Phase II Level 1 Taus

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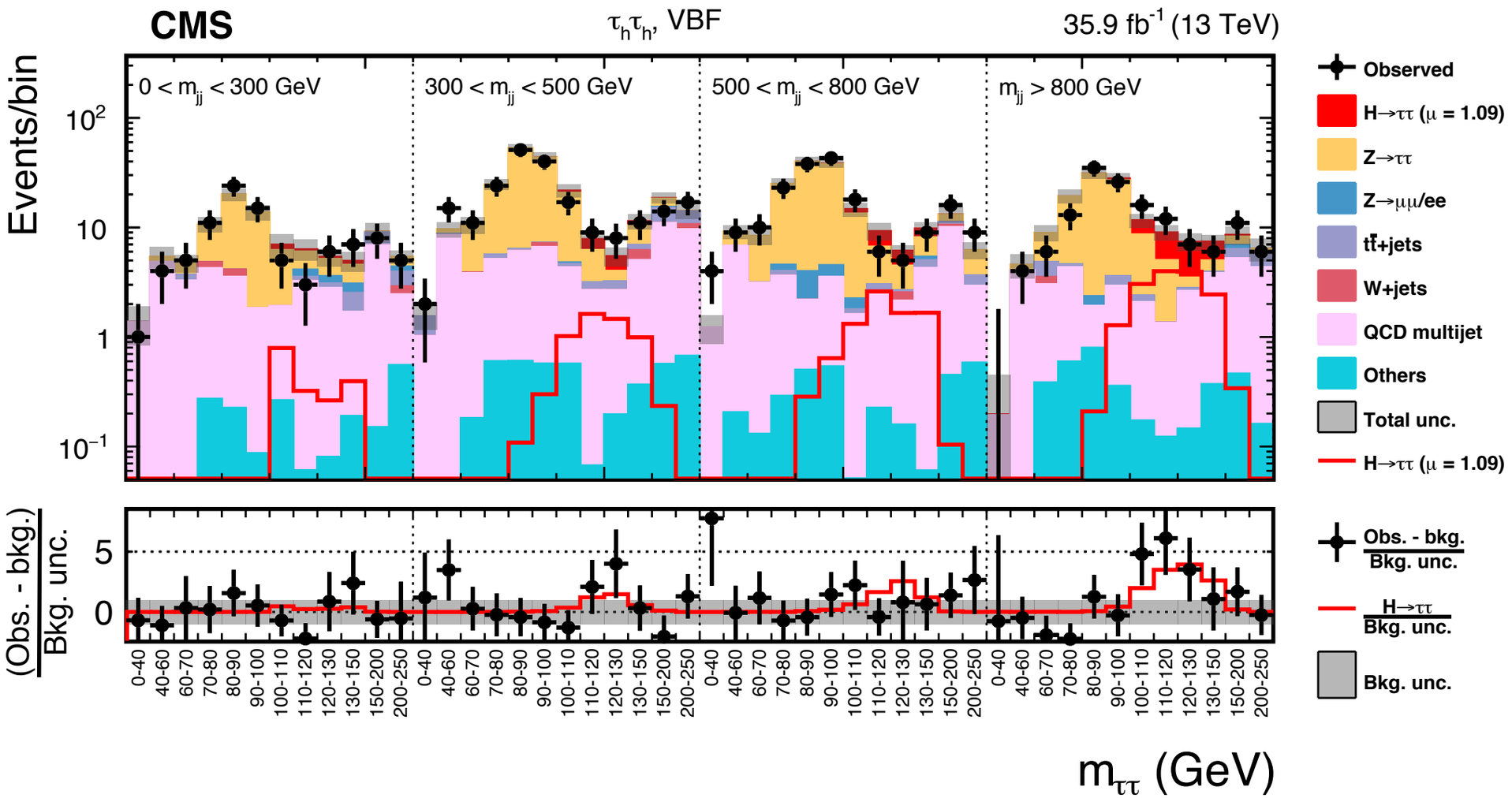
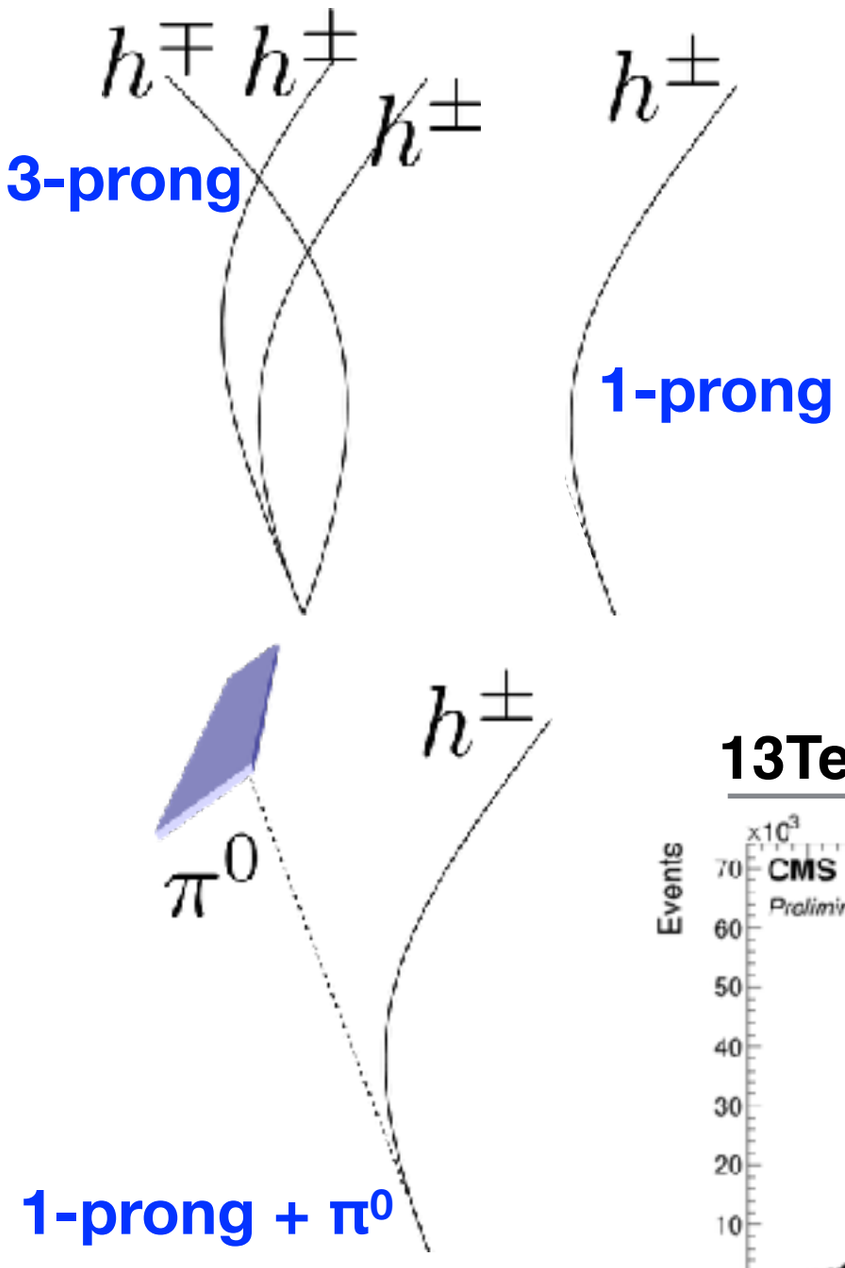
Introduction

