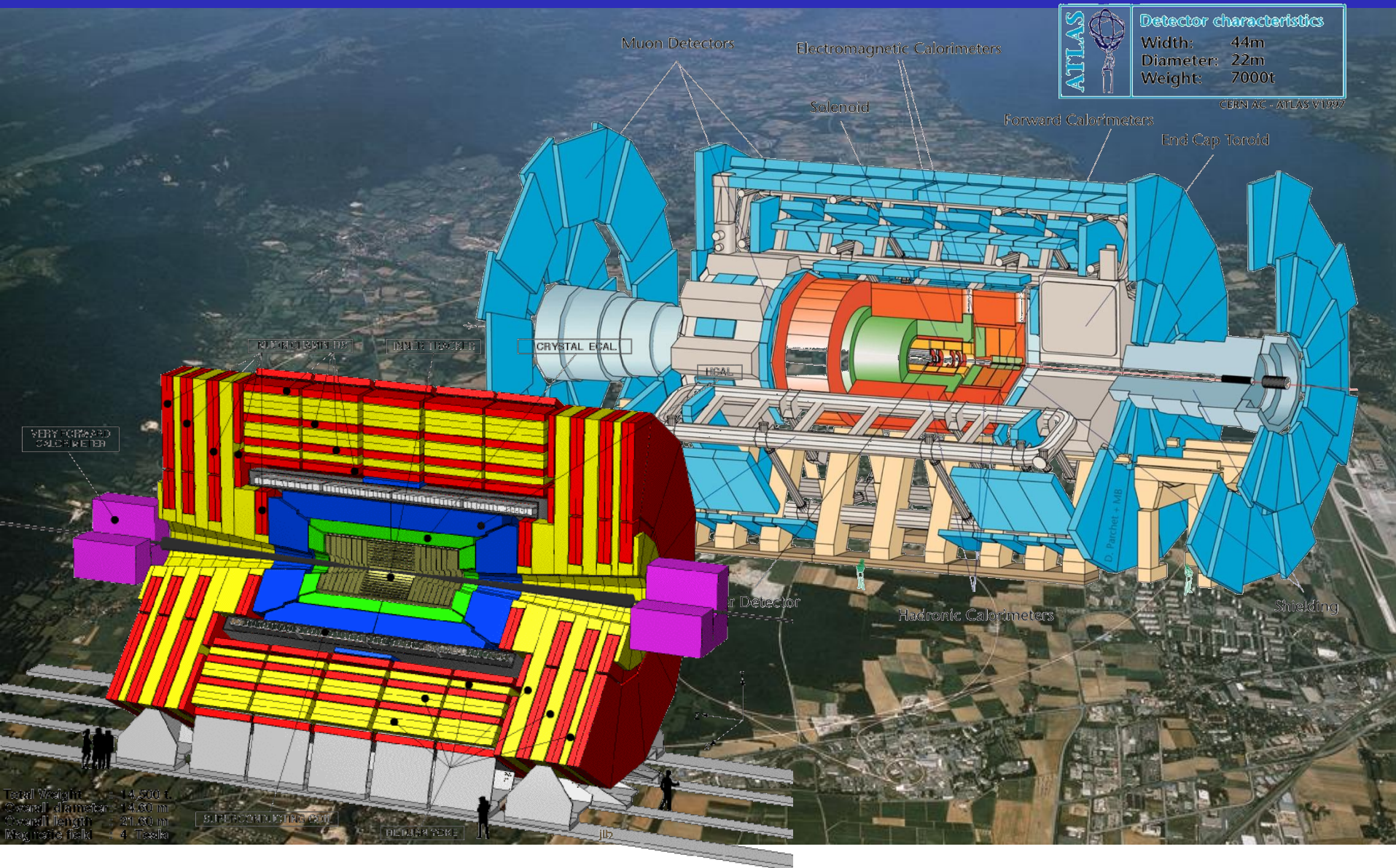# detector challenges for future hadron colliders

