Tau Trigger in ATLAS

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- Physics objectives; hadronic environment and trigger constraints
- Tau trigger slice ingredients (L1, L2, EF)
- Tau trigger menus and interplay with $\not{E}_T$.
- Current status, problems and improvements

TDR tau trigger motivation

- *In coincidence with muon or electron trigger it could improve efficiency of* $Z \rightarrow \tau\tau$ *or low mass* $A \rightarrow \tau\tau$.
- *In coincidence with* $\not{E}_T$ *it could provide trigger for* $W \rightarrow \tau\nu$ *and* $Z \rightarrow \tau\tau$ *hadronic decays (at* 10^{33} *luminosity)*
- *It could select high* E_T *hadrons for calibration of hadronic calorimeter*

But it can be implemented relatively easily and cheaply at LVL1 using the same inputs and same logic as for Egamma trigger.

Personal motivation

- Taus are main decay products of staus. Staus are lightest sleptons. Therefore taus are produced in majority of slepton decays.

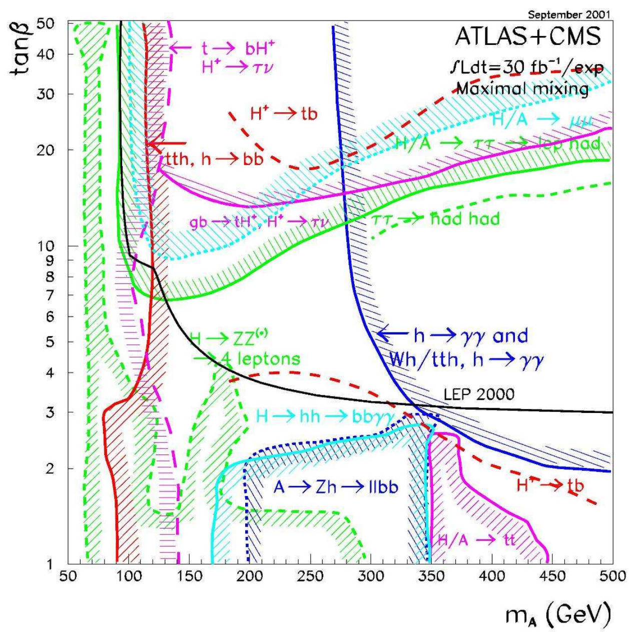
- In case of large $\tan\beta$ the only allowed 2 body SUSY decays (used for end-point analysis) are $\tilde{\chi}_2^0 \to \tau\tilde{\tau} \to \tau^+\tau^-\tilde{\chi}_1^0$ (ATL-PHYS-2000-009). So you need taus to make SUSY discovery.

- Taus are needed to discover light ($M < 140$ GeV) SM Higgs ($H \to \tau\tau$), and very useful for observation of non-SM Higgs.

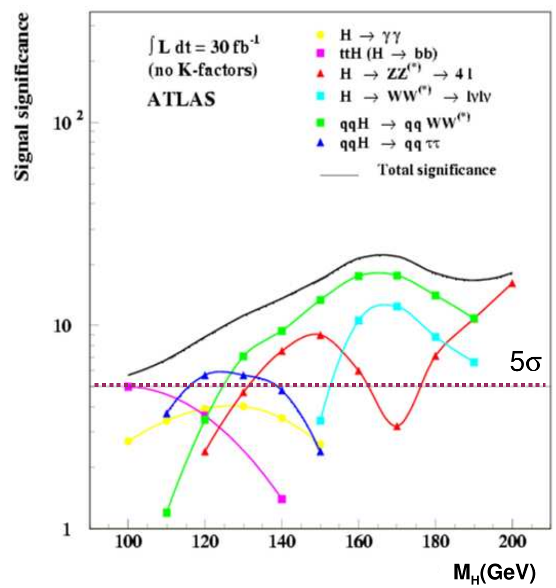
- I am interested in Lepton flavor violation which might be measurable in production of taus (e.g. $\tilde{\chi}_2^0 \to \mu\tilde{\tau} \to \mu\tau\tilde{\chi}_1^0$)

Examples: 5σ discovery reach

SUSY



SM Higgs



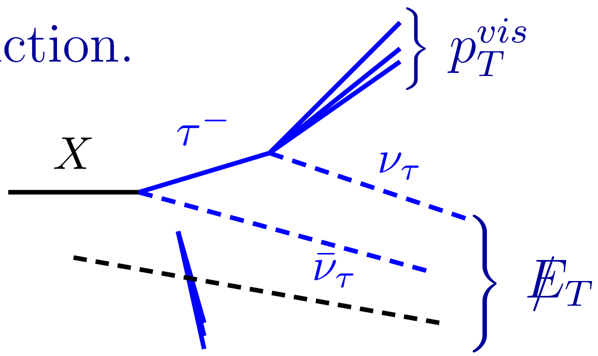
Having efficient tau trigger gives more data for these studies.
The problem is not to give more background.

Taus in LHC environment.

- Most studies focus on tau (abundant) production.

	$\mathcal{B}$
$W \to \tau\nu$	10%
$Z \to \tau\tau$	3.4%
$B \to \tau\nu X$	2.3%
$D_s \to \tau\nu$	2.9%

  not to mention SUSY or Higgs decays.



- Event with tau also contains neutrino(s)
  - One can never reconstruct full tau mass
  - Visible p_T^{vis} characterizes taus $p_T^{vis} = p_T^\tau - \sum p_T^\nu$
  - In comparison with e or μ from similar processes, taus are always *softer*. So, p_T^ρ from $W \to \tau\nu \to \rho\nu\nu$ or p_T^e from $W \to \tau\nu \to e3\nu$ are softer than p_T^e from $W \to e\nu$.
  - There is always $\not{E}_T$ in the event with tau.
    However, $\not{E}_T$ is *event* property.

