Phase-2 Upgrade Of Level-1 Trigger

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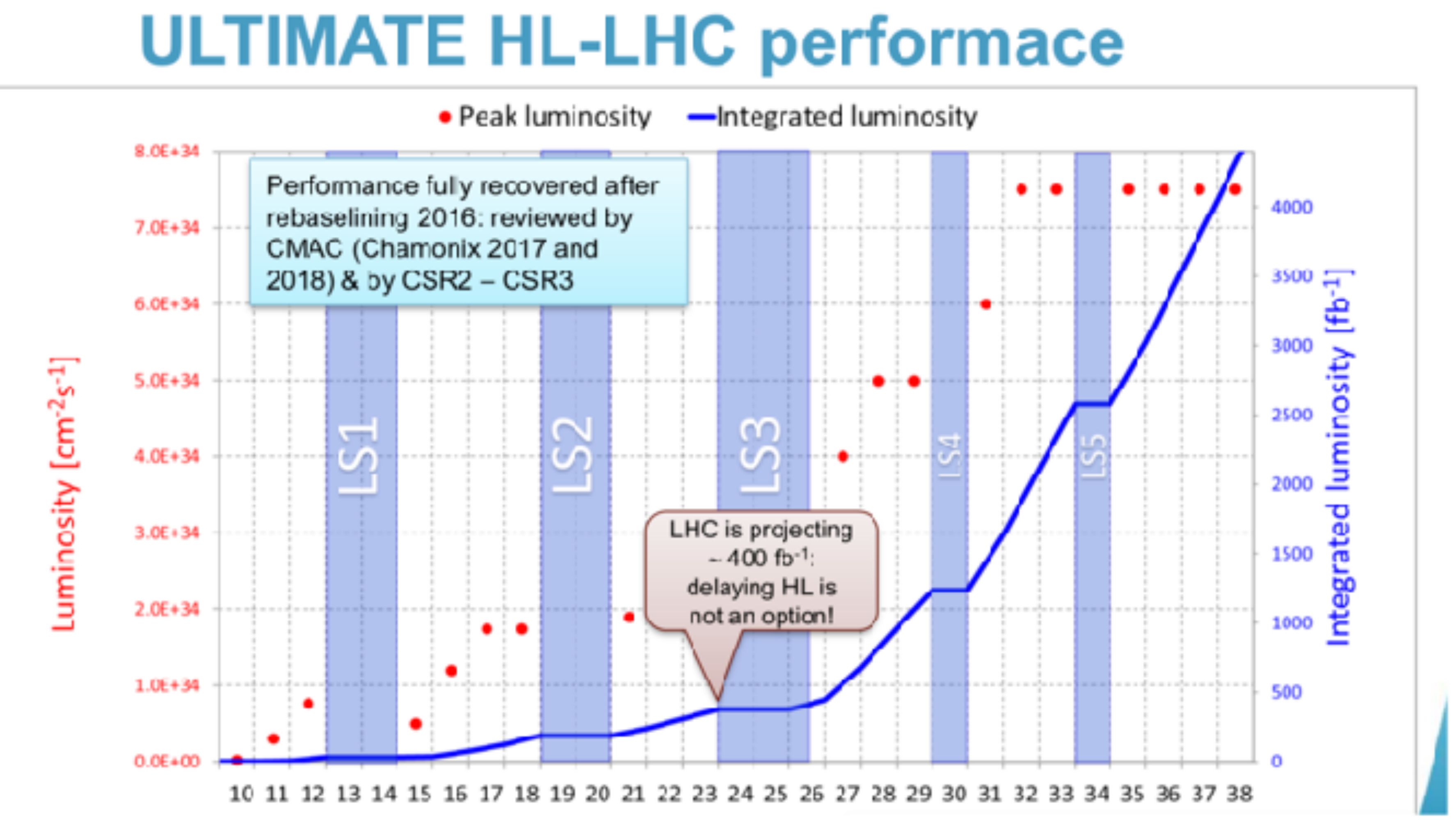
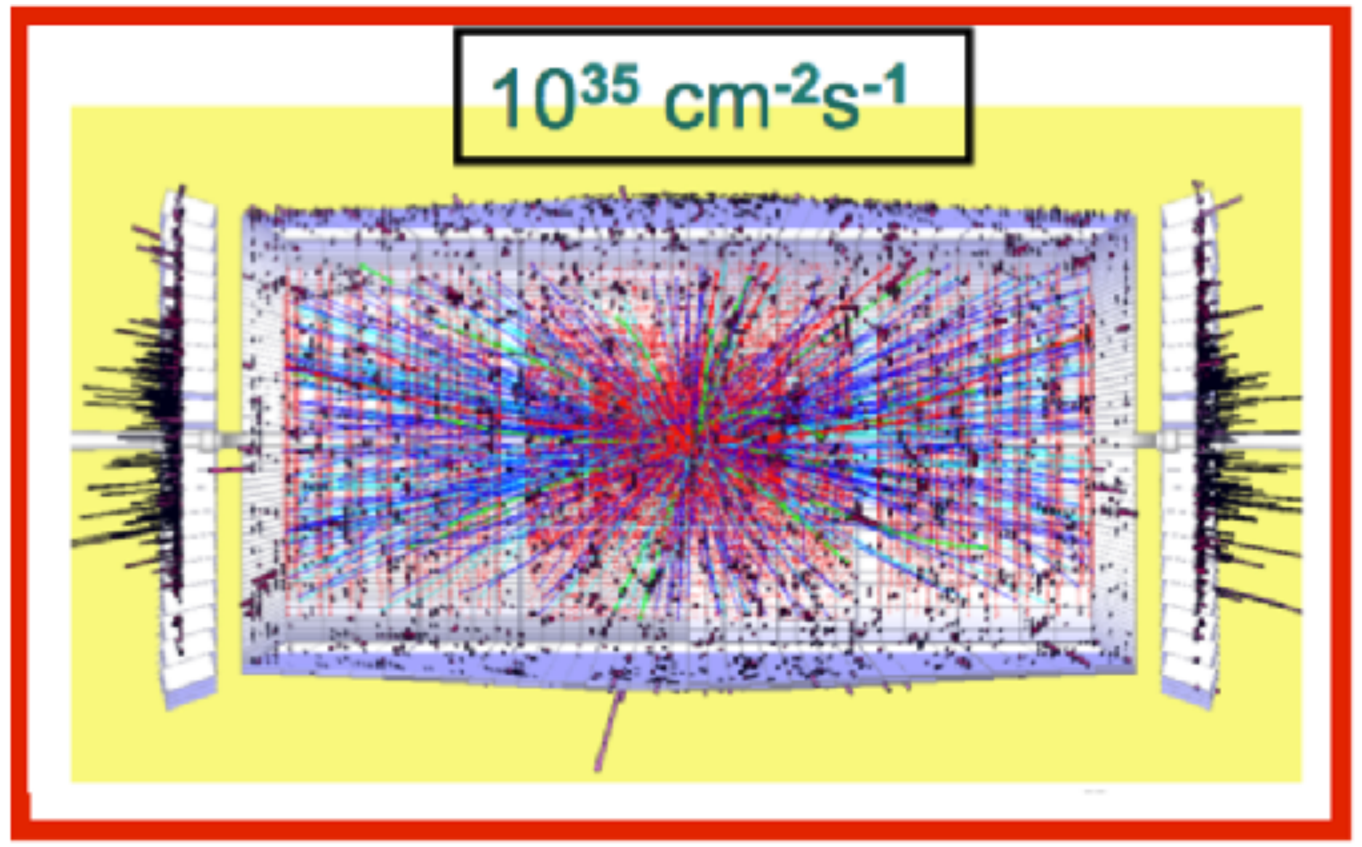
on behalf of the CMS Collaborations

The Phase II (HL-LHC) project established in 2010, is already more than half-way through:
- Inst. Luminosity up to 7.5e34 (updated projection for Integrated 4000 fb-1)
- Energy: 14 TeV or more (discussion ongoing on availability of the machine)
- Filling schemes considered: similar to previous experience (8b4e, 48b etc.)

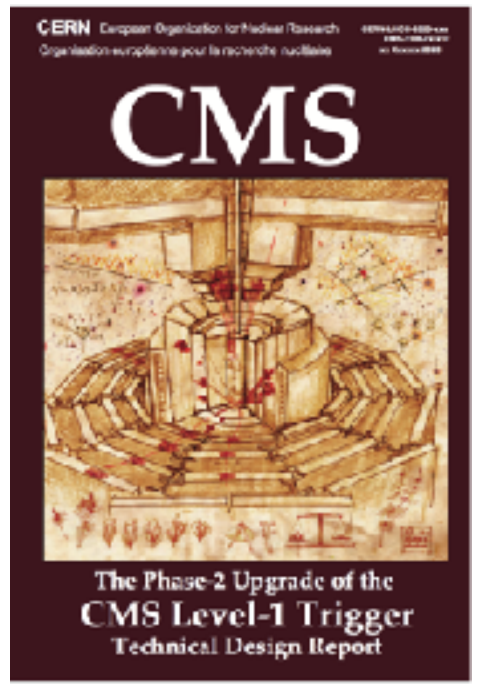
Recently updated schedule

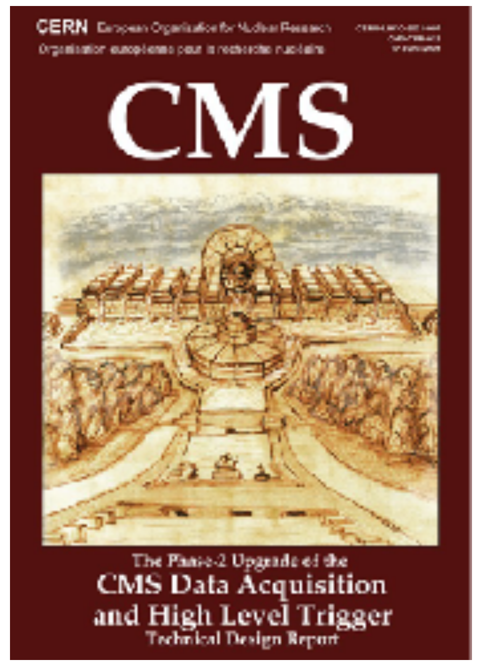


p-p collisions in HL-LHC
- Interaction region with Gaussian spread 45 mm along beam axis
- Average number of collisions : <μ> 200
  - Average interaction density: 1.8 collisions/mm



Major challenge for tracking detectors in ATLAS & CMS
- Efficiently reconstruct charged particles from primary interactions -> up to 0(10k) tracks / bunch crossing
  - Correctly assign them to production vertices





-Trigger HLT/DAQ

https://cds.cern.ch/record/2714892
https://cds.cern.ch/record/2759072

- Tracks in L1-Trigger at 40 MHz
- PFlow selection 750 kHz L1 output
- HLT output 7.5 kHz
- 40 MHz data scouting

Beam Radiation Instr. and Luminosity

http://cds.cern.ch/record/2759074

- Bunch-by-bunch luminosity measurement: 1% offline, 2% online

Barrel Calorimeters

https://cds.cern.ch/record/2283187

- ECAL crystal granularity readout at 40 MHz with precise timing for e/γ at 30 GeV
- ECAL and HCAL new Back-End boards

Muon systems

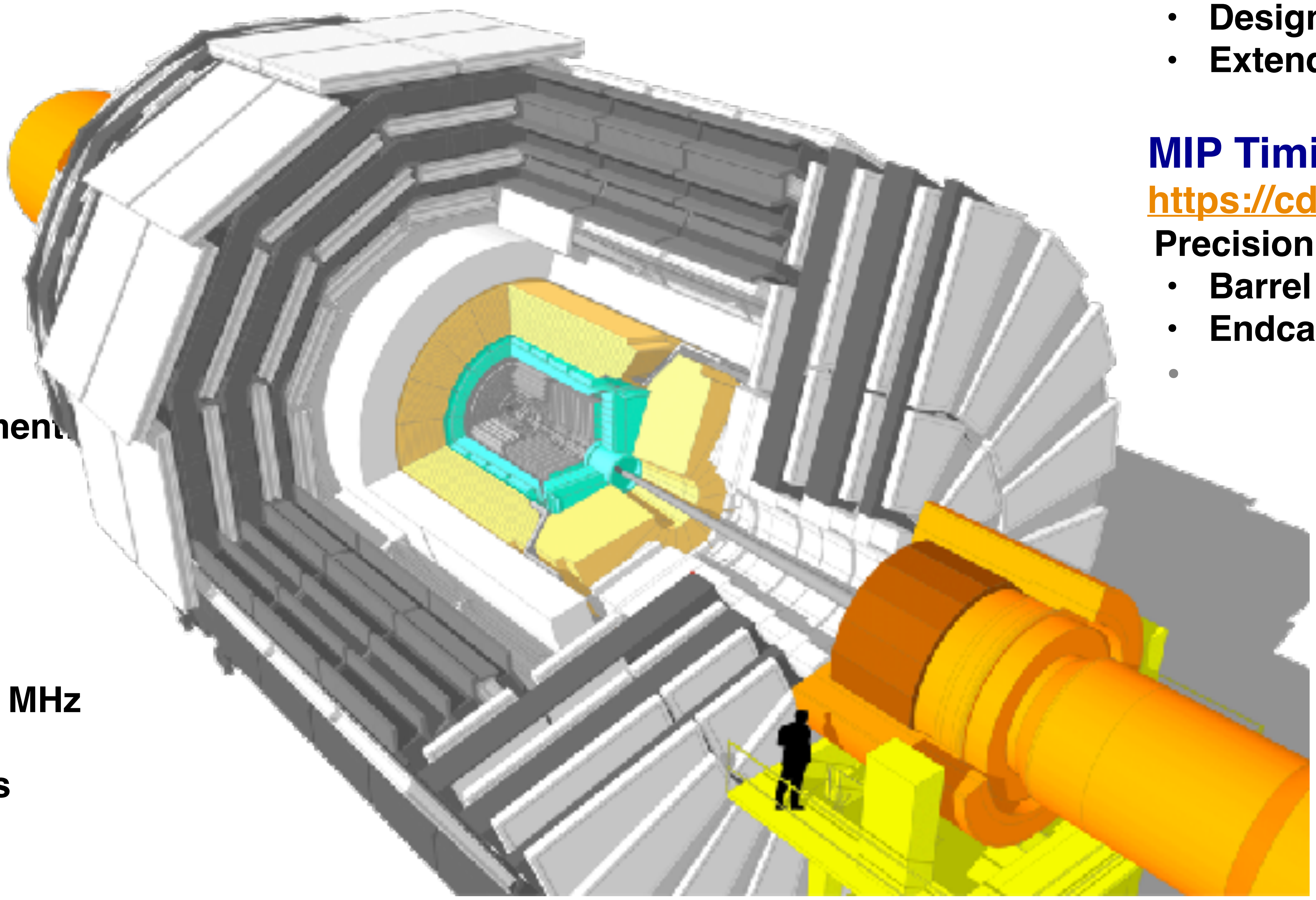
https://cds.cern.ch/record/2283189

- DT & CSC new FE/BE readout
- RPC back-end electronics
- New GEM/RPC $1.6 < \eta < 2.4$
- Extended coverage to $\eta \simeq 3$

Calorimeter Endcap

https://cds.cern.ch/record/2293646

- 3D showers and precise timing
- Si, Scint+SiPM in Pb/W-SS



Tracker https://cds.cern.ch/record/2272264

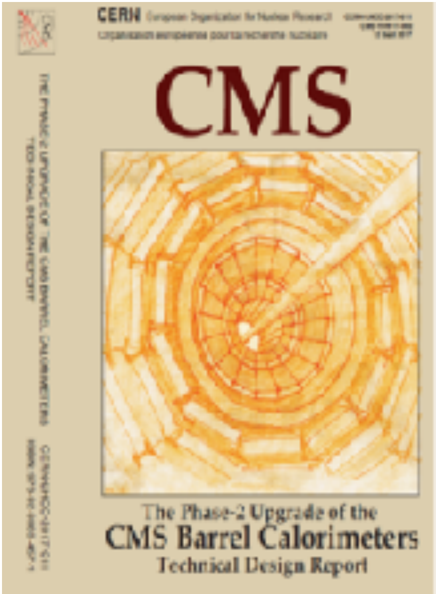
- Si-Strip and Pixels increased granularity
- Design for tracking in L1-Trigger
- Extended coverage to $\eta \simeq 3.8$

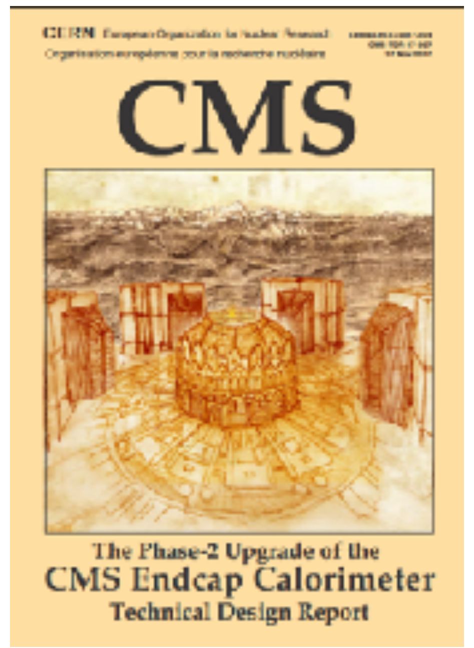
MIP Timing Detector

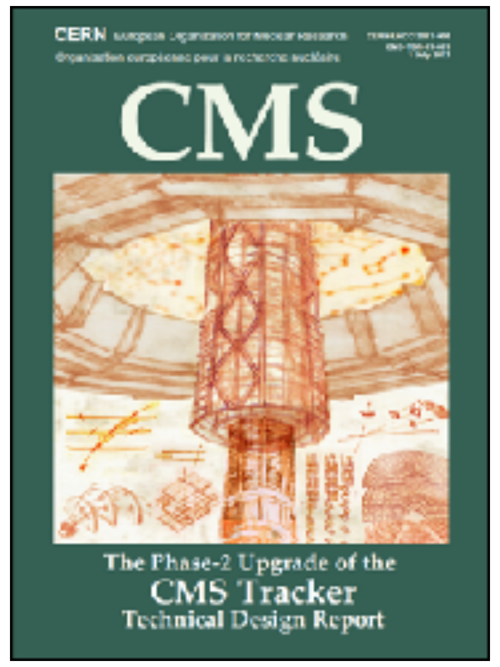
https://cds.cern.ch/record/2667167

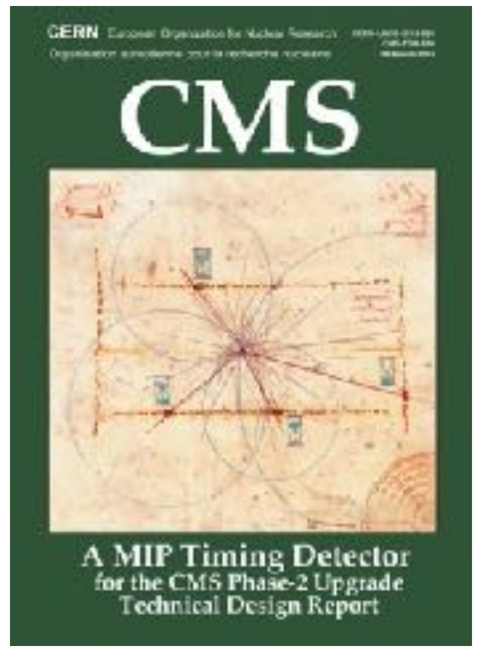
Precision timing with:

- Barrel layer: Crystals + SiPMs
- Endcap layer: Low Gain Avalanche Diodes



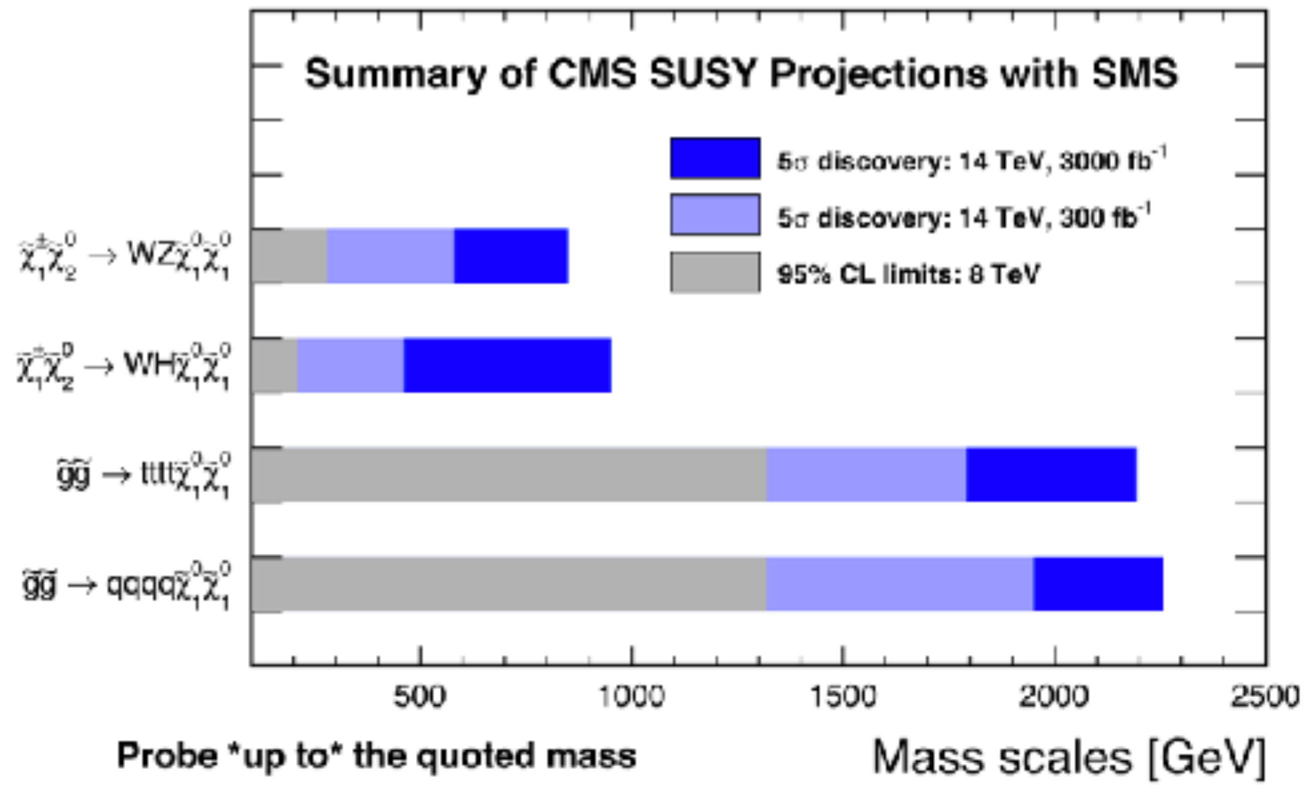




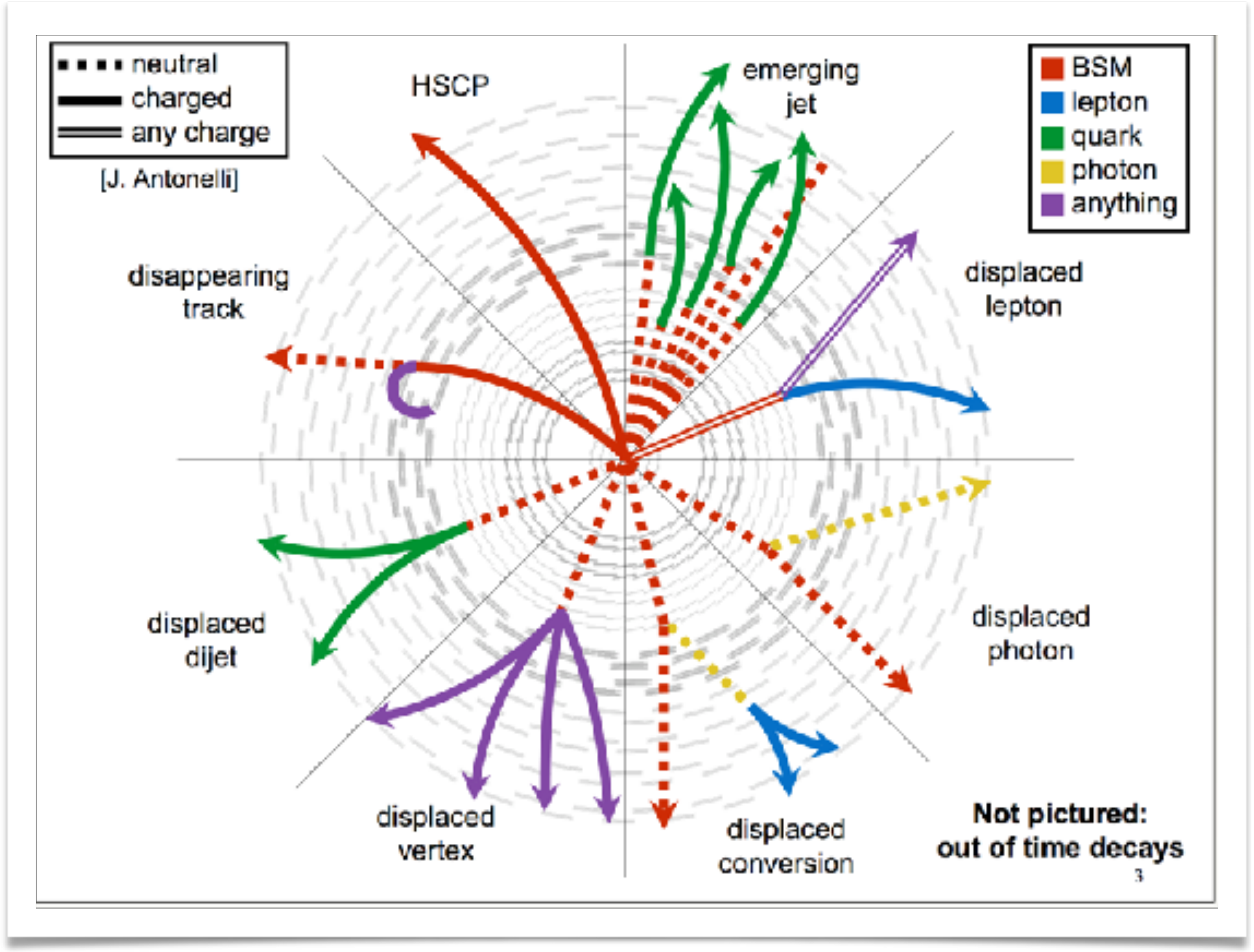


Significantly extend the physics program with HL-LHC (10x data of LHC)

- SM Precision measurement: Higgs, PDFs, QCD,
- New Physics: DM, SUSY, BSM, extra dim.



