Charm Activities

Giulia Casarosa - INFN Pisa

outline:

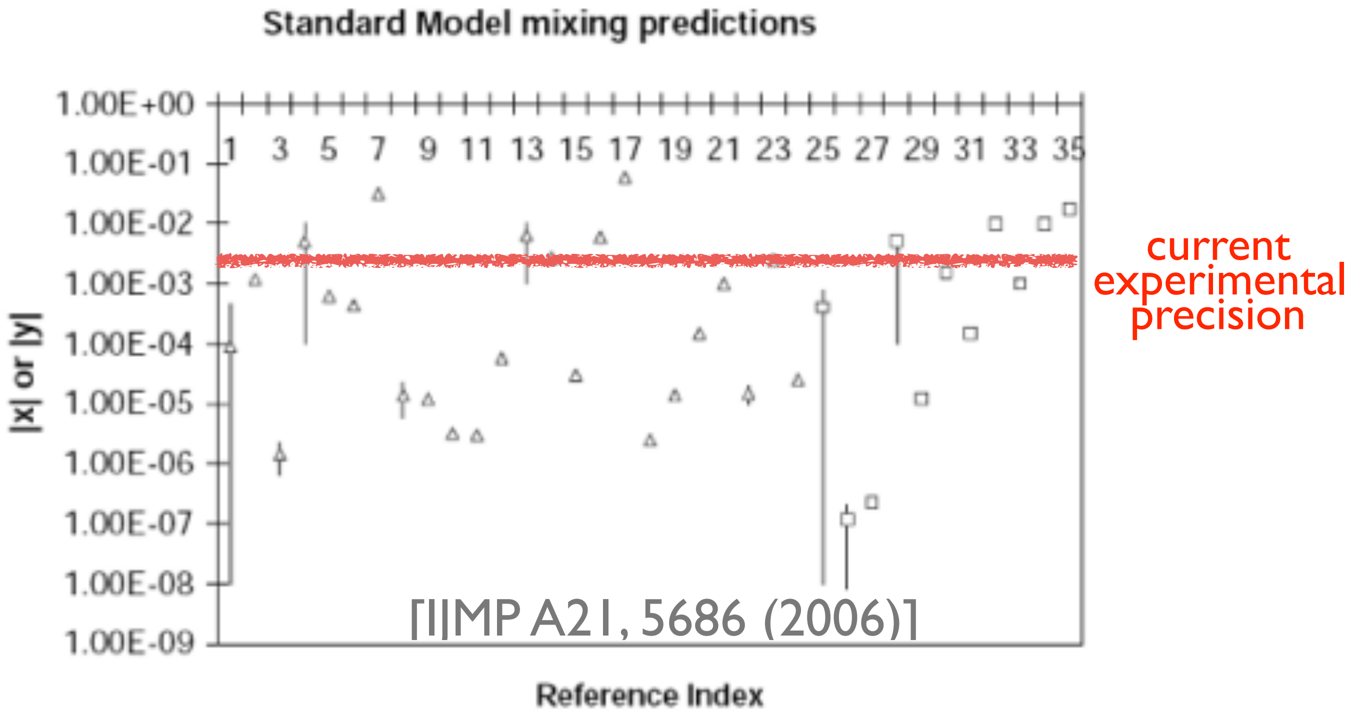
- *charm golden channels*
- *status of the ongoing work*
- *new ideas & projects*

4^{th} *Belle II* Italia ~ Roma December, 21^{st} 2015

Are there Golden Channels in Charm?

➡ The Standard Model *predictions* on mixing and CP Violation parameters are affected by large uncertainties due to the difficulties in the computation of the dominant long-distance contributions:

- computation of D-mixing diagrams is non perturbative
- the available computational power is not enough for lattice QCD



➡ **Theory needs experimental inputs not only to check the final predictions but also to test the model hypotheses**

- employ a parameterisation that is appropriate for the level of precision expected in the *BelleII*/LHCb-upgrade era
- infer the presence of NP in direct CPV measurements using SM SU(3) relations (+ evaluate SU(3) breaking)

➡ **Golden Channel does not only mean "sensitive to NP" charm.**

- e.g. $D^+ \to \pi^+\pi^0$ is golden since SM contribution to A_{CP} is small and there are no QCD penguins to estimate

The (many) Charm Golden Channels

2. Hadronic Modes

time-dependent CPV & mixing, time-integrated analyses, A_{CP} ⟵ (a) $D^0 \to K^+\pi^-, K^+K^-, \pi^+\pi^-$

time-integrated analyses, A_{CP} ⟵ (b) $D^0 \to K^0_S K^0_S, \pi^0\pi^0, D^+ \to \pi^+\pi^0$, $D^0 \to K_S\pi^0$, more FCNC

Dalitz Plot Analyses time-dependent CPV & mixing ⟵ (c) $D^0 \to K^0_S K^+K^-, K^0_S K^+\pi^-, K^+\pi^-\pi^0, K^0_S\pi^+\pi^-, \pi^+\pi^-\pi^0$

+ T violation with $D^0 \to K_S\pi^0\pi^+\pi^-$

3. Semileptonic Modes

4. Leptonic and Radiative Decays

important for lattice QCD ⟵ (a) $D^+_{(s)} \to e^+\nu, \mu^+\nu, \tau^+\nu$

NP searches ⟵ (b) $D^0 \to \rho^0\gamma$, $D^0 \to \omega\gamma$, $D^0 \to \gamma\gamma$