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Brown University

hadron colliders/detectors

LHC schedule

- 2013-2014 – LS1 (prepare LHC for design energy, phase 0 upgrades)
- 2015-2017 – physics at 6.5-7 TeV
  - $\int \mathcal{L} dt \sim 50 - 100/fb$ @ $\mathcal{L} \sim 10^{34} /cm^2/s$
  - pile up: $\langle n \rangle \sim 40$
- 2018 – LS2 (injector/LHC upgrade to ultimate lumi, phase 1 upgrades)
- 2019-2021 – physics with ultimate LHC parameters
  - $\int \mathcal{L} dt \sim 300/fb$ @ $\mathcal{L} \sim 2 \times 10^{34} /cm^2/s$
  - pile up: $\langle n \rangle \sim 50 - 100$
- 2022 – LS3 (focusing magnets and crab cavities, phase 2 upgrades)
- 2023-2035 – physics with HL-LHC (3000/fb)
  - $\int \mathcal{L} dt \sim 3000/fb$ @ $\mathcal{L} \sim 5 \times 10^{34} /cm^2/s$
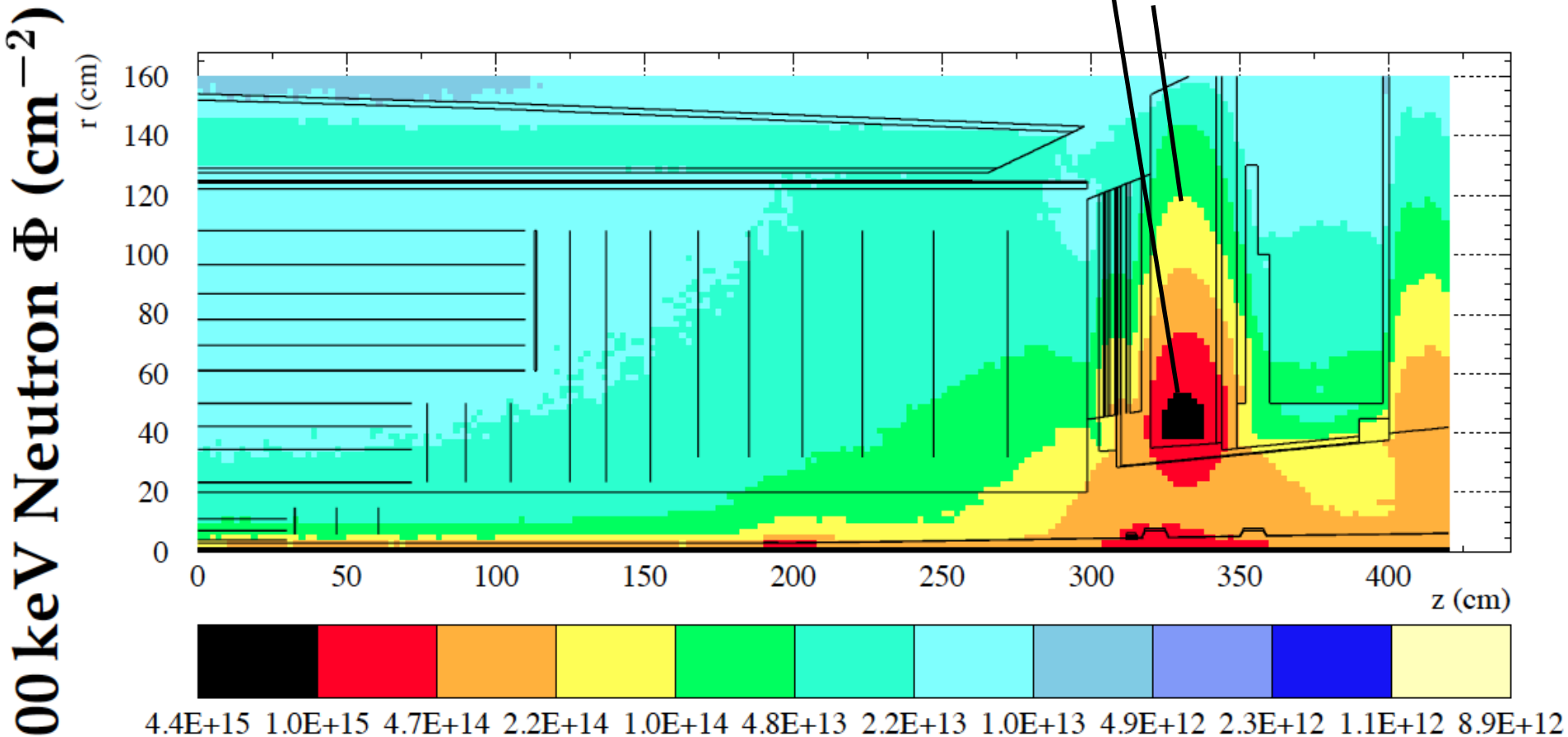 - pile up: $\langle n \rangle \sim 150 - 250$

the challenge

- ATLAS $Z \to \mu\mu$ event with 25 vertices
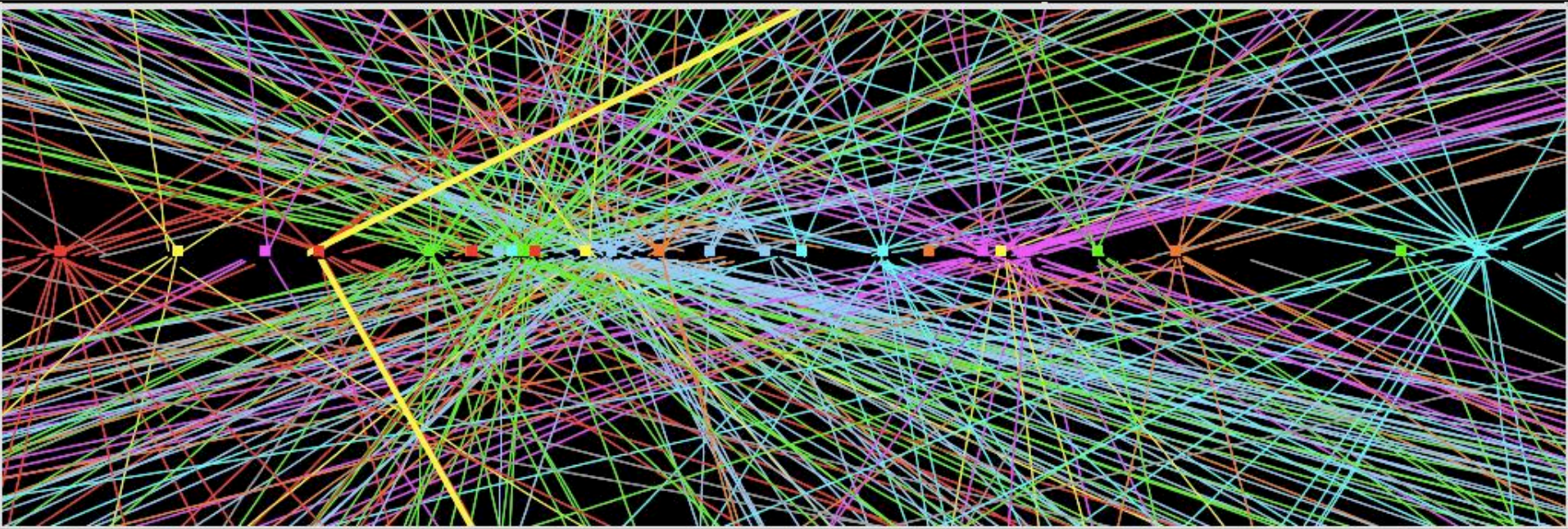
the challenge