Taus in LHC environment

- Use tau decay for identification :
  - Leptonic decays : $\tau \longrightarrow e\nu\nu, \mu\nu\nu$ (17.5% each)
  - Hadronic decays : $\tau \longrightarrow \rho\nu$ (25%), $\tau \longrightarrow \pi\nu$ (11%), $\tau \longrightarrow 3h\nu$ (15%), $\tau \longrightarrow \pi 2\pi^0$ (9%), etc

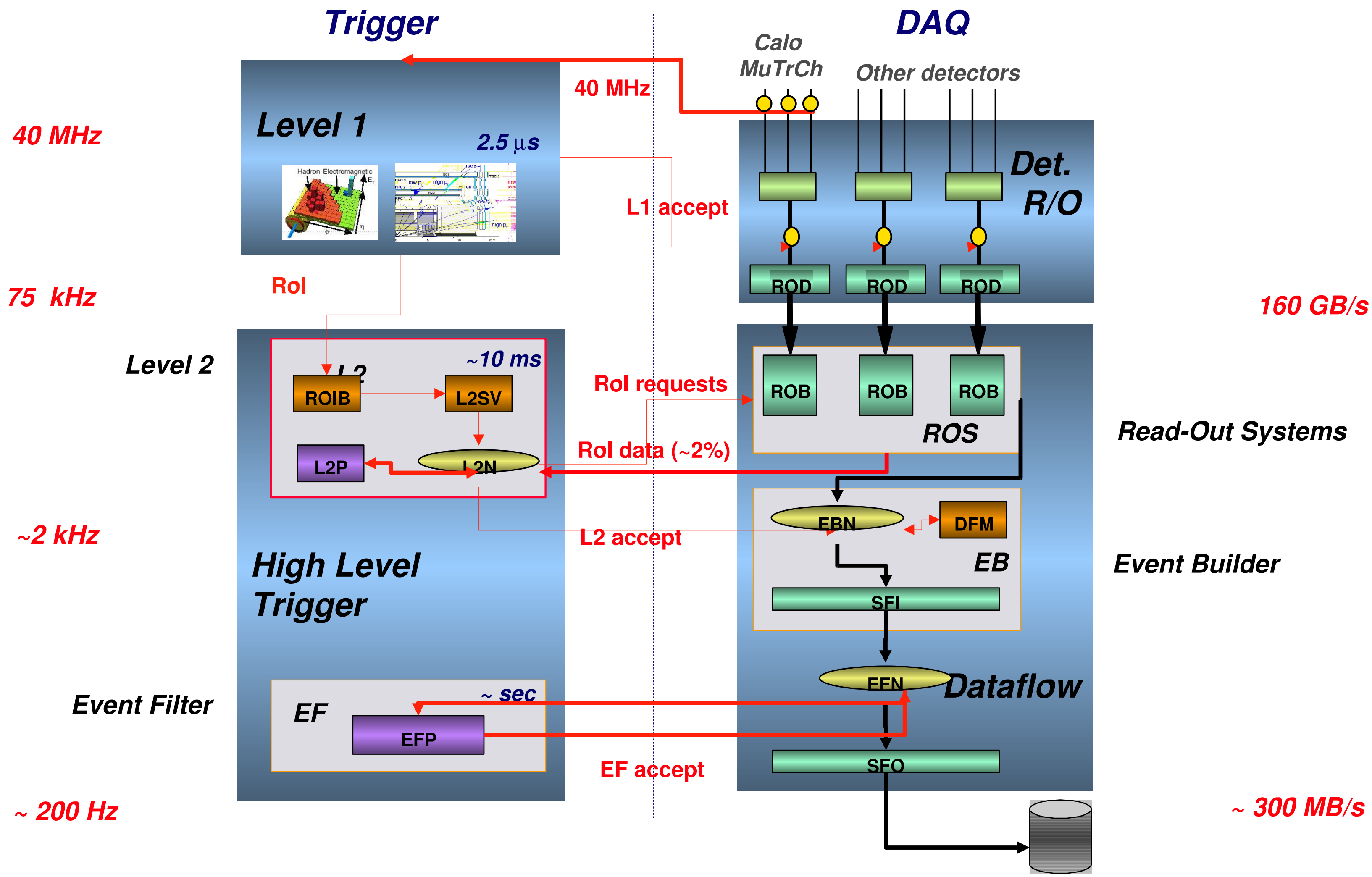
- As it is hard to differentiate between e and μ from taus and from other sources. Therefore use hadronic tau decays : look for low multiplicity narrow jet. Presence of $\not{E}_T$ or another lepton in event is often checked as well.

- Usual *jets* are main background (and rather unknown background).

Many taus around, but they are not easy to identify

True also for other experiments, including e^+e^- collisions

Trigger architecture overview. Nominal rates



HLT rate is controled by number of nodes and by output rate.

Revised rates and time budget targets

Originally, it was planned to use 8GHz CPU for L2P. Now, it is replaced by 2-3 3GHz CPUs. It provides comparable throughput, but increases allowed latency by 2. Updated table is :

Latency		Nominal	2008
		40 MHz	40 MHz
2.5 μs	LVL1		
		75 kHz	45 kHz
20 ms	LVL2		
		2 kHz	1 kHz
2 s	EF		
		200 Hz	200 Hz

That allows about 2.5 ms per LVL2 algorithm and 0.25s per EF algorithm.

`https://twiki.cern.ch/twiki/bin/view/Atlas/TriggerPerformanceTargets`

Tau Trigger vertical slice: one among many

There are several *vertical* trigger slices : Egamma, Muon, Tau, Jets and $\not{E}_T$.

