Workshop on Charm Physics at Threshold: a short summary

Nicola Neri
INFN, Sezione di Milano

Frascati, 11 December 2011

Aim of the workshop

- Discuss the benefits of the measurements made at charm threshold at existing experiments (CLEOc, BESIII) and explore the potential for those measurements in the future:
  - benefits of a boosted center of mass at charm threshold at SuperB;
  - impact of charm threshold measurements on other flavor physics experiments: SuperB at $\Upsilon(4S)$, Belle II, LHCb.

Program of the Workshop

http://indico.ihep.ac.cn/conferenceTimeTable.py?confId=2171#20111021.detailed

Friday 21 October

Time	Title	Speaker	Location	Slot
08:00	**Registration**		*IHEP, Beijing*	08:00 - 08:30
	Welcome	*LI, Weiguo*	*IHEP, Beijing*	08:30 - 08:50
09:00	**Status of Super-B in Italy**	*MARCELLO, Giorgi*	*IHEP, Beijing*	08:50 - 09:30
	Status of Belle-II	*LIU, Chao*	*IHEP, Beijing*	09:30 - 10:10
10:00	**Coffee break**		*IHEP, Beijing*	10:10 - 10:30
	Status of BESIII	*ZHANG, Jingzhi*	*IHEP, Beijing*	10:30 - 11:10
11:00	**Charm program at LHCb**	*BONIVENTO, Walter Marcello*	*IHEP, Beijing*	11:10 - 11:50
14:00	**Flavor puzzles and a chance in the charm sector**	*XING, Zhizhong*	*IHEP, Beijing*	14:00 - 14:40
15:00	**Time-dependent D physics at LHCb**	*BACHMANN, Sebastian*	*IHEP, Beijing*	14:40 - 15:20
	Quantum Correlations and Charm Mixing Measurements at Threshold	*SOKOLOFF, Michael*	*IHEP, Beijing*	15:20 - 16:00
16:00	**Coffee break**		*IHEP, Beijing*	16:00 - 16:20
	Relevance of DDbar threshold data for mixing and CP violation	*NERI, Nicola*	*IHEP, Beijing*	16:20 - 17:00
17:00	**Sensitivity studies for mixing and CP violation at SuperB**	*RAMA, Matteo*	*IHEP, Beijing*	17:00 - 17:40
18:00	**Reaches of rare charm decays**	*BEVAN, Adrian*	*IHEP, Beijing*	17:40 - 18:10

Saturday 22 October

Time	Title	Speaker	Location	Slot
09:00	**Time-dependent CPV observation on charm at threshold**	*MEADOWS, Brian*	*IHEP, Beijing*	09:00 - 09:40
10:00	**Strong phase at BESIII**	*ZHOU, xiaokang*	*IHEP, Beijing*	09:40 - 10:10
	Charm observables and the extraction of the CKM angle γ/φ3	*CHARLES, Jerome*	*IHEP, Beijing*	10:10 - 10:40
	Coffee break		*IHEP, Beijing*	10:40 - 11:00
11:00	**D->Kpi l nu as a probe of low-energy QCD**	*DESCOTES-GENON, Sebastien*	*IHEP, Beijing*	11:00 - 11:30
12:00	**Decay constants and form factors of charm mesons from LQCD**	*BAILEY, Jon*	*IHEP, Beijing*	11:30 - 12:10
	Preliminary results on charm decays at BESIII	*JIANG, Lili*	*IHEP, Beijing*	12:10 - 12:40
14:00	**Implications of recent data on CKM global analyses**	*CHARLES, Jerome*	*IHEP, Beijing*	14:00 - 14:40
15:00	**Systematic uncertainty on charm decays at CLEO-c**	*BRIERE, Roy*	*IHEP, Beijing*	14:40 - 15:20
	D→Ksn+n- Dalitz analysis at BESIII	*FU, Chengdong*	*IHEP, Beijing*	15:20 - 15:50
16:00	**Coffee break**		*IHEP, Beijing*	15:50 - 16:10
	Physcs potential at super B factories	*BEVAN, Adrian*	*IHEP, Beijing*	16:10 - 16:50
17:00	**Free discussion**		*IHEP, Beijing*	16:50 - 18:00

In this summary

- I will not cover LHCb reports (see W. Bonivento talk this afternoon) and a specific talk on time-dependent CPV in charm (see G. Inguglia this afternoon);
- I will not cover SuperB (and Belle II) general/ physics status reports. Detailed discussion during the incoming week.

Recent results from BESIII

Jingzhi Zhang
(IHEP, Beijing)

Workshop on charm physics at threshold
Beijing, IHEP
(21- 23 October, 2011)

Physics activities @ BESIII

Charmonium physics:
- spectroscopy
- transitions and decays

Light hadron physics:
- meson & baryon spectroscopy
- glueball & hybrid
- two-photon physics
- e.m. form factors of nucleon

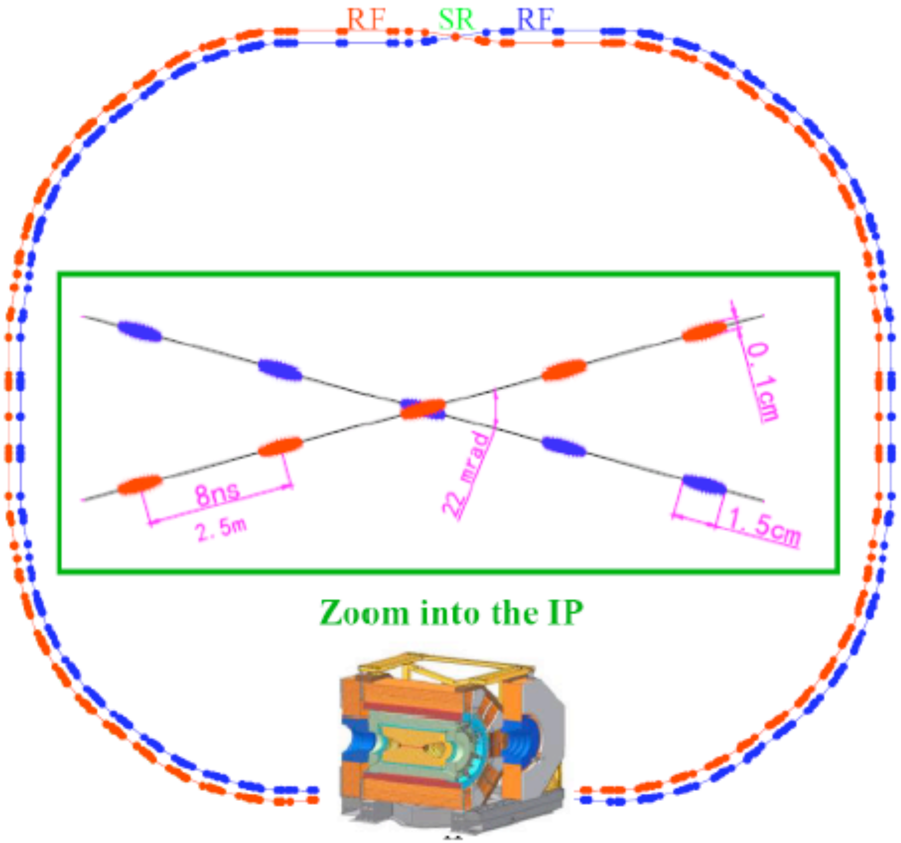
Charm physics:
- (semi)leptonic/ hadronic dec
- decay const., form factors
- CKM matrix: V_{cd}, V_{cs}
- D^0-D^0bar mixing and *CPV*
- rare/forbidden decays

Tau physics:
- τ decays near threshold
- τ mass scan

More…

Not in this talk

BEPCII storage rings



Beam energy: 1.0 – 2.3 GeV

Peak Luminosity:

Design: 1×10^{33} cm^{-2}s^{-1}

Achieved: **0.65×10^{33} cm^{-2}s^{-1}**

Optimum energy: 1.89 GeV

Energy spread: 5.16×10^{-4}

Circumference: 237 m

Beam energy measurement: Using Compton backscattering technique. Accuracy up to **5×10^{-5}**

BESIII Detector

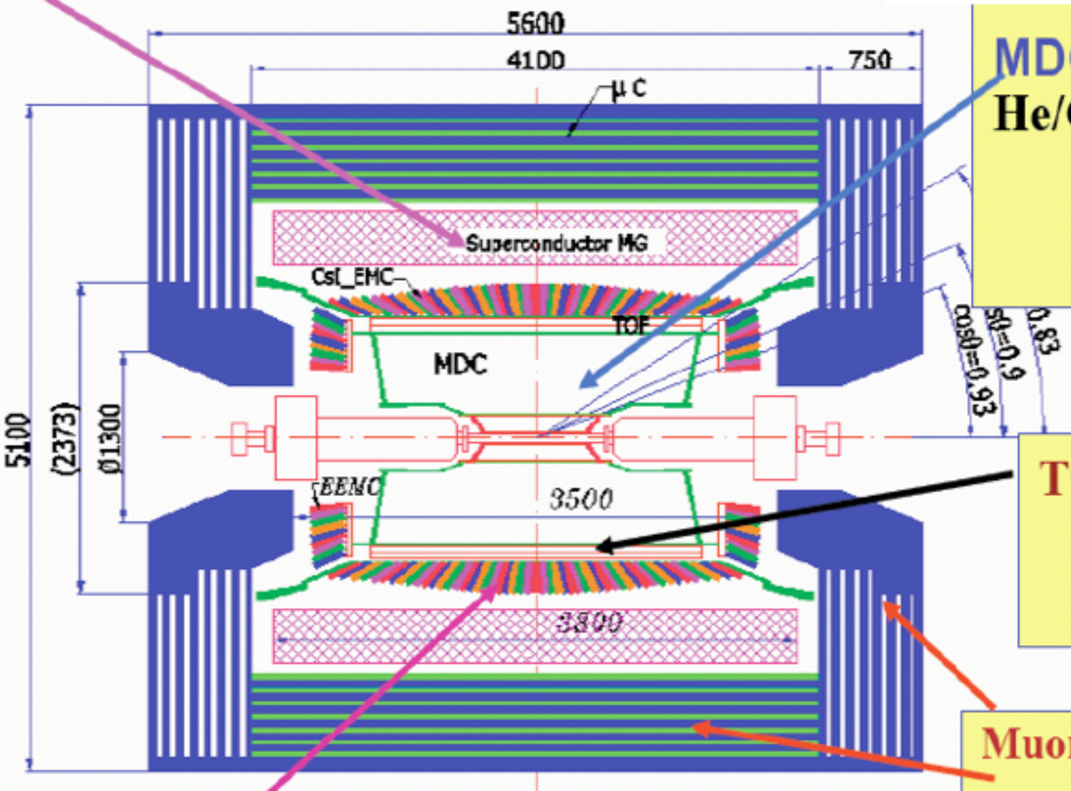
BESIII detector: all new !

