Search for a heavy neutral resonance in tau pair decay channel

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Outline

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- τ decay modes & its basic reconstruction
- Missing transverse energy measurement
- Search strategy
- $Z' \rightarrow \tau\tau \rightarrow \mu + \tau_{had}$ channel
- $Z' \rightarrow \tau\tau \rightarrow e + \tau_{had}$ channel
- $Z' \rightarrow \tau\tau \rightarrow e + \mu$ channel
- $Z' \rightarrow \tau\tau \rightarrow \tau_{had} + \tau_{had}$ channel
- Cut optimization
- Sensitivity
- Conclusions & Ongoing work

Introduction

- New heavy gauge bosons Z',W' occur quite frequently in various extensions of Standard Model like Grand Unified Theories(GUTs), Extra Dimensions, Superstring, Little Higgs model etc.

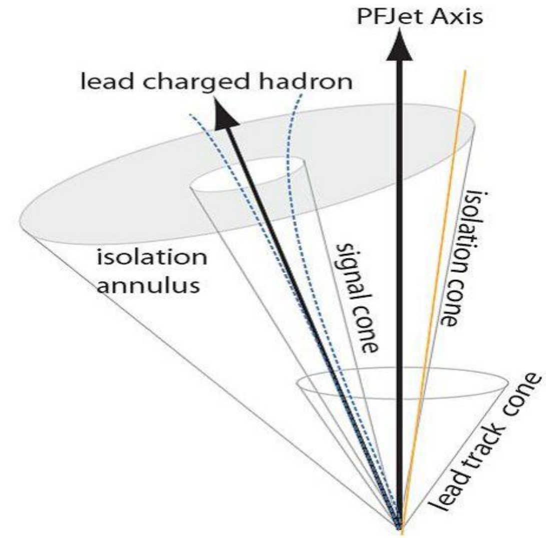
- A Z' with universal couplings is most likely to be discovered in its e^+e^- or $\mu^+\mu^-$ decay modes first. The decay to $\tau^+\tau^-$ would be important for testing the universality of the couplings.

- Models with non-universal couplings, some with enhanced coupling to third generation fermions, present the opportunity to discover a Z' via its di-tau decay.

- The current limits set by the Tevatron is 350-400 GeV/c^2 depending on the model.
  - Ref: Zongru Wan, A search for New Physics with High Mass Tau Pairs in Proton-Antiproton Collisions at $\sqrt{s}$ = 1.96 TeV at CDF, arXiv: hep-ex/0504060v2, 2 May 2005

Decay modes of τ & its basic reconstruction

Decay mode	Branching ratio
$e^- + \nu_e(\text{bar}) + \nu_\tau$	17.84 %
$\mu^- + \nu_\mu(\text{bar}) + \nu_\tau$	17.36 %
$1\pi + n\pi^0 + \nu_\tau$	49.2 %
$3\pi + n\pi^0 + \nu_\tau$	14.6 %



- A jet having p_T > 15 GeV/c with at least one charged hadron with p_T > 5 GeV/c located at a distance of less than 0.1 in the (η,ϕ) space from jet direction.
- The highest p_T charged hadron satisfying this condition is called "leading track" of the jet.
- A narrow signal cone is defined around leading track which is expected to contain all decay products.
- An "isolation annulus" (larger cone excluding the signal cone itself) in which a little activity (in particular no charged hadron or photon candidates above the p_T threshold of respectively 1 and 1.5 GeV/c) is expected due to the isolation characteristics of τ-jets.

Measurement of missing transverse energy

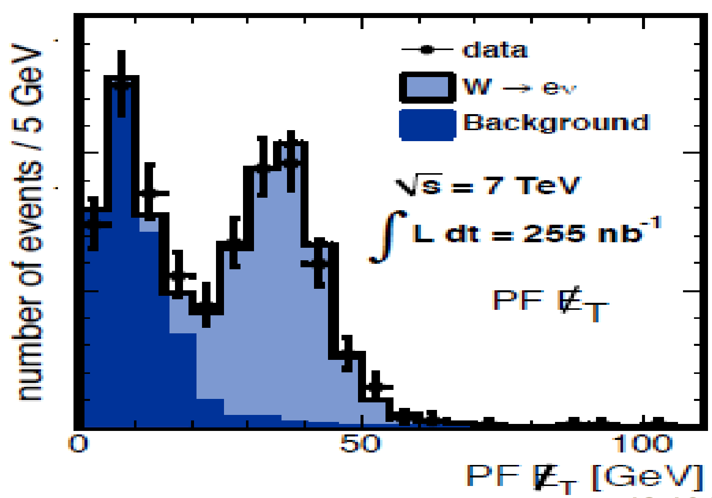
- Many interesting processes & decay of some exotic particles involve production of τ leptons in the final states. The subsequent decays of τ leptons involve neutrinos which generally escape the ordinary detection.

