Search for the rare decay $D^0 \rightarrow \mu^+\mu^-$ with CMS

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On behalf of the CMS Collaboration

Overview

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- $D^0(K^-\mu^+\nu)\ \pi^+$ and $D^0(\mu^-\mu^+)\ \pi^+$ analyses
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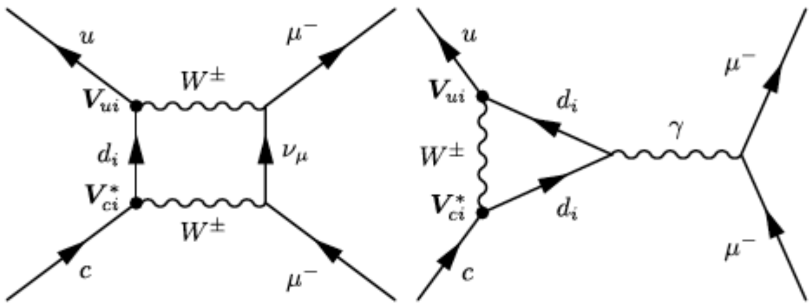
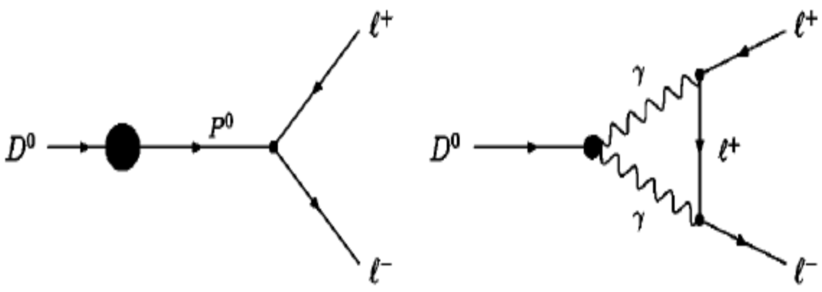
Motivation

- FCNC decay $D^0 \rightarrow \mu^+\mu^-$ is highly suppressed in SM

(~10^{-18} from short-distance, increasing to ~10^{-13} when long-distance processes are included, [Burdnam et al.,Phys.Rev.D66:014009,2002])





short-distance **long-distance**

New Physics models, however, can enhance these estimates by several orders of magnitude. LHC experiments have the possibility to detect this rare decay mode. Furthermore, as charm is an up-type quark, the search for FCNC in the charm sector is complementary to B and K decay searches.

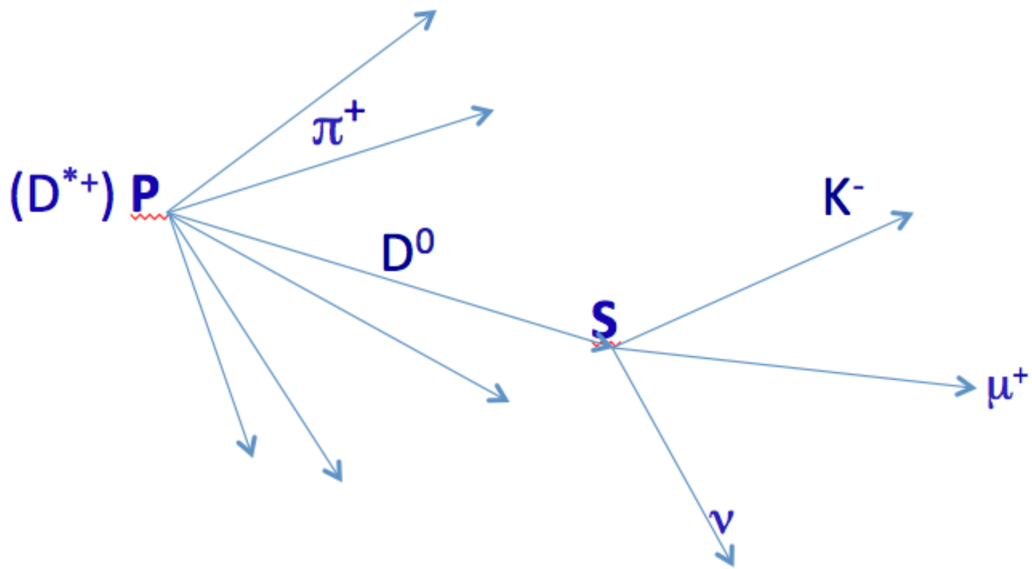
Strategy

- the strategy of the analysis is to measure the ratio of branching fractions in such a way that most of the systematic uncertainties cancel out
- determination of the branching fraction $D^0 \to \mu^+\mu^-$ by means of the ratio:

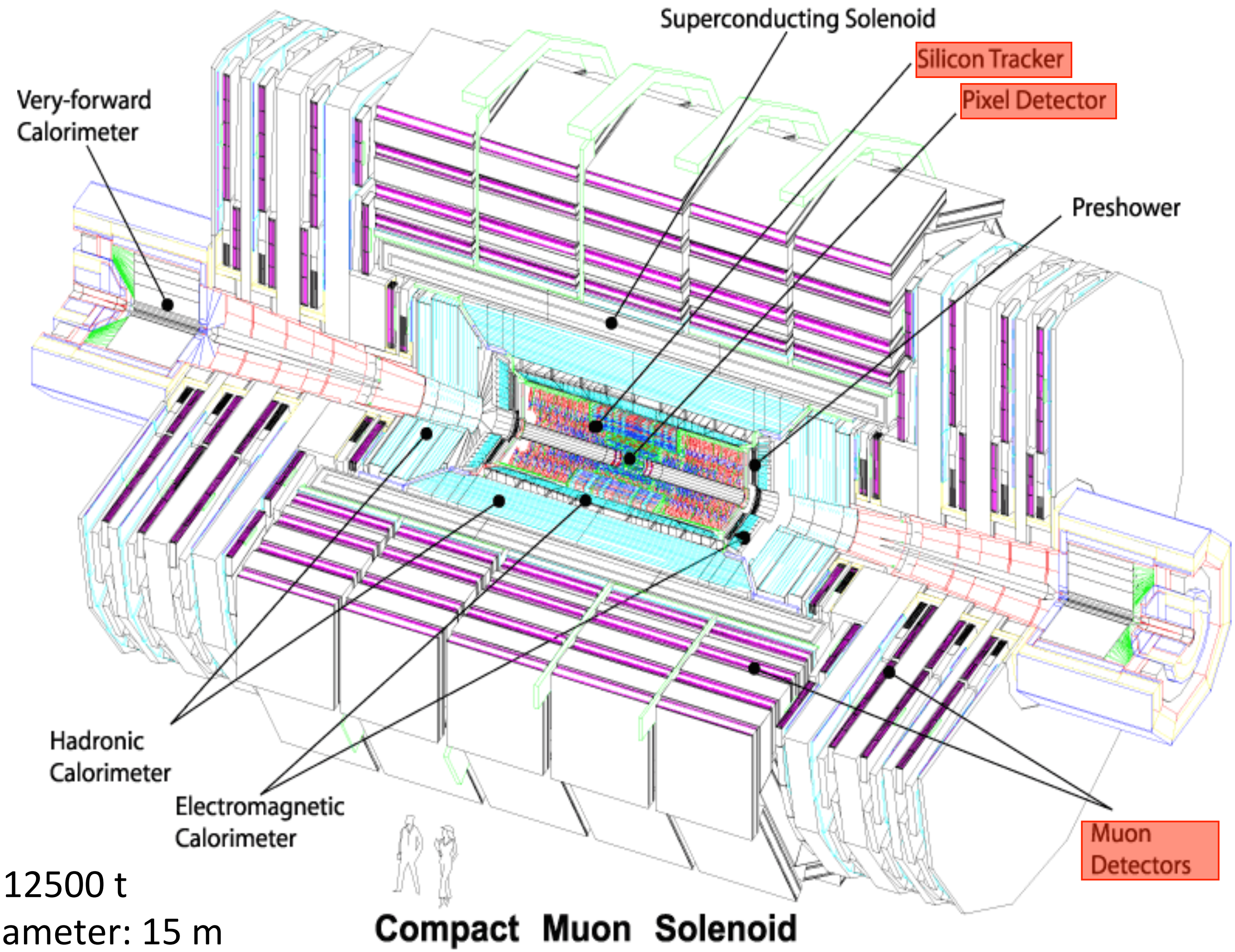
  $$D^{*+} \to D^0(\mu^-\mu^+)\,\pi^+ \,/\, D^{*+} \to D^0(K^-\mu^+\nu)\,\pi^+$$
- but is it possible to study charm physics in CMS? The problem is linked to the enormous trigger rate of charm particles. The major part of the charm particles produced are discarded.
- the detection of a decay mode into two muons, like $D^0 \to \mu^-\mu^+$, is feasible in CMS, **the real problem is to reveal the normalization mode** (single muon trigger). The semileptonic decay $D^0 \to K^-\mu^+\nu$ was chosen to minimize the differences at the trigger level.