5. Other (more exotic stuff)

e.g. light dark matter searches ⟵ (a) missing energy modes

(b) glueballs

(c) $D^+_s \to p\bar{n}$

basf2 Simulation Studies

Alan is studying BelleII sensitivity to CPV, given the improvement in t resolution

Giulia (+…any volunteer?) will start looking at the A_{CP} analysis in basf2

time-dependent CPV & mixing, time-integrated analyses A_{CP} ⟵ (a) $\boxed{D^0 \to K^+\pi^-}$, K^+K^-, $\pi^+\pi^-$

what's the ultimate prediction on x?

ti ⟵ (b) $D^0 \to K^0_S K^0_S$, $\pi^0\pi^0$, $D^+ \to \pi^+\pi^0$, $\boxed{D^0 \to K_S \pi^0}$, more FCNC

Dalitz Plot Analyses time-dependent CPV & mixing ⟵ (c) $D^0 \to K^0_S K^+K^-$, $K^0_S K^+\pi^-$, $K^+\pi^-\pi^0$, $K^0_S \pi^+\pi^-$, $\pi^+\pi^-\pi^0$

The $D^0 \to K_S\pi^0\pi^+\pi^-$ analysis is ongoing in Belle, ➪ estimate sensitivity at BelleII (Chennai)

+ $\boxed{T \text{ violation with } D^0 \to K_S \pi^0\pi^+\pi^-}$

4. Leptonic and Radiative Decays

important for lattice QCD ⟵ (a) $\boxed{D^+_{(s)} \to e^+\nu,\ \mu^+\nu,\ \tau^+\nu}$

Jake (CMU) will start looking at leptonic reconstruction in basf2

NP searches ⟵ (b) $\boxed{D^0 \to \rho^0\gamma,\ D^0 \to \omega\gamma,}$ $\boxed{D^0 \to \gamma\gamma}$

The $D^0 \to V\gamma$ analysis is near completion in Belle, ➪ estimate sensitivity at BelleII (Ljubljana)

tic stuff)

The $D^0 \to \gamma\gamma$ analysis is near completion in Belle, ➪ estimate sensitivity at BelleII (TATA)

e.g. light dark matter searches ⟵ (a) missing energy modes

(b) glueballs

(c) $D^+_s \to p\bar{n}$

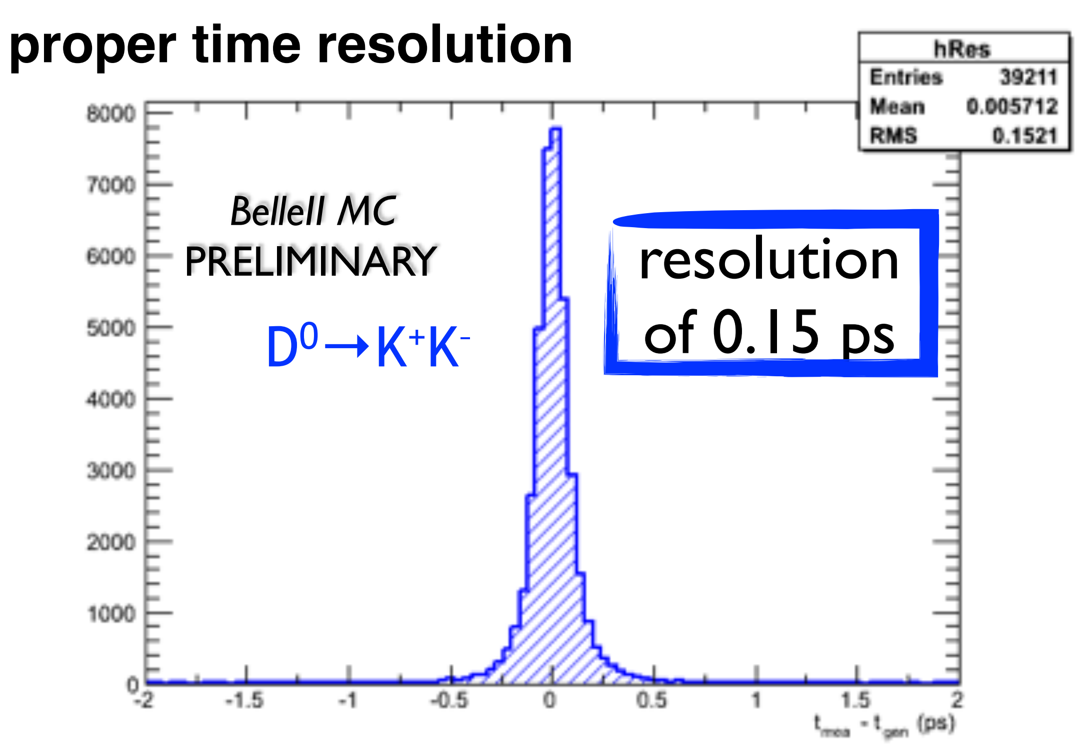
*Giacomo (Pisa) is studying the feasibility of **prompt D^0 flavour tagging**: increase the statistics + provide control samples for many analysis*

