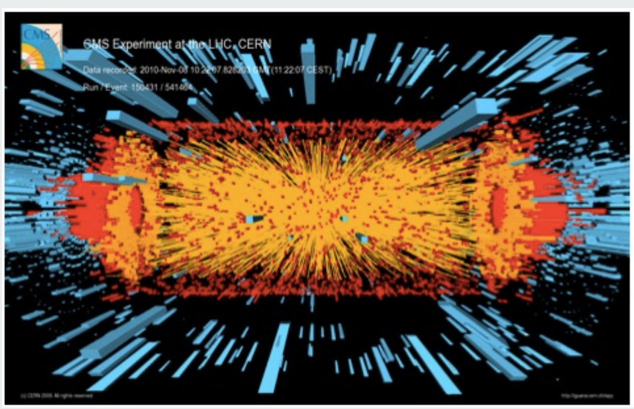
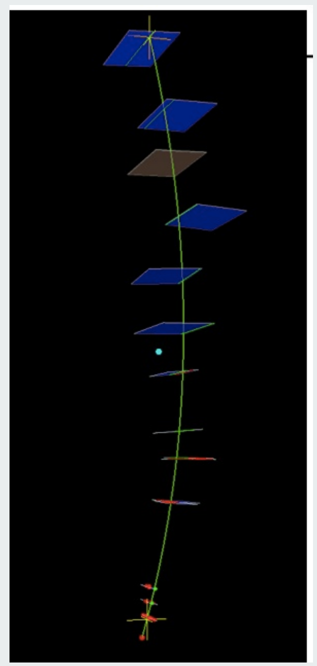
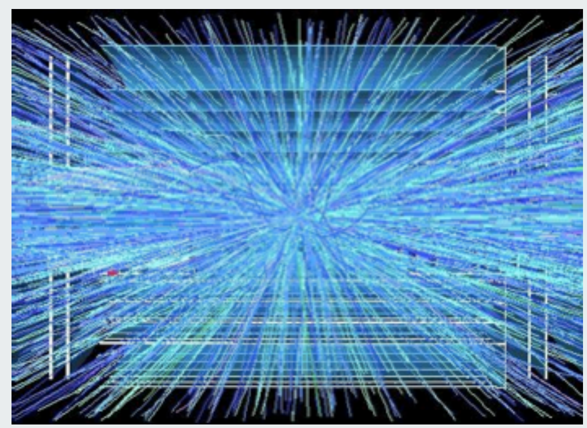
Possible future direction for Precision Position and Timing detector R&D using 3DIC technology - Ted Liu (FNAL)

July 30, 2020

Snowmass IF07 Electronics ASIC Flashrtalks workshop







Detector design for triggering

Tracking Trigger challenges at HL-LHC

Data reduction
using "stub finding"

Data transfer

Data formatting

Partition detector into
trigger towers/sectors

Pick your favorite method:
Associative Memory Approach
Hough Transformation
Adaptive Pattern Recognition
Biology Inspired …
your choice here…

Pattern Recognition

Finer pattern recognition

Track Fitting

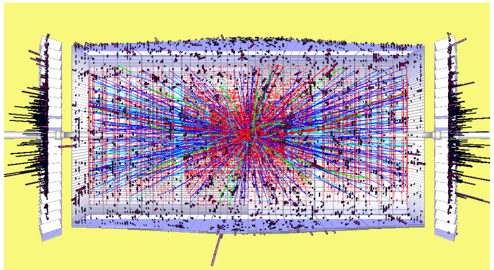
- *Challenging issues*

(1) Data Reduction at detector/sensor stage
(2) Data Transfer (rad hard, high bandwidth, low power link)
(3) Data Formatting
(4) Pattern Recognition
(5) Track Fitting …

Will only use HL-LHC tracking trigger as an example here:

The need for precision timing and position detector in the future (beyond HL-LHC)

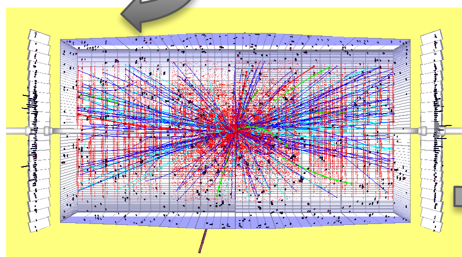
(there are many other motivations for precision timing & position detector)



Raw info produced by CMS tracker at HL-LHC

Bandwidth required:
~ 100 Tbps

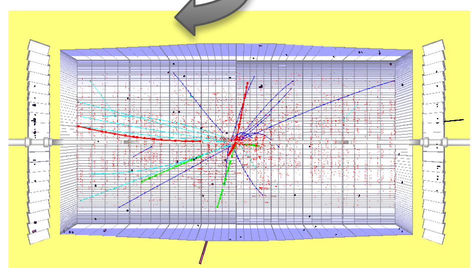
"Stub finding" is a crucial step to reduce the raw data volume …



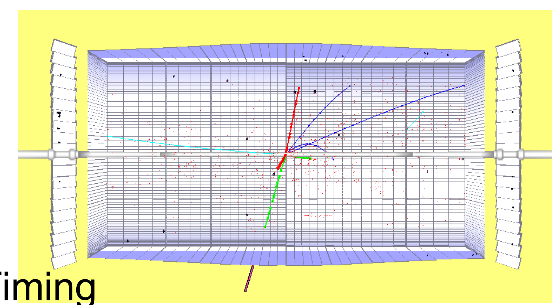
After stub finding at module level
(~ 10 -20 reduction)

