ATLAS Phase-II Trigger Architecture and Menu

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Overview of ATLAS Trigger Upgrades

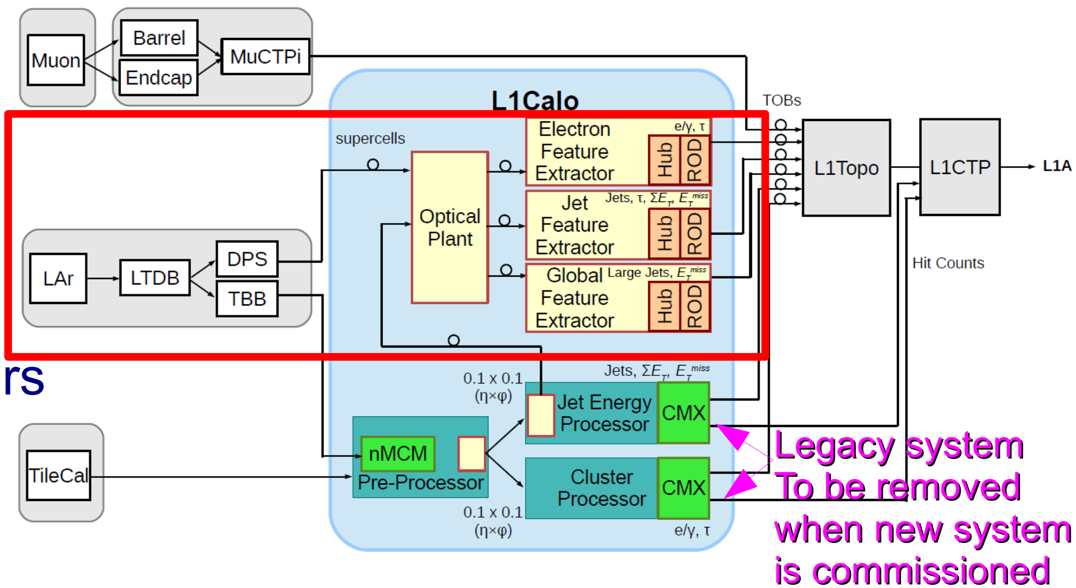
ATLAS has an extensive program of trigger upgrades and consolidations for the LHC shutdowns

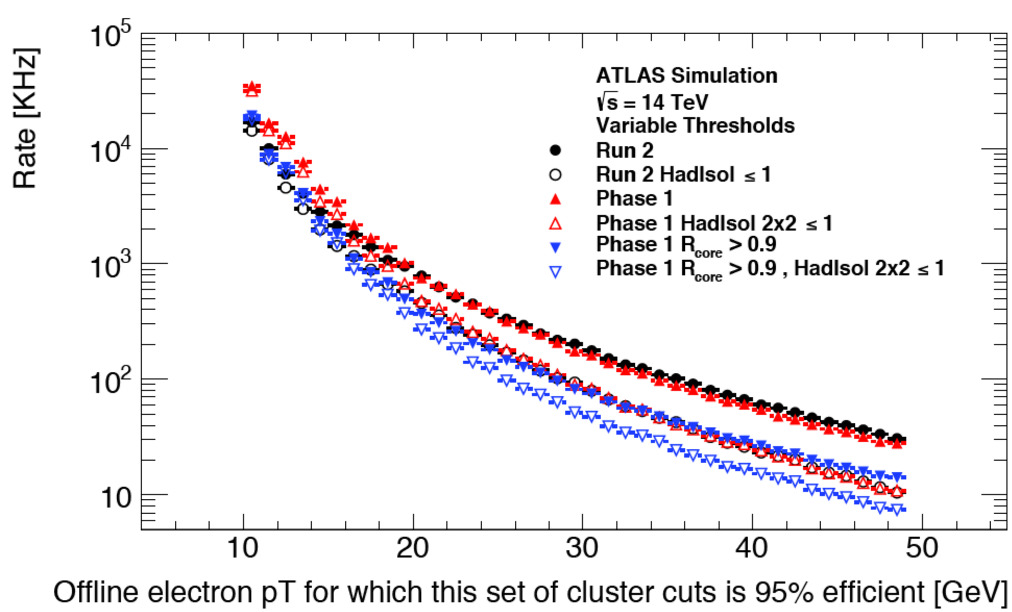
- LS1 (2013-2014):
  - New L1 topological trigger module and upgraded central trigger
  - Muon-HCAL coincidence to reduce fake L1 endcap muons
  - New digitization module for the L1 calorimeter trigger
  - Fast TracKer (FTK) for HLT (partial – completed by 2018)
- LS2 (Phase-I, 2018-2019):
  - High granularity L1 calorimeter trigger with modern FPGAs
  - New “small-wheel” coincidence for endcap L1 muon triggers
  - Described in Phase-I TDAQ TDR (LHCC-2013-018)
- LS3 (Phase-II, 2023-2025):
  - New split L0/L1 trigger scheme with higher latency and rates
  - New MDT-based muon trigger for L0
  - Seeded track trigger at L1
  - New, full granularity L1 calorimeter trigger at L1
  - Described in Phase-II Upgrade LoI (LHCC-2012-022), but with some update as described in this talk
  - TDAQ Phase-II TDR currently planned for 2017

