Reconstruction and identification of tau decays at CMS

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On behalf of the CMS collaboration

Outlook

- Motivations: tau physics at LHC
- CMS experiment
- tau identification
  - algorithms performance
- tau trigger strategy
- startup physics: HLT "exercise"
- conclusions
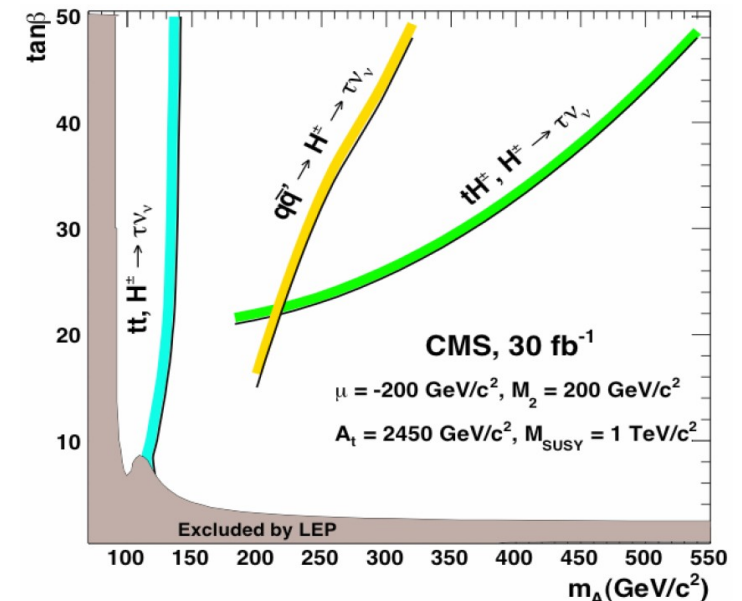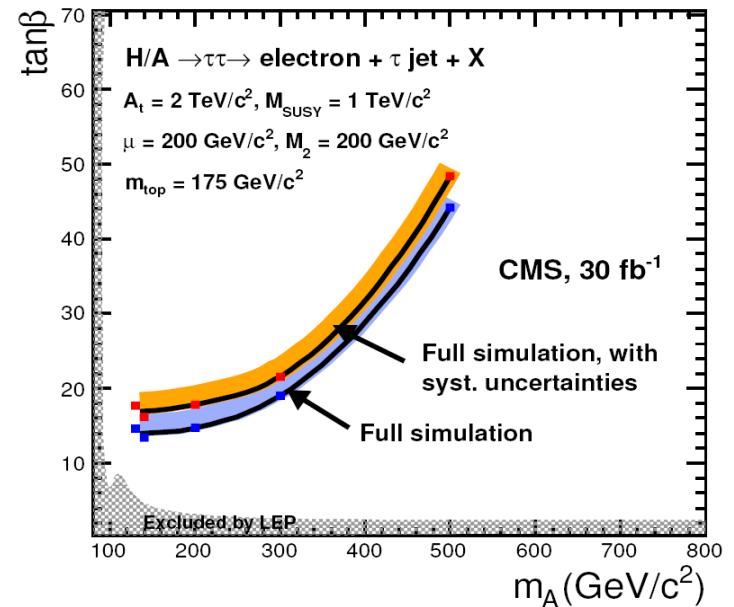
tau physics at LHC

- **Standard model processes**
  - Z -> $\tau\tau$, W -> $\tau\nu$
    - Useful for validation, tuning of the algorithms, calibration
- **Searches**
  - Many relevant discovery channels involve tau leptons in the final state:
    - MSSM Higgs (A/H, H$^+$)
      - A/H -> $\tau\tau$, H$^+$-> $\tau\nu$
    - SM Higgs
      - qqH->qq$\tau\tau$, ttH->tt$\tau\tau$

tau decay modes

- $c\tau \sim= 87\mu m$, $m_\tau = 1.78$ Gev/c^2

- ## Leptonical decays

  - $\tau \rightarrow e(\mu)\ \nu\ \nu$: $\sim 35.2\ \%$
    - Identification done through the final lepton

- ## Hadronical decays

  - 1 prong
    - $\tau \rightarrow \nu_\tau + \pi^{+/-} + n(\pi^o)$: $49.5\ \%$
  - 3 prongs
    - $\tau \rightarrow \nu_\tau + 3\pi^{+/-} + n(\pi^o)$: $15.2\ \%$
  - **"τ–jet" is produced**

Quite often taus are produced in pairs: 42% of final states contains two "tau-jet"

$\tau\tau$ decay mode	BR
$\ell\ell\ \nu$	12 %
ℓjet ν	46 %
jet jet ν	42 %

- tau jets at LHC:
  - very collimated
    - 90% of the energy is contained in a 'cone' of radius R=0.2 around the jet direction for ET>50 GeV
  - **Low multiplicity**
    - One, three prongs
  - **Hadronic, EM energy deposition**
    - Charged pions
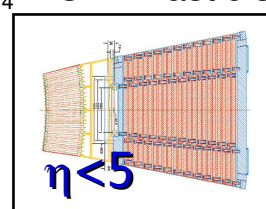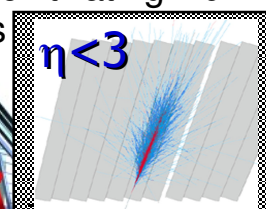   - Photons from π^o

CMS (Compact Muon Solenoid)

TRACKER(s)

$\eta < 2.4$

Pixels and Silicon Microstrips

SUPERCONDUCTING COIL (B=4 Tesla)

CALORIMETERS:

ECAL Scintillating $PbWO_4$ Crystals
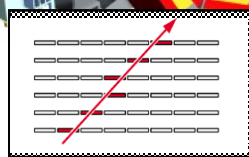
HCAL Plastic scintillator copper sandwich

$\eta < 3$

$\eta < 5$

IRON YOKE

MUON BARREL
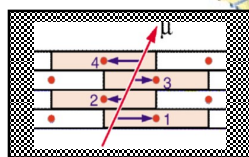
Drift Tube Chambers (**DT**)

Resistive Plate Chambers (**RPC**)

MUON ENDCAPS
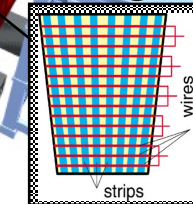
Cathode Strip Chambers (**CSC**)
Resistive Plate Chambers (**RPC**)

Key:
— Muon
— Electron
— Hadron (e.g. Pion)
---- Photon

γ

e

π

μ

Silicon Tracker

Electromagnetic Calorimeter

Hadron Calorimeter

Superconducting Solenoid

Iron return yoke interspersed with Muon chambers

Transverse slice through CMS
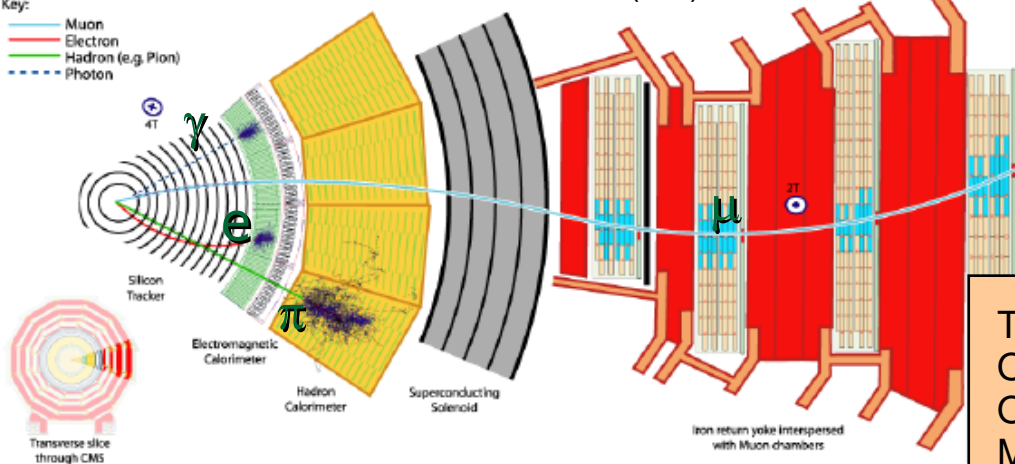
Total weight : 12,500 t
Overall diameter : 15 m
Overall length : 21.6 m
Magnetic field : 4 Tesla

5

How hadronic tau decays can be identified

- tau tagging basic ingredients
  - Calorimetric isolation and shape variables
  - Charged tracks isolation
  - Other tau characteristics suitable for tagging:
    - **Impact parameter**
    - **Decay length**
    - **Invariant Mass**

- **Main backgrounds for taus**
  - **QCD jets**
  - Electron that shower late or with strong bremstrahlung
  - Muons interacting in the calorimeter

- **Only hadronic tau decays are considered since the leptonic tau decays produce standard electrons/muons**
  - Identification through the final lepton

