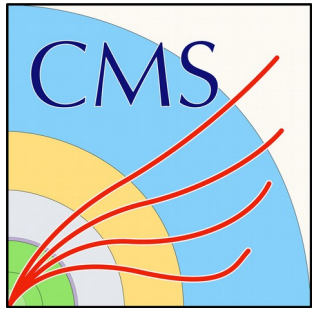
Some examples of trigger ideas for improving sensitivity to new physics in Run III with CMS

Michalis Bachtis

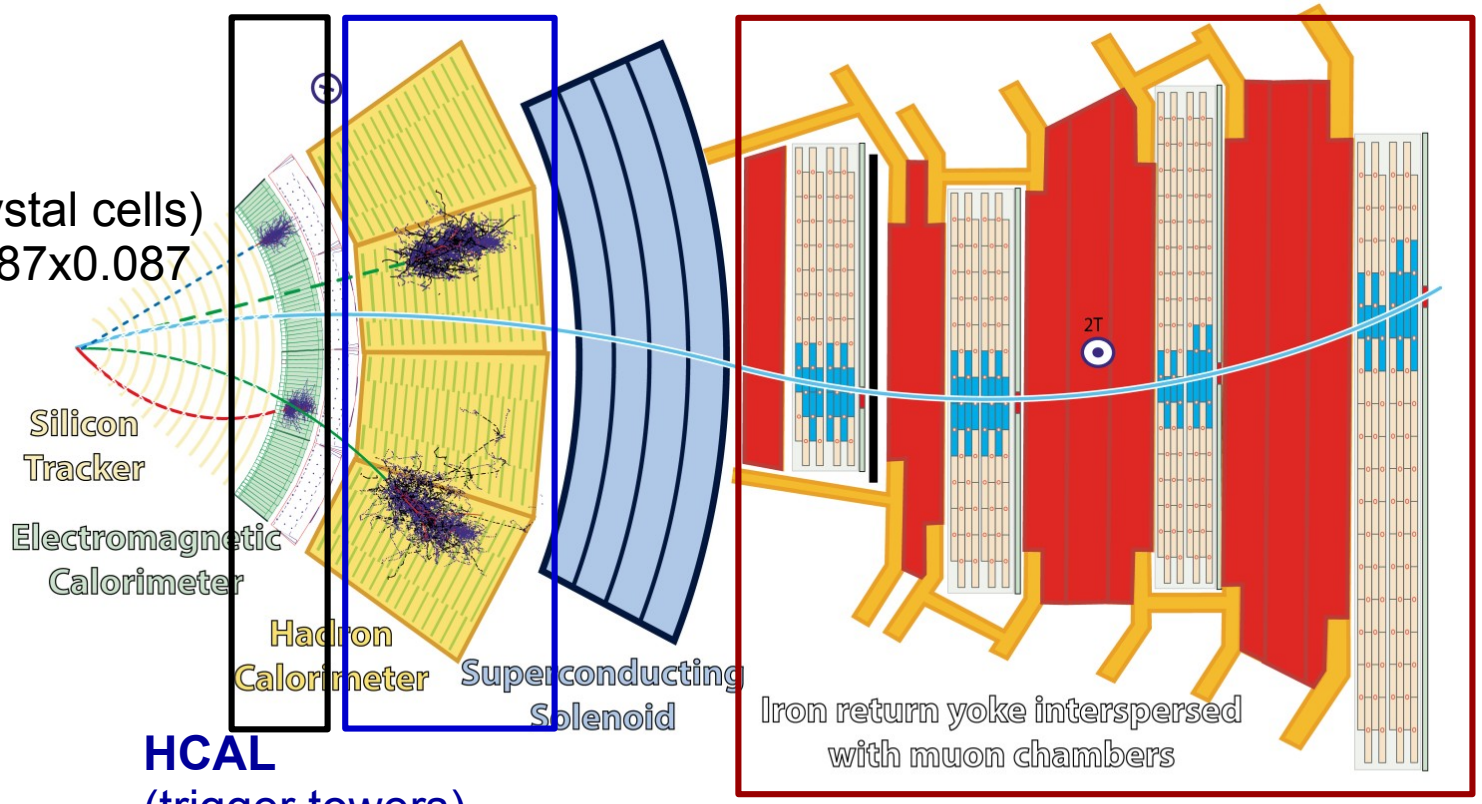
West Coast LHC Physics Jamboree

SLAC, Oct. 23^{d} 2019



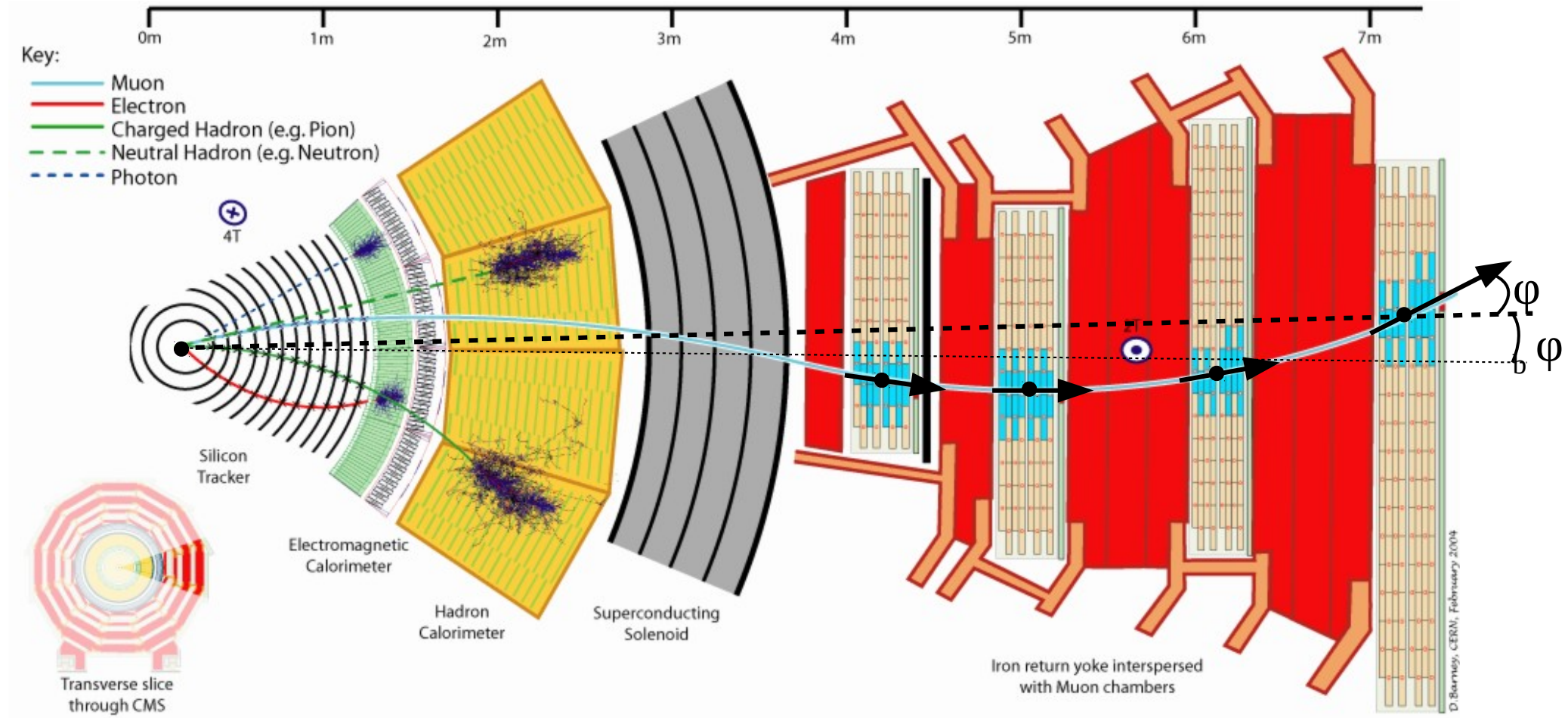
UCLA

The CMS L1 Trigger system in Run III



- L1 Trigger receives data from the Calorimeters and the Muon system → output ~100 kHz
  - Each subsystem creates objects (muons, e/γ , jets ,taus, HT, MET)
  - The L1 Global trigger makes a decision and sends the data to the HLT
- System upgraded before Run II