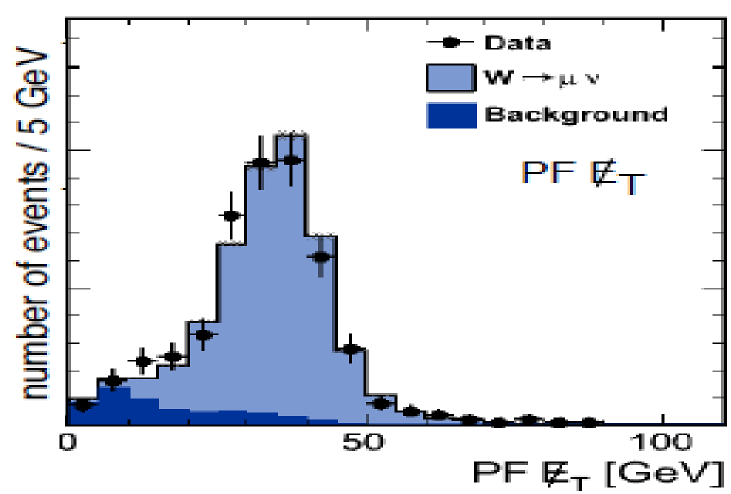
- The neutrinos are detected as the vector momentum imbalance in the plane perpendicular to beam direction which is known as missing transverse momentum. Its magnitude is called missing transverse energy(MET).

- The study of channels involving τ's require efficient MET measurements.

- Particle flow (PF) reconstruction algorithm provides a global description of an event at the level of individually reconstructed particles by optimal combination of the information coming from different sub-detectors (Tracker, Calorimeters, Muon Chambers). Particles are then clustered to derive composite physics objects like jets.

- PF MET distribution in $W \rightarrow e\nu$ & $W \rightarrow \mu\nu$ candidate events in 7 TeV collision data from Large hadron Collider (LHC) reflects the excellent MET performance of the compact muon solenoid (CMS) detector.





Search strategy

- The study is based on two scenarios for most of the channels:
  - With & without MET related cuts/variables.
  - Without MET path is just a backup plan in case MET is not well understood for particular event topologies we are interested in.

- Cuts have been tuned in such a way that it is possible to see the clean $Z \rightarrow \tau\ \tau$ control region in the low mass region.
  - We need to make sure that we indeed see τ's.
  - For safe extrapolation to signal, we should obtain a relatively clean sample of $Z \rightarrow \tau\ \tau$ by relaxing just a few cuts only.

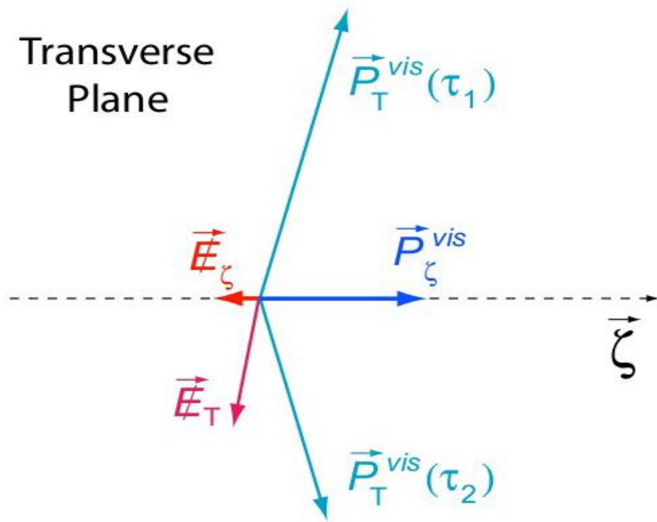
- Cuts are optimized in such a way that systematic effects are reduced to minimum & "best limit" is achieved.

- All channels ($e\tau_{had}$, $\mu\tau_{had}$, $e\mu$, $\tau_{had}\ \tau_{had}$) would be combined for setting up final limit.

MET path
Baseline selections for $\mu+\tau_{had}$, $e+\tau_{had}$, $e+\mu$, $\tau_{had}+\tau_{had}$ channels

- The basic selections are common among different channels.

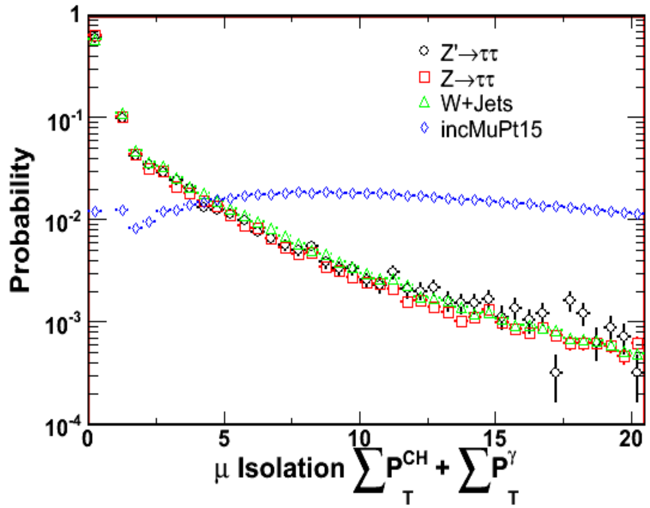
- **Acceptance**
  - L_1 p_T >20 GeV/c , L_1 $|\eta|$< 2.1 & L_2 p_T >20 GeV/c , L_2 $|\eta|$< 2.1, where $L_1 = \mu, e$ & $L_2 = \tau$
  - L_i p_T > 15 GeV/c for $L_i = \tau$ & i =1, 2
  - τ lead PF charged hadron p_T > 5 GeV/c
  - $\Delta R(L_1, L_2)$> 0.7, where $L_1, L_2 = \mu, e, \tau$

