

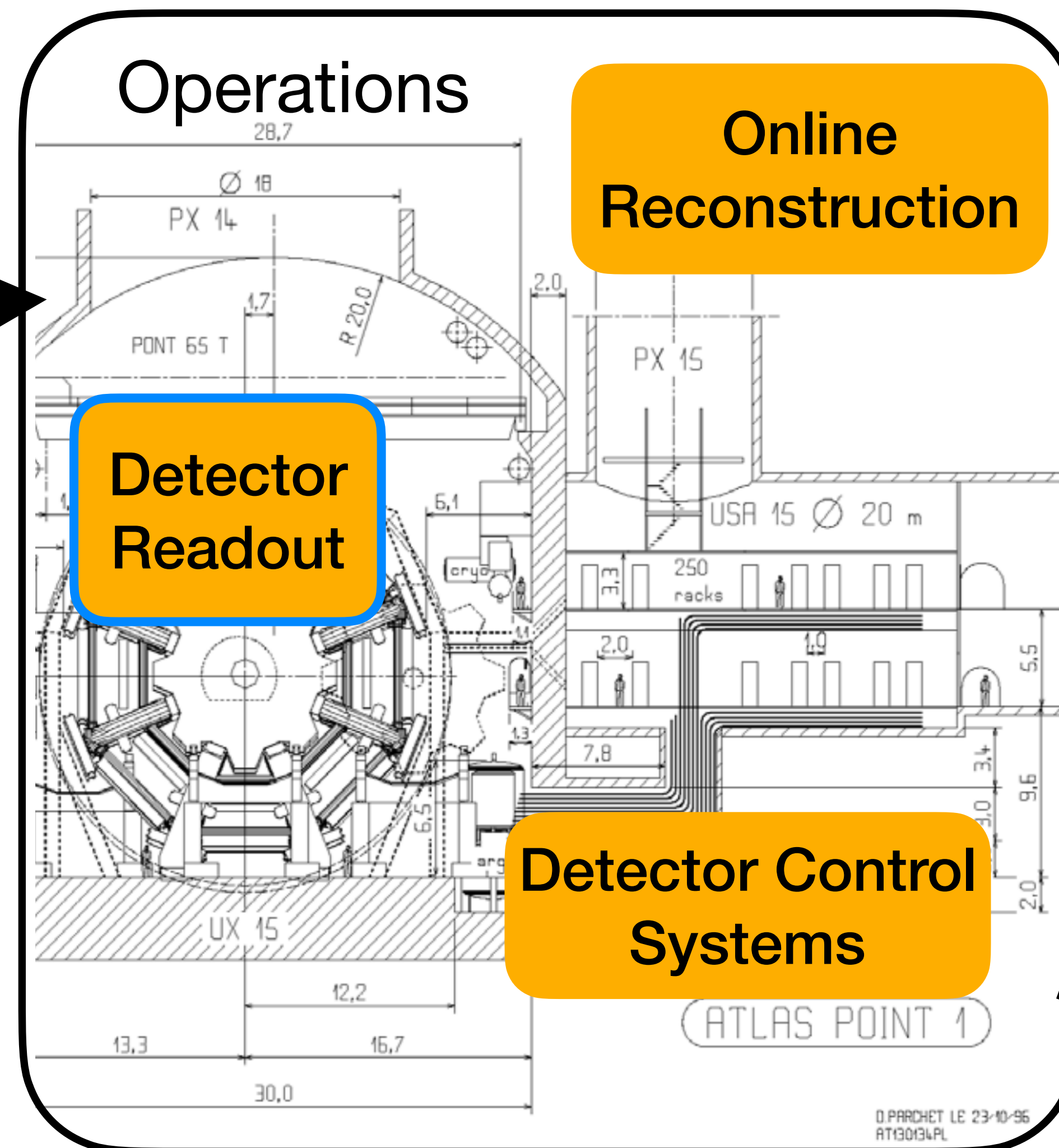
AI × Detector R&D: Smart Pixels

AI4MuC — June 30, 2026
Ryan Roberts on behalf of the
Smartpixels Collaboration



Experimental Construction:
Automation of Assembly,
Testing, Project
Management

Experimental Design:
Codesign, Digital Twins
Accelerator+Detector



AI/ML can play a role
before, during, and after
data-taking