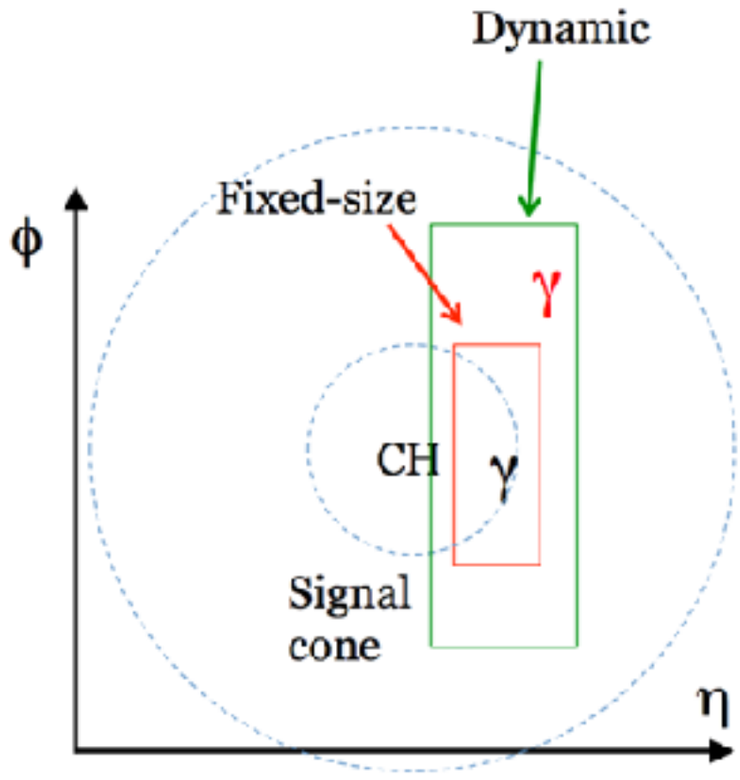


- Hadronic τ (τ_h) Decay can be **cleanly reconstructed**
  - **despite short lifetime**
- 3rd Generation Lepton, and largest lepton Yukawa coupling
- Perhaps enhanced couplings to **2HDM**, **LFV**, **LLP**s
- Phase 2 Tau Requirements
- Trigger Taus from SM processes with high Efficiency
- Opportunities to trigger on exotic physics? Boosted or Long

Tau Decay at CMS

Offline Tau Reconstruction uses a Cut-Based Hadron Plus Strips (HPS) Algorithm to Reconstruct **1-prong**, **1-prong + π^0** and **3-prong** Taus from Particle Flow Charged Hadron and e/gamma Candidates



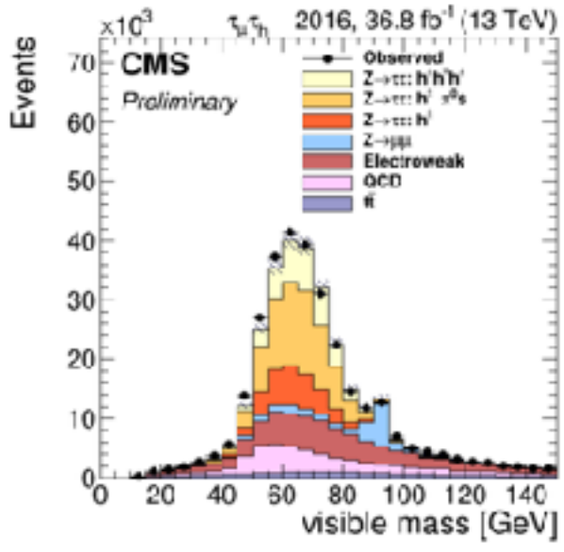


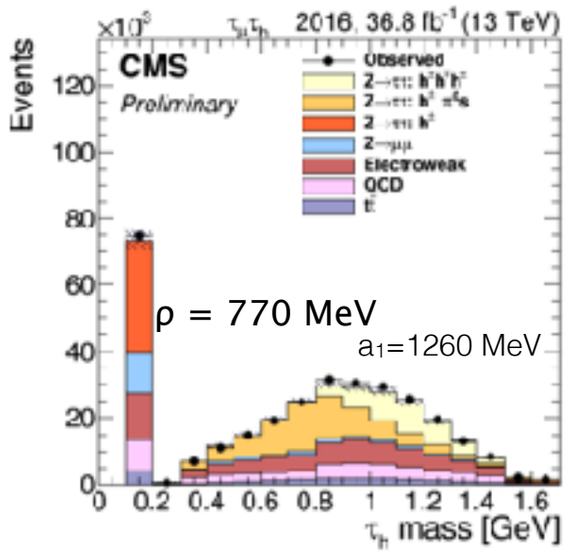
- Charged Hadrons produce tracks and deposit energy in both calorimeters

