CMS Trigger @ HL LHC

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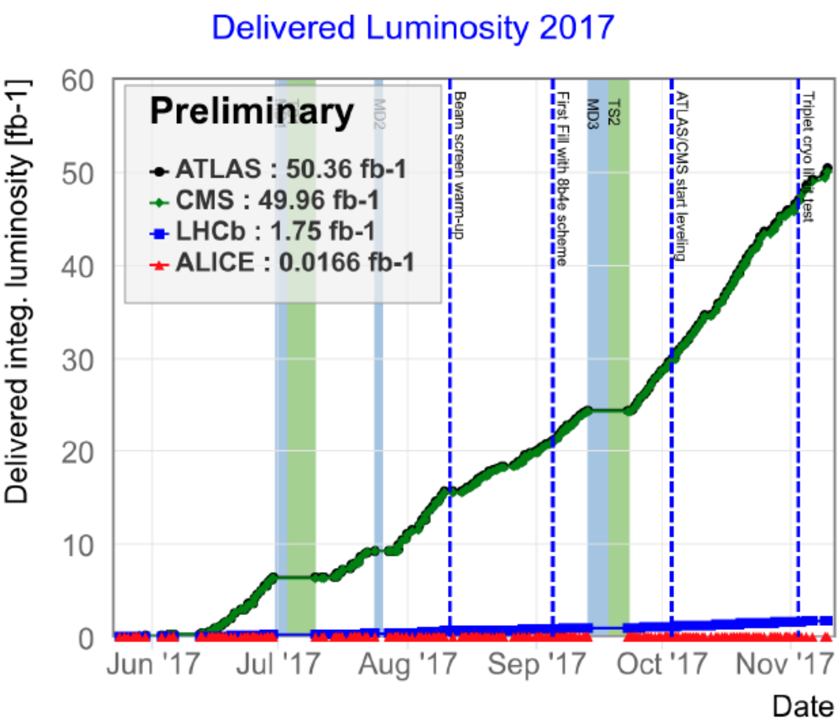
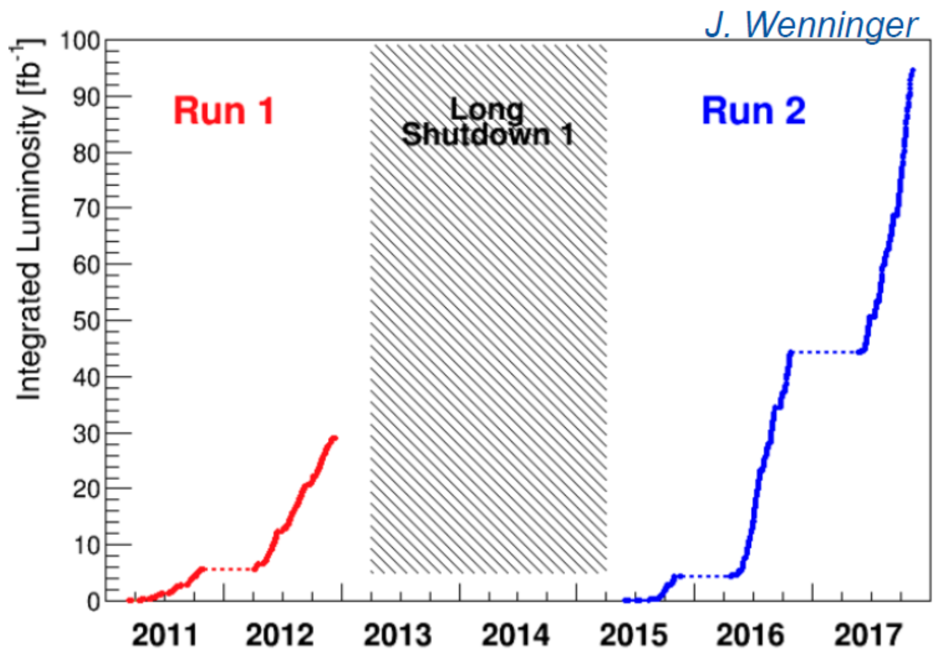
TDII-2018: Second Workshop on Triggering Discoveries in High Energy Physics, 29 Jan-2 Feb 2018, Puebla (Mexico)

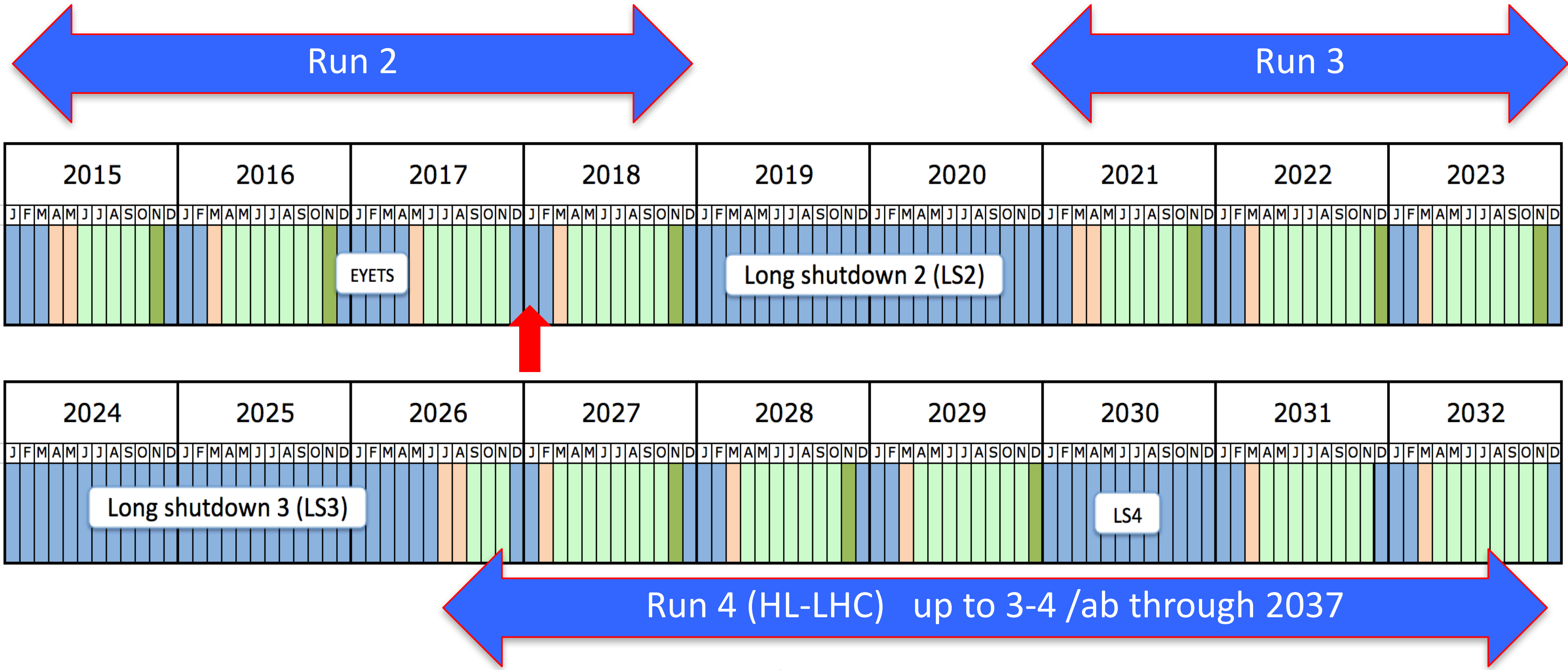
- In 2017 LHC met the goal, delivered ~50/fb to ATLAS and CMS!
  - Max inst. luminosity 2.0 x $10^{34}/cm^2/s$,
    - leveled to 1.5 x $10^{34}/cm^2/s$ with peak pileup ~50
  - Best fill 0.77/fb, best week 5.3/fb

- Run 2 int.lumi. is 100/fb delivered. Expected another 50/fb in 2018

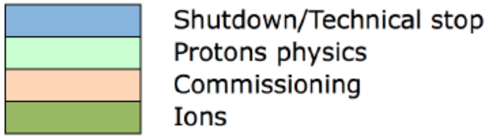




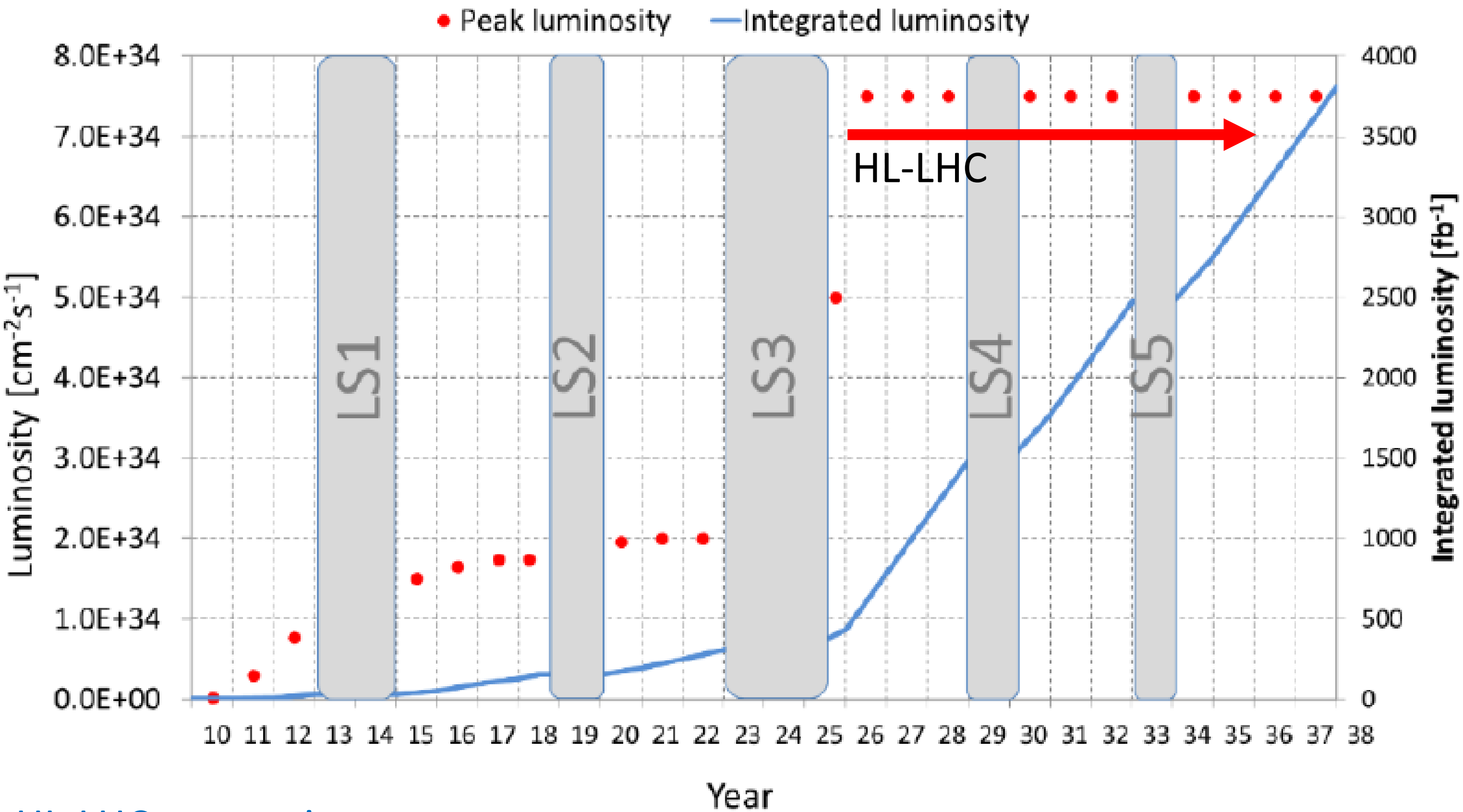
Long term LHC schedule



- Run 2 finishes end of 2018, with ~150/fb @ 13TeV total int.lumi
- In Long Shutdown 2 injector upgraded to increase energy to 7 TeV per beam
  - Run 3 is >150/fb@14 TeV
- Main HL-LHC upgrades in LS3
  - Run 4 ~1-1.5/ab starting fall 2026



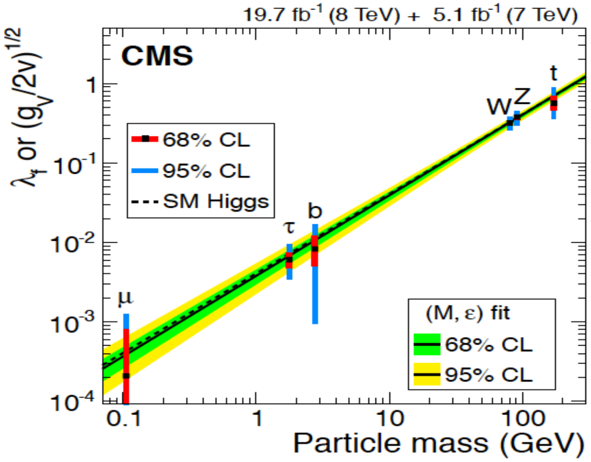
HL-LHC expected luminosity



- HL-LHC properties:
  - Luminosity initially increasing from 1-2E34/cm^2/s pre-HL-LHC → 5-7.5E34/cm^2/s
  - Similar number of bunches, 2x p/bunch, 4x smaller beta*
    - Luminosity could go as high as 2E35/cm^2/s peak capability
    - Level to 5 to 7.5E34/cm^2/s to deliver 250-400/fb/yr per experiment.
    - <PU> up to 200
- Last for ~10 years → 3-4/ab by 2038

Physics motivations

- New Physics (NP) could show up
  - as small deviations from SM predictions
    - Indirect searches via precision measurements
      - Ex. Measure SM Higgs couplings to ~1% to test for NP at 1TeV scale
  - in phase spaces not yet covered in Run2
    - Direct searches BSM involving weak-scale couplings with possible explanations for the observed gauge hierarchy or the quantum nature of dark matter.



