CMS Phase II Trigger and L1 menu

Trigger, Online and Offline Computing Workshop
Sep 4 and 5 at CERN

O. Buchmueller
Imperial College London

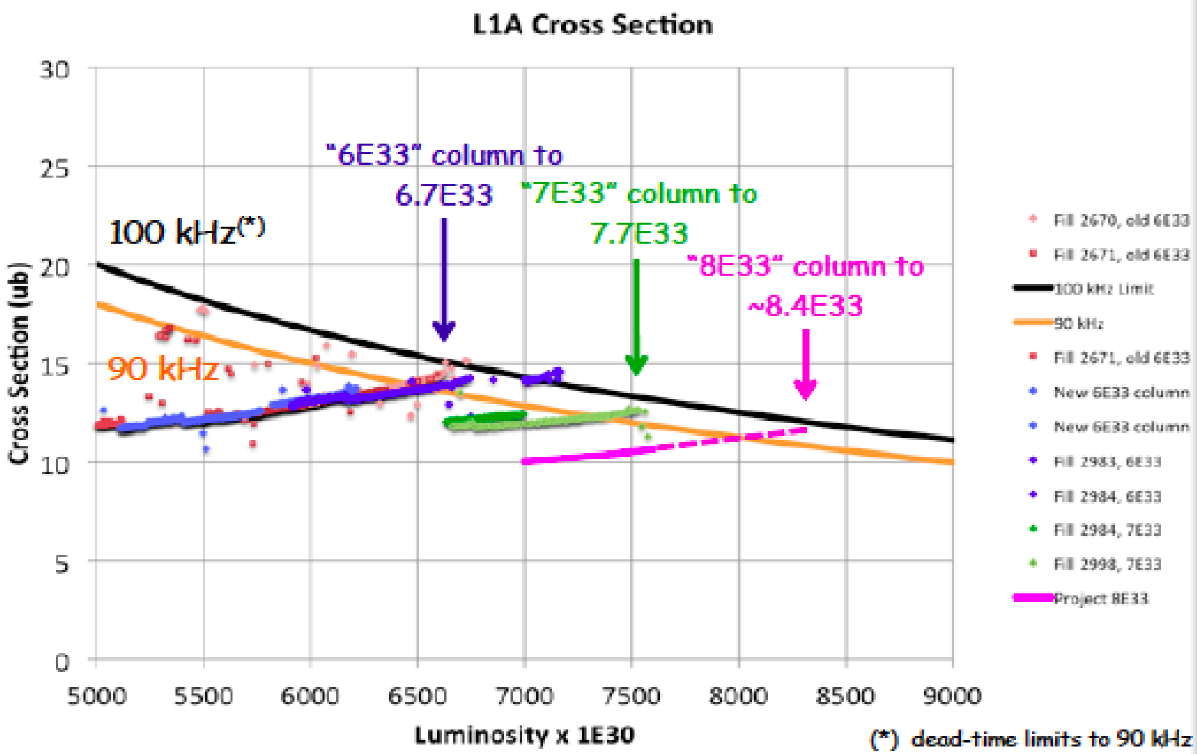
Imperial College London

THE CHALLENGE

The challenge

L1T menu performance in 2012

Arno.Heister@cern.ch



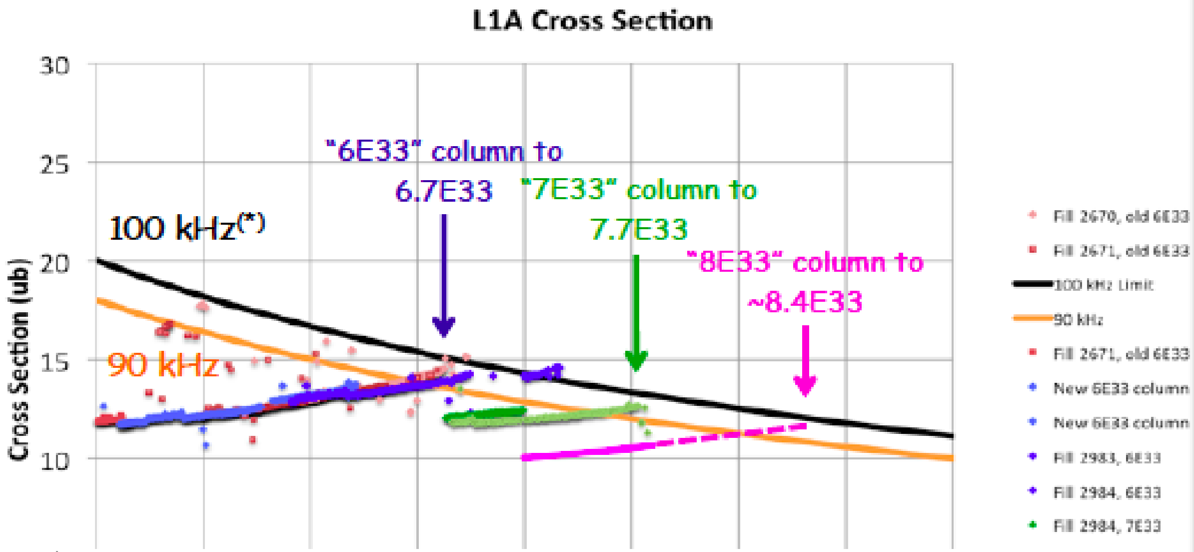
- A L1 trigger menu consists of up tp 128 different algorithms with fixed logic incl. thresholds (plus 64 *technical* triggers).
- To adjust the L1 trigger output rate of for a given LHC run condition i.e. peak luminosity we use a) pre-scales b) back-up L1 algorithms with different thresholds, logic, etc.

4

The challenge

L1T menu performance in 2012

Arno.Heister@cern.ch

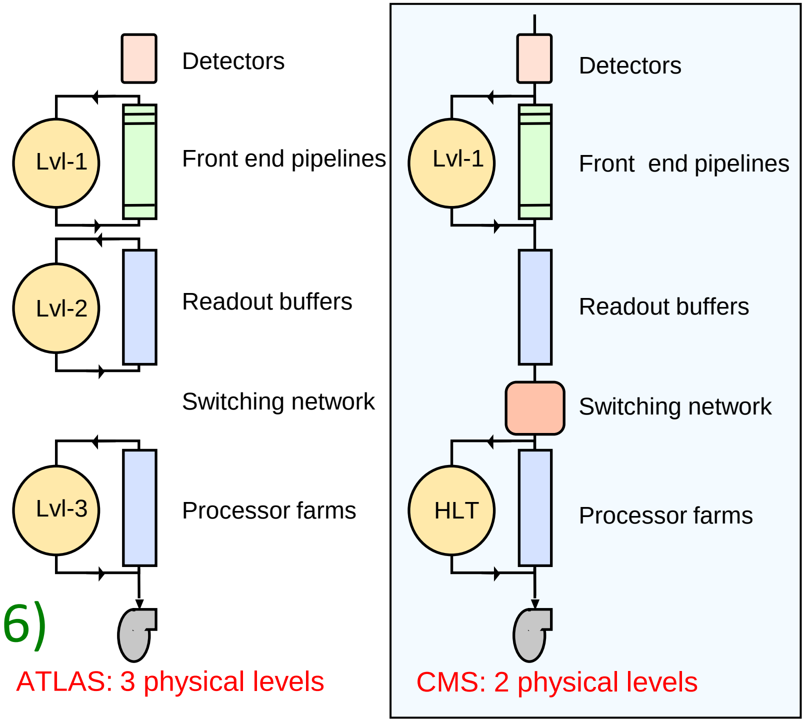


Roughly speaking, considering also the change of energy to ~14 TeV, we are looking at an order of magnitude increase!

- A L1 trigger menu consists of up tp 128 different algorithms with fixed logic incl. thresholds (plus 64 *technical* triggers).
- To adjust the L1 trigger output rate of for a given LHC run condition i.e. peak luminosity we use a) pre-scales b) back-up L1 algorithms with different thresholds, logic, etc.