After Pattern Recognition
(~ 10 reduction)

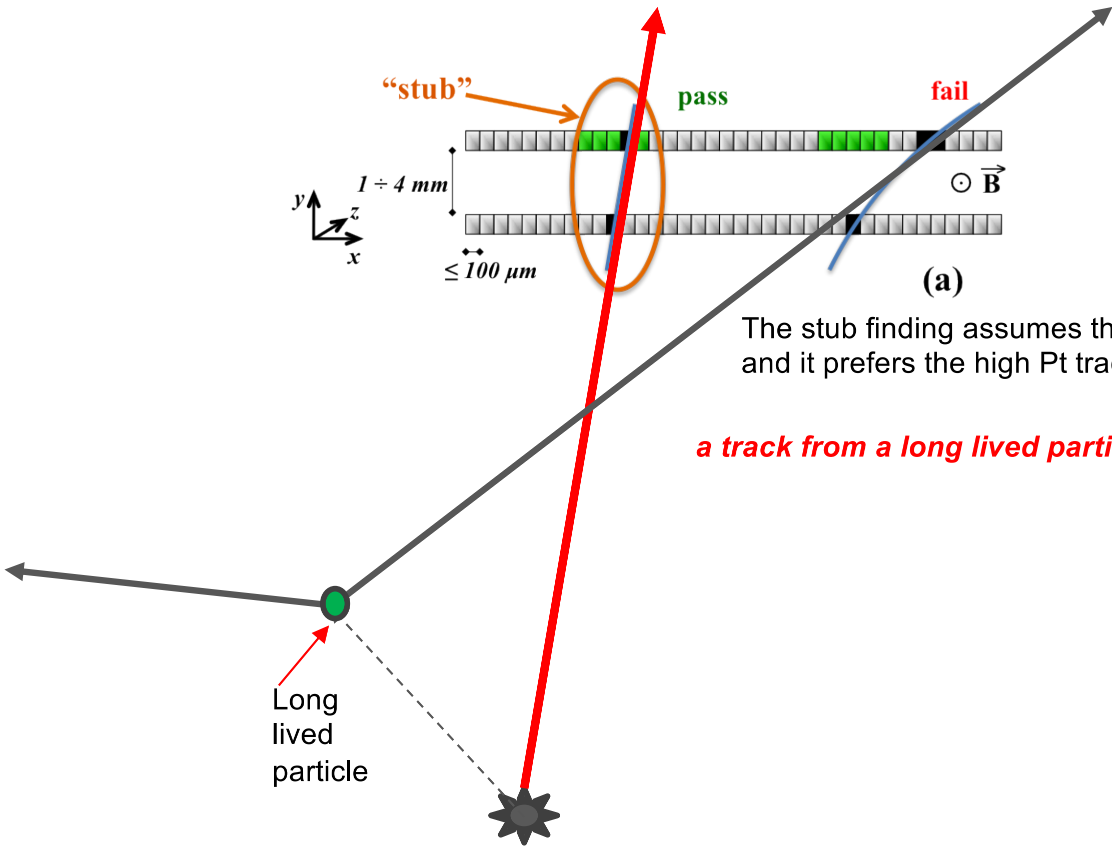
*One way to **imagine** different stages of processing (just conceptually)*



After ***Track Fitting***
and later
event vertexing



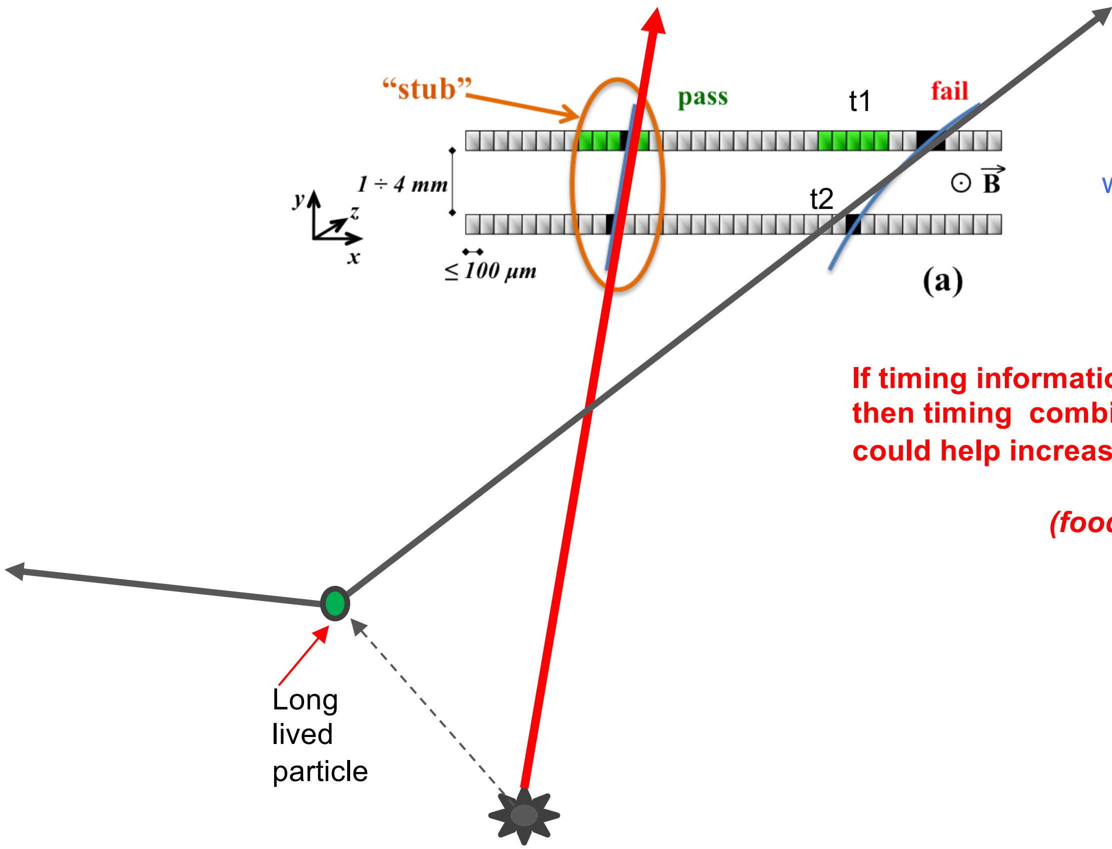
Essence of stub finding: the short coming