$D^0 \rightarrow K^- \mu^+ \nu$ and $D^0 \rightarrow \mu^- \mu^+$ analyses

Both analyses are topological: determination of a primary and of a secondary vertex.
Then using of the technique described by E691 [Phys.Rev.Lett.62:1587 (1989)], the cascade decay $D^{*+} \rightarrow D^0(K^- \mu^+ \nu)\, \pi^+$ is reconstructed (if the D^0 direction is measured with sufficient precision).



CMS – Compact Muon Solenoid



Weight = 12500 t
Overall diameter: 15 m
Overall length: 21.6 m
Solenoid B = 3.8 T

$D^0 \rightarrow K^- \mu^+ \nu$ and $D^0 \rightarrow \mu^- \mu^+$ analyses

- very tight cuts on muons (excellent p_T resolution and efficiency, large pseudorapidity coverage)
- tight cuts on kaon
- soft cuts on pion
- CL of primary vertex > 1%
- CL of secondary vertex > 1%
- for $D^0 \rightarrow \mu\mu$ analysis: D^0 pointing back to the primary
- L/S cut, that is the 3D-detachment between the primary and secondary vertices divided by its error (L/S > 3)
- D^0 candidate is combined with one track originating from the primary vertex to form D^{*+}

The only difference between the two analysis ($\mu^- \mu^+$ and $K^- \mu^+ \nu$) is that in one case there is a muon and in the other a kaon.