LS2 (Phase-I) Trigger Upgrades

LS2 L1Calo Trigger Upgrade

- Higher granularity, digital readout from ECAL to L1Calo
  - Higher precision energy as well
- Electron, photon and tau trigger:
  - Split 0.1x0.1 towers in 4 separate layers to give depth segmentation
  - For 2 middle layers split 0.1x0.1 towers into 0.025x0.1 for shower shape cuts
- Jet and Etmiss triggers
  - 0.1x0.1 towers instead of 0.2x0.2
  - Full calorimeter (0.2x0.2 towers) in single board for large jets etc.

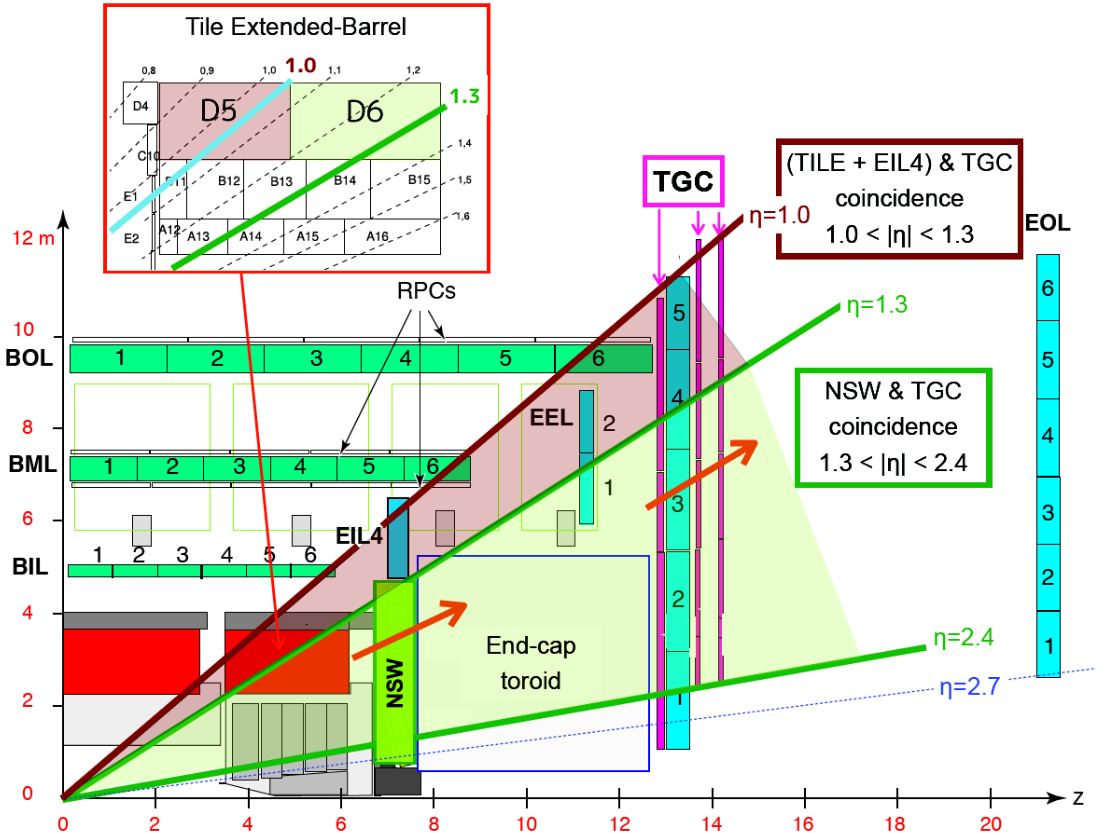


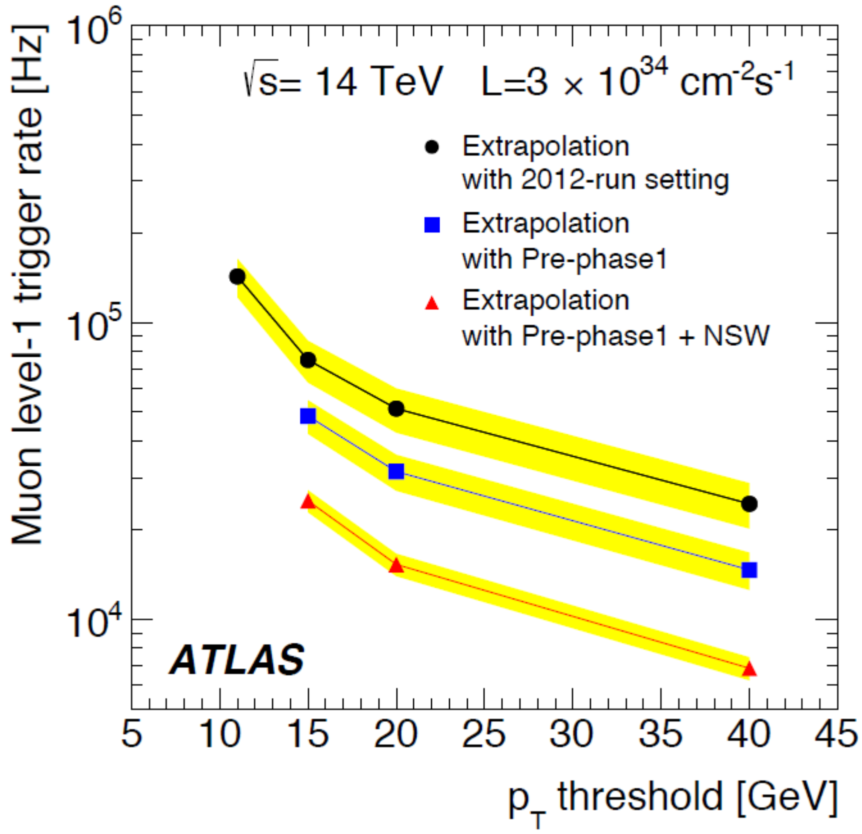


- Use of shape variables gives an estimated factor 2-3 extra rejections for electrons
  - R_{core}: fraction of energy in central cell
  - f_3: fraction of energy in last LAr layer
- Improved resolution and pileup suppression for jets and Etmiss
  - More later

LS2 L1Muon Endcap Trigger Upgrade

- High-pT L1Muon triggers dominated by fakes
- New small wheel provides additional coincidence hits
  - Kills most fakes in 1.3<|η|<2.4
  - 1.0<|η|<1.3 covered by EIL4-TGC, outer Tile layer and new RPC chamber
- Rate of 20 GeV muon triggers reduced by factor 3(2) wrt Run 1(2)
  - Sufficient to run unprescaled through Run 3