The stub finding assumes the track is originated from IP (interaction point), and it prefers the high Pt tracks while rejecting slow moving tracks (curved)

a track from a long lived particle (due to new physics) decay would fail the selection

Essence of stub finding: timing can help here



For beyond HL-LHC in the future

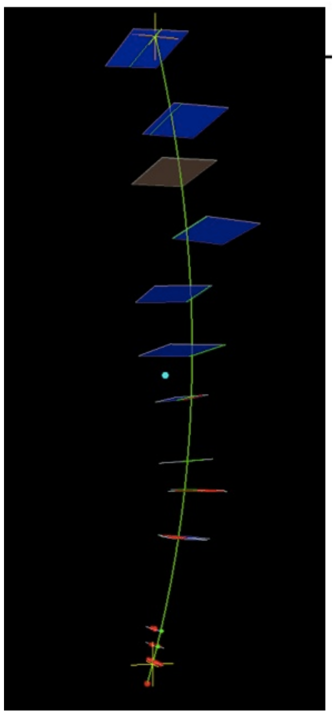
with arrival time and position info

If timing information is also available for each layers,
then timing combined with position info
could help increasing the efficiency for long lived particle

(food for thought)

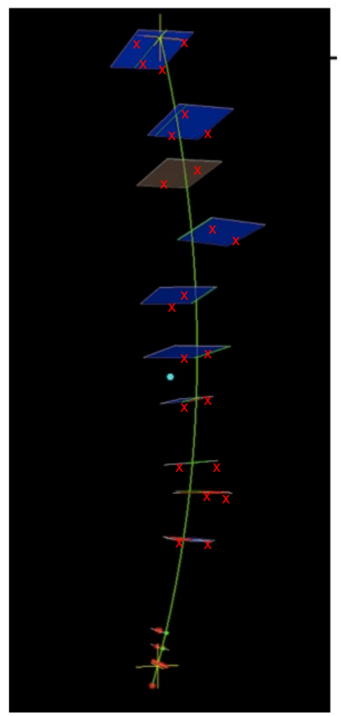
Pattern recognition and track fitting stage

Low luminosity case vs. High luminosity case high luminosity case with timing



In the high luminosity case,
many random hits will still survive pattern recognition stage

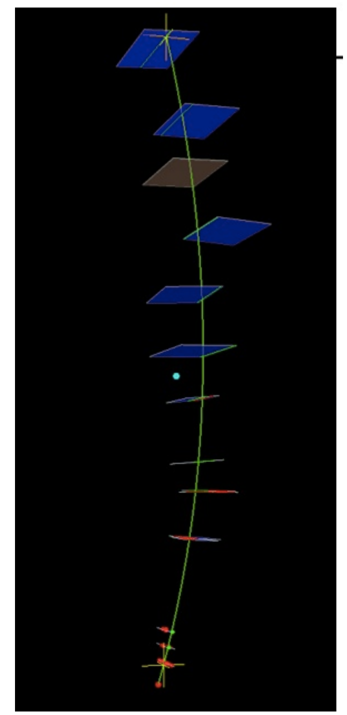
Track fitting stage has to try out all combinations



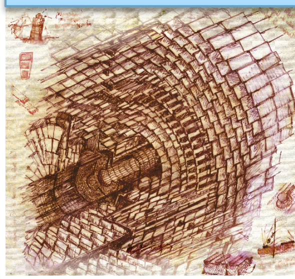
If precision timing information is available, and used in the pattern recognition stage, most of the random hits could be removed ….