Each vertical slice includes LVL1 (hardware), LVL2 and EF (software) steps, as presented above. The time and space budget is shared between everyone. However, there is an overlap between different triggers (in particular, of EM and Tau triggers) which needs to be taken into account when rejections factors are analysed. Currently, this overlap is ignored, and numbers in this talk are given for tau slice only.

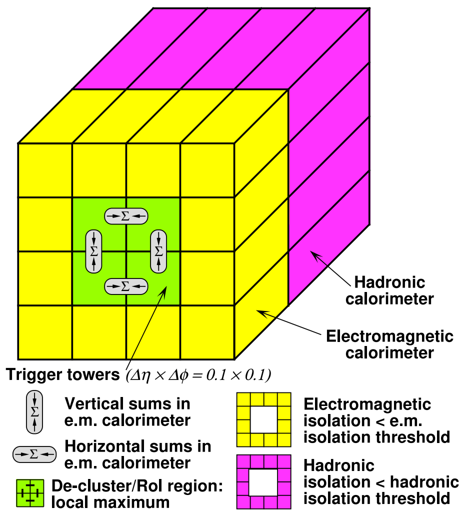
Current requirements for tau trigger are :

	$\mathcal{L} = 10^{31}$ (all menus)	$\mathcal{L} = 2 \cdot 10^{33}$ (TDR - τ20+MET30)
LVL1 :	7 kHz	2 kHz
HLT :	10 Hz	40 Hz

Tau LVL1 is based on calorimeter info only, while both LVL2 and EF use calorimeter and tracking.

LVL1 - tau hadronic trigger

ATL-DAQ-2004-011



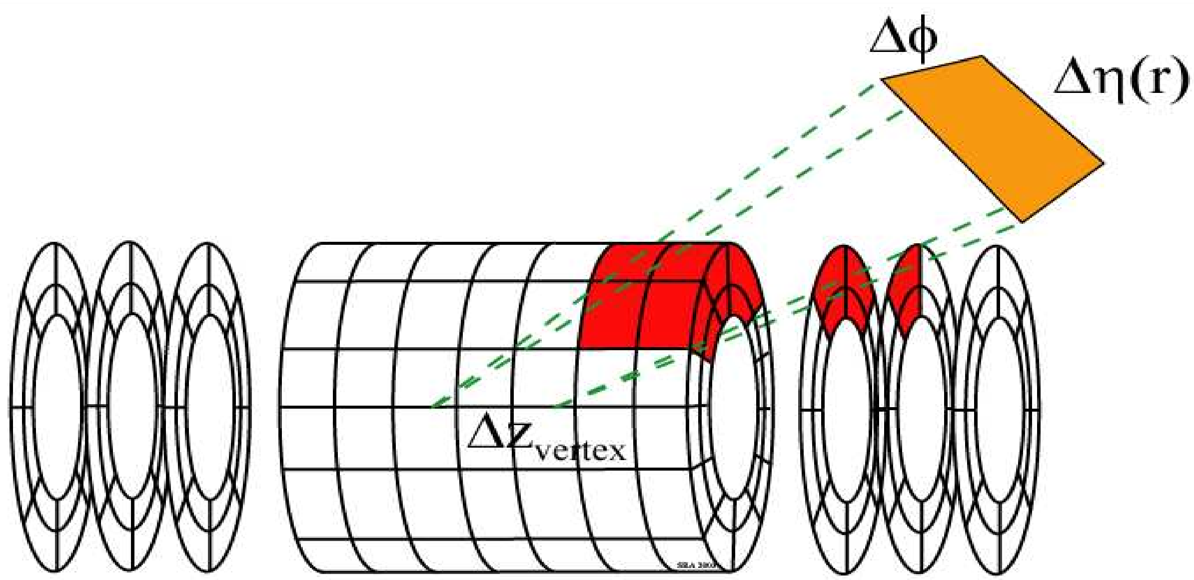
A cluster of 4×4 trigger towers ($\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ each) is selected with :

- E_T of Tau Cluster (Sum of most energetic 1x2 or 2x1 EM towers with 2x2 hadronic core. Has to be local E_T maximum)
- E_T of EM isolation area
- E_T of HAD isolation area

A set of cuts (a threshold) is applied. There are 8 thresholds which can be used for tau and/or EM LVL1 triggers, in addition to 8 EM-only thresholds.

The relative responce of EM and HAD part is important for proper energy reconstruction. At high lumi, the HAD part is scaled to get a proper *jet* energy, which underestimates average tau p_T due to different $\pi^0/\pi^{\pm}$ ratio.

RoI: Region of Interest



There is no time to unpack whole detector at LVL2. Instead part of data is unpacked, in a *RoI* area with center given by LVL1 seed and size (dR) determined by algorithm. Cashing mechanism is in place to optimize the performance. Each algorithm is executed once per RoI (not per event) of given type/threshold. Currently it takes about 3ms at LVL2 to unpack calorimeter and about 3ms to unpack InDet within typical tau RoI of 0.3×0.3

LVL2 tau trigger, Calorimeter part

On the second level, the simple calorimeter (tau oriented) calibration is applied and cluster parameters are refined. Also more cluster characteristics are calculated and are cut on:

- E_T^{raw} or E_T^{calib} of the cluster
- EMRadius2 $= (\sum E_{cell} \cdot dR^2)/(\sum E_{cell})$
- Isolation fraction
  $(E(dR < 0.2) - E(dR < 0.1))/E(dR < 0.3)$
- Strip width
  $\sqrt{(\sum \eta^2 \cdot E_{cell})/(\sum E_{cell}) - [(\sum \eta \cdot E_{cell})/(\sum E_{cell})]^2}$

