Very Rare and Multibody Charm Decays At LHCb

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(On behalf of the LHCb charm group)

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Overview

- **Thanks to large cross sections, LHCb can reconstruct very large charm decay yields.**
- **The tiny CPV or the BF of very rare decays might be reachable.**

What do we have or expect in the months to come ?

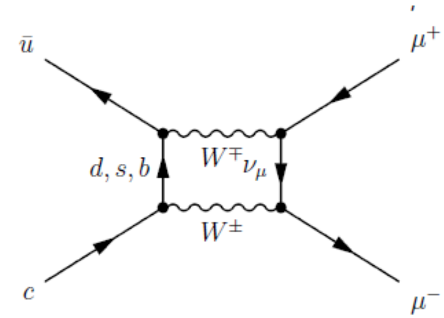
- **Rare Charm Decays**
  - **Motivations**
  - **$D^0 \to \mu\mu$ (Winter conf.)**
  - **Expectations for $D \to h\mu\mu$ and $D \to hh\mu\mu$**

$$\sigma(D^0) = 1488 \pm 41 \pm 34 \pm 174\,\mu b = 1488 \pm 182\,\mu b$$
$$\sigma(D^{*+}) = 676 \pm 64 \pm 21 \pm 119\,\mu b = 676 \pm 137\,\mu b$$
$$\sigma(D^+) = 717 \pm 39 \pm 26 \pm 98\,\mu b = 717 \pm 109\,\mu b$$
$$\sigma(D_s^+) = 194 \pm 23 \pm 16 \pm 26\,\mu b = 194 \pm 38\,\mu b\ .$$

- **Multibody Decays**
  - **Motivations**
  - **$D^+ \to K^- K^+ \pi^+$ (from 2010 data)**
  - **Expectations for $D^+ \to 3h$, $D^0 \to 4h$**

$D^0 \rightarrow \mu\mu$

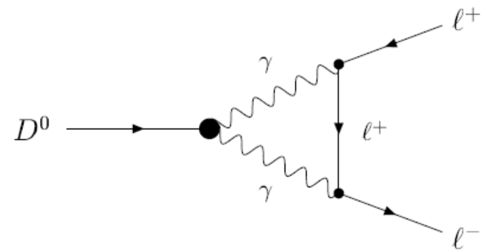
$D^0 \to \mu\mu$



- **In the SM, BF dominated by Long Distance (LD) contributions. Quite reliably estimated via:**

$$\mathcal{BR}^{(\gamma\gamma)}(D^0 \to \mu^+\mu^-) \simeq 2.7 \times 10^{-5}\mathcal{BR}(D^0 \to \gamma\gamma)\,.$$

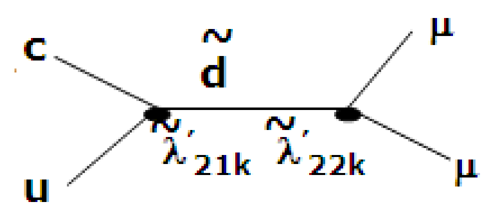
$$\mathcal{BR}^{SM}(D^0 \to \mu^+\mu^-) \gtrsim 10^{-13}$$



- **A variety of NP scenarios[1] on the market**
  - Loop amplitudes (4th quark generation, RPV-SUSY,…)
  - Tree level amplitudes (Heavy vector-like quarks, New Z′ bosons, RPV-SUSY)

- **NP up to ~10^{-9} with RPV-SUSY tree level transitions**

$$\mathcal{BR}^{\not R_p}_{D^0\to\mu^+\mu^-} \simeq 4.8\times 10^{-7} x_D \left(\frac{300\ \text{GeV}}{m_{\tilde{d}_k}}\right)^2 \leq\ 4.8\times 10^{-9}\left(\frac{300\ \text{GeV}}{m_{\tilde{d}_k}}\right)^2$$



Constraints from the D0 mixing

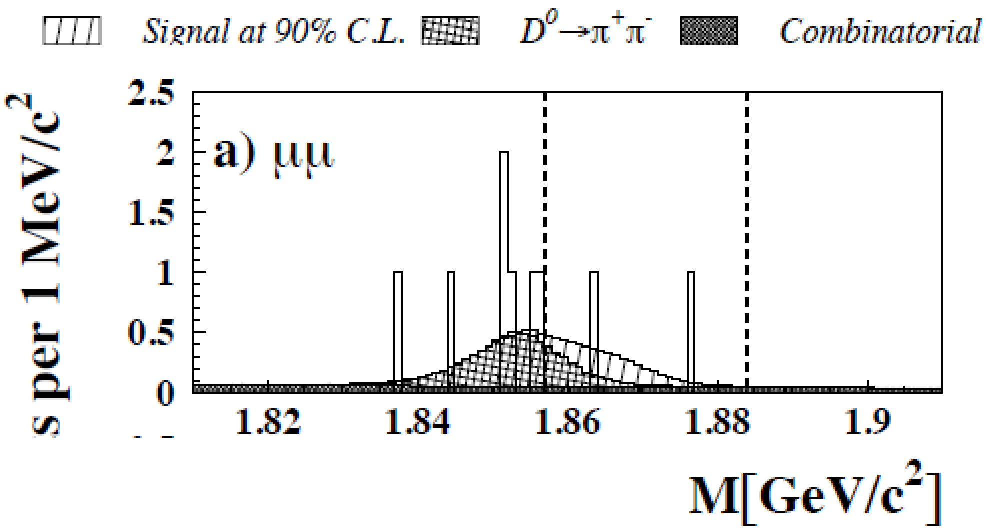
[1] see:

G. Burdman, E. Golowich, J. L. Hewett, and S. Pakvasa, "Rare Charm Decays in the Standard Model and Beyond", *Phys. Rev.* D66 (2002) 014009, arXiv:hep-ph/0112235.

E. Golowich, J. Hewett, S. Pakvasa, and A. A. Petrov, "Relating $D^0-\bar{D}^0$ Mixing and $D^0 \to l^+l^-$ with New Physics", *Phys. Rev.* D79 (2009) 114030, arXiv:0903.2830 [hep-ph].

$D^0 \to \mu\mu$: previous searches

- **Belle, 660 fb^{-1}** *(Petric & al, arXiv:1003.2345)*
- **$D^0 \to \mu\mu$ searched for in the decay of a D^*, normalized to $D^0 \to \pi\pi$**



$$\mathcal{B}\left(D^0 \to \mu^+\mu^-\right) < 1.4 \times 10^{-7}$$

D→μμ at LHCb

Measurement relative to the $D^0 \to \pi\pi$ channel (as Belle)

$$\mathcal{B}(D^0 \to \mu^+\mu^-) = \frac{\boxed{N_{D^{*+}\to D^0(\to\mu^+\mu^-)\pi^+}}}{\boxed{N_{D^{*+}\to D^0(\to\pi^+\pi^-)\pi^+}}} \frac{\varepsilon_{\pi\pi}}{\boxed{\varepsilon_{\mu\mu}}} \cdot \mathcal{B}(D^0 \to \pi^+\pi^-)$$

Need low backgrounds…

- →**Low π-μ misID rate(<1%)**
- →**Keep D→ππ quiet although B(ππ)/B(μμ)>10^5**
- →**Combinatorial high in pp collisions.**

… and high efficiency….

- →**Good muon-ID**
- →**Very efficient muon trigger (>90%)**

… and large yields.

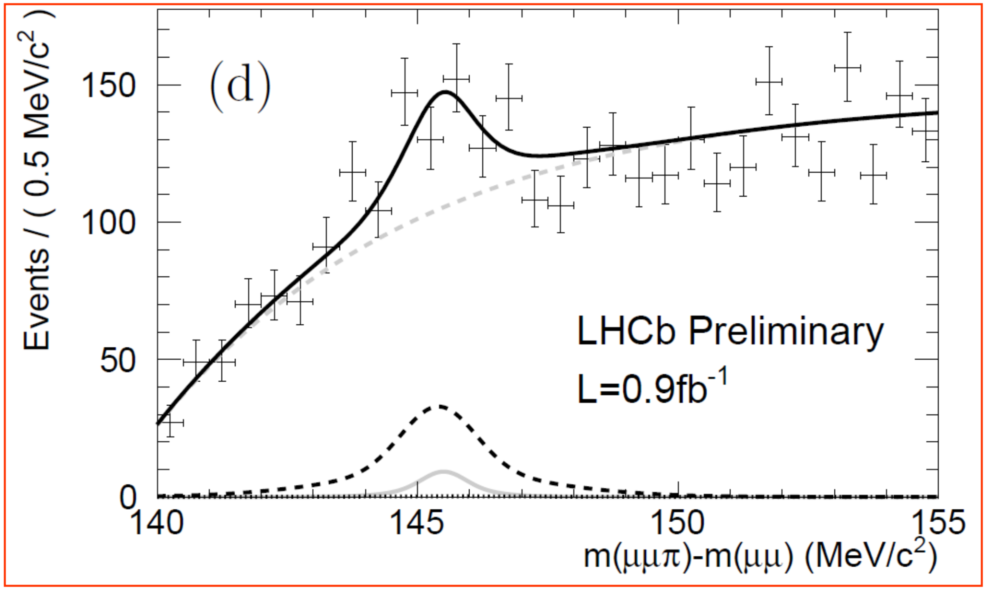
- →**Large X-sections: $\sigma(D^{*+})$= 676±137 μb**
- →**Can use D* and still have large yields**

… and everything precisely known !

- →**Easy to have large control samples: D→Kπ for (efficiency and misID rate), J/psi(μμ) (trigger and muID efficiency), etc…**
- → **All stored thanks to a flexible trigger (many channels, prescales, etc…)**

D→μμ

CERN-LHCb-CONF-2012-005



Comb. background:

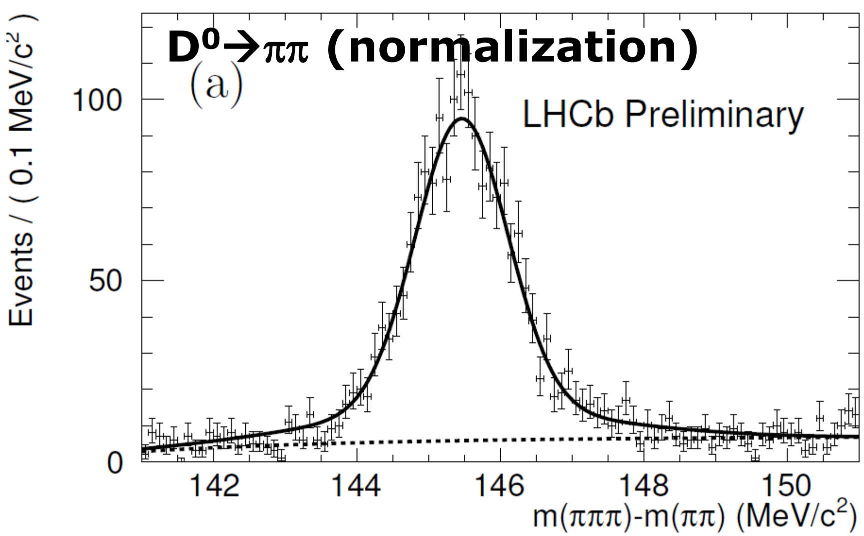
Reduced by Boosted Decay Tree (PT's + topology).