Ecal isolation

Legend:
- ● τ jets, 30-50 GeV
- ■ τ jets, 50-70 GeV
- ▲ τ jets, 80-110 GeV
- ★ τ jets, 130-150 GeV
- ○ QCD jets, 30-50 GeV
- □ QCD jets, 50-70 GeV
- △ QCD jets, 80-110 GeV
- ✦ QCD jets, 130-150 GeV
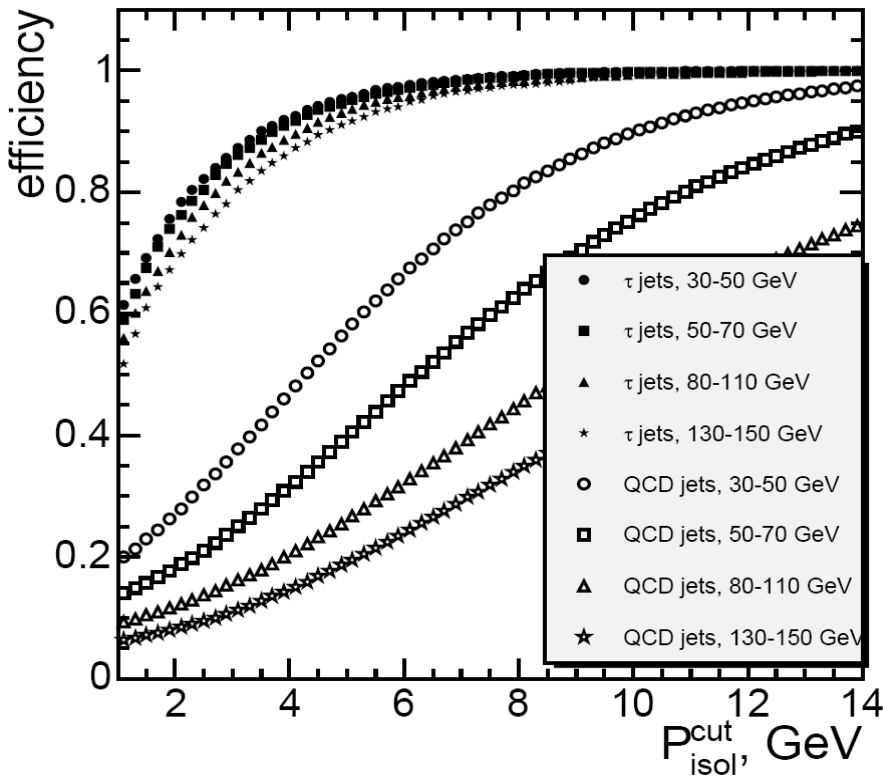
$$P_{isol} = \sum_{\Delta R < 0.40} E_T - \sum_{\Delta R < 0.13} E_T$$

CMS get a signal efficiency of about 80% with a bkg rejection of 5 for QCD jets with pT>80 GeV/c

The efficiency of the electromagnetic isolation for τ jets and QCD jets in the different bins of the true transverse energy when the value of P_{isol}^{cut} is varied.

Tracker isolation

τ-jet axis

tr₁

signal cone R_s

jet-track matching cone R_m

isolation cone R_i

p   p
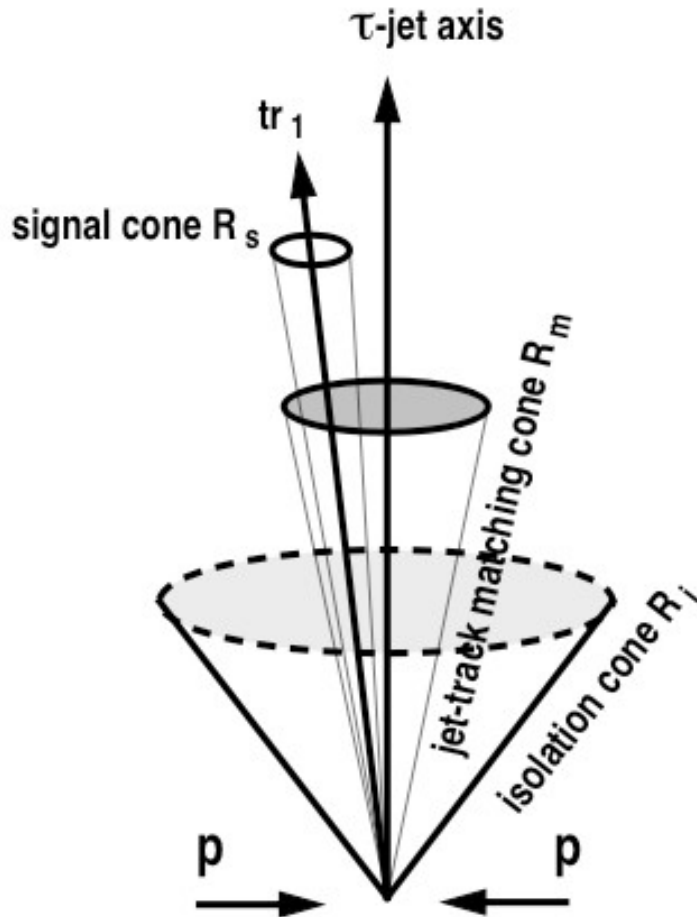
- **Isolation based on the number of tracks inside the isolation cone (R_I) is applied.**
- **Only good tracks are considered:**
  - Associated to the Primary Vertex
  - P_T of the Leading Track (i.e. highest p_T track) must exceed a few GeV/c
  - Leading Track must be found inside the Matching cone
- R_M : calo jet - leading track matching cone

- p_T^{LT} : cut on pT of the leading track in matching cone
- R_S : signal cone around leading track
- R_I : isolation cone (around jet axis or leading track)
- p_T^i : cut on pT of tracks in the isolation cone

- Dz : cut on the distance between z ip of the leading track and z ip of other tracks considered by algorithm (association with pxl primary vertex at HLT; see later)

Tracker Isolation: tau jets and QCD jets efficiency
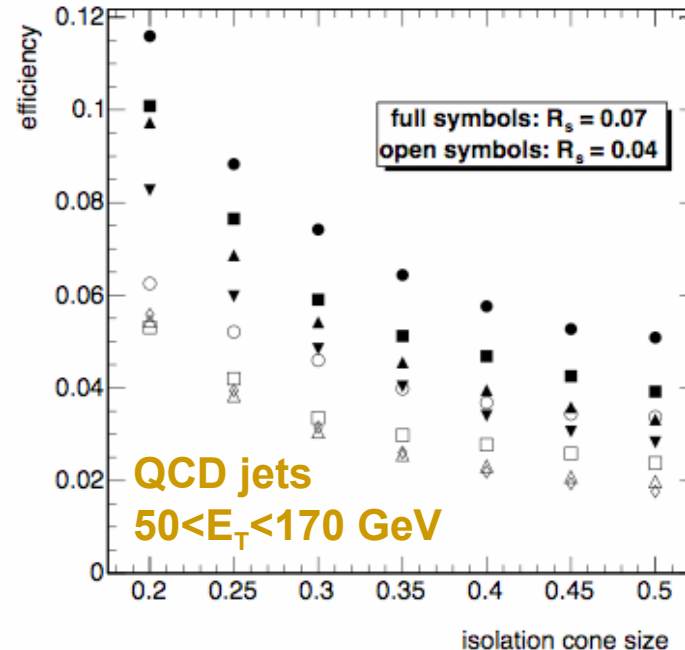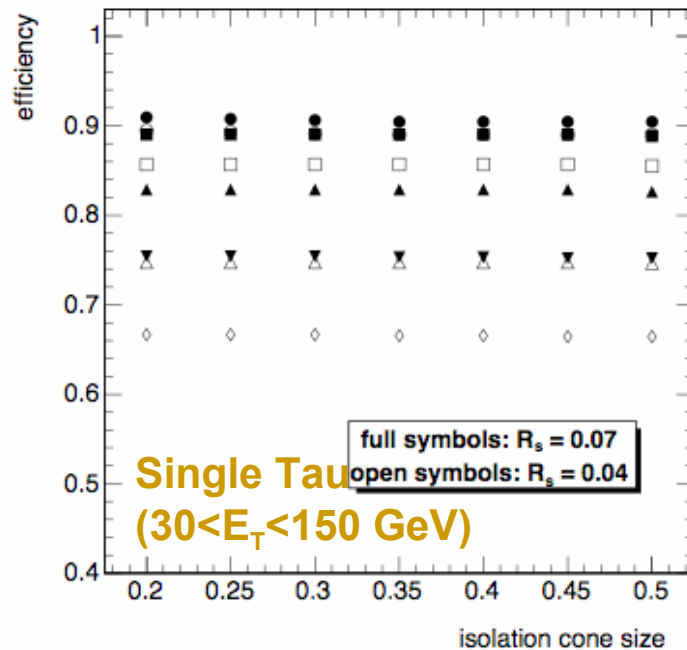
In the order of decreasing efficiency
symbols correspond to decreasing MC E_T intervals

Cuts used:
8 hits per track, Norm. Chi² < 10
P_t^{LT} > 6 GeV/c, R_M = 0.1, R_I = 0.2-0.5, P_T^I > 1 GeV, |Dz| < 2mm