CsI calorimeter

Precision tracking

Time-of-flight + dE/dx PID

Magnet: 1 T Super conducting



MDC: small cell & Gas:
He/C_3H_8 (60/40), 43 layers
σ_{xy}=130 μm
σ_p/p = 0.5% @1GeV
dE/dx=6%

TOF:
σ_T = 100 ps Barrel
110 ps Endcap

Muon ID: 9 layers RPC
8 layers for endcap

EMC: CsI crystal, 28 cm
$\Delta E/E$ = 2.5% @1 GeV
$\sigma z = 0.6\ \mathrm{cm}/\sqrt{E}$

Data Acquisition:
Event rate = 4 kHz
Total data volume ~ 50 MB/s

BES III Data Samples

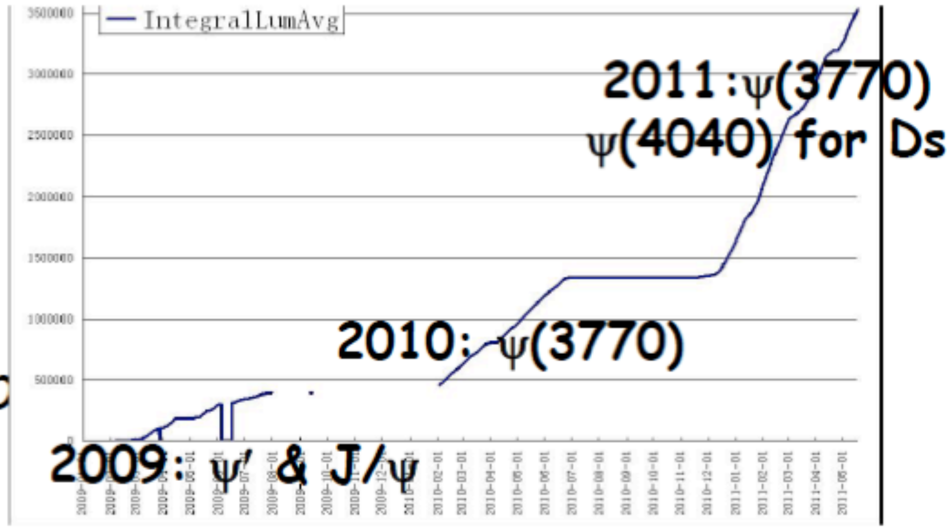
- *BESIII collected*
  - 2009: **225 M** J/ψ
  - 2009: **106 M** ψ'
  - 2010-11: **2.9 fb^{-1}** ψ(3770)

    (3.5 × CLEOc 0.818 fb^{-1})
  - 2011-05:**477 pb^{-1}** @4010MeV

    (for D_S and XYZ spectroscop

Int. luminosity: 2009.01– 2011.06

~ 4.0 fb^{-1} @ all energies



- *BESIII data-taking plans*
  - 2012: 1 billon J/ψ, 0.7~1 billon ψ'
  - 2013: @4170 MeV D_S physics; R scan
  - 2014: ψ'/T/ R scan
  - ψ(3770) 5-10 fb^{-1}

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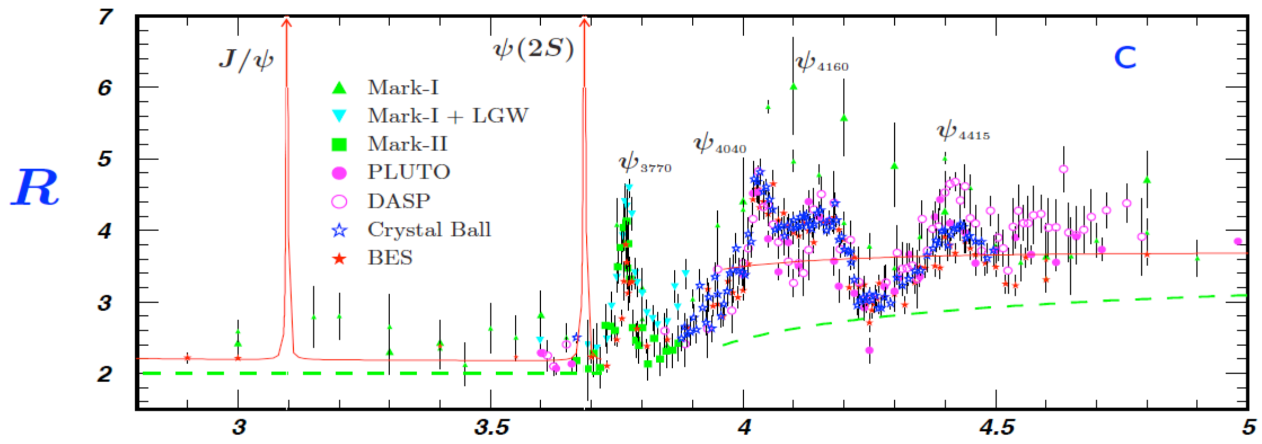


Figure 1.1: R value above Charm threshold.

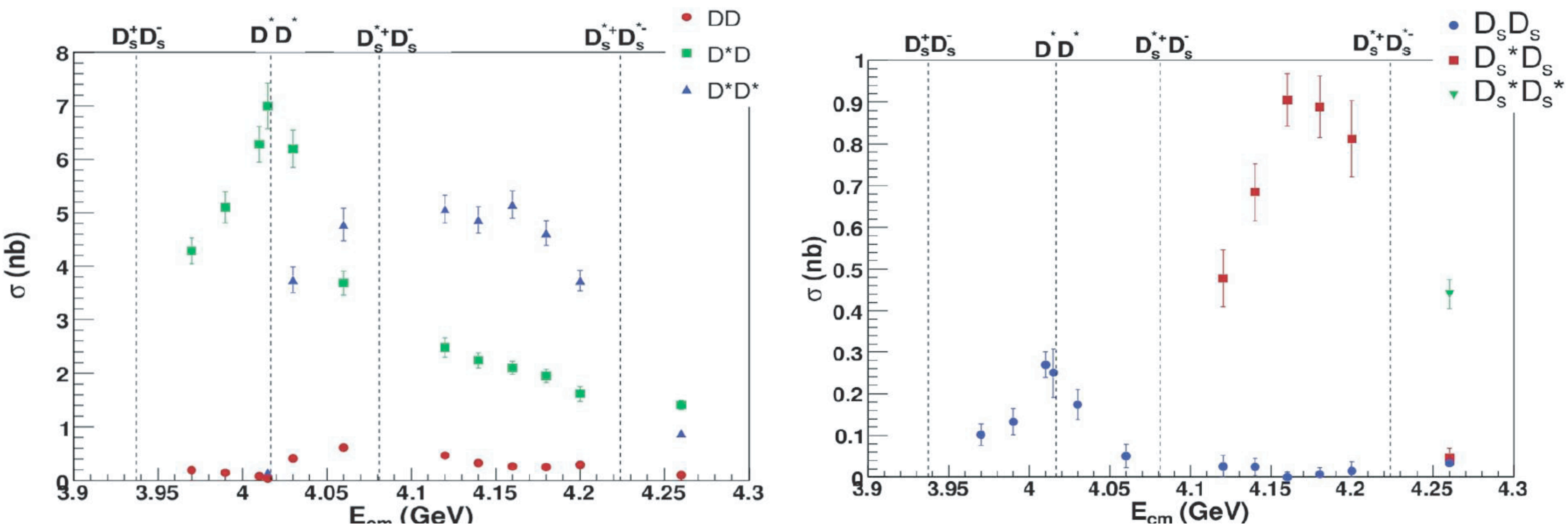


Figure 1.2: Charm cross section for $D\overline{D}$, $D^*\overline{D}$, $D^*\overline{D^*}$, $D_s\overline{D_s}$, $D_s^*\overline{D_s}$ and $D_s^{*\pm}D_s^{*\mp}$ for the CLEO-c scan run.

BES III Publications

- Charmonium Spectroscopy and Transitions
  - Properties of the h_c *(PRL 104, 132002 (2010))*
  - $\psi' \to \gamma\gamma J/\psi$ *(to be submitted soon)*
- Charmonium Decays
  - $\psi' \to \gamma\pi^0, \gamma\eta, \gamma\eta'$ *(PRL 105, 261801 (2010))*
  - $\chi_{cJ} \to \pi^0\pi^0, \eta\eta$ *(PRD 81, 052005 (2010))*
  - $\chi_{cJ} \to \gamma\rho, \gamma\omega, \gamma\phi$ *(PRD83,112005(2011))*
  - $\chi_{cJ} \to \omega\omega, \phi\phi, \omega\phi$ *(PRL 107, 092001(2011))*
  - $\chi_{cJ} \to 4\pi^0$ *(PRD 83, 012006 (2011))*
  - $\chi_{cJ} \to ppK^+K^-$ (PRD 83, 112009(2011))
  - $\eta' \to \eta\pi^+\pi^-$ matrix element *(PRD 83, 012003 (2011))*
  - *Search for CP/P violation process pseudoscalar decays into pipi* (PRD 84, 032006(2011))
- Light Quark States
  - $a_0(980) - f_0(980)$ mixing *(PRD 83, 032003 (2011))*
  - X(1860) in $J/\psi \to \gamma pp$ *(Chinese Physics C 34, 4 (2010))*
  - X(1835) in $J/\psi \to \gamma\eta'\pi^+\pi^-$ *(PRL 106, 072002 (2011))*
  - X(1870) in $J/\psi \to \omega\eta\pi^+\pi^-$ *(accepted by PRL)*
  - *PWA on* $J/\psi \to \gamma pp$ *(to be submitted soon)*
  - *PWA on* $\psi' \to \eta pp$ *(to be submitted soon)*

Prospects for Charm at BESIII

With increased luminosity, BESIII will achieve high precision

CLEOc errors with 818 pb^{-1}@3770	BESIII ($10fb^{-1}$)
f_{D+} ($D^+ \to \mu^+ \nu$): $\pm$**4.1%** (stat.) $\pm$ **1.2%**(sys.)	$\pm$**1.2%** (stat.)
$f_\pi(0)$ ($D^0 \to \pi l \nu$): $\pm$**5.3%** (stat.) $\pm$ **0.7%**(sys.)	$\pm$**1.5%** (stat.)
BF($D^0 \to K\pi$): $\pm$**0.9%** (stat.) $\pm$ **1.8%**(sys.)	limited by syst.
BF($D^+ \to K\pi\pi$): $\pm$**1.1%** (stat.) $\pm$ **2.0%**(sys.)	limited by syst.

CLEOc errors with 600pb^{-1}@4170 MeV	BESIII($5fb^{-1}$)
f_{Ds}($Ds^+ \to \mu^+ \nu, \tau\nu$): $\pm$**2.5%** (stat.) $\pm$ **1.2%** (sys.)	$\pm$**0.9%** (stat.)
BF($Ds^+ \to KK\pi$): $\pm$**4.2%** (stat.) $\pm$ **2.9%**(sys.)	$\pm$**1.5%** (stat.)

For D_S study, data taken at 4010 MeV & 4170 MeV:

4010 MeV (clean, lower X-section, 0.3 nb) → BESIII 0.5 fb^{-1}

4170MeV (more BKG, higher X-section, 0.9 nb) → CLEOc 0.6 fb^{-1}

Strong Phase at BESIII

Xiaokang Zhou
(for the BESIII Collaboration)
Graduate University of Chinese Academy of Sciences

Workshop on charm physics at threshold

Neutral-D Mixing

parameters: A_D A_M ϕ δ R_D x y

$$R_D^+ = \frac{(1+A_M)^2}{(1+A_D)^2} R_D, \quad R_D^- = \frac{(1+A_D)^2}{(1+A_M)^2} R_D$$

$$x'_\pm = x\cos(\delta \pm \phi) + y\sin(\delta \pm \phi)$$

$$y'_\pm = y\cos(\delta \pm \phi) - x\sin(\delta \pm \phi)$$

CPV

$A_D \neq 0$ direct CPV (decay)

$A_M \neq 0$ indirect CPV (mixing)

$\phi \neq 0$ CP violation in the interference between decays with/without mixing

Define:

$$\frac{\langle f \mid \overline{D} \rangle_{DCS}}{\langle f \mid D \rangle_{CF}} \equiv \sqrt{R_D} \cdot e^{-i\delta}$$

$$R_D \equiv \left| \frac{\langle f \mid \overline{D} \rangle_{DCS}}{\langle f \mid D \rangle_{CF}} \right|^2$$

δ is very important for study mixing and CPV!

