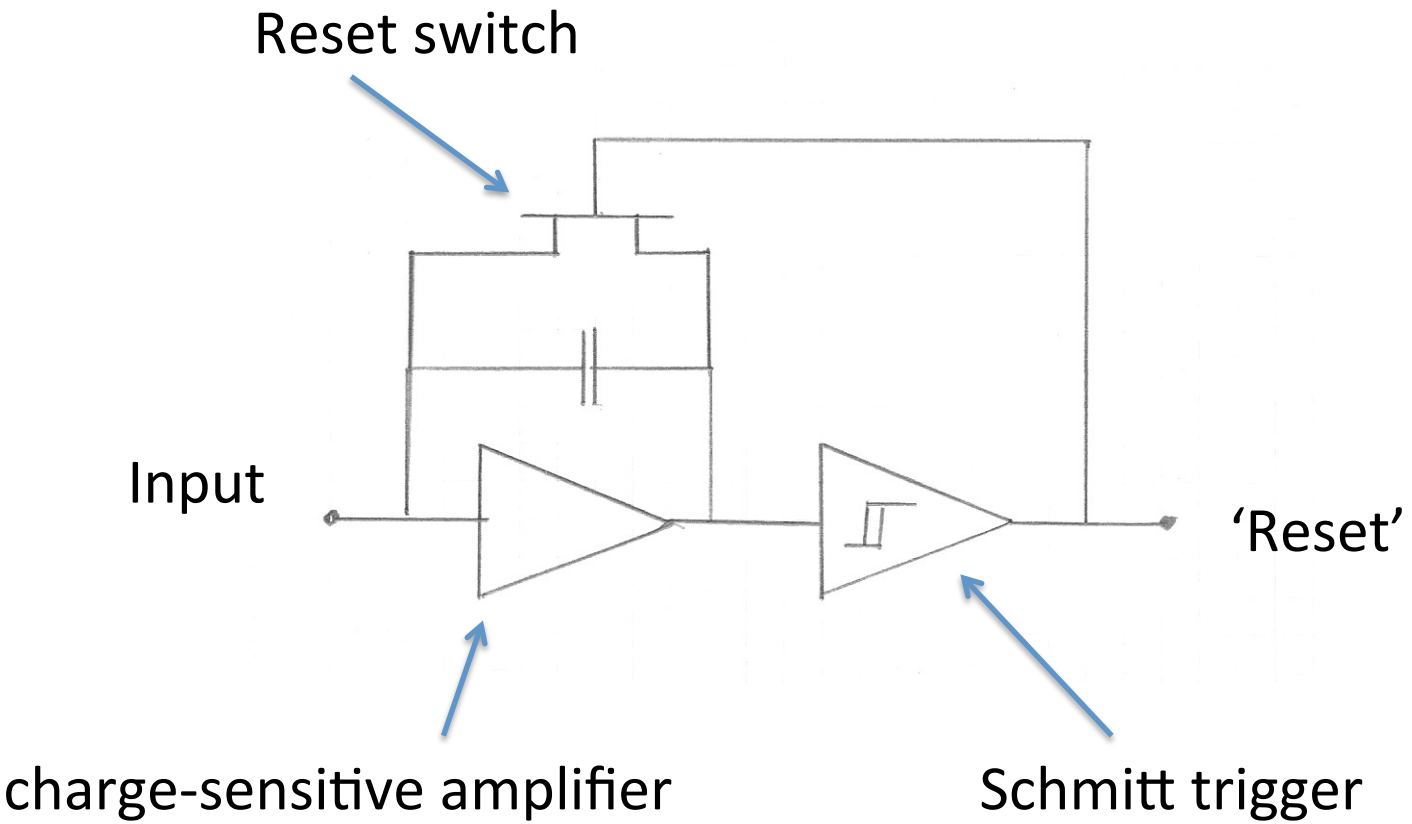
The Lowly Charge Pump



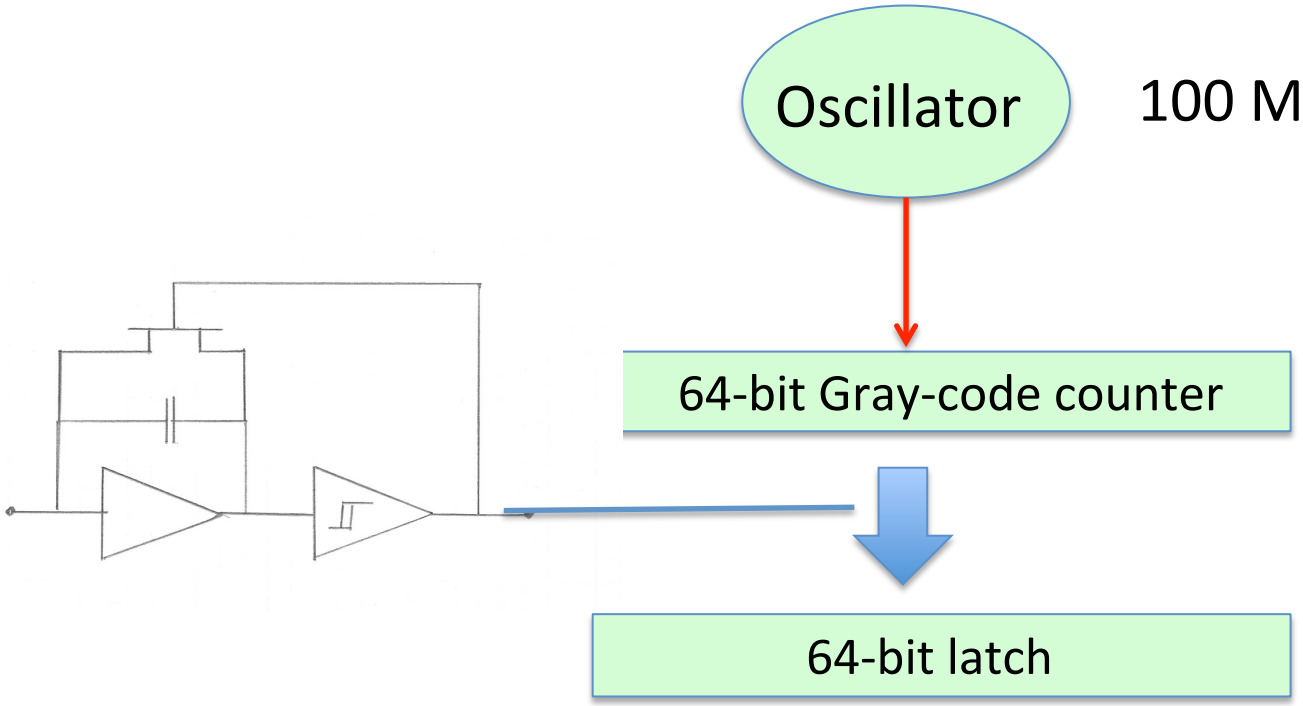
Classical Charge Pump Behavior

- Current arriving at input is integrated on C
- After integrating charge δQ on C, V_{th} is met
- Comparator triggers, closing switch
- Capacitor C is discharged, returned to baseline