Basic Numbers: “Today vs HL-LHC”

- 2012-2013 run:
- Lumi = 7 x 10^{33}, PU = 30, E = 7 TeV, 50 nsec bunch spacing
- 2012 CMS operating:
  – Input to L1: ~16 MHz
  – L1 Accept ≤ 100 kHz,
  – Latency ≤ 4 μsec (AT <2.5)
  – HLT Accept ≤ 1 kHz



- Where are we expected to be:
- Lumi = ~ 10^{35} (increase × ~10)
- <PU> = 140, Peak PU = 192 (increase × 6)
- E = 14 TeV (increase × 2)
- 25 nsec bunch spacing (reduce × 2)
- Integrated Luminosity > 250 fb^{-1} per year (increase × ~10)

THE GOAL

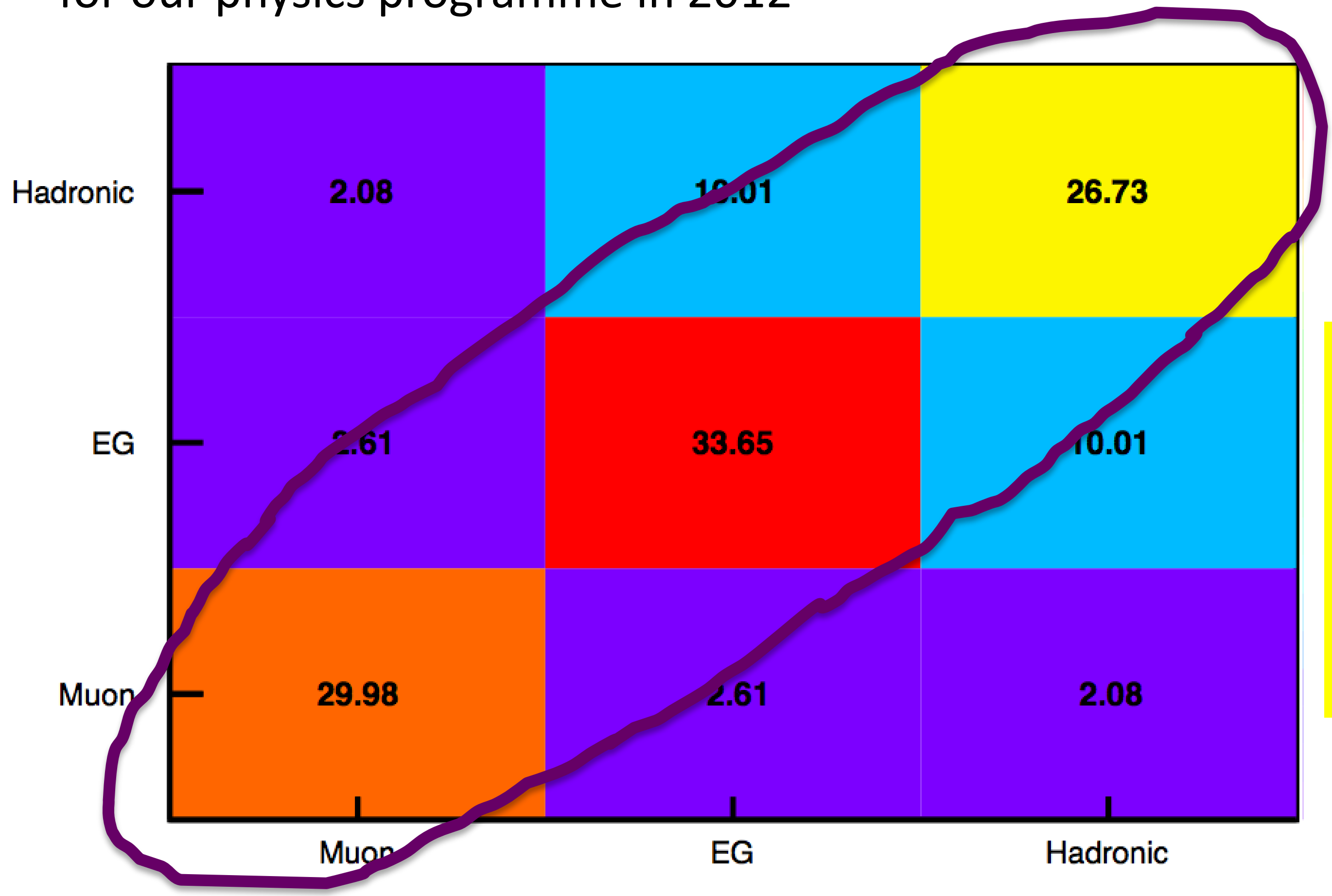
Main Goal of the Phase II Upgrade

Keep Physics acceptance similar to what we had in RUN-I

Especially for Higgs and searches but also for SM processes!

L1 menu breakdown in 2012

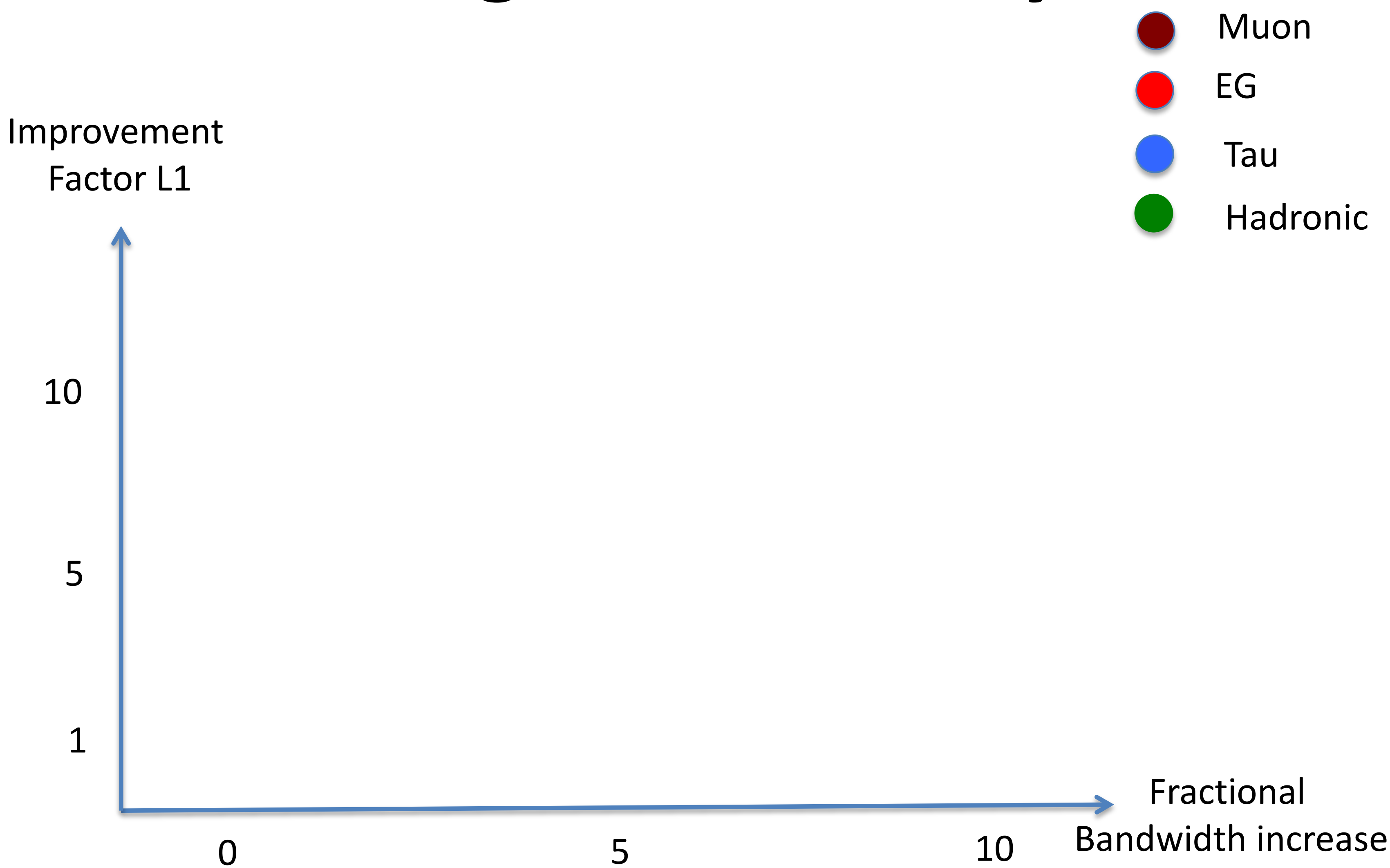
Crude rate breakdown in Muon, EG, and Hadronic triggers of the last L1 menu operated in 2012 (7e33 menu).
This breakdown gives a feeling on the relevance of this three categories for our physics programme in 2012