Measure ϕ_3/γ in B-factory

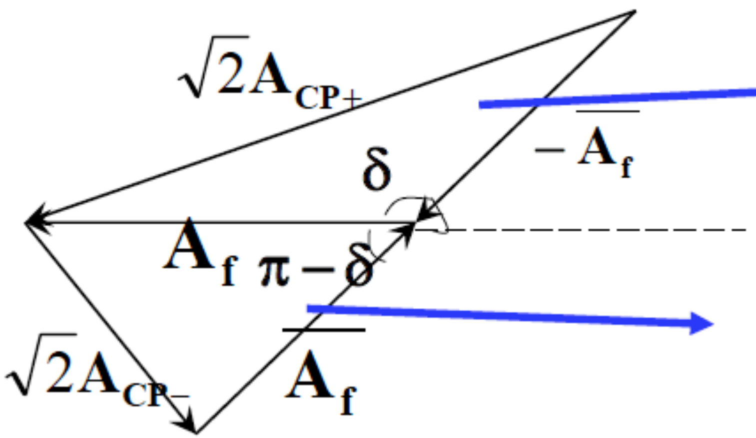
- Decay rates: $\boxed{\Gamma\left(B^\pm \to (f)_D K^\pm\right) \propto r_B^2 + r_D^2 + 2 r_B r_D \cos(\delta_B + \delta_D \pm \phi_3)}$
- r_D, δ_D :measured from BESIII
- (r_B, δ_B, ϕ_3) 3 unknowns, 4 measurements $\Rightarrow$ ϕ_3

Measure δ

CP eigenstate: $|D^{CP\pm}\rangle = \frac{1}{\sqrt{2}}(|D^0\rangle \pm |\overline{D^0}\rangle)$

$$\langle f\,|\,D^{CP\pm}\rangle = \frac{1}{\sqrt{2}}(\langle f\,|\,D^0\rangle \pm \langle f\,|\,\overline{D^0}\rangle) \Rightarrow \sqrt{2}A_{CP\pm} = A_f \pm \overline{A_f}$$

Construct:



$$\cos\delta = \frac{|A_f|^2 + |\overline{A_f}|^2 - |\sqrt{2}A_{CP+}|^2}{2\cdot|A_f|\cdot|\overline{A_f}|}$$

$$\cos(\pi-\delta) = \frac{|A_f|^2 + |\overline{A_f}|^2 - |\sqrt{2}A_{CP-}|^2}{2\cdot|A_f|\cdot|\overline{A_f}|}$$

$$2\sqrt{R_D}\cdot\cos\delta \approx \frac{|A_{CP-}|^2 - |A_{CP+}|^2}{|A_{CP-}|^2 + |A_{CP+}|^2} = \frac{Br(D^{CP-}\to f) - Br(D^{CP+}\to f)}{Br(D^{CP-}\to f) + Br(D^{CP+}\to f)}$$

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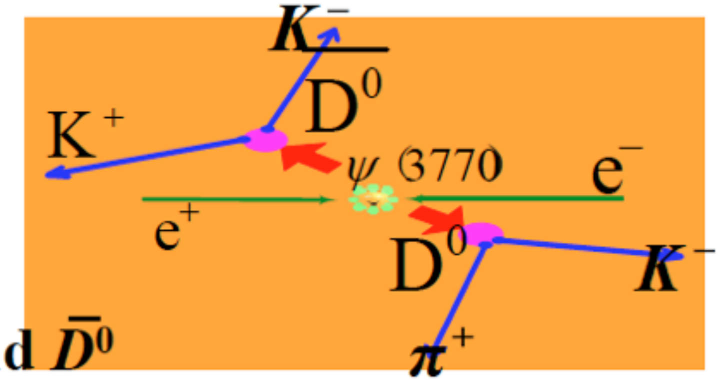
Single Tag and Double Tag



- Single tag(ST): fully reconstruct one D

$$N_f = N_{D\bar{D}} \cdot Br(D^0 \to f) \cdot \varepsilon_f,$$

$$N_{CP} = 2N_{D\bar{D}} \cdot Br(D^0 \to CP) \cdot \varepsilon_{CP}$$

- Double tag(DT): reconstruct both D^0 and $\bar{D}^0$

$$N_{f,CP^\pm} = 2N_{D\bar{D}} \cdot Br(D^0 \to CP\mp) \cdot Br(D^{CP\pm} \to f) \cdot \varepsilon_{f,CP^\pm}$$

$$\Rightarrow Br(D^{CP\pm} \to f) = \frac{N_{f,CP^\pm} \times \varepsilon_{CP^\pm}}{N_{CP^\pm} \times \varepsilon_{f,CP^\pm}}$$

- CP channels:

✓ cp+

- K^-K^+ $(3.94 \pm 0.07) \cdot 10^{-3}$
- $\pi^-\pi^+$ $(1.397 \pm 0.026) \cdot 10^{-3}$
- $K_s^0\pi^0\pi^0$ $(8.3 \pm 0.6) \cdot 10^{-3}$
- $K_L^0\pi^0$ $(10.0 \pm 0.7) \cdot 10^{-3}$

✓ cp-

- $K_s^0\pi^0$ $(1.22 \pm 0.05)\%$
- $K_s^0\eta$ $(4.29 \pm 0.27) \cdot 10^{-3}$
- $K_s^0\omega$ $(1.11 \pm 0.06)\%$

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DTag Status

- With the 1st round of $\psi(3770)$ data(~929pb-1)

Modes	Yields	Effs(%)*	CLEO-c's effs(%)#
$K\pi$	149,085	60.83+/-0.10	65.32
$K\pi\pi^0$	300,706	32.75+/-0.05	35.15
$K\pi\pi\pi$	190,667	39.70+/-0.07	45.55
$K\pi\pi$	213,944	48.99+/-0.07	55.42
$K\pi\pi\pi^0$	66,344	25.01+/-0.09	27.39
$Ks\pi$	28,763	50.33+/-0.25	51.10
$Ks\pi\pi^0$	66,438	26.49+/-0.09	28.74
$Ks\pi\pi\pi$	36,311	31.46+/-0.10	43.58
$KK\pi$	17,682	40.34+/-0.21	42.07

*:the efficiencies do not include the branch fractions of $Ks\rightarrow\pi+\pi-$, $\pi^0\rightarrow\gamma\gamma$

#:from **PRD 80, 032005 (2009)**

The efficiencies are lower than CLEO-c

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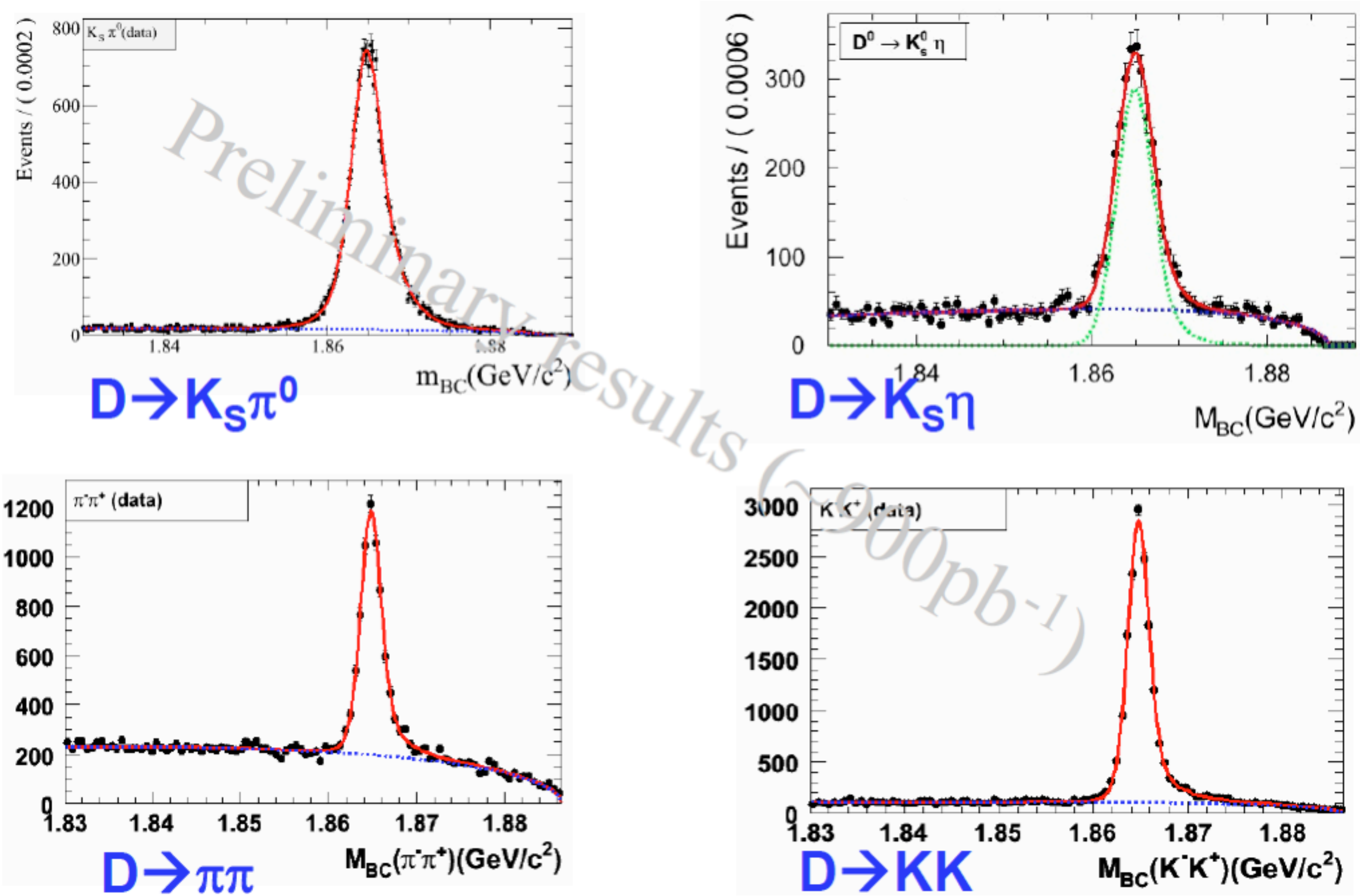
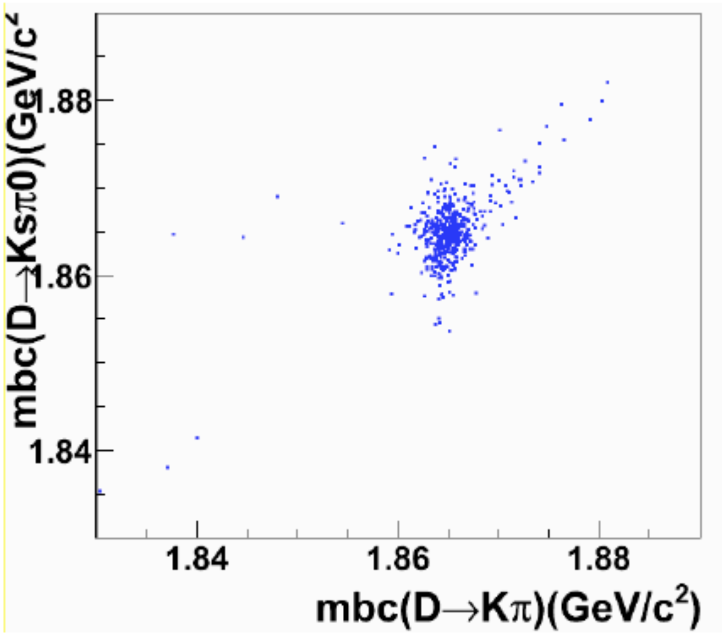
$MC\ shape \otimes gauss(sig) + Argus(bg)$



