Present status of Charm Measurements

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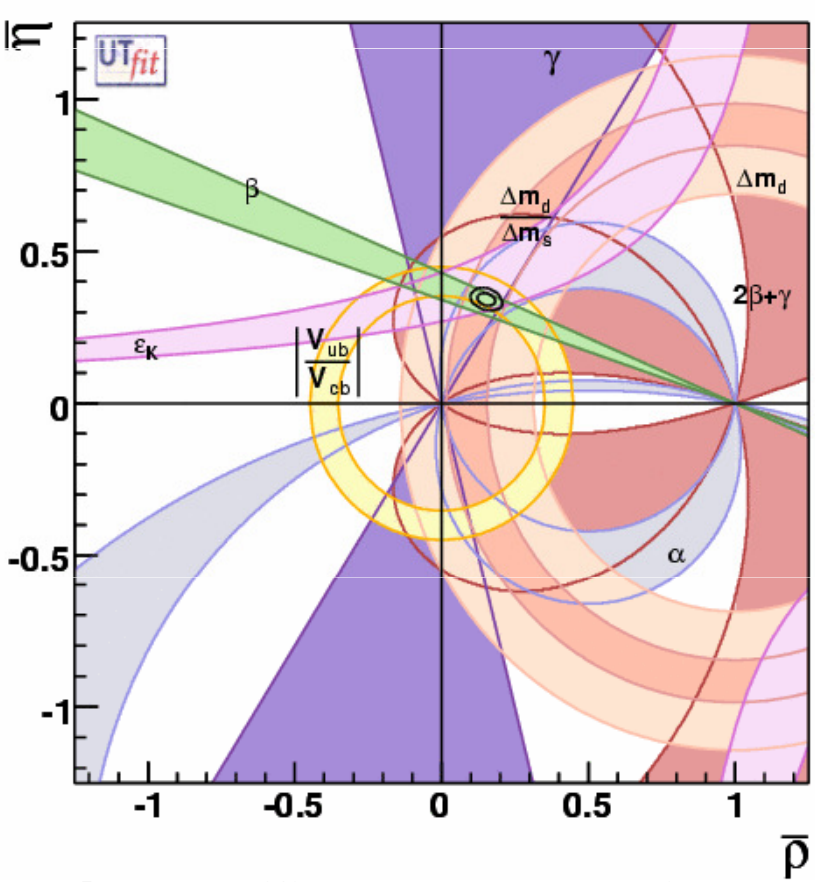
Outline:

- Introduction
- Charm fragmentation
- Leptonic decays
- Semileptonic decays
- Mixing and CP violation
- Rare and forbidden decays
- Hadronic decays

Introduction: why charm?

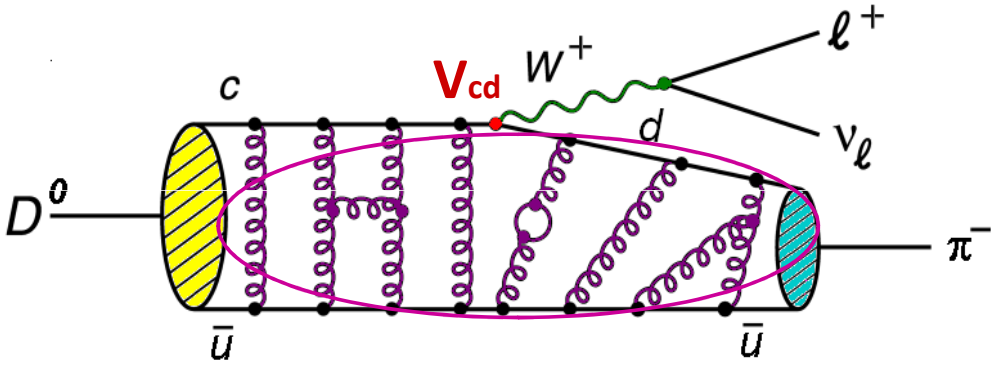
The aim: find NEW PHYSICS

1) Overconstraining the UT



2) Specific processes with c-hadrons

The role of charm:



- Understand the strong interaction: Hadronic effects in leptonic and semileptonic decays, fragmentation, hadronic decays

  Help for inputs in B decays (more sensitive to NP) validating Lattice QCD computations

- Search for New Physics in Mixing and CP violation, rare and forbidden decays

Charm Landscape

B-Factories	Charm-"Factories"	Hadronic production
$e^+e^- \to \Upsilon(4S)$	$e^+e^- \to \psi(3770)$	

Charm Data Samples

Physics at charm threshold: ($D\bar{D}$)

CLEO-c:

0.818 fb^{-1} @ ψ(3770)

~ 10^6 D^+D^- pairs

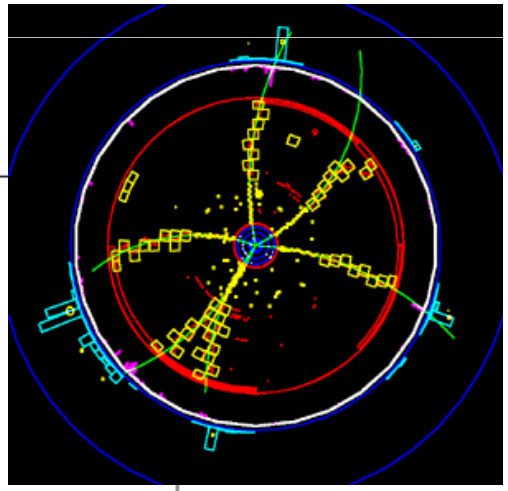
0.586 fb^{-1} @ ψ(4170)

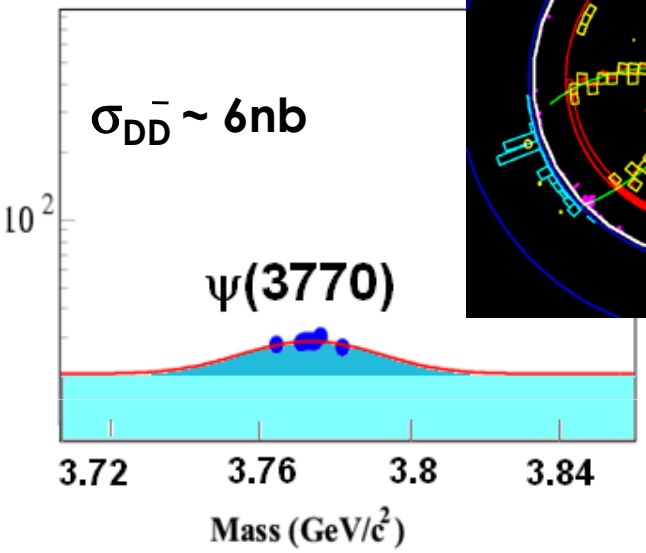
~ 10^6 $D^*_sD_s$ pairs

BESIII:

~ 1 fb^{-1} @ ψ(3770)

($\rightarrow$ 10fb^{-1} in 6 years ?)





- Clean environment:
  - less background
  - easy to recontruct all decay products

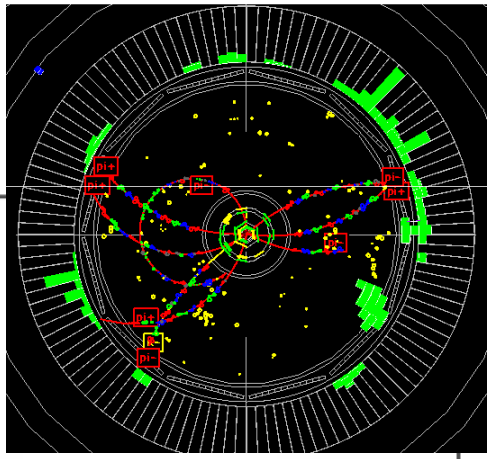
Physics at Υ(4S) : ($B\bar{B}$ threshold)

BELLE: (1000 fb^{-1})

711 fb^{-1} @ Υ(4S)

BaBar: (530 fb^{-1})

433 fb^{-1} @ Υ(4S)