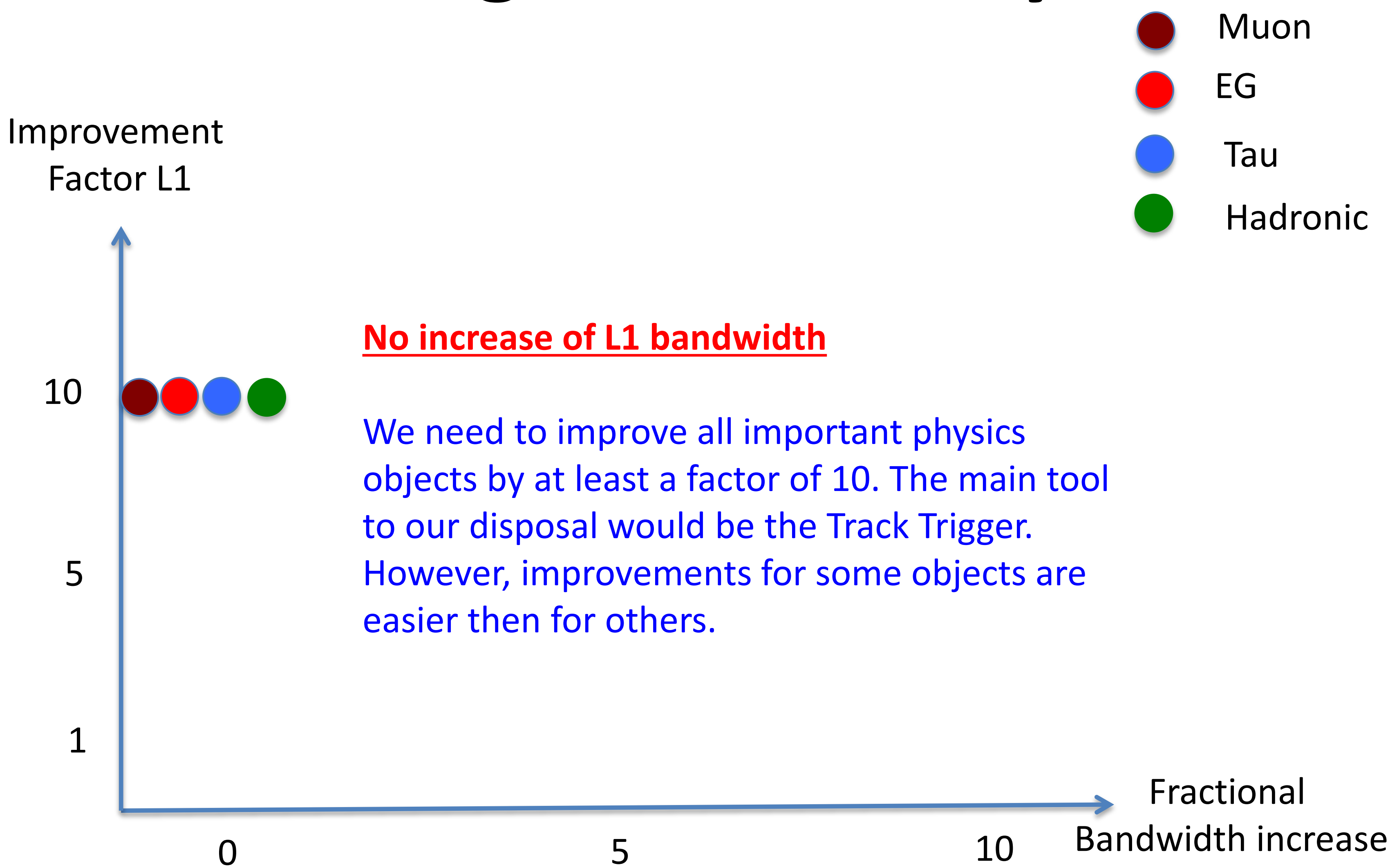
Bottom line: Approximately equal importance among the three categories.

THE STRATEGY

Aiming for Flexibility



Aiming for Flexibility



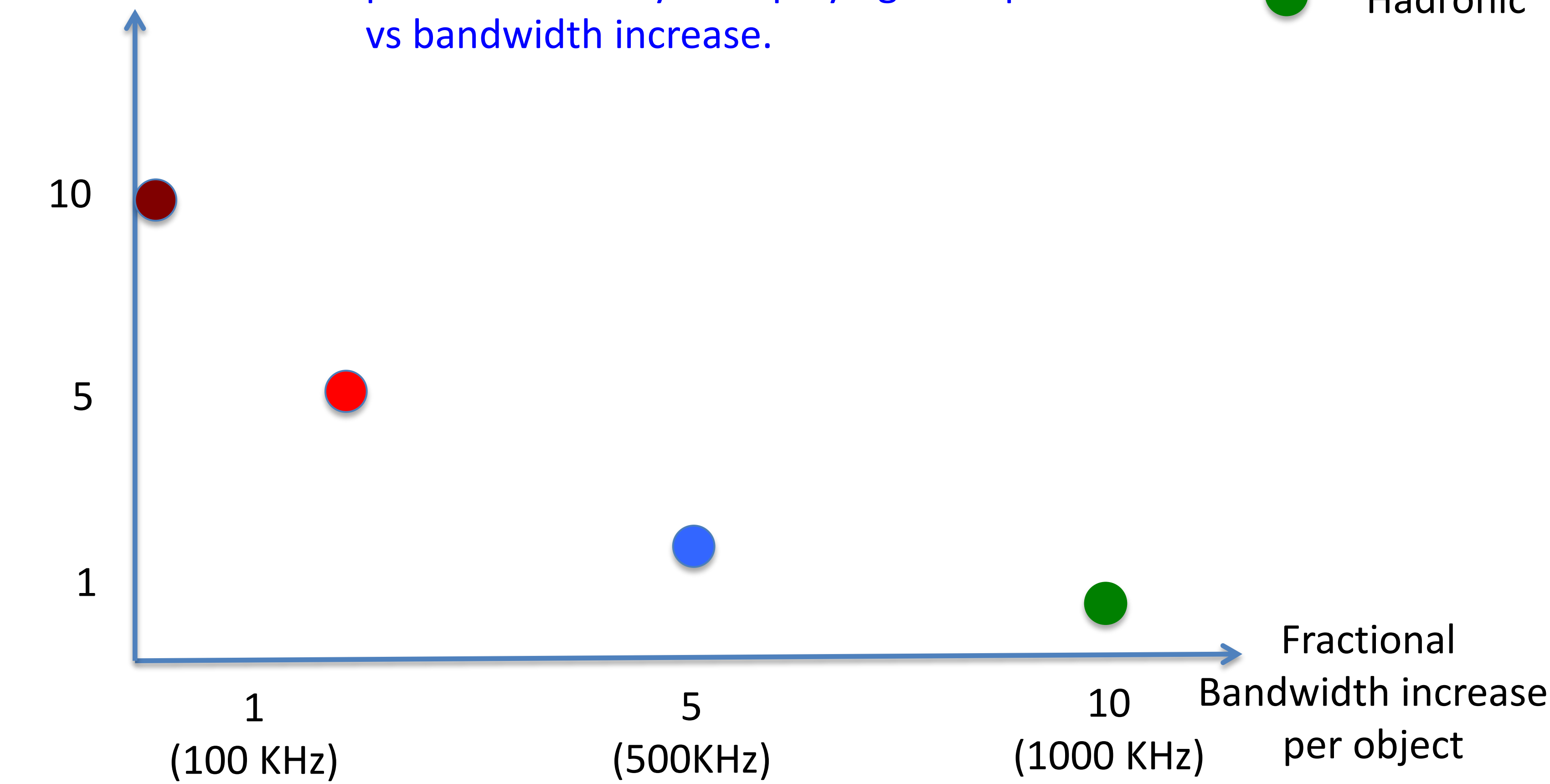
No increase of L1 bandwidth

We need to improve all important physics objects by at least a factor of 10. The main tool to our disposal would be the Track Trigger. However, improvements for some objects are easier then for others.

Aiming for Flexibility

<u>**Significant increase of L1 bandwidth**</u>

Going significantly beyond 100 KHz would provide flexibility to in playing L1 improvement vs bandwidth increase.