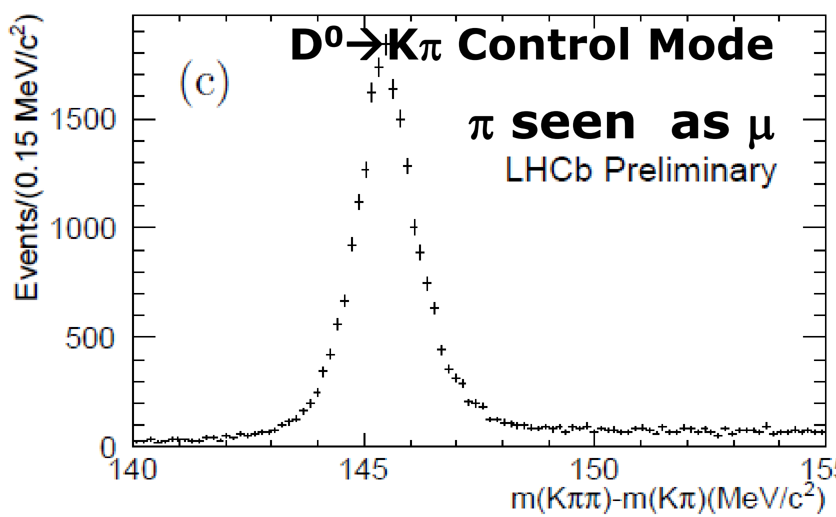
Peaking backgrounds (D→ππ)

Muon ID.

Fitted & controlled using D→Kπ with π⇔μ

Signal





$D \to \mu\mu$

- **Single event sensitivity**

Quantity	Value
$N^{sig}_{D^0 \to \pi^+\pi^-}$	1710 ± 47
$\varepsilon_{trig}(\pi\pi)$	$(13.96 \pm 1.24)\%$
$\varepsilon_{trig}(\mu\mu)$	$(82.54 \pm 3.13)\%$
$\frac{\varepsilon_{sel}(\pi\pi)}{\varepsilon_{sel}(\mu\mu)}$	0.95 ± 0.06
Prescale on $D^0 \to \pi^+\pi^-$	0.0015
$\mathcal{B}(D^0 \to \pi^+\pi^-)$	$(1.397 \pm 0.026) \cdot 10^{-3}$
α	$(1.96 \pm 0.23) \cdot 10^{-10}$

- **Yields**

Channel	Fitted value
$D^{*+} \to D^0(\to \pi^+\pi^-)\pi^+$	204 ± 33
$D^{*+} \to D^0(\to \mu^+\mu^-)\pi^+$	$(0.49 \pm 0.42) \cdot 10^{-8}$
$D^{*+} \to D^0(\to K^-\pi^+)\pi^+$	380.3 ± 34.1
Comb. background	7439.6 ± 95.9

$$\boxed{\mathcal{B}(D^0 \to \mu^+\mu^-) < 1.3\ (1.1) \cdot 10^{-8} \quad \text{at } 95\ (90)\%\text{CL}}$$

LHCb Preliminary

One order of magnitude below Belle.

D→μμ

$$\boxed{\mathcal{B}(D^0 \to \mu^+\mu^-) < 1.3\ (1.1) \cdot 10^{-8} \quad \text{at } 95\ (90)\%\text{CL}}$$

LHCb Preliminary

- **Will be updated for ICHEP**
  - **Same sample**
  - **Improved slow π reconstruction to get an better m(πμμ)-m(μμ)**

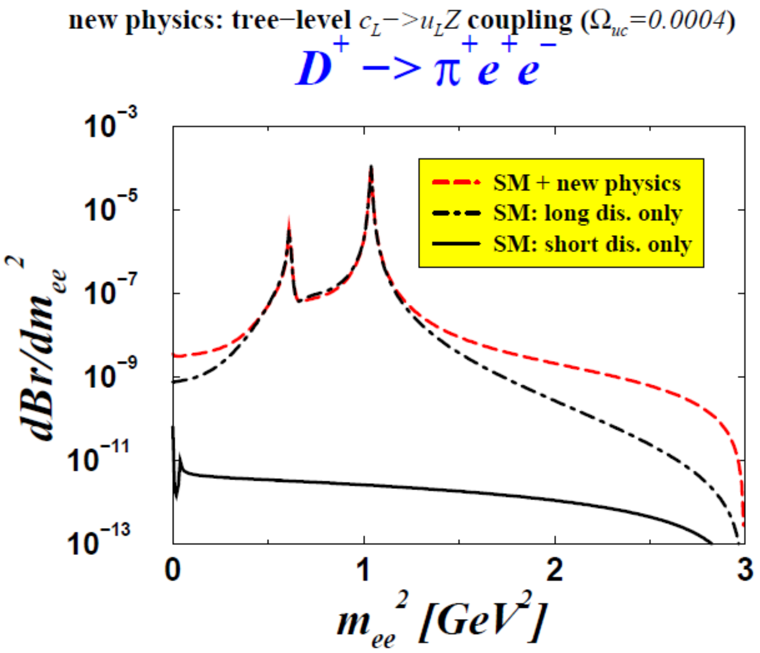
- **Longer term**
  - **Statistics will bring the limit down (End 2012: ~2.5fb^{-1} ; 2016 ~5fb^{-1})**
  - **More work/experience will improve the analysis (ex: mu-ID)**

→ Expect 90% CL limit around $5{\times}10^{-9}$ in the coming years.

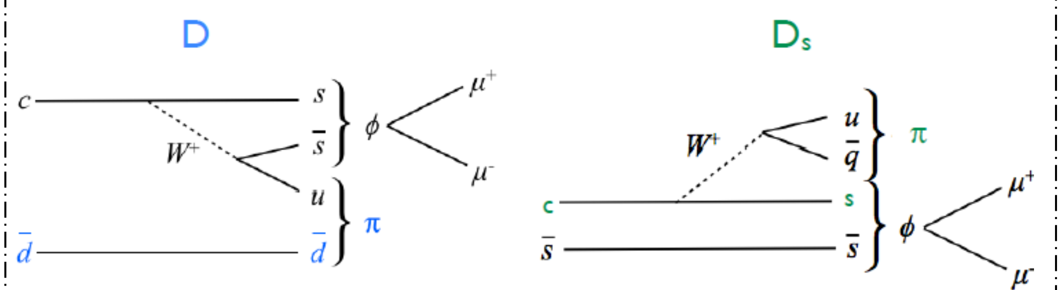
$D^{+}_{(s)} \rightarrow \pi^{+}/K^{+} \mu\mu$

$D^+_{(s)} \to h^+\mu^+\mu^-$

- **Short distance contributions very suppressed in the SM.**
- **Dominated by resonant Long Distance contributions.**
- **NP could change that (again a variety of models [1])**



SM LD ~ 2×10^{-6}



SM SD~10^{-11}

NP up to 10^{-8} ?

[1] see

-[1] Artuso & al, arXiv:0801.1833v1
-[2] Fajfer & al, arXiv:0706.1133v2, Fajfer & al, arXiv:hep-ph/0511048v2

$D^+_{(s)} \rightarrow h^+\mu^+\mu^-$

- **Present experimental status**

DØ: BF < 3.9×10^{-6} (90% CL)

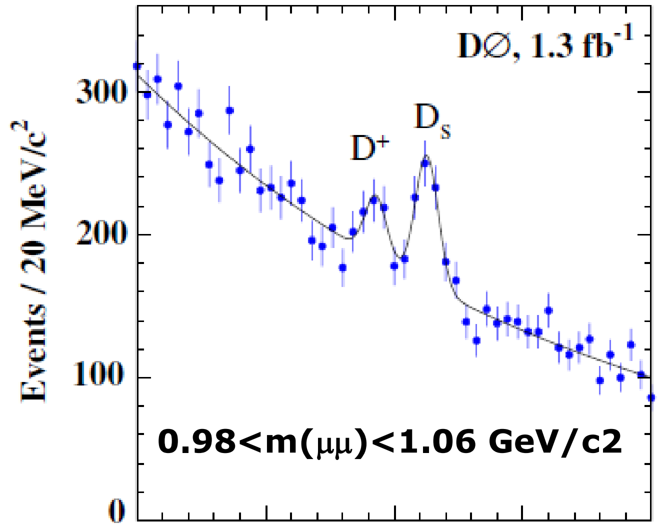
Abazov et al. PRL 100, 101801 (2008)

http://link.aps.org/doi/10.1103/PhysRevLett.100.101801

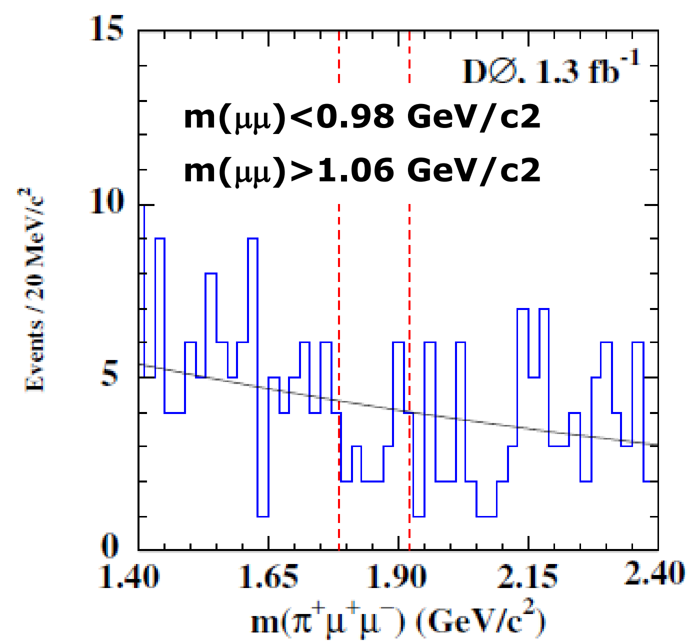
Babar: BR < 6.5×10^{-6} (90% CL)