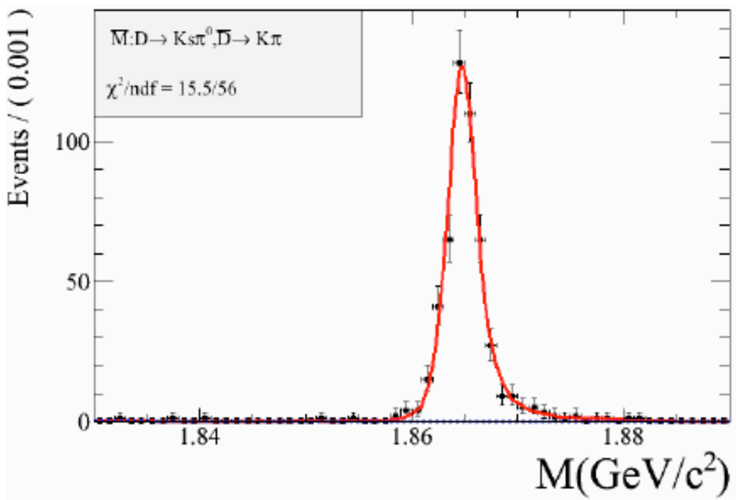
Doubly Tag $D\bar{D}$ Decay

- We form DTs by combining two ST candidates passing the selection criteria. If multiple candidates, we choose one per mode per event with M closest to measured D mass, where:

$$M \equiv [m_{BC}(D^0) + m_{BC}(\overline{D^0})]/2$$



get DT yields by fitting M with combine requirements on 2 D mesons



Statistical Sensitivity

- Using **~0.9fb^{-1}** data, we get

$$\boxed{2\sqrt{R_D} \cdot \cos\delta = (XXX \pm 3.125(stat.))\%}$$

If using HFAG 2010 average of R_D, that is (3.37+/-0.09) ‰,we got:

$$\cos\delta = 0.XXX \pm 0.270(stat.)$$

The result is still need to be optimize. The statistics error is comparable to CLEO-c

Preliminary Results on Charm Decays at BESIII

L.L. Jiang
[For BESIII Collaboration]
Institute of High Energy Physics, Beijing, China

The Major Physics Topics [1]

Purpose: Overcome the non-perturbative QCD roadblock, test pQCD calculations and probe for new Physics beyond SM

- **Semileptonic decays of D and D_s**

  $|V_{cs}|$, $|V_{cd}|$ and form factor

- **Purely leptonic decays of D^+ and D_s^+**

  decay constants f_D & f_{Ds}

- **Absolute hadronic branching fractions**

  To normalize B and Z physics

Which can be test QCD techniques in charm sector and apply to B sector. More to Improve determinations of $|V_{ub}|$, $|V_{cb}|$, $|V_{td}|$ and $|V_{ts}|$.

The Major Physics Topics [2]

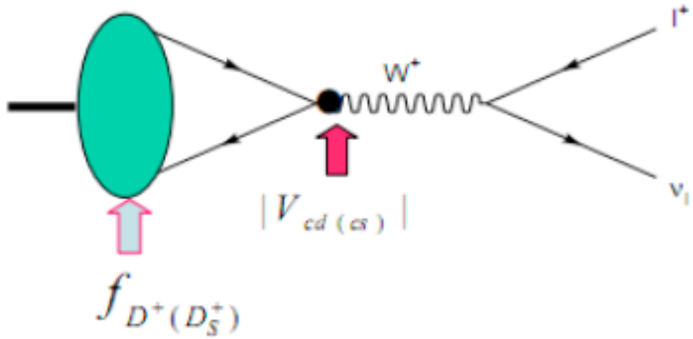
Probe for New Physics

- *D^0D^0 mixing*
- *Searching for CP Violation decays of D*
- *Searching for Rare Decays of D and D_s mesons*

Precision measurements on charm decays can be served as precisely test the Standard Model.

Purely-leptonic decays

Lattice QCD predicts f_D and f_{Ds}. More precisely measured f_D and f_{Ds} can be used to calibrate the LQCD calculations.



The decay diagram for $D^+ \to l^+ \nu$

The decay constant f_{D+} is related to the decay rate by:

$$\Gamma(D^+ \to l^+ \upsilon_l) = \frac{G_F^2 f_{D^+}^2}{8\pi} |V_{cd}|^2 m_l^2 m_{D^+} \left(1 - \frac{m_l^2}{m_{D^+}^2}\right)^2$$

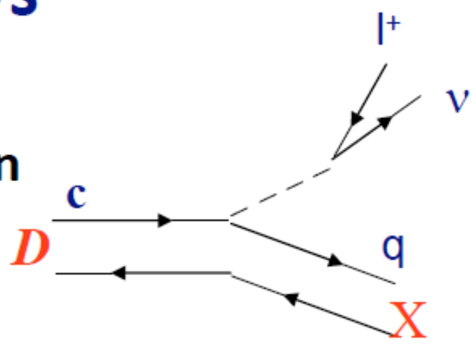
- **Ongoing analysis of the purely leptonic decays:**

$D^+ \to \mu^+\nu_\mu,\ \tau^+\nu_\tau,\ e^+\nu_e$

$D_s^+ \to \mu^+\nu_\mu,\ \tau^+\nu_\tau$

EXP or Theory	f_{D+} (MeV)
BESIII expectation [2.9 fb^{-1}]	~2.8% (stat.)
CLEO-c (818 pb^{-1})	206 ± 9 [4.1% stat]

Semi-leptonic decays



- Extract out the form factor, which in turn be used to calibrate LQCD calculations

- Extract the $|V_{cs}|$ and $|V_{cd}|$. Any significant inconsistency between the measured values and the ones obtained from the CKM fit could provide a valuable indication of the NP beyond the SM in the first two quark generation

- Ongoing analysis of the semi-leptonic decays:

$D^0 \rightarrow K^- e^+ \nu_e$, $\pi^- e^+ \nu_e$

$D^+ \rightarrow \omega e^+ \nu_e$, $\phi e^+ \nu_e$

$D^+ \rightarrow \pi^0 e^+ \nu_e$, $\eta e^+ \nu_e$

The accuracy levels for measurements of Br[$D^0 \rightarrow K^- e^+ \nu_e$] and Br[$D^0 \rightarrow \pi^- e^+ \nu_e$] are , respectively, ~0.8% and ~1.9% with 2.9fb^{-1} $\psi(3770)$ data at BESIII.

Semi-leptonic decays

For the transition to pseudoscalar meson, the decay rates Γ ralates to the CKM matrix elements and the form factors by:

$$\Gamma(D^0 \to K^- e^+ \nu_e) = 1.53 \times |V_{cs}|^2 \times |f_+^K(0)|^2 \times 10^{11} s^{-1}$$

$$\Gamma(D^0 \to \pi^- e^+ \nu_e) = 3.01 \times |V_{cd}|^2 \times |f_+^\pi(0)|^2 \times 10^{11} s^{-1}$$

- **$f^K_+(0)$ and $f^\pi_+(0)$**

$$\frac{\Delta|f_+^{K(\pi)}(0)|}{|f_+^{K(\pi)}(0)|} = \sqrt{\left(\frac{\Delta B}{2B}\right)^2 + \left(\frac{\Delta\tau_D}{2\tau_D}\right)^2 + \left(\frac{\Delta V_{cs(cd)}}{V_{cs(cd)}}\right)^2}$$

- **$|V_{cs}|$ and $|V_{cd}|$**

$$\frac{\Delta|V_{cq}|}{|V_{cq}|} = \sqrt{\left(\frac{\Delta B}{2B}\right)^2 + \left(\frac{\Delta\tau_D}{2\tau_D}\right)^2 + \left(\frac{\Delta f}{f}\right)^2}$$

$\Delta Br/Br$ = 0.8%, 1.9%, with 2.9fb^{-1} $\psi(3770)$ data.

$\Delta\tau_D/\tau_D$ = 0.4%, [PDG10]

$\Delta f/f$ = 2.5% [HPQCD]

$\Delta|V_{cs}|/|V_{cs}|$ = 0.02%, $\Delta|V_{cd}|/|V_{cd}|$ = 0.3%, [PDG10 CKMfitter]

$$\frac{\Delta|f_+^K(0)|}{|f_+^K(0)|} = 0.4\%, \quad \frac{\Delta|f_+^\pi(0)|}{|f_+^\pi(0)|} = 1.0\%,$$

$$\frac{\Delta|V_{cs}|}{|V_{cs}|} = 2.5\%, \quad \frac{\Delta|V_{cd}|}{|V_{cd}|} = 2.7\%,$$

PDG10: $\Delta V_{cs}/V_{cs}$~ 3.5% $\Delta V_{cd}/V_{cd}$~ 4.8%

Systematic Uncertainties from CLEO-c $D_{(s)}$ Physics: A Perspective

Roy A. Briere
Carnegie Mellon

(+ CLEO-c & BESIII)

From my talk at FPCP 2009…

Look at the size of the stat / syst / FSR errors from CLEO-c

$\psi(3770)$: D^0 and D^+ physics with ~ 820/280 pb^{-1}

** f_D ($D^+ \to \mu\nu$): ± 4.1% ± 1.2%

** $f(q^2=0)$ ($D^0 \to \pi l \nu$): ± 5.3% ± 0.7 % [3-par. series fit]

Br($D^0 \to K\pi$): ± 0.9% ± 1.5% ± 0.9% [281 pb^{-1}]

Br($D^+ \to K\pi\pi$): ± 1.1% ± 1.8% ± 0.8% [281 pb^{-1}]

@4170 MeV: D_s physics with ~ 600/300 pb^{-1}

* f_{Ds} ($D_s^+ \to \mu\nu, \tau\nu$): ± 2.5% ± 1.2%

* Br ($D_s^+ \to KK\pi$): ± 4.2% ± 2.9% [298 pb^{-1}]

Often significant gains to be made with increased data samples, even if systematic errors are simply matched, not improved.

ALSO: analyses using Quantum Correlations, CP-tags, etc. are also statistics-starved at CLEO-c

D Tagging

For us, a "tag" is a fully-reconstructed D decay

This is generally, a hadronic final state

[but it can also be a (semi)leptonic one opposite a hadronic one]

D tag method allows an absolute normalization of BFs

Key point: D's are produced in pairs

# single tags, mode i:	$N_j = N_{DD}\, \varepsilon_j\ B_j$
# double tags, modes i,j:	$N_{ij} = N_{DD}\, \varepsilon_{ij}\ B_i B_j$
Combine and solve:	$B_i = (N_{ij} / N_j)\, (\varepsilon_j / \varepsilon_{ij})$

N_{DD} cancels with algebra

- No need for more difficult normalization tricks (D*, etc.)
- low sensitivity to tag efficiency: $(\varepsilon_{ij} / \varepsilon_j) \sim \varepsilon_i$

Tags also allow for many nice systematics studies:

efficiencies, with missing mass, etc.

Standardization of D Tags

D Tags

CLEO-c had "standard" D Tags

Users still have a lot of flexibility:

> Select which modes to use

> Choose m_{BC}, ΔE cuts

3σ to 2σ in 2-D can cut background

by more than 1/2 with modest signal loss

(and counting #tags is still low-systematics)

But beware! On "signal side", users can use other cuts.

and this is the efficiency that really matters !!!

Tracking Efficiency: Summary

Total error is from:

1) Main studies, summarized in previous two tables:
   average error **0.22%**
2) Added uncertainty of **0.2%** for tracks near acceptance limits
   ($|\cos\theta|$ from 0.90-0.93) excluded from study,
   due to resolution on direction of missing momentum
   (look at inefficiency, and at $\cos\theta$ distributions)
3) Added uncertainty of **0.1%** for possible larger effects on
   the small fraction of low-momentum tracks

Total systematic of 0.3%

It's also nice to understand the source of what's being measured,
that is, why is there any inefficiency at all?
(in addition to trivia like beam holes and very soft tracks)
If we understand, we know what's important in MC, etc.

Tracking Efficiency: Sources

Mostly due to interactions and decay in flight

Kaon inefficiencies are <u>much larger</u> than pion:

In $D \rightarrow K\pi$ case, kaon inefficiency is ~6% larger than pion

For lower momenta, 0.2-0.5 GeV, the difference is ~17%

To set the scale:

Kaon $c\tau$ = 3.71 m

14% decay in 1.0 m at 0.86 GeV

Pion $c\tau$ = 7.80 m

2% decay in 1.0 m at 0.86 GeV

[0.86 GeV is the Center-of-mass momentum for $D^0 \rightarrow K\pi$]

Pions benefit not only from longer $c\tau$, but larger $\beta\gamma = p/m$

Also note that polar angle and curvature add to track length

(it's not just radial motion…)

$D^+ \rightarrow \mu^+ \upsilon$

Error is 1/2 of this for f_D

TABLE III. Systematic errors on the $D^+ \to \mu^+ \nu$ branching ratio.