Other tagging methods

Tracker isolation is a primary requirement for the tau jet identification

All the following tagging methods are applied to jets which preliminarly pass the Tracker Isolation:

- **Tagging with IP**
- **Tagging with decay length**
- **Mass tag**

Default isolation parameters

$R_S = 0.07$

$R_I = 0.4$

$R_M = 0.1$

$P_T^{LT} > 10 \text{ GeV/c}$

$P_T^I > 1 \text{ GeV/c}$

$|Dz| < 2\text{mm}$

1 || 3 Tracks inside the signal cone

I.P. distribution

**Tau
1 prong**

myhisto	
Entries	31390
Mean	0.072
RMS	0.18

τ
1 track
$E_T^{MC} < 150$ GeV

**QCD
1 track**

myhisto	
Entries	4358
Mean	1.09
RMS	1.38

QCD
1 track
$E_T^{MC} < 150$ GeV

IP_T, mm
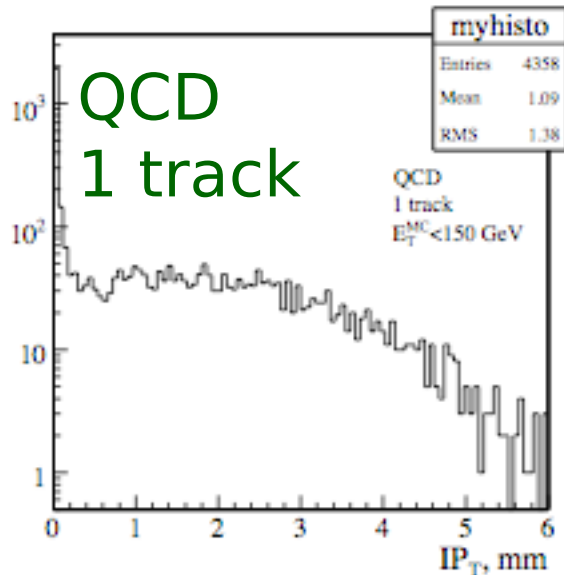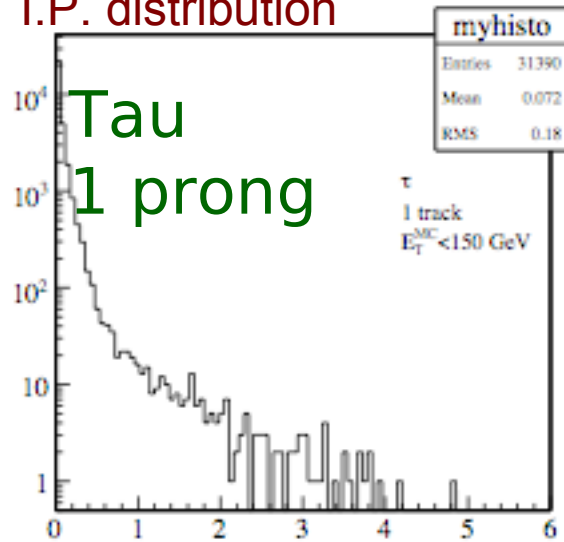
Transverse I.P. efficiency

1 track
$IP_T < 300$ µm
First cut=0
Cut step=1

▲	30-50 GeV
▼	50-70 GeV
○	80-110 GeV
□	130-150 GeV

Signal efficiency

Background efficiency
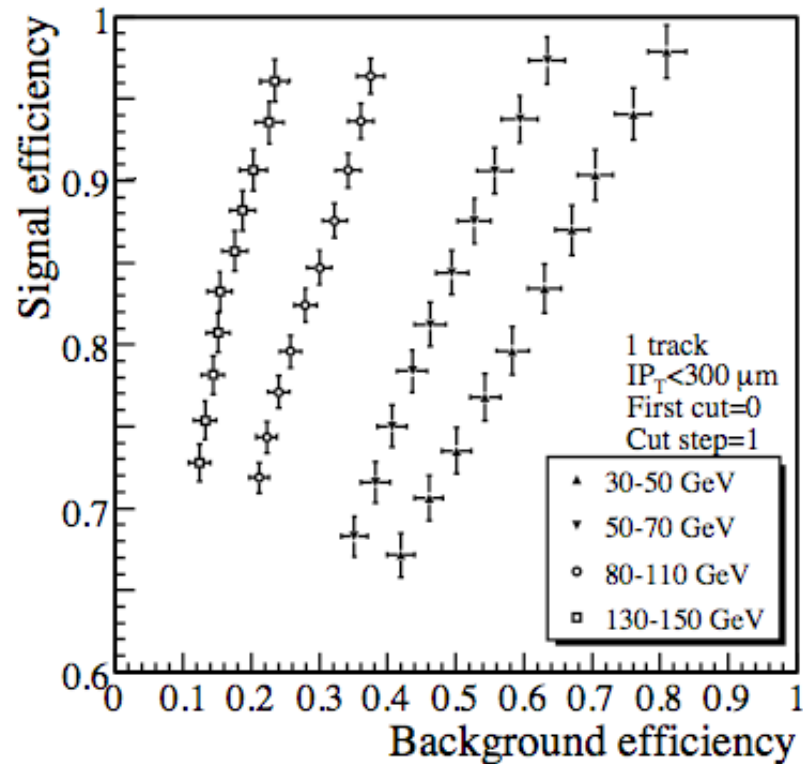
leading track selection:

- $N_{pixels\_hits} >= 2$
- $N_{tracker\_hits} >= 8$
- Chi2<10
- $P_T > 1$ GeV

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identification of tau decays at CMS

Tagging with decay length

- The lifetime of the tau lepton ($c\tau = 87\ \mu m$) allows for the reconstruction of the secondary vertex for the 3 (and 5) prongs decay

- Events are required to pass tracker isolation, only tracks inside signal cone are used in the kalman vertex fitter
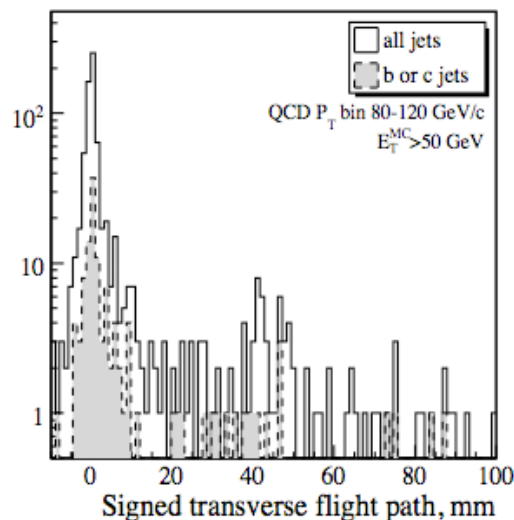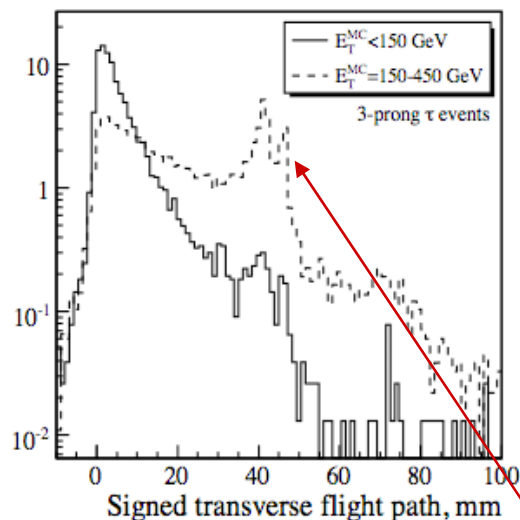
3D decay length

Fake vertices in the pixel material removed by cutting on the transverse flight distance (< 4 cm)
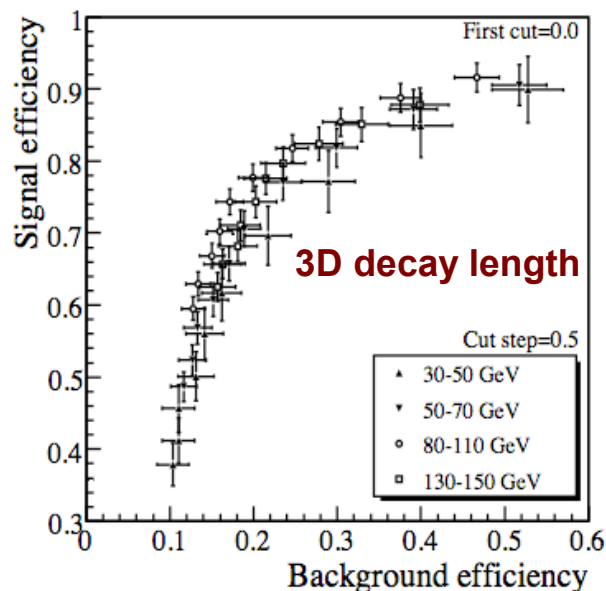
• **Both "Transverse" decay length and 3D decay length considered**