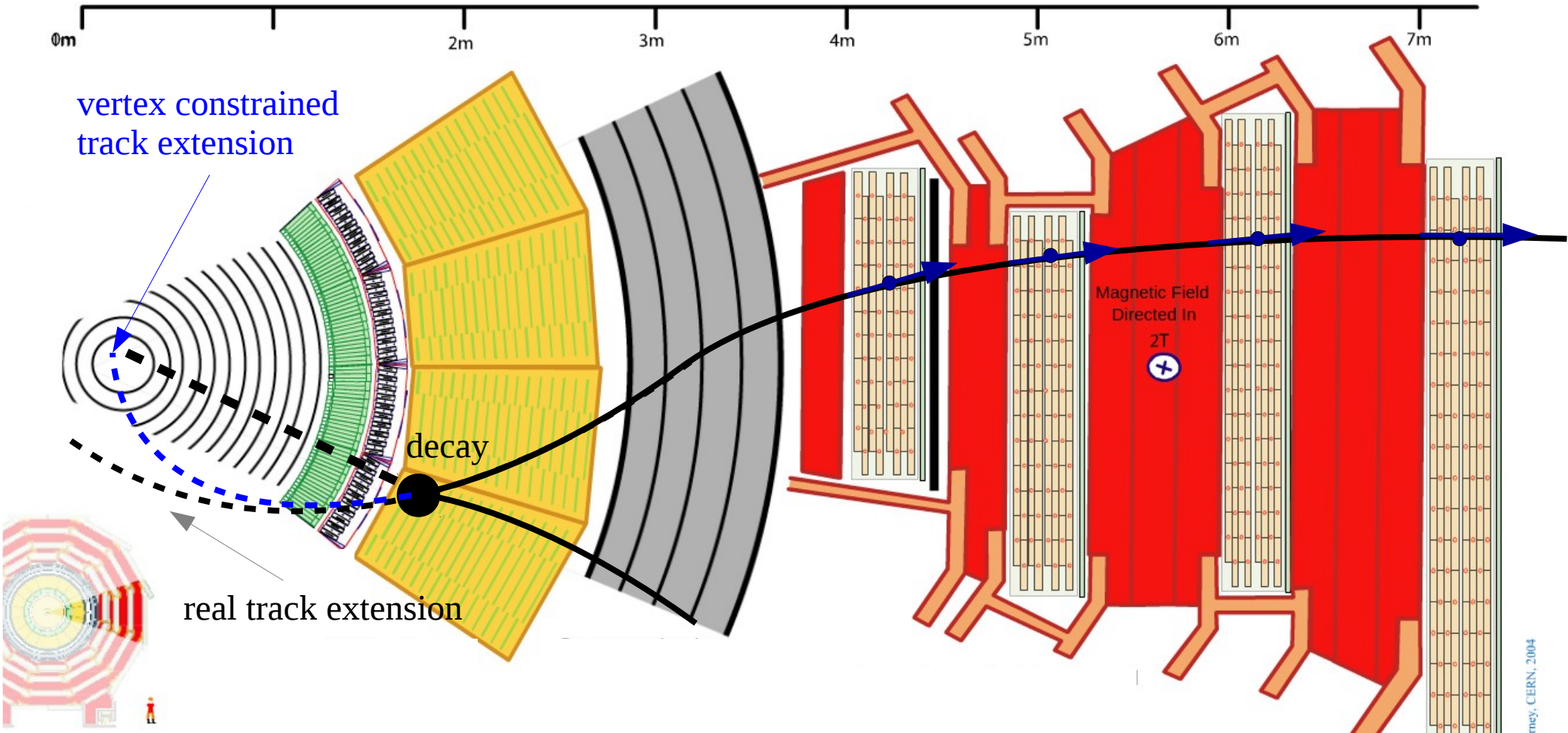
How do we reconstruct muons in L1?