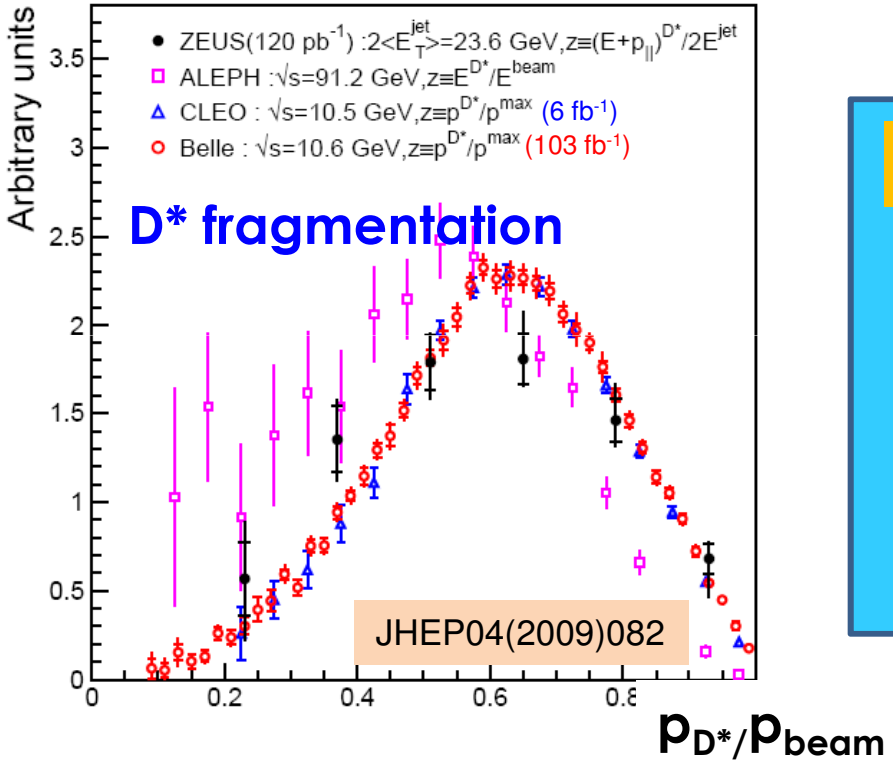


- More statistics ~10^9 $D_{(s)}^{(*)(**)}$
- More background
- Fragmentation:
  access to D*, D**, D_s, Λ_c, etc…

Charm Fragmentation

- @ the $\Upsilon(4S)$ the c quark hadronizes into D, D*, D**, D_s , baryons…

The charm fragmentation:
- Provide reference data on D_s, D**, charm baryons.
-Help in the understanding of the QCD processes (test of models)
→Important to validate simulations in other environments (LHC)



Present Status:

- Old measurements from Belle and CLEO-III (BaBar on the way)

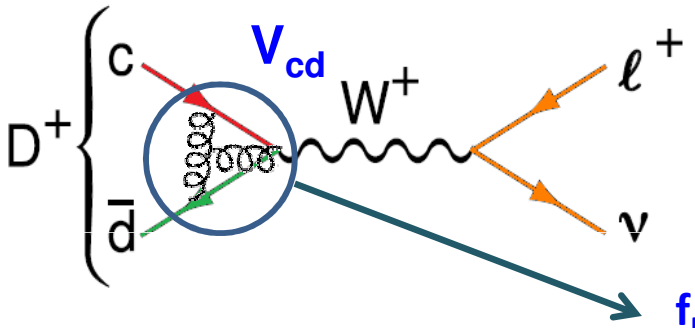
-Would like to have all (D, D*, D**, Ds, Λc, etc…) fragmentation functions

- Important to separate perturbative and non-perturbative parts

Leptonic Decays:

SM: $D \to \ell\nu = 2.35 \times 10^{-5} : 1 : 2.65$ (e:μ:τ)

Measurement of decay constants: f_D, f_{Ds}

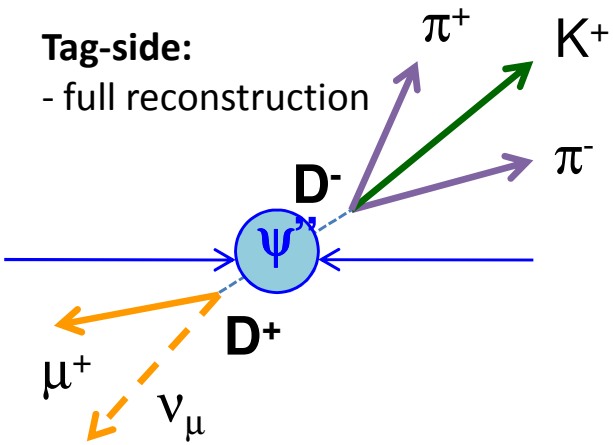


$$\Gamma = \frac{1}{8\pi} G_F^2 f_D^2 m_\ell^2 M_D \left(1 - \frac{m_\ell^2}{M_D^2}\right)^2 |V_{cd}|^2$$

$f_{D(s)}$ provides Lattice-QCD validation

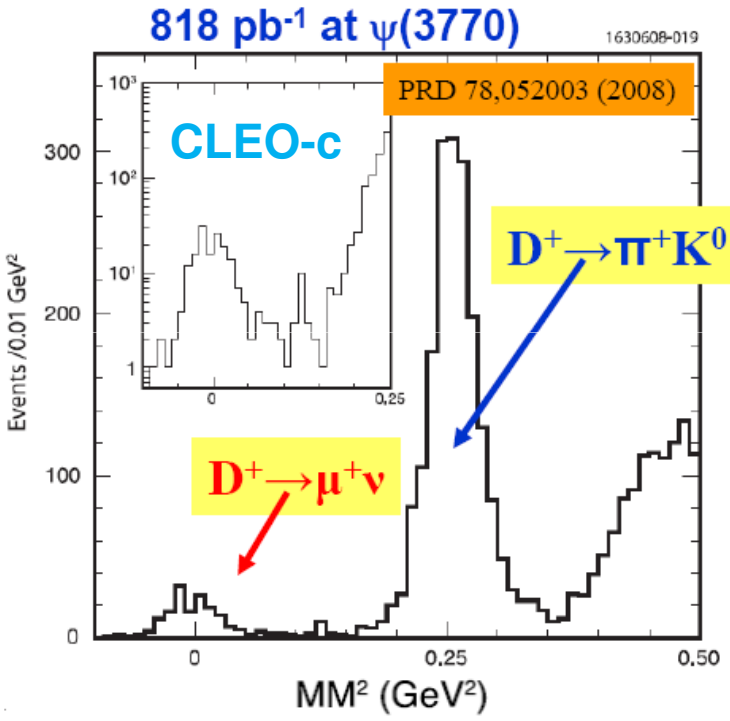
@ charm threshold:

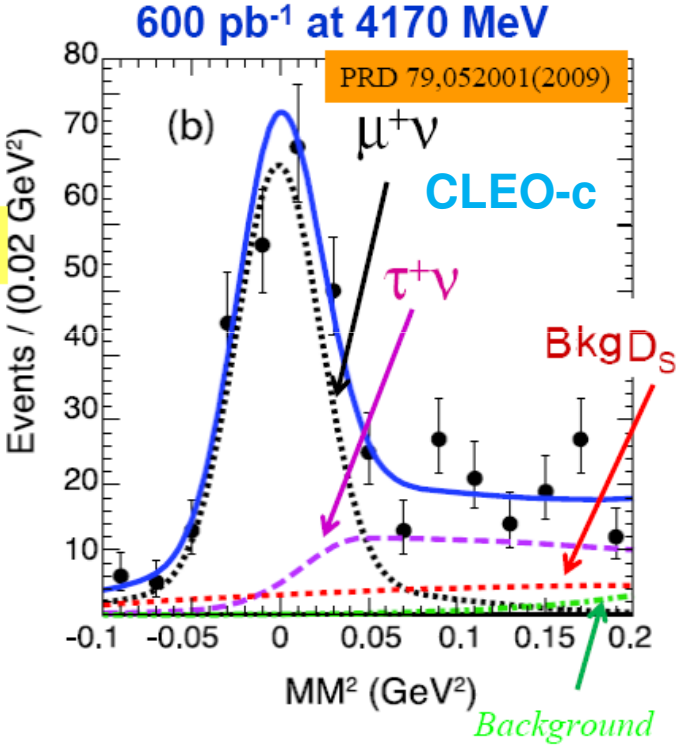
Tag-side:
- full reconstruction



Signal-side:
- Missing mass squared:

$$MM^2 = (E_D - E_\mu)^2 - (\vec{P}_D - \vec{P}_\mu)^2$$





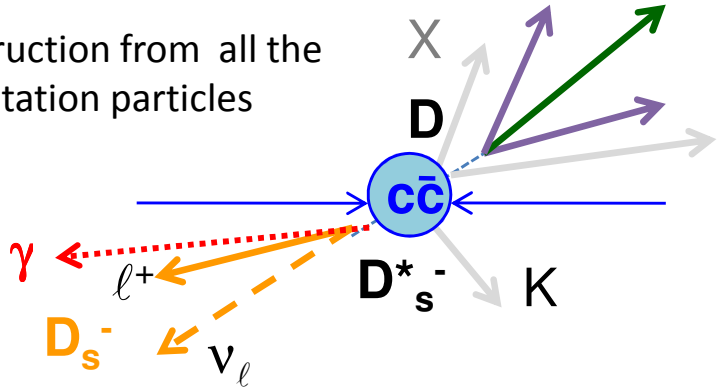
Leptonic Decays:

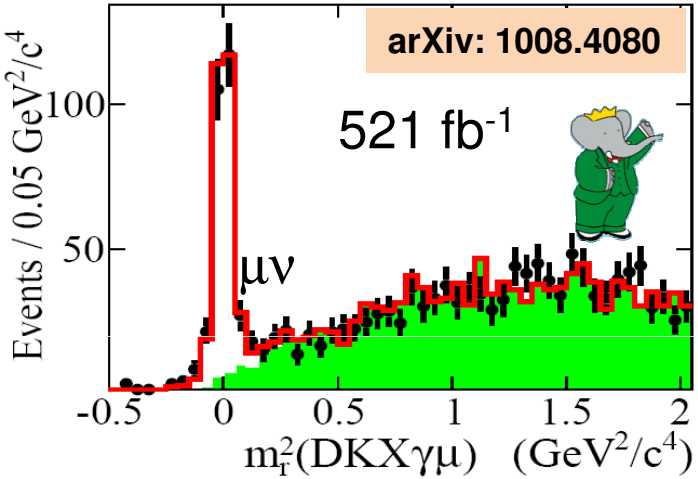
@ B-factories:

- D_s ($D_s^* \to D_s\gamma$) reconstruction from all the event including fragmentation particles

- Reconstructed mass:

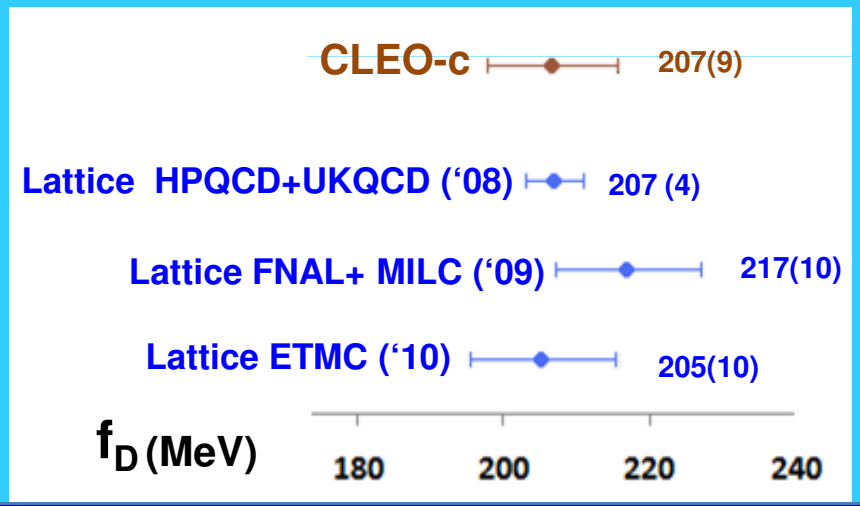
$m_r^2(DKX\gamma\mu)$

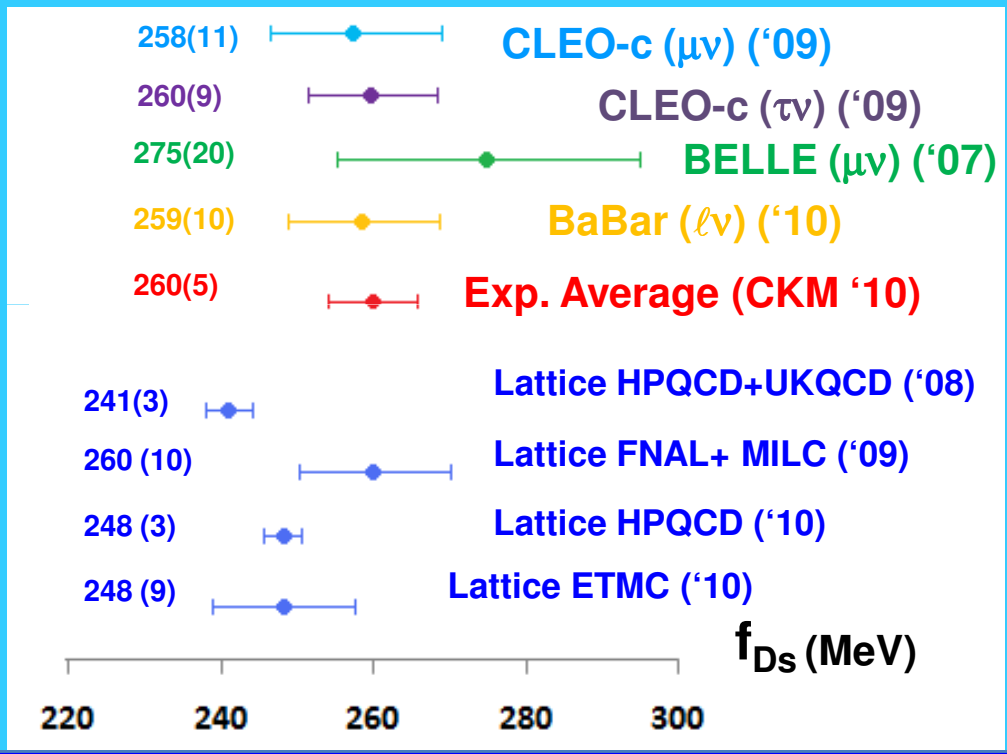




Present Status:

- **Good agreement between lattice and experiments on f_D, not so good (2σ) on f_{Ds}.**
- **Lattice quite precise.**

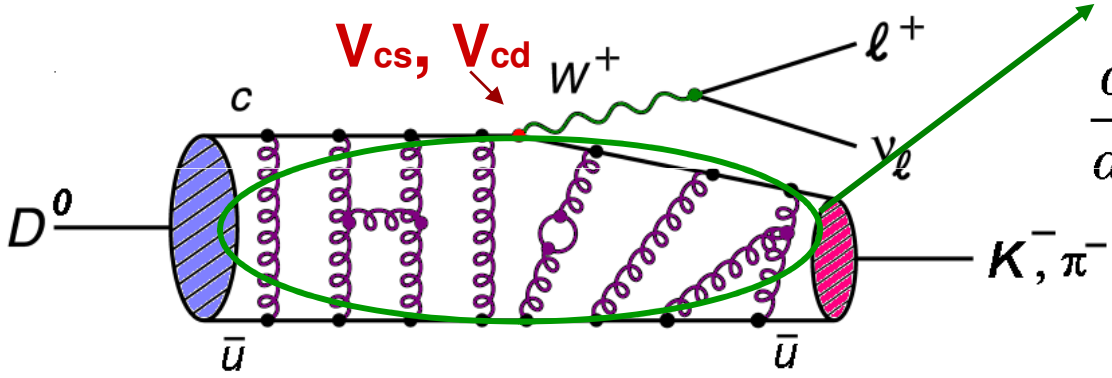




Semileptonic Decays

Measurement of form factors $f_+(q^2)$:

$q^2=(p_\ell+p_\nu)^2=(p_D-p_x)^2$



hadronic effects→
parameterized by form factors f(q²)

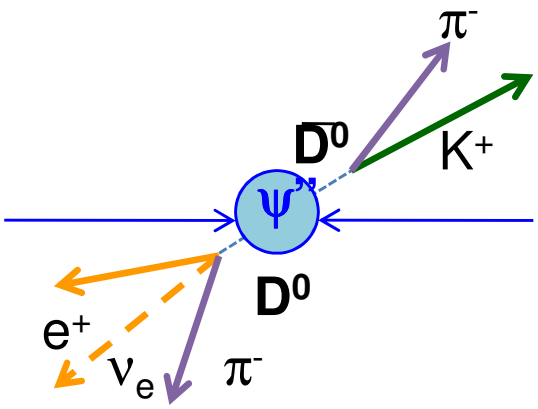
$$\frac{d\Gamma}{dq^2} = \frac{G_F^2}{24\pi^3} |V_{cd}|^2 p_\pi^3 (q^2) \left| f_+(q^2) \right|^2$$

Tests of Lattice-QCD calculations

1) Pseudoscalar: 1 form factor; D→Pℓν (P=K,π)

2) Vectorial: 3 form factors; $D_{(s)}$→Vℓν (V=K*, ρ,ϕ)