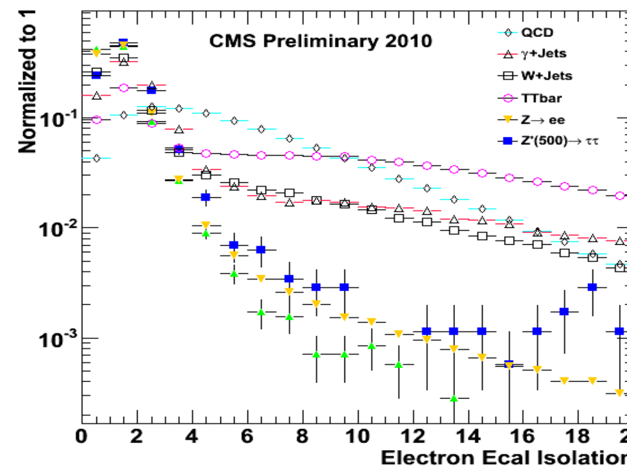


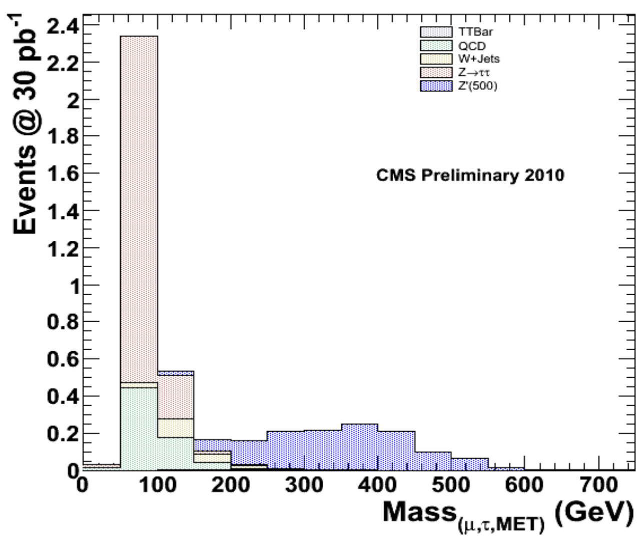
- **ID cuts(To discriminate from the fakes)**
  - Isolated objects (μ, e)
  - Isolated τ with exactly 1 prong

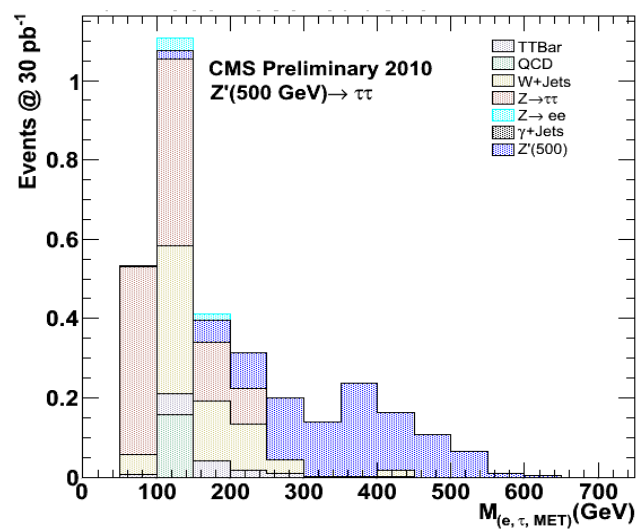
- **Topology**
  - Oppositely charged objects with $\cos\Delta\phi(L_1, L_2)$< -0.95, where $L_1, L_2 = \mu, e, \tau$
  - $[p_T(L_1) - p_T(L_2)] / [p_T(L_1) + p_T(L_2)] > X$, where $L_1, L_2 = \mu, e$
  - MET > 30 GeV
  - Zeta Cut: $P_\zeta - 0.875 * P_\zeta^{vis} > -7$ (This cut uses the projection of visible momentum and MET onto the bisection vector as shown on the picture).