This talk: R&D to put
intelligence directly in the
detector

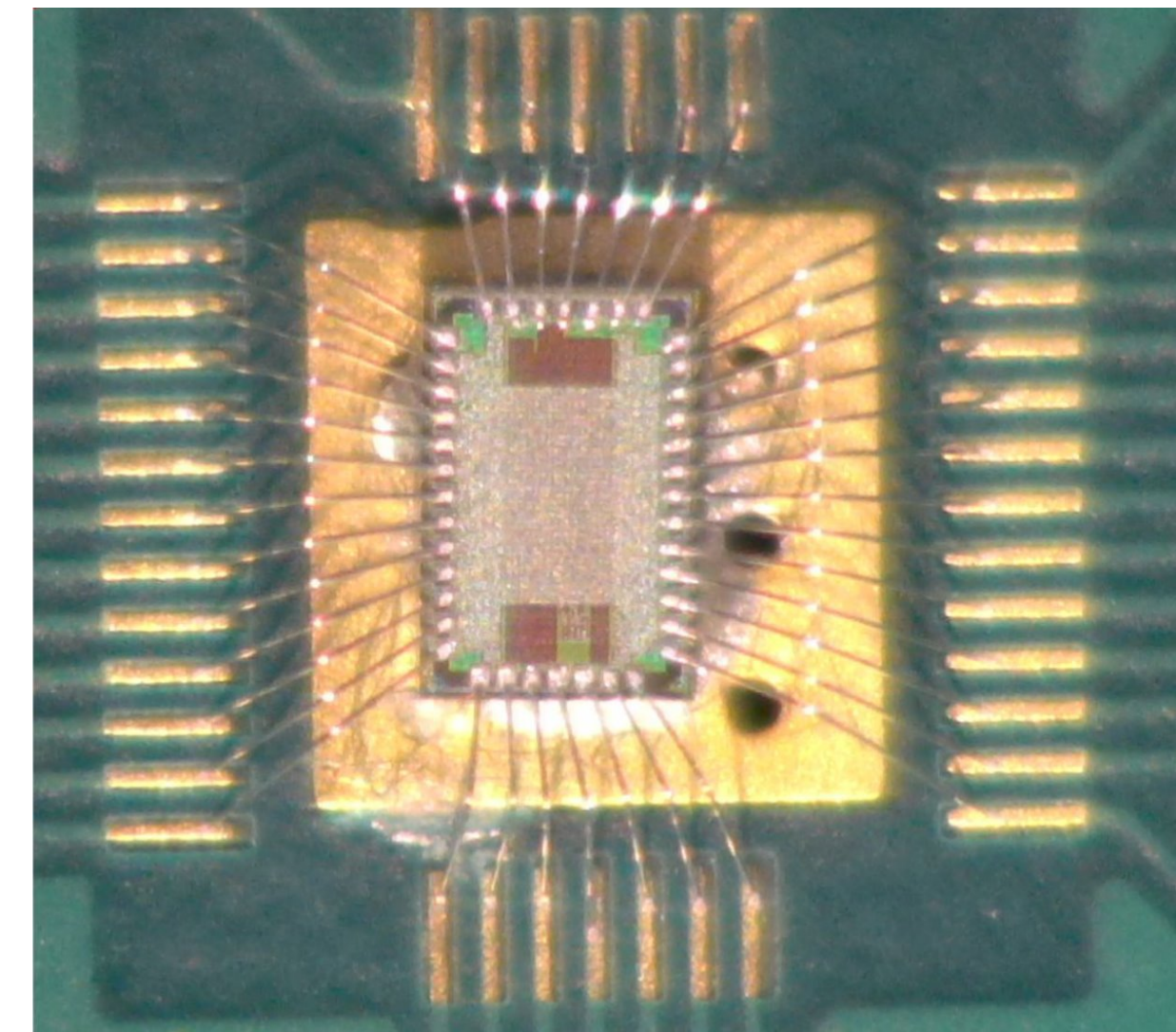
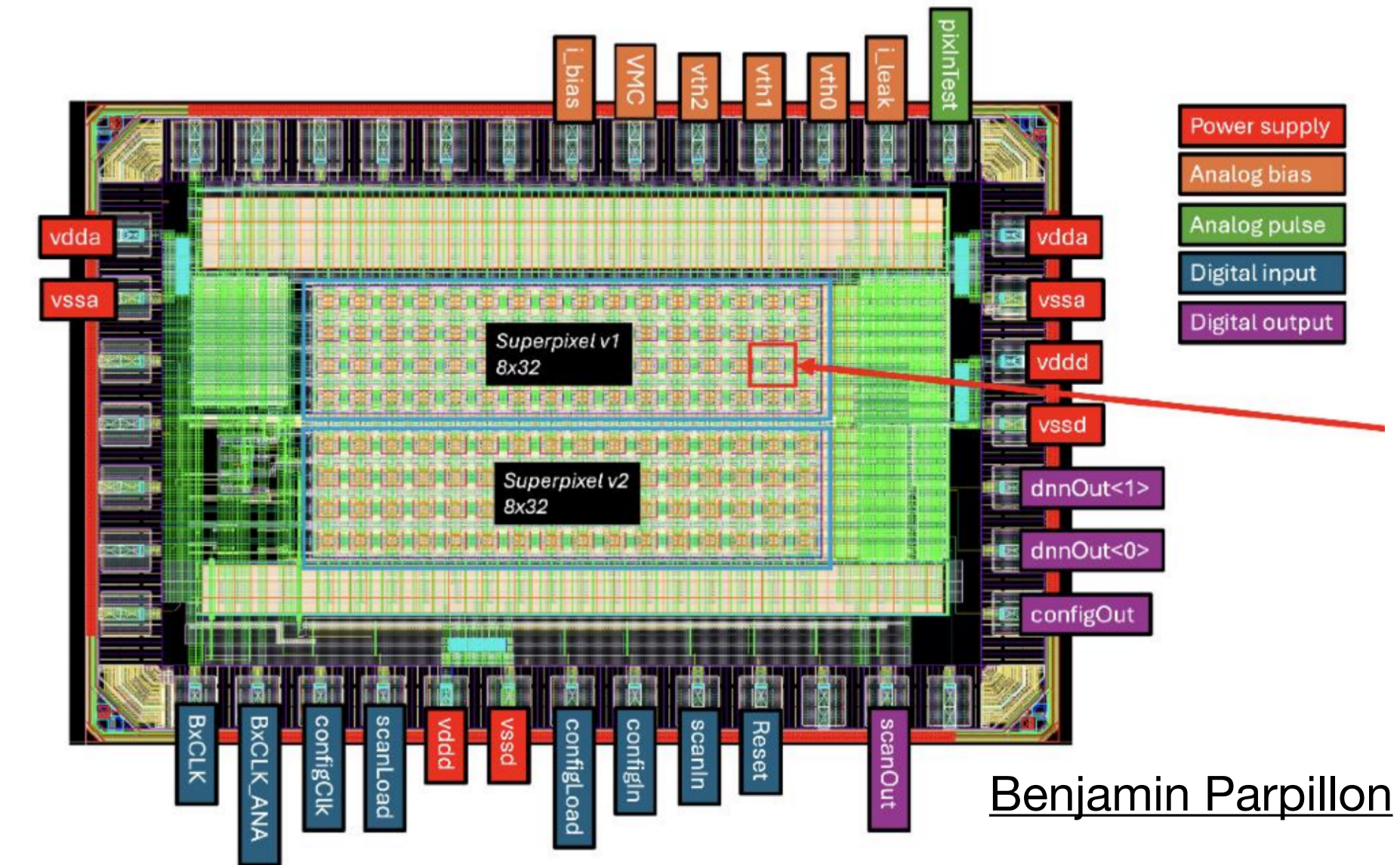
Could also consider
using AI to boost
detector R&D

Offline Analysis:
Advanced Likelihoods,
Automated Tool Use
and Optimization

**AI for
Theory**

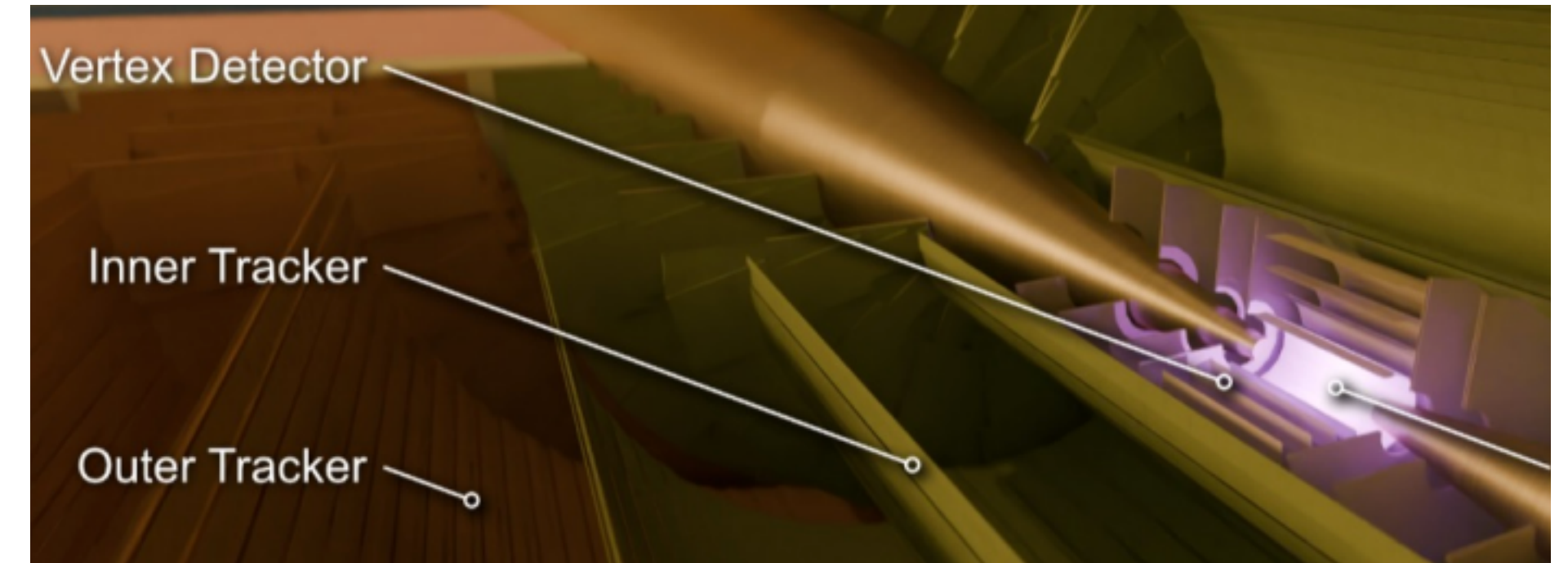
Constraints for ML in Readout Electronics