Lees et al. SLAC-PUB-14482 (2011)

http://arxiv.org/abs/1107.4465v1

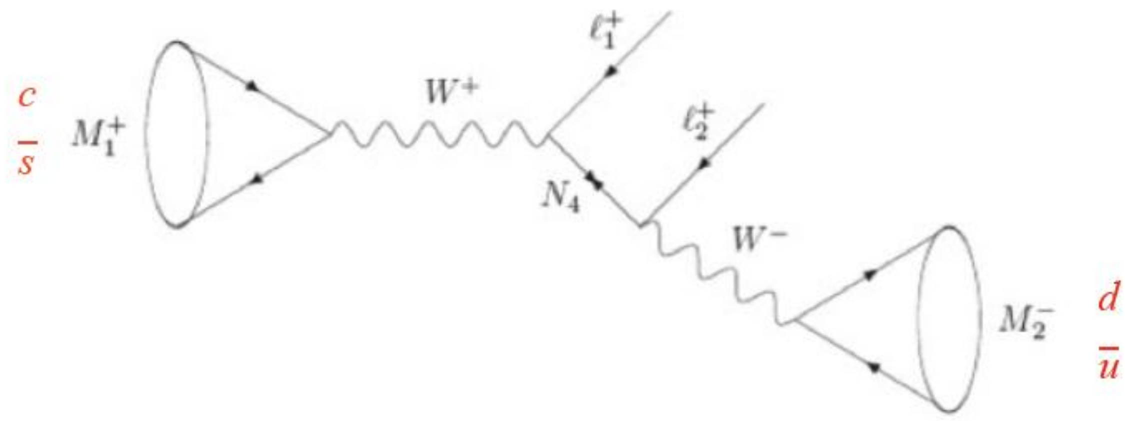


D0 analysis normalized to
115±30 $D^+ \rightarrow \phi(\mu\mu)\pi$ events



$D^+_{(s)} \rightarrow h^-\mu^+\mu^+$

- **Search for lepton number violation. Forbidden in the SM**
- **Ex: Majorana neutrino. $D_s \rightarrow \pi$ interesting (no CKM suppr).**



- **Exp: $BF(D^+ \rightarrow \pi\mu^+\mu^+) < 4.8\ 10^{-6}$ @90% CL [3]**

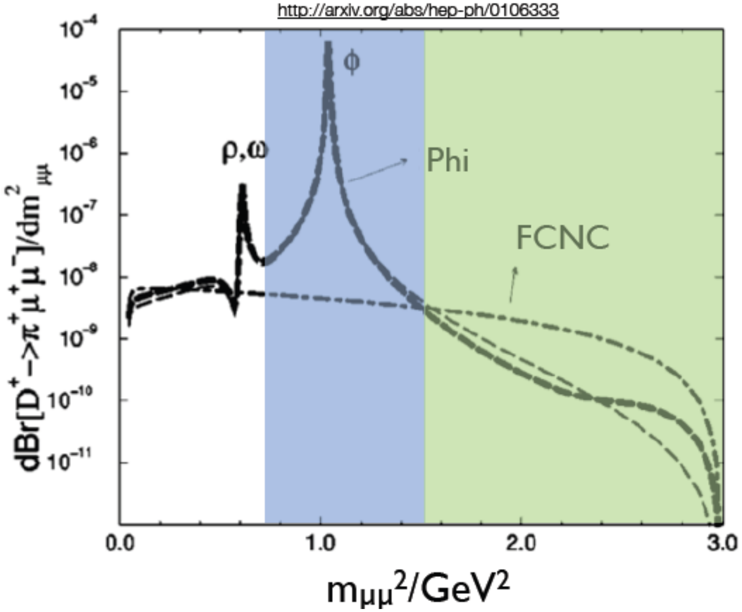
  $BF(D_s \rightarrow \pi\mu^+\mu^+) < 29\ 10^{-6}$

[3] FOCUS Phys.Lett. B572 (2003) 21-31
e-Print: hep-ex/0306049, hep-ex/0306049

$D^+_{(s)} \rightarrow h^+\mu^+\mu^-$ & $h^-\mu^+\mu^+$

- **LD contributions: normalization modes with same final state !**

S. Faijfer, S. Prelovsek & P. Singer PRD 64, 114009 (2001)
http://arxiv.org/abs/hep-ph/0106333



Phi Region — $D_{(s)} \rightarrow h\ \phi(\mu^+\mu^-)$

Region where FCNC visible — $D_{(s)} \rightarrow h\mu^+\mu^-$

- **LHCb will reconstruct thousands of $D_{(s)} \rightarrow h\ \phi(\mu^+\mu^-)$ events.**

- **D0→$\mu\mu$ meas't proved peaking bkg (ex $D^+_{(s)} \rightarrow \pi\pi\pi$) manageable.**

$D^+_{(s)} \rightarrow h^+\mu^+\mu^-$ & $h^-\mu^+\mu^+$

- **LD contributions: normalization modes with same final state !**

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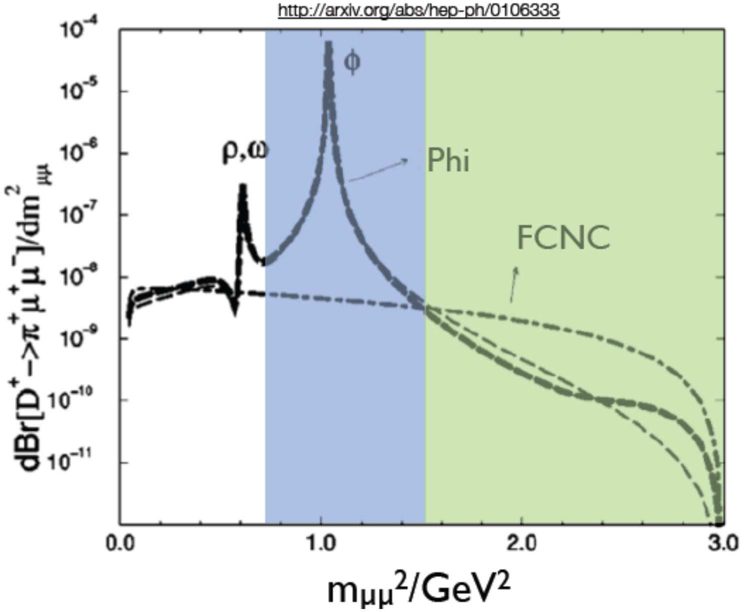

Phi Region — $D_{(s)} \rightarrow h\ \phi(\mu^+\mu^-)$

Region where FCNC visible — $D_{(s)} \rightarrow h\mu^+\mu^-$

Expected Limits (with 1 fb^{-1})

- **$D^+ \rightarrow (\pi,K)^+\mu^+\mu^-$ & $D^+ \rightarrow (\pi,K)^-\mu^+\mu^+$: few 10^{-8}**
- **$D_S \rightarrow (\pi,K)^+\mu^+\mu^-$ & $D^+ \rightarrow (\pi,K)^-\mu^+\mu^+$: few 10^{-7}**

Improve current limit on $D^+ \rightarrow \pi^+\mu^+\mu^-$ by more than 1 order of mag.

Will start challenging NP models when 2012 data set is included.

$D^0 \rightarrow hh\mu\mu$

$D \to KK\mu\mu$ and $D \to \pi\pi\mu\mu$

- **BF not known: $B(D^0 \to KK\mu\mu) < 3.10^{-5}$ & $B(D^0 \to \pi\pi\mu\mu) < 3.10^{-5}$ [PDG]**

  Question: What can this BF be in reality ? 10^{-7} ? 10^{-6} ?

- **Assuming $B \sim 10^{-5}$ and the same efficiency as for $D^0 \to 4h$ (see yields later): just a few 10^3 events in 1 fb^{-1}**

  ➔ ***Several more years, or even the upgrade to measure observables like A_{FB} [1] or T-odd asymmetries [4] at the percent level…***

  Question: are there good reasons to expect NP in D^0 decays via T-odd distributions ? It seems the only place where a mechanism is foreseen to produce a large effect are D_L decays (analogy with $K_L \to \pi\pi ee$).

  Question: more hope with $D^0 \to K^- \pi^+ \mu^+ \mu^-$?

➔ ***Our plan for 2011/2012: measure Branching ratios !***

- *[4] Bigi & al, arXiv:1110.2862v1, [1] Artuso & al, arXiv:0801.1833v1*

D→3h, D→4h

Motivations

- NP can be subtle and happen only in some particular regions of the phase space.
- In this case, differential measurements are more sensitive.
  - Dalitz plots
  - T-odd distributions.

- It takes a lot of statistics:

  LHCb can provide it !

$$\sigma(D^0) = 1488 \pm 41 \pm 34 \pm 174\,\mu b = 1488 \pm 182\,\mu b$$
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$$\sigma(D_s^+) = 194 \pm 23 \pm 16 \pm 26\,\mu b = 194 \pm 38\,\mu b\ .$$

- At LHCb:
  - $D^+ \to K^- K^+ \pi^+$
  - $D^0 \to \pi^- \pi^+ \pi^+ \pi^-$
  - $D^0 \to K^+ K^- \pi^+ \pi^-$
  - $D^+ \to \pi^- \pi^+ \pi^+$
  - $D_s \to \pi^- \pi^+ K^+$
  - $D^+ \to \pi^- \pi^+ K^+$
  - $D^+ \to K^- K^+ K^+$

$D^+ \to K^- K^+ \pi^+$

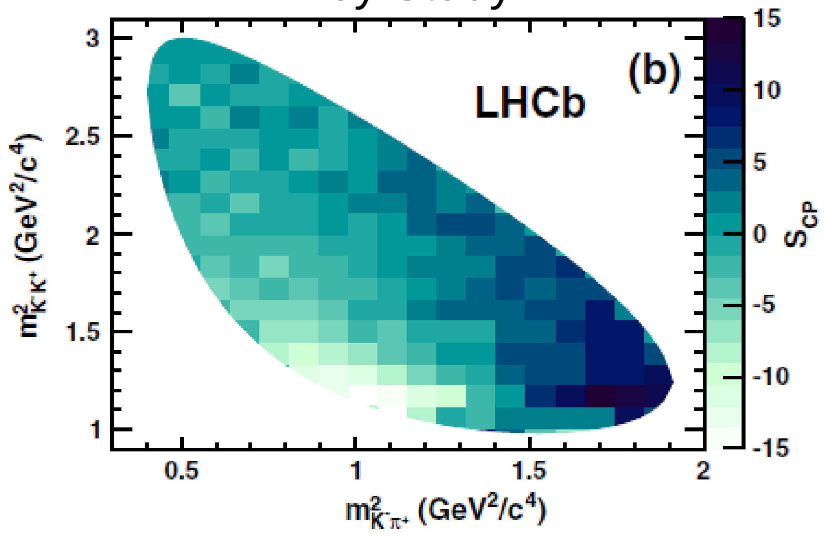
- **One of our 1st results, based on 2010 data (35 pb^{-1})**