- More sensitive to BSM signatures:
- Displaced-objects, Disappearing tracks, Emerging jets, HSCP, …



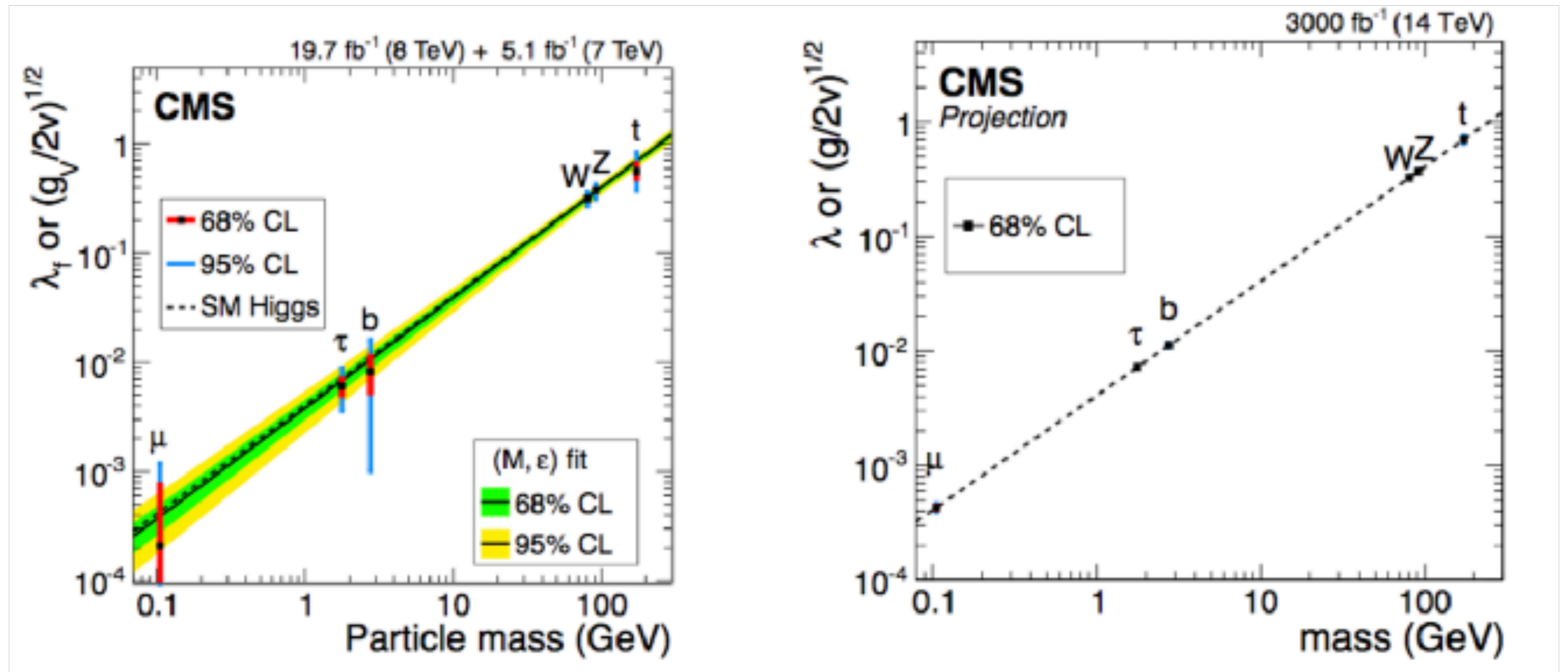


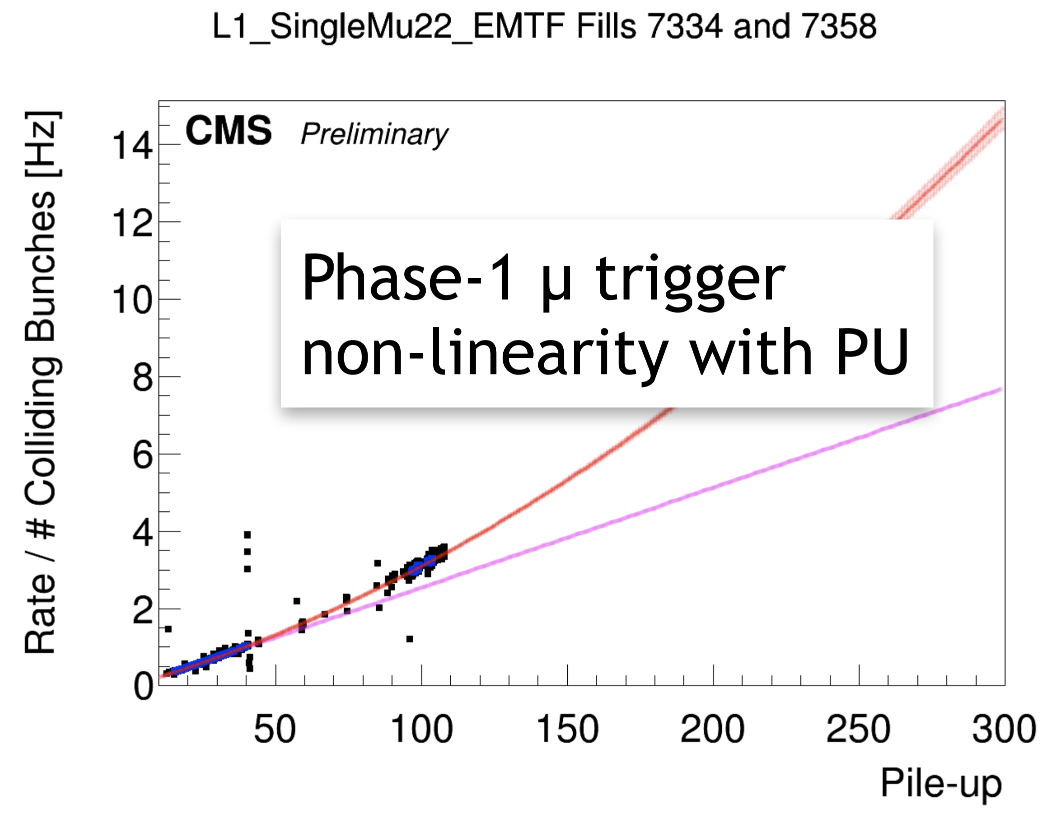
Figure 1.10: Observed and projected precision on Higgs boson couplings as a function of boson or fermion masses.

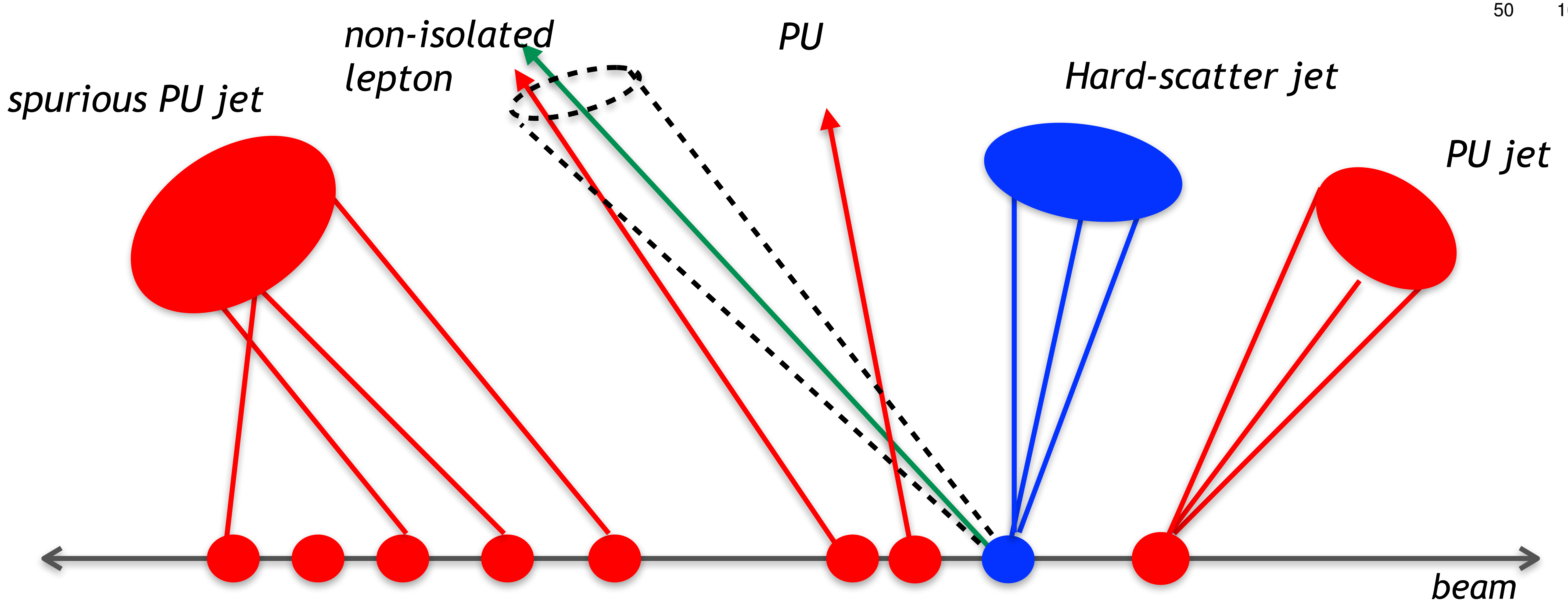
Major challenge for tracking detectors in HL-LHC experiments, CMS

- Efficiently reconstruct charged particles from primary interactions
  - Correctly assign them to production vertices
  - Need upgraded detectors for Phase-2.

Main challenge - effects of PU

- Negative effects on:
  - discriminate reconstructed particles from a hard scatter vs. those from many superimposed soft events
  - separation of electrons from background jets
  - calculation of global event quantities like E^{miss}
  - jet energy resolution
  - separation of *b*-jets from light jets



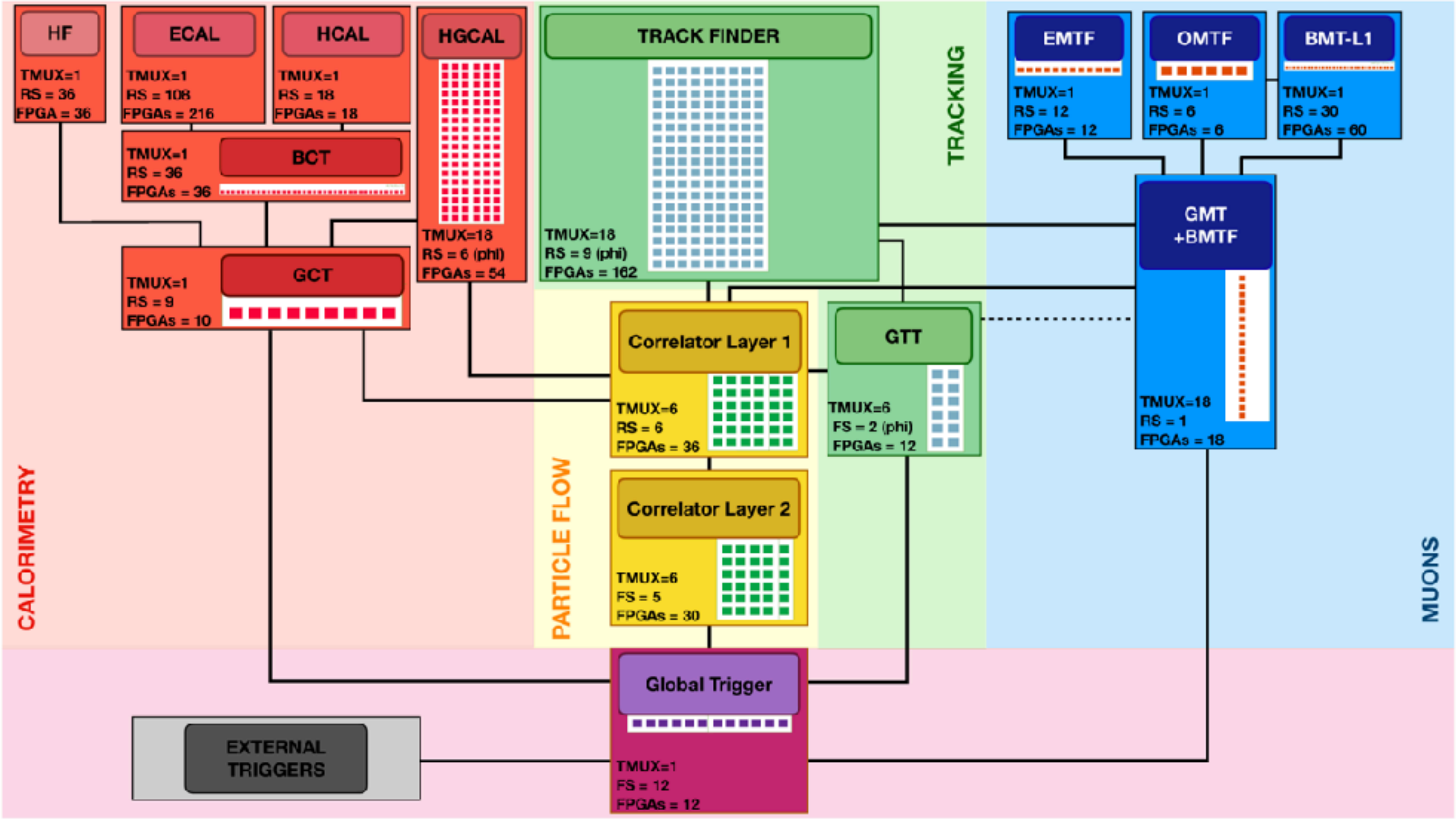


- **Approach to solving problem:** Use of tracking to identify a primary vertex and associate reconstructed objects.
- **Objective**: exclude from relevant quantities charged particles not associated with hard interaction.
  —> build time-of-flight detector to assign time tag to particle signatures
  —> use tracking in the trigger and higher detector granularity

CMS detector	LHC Run-2	HL-LHC Phase-2	
Peak ⟨PU⟩	60	140	200
L1 accept rate (maximum)	100 kHz	500 kHz	750 kHz
Event Size	2.0 MB [a]	5.7 MB [b]	7.4 MB
Event Network throughput	1.6 Tb/s	23 Tb/s	44 Tb/s
Event Network buffer (60 seconds)	12 TB	171 TB	333 TB
HLT accept rate	1 kHz	5 kHz	7.5 kHz
HLT computing power [c]	0.5 MHS06	4.5 MHS06	9.2 MHS06
Storage throughput	2.5 GB/s	31 GB/s	61 GB/s
Storage capacity needed (1 day)	0.2 PB	2.7 PB	5.3 PB

CMS - Trigger for Phase-2

- Level-1: Complete change of electronics
  - Replace μTCA with custom ATCA based boards, with
    - Virtex Ultrascale FPGAs and high speed optical links
  - Architecture organized in layers
    - Calo, Tracker, Muon,
    - GlobalCalo, Global Tracker, GlobalMuon, Correlator,
    - Global Trigger



- DAQ/HLT: Complete change of electronics
  - Optical links from FE to BE
  - Custom ATCA based DAQ & TCDS Hub aggregates data from BE
  - Transfer data to surface via comercial optical link 100 Gb/s
  - Full event building and HLT
  - Output rate 7.5 kHz, @ 7.4 MB/event

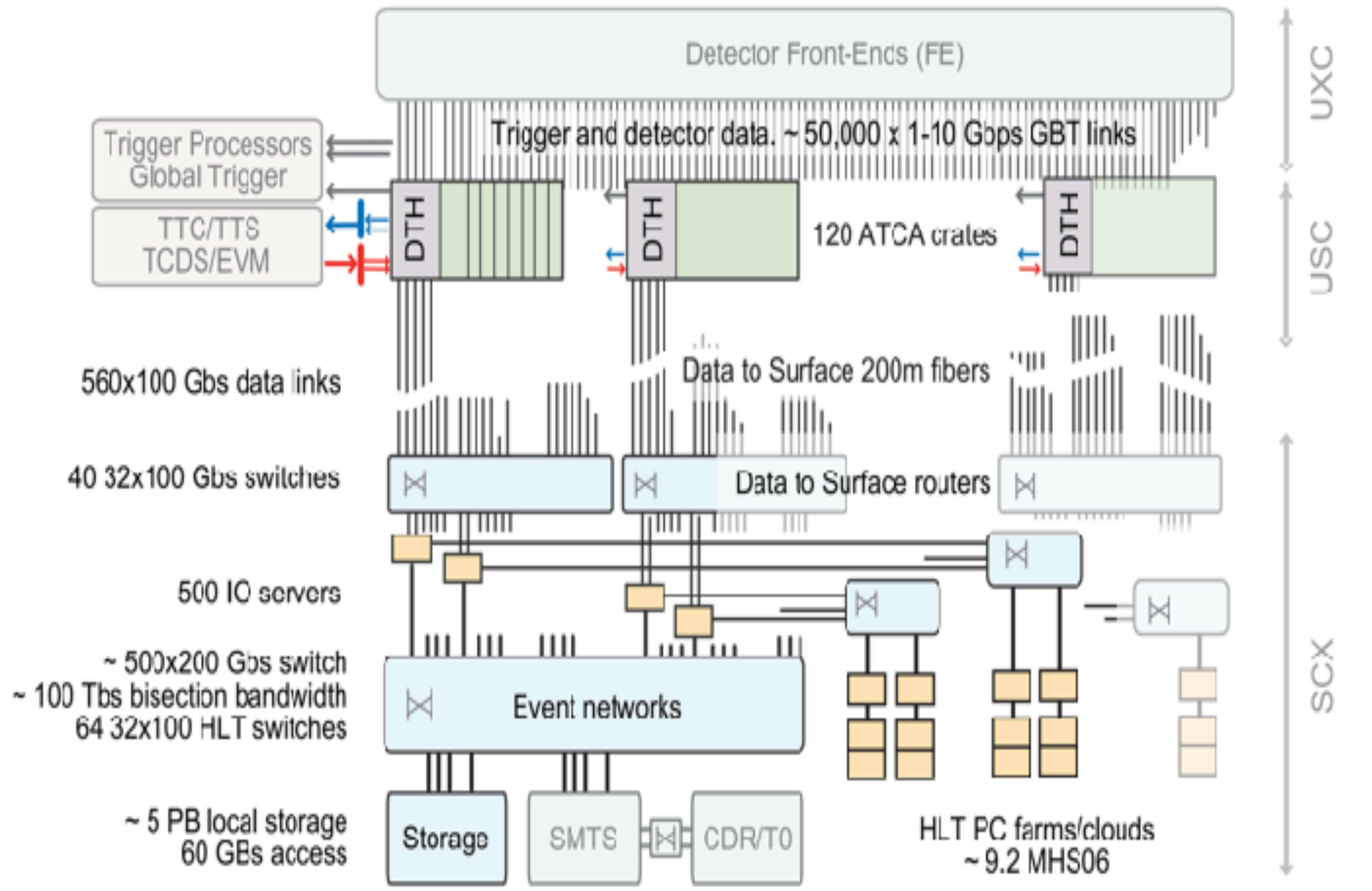
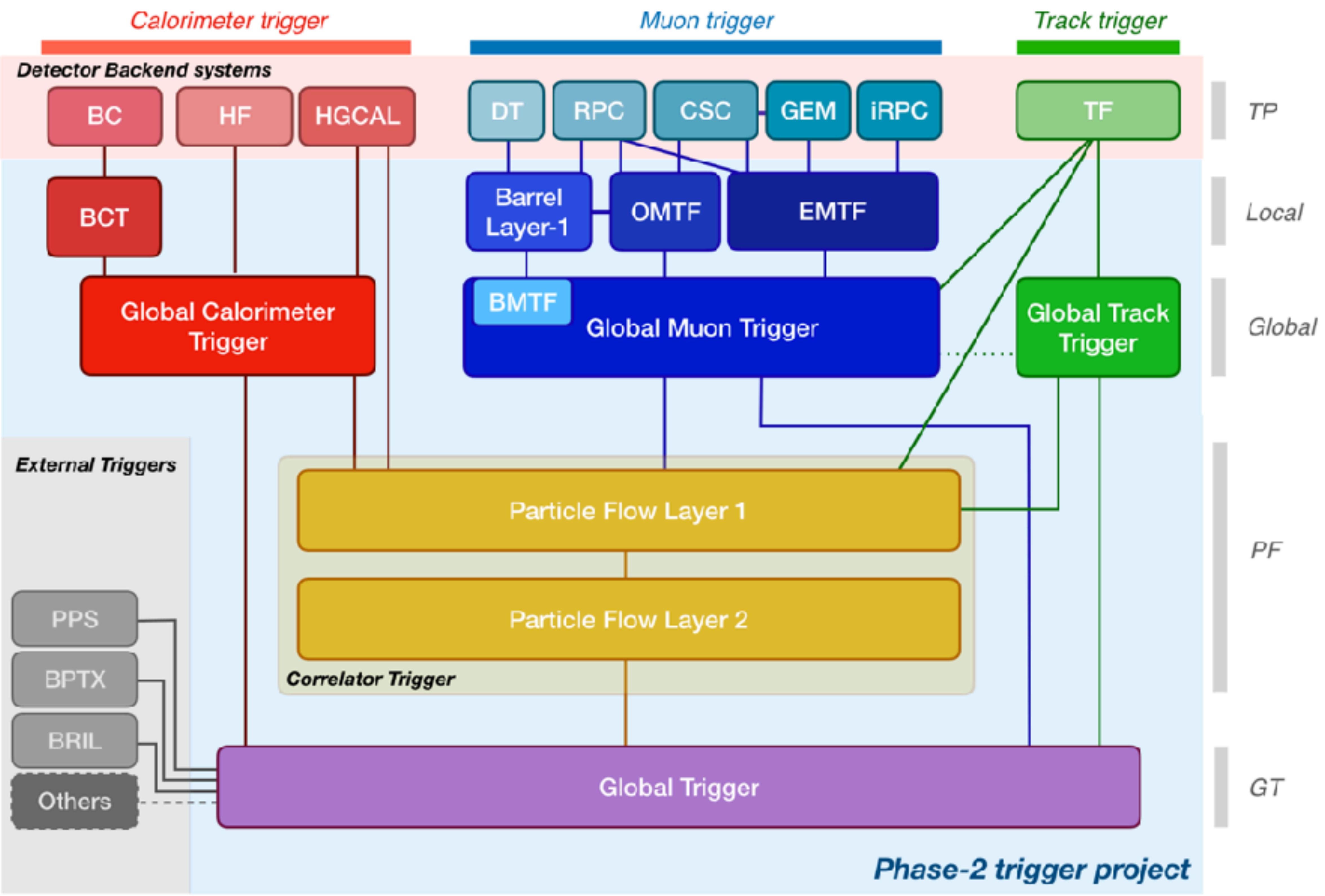


Figure 2.1: Principle schematics of the baseline Phase-2 CMS DAQ.

CMS - L1 Trigger



Improved triggering with full detector view:
Trigger decision includes calorimeters, muons & tracker (~5us latency)

→ L1Rate = **750 kHz**
→ Latency = **12.5 us latency**
→ Bandwidth: ~ **50 Tb/s**
(1.8 Tb/s in Phase I)

Processing step	Time (μs)
Input data received by CT	5
Trigger objects received by GT	7.5
L1A received by TCDS	8.5
L1A received by front-ends	9.5

CMS Phase II Level-1 Trigger system intends to perform precise physics selection using a **global event** reconstruction based on enhanced granularity already at hardware level.

- Exploit
  - presence of tracks at L1T and higher detector granularity
  - larger latency and new electronics allows for more complex reconstruction algorithms
- Move as much of HLT and Offline reconstruction to HW to improve efficiency and purity @ L1
  - Match Tracks to Muon and Calorimetry objects (improved resolution and lower rate x 10)
  - Reconstruct Vertices
  - Use Particle Flow (best use of all detectors)

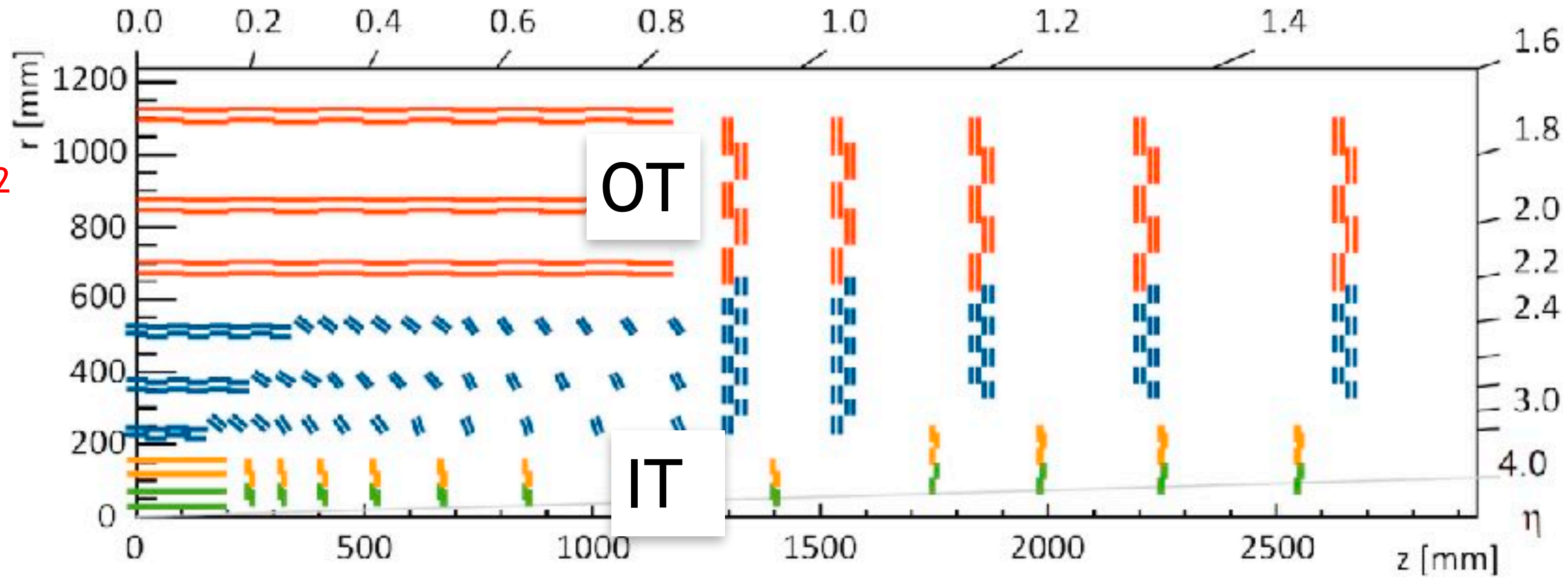
Low material budget and high granularity w/ > 1 billion silicon pixels and strips

Outer Tracker |η| < 2.4: In Level-1 Trigger

- modules pixel-strip (PS):
  - pixel (1.5 mm x 100 μm),
  - strip (2.4 cm x 100 μm)
  - tilted in Barrel (hermetic coverage)
- modules strip-strip (2S):
  - strip (5 cm x 90 μm)

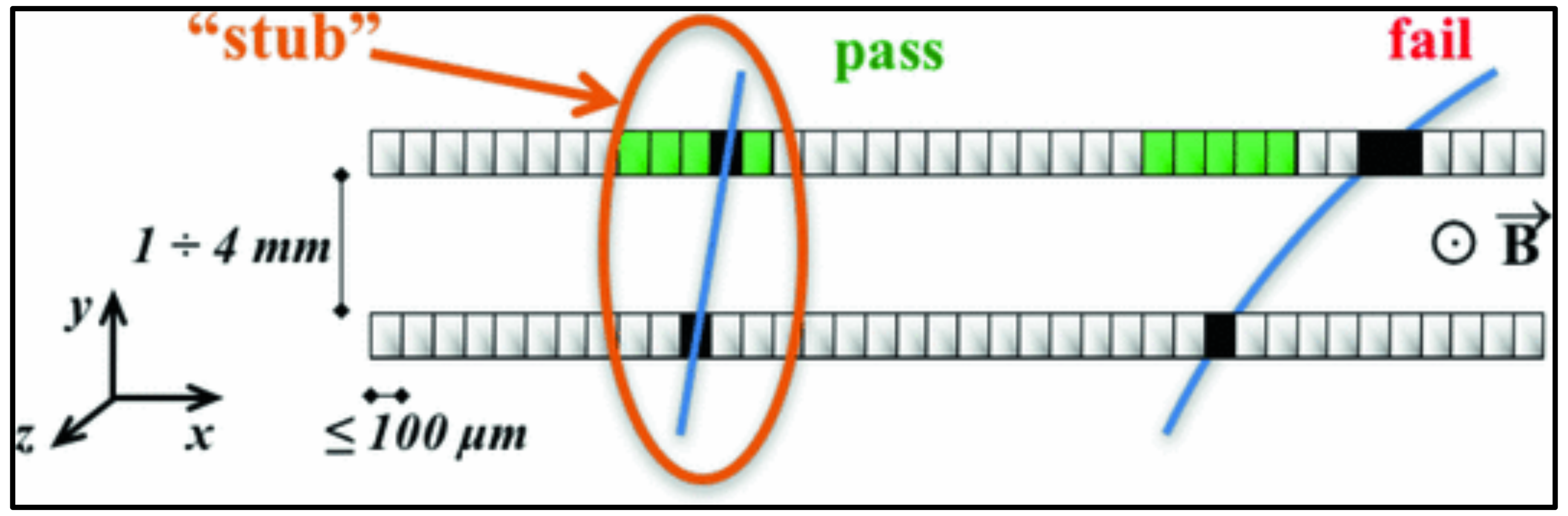
42M Si-strips in 192 m^2

170M macro-pixels in 25 m^2



L1 Trigger Each module consists of 2 closely spaced sensors (~mm) => allows for on-module pT measurement

programable search window



Inner Tracker - not in L1 Trigger:

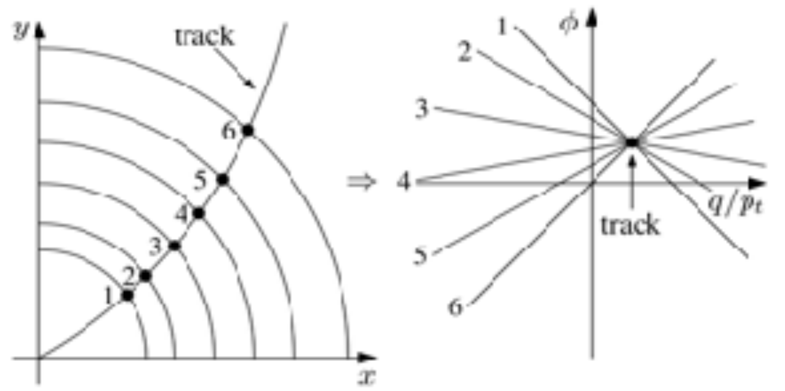
- Pixels w/ extended coverage up to |η| < 4.0
- 6x granularity of Phase-1 pixel (~1B chanels)
- improved material budget and radiation tolerance