Probability distributions for basic variables & mass





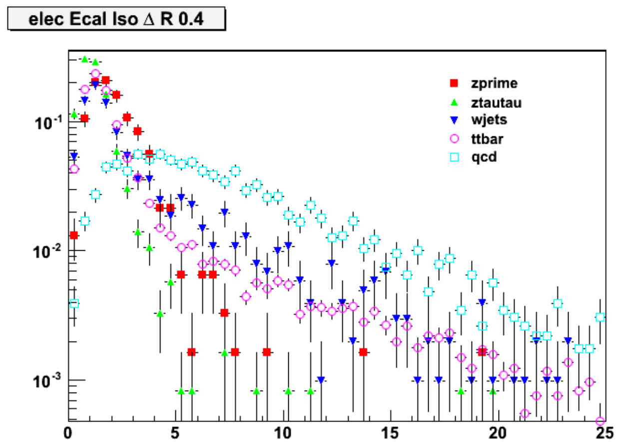


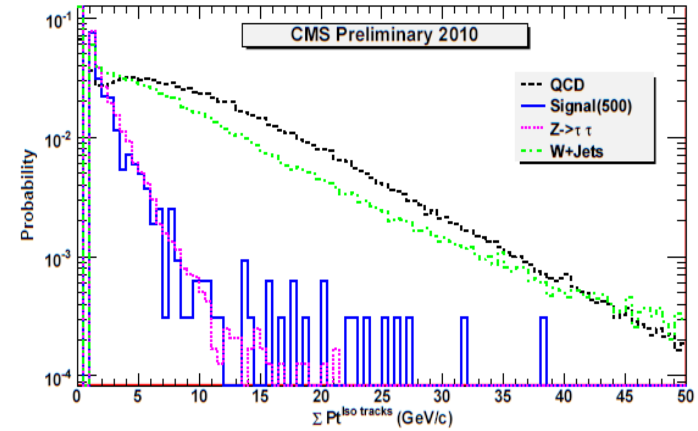


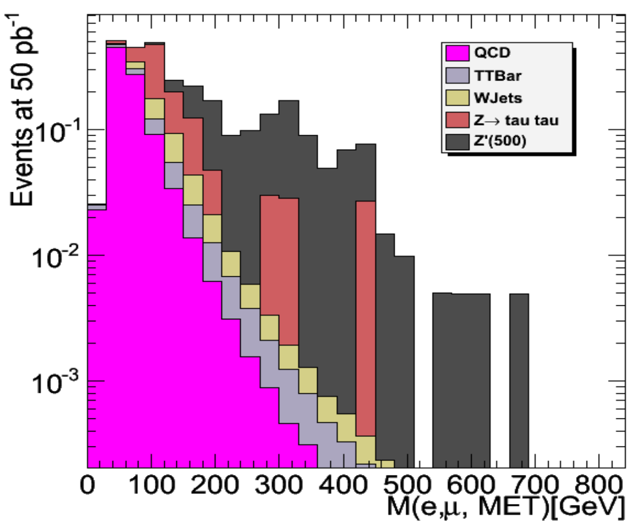
$\mu + \tau_{had}$

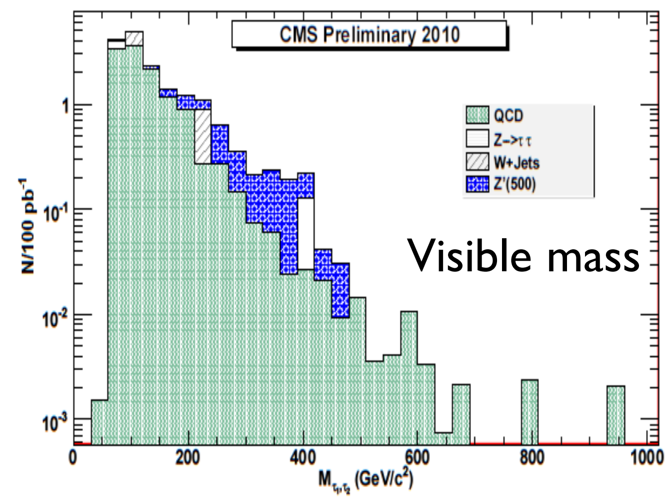
$e + \tau_{had}$

Probability distributions for basic variables & mass









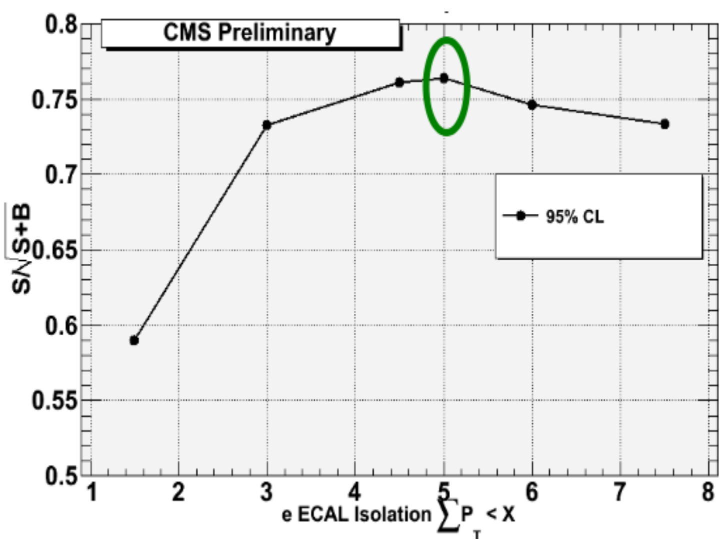
e + μ

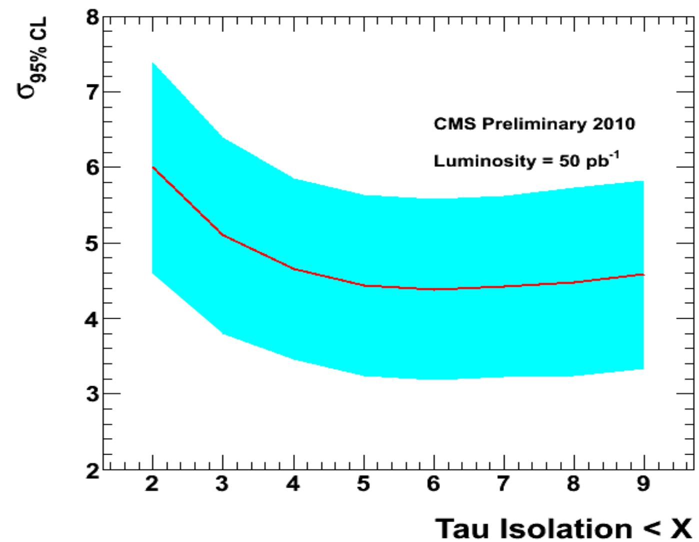
$\tau_{had} + \tau_{had}$

Optimization of analysis cuts

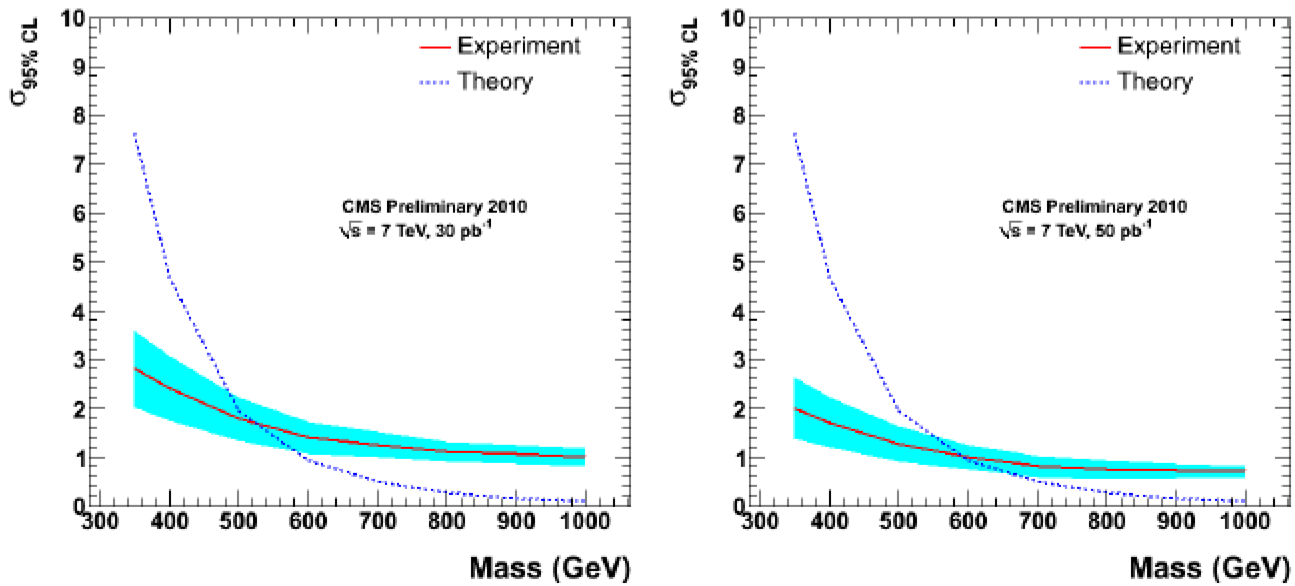
- Optimization of cuts was performed in two steps.
  - First searched for cuts that improve signal significance. From these cuts baseline selection was achieved.