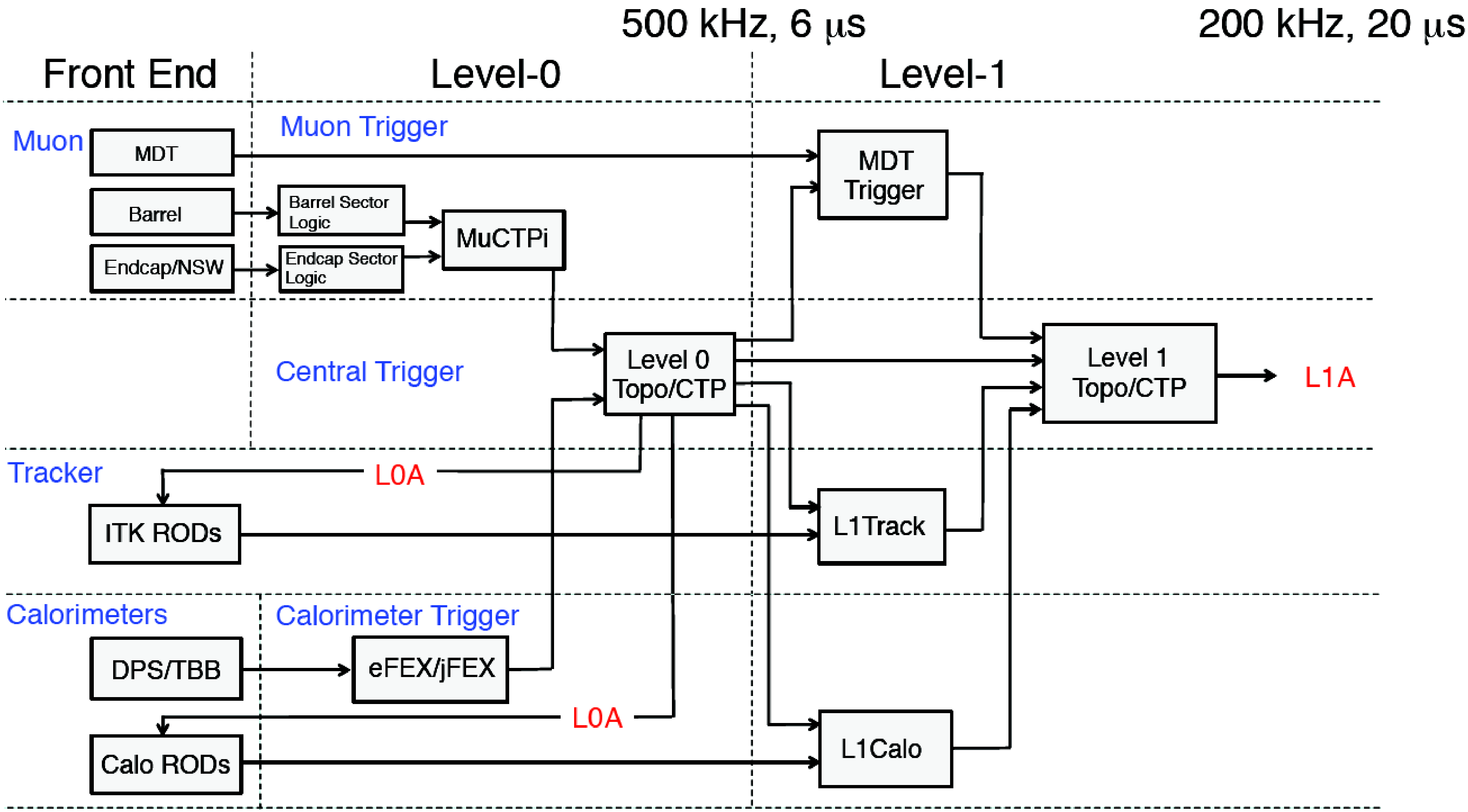




LS3 (Phase-II) Trigger Upgrades

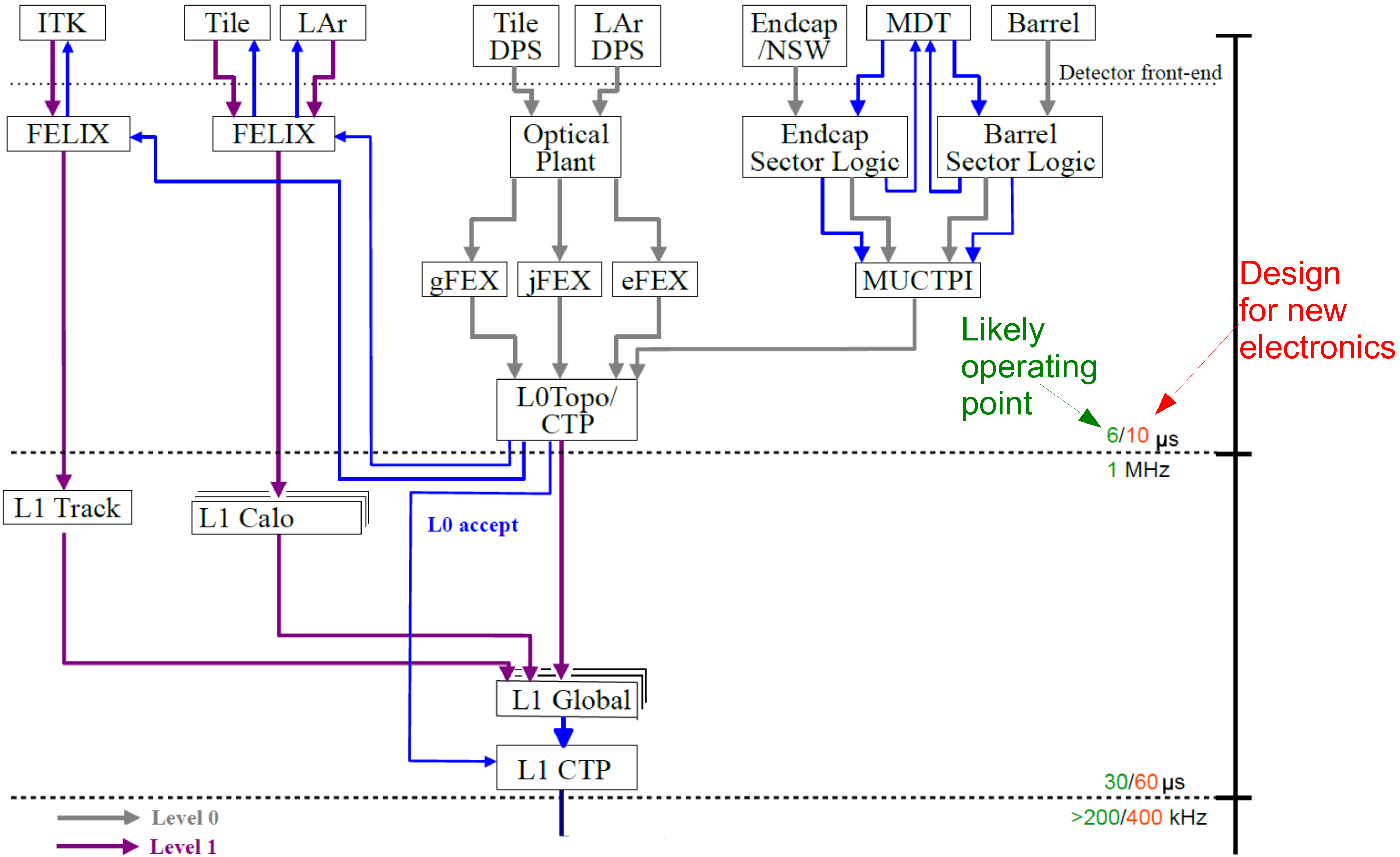
Baseline Trigger Architecture from LoI

Hardware trigger split in two levels to accommodate legacy electronics – Phase-II L0 trigger is essentially the Phase-I L1 trigger



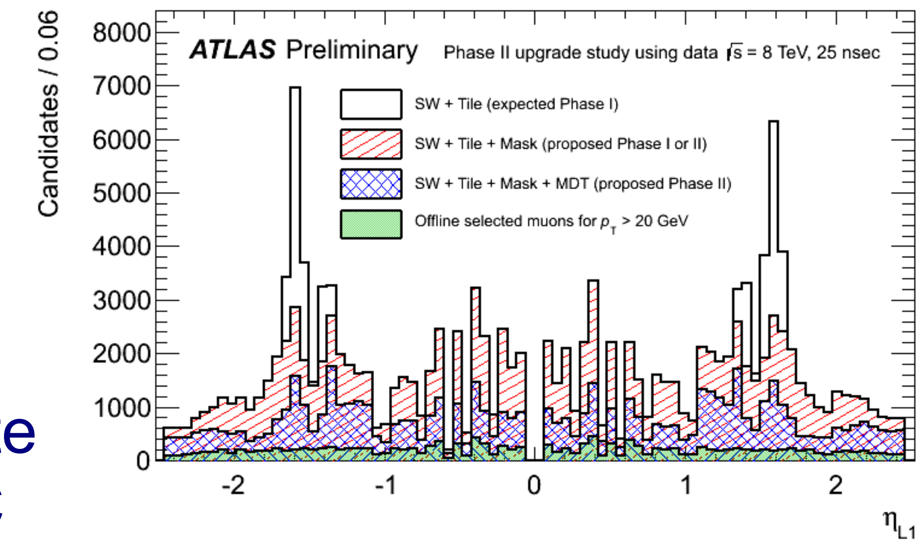
Updated Baseline Trigger Scheme

Revised rates and latency targets for greater flexibility
MDT trigger now at L0 instead of L1 in baseline



Phase-II Baseline Components

- L0 Calorimeter trigger is same as L1Calo in phase-I
  - Now with digital input from hadronic calorimeter as well
- New L0 Muon electronics
  - To deal with higher latency/rate
  - Will replace coincidence ASIC with more flexible FPGA



- Augment L0 Muon trigger with precision MDT tracking
  - Estimated to give factor 2 rejection across η
- L0 Central trigger and topology trigger to be replaced
  - Need to provide Regions-of-Interest to L1
- L1 Track trigger in RoIs from L0 triggers
  - Details in talk by Nikos
- New full(?) granularity L1 calorimeter trigger
  - Architecture and possible algorithms under study

Rate and Latency Limitations

- L0 limitations mostly set by new inner detector readout
  - Power/cooling limitation
- L1 latency and rate limits set by legacy electronics
  - Most of the innermost MDT layer electronics likely not replaceable in LS3 without a further major delay (under study)
  - Not yet clear it can handle >200 kHz L1 rate (occupancy dependent)
  - Also a primary motivation for split architecture (can ignore L0)

- If MDT electronics can be changed, higher rates possible
  - Hence the higher requirements for new electronics
  - 400 kHz L1 rate would allow a very open menu as shown next
- The ITK is evaluating possibility of full readout at L0 rate
  - Simplifies design at cost of higher bandwidth requirement
  - Not required for seeded L1 track trigger
  - Would allow for (later) full-acceptance tracking at L1
  - Without legacy electronics, could even consider dropping L1 and put 1 MHz into HLT (Note: this is far from current baseline!)