CMS Phase 2 Trigger Scenario

- **L1 Accept rate up to 750 kHz**
  - Plan for L1A rate up to 500 kHz @ 140 PU and 750 kHz @ 200 PU
  - Driven by keeping acceptance consistent with Run 1 and Phase 1 Upgrade
  - Includes acceptance of consecutive 25 ns beam crossings (not gap of 3 as present)
  - Provides more acceptance and lower thresholds
  - Limited by pixel readout, impacts on DAQ readout, EVB, & HLT CPU
- **Tracking Trigger**
  - Driven by keeping acceptance consistent with Run 1 and Phase 1 Upgrade
  - Leptons: P_T cut & isolation, Jets: Vertex
- **New L1 Trigger (Calorimeter, Muon, Global) to incorporate Track Trigger**
  - Finer calorimeter cluster trigger, muon & calorimeter seeds for track match
  - Also incorporate additional muon chambers for $|\eta| > 1.5$ (e.g. GEMs)
- **Latency of 12.5 μsec**
  - Driven by Tracking Trigger and logic to incorporate it.
  - Limit from complications for outer tracker readout
- **HLT Output Rate up to 7.5 kHz**
  - Plan for 5 kHz @ 140 PU and 7.5 kHz @ 200 PU
  - Limit from Computing (e.g. cost), no limit from DAQ
  - Same reduction of L1 rate (~100) as present

Impact on Existing Subsystems

- **Replace ECAL Barrel (and Endcap) Front End electronics**
  - Allows L1 latency & accept rate increases
  - Includes providing individual crystal level (not 5x5 sums) trigger information
    - *Resolution based on $\Delta\eta\times\Delta\phi = 0.087\times0.087 \rightarrow 0.017\times0.017$*
    - *Improved spike rejection in EB*
  - Assume: EE electronics replaced with EE replacement
- **Replace CSC on-Chamber Cathode Front End Boards (CFEBs) on ME2/1, 3/1, 4/1**
  - Present CFEBs on ME2/1, 3/1, 4/1 limited to 6 μs latency, 400 kHz rate without significant loss in readout and trigger efficiency (> 2% per chamber)
  - Replace 108 out of a total of 468 CFEBS with digital CFEBs similar to those installed on ME1/1 during LS1
  - Then entire CSC system has high efficiency up to 20 μs and 1 MHz L1A.
- **(Replace DT Readout Boards (ROBs) in on-detector minicrates)**
  - Replacement planned anyway due to lifetime issues
  - Presently limited to 300 kHz
  - 1500 ROBs
  - After replacement, no limitation up to 20 μs latency, 1 MHz rate
- **Modifications to HCAL μHTR system**
  - Replacement of AMC13 card, modification of uTCA architecture – not major
  - HE replacement planned anyway

Level-1 Tracking Trigger

- Require:
  - Highest possible efficiency over all η for isolated high P_T tracks
  - Good efficiency for tracks in jets for vertex identification
  - P_T > 2-3 GeV (small difference within this range)
    - Expect ~ 115 charged tracks with P_T > 2 GeV at PU = 140
    - Design for 300 tracks per bunch crossing
  - Vertex resolution ~ 1 mm
- Use:
  - Charged Lepton ID
  - Improve P_T resolution of charged leptons
  - Determine isolation of leptons and photons
  - Determine vertex of charged leptons and jet objects
  - Determine primary vertex and MET from L1 Tracks from this vertex
- Pixel Trigger Option
  - Under consideration for now, but need a strong physics case
  - Challenging to meet 12.5 µsec latency

Two main fields of studies in TPS

Track Trigger studies:

These take place in a dedicated sub-group of the TPS, called the Track Trigger Integration group. Goal is to develop a comprehensive, cross detector, strategy for the integration of the Track Trigger in L1.

Conveners: E. Perez and A. Ryd

Main Responsibility: Integration of Track Trigger in L1. Provides L1 algorithms to L1 menu team.

L1 menu studies:

Based on the L1 menu studies for the L1 TDR, we investigate the impact on change in basic parameters like bandwidth as well as upgrade options like the Track Trigger on the thresholds of important triggers.

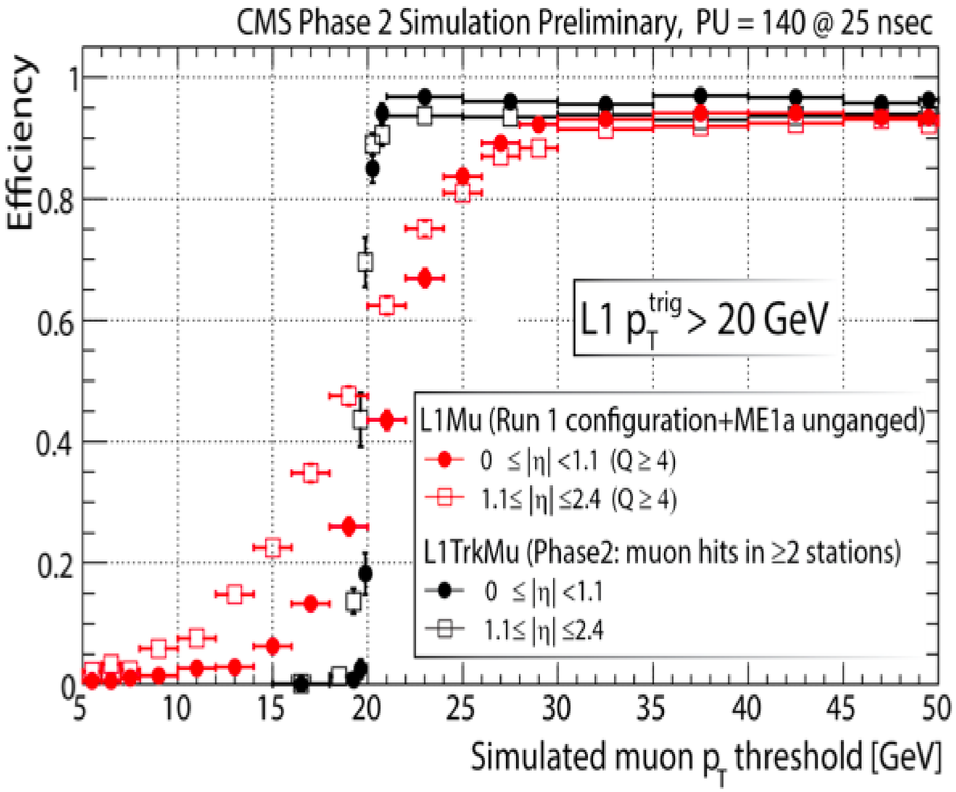
L1 menu team: B. Winer, G. Karapostoli, and M. Grimes

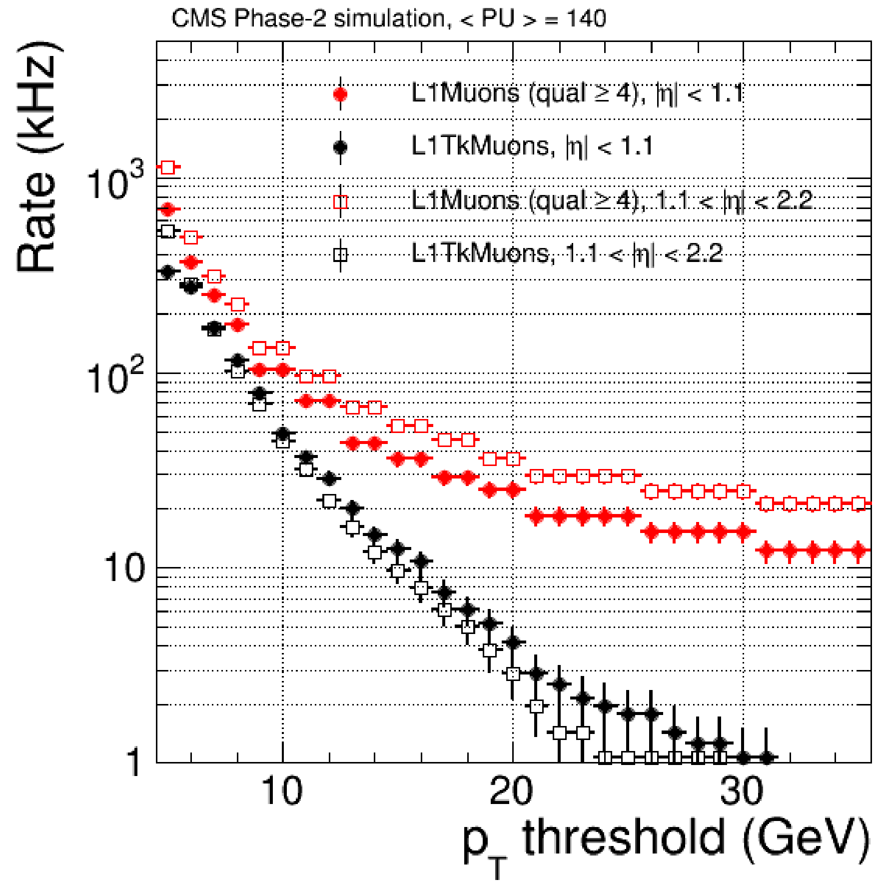
Main Responsibility: Menu development for Phase II

See talk from A. Ryd for more details!