  - Once baseline selection was established, cuts were varied such that signal significance become maximum and the best 95% CL limit was achieved.

- Consistent results from both methods.





Combined limit



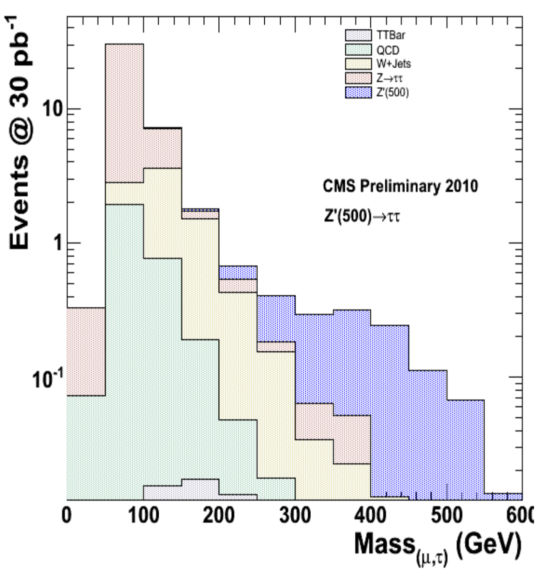
- Limits obtained by combination of $\mu\tau_{had}$, $e\tau_{had}$, $e\mu$ channels.
- This shows that its possible to surpass the Tevatron sensitivities with about 30pb^{-1} of data.
- We expect the combination of all channels will allow us to set a limit for $Z' \rightarrow \tau\ \tau$ masses up to ~600 GeV with 50pb^{-1}.