(for beyond HL-LHC)

Food for thought



Detector design for triggering



Trigger @ future hadron collider(s) → the view from HL-LHC (or a wild guess)

Data transfer (rad hard) high bandwidth low power data link

Data formatting

Pattern Recognition

Machine learning …

Track Fitting

Modern FPGAs

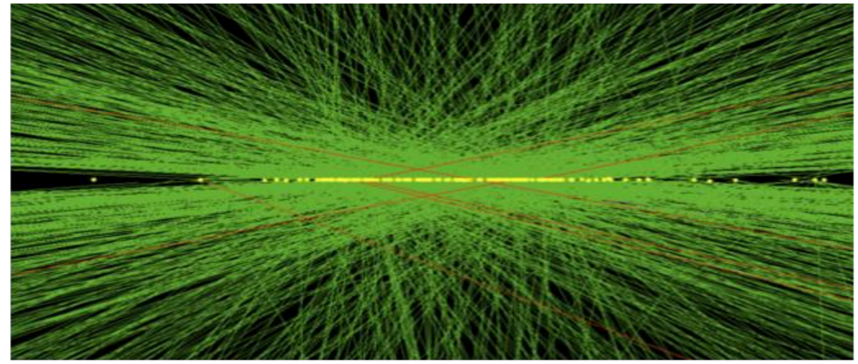
HLT

There are new challenges:

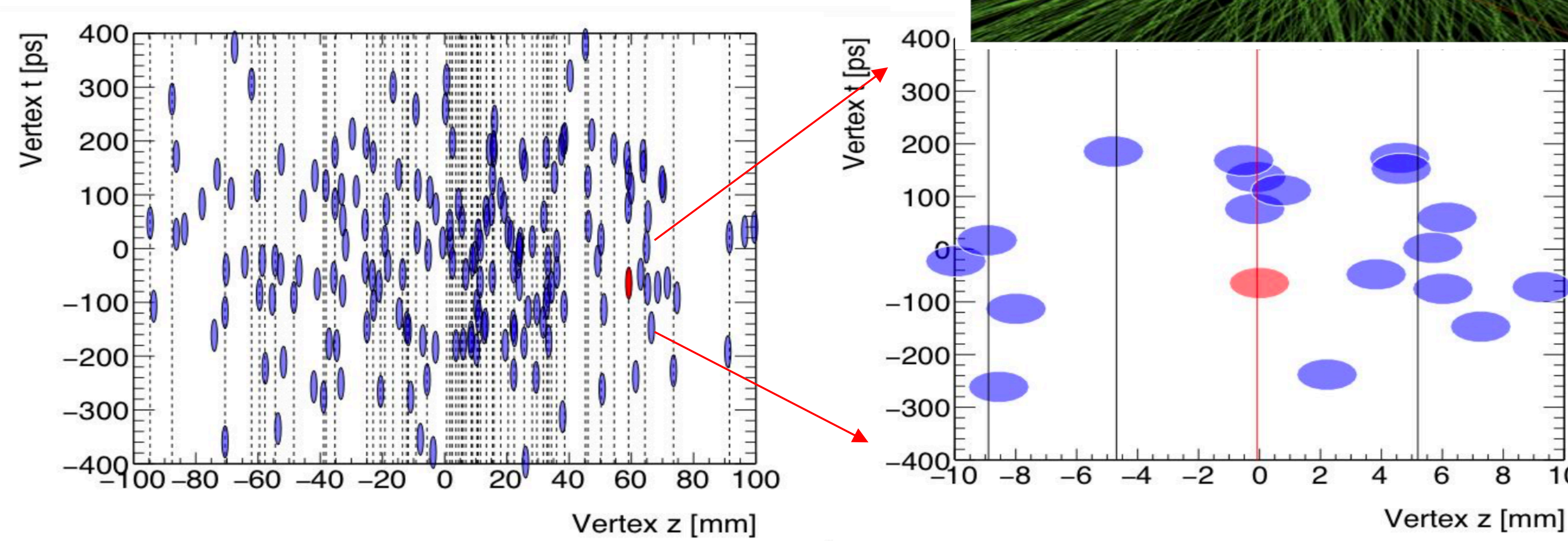
- *(0) tracker with precision timing & position*
- *(1) Data Reduction at detector/sensor stage with precision timing & position info*
- *(2) Data Transfer (rad hard, high bandwidth, low power link)*
- *(3) Data Formatting (with precision timing info)*
- *(4) Pattern Recognition (with precision timing info)*
- *(5) Track Fitting (with precision timing info)*

Open question: what if fast timing be used in tracking trigger?
(pattern recognition and tracking in 4D: both space and time)
what is the highest luminosity one could handle? (beyond 1E35?)

Precision timing detectors for HL-LHC



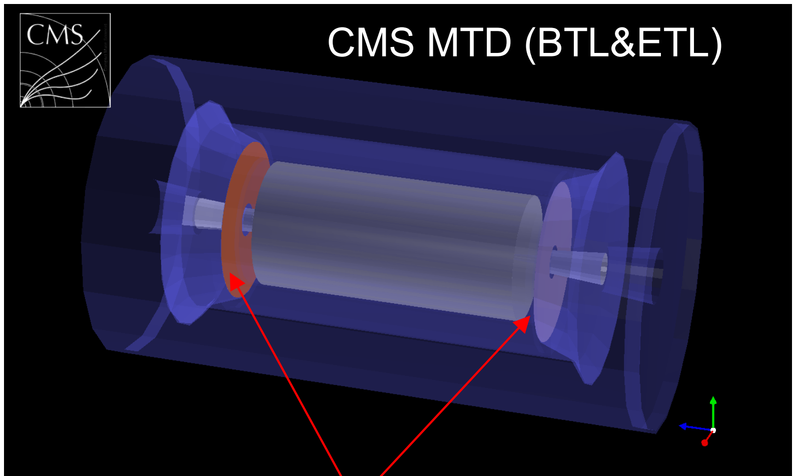
Precision timing & event vertex association