  - Both need high-statistics data sets and improved detectors
    - => High Luminosity LHC, and Phase-II CMS Upgrade

HL-LHC and CMS

- The High-Luminosity LHC (HL-LHC) has been identified as the highest priority program in High Energy Physics by both the European Strategy Group and the US Particle Physics Project Prioritization Panel (CERN-LHCC-2015-019)
- CMS learnt lessons from Run-I & II.
- We want:
  - New tracker with smaller material budget (improve photon energy res. in ECAL)
  - Extended tracker coverage from η 2.4 to 4.0 (extend use ParticleFlow)
  - More precise calorimeter in forward region (photon, lepton, forward jets crucial for VBF)
  - Extended coverage of muons to increase acceptance
  - Could take advantage of TOF

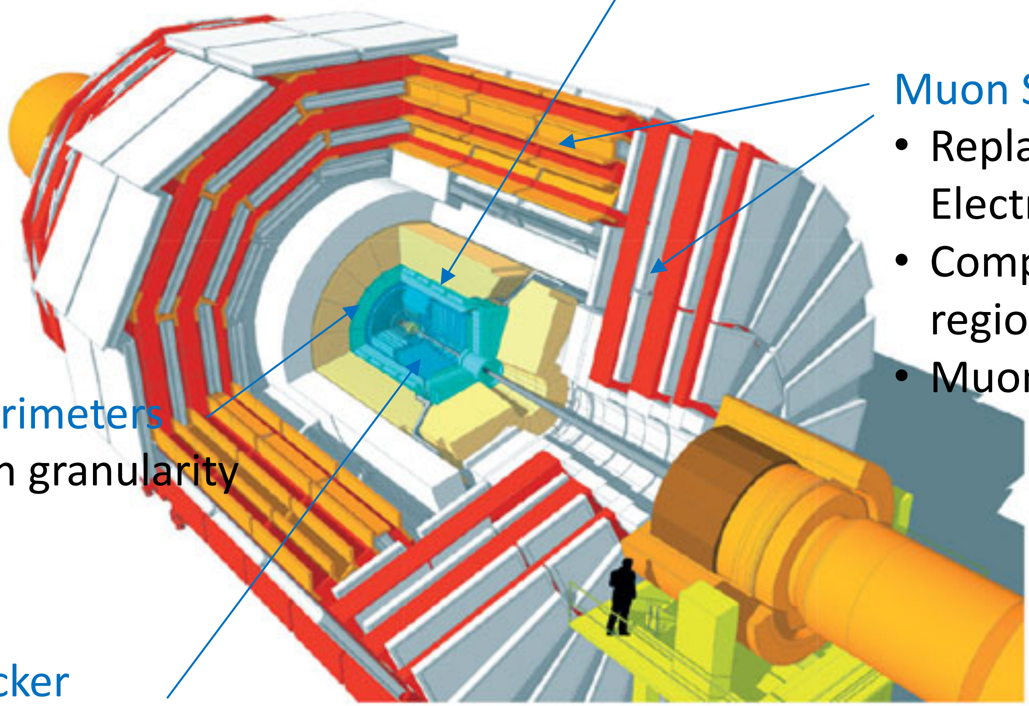
CMS-TDR-15-02

Trigger/HLT/DAQ

- Track information in L1-Trigger
- L1-Trigger: 12.5 μs latency – output 750 kHz
- HLT output 7.5 kHz

Barrel ECAL/HCAL

- Replace FE/BE electronics
- Lower ECAL operating temp. (8 □C)



Muon Systems

- Replace DT & CSC FE/BE Electronics
- Complete RPC coverage in region 1.5<η<2.4
- Muon tagging 2.4<η<2.8

Replace Endcap Calorimeters

- Rad. tolerant – high granularity
- 3D capable

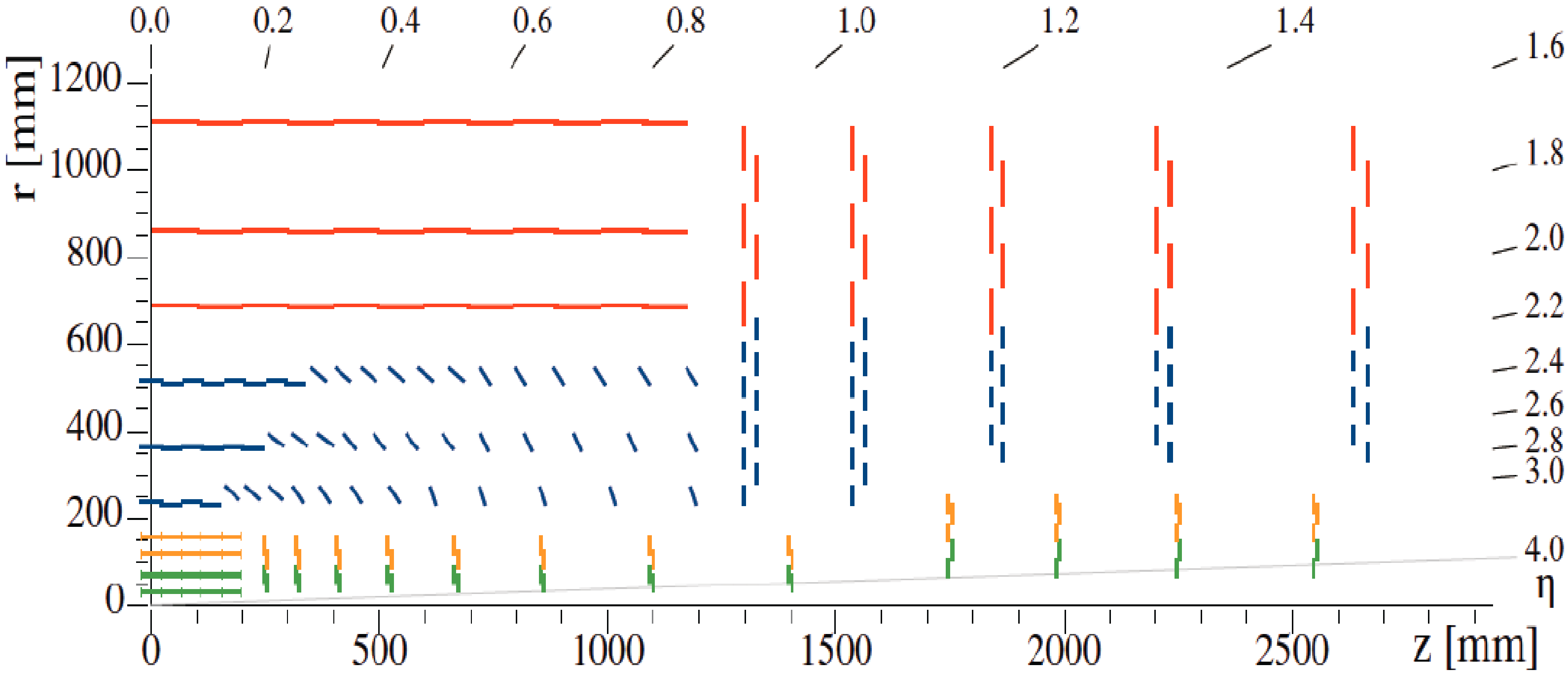
Replace Tracker

- Rad. tolerant – high granularity – significant less material
- 40 MHz selective readout (p_T>2 GeV) in Outer Tracker for L1 -Trigger
- Extended coverage to η=4

Phase 2 Upgraded Tracker System

CMS-TDR-014

Material budget decreased by ~50% for eta<2 w.r.t. current.
Outer (silicon layers) and Inner (pixels)



Outer tracker:
r = 25 -110 cm
eta < 3

Pixel tracker:
r=3 - 25 cm
eta < 4

Outer tracker has double-layer geometry for L1 track trigger stubs

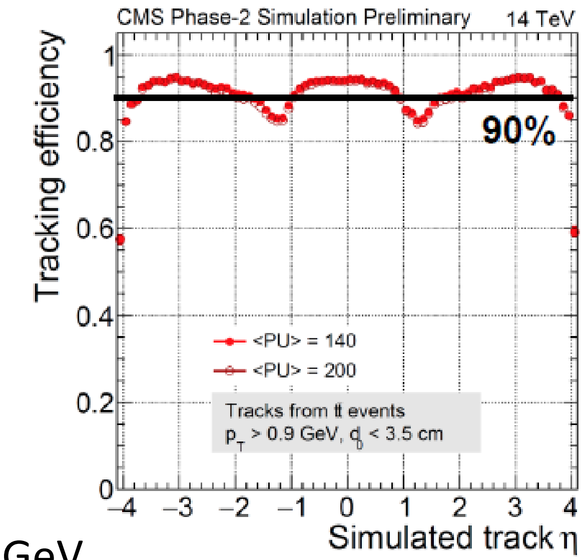
Phase-II Tracker Performance

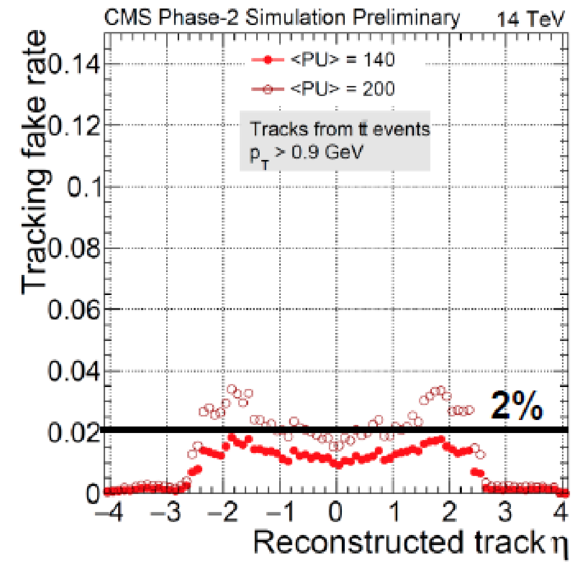
CMS-TDR-014

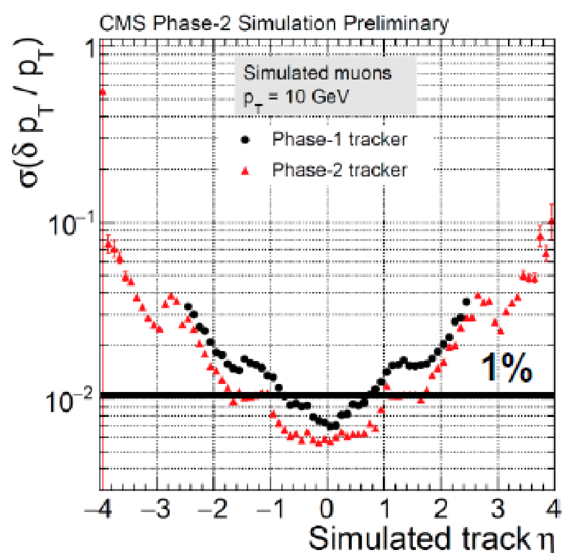
Good performance for track pT as low as 0.9 GeV
- good efficiency ~ 90%
- low fake rate ~2%

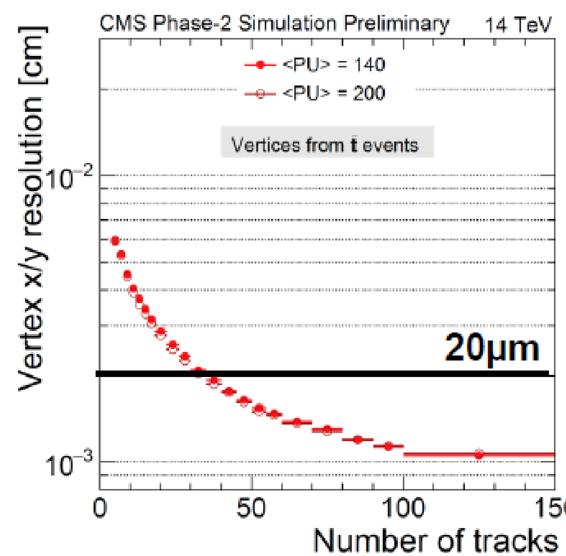
High pT resolution, ~1% @ pT = 10 GeV
God vertex resolution, ~20 um