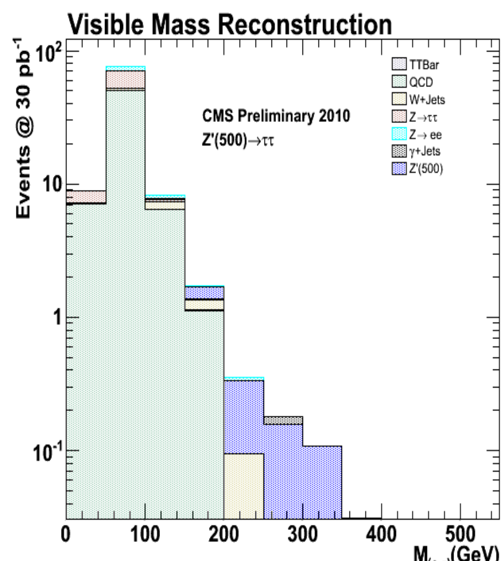
Combined limit w/o MET related cuts/variables

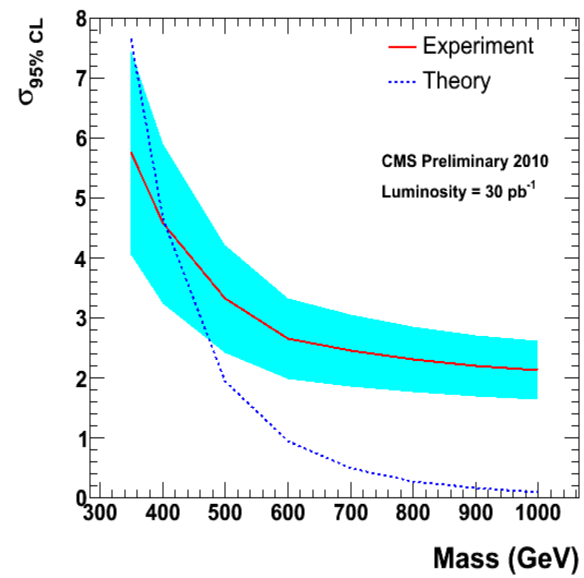
Strategy:

Remove the MET related variables and cut harder on a few main discriminating variables e.g.

- Cut harder on isolations.
- Cut harder on p_T asymmetry i.e. $\Delta p_T(L_1, L_2)$. It is quite similar to MET, but lesser prone to systematic effects, much simpler & easier to understand.







Conclusions & Work in progress

- The analysis has been set in such a way that each individual channel could be competitive with the Tevatron limits just with the early LHC data.

- Combination of all channels would allow us to exclude a $Z' \rightarrow \tau\ \tau$ with mass up to 600 GeV/c^2 with ~50pb^{-1} of data.

- We have started looking at the real data for establishing our control region and extracting background shapes.

- We are always eager to do further possible improvements in the analysis & making it more robust against systematic uncertainties.

High Pt Tau Group

- Many thanks to everyone for contributing in this talk.

- Alexei Safonov
- Simone Gennai
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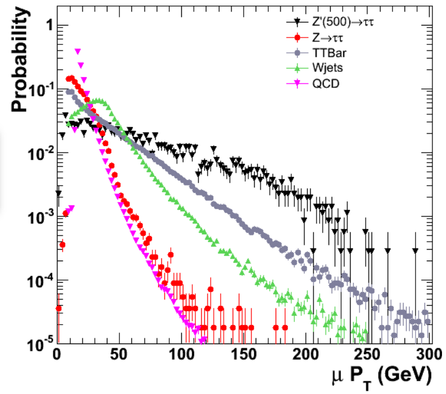
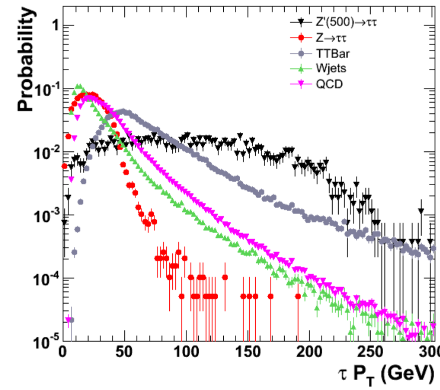
- Andres Florez
- Alfredo Gurrola
- Kajari Mazumdar
- Jasbir Singh
- John Cumalat
- Nil Valls
- Indara Suarez
- Alyssa Proulx