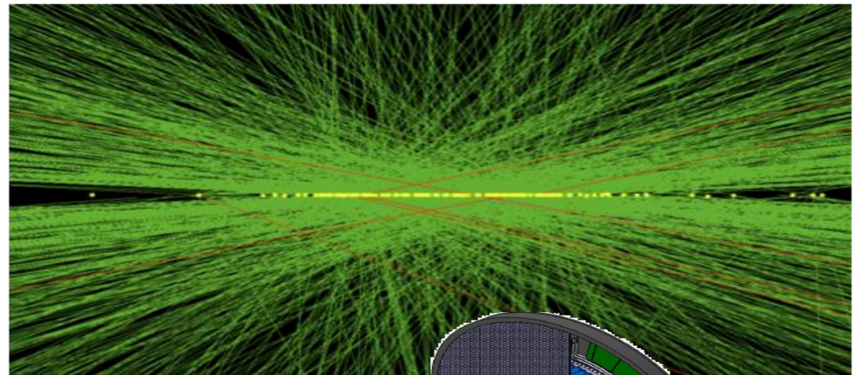
Event display showing the time and z position of all vertices in an event with 200 additional interactions. Blue ellipses correspond to truth vertices. The size of the ellipses are 30ps and 1mm. The red ellipse indicates the truth hard-scatter vertex. The dotted lines indicate the position of the reconstructed primary vertices in the event. The right plot is a zoom around the hard-scatter vertex.

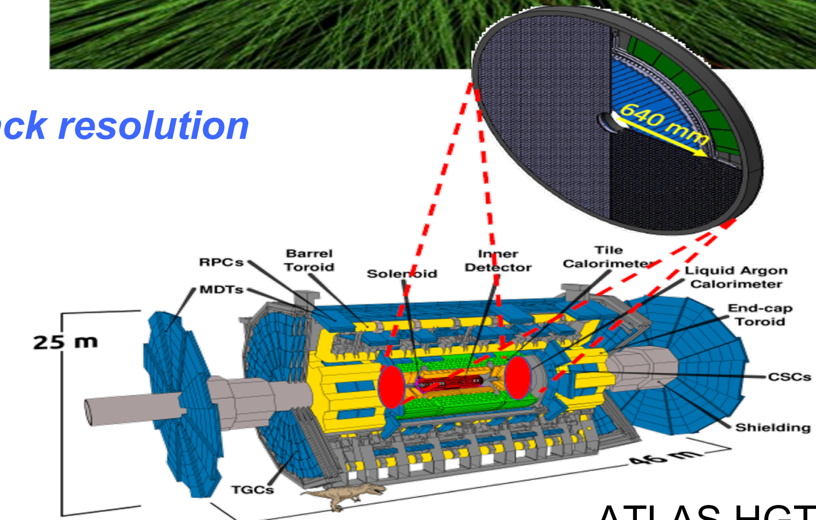
Precision timing detectors for HL-LHC

What we have learned and challenges ahead of us
to develop precision timing & position detectors
for beyond HL-LHC …



~ 30 ps per track resolution





ATLAS HGTD

Will use CMS ETL (Endcap) as an example: ETROC chip
The LGAD sensor (2cm x 4cm) has a pixel size of 1.3 mm x 1.3mm (quite large)

For LGAD sensor for precision timing applications, see Abe Seiden's talk today:
https://indico.fnal.gov/event/44596/

ETROC (CMS ETL ReadOut Chip) in 65nm

The 16x16 pixel array ETROC is bump-bonded to 16x16 sensor pixel array of LGAD

The size of pixel: 1.3 mm x 1.3mm
(the same size for ATLAS HGTD)

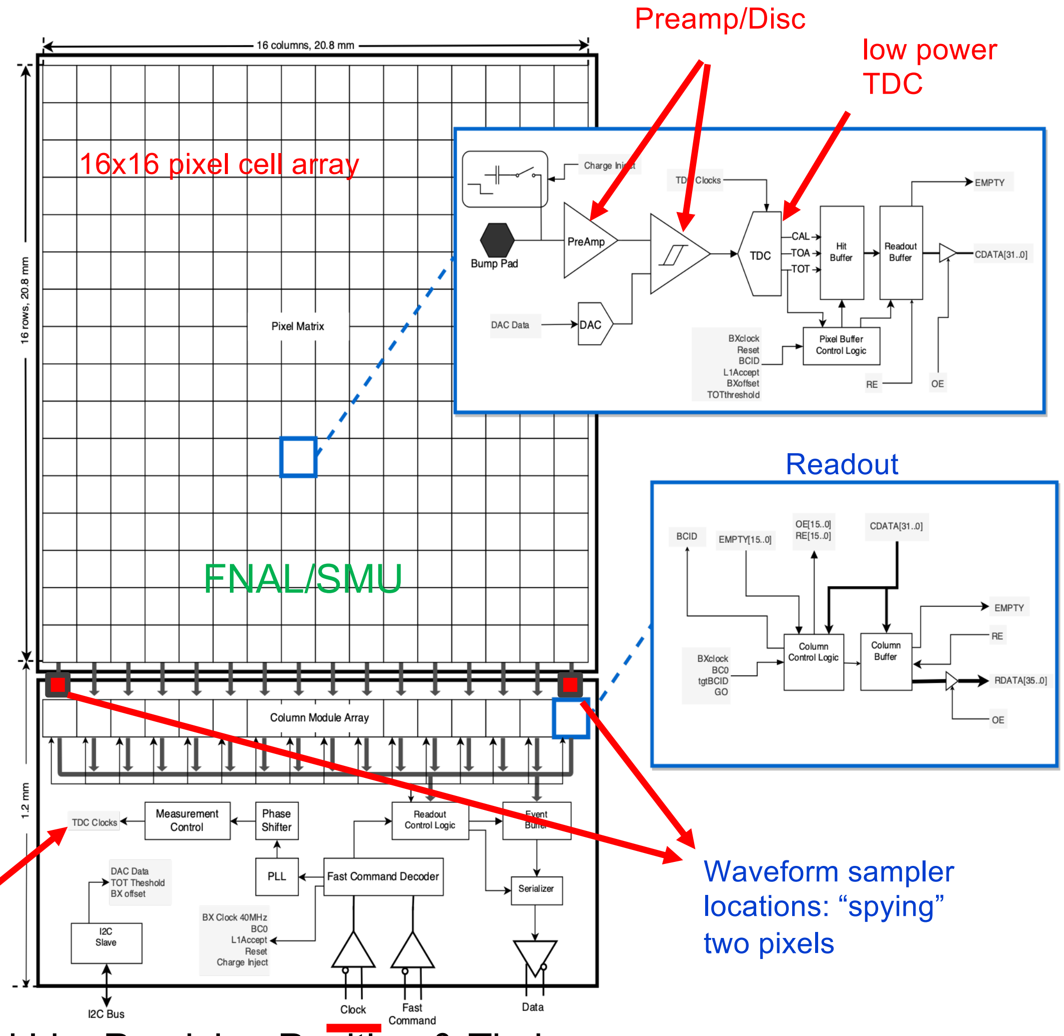
LGAD size: ~ 2cm x 4cm
ETROC size: ~2cmx2cm