Minimal performance loss at higher range of HL-LHC pileup



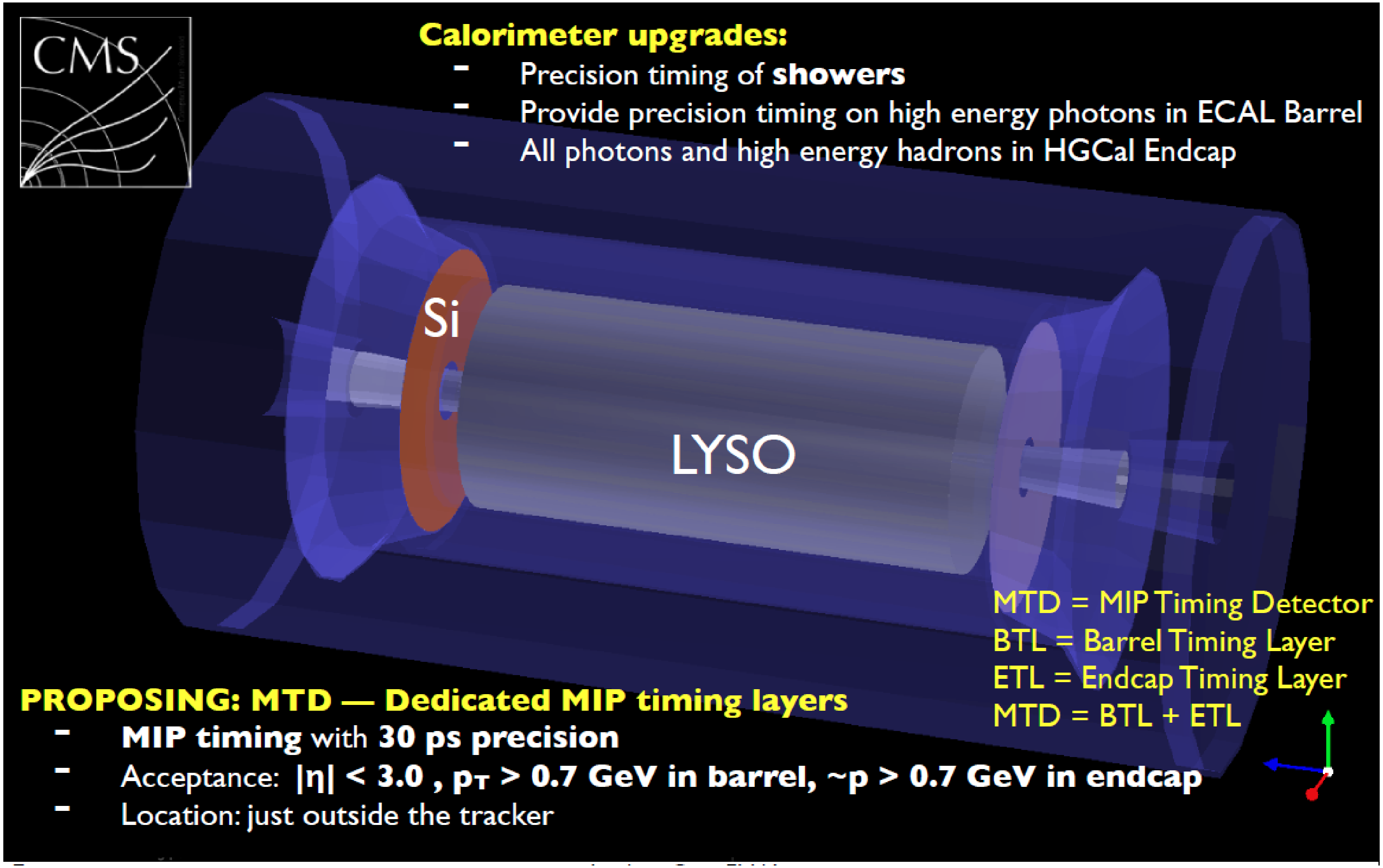






Phase 2 MIP Timing Detector

CMS-TDR-014



BTL: LYSO with SiPM ETL: Si with LGAD

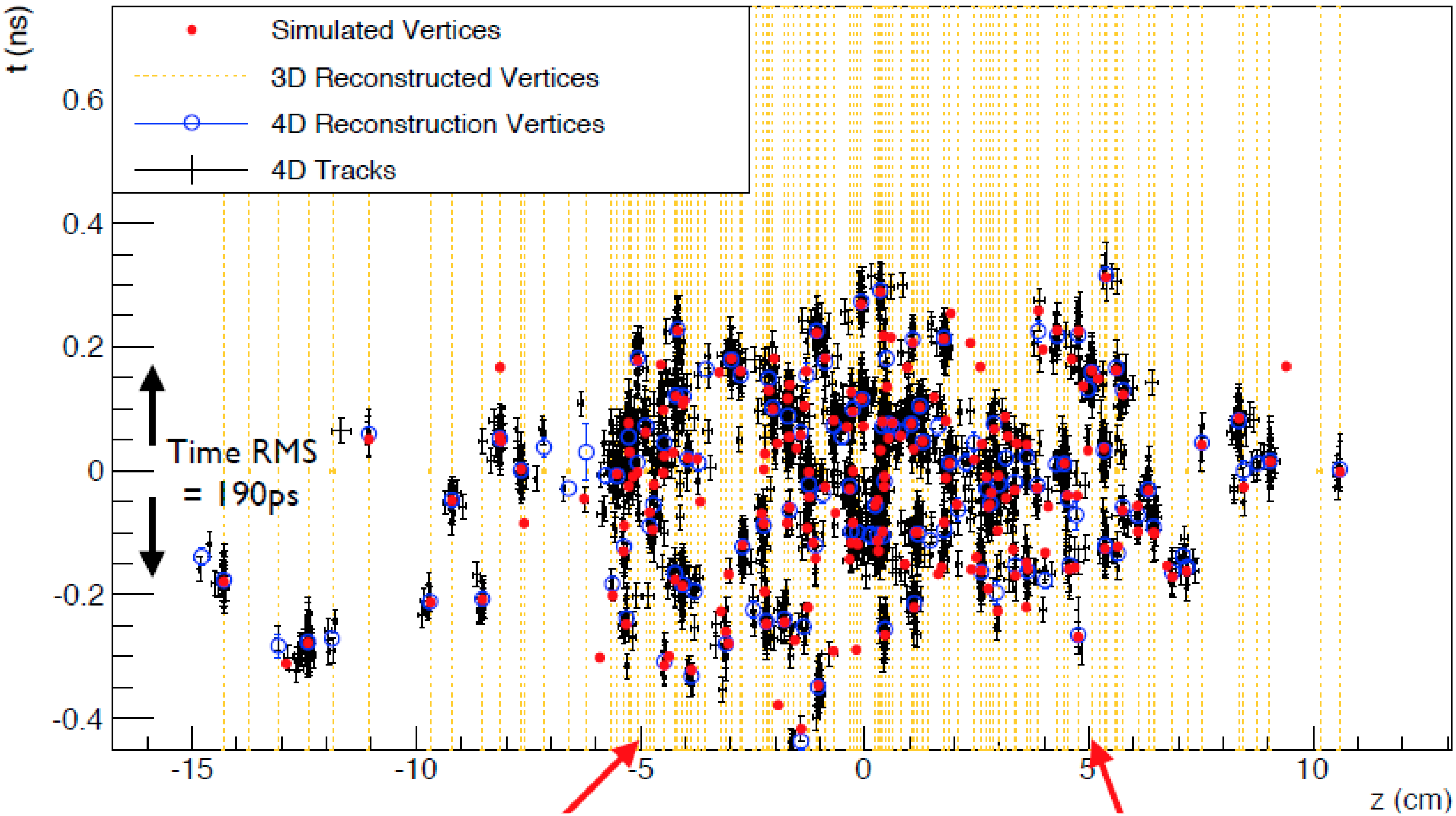
30ps timing out to eta of 3.0 for MIP Pt >0.7 GeV

Phase 2 MIP Timing Detector: **4D tracking**

CMS-TDR-014

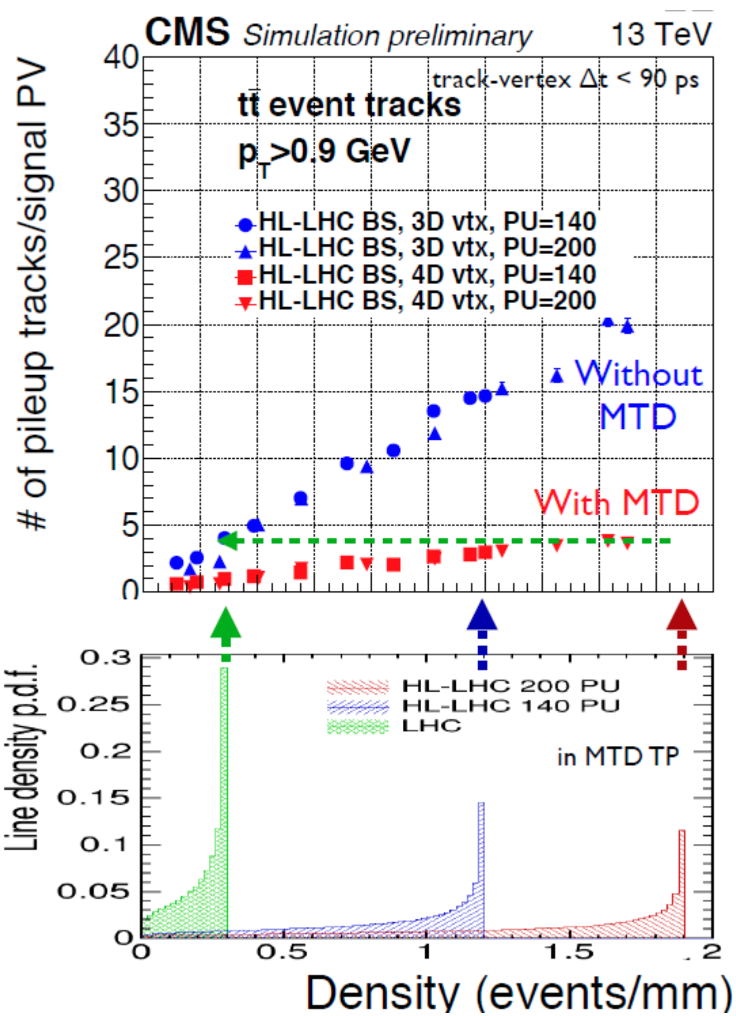
Time measurement resolution ~30 ps allows for separating charged track-vertex assignment in 4-5 time-windows:

HL-LHC charged PU=200 starts looking like **2017 PU=50** conditions.

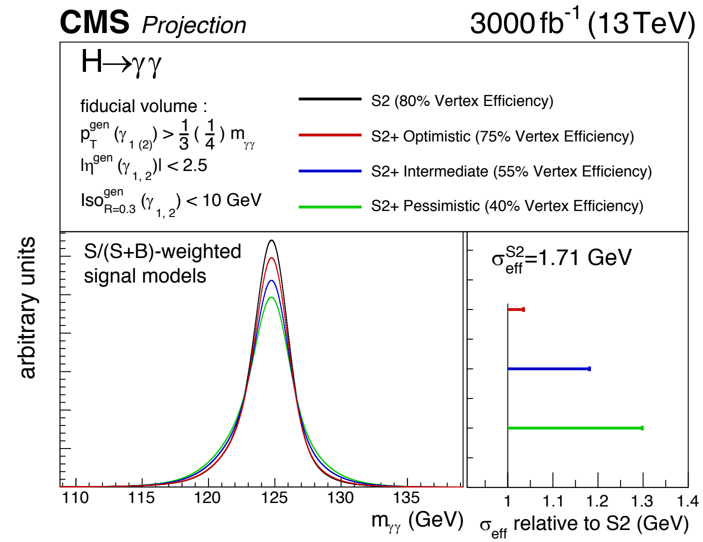


Phase-II w/MIP Timing Detector

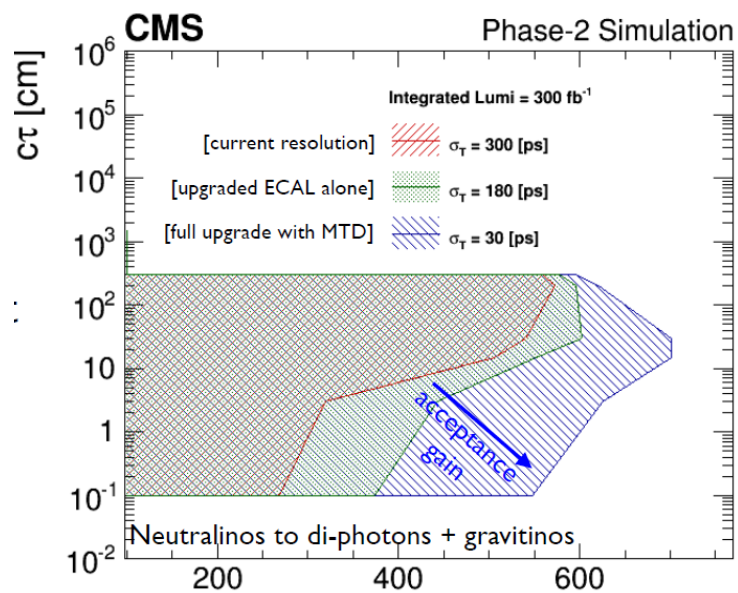
Vertexing:
With use of MTD, 3-4x reduction of PU tracks associated with signal (wrong) vertex.



Higgs physics

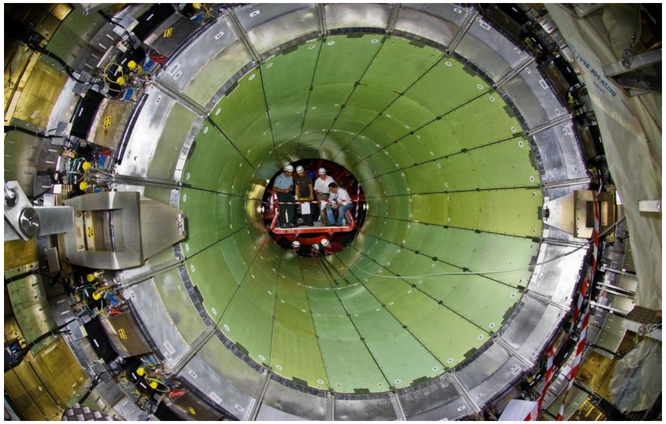


Extended sensitivity to BSM searches (LLP)

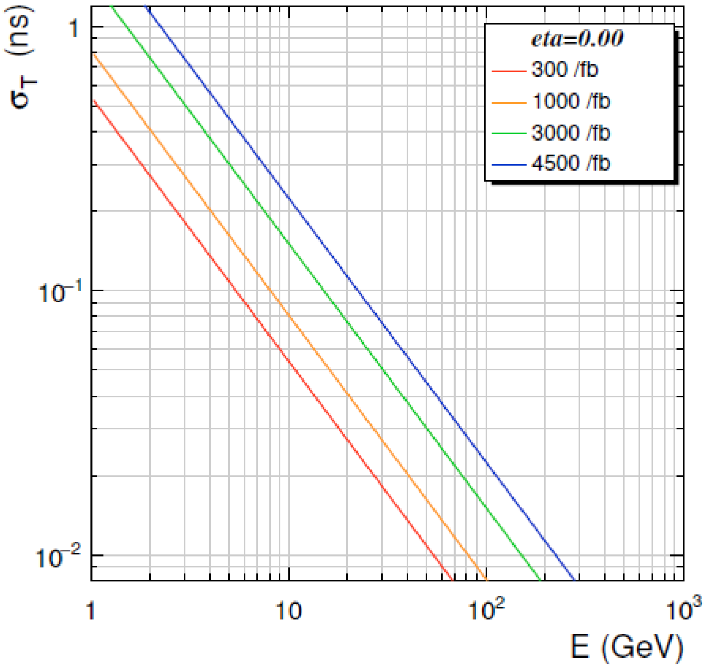


Phase 2 Barrel Calorimeter -- ECAL

- 36 Supermodules in eta < 1.5 region will be refurbished.
- All on board active electronics will be replaced.
- Only 61200 crystals and their APDs left untouched.



