Status and plans of $\tau \longrightarrow 3\mu$ at CMS

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Standard model

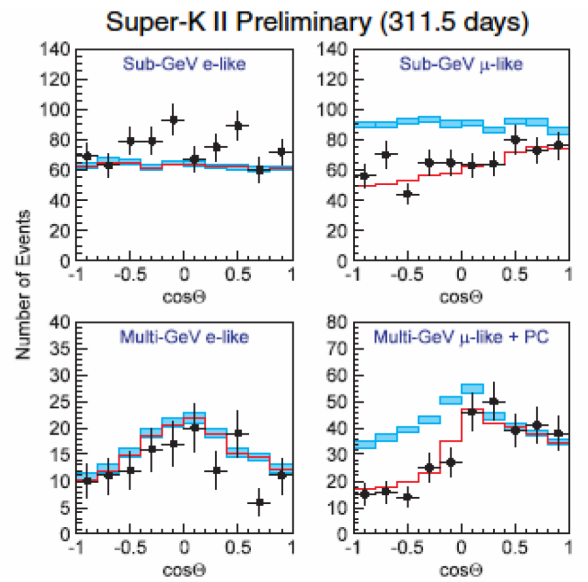
- In the Standard Model lepton numbers are conserved for each generation seperatly (lepton family number conservation)
- However there is no fundamental symmetry associated with this conservation law
- Up to now there is no evidence for LFV decays

Current limits of LFV τ-decays (PDG 2005 @ 90%CL)

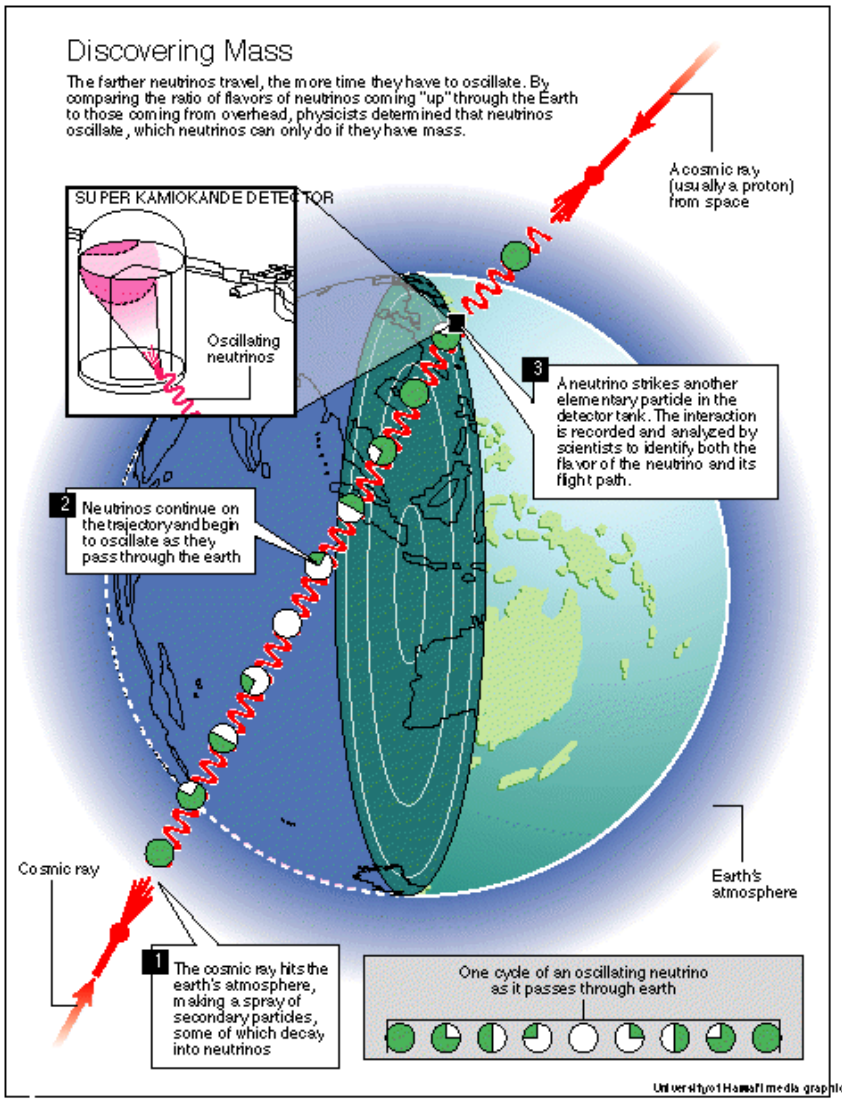
$\mathrm{BR}(\tau \longrightarrow e\gamma)$	$<$	$3{,}9 \cdot 10^{-7}$	
$\mathrm{BR}(\tau \longrightarrow \mu\gamma)$	$<$	$6{,}8 \cdot 10^{-8}$	(Newest limit of BaBar)
$\mathrm{BR}(\tau \longrightarrow e^-e^+e^-)$	$<$	$2{,}0 \cdot 10^{-7}$	
$\mathrm{BR}(\tau \longrightarrow e^-\mu^+\mu^-)$	$<$	$2{,}0 \cdot 10^{-7}$	
$\mathrm{BR}(\tau \longrightarrow e^+\mu^-\mu^-)$	$<$	$1{,}3 \cdot 10^{-7}$	
$\mathrm{BR}(\tau \longrightarrow \mu^-e^+e^-)$	$<$	$1{,}9 \cdot 10^{-7}$	
$\mathrm{BR}(\tau \longrightarrow \mu^+e^-e^-)$	$<$	$1{,}1 \cdot 10^{-7}$	
$\mathrm{BR}(\tau \longrightarrow \mu^-\mu^+\mu^-)$	$<$	$1{,}9 \cdot 10^{-7}$	