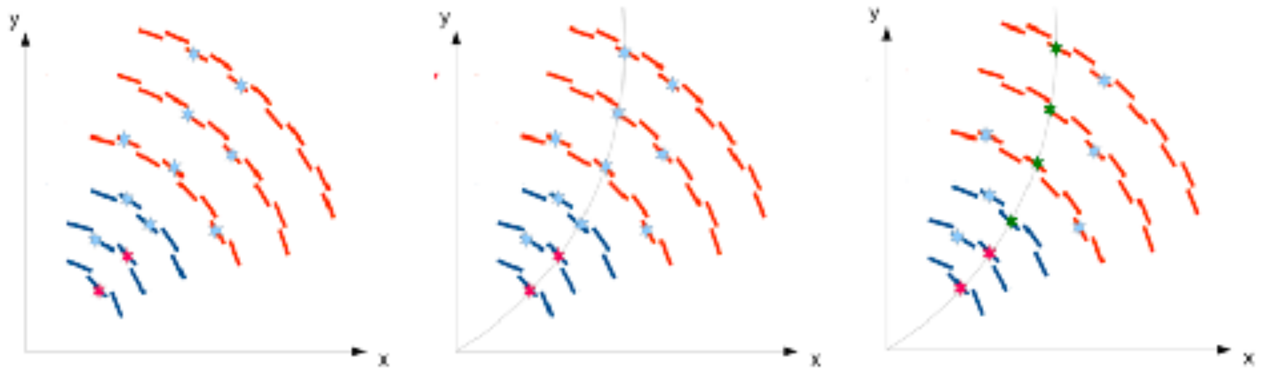
CMS L1 Track Finder with OT

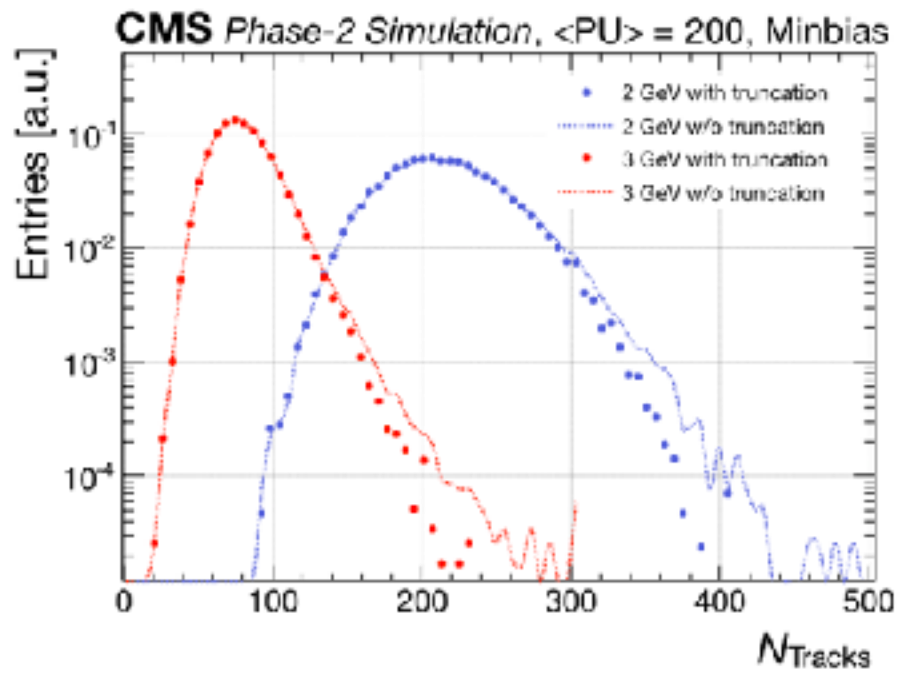
CMS-TDR-014 CMS-TDR-021

- OT designed to provide tracks (pT > 2 GeV) at 40 MHz to L1 trigger
- Pattern Recognition (PR) and Fitting - both done in FPGAs on ATCA architecture
- Algorithm based on

1. Hough Transform
   - PR: line identification (Hough) and stub grouping
   - Fit: Kalman Filter
2. Tracklet - road search
   - PR: 2-initial stubs project to layers/discs to find matching stubs
   - Fit: linearized x^2 fit to matched stubs, update track params



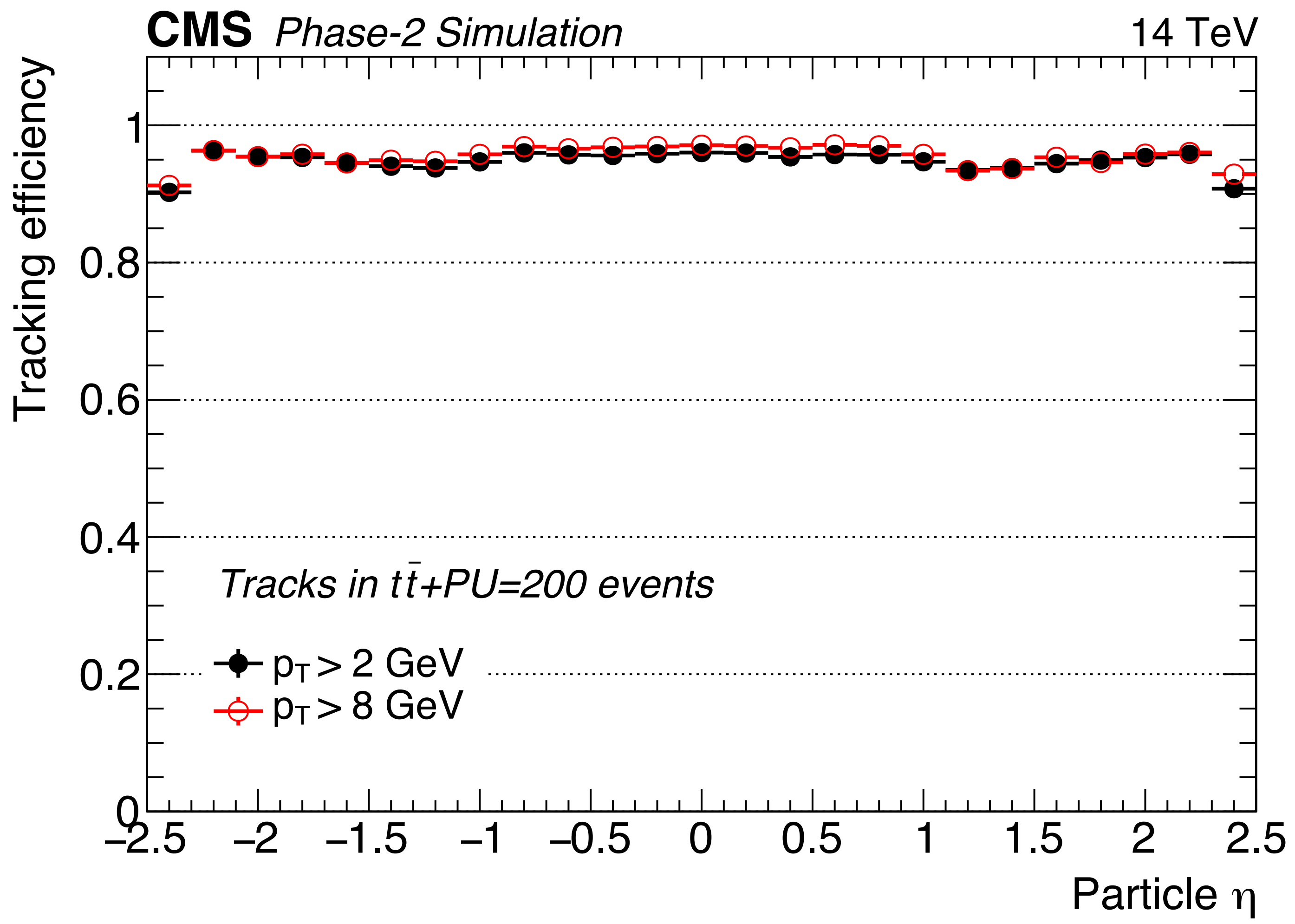


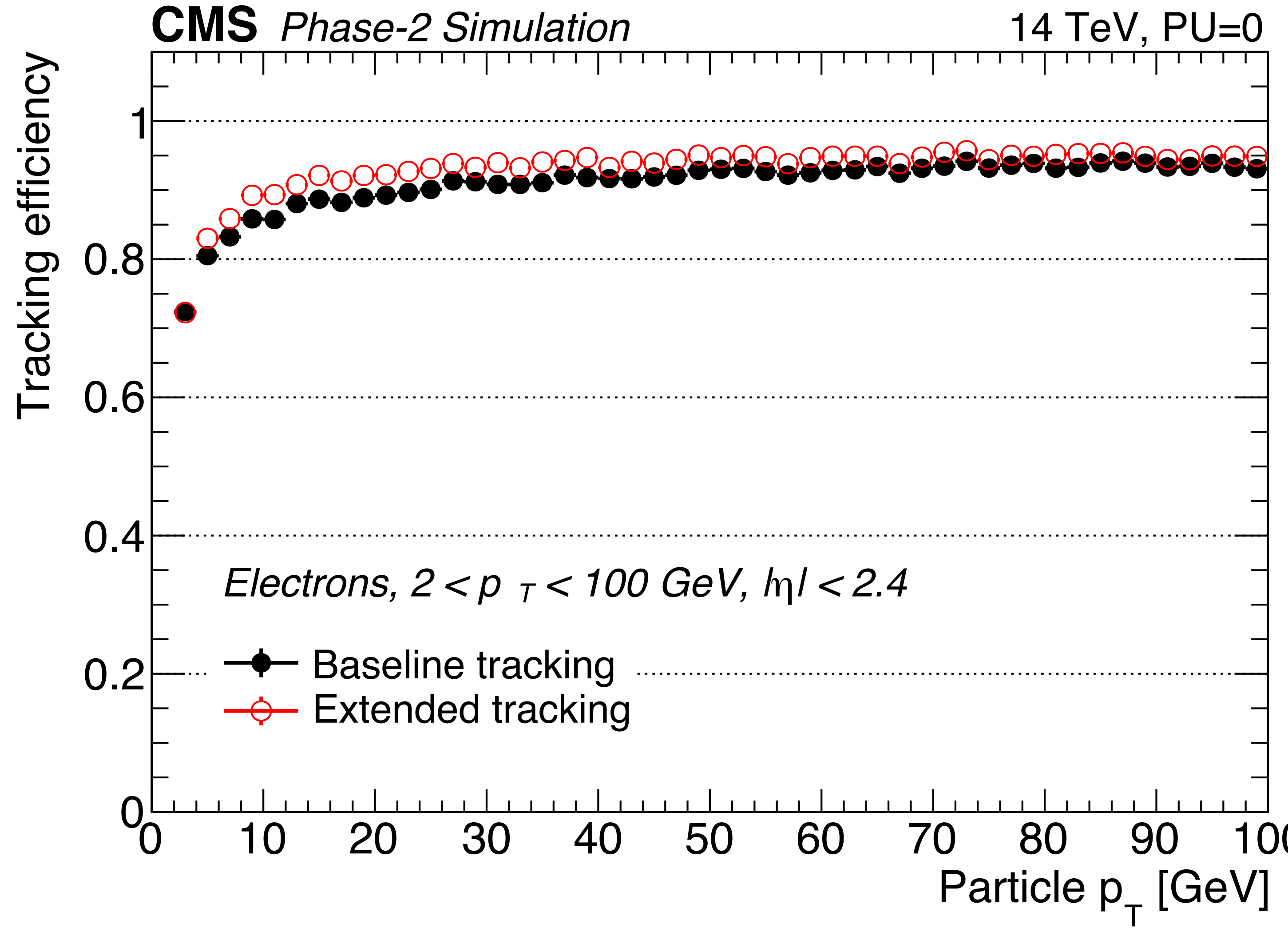


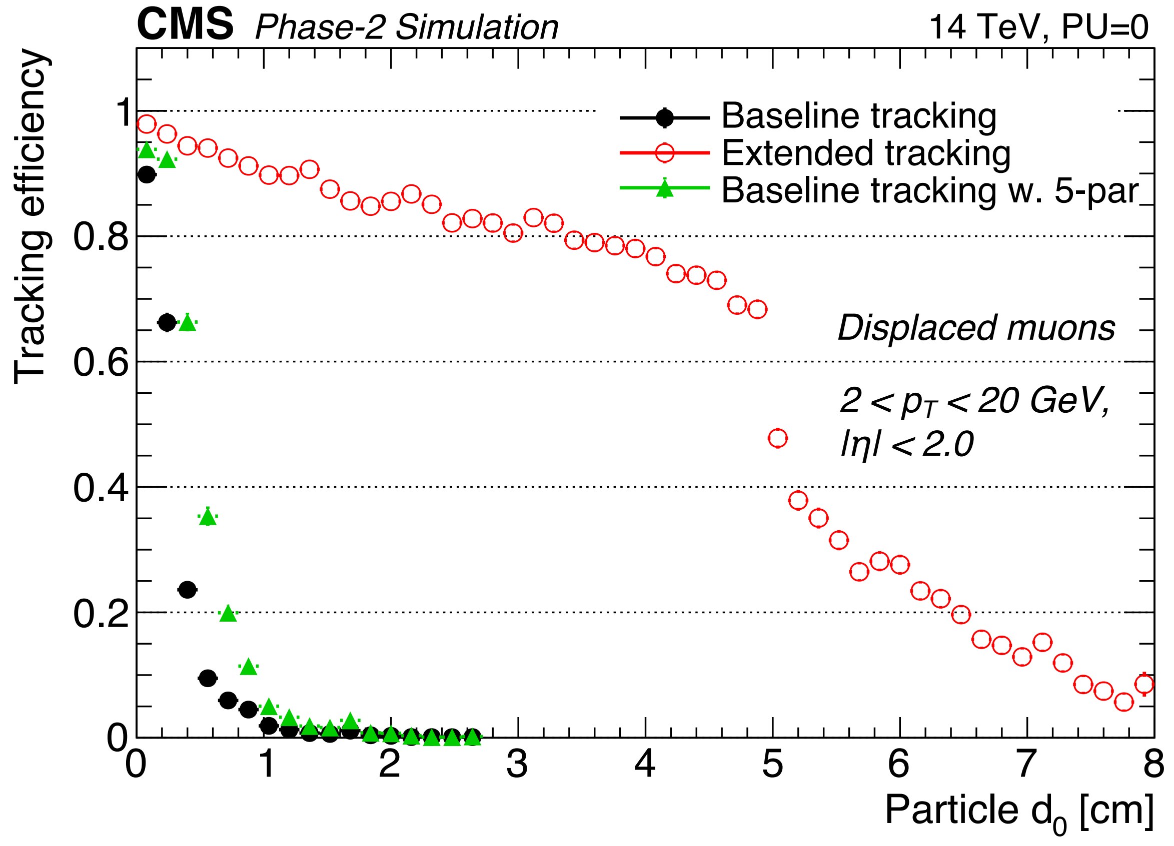
Two L1 track trigger track reconstruction algos

- Baseline: for prompt tracks
- Extended: for displaced tracking

Good L1 tracker performance , μ, *e*



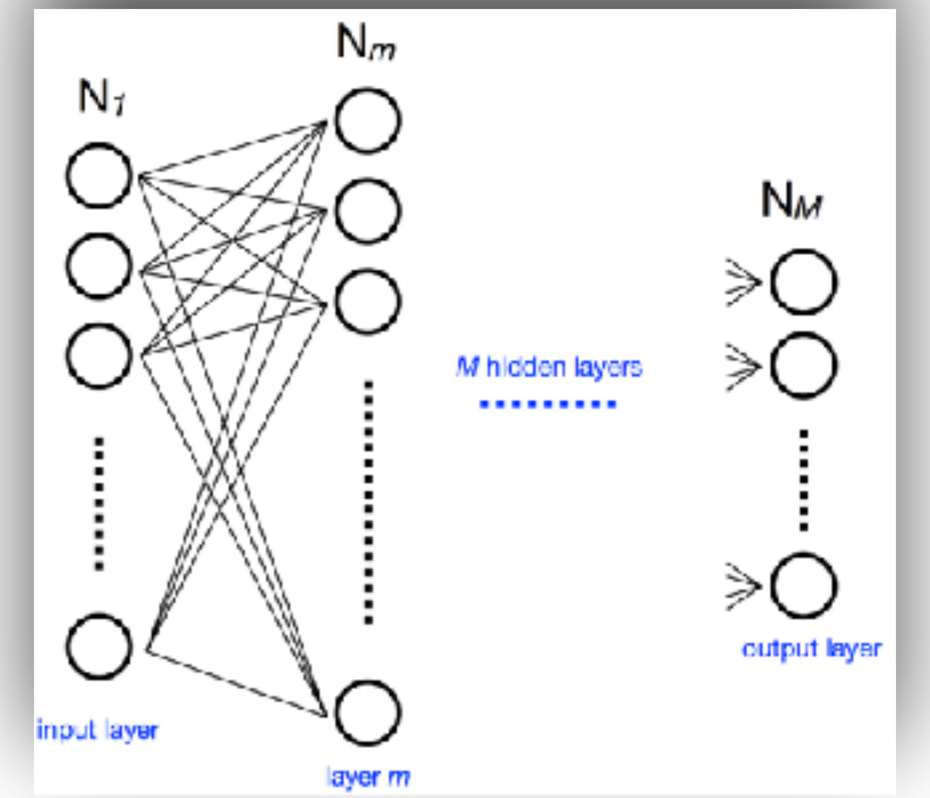




ML in L1-Trigger for Phase-2

- ML technics successfully exploited in LHC experiments in Run2:
  - HLT and Offline
  - In a few cases in hardware L1Trigger (eg. BDT in EndCap FPGAs)

- New developments in the FPGA technology provide considerable boost in computing resources
  - LUTS, FFs, BRAM
  - Allows for O(10k) parallel operations
  - Clocks O(200-300 MHz)

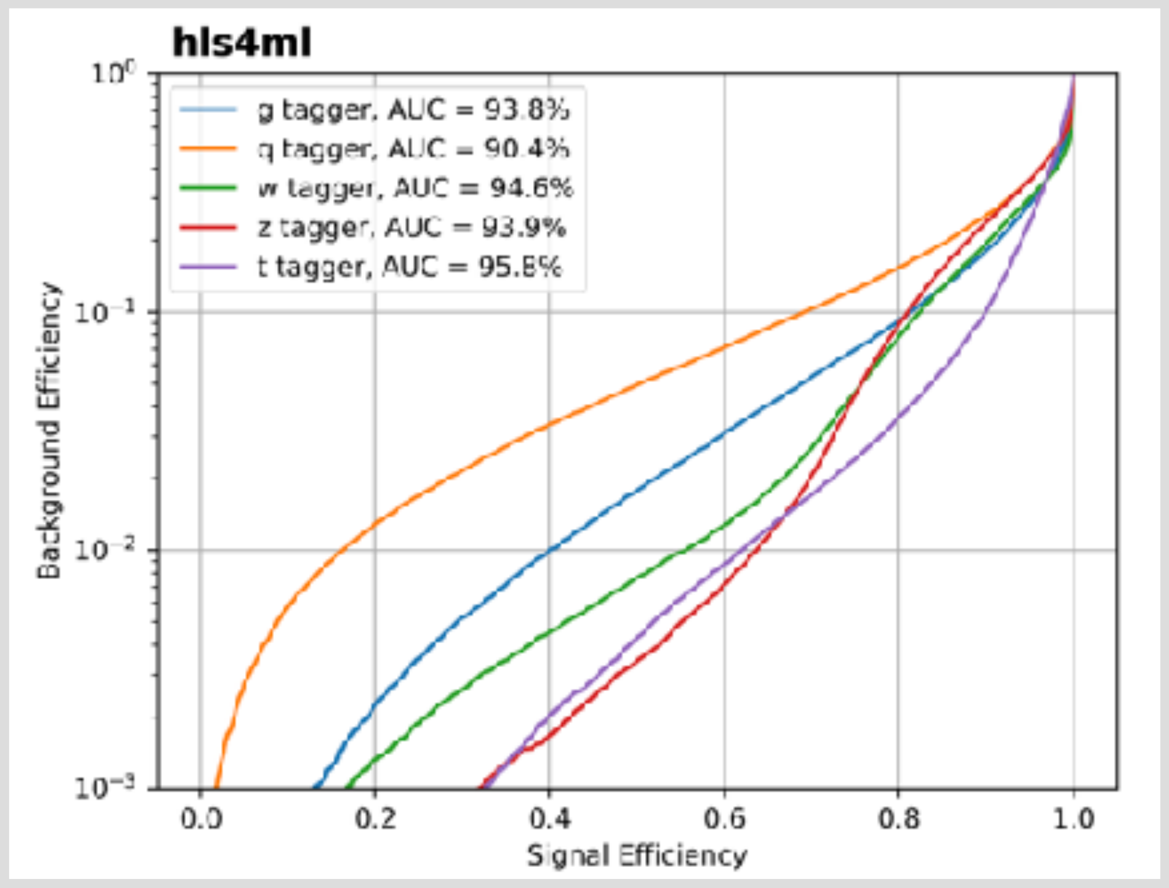


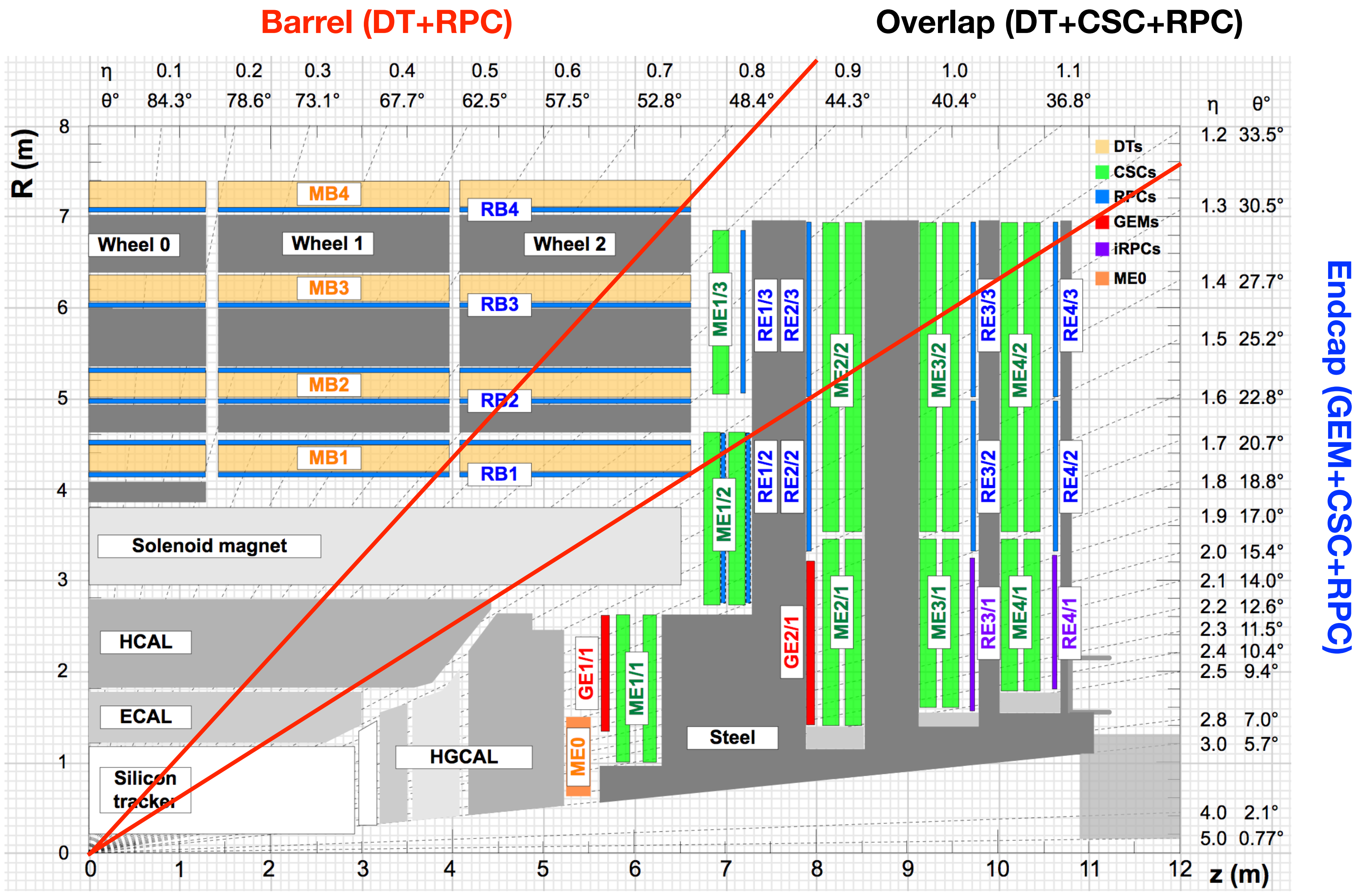
- Ideal for more advanced ML, Neural Networks for example, to be moved from HLT to L1T
  - Calculate in parallel output of each neuron in a layer,

$$\boldsymbol{x}_m = g_m\left(\boldsymbol{W}_{m,m-1}\boldsymbol{x}_{m-1} + \boldsymbol{b}_m\right)$$

  1 layer per clock.

- New tools available: hls4ml
  - Software package based on High Level Synthesis developed for building ML models in FPGAs
    - "Fast inference of deep neural networks in FPGAs for particle physics" https://arxiv.org/abs/1804.06913
  - Example: DNN classifier for jet-substructure model
    - signal efficiency versus misidentification rate for quark, gluon, W boson, Z boson, and top quark jet identif
    - latency ~100ns
  - Output: HLS package
    - drastic decrease firmware development time !!



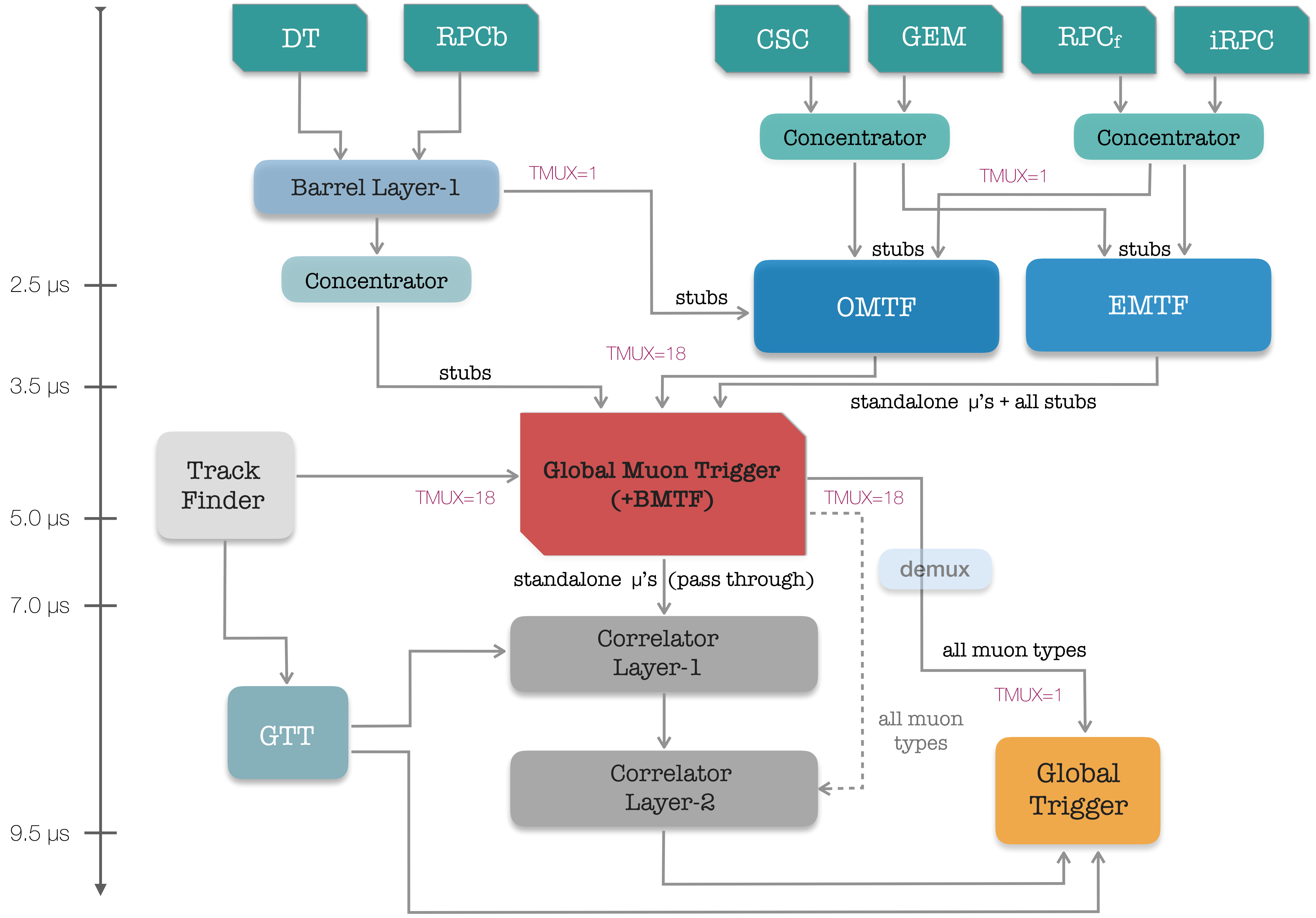


Upgrade Detector

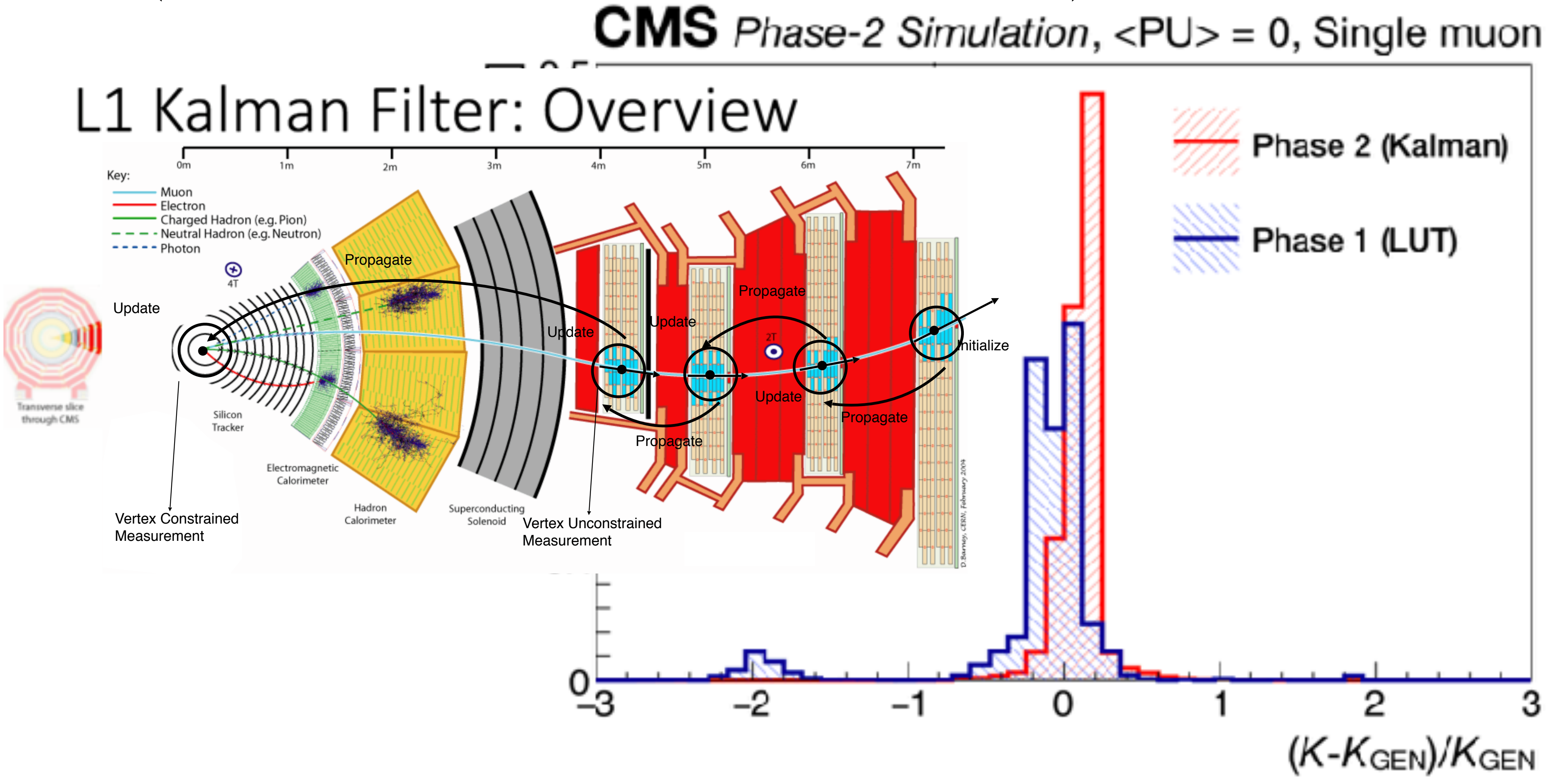
- DT and RPC: new readout, improved σ(z) , σ(t)~1ns
- CSC in forward: new readout at high bandwidth
- New stations in forward stations GEM, iRPC at |η| ≤ 2.4 and ME0 at 2.4 ≤ |η| ≤ 2.9