- Real time operations with $\mathcal{O}(30 \text{ kHz})$ collisions
- Total latency should also be $\mathcal{O}(30 \mu s)$ to reduce buffer sizes
- Limited budget for space, mass, power/cooling ($\approx 1 \text{ W/cm}^2$)
 $\implies$ Limited computational power
- Fast/edge ML
 $\implies$ Small models implemented on ASICs
- Must operate reliably for $\mathcal{O}(10 \text{ yr})$ with radiation, thermal cycles, and changing conditions

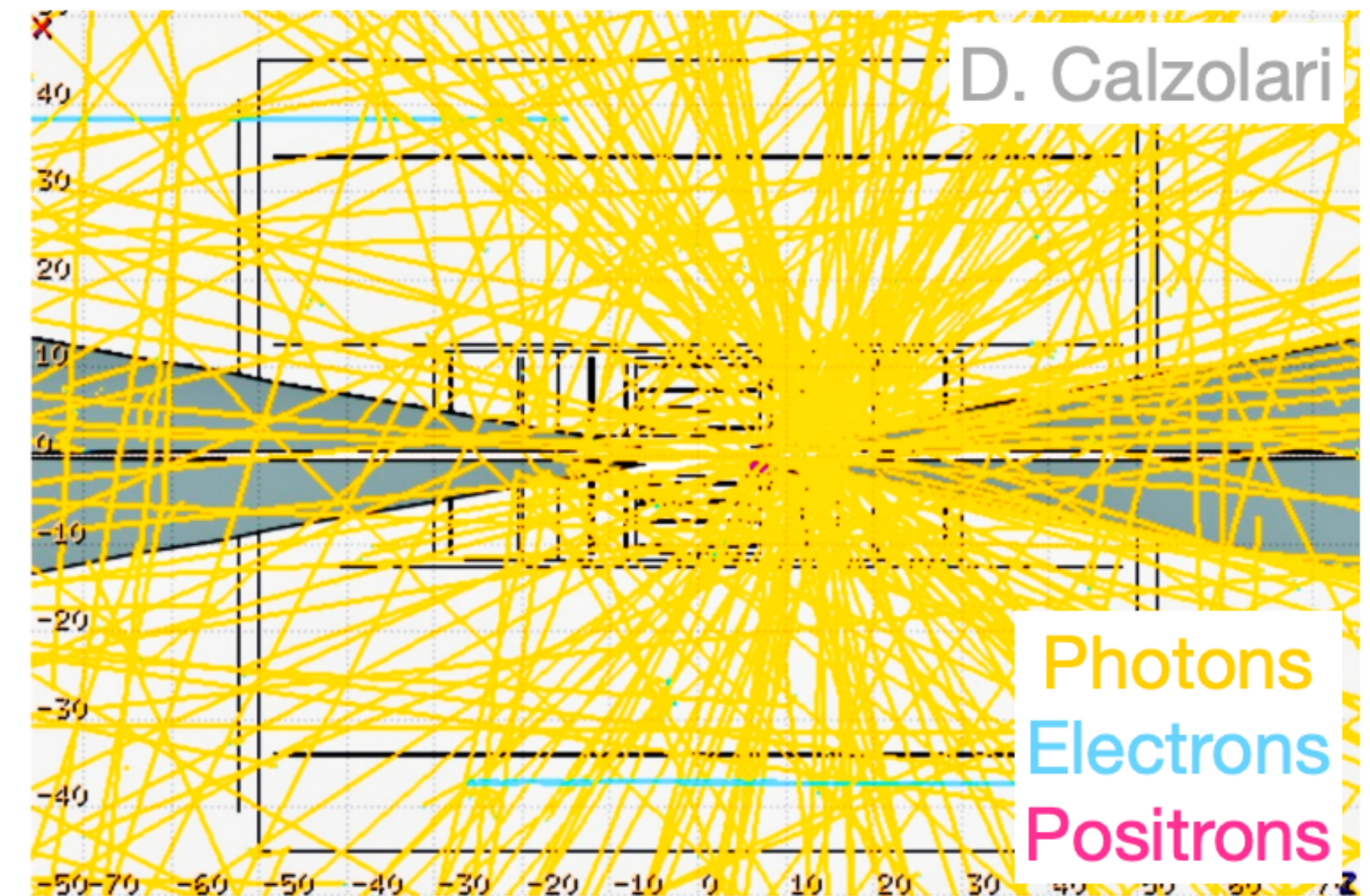


Need for BIB Suppression in Vertex Detector

- Vertex detector must be close to the IP
- Silicon pixels for resolution, robustness
- Densest backgrounds
- Occupancy $\mathcal{O}(1 - 10\%)$
- Naive data rate approximately 75 Gbps/cm^2
 - Phase II detectors order 1 Gbps/cm^2
- All figures depend on accelerator design!