- Cool APDs to 8C to **reduce radiation-induced noise.**
- Change shaping time of preamp to reduce noise, improve background spike rejection, and allow for **30 ps timing resolution@ 50 GeV** (H→ $\gamma\gamma$ vertexing)



Upgrade readout electronics to output 750 kHz of data to DAQ and send **single crystal energies and timing data to L1 trigger (**was 5x5 energy sums) 0.0174x0.0174 in eta-phi

Quantity	N bits
E_T	10
time	5
spike flag	1
Total	16

Phase 2 Barrel Calorimeter -- HCAL

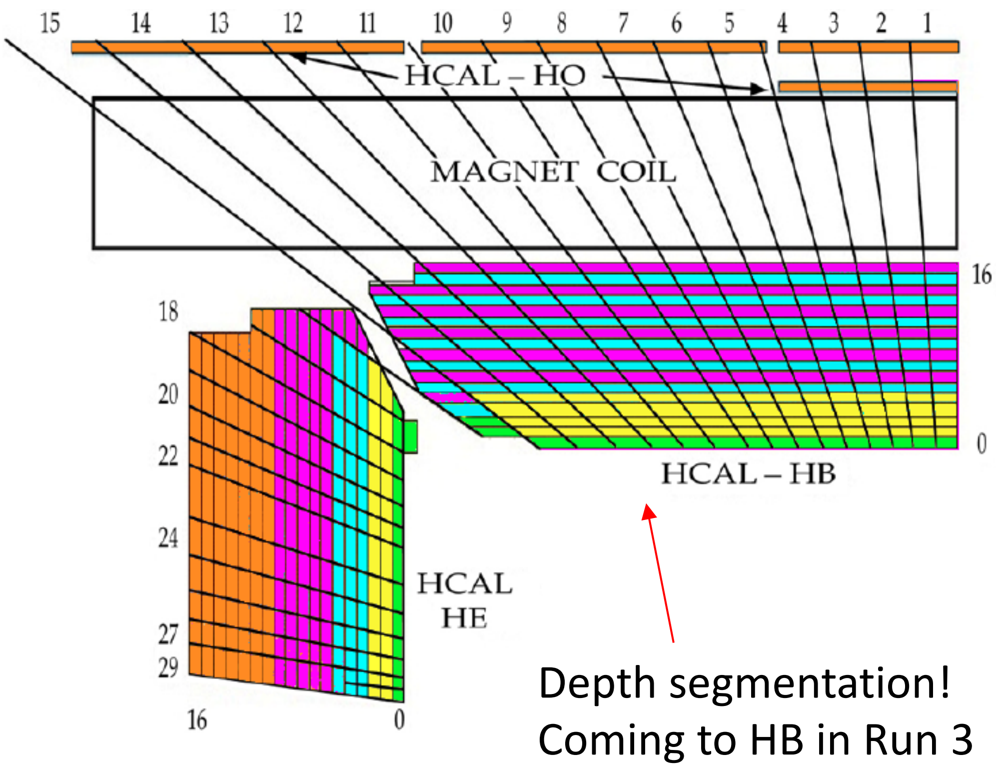
HCAL Barrel and HF readout electronics upgraded/expanded to accommodate 750 kHZ output to DAQ

Same FPGA boards used for HB as will be used for ECAL upgrade

Summing 4 readout depths per trigger tower,

10 energy bits + 6 “feature bits” output to L1 trigger, still under definition and study

Offline HB (HF) data payload includes 8 (3) time samples of each channel and 4 (2) bunch crossing of trigger primitives



Phase 2 Endcap Calorimeter - new detector

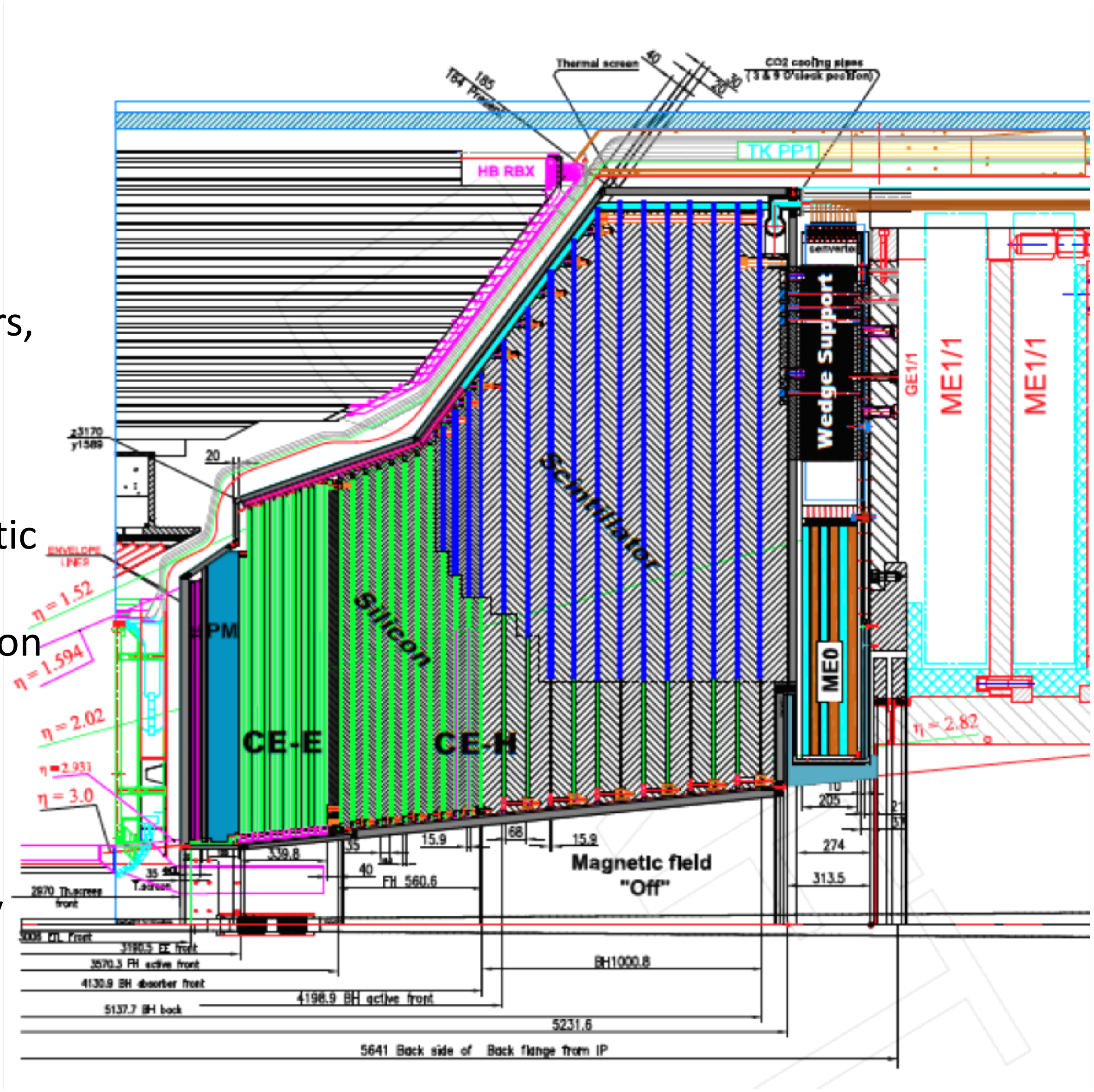
Brand new endcap calorimeter spanning 1.5 < eta < 3.0

SS/Cu/WCu+Si sensors in front layers,
SS+Si in forward hadronic layers
Scintillating tiles+SiPMs in the back

28 sampling layers in electromagnetic section “CE-E”
24 sampling layers in hadronic section “CE-H”

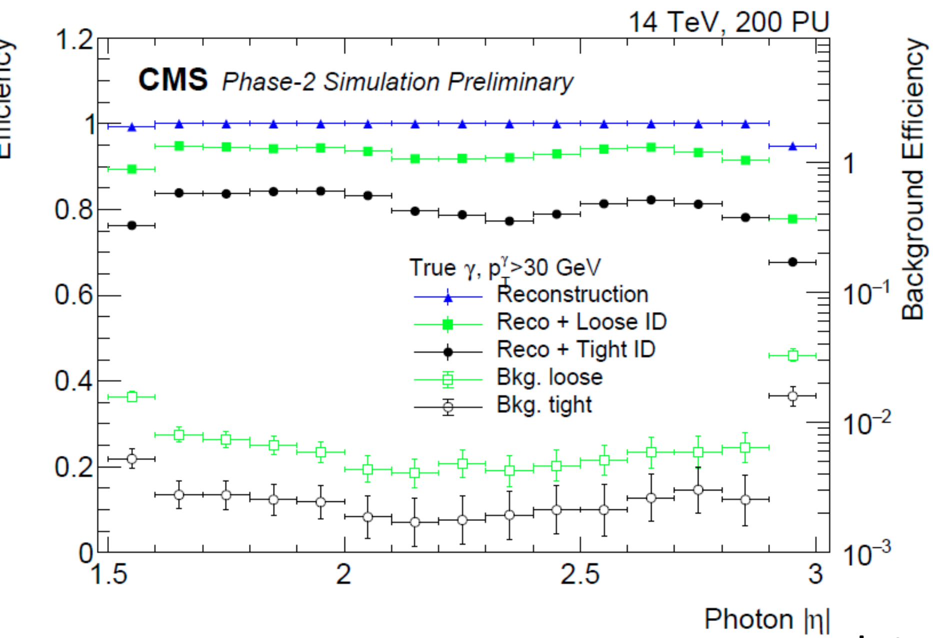
3-D shower reconstruction

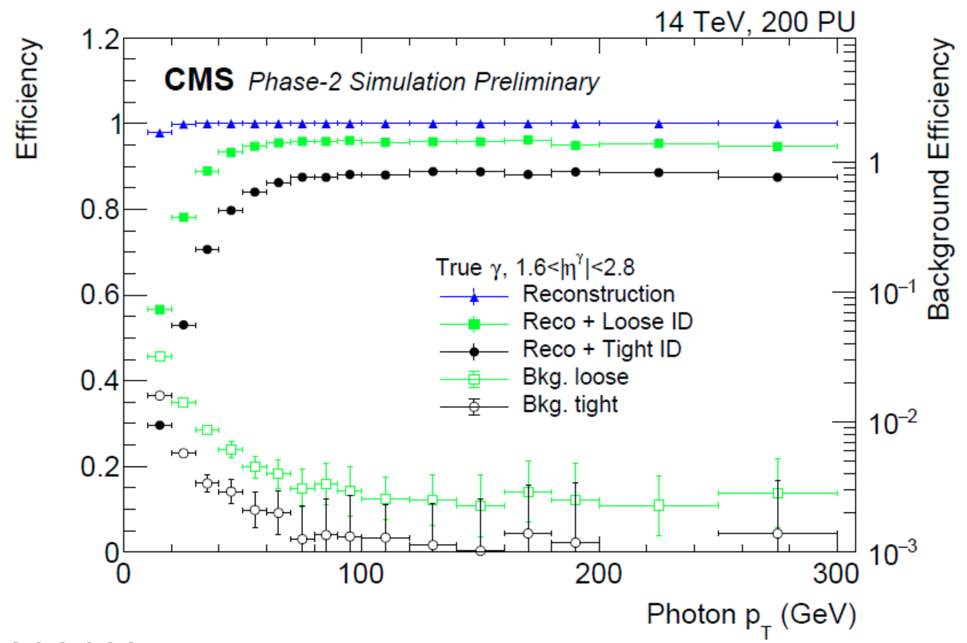
~25ns shower max timing capability



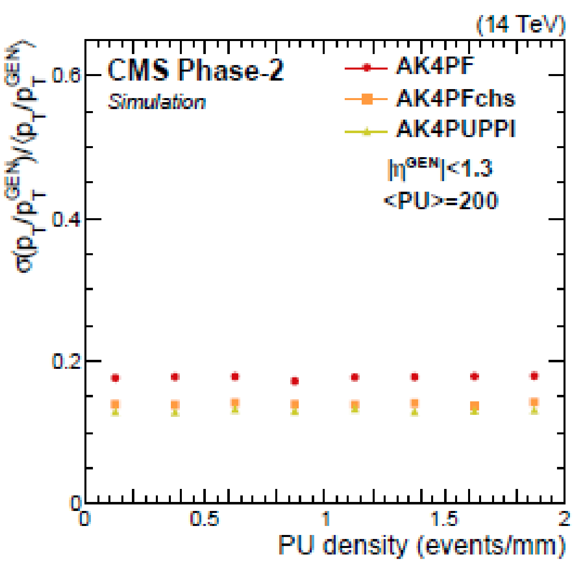
Phase-II Endcap Calorimeter Performance

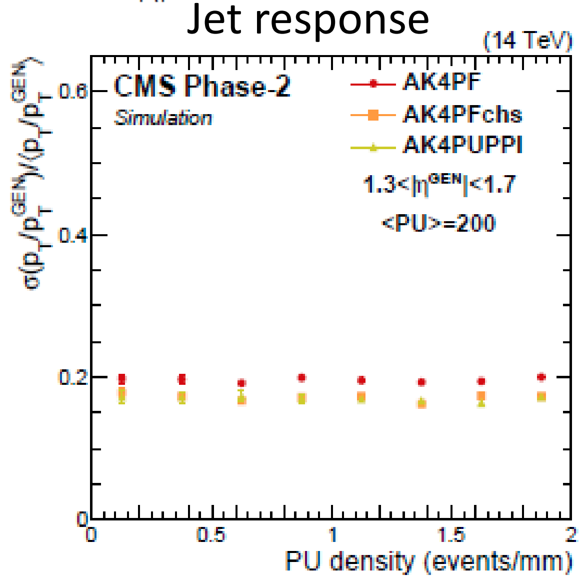
Photon Identification

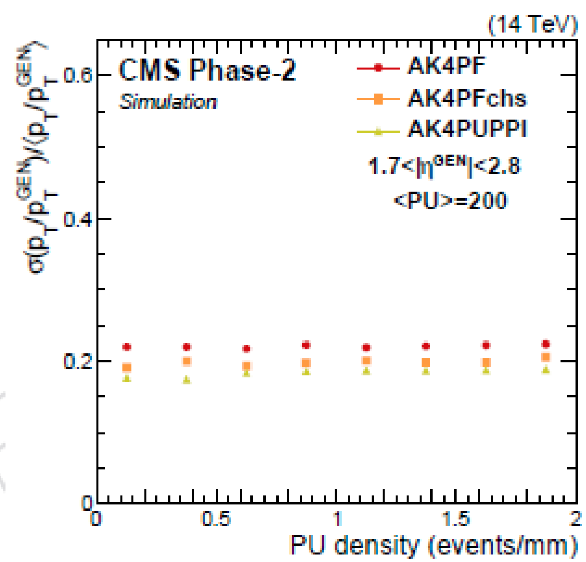




Jet response

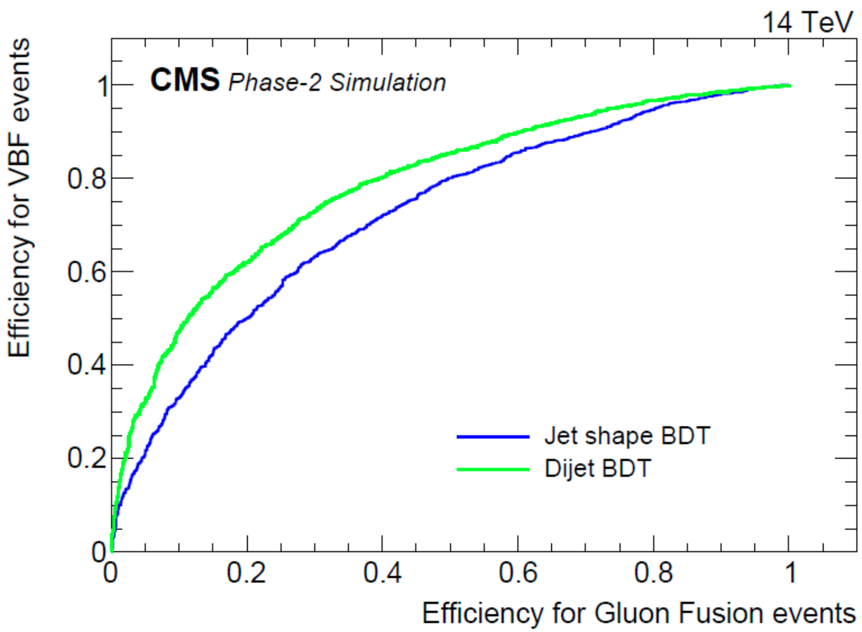




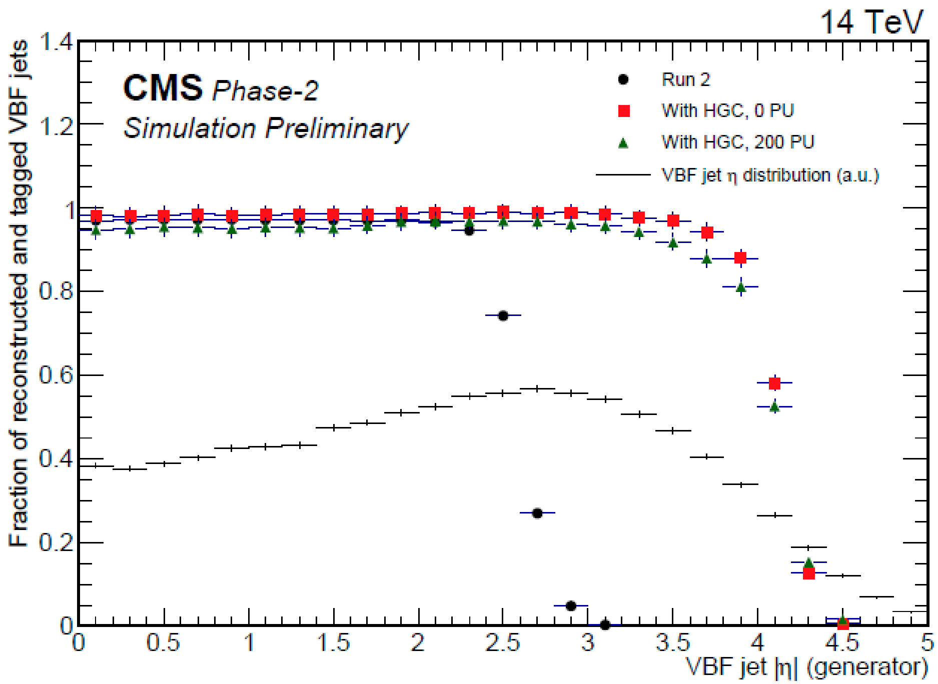


Phase-II Endcap Calorimeter Performance

Good discrimination of ggH and qqH



Excellent VBF jet reco performance out to eta=4



Plus:

Increased acceptance ~+12% H->gg with much better endcap performance.