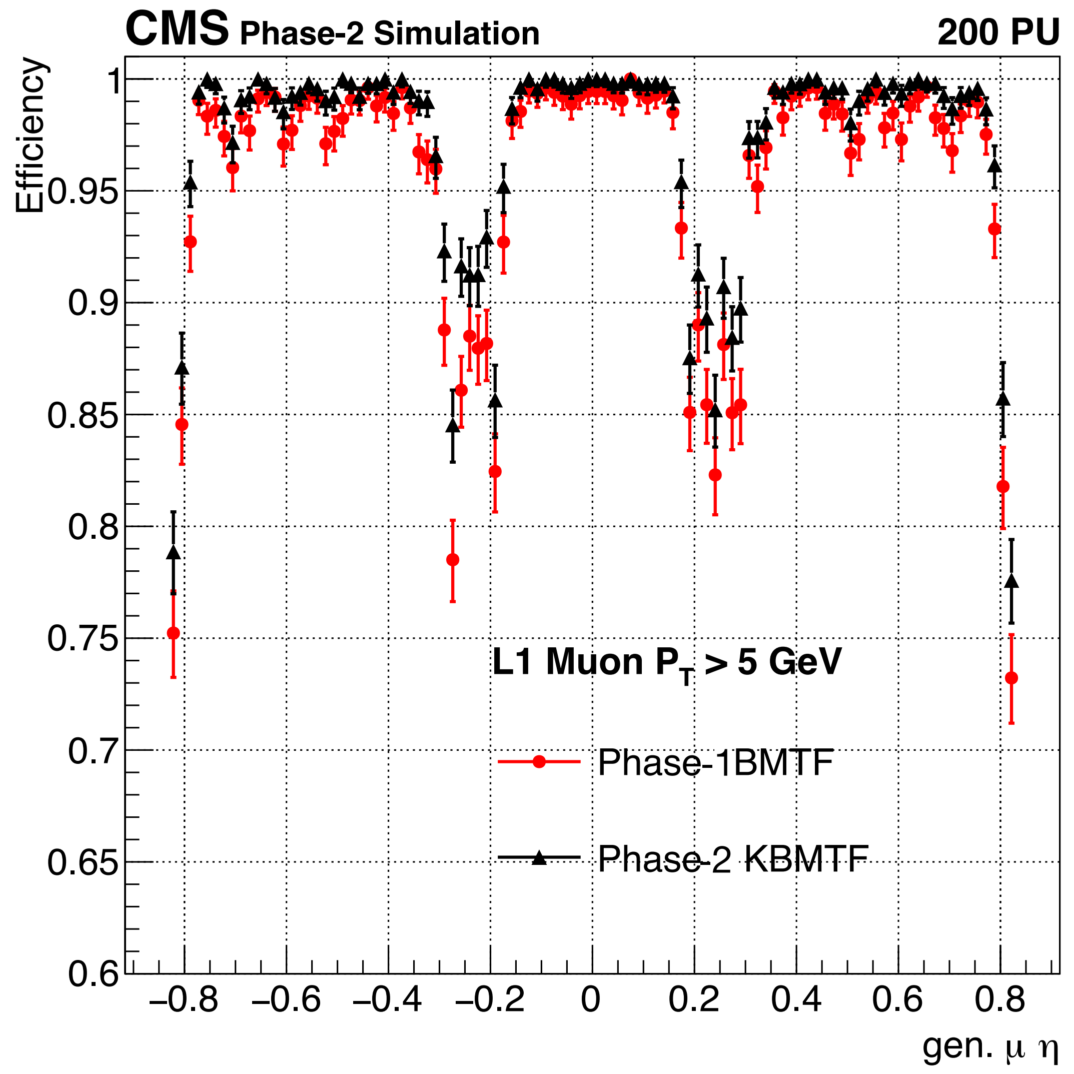
Upgraded trigger Muon L1T

- Improved input with additional η coverage,
  - For higher occupancy, Improved bandwidth and redundancy
- Improved Muon tracking (Barrel, Overlap, EndCap)
  - New technics in StandAlone Muon Track Finder (μ-track)
- New Global Muon Trigger w/ presence of Tracker Tracks:
  - Tracker Trigger Track + μ-track or μ-hit
  - Topological triggers with correlations

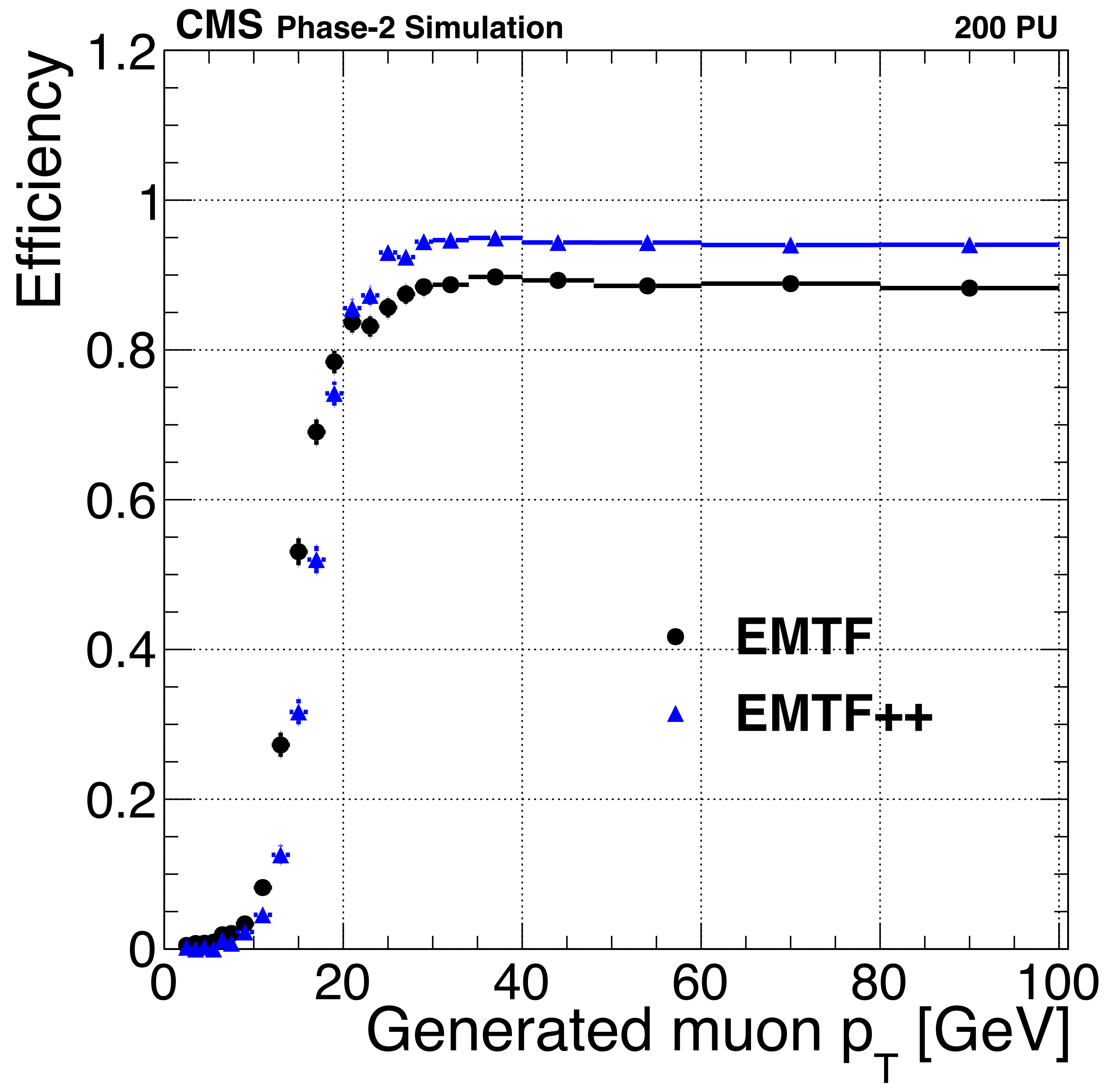


SA Barrel μ track:
Use Kalman Filter on input DT and CSC hits (vertex-constrained and not)

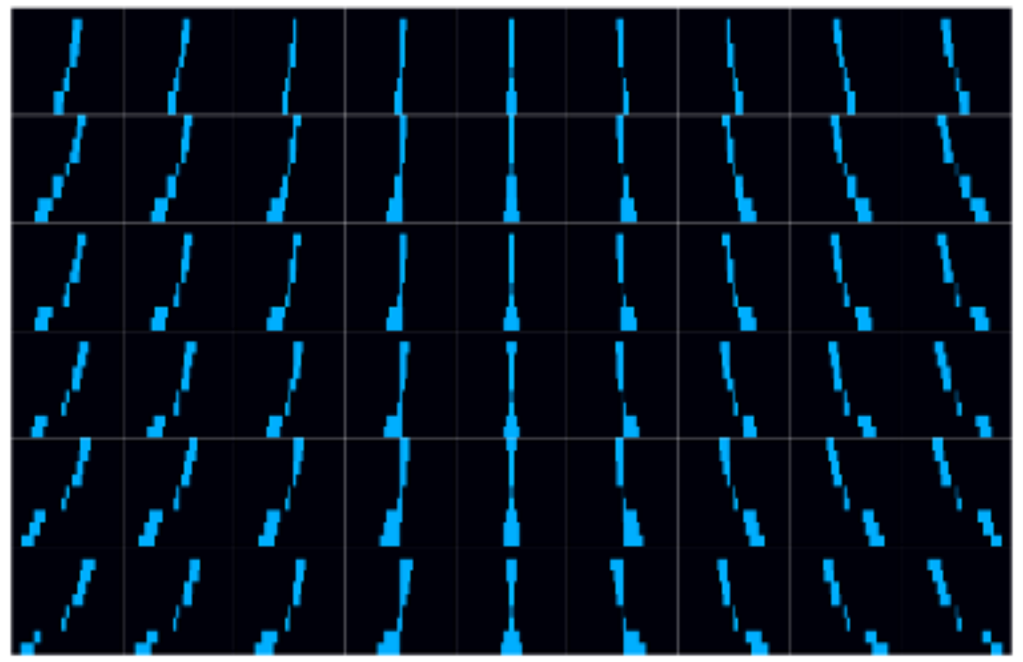


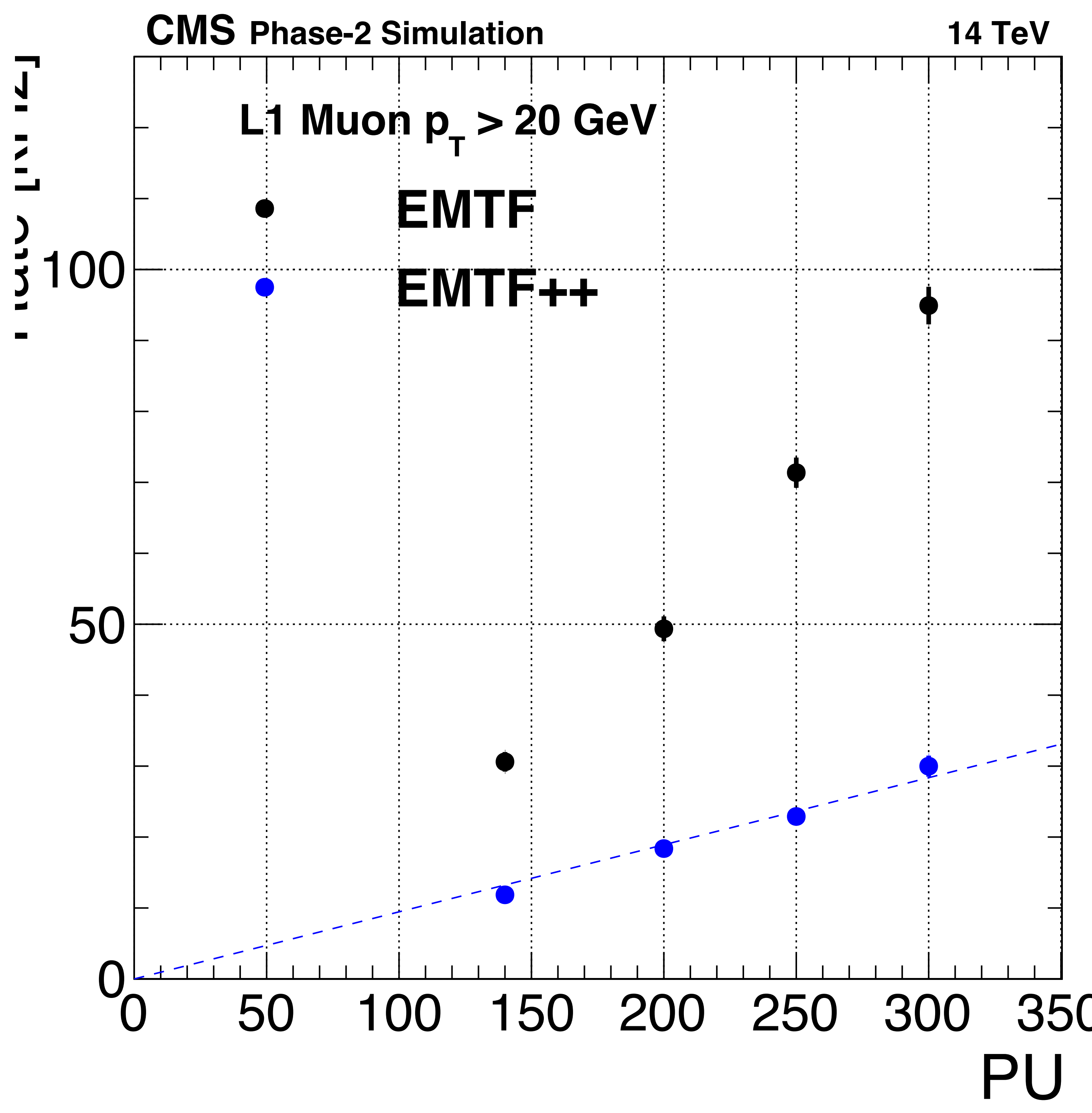


SA EndCap μ track:
Use Neural Networks (vertex constrained and not)



Muon stubs from all EC detectors as input patterns for ML algos

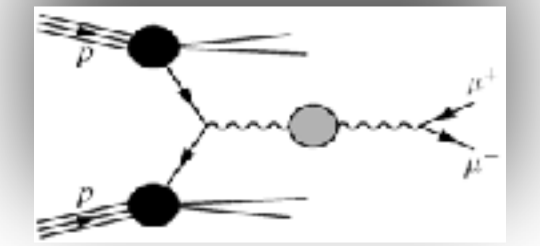




- With improved computing power in FPGA, using only muon detector information, can trigger on muons not originating from the primary vertex, (*e.g. decays of dark photons*)

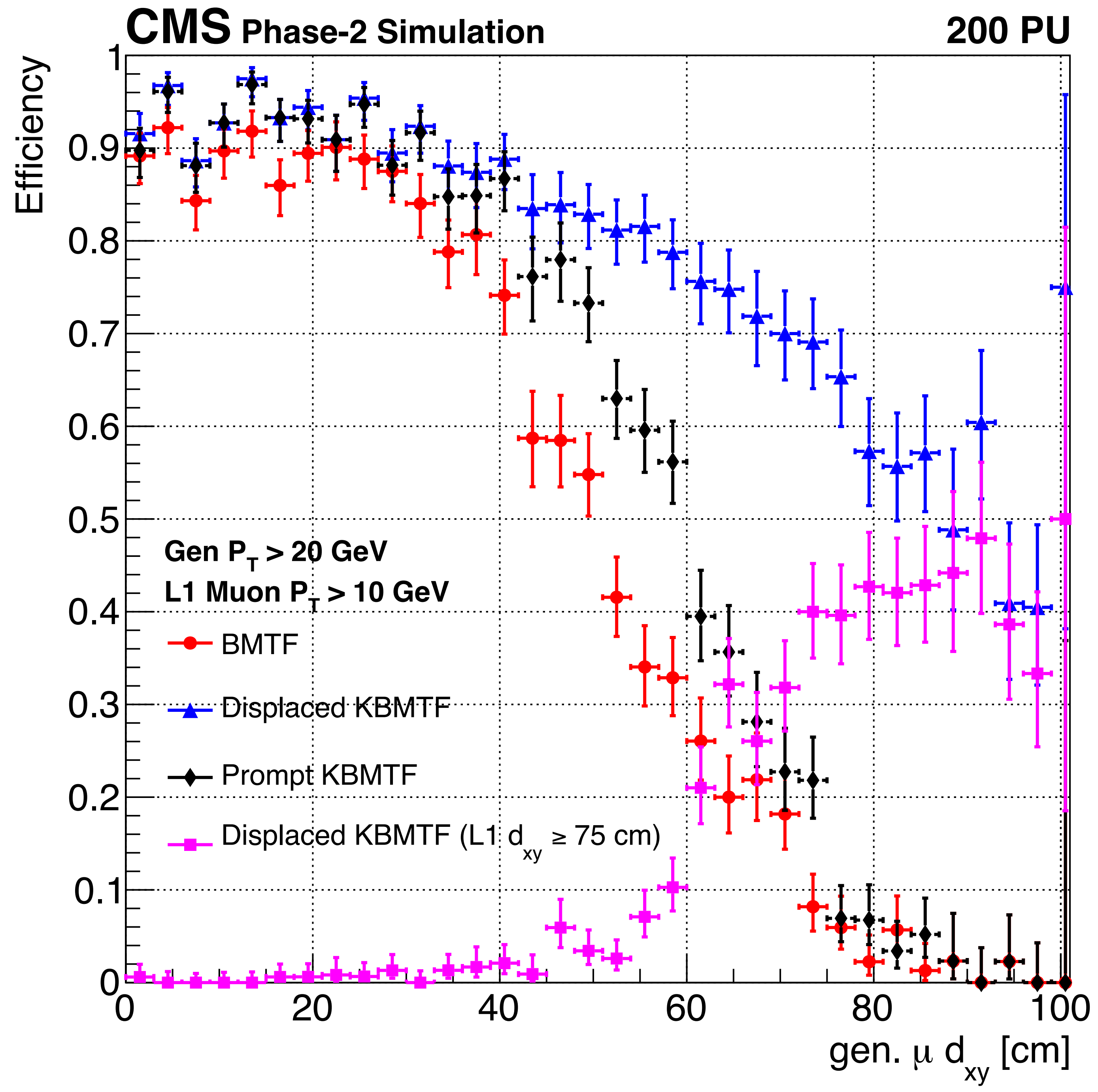
SA Barrel displaced μ
(Kalman non-vtx-constrained)

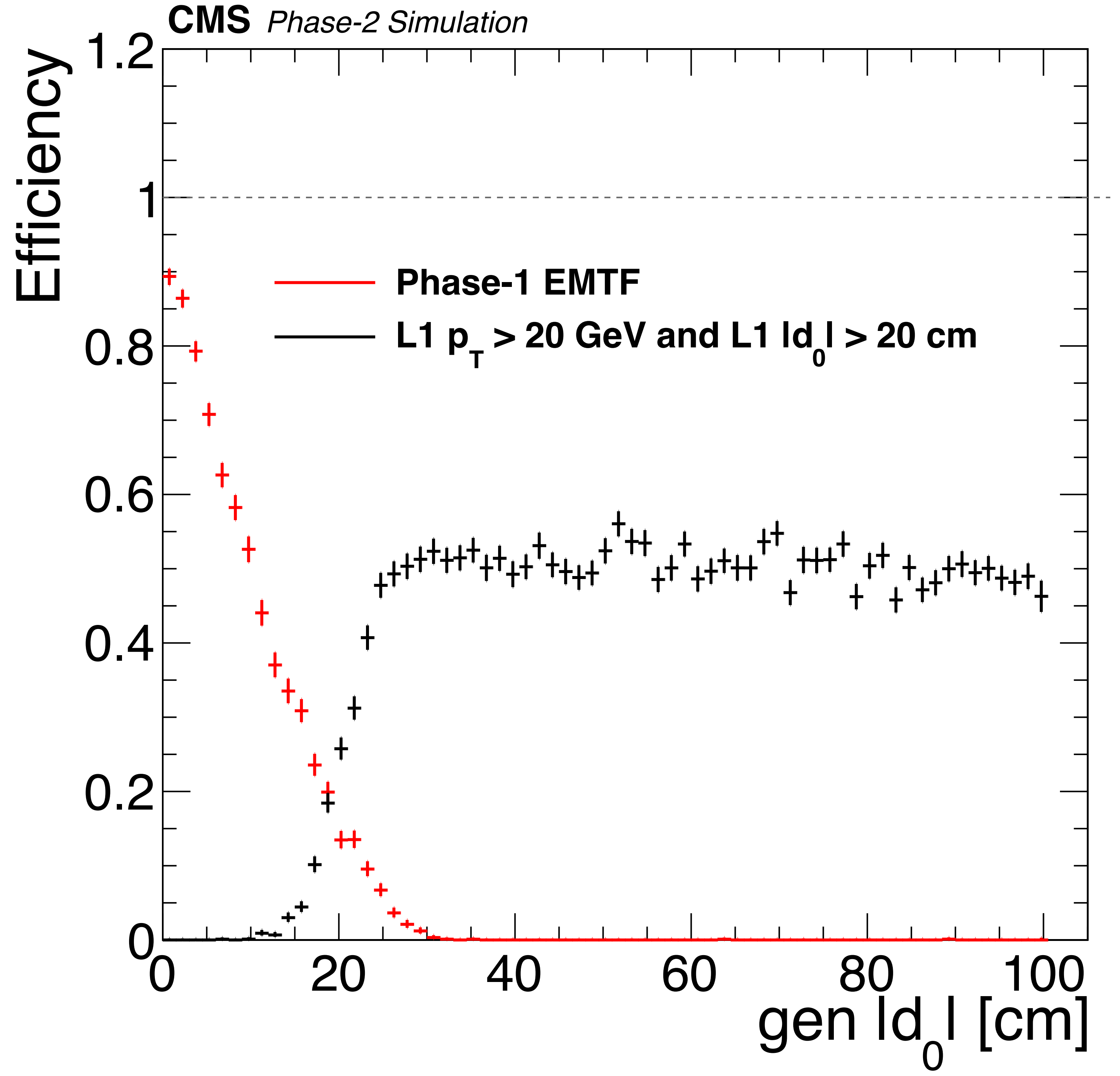
Dark γ (displaced μ)

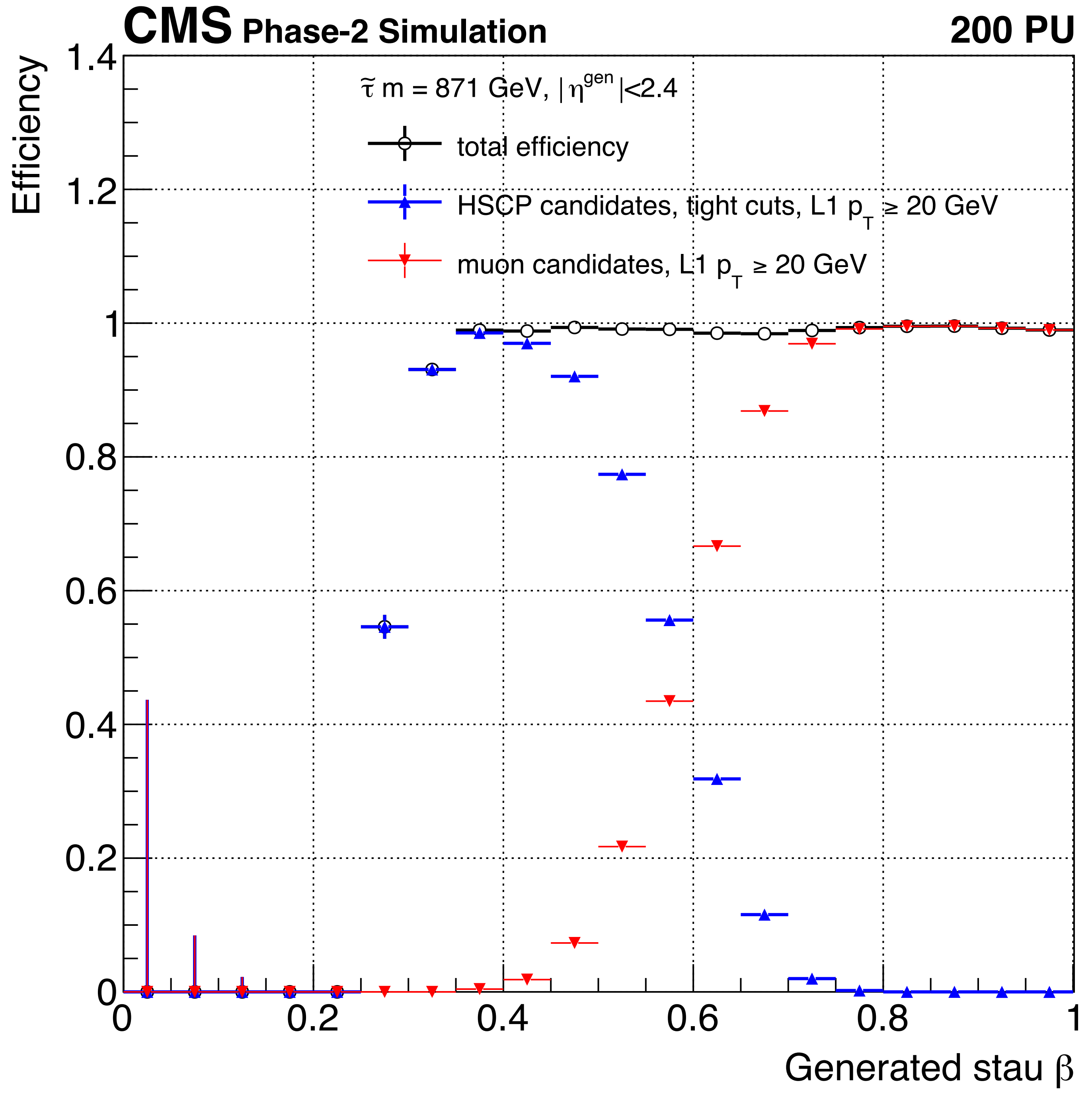


SA EndCap displaced μ
(NN non-vtx-constrained)

Heavy Stable Charged Particle
(with Timing in RPC)