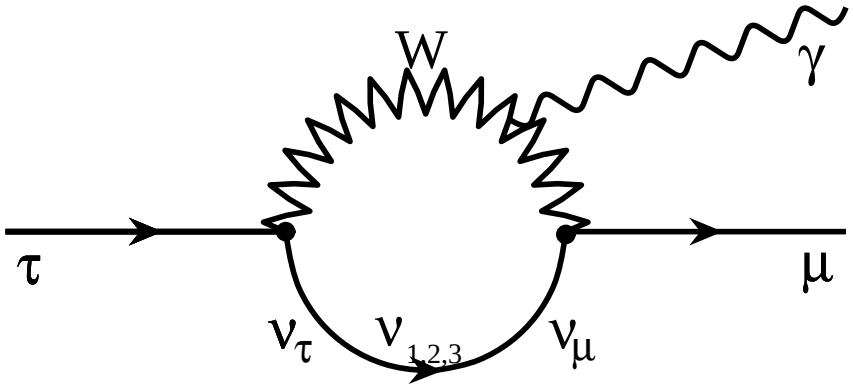
Neutrino oscillations

- Kamiokande, SNO:
  $\Rightarrow$ Neutrino oscillations
- Neutrino oscillations are violating lepton family number conservation
- Oscillation $\nu_\mu \longrightarrow \nu_\tau$ is established

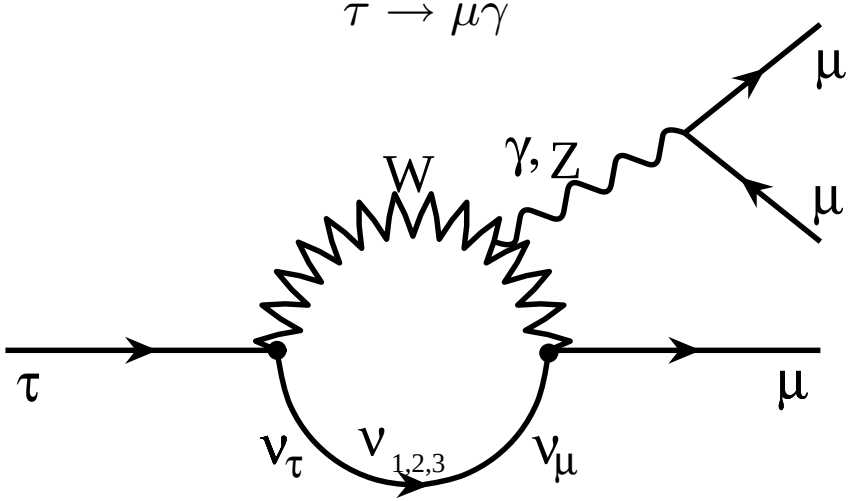


$\Rightarrow$ LFV in τ-decays is possible





$\tau \longrightarrow \mu\gamma$



$\tau \longrightarrow \mu\mu\mu$

Neutrino mixing matrix:

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \cdot \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

like CKM matrix in the quark sector.

There are 3 contributing diagrams to each process.

Standard Model + Neutrino masses

GIM mechanism in the lepton sector

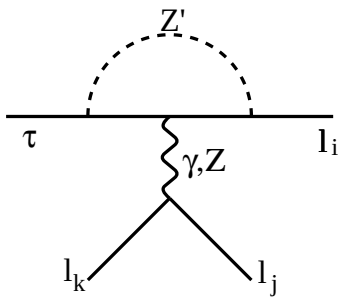
There is an almost complete cancelation of the amplitudes coming from the 3 contributing undistinguishable diagrams, due to the unitarity of the mixing matrix

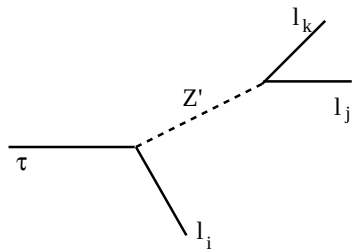
Branching ratios in the SM

- The BR in the Standard Model are therefore rather small ($O(10^{-40})$) and not measurable in current experiments

$\Rightarrow$ Observations of LFV tau decays will be an unambiguous sign of new physics.