Phase-II L0/L1 Menu Studies

Menu Development Approach

- Menu design should be driven by physics requirements
  - However, detailed physics studies for complex physics cases for phase-II are very limited at the moment
  - Design an as inclusive trigger menu as possible
- In practice aim to preserve/improve on Run 1 performance
  - This is more ambitious than what is being done for phase-I
- Trigger upgrades should provide:
  - Increased rejection to compensate luminosity increase
  - Improved pileup suppression
  - Increased acceptance
- With possible menus for different rate limitations, we can better define future physics studies for supporting choices
  - Assume two-stage L0/L1 system with up to 1 MHz L0 and 400 kHz of L1 maximum rates
    (must adapt to a lower value if required by legacy MDTs)

Physics Motivation

- So far menu choices mostly based on Run 1 experience and Phase-II LoI
- Large emphasis on keeping low-pt single lepton triggers
  - Already fairly well-motivated simply by their overall gain in EW physics processes
- Some benchmark physics channels to be studied for other trigger justifications in Phase-II TDAQ TDR:
  - $H\to\tau\tau$ and $HH\to bb\tau\tau$ for tau triggers
  - $HH \to b\bar{b}b\bar{b}$ for multi-jet, HT and fat jet triggers
  - $t\bar{t}H \to t\bar{t}b\bar{b}$ for multi-jet and HT triggers
  - VBF $H \to bb/\tau\tau$/invisible, VBF SUSY (no trigger specified yet)
  - $H^{+}\to\tau\nu$ for τ+MET trigger
  - Inclusive SUSY searches for missing ET and multi-jet
  - Mono-(b)jet for jet+MET

Luminosity Target and Rates Scaling

- Expected HL-LHC luminosity 5×10^{34} $cm^{-2}s^{-1}$ (after luminosity leveling), but we use $L = 7 \times 10^{34}$ $cm^{-2}s^{-1}$
  - Corresponds to 200 interactions/BX (for 25ns running)
  - Adds some contingency to the menu
  - Opens up possibility of running at higher luminosity point
- Assume center-of-mass energy of 14 TeV
  - Increases rates by a further factor 2-3 over 8 TeV rates
  - Use MC ratio to go from 8 TeV to 14 TeV where possible
- Trigger rates from 2012 data scaled to high luminosity with $\sqrt{s}$ correction and reduction factors for new triggers
- Multi-object triggers can have significant contribution from random coincidences
  - The rate for these goes as μ^n for n-object triggers, so quickly can become dominant
  - This is largely taken into account in rate predictions

Assumed Improvements

- Do not yet have full simulation of the Phase-II triggers
- Instead mostly apply additional reduction factor on top of the scaled 2012 L1 rates
  - For L0 use conservative reduction factors based on phase-I TDR – ignores p_T dependence for the reduction:

Electrons:	Factor 2 rate reduction (factor 3 for 2EMx)
Taus:	Conservatively no improvement
Jets/MET:	Rely on high lumi MC simulation with phase-I trigger emulation
Muons:	NSW rates + factor 2 at high-pt with L0-MDT

  - For L1 use LoI numbers and guesses

L1 tracking:	Factor 5 rate reduction (also for multi-objects) Remove combinatorics in multi-object triggers
L1Calo:	Factor 2 rejection for e/γ/τ (guess/target)

Note: use Run-1 L1 trigger notation and energy scale in the following trigger tables – *look at offline target*

