Reconstruction and selection of $Z \rightarrow \tau\tau \rightarrow \mu + \tau\text{-jet} + \nu$'s decays at the CMS experiment

Letizia Lusito (University & INFN Bari, CERN)

On behalf of the CMS Collaboration

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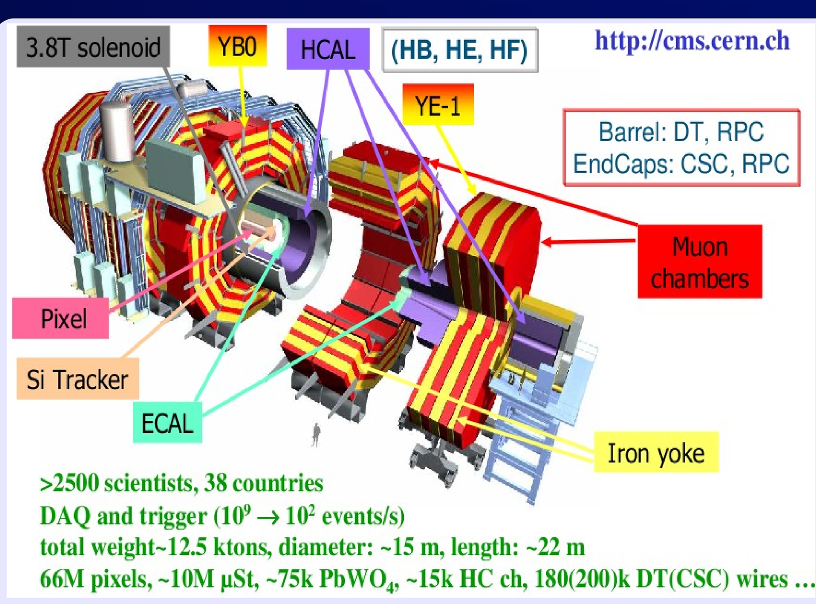
$Z \rightarrow \tau\tau$ decays can be considered as a "standard candle" process for the commissioning of the tau reconstruction as well as a test bench for analogous $H \rightarrow \tau\tau$ decays. We have implemented a technique for the selection and reconstruction of $Z \rightarrow \tau\tau \rightarrow \mu + \tau$-jet + ν's events optimized to the first measurement of the $Z \rightarrow \tau\tau$ production cross-section at the Compact Muon Solenoid experiment using first LHC collision data. The analysis has been performed considering simulated p-p collision data at the centre-of-mass energy of $\sqrt{s}$ = 10 TeV corresponding to an integrated luminosity of 200 pb^{-1}. Also we have established a data-driven method, the "Template Fitting" aimed at the estimation of background contribution to the final visible mass peak of Z boson

The Compact Muon Solenoid



The Compact Muon Solenoid is a general purpose proton-proton detector designed to run at the Large Hadron Collider

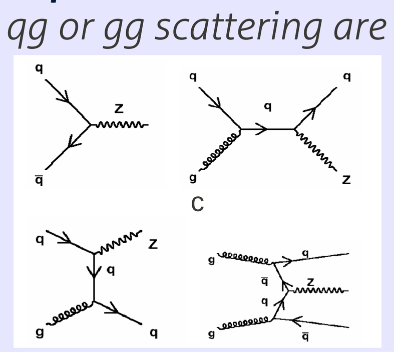
- *Magnetic Field: 4 T (3.8 T at the start-up)*
- *Tracker, ECAL and HCAL inside the superconducting solenoid*
- *Muon detector in the return yoke*
- *Barrel + 2 Endcaps + forward detectors*

Besides the sub-detector components, a major role is played by the trigger and data acquisition systems, and from the software point of view by the reconstruction and simulation

Z boson production and tau properties

Z production *occurs by* $q\bar{q} \rightarrow Z$

qg or gg scattering are subdominant



$$\sigma_Z = \sum_{ab} \sigma_{ab \rightarrow Z} \cdot PDF(x_a, x_b, Q^2)$$

$$\sigma_Z \cdot BR(Z \rightarrow ll) = \frac{N_Z - N_{Z,bkg}}{A_Z \cdot \epsilon_Z \cdot L}$$