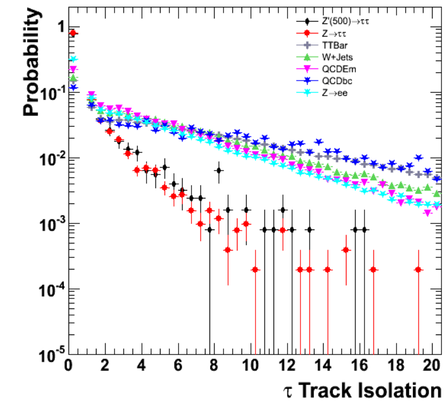
Back Up

Some basic distributions

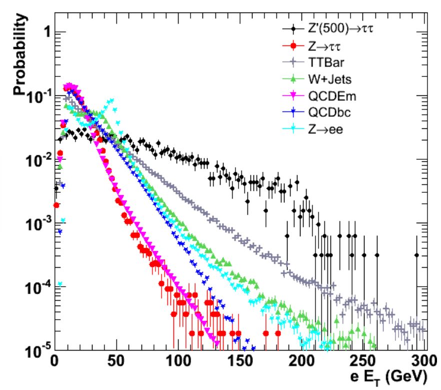
$\mu + \tau_{had}$

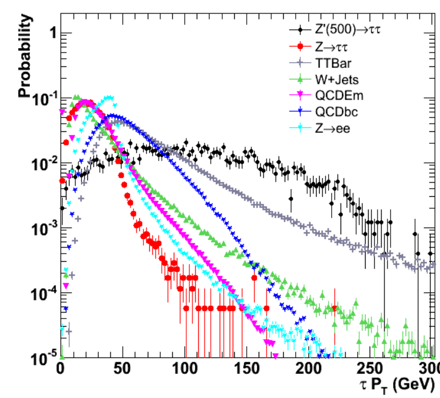


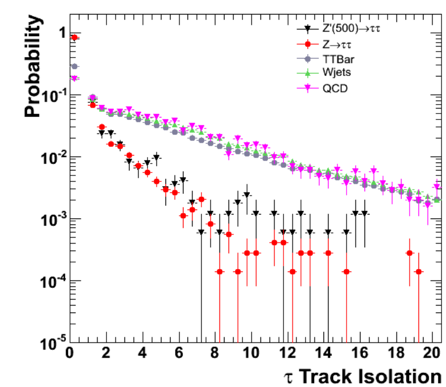




$e + \tau_{had}$

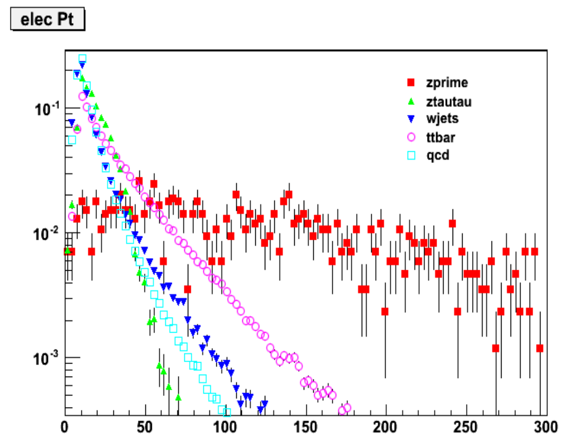


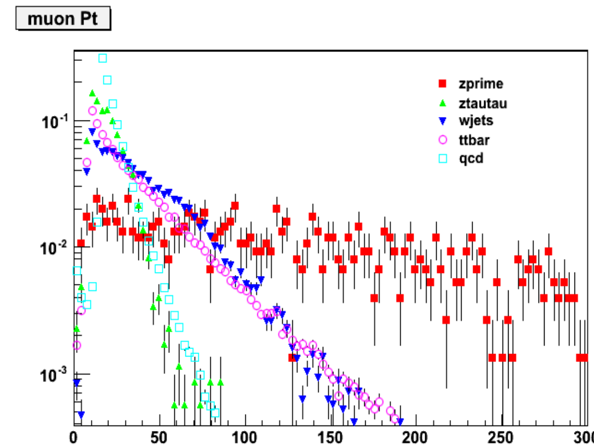




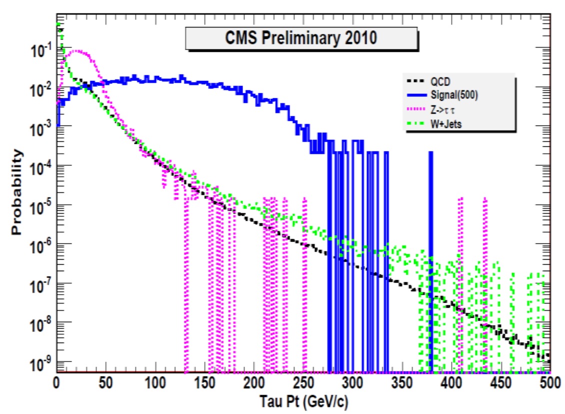
Some basic distributions

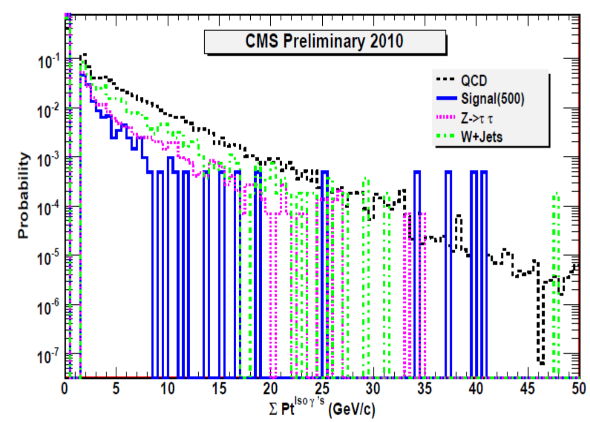
e + μ





$\tau_{had} + \tau_{had}$





Setting exclusion limits

- Likelihood for each channel is based on the Poisson probability of observing n events given and expectation of μ events

$$\mathcal{L} = \prod_{i=1}^{N_{ch}} \frac{\mu_i^{n_i} e^{-\mu_i}}{n_i!}$$

- The expected number of events: $\mu_i = L_i \sigma_{\mathrm{sig}} \epsilon_i + b_i$

- Systematics are incorporated as nuissance parameters.