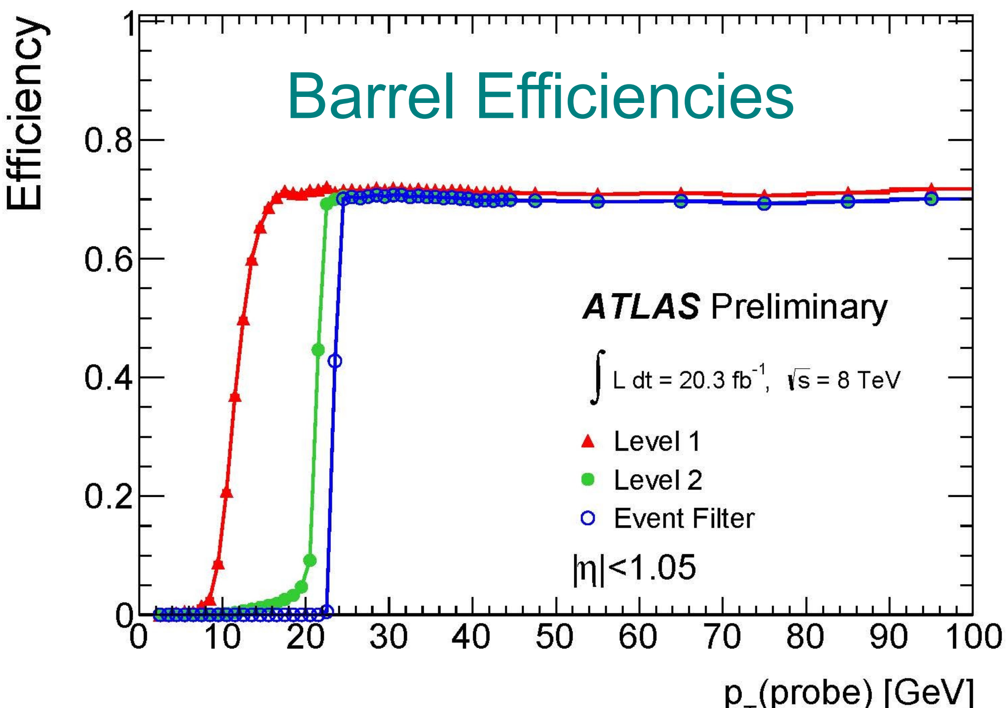
Single Lepton Triggers

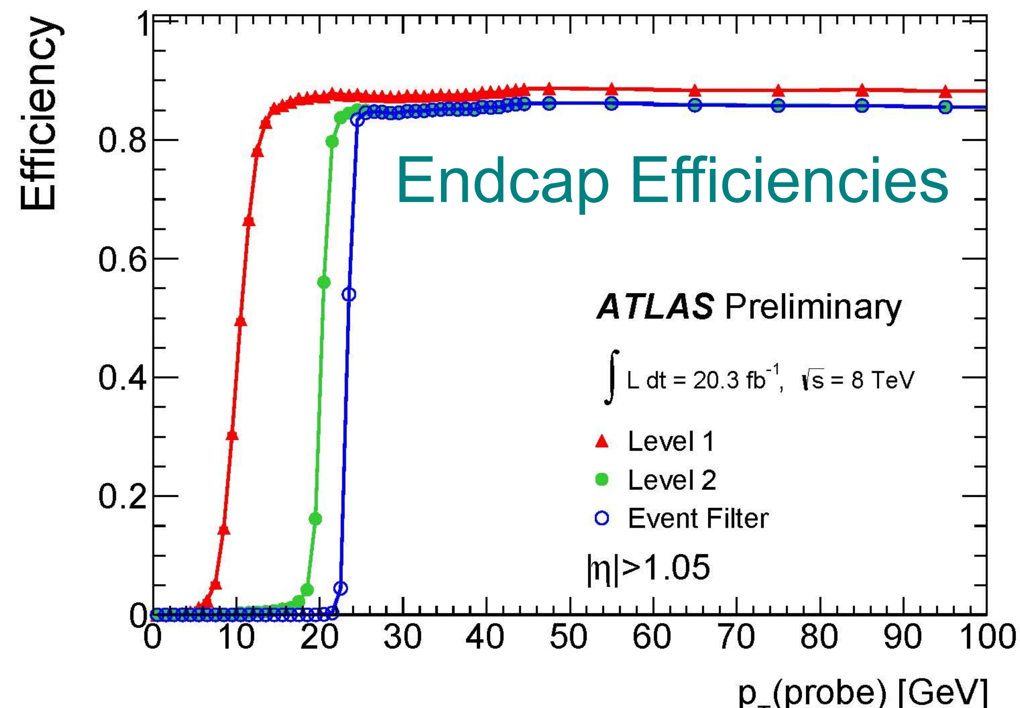
- These are expected to provide majority of the physics
  - Aim for thresholds of 20-25 GeV as in Run 1
- Need high efficiency, so minimize use of L1 trigger except when necessary
- Added new speculative muon barrel trigger for recovering barrel efficiency
  - The assigned rates for this trigger are essentially only place holders

Offline Target	L0 Trigger	L0 Rate	L1 Trigger	L1 Rate	Run 1
Iso. e>22 GeV	EM16VHI	200 kHz	Track+Calo	40 kHz	EM18VH
e(γ)> 35 GeV	EM30VH	60 kHz	Calo	30 kHz	EM30
μ>20 GeV	MU15	40 kHz	Uses L0MDT	40 kHz	MU15
μ>20 GeV	MDT15Barrel	50 kHz	Track	10 kHz	-
	Total	**300 kHz**		**110 kHz**	

Muon Trigger Upgrade Motivation

- Muon barrel trigger upgrade motivated by 72% efficiency for high-p_T in 2012 run
  - Mostly by geometrical acceptance for 3-station coincidence
  - A few percent increase expected in 2015 from extra chambers
- Design of new barrel trigger, if any, still to be decided
  - Could be additional RPC chambers
  - Could be coincidence between outer RPC and MDTs





Multi Lepton Triggers

- Di-lepton triggers allow lower thresholds in dilepton physics channels
  - Use symmetric cuts here for simplicity, though many analysis tend to prefer asymmetric ones
  - Aim for p_T~10-15 GeV on second lepton
- Very large uncertainty due to large combinatorial L0 rate
  - Leave 3-lepton triggers out for now and assume thresholds will be set to keep unique rate low for these as in Run 1/2