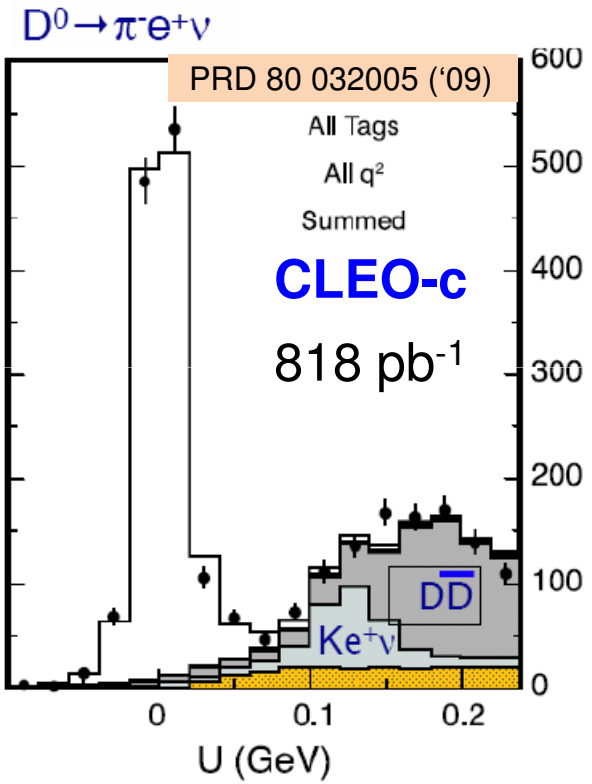
1) D→(K or π) ℓν



@ charm threshold:

-Full reconstruction in the tag side
- pion + lepton in the signal side
- U = $E_{miss} - |p_{miss}|$

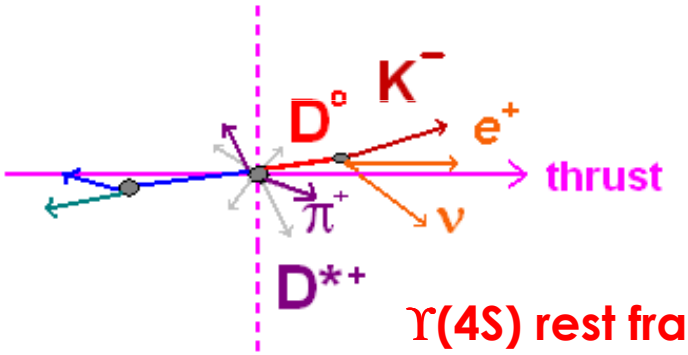
→ good signal/bkg separation
→ good q^2 resolution (~20 MeV²)

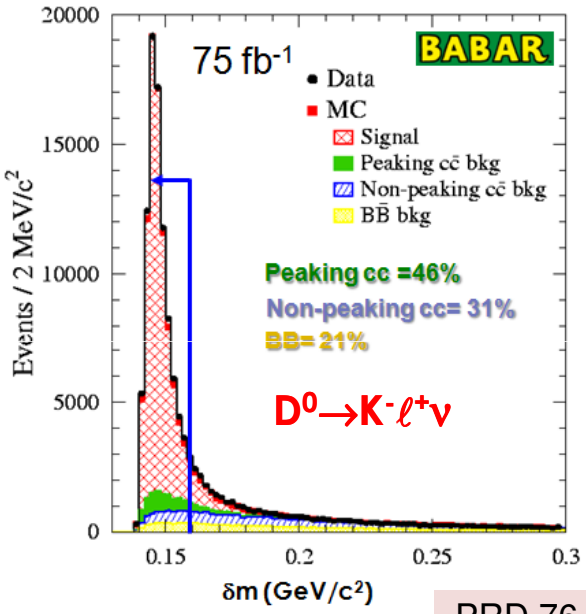


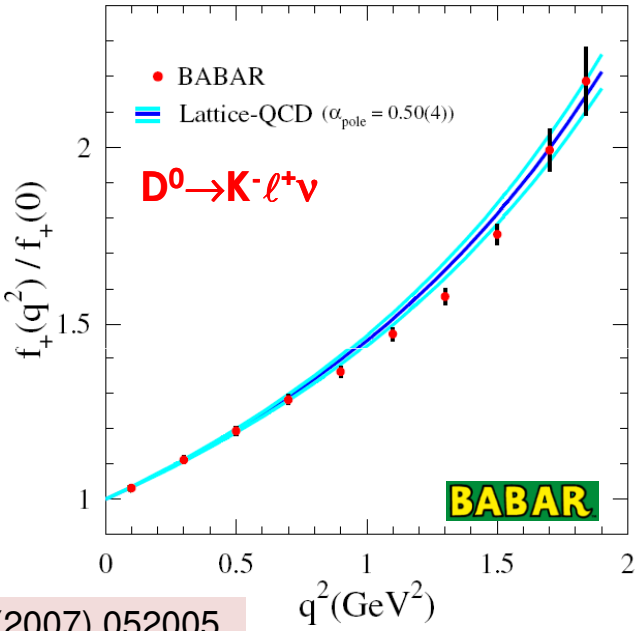
Semileptonic Decays

@ B-factories:

- Partial reconstruction (D* tag) @ BaBar and full reconstraction @ Belle (CLEO-c like)







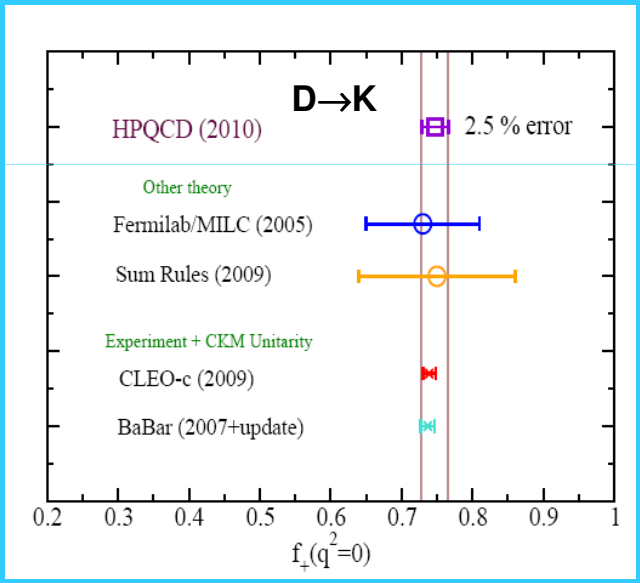
PRD 76 (2007) 052005

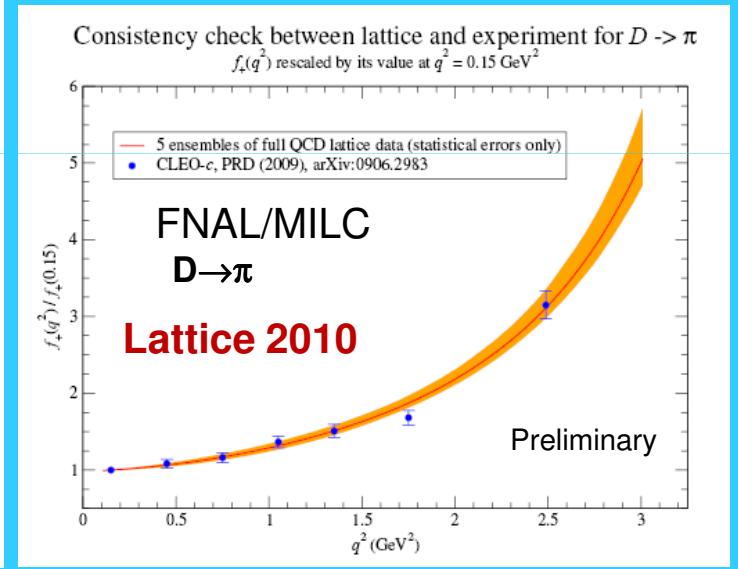
Present Status:

- Precise measurements of D→Kℓν and D→πℓν form factors (BaBar, CLEO-c)

- New precise results from Lattice agree with experiment

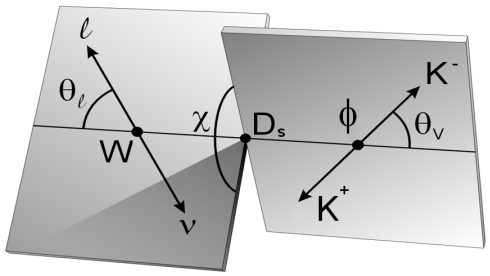
- New preliminary results from CLEO-c on D→η ℓν form factor