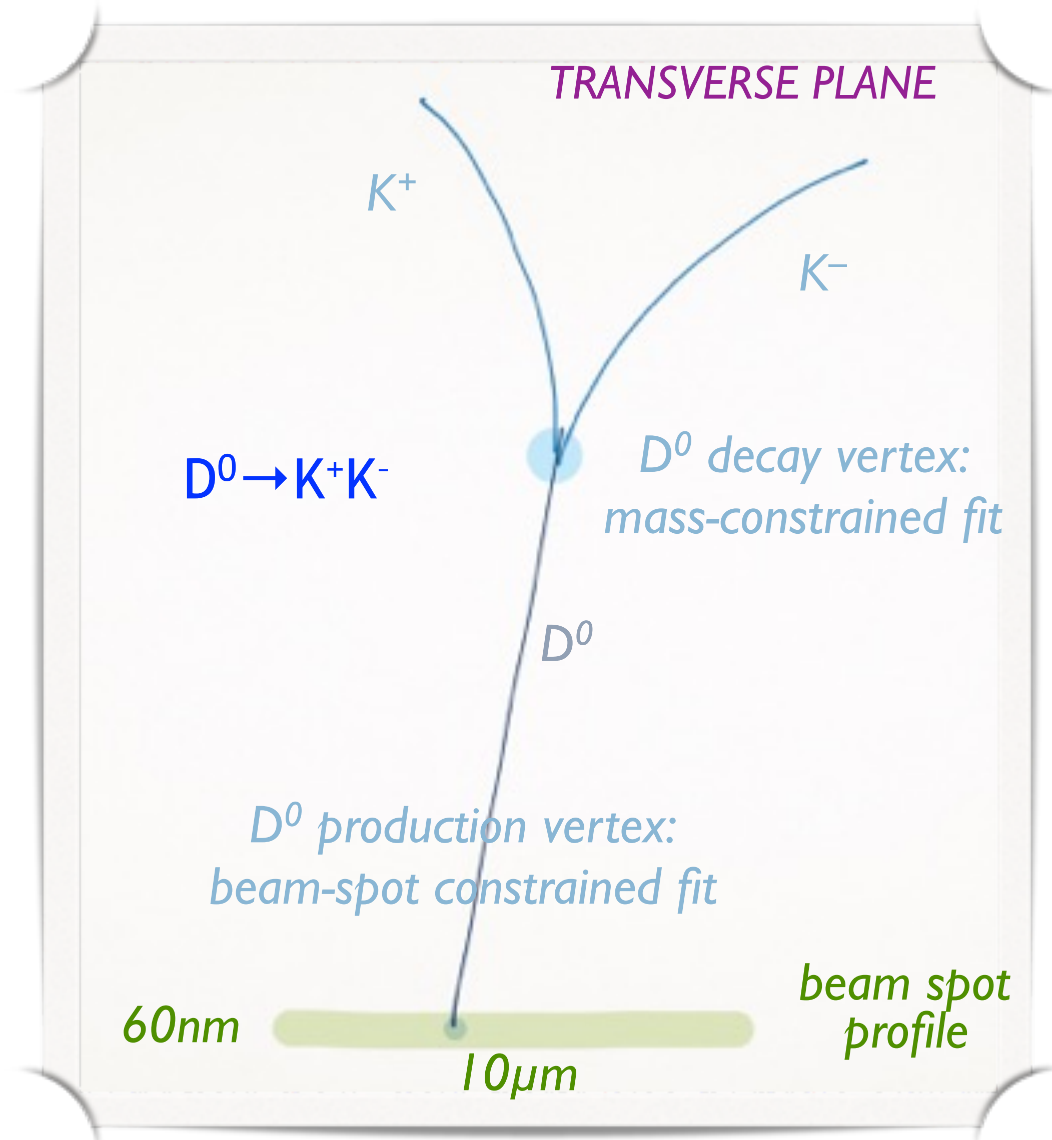
Proper Time Resolution for $e^+e^- \to D\,X$

➡ We can measure the proper time of D^0 coming directly from the hadronization of the charm quark with comparable precision.

➡ This measurement was not possible at B-Factories

➡ The flavour of the D^0 at production cannot be tagged in the standard way ($D^* \to D^0\pi$)