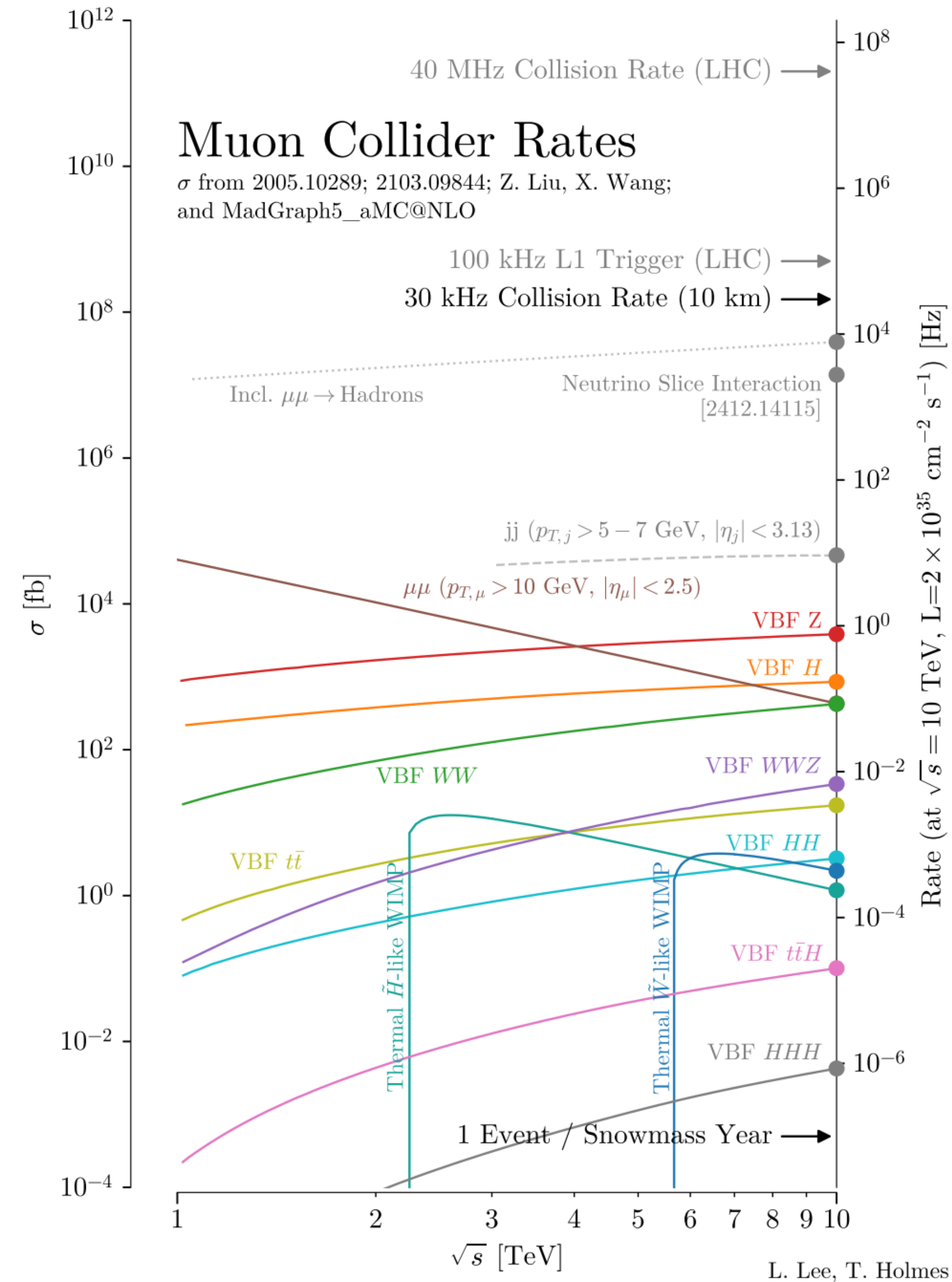


0.0003% of a BIB event



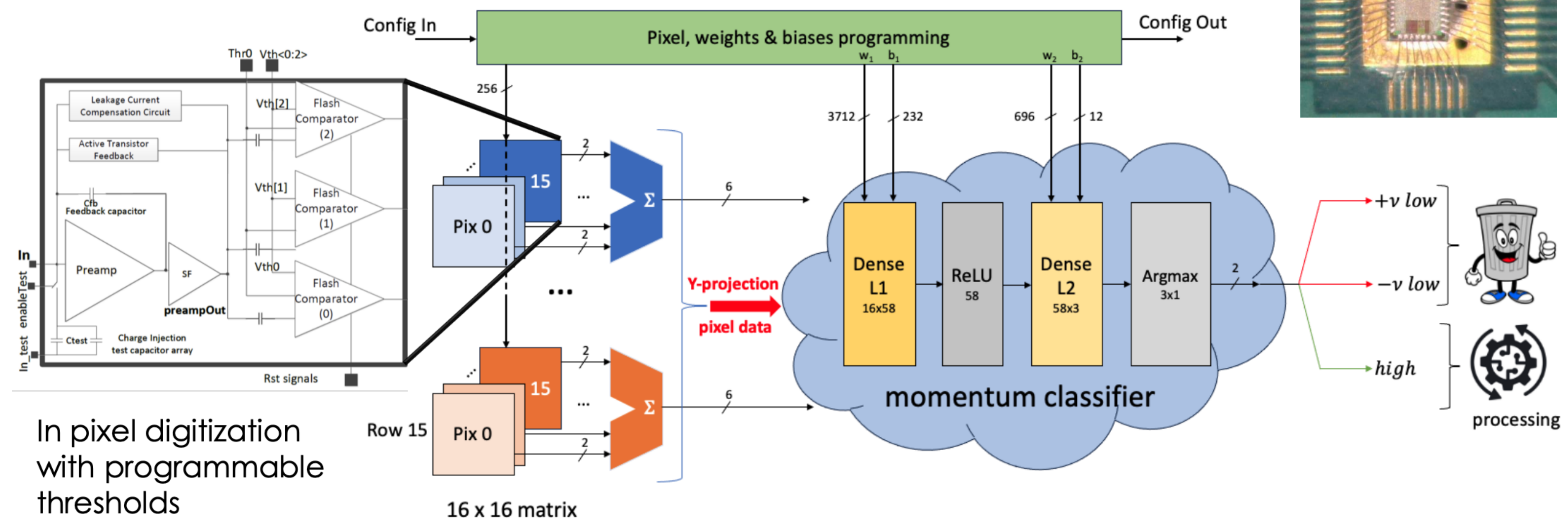
Aside: Physics Impact of Triggering

- When the data rate is too large, we can't save every event
- Decide which events to save and which to discard in real time (triggering)
- ...but throwing away data may reduce our physics reach!
- Even rare processes may be hard to identify without tracking information