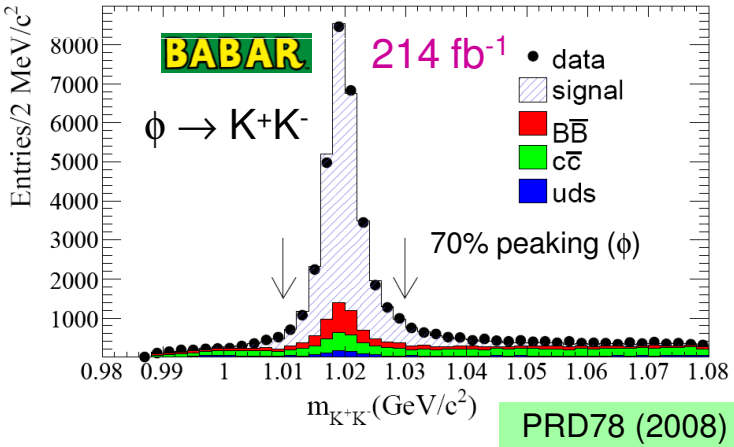
Semileptonic Decays

2) $D_s \to \phi \ell \nu$



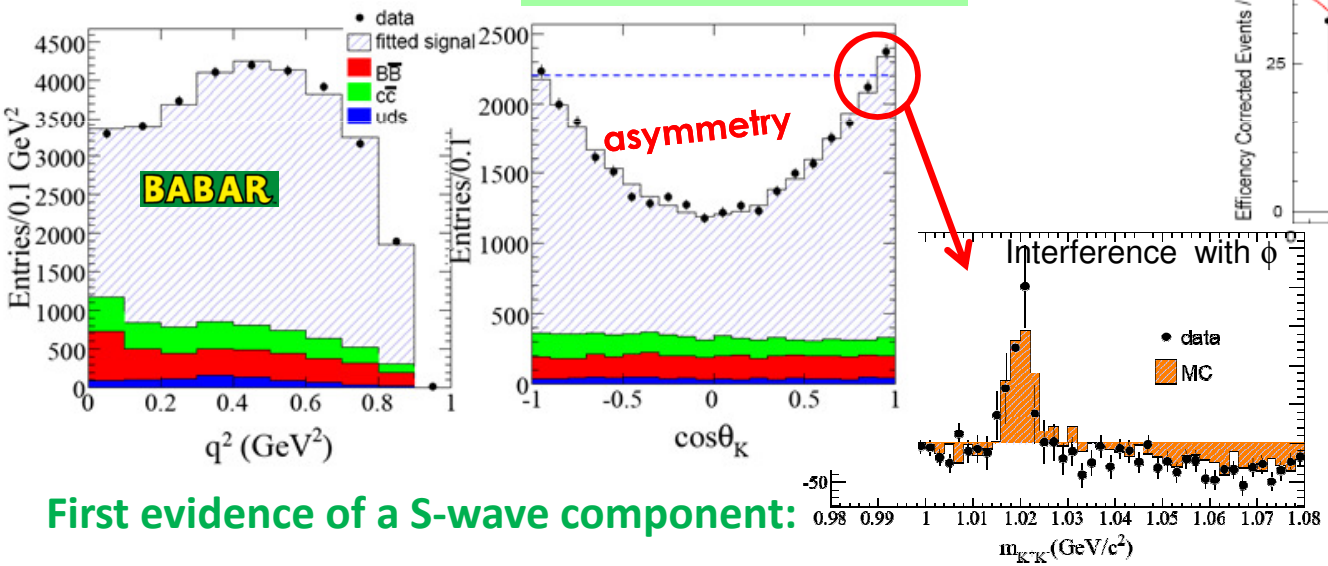
@ B factories : $D_s \to KK e\nu$

-Partial reconstruction method



dΓ depends on
$q^2, \theta_V, \theta_l, \chi$
and 2 form factor ratios:
r_V and r_A

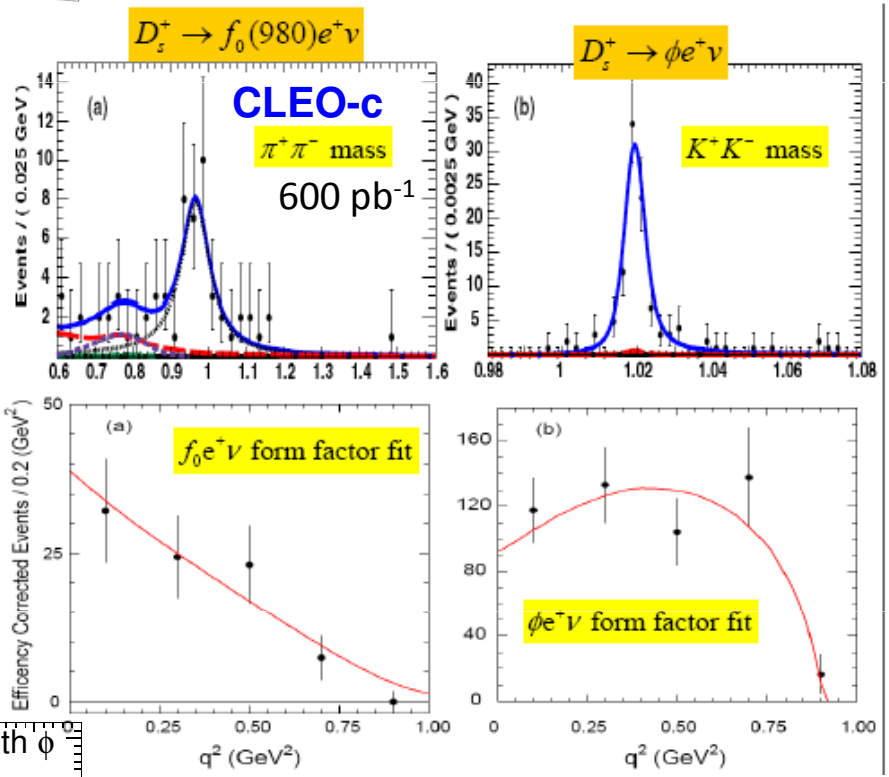
PRD78 (2008) 051101 (RC)



First evidence of a S-wave component:

@ charm threshold:

- Full reconstruction method
-Also visible the 0^+: f_0 (980)



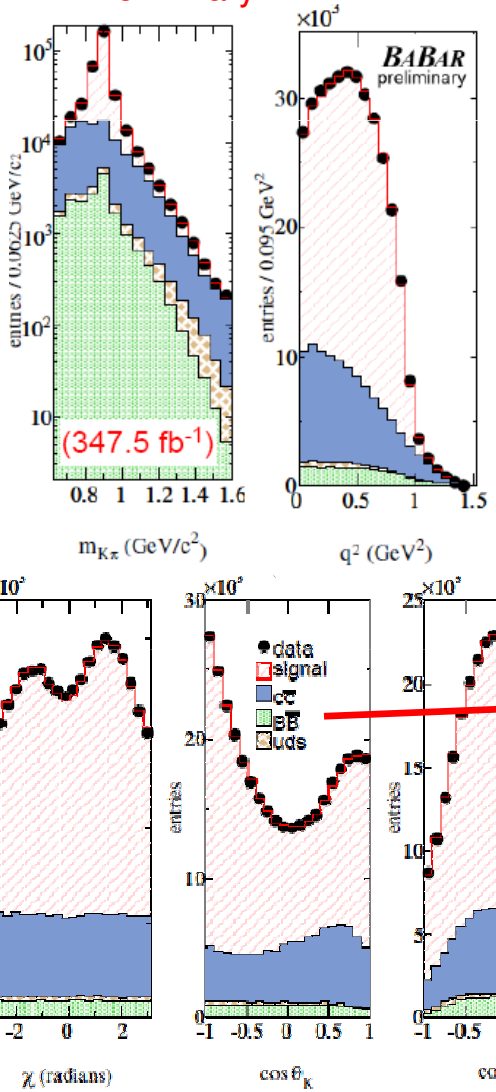
PRD 80 (2009) 052009

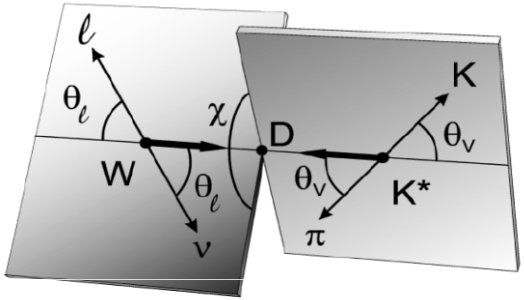
Semileptonic Decays

2) D→K*ℓν

@ B factories : D→Kπeν

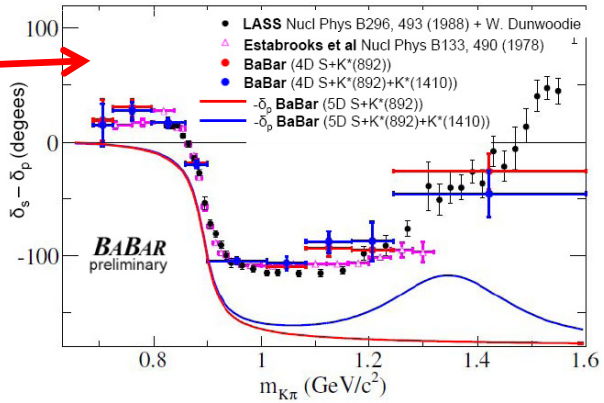
Preliminary





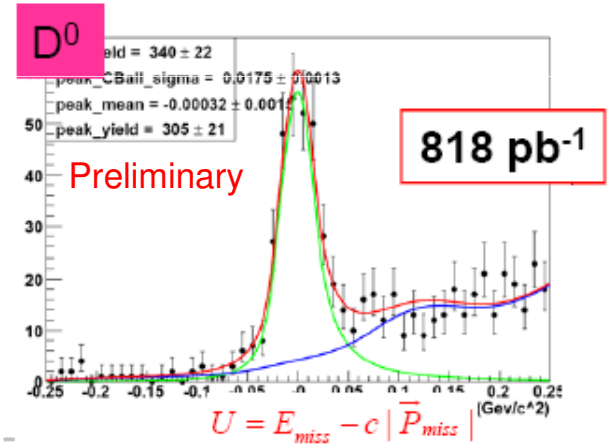
dΓ depends on
m, q^2, θ_V, θ_l, χ
and 2 form factor ratios:
r_V and r_2