Offline Object	L0 Trigger	L0 Rate	L1 Trigger	L1 Rate	Run 1
2e>15 GeV	2EM10VH	90 kHz	Track+Calo	10 kHz	2EM10VH
2γ>25 GeV	2EM16VH	8 kHz	Calo	4 kHz	2EM12_EM16V
2μ>15 GeV	2MU10	20 kHz	None	20 kHz	2MU6(10)
e,μ>15 GeV	EM10VH_MU10	65 kHz	Track+Calo	10 kHz	EM10VH_MU6
	Total	**175 kHz**		**30 kHz**	

Tau Triggers

- With 20 GeV single lepton trigger, lepton+hadronic tau trigger likely not needed
- Di-hadronic tau trigger expensive, but doable if we can get sufficient L1 track trigger rejection
  - Primarily for VBF Higgs and $HH \rightarrow b\bar{b}\tau\tau$
- Generic tau+ETmiss trigger for charged Higgs and SUSY searches

Offline Object	L0 Trigger	L0 Rate	L1 Trigger	L1 Rate	Run 1
τ>150 GeV	TAU75	20 kHz	Calo	10 kHz	TAU40
2τ>40,30 GeV	2TAU15I	200 kHz	Calo+Track	30 kHz	2TAU11I_TAU15
τ>40 Gev, $\not{E}_T$>125 GeV	TAU15I_XE50	50 kHz	Calo+Track	10 kHz	TAU15_XE35
	Total	**250 kHz**		**50 kHz**	

Hadronic Triggers

- Single jet and 4-jet triggers the workhorses in Run 1
  - Will add sum of jets (HT) and fat jet (Gxx) triggers in phase-1
- MET trigger is critical for SUSY/BSM searches
  - Also used for associated Higgs production measurements
- L0 rates estimated from $L=7\times10^{34}$ $cm^{-2}s^{-1}$ simulation
- Reduction possible at L1 not clear yet
  - Put a target reduction of a factor 2 at L1

Offline Object	L0 Trigger	L0 Rate	L1 Trigger	L1 Rate	Run 1
j>180 GeV	J100	45 kHz	Calo	25 kHz	J75
j>275 GeV	G175	30 kHz	Calo	15 kHz	J75
4j>75 GeV***	4J20	40 kHz	Track/Calo	20 kHz	4J15
ht>500 GeV	HT250	45 kHz	Track/Calo	25 kHz	J75
$\not{E}_T$>200 GeV	XE/MHT80	35 kHz	Calo	20 kHz	XE40
j>150 GeV, $\not{E}_T$>125 GeV	J80_XE/MHT50	45 kHz	Calo	15 kHz	J30_XE40
	Total	**190 kHz**		**100 kHz**	

*** Likely conservative guess – needs better jet algorithm and pileup subtraction for better estimate

Summary Tables

- Overall menu stays with design L0/L1 rate constraints

Trigger	L0 Rate	L1 Rate
Single Lepton	330 kHz	110 kHz
Multi-lepton	175 kHz	30 kHz
Taus	250 kHz	50 kHz
Hadronic Triggers	190 kHz	100 kHz
Others (exotics, VBF, etc.)	50 kHz	50 kHz
Total	**995 kHz**	**340 kHz**

  - L1 rate possibly exceeds capability of MDT legacy electronics → might need to use tighter L1 selections

- Input rates for different L1 trigger types:

Trigger	L0 Rate
Track trigger	710 kHz
L1Calo	770 kHz

Summary

Summary

- Baseline Phase-II trigger architecture mostly unchanged since 2012 Letter-of-Intent
  - Two-level hardware trigger to accommodate legacy electronics
  - Baseline latency and rates have been increased (Final limit from remaining legacy electronics under study)
- Simplified menu designed
  - Provides inclusive selections with close to Run-1 performance

Trigger	L0 Rate	L1 Rate
Single Lepton	330 kHz	110 kHz
Multi-lepton	175 kHz	30 kHz
Taus	250 kHz	50 kHz
Hadronic Triggers	190 kHz	100 kHz
Others (exotics, VBF, etc.)	50 kHz	50 kHz
Total	**995 kHz**	**340 kHz**

- Further refinements expected towards TDR in 2017

Backup

Phase-II LoI Menu

Original LoI Menu (now obsolete)

Object(s)	Trigger	Estimated Rate	
		no L1Track	with L1Track
e	EM20	200 kHz	40 kHz
γ	EM40	20 kHz	10 kHz*
μ	MU20	$>$ 40 kHz	10 kHz
τ	TAU50	50 kHz	20 kHz
ee	2EM10	40 kHz	$<$ 1 kHz
$\gamma\gamma$	2EM10	as above	~5 kHz*
$e\mu$	EM10_MU6	30 kHz	$<$ 1 kHz
$\mu\mu$	2MU10	4 kHz	$<$ 1 kHz
$\tau\tau$	2TAU15I	40 kHz	2 kHz
Other	JET + MET	~ 100 kHz	~ 100 kHz
Total		~ 500 kHz	~ 200 kHz