$D^0 \to K^- \mu^+ \nu$ and $D^0 \to \mu^- \mu^+$ analyses

DATA: pp collisions at √s = 7 TeV, integrated luminosity ≈ 90 pb^{-1}

2010 Run: all data collected with unprescaled single muon trigger, p_T increased 6 times from 3 to 15 GeV/c

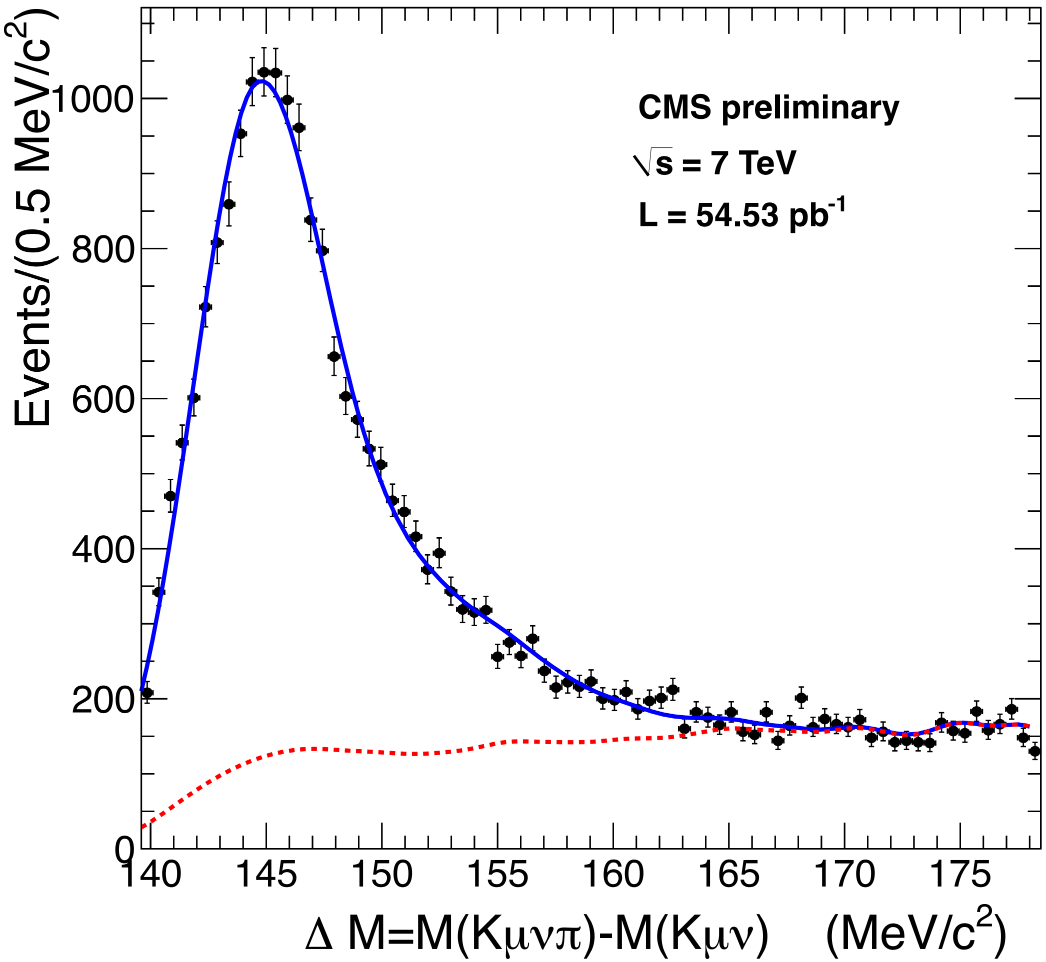
2011 Run: 54 pb^{-1} collected with unprescaled muon trigger, p_T > 15 GeV/c

The total sample is divided, therefore, in 7 periods.

Period	Muon p_T cut	Luminosity (pb-1)
1	p_T > 3 GeV/c	0.086
2	p_T > 5 GeV/c	0.206
3	p_T > 7 GeV/c	2.87
4	p_T > 9 GeV/c	5.31
5	p_T > 11 GeV/c	10.21
6	p_T > 15 GeV/c	17.15
7	p_T > 15 GeV/c	54.53

$D^{*+} \rightarrow D^0(K^-\mu^+\nu)\,\pi^+$ analysis

The 7th period with more statistics:



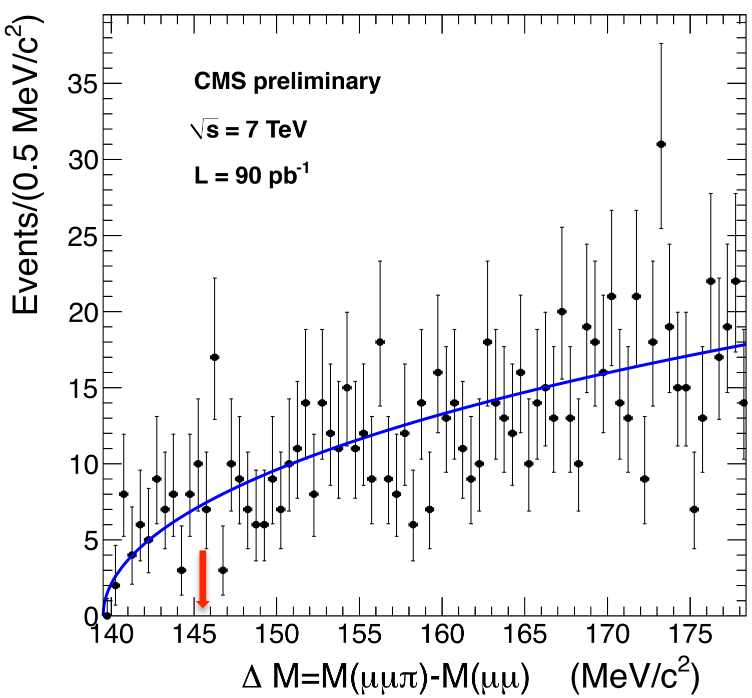
The superimposed fit to the unbinned data consists of two Gaussians with the same mean plus a background function modeled by the Data (Wrong Sign sample).