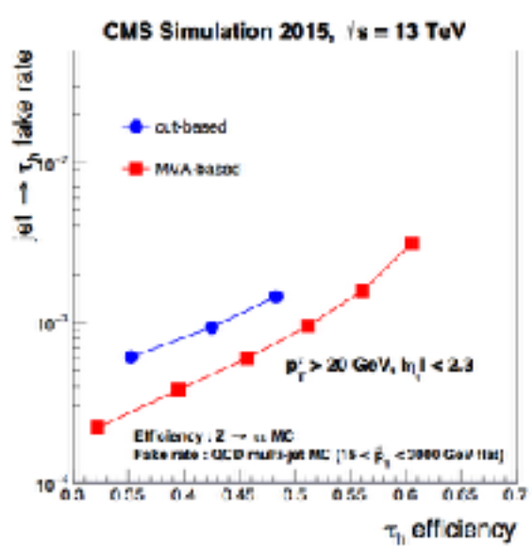
- Neutral pi0 forms e/gamma strips

- Large Jet/e/Mu Fake Probability

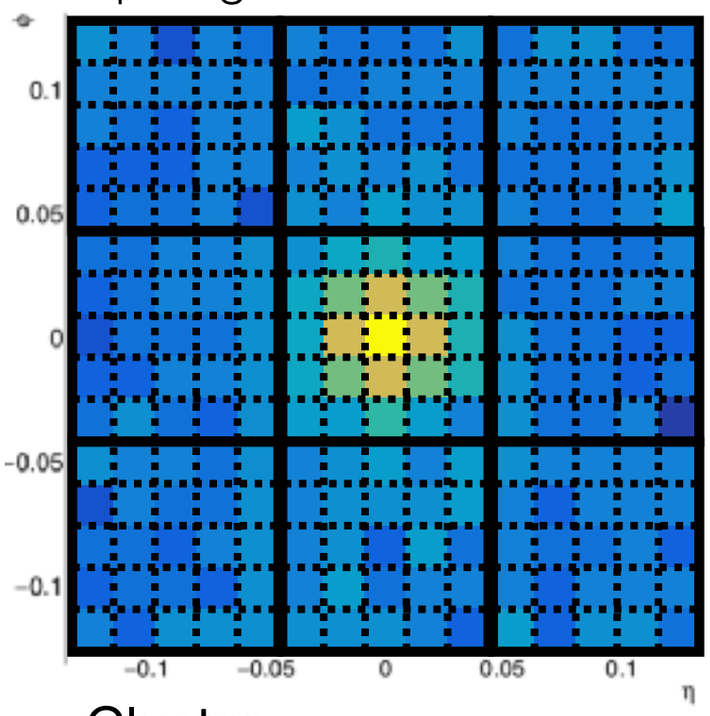
13TeV Performance

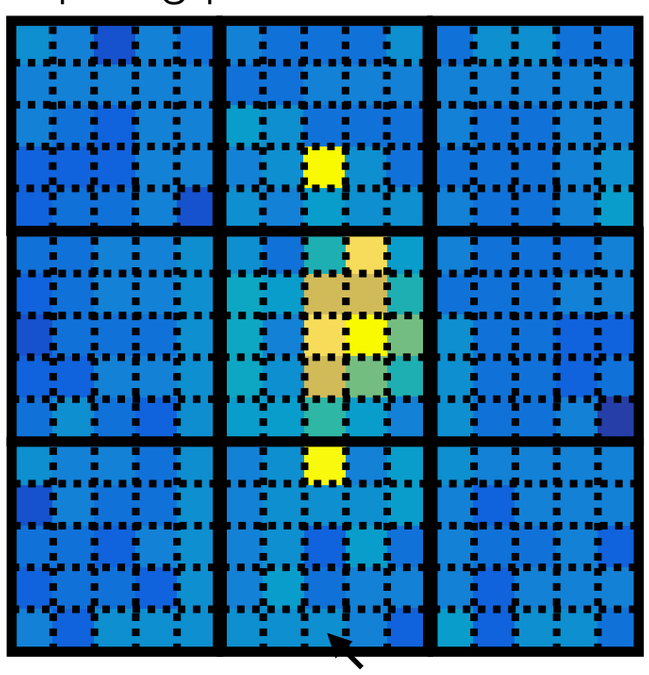


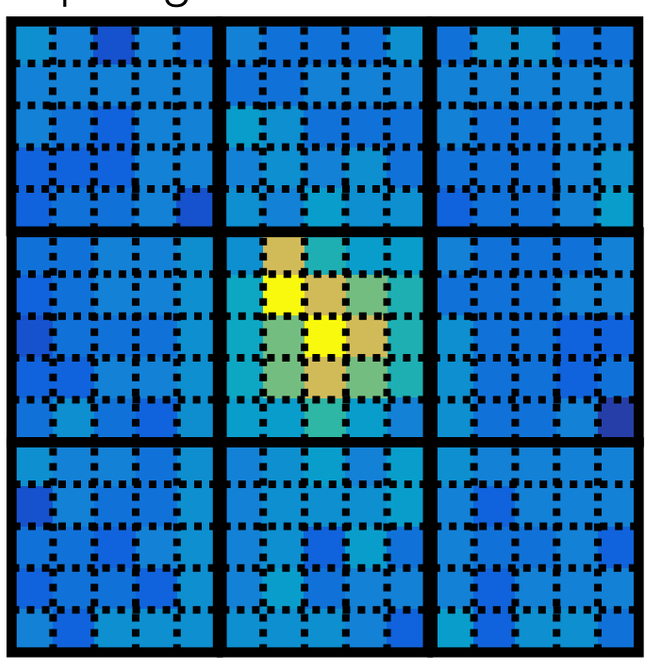




Tau Signature in Phase 2 Trigger





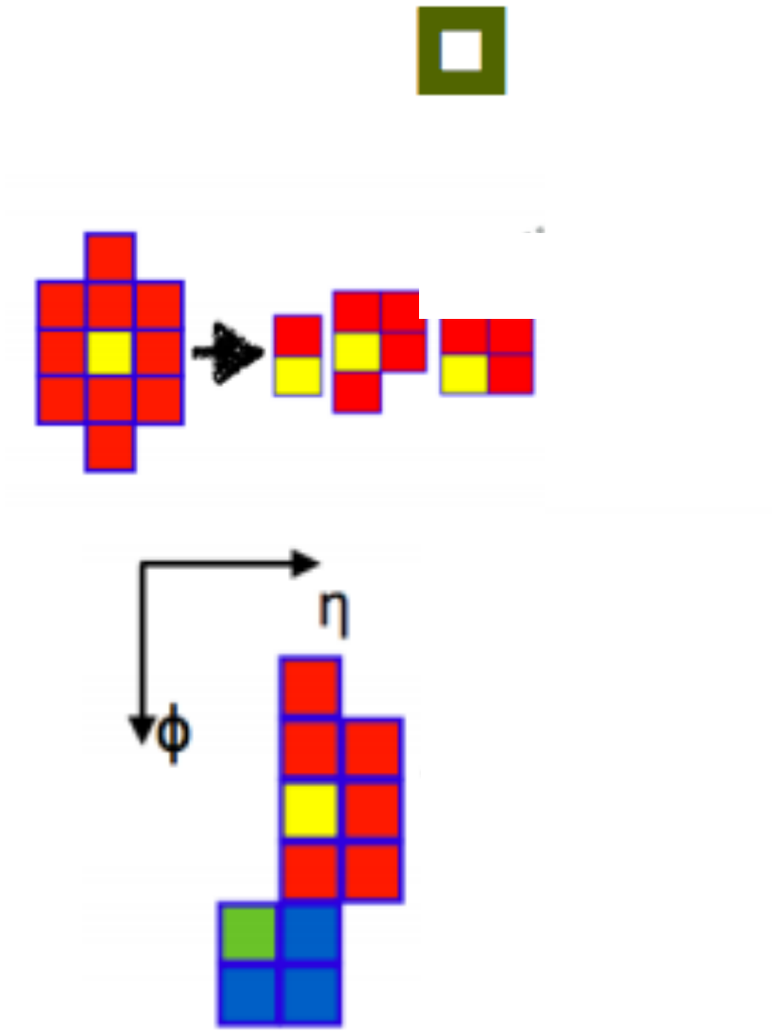


Taus deposit most of their energy in a ~0.1 (DeltaR) for 1 prong and 3 prong decays, however, 1 prong pi0 and 3 prong pi0 can have spreading of strips up to 0.2 in Phi