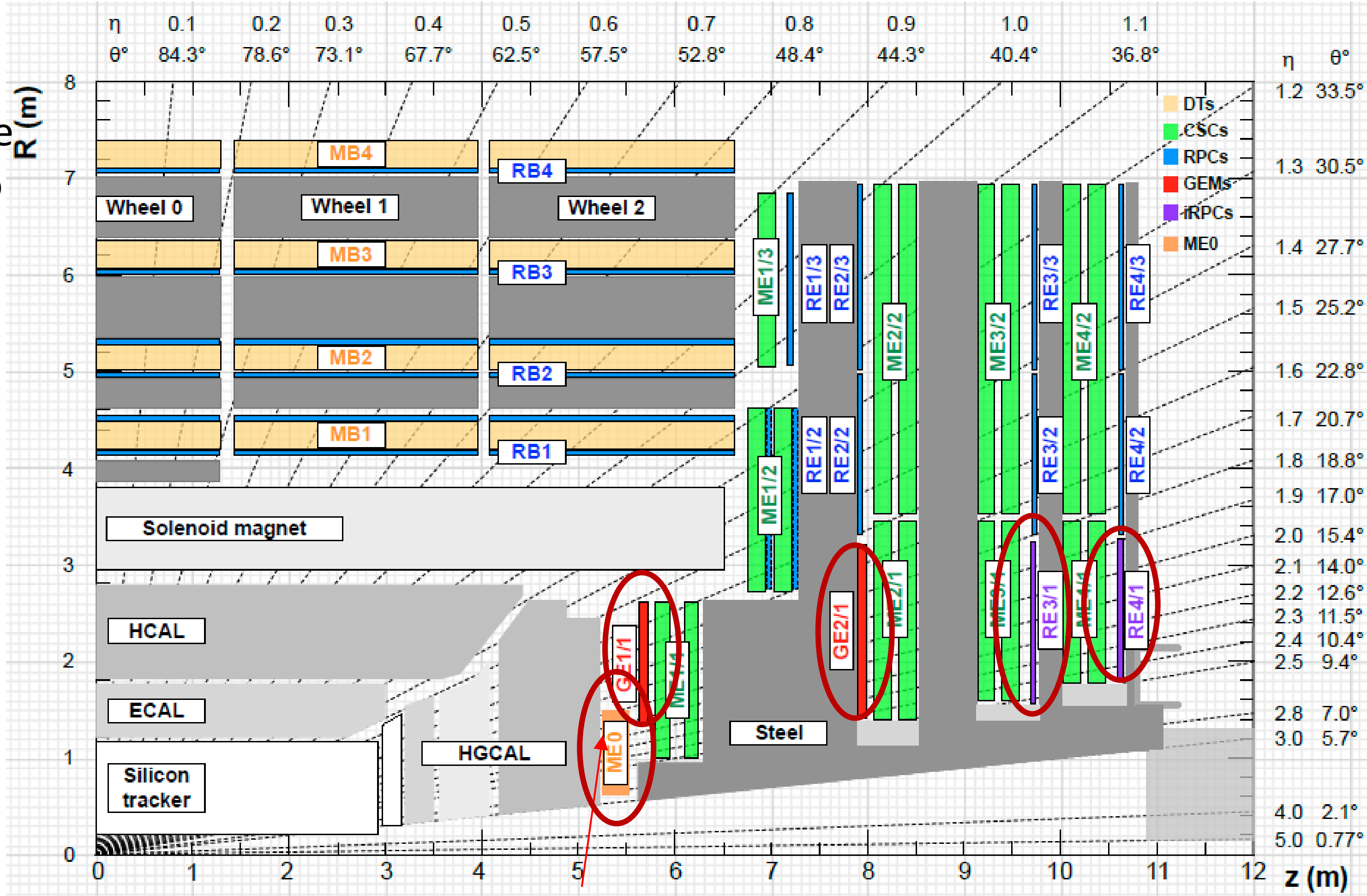
Improved b-tagging and tau reconstruction.

Phase-II Muon System

CMS-TDR-016

New electronics throughout to reduce latency and accommodate 750 kHz output to DAQ

GEMs and new RPCs to improve forward coverage and redundancy for better eff.

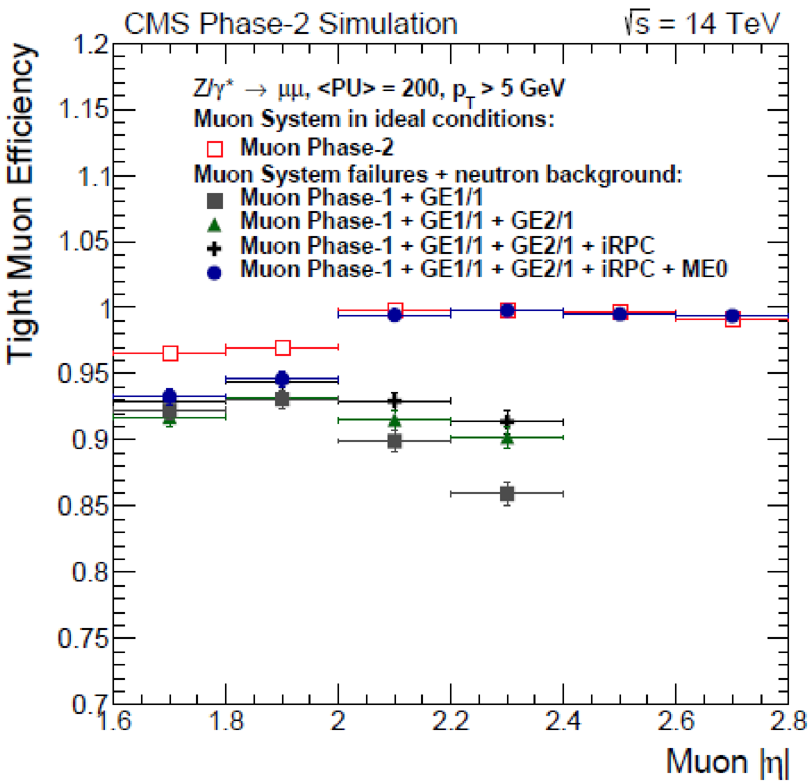


New ME0 layer expands coverage from 2.4 < eta < 2.8

Phase 2 Muon System Performance

CMS-TDR-016

GEMs and new RPCs to improve forward coverage and redundancy

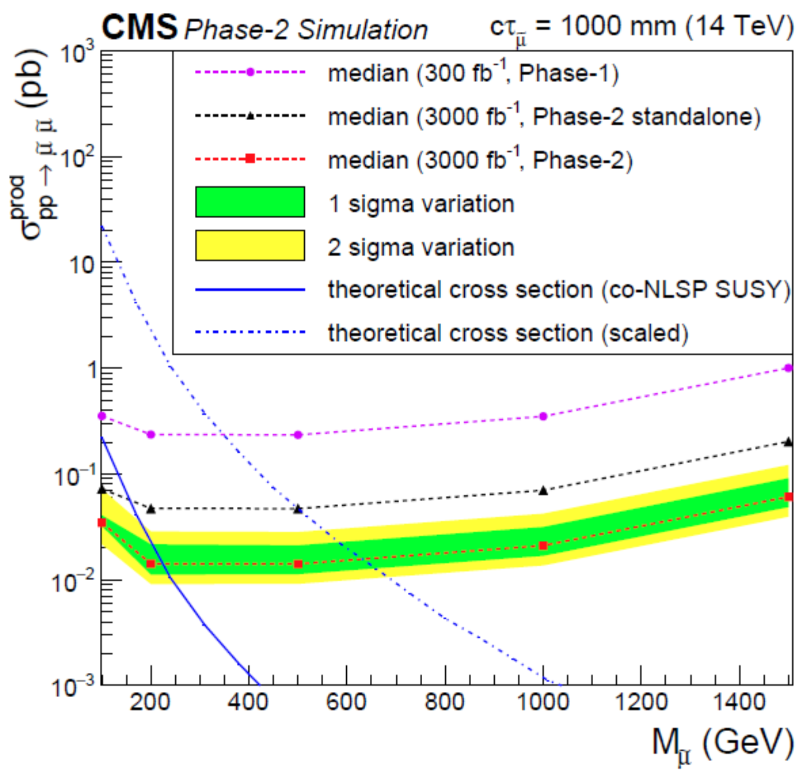


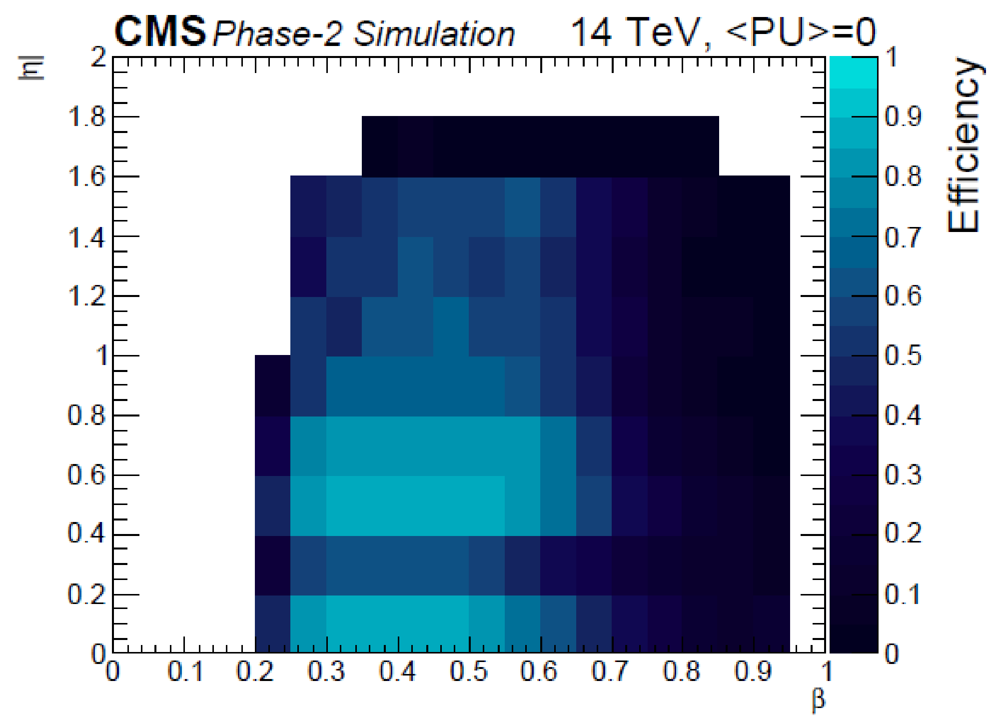
Phase-II Muon System

CMS-TDR-016

With standalone tracking precision aided by GEMs, displaced muon (ct<100cm) sensitivity improves by 3X

New RPCs will extend HSCP sensitivity down to β ~0.2





Plus:

Tau → 3mu sensitivity 2x better

H →4mu acceptance up 17%

Trigger Upgrade

- Phase-I DAQ capable of readout at **100 kHz and 3.8 us** latency for a L1 trigger decision.

- Phase-II we will have 5-7x more inst.lumi.
  - Q: How to upgrade L1T to have the same or better trigger menu and efficiency of today?

- Will have expended DAQ capabilities: readout **750 kHz (from 100 kHz),** latency **12.5 us (from 3.8 us)**
  - This accounts for increase in increase in signal rate (linear with increased lumi)
  - Does not account for non-linear increase in background due to extreme PU (200)

$\Rightarrow$ Must improve in purity of L1T filtering

Trigger Upgrade Strategy

- Exploiting the **more refined data** from new subdetectors (HGC, GEM, RPC) and electronics upgrades of existing subdetectors (CSC, DT, EB, HB).