Illustrative scenario:





LFV in new physics:

- Beyond the SM a large number of theories give rise to LFV in the range of current experimental limits
- Mass dependent couplings prefer τ-LFV with respect to lighter leptons
- $\tau \longrightarrow l\gamma$ and $\tau \longrightarrow lll$ have different sensitivity to new physics

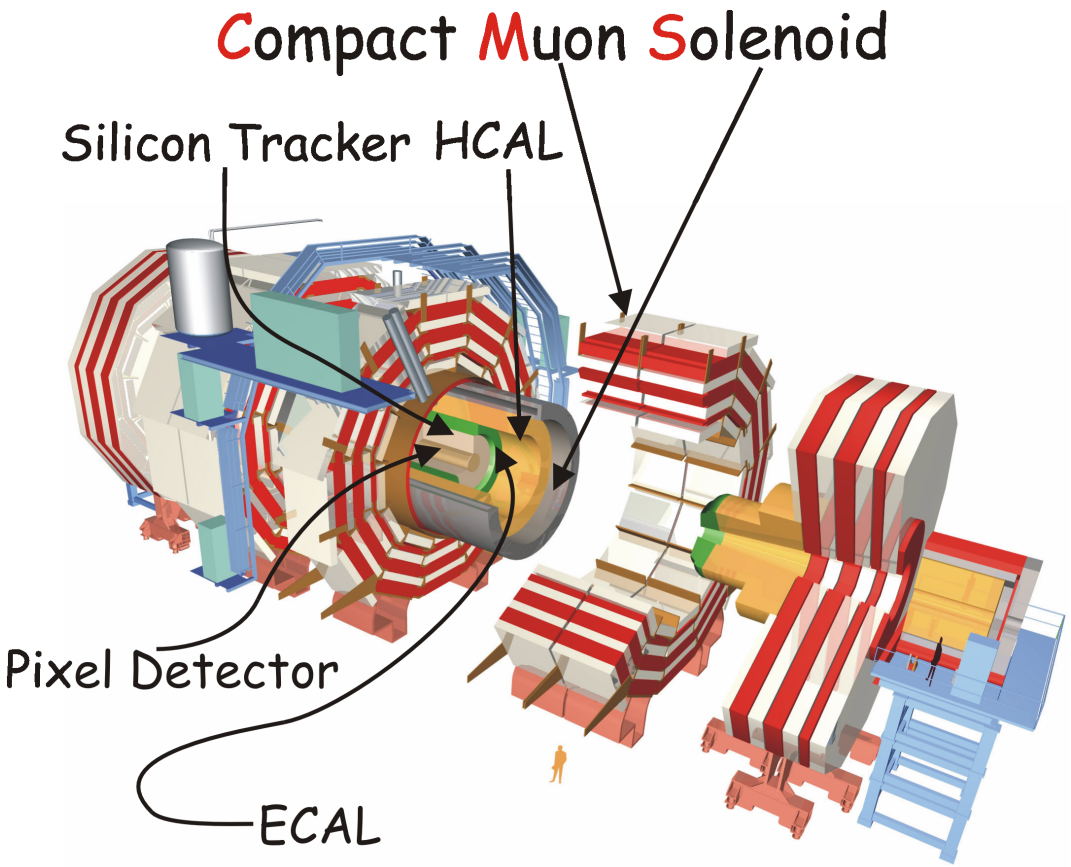
Some predictions in BSM models

	BR($\tau \longrightarrow l\gamma$)	BR($\tau \longrightarrow lll$)
mSUGRA+seesaw (EPJC14(2000)319, PRD66(2002)115013)	10^{-7}	10^{-9}
SUSY SO(10) (NPB649(2003)189, PRD68(2003)033012)	10^{-8}	10^{-10}
SUSY Higgs (PLB549(2002)159, PLB566(2003)217)	10^{-10}	10^{-7}
Non-Universal Z' (PLB547(2002)252)	10^{-9}	10^{-8}
SM+Heavy Majorana ν_R (PRD66(2002)034008)	10^{-9}	10^{-10}

Swagato Banerjee (talk at the CERN flavour workshop (11/05))

$\Rightarrow$ LFV is an interesting option in search of new physics!

The CMS detector



Well suited for studying $\tau \longrightarrow 3\mu$:

- vertexing
- large muon system

Luminosity goals:

2007:	$1\,\mathrm{fb}^{-1}/\mathrm{y}$	(initial operation)
2009:	$10 - 30\,\mathrm{fb}^{-1}/\mathrm{y}$	(low lumi)
2010:	$100 - 300\,\mathrm{fb}^{-1}/\mathrm{y}$	(high lumi)

LFV in τ-decays at CMS

Possible decay channels@low lumi

- $\tau \longrightarrow \mu\gamma$ (huge background)
- $\tau \longrightarrow \mu\mu\mu$

At high lumi?

- More pile-up
- More stringent trigger

Other LFV τ-decays like $\tau \longrightarrow e\gamma$, $\tau \longrightarrow eee$, $\tau \longrightarrow \mu ee$, $\tau \longrightarrow \mu + \text{hadrons}$ probably not detectable at CMS, but this needs to be studied.