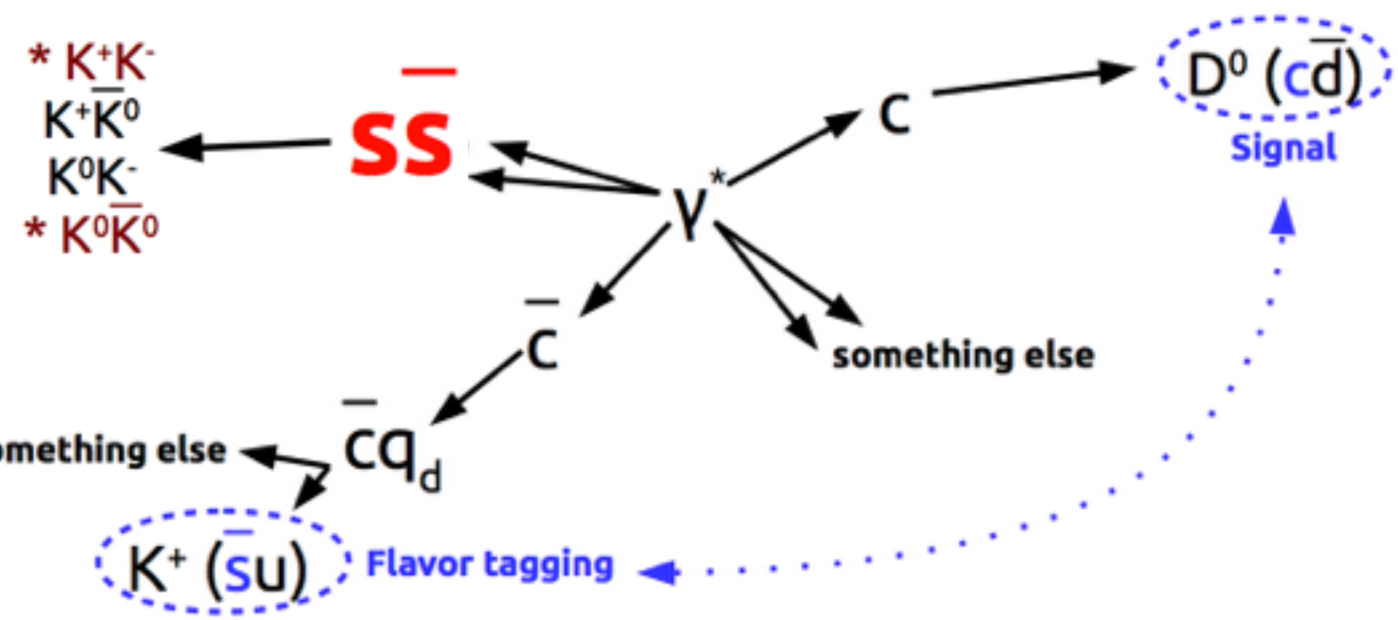


NOTE: the cartoon is not to scale

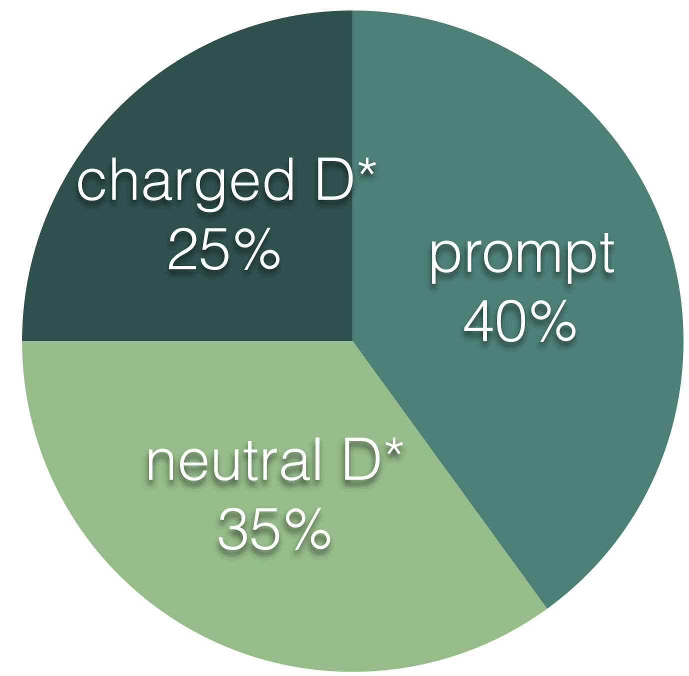
Prompt D^0 Flavour Tagging

Giacomo De Pietro

- ➡ Only 1/4 of the D^0 produced in the $e^+e^- \to c\bar{c}$ events are flavour tagged with $D^{*+} \to D^0\pi^+$ and used for CP violation measurements
- ➡ Implement a reconstruction technique that allows to tag the flavour the rest 75% of produced D^0 looking at the rest of the event
  - select events with one single charged K in the rest of the event



D⁰ mothers in cc̄ events



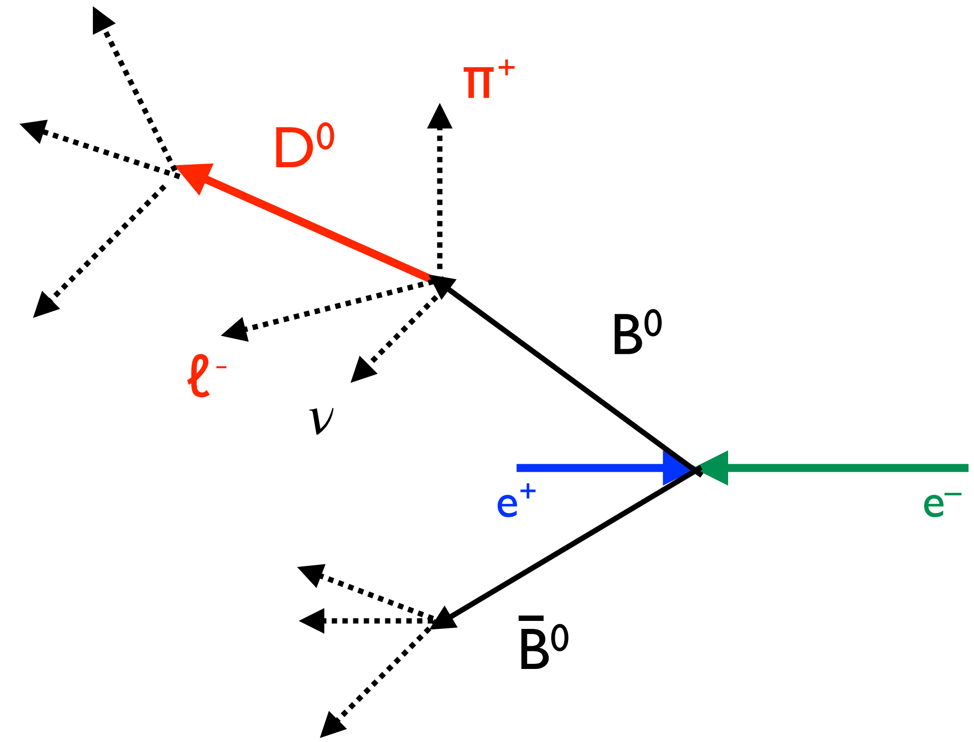
- ➡ First Results are encouraging 20% reconstruction efficiency