- We perform a momentum assignment through a lookup table using info from 2 stations
- We assume that the track **originated from the primary interaction point**

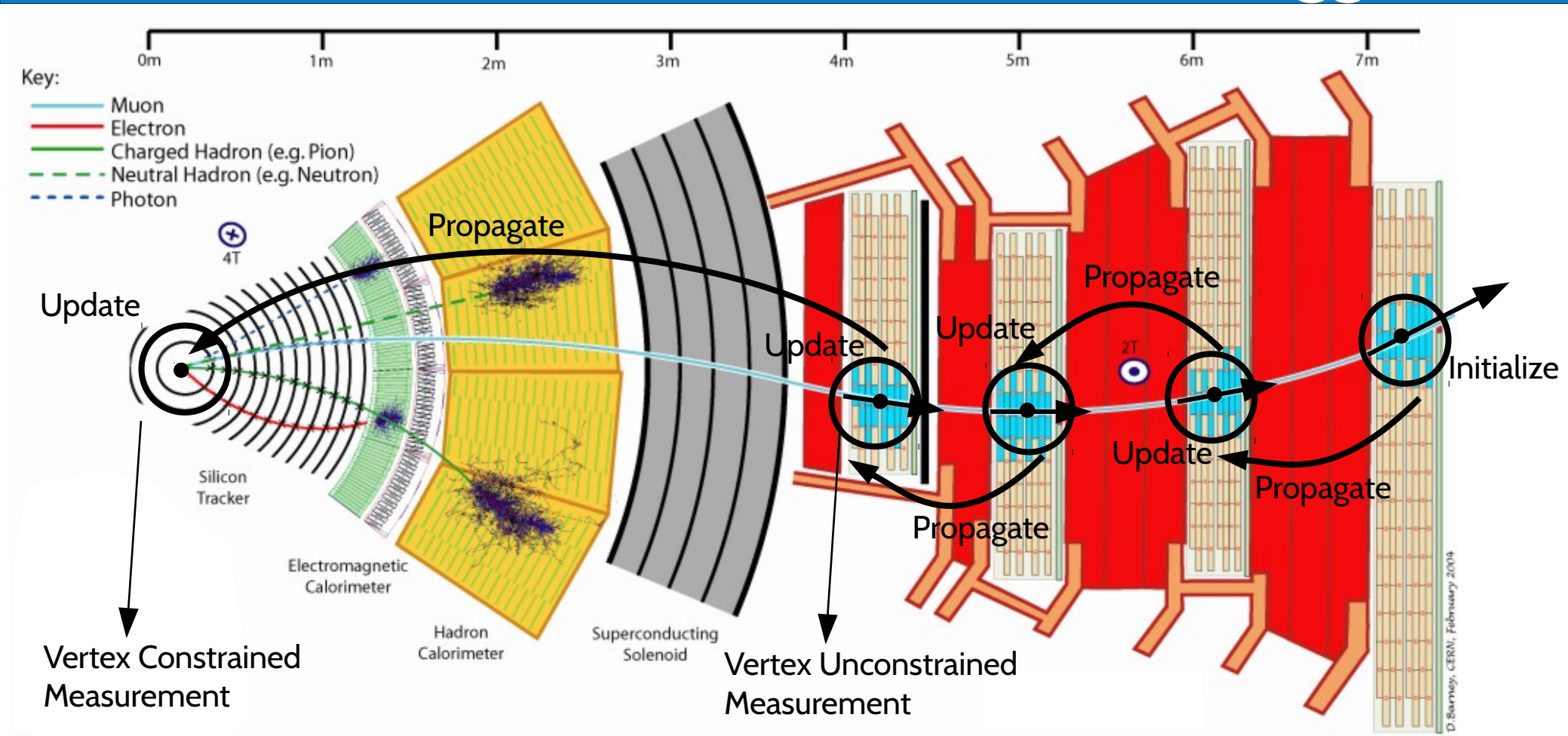
$$\frac{\sigma p_T}{p_T} \sim \frac{1}{BL^2}$$

Why it does not work for LLPs?