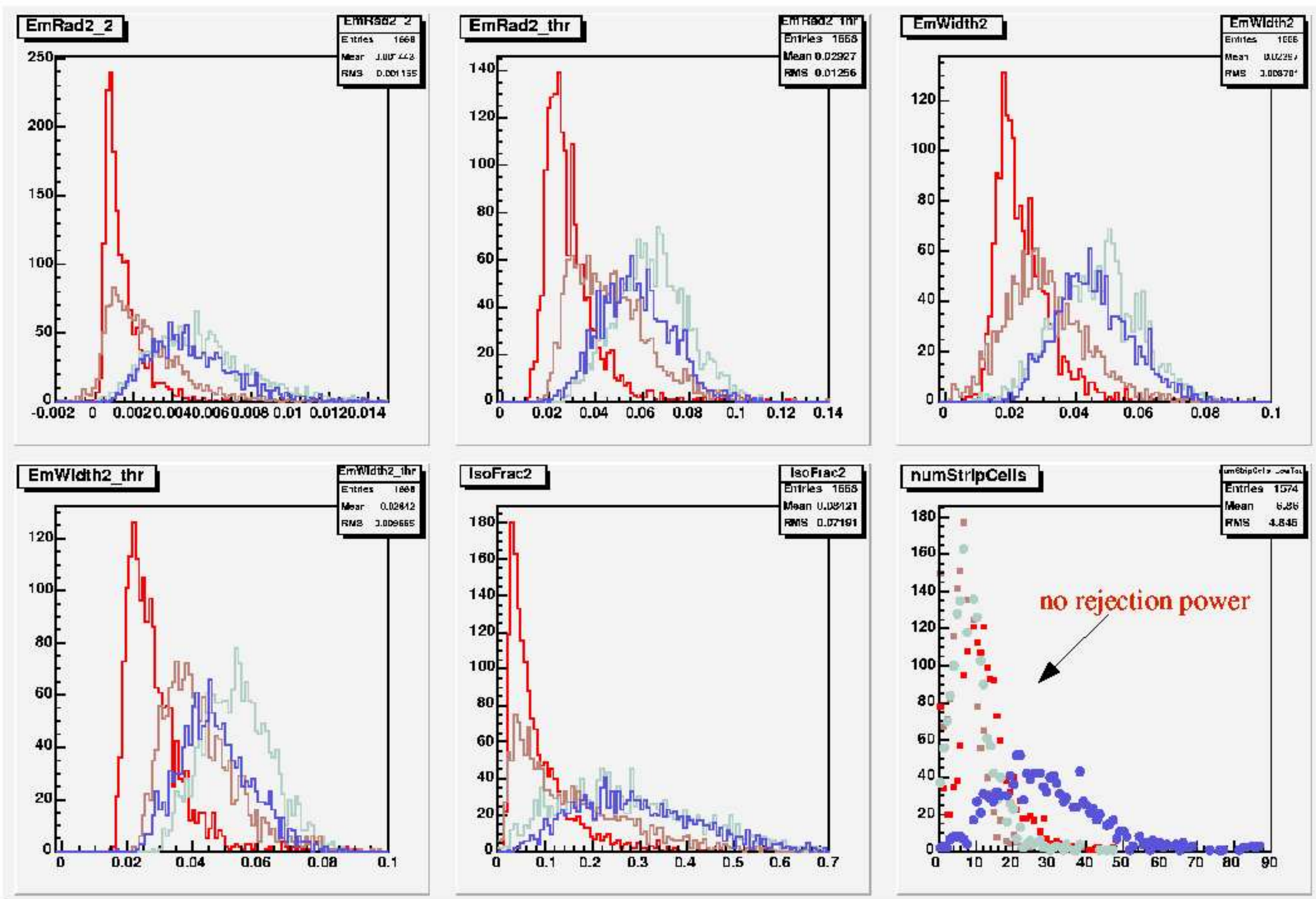
These variables are inspired by offline reconstruction, but calculations are somewhat simplified and are done in smaller dR cone.

LVL2 tau trigger, Calorimeter part

C.Osuna

- **All variables:**

Taus : 20 GeV < VisEt < 60 GeV
Taus : 100 GeV < VisEt < 200 GeV
Jets : 20 GeV < VisEt < 60 GeV
Jets : 100 GeV < VisEt < 200 GeV



The cut values depend on the trigger menu.

LVL2 tau trigger, Second step : Tracking in InDet

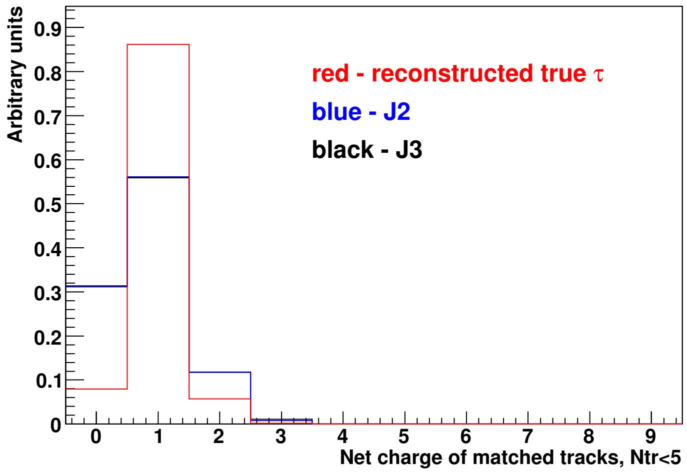
Tracks are reconstructed in InDet within RoI window, and are matched to cluster. Only few tracks per RoI are allowed, as main background is due to jets with large track multiplicity. RoI is divided on 2 areas : basic RoI (square $dR < 0.15$) and isolation area (square $0.15 < dR < 0.3$).