$\text{Yield}(D^{*+} \rightarrow D^0(K^-\mu^+\nu)\,\pi^+) = 16458 \pm 204$ candidates

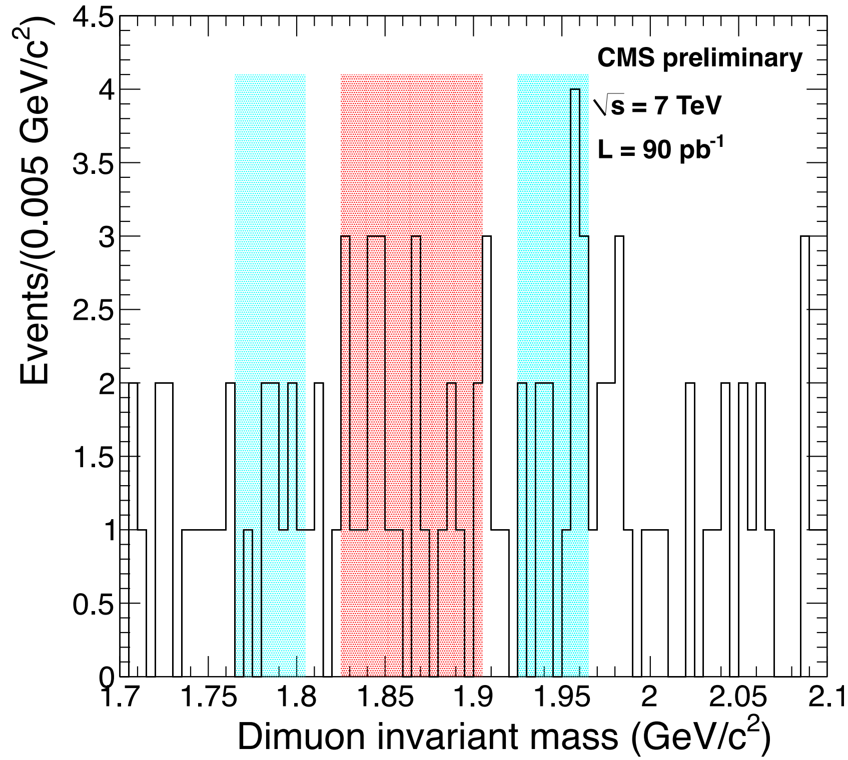
$D^{*+} \rightarrow D^0(\mu^-\mu^+)\,\pi^+$ analysis

All periods added together

$D^{*+} \rightarrow D^0(\mu^-\mu^+)\,\pi^+$



$M(\mu^-\mu^+)$ requiring $|\Delta M - \Delta M_{PDG}| < 3$ MeV



$F(\Delta M) = P3 \times [(\Delta M - M_\pi)^{**}1/2 + P4 \times (\Delta M - M_\pi)^{**}3/2]$,
function used to model the background.