Tagging with invariant mass

- Mass reconstruction is performed using tracks and Ecal clusters

•**Only clusters within a cone of 0.4 from the jet axis have been considered.**
•**Remove clusters which have a track within a cone of 0.08 at the track impact point: avoid double counting**

p_T: 50-70 GeV/c

p_T: 130-150 GeV/c
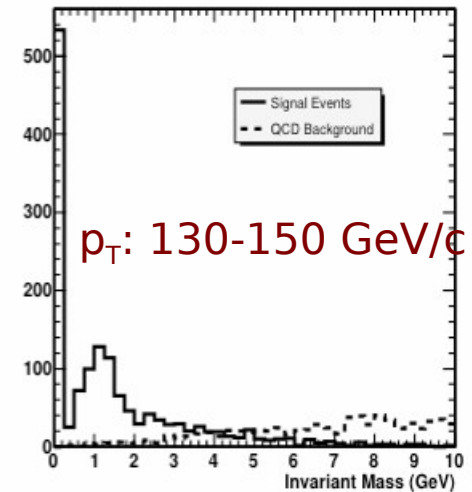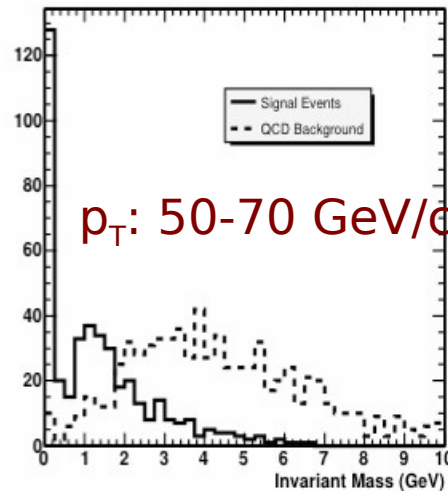
Efficiency requiring $M_{TAU} < 2.5$ GeV/c^2

Pt bins (GeV)	30-50	50-70	80-110	130-150
Signal eff.(%)	86.32	82.27	83.02	80.76
Background eff.(%)	33.67	19.16	6.05	2.47

tau Trigger outline

- Trigger algorithms are developed taking into account some benchmark channels:
  - bbA/H$\rightarrow\tau\tau\rightarrow$ 2jets
  - gg->tbH$^+$, gb->tH$^+$
    - H$^+$->$\tau\nu\rightarrow$jet + MET
  - Z$\rightarrow\tau\tau$, W->$\tau\nu$ (mostly at low luminosity)
- The trigger efficiency is evaluated as a function of the background rejection capability
- The basic ingredients are the same than off-line tau identification
  - For High Level Trigger algorithms speed is a basic requirement

CMS general trigger scheme

40 MHz
Clock driven
Custom processors

~100 kHz
Event driven
PC network
Totally software

~100 Hz
To mass storage
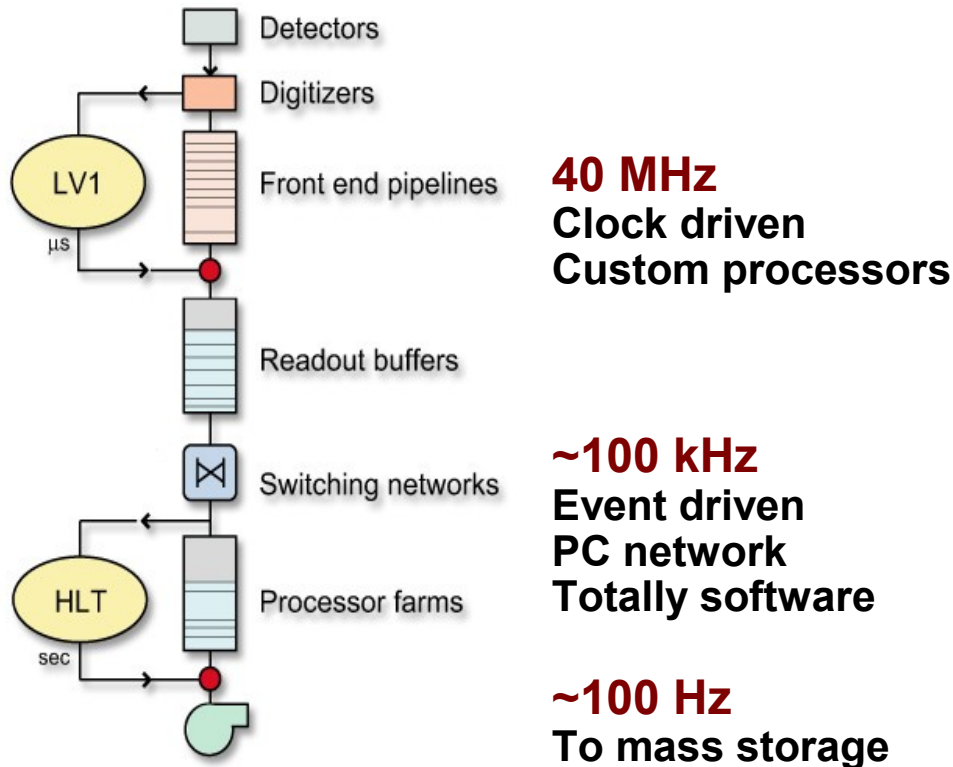
two trigger levels

Level-1 (~µs) 40 MHz
High-Level (ms-sec) 100 kHz
Event Size ~ 10^6 Bytes

onstruction and
ys at CMS
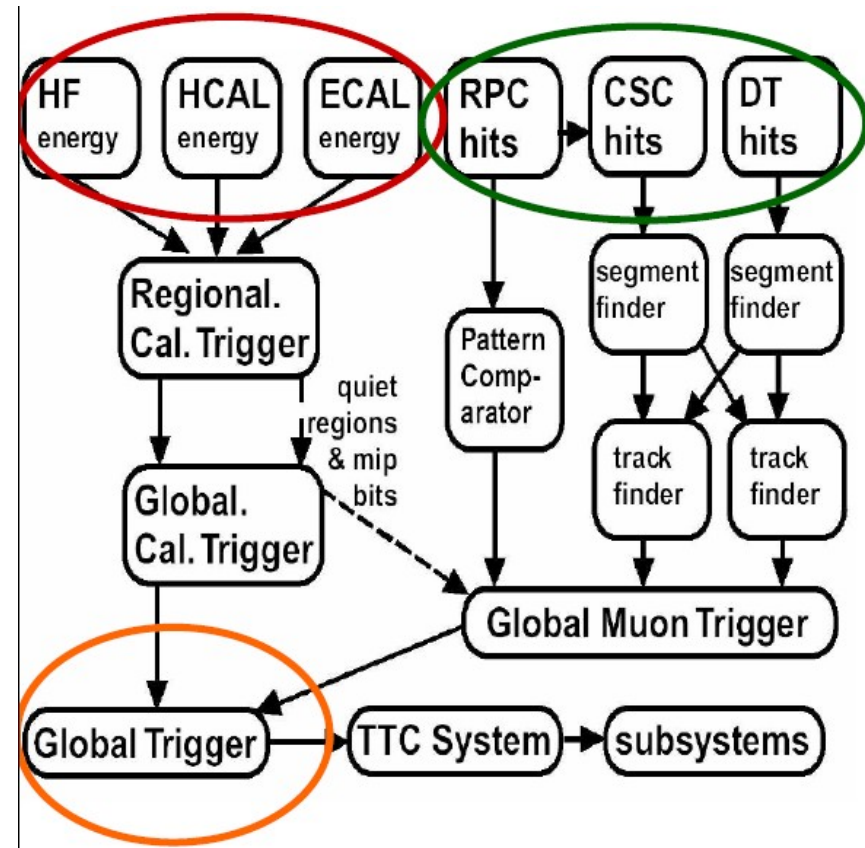
CMS: L1 trigger for tau jets