see Giacomo's slides

Charm from B Decays

$B^0 \rightarrow D^{*+} \ell^- \nu,$

$\quad\hookrightarrow D^0 \pi^+$



Partial Reconstruction of the B assuming…

- ➡ B^0 is at rest in the center-of-mass of the Υ(4S) (p=380MeV/c)
- ➡ D^0 produced at rest in the center-of-mass of the D^{*+}, therefore:
  - $p(D^{*+}) = \alpha + \beta\, p(\pi_s)$
  - D^{*+} and π_s have the same direction

…allows to compute the M_ν^2 peaking at 0 for signal.

Estimate from BABAR (200fb^{-1}onPeak + 22 fb^{-1} offPeak):
[M.Rotondo, F.Simonetto]

tag	# signal	purity
e	2150	52%
μ	1740	55%

1 ab^{-1}
6M
4.8M

= 10M/ab tagged D^0

Dark Matter Searches in Charm?

- $D \to \nu\nu$ decay is helicity suppressed in the SM resulting in a tiny branching ratio:
  - $BR(D \to \nu\nu) \simeq 1.1\ 10^{-30}$, adding a photon in the final state $BR(D \to \nu\nu\gamma) \simeq 4\ 10^{-14}$
- **New Physics** may enhance the branching ratio:
  - add a particle in the final state
  - introduce other ways of flipping helicity
- Missing Energy does not always mean neutrinos!
  - can be **light dark matter** candidates: $D \to$ invisible puts nice constraints on light dark matter properties!
- *Extremely* challenging from the experimental side
  - can use D from B decays and fully reconstruct the other B…
  - expected dominant background from K_L

Conclusions

➡ *BelleII* can do better in charm w.r.t. B-Factories than just luminosity scaling!

➡ basf2 simulations are needed in order to better estimate the improvements of channels already done at B-Factories and to have the first estimations on new channels/analyses

➡ The simulation activity has started!

- mostly Belle students extrapolating to *BelleII*
- Giacomo De Pietro on prompt D^0 tagging
- Jake Bennet (on leptonic/semileptonic reconstruction)
- more people needed…

➡ There are interesting things to do: new/better detector = new things we can do

➡ Let's grow the Italian contribution to charm…


WHOA!
SCREECH
MIKE KEEFE THE DENVER POST 2005
Charm
RECRUITING
JOIN
TODAY,
GET A
FREE
iCharm


iCharm
Home Button Accessory
for
ヨドバシは税込価格
¥
Belle II
消費税8%を含んだ価格です

backup slides

General Comments from the Experimental Side

"Golden mode" definition:

a mode in which Belle II will be competitive (with LHCb) and, if NP is present at a sufficiently large level, its signature will be measured/identified

★ good criteria to select among the many channels and observables

Future work to complete our report:

A. Schwartz

- *Belle II decay time resolution: improvement over Belle due to pixel layers*
- *Systematic error budget: which errors are scalable with luminosity, which are not (and how to treat them)*
- *BASFII simulation: more realistic MC study with proper Belle II detector acceptance/response (esp: pixels, SVD, CDC tracking, iTOP)*

★ Need basf2 simulation studies in order to have a better estimate of the expected precision that takes into account improvements in the detector & reconstruction techniques for the other channels

- the impact of the better time resolution on the mixing parameters has been evaluated with basf2 simulation + ToyMC

CP Asymmetries

2. Hadronic Modes

time-dependent CPV & mixing, time-integrated analyses, A_{CP} ⟵ (a) $D^0 \to K^+\pi^-, K^+K^-, \pi^+\pi^-$

time-integrated analyses, A_{CP} ⟵ (b) $D^0 \to K^0_S K^0_S, \pi^0\pi^0, D^+ \to \pi^+\pi^0$, $D^0 \to K_S \pi^0$, more FCNC

time-depe

$\pi^0\pi^+\pi^-$

impo

e.g. light c

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

- [t] remember the ΔA_{CP} saga: is it NP or SM? Need to estimate the size of penguin/penguin contractions VS tree: hard to do
- [t] measuring BR and A_{CP} one can combine modes using sum rules and getting rid of the direct estimation of the SM contribution
- [e] it's worth doing these evergreen modes, the extrapolated final precision is comparable with LHCb

$D^+ \to \pi^+\pi^0$

- [t] golden since SM contribution to A_{CP} is small
- [t] no QCD penguin contribution (hard to estimate)

- [e] can do modes with neutrals in the final state that LHCb can't do
- [e] improved K_S reconstruction efficiency