Following criteria are considered :

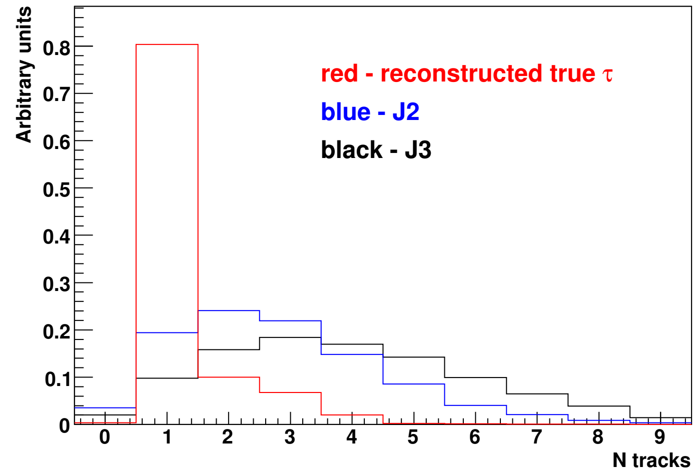
- Number of tracks in basic RoI
- Total charge in basic RoI
- Number of *slow* tracks in basic RoI with $p_T < p_T^{menu}$
- Number of tracks in isolation area
- Number of tracks matching cluster

LVL2 tau trigger, Tracking in InDet

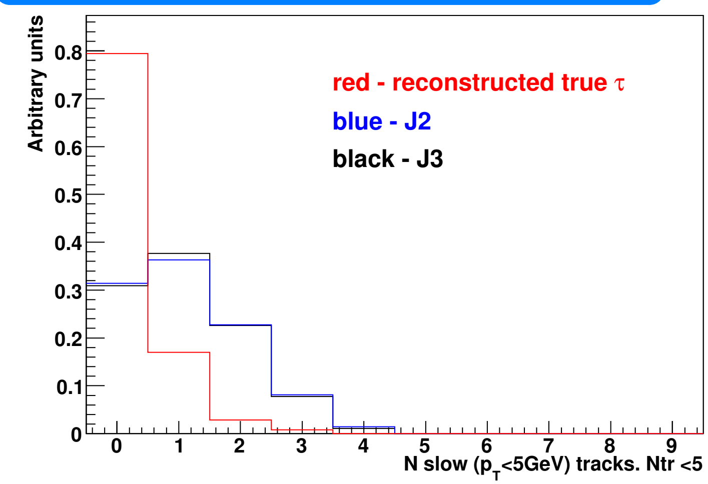
Total charge



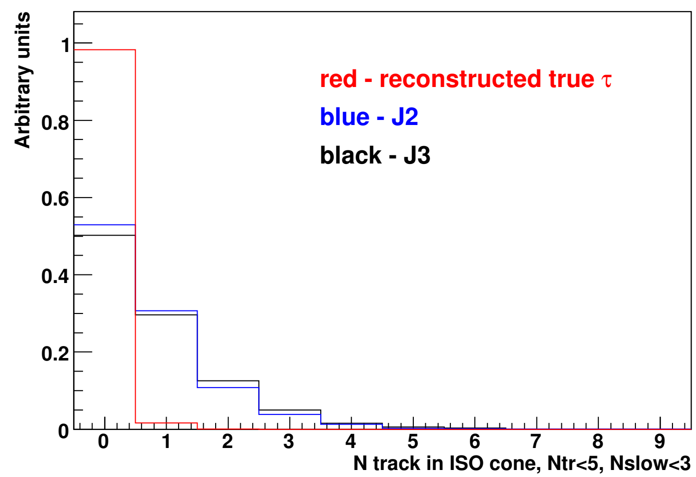
N tracks



N slow tracks ($p_T < 5\text{GeV}$)



N tracks in ISO cone



Calorimeter versus Tracking approach at LVL2

Calorimeter based approach

Cluster reconstruction, (η, ϕ)
Cut on clus ter shape, isolation

↓

Tracking
Cut on N tracks, isolation, charge

↓

Final decision
Cluster-track match, combined energy estimate

Tracking based approach

Tracking, (η, ϕ)
Cut on N tracks, isolation, charge

↓

Cluster reconstruction
Cut on cluster shape, isolation

↓

Final decision
Cluster-track match, combined energy estimate

Currently calorimeter based approach is default. Final choice will depend on rejection rate versus CPU time needed by algorithm (including data preparation) per menu.

L2 Implementation

Calorimeter based LVL2 Tau slice

Trigger element	FEX Algo feature preparation	Hypothesis Algo feature analysis
TAUROI/EMROI		
TrigTauCluster	T2CaloTau →	T2CaloTauHypo
TrigInDetTrack	IDSCAN or SiTrack or TRTxK →	T2IDTauHypo
TrigTau	T2TauFinal →	T2TauHypo

Event Filter

Event Filter runs *offline* tau reconstruction algorithm, but within given RoI window. Improved calibration constants (but not yet final) are available then. More time to be careful with reconstruction.

There are 2 tau specific offline packages available : *tauRec* (calorimeter based) and *tau1p3p* (tracking based). tauRec is optimized for high p_T taus in high lumi enviroment. tau1p3p targets taus from W and Z decays while low lumi running. Only tauRec is adapted for EF yet, while second algorithm is forseen.

Even trigTauRec is rather new addition to the tau slice

Defining tau trigger menu

Three objectives : prepare menu for low lumi running, for high lumi running and for commissioning.