- neutron flux for 2,500 fb^{-1}
 - M. Huhtinen, SLHC Workshop 2004

> 10^{15} neutrons/cm^2

> 10^{14} neutrons/cm^2

tracking detectors

- 250/fb ~ 1.5×10^{15} n_{eq}/cm^2 for innermost layer
- increased leakage current
  - need to run detectors cold to limit current
- increased bias voltage
  - less charge sharing ➔ decreased resolution
  - breakdown
- current detectors designed for $\approx$500/fb
  - exchange/addition of innermost pixel layer
- need radiation hard material

tracking detectors

- ## CMS: HPK project
  - irradiate > 150 Si wafers with protons and neutrons
  - different materials:
    - Float-zone (FZ), Magnetic Czochralski (MCz), Epitaxial (Epi)
  - different thicknesses and technologies
    - n-bulk, p-bulk with p-spray and p-stop isolation, 2nd metal layer
  - different geometries
  - choose material and technology for phase 2 tracker upgrade by early 2013
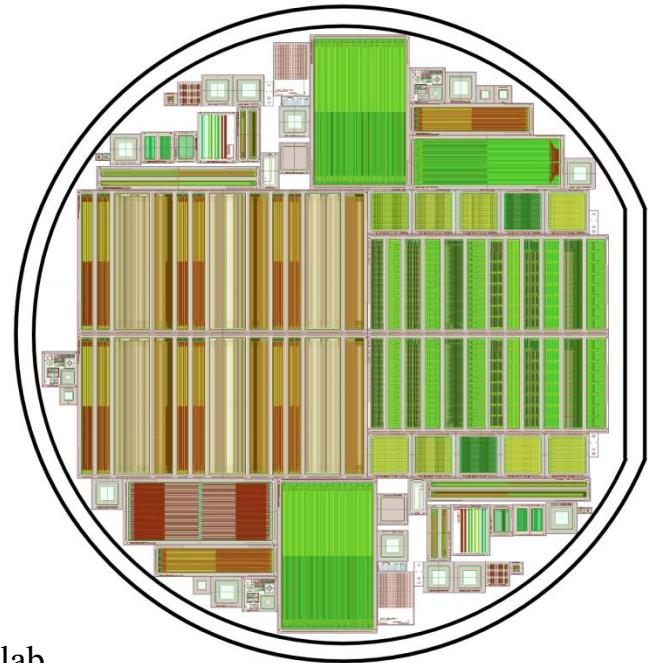
tracking detectors

- ATLAS n-in-p detectors

Signal: Charge collection post-rad (RD50)


Ulrich Heintz – CPM Fermilab
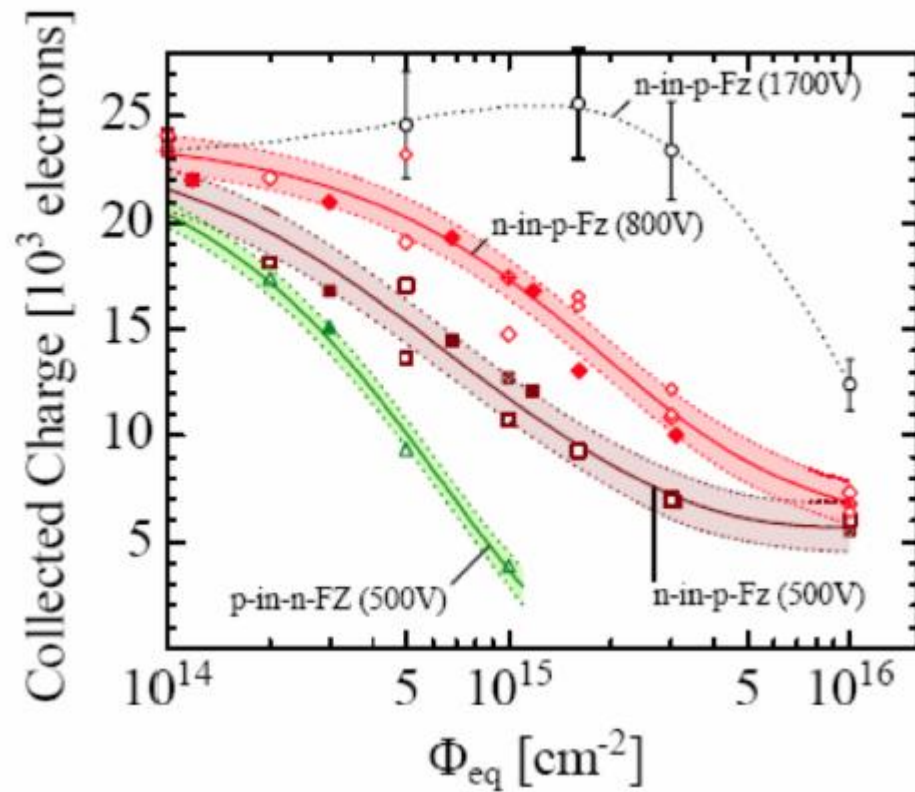
3D silicon detectors