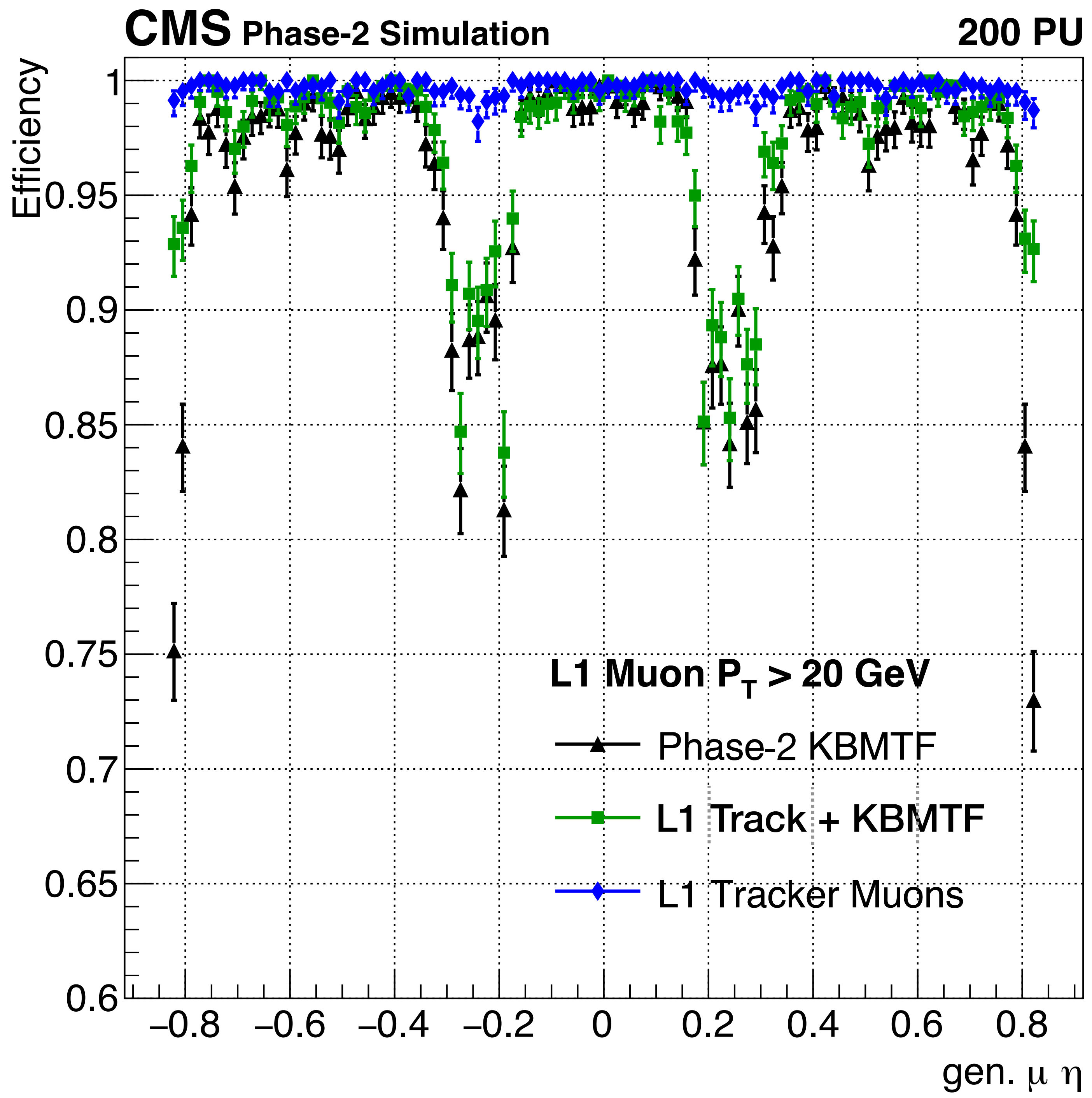


Global Muon Trigger: Tracker Track + μ-info

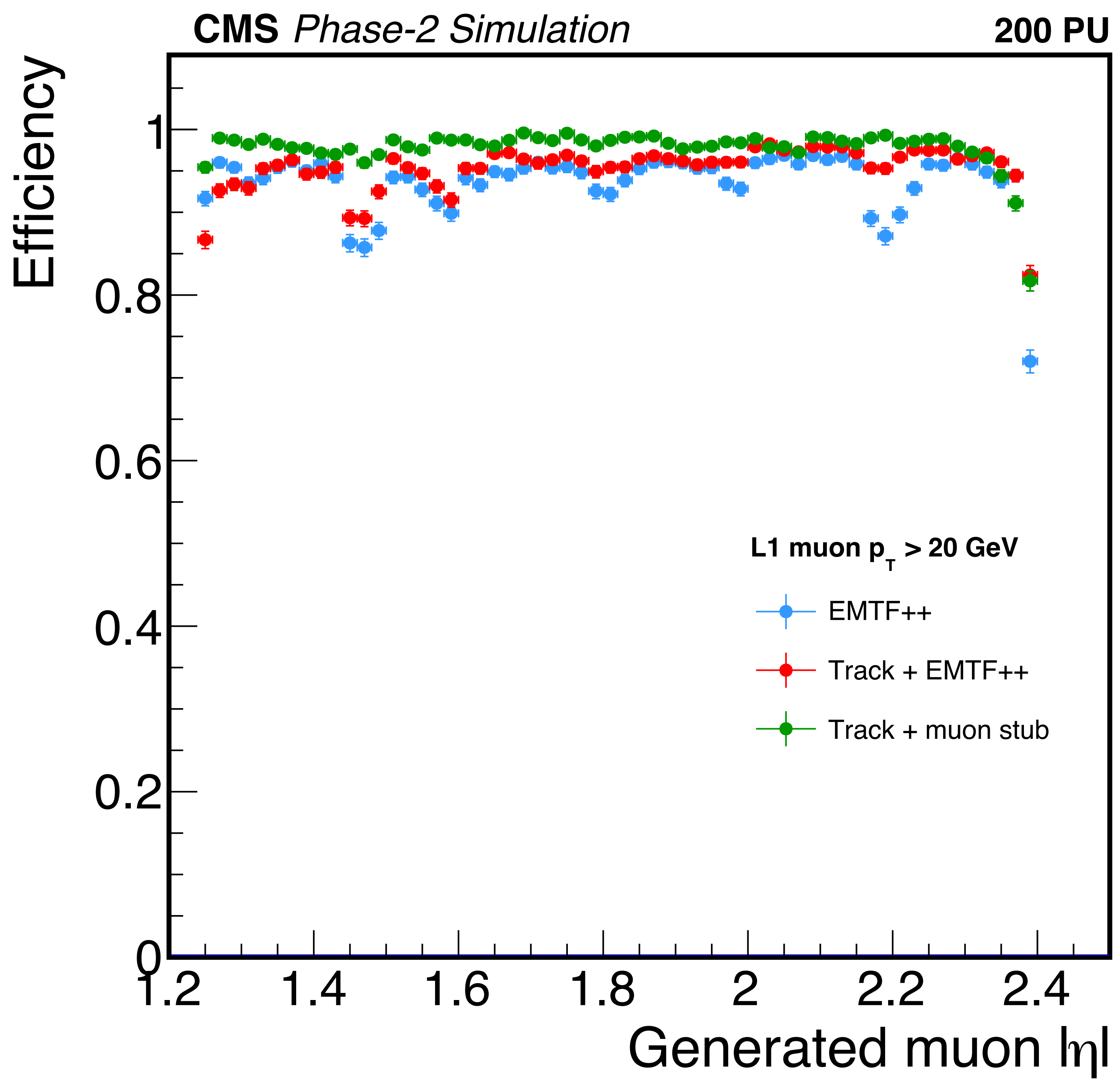
(CMS-TDR-021)

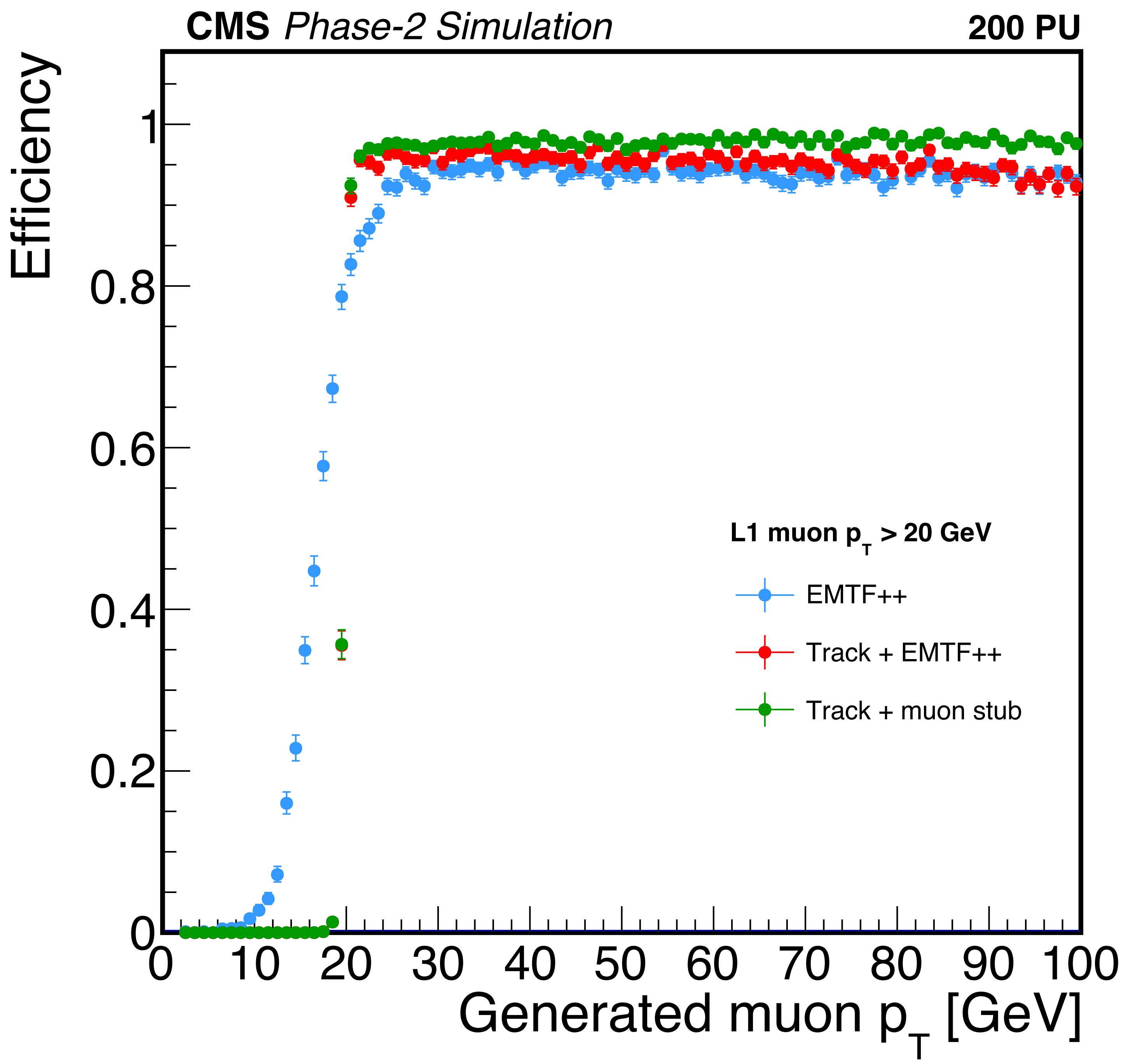
- Match Tracker L1 Tracks with μ-track (TkMu) or μ-hit (TkMuStub),
  - Matching with L1 Tracker Tracks significantly improves the pT resolution
    - That of a track trigger track (1-5 %) across pseudorapidity
  - Matching with μ-hit (any station) recovers inefficiencies in gaps b/w chambers

Barrel: SA, TkMu, TkMuStub



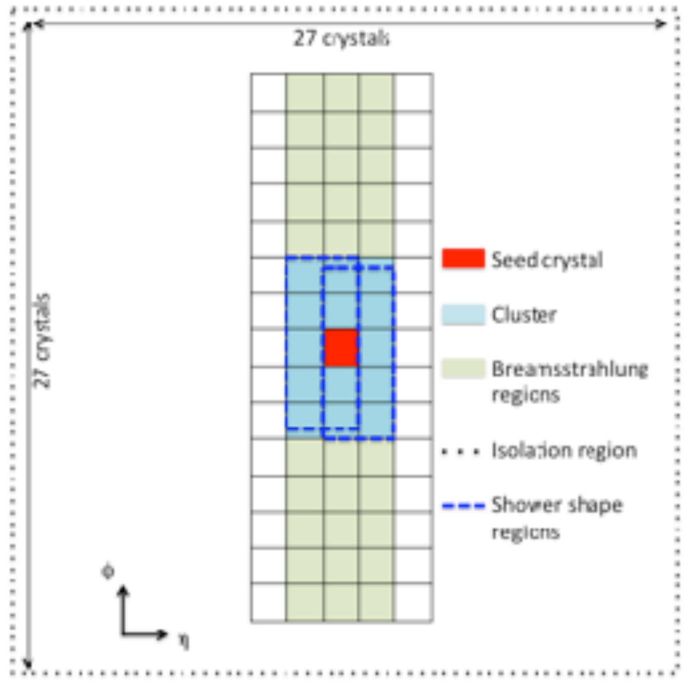
EndCap: SA, TkMu, TkMuStub



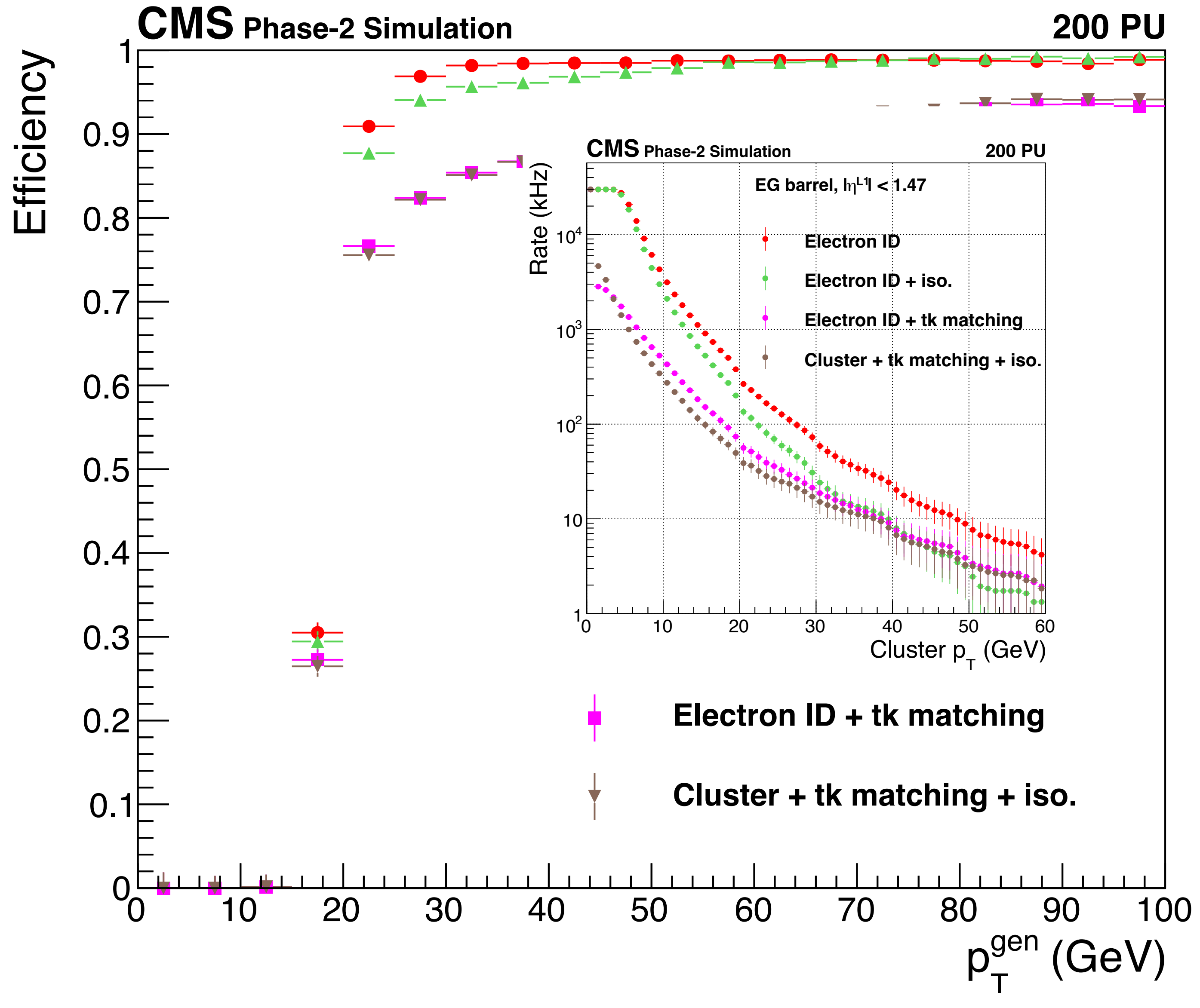


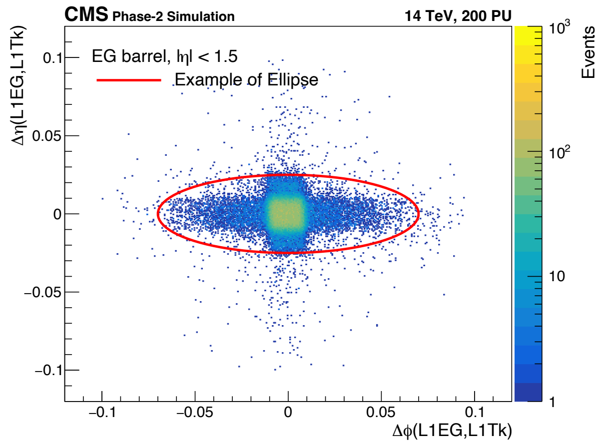
CMS - L1 $e/\gamma/\tau$ Trigger

- ECAL : maintain PbWO4 crystal granularity readout (Avalanche PhotoDiodes) at 40 MHz in high PU conditions, and replace front-end electronics, 30 ps resolution for 30 GeV e/γ:
  – 160 MHz sampling against spikes (hadron interactions within APD volume)
- HGCAL: high granularity, EM and Hadronic parts

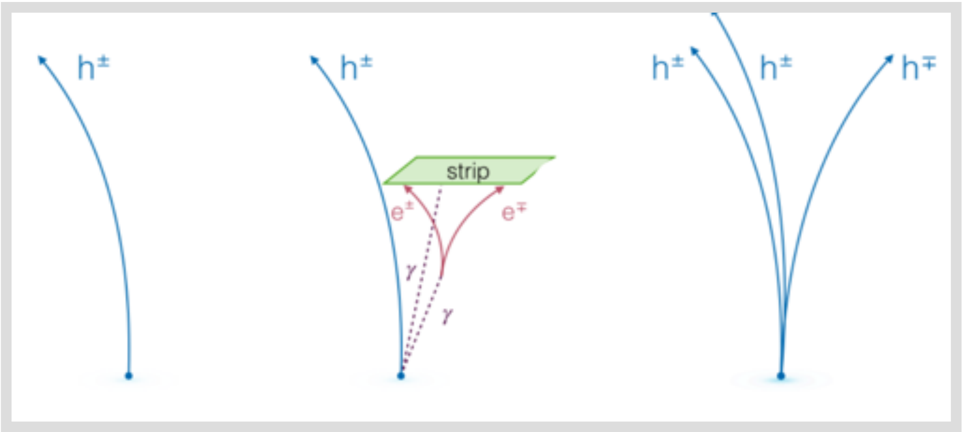


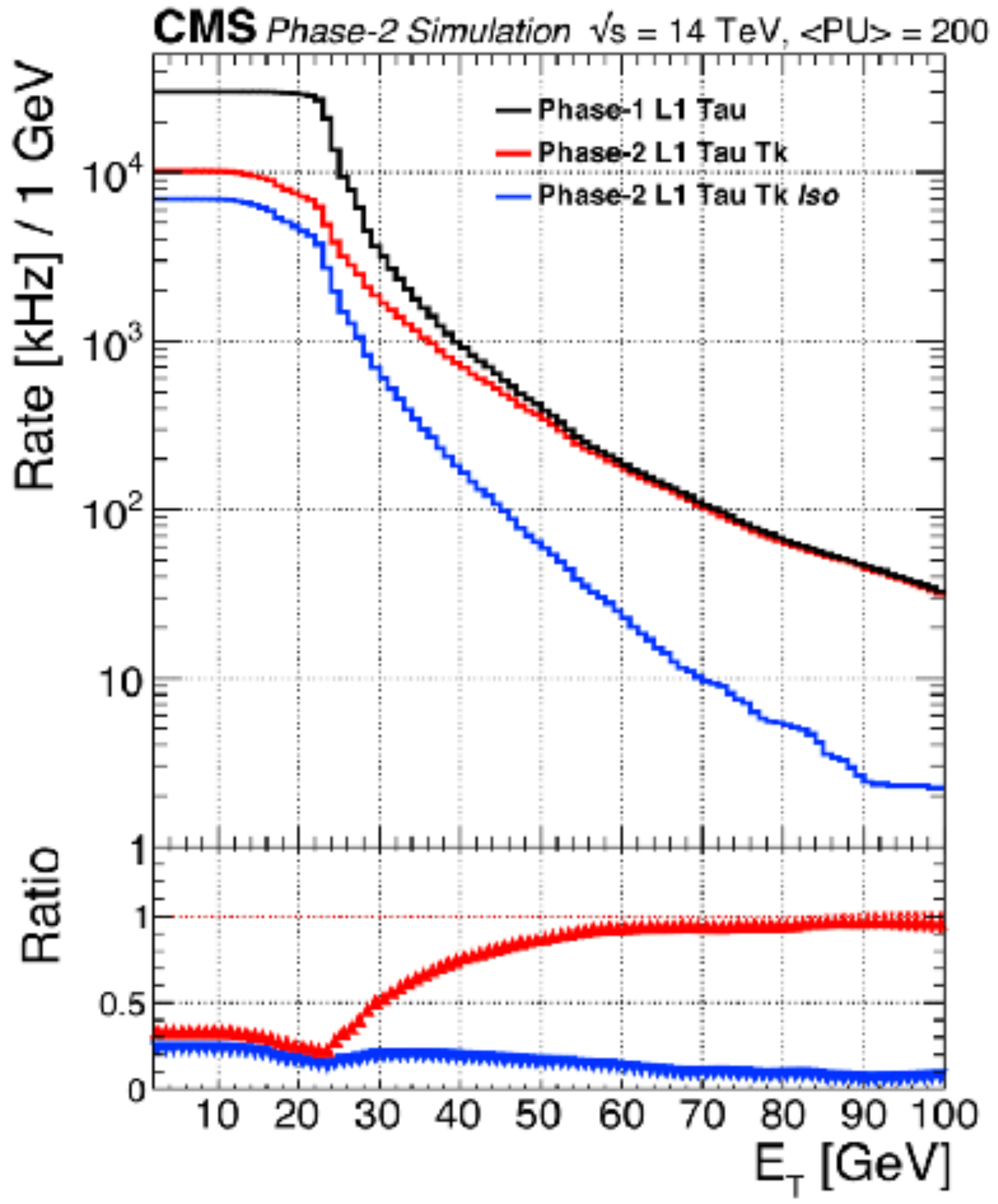
- Level-1 Trigger e/γ
  – EG cluster energy resolution improved w/ ML exploiting high granularity
  – To control rates of electrons match clusters to TrackTrigger Tracks to control rates of electrons





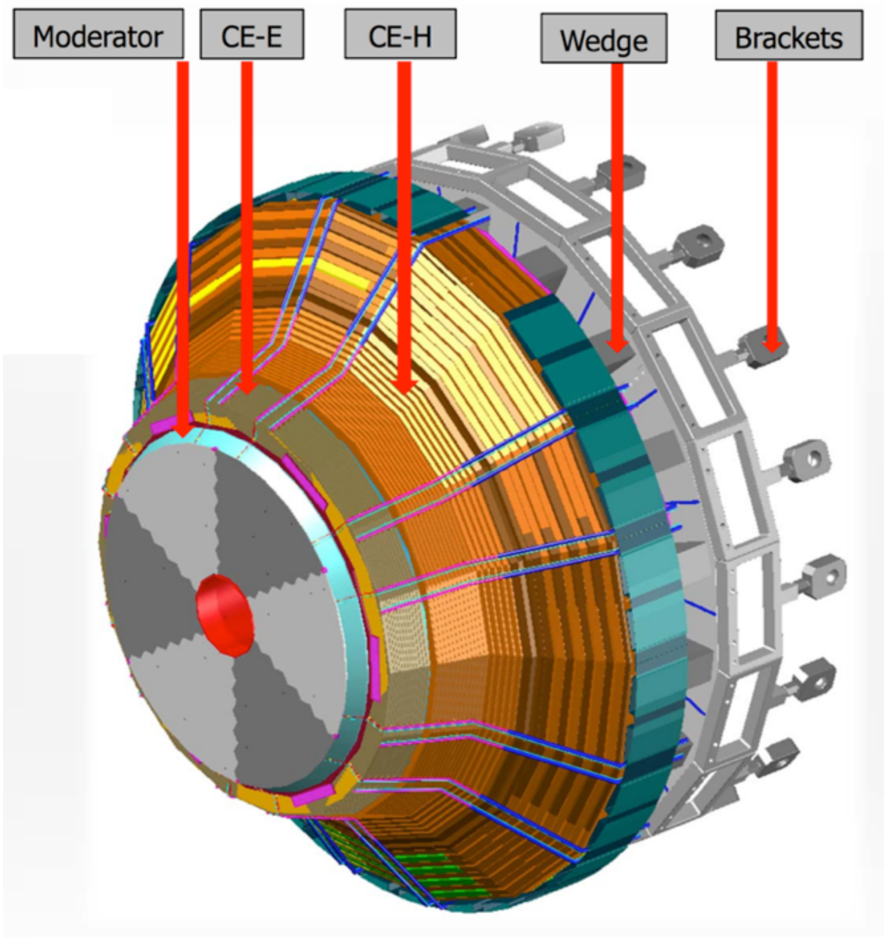
- Level-1 Trigger τ
  – Exploit high granularity,
  – Algorithm Track+Strip

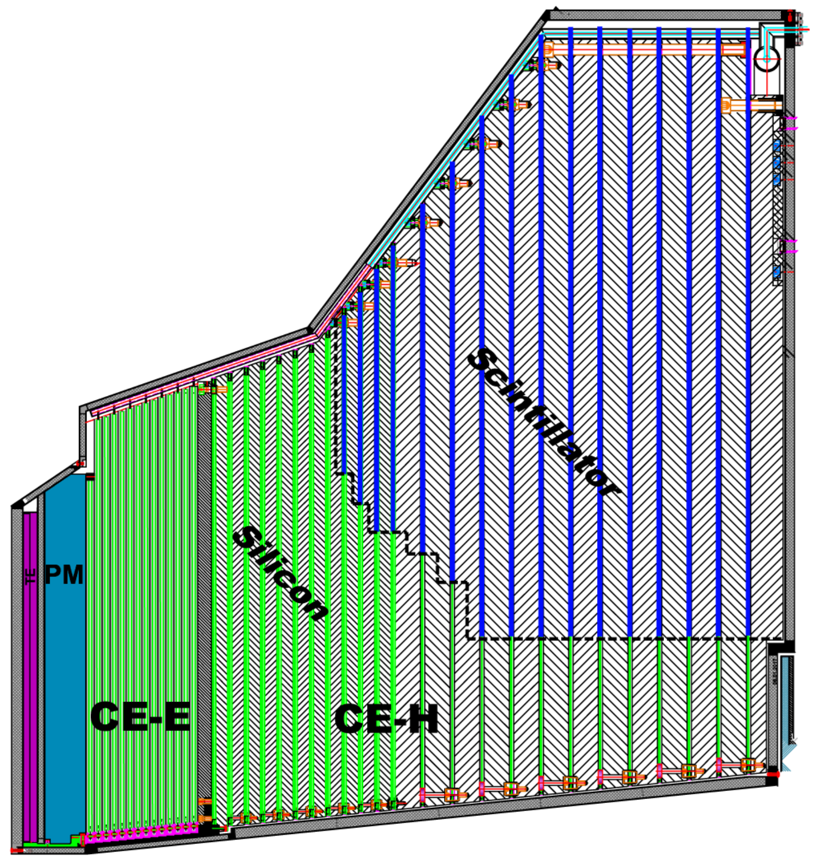


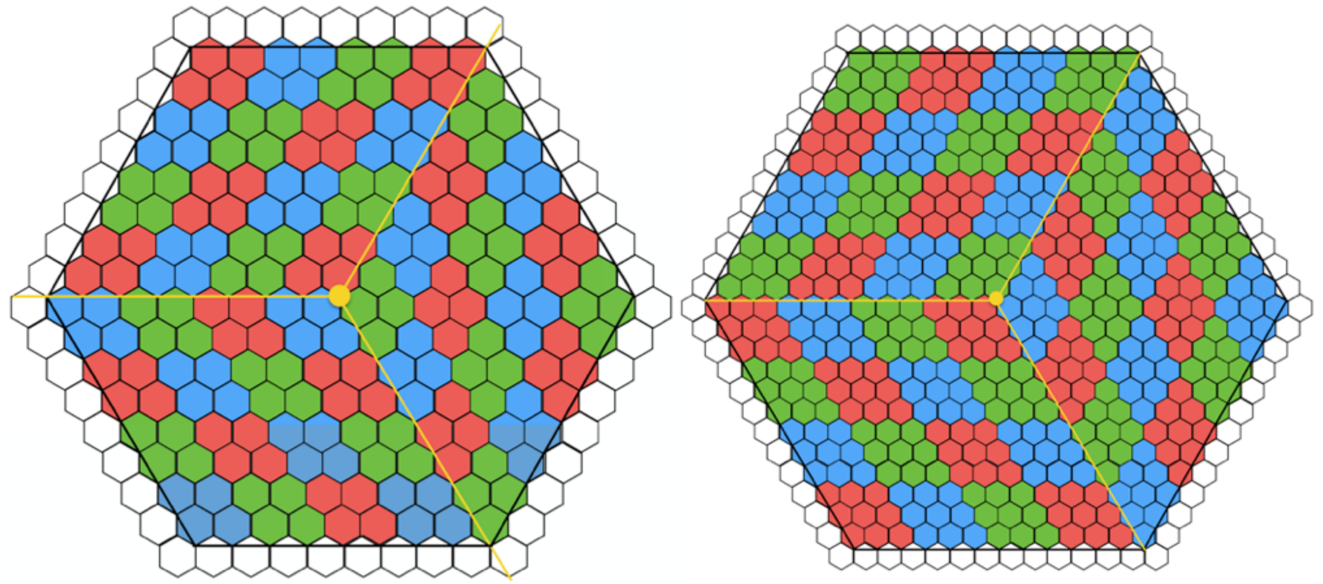


Showing Barrel only.