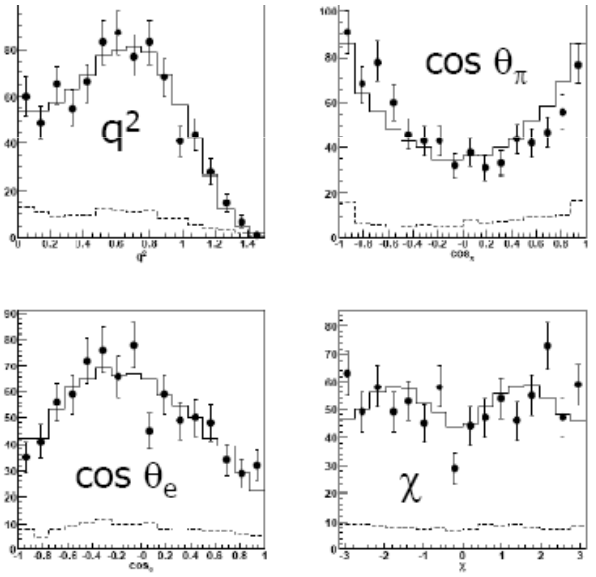
Also measures the phase difference between S and P waves:



@ charm threshold:

- Full reconstruction method
- Also measure the suppressed decay D→ ρeν (ρ→ππ)



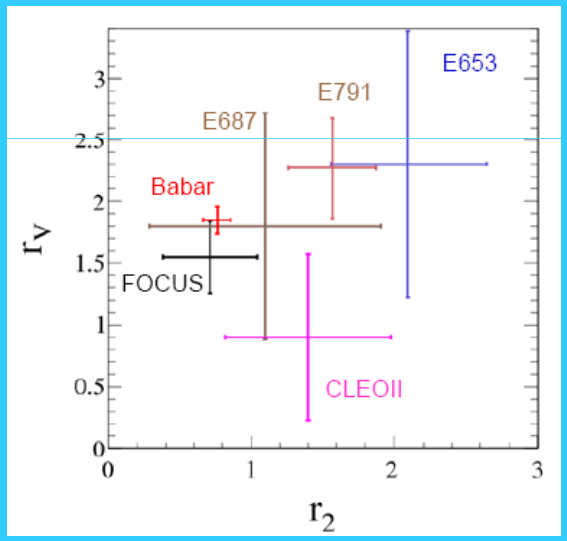


Semileptonic Decays

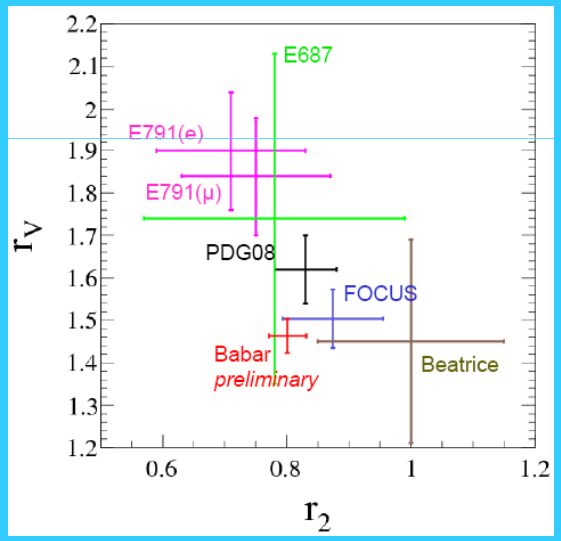
Present Status:

- Accurate measurements of form factors:

Ds→φℓν

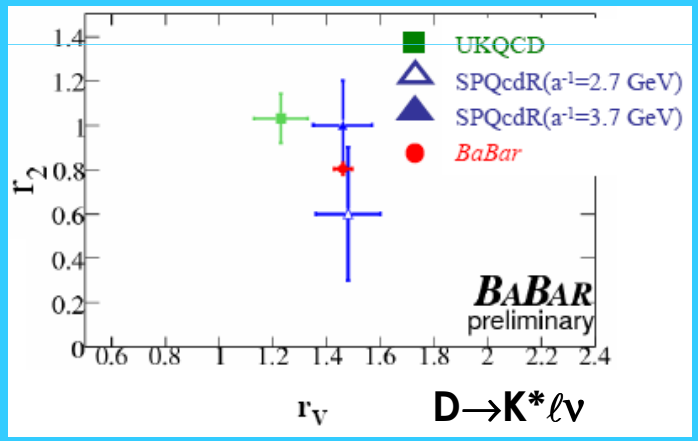


D→K*ℓν



- Lattice lacks precision:

Comparison with LQCD:



Flavour independence of D → Veν

	$D^+_s \to \phi e^+ \nu$	$D^+ \to K^{*0} e^+ \nu$
$A_1(0)$	0.61±0.03	0.62±0.01
r_2	0.76±0.10	0.80±0.03
r_V	1.85±0.11	1.46±0.04
m_A (GeV/c^2)	2.3±0.3 BaBar	2.63±0.16 BaBar

Preliminary

D→ρℓν
0.83 ± 0.15
1.48 ±0.12
CLEO-c

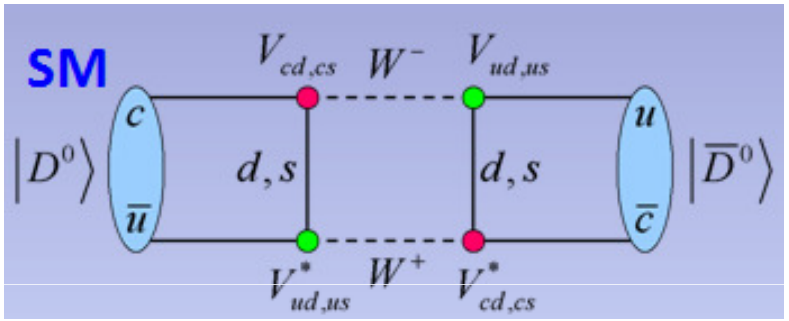
- No evidence of flavour dependence of form factors

Mixing and CP Violation

- **Charm mixing:**
  mass and flavor eigenstates are different

$$|D_{1,2}\rangle = p|D^0\rangle \pm q|\overline{D}^0\rangle$$

$$|p|^2 + |q|^2 = 1$$



The mixing is measured with two parameters: x and y

$x=(m_1-m_2)/\Gamma$ (with $\Gamma=(\Gamma_1+\Gamma_2)/2$)

$y=(\Gamma_1-\Gamma_2)/2\Gamma$

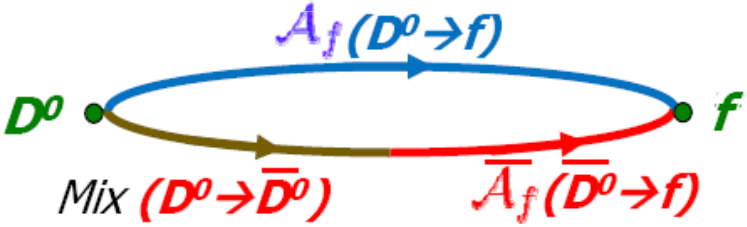
In the SM $|x|$ and $|y| << 10^{-2}$

- **New Physics can enter in x**
- **Long distance hadronic effect enter in x and y**

- **CP Violation in the SM may occur at per mil level and could be found:**

  - **In the decay (direct)** $\left|\frac{\overline{A}_{\overline{f}}}{A_f}\right| \neq 1$