- **Model independent search for CPV (Miranda Approach)**
  - **Compare D+ and D- Dalitz plots bin per bin.**
  - **Look for an overall significant difference.**

$$\mathcal{S}^i_{CP} = \frac{N^i(D^+) - \alpha N^i(D^-)}{\sqrt{N^i(D^+) + \alpha^2 N^i(D^-)}}, \quad \alpha = \frac{N_{\rm tot}(D^+)}{N_{\rm tot}(D^-)},$$

$$\chi^2 = \sum (\mathcal{S}^i_{CP})^2$$

Toy Study

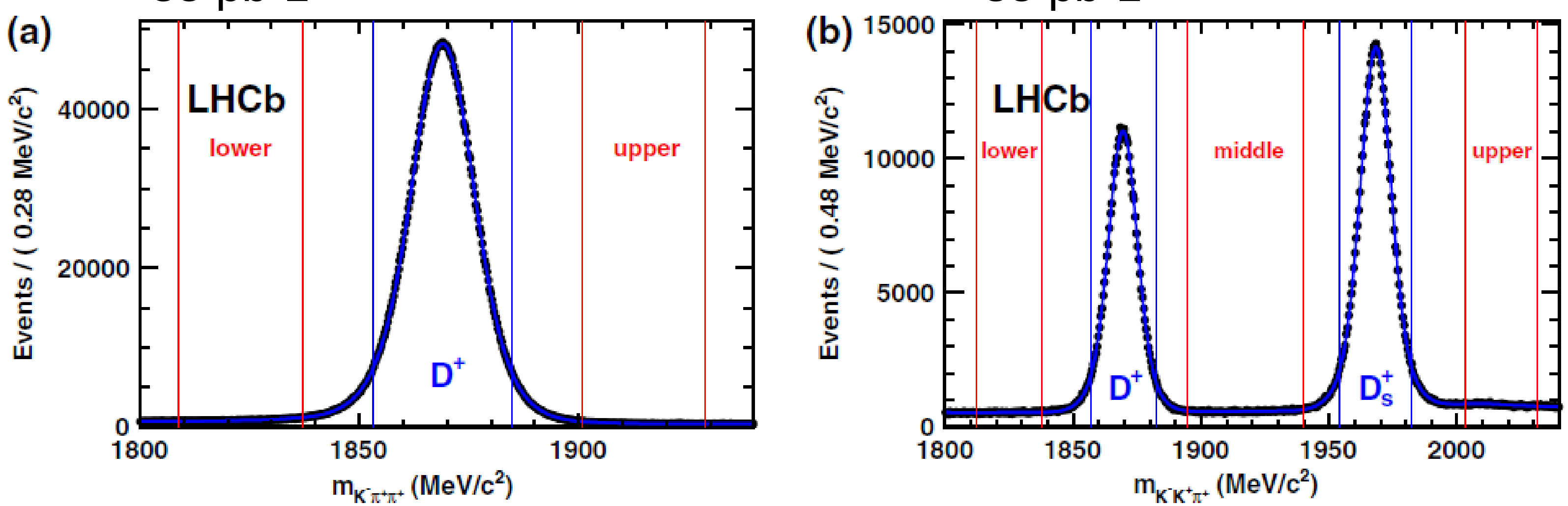


$D^+ \to K^- K^+ \pi^+$

PHYSICAL REVIEW D 84, 112008 (2011)

- **Key features:**
  - **High signal statistics.**
  - **Control of the artificial asymmetries thanks to large control samples**: *$D^+ \to K^- \pi^+ \pi^+$, $D_S \to K^- K^+ \pi^+$*

35 pb-1 35 pb-1



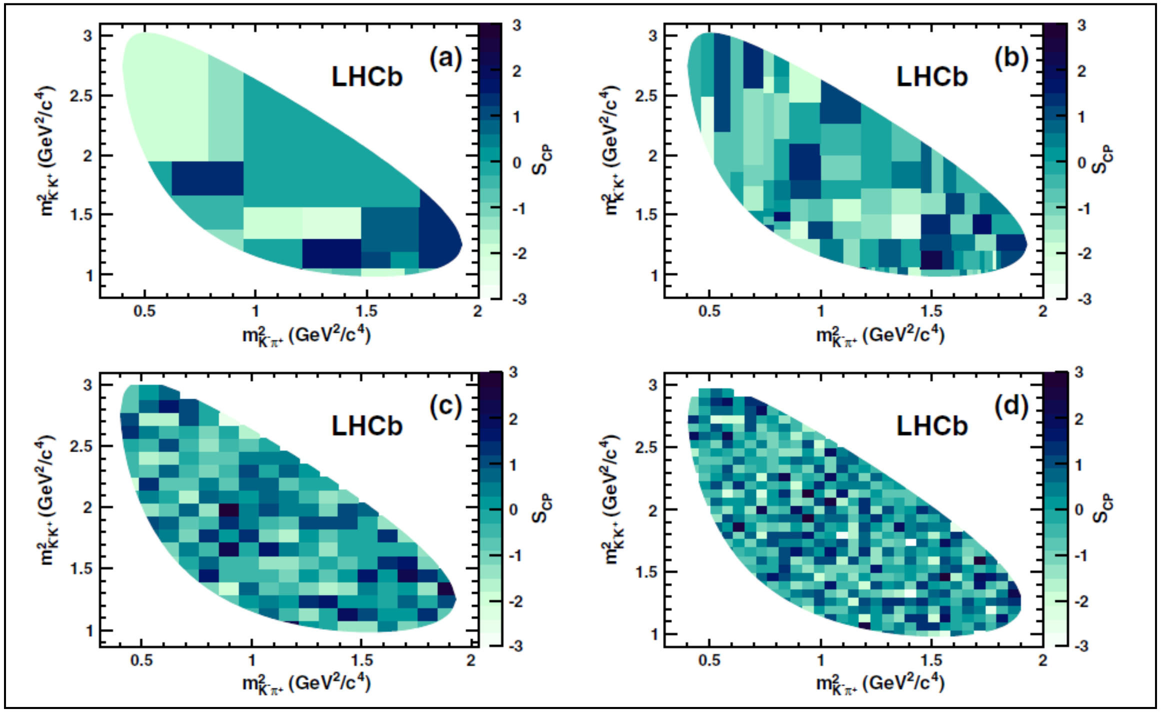
$$D^+ \to K^- K^+ \pi^+ \quad (3.284 \pm 0.006) \times 10^5$$
$$D_s^+ \to K^- K^+ \pi^+ \quad (4.615 \pm 0.012) \times 10^5$$
$$D^+ \to K^- \pi^+ \pi^+ \quad (3.3777 \pm 0.0037) \times 10^6$$

Larger than in all previous studies (Babar, Belle, CLEO-c)

$D^+ \to K^- K^+ \pi^+$

PHYSICAL REVIEW D 84, 112008 (2011)

- **Key features: adaptive binning to enhance sensitivity to CPV**



S_{CP} across the DP for the signal

Similar plots for the control samples reveal no artificial asymmetry.

Result: p-value corresponding to $\chi^2 = \sum (\mathcal{S}^i_{CP})^2$

Binning	Fitted mean	Fitted width	χ^2/ndf	p-value (%)
Adaptive I	0.01 ± 0.23	1.13 ± 0.16	32.0/24	12.7
Adaptive II	-0.024 ± 0.010	1.078 ± 0.074	123.4/105	10.6
Uniform I	-0.043 ± 0.073	0.929 ± 0.051	191.3/198	82.1
Uniform II	-0.039 ± 0.045	1.011 ± 0.034	519.5/529	60.5

No evidence for CPV !

Near future: 2011 data set (1 fb^{-1})

- **Update of the 2010 analysis**
  - **$D^+ \rightarrow K^-K^+\pi^+$ expected yield: $O(10^7)$**

- **Additional SCS modes in the game**
  - **$D^+ \rightarrow \pi^-\pi^+\pi^+$ expected yield: $O(10^6)$**
  - **$D_S \rightarrow \pi^-\pi^+K^+$ expected yield: $O(10^6)$**

May be good enough to discover CPV, if any, if large enough.

At the condition of an even better control of fake asymmetries

- **Add DCS modes: lower BF, but less SM background to CPV**
  - **$D^+ \rightarrow K^-K^+K^+$ expected yield: $O(10^5)$**
  - **$D^+ \rightarrow \pi^-\pi^+K^+$ expected yield: $O(10^5)$**

$D^0 \to \pi^+\pi^-\pi^+\pi^-$ & $D^0 \to K^+K^-\pi^+\pi^-$

- **A similar model-independent approach is used again here.**

  (Analysis on going)

- **Many common features**
  - **Need for a large control sample: $D^0 \to K^- \pi^+\pi^+\pi^-$**
  - **sophisticated binning determination across Dalitz plots**

- **One difference: harder to reach high purity with a 4-body f-state**

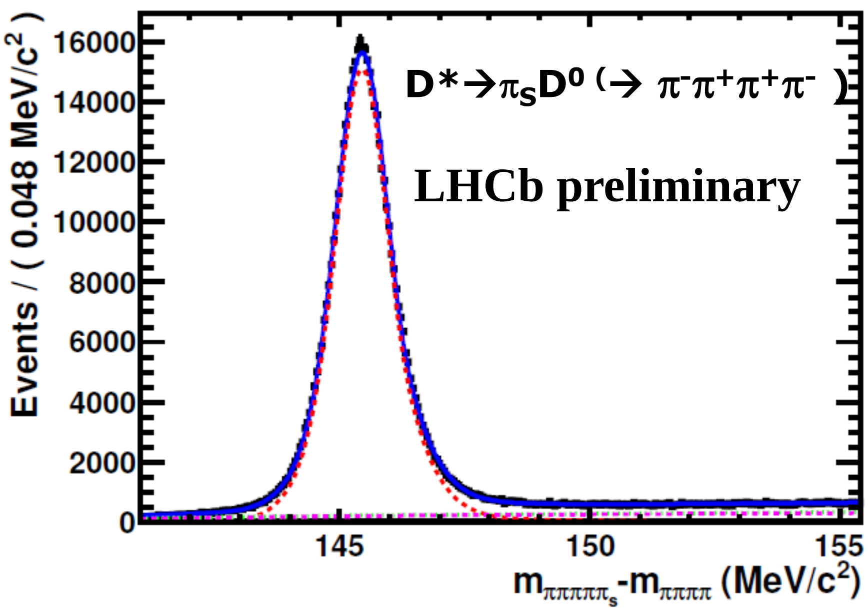
  → *A Neural Network has to be used.*

$D^0 \rightarrow \pi^+\pi^-\pi^+\pi^-$ & $D^0 \rightarrow K^+K^-\pi^+\pi^-$

- **Expected yields (still under study) in 1 fb^{-1}:**
  - **$D^0 \rightarrow \pi^-\pi^+\pi^+\pi^-$ expected yield: $\sim 5\times10^5$**
  - **$D^0 \rightarrow K^-K^+\pi^+\pi^-$ expected yield: $\sim 1\times10^5$**
  - **$D^0 \rightarrow K^-\pi^+\pi^+\pi^-$ expected yield: $\sim 1\times10^7$**

One order of magnitude below the 3-body modes.