Jets correspond to several clusters of energy deposit around a maximum cluster extending up to 0.4 or 0.8 in DeltaR

Phase I Level 1 Tau Algorithm

- Implemented in firmware running at 240MHz clock



Calibration

▼

Clustering

▼

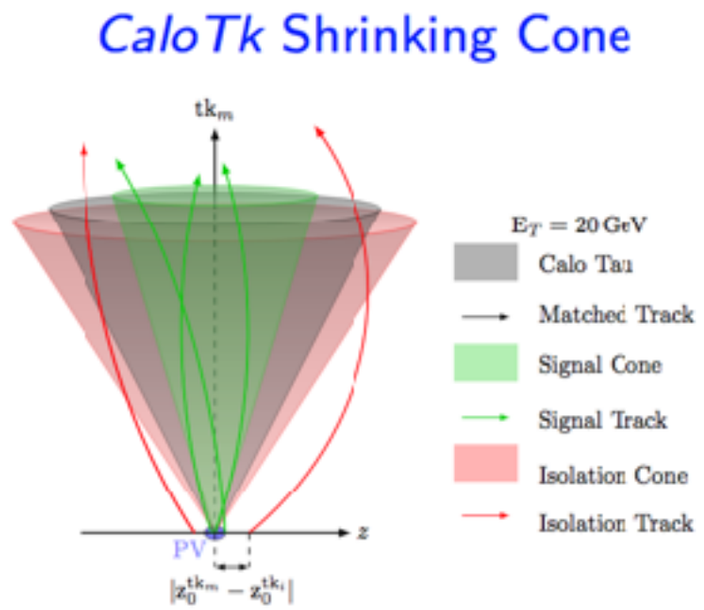
Merging

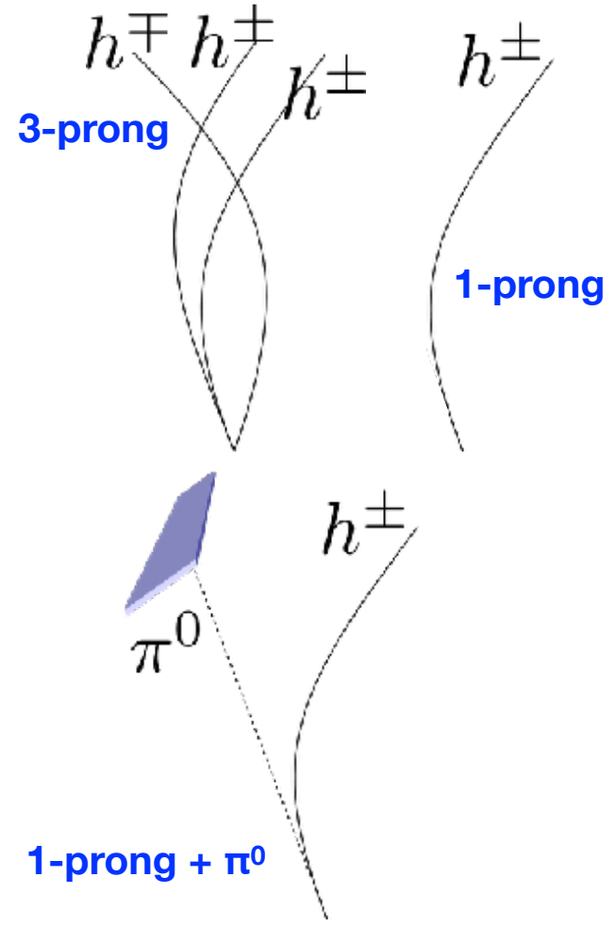
- Trigger Towers are **Calibrated** to mimic true offline response
- **Clustering** is performed around a central seed
- **Merging** of clusters to form **L1 Tau Objects**

Phase II Level 1 Taus

Three Algorithms currently being explored for Phase II Level 1 Taus:

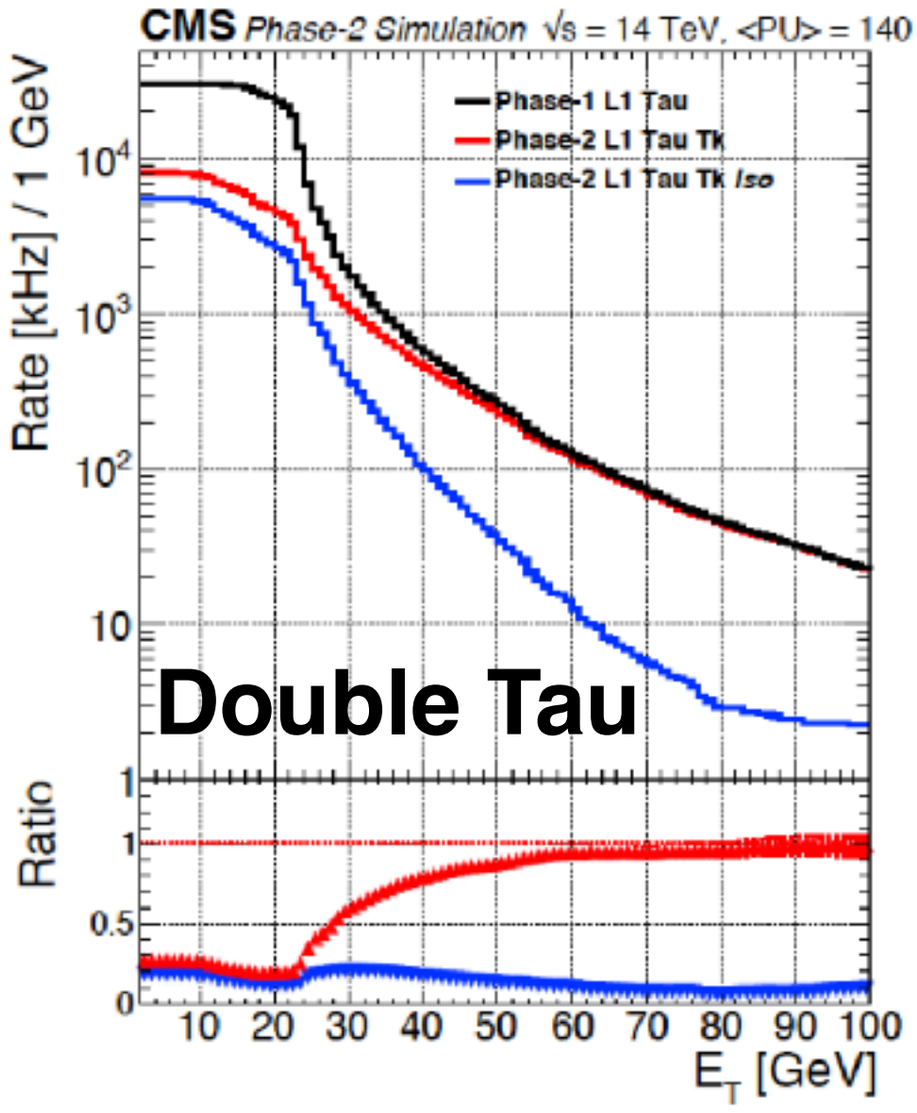
- **Decay Mode Reconstruction at Level 1**
  - **Similar to Offline Reconstruction**
  - **Must not import too many complexities into Level 1 (parallelism!)**
- **Shrinking Tau algorithm matched to L1Tracks**
  - **Similar to current HLT algorithm**
- **Calo Taus using modified e/g algorithm**
  - **Seed for later PF steps**
  - **Displaced and high P_T Taus where L1 Tracks may be merged or not well reconstructed**