	Systematic errors (%)
Track finding	0.7
PID cut	$\boxed{1.0}$
MM^2 width	0.2
Minimum ionization cut	$\boxed{1.0}$
Number of tags	0.6
Extra showers cut	0.4
Radiative corrections	$\boxed{1.0}$
Background	0.7
Total	2.2

No single dominant error.

Also have additional external errors to get from BF to f_D :
lifetime & V_{cd}

Note on the three largest items:

The "min-I cut" (on the CsI energy) listed is one part of the muon ID used here

The "PID cut" here refers to vetoing kaons as muon candidates

The final 1.0% error, radiative corrections, is conservative…

$D_s \to \mu^+\upsilon$ & $\tau^+\upsilon$
$(\tau^+ \to \pi\,\upsilon)$

Error on f_{Ds} is 1/2 on this

TABLE III. Systematic errors on determination of the $D_s^+ \to \mu^+\nu$ branching fraction.

Error Source	Size (%)
Track finding	0.7
Particle identification of μ^+	1.0
MM^2 width	0.2
Photon veto	0.4
Background	1.0
Number of tags	2.0
Tag bias	1.0
Radiative Correction	1.0
Total	3.0

Largest single error is # tags:
might be better at 4030 MeV, with no D_s*
(but only 30% of cross-section !)

"Tag Bias": it is easier to reconstruct a D tag vs. signal compared to inclusive tags that fix normalization

Error here is 20% of MC-predicted effect

Decay Constant: External Systematics

Effects on decay constants are listed; this is 1/2 of the effect on BF

these are not currently dominant

$D_{(s)}$ Lifetimes:

0.34% for D **0.7% for D_s** **(mainly from FOCUS)**

Radiative corrections on $D_{(s)} \rightarrow \mu^+\upsilon$:

0.5% **(conservative? improvable?)**

τ BFs for $D_s \rightarrow \tau^+\upsilon$ ($\tau^+ \rightarrow e^+\upsilon\upsilon$, $\pi^+\upsilon$, $\rho^+\upsilon$):

0.14%, 0.32%, 0.18%

V_{cd} : 0.5% **V_{cs}, masses: negligible**

Charm observables and the extraction of the CKM angle γ/ϕ_3

Workshop on Charm physics at threshold, Beijing, October 20-23 2011

Jérôme Charles (CPT - Marseille)

the CKMfitter group

JC, theory, Marseille

Olivier Deschamps, LHCb, Clermont-Ferrand

Sébastien Descotes-Genon, theory, Orsay

Ryosuke Itoh, Belle, Tsukuba

Andreas Jantsch, ATLAS, Munich

Heiko Lacker, ATLAS, Berlin

Andreas Menzel, Atlas, Berlin

Stéphane Monteil, LHCb, Clermont-Ferrand

Valentin Niess, LHCb, Clermont-Ferrand

Jose Ocariz, BaBar, Paris

Jean Orloff, theory, Clermont-Ferrand

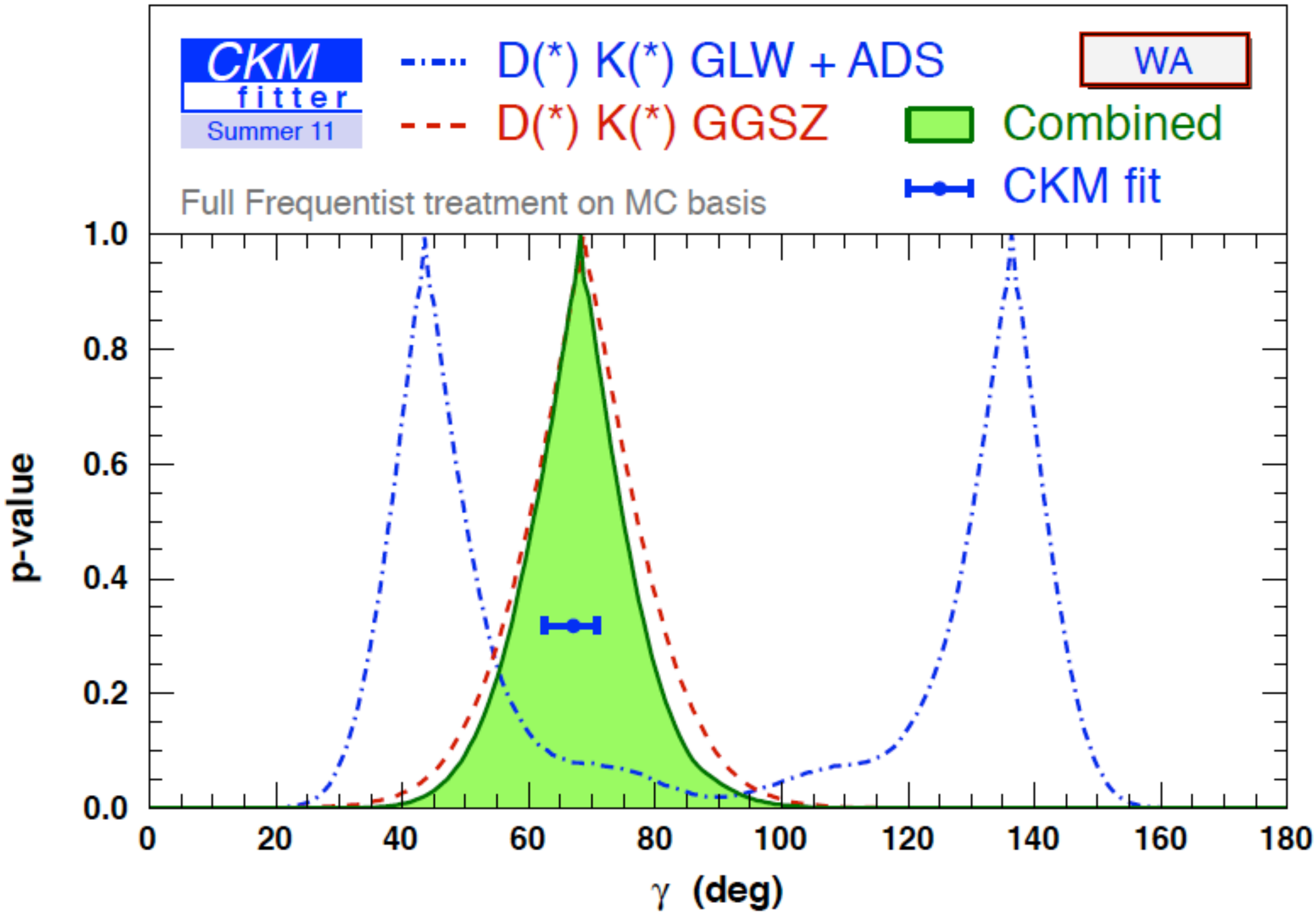
Stéphane T'Jampens, LHCb, Annecy-le-Vieux