Active towers patterns allowed for tau jets candidates
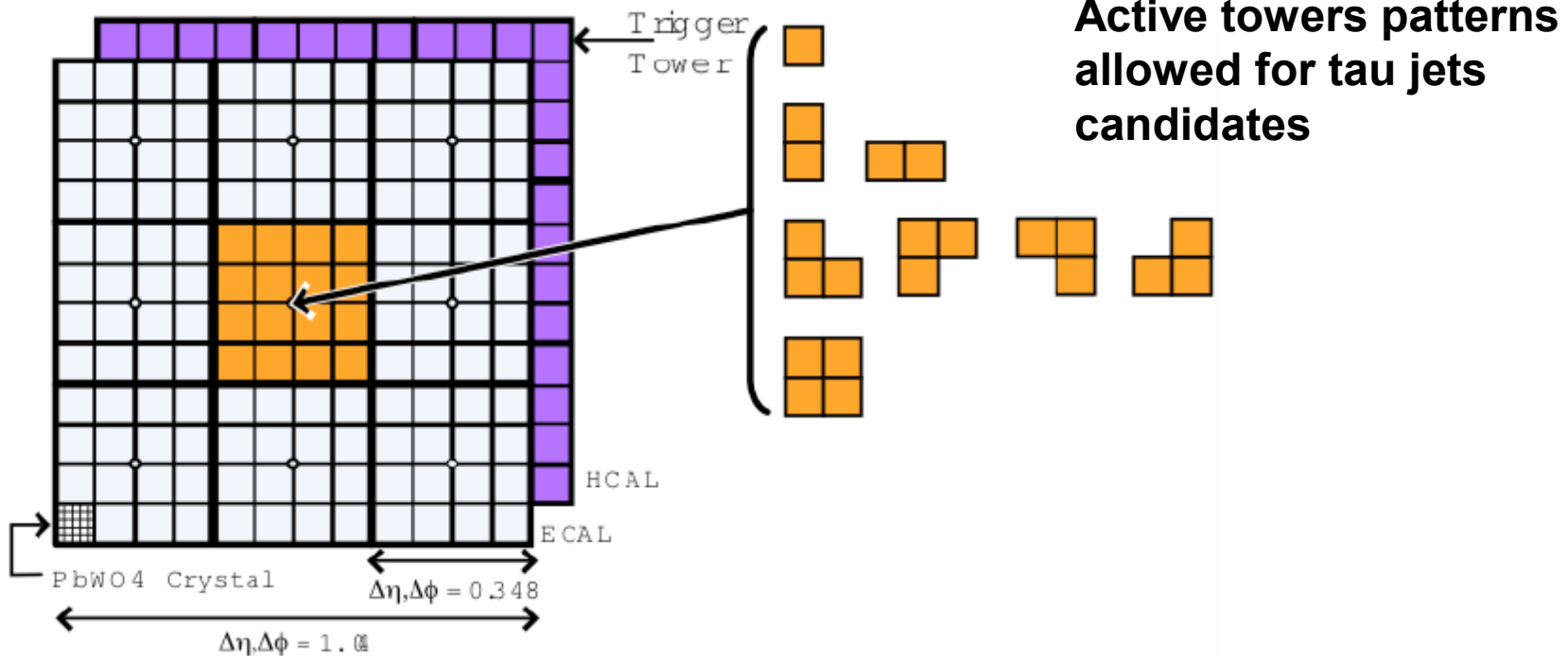
- QCD E_T samples in the range 50-170 GeV have been used for the HLT studies. They represent more than the 90% of the total L1 Rate
- A factor ~10^3 of QCD background rejection is required at HLT
  - Reduce rate from ~kHz -> ~Hz

Ecal isolation at HLT

Calorimeter isolation is applied to the 1st (i.e. most energetic) HLT Calo jet.

$$P_{isol} = \sum_{\Delta R < 0.40} E_T - \sum_{\Delta R < 0.13} E_T$$

Efficiency has been evaluated for bbH->bb+tautau sample.

The main rate is represented by QCD di-jet events (p_T^{hat}:50-170 GeV/c), which is our bkg reference sample.

Rejection factor 3 is provided with P_{isol} < 5.0 GeV

It is used in association with the Pixel isolation (see following slides)

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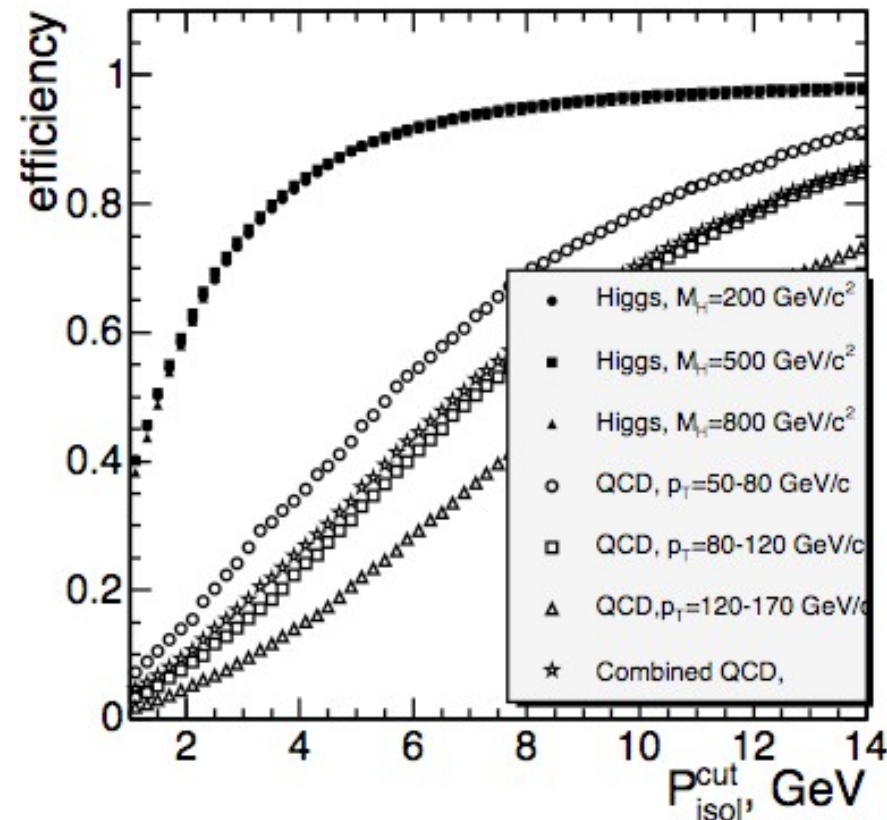
HLT with Tracker isolation

- HLT tracker isolation is ~same than offline isolation

- Primary Vertex is made using only pxl
- Pixels + layers of silicon tracker is used to reconstruct tracks
  - Regional seeding with 2 out of 3 pxl hits
- Isolation cone is around Leading Track
- Tracks are associated to the 1st PV in the list
  - PV are sorted by the Σp_T^2 of the associated tracks.
- P_T Lead Tk > 6 GeV/c
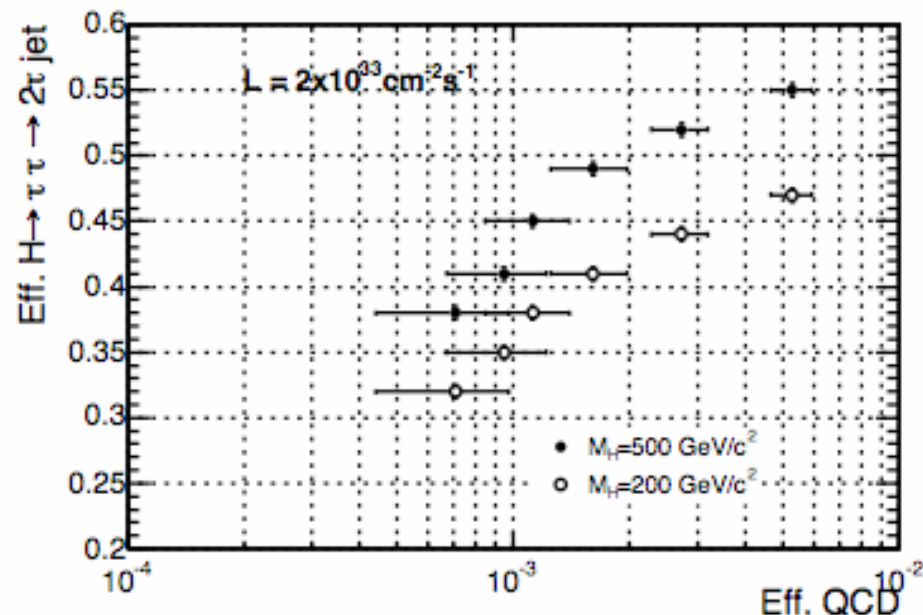
Selection efficiency vs QCD efficiency
Benchmark channel:
•$H{-}{>}\tau\tau{-}{>}2\tau{-}$jets
•HLT selection is applied to both taus