- Since the momentum assignment assumes a vertex constraint, often we get mismeasurement
  - A high pt displaced muon is reconstructed as low P_T and fails thresholds
- We need non-vertex constrained measurement in L1

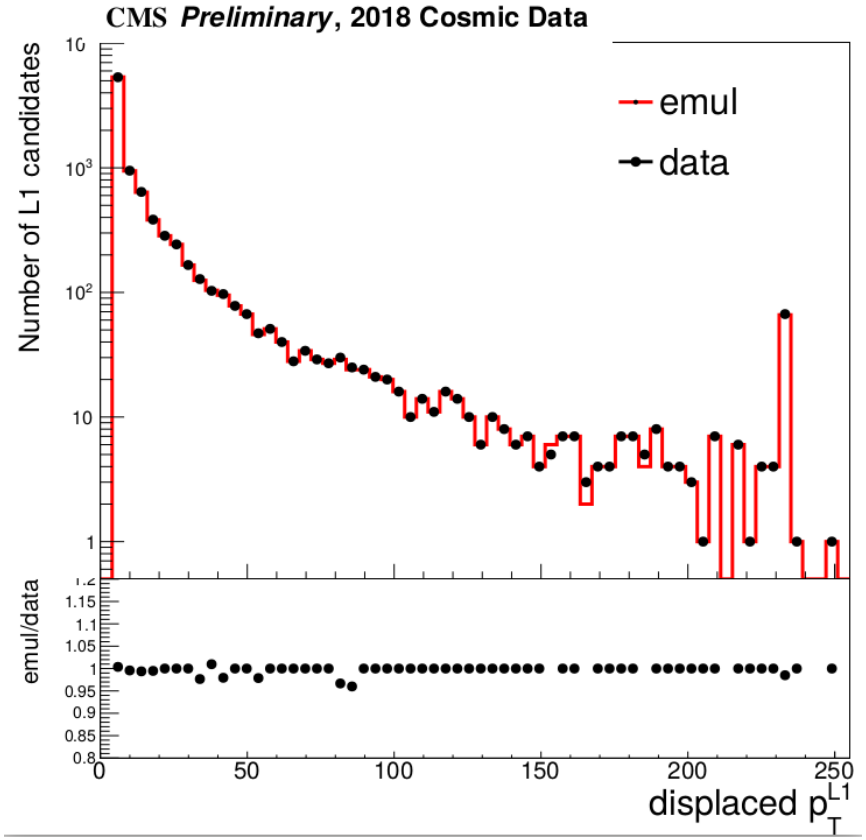
A Kalman Filter in FPGAs for the Barrel Trigger



- Sequential algorithm: (mathematically equivalent to a χ^2 fit)
  - Propagate track inwards from station to station and match with a stub
  - Update track parameters and continue
- After reaching station 1 → save measurement without vertex constraint
- Propagate to vertex and update → vertex constrained measurement
- Challenge for an FPGA implementation → **Matrix algebra → implemented using DSP cores in modern FPGAs after doing some approximations**

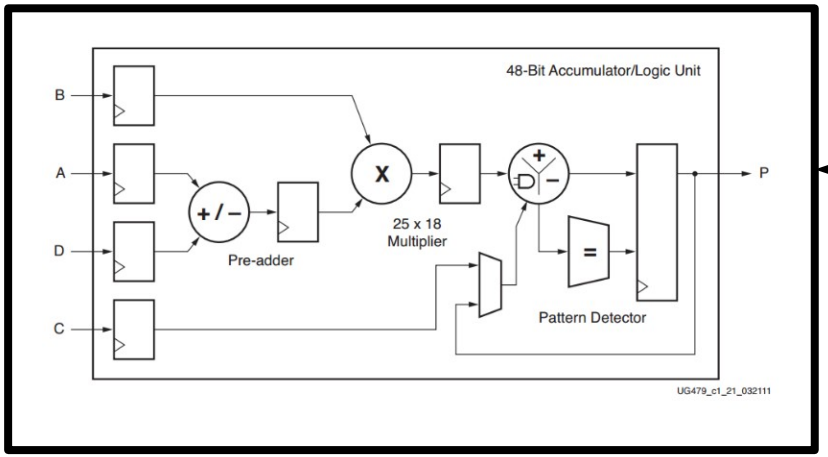
Commissioning and Results

- Kalman Filter did run in parallel with default Barrel Muon Track finder in the end of Run II
  - Both in the same FPGA
  - Trigger with default track finder
  - Kalman filter included in readout
- Efficiency measured in cosmics, agreement established between data and emulator
- Default algorithm for Run III
- Five times better efficiency for displacements of > 50cm