Vincent Tisserand, BaBar, Annecy-le-Vieux

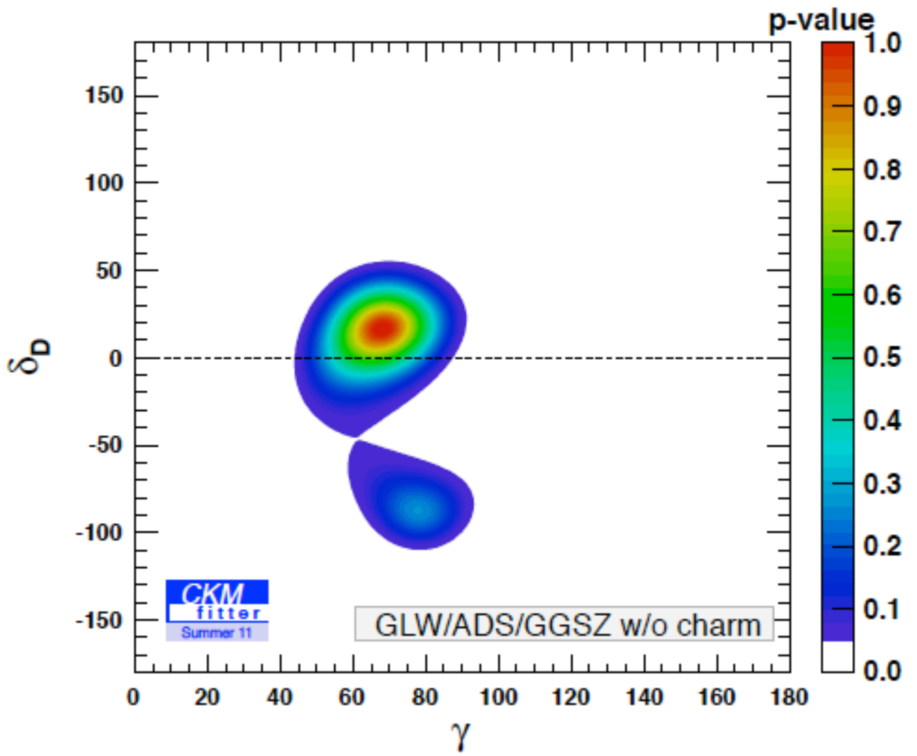
Karim Trabelsi, Belle, Tsukuba

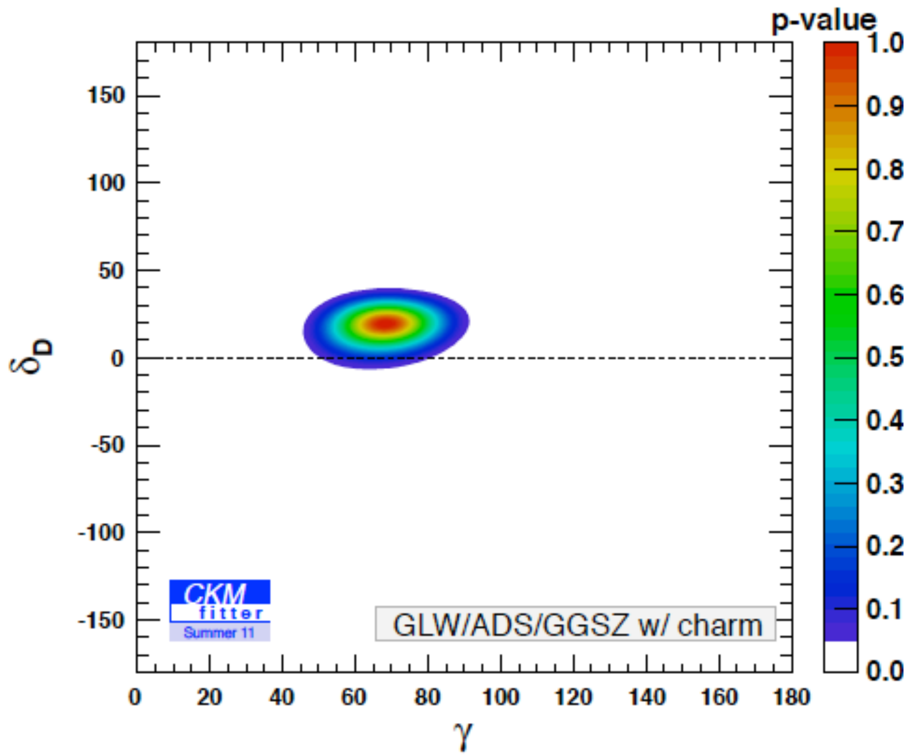
http://ckmfitter.in2p3.fr

After Summer 2011: $\gamma = (68 \pm 10)^\circ$



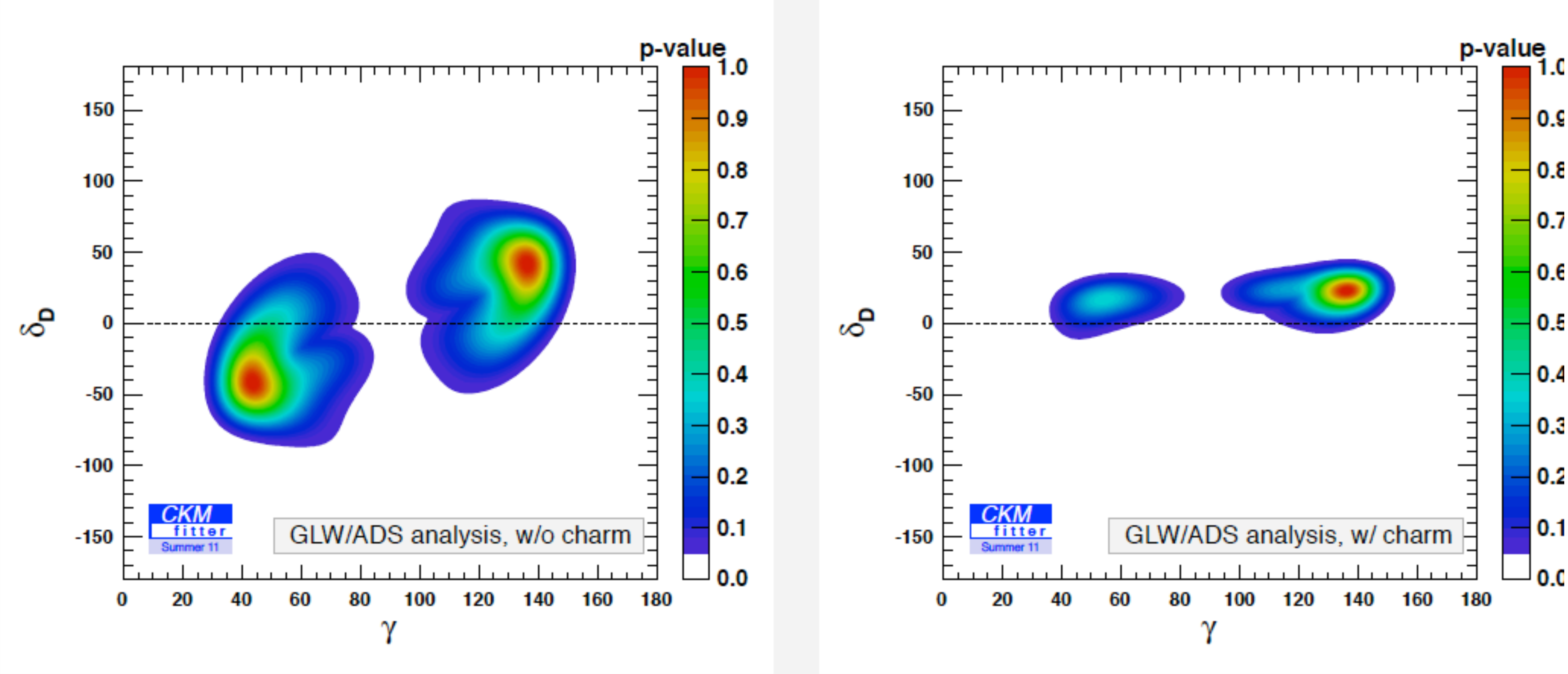
The full GGSZ/GLW/ADS analysis with and without charm observables





clearly the effect is more in the δ_D direction than the γ one

The GLW/ADS analysis with and without charm observables



without GGSZ observables the impact of charm observables is more important, with a slight preference for the 'wrong' γ solution the impact of charm observables on γ analysis, through the contraint on δ_{D}, is significant but mainly concern δ and the related ADS observables: it does not significantly improve the error on γ itself

it may change in the future, especially if one decides to remove the model-dependent, resonance-based, version of GGSZ: the binned approach is much cleaner theoretically but less precise at present, so that the contribution of ADS observables on the extraction of γ will be enhanced

Possible approaches for improving sensitivity on mixing and CPV using threshold data

- SuperB is considering to run at Ψ(3770) (i.e. $D\bar{D}$ threshold) with center-of-mass boost of $\beta\gamma \sim 0.5$. Integrated luminosity is about 500 fb^{-1} corresponding to few months of running. About x100 BESIII and x500 CLEOc data samples.
- Unique possibility of performing time-dependent measurements at $D\bar{D}$ threshold using quantum coherence.

Model independent approach for 3-body decays

- *A. Bondar, A. Poluektov, V. Vorobiev* have proposed a model independent analysis of 3-body D^0 decays for mixing and CPV. See **Phys. Rev. D 82, 034033 (2010)**

Sensitivity relies on the variation of the yields in different regions of the Dalitz plot along the time. No amplitude analysis is required.

Time dependence for flavor tagged decays (i.e. D* tagged at ϒ(4S))

$$\begin{aligned}\frac{d\Gamma_i[D^0_{\rm phys}\to f]/dt}{e^{-\Gamma t}\mathcal{N}_f} &= \Bigg[\left(T_i + |\frac{q}{p}|^2\bar{T}_i\right)\cosh(\Gamma y t) + \left(T_i - |\frac{q}{p}|^2\bar{T}_i\right)\cos(\Gamma x t)\\ &+ 2\left(c_i\sqrt{T_i\bar{T}_i}\left|\frac{q}{p}\right|\cos\phi - s_i\sqrt{T_i\bar{T}_i}\left|\frac{q}{p}\right|\sin\phi\right)\sinh(\Gamma y t)\\ &- 2\left(c_i\sqrt{T_i\bar{T}_i}\left|\frac{q}{p}\right|\sin\phi + s_i\sqrt{T_i\bar{T}_i}\left|\frac{q}{p}\right|\cos\phi\right)\sin(\Gamma x t)\Bigg]\end{aligned}$$

where: i = *region of Dalitz plot*

$$A_f = |A_f|e^{i\delta_f} \qquad \bar{A}_f = |\bar{A}_f|e^{i\bar{\delta}_f}$$

$$\int_i |A_f|^2 d\mathcal{P} = T_i \qquad \int_i |\bar{A}_f|^2 d\mathcal{P} = \bar{T}_i$$

proportional to number of events in bin i
Can be measured at ϒ(4S) or at ψ(3770)

$$\frac{\int_i \mathcal{R}e(A_f^*\bar{A}_f)d\mathcal{P}}{\sqrt{T_i\bar{T}_i}} = \frac{\int_i |A_f||\bar{A}_f|\cos(\bar{\delta}_f - \delta_f)d\mathcal{P}}{\sqrt{T_i\bar{T}_i}} = c_i$$

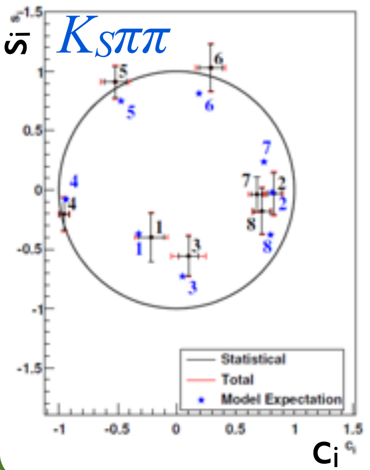
$$\frac{\int_i \mathcal{I}m(A_f^*\bar{A}_f)d\mathcal{P}}{\sqrt{T_i\bar{T}_i}} = \frac{\int_i |A_f||\bar{A}_f|\sin(\bar{\delta}_f - \delta_f)d\mathcal{P}}{\sqrt{T_i\bar{T}_i}} = s_i$$

$D^0 - \bar{D}^0$ relative phase.
Accessible at ψ(3770)

Determination of Dalitz plot parameters: T_i, c_i, s_i

- c_i, s_i determination requires $D\bar{D}$ coherent production. The method has been proved to work well by CLEO-c. See **Phys. Rev. D 82, 112006 (2010).**
- c_i, s_i from time integrated analysis of ψ(3770) data is affected by $\mathcal{O}(x^2, y^2)$ approximations (relatively small).
- c_i, s_i extraction: no CP conservation assumption required if doubling number of bins in the Dalitz plot.

Good agreement between BaBar/Belle Dalitz model expectation and CLEO-c model independent determination of D^0-$\bar{D}^0$ relative phases.

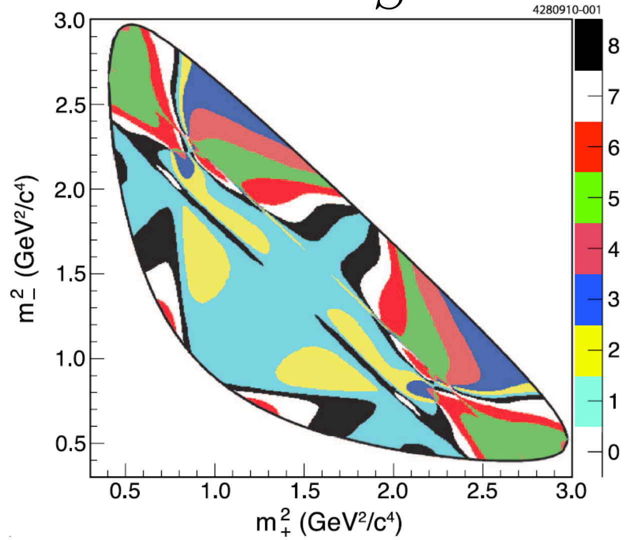


Modified optimal BABAR 2008

$\chi^2/DOF = 13.8/16$

from Stefania Ricciardi talk at CKM 2010.

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



the i^{th} bin is defined by the condition

$$2\pi(i-3/2)/\mathcal{N} < \Delta\delta_D(m_+^2, m_-^2) < 2\pi(i-1/2)/\mathcal{N},$$

- $T_i, \bar{T}_i$ can be measured at ψ(3770) with a time-integrated analysis and then fixed in the time-dependent mixing analysis at the ϒ(4S).
- $T_i, \bar{T}_i$ can also be determined simultaneously in the time-dependent mixing analysis at the ϒ(4S) if helpful for reducing systematic errors (different efficiencies, resolutions, etc.)

Sensitivity results for mixing and CPV parameters for $D^0 \to K_S \pi^+ \pi^-$

- Sensitivity studies for mixing and CPV with model independent approach. From **Phys.Rev.D82, 034033 (2010):**
  - assume perfect proper time resolution and no bkg;
  - assume very precise determination of c_i, s_i (considering 2×10^6 flavor tagged $D^0 \to K_S \pi^+ \pi^-$ decays at $\Psi(3770)$, will be available at SuperB).

TABLE II: Statistical sensitivity to the mixing and $\mathcal{CP}$ violation parameters for the time-dependent Dalitz plot analysis. Two strategies are considered: (i) T_i fixed from charm factory data and (ii) T_i taken as free parameters.

Parameter	Precision		Precision	
	T_i fixed	T_i floated	T_i fixed	T_i floated
x_D (10^{-4})	17	22	2.0	2.5
y_D (10^{-4})	13	16	1.5	1.8
$\|q/p\|(10^{-2})$	9	9	1.0	1.0
$\|\varphi\|$ $(^\circ)$	5	5	0.6	0.6

B Factories 1M signal events — SuperB 75 M signal events

- Similar approach is valid also for $D^0 \to K^+ \pi^- \pi^0$: very sensitive decay mode for mixing and CP violation. Using a model independent approach is possible to extract mixing parameters x, y directly also in this case.