Charged Higgs HLT trigger

Channel considered

- **gg->tbH+, gb->tH$^+$**
  - **H$^+$ ->$\tau\nu$ (tau hadronic decay)**

- **L1 output rate: ~ 3kHz**

HLT selection

- **E$_T^{miss}$>65 GeV: output rate ~30 Hz**

- **After applying Tracker isolation + momentum cut (P$_T^{LT}$>20GeV):**
  - **output rate: ~ 1Hz**
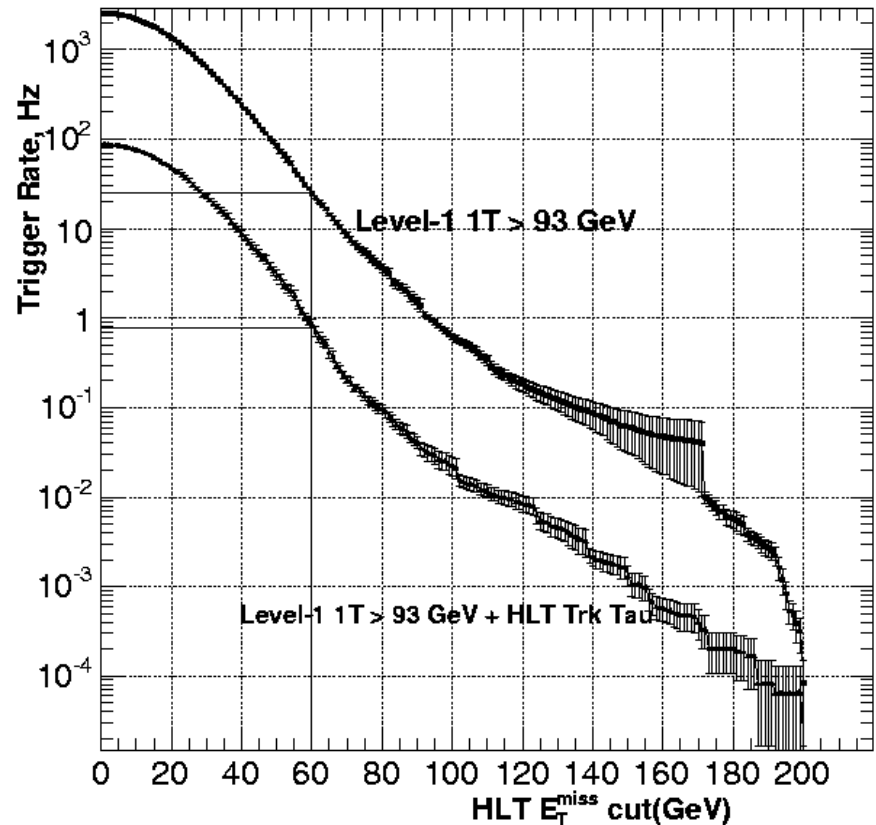
Important progress in 2007
The "HLT exercise"

"What is the CPU performance of the HLT?"

- Implement L1 emulator, HLT algorithms in <u>CMSSW</u> : Integration
- Compile candidate Trigger Menu that covers CMS needs
- Determine CPU-performance for HLT algorithms

- Initially focusing on studies without pile-up: 1E32 cm^{-2}s^{-1}
  - ➢ Implementation of 2008 physics-run (14 TeV) trigger menu
  - ➢ Accept rates: L1= 17 kHz (safety factor of 3), HLT=150 Hz
- Determine CPU-performance for early physics-run Trigger Menu
- Driven by need to purchase Filter Farm at end of 2007

DAQ-TDR (Dec 02): "In 2007, for a L1 accept rate of 50 kHz and 2000 CPUs we need an average processing time of 2000/50 kHz ~ 40 ms/evt"

Improvements...

What's new wrt previous studies (DAQ-TDR, PTDR vol 2):

- **Framework:** Studies done with software to be used for data-taking
  - ➢ L1 emulator, HLT algorithms implemented & integrated in CMSSW
  - ➢ Previous studies used (obsolete) ORCA framework
- **L1 emulator:** Designed to reproduce L1 hardware decisions bit-by-bit
  - ➢ Previous studies use parameterized L1 simulation
  - ➢ HLT algorithms now use L1 objects as reconstruction seeds
- **Data-unpacking:** HLT paths now start with "raw" information
  - ➢ This is what HLT will deal with in on-line environment
  - ➢ Data-unpacking is included in CPU-time budget of the HLT
- **Trigger Menu integration:** Full L1 + HLT chain optimized coherently
  - ➢ Overlaps between trigger rates, CPU-processing taken into account
  - ➢ Extended effort across CMS to optimize CPU-performance of (CMS code and) HLT algorithms

HLT exercise: the most realistic trigger studies done so far in CMS

Improvements (cont.)

- **HLT algorithms:**
  - ➢ Improved L2 muon propagator
  - ➢ Optimization of tau and b-jet HLT paths
- **Unpacking code & "local reconstruction" (RecHit/Clusterizing):**
  - ➢ Further speedup of siStrip unpacking/RecHit code
  - ➢ Egamma and Muon HLT paths now using regional ECAL unpacking
- **Computing:**
  - ➢ Code performance: profiling studies done on different machines
  - ➢ Core-2: CPU architecture that matches the HLT needs

- **Compilation and optimization of Trigger Menu:**
  - ➢ Tune L1/HLT thresholds according to feedback from CMS groups
  - ➢ Calculate trigger rates for all HLT paths, overlaps, "grand total"
  - ➢ Calculate average processing time for full Trigger Menu

L1 Trigger efficiency definition

L1 Efficiency Definitions:

– **„Global Efficiency":**

> Fraction of events passing L1trigger without any MC requirements
> → include fakes which will be rejected at offline anyway

- **„Pure Efficiency"**

> Events passing trigger and L1 objects match with generated objects in acceptance region:
> - **GenTauEt > 15 GeV, |GenTauEta| < 2.5, DeltaR < 0.5**
> - **GenElecEt > 10 GeV, |GenElecEta| < 2.5, DeltaR < 0.5**
> - **GenMuonEt > 5 GeV, |GenMuonEta| < 2.5, DeltaR < 0.5**
>
> - **Normalised to expected number of events in the corresponding channel from MCTruth (GenObjects in acceptance region)**

→ **gives good estimate of physics performance without knowing final analysis selection cuts**

L1 Global Vs Pure Efficiency

L1 Rates & Global Efficiencies:

Table 11.3: "Global" efficiencies for Level-1 tau trigger paths.

Samples/Trigger	SingleTau	DoubleTau	IsoEM+Tau	Muon+Tau	Tau+MET
$Z^0 \to \tau\tau$	9%	18%	46%	59%	18%
$W^\pm \to \nu\tau$	4%	–	–	–	12%
$H^\pm \to \tau\nu$ ($m_H = 200$ GeV/c^2)	62%	–	–	–	83%
$H^\pm \to \tau\nu$ ($m_H = 400$ GeV/c^2)	71%	–	–	–	90%
$A^0/H^0 \to \tau\tau$ ($m_H = 200$ GeV/c^2)	53%	40%	24%	23%	44%
$A^0/H^0 \to \tau\tau$ ($m_H = 500$ GeV/c^2)	78%	49%	22%	28%	71%
QCD Rate	0.68 kHz	2.36 kHz	1.95 kHz	0.66 kHz	1.96 kHz

L1 Pure Efficiencies:

Table 11.4: "Pure" efficiencies for Level-1 tau trigger paths.

Samples/Trigger	SingleTau	DoubleTau	IsoEM+Tau	Muon+Tau	Tau+MET
$Z^0 \to \tau\tau$	10%	36%	68%	67%	21%
$W^\pm \to \nu\tau$	5%	–	–	–	24%
$H^\pm$ ($m_H = 200$ GeV/c^2)	42%	–	–	–	66%
$H^\pm$ ($m_H = 400$ GeV/c^2)	54%	–	–	–	69%
A^0/H^0 ($m_H = 200$ GeV/c^2)	53%	55%	71%	71%	44%
A^0/H^0 ($m_H = 500$ GeV/c^2)	70%	50%	56%	66%	64%

HLT performance for tau

HLT efficiency:Higgs

Table 5.2: Efficiencies and rates of the SingleTau HLT path.

	$H^{\pm} \rightarrow \tau\nu$		QCD
	$M_H = 200\,GeV/c^2$	$M_H = 400\,GeV/c^2$	$\hat{p}_T$ 120-170
Level-2 $\not{E}_T$ cut	59%	81%	6%
Level-2 Jet Reconstruction and Ecal Isolation	81%	85%	53%
Level-2.5 SiStrip Isolation	67%	76%	27%
Level-3 SiStrip Isolation	70%	72%	18%
HLT	23%	38%	0.15%
L1 * HLT	16%	29%	-

Can increase Higgs/*W/Z→ τ* efficiencies with different L1 bandwidth, isolation at HLT

Timing: Tau + MET

HLT step	Running time (ms)	Averaged time (ms)
ECAL unpacking	13.6	13.6
ECAL RecHits	9	9
HCAL unpacking	1	1
HCAL RecHits	3	3
Tower maker	4.5	4.5
Jet reconstruction	3	3
Pixel unpacking	2	0.1
Pixel clustering	6	0.3
Pixel recHits	2	0.1
Pixel Tracks	10	0.5
L2.5 Regional Seeding	11	0.5
L2.5 track reconstruction	60	2.7
L3 Regional Seeding	26	0.2
L3 track reconstruction	280	2.0
Total	421	41.5

Before opt. it was: 430 ms!

Z and W efficiencies with hadronic taus

HLT efficiency: $Z{-}{>}\tau\tau{-}{>}$taujet+taujet

Table 5.4: Efficiencies and rates of the DoubleTau HLT path.

	$Z \to \tau\tau$	QCD $\hat{p}_T$ 120-170
Level-2 jet reconstruction	91%	58%
Level-2 Ecal Isolation	86%	37%
Level-2.5 Pixel Isolation	28%	0.77%
HLT	22%	0.17%
L1 * HLT	8.6%	-

HLT efficiency: $W{-}{>}\tau\nu{-}{>}$taujet+MET

Table 5.3: Efficiencies of the TauWithMET HLT path.