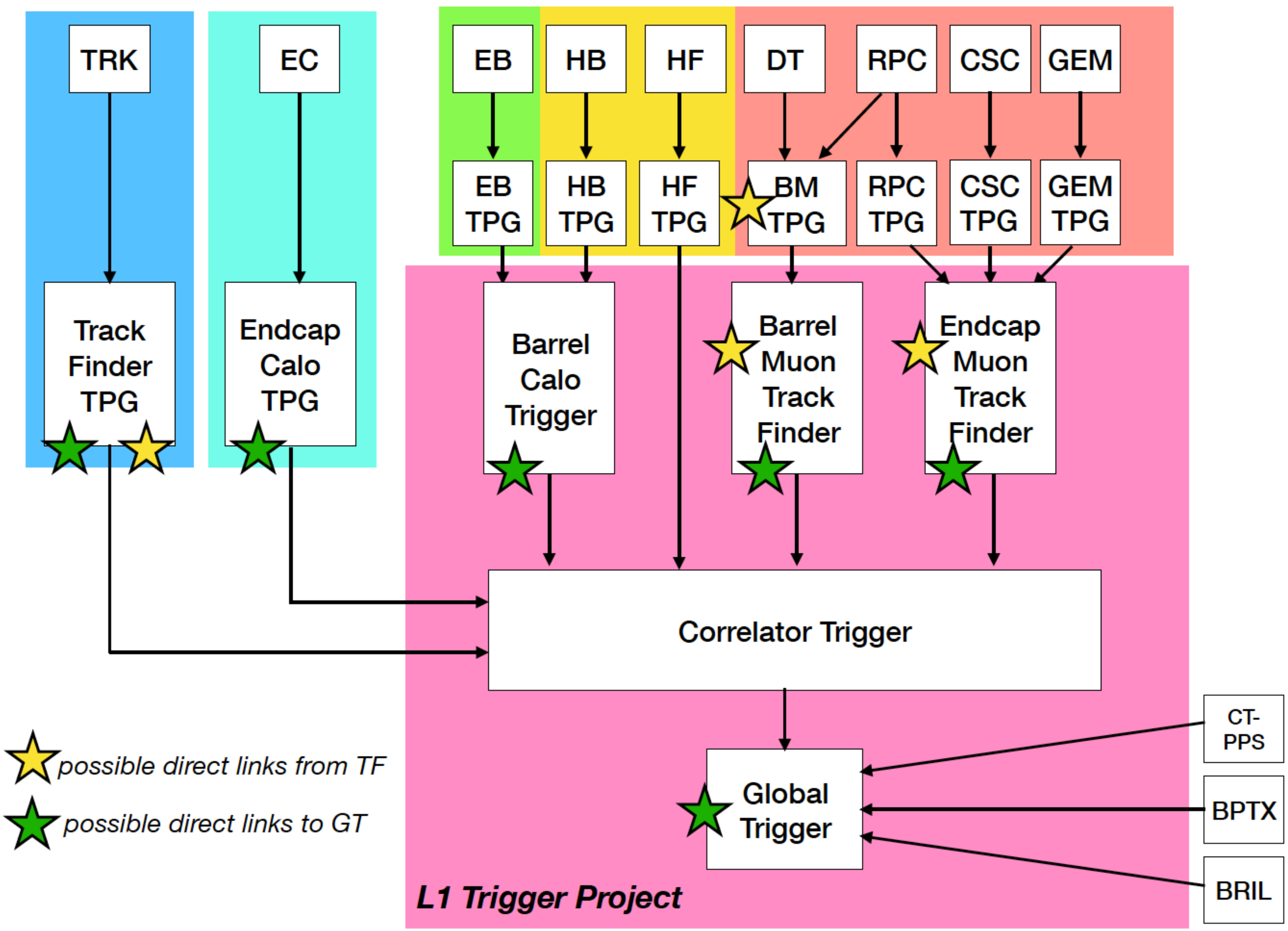
- Combine the tracking data from the **Track Trigger** and the rest of the detector to provide best resolution for particle energy/momentum and remove the effects of pileup.

- **Offline-like (Particle flow + Puppi)** reconstruction techniques to minimize PU effect

$\Rightarrow$ **Requires rebuild of entire backend + L1 system**

- CMS published "**Interim Technical Design Report**" (CMS-TDR-17-004), the rest of the talk.
  - Mostly discussion of algorithms
  - Input data and algorithms will drive final HW design
    - will take a full advantage of FPGAs and optical link technology expected to advance in coming years

High-level view of Phase-II L1 trigger



Trigger Latency of 12.5 us

- Detector readout and DAQ systems will allow 12.5 µs latency
  - Tracking information for the L1 trigger require increase in L1 latency
    - Input data received by CT: 5 µs (needed by L1 track trigger)
    - Trigger objects received by GT: 7.5 µs (tracks processed to find the PV, associated to PV, matched with Calo and Muon objects, used to compute isolation …)
    - L1A received by TCDS: 8.5 µs (global sums, kinematic calculations, trigger decision logic…)
    - L1A received by front-ends: 9.5 µs (plus 30% of safety factor)

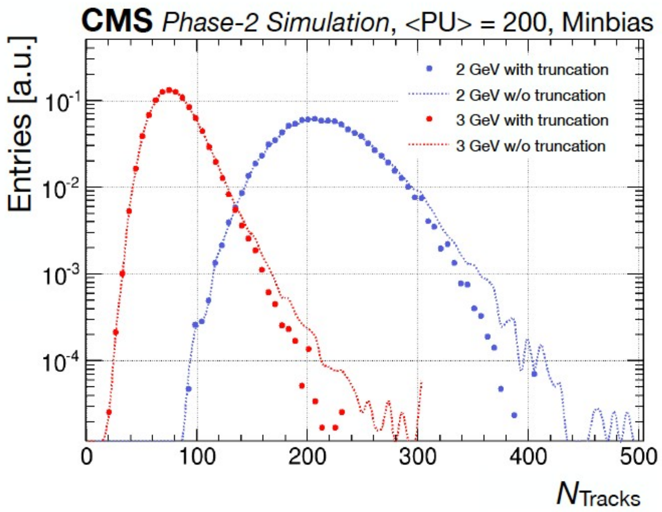
- Detector readout and DAQ systems will allow L1A rate of 750 KHz
  - adding L1 tracking information matched to improved L1 Calo and Muon trigger objects rate substantially reduced:
    - from L1 Menu studies 260(500) KHz @ PU140(200) + 50% uncertainty

L1 Trigger Algorithm Development

- Needed to maintain current low thresholds
  - Determine PV with heavy use of tracking, to mitigate PU
  - As always, strive for hight L1T object pT resolution to improve efficiency turn-on curves and reduce rate.
    - Mimic offline object-reconstruction as much as possible. Exploit Track Trigger info.

- R&D
  - Simple stand-alone L1T objects (calo based, muon based):
    - e, tau, photons, jets, sums, muons.
  - L1T Track + L1T-standalone object, matched in eta-phi
    - Large improvement in rate w.r.t stand-alone
  - Particle Flow (PF) at L1T
    - Take advantage of full detector info and use a simplified version (limited resources) of offline Particle Flow ID algorithm.

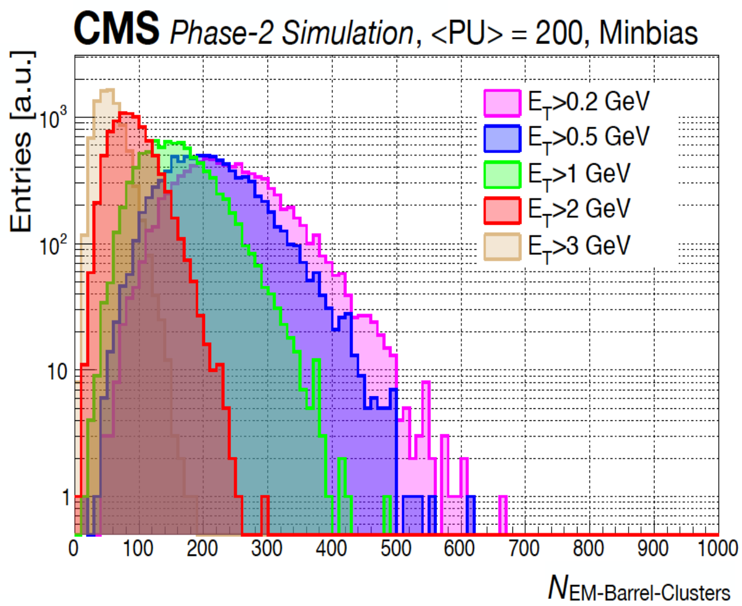
Trigger Primitives (TP) - inputs to L1T

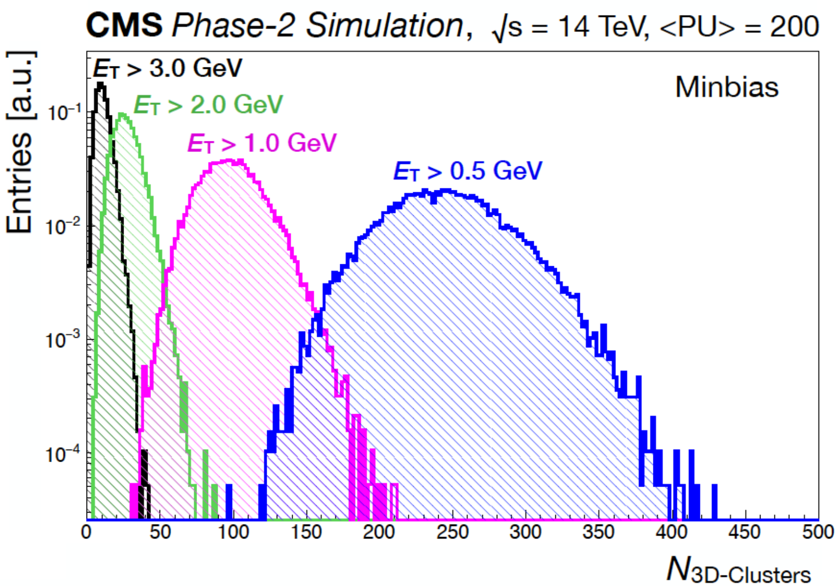


@ PU 200, 15000 stubs sent to Track Trigger TPG that must create tracks in 5 us.
<200> tracks to be sent to L1T, with 100 bits each.

HGCAL (Forward)
2D clusters from trigger cells,
depth combined to form 3D clusters

ECAL Barel TP: Individual crystals.





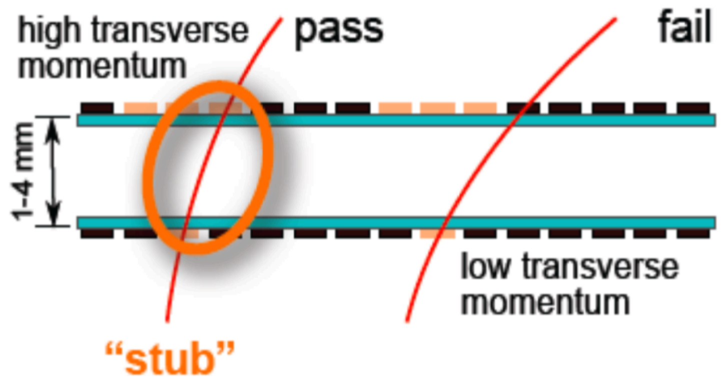
Trigger Primitives Data

Table 2.1: Summary of the logical input data to the Phase-2 L1 trigger.

Detector	Object	N bits/object	N objects	N bits/BX	Required BW (Gb/s)
TRK	Track	100	400	40 000	1 600
EB	Crystal	16	61 200	979 200	39 168
HB	Tower	16	2 304	36 864	1 475
HF	Tower	10	1 440	13 824	553
EC	Cluster	200	400	80 000	3 200
EC	Tower	16	2 400	38 400	1 536
MB DT	Stub	70	240	33 600	1 344
MB RPC	Cluster	15	3 200	48 000	1 902
ME CSC	Stub	32	1 080	34 560	1 382
ME RPC	Cluster	15	2 304	34 560	1 382
ME iRPC	Cluster	41	288	11 808	472
ME GEM	Cluster	14	2 304	32 256	1 290
ME0 GEM	Stub	24	288	6 912	276
Total	-	-	-	-	53 980

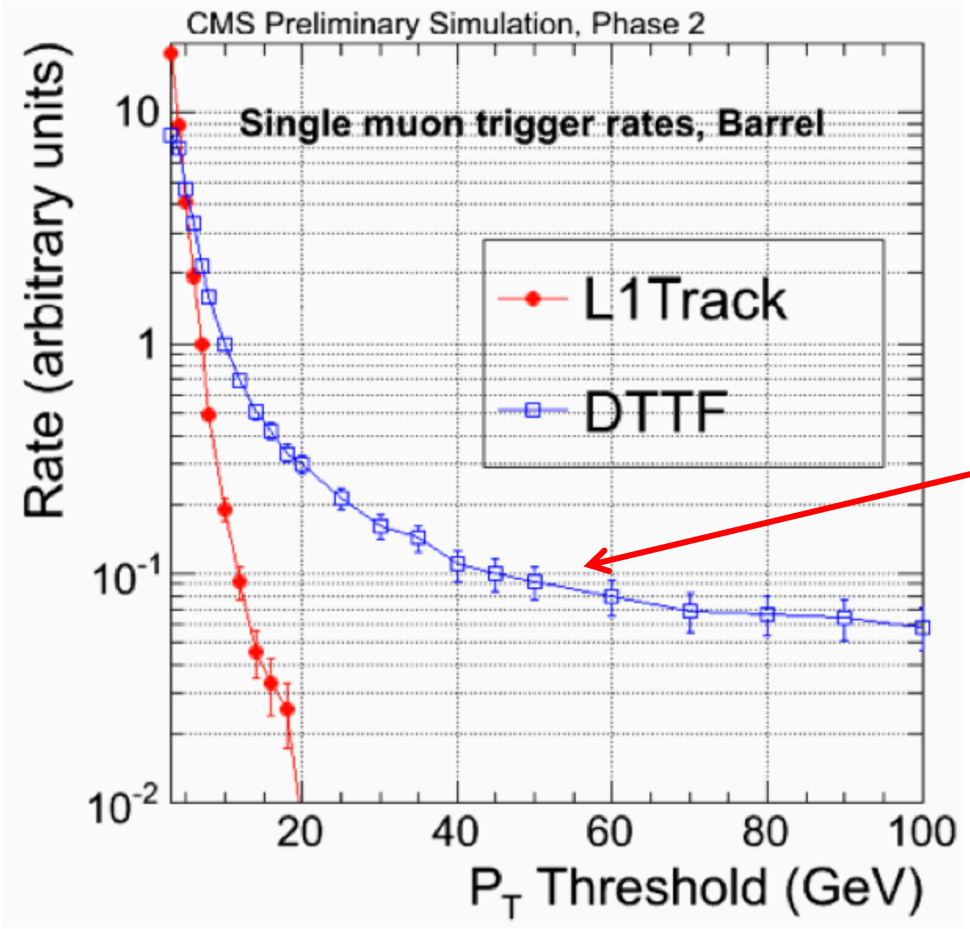
L1 Trigger will receive ~50 Tb/s

- Design modules with pT discrimination
  - Correlate hits in two closely-spaced sensors to provide vector (stub) in transverse plane: angle is a measure of pt
  - Exploit the strong magnetic field of CMS
- Level-1 "stubs" are processed in the back-end
  - Form Level-1 tracks, pT above 2~2.5 GeV
  - Use to improve different trigger channels (rate reduction x 5-10 for lepton triggers)



- CMS has at least two track-finding designs with FPGAs which build tracks (prompt) within eta < 2.4