Tau: *mass 1.777 GeV/c^2, lifetime $290 \cdot 10^{-15}$ s*

heaviest of the three leptons

Decay Products	Branching Ratio
$e^- + \bar{\nu}_e + \nu_\tau$	(17.84±0.05)%
$\mu^- + \bar{\nu}_\mu + \nu_\tau$	(17.36±0.05)%
$1\pi + n\pi^0 + \nu_\tau$	49.2%
$3\pi + n\pi^0 + \nu_\tau$	14.6%

Leptonic decays

Hadronic decays (τ-jets)

- *Collimation, isolation*
- *Low charged tracks multiplicity*
- *HCAL & ECAL energetic deposits*

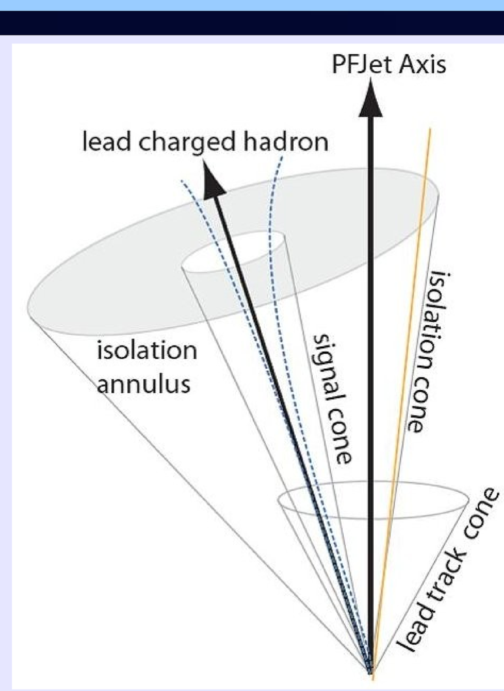
Significant fraction of τ momentum escapes undetected with ν_τ

Muon and tau lepton reconstruction

Global reconstruction (GM): *muon stations + tracker hits*

Muon identification: *calorimeter and segment compatibility probabilities*

Muon isolation: *isolated muons coming from Z can be discriminated from μ's in soft jets from K and π by calculating the sum of energy deposits and track p_T in a cone around muon track direction at vertex. Muon contribution to the sum can be vetoed*



Particle Flow algorithm: *complete event description with the reconstruction and identification of all stable particles*

Preselection: *PF-jet with a leading charged hadron, definition of matching, signal and isolation cones: a τ-jet is defined isolated if no charged hadron or photon is found in the isolation annulus*

Fixed or Shrinking cone definitions: *τ-jet become more collimated at high energies and better recovery of three prongs decays*

Discriminators against Muons, Electrons

Data samples and event selection

Processes	σ(pb)	e_G	Events	L(pb^{-1})	Gen MC
Z→ ττ	1086	1	1210500	1115	Pythia6
Z→μμ	1233	0.509	501025	798	Pythia6
pp→μ X (QCD) high pT	5091x10^5	0.00034	6089180	50	Pythia6
pp→μ X (QCD) low pT	5156x10^7	0.0023	5021444	0.04	Pythia6
ttbar+jets	317	-	946644	2986	MadGraph
W(→ ℓν)+jets	40000	-	9745661	244	MadGraph
Z(→ee)+jets	3700	-	1262816	341	MadGraph

HLT_Mu15 || HLT_IsoMu11

Vertex reconstruction and quality cuts

Muon kinematic: p_T>15 GeV/c , |η|<2.1, 1 Global muon

Tau kinematic: p_T>20 GeV/c, |η|<2.1 not overlapping with the μ

Muon Iso value<1 in a cone with ΔR=0.6

Pion rejection (muon compatibility)