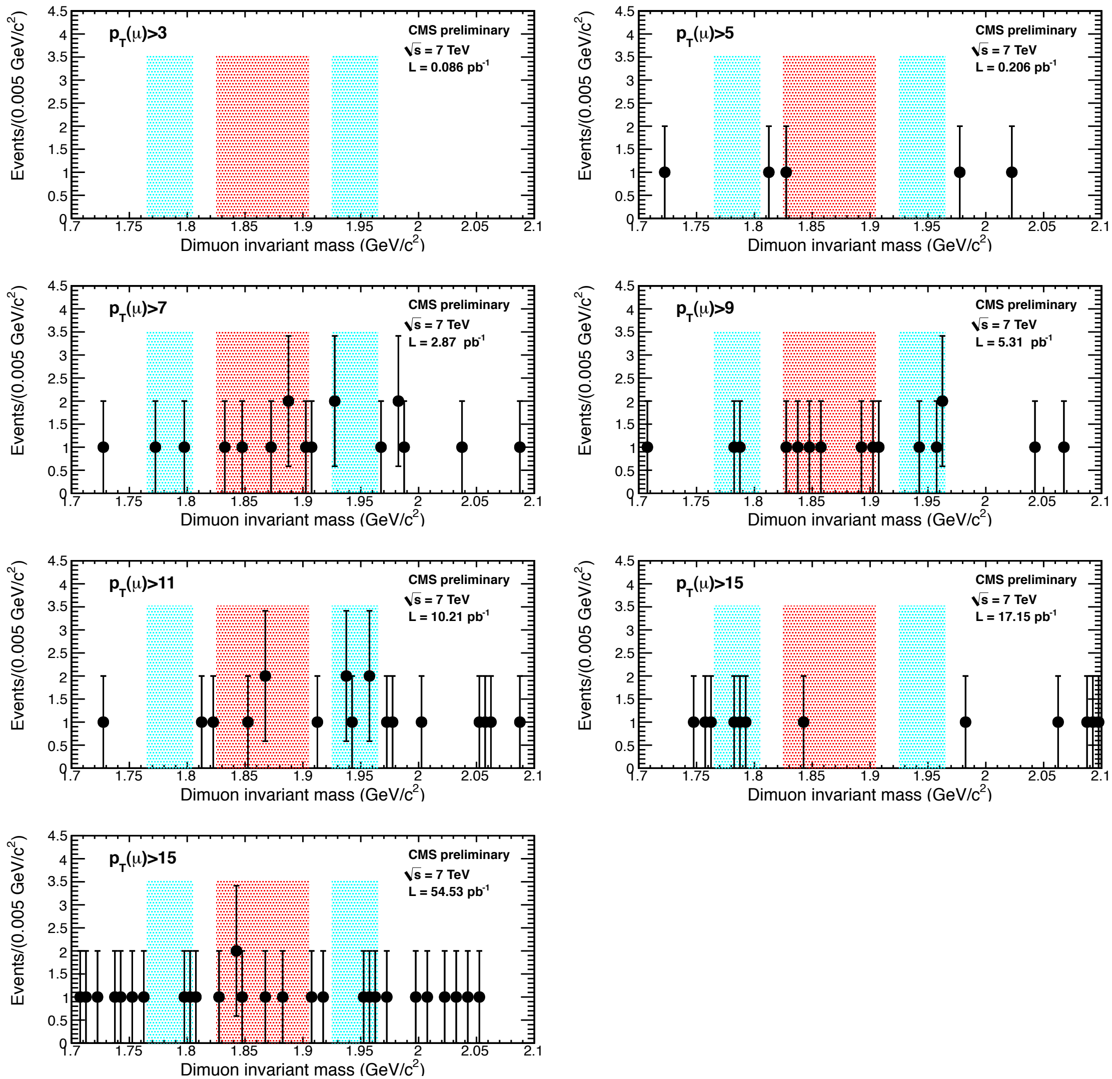
N_{obs} = 23 events (signal region)

N_{bkg} = 23 events (sidebands)

No evidence of $D^0 \rightarrow \mu^-\mu^+$ from D^{*+}.

$D^{*+} \rightarrow D^0(\mu^-\mu^+)\, \pi^+$ analysis

Events in dimuon mass window requiring $|\Delta M-\Delta M_{PDG}|< 3$ MeV for each trigger period



No evidence of $D^0 \rightarrow \mu^-\mu^+$ from D^{*+}.

Estimate of background for N($\mu\mu$)

Since there is no clear evidence of $D^0 \rightarrow \mu^-\mu^+$ the upper limit on N($\mu\mu$) is determined assuming that the number of events found in the signal region is the sum of signal and background events (both obeying Poisson statistics).

One possible contamination is a peaked contribution from $D^0 \rightarrow \pi^- \pi^+$. In CMS the π-μ misidentification (very tight cuts) has been determined from Data [CMS PAS MUO-10-002] $\sim 10^{-4} \rightarrow 10^{-5}$ events. (the effect of this contamination is therefore negligible for this analysis)

From the previous plots it is clear that a linear assumption for the background is enough to describe the background. Therefore an estimate of the background is made from the sidebands.