But a 5-dimensional phase space to explore.



Search for a T-odd asymmetry

- **$D^0 \rightarrow K^-K^+\pi^+\pi^-$ can be used for that.**
- **The ϕ angle between the KK and $\pi\pi$ decays planes is a T-odd variable that can be used to find T/CP violation effect.**

$\rightarrow T\Phi = -\Phi$ $\rightarrow T\cos\Phi\sin\Phi = -\cos\Phi\sin\Phi$

$$\frac{d\Gamma}{d\phi} = \Gamma_1 \cos^2\phi + \Gamma_2 \sin^2\phi + \Gamma_3 \cos\phi \sin\phi.$$

$$A = \frac{\int_0^{\pi/2} d\phi \frac{d\Gamma}{d\phi} - \int_{\pi/2}^{\pi} d\phi \frac{d\Gamma}{d\phi}}{\int_0^{\pi} d\phi \frac{d\Gamma}{d\phi}} = \frac{2\Gamma_3}{\pi(\Gamma_1 + \Gamma_2)}.$$

$A \neq 0$ possible even with no T/CPV, due to strong phases. Look at:

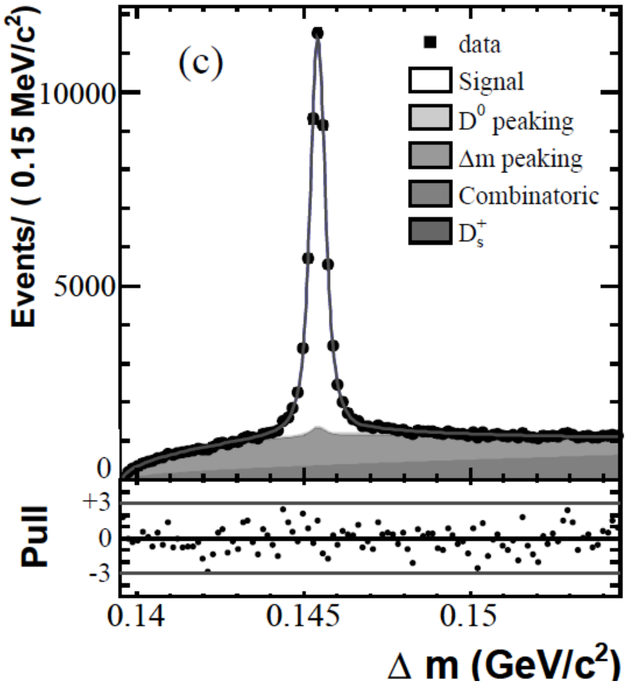
$$A_T^{CP} = \frac{1}{2}\left(A_T - \overline{A_T}\right) \propto \sin(\Phi_{weak})\cos\left(\delta_{FSI,strong}\right)$$

Search for a T-odd asymmetry

- **$D^0 \rightarrow K^-K^+\pi^+\pi^-$ can be used for that.**

- **Babar [5]**

$$\mathcal{A}_T = (1.0 \pm 5.1_{\text{stat}} \pm 4.4_{\text{syst}}) \times 10^{-3}$$



- **In 1 fb-1: signal yield ~2× larger at LHCb**

$\rightarrow$ *A few more years, or the upgrade to be sensitive to asymmetries of a few 10^{-3}*

[5] P. del Amo Sanchez & al, arXiv:1003.3397v1

1 fb^{-1} @ LHCb = one/two orders magnitude better.

Modes	Observable	Previous limit /sensitivity/yield	LHCb 1 fb^{-1}
$D^0 \to \mu\mu$	BF	BF < 1.4×10^{-7}	BF < 1.1×10^{-8} New!
$D^+ \to h\mu\mu$	BF	BF < 3.9×10^{-6}	BF < $O(10^{-8})$
$D_s \to h\mu\mu$	BF	BF < 3×10^{-5}	BF < $O(10^{-7})$
$D^0 \to \pi^+ \pi^- \mu^+\mu^-$	BF	BF < 3×10^{-5}	BF @ 3σ if 10^{-6}
$D^0 \to K^+ K^- \mu^+\mu^-$	BF	BF < 3×10^{-5}	BF @ 3σ if 10^{-6}
$D^+ \to K^-K^+\pi^+$	A_{cp} /Dalitz	O(200k)	$O(10^7)$
$D^0 \to \pi^-\pi^+ \pi^+\pi^-$	A_{cp} /Dalitz/T-odd		$O(10^5\text{-}10^6)$
$D^0 \to K^+K^- \pi^+\pi^-$	A_{cp} /Dalitz/T-odd	O(50k)	$O(10^5)$
$D^+ \to \pi^-\pi^+\pi^+$	A_{cp} /Dalitz		$O(10^6)$
$D_S \to \pi^-\pi^+K^+$	A_{cp} /Dalitz		$O(10^6)$
$D^+ \to K^-K^+K^+$	A_{cp} /Dalitz		$O(10^5)$
$D^+ \to \pi^-K^+K^+$	A_{cp} /Dalitz		$O(10^5)$

Conclusions

- **LHCb is a charm factory: many rare or multibody charm decay modes are studied (more modes than physicists !).**

  Work has started on modes not mentioned here
  - **Ex: $\Lambda_c \rightarrow p\mu\mu$**

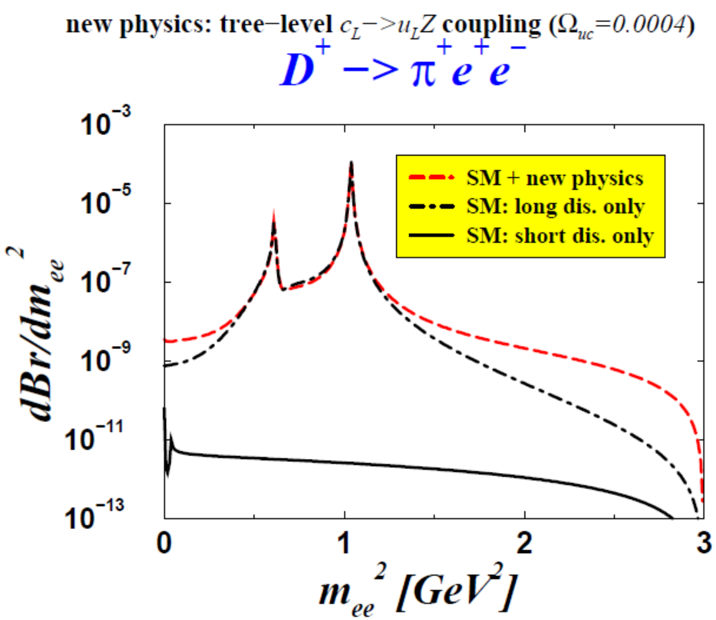
- **First results are there, or will be in months to come.**

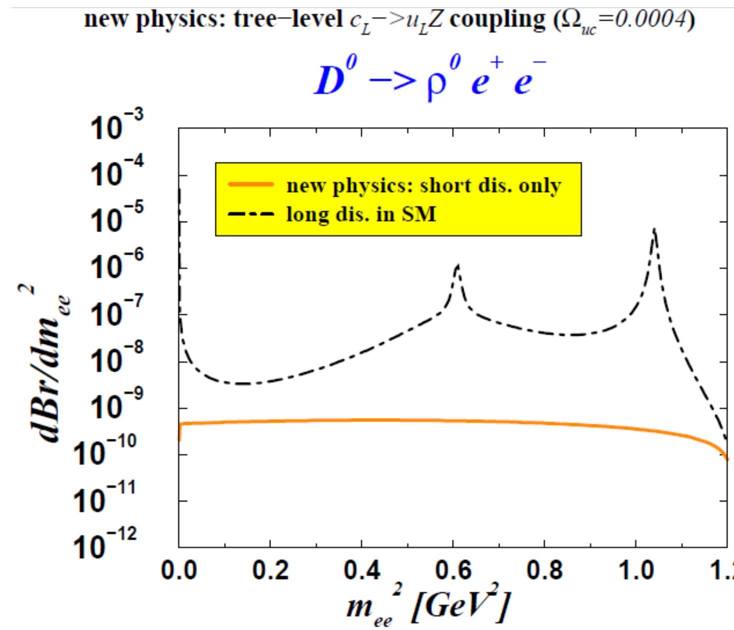
- **Should improve our knowledge by one/two orders of magnitude.**
  - **High stat but also control of the systematics more and more crucial.**

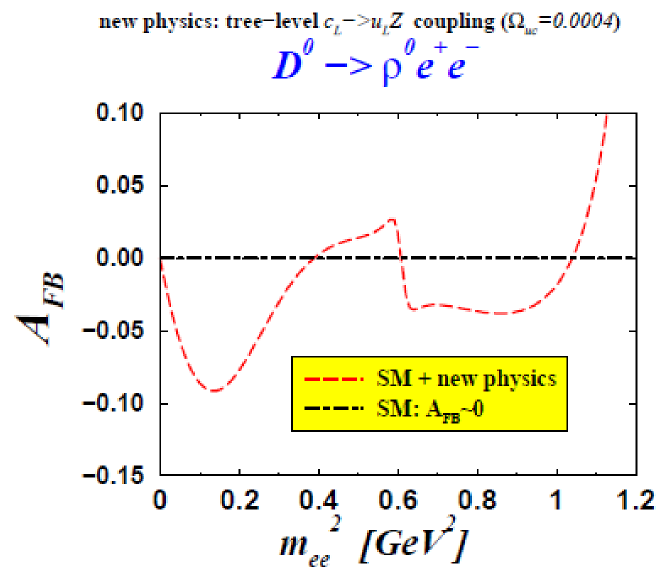
- **Impact on NP models ?**

Back-up

Figures store…

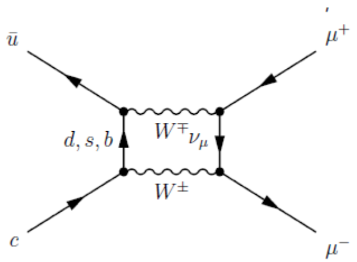


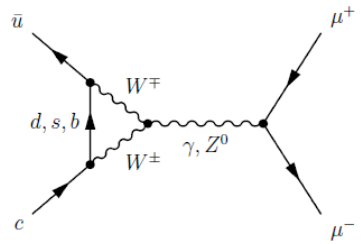




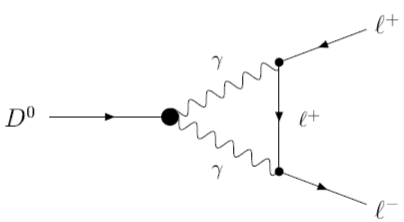
$D^0 \to \mu\mu$

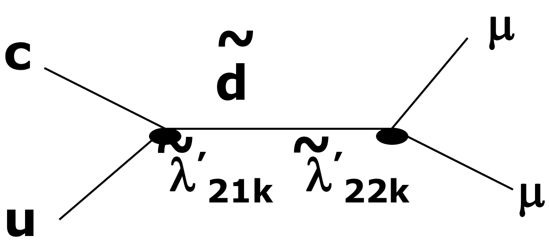
- **In the SM:**
  - **Short Distance (SD) highly suppressed**