- Cycle begins again, *ad infinitum*
- Classically, trigger augments a counter by one.
- Number of counts is proportional to total Q

The Advanced Charge Pump



We do something different



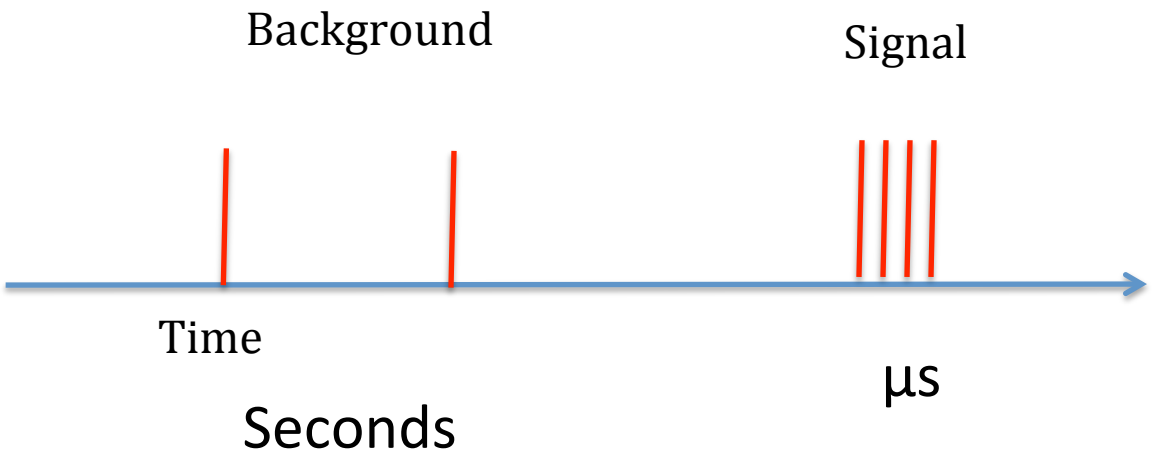
Reset trigger latches the contents of counter–
this action captures **local time** at instant of reset

Now what ?