Deep learning in FPGAs in L1

- The endcap muon trigger uses a large lookup table (1 GB) in an external memory to perform momentum assignment
  - Boosted decision tree implemented inside the LUT
- Presence of DSP cores inside the FPGA enables implementation of deep neural networks inside the chip
  - Multiplications for free ~ 3K DSP cores in Virtex 7 FPGAs
- Plan for Run III
  - Implemented momentum assignment for displaced and prompt muons in neural nets
  - First implementations very promisir~ !
- **Javier will give more details**



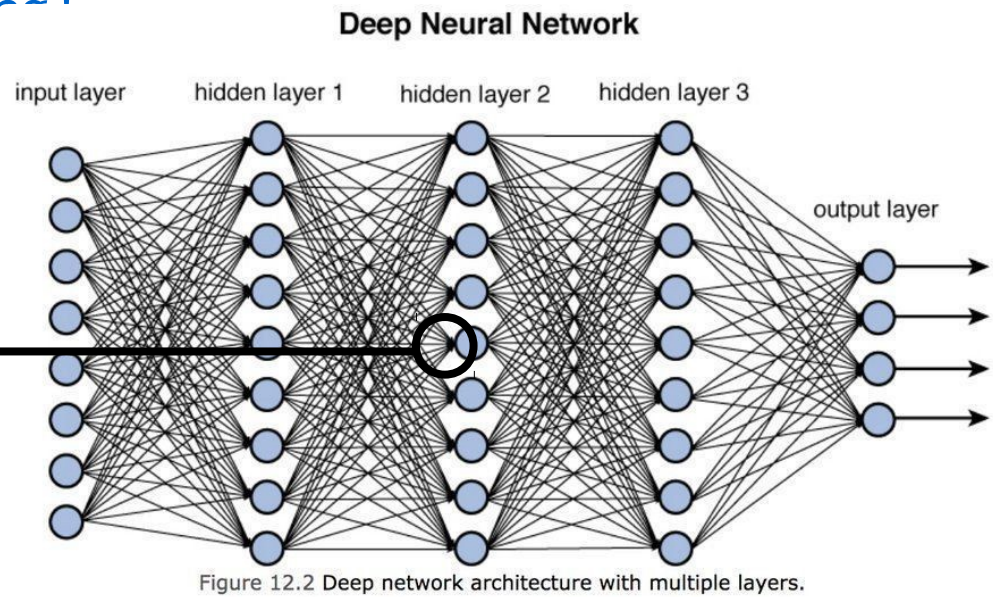
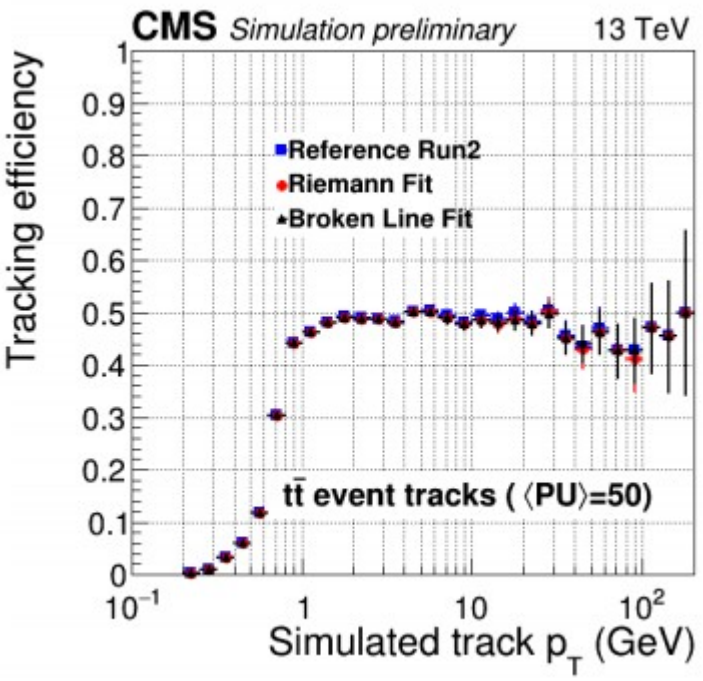
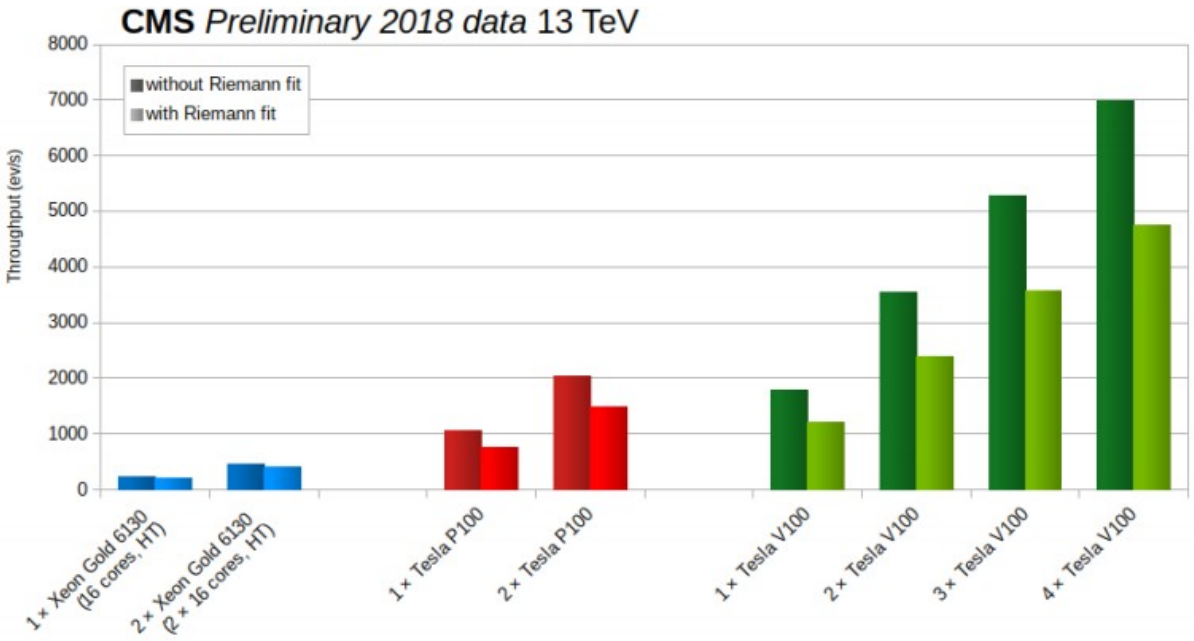