  - **Long Distance (LD) dominates**





$D^0 \to KK\mu\mu$, $\pi\pi\mu\mu$

- **One of the largest known CPV effect in $K_L \to \pi\pi ee$, via T-odd distrib.**
  Same in $D \to hh\mu\mu$?

$$D_L \xrightarrow{\cancel{CP}} h^+h^- \xrightarrow{\text{IB}} h^+h^-\gamma \text{ and } D_L \xrightarrow{\text{M1,E1}} h^+h^-\gamma,$$

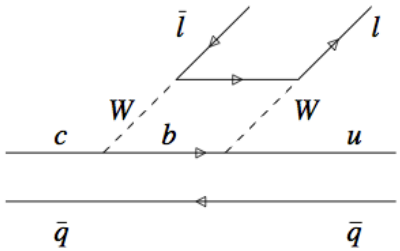
- Two amplitudes. First is small (violates CP). Second happens to be as small.

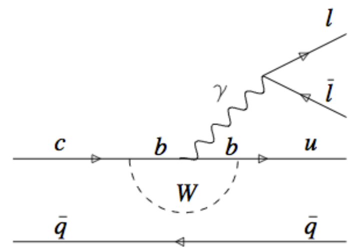
- This causes large interference ⇔ Large CPV.

- Theoretical Predictions are difficult in practice. Bigi & al: up to ~1% [1]

Physics Motivations

- **GIM mechanism very strong in charm decays (m_d-m_b << m_u-m_t).**
- **Provides very rare FCNC decays (SM): powerful tool to seek NP.**





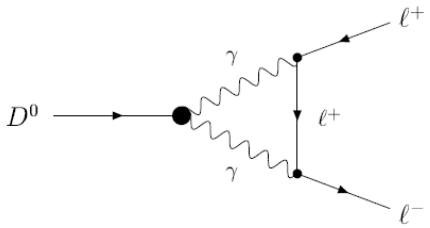
$D^0 \to \mu\mu$

- **In the SM, BF dominated by Long Distance (LD) contributions.**

  Quite reliably estimated via:

$$\mathcal{BR}^{(\gamma\gamma)}(D^0 \to \mu^+\mu^-) \simeq 2.7 \times 10^{-5} \mathcal{BR}(D^0 \to \gamma\gamma)\,.$$

$$\mathcal{BR}^{SM}(D^0 \to \mu^+\mu^-) \gtrsim 10^{-13}$$



- **A variety of NP scenarios[1]…**
  - Tree level ($Z \to uc$) amplitudes (Heavy vector-like quarks, New Z' bosons, …)
  - Loop amplitudes (4th quark generation, RPV-SUSY,…)

..should enhance this BF: ~10^{-11} to 10^{-9}.

---

[1] **See for instance**

G. Burdman, E. Golowich, J. L. Hewett, and S. Pakvasa, "Rare Charm Decays in the Standard Model and Beyond", *Phys. Rev.* D66 (2002) 014009, arXiv:hep-ph/0112235.

E. Golowich, J. Hewett, S. Pakvasa, and A. A. Petrov, "Relating $D^0 - \bar{D}^0$ Mixing and $D^0 \to l^+l^-$ with New Physics", *Phys. Rev.* D79 (2009) 114030, arXiv:0903.2830 [hep-ph].

D→μμ MVA variables

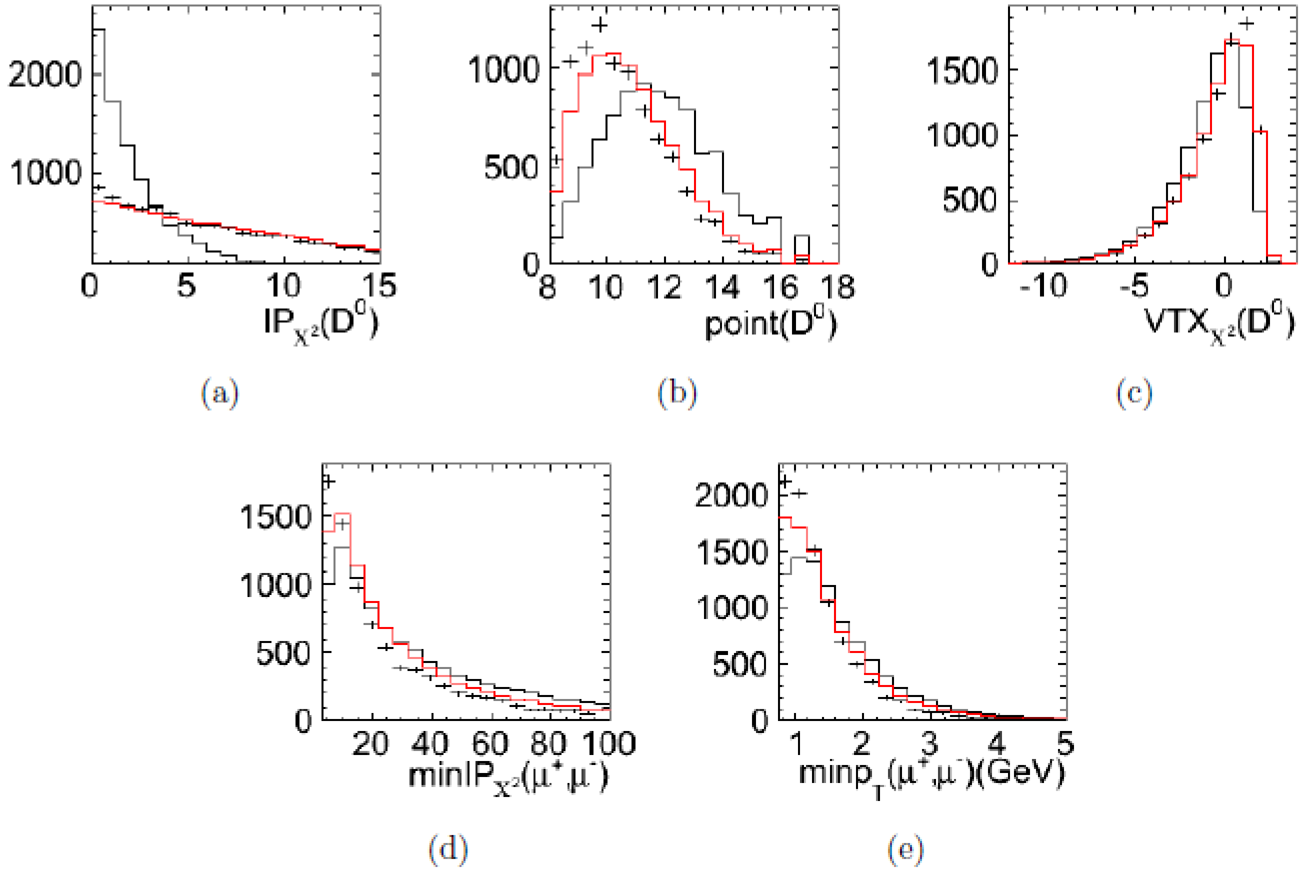


Figure 4: Distributions of the input variables for the multivariate selection for the
tagged samples for the $D^0 \to \mu^+\mu^-$ MonteCarlo, continuous line, for the $D^0 \to \mu^+$
pre-selected sideband data, black dots and for the $b\bar{b} \to \mu^+\mu^-$ MC, red line. The trig
selection is applied to both data and MC.