- Take the difference between sequential resets
- This is the **reset time difference = RTD**
- **RTD** is a good measure of average currents
  - Small average current (background): Large RTD
  - Large average current (signal): Small RTD
- Choose δQ such that Min-I track will cause several resets: δQ = 1 fC

Signal: a contiguous sequence of small RTDs

The RTD patterns



In other words…

- RTD = inversely proportional to input current
- Background: ^{39}Ar decays lead to 'heartbeat'
  - heartbeat RTD ~20 seconds
  - natural calibration available – form histograms
- Signal: typically a few na, → RTD < 1 μs
  - At least three or four contiguous small RTDs
  - Easy to recognize signal against background!
  - No signal differentiation! (unlike induction wires)

Precision?

- The charge pump has better 'resolution' for small currents, such as for electron showers
- How much dynamic range is really needed?
  - proton decay within Ar → nuclear fragmentation
  - not so clear what is needed
- Remember:
  - Charge resolution here is "exactly" δQ
  - Time resolution is ~10 ns

*Marcel Demarteau: …"data of the utmost precision…"

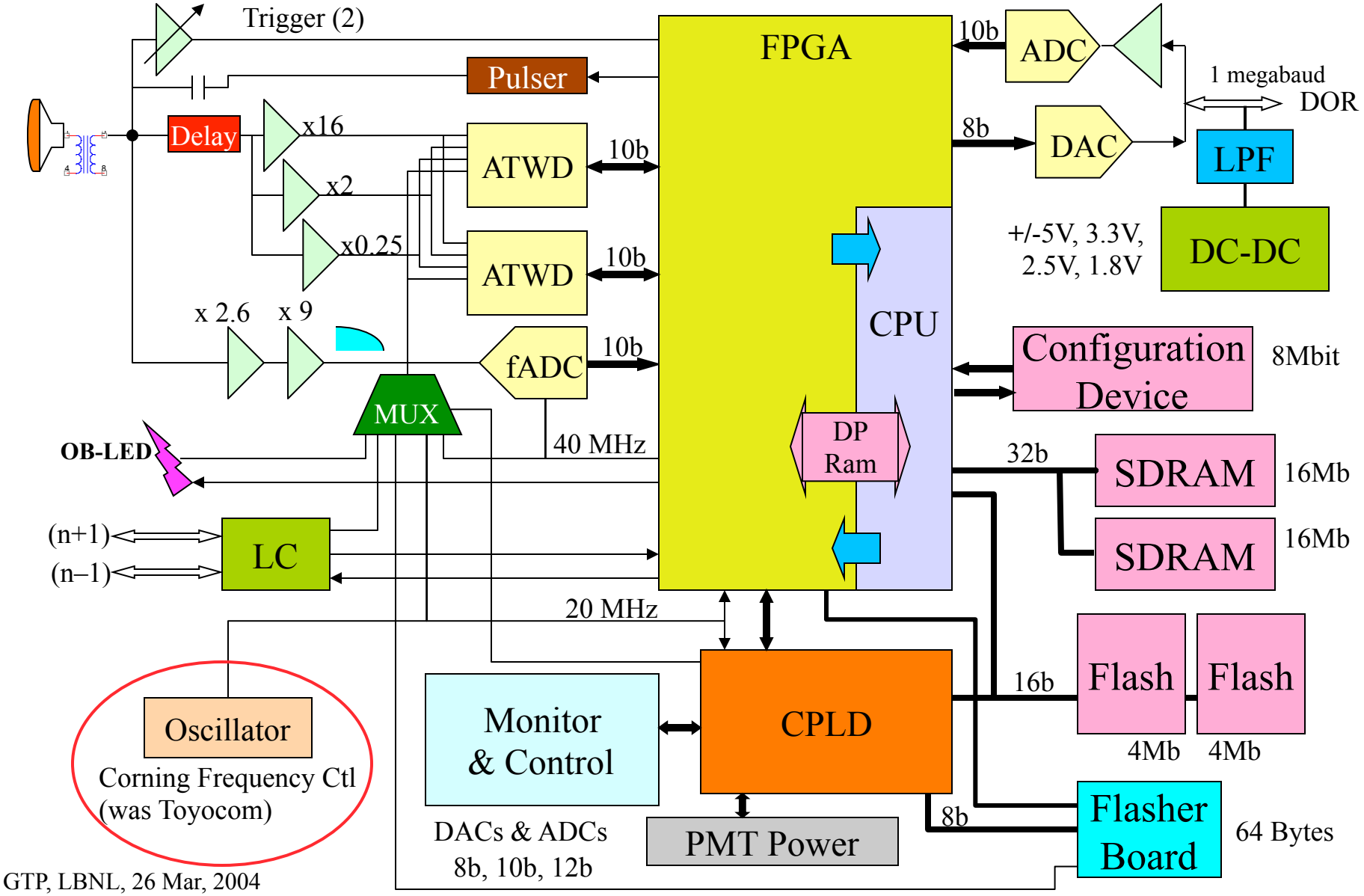
Time-stamped Waveforms ?