τ-sources at the LHC (Pythia)

decay channel	$N_\tau/_y$ (low lumi)
$W \longrightarrow \tau\nu_\tau$	$1.7 \cdot 10^8$
$\gamma/Z \longrightarrow \tau\tau$	$3.2 \cdot 10^7$
$B^0 \longrightarrow \tau X$	$4.0 \cdot 10^{11}$
$B^\pm \longrightarrow \tau X$	$3.8 \cdot 10^{11}$
$B_s \longrightarrow \tau X$	$7.9 \cdot 10^{10}$
$D_s \longrightarrow \tau X$	$1.5 \cdot 10^{12}$

Trigger at CMS (L1)

- single muon $p_t > 14\,\text{GeV}$
- di-muon $p_t > 3\,\text{GeV}$

High Level Trigger (HLT)

- single muon $p_t > 19\,GeV$
- di-muon $p_t > 7\,\text{GeV}$

$\tau \longrightarrow \mu\mu\mu$ (W/Z-Source)

Older results:

CMS NOTE 2002/37
hep-ex/0210033

Expected limit:(W-Source)

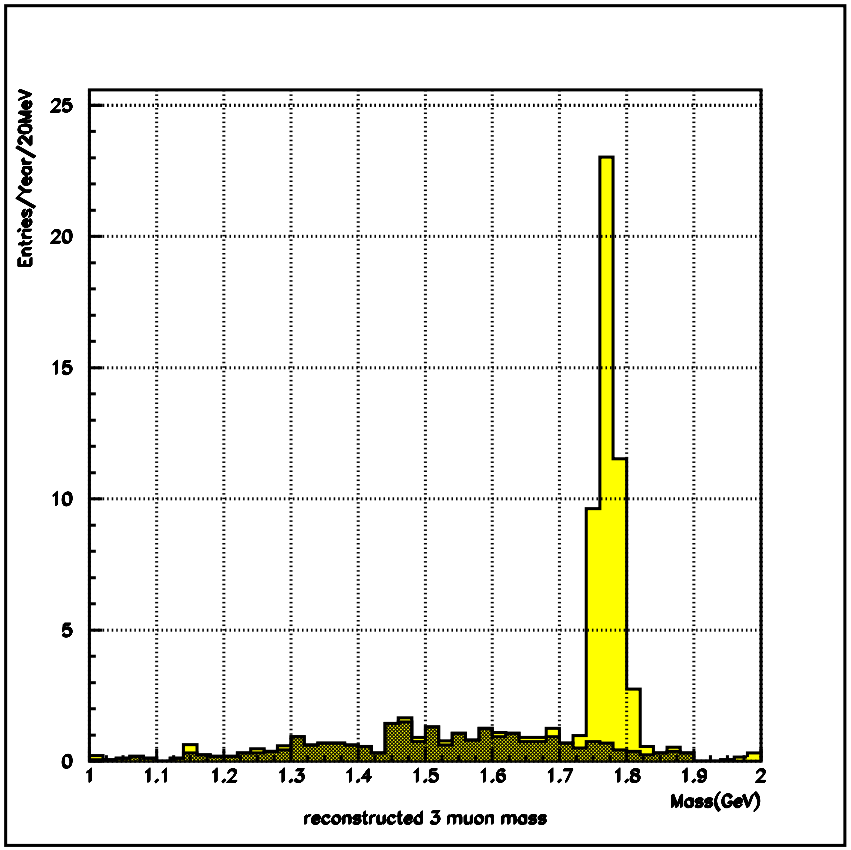
- $\mathrm{BR}(\tau \longrightarrow \mu\mu\mu) = 7.0 \cdot 10^{-8}$ $(10\,\mathrm{fb}^{-1})$
- $\mathrm{BR}(\tau \longrightarrow \mu\mu\mu) = 3.8 \cdot 10^{-8}$ $(30\,\mathrm{fb}^{-1})$

Expected limit:(Z-Source)

- $\mathrm{BR}(\tau \longrightarrow \mu\mu\mu) = 3.4 \cdot 10^{-7}$ $(30\,\mathrm{fb}^{-1})$

Prospects for analysis update:

- Now a more detailed detector and trigger simulation is available
- Rare decays to be studied with higher MC statistics



CMS NOTE 2002/037

hep-ex/0210033

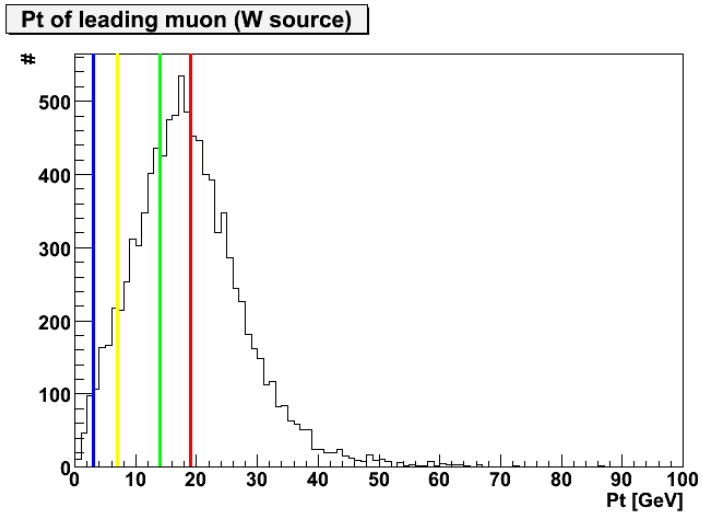
$\tau \longrightarrow \mu\mu\mu$ (W-Source)