D→μμ MVA variables

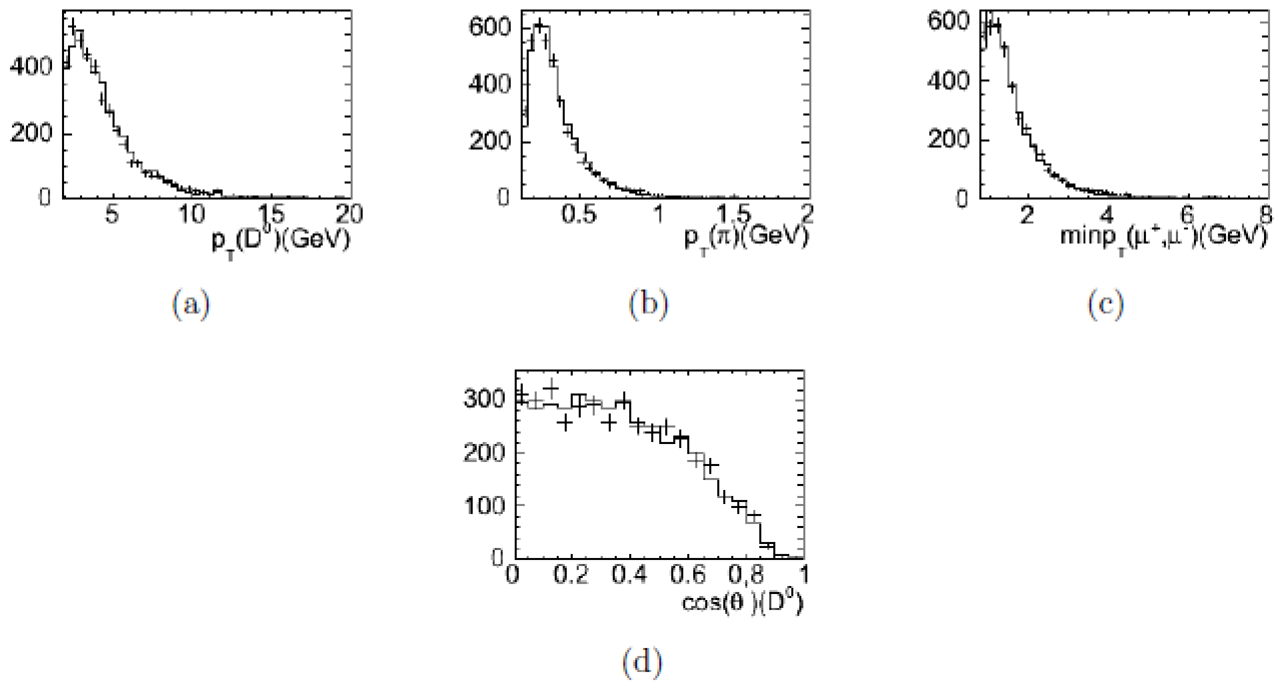
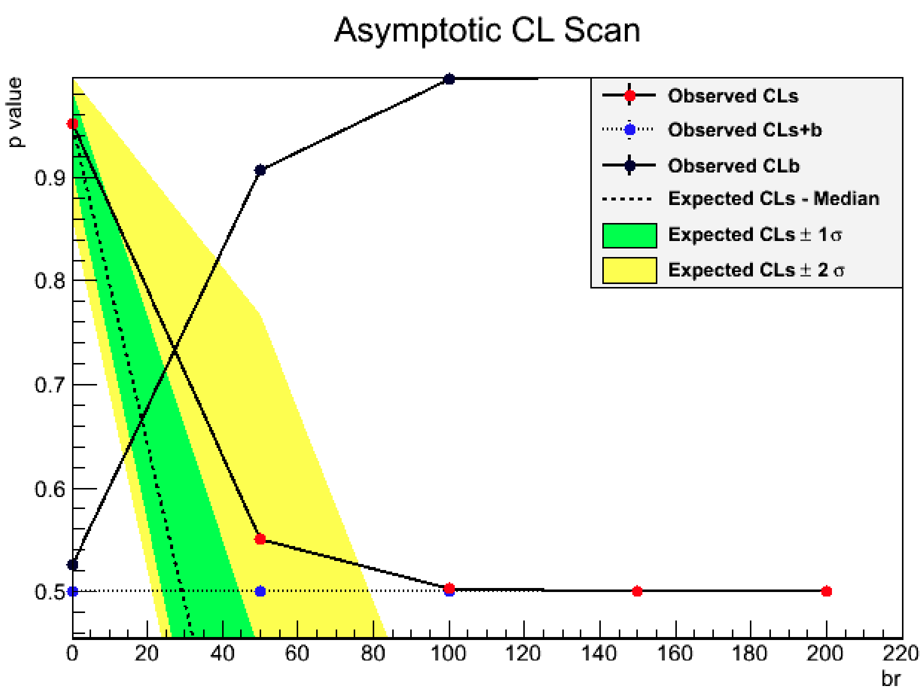
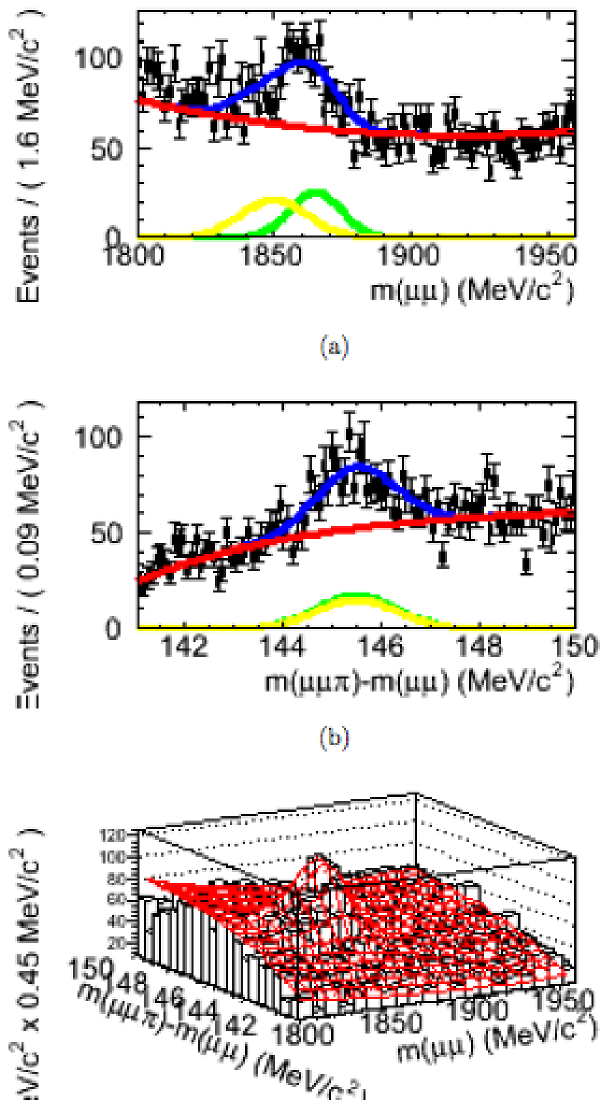


Figure 8: Data (TIS L0 and Hlt1) vs MC for $D^{*+} \to D^0(\to K^-\pi^+)\pi^+$ events after cutting in ΔM between 144 and 147MeV.

Fit and Limit

- **Implemented blinding procedure adding some (unknown) amount of MC D*→$D^0(\mu\mu)\pi$ (will be removed in due time, don't worry!)**





(a)

(b)

(c)

➔ **MVA-Expected Upper Limit: 8×10-9 @90% C.L.**

Strategy for D rare decays @ LHCb.

$$\mathcal{B}(D^0 \to \mu^+\mu^-) = \frac{N_{D^{*+}\to D^0(\to\mu^+\mu^-)\pi^+}}{N_{D^{*+}\to D^0(\to\pi^+\pi^-)\pi^+}} \frac{\varepsilon_{\pi\pi}}{\varepsilon_{\mu\mu}} \cdot \mathcal{B}(D^0 \to \pi^+\pi^-)$$

Large Yields

→**Large X-sections: $\sigma(D^{*+})$= 676±137 μb**

→**Can use D* and still have large yields**

High Efficiencies

→**Good muon-ID**

→**Very efficient muon trigger (>90%)**

Backgrounds under control

→**Low π-μ misID rate(<1%)**

→**Keep D→$\pi\pi$ quiet although B($\pi\pi$)/B($\mu\mu$)>10^5**

Systematics under control in a hadronic environment

→**Easy to have large control samples: D→Kπ for (efficiency and misID rate), J/psi($\mu\mu$) (trigger and muID efficiency), etc…**

→ **All stored thanks to a flexible trigger (many channels, prescales, etc…)**

Strategy for D rare decays @ LHCb.

$$\mathcal{B}(D^0 \to \mu^+\mu^-) = \frac{\boxed{N_{D^{*+}\to D^0(\to\mu^+\mu^-)\pi^+}}}{\boxed{N_{D^{*+}\to D^0(\to\pi^+\pi^-)\pi^+}}} \frac{\varepsilon_{\pi\pi}}{\boxed{\varepsilon_{\mu\mu}}} \cdot \mathcal{B}(D^0 \to \pi^+\pi^-)$$

Keep large backgrounds under control…

→ **Backgrounds should dominate: B(D→ππ)/B(D→μμ)>10^5 + combinatorial**

Solution: Low π-μ misID rate(<1%) + use D*

…While still sensitive to small signal…

→**Efficient muon-ID & muon trigger (>90%)**

→ **Large X-sections: σ(D^{*+})= 676±137 μb**

…With low systematics despite the hadronic context !

→**Large control samples:**

D→Kπ (eff. & misID rate), J/psi(μμ) (trigger & muID eff.), etc…

→ **All stored thanks to a flexible trigger (many channels, prescales, etc…)**

Strategy for D rare decays @ LHCb.

Measurement relative to the $D^0 \to \pi\pi$ channel (as Belle)

$$\mathcal{B}(D^0 \to \mu^+\mu^-) = \frac{\boxed{N_{D^{*+}\to D^0(\to\mu^+\mu^-)\pi^+}}\;\varepsilon_{\pi\pi}}{\boxed{N_{D^{*+}\to D^0(\to\pi^+\pi^-)\pi^+}}\;\boxed{\varepsilon_{\mu\mu}}} \cdot \mathcal{B}(D^0 \to \pi^+\pi^-)$$

Need low and precisely known backgrounds…

- →**Low π-μ misID rate(<1%)**
- →**Keep $D \to \pi\pi$ quiet although $B(\pi\pi)/B(\mu\mu) > 10^5$**
- →**Easy to have large control samples: $D \to K\pi$ for (efficiency and misID rate), J/psi($\mu\mu$) (trigger and muID efficiency), etc…**
- → **All stored thanks to a flexible trigger (many channels, prescales, etc…)**

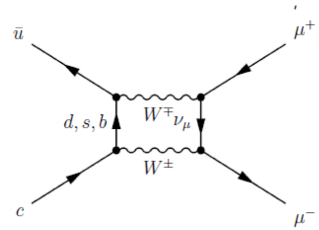
… and high efficiency….

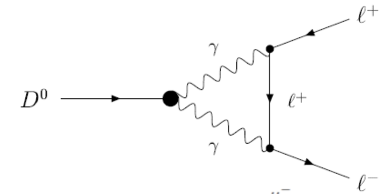
- →**Good muon-ID**
- →**Very efficient muon trigger (>90%)**

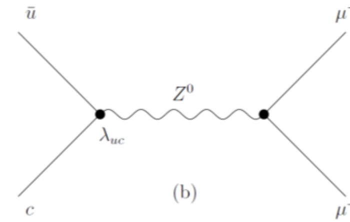
… and large yields.