Time-Dependence on A_{CP}

2. Hadronic Modes

time-dependent CPV & mixing, time-integrated analyses, A_{CP} ← (a) $D^0 \to K^+\pi^-$, K^+K^-, $\pi^+\pi^-$

time-integrated analyses, A_{CP} ← (b) $D^0 \to K^0_S K^0_S$, $\pi^0\pi^0$, $D^+ \to \pi^+\pi^0$, $D^0 \to K_S\pi^0$, more FCNC

Dalitz Plot Analyses time-dependent CPV & mixing ← (c) $D^0 \to K^0_S K^+K^-$, $K^0_S K^+\pi^-$, $K^+\pi^-\pi^0$, $K^0_S\pi^+\pi^-$, $\pi^+\pi^-\pi^0$

+ T violation with $D^0 \to K_S\pi^0\pi^+\pi^-$

3. Semileptonic Modes

import

e.g. light da

(b) glueballs

(c) $D_s^+ \to p\bar{n}$

$A_{CP}(t)$

[t] study the time-dependence of A_{CP} to increase sensitivity to CPV in the interference between decays with and without mixing

[e] We can do it. Time resolution may not be sufficient to give precision measurement of the *difference* in oscillation period between D^0 and $\overline{D^0}$, need to be studied.

[e] D^0 from D^* and prompt D^0 have compatible time resolutions, and a factor 2 better than Belle

NP Searches in Radiative Decays

2. Hadronic Modes

time-depen

time-inte

time-inte

time-depen

FCNC

$\pi^-\pi^0$

$\pi^0\pi^+\pi^-$

$D^0 \to \rho^0\gamma$, $D^0 \to \omega\gamma$ (i.e.: $D^0 \to V\gamma$)

- [e] *BelleII* can do modes with photons in the final state that LHCb can not do
- [t] long distance (LD) contributions are dominant
- [t] LD contributions complicate the interpretations of the measurements
- [t] find combinations of channels in which the LD contributions cancel:

$$R_{uu\gamma} = (\ \Gamma(D^0 \to \omega\gamma) - \Gamma(D^0 \to \rho\gamma)\ ) / \Gamma(D^0 \to \omega\gamma)$$

$$\rho^0 = (\underline{u}u - \underline{d}d)/\sqrt{2} \quad \text{vs} \quad \omega = (\underline{u}u + \underline{d}d)/\sqrt{2}$$

import

NP searches ⟵ (b) $\boxed{D^0 \to \rho^0\gamma,\ D^0 \to \omega\gamma}$ $D^0 \to \gamma\gamma$

5. Other (more exotic stuff)

e.g. light da

- [t] also consider isospin asymmetries:

$$R_I = (\ 2\Gamma(D^0 \to \rho^0\gamma) - \Gamma(D^+ \to \rho^+\gamma)\ ) / (\text{the sum})$$

[same for ω]

Modes with K_S in the Final State

2. Hadronic Modes

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Dalitz Plot Analyses, time-dependent CPV & mixing ⟵ (c) $D^0 \to K^0_S K^+K^-,\ K^0_S K^+\pi^-,\ K^+\pi^-\pi^0,\ K^0_S\pi^+\pi^-,\ \pi^+\pi^-\pi^0$

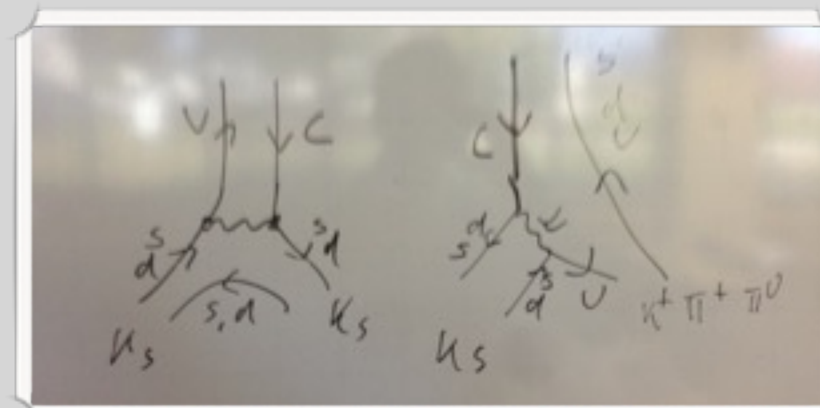
3. Semileptonic Modes — T violation with $D^0 \to K_S\pi^0\pi^+\pi^-$

import

e.g. light da

$D^0 \to K_SK_S$ & K_S in the final states

[t] Uli Nierste: SM direct CPV contribution smaller than 1.1% ($D^0 \to K_SK_S$)
(Phys. Rev. D **92**, 054036)



[e] K^0 regeneration in the material may be one of the limiting systematics at 50 ab^{-1} for A_{CP} measurements and it should be carefully evaluated

[e] CPV in K^0 should also be treated correctly

Other Scattered Comments on Hadronic Modes

2. Hadronic Modes

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3. Semileptonic Modes

+ T violation with $D^0 \to K_S\pi^0\pi^+\pi^-$

impo

[t] look for CP asymmetries in localised regions of the Dalitz Plots

[e] Yes we can do it, done already with $D^0 \to K^+\pi^-\pi^0$ at *BABAR*

[t] $D \to VV$ modes can help constrain LD contributions to the mixing parameters