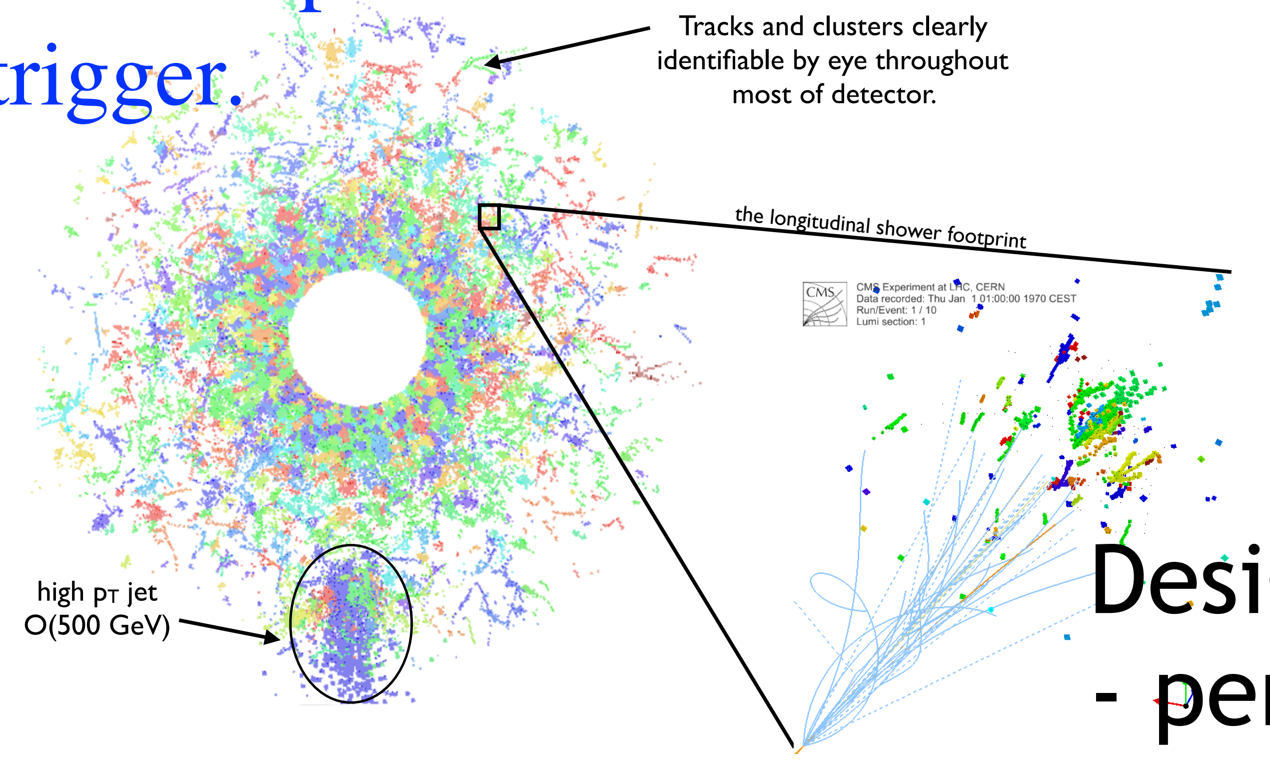
- HGCAL: 4D shower topology with timing resolution ~50 ps
  - electromagnetic section: 28 layers Silicon/W-Pb (25 X0 - 1.7 λ)
  - hadronic section: 22 layers Si and mixed Si-Scintillators in stainless still absorber (8.1 λ)
  - 8’ sillicon sensors will be hexagonal, divided with 3-fold symmetry into hexagonal cells.

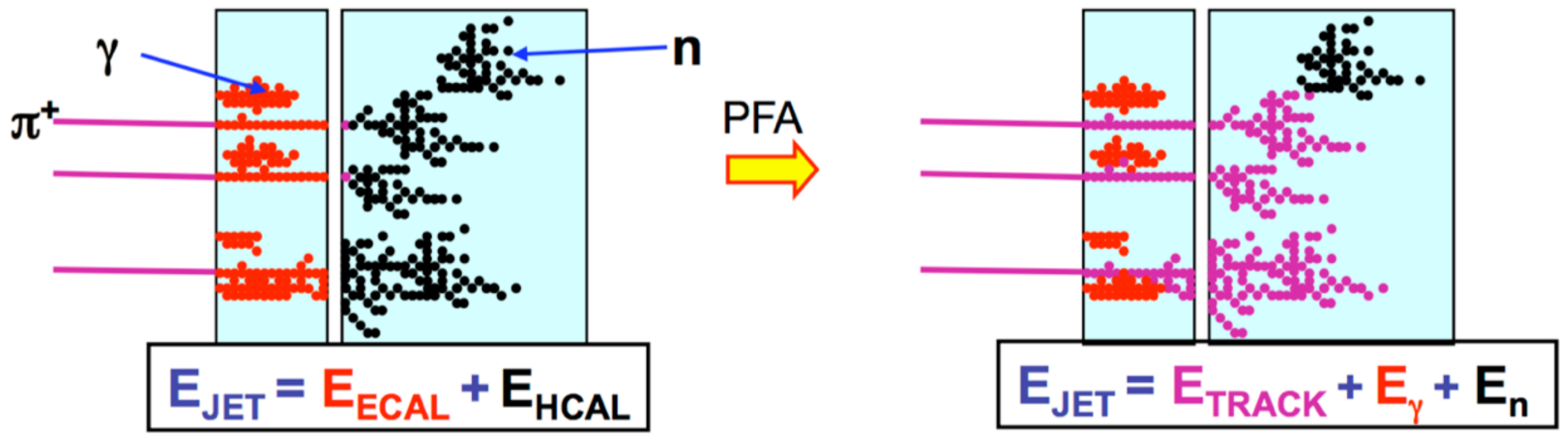






New endcap calorimeter will identify energy clusters with excellent spatial resolution and send them to the L1 trigger.

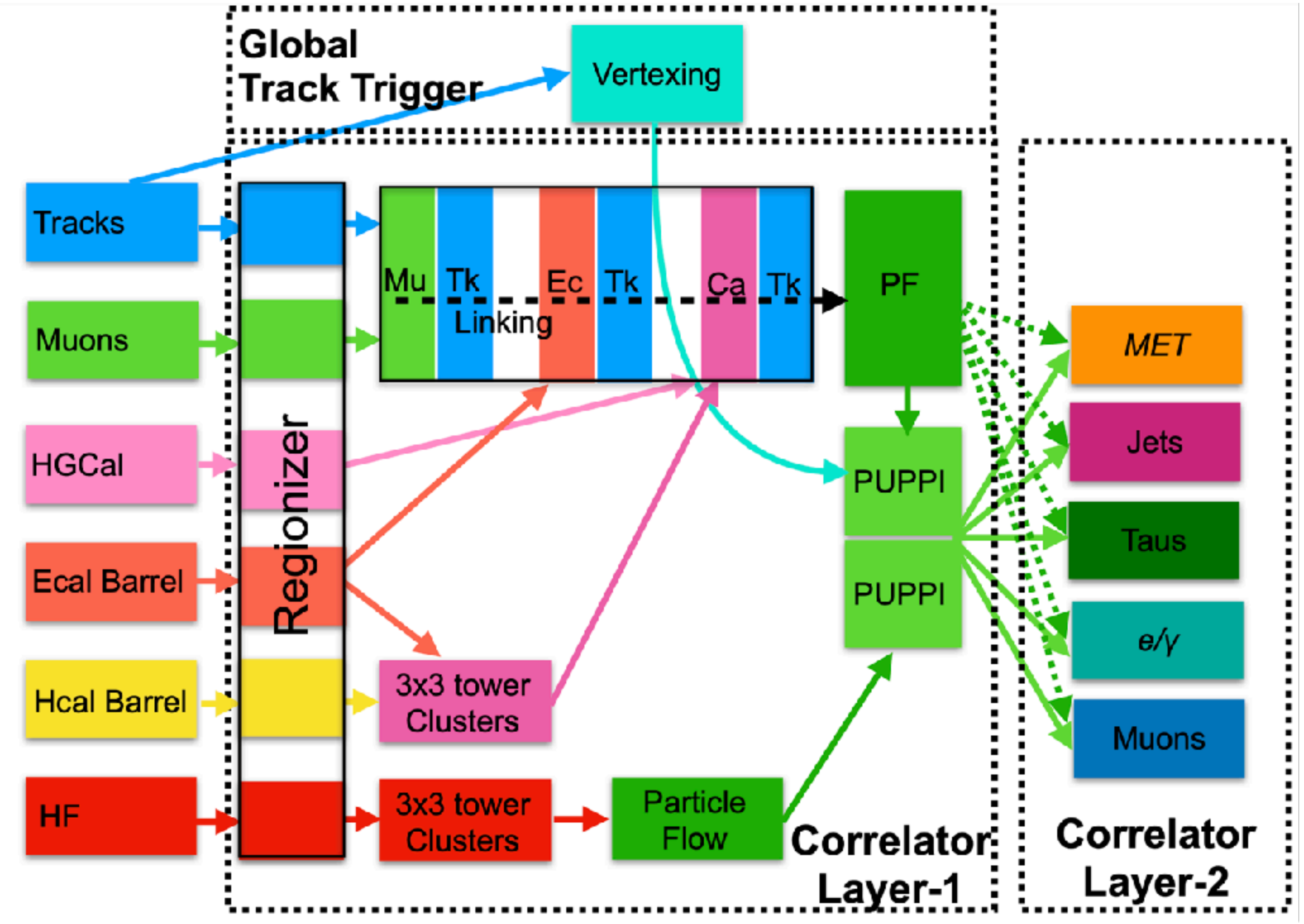




Designed to see showers
- perfect for ParticleFlow

Level-1 Correlator Trigger (Particle Flow + PUPPI)

- Schematic diagram of the algorithm flow (left to right)
  - Correlator Layer 1: Builds PF candidates and PUPPI weights
  - Correlator Layer 2: Builds PF and PUPPI MET, Jets, Taus, e/γ, Muons

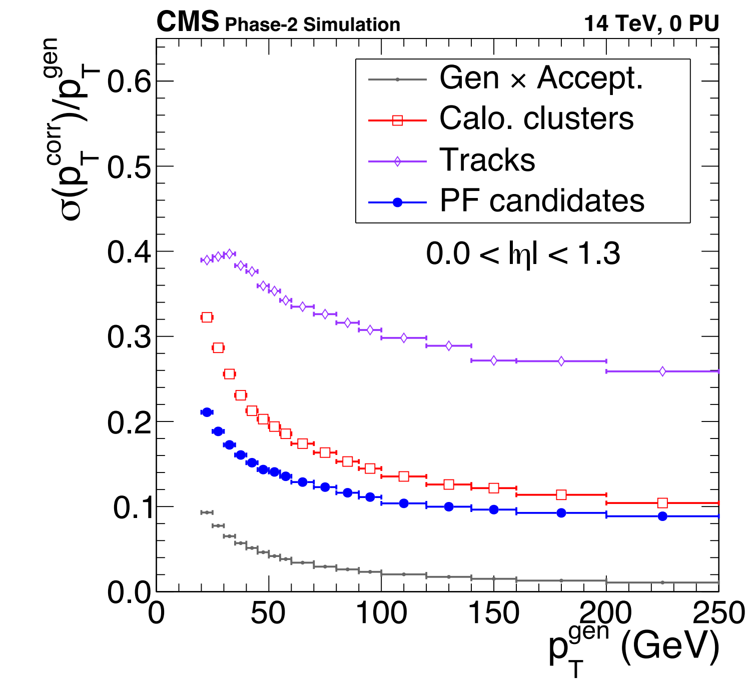


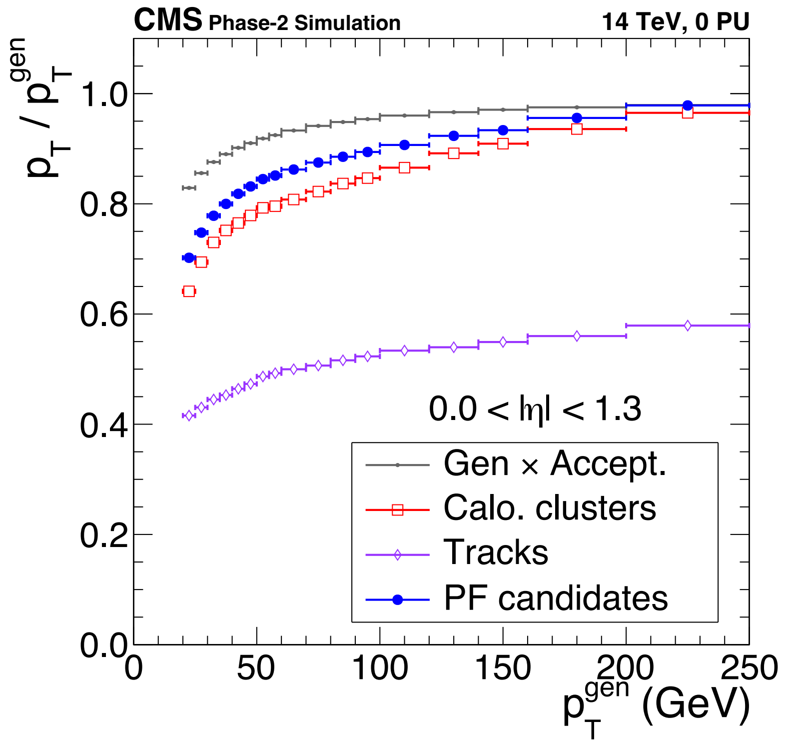
CMS Level1 Trigger - Vertexing and PUPPI

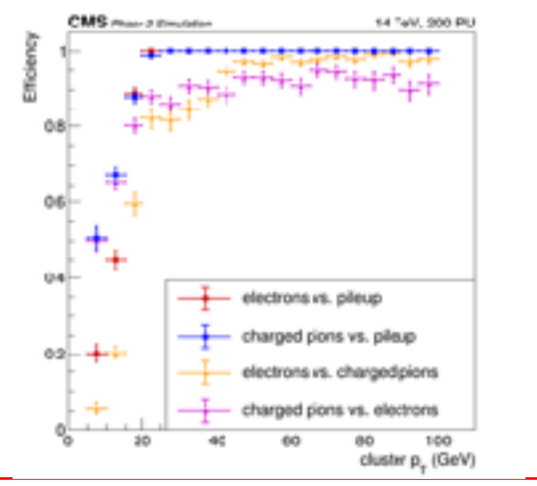
(CMS-TDR-021)

<u>Particle flow reconstruction @ Level1</u>: With the addition of tracking information, Level-1 algorithms can match the performance of HLT/Offline algorithms Benefiting from the Enhanced particle separation and identification –> improved response/spacial resolution

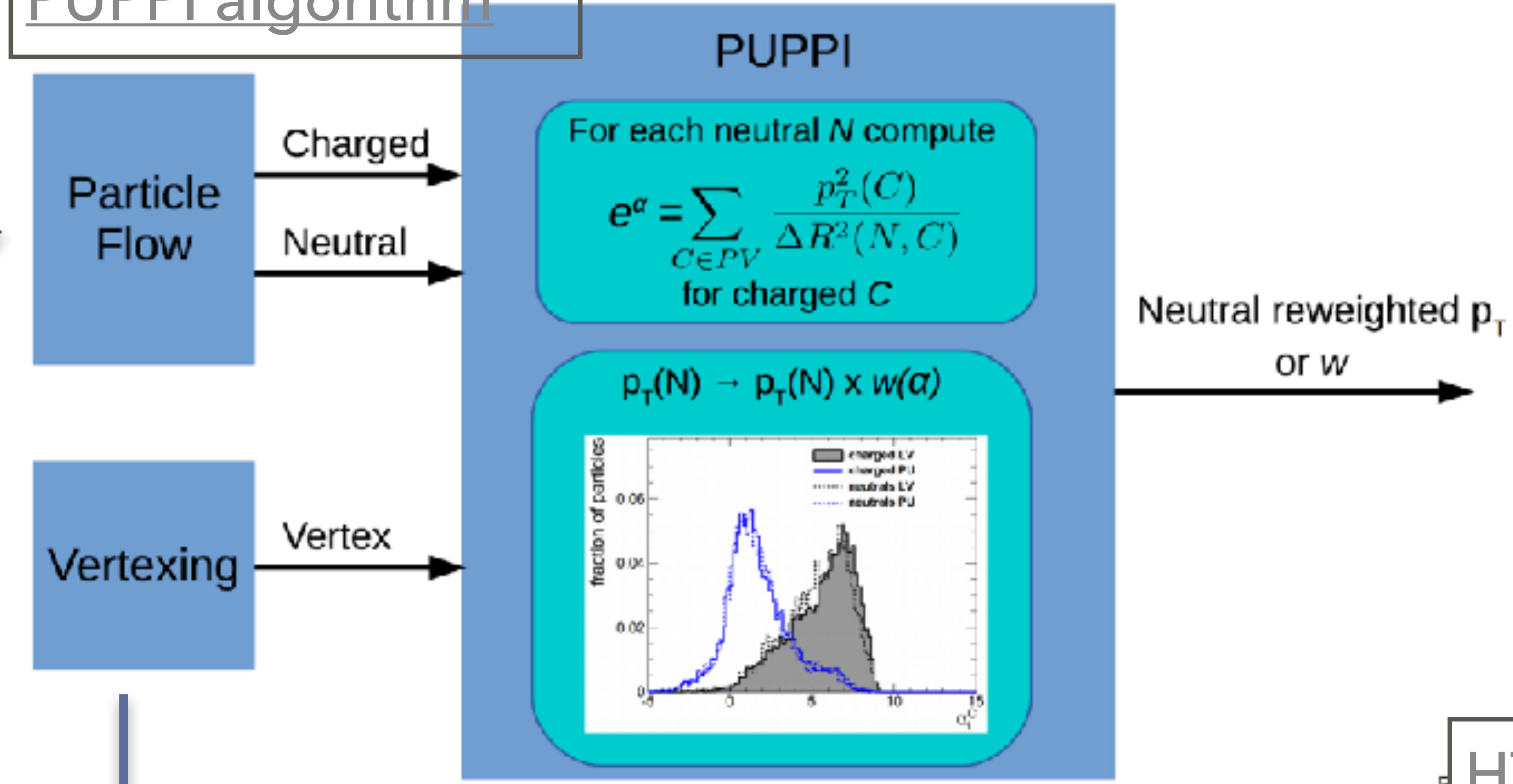
<u>Approach used here</u> **Combine PFlow & PileUP per particle Identification (PUPPI)**





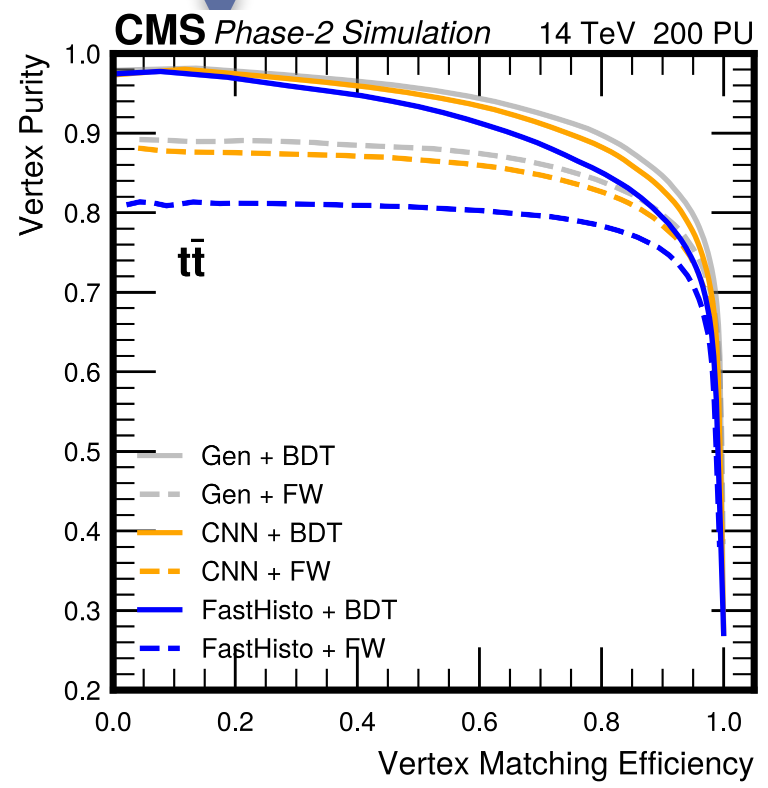


PUPPI algorithm



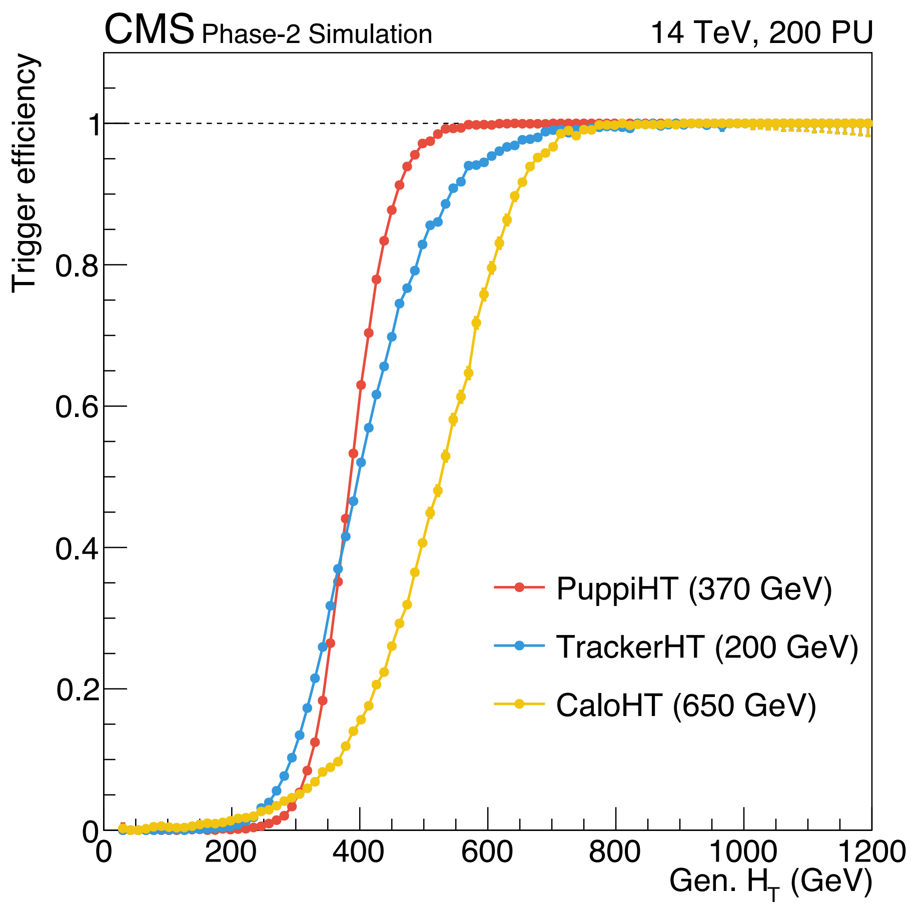
jet response

jet resolution



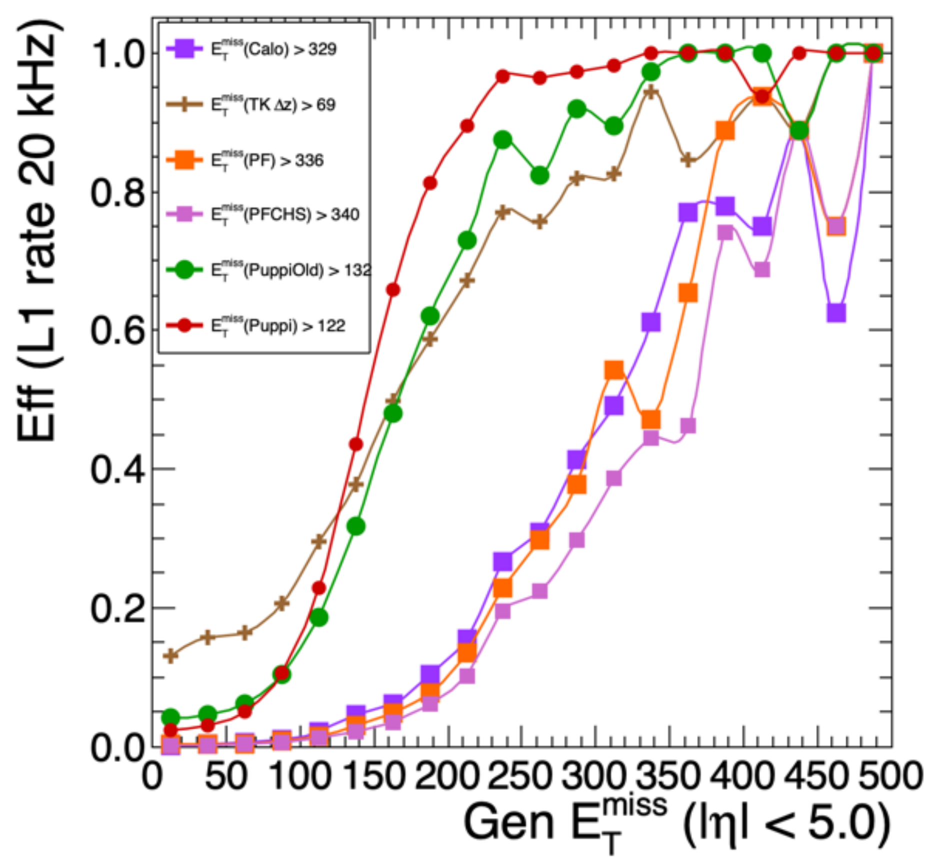
Vertexing efficiency

HT Trigger

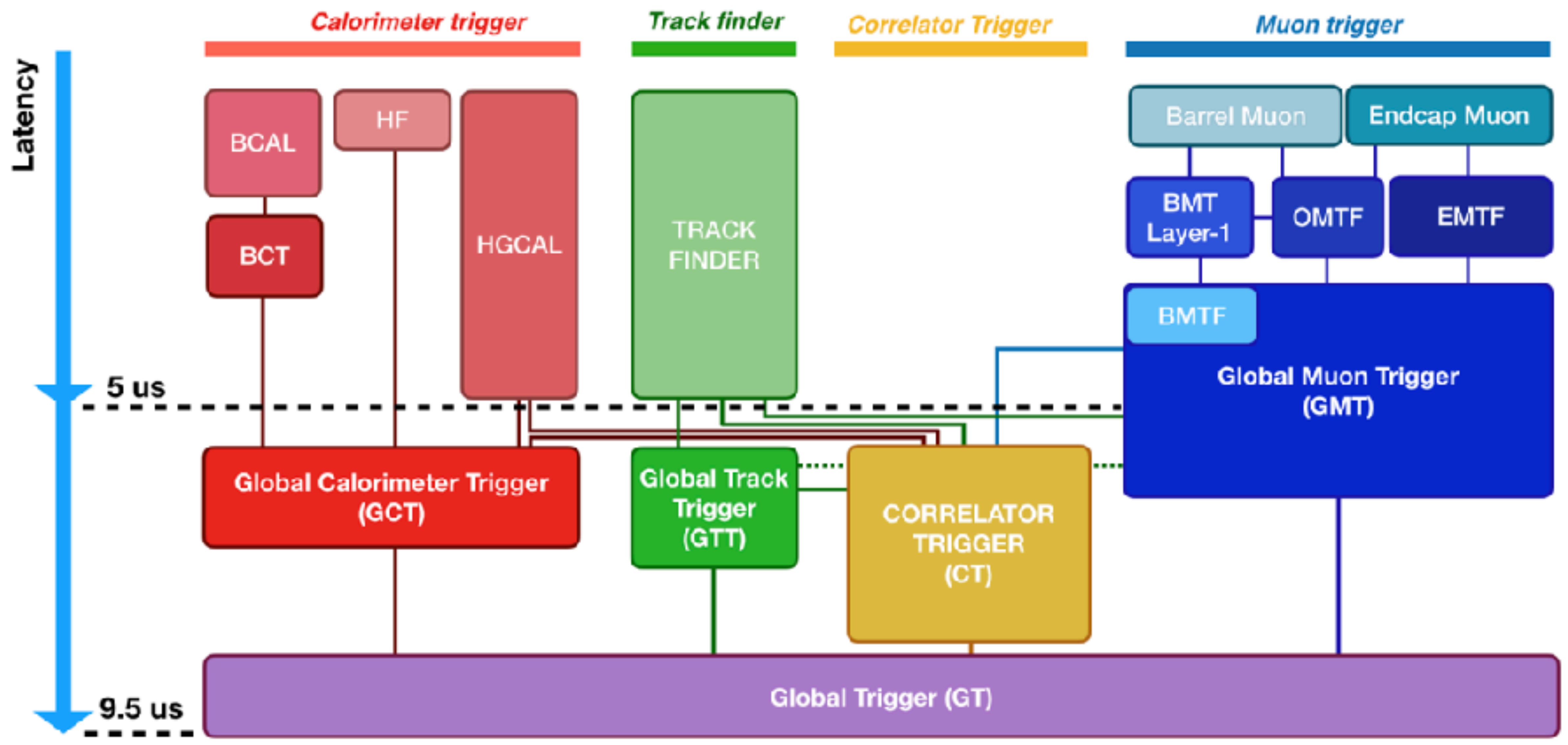


MET Trigger

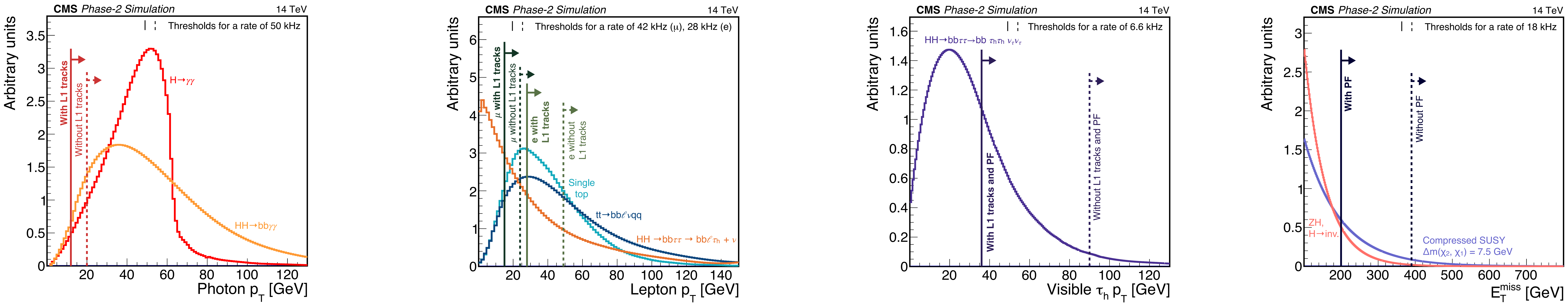
ttbar PU200



- Make selection on objects built in Muon Global Trigger, Calo Global Trigger, Correlator Layer2