- With systematics

$$\mu'_i = (1+g_L) L \sigma_{\mathrm{sig}} (1+f_{\epsilon i})(1+g_\epsilon)\epsilon_i + (1+f_{bi})(1+g_b) b_i$$

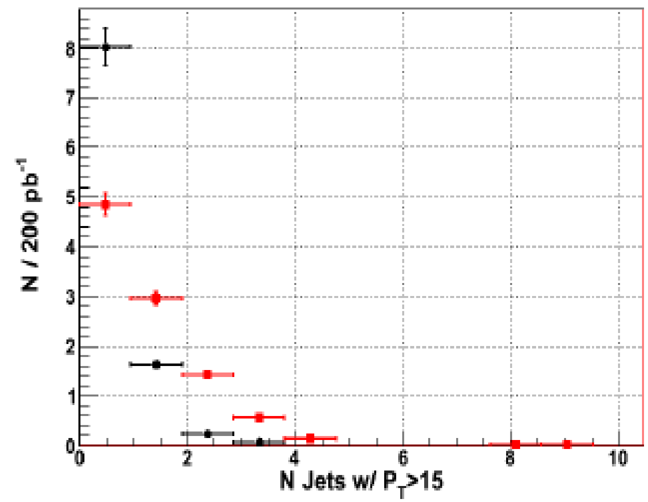
where the f and g represent uncorrelated and correlated relative errors.

- The limit is extracted via

$$0.95 = \frac{\int_0^{\sigma_{95}} \mathcal{L}(\sigma) d\sigma}{\int_0^{\infty} \mathcal{L}(\sigma) d\sigma}$$

Systematics

Quantity	Souce	Effect
σ	PDF's	5.25%
Efficiency	PDF's	4.10%
Mass	PDF's	Negligible
σ	JES – 10%	None
Efficiency	JES – 10%	39.53%
Mass	JES – 10%	Yes – Large
σ	Tau Eta Resolution	None
Efficiency	Tau Eta Resolution	Negligible
Mass	Tau Eta Resolution	Negligible
σ	Tau PT Resolution 10%	None
Efficiency	Tau PT Resolution 10%	0.26%
Mass	Tau PT Resolution 10%	Negligible

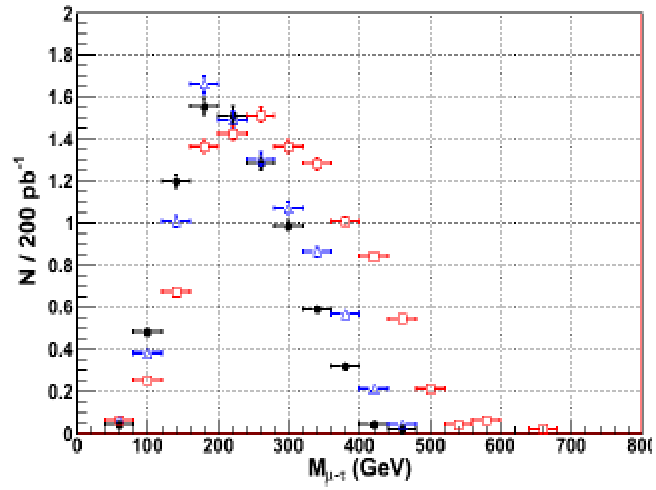


Black – No Smearing
Red – 10% JES Smearing

Initially, we tried to supress TTBar using a jet veto cut. After studying systematic effects of JES, we decided against it.

Systematics

Quantity	Souce	Effect
σ	Lepton Eta Resolution	None
Efficiency	Lepton Eta Resolution	Negligible
Mass	Lepton Eta Resolution	Negligible
σ	Lepton PT Resolution 10%	None
Efficiency	Lepton PT Resolution 10%	0.2%
Mass	Lepton PT Resolution 10%	Negligible
σ	Tau PT Scale 5%	None
Efficiency	Tau PT Scale 5%	3.93%
Mass	Tau PT Scale 5%	Yes
σ	Lepton PT Scale 1-2%	None
Efficiency	Lepton PT Scale 1-2%	0.2 – 0.5%
Mass	Lepton PT Scale 1-2%	Yes - Small



Black – No Smearing
Blue – 10% Tau PT Scale Smear
Red – 50% Tau PT Scale Smear

Not only does momentum scale affect overall acceptance, but also the shape of our mass distributions

Systematics

Quantity	Souce	Effect
σ	ISR	None
Efficiency	ISR	4%
Mass	ISR	Yes – Small
σ	FSR	None
Efficiency	FSR	1.6%
Mass	FSR	Negligible
σ	Tau ID	None
Efficiency	Tau ID	2%
Mass	Tau ID	None
σ	MET – Data Mixer	None
Efficiency	MET – Data Mixer	In Progress
Mass	MET – Data Mixer	In Progress

All systematics shown on these set of tables were taken in to account when calculating the expected 95% CL in the previous slides