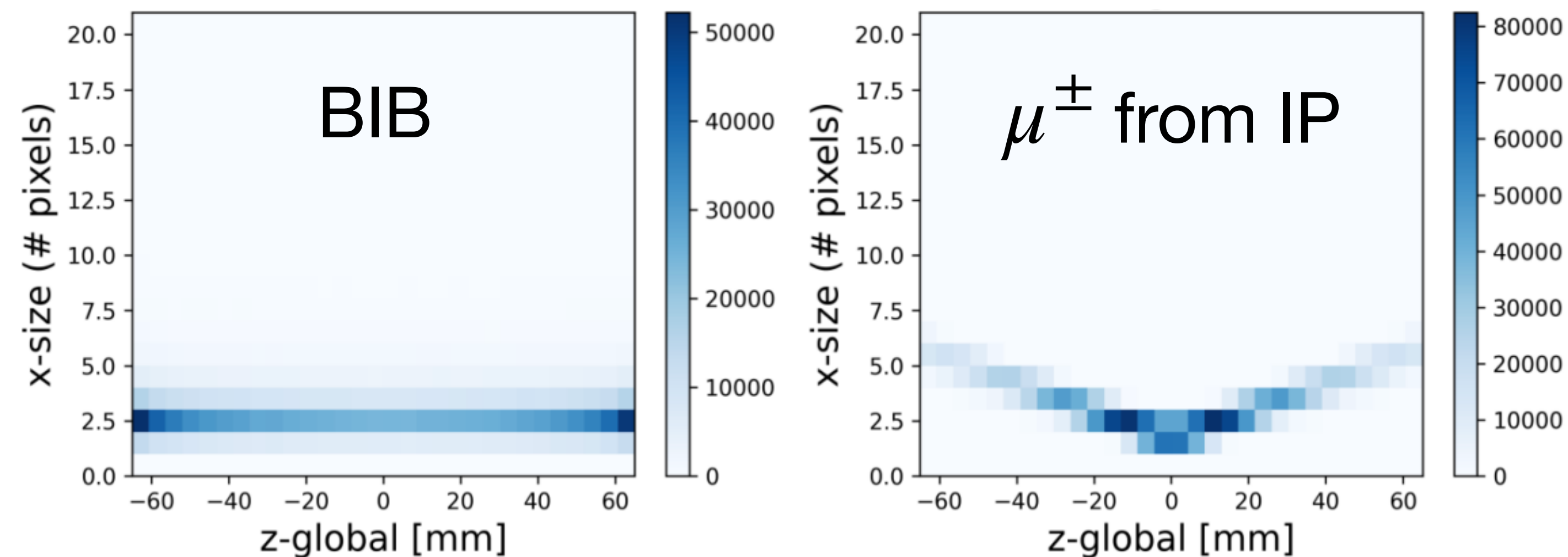
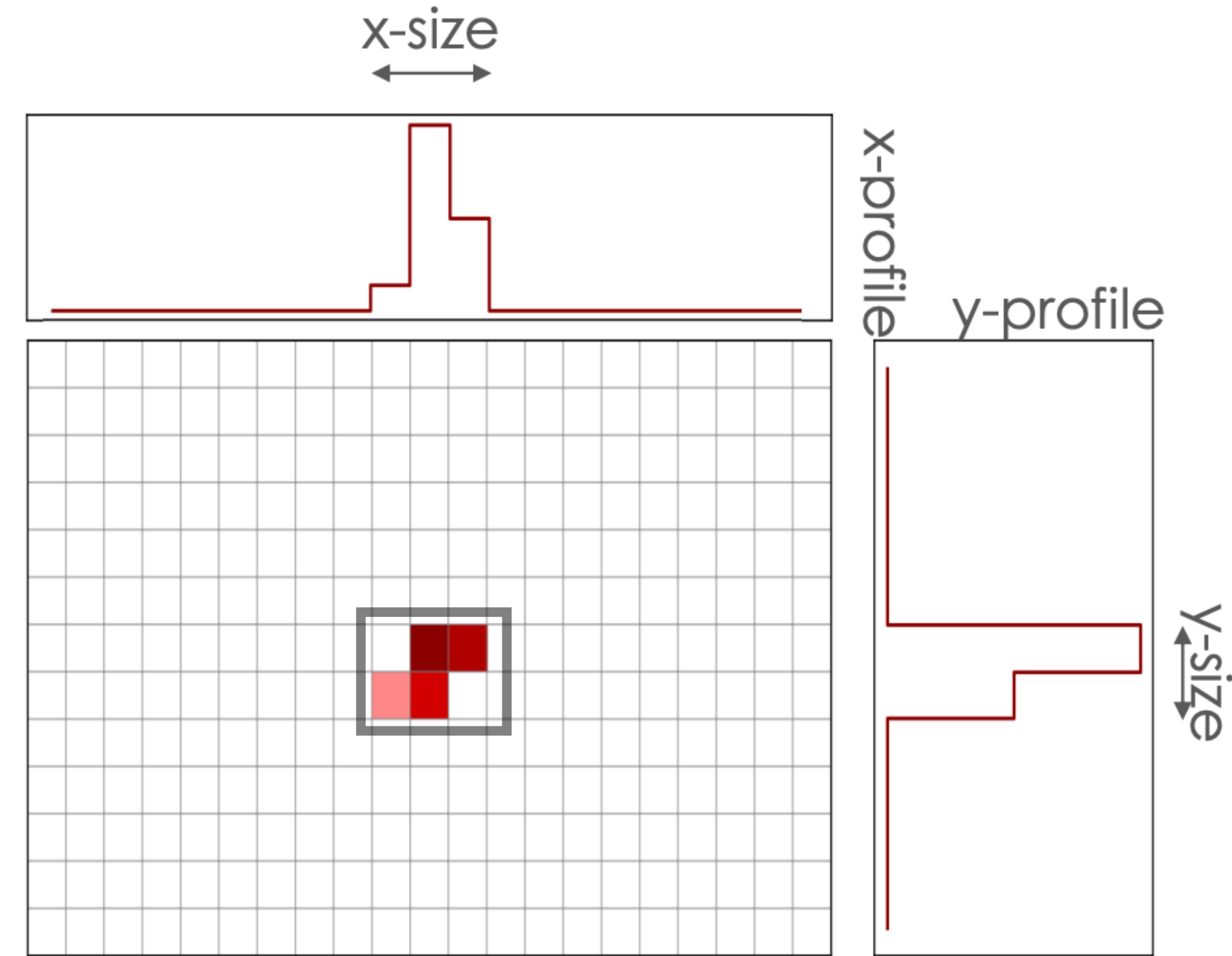
Smart Pixels Collaboration

- Smartpixels Collaboration investigating embedded intelligence for silicon trackers
- Prototype ASIC to select high p_T HL-LHC operation in CMS designed in 28 nm CMOS, produced, and tested
- Alternate approach to directly regress track parameters



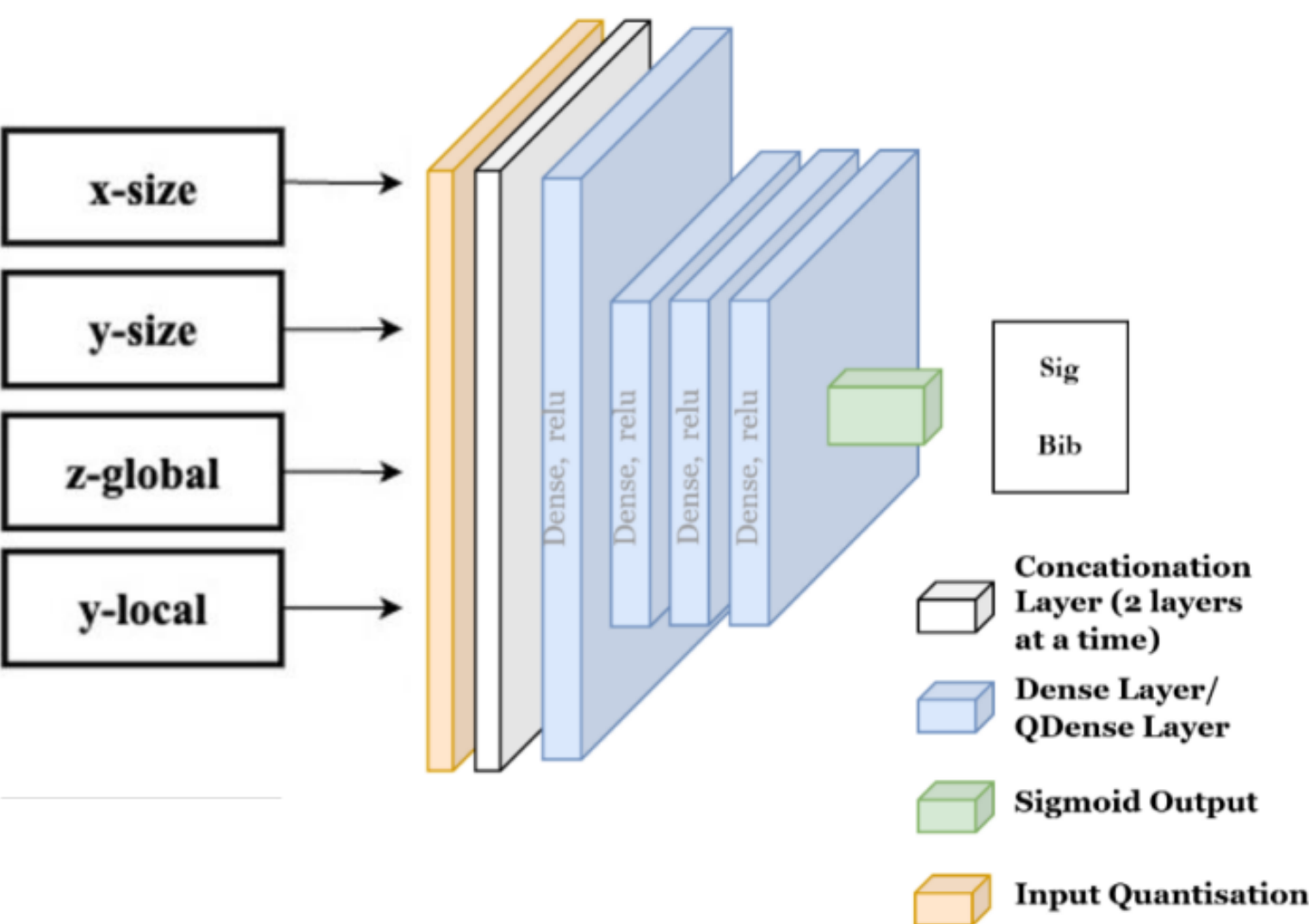
Smart Pixels for Muon Collider

- Focusing on innermost layer of the vertex detector barrel (VXB)
 - $25\ \mu\text{m}$ pixels, 3 cm from IP, 13 cm barrel
- Charge deposited in each pixel simulated with PixelAV
- Filtering approach — reject background on-chip
 - Binary classifiers trained on cluster features
 - Hls4ml to estimate chip resource usage