The menus are not quite optimized yet, and the following is more an starting point than a well defined list.

Low luminosity menu $\mathcal{L} = 10^{31}$:

HLT menu	L1 settings	
tau15i	TauEn>13GeV, EmIsol< 5GeV	no prescale
tau10i	TauEn>8GeV, EmIsol< 5GeV	prescaled or combined with MET
tau10	TauEn>8GeV	prescaled, minimum biased
tau15	TauEn>13GeV	prescaled, minimum biased

High luminosity menu $\mathcal{L} = 2 \cdot 10^{33}$:

tau20i	TauEn>17GeV, EmIsol< 6GeV	combined with MET
tau25i	TauEn>22GeV, EmIsol< 6GeV	combined with MET
tau35i	TauEn>30GeV, EmIsol< 6GeV	TDR: tau35i+MET45

Also available very loose *tauNoCut* for performance studies

Co-existence of different menus

- Can have up to 8 menus (unless EM claims some)
- Menus have independent cuts (HYPO) and all run independently. HYPOs are usually very fast.
- Objects created by FEX are cashed and re-used. - One FEX per *active* RoI, independent on number of menus.
- *Topological* menus will combine taus with other slices, e.g. *tau35i + MET45*. Low MET thresholds in the range 20-60 GeV will be available.

Optimization of tau trigger performance

Performance of the trigger is rather open (*tunable*) question.

- Trade off between best knowledge of parameter and time for calculations -

  Do as much as we can within time we allowed to take. But have to think about other packages

- Trade off between efficiency and rate suppression.

  Optimize cuts to have best signal efficiency, but keep within given rate.

- Trade off between bias and efficiency

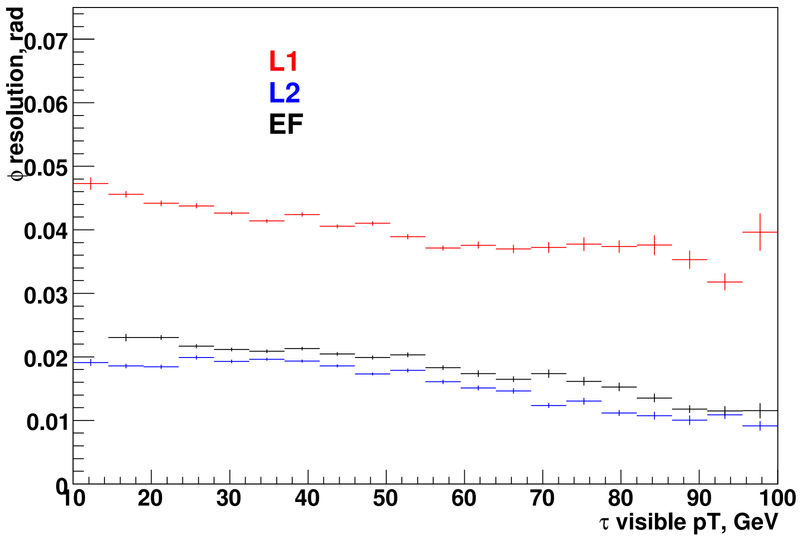
  If rate is too high - use prescales or cut more.

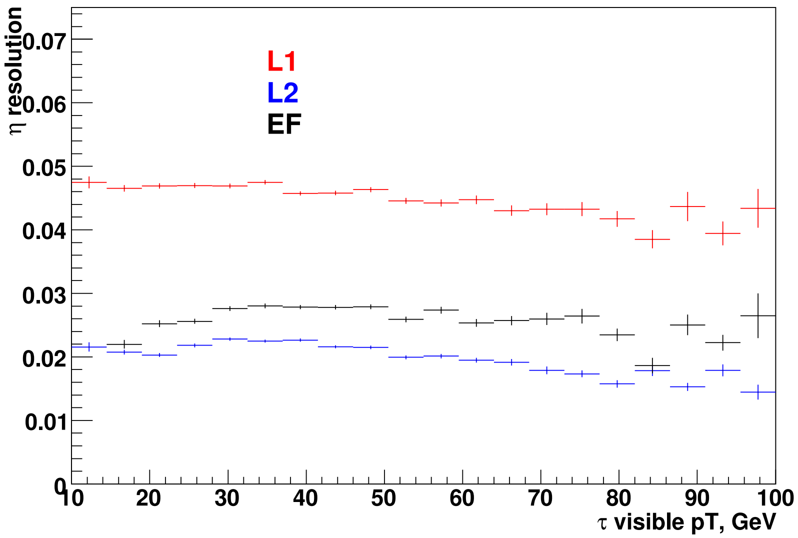
- Trade of between truth and offline reconstruction - Should we trigger as much as possible, or should we trigger only what could be reconstructed offline? If latter, how to anticipate future improvements in offline reconstruction?

  Keep an eye on both..

We are at the beginning of this process now. No simple path ahead.