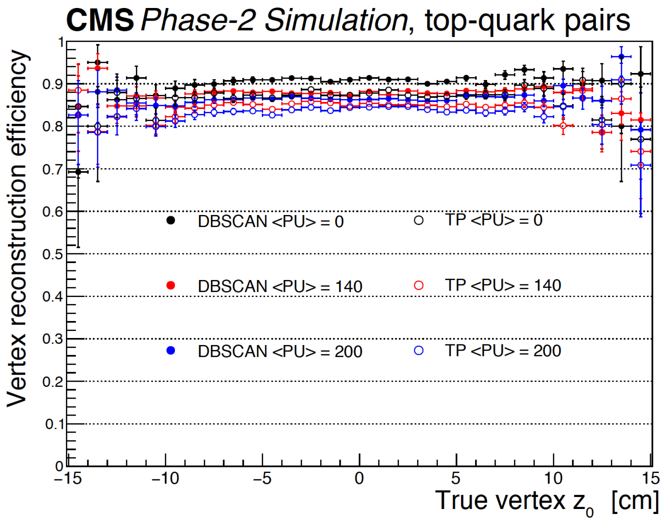
- Mostly, to keep low threshold on muon trigger and determine primary vertex (PV)



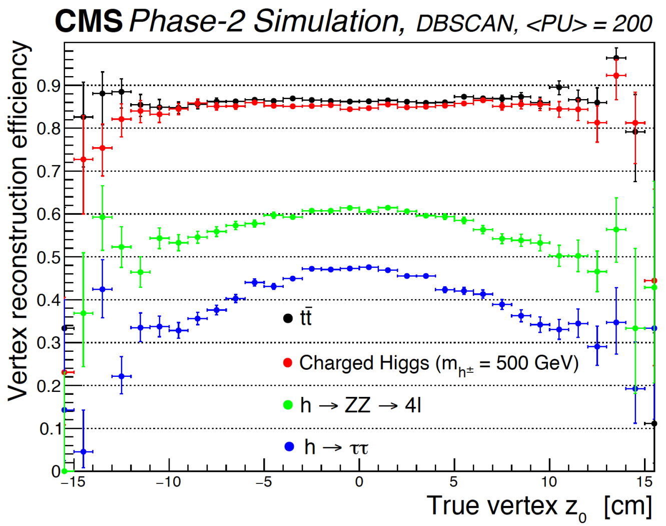
Flattening of the rate due to poor momentum resolution

L1T Vertexing

- Vertexing algorithms
  - Histograming z0 for all tracks weighted by pT, Define PV as one maximizing total scalare pT for consecutive 3 bins.
  - **Preferred**: density-based spatial clustering of application with noise (DBSCAN) algorithm.
    - High Efficiency and very tolerant to fakes.
    - Implemented in FPGAs

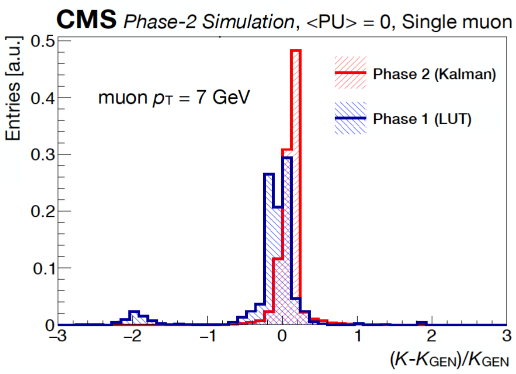


- DBSCAN algo performance:
  - correctly identifies PV for events with high multiplicity of high-pT tracks (ttbar)
  - underperforms in events with a low multiplicity of high-pT tracks. (H-> ZZ->4L, H->tau tau)

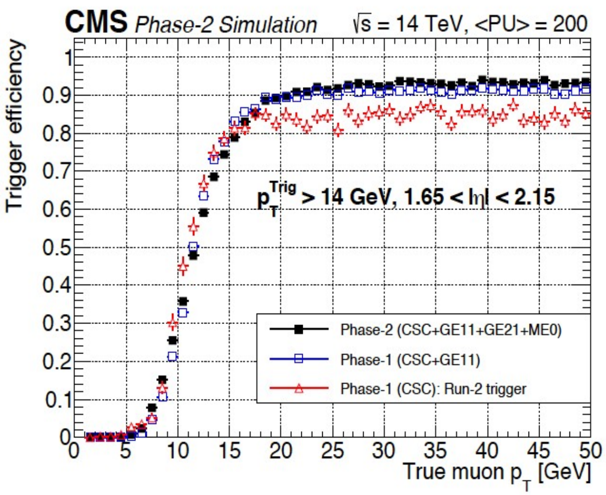


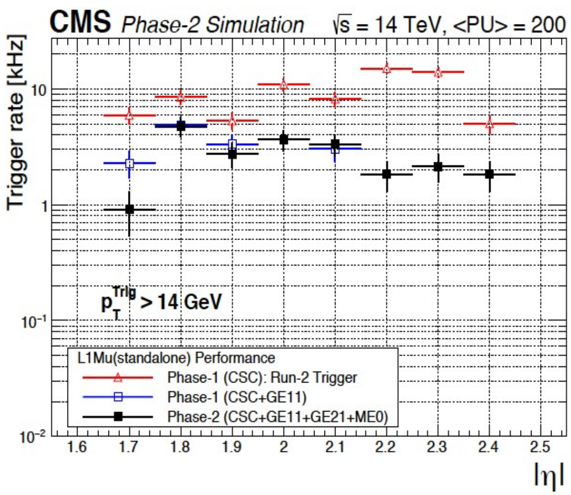
- lepton and photon trigger paths would not typically require PV constraint. => signal processes triggered by leptons or photons would not be affected by the inefficiencies of PV identification.

- Standalone L1T Muon is usually very pure, but can give high rate due to to mis-measured pT.
  - Usually one has significantly lower L1T vs Offline threshold due to slow eff turn-on.
  - High tails (low pT muons measured as high pT L1T) keep the rate flat for high pT muons
- Can further improve pT resolution in Phase-II with
  - Improved spacial resolution in DTs (improved electronics)
  - New algos with improved recourses (FPGA DSPs & LUTs)
  - New techniques for pT assignement (Kalman filter)
    – Account for energy loss and multiple scattering.
    – Extrapolate and refit from outside in.
    – Can fit in FPGAs

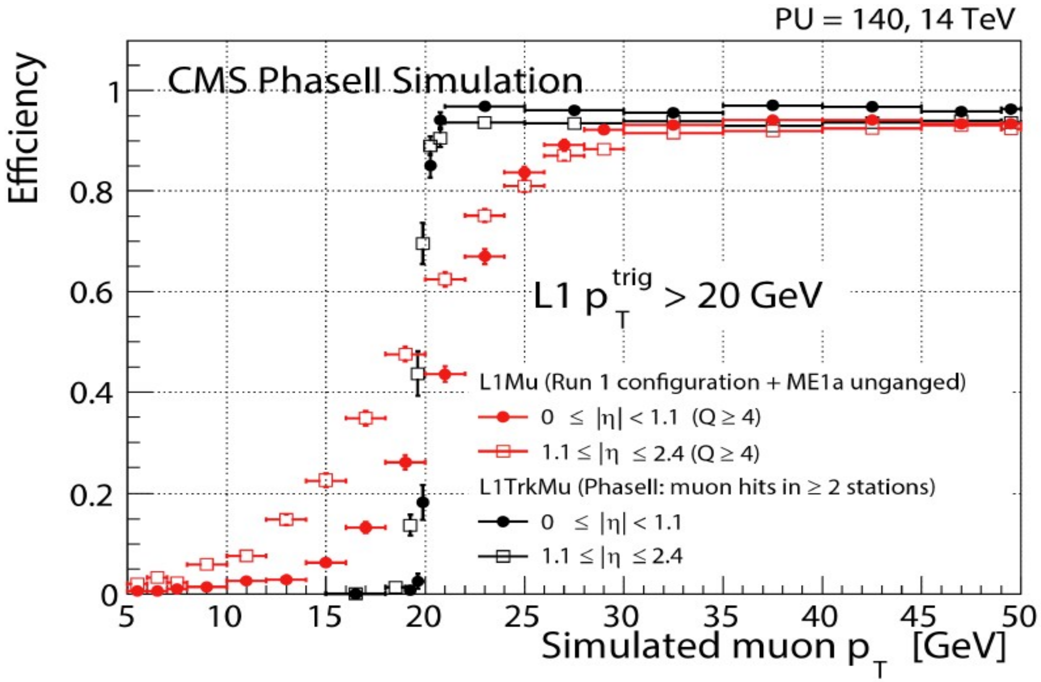


- New chambers in EndCap lead to improved resolution and rate reduction



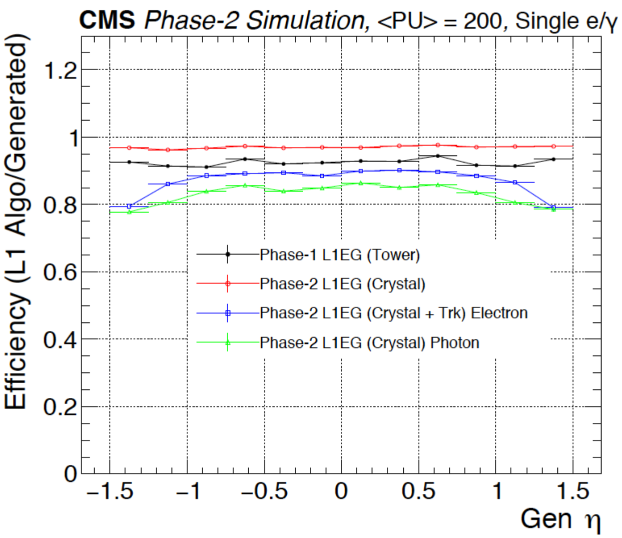


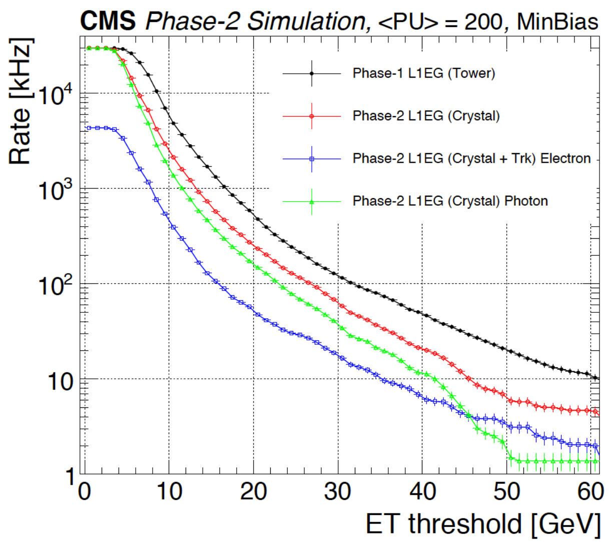
- Match standalone L1 Muon with L1T Track significantly improves pT measurement
  - Sharpens turn on curve, allows for closer L1T vs Offline (95%)
  - Factor 6-10 rate reduction for muon pT > 20 GeV



- Standalone L1T EgammaECAL crystal-level based algorithm gives improvement w.r.t. Phase-I cluster-based.
  - 99% efficiency, 5% improvement

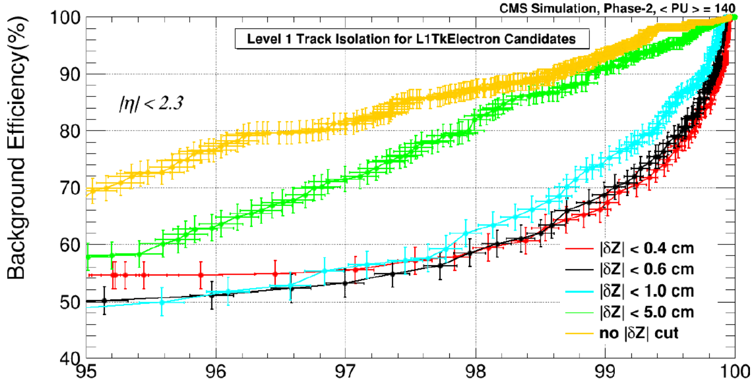
- Matching L1T Track
  - Tracks are extrapolated to ECAL inner surface and matched to EM clusters of 3x5 crystals centered around seed of > 1 GeV (simplified offline version)
  - Different matching windows for high/low pT and for tracks with different hit structure
  - Track-matched electron object with 90% efficiency and factor of 5 rate reduction.

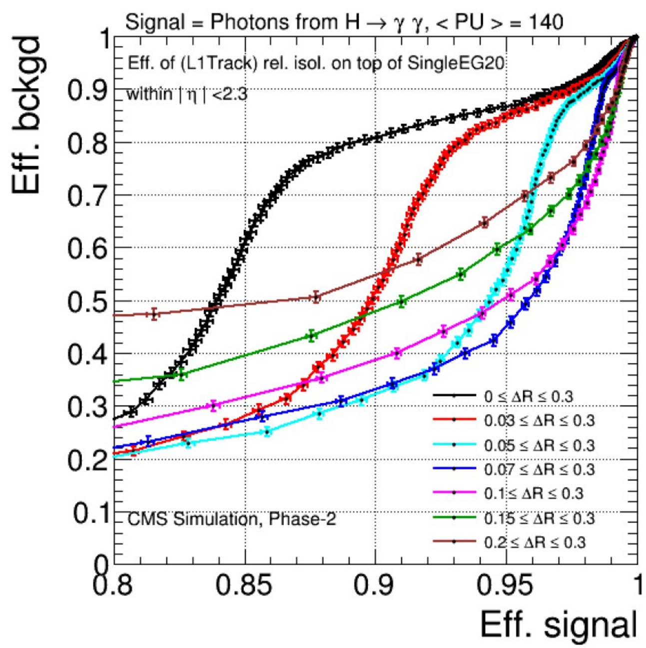




Tracker Isolation

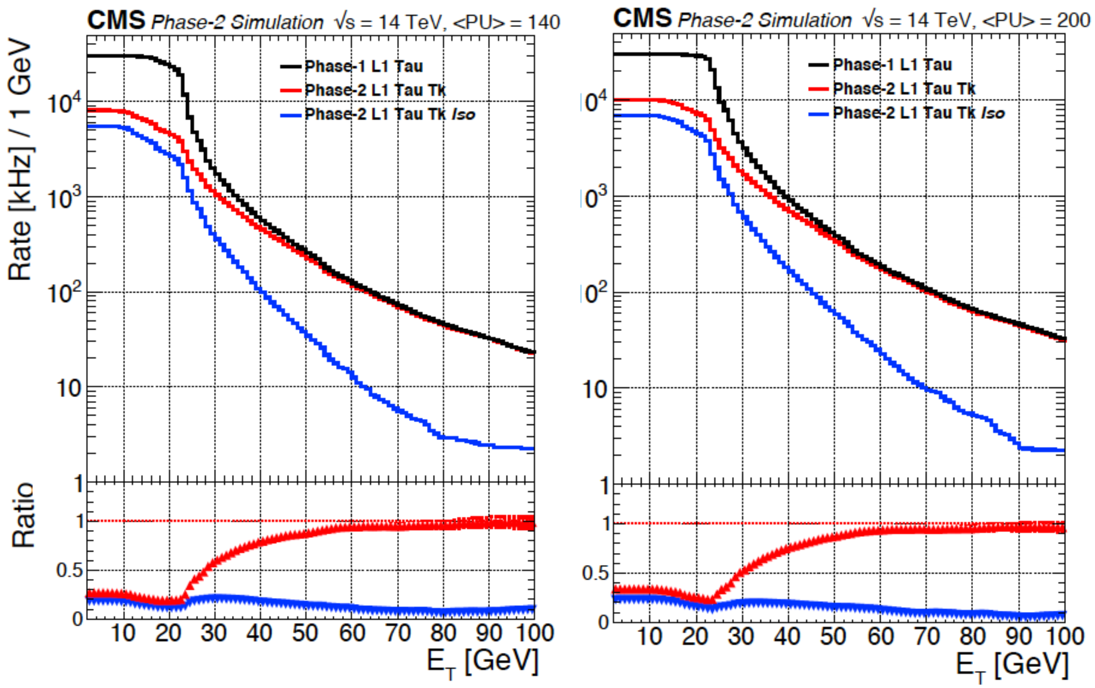
- Exploit L1T tracks to improve purity of electron & photon objects
  - Track isolation is more robust against PU than calorimeter based isolation
- Electrons & Muons
  - Consider scalar sums of tracks pT in a cone dR (0.2-0.3) around the leptons. Only consider tracks passing good quality requirement and $track_{z0}$ consistent with $lepton_{z0}$ within tolerance.
- Photons
  - Consider all good tracks in the cone $\Delta R_{min} < \Delta R < \Delta R_{max}$
  - Use calorimeter coordinates
- Background rejection by factor 2 for 95% efficiency