  - **In mixing (indirect)** $\left|\frac{q}{p}\right| \neq 1$



  - **In the interference between mixing and decay**

Weak phase:

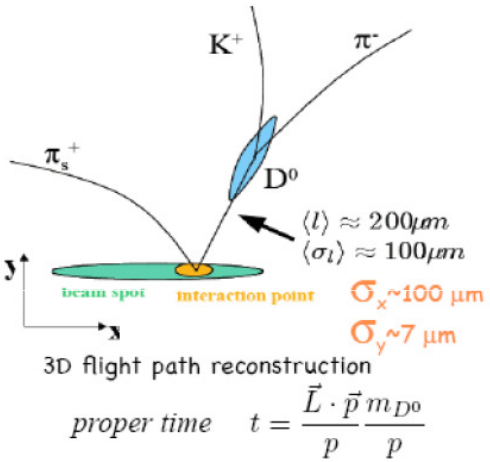
$$\phi_f = \arg\left(\frac{q}{p}\frac{\overline{A}_f}{A_f}\right) \neq 0, \pi$$

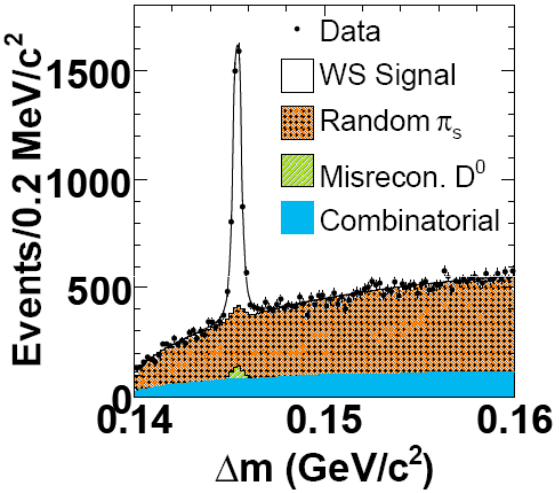
Mixing and CP Violation

@ B factories:

Time dependent mesurements:

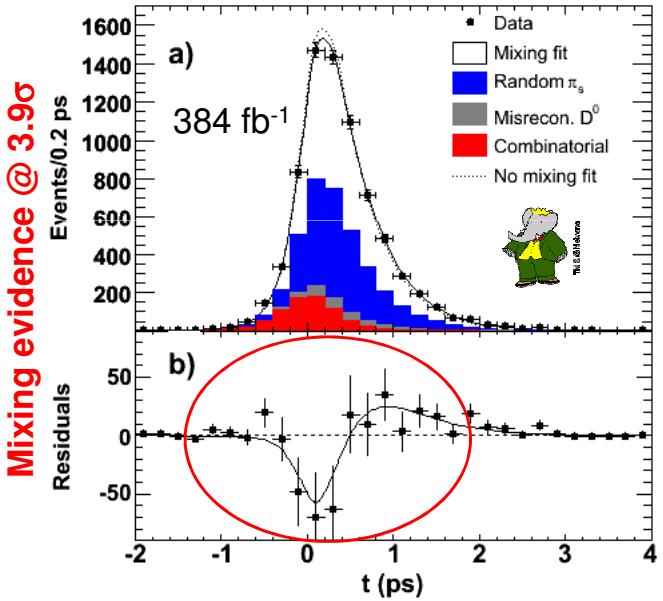
- Select D^0 mesons from $D^{*+} \to D^0\pi^+$ (tags flavour)
- $\Delta m = mD^{*+} - mD^0$ to supress bkg.
- Measure the decay time ($\sigma_t \sim 0.2$ ps)





First evidence for D^0-D^0 mixing

Wrong sign $D^0 \to K^+\pi^-$ decays:
RS/WS ratio as function of time,
extract rotated mixing parameters (x'^2, y').



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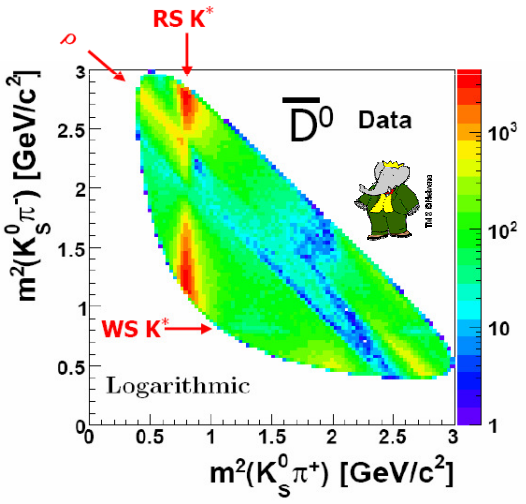
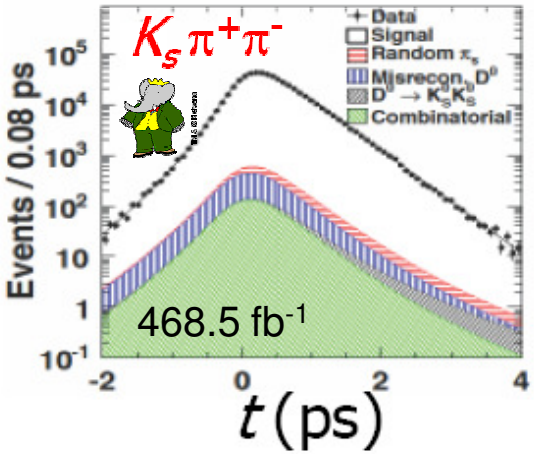
Amplitude analysis of $D^0(t) \to K_s\, h^+h^-$

Average decay time as function of Dalitz-plot position allows to get the mixing parameters x and y





Mixing and CP Violation

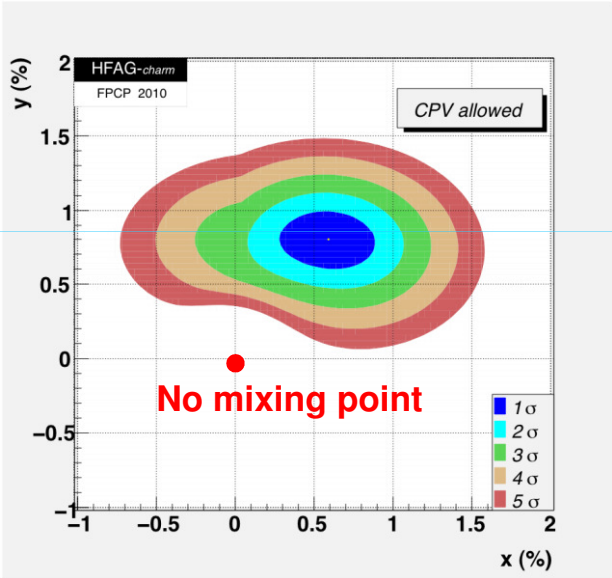
Present Status:

- Time dependent measurements, many experimental results (no individual 5σ):

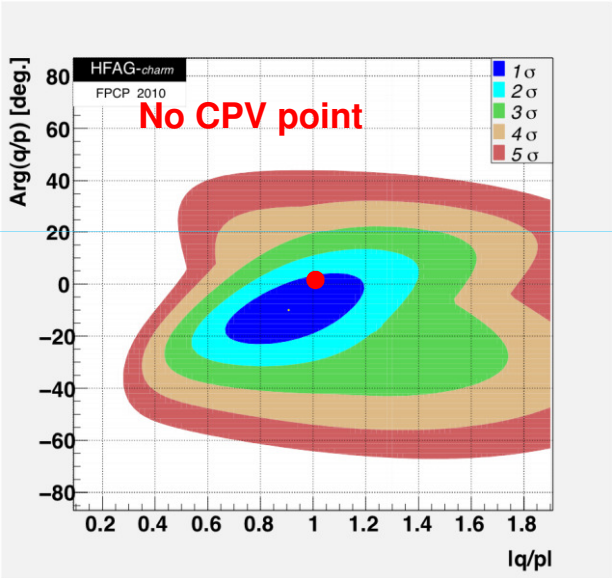
$D^0 \to K^+\pi^-$	★ B D	*study of the time dependence*
$D^0 \to K^+K^-, \pi^+\pi^-$	★ B	*lifetime ratio wrt* $D^0 \to K^-\pi^+$
$D^0 \to \phi K^0_S$	B	*lifetime difference between CP-even and CP-odd eigenstates*
$D^0 \to K^+\pi^-\pi^0$	★	*time-dependent Dalitz plot analysis*
$D^0 \to K^0_S\pi^+\pi^-$	New ★ B	*time-dependent Dalitz plot analysis*
$D^0 \to K^0_S K^+K^-$	New ★	*time-dependent Dalitz plot analysis*
$D^0 \to K^{(*)}l\nu$	B	*time-integrated analysis*