TRACK TRIGGER PERFORMANCE

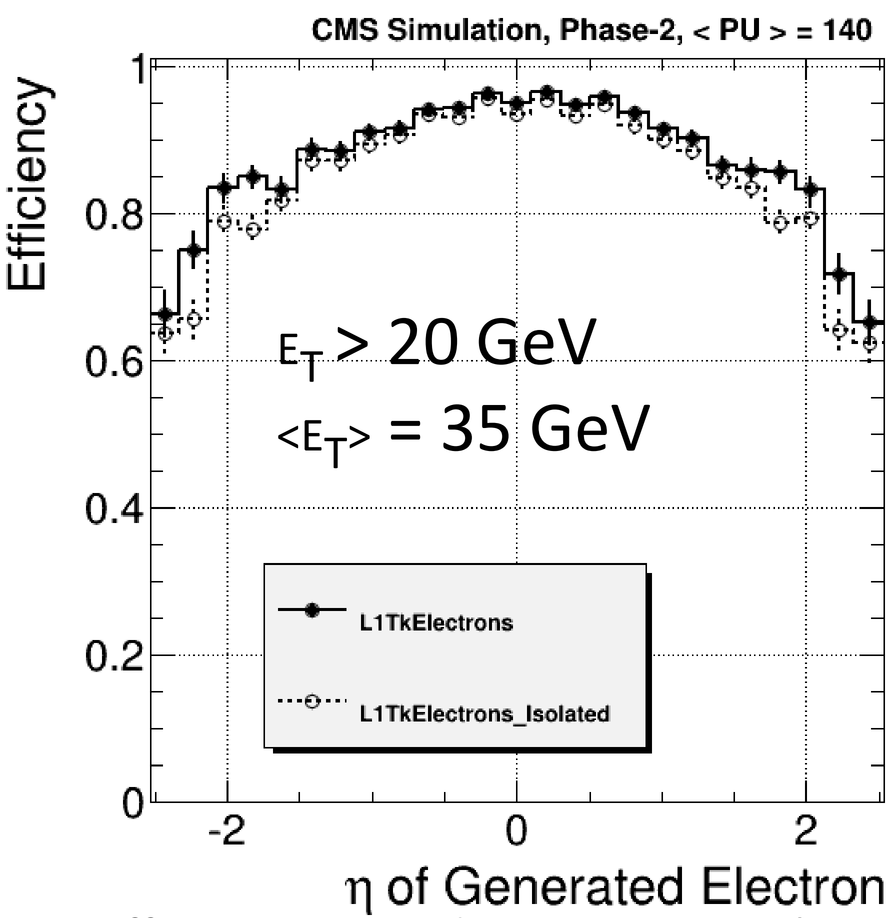
Track Trig. Performance: muons

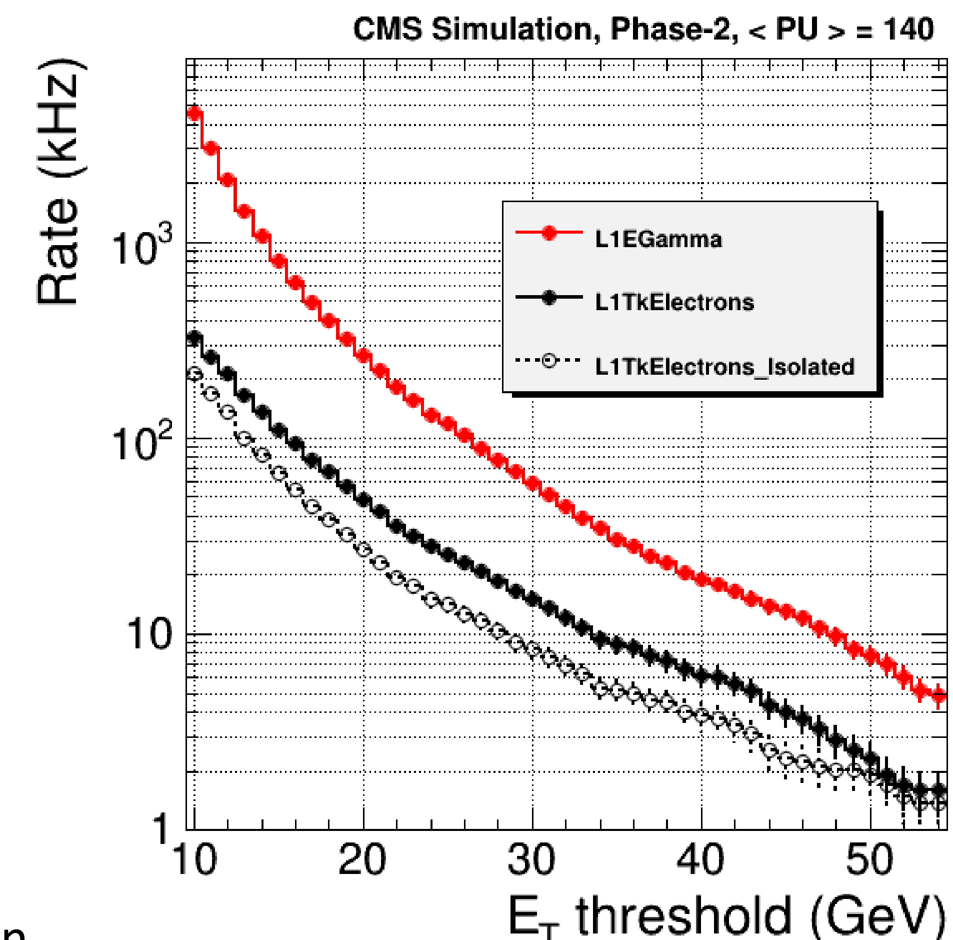




- Sharpens (!) turn-on curve, improves efficiency
- For a threshold of ~ 20 GeV, rate of single muon trigger can be reduced by a factor of O(10)