Track transverse impact parameter < 2 cm

1 or 3 signal charged tracks in τ-jet

Charge of τ-jet = ± 1

Discriminator against muons

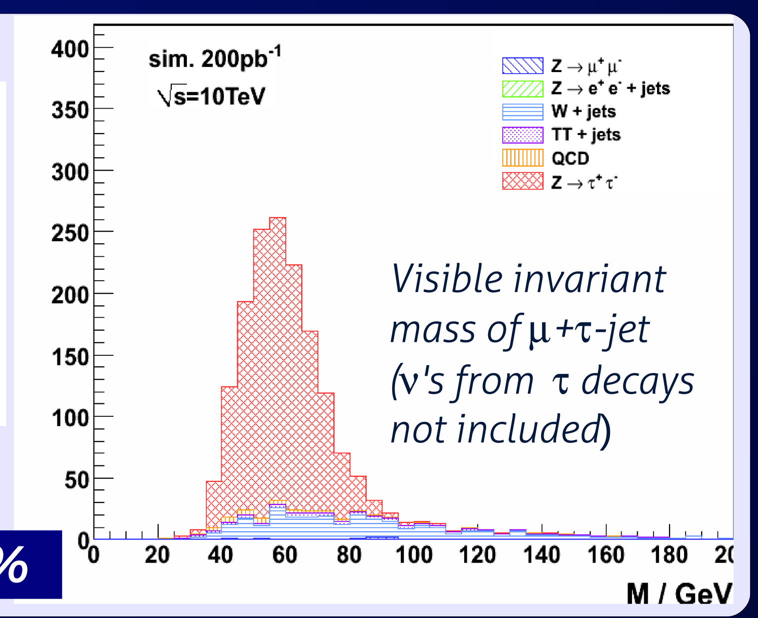
ΔR (muon, τ-jet) > 0.7, M_T (muon, MET) < 50, ζ cut

Selection final results:

Cut	Z→ ττ	QCD	$t\bar{t}$+jets	W+jets	Z(→ee)+jets	Z→ μμ
gen. Phase-Space	23878	2938604	25640	445242	732	122893
mu15 || isoMu11 Trigger	14599	2280552	15439	325421	75	115736
Vertex	14599	2280552	15439	325421	75	115736
$p(\chi^2_{vtx}) > 0.01$	14581	2280416	15438	325326	75	115578
$-25 < z_{vtx} < +25$ cm	14581	2280416	15438	325326	75	115578
1 global Muon	12785	2045261	10397	316790	68	6021
$\|\eta^\mu\| < 2.1$	12735	2039853	10374	315441	68	5942
$p_T^\mu > 15$ GeV/c	9654	2011583	9888	295449	63	5675
μ and τ-jet not overlapping	9654	2011583	9888	295449	63	5673
$\|\eta^{\tau-jet}\| < 2.1$	9622	2009483	9888	294769	63	5581
$p_T^{\tau-jet} > 20$ GeV/c	5847	1081183	9663	112673	57	1996
Muon Track iso.	3490	19768	2984	61991	2	1183
Muon ECAL iso.	3092	2109	2329	53085	-	1037
Muon π-Veto	3055	2049	2303	52522	-	1023
Muon Track d_0	3053	2004	2302	52522	-	1023
τ-jet lead. track find.	2852	1669	2246	47586	-	908
τ-jet lead. track p_T	2687	1527	2197	44613	-	869
τ-jet Track iso.	1930	292	786	9458	-	567
τ-jet ECAL iso.	1728	202	569	6827	-	539
τ-jet 1||3-Prong	1541	83	375	2897	-	502
Charge(τ-jet) = ± 1	1530	71	351	2512	-	499
(μ, τ-jet) Veto	1522	71	348	2504	-	39
$\Delta R_{\mu,\tau-jet} > 0.7$	1522	71	345	2496	-	39
$Charge_\mu + Charge_{\tau-jet}) = 0$	1500	38	307	1959	-	25
M_T (μ-MET) < 50 GeV/c^2	1433	37	99	596	-	12
$P_\zeta - 1.5 * P_\zeta^{vis} > -20$ GeV	1330	30	59	275	-	10

Events expected from Z → ττ and different backgrounds processes (expectations for 200 pb^{-1})