Time-dependent measurements at $D\bar{D}$ threshold: preamble

- SuperB will have the possibility to operate with energy asymmetric beams also at the $\psi(3770)$ allowing time-dependent measurement of $D\bar{D}$ quantum coherent pairs.
- This is a unique feature of the SuperB machine to be studied and possibly exploited:
  - additional tag states (e.g. CP tag), other than flavor eigenstates, will be available at threshold thanks to the quantum coherence;
  - background free time-dependent measurements (e.g. $D^0 \rightarrow K^+\pi^-\pi^0$)
  - access to the mixing and CP violation parameters along with relative D^0-$\bar{D}^0$ relative phases from the same data;
  - possibility of time-dependent CPT tests exploiting using quantum coherence as for the Kaon and B meson systems;
  - possibility to double check a possible discovery of CP violation in the charm sector in different energy regimes and experimental environments with different systematic errors.

Time-dependent measurements at $D\bar{D}$ threshold: general considerations

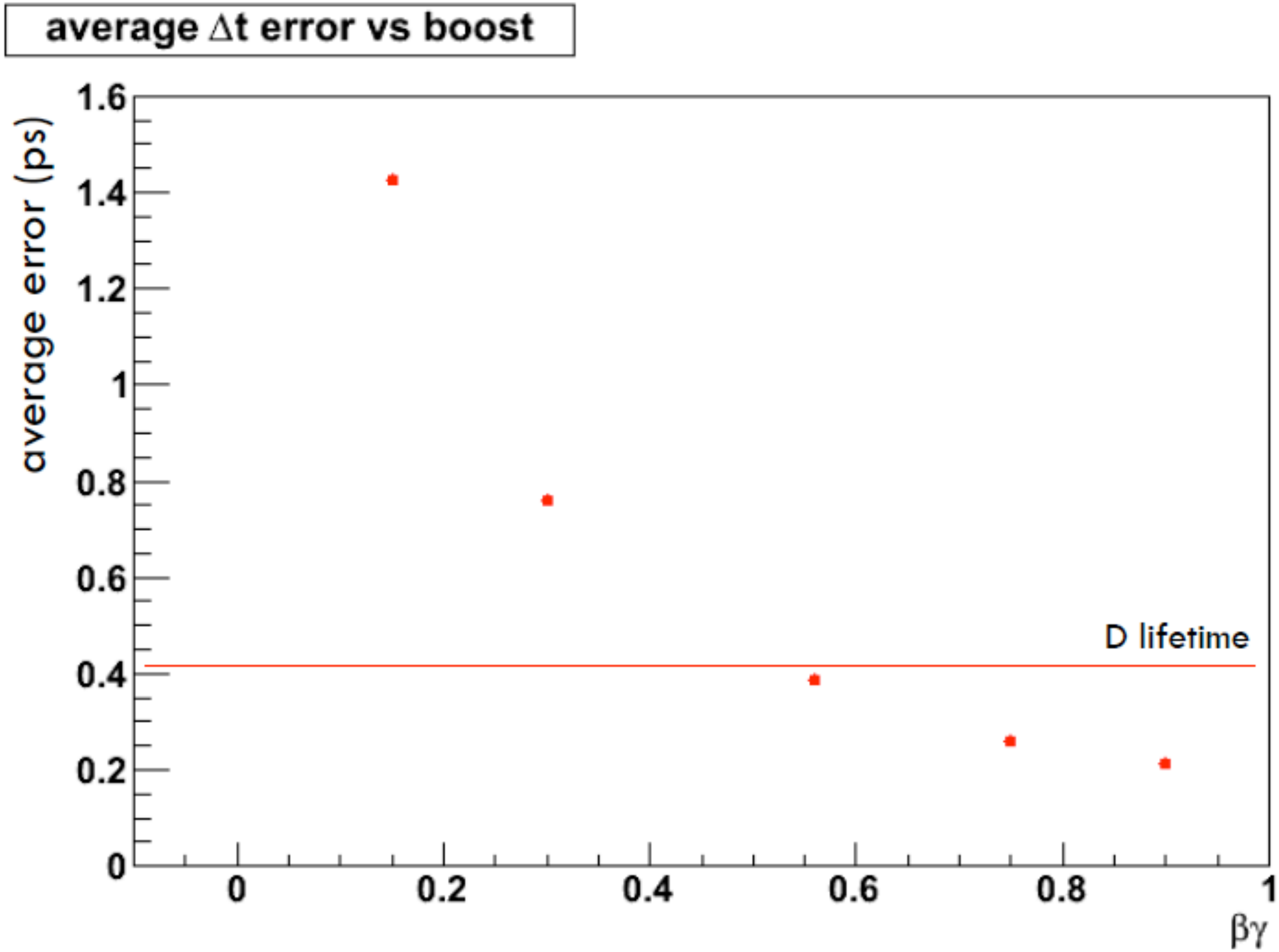
- At $\Upsilon(4S)$
  - Flavor tagged D^0 through $D^{*+} \to D^0\pi^+$ decay. Flavor mistag ≈ 0.2%
  - We denote the D* flavor tag with label *l*X
  - D^0 can be reconstructed in flavor *l*X, CP, Kπ and multibody (e.g. Ksππ) final states. Relatively high purity due to $m(D^0)$ and $\Delta m = m(D^{*+}) - m(D^0)$
  - Proper time resolution is about $\tau(D^0)/4 \approx 0.1$ ps
- At $\psi(3770)$
  - Coherent $D^0\bar{D}^0$ production
  - Both D mesons can be reconstructed in *l*X, CP, Kπ and Ksππ final states, with very low background
  - Flavor mistag ≈ 0.2% with eX, but ≈ 2% with μX (large μ misid @ low p)
  - Time-dependent measurements require larger CM boost compared to the $\Upsilon(4S)$ case to achieve time resolution, but reconstruction efficiency decreases with large CM boost. Need to determine the optimal boost value.

Double tags @ $\Psi(3770)$

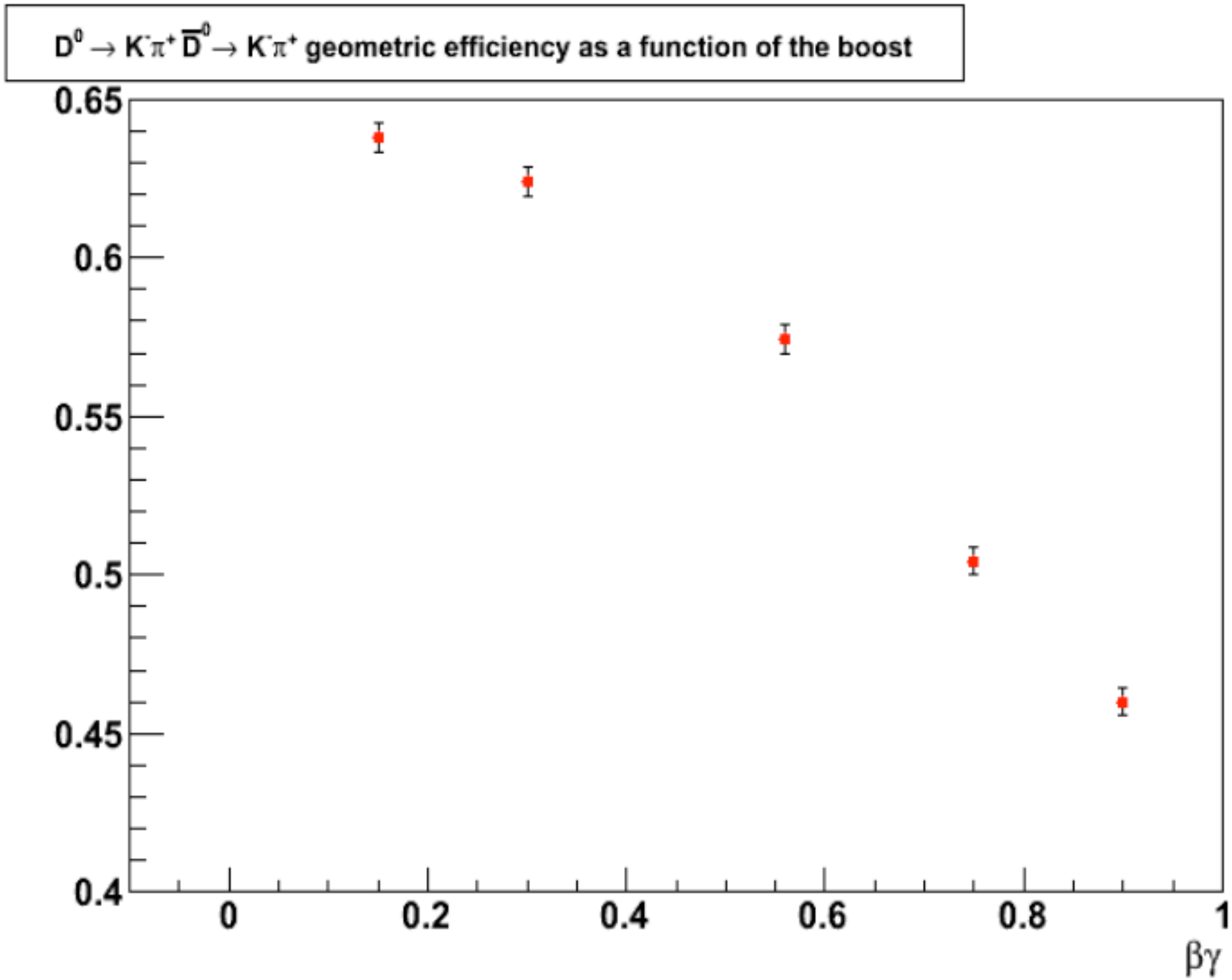
Modes with D* tag @ $\Upsilon(4S)$

	CP–	Kπ	*l*X	Ksππ
CP+	X	X	XX	X
CP–		X	XX	X
Kπ		X	XX	X
*l*X			XX	XX
Ksππ				X

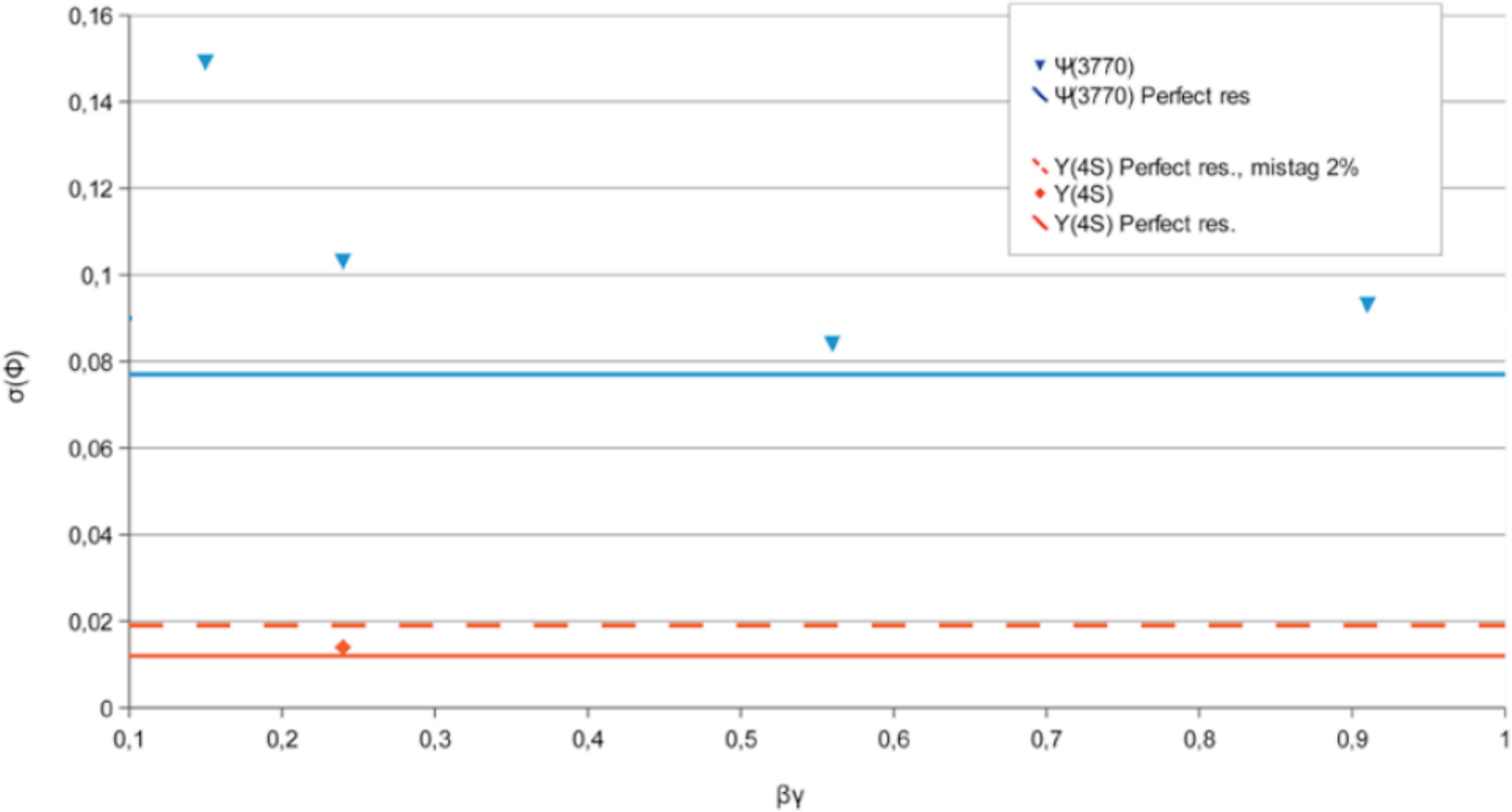
FastSim studies: Δt resolution vs CM boost