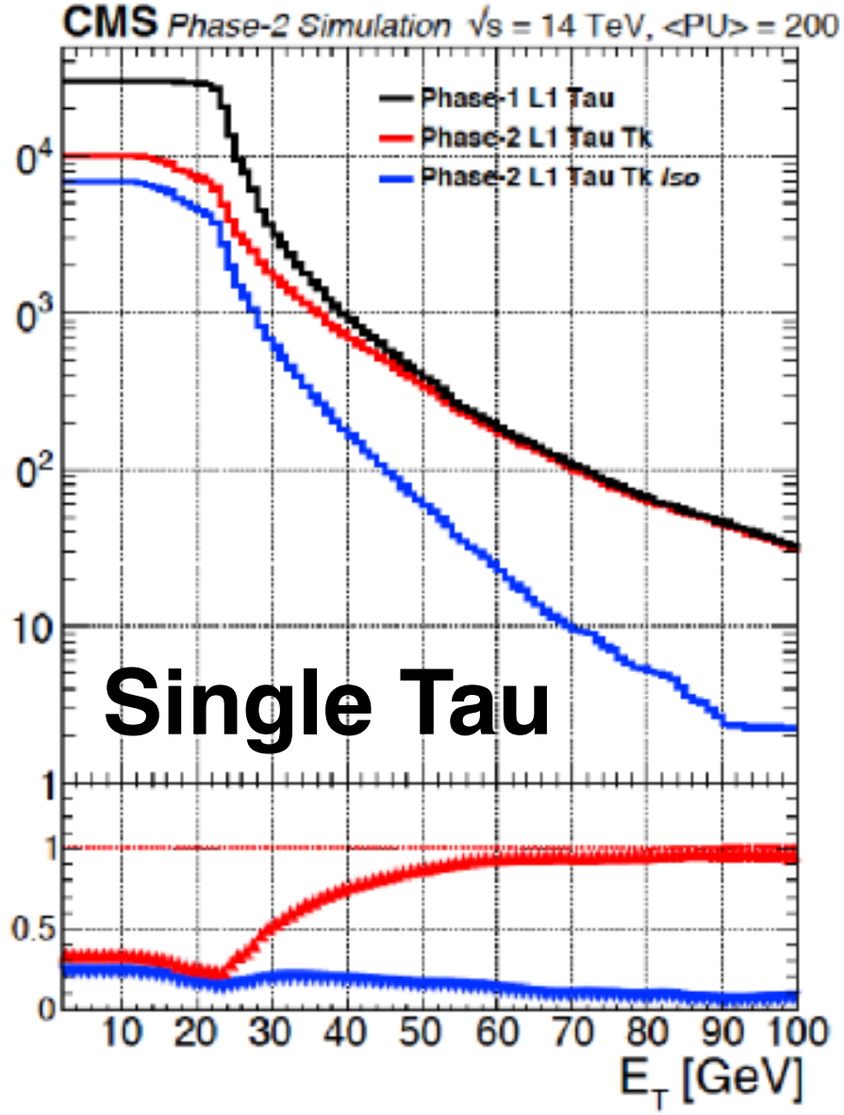




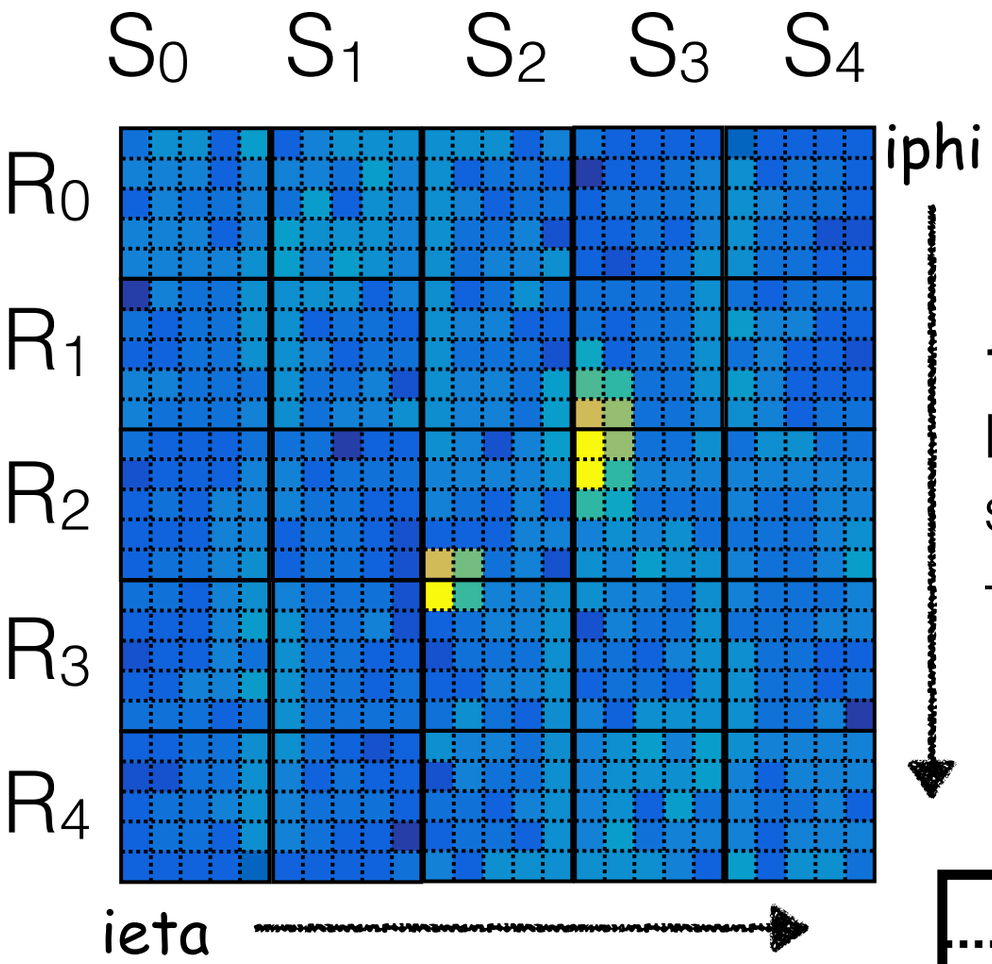
L1 Tracking and Taus

- **Tracking bring major improvement to Tau ID at Level 1**
- **By matching Phase 1 Calo-Taus to High PT Level 1 Tracks and isolating from low PT Tracks a factor of 10 in rate reduction is seen**





- Non-optimal p_T resolution



HPS Tau Reconstruction @ Level 1

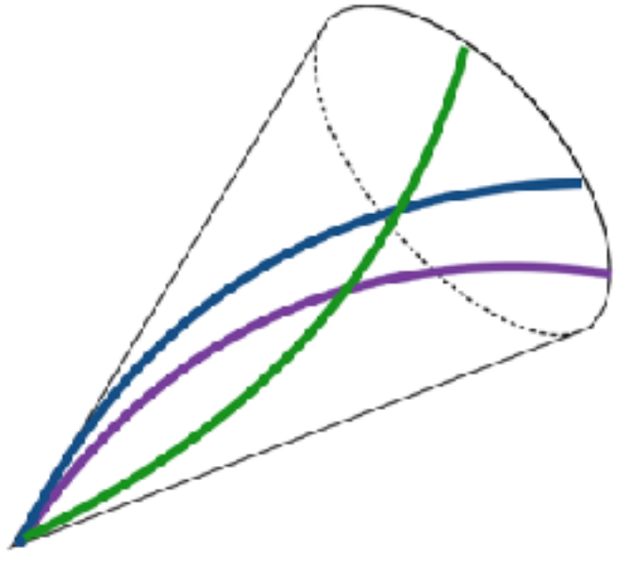
1.) Charged Hadron Seeding

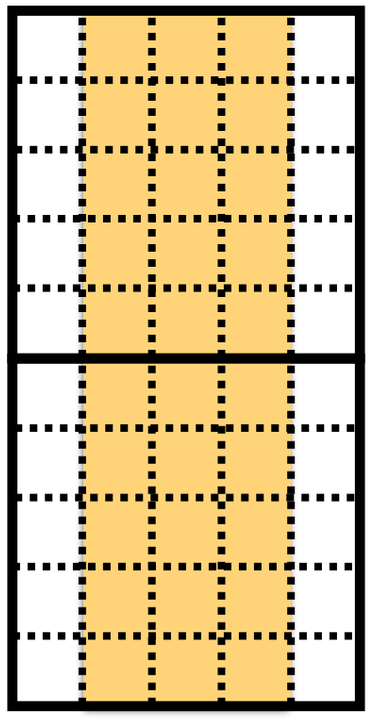
Linked Cluster-Tracks above a threshold are used as seeds for Tau Finding

-> 1 Charged Hadron to find the taus as **1 Prong**, **1 Prong** + **Pi0** or **3 Prong**