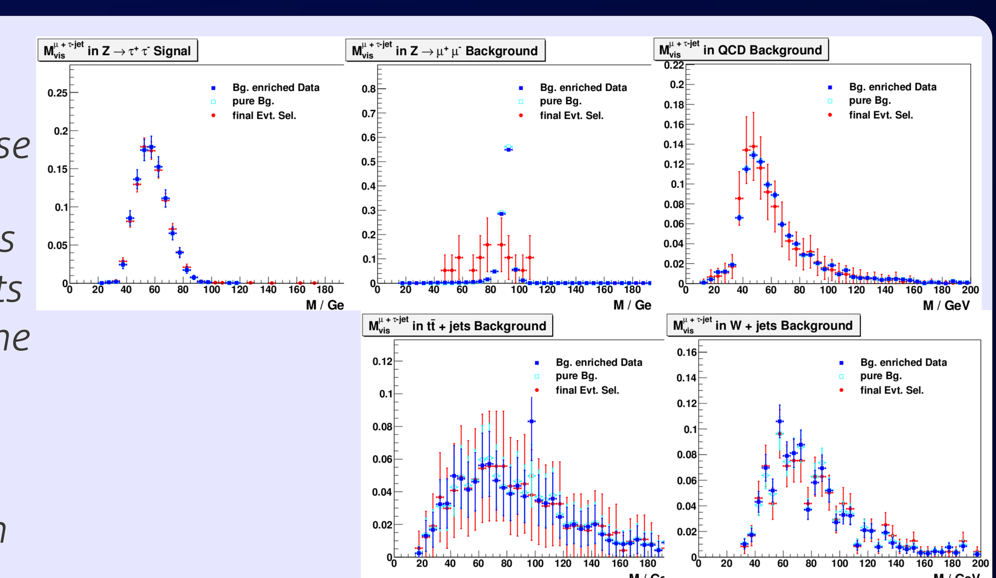
S/S+B = 78%



Visible invariant mass of μ+τ-jet (ν's from τ decays not included)

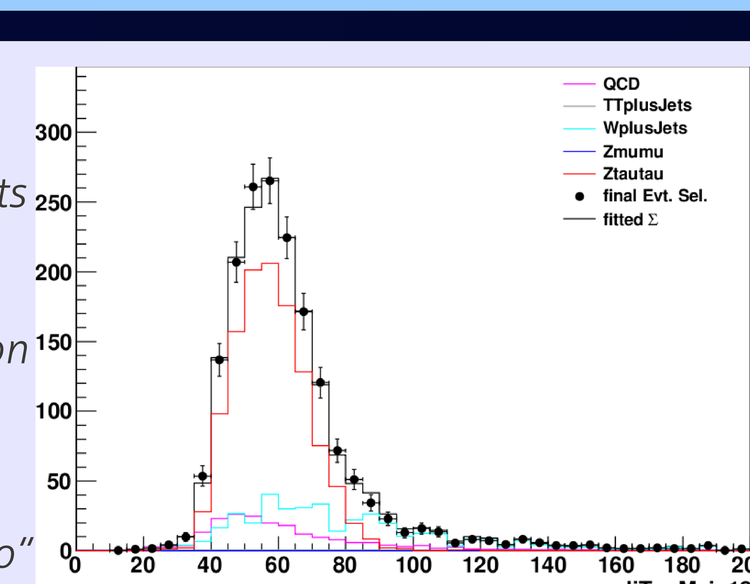
The data-driven background estimation

- *Contribution of Z → ττ and all background determined by control samples (obtained through dedicated selections in different phase space regions)*
- *Template of a background process defined as the visible μ + τ-jet mass distribution of events in the phase space region corresponding to the control sample relative to that process, normalized to unit area*
- *Template of Z → ττ obtained from Z → μμ events substituting reconstructed muons with simulated tau decay products*



Results of the template fitting method

Good agreement between the fit of the sum of simulated events of Z→ττ and other background events which pass the selection aimed to the cross section measurement and BR in the channel Z→ττ→μ+τ-jet ("pseudo" data, black points) with template distributions (coloured curves)



- *Efficient selection of control samples with a good compromise between purity and statistics*
- *Visible Mass not correlated with selection criteria used used in the determination of phase space regions → could be used as the template distribution*
- *Bias in the template shapes due to contamination of control samples by other background processes and signal itself is negligible*

Conclusions

The reconstruction and selection techniques presented here demonstrate the capability of CMS of correctly and efficiently identify tau leptons decaying leptonically (in muons) as well as tau-jets with good efficiency and good background rejection (expected S/S+B = 0.78). This achievement can serve as a basis for other analysis with tau in final state and are been currently tested and optimized in real p-p collision events.

Moreover, the data-driven estimation of background via the template fitting method can be fully applied to determine the contributions of signal and background processes to the Z boson visible mass. Possible biases in the shape templates are well under control. The results obtained are found to be in agreement with MC predictions. The combined statistical and systematics uncertainties are of the order of 10%.

References:

L. Lusito, "Reconstruction and selection of Z→ ττ → μ + τ-jet + ν's decays at the CMS experiment", CMS TS 2010/006