Figure 12.2 Deep network architecture with multiple layers.

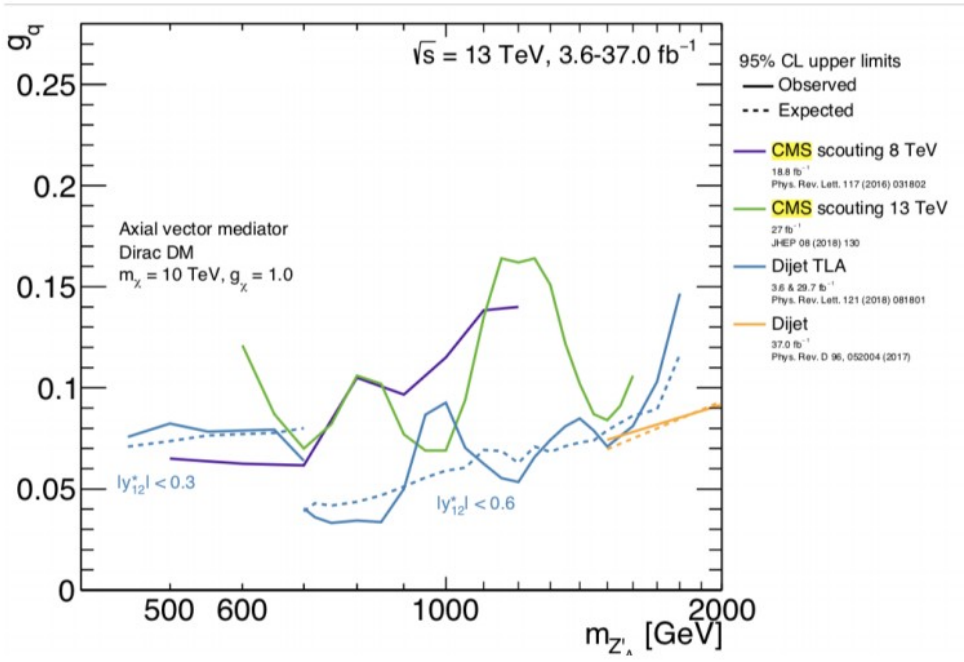
Fast pixel tracking with GPUs at the HLT