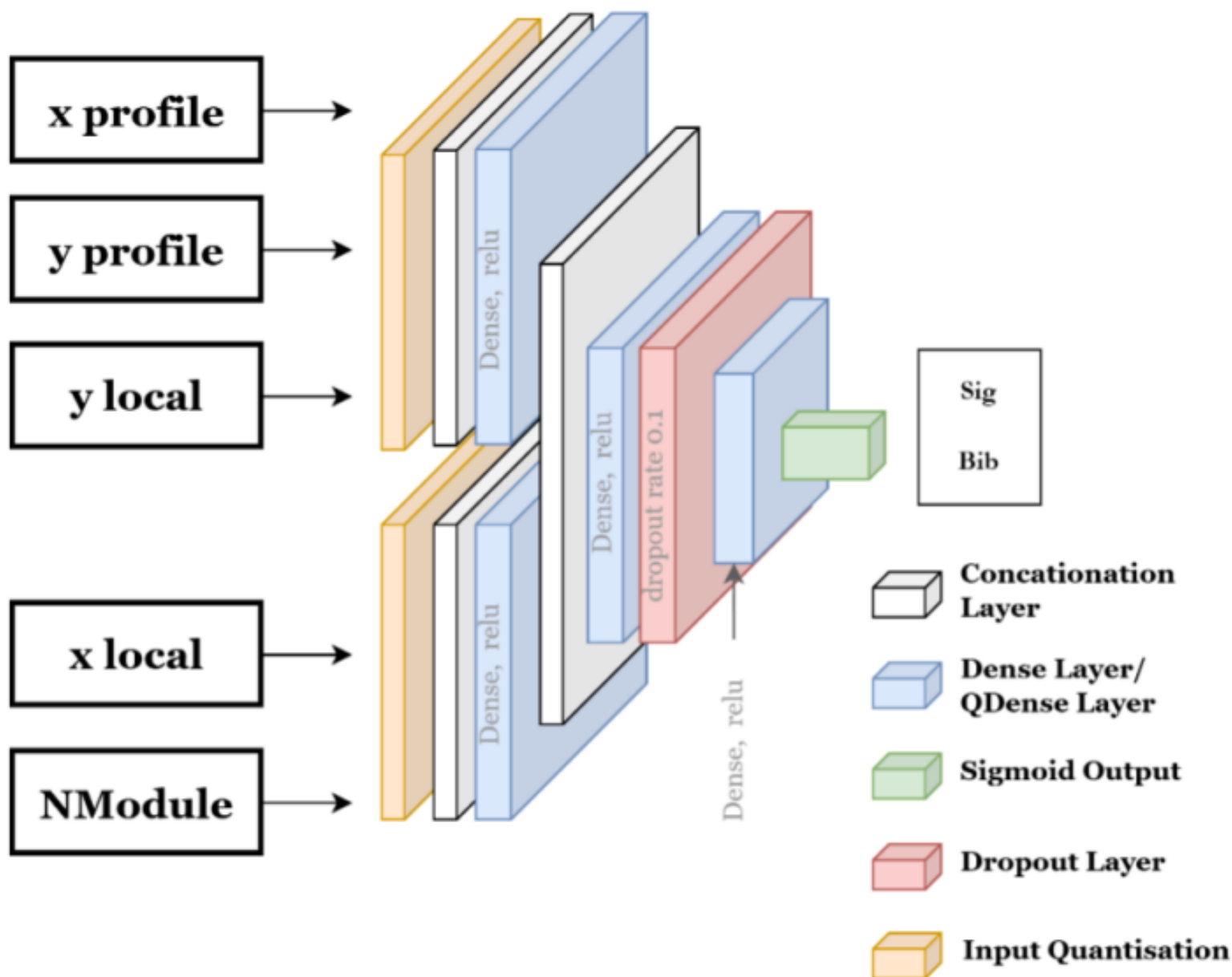


Trained Models

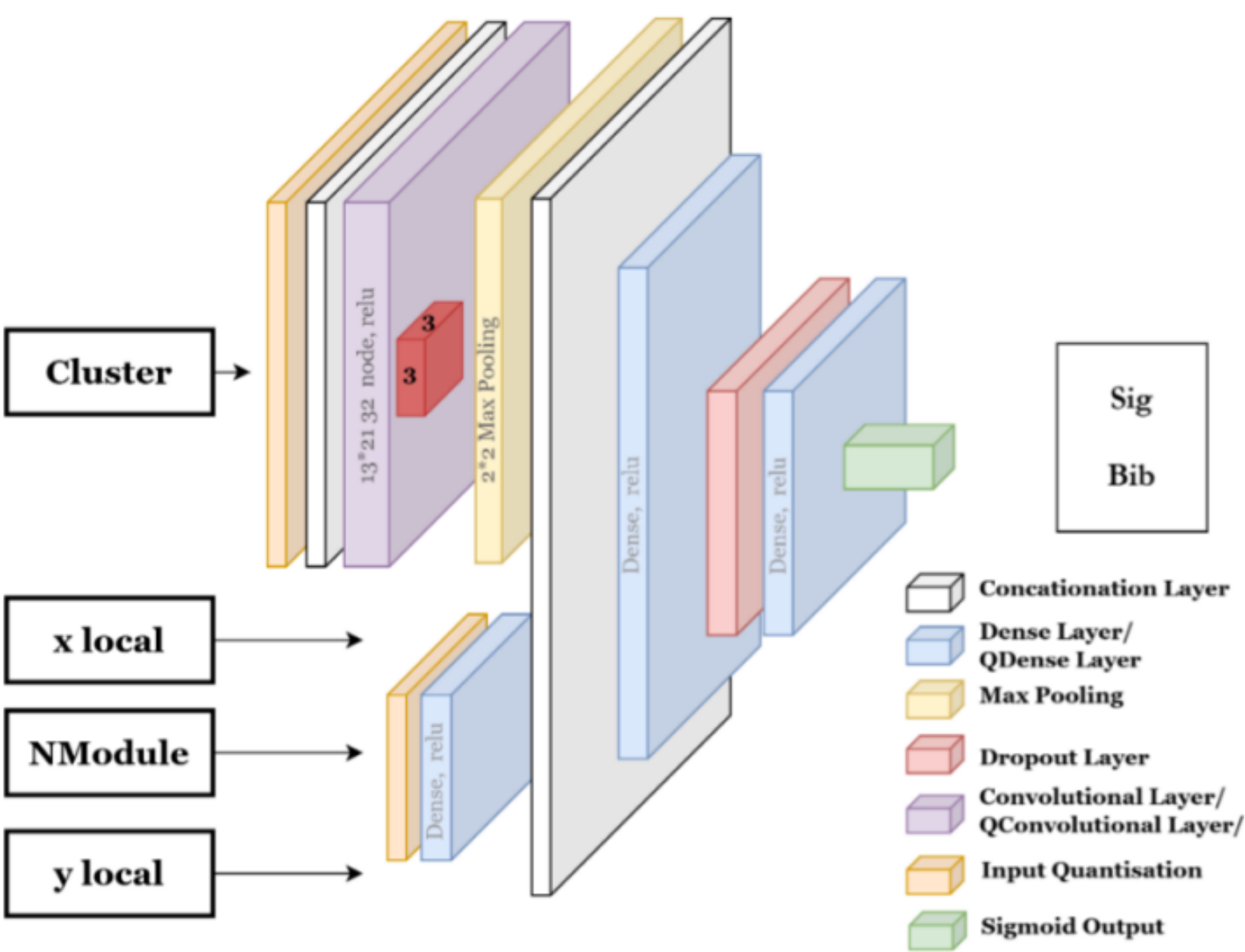
Model 1



Model 2

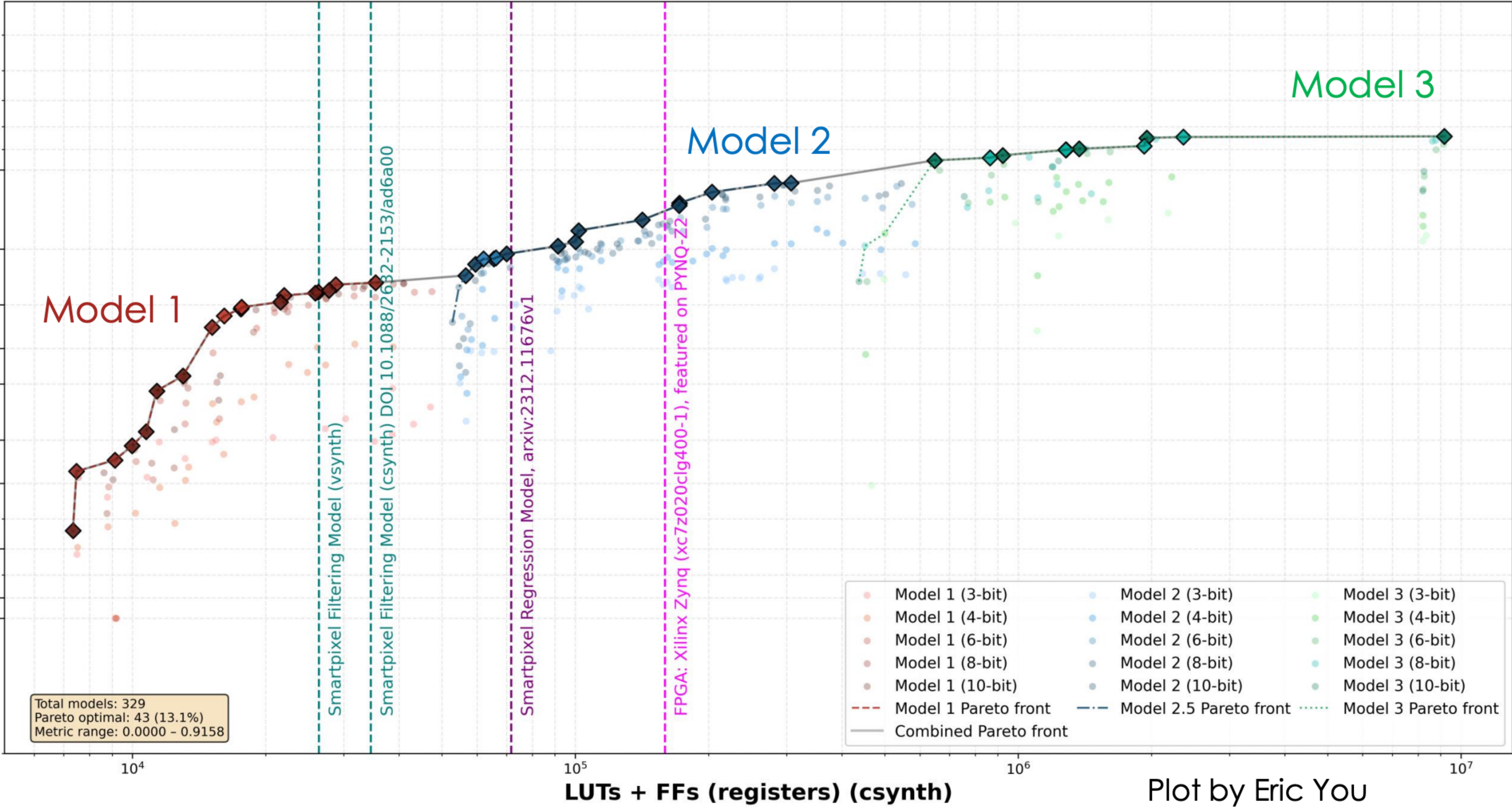


Model 3

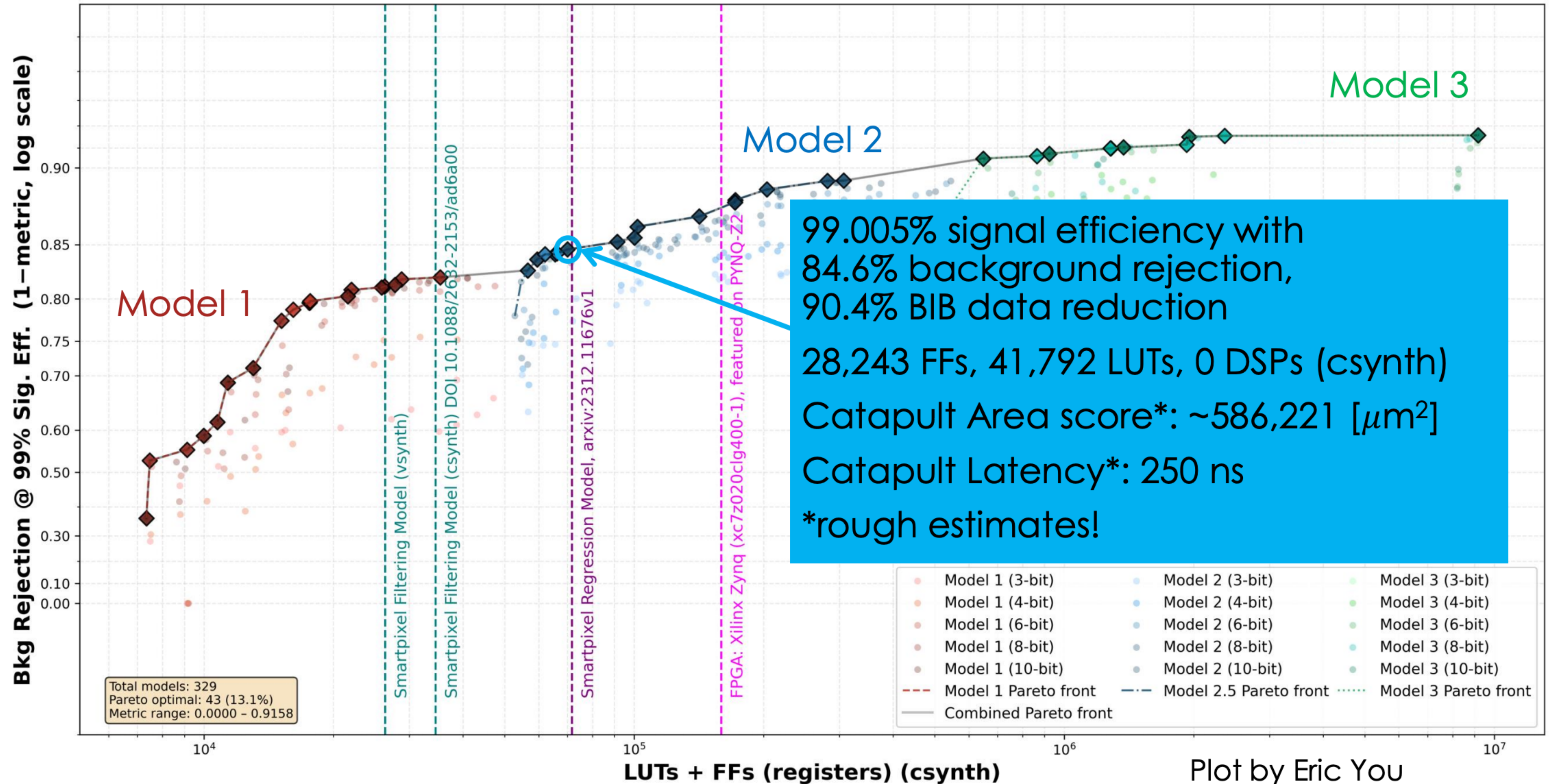


Model 1 vs Model 2 vs Model 3 — Sub-fronts + Combined Pareto
Bkg Rejection @ 99% Sig. Eff. vs LUTs + FF [x-log, y: 1–metric log]

Bkg Rejection @ 99% Sig. Eff. (1–metric, log scale)

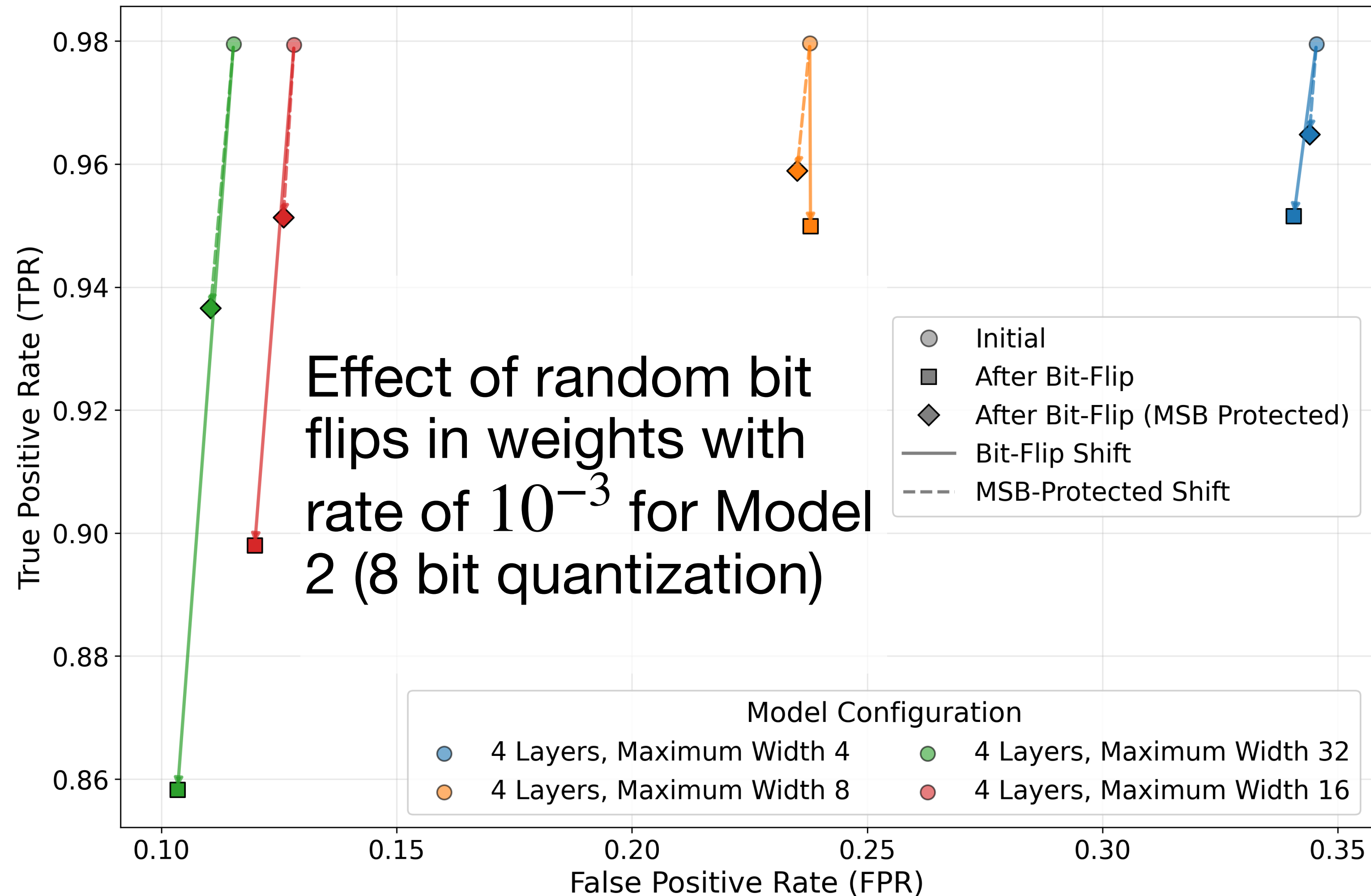


Model 1 vs Model 2 vs Model 3 — Sub-fronts + Combined Pareto Bkg Rejection @ 99% Sig. Eff. vs LUTs + FF [x-log, y: 1-metric log]



Operational Considerations — Radiation

- Radiation environment less difficult than HL-LHC
- Sensor damage from total dose