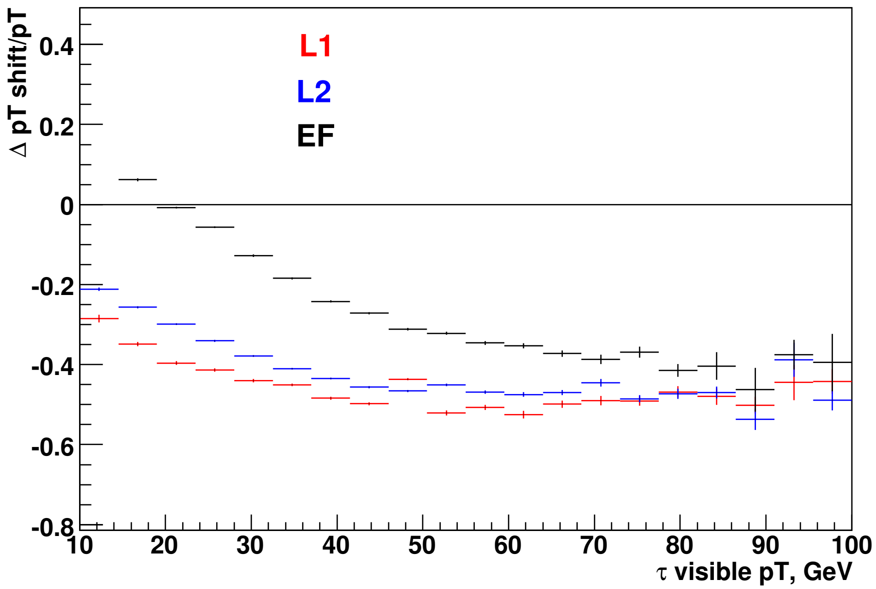
Knowledge of tau direction

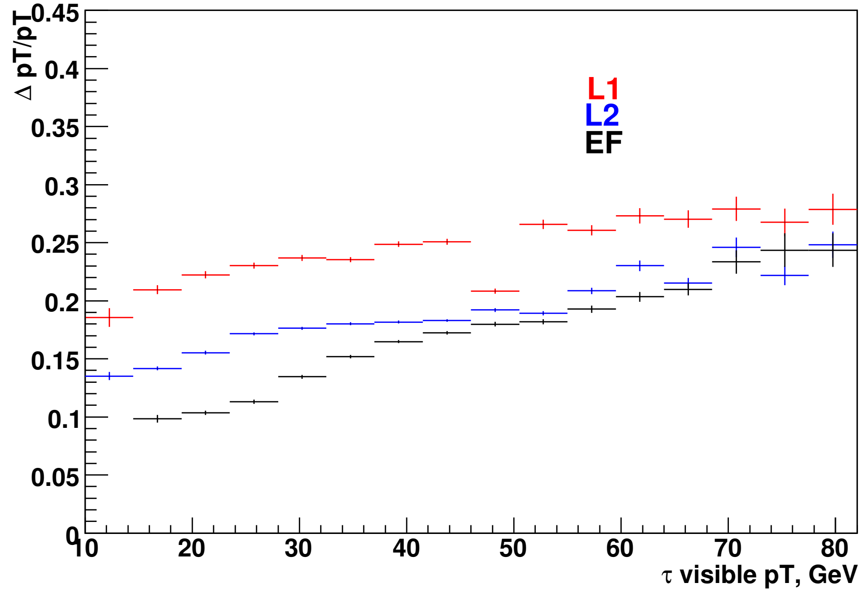




- Effects of mis-calibration are not taken into account (will degrade L1/L2 performance)
- EF uses tauRec (calorimeter based). tau1p3p claims to have 0.02 rad resolution.

p_T measurement

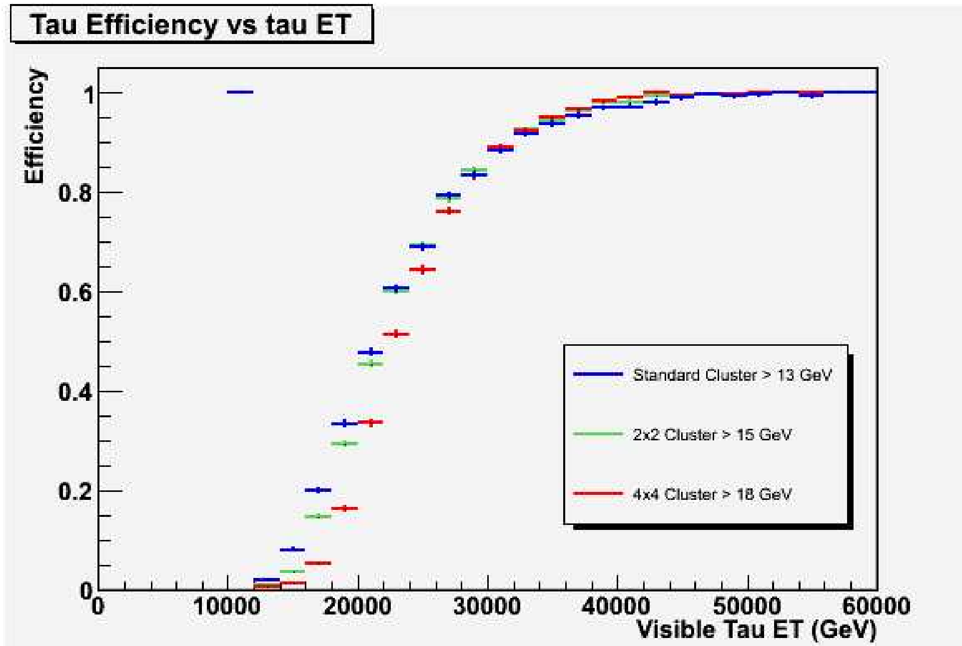




All levels are calorimeter based. Energy of the candidate is underestimated (due to small RoI window ($dR_{L1} = 0.2, dR_{L2} = 0.3, dR_{EF} = 0.4$). Track info can also improve L2 a bit.) Effects of mis-calibration are not taken into account, but calibration constants are not optimal here.

L1 efficiency - where and what to cut on

A.Watson



- Turn on curve of L1 (also L2, EF) is not very fast.
- *standard* definition of L1 tau cluster is less accurate than *4x4* cluster. However, efficiency/rejection rate is quite comparable. Usage of 4x4 cluster requires modification of firmware and is not done.