This is the first generation precision timing detector (~30 ps level)… but by no means precision position detector.

To also have precision position information, the pixel size needs to be scaled from 1.3mm x 1.3mm down to about ~ 100 um x 100 um level or so …

(a factor of ~170)

This is challenging!

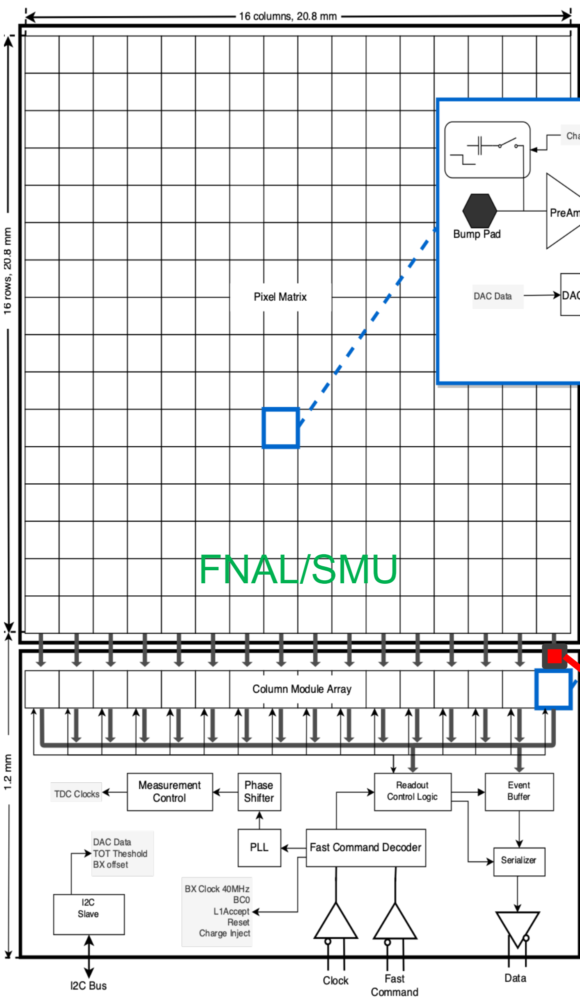


Precision clock distribution to all pixels

What we have learned from ETROC (CMS ETL ASIC)

65nm implementation

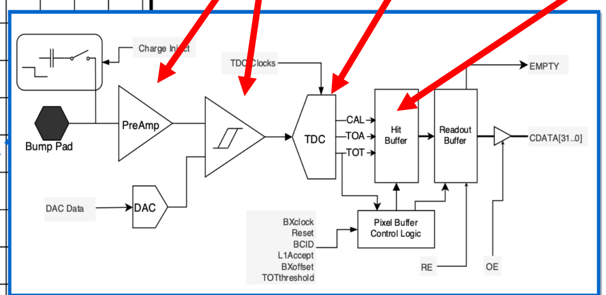
16x16 pixel cell array (1.3mm x 1.3 mm)