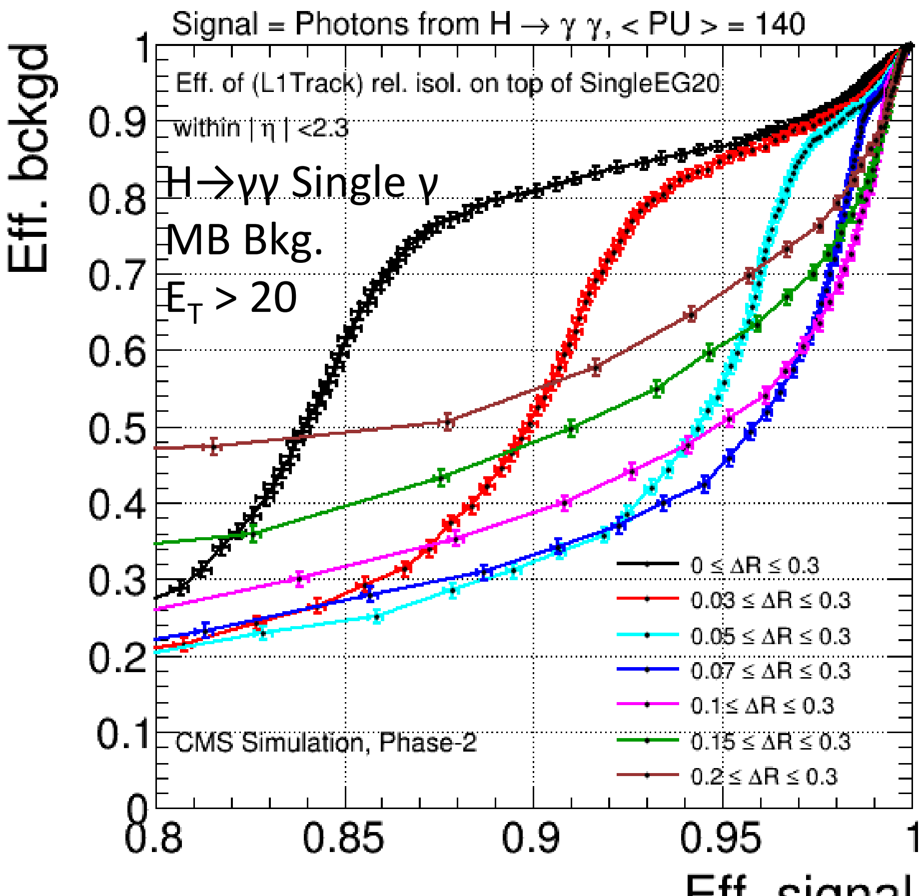
Track Trig. Performance: electrons

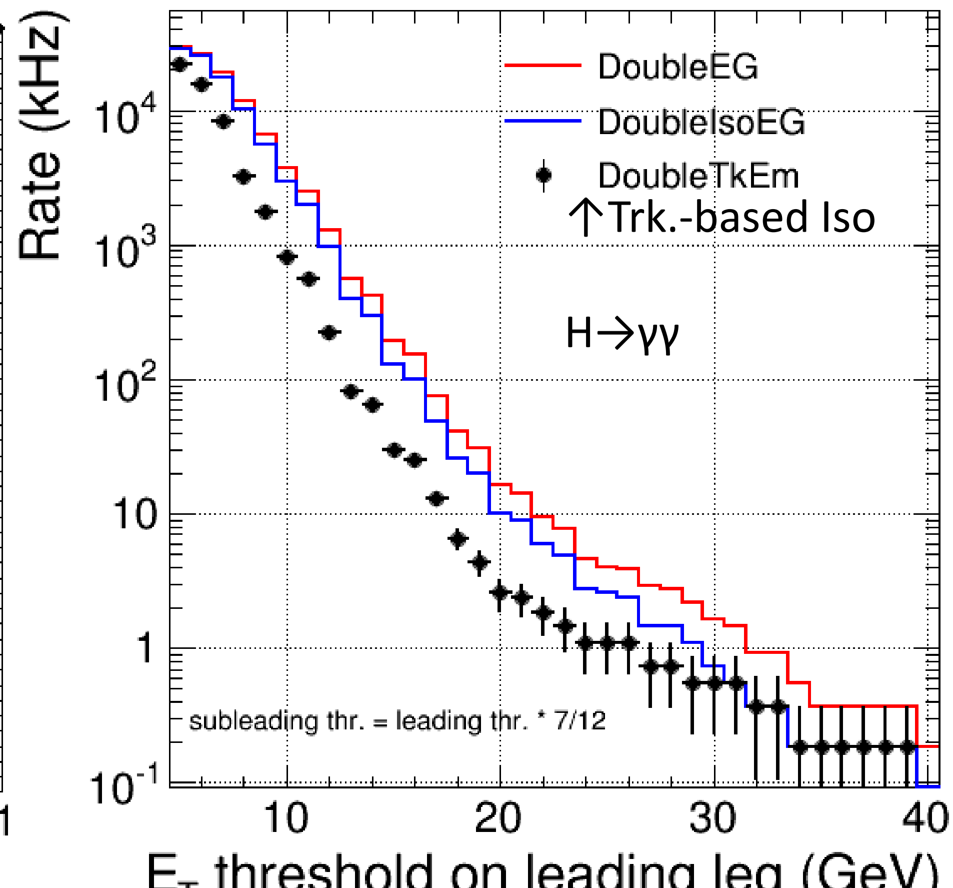




- Efficiency exceeds 90% in central region
- Match with Track Trigger plus track-based isolation retains good efficiency with rate reduction of O(10)
-

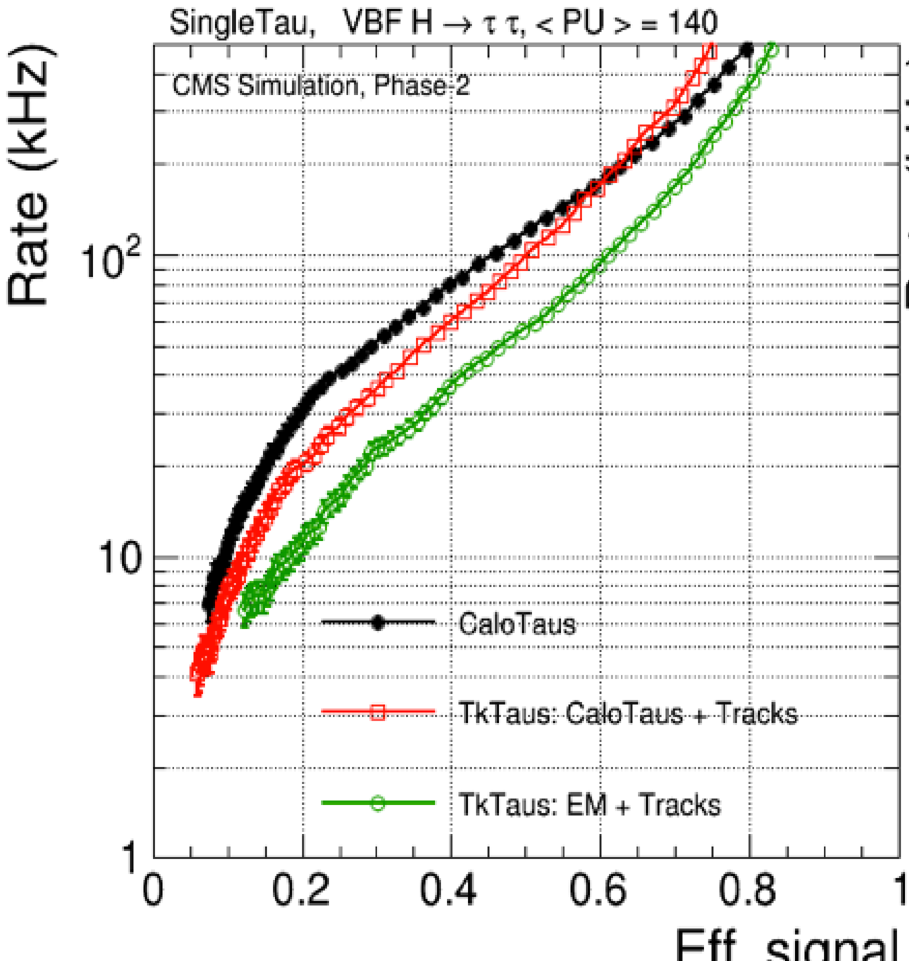
Track Trig. Performance: photons

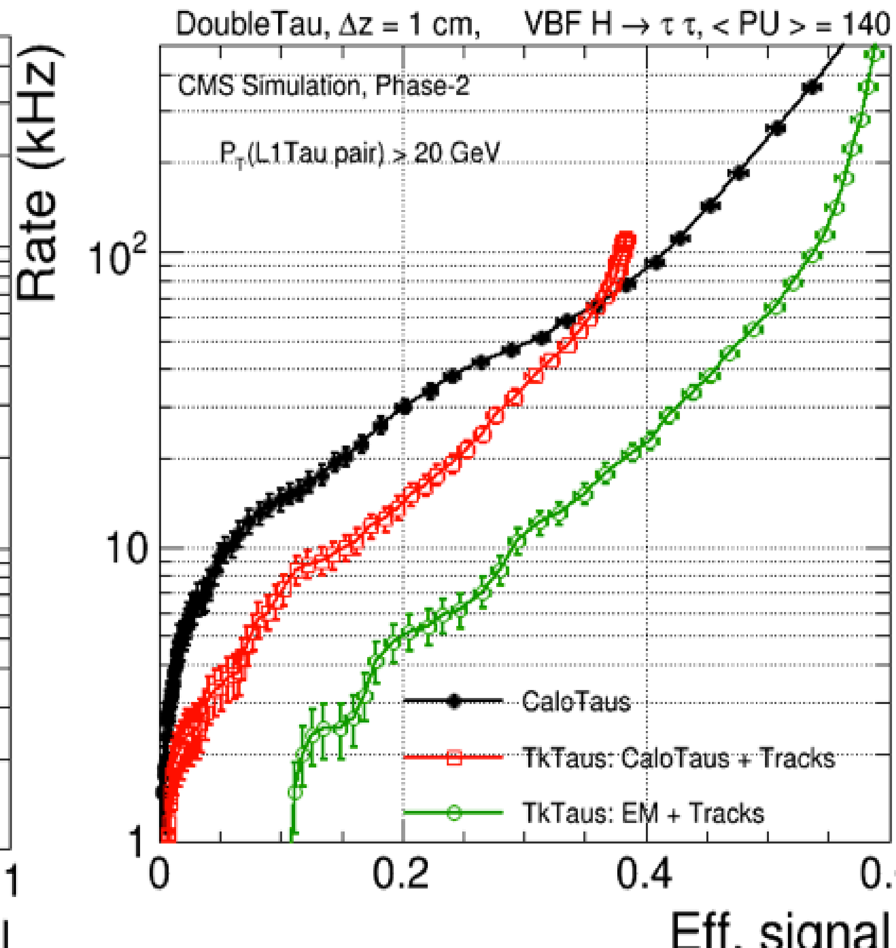




- Track-based isolation excludes tracks from conversions
- For thresholds of ~ 18,10 GeV on leading, subleading legs, the rate can be reduced by a factor of > 6