Performance of tau15i for $\mathcal{L} = 10^{31}$

	ε_τ, ($p_T^{vis} > 15$ GeV)	Di-jets	MinBias
L1	62%	1.8 kHz	2.3 kHz
L2Calo	52%	1.3 kHz	1.7 kHz
L2Track	47%	800 Hz	1 kHz
EF	23%	90 Hz	?

L1 rate is acceptable, while HLT rate needs to be further reduced by 10. Will be rescaled or combined with another trigger

All numbers are preliminary. The work is ongoing and cuts are being optimized

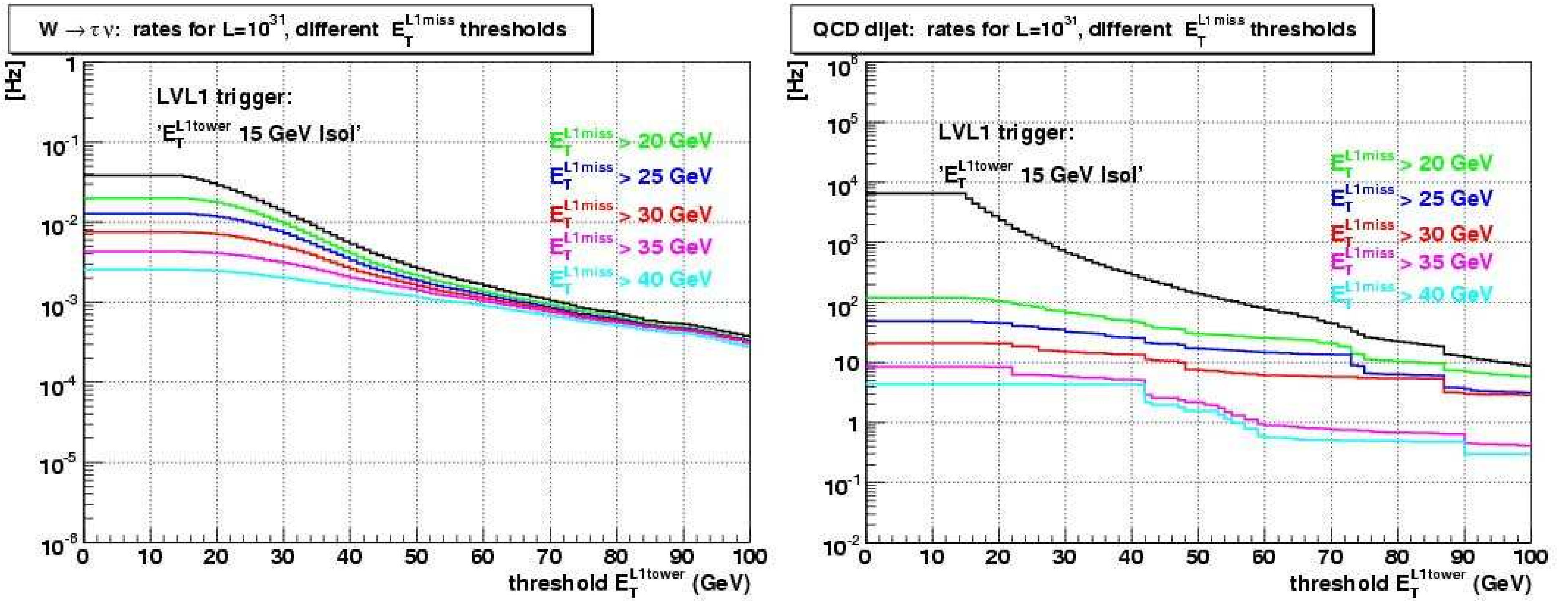
Performance of tau35i for $\mathcal{L} = 10^{31}$

	ε_τ, ($p_T^{vis} > 35$ GeV)	Di-jets	MinBias
L1	53%	160 Hz	190 Hz
L2Calo	49%	135 Hz	140 Hz
L2Track	41%	50 Hz	45 Hz
EF	22%	?	?

All numbers are preliminary. The work is ongoing and cuts are being optimized

Combination with $\not\!\!E_T$ slice

fast simulation, E.Richter-Was



Combination with $\not\!\!E_T$ trigger should give additional suppression of 10.

Current status

Work, work, work

- The slice is under intensive development : tau tracking is available since May and tau EF since August. Latest 12.0.4 release (Dec 20) is a first release with complete tau trigger slice
- Currently work concentrates much on debugging and performance studies. Still a lot to polish and optimize: cuts, sequence, time performance, monitoring histograms.
- Plans are still to add some more cuts at L2 (p_T balance of tracks, energy flow algorithm), track based EF tau reconstruction
- Testing of tau slice in *online* environment has progressed recently. (thanks very much, Sarah)
- CSC tau trigger note is to be written within next 2 months. This will go in parallel with chain optimization
- 12.0.4 CSC production will provide *realistic* trigger decision to physics studies [before, only simple trigger simulation was used]

Much has been done last year,
but this year, we really will make this trigger working!

Backup slides

$\not{E}_T$ vertical slice

- at LVL1 sum of E_x and E_y variables (in the area $|\eta| < 4.9$). Calculation of E_T from E_x and E_y is based on LUT. 8 thresholds are allowed. Also scalar sum of deposited transverse energy is calculated and compared against 4 thresholds.

- Nothing is done at LVL2. Do not have time to unpack whole calorimeter.

- EF algorithm is being worked on. Currently it calculates $\not{E}_T$ from all calorimeter Lar and Tile cells and can use only L1 FEB headers (faster but less accurate). Correction for muons is anticipated but not implemented yet.

LVL1 $\not{E}_T$ is ready, while EF is in progress.