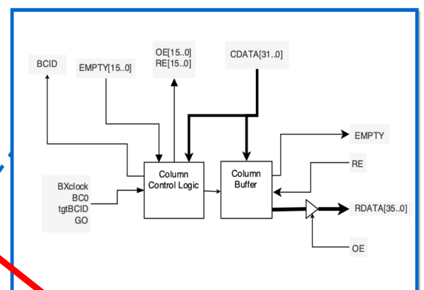


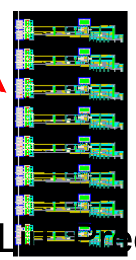
Preamp/Disc

low power TDC

Hit buffer



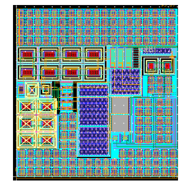




300um x 800um

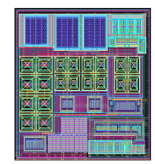
3.2GS/s waveform sampler

90 um X 94 um



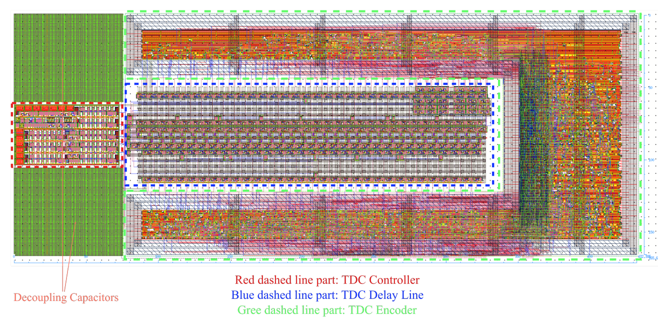
Preamp

81 um X 67 um



Discriminator

467 um X 166 um (can be subdivided)



TDC

SRAM hit buffer
250 um x 150 um

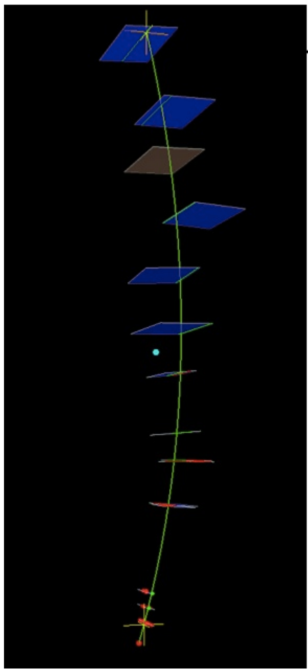
(can be subdivided)

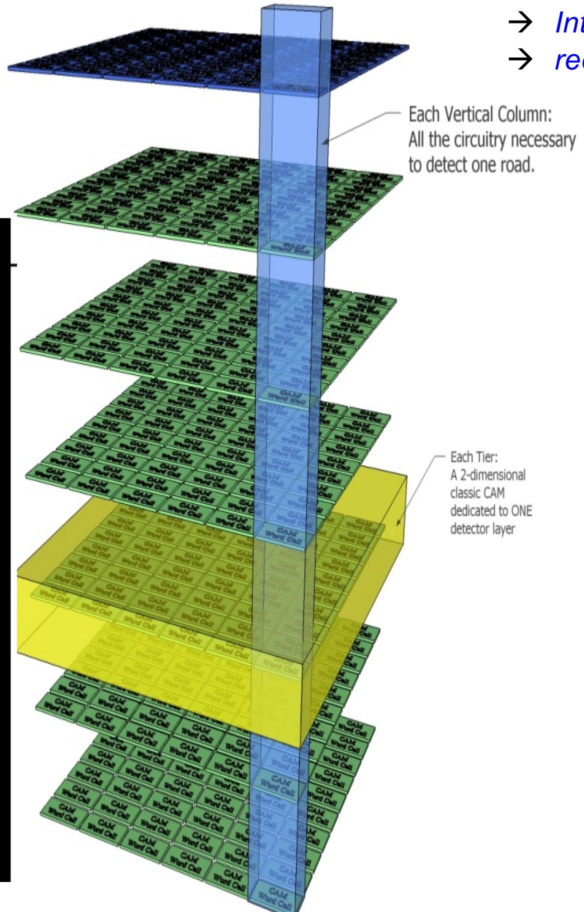
Hit circular buffer

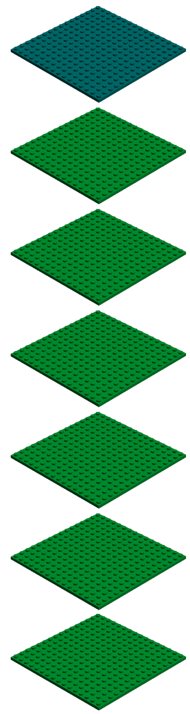
3DIC Technology

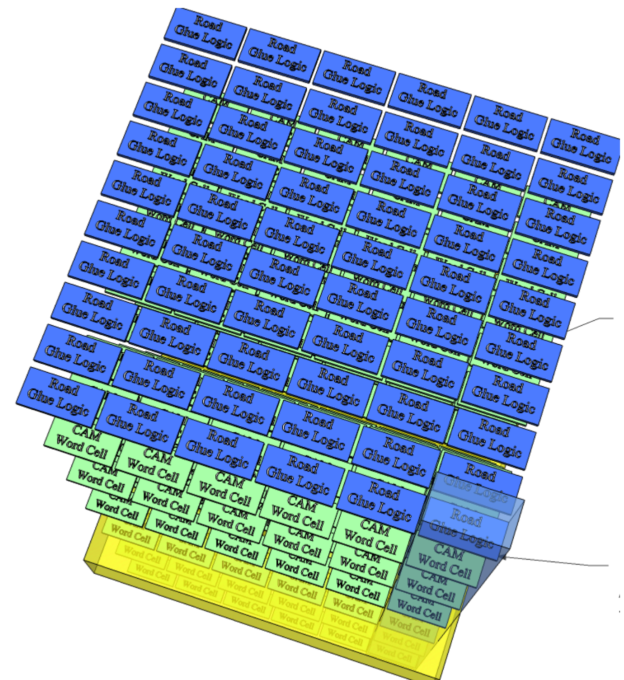
The 3DIC stack can be very thin (< ~ 10 um per tier)