- advantages
  - short drift distances
  - voltage breakdown less likely
  - deplete at lower bias voltages
  - less impact of radiation damage
  - fast charge collection
  - μm dead regions at the edges
- disadvantages
  - more processing/expensive
- 25% of ATLAS pixel B layer
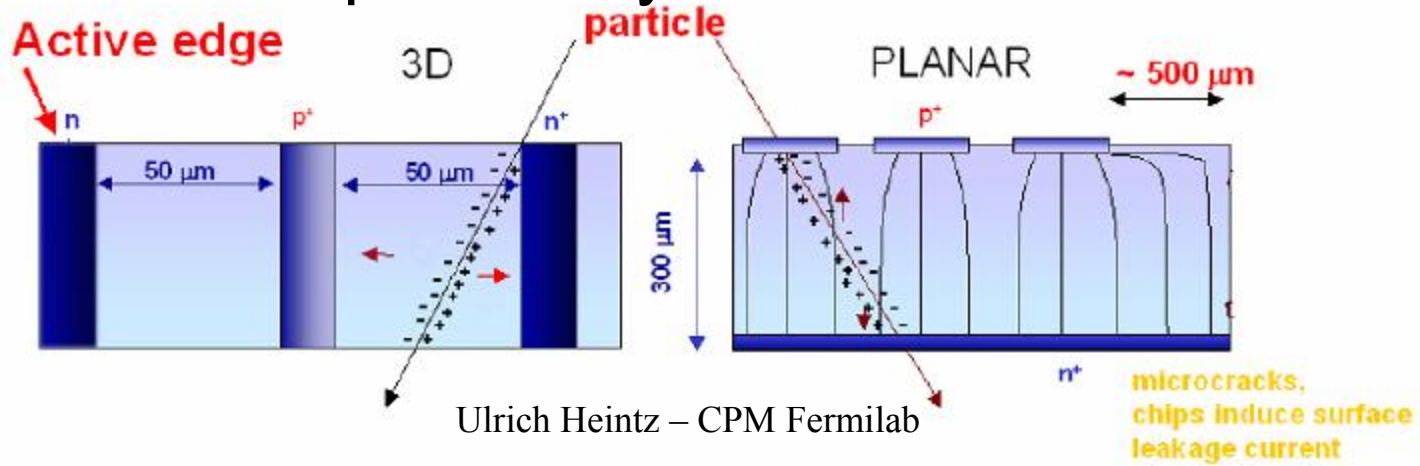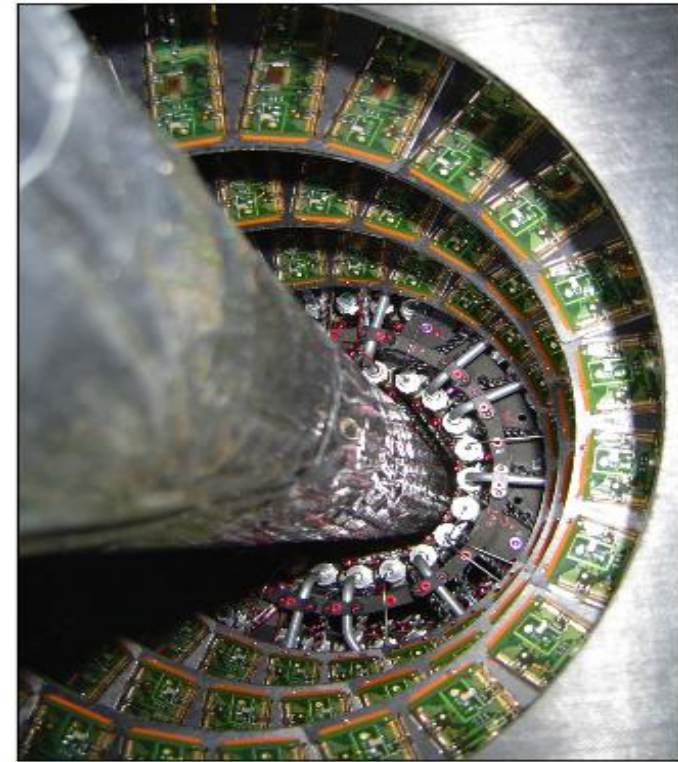
trigger

- keep output rate fixed at 100k
  - increasing input rate
  - larger event size
  - avoid raising thresholds
- better algorithms
- single muon rates saturate
- calorimeter isolation insufficient to control rates
- move capabilities to lower trigger levels
  - L1 track trigger
  - vertexing for pileup rejection
 - finer grained spatial resolution in calorimeter for matching
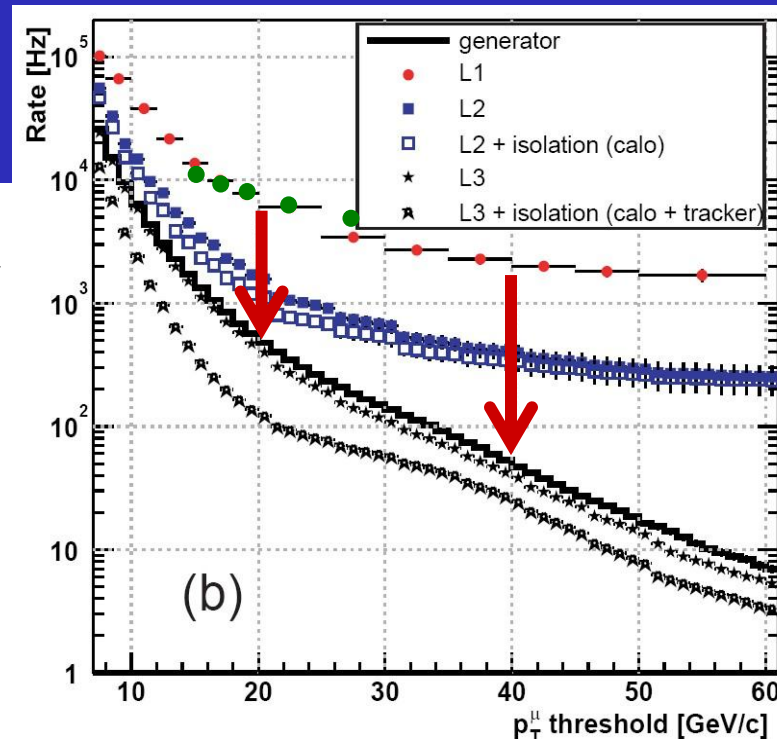
CMS L1 track trigger