- Addition of new pixel layer → can measure all track parameters
- Parallel fitting techniques investigated and implemented in GPUs
  - e.g Riemann Fit
- Large throughput compared to scalar processors
- **Plan to add GPUs in the HLT farm for Run III**

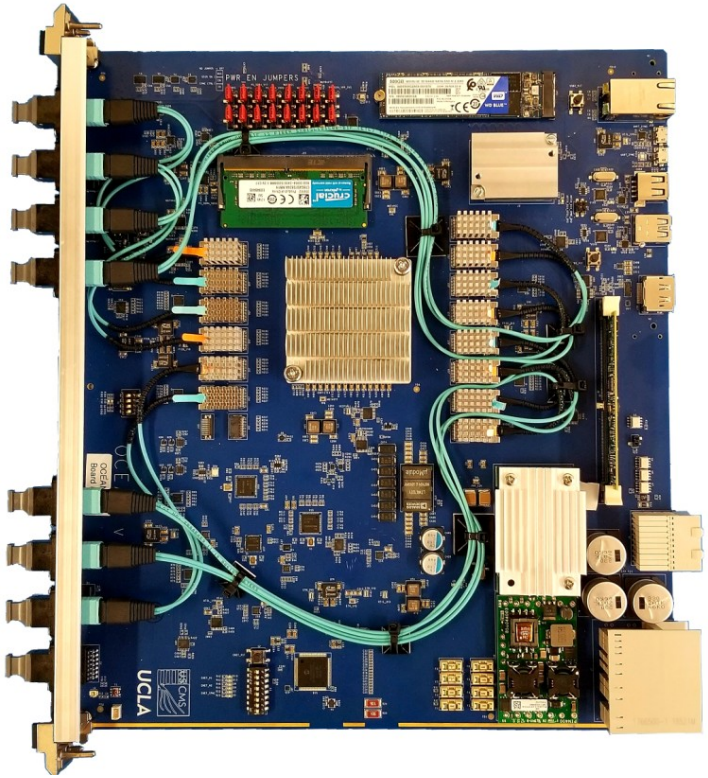
Improving HLT scouting



- CMS limited by Calorimeter-only jet reconstruction and the L1 trigger seeding path
- Attempt to improve jet mass resolution by using pixel tracks, and implementing Particle Flow regionally
- Muon related scouting to improve seeding with the displaced L1 triggers
  - Low pt displaced muon scouting possible at Run III

Scouting at 40 MHz

- Do physics analysis analyzing every single collision
- Read out L1 objects at full rate
  - In Phase 2 with a L1 track trigger we can do the full current HLT scouting in L1
  - In Run III capabilities are limited by only Calo and Muon data
- We plan to store all the L1 muons
  - **Thinking what to do with them…?**
- Hardware R&D for L1 also considering scouting capabilities:
- Example: OCEAN ATCA blade
  - Build as general purpose L1 trigger processor
  - Features a ZYNQ Ultrascale+ with quad core processor inteconncted with DDR memory and FPGA logic
  - Can receive L1 data and stream preselected data to memory
    - Processor can process further and write reduced event content to SSD



Summary

- Run III: factor of ~three in luminosity - need to be creative
- Limitations from the L1 Trigger are present at least till we have the full detector in L1 in HL-LHC
- Before then focus on improvements targeting specific physics models
  - Long Lived particle searches are enabled by new L1 trigger paths that provide displaced muon triggers without a vertex constraint
  - New HLT capabilities with pixel tracks using GPU accelerators
  - Upgraded HLT scouting program with Particle Flow capabilities
  - L1 scouting at 40 MHz is an interesting new case but we need a physics case to motivate it