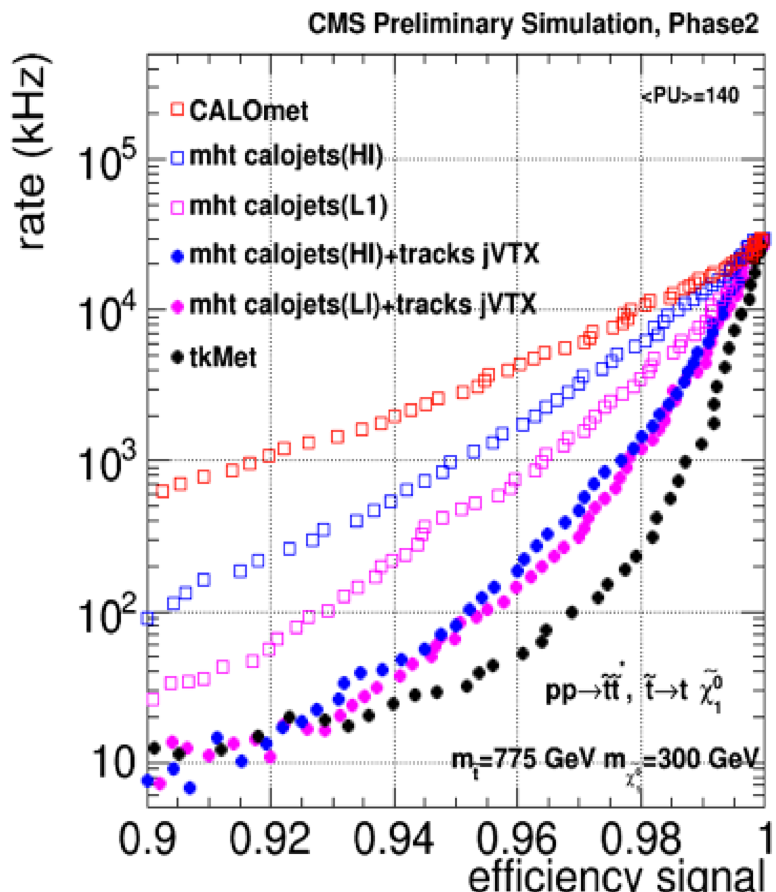
Track Trig. Performance: taus

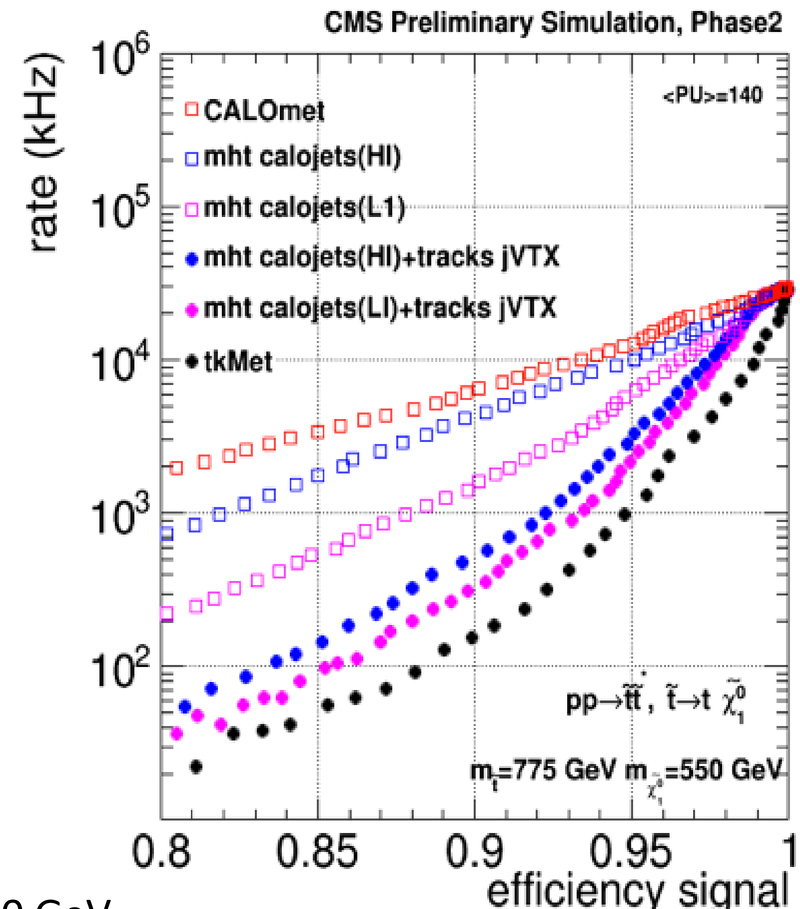




- Two approaches: (1) start with calo. taus, add tracks, track-based isolation or (2) start w/tracks, add crystal L1 EM objects.
- Select approach (2): can maintain 50 kHz trigger rate with 30% efficiency for VBF H →ττ
-

Track Trig. Performance: MET, MHT





- Two SUSY scenarios generating MET of 200, 300 GeV
  - Stop pair decays to top and neutralino
- Signal defined to be events with gen. MET > 100 GeV
- MHT plus vertex constraint 95% efficient with few 10's kHz rate
- Track-based MET reduces rate over calo MET by 2 orders of magnitude while maintaining 80-85% efficiency in "Low MET" scenario

FIRST LOOK AT A L1 MENU FOR PHASE II

L1 Menu Studies

- Goal: maintain overall physics performance + acceptance of L1 Trigger Upgrade TDR (e.g. thresholds near the end of run 1)
  - Study a sample menu using ~70% of bandwidth
    - Not included: any prescaled trigger (minbias, triggers with lower thresholds), triggers involving forward calorimeter, MET/MHT, three lepton triggers, other acceptance, diagnostic and calibration triggers.
  - Compensate by increasing found total rate by 30%
- Benchmark conditions: 140PU
  - Use Minbias Sample with PU = 140
  - Assume bunch spacing at 25 ns: L ~ 5.6 E34
- Use Tracking Trigger
  - Assume "perfect" performance
- High PU Conditions: 200 PU
  - Use private production of 200 PU events
  - Assume bunch spacing at 25 ns: L ~ 8 E34
- Uncertainties: Need Safety factor of at least 1.5
  - Simulation uncertainty
  - Readout underachievement
  - Realistic Tracking Trigger performance