  - Retain object thresholds of Run1/2, made possible mostly due to use Level-1 Tracker tracks in GMT, GCT, GTT, Correlator



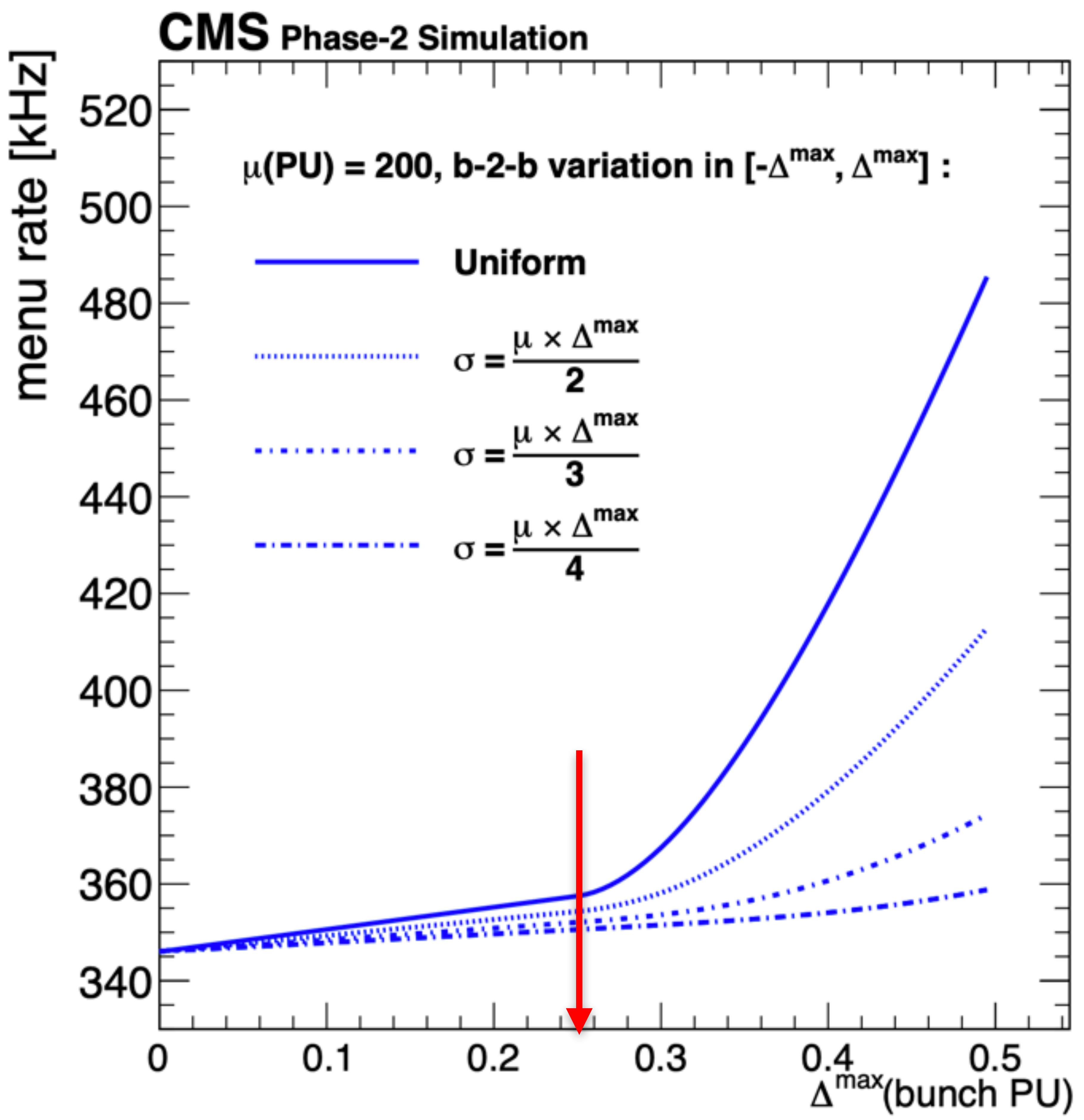
- Using objects built in Muon Global Trigger, Calo Global Trigger, Correlator Layer1, devised a Level-1 Trigger physics menu
  - Retain object thresholds of Run1/2, with rate below 500 kHz @ PU 200 (with accounting for 30% of uncertainty)

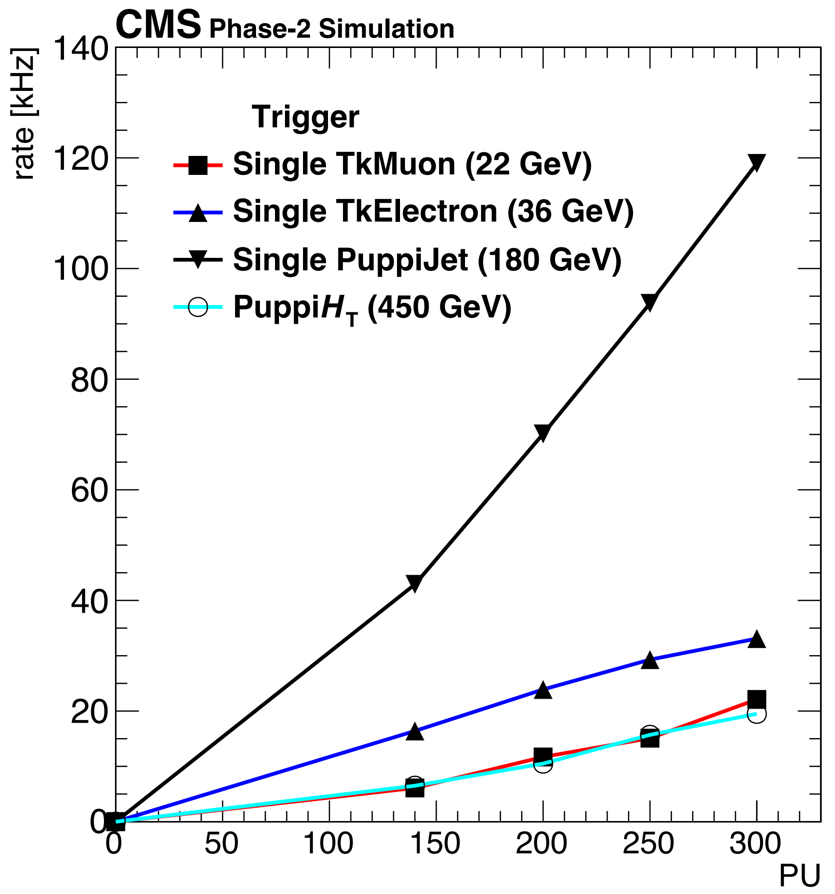
L1 Trigger seeds	Offline Threshold(s) at 90% or 95% (50%) [GeV]	Rate $\langle PU \rangle = 200$ [kHz]	Additional Requirement(s) [cm, GeV]	Objects plateau efficiency [%]
Single/Double/Triple Lepton (electron, muon) seeds				
Single TkMuon	22	12	$\lvert\eta\rvert < 2.4$	95
Double TkMuon	15,7	1	$\lvert\eta\rvert < 2.4, \Delta z < 1$	95
Triple TkMuon	5,3,3	16	$\lvert\eta\rvert < 2.4, \Delta z < 1$	95
Single TkElectron	36	24	$\lvert\eta\rvert < 2.4$	93
Single TkIsoElectron	28	28	$\lvert\eta\rvert < 2.4$	93
TkIsoElectron-StaEG	22, 12	36	$\lvert\eta\rvert < 2.4$	93, 99
Double TkElectron	25, 12	4	$\lvert\eta\rvert < 2.4$	93
Single StaEG	51	25	$\lvert\eta\rvert < 2.4$	99
Double StaEG	37,24	5	$\lvert\eta\rvert < 2.4$	99
Photon seeds				
Single TkIsoPhoton	36	43	$\lvert\eta\rvert < 2.4$	97
Double TkIsoPhoton	22, 12	50	$\lvert\eta\rvert < 2.4$	97
Taus seeds				
Single CaloTau	150(119)	21	$\lvert\eta\rvert < 2.1$	99
Double CaloTau	90,90(69,69)	25	$\lvert\eta\rvert < 2.1, \Delta R > 0.5$	99
Double PuppiTau	52,52(36,36)	7	$\lvert\eta\rvert < 2.1, \Delta R > 0.5$	90
Hadronic seeds (jets,H_T)				
Single PuppiJet	180	70	$\lvert\eta\rvert < 2.4$	100
Double PuppiJet	112,112	71	$\lvert\eta\rvert < 2.4, \Delta\eta < 1.6$	100
PuppiH_T	450(377)	11	jets: $\lvert\eta\rvert < 2.4, p_T > 30$	100
QuadPuppiJets-PuppiH_T	70,55,40,40,400(328)	9	jets: $\lvert\eta\rvert < 2.4, p_T > 30$	100,100
E_T^{miss} seeds				
PuppiE_T^{miss}	200(128)	18		100
Cross Lepton seeds				
TkMuon-TkIsoElectron	7,20	1	$\lvert\eta\rvert < 2.4, \Delta z < 1$	95, 93
TkMuon-TkElectron	7,23	3	$\lvert\eta\rvert < 2.4, \Delta z < 1$	95, 93
TkElectron-TkMuon	10,20	1	$\lvert\eta\rvert < 2.4, \Delta z < 1$	93, 95
TkMuon-DoubleTkElectron	6,17,17	0.1	$\lvert\eta\rvert < 2.4, \Delta z < 1$	95, 93
DoubleTkMuon-TkElectron	5,5,9	4	$\lvert\eta\rvert < 2.4, \Delta z < 1$	95, 93
PuppiTau-TkMuon	36(27),18	2	$\lvert\eta\rvert < 2.1, \Delta z < 1$	90, 95
TkIsoElectron-PuppiTau	22,39(29)	13	$\lvert\eta\rvert < 2.1, \Delta z < 1$ $\Delta R > 0.3$	93, 90

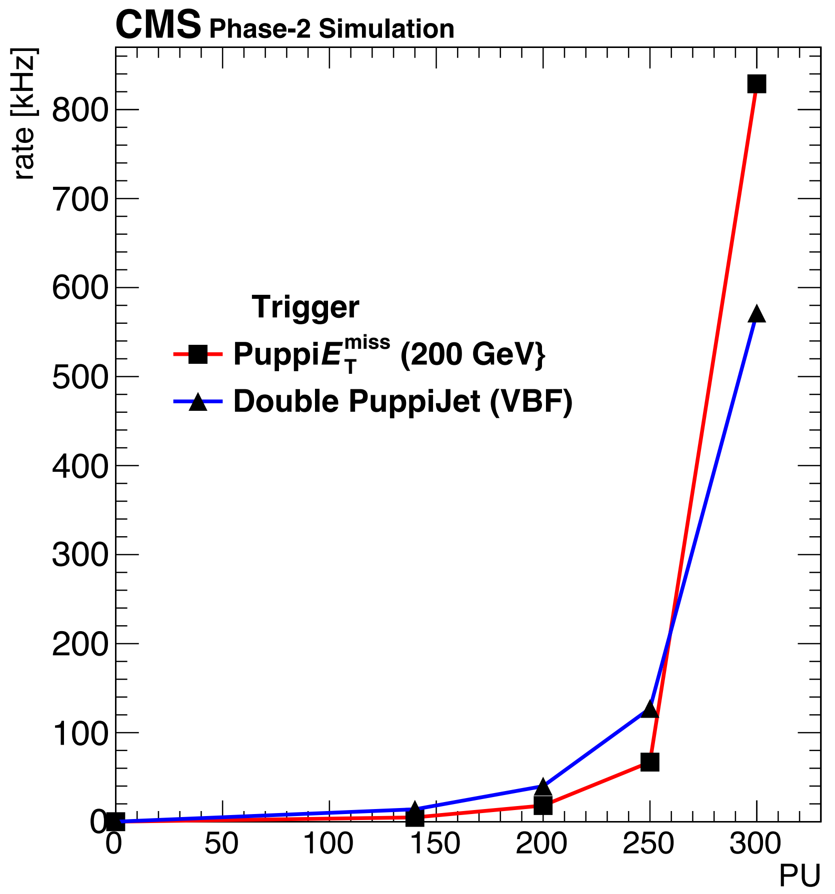
L1 Trigger seeds	Offline Threshold(s) at 90% or 95% (50%) [GeV]	Rate $\langle PU \rangle = 200$ [kHz]	Additional Requirement(s) [cm, GeV]	Objects plateau efficiency [%]
Cross Hadronic-Lepton seeds				
TkMuon-PuppiH_T	6,320(250)	4	$\lvert\eta\rvert < 2.4, \Delta z < 1$	95,100
TkMuon-DoublePuppiJet	12,40,40	10	$\lvert\eta\rvert < 2.4, \Delta R_{j\mu} < 0.4,$ $\Delta\eta_{jj} < 1.6, \Delta z < 1$	95,100
TkMuon-PuppiJet-PuppiE_T^{miss}	3,100,120(55)	14	$\lvert\eta\rvert < 1.5, \lvert\eta\rvert < 2.4,$ $\Delta z < 1$	95,100, 100
DoubleTkMuon-PuppiJet-PuppiE_T^{miss}	3,3,60,130(64)	4	$\lvert\eta\rvert < 2.4, \Delta z < 1$	95,100, 100
DoubleTkMuon-PuppiH_T	3,3,300(231)	2	$\lvert\eta\rvert < 2.4, \Delta z < 1$	95,100
DoubleTkElectron-PuppiH_T	10,10,400(328)	0.9	$\lvert\eta\rvert < 2.4, \Delta z < 1$	93,100
TkIsoElectron-PuppiH_T	26,190(124)	9	$\lvert\eta\rvert < 2.4, \Delta z < 1$	93,100
TkElectron-PuppiJet	28,40	34	$\lvert\eta\rvert < 2.1, \lvert\eta\rvert < 2.4,$ $\Delta R > 0.3, \Delta z < 1$	93,100
PuppiTau-PuppiE_T^{miss}	55(38),190(118)	4	$\lvert\eta\rvert < 2.1$	90,100
VBF seeds				
Double PuppiJets	160,35	40	$\lvert\eta\rvert < 5, m_{jj} > 620$	100
B-physics seeds				
Double TkMuon	2,2	12	$\lvert\eta\rvert < 1.5, \Delta R < 1.4,$ $q1 * q2 < 0, \Delta z < 1$	95
Double TkMuon	4,4	21	$\lvert\eta\rvert < 2.4, \Delta R < 1.2$ $q1 * q2 < 0, \Delta z < 1$	95
Double TkMuon	4.5,4	10	$\lvert\eta\rvert < 2.0, 7 < m_{\mu\mu} < 18,$ $q1 * q2 < 0, \Delta z < 1$	95
Triple TkMuon	5,3,2	7	$0 < m_{\mu 5 \mu 3, q1*q2<0} < 9$ $\lvert\eta\rvert < 2.4, \Delta z < 1$	95
Triple TkMuon	5,3,2.5	6	$5 < m_{\mu 5 \mu 2.5, q1*q2<0} < 17$ $\lvert\eta\rvert < 2.4, \Delta z < 1$	95
Rate for above Trigger seeds				346
Total Level-1 Menu Rate (+30%)				**450**

Stability of the Rate with PU variation between HL-LHC bunches (CMS-TDR-021)

- L1 trigger rate of 347 kHz at <PU> = 200 is stable with PU bunch-to-bunch variation of about 25% and increases by ~10 kHz
  - even for the case of the most drastic (uniform) bunch-to-bunch PU variation

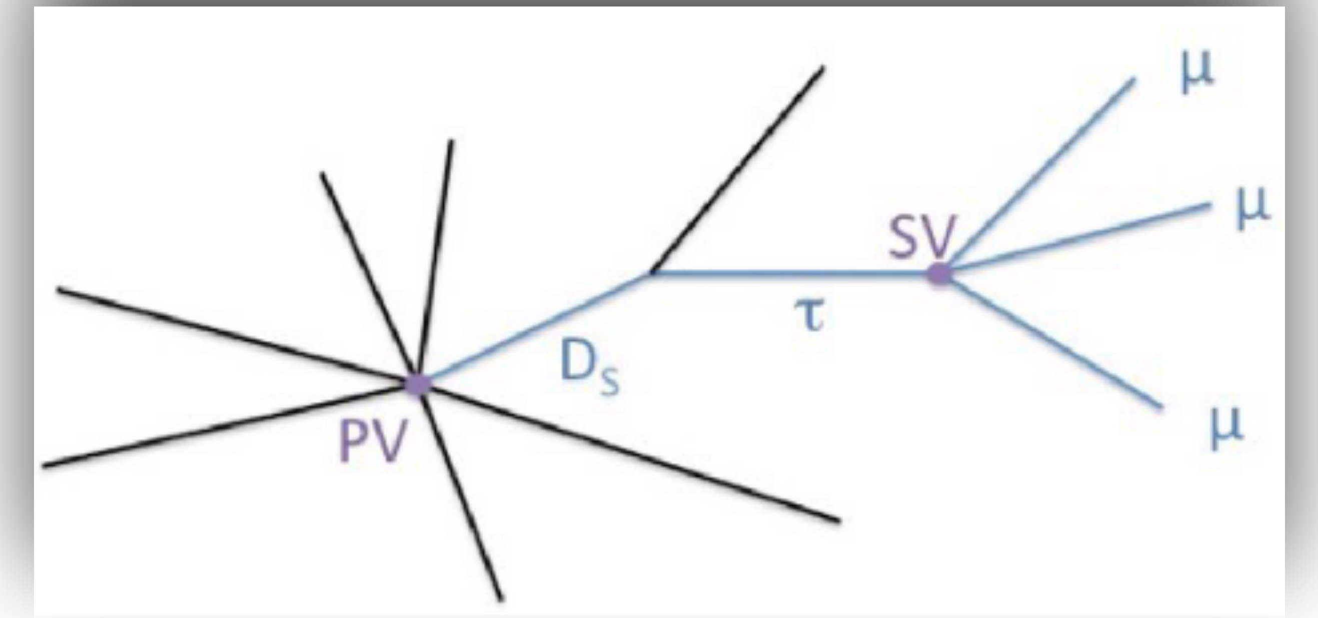


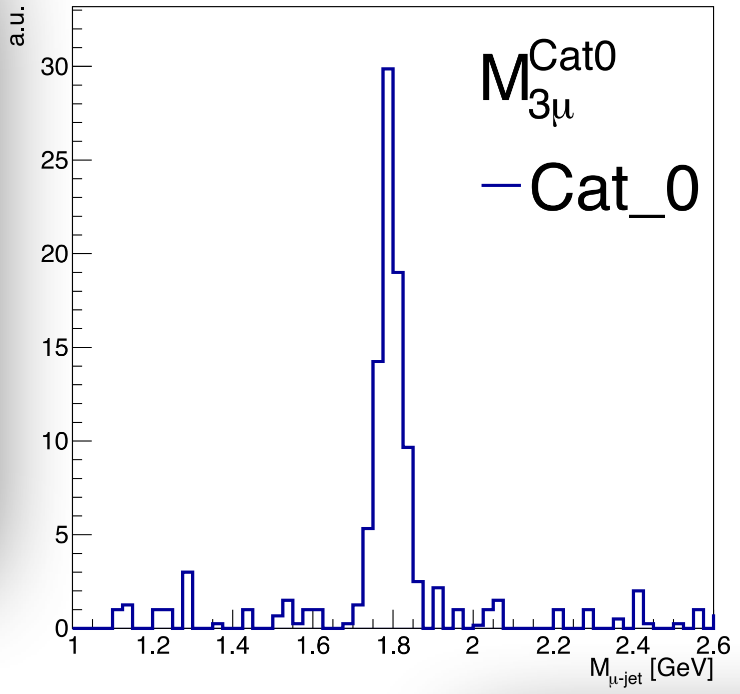


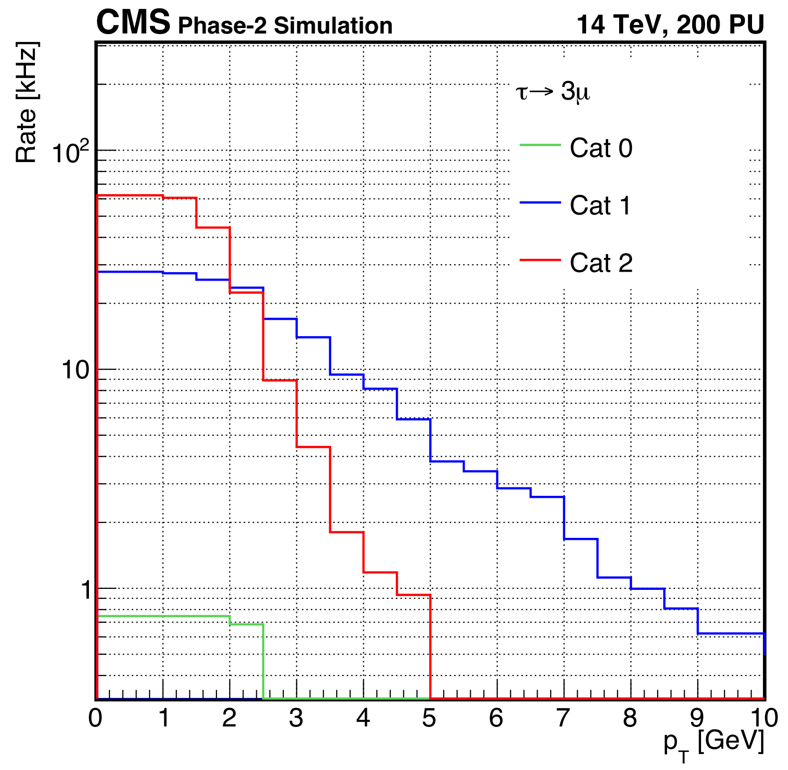


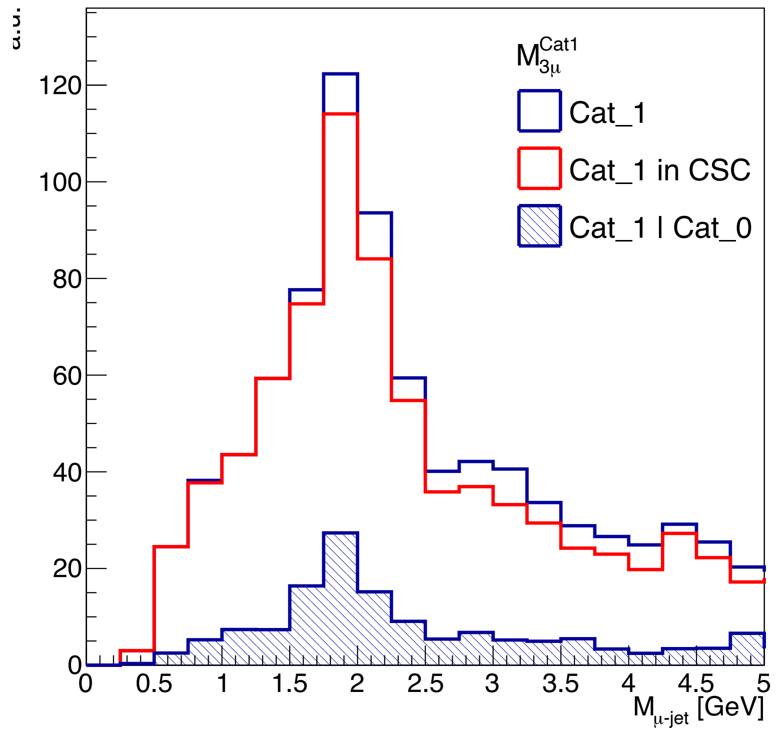
- Presence of Tracker Trigger Tracks allows for a more precise reconstruction
  - low mass resonances decaying to charged particles with an acceptable Level-1 trigger rate