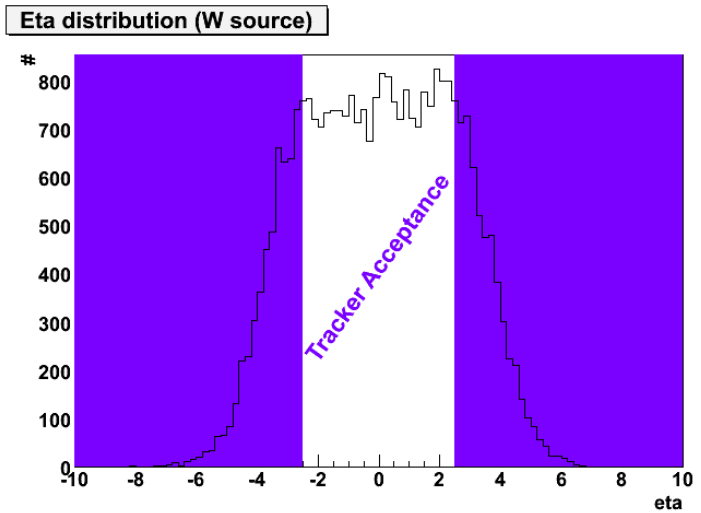
CMS Trigger L1(HLT):

- single muon $p_t > 14\,\mathrm{GeV}\,(19\,\mathrm{GeV})$
- di-muon $p_t > 3\,\mathrm{GeV}\,(7\,\mathrm{GeV})$

Signal studies so far:

- Only generator studies
- Toy MC: $\tau \longrightarrow \mu\nu_\mu\nu_\tau$ and $(\nu \longrightarrow \mu)$





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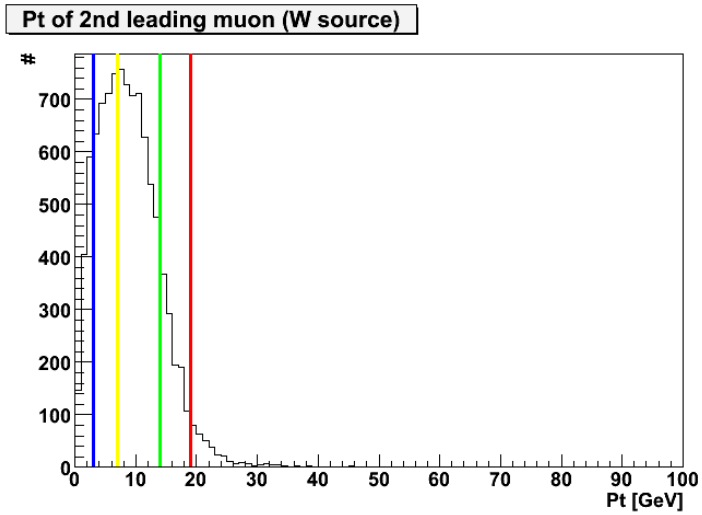

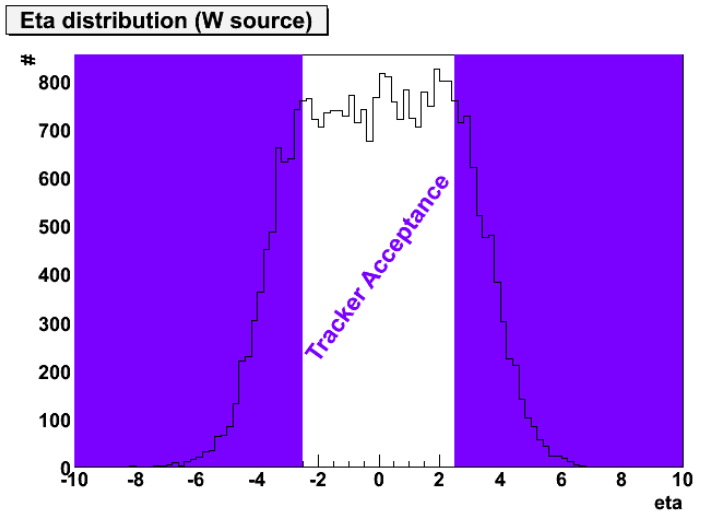

$\tau \longrightarrow \mu\mu\mu$ (D_s-Source)

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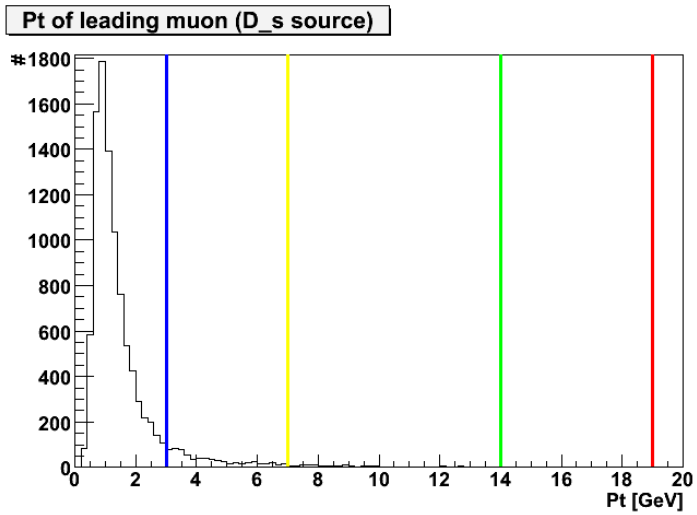
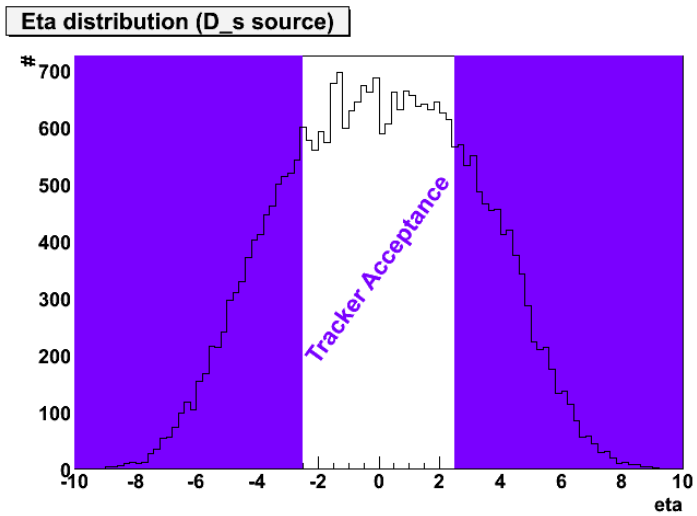
Background:

$$D_s \longrightarrow \mu\nu\phi$$
$$\phi \longrightarrow \mu\mu, \mu\mu\gamma$$

- $\phi \longrightarrow \mu\mu$: Reducible by invariant mass cut
- $\phi \longrightarrow \mu\mu\gamma$: Although BR is only 10^{-5} this is a dangerous BG (irreducible?)

The work has just begun!





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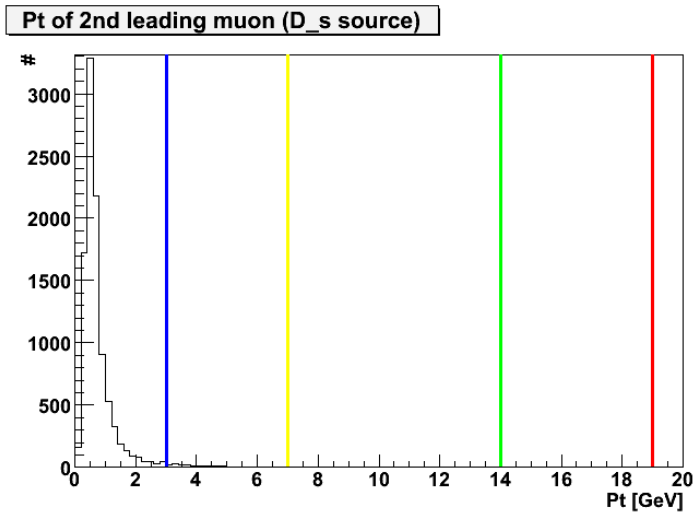

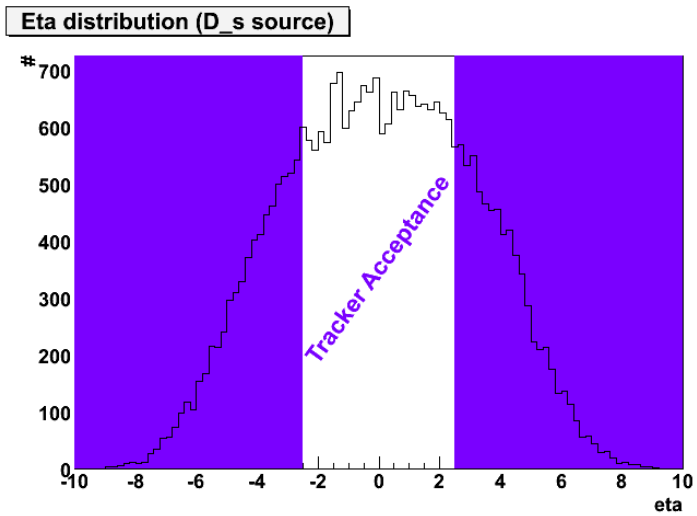

$\tau \longrightarrow \mu\mu\mu$ (B-Sources)

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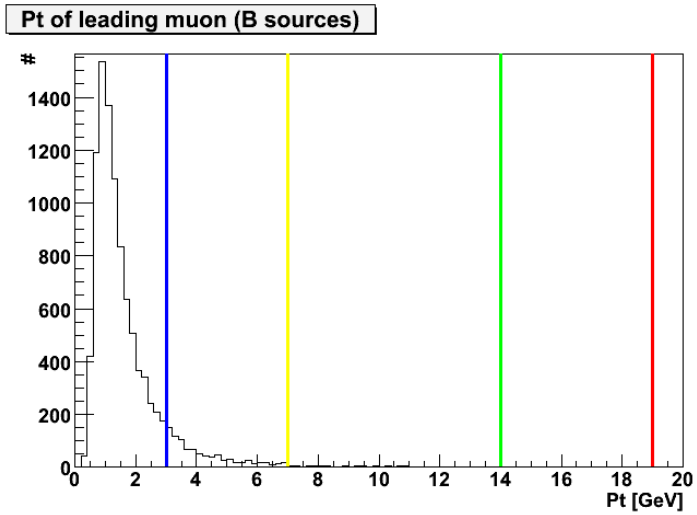