L1 Trigger Menu at 140 PU with L1 Tracking Trigger

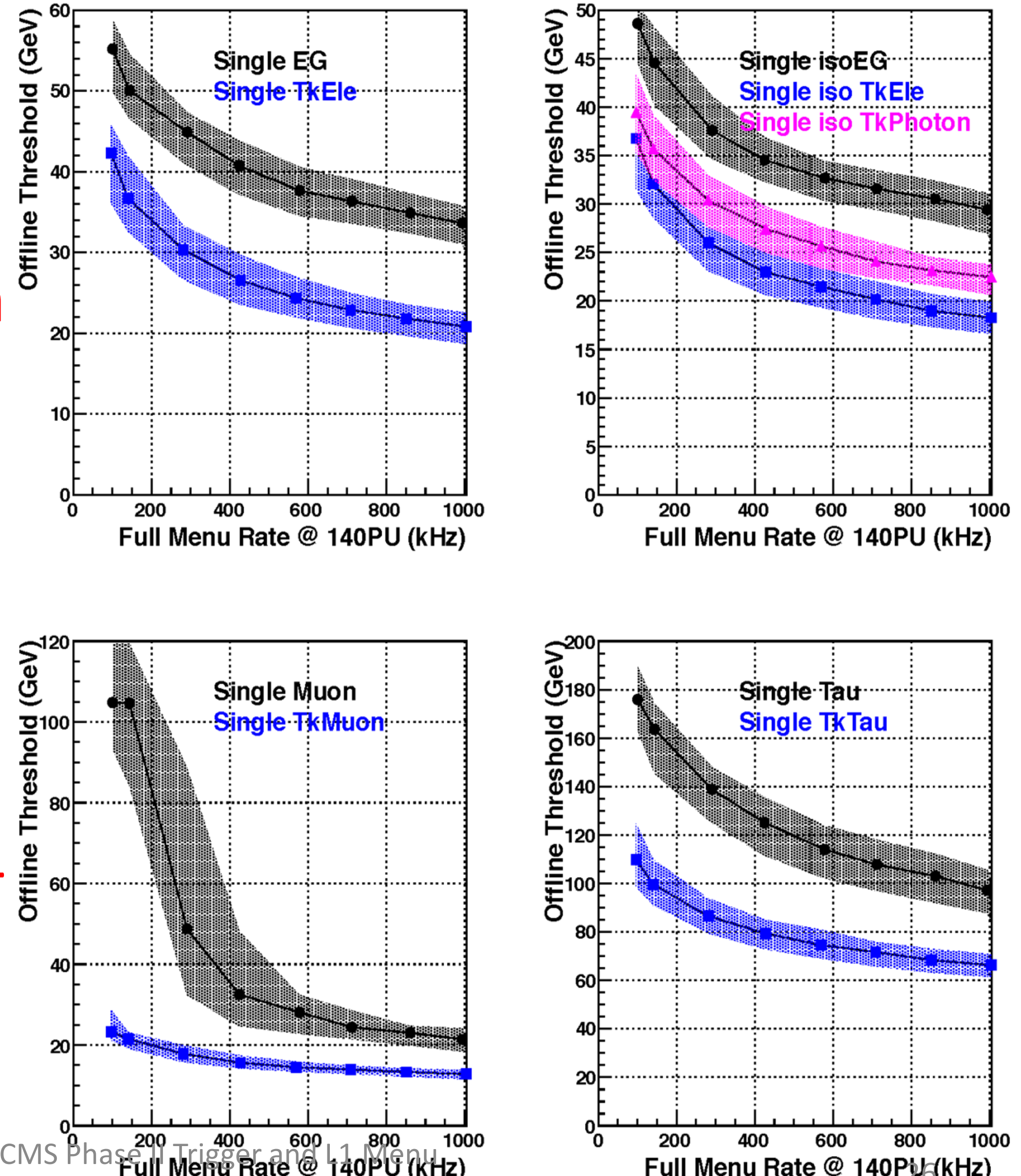
- Menu w/o Tracking Trigger produces a total rate of 1.5 MHz at 140 PU
  - Tracking trigger provides factor of 5.5 reduction to 260 kHz →
  - w/ 1.5 safety factor: 390 kHz
  - Use 500 kHz as benchmark
- Menu w/Tracking Trigger produces total rate of 500 kHz at 200 PU
  - w/ 1.5 safety factor: 750 kHz
  - w/o track trig., approach 4 MHz!
    - (6 MHz w/safety!)

Warning: this menu is just a sample table only for evaluating bandwidth

$L = 5.6 \times 10^{34}$ cm^{-2}s^{-1} $\langle PU \rangle = 140$	Level-1 Trigger with L1 Tracks	
Trigger Algorithm (Menu with L1 Track Trigger)	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-veto)	31	31
ele (iso tk) + e/γ	11	22 16
Double γ (tk-veto)	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@125
Quad Jet (tk)	12	4@72
Single ele (tk) + Jet	15	23 66
Single Mu (tk) + Jet	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**	

L1 Thresholds vs. Bandwidth: Single Lepton Triggers

- Allocate initial BW for each algorithm in full menu according to BW fractions used in sample menus with and without L1 Tracking
  - Determine trigger thresholds necessary to fit assigned rate
  - Repeat for a range of total bandwidths
- Plots show rates for full menus with and without L1 Tracking @ 140 PU
  - No safety factors applied



HLT & DAQ

- HLT: Main challenge is factor of up to 45 increased HLT processing power over 2012 Run
  - up to x 7.5 increase in L1 input rate (500 kHz @ PU=140, 750 kHz @ PU=200)
  - x 6 for increased complexity due to higher PU, tighter L1 selection and higher energy
    - Estimated from Run 1 CPU dependence on PU, increase in L1 menu cross section with energy
    - Some mitigation due to prompt access to tracking info.
- CPU:
  - CERN estimates x10 increase w/flat budget
  - Rest from emerging technologies using many-cores, parallelism
    - Same as for offline.
- DAQ: For a 10 MB event size at 750 kHz, total required throughput is around 75 Tbps (80% efficiency).
- This could be provided by a DAQ system of 750 FEDs and a "DAQ link" of 100 Gbps.
  - Switching capacity of 100 Tbps is very modest, since InfiniBand switch today provides 32 Tbps unidirectional bandwidth. Costs of this infrastructure are likely below those of existing system
  - Scale back to 50 Tbps, 500 FEDs for 500 kHz at PU=140

CMS Phase 2 Trigger Summary

- Architecture:
  - Level-1 Accept: 500 kHz @ 140 PU, 750 kHz @ 200 PU
  - Level-1 Latency: 12.5 μsec
  - HLT Output rate: 5 kHz @ 140 PU, 7.5 kHz @ 200 PU
- Features:
  - Level-1 Track Trigger
  - Upgraded Calorimeter, Muon, Global Triggers
- Performance:
  - Track Trigger reduces L1 Menu rate by factor of 5.5
  - Track Trigger combined with L1A rate maintains overall physics performance + acceptance of L1 Trigger Phase 1 Upgrade TDR (e.g. thresholds near end of run 1)
- Schedule:
  - R&D Program underway now…important to validate design, techniques & technologies

Backup

Forming a L1 Menu

- The L1 Trigger rate must fit within a specified bandwidth
  - Run I and Phase 1: 100 kHz
  - Phase 2: Study 100 - 1000 kHz

Slide from B. Winer

- Because of overlap between trigger algorithms, the total L1 rate is not the simple sum of rates.
  - Must measure the total L1 rate by simultaneously testing a set of triggers.
- An operational L1 Menu will involve hundreds of algorithms.
  - Requires many months of development with careful consideration of physics channels and priorities.
  - For TP we adopted the approach used for the L1 TDR (Phase 1)
    - Use a set (~20) trigger algorithms that capture much of the basic physics. This set of triggers represents the working horse triggers in 2012 and correspond to approximately 70% rate of a total menu
    - Use this toy menu to explore correlations/overlaps
    - **Note: It is impossible for this to capture *every* possible capability of the upgraded system but it should provide a reasonable first guideline.**

Phase 2 L1 Trigger Latency

(preliminary estimate)

- Estimate L1 Track Trigger result available 5 μs after interaction occurred.
  - L1 Track trigger is a "push" system, not region of interest
- Regional processing involves (+2.5 μs ⇒ 7.5 μs) :
  - Using tracks to find primary vertex – 0.5 μs
  - Associating tracks with the primary vertex – 0.5 μs
  - Associating tracks with calorimeter objects
  - Associating tracks with and fitting tracks with muon tracks

    } **0.5 μs**
  - Defining track-correlated L1-objects and their characteristics – 0.5 μs
  - Using tracks to calculate isolation of calorimeter and muon objects – 0.5 μs.
- Global processing involves +(1 μs ⇒ 8.5 μs):
  - Global sums, kinematic calculations, correlations between trigger objects, trigger decision logic (incl. trigger rules)
- Propagation back to detector front ends (+1 μs ⇒ 9.5 μs)
  - 38 bx in present system (0.95 μs)
- Safety Factor of 30% ⇒ 12.5 μs
  - NB: Original Trig. TDR Latency: 127 bx, Run 1: 157 bx (+ 0.8 μs), req'd: 168 bx
    - Phase 1 may go longer (e.g. use up to 164 bx)
  - Safety factor could be absorbed completely by Track Trigger
- Set 12.5 μs as minimum design latency
  - Once 6 μs exceeded, 12.5 μs is the next point where consequences

L1 menu workflow (fixed thresholds)

Slide from B. Winer