- phase 2
- need to gather data from 10^8 pixels in 200m^2 of silicon at 40 MHz
- power & bandwidth to send off-detector prohibitive
- one of several proposed designs uses 3D electronics to connect a single readout chip to two closely spaced sensors
- locally correlate hits to filter on p_T
- off-detector processing in 15° sectors using state of the art FPGAs
- drives tracker design
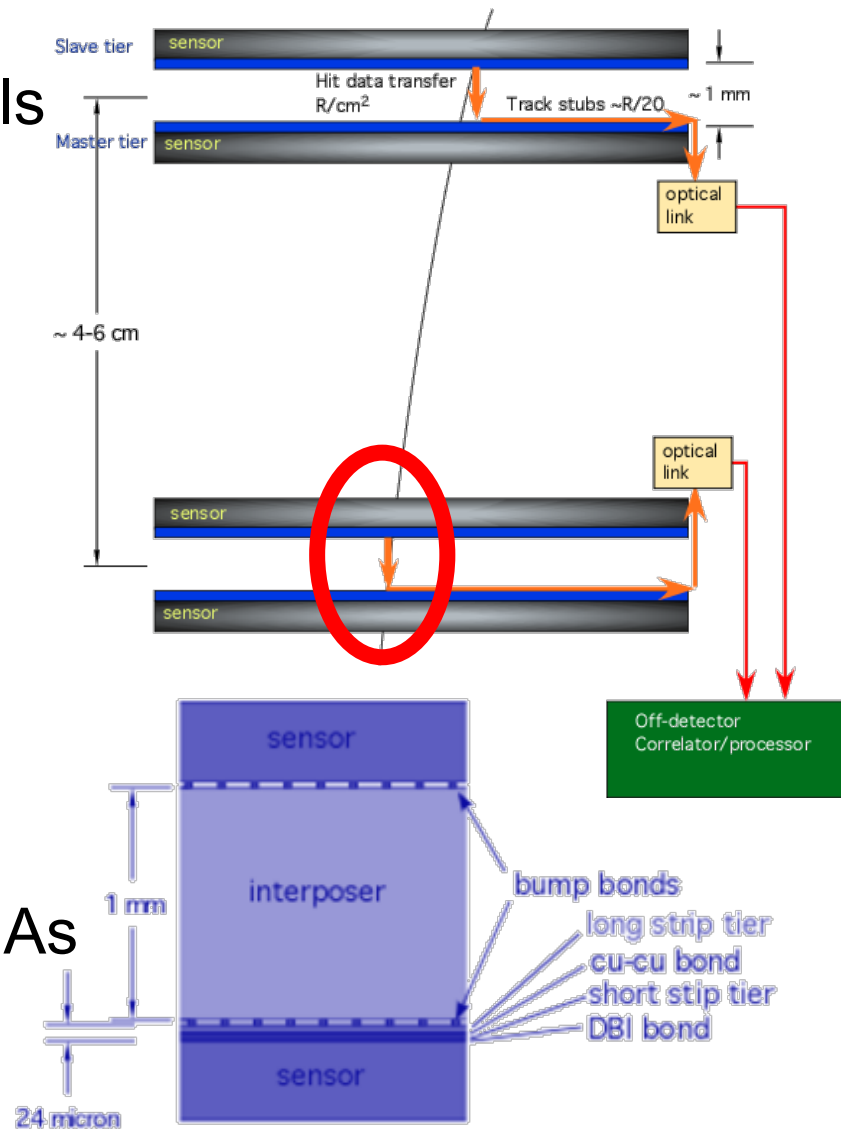
- phase 1
- Dedicated hardware processor completes track reconstruction by beginning of level-2 processing.
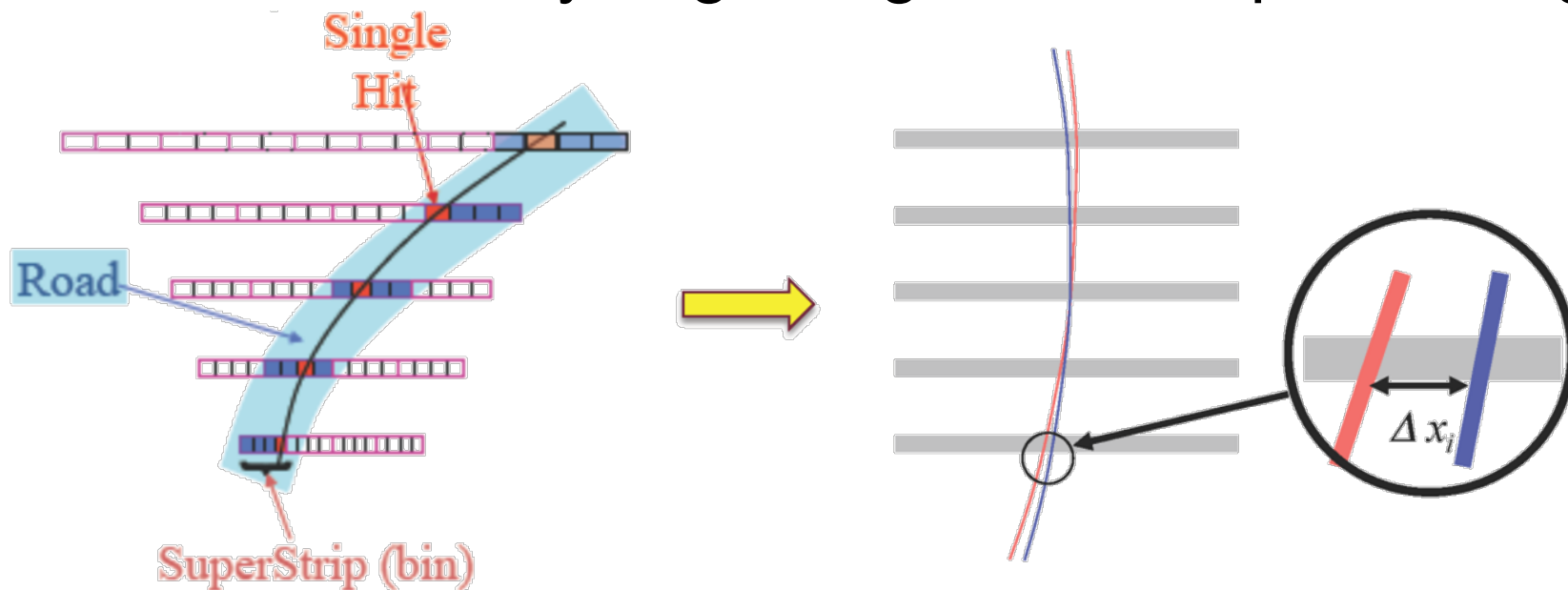
Pattern recognition in coarse resolution (superstrip➜road)