- Local Time-stamp is provided by taking the full 64 bit value of shortest RTD value
- A contiguous sequence of short RTDs provides a good representation of arbitrary waveforms
- Our waveform: varying time intervals between equal charge quanta.
- Conventional: varying charges between equal time quanta

Time-stamping ?

- The local clock runs freely at f ~100 MHz
  - No phase-locked loop
  - Must be stable: $\delta f/f < 1 \times 10^{-6}$ per second
  - Once a second, ask ASIC "What time is it?"
  - ASIC captures local time and sends it @ 1Hz
  - Simple linear transformation: $T = A \bullet F/f + B$
  - F is master clock synched to GMT
- **But we have seen this before!**

IceCube: Digital Optical Module Block Diagram



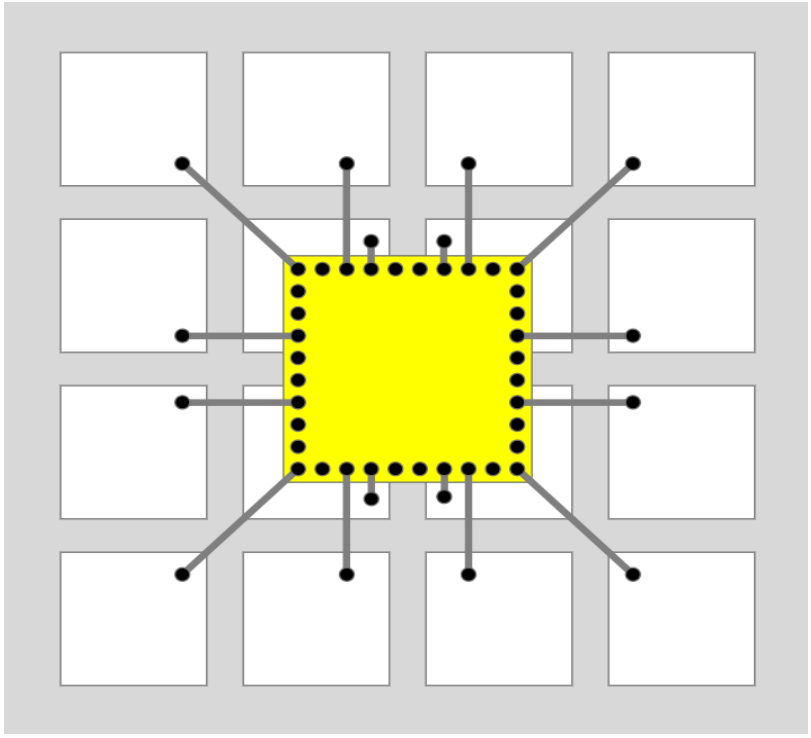
GTP, LBNL, 26 Mar, 2004

Clocks…

- IceCube: ±2 ns rms within 1 km^3 of ice!
  - works flawlessly and invisibly
- Oscillator precision in IceCube is ~1 x 10^{-10}/s
  - hard to measure!
- DUNE: ±1 μs precision
  - requires $\delta f/f < 1 \times 10^{-6}$ per second for local clock
  - This is probably easy to achieve in LAr
- What works in IceCube can work in DUNE