LFV: Tau-> 3μ with L1 Muon Jets in GMT

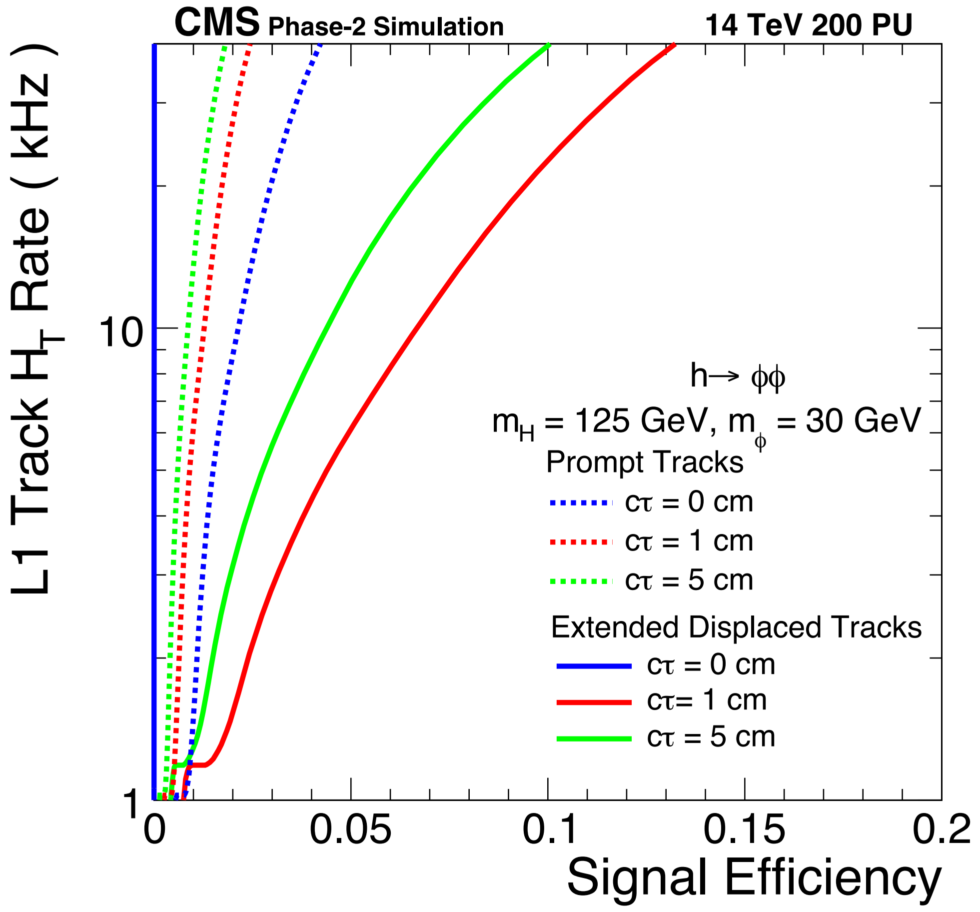




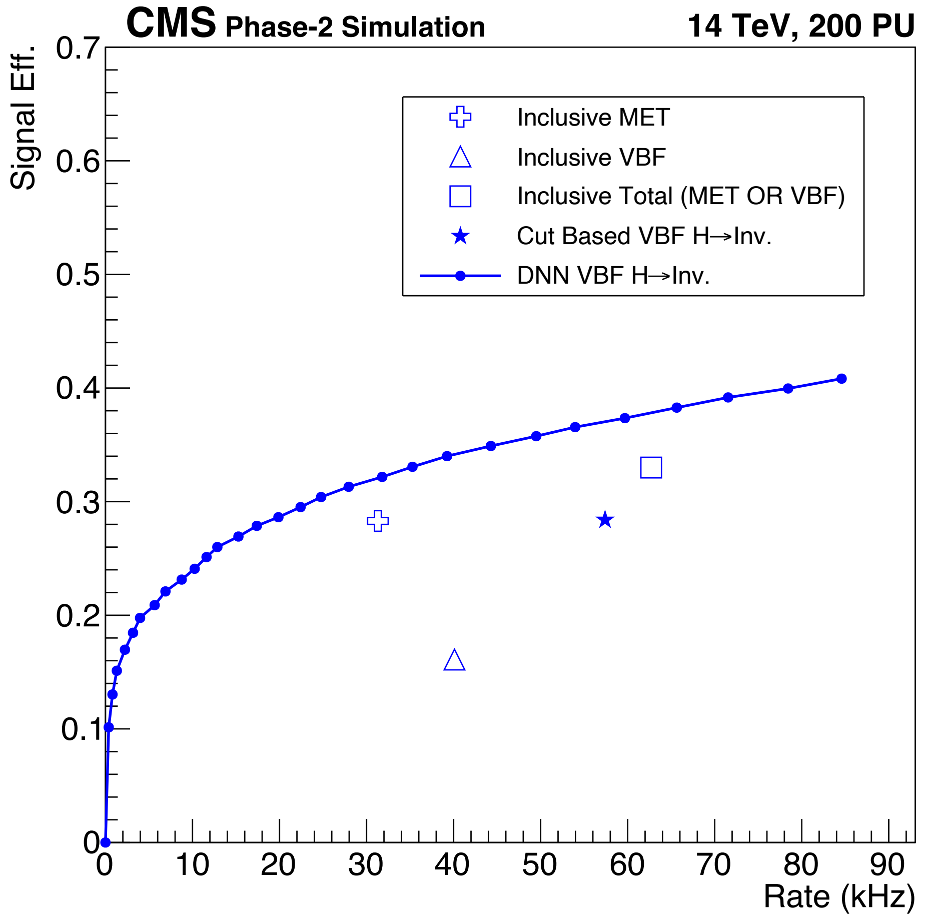




Extended tracking - L1 tracker HT trigger for displaced signatures H->φφ in GTT



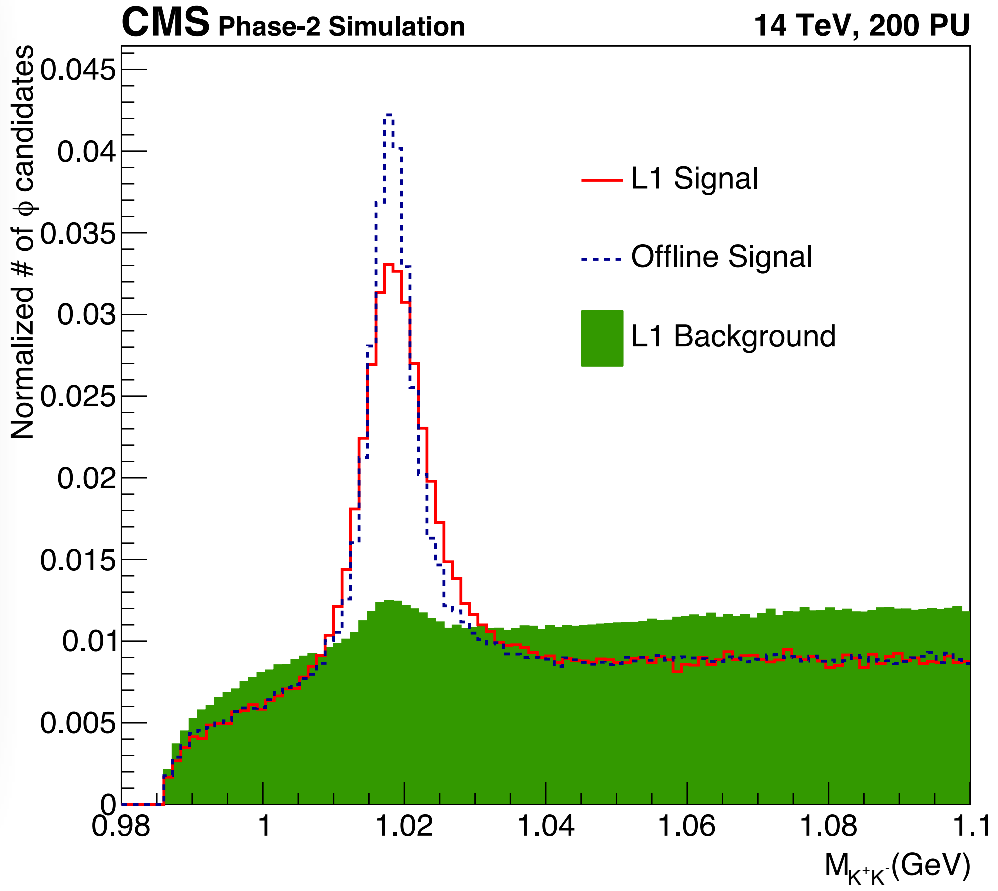
DNN in GT for VBF H->inv



Extended Menu

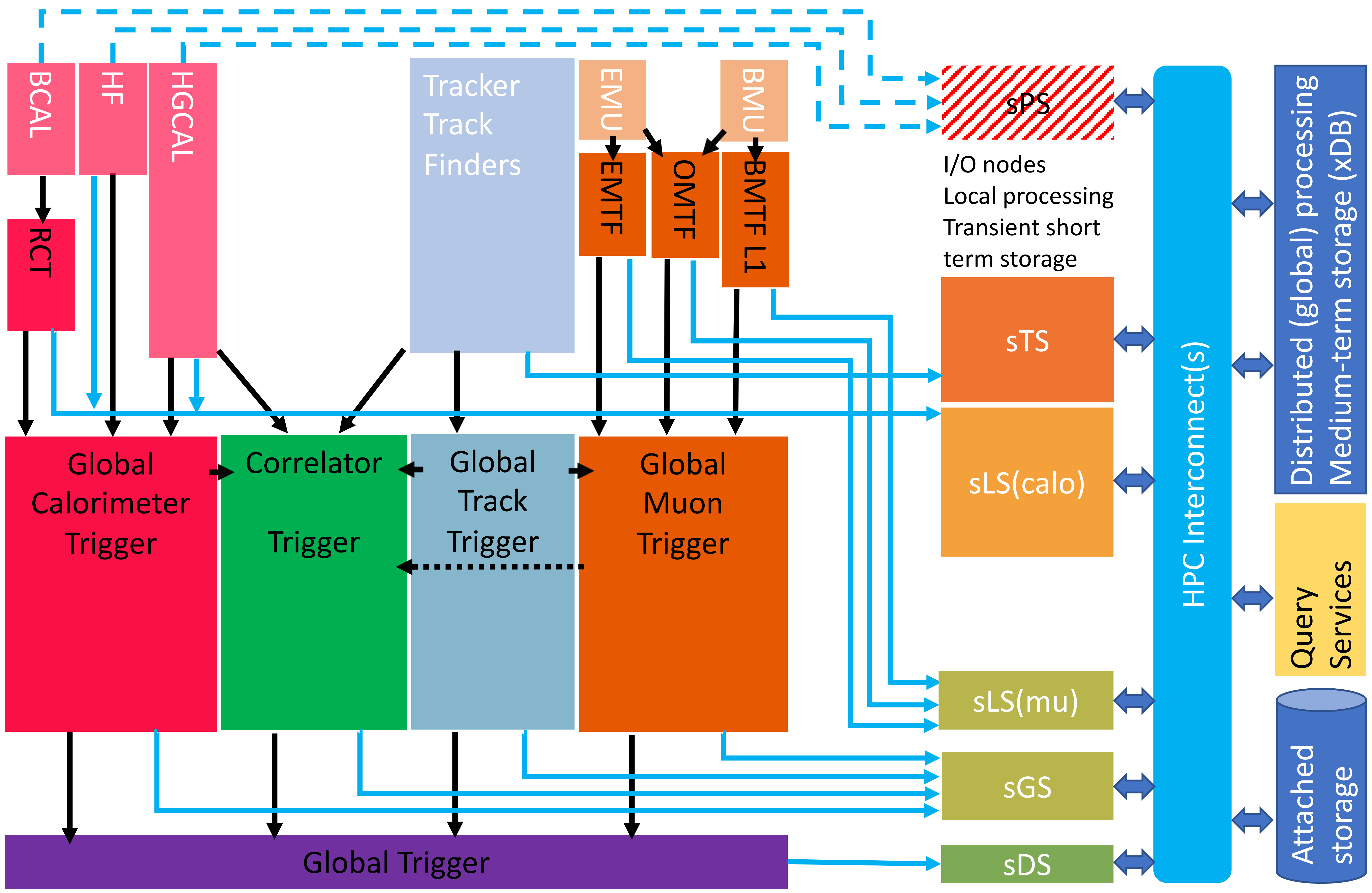
L1 Triggers	Online Threshold(s) (* for Offline) [GeV]	Rate $\langle PU \rangle = 200$ [kHz]	Additional Requirement(s) [cm, GeV, ns]
Single StaEG ext. eta	36 *	12	$2.4 < \lvert\eta\rvert < 3.0$
Muon-Jet (Cat0+Cat1)	2, 2, 0.5	27	$\lvert\eta\rvert < 2.4, \Delta R < 1, \Delta z < 1, m_{\mu-jet} < 3$
Tracker B_s^0	12	15	$\lvert\eta\rvert < 2.4, \Delta z < 0.6, 5.0 < m_{\mu\mu} < 5.8$
Displaced Single Muon	22	14	$\lvert\eta\rvert < 0.9$ $(1.2 < \lvert\eta\rvert < 2.4)$, $d_{xy} > 75(20)$
Displaced Double Muon	20, 15	2	$\lvert\eta\rvert < 0.9$ $(1.2 < \lvert\eta\rvert < 2.4)$
Displaced Tracker H_T	248(153) *	20	jets: $\lvert\eta\rvert < 2.0, p_T > 5$
Displaced Calo-Jet	40	20	$\lvert\eta\rvert < 1.44, \Delta t > 1$
Total rate for above triggers			110 kHz

Bs->KK->4 tracks in GTT



Scouting

- During the data taking Global Trigger is reprogrammed several times per year, as the operations and physics need evolve
  - Desirable to detect any data inconsistencies as fast as possible
    - Achieved by receiving both the inputs and outputs of the GT, the 40 MHz —> Scouting System

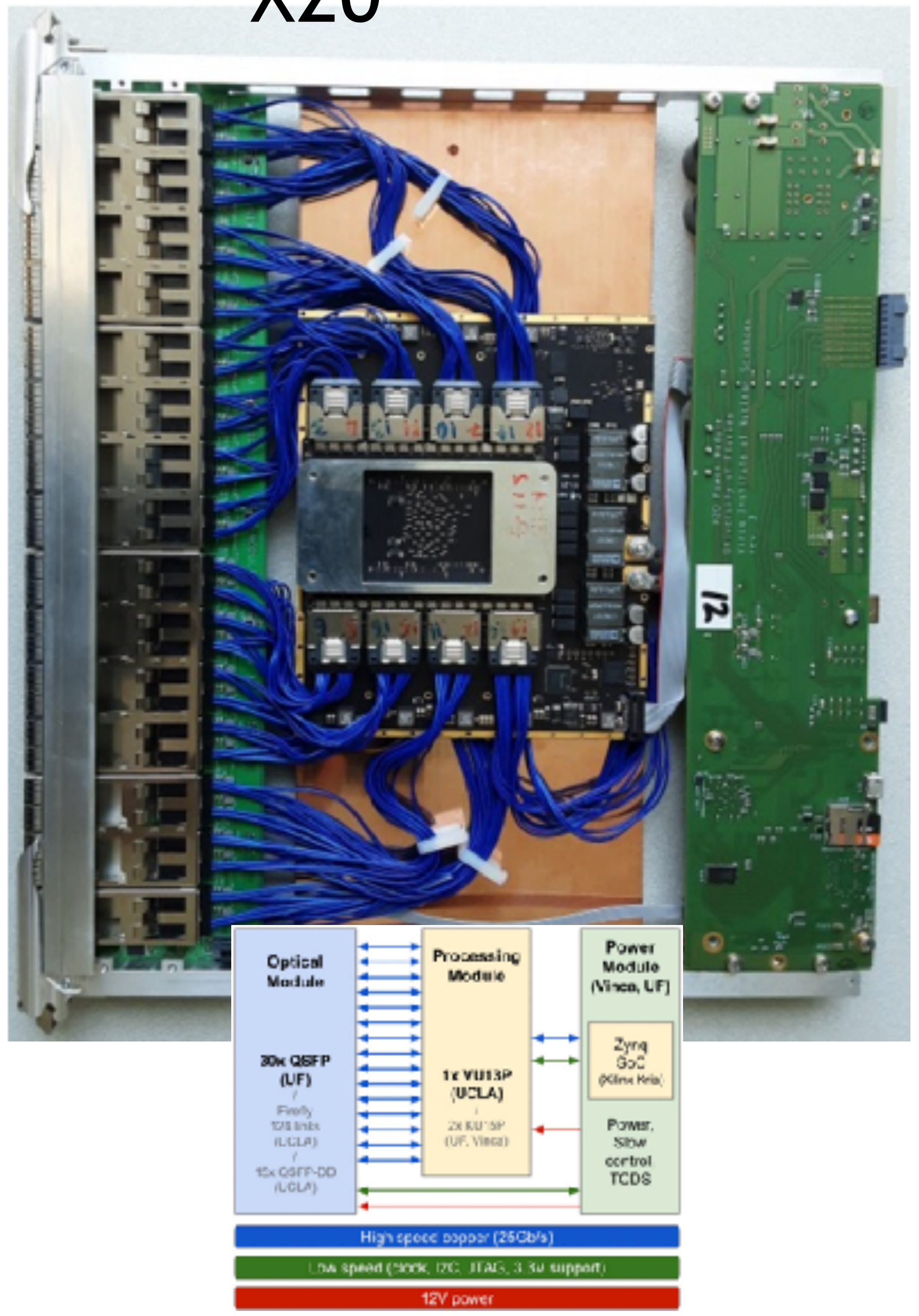


- Intermediate data from the different trigger processors will be read out and processed at the Level-1 accept rate by the DAQ system for triggered events, similar way as detector data.
- Scouting system represents a second, parallel readout chain running as an ”opportunistic experiment”, processing copies of the output streams feeding the different components of the Level-1 at 40 MHz

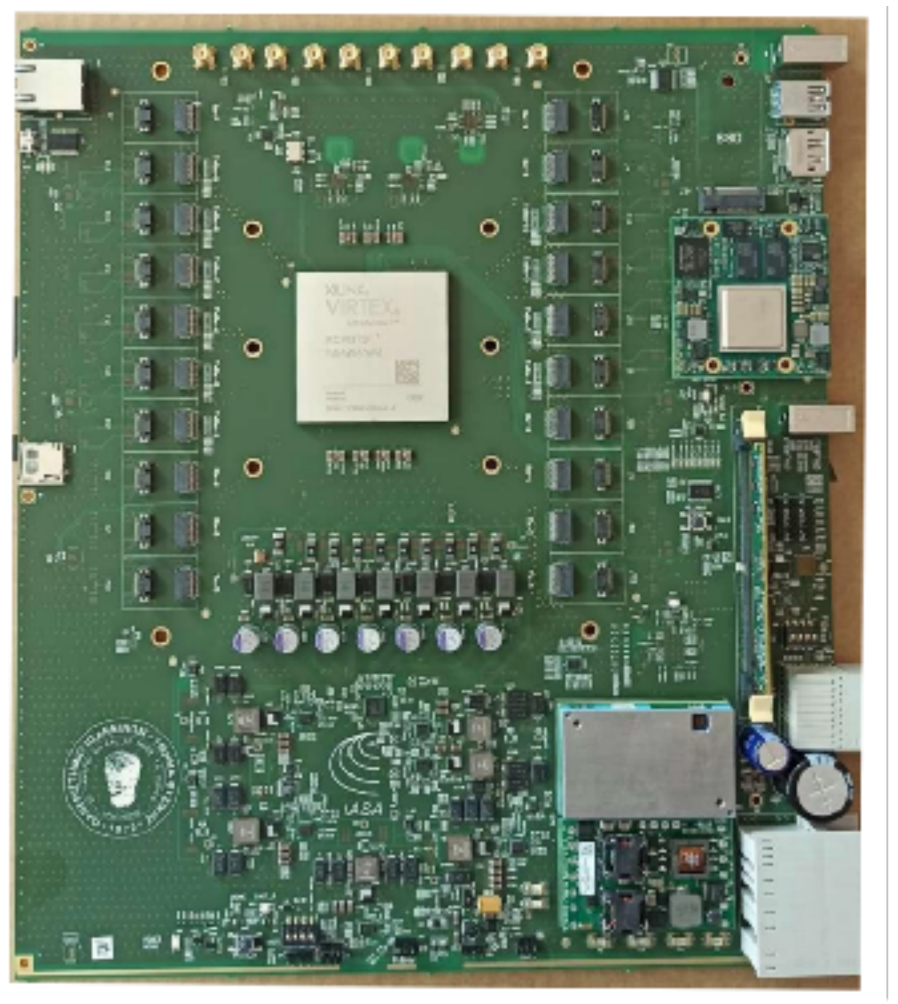
HW baseline eight-optical-input half-size PCIe board with a modest FPGA, supporting four optical links with 25 Gb/s

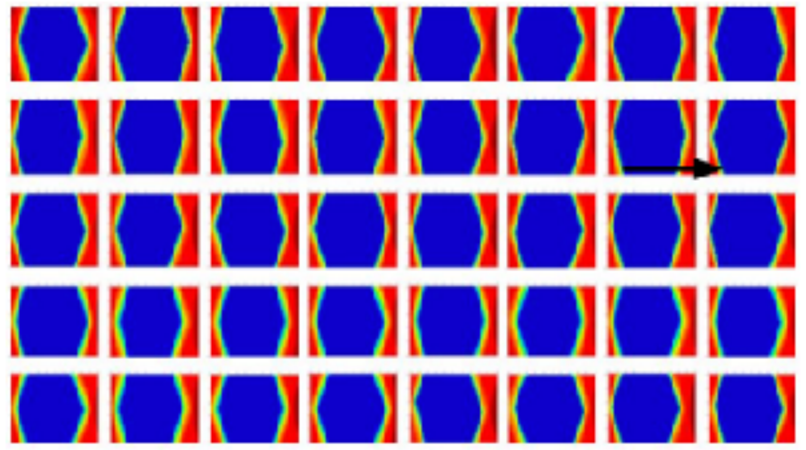
- ATCA boards hosting powerful Xilinx Ultrascale+ FPGAs with high I/O are designed
- Prototypes vailable in different flavors for Phase-2 L1-Trigger (optics Firefly or QSFP)
  - "X2O" for OMTF, EMTF, GMT (moving from Ocean in TDR)
  - BMTL1
  - "Serenity" for GCT, Correlator, GT
  - "APx" (GCT)

X20



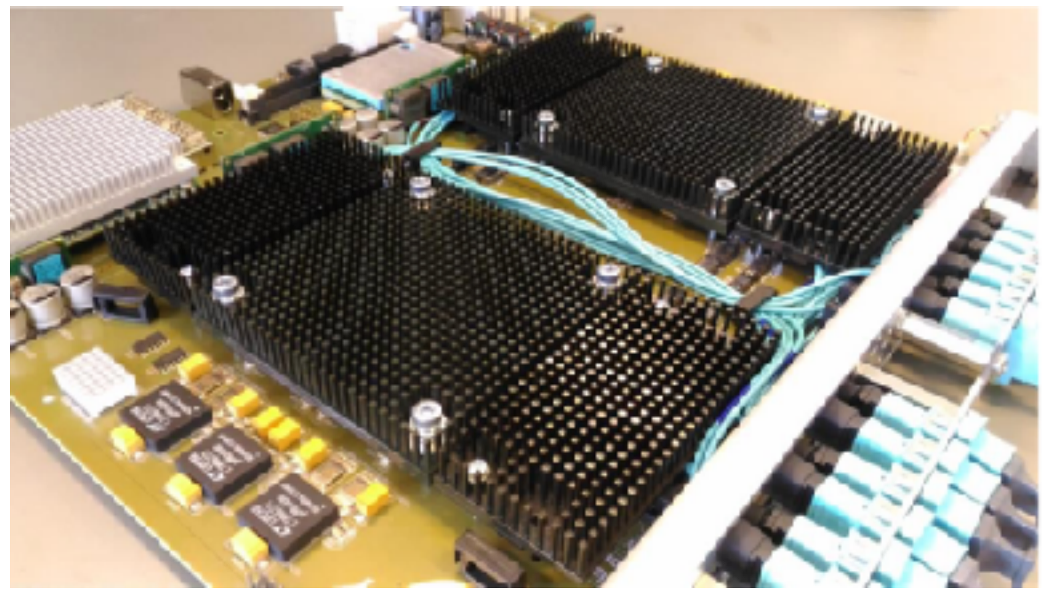
BMTL1



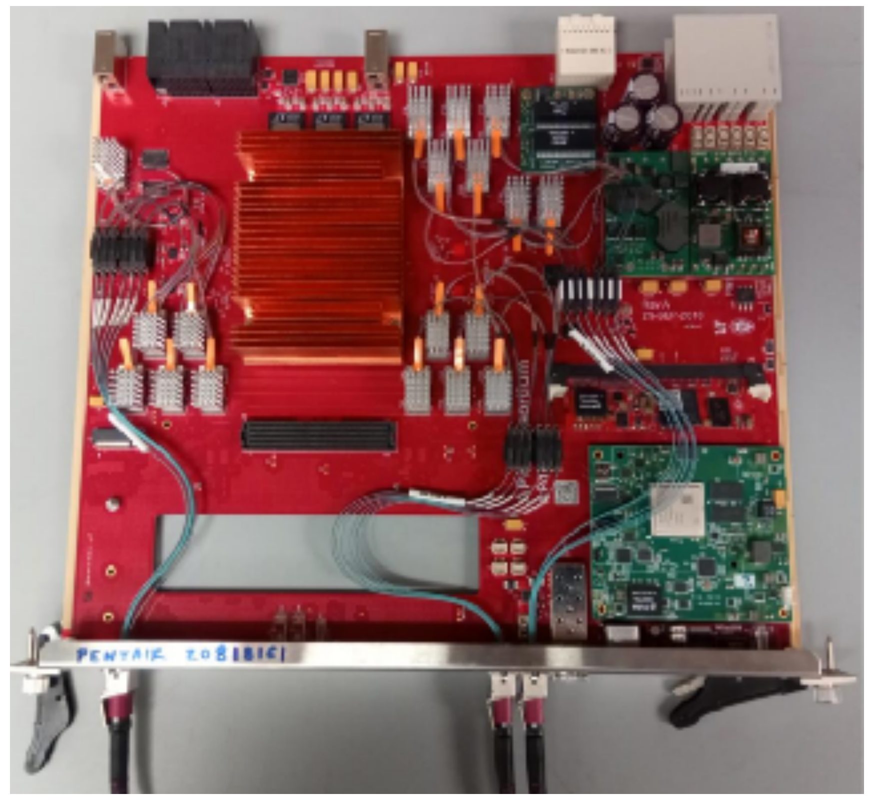


Excellent results of optics tests

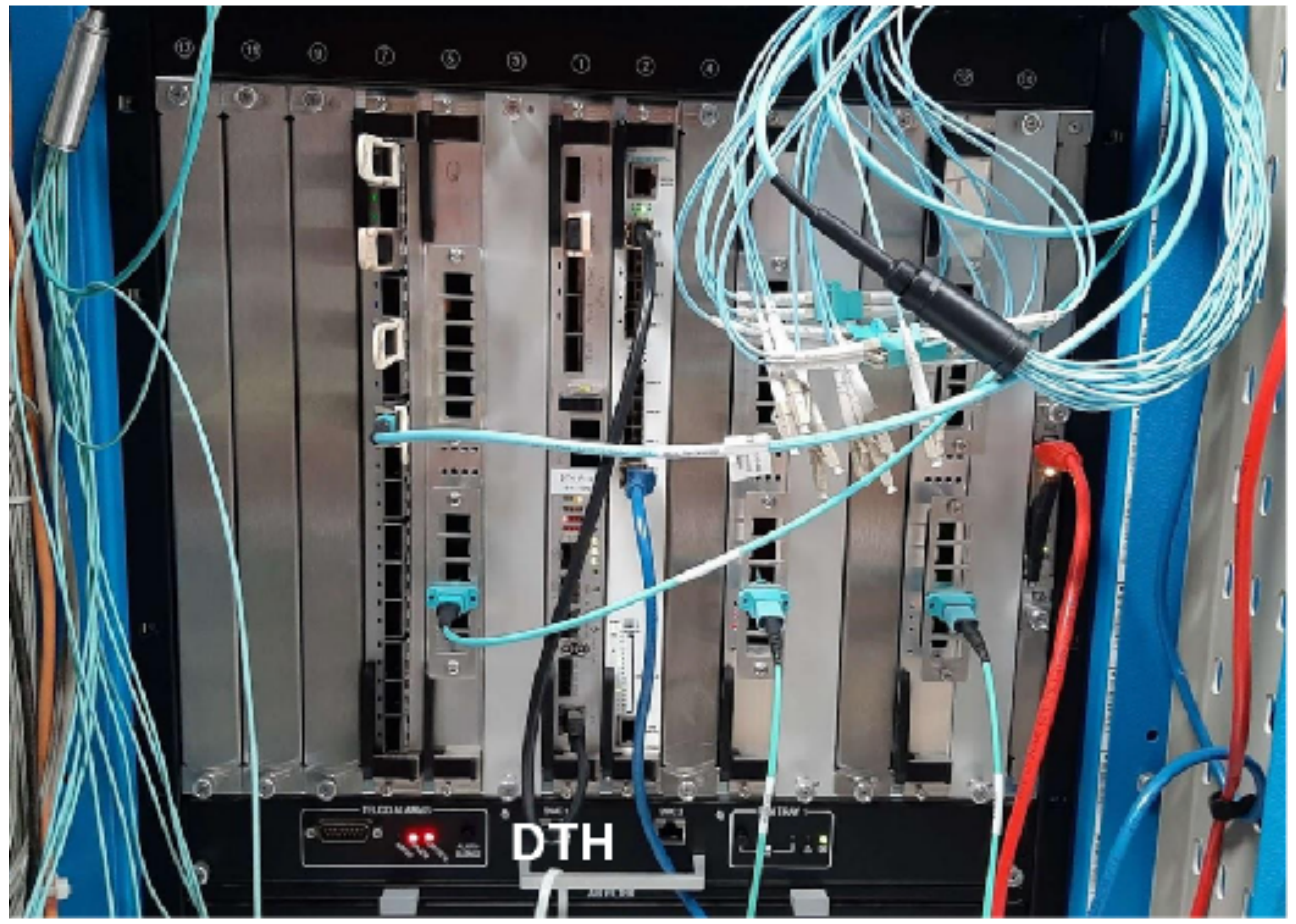
Serenity



APx

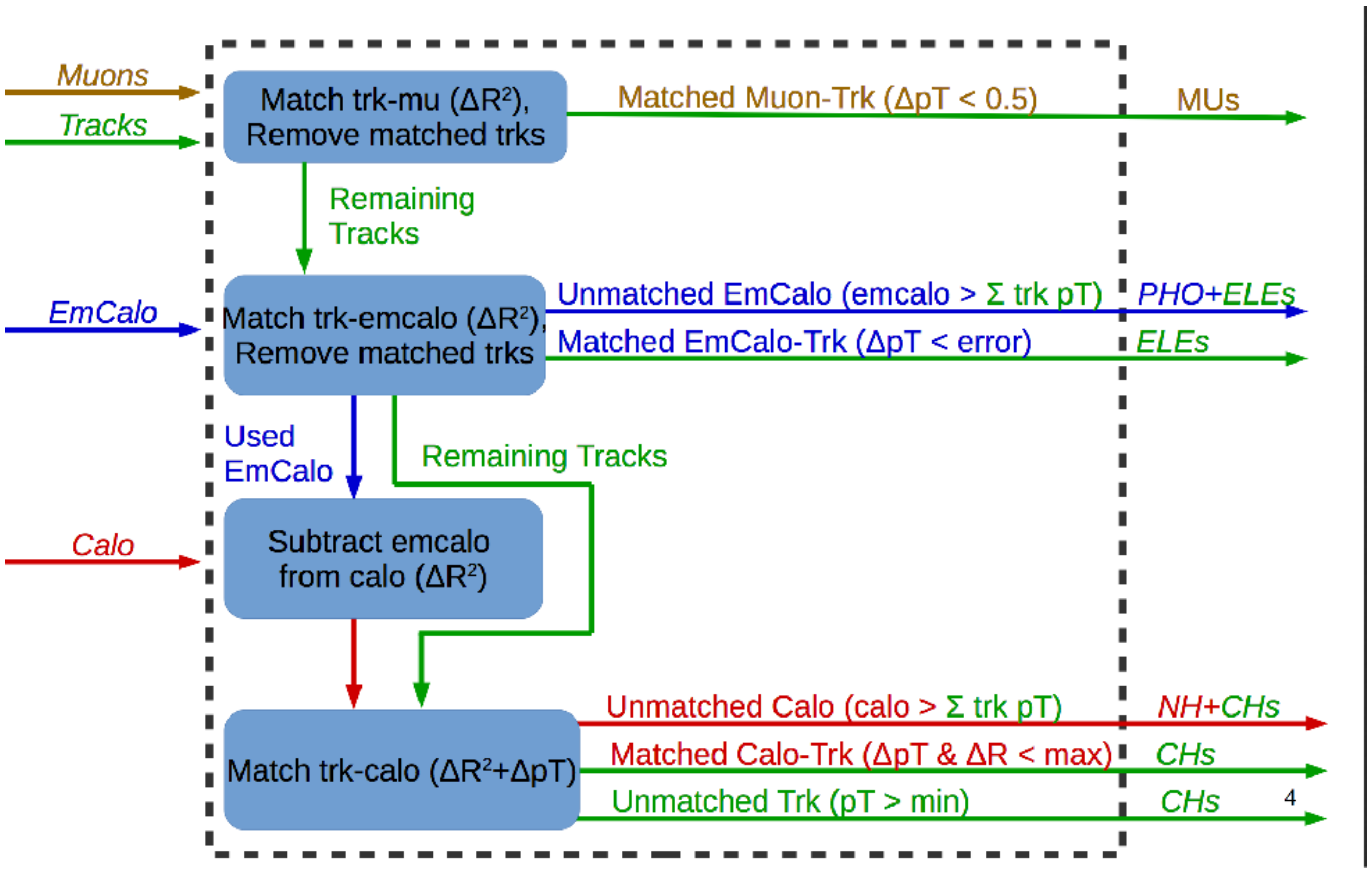


Ongoing Slice Test of FW with hardware connecting multiple boards of different flavors.



Progressing well towards electronics readiness review in Q1/2 2023.

BACK-UP



[PFlow algorithms]