2a.) Prong Finding

-> Search through PF Charged Candidates find matching Charged Hadrons





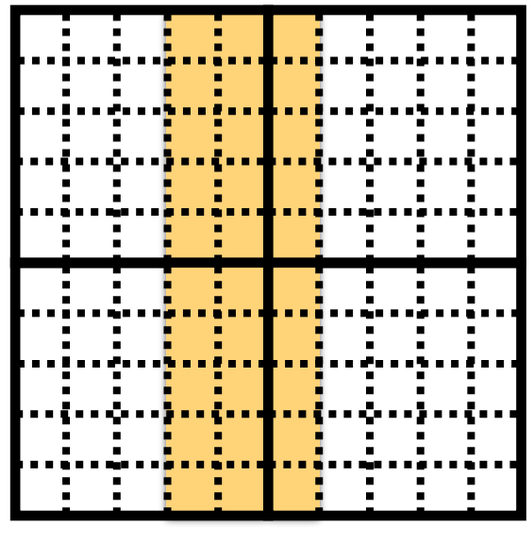
2b.) Strip Stub Finding

-> First merge matched photons and Electrons

-> Then merge matched Strips

3.) Strip Stub Merging

-> Strip stubs which fall on boundaries are merged



High Level Synthesis to Study Performance

```
================================================================
== Vivado HLS Report for 'tau_alg'
================================================================
* Date:           Mon May 22 23:10:44 2017

* Version:        2016.4 (Build 1756540 on Mon Jan 23 MST 2017)
* Project:        phase2_demonstrator
* Solution:       pf_tau_solution_1
* Product family: virtex7
* Target device:  xc7vx690tffg1927-2

================================================================
== Performance Estimates
================================================================
+ Timing (ns):
    * Summary:
    +--------+-------+----------+------------+
    |  Clock | Target| Estimated| Uncertainty|
    +--------+-------+----------+------------+
    |ap_clk  |   4.16|      4.28|        0.52|
    +--------+-------+----------+------------+

+ Latency (clock cycles):
    * Summary:
    +-----+-----+-----+-----+----------+
    |  Latency  |  Interval | Pipeline |
    | min | max | min | max |   Type   |
    +-----+-----+-----+-----+----------+
    |  120|  120|    6|    6| function |
    +-----+-----+-----+-----+----------+


================================================================
== Utilization Estimates
================================================================
* Summary:
+-----------------+---------+-------+--------+--------+
|       Name      | BRAM_18K| DSP48E|   FF   |   LUT  |
+-----------------+---------+-------+--------+--------+
|DSP              |        -|      -|       -|       -|
|Expression       |        -|      -|       0|    3305|
|FIFO             |        -|      -|       -|       -|
|Instance         |        -|      -|   19025|    5925|
|Memory           |        -|      -|       -|       -|
|Multiplexer      |        -|      -|       -|  167416|
|Register         |        -|      -|  282917|    1176|
+-----------------+---------+-------+--------+--------+
|Total            |        0|      0|  301942|  177822|
+-----------------+---------+-------+--------+--------+
|Available        |     2940|   3600|  866400|  433200|
+-----------------+---------+-------+--------+--------+
|Utilization (%)  |        0|      0|      34|      41|
+-----------------+---------+-------+--------+--------+
```

L1 PF Tau Algorithm:

Input: 10 Charged PF Objects
100 Neutral L1 PF Objects

Output: 3 PF L1 Taus

1 prong

```
void tau_alg(pf_charged_t pf_charged[N_TRACKS],
             cluster_t neutral_clusters[N_CLUSTERS],
             algo_config_t algo_config,
             pftau_t tau_cands[12]){
...
      //Create the 1 prong taus
      if(n_prongs_found < 3 && n_taus < 12){
        if(seed_hadron.et > algo_config.one_prong_seed){
          tau_cands[n_taus].et           = seed_hadron.et;

          tau_cands[n_taus].iso_charged = iso_sum_charged_hadron +
                                          prong_cands[2].et;

          tau_cands[n_taus].tau_type     = 0;
          n_taus++;
        }
      }
```

3 prong

```
      //Create the 3 prong taus
      if(n_prongs_found == 3 && n_taus < 12)

        if(seed_hadron.et > algo_config.three_prong_seed){

          tau_cands[n_taus].et           = prong_cands[0].et +
                                           prong_cands[1].et +
                                           prong_cands[2].et;

          tau_cands[n_taus].tau_type     = 10;
...
          n_taus++;
        }
      }

      //Process the strips in a separate module

      for(ap_uint<4> i = 0; i < 12 ; i++){

#pragma HLS UNROLL

        if(tau_cands[i].tau_type == 0){

        strip_alg(tau_cands[i], electron_grid[i],
                  neutral_clusters, algo_config);
        }
        else{
             tau_cands[i].tau_type = 0;}
        }
}
```

1 prong pi0

High efficiency algorithm, able to easily explore optimization for resource usage and increased rate reduction, ***already tested on Phase I Cards!***

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        if(seed_hadron.et > algo_config.one_prong_seed){
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```

- Sharper Efficiency Turn On
- Improved Pileup Removal
- Targeting Offline Reconstruction Techniques
- Potential to explore **Boosted Topologies**

```
|       Name       | BRAM_18K| DSP48E|    FF    |    LUT   |
+------------------+---------+-------+----------+----------+
|DSP               |        -|      -|         -|         -|
|Expression        |        -|      -|         0|      3305|
|FIFO              |        -|      -|         -|         -|
|Instance          |        -|      -|     19025|      5925|
|Memory            |        -|      -|         -|         -|
|Multiplexer       |        -|      -|         -|    167416|
|Register          |        -|      -|    282917|      1176|
+------------------+---------+-------+----------+----------+
|Total             |        0|      0|    301942|    177822|
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         }
}
```

1 prong pi0

High efficiency algorithm, able to easily explore optimization for resource usage and increased rate reduction, ***already tested on Phase I Cards!***

Phase II L1 Calo Taus

Clustering of Taus in the Level 1 Calorimeter Trigger:

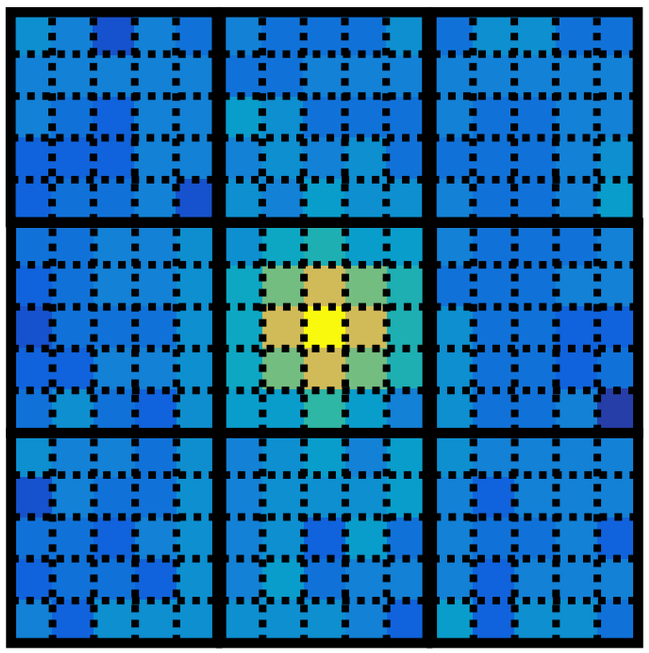
– Size of the **clusters slightly larger than e/gamma**