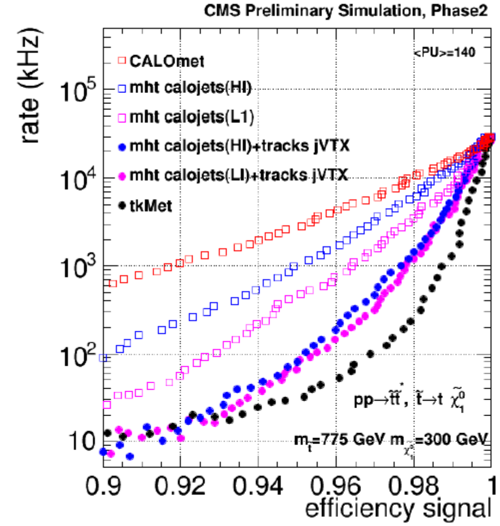
- Tracking is critical for good Identification of hadronic taus (τ_h)
  - Use Phase-I algorithm to construct tau clusters from isolated calorimetric clusters (***Phase1L1Tau***)
  - Match high pT tracks to tau clusters (***Phase2L1TauTrk***)
  - Apply track isolation (***Phase2L1TauTrkIso***)

- Single Tau trigger
  - 50 kHz at PU 200 (140) w/ pT **90(78), 90(78), 52(46) GeV**
- Double Tau trigger
  - Required be from same vertex
  - 50 kHz at PU 200 (140) w/ pT **46(41), 40(36), 25(22) GeV**

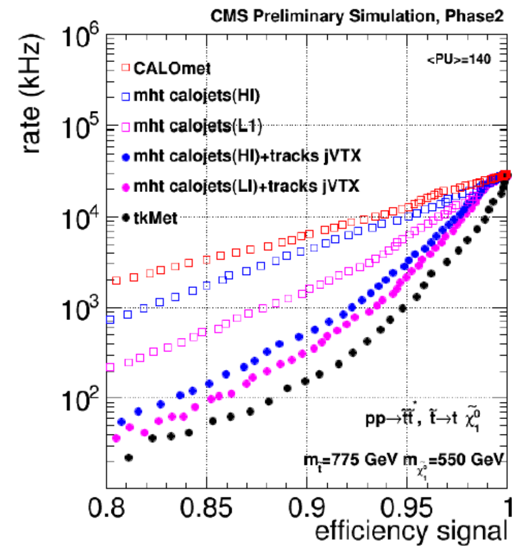


Jets, H_T, MH_T, E_T^{mis}

- Multijet trigger is very sensitive to PU
  - For Jets, H_T, MH_T, dependency reduced if jets required be from same vtx.
    - Match in eta-phi L1Calo jets to L1 Tracks
    - Determine z0 of jet by track pT weighted average of track z0
      - 1mm resolution
      - 95% efficiency to reconstruct true vtx in ttbar events (with jets pT>70 GeV)
  - Tracking based E_t^{mis}: vectorial sum of all tracks pT that come from PV
    - z0 considered consistent with PF if within ~1cm
    - Use track-quality cut to reduce mis-measurement



E_T^{miss} ~ 300 GeV



E_T^{miss} ~ 200 GeV

Simple Trigger Menu

- Created a simple version of Trigger Menu similar as done for Phase-I TDR
  - 20 main physics paths that cover basic physics goals of CMS
  - Should be about 70% of the rate of the full menu
    - Remaining 30% will be covered by
      - Specific physics triggers
      - High eta triggers
      - Control and prescaled triggers

- Useful as an estimate of individual trigger rates and total L1T output bandwidth when covering major physics goals and keeping thresholds on the level of Phase-I TDR O(20-50 GeV)

- It shows the power of using L1T Tracks

- Although using Phase-II Upgrade detector geometry, the Trigger Prmitives are not finalized.
    - Phase-2 tracking, Phase-1 pixel, Phase-1 clusters, Phase-1 CSC
    - Changes expected with the development of Trigger Primitives

Trigger Menu

- **Thresholds scaled from online to offline values**
  - scaling chosen such that the trigger object is **95% (85% for taus) of the plateau efficiency for an offline cut at the threshold**
- **Single lepton triggers** include tracking requirements
- γ/e have to be kept separate: **inclusion of single and double γ paths**
- **Isolated e/γ** use tracking isolation
- **Dilepton triggers** make use of tracking info on first leg, and sometimes also on second leg
  - if both legs have a L1Track **'same-vertex' requirement ($\Delta z \leq$ 1cm)**
- **Multijets, H_T and H_T^{miss} triggers** use collections of jets that are consistent with coming from the event-vertex, $|z - z_{PV}| <$ 1cm

Trigger Menu Description

- Thresholds are obtained by scaling from offline to L1T
  - Scaling is chosen so that L1 object is 95% (85% for taus) of the plateau efficiency for an offline cut at the threshold.
  - All single leptons require matching with tracks
  - Isolated electron/photon triggers use track isolation
  - Dilepton triggers require track matching on 1^{st} leg
    - Sometimes on 2^{nd} leg as well
      - If both legs have track-match, require same Vtx
  - Jets, H_T, MH_T, use collection of jets consistent with same Vtx

Strawman Trigger Menu for PU 200

$L = 5.6 \times 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$ $\langle PU \rangle = 140$	Level-1 Trigger with L1 Tracks	
Trigger Algorithm	Rate [kHz]	Offline Threshold(s) [GeV]
Single Mu (tk)	14	18
Double Mu (tk)	1.1	14 10
ele (iso tk) + Mu (tk)	0.7	19 10.5
Single Ele (tk)	16	31
Single iso Ele (tk)	13	27
Single γ (tk isol)	31	31
ele (iso tk) + e/γ	11	22 16
Double γ (tk isol)	17	22 16
Single Tau (tk)	13	88
Tau (tk) + Tau	32	56 56
ele (iso tk) + Tau	7.4	19 50
Tau (tk) + Mu (tk)	5.4	45 14
Single Jet	42	173
Double Jet (tk)	26	2@136
Quad Jet (tk)	12	4@72
Single ele (tk) + Jet (tk)	15	23 66
Single Mu (tk) + Jet (tk)	8.8	16 66
Single ele (tk) + $H_{\mathrm{T}}^{\mathrm{miss}}$ (tk)	10	23 95
Single Mu (tk) + $H_{\mathrm{T}}^{\mathrm{miss}}$ (tk)	2.7	16 95
H_{T} (tk)	13	350
Rate for above Triggers	180	
Est. Total Level-1 Menu Rate	**260**	

- HLLHC 200 pile-up events per beam crossing
  - No tracking at L1: rate ~ 4000kHz
  - **Tracking at L1: rate ~ 500 kHz**
- No uncertainties on actual detector performance,
  and detector readout electronics
  - allow 50% margin
  - max design rate 750 kHz
- **Light lepton, Photon HLLHC thresholds are comparable with RunI, Phase-1**
- **Hadronic algos need more work to be comparable with RunI, Phase-1**
  - **how to improve further?**

Strawman Trigger Menu

$L = 5.6 \times 10^{34}$ cm^{-2}s^{-1}, $\langle PU \rangle = 140$ $L = 8.0 \times 10^{34}$ cm^{-2}s^{-1}, $\langle PU \rangle = 200$	L1 trigger with L1 tracks		
Trigger algorithm	Rate [kHz]		Offline threshold(s) [GeV]
$\langle PU \rangle$	140	200	
Single Mu (tk)	14	27	18
Double Mu (tk)	1.1	1.2	14 10
Ele* (iso tk) + Mu (tk)	0.7	0.2	19 10.5
Single Ele* (tk)	16	38	31
Single iso Ele* (tk)	13	27	27
Single γ^* (tk-iso)	31	19	31
Ele* (iso tk) + e/γ^*	11	7.3	22 16
Double γ^* (tk-iso)	17	5	22 16
Single Tau (tk)	13	38	88
Tau (tk) + Tau	32	55	56 56
Ele* (iso tk) + Tau	7.4	23	19 50
Tau (tk) + Mu (tk)	5.4	6	45 14
Single Jet	42	69	173
Double Jet (tk)	26	43	2@136
Quad Jet (tk)	12	45	4@72
Single ele* (tk) + Jet	15	15	23 66
Single Mu (tk) + Jet	8.8	12	16 66
Single ele* (tk) + H_T^{miss} (tk)	10	45	23 95
Single Mu (tk) + H_T^{miss} (tk)	2.7	8	16 95
H_T (tk)	13	24	350
Rate for above triggers*	180	305	
Est. rate (full EG eta range)		390	
Est. total L1 menu rate (× 1.3)	**260**	**500**	

Total output rate
- 500 kHz using L1 Tracks
- 4000 kHz w/o L1 Tracks

Not considered performance uncertainties on detector or electronics.
- Considered ideal conditions, so left 50% margin

Observations:

- Lepton and photon thresholds are consistent with Phase-I (GOOD)
- Hadronic triggers need further work on development to be on the order of Phase-I

Strawman Trigger Menu – effect of L1T Track (example with PU 140)

CMS Technical Proposal, LHCC-P-008

$L = 5.6 \times 10^{34}$ cm^{-2}s^{-1} $\langle PU \rangle = 140$	Level-1 Trigger with L1 Tracks	
Trigger Algorithm	Rate [kHz]	Offline Threshold(s) [GeV]
Single Mu (tk)	14	18
Double Mu (tk)	1.1	14 10
ele (iso tk) + Mu (tk)	0.7	19 10.5
Single Ele (tk)	16	31
Single iso Ele (tk)	13	27
Single γ (tk isol)	31	31
ele (iso tk) + e/γ	11	22 16
Double γ (tk isol)	17	22 16
Single Tau (tk)	13	88
Tau (tk) + Tau	32	56 56
ele (iso tk) + Tau	7.4	19 50
Tau (tk) + Mu (tk)	5.4	45 14
Single Jet	42	173
Double Jet (tk)	26	2@136
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Single ele (tk) + Jet (tk)	15	23 66
Single Mu (tk) + Jet (tk)	8.8	16 66
Single ele (tk) + H_T^{miss} (tk)	10	23 95
Single Mu (tk) + H_T^{miss} (tk)	2.7	16 95
H_T (tk)	13	350
Rate for above Triggers	180	
Est. Total Level-1 Menu Rate	**260**	

Rate w/o L1Tk

139
177

huge help for the muons

52
185
73

Great help for jets

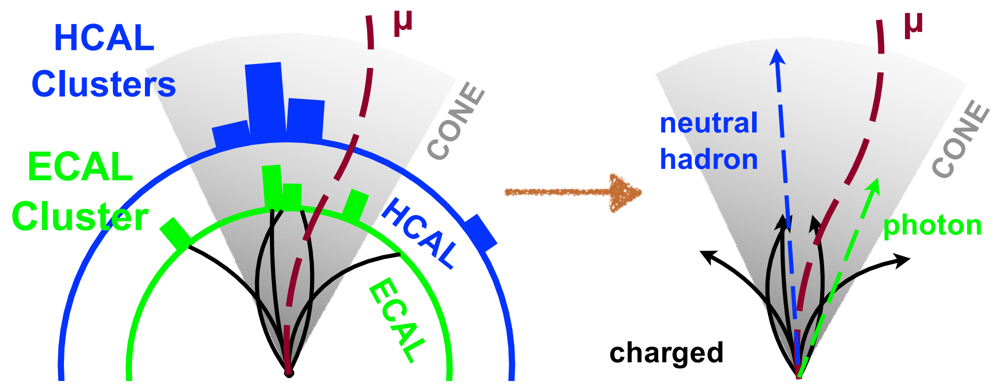
the lower the pT the greater the help

New algorithms – Particle Flow at L1T

- From **combining the complete detector information using the Particle-Flow algorithm** closely matching offline and HLT:

EM Clusters (from ECAL and HGCAL EM Clusters TPs),
Calo Clusters (from EM Clusters + HCAL Towers + HGCAL Hadronic trigger cells),
Tracks (from L1TF),
Stand Alone Muons TPs

L1 PF Candidates: Charged and neutral hadrons, photons, muons, electrons



- **Pile-Up-Per-Particle-Identification (PUPPI)** on PF candidates greatly mitigate PU effects
  - uses **vertexing info from tracks and QCD-based ansatz function** to define a particle weight
  - vertexing done in parallel w/PF and PU estimate
  - L1 PUPPI runs on global list of candidates from PF step and **select prompt physics objects**

E_T^{miss}, H_T, jets, prompt μ, electrons, τ_h, photons

Conclusions

- CMS has an advanced program for Trigger Phase-II Upgrade Project.
- First algorithms with Phase-II upgraded detectors have been developed.
- A basis trigger menu developed as a baseline
- Improvements in trigger performance observed due to upgraded detectors, new standalone algorithms, and use of track trigger.
- Clear road map for future developments has been set.
- Finalization of HW design in the future.
- Expect a completion of a full TDR by beginning of 2020