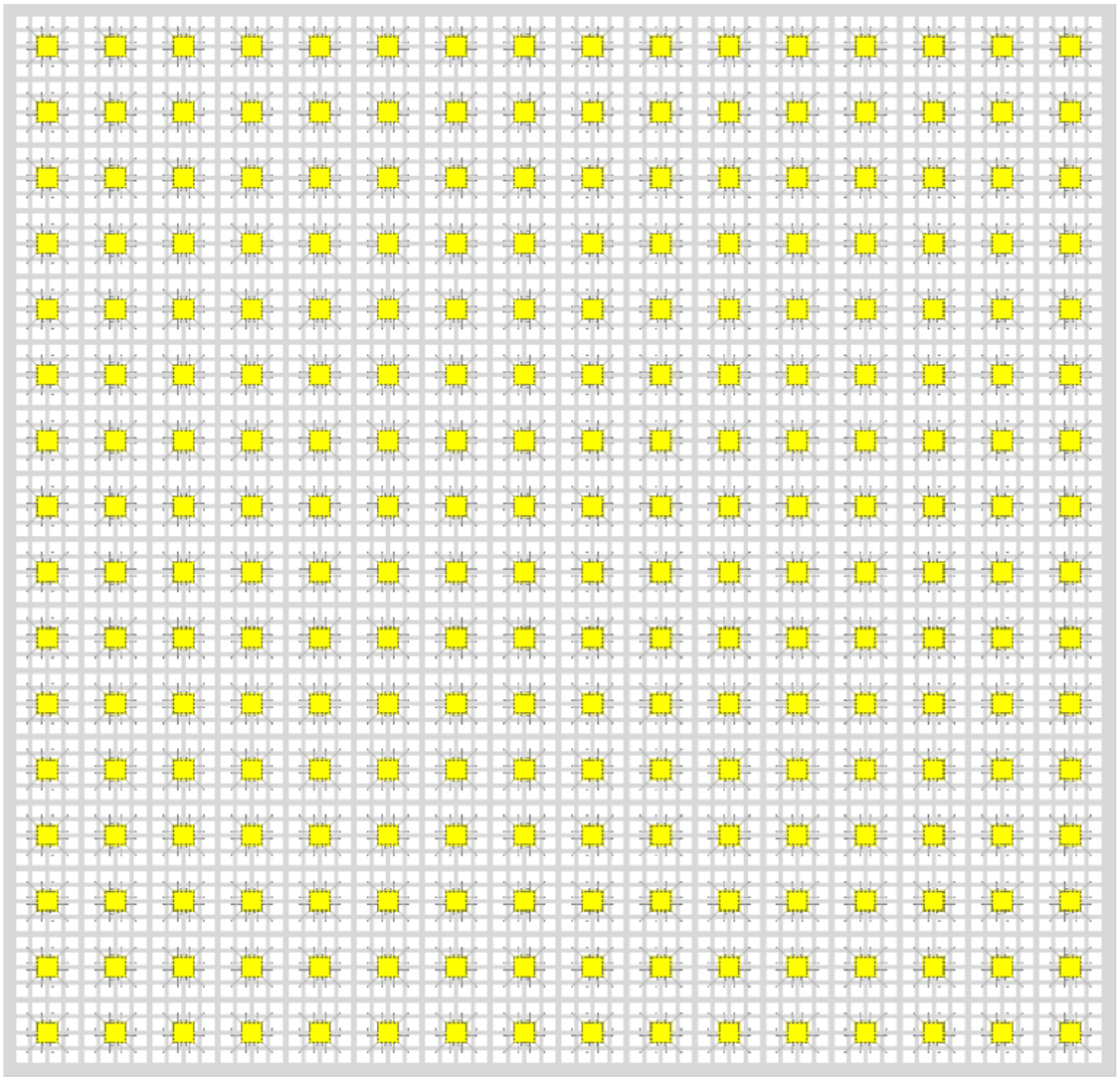
Pixel Array ?