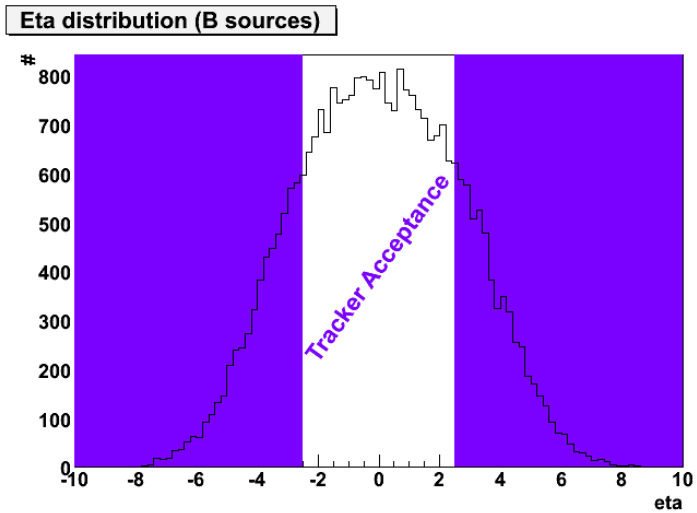

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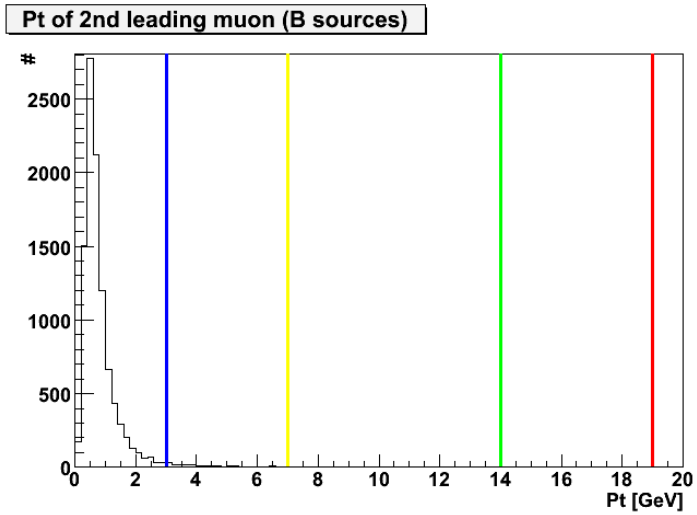

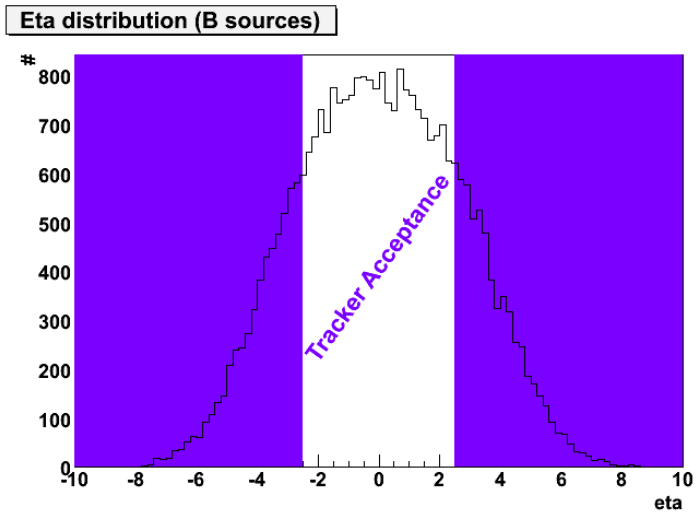

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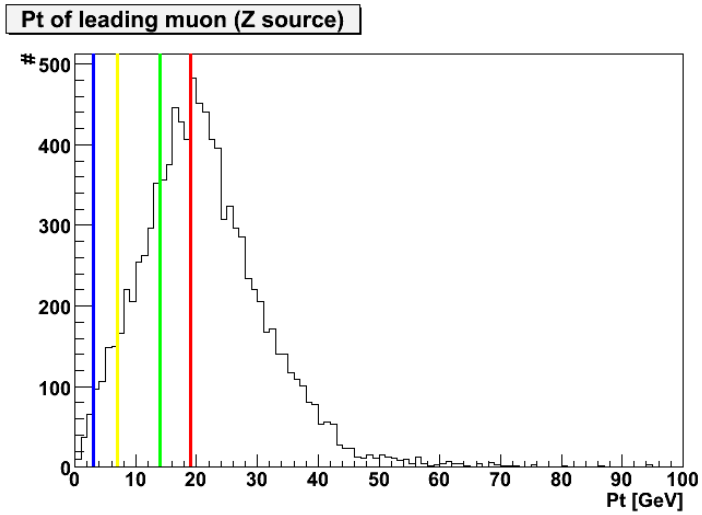