- →**Large X-sections: $\sigma(D^{*+})$= 676±137 μb**
- →**Can use D* and still have large yields**

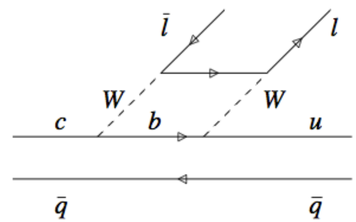
State of the Art

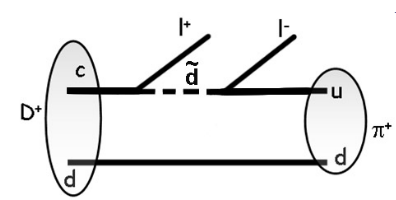




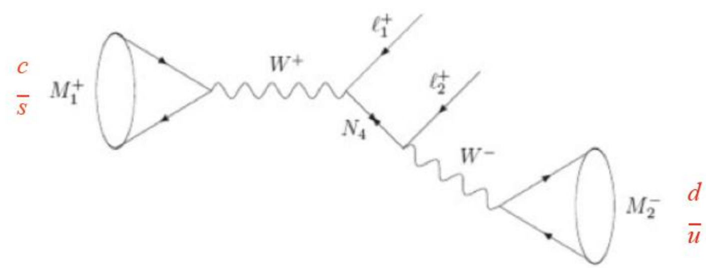


- **$D^0 \to \mu^+\mu^-$**
  - *- SM: BF~10^{-13} [1]*
  - *- NP: BF ~ 10^{-11} to 10^{-9} ? [2]*
  - *- Exp: BF($D^0 \to \mu\mu$)< 1.4 10^{-7} @90% CL [3]*





- **$D^+_{(s)} \to \pi^+/K^+ \mu^+\mu^-$**
  - *- SM: BF<10^{-11} [4]*
  - *- NP: BF up to 10^{-8} ? [4,5]*
  - *- Exp: BF($D^+ \to \pi^+\mu\mu$)< 4 10^{-6} @90% CL [6]*



- **$D^+_{(s)} \to \pi^-/K^- \mu^+\mu^+$ (probes Majorana)**
  - *- Exp: BF($D^+ \to \pi\mu^+\mu^+$)< 4.8 10^{-6} @90% CL [7]*

- **$D^0 \to K^+K^-\mu^+\mu^-$, $\pi^+\pi^-\mu^+\mu^-$**
  - *- Effect of NP on BF might be small [4,5]*
  - *- Measuring BF useful to evaluate the potential of other observables: FB asymmetries [4], T-odd asymmetries [8]*

References

- **Theory**
  - *[1] Buchalla & al, arXiv:hep-ph/9512380.*
  - *[2] Golowich & al, arXiv:0903.2830v2*
  - *[4] Artuso & al, arXiv:0801.1833v1*
  - *[5] Fajfer & al, arXiv:0706.1133v2,*
    Fajfer & al, arXiv:hep-ph/0511048v2
  - *[8] Bigi & al, arXiv:1110.2862v1*

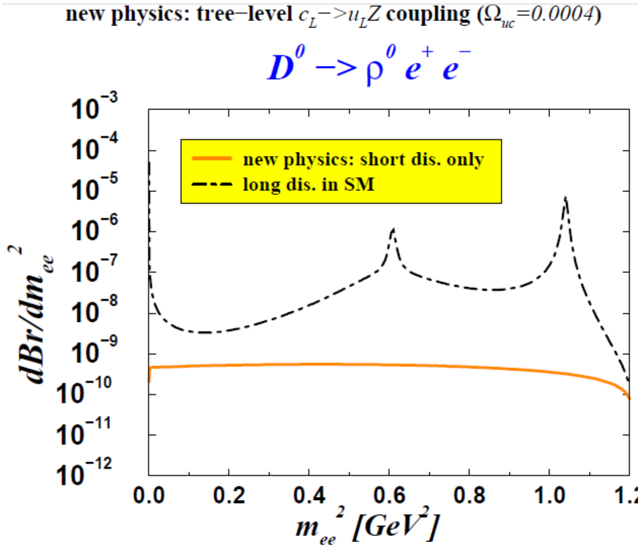
From variety of NP scenarios…

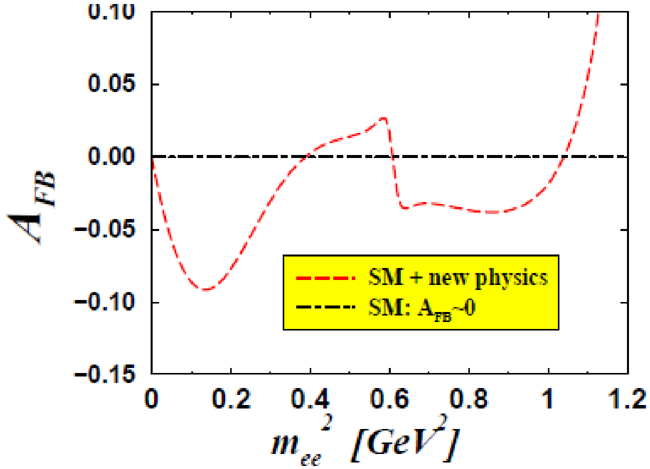
- *Tree level (Z→uc) amplitudes*
  (Heavy vector-like quarks, New Z' bosons, Little Higgs, RPV-SUSY…)
- *Loop amplitudes (4th quark generation, RPV-SUSY,…)*

- **Experiments**
  - *[3] Petric & al, arXiv:1003.2345, Belle Collaboration*
  - *[6] Abazov et al, PRL, 100, 101801 (2008), arXiv:0708.2094v1, D0 with 1.3 fb^{-1}*
    Also an analysis by Babar **:** *arXiv:1107.4465v1*

$D^0 \to \pi\pi\mu\mu$

- Natural extension to $D^+_{(s)} \to h\,\mu\mu$
- Not all NP model predict large effects on the Branching Ratio
- FB asymmetry looks more promising (Ex: [,]). Although only ~5%.
- One can also look for CP violation in T-odd distributions [8]
- LHCb plans ?



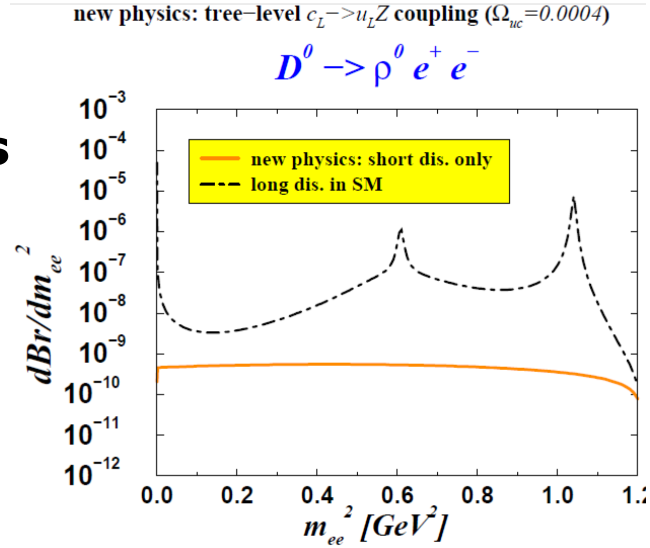


- [] Artuso & al, arXiv:0801.1833v1
- [] Burdman & al, arXiv:hep-ph/0112235v2
- [8] Bigi & al, arXiv:1110.2862v1

$D^0 \to \pi\pi\mu\mu$

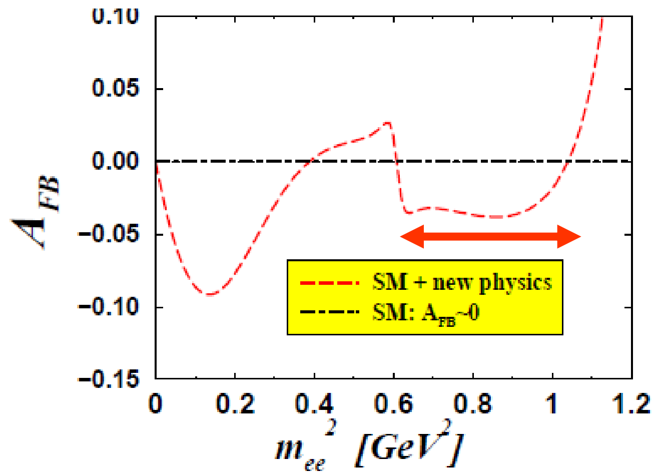
- Later in this talk we'll see $D^0 \to \pi\pi\pi\pi$ peaks

  Assuming a similar efficiency (muons help but it's harder to be pure with a smaller branching ratio).



➔ Expect in 2011 data (1fb^{-1})

  only a few events in the high A_{FB} zone



- [] Artuso & al, arXiv:0801.1833v1
- [] Burdman & al, arXiv:hep-ph/0112235v2
- [8] Bigi & al, arXiv:1110.2862v1

T-odd measurements with D→KK$\mu\mu$ and D→$\pi\pi\mu\mu$

- The ϕ angle between the hh and $\mu\mu$ decays planes is a T-odd variable that can be used to find T/CP violation effects [8]
- D^0 decays can be used

$\rightarrow$ TΦ = - Φ $\quad\quad$ $\rightarrow$ TcosΦsinΦ = -cosΦsinΦ

$$\frac{d\Gamma}{d\phi} = \Gamma_1 \cos^2\phi + \Gamma_2 \sin^2\phi + \Gamma_3 \cos\phi \sin\phi.$$

$$A = \frac{\int_0^{\pi/2} d\phi \frac{d\Gamma}{d\phi} - \int_{\pi/2}^{\pi} d\phi \frac{d\Gamma}{d\phi}}{\int_0^{\pi} d\phi \frac{d\Gamma}{d\phi}} = \frac{2\Gamma_3}{\pi(\Gamma_1 + \Gamma_2)}.$$

A≠0 possible even with no T/CPV, due to strong phases. Look at:

$$A_T^{CP} = \frac{1}{2}\left(A_T - \overline{A_T}\right) \propto \sin(\Phi_{weak})\cos\left(\delta_{FSI,strong}\right)$$

- *[8] Bigi & al, arXiv:1110.2862v1*

T-odd measurements with D→KKμμ and D→ππμμ

- **In [8], it looks like the only place where one can think of specific mechanism for large T/CP violation is D_L decays , in analogy with K_L→ππee…**

$$D_L \xrightarrow{\cancel{CP}} h^+h^- \xrightarrow{\mathrm{IB}} h^+h^-\gamma \text{ and } D_L \xrightarrow{\mathrm{M1,E1}} h^+h^-\gamma,$$

- Two amplitudes. First is small (violates CP). Second happens to be as small.

- This causes large interference ⇔ Large CPV.

D_L are difficult to prepare at LHCb…

➔ *Plans for D→hhμμ: start with BF measurements*

- Clarify the situation.

- Small values would suggest a suppression mechanism that can make the above interference larger.

- Would motivate Super flavor factories to run at the ψ(3770).

- *[8] Bigi & al, arXiv:1110.2862v1*

LHCb's Motivations for rare charm

- **GIM mechanism very strong in charm decays (m_d-m_b << m_u-m_t).**
- **Provides very rare FCNC decays (SM): powerful tool to seek NP.**

- **Winter conferences:**
  - **- $D^0 \to \mu^+\mu^-$**
- **Summer 2012**
  - **- $D^+_{(s)} \to \pi^+/K^+ \mu^+\mu^-$**
  - **- $D^+_{(s)} \to \pi^-/K^- \mu^+\mu^+$**
- **Longer term:**
  - **- $D^0 \to KK\mu\mu$, $\pi\pi\mu\mu$**

$$\sigma(D^0) = 1488 \pm 41 \pm 34 \pm 174\,\mu b = 1488 \pm 182\,\mu b$$
$$\sigma(D^{*+}) = 676 \pm 64 \pm 21 \pm 119\,\mu b = 676 \pm 137\,\mu b$$
$$\sigma(D^+) = 717 \pm 39 \pm 26 \pm 98\,\mu b = 717 \pm 109\,\mu b$$
$$\sigma(D_s^+) = 194 \pm 23 \pm 16 \pm 26\,\mu b = 194 \pm 38\,\mu b\ .$$