- The local clock serves 16 pixels in one ASIC



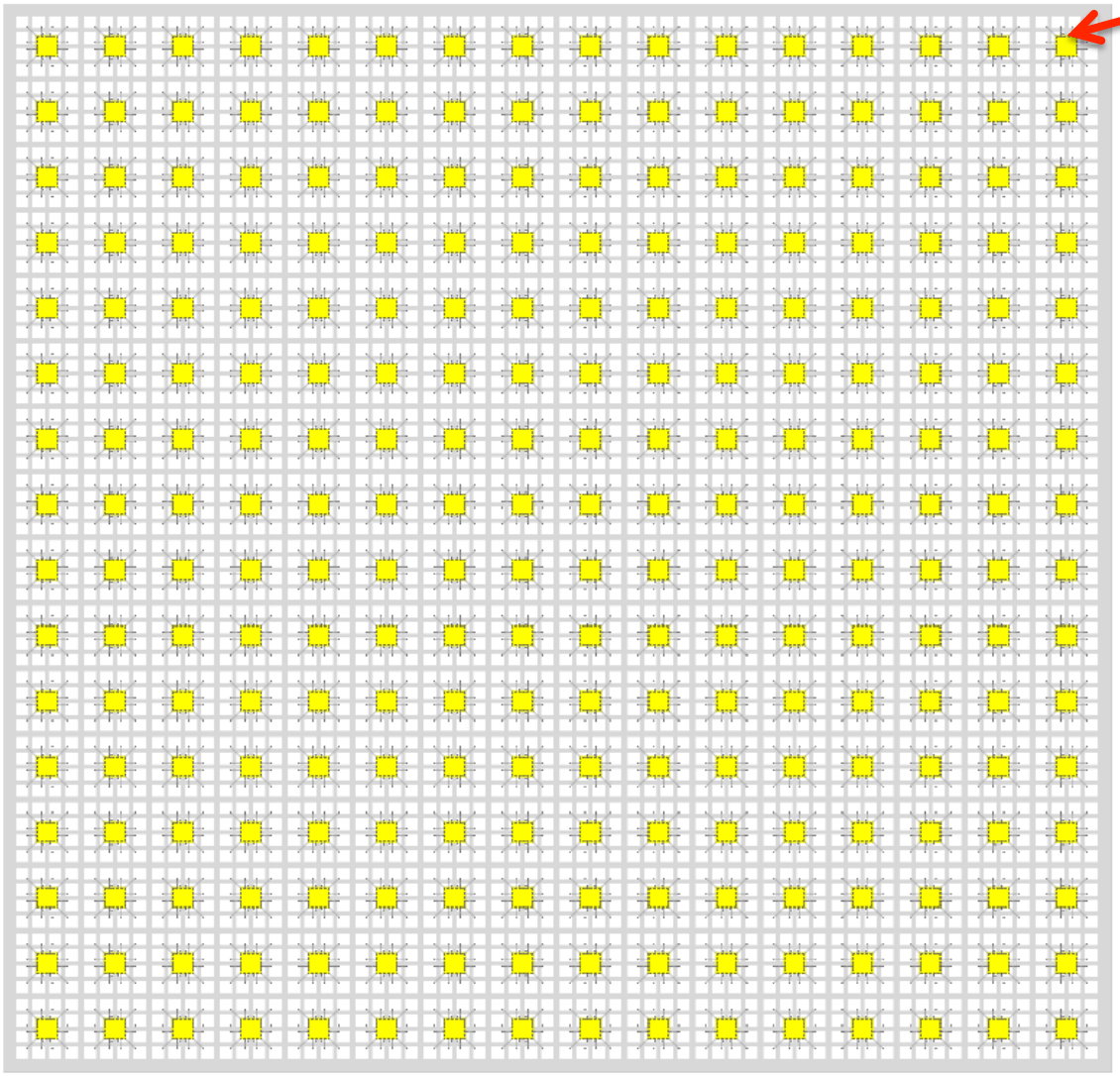
View from inactive side

Wire-bonds connect each pixel to ASIC; via connects to small button on active side, minimizing capacitance and noise