Track fit in full resolution (hits in a road)

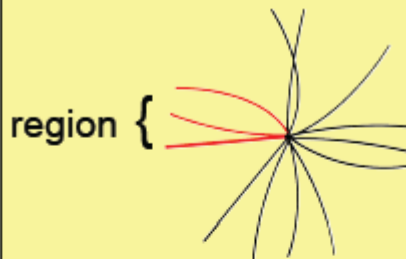$$F(x_1, x_2, x_3, \ldots) \sim a_0 + a_1 \Delta x_1 + a_2 \Delta x_2 + a_3 \Delta x_3 + \ldots = 0$$

ATLAS phase 2 track trigger
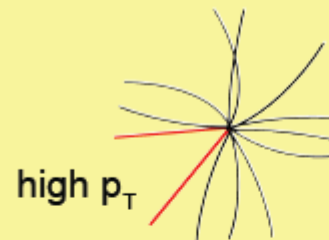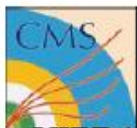
FNAL R&D on 3D-stacked AM chips

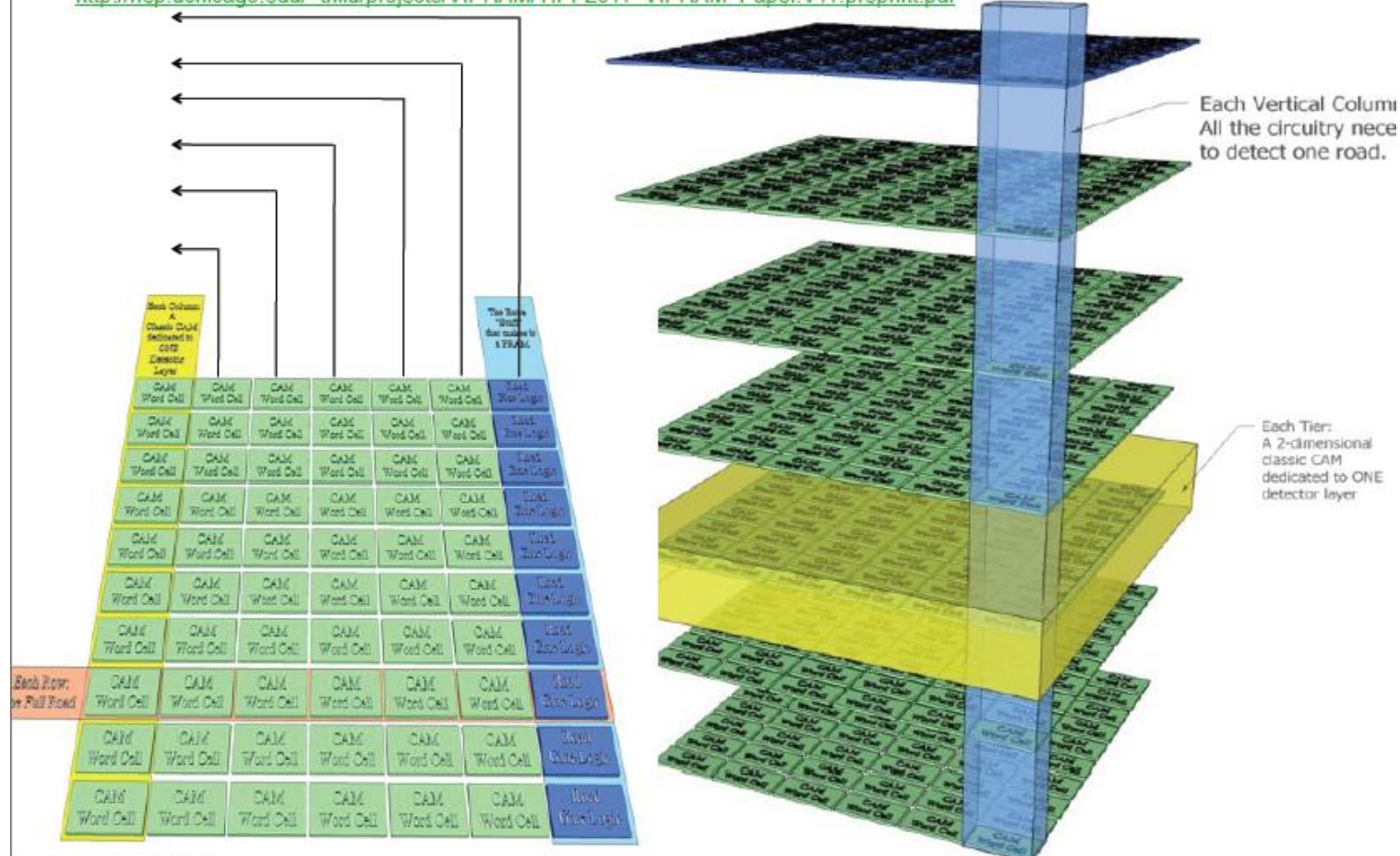VIPRAM concept (developed at Fermilab):
http://hep.uchicago.edu/~thliu/projects/VIPRAM/TIPP2011_VIPRAM_Paper.V11.preprint.pdf

Each Vertical Column
All the circuitry nece
to detect one road.