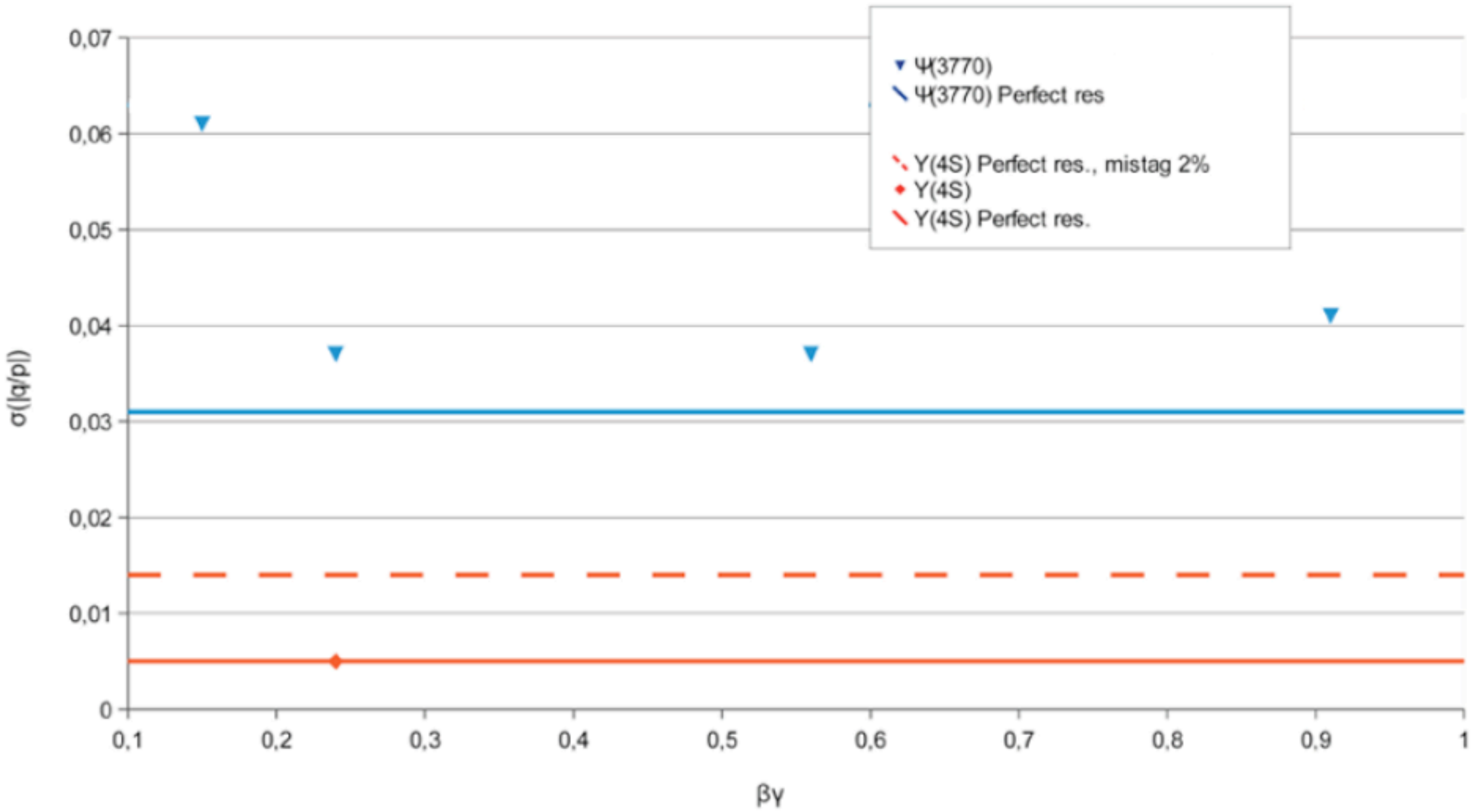
FastSim studies: ε_{geo} vs CM boost



Sensitivity: ϕ=arg(q/p)



Sensitivity: |q/p|



Summary

- Flavor tag at $D\bar{D}$ threshold provides identical time-dependence than at $\Upsilon(4S)$ using D* tagging, and less events, although in a different environment
- $D\bar{D}$ threshold is unique to provide CP, $K\pi$ and $Ks\pi\pi$ tags
- Variation of Δt resolution and geometrical acceptance vs CM boost was evaluated
- Estimated the impact on physics with 2-body decays
  - Combined fit to all 2-body double-tags allows determination of x, y, arg(q/p), |q/p|
  - Best sensitivity at $\Psi(3770)$ for intermediate boost, $\beta\gamma \approx 0.3$-0.6

Parameter	Sensitivity @ $\Upsilon(4S)$ with time resolution, no mistag. 75 ab^{-1}	Best sensitivity @ $\psi(3770)$ with time resolution ($\beta\gamma$=0.56), no mistag. 0.5 ab^{-1}
x	0.017%	0.11%
y	0.008%	0.05%
Arg(q/p)	0.8 deg	4.8 deg
|q/p|	0.5%	3.7%

Relative effect of flavor mistag similar at $\Psi(3770)$ and $\Upsilon(4S)$

  - error per ab^{-1} at Y(3770) ~ ½ error per ab^{-1} at Y(4S) (2-body only, no mistag)
  - error at $\Psi(3770)$ [0.5ab^{-1}] ~ 6x error at $\Upsilon(4S)$ [75ab^{-1}] (2-body only, no mistag)

Next steps

- Finalize 2-body sensitivity studies
- Sensitivity studies on mixing and CPV parameters for 3-body decays with a time-dependent Dalitz plot analysis:
  - Dalitz plot model independent approach is to be pursued at SuperB. For this, it is crucial to have access to $\Psi(3770)$ data
- Consider two different scenarios:
  - Time-dependent measurements at $\Upsilon(4S)$ with model independent coefficients (c_i, s_i) obtained with time-integrated Psi(3770) data
  - Time-dependent measurements at $\Psi(3770)$
- Set up simulation technology for 3-body Toy MC studies.

Correlated D decays at the $\Psi(3770)$

Rolf Andreassen, *Richard Gass* and *Michael D. Sokoloff*
Physics Department, University of Cincinnati
October, 2011

To calculate correlated D decay rates at the $J/\Psi(37700$ we calculate the correlated amplitude for the D and the $\overline{D}$ to decay to the states α and β at times t_1 and t_2 respectively, where the times are measured in the center-of-mass (CM) system and $t = 0$ is the time of the $e^+e^- \to c\bar{c}$ production. Because the $\Psi(3770)$ is $J^{PC} = 1^{--}$ state, we antisymmetrize the amplitude with respect to charge conjugation.

$$\mathcal{M} = \frac{1}{\sqrt{2}}\left[\langle\alpha|\mathcal{H}|D^0(t_1)\rangle\langle\beta|\mathcal{H}|\overline{D}^0(t_2)\rangle - \langle\beta|\mathcal{H}|D^0(t_2)\rangle\langle\alpha|\mathcal{H}|\overline{D}^0(t_1)\rangle\right] \tag{1}$$

The time evolution of the D^0–$\overline{D}^0$ system is described by the Schrödinger equation

$$i\frac{\partial}{\partial t}\begin{pmatrix} D^0(t) \\ \overline{D}^0(t) \end{pmatrix} = \left(\mathrm{M} - \frac{i}{2}\Gamma\right)\begin{pmatrix} D^0(t) \\ \overline{D}^0(t) \end{pmatrix}, \tag{2}$$

where the M and Γ matrices are Hermitian, and CPT invariance requires $M_{11} = M_{22} \equiv M$ and $\Gamma_{11} = \Gamma_{22} \equiv \Gamma$.

Sensitivities

channel	# of events	δx	δy	Comments
$K_S^0\pi^-\pi^+,\ K^-e^+\nu_e$	720K	0.15%	0.09%	BaBar $K_S^0\pi^-\pi^+$ amplitudes
$K_S^0\pi^-\pi^+,\ K^-\pi^+$	865K	0.18%	0.05%	$\cos\delta_{K\pi} = 0.95$
$K_S^0\pi^-\pi^+,\ h^-h^+$	110K	–	0.21%	
$K_S^0\pi^-\pi^+,\ K_S^0\pi^-\pi^+$	285K	0.24%	0.16%	
$K^-\pi^+\pi^0,\ K^-e^+\nu_e$	4500	0.06%	0.06%	$\cos\delta_{K\pi\pi^0} = 0.95$, $R_D = 0.16\%$ BaBar $K\pi\pi^0$ amplitudes
$K^-\pi^+\pi^0,\ K^-\pi^+$	5000	0.06%	0.05%	
$K^-\pi^+\pi^0,\ K^-\pi^+\pi^0$	7200	0.07%	0.06%	
$K^-\pi^+\pi^0,\ h^-h^+$	460K	–	0.10%	
$K^-\pi^+,\ K^-e^+\nu_e$	10,600	0.27%	0.08%	$\cos\delta_{K\pi} = 0.95$
$K^-\pi^+,\ h^-h^+$	187K	–	0.16%	$\cos\delta_{K\pi} = 0.95$
$h^-h^+,\ K^-e^+\nu_e$	345K	–	0.12%	
$\pi^-\pi^+\pi^0,\ K^-e^+\nu_e$	120K	0.28%	0.22%	BaBar $\pi^-\pi^+\pi^0$ amplitudes
$\pi^-\pi^+\pi^0,\ K^-\pi^+$	120K	0.56%	0.15%	
$\pi^-\pi^+\pi^0,\ h^-h^+$	20K	–	0.5%	

Wrong Sign $D^0 \rightarrow K^+\pi^-\pi^0$ is the most sensitive decay mode!

Summary of the summary

- Major topics of charm threshold physics are: overcome the non−perturbative QCD roadblock, test pQCD calculations and search for new physics beyond Standard Model.

- Impact of charm physics at threshold on flavor physics measurements is relevant:

  - remove Dalitz model dependency in D^0 mixing and CP violation measurements and γ/Φ_3 measurements;

  - measurement of |Vcs|, |Vcd| and $D_{(s)}$ form factors;

  - measurement of decay constants of f_D, f_{Ds};

  - searches for rare or forbidden decays;

- Systematic errors do not seem to be a roadblock for the relevant measurements and future high statistics data sample will be beneficial.

Backup slides

Time-dependent CP asymmetries in D and B decays

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B. Meadows
University of Cincinnati, Cincinnati, Ohio 45221, USA