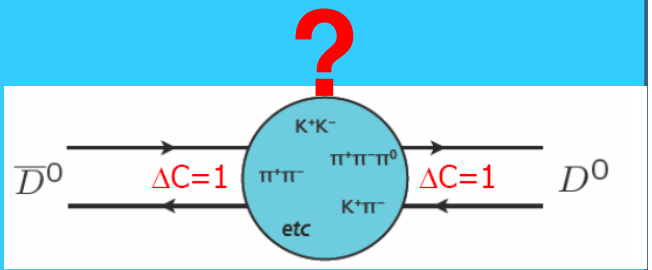
Legend: ★ = mixing evidence > 3σ New = new result

- Mixing established at 10.2σ



- No CPV point within 1σ





- SM predictions difficult due to non-perturbative (long-distance) contributions…

Mixing and CP Violation

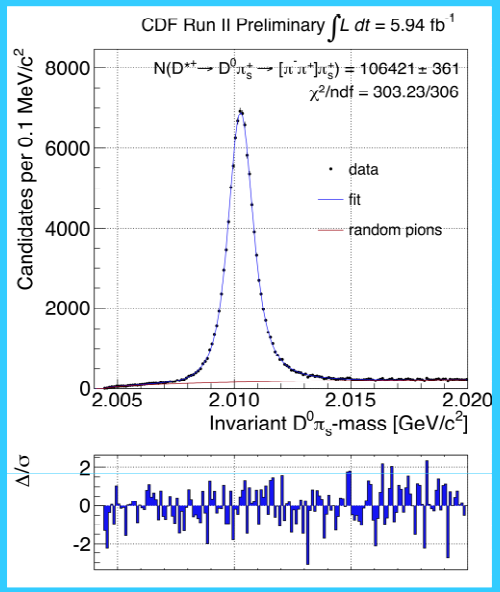
Present Status:

- Direct CP Violation

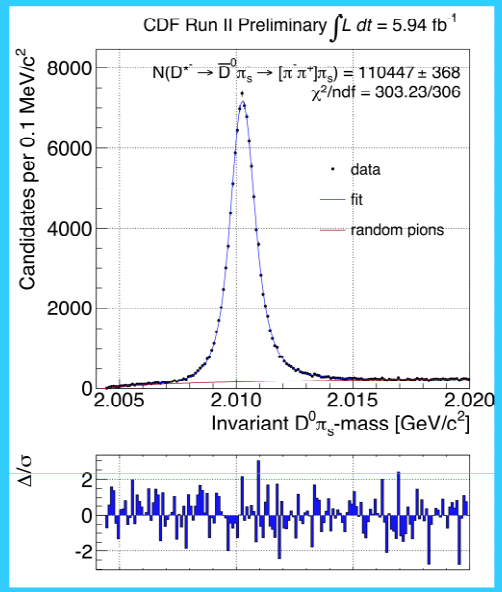
$$A_{CP}^{f} = \frac{\Gamma(D^0 \to f) - \Gamma(\bar{D}^0 \to f)}{\Gamma(D^0 \to f) + \Gamma(\bar{D}^0 \to f)}$$

New result from CDF ($D^0 \to \pi^+\pi^-$): ~ 220,000 $D^{*+} \to D^0 \pi^+ \to (\pi^+ \pi^-) \pi^+$

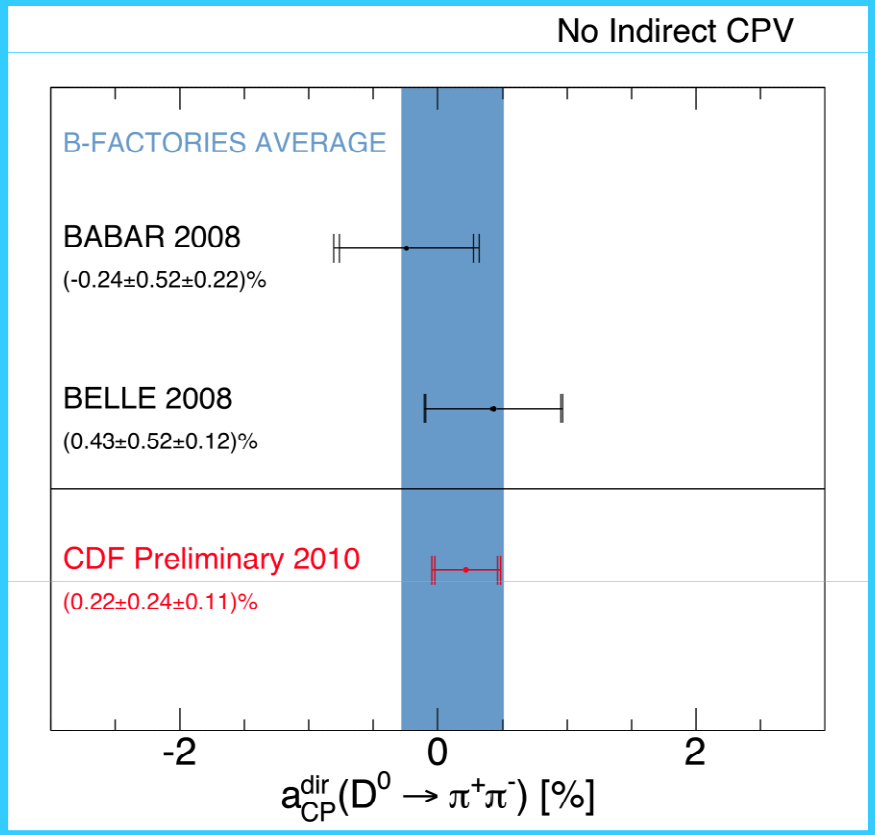
(Released to public October 1st, 2010)



$N^+ = 106{,}421 \pm 361$



$N^- = 110{,}447 \pm 368$



Further info: www-cdf.fnal.gov/physics/new/bottom/100916.blessed-Dpipi6.0/

$-A_{CP}$ (K^+K^-) = -0.0016 ± 0.0023 (HFAG)

No direct CPV @ permil level

Rare and forbidden decays

- **Lepton decays** ($D^0 \to \ell^+\ell^-$), **GIM suppressed decays** ($D \to$ Meson $\ell^+\ell^-$), decays violating **Lepton Flavour** ($D \to e\mu$) or **Lepton Number** ($D^+ \to$ Meson $\ell^+\ell^+$)

  → Very suppressed ($B < 10^{-6}$), ultra-suppressed or forbidden in the SM

  → New Physics could enhance the rates through virtual non-standard particles

Present Status:

- Some present results and projections (BESIII with $20fb^{-1}$)

	SM 10^{-6}	Current limit 10^{-6}	BESIII 10^{-8}
$D^+ \to K^-e^+e^+$	0	4.5 (CLEO-c)	6.7
$D^+ \to \pi^-e^+e^+$	0	3.6 (CLEO-c)	5.6

	SM ($\times 10^{-6}$)	Current limit ($\times 10^{-6}$)	BESIII 10^{-8}
$D^+ \to K^+\mu^-\mu^+$	-	9.2 (FOCUS)	10.5
$D^+ \to \pi^+\mu^-\mu^+$	1.9	8.8 (FOCUS)	8.7
$D^+ \to K^+e^-e^+$	-	3 (CLEO-c)	6.7
$D^+ \to \pi^+e^-e^+$	2.0	5.9 (CLEO-c)	5.6

	SM	Current Limit	CLEO-c	BESIII
$D^0 \to e^+e^-$	10^{-23}	7.9×10^{-8} (Belle)	6.9×10^{-7}	2.4×10^{-8}
$D^0 \to \mu^+\mu^-$	10^{-13}	1.4×10^{-7} (Belle)	--	1.7×10^{-7}
$D^0 \to e^\pm\mu^\mp$	0	2.7×10^{-7} (Belle) 8.1×10^{-7} (BaBar)	-	4.3×10^{-8}

Summary

Measurements in the charm sector are important for the CKM picture → control of hadronic effects, validation of Lattice QCD
It can also give signs of New Physics

- **Leptonic decays:**
  theory and experiment agree on $D \to \ell\nu$, not so well on $D_s \to \ell\nu$ (2σ)
  Some results from LQCD more accurate than experiment (BESIII?)

- **Semileptonic decays:**
  Experimental results from B-Factories and CLEO-c agree
  Theory lacks precision (LQCD for sl decays improving…)

- **Charm mixing:**
  Charm mixing established, need to separate x and y. No CPV at present.
  What does the SM say?

- **Rare decays:**

  Sensitivity ~10^{-6} -10^{-7}, waiting BESIII (~10^{-8} with 20fb^{-1}) and/or SuperB, LHC-b?