Each Tier:
A 2-dimensional
classic CAM
dedicated to ONE
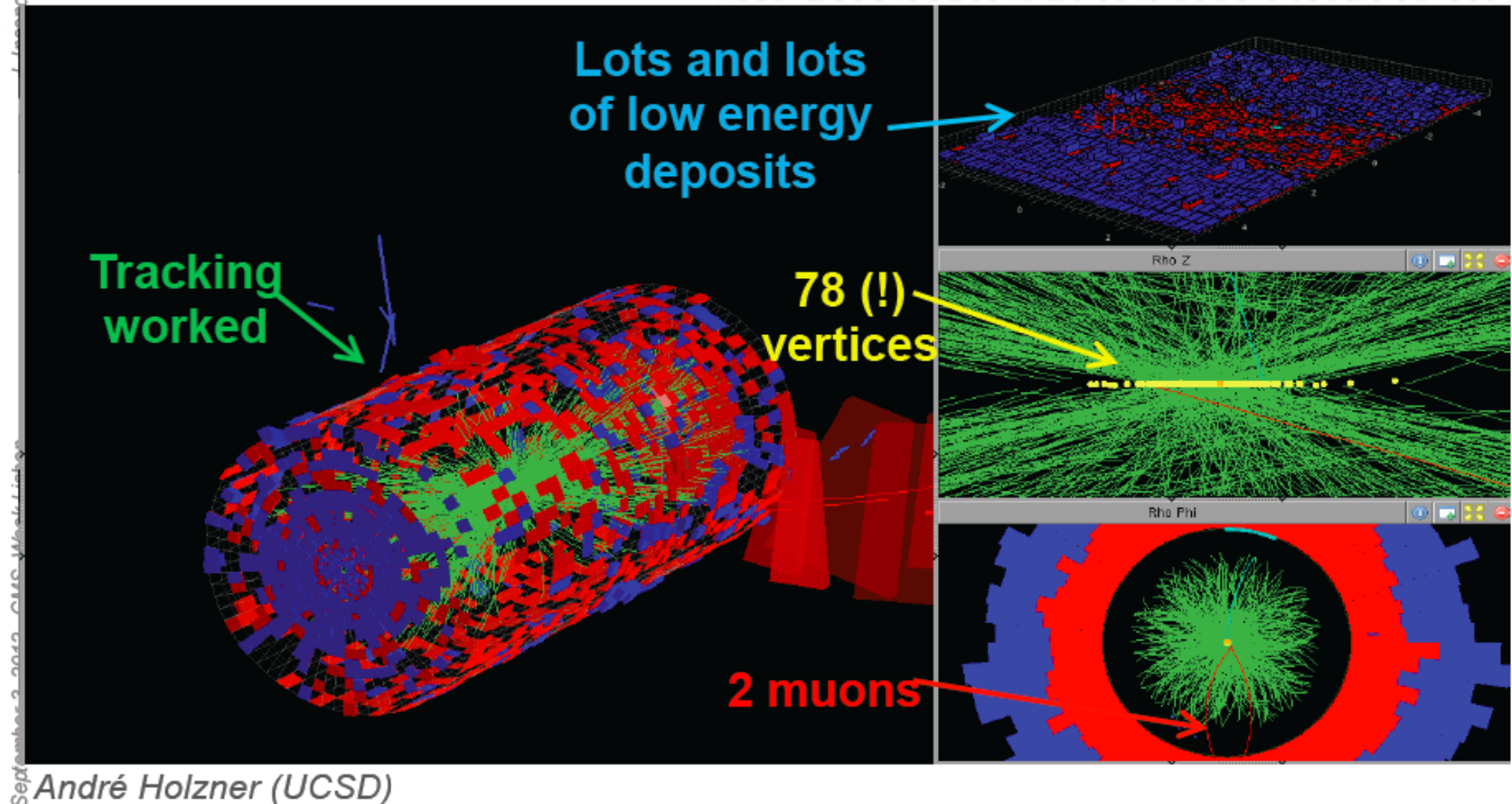detector layer