– Shape variables and isolation being studied to match Hadronic Tau Decays

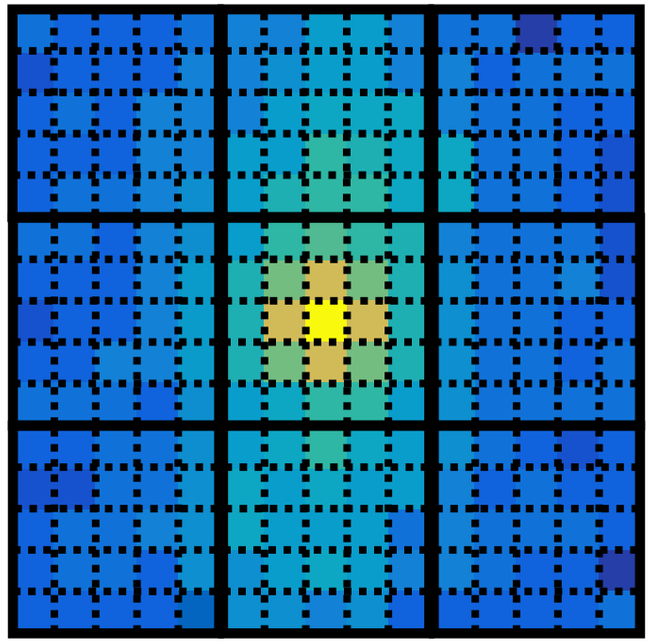
– **HCAL energy deposits** combined with **ECAL clusters** are important to reconstruct the charged pions -> Worse p_T resolution when using calorimeter clusters only

- Useful as seeds to **Track-Calo Tau** matching
- Standalone Tau Algorithm for Exotic Signatures (displaced or poorly reconstructed tracks)

1 prong



3 prong 1 pi0

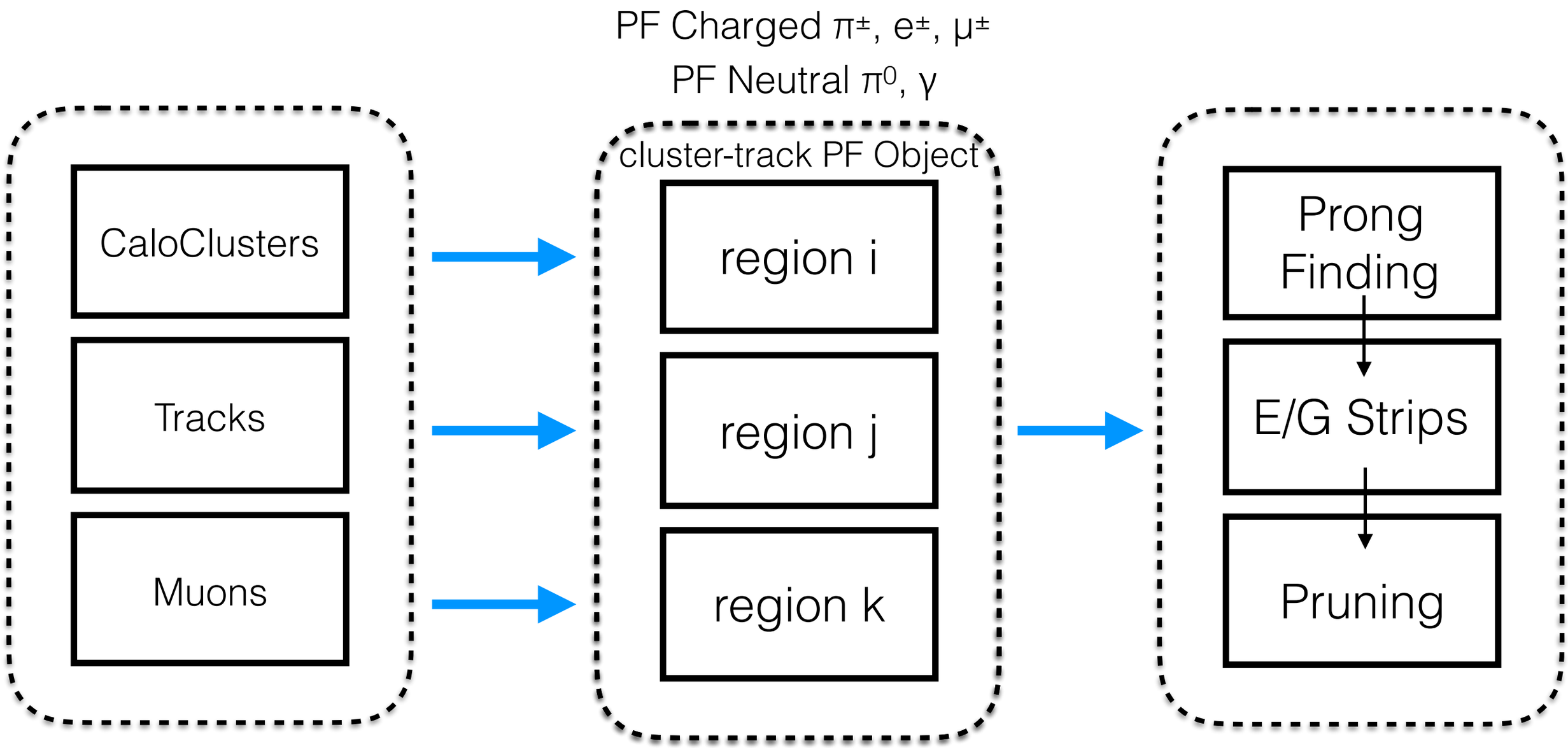


Conclusions

- **A lot of work towards designing and implementing the future Phase II Trigger for CMS**
- Integration of the tracker in the CMS L1 Trigger **reduces the rate for Level 1 Taus**, possible to do EWK physics at CMS with the HL-LHC
- New Level 1 Tracking and Particle Flow techniques at Level 1 improve Level 1 Tau Reconstruction and Jet Rejection
- **Three Algorithms currently being explored:**
  - HPS at Level 1
  - Shrinking Cone algorithm matched to L1Tracks
  - Calo Taus using modified e/g algorithm
- Explore ways to **make the most of BSM signatures at Level 1**
- **Simulation** and **Programmability** of **huge FPGAs** allows **testing of different algorithms before the system is built**

We need ideas of where new physics could be so we can be sure to collect the data!

HPS Tau Reconstruction @Level 1



Patterns from Simulation

PF Cluster -Track Matching Module

Tau Finding Algorithm

Modules can be Synchronous with Emulator