Upper limit on $D^0 \rightarrow \mu^+\mu^-$

$B(D^0 \rightarrow \mu^+\mu^-) \leq B(D^0 \rightarrow K^-\mu^+\nu) \times N_{Data}(\mu\mu)/N_{Data}(K\mu\nu) \times$
$a(K\mu\nu)/a(\mu\mu) \times \varepsilon_{trig}(K\mu\nu)/\varepsilon_{trig}(\mu\mu) \times$
$\varepsilon_{rec}(K\mu\nu)/\varepsilon_{rec}(\mu\mu)$

$B(D^0 \rightarrow K^-\mu^+\nu) = (3.30 \pm 0.13) \times 10^{-2}$ (PDG 2010)

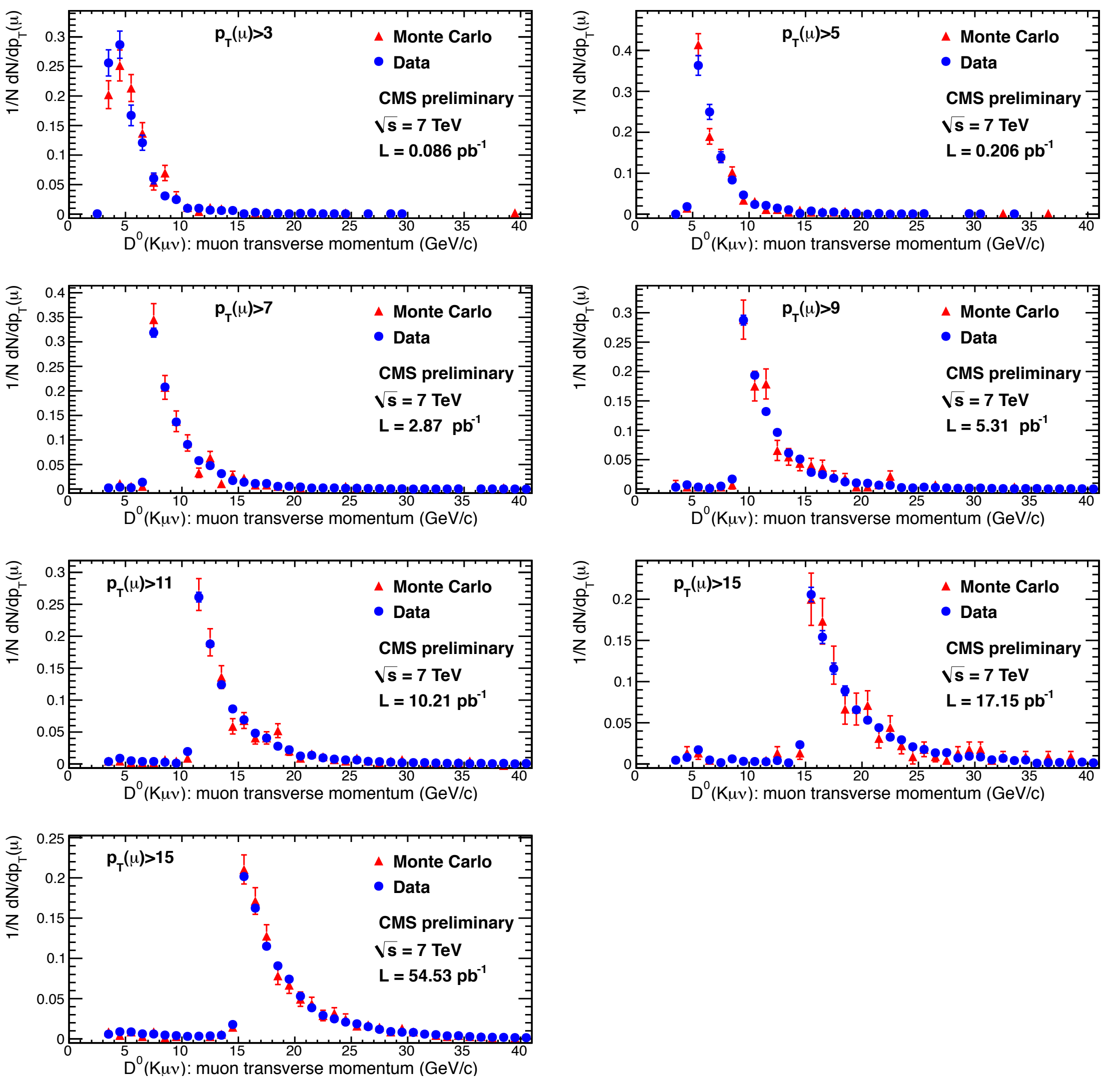
From Monte Carlo:

$a(K\mu\nu)/a(\mu\mu)$

$\varepsilon_{trig}(K\mu\nu)/\varepsilon_{trig}(\mu\mu)$

$\varepsilon_{rec}(K\mu\nu)/\varepsilon_{rec}(\mu\mu)$

Comparison Data versus Monte Carlo
Muon p_T in the 7 periods



The 7 periods are simulated with the corresponding trigger tables and run conditions, including simulation of the pile-up.

The determination of the relative efficiencies and acceptances are well understood because the important underlying kinematic distributions agree between Data and MC.

Systematic uncertainties

It is a ratio of Branching fractions, therefore most of the systematics cancel out. Systematic error linked to the production mechanism are, for construction, eliminated because what is computed is the quantity

$$D^{*+} \rightarrow D^0(\mu^-\mu^+)\,\pi^+ \,/\, D^{*+} \rightarrow D^0(K^-\mu^+\nu)\,\pi^+$$

Each term in the master formula can be a source of systematic uncertainty.

Source	Fraction
$a(K\mu\nu)/a(\mu\mu)$	0.3%
ε_{trig}	13.1%
$\varepsilon_{rec}(K\mu\nu)/\varepsilon_{rec}(\mu\mu)$	5%->12% (periods)
$\varepsilon_{rec}(K)$	3.9%
$\varepsilon_{rec}(\mu)$	1.0%
Yield($K\mu\nu$), fit variant	1%->9% (periods)
$D^0 \rightarrow K^{*-}(K^-\pi^0)\mu^+\nu$	1.8%
$B(D^0 \rightarrow K^-\mu^+\nu)$	3.9%
Total uncertainty	15%->19% (periods)

Determination of upper limit using CLs

The 90% confidence level upper limit is computed using the CLs approach combining the results of the 7 periods.

Period	$Y(D^0 \to K^- \mu^+ \nu)$	Nobs, Nbkg	syst. uncert.
1	2412 ± 145	0, 0	19.1%
2	2447 ± 357	1, 0	18.0%
3	11799 ± 215	6, 4	19.0%
4	9982 ± 176	6, 6	17.4%
5	10079 ± 185	3, 5	16.4%
6	5302 ± 118	1, 3	17.9%
7	16458 ± 204	6, 5	15.6%

Results from CLs:

$$B(D^0 \to \mu^+ \mu^-) \leq \mathbf{5.4 \times 10^{-7}} \text{ (at 90\% CL)}$$

Conclusions

With $\approx 90\ pb^{-1}$ (2010 and initial period of 2011 Data) an upper limit for the Branching Fraction $B(D^0 \rightarrow \mu^+\mu^-)$ is determined.

This result is shown in the following table where is compared to the present best limits:

Experiment	Upper limit at 90% CL
BABAR	$< 1.3 \times 10^{-6}$
CDF	$< 2.1 \times 10^{-7}$
BELLE	$< 1.4 \times 10^{-7}$
this analysis	$< 5.4 \times 10^{-7}$

Although this upper limit is not the best limit for this FCNC decay, it is the first time a semileptonic decay is used as normalization decay mode.

Backup slides

Comparison Data versus Monte Carlo Number of primary vertices

Trigger	Data average #	MC average #
HLT_Mu3 (2010)	<1.7>	<1.7>
HLT_Mu5 (2010)	<1.7>	<1.7>
HLT_Mu7 (2010)	<1.9>	<2.0>
HLT_Mu9 (2010)	<2.4>	<2.5>
HLT_Mu11 (2010)	<2.4>	<2.5>
HLT_Mu15 (2010)	<2.9>	<3.0>
HLT_Mu15 (2011)	<5.5>	<5.3>