Wednesday, May 23, 2012

calorimeter

- radiation damage after LS2
  - loss of light transmission
  - degradation of photo detectors
  - need detailed detector evolution model
- CMS uses particle flow technique for reconstruction
  - energy from charged particles can be associated with vertex using track
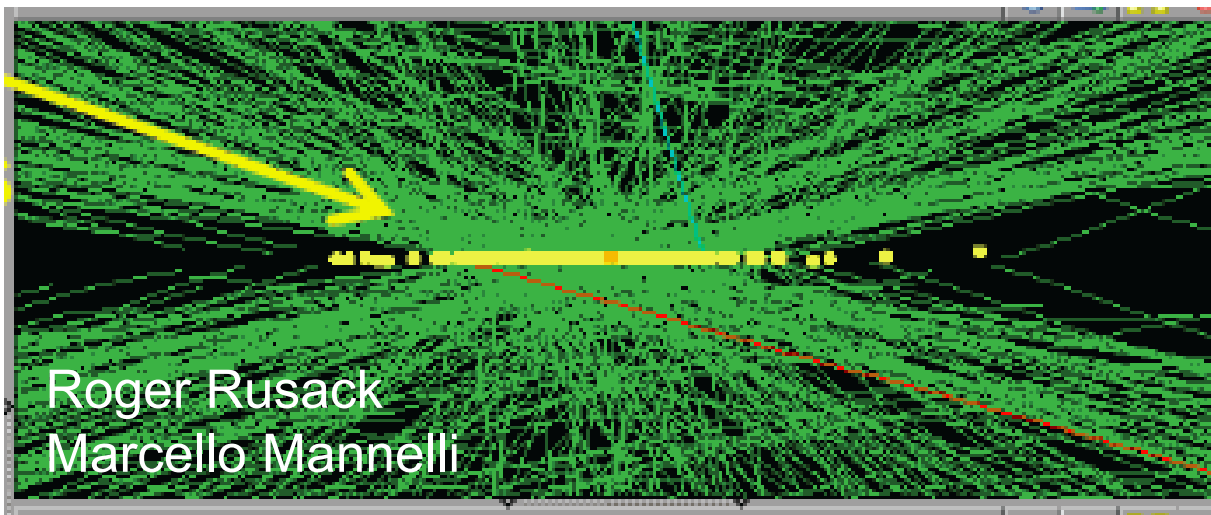 - not possible for energy from neutrals

calorimeter

Reconstructed event w/largest pileup:
78 reconstructed vertices

Lots and lots of low energy deposits

Tracking worked

78 (!) vertices

2 muons

Rho Z

Rho Phi

André Holzner (UCSD)

calorimeter pileup mitigation
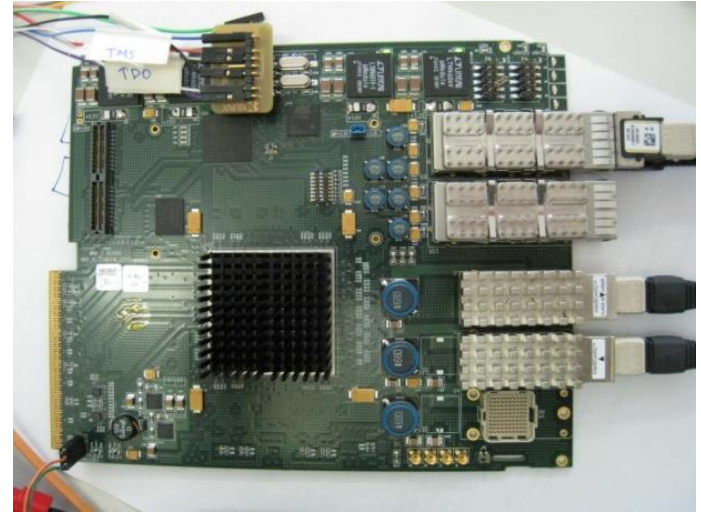

Roger Rusack
Marcello Mannelli

- time of calorimeter signal at large η depends on position of the collision
- for a luminous region of 10cm, collisions are distributed over 300ps
- need 10~20ps TOF measurement together with tracker coverage
  - tracking identifies location of interesting collision
  - TOF of charged particles from that collision identifies its time
  - use location and time to select calorimeter clusters from this collision
- current state of the art for large scale systems is ~75ps (ALICE TOF)
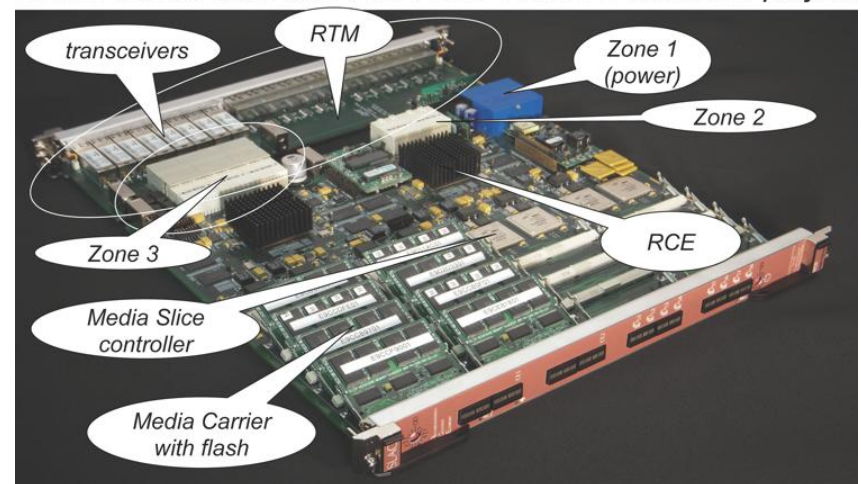- 10~20ps TOF resolution is ambitious...

new materials

- forward region is important e.g. for Higgs bosons produced via VBF

- consider new radiation hard materials for forward region

- calorimeter
  - quartz detectors
  - amorphous silicon

- muon detector
  - GEM detectors
  - micromegas

electronics

- move to new platforms developed by telecommunications industry
- μTCA platform (CMS)

- ATCA platform (ATLAS)

Board shown here with 1TB FlashRAM for PetaCache project

transceivers | RTM | Zone 1 (power) | Zone 2 | Zone 3 | RCE | Media Slice controller | Media Carrier with flash

conclusion

- the challenges are obvious
  - high radiation levels
  - large even sizes and rates
  - high pile up
- goal
  - identify the challenges and technology issues most critical to achieving the physics goals at the energy frontier
  - my list is surely incomplete
  - your input is needed

- thanks to:
  - Frank Hartmann, Ron Lipton, Marcello Manelli, Srini Rajagopalan, Roger Russak, Abe Seiden, Wesley Smith, many others...