	$W \to \tau\nu$	QCD $\hat{p}_T$ 120-170
Level-2 $\not{E}_T$ cut	53%	35%
Level-2 Jet Reconstruction and Ecal Isolation	78%	57%
Level-2.5 SiStrip Isolation in the small rectangle	37%	30%
Level-3 SiStrip Isolation in the final rectangle	61%	20%
HLT	10%	1.2%
L1 * HLT	1.8%	-

HLT electron + τ combined trigger

Trigger/Samples	$Z \rightarrow e + \tau$-jet	QCD $\hat{p}_T$ 15-170 GeV/c
Level-1 $e + \tau$	$(43.9 \pm 0.4)\%$	$(1.92 \pm 0.05)\,\text{kHz}$
HLT $e + \tau$	$(30.2 \pm 0.6)\%$	$(1.01 \pm 0.5)\,\text{Hz}$
Level-1 + HLT $e + \tau$	$(13.2 \pm 0.3)\%$	$(0.13 \pm 0.07)\,\text{Hz}$
Level-1 $e + e\tau$	$(55.8 \pm 0.4)\%$	$(3.15 \pm 0.07)\,\text{kHz}$
Level-1+HLT $e + e\tau$	$(24.5 \pm 0.4)\%$	$(14.08 \pm 3.58)\,\text{Hz}$

HLT Signal Purity = 55%

- e-τ colinearity only checked at L1

- τ path of eτ trigger uses L2TauJets from Single and Double τ L1 streams that do not check e-τ collinearity

- This makes it necessary to check for e-τ colinearity at HLT

Trigger/Samples	$Z \rightarrow e + \tau$-jet	QCD $\hat{p}_T$ 15-170 GeV/c
HLT $e + \tau$	$(16.4 \pm 0.4)\%$	$(0.37 \pm 0.36)\,\text{Hz}$
Level-1 + HLT $e + \tau$	$(7.2 \pm 0.2)\%$	$(0.04 \pm 0.04)\,\text{Hz}$
Level-1+HLT $e + e\tau$	$(22.9 \pm 0.4)\%$	$(12.41 \pm 3.96)\,\text{Hz}$

HLT Signal Purity = 96%

- e-τ collinearity checked at L1 and HLT to be added in CMSSW_1_6_0

HLT muon + τ combined trigger

Step / Efficiency	qqh	Z	muX	Parameters
L1 $\mu + \tau$	0.58	0.28	0.24	$p_T(\mu) > 7^*, E_T(\tau) > 20$
Isol. L2 μ	0.76	0.62	0.11	$p_T(\mu) > 15$
Ecal isolation	0.92	0.91	0.32	$0.13 < \Delta R < 0.4, P_{isol} = 5.$
Pixel isolation	0.46	0.37	0.05	$\Delta R_{iso} = 0.45$
Isol. L3 μ	0.84	0.76	0.40	$p_T(\mu) > 15$
Total HLT	0.27	0.16	0.0008	

Signal vs bkg efficiency, as a function of R_i for a Higgs boson of mass 135 GeV/c².

DR_{ISO}=0.05... 0.5 in steps of 0.05

Study to be done for Z
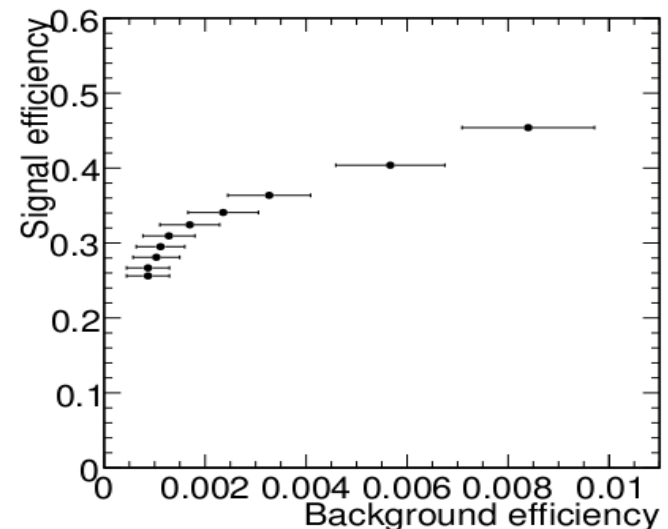
Conclusions

- Tau jet identification at LHC is crucial for many discovery channels
- Triggering path for "tau channels" well understood and established
    - HLT algorithms based on isolation work very well
    - Low energy taus from Z,W decays can triggered at low luminosity
- Off-line tau tagging based on isolation + additional methods
    - Good results
    - Likelihood/multivariate approach under development
- General energy flow is being developed in CMS…
    - First results very interesting (not yet published
- Methods to evaluate tag efficiency from data and background rejection are under study

BACKUP SLIDES

Tau Jet energy scale

- **Both Atlas and CMS apply energy scale corrections**

- **Tau jets need softer corrections to their energy, wrt QCD jets.**

  - At the same transverse energy, pions in Tau jets have harder transverse momentum than pions in QCD jets

  - In Tau jets there is a larger amount of electromagnetic energy (due to the presence of π^0)

CMS $|\eta^{MC}| < 2.2$

solid - before corrections

dashed - after corrections

Vertical axis: $\langle E_T^{reco}/E_T^{MC} \rangle$; horizontal axis: E_T^{MC}, GeV
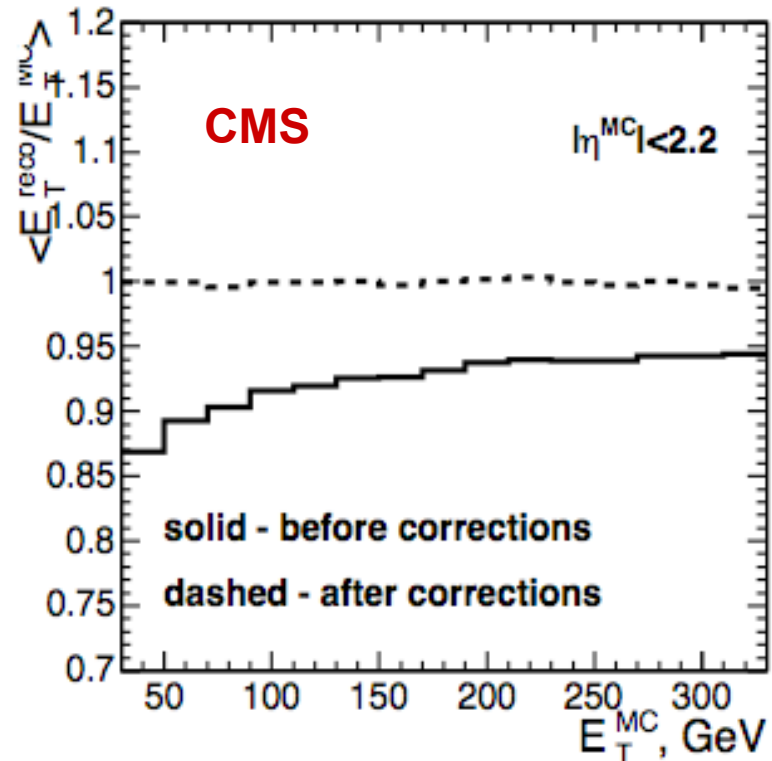
The jets corrections optimised for true hadronic taus significantly underestimate energy scale for QCD jets

CMS HLT: Calo+Pxl or Trk Trigger?

CMS has developed two similar HLT trigger algorithms:

"Calo+Pxl trigger " and "Trk trigger"

- "Calo+Pxl trigger": only the pixels hits and the Level2 calo isolation used
  - **fast**
  - **good performance for isolation**
  - **preferred for decays with two taus in the final state (like A/H->tautau)**

- "Trk trigger": (some) hits of the microstrip inner tracker used, no Level2 calo isolation
  - **slower than Calo+Pxl**
  - **much better resolution for track momenta**
  - **useful in channels like charged Higgs boson decay**
    - **tight cut on the pT of the leading track**

CMS: tau tag efficiency from data

- The tag efficiency can be estimated from the ratio:

$$\frac{Z \rightarrow \tau\tau \rightarrow \mu + \tau_{\text{jet}} + X}{Z \rightarrow \mu\mu}$$

$$N_{Z \rightarrow \tau\tau \rightarrow \mu + \tau_{jet}} = \sigma_{DY} \times L \times BR(Z \rightarrow \tau\tau \rightarrow \mu + \tau_{jet}) \times \epsilon_{HLT_{1\mu}} \times \epsilon_{\tau\ tag} \times \epsilon_{other} = N_{\mu+\tau_{jet}}^{meas} - N_{\mu+\tau_{jet}}^{bkg.}$$

$$N_{Z \rightarrow \mu\mu} = \sigma_{DY} \times L \times BR(Z \rightarrow \mu\mu) \times \epsilon_{HLT_{1\mu}} \times \epsilon_{mass\ reco} = N_{\mu+\mu}^{meas} - N_{\mu+\mu}^{bkg.}$$