5. Other (more exotic stuff)

e.g. light dark matter searches ⟵ (a) missing energy modes

(b) glueballs

(c) $D_s^+ \to p\bar{n}$

Leptonic Decays

2. Hadronic Modes

time-depe

time-int

time-int

time-depe

[e] D^+ decays not measured at Belle: no estimation on BR
[e] Anze has provided some results with Belle MC
[e] K_L will be the limitation of this measurement, a veto must be studied
[e] can try new reconstruction techniques given the better performances of tracking and vertexing

FCNC

$^+\pi^-\pi^0$

$\pi^0\pi^+\pi^-$

4. Leptonic and Radiative Decays

important for lattice QCD ⟵ (a) $\boxed{D^+_{(s)} \to e^+\nu,\ \mu^+\nu,\ \tau^+\nu}$

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Dark Matter Searches

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time-integrated analyses A_{CP} ⟵ (b) $D^0 \to K^0_S K^0_S, \pi^0\pi^0, D^+ \to \pi^+\pi^0$ $D^0 \to K_S \pi^0$, more FCNC

$\pi^-\pi^0$

time-depen

$\pi^0\pi^+\pi^-$

import

$D \to$ invisible, $D \to$ invisible γ

- [t] branching ratio of $D \to \nu\bar{\nu}$ is tiny in SM (helicity suppression)
- [t] branching ratio of $D \to \nu\bar{\nu}(\gamma)$ is still tiny in SM
- [t] missing energy can be something different from neutrinos!
- [t] nice constraints on light dark matter (and light higgs) properties
- [e] experimentally very challenging. Can think of using D from fully reconstructed B events to reduce the background, but pay in terms of reconstruction efficiency

e.g. light dark matter searches ⟵ (a) $\boxed{\text{missing energy modes}}$

(b) glueballs

(c) $D_s^+ \to p\bar{n}$

Theory Motivational Speech

What did we learn from Δa_{CP} saga?

★ Is it Standard Model or New Physics? Theorists used to say...

Naively, any CP-violating signal in the SM will be small, at most $O(V_{ub}V_{cb}^*/V_{us}V_{cs}^*) \sim 10^{-3}$
Thus, O(1%) CP-violating signal can provide a "smoking gun" signature of New Physics

...what do you say now?

★ assuming SU(3) symmetry, $a_{CP}(\pi\pi) \sim a_{CP}(KK) \sim 0.15\%$. Looks more or less 0.1%...
★ let us try Standard Model
- need to estimate size of penguin/penguin contractions vs. tree

Find new observables!

★ Find processes where the Standard Model contribution to Acp is small

★ Look at non-leptonic decays $D \to \pi\pi$ ★ Look at non-leptonic decays $D \to K_S K_S$

no contributions from QCD penguins

A. Petrov

Rare and radiative decays

★ Can New Physics be "hiding" in the up-type quark transitions
- explicit models can be constructed where it can be done
- long-distance effects complicate interpretation
- must use exp and theo tricks to sort out

Maybe correlations between different measurements can help sorting out NP in charm?

★ Standard Model contribution to $D \to \gamma\gamma$ - SM contribution is dominated by LD effects

★ Try to find combinations of decays where LD contributions cancel

★ Radiative decays $D \to \gamma X, \gamma\gamma$: FCNC transition $c \to u\, \gamma$

- SM contribution is dominated by LD effects
- dominated by SM anyway: useless for NP studies?

★ Consider exclusive decays $D \to \gamma\rho, \gamma\omega$: $\omega^{(I=0)} = \frac{1}{\sqrt{2}}(\bar{u}u + \bar{d}d)\,, \quad \rho^{(I=1)} = \frac{1}{\sqrt{2}}(\bar{u}u - \bar{d}d)$

- Extract $c \to uu\, \gamma$: LD contribution cancels $R_{uu\gamma} = \frac{\Gamma(D^0 \to \omega\gamma) - \Gamma(D^0 \to \rho\gamma)}{\Gamma(D^0 \to \omega\gamma)}$
- Consider isospin asymmetries $R_I = \frac{2\Gamma(D^0 \to \rho^0\gamma) - \Gamma(D^+ \to \rho^+\gamma)}{2\Gamma(D^0 \to \rho^0\gamma) + \Gamma(D^+ \to \rho^+\gamma)}$
- isospin asymmetries are sensitive to 4-fermion operators with photon emissions from "spectators"

★ Standard Model contribution to $D \to \mu\mu$

- could be used to study NP effects in correlation with D-mixing

Rare D(B)-decays with missing energy

- D-decays with missing energy can probe both heavy and light (DM) NP

★ SM process: D → $\nu\nu$ and D → $\nu\nu\gamma$:
- for B-decays $J^{\mu}_{Qa} = \bar{q}_L \gamma^{\mu} b_L$
- for D-decays $J^{\mu}_{Qq} = \bar{u}_L \gamma^{\mu} c_L$

★ For B(D) → $\nu\nu$ decays SM branching ratios are tiny
- SM decay is helicity suppressed, e.g.

$$\mathcal{B}(B_s \to \nu\bar{\nu}) = \frac{G_F^2 \alpha^2 f_B^2 M_B^3}{16\pi^3 \sin^4\theta_W \Gamma_{B_s}} |V_{tb}V_{ts}^*|^2 X(x_t)^2 x_\nu^2$$

- NP: other ways of flipping helicity?
- add a third particle to the final state?