 - System should be robust to changing detector conditions
- Instantaneous effects in digital logic
- Trade-off between traditional protection and model size



Food for Thought

- Differentiable description of readout hardware may integrate naturally with AI design tools.
 - And maybe with physics performance studies?
- What can we do beyond data reduction?
- We should expect technology to improve between now and final detector design.
- We should expect the detector technology to be outdated by the time of operations.

Smart Pixels Collaboration

- Cornell University: Jennet Dickinson, Ben Weiss
- Fermi National Accelerator Laboratory: Douglas Berry, Giuseppe Di Guglielmo, Farah Fahim, Abhijith Gandrakota, Lindsey Gray, James Hirschauer, Ron Lipton, Benjamin Parpillon, Chinar Syal, Nhan Tran
- Johns Hopkins University: Petar Maksimovic, Morris Swartz
- Northeastern University: Nicholas Manganelli
- Purdue University: Miaoyuan Liu, Arghya Ranjan Das, Shiqi Kuang
- University of Chicago: Karri DiPetrillo, Anthony Badea, Benjamin Roberts, Daniel Abadjiev, Eliza Howard, Mira Littmann, Ryan Michaud, Eric You
- University of Colorado Boulder: Keith Ulmer, Jannicke Pearkes, Ricardo Silvestre
- University of Illinois Chicago: Corrinne Mills, Harshul Gupta, Danush Shekar, Amit Trivedi, Mohammad Abrar Wadud
- University of Illinois Urbana-Champaign: Mark S. Neubauer, David Jiang

smartpixels