$\epsilon_{\tau\ tag}$ - τ isolation in cone, requirement for 1 or 3 tracks in the signal cone

ϵ_{other} - selections rejecting background to the $Z \rightarrow \tau\tau \rightarrow \mu + \tau_{jet}$: $t\bar{t}$ and $W + jet$ and mass window selection

$\epsilon_{mass\ reco}$ - efficiency to find the second muon and mass window selection efficiency

$$\epsilon_{\tau\ tag} = \frac{N_{\mu+\tau_{jet}}^{meas} - N_{\mu+\tau_{jet}}^{bkg.}}{N_{\mu+\mu}^{meas} - N_{\mu+\mu}^{bkg.}} \times \frac{BR(Z \rightarrow \mu\mu)}{BR(Z \rightarrow \tau\tau \rightarrow \mu + \tau_{jet})} \times \frac{\epsilon_{HLT_{1\mu}}^{\mu\mu}}{\epsilon_{HLT_{1\mu}}^{\mu\tau_{jet}}} \times \frac{\epsilon_{mass\ reco}^{\mu\mu}}{\epsilon_{other}^{\mu\tau_{jet}}}$$

Things in black - known from experiment (introduces statistical error)

Things in red - to be obtained from Monte Carlo and data (introduces systematical error)

CMS: tau tag efficiency from data
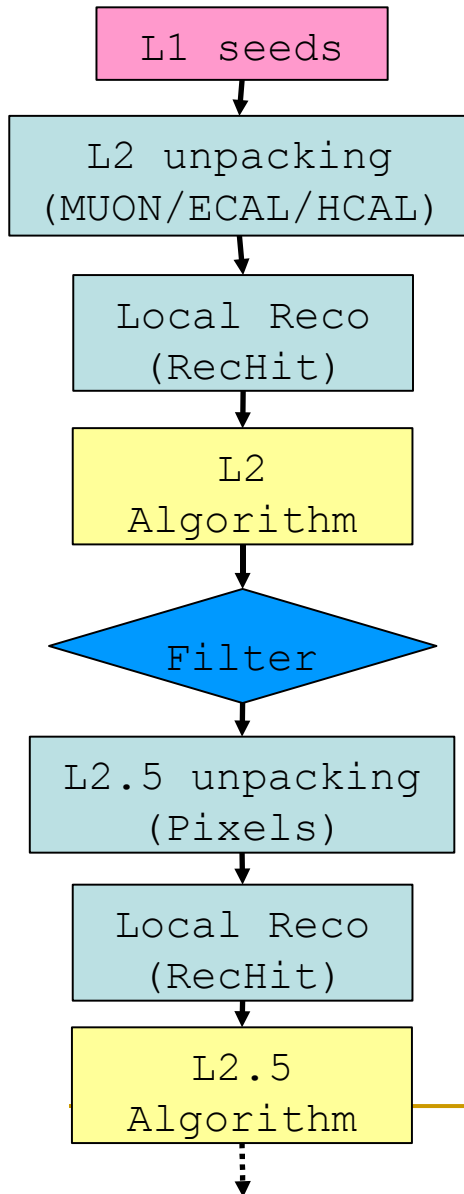
Selection table for 30 fb^{-1} Signal   Background

Process:	$Z \to \mu\mu$	$Z \to \mu + \tau_{jet}$	$t\bar{t}$	$W + jet$	bb
$\sigma \times BR\,[pb]$	2127	468	830	41457	22904478
Events for 30 fb^{-1}	63810000	14038200	24900000	1243720312	687134340000
HLT (single μ, $p_T > 19\,GeV/c$)	12113522	532024	1714285	12825148	1658017
only one, $\mu\ p_T > 20\,GeV/c$	not applied	449087	1093926	11256357	1044637
$\tau_{jet}\ E_T > 45\,GeV$	not applied	82211	534301	2174934	51228
leading $\tau_{jet}\ tk.\ p_T > 40\,GeV/c$	not applied	17030	204978	466396	4609
τ tag	**not applied**	**12379**	**137657**	**190844**	**2499**
$m_T(\mu, MET) < 30\,GeV/c^2$	not applied	8588	21407	32485	1464
$\Delta\varphi(\mu, \tau_{jet}) < 175°$	not applied	6820	20107	25663	1266
$E_{\nu_1,\nu_2} > 0$	not applied	3665	8531	5633	694
Electron veto	not applied	3032	2664	3839	504
Jet veto (1 central jet)	not applied	1666	682	1460	116
Mass window	7191968 ± 28658	988 ± 99	63 ± 22	42 ± 30	61 ± 34
Mass window (wide)	7191968 ± 28658	1291 ± 113	206 ± 40	271 ± 75	75 ± 37

- **Error contribution on ε_{tag} for 30 fb^{-1}**

Source:	Number of $\mu\tau_{jet}$ events	Calorimtery scale uncert.	background uncertainty	**Total**
Contribution [%]:	3.4	8	1	**8.7**

HLT algorithm design

```
┌─────────────────┐
│    L1 seeds     │
└─────────────────┘
        ↓
┌─────────────────┐
│  L2 unpacking   │
│(MUON/ECAL/HCAL) │
└─────────────────┘
        ↓
┌─────────────────┐
│   Local Reco    │
│    (RecHit)     │
└─────────────────┘
        ↓
┌─────────────────┐
│      L2         │
│   Algorithm     │
└─────────────────┘
        ↓
      ◇ Filter ◇
        ↓
┌─────────────────┐
│ L2.5 unpacking  │
│    (Pixels)     │
└─────────────────┘
        ↓
┌─────────────────┐
│   Local Reco    │
│    (RecHit)     │
└─────────────────┘
        ↓
┌─────────────────┐
│     L2.5        │
│   Algorithm     │
└─────────────────┘
        ↓
```

"Global" vs. "Regional":

➢ All algorithms (except for Jets) regional by now
  ○ Seeded by previous levels (L1, L2, L2.5)

➢ Will benefit significantly by doing regional data-unpacking and local reconstruction across HLT

➢ Have implemented regional ECAL unpacking/RecHit for Egamma and Muon trigger paths

➢ Started planning (& development) of regional unpacking across rest of detectors, HLT paths

"Local": using one sub-detector only
"Regional": using small (η, φ) region

"Alternative" Trigger Menus

- "What happens if we give more bandwidth to tau HLT (more tracking)?"
  - L1 Single-tau: 80 → 60 GeV; L1 Double-tau: 40 → 35 GeV
  - eff(W): 10% → 17% ; eff(H_{200}): 15% → 32% ; eff(H_{400}): 28% → 44%
  - Replace "MET" by "MET + H_T" condition for jet triggers to balance L1
  - <T>: 43 ms → 45.8 ms (min.bias), 45.2 ± 3.4 ms (QCD/W/Z/μ mix)
  - Minor increase in CPU-processing time

- "What happens if we raise L1 thresholds to 2E33 menu from PTDRv2?"
  - Contributions from high-P_T QCD bins become more relevant
  - Assume average HLT processing time per sample remains ~same
    - In reality, it will increase because of pile-up
  - <T>: 45.2 ms → 55.6 ± 4.2 ms (QCD/W/Z/μ mix)
  - Larger increase in CPU-processing time, still under control

- Higher luminosities are expected to increase HLT processing
- Have option of adjusting Trigger Menu (at lower efficiencies)

Safety factors

➢ Safety factor of 3 in allocation of L1 bandwidth; only 17 kHz allocated to simulated channels – to account for:
  - Uncertainty in maximum DAQ bandwidth (especially at startup)
  - Input cross sections (especially QCD; Tevatron shows factors of ~2)
  - All that we have not simulated:
    - beam conditions, noise spikes, other electronics correlations…

➢ Safety factor of 2 in HLT accept rate; only 150 Hz allocated to simulated channels – to account for
  - Uncertainties in cross sections (e.g. heavy-flavor cross section)
  - Uncertainties in simulation (e.g. rate for a jet faking an electron: experience from Tevatron experiments shows Monte Carlo reliable to within a factor 2)

Systematic uncertainties

- **Calibration & alignment uncertainties: impact on trigger rates**
  - ➤ Have not been studied yet; Focus of work beginning now
- **b-bbar contributions to leptonic rates**
  - ➤ Difficult to quantify muon contributions
    - ▪ Multiple cross-checks with different MC samples
  - ➤ Electron contributions are underestimated
    - ▪ Effect: ~few Hz, mostly affecting double-electron trigger
  - ➤ Limited statistics of MC samples: a more general problem for LHC
    - ▪ Months of MC production yielded 30M min.bias events
    - ▪ ~25k evts survived L1: equivalent to 1-2 seconds of LHC running!

Alternative trigger table optimization

- **Level1 Thresholds:**
  - for SingleTau moved from 80 to 60 GeV
  - For DoubleTau moved from 40 to 35 GeV
- **Modification at HLT**
  - Increase signalCone size from ~0.07 to 0.1
- **Total L1+HLT Efficiency**
  - Z->tautau: from 8.6% to 12%
  - W->tau nu: from 1.8% to 3.2%