What would happen if a photon is added to the final state?

★ For B(D) → $\nu\nu\gamma$ decays SM branching ratios are still tiny
- need form-factors to describe the transition
- helicity suppression is lifted

★ BUT: missing energy does not always mean neutrinos
- nice constraints on light Dark Matter properties!!!

Decay	Branching ratio
$B_s \to \nu\bar{\nu}$	3.07×10^{-24}
$B_d \to \nu\bar{\nu}$	1.24×10^{-25}
$D^0 \to \nu\bar{\nu}$	1.1×10^{-30}

Decay	Branching ratio
$B_s \to \nu\bar{\nu}\gamma$	3.68×10^{-8}
$B_d \to \nu\bar{\nu}\gamma$	1.96×10^{-9}
$D^0 \to \nu\bar{\nu}\gamma$	3.96×10^{-14}

Badin, AAP (2010)

Extrapolations on Time-Integrated Measurements

mode	$\mathcal{L}$ (fb^{-1})	A_{CP} (%)	Belle II at 50 ab^{-1}
$D^0 \to K^+K^-$	976	$-0.32 \pm 0.21 \pm 0.09$	± 0.03
$D^0 \to \pi^+\pi^-$	976	$+0.55 \pm 0.36 \pm 0.09$	± 0.05
$D^0 \to \pi^0\pi^0$	976	$\sim \pm 0.60$	± 0.08
$D^0 \to K_s^0\pi^0$	791	$-0.28 \pm 0.19 \pm 0.10$	± 0.03
$D^0 \to K_s^0\eta$	791	$+0.54 \pm 0.51 \pm 0.16$	± 0.07
$D^0 \to K_s^0\eta'$	791	$+0.98 \pm 0.67 \pm 0.14$	± 0.09
$D^0 \to \pi^+\pi^-\pi^0$	532	$+0.43 \pm 1.30$	± 0.13
$D^0 \to K^+\pi^-\pi^0$	281	-0.60 ± 5.30	± 0.40
$D^0 \to K^+\pi^-\pi^+\pi^-$	281	-1.80 ± 4.40	± 0.33
$D^+ \to \phi\pi^+$	955	$+0.51 \pm 0.28 \pm 0.05$	± 0.04
$D^+ \to \eta\pi^+$	791	$+1.74 \pm 1.13 \pm 0.19$	± 0.14
$D^+ \to \eta'\pi^+$	791	$-0.12 \pm 1.12 \pm 0.17$	± 0.14
$D^+ \to K_s^0\pi^+$	977	$-0.36 \pm 0.09 \pm 0.07$	± 0.03
$D^+ \to K_s^0K^+$	977	$-0.25 \pm 0.28 \pm 0.14$	± 0.05
$D_s^+ \to K_s^0\pi^+$	673	$+5.45 \pm 2.50 \pm 0.33$	± 0.29
$D_s^+ \to K_s^0K^+$	673	$+0.12 \pm 0.36 \pm 0.22$	± 0.05

$$\sigma_{BelleII} = \sqrt{(\sigma^2_{stat} + \sigma^2_{sys})\frac{\mathcal{L}_{Belle}}{50\ \mathrm{ab}^{-1}} + \sigma^2_{\mathrm{ired}}}$$

Extrapolations on Time-Dependent Measurements

$D^0 \to K^{(*)-}\ell^+\nu$	492 fb^{-1}	50 ab^{-1}
R_M	$(1.3 \pm 2.2 \pm 2.0) \times 10^{-4}$	$\pm 0.3 \times 10^{-4}$
$D^0 \to K^+K^-, \pi^+\pi^-$	976 fb^{-1}	50 ab^{-1}
y_{CP}	$(1.11 \pm 0.22 \pm 0.11)\%$	$\pm 0.04\%$
A_Γ	$(-0.03 \pm 0.20 \pm 0.08)\%$	$\pm 0.03\%$
$D^0 \to K^+\pi^-$	400 fb^{-1}	50 ab^{-1}
x'^2	$(1.8 \pm 2.2 \pm 1.1) \times 10^{-4}$	$\pm 0.22 \times 10^{-4}$
y'	$(0.06 \pm 0.40 \pm 0.20)\%$	$\pm 0.04\%$
A_M	0.67 ± 1.20	± 0.11
$\lvert\phi\rvert$	0.16 ± 0.44	± 0.04
$D^0 \to K_s^0\pi^+\pi^-$	921 fb^{-1}	50 ab^{-1}
x	$(0.56 \pm 0.19 \pm 0.06 \pm 0.08)\%$	$\pm 0.08\%$
y	$(0.30 \pm 0.15 \pm 0.06 \pm 0.04)\%$	$\pm 0.05\%$
$\lvert q/p\rvert$	$0.90 \pm 0.16 \pm 0.04 \pm 0.06$	± 0.06
ϕ	$-0.10 \pm 0.19 \pm 0.04 \pm 0.07$	± 0.07

$$\sigma_{BelleII} = \sqrt{(\sigma^2_{stat} + \sigma^2_{sys})\frac{\mathcal{L}_{Belle}}{50\ \mathrm{ab}^{-1}} + \sigma^2_{\mathrm{ired}}}$$