→ *Interconnection much better than bump-bonding*
→ *reduced power density or increased speed*







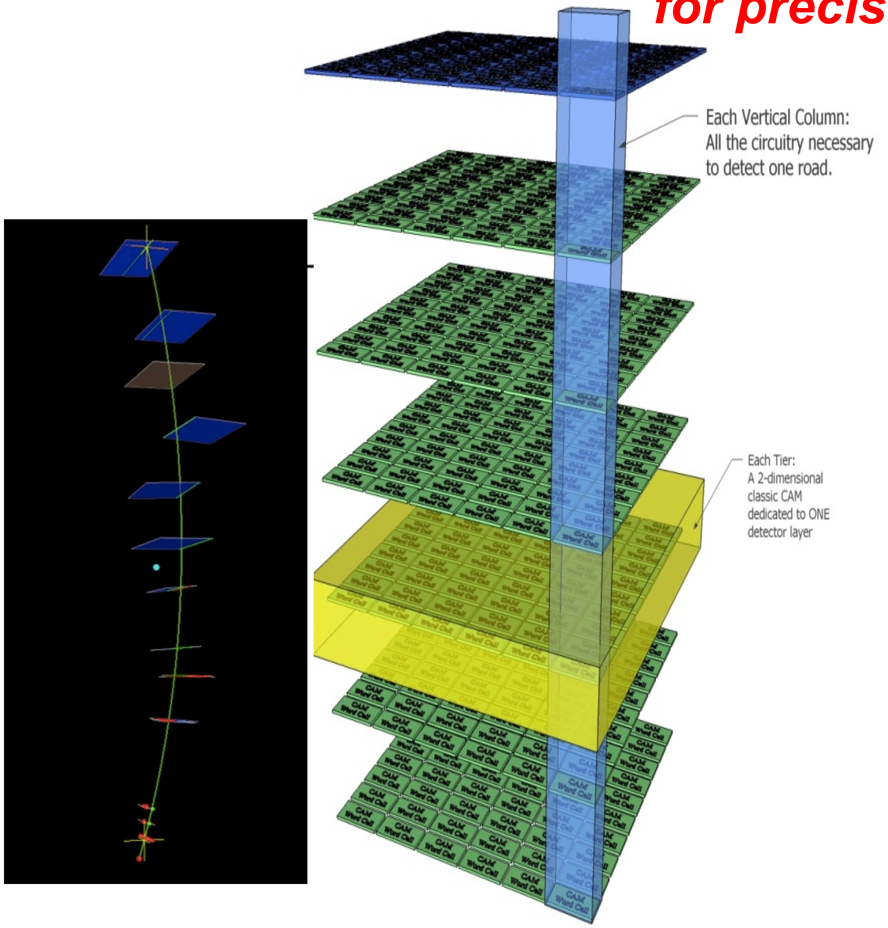


- In 3D, with 130 nm, VIRPAM ~160K AM patterns/cm^2
- CDF AMchip03: 180 nm, standard cell, 5K AM patterns/chip

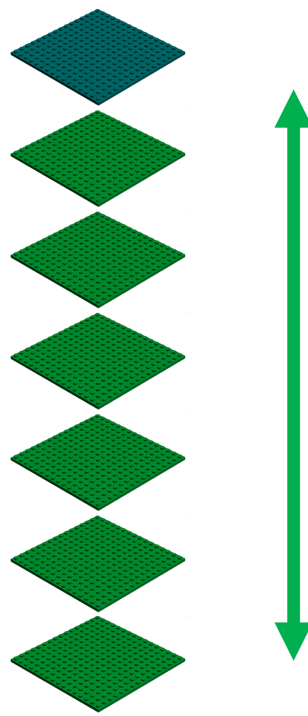
"A New Concept of Vertically Integrated Pattern Recognition Associative Memory"
TIPP 2011 Proceedings http://www.sciencedirect.com/science/article/pii/S1875389212019165

3DIC Technology

How could 3DIC help to scale to smaller pixel size for precision position & timing detectors



An open flexible architecture for precision position and timing detector
(one example below)



Readout and interfaces

Hit buffer

Clock distribution

TDC

Discriminator

preamp stage

Sensor pixels (~100 um x ~ 100um each)

3DIC allows repartition of the design blocks vertically for the whole processing chain… also combination of different technology, Or even sensors …

Outlook:
Precision Position & Timing detector & Future Hadron Colliders

- Generally speaking, the ultimate physics reach of any higher energy hadron collider (given a center-of-mass energy) will be governed by its luminosity.
- Given the huge cost associated with any future higher energy hadron collider, *it is crucial to push for higher luminosity* (similar to HL-LHC). This is to maximize the new physics reach of the huge investment already made, before a new higher energy collider can be proposed or built.
- *Because precision position & timing information is the most effective means for triggering and high pile-up mitigation,* ***high precision position and timing tracking detector will be mandatory for any future hadron colliders***
- ***3DIC technology allows an open flexible architecture for future precision position and timing detector development (within and beyond HEP)***

The existing new precision timing detector projects (such as CMS MTD, ATLAS HGTD): not only will they be important for the success of physics program in the HL-LHC era, they also lay some of the technological foundations for the future of the field…