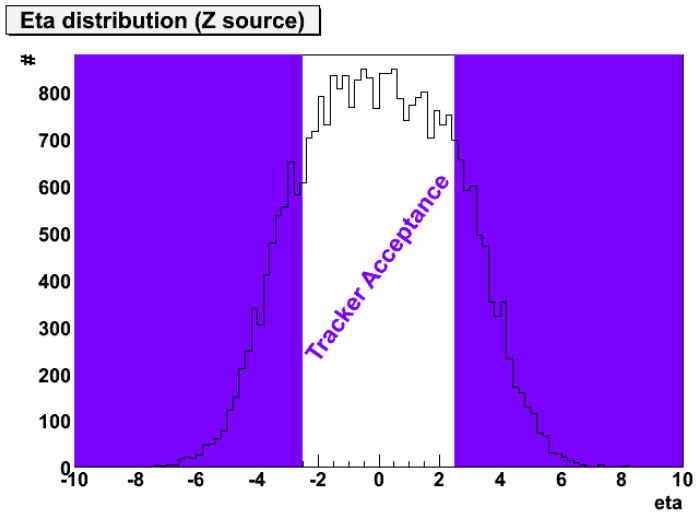

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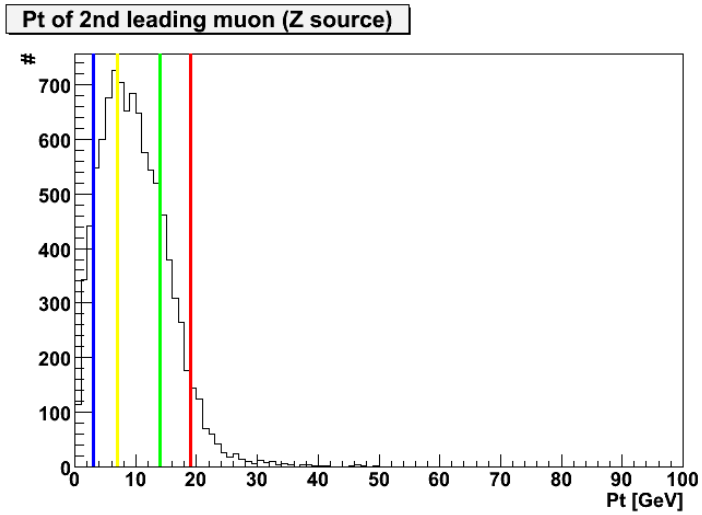

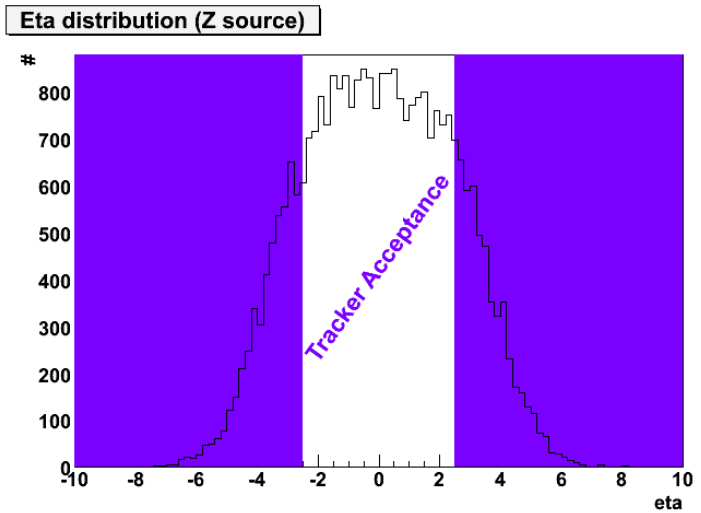

Problems & Plans

Trigger

L1:

- Completely based upon hardware
- Difficult to impossible to change trigger setup
- No major improvements possible

HLT:

- Based upon software
- Contains a veto on a third track inside a small cone around $\mu_1\mu_2$
- Perhaps a modification of trigger thresholds/veto is possible
- An invariant mass cut to reduce raising backgrounds might be applicable

$\phi \longrightarrow \mu\mu\gamma$-Background

- Maybe reducible by a cut applied to the angular distribution
- Therefore the correct angular distribution for signal (model dep.) and BG in MC is needed (Matrix elements to be implemented in Pythia?)

Other rare decays

- Other rare BGs (η, η') have to be studied as well

Muon ID

- Muon ID efficiency for low p_t muons can become an issue
- This might be solved by an alternative muon ID algorithm based upon tracker+ECAL

$\tau \longrightarrow 3\mu$ vertex fit

- Study the improvements of a $\tau \longrightarrow 3\mu$ vertex fit

- Copiuos τ-production at LHC already at low lumi phase
- Main source for τ's is $D_s \rightarrow \tau X$, but also via B, W, Z
- Dangerous $D_s \rightarrow \mu\nu\phi$, $\phi \rightarrow \mu\mu\gamma$ background
- Current CMS trigger thresholds will suppress most of the signal coming from the D_s source, some improvements possible
- Muon ID efficiency for low p_t muons to be improved

- Study (and correction) of signals(?) and $D_s \to \mu\nu\phi(\to \mu\mu\gamma)$ backgrounds angular distribution.
- Other BG rare decays with η, η' have to be studied
- Proposal for additional high level triggers to CMS
- Improvements for muon ID e.g. using tracker and ECAL
- Determination of the expected exclusion limit in the $\tau \to \mu\mu\mu$ channel
- Study the improvements of a $\tau \to 3\mu$ vertex fit
- Extend LFV studies by $Z \to \mu\tau$ (diploma thesis)
- Compatitive with B-factories, Super-B?