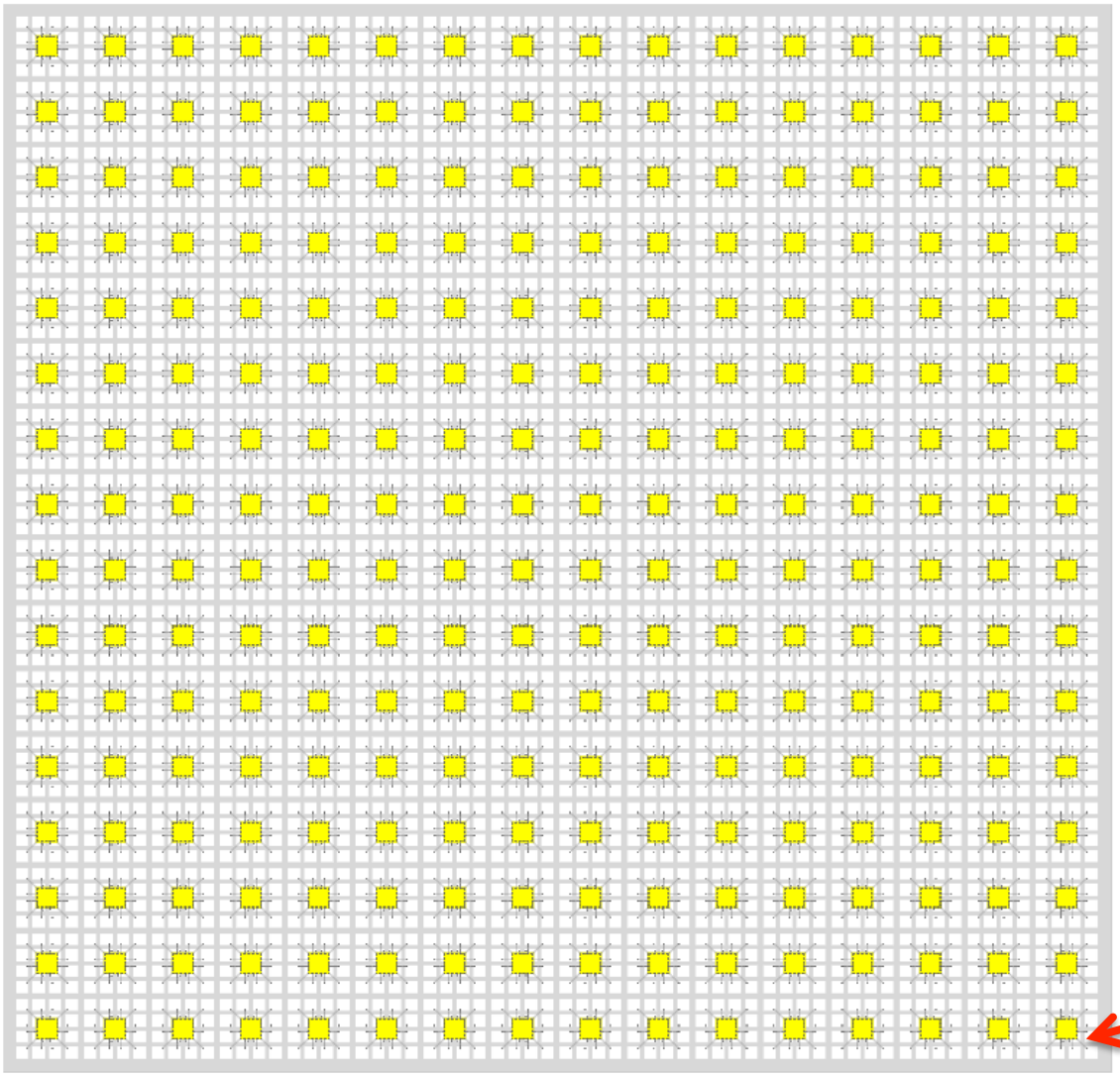


16 x 16 Tile
of 256 ASICs,
4092 pixels

here…



Local clock interrogation signal enters at any corner of tile, and propagates as a wave to any neighbor



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Or here…

No single-point failures

- Local clock interrogation ‘wave’ sweeps around any dead ASIC;
- Any of four corners provides entry point for interrogation and for data recovery.
- Wave mode seems fanciful, but I don’t see why it couldn’t work…

Perspective

- IceCube demonstrated that it is rational to embed complex electronics in perpetuity
  - care taken in design phase to avoid bleeding edge
  - care taken in qualifying parts list
  - care taken in fabrication & test
- IceCube demonstrated that unorthodox time-stamp method meets high performance goals.

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- The charge-pump pixel extracts all available energy, spatial and time information with high precision and appropriate dynamic range.
- Several aspects are just assertions at this point
- It seems plausible that an unorthodox scheme to realize a fully pixelized DUNE might work.
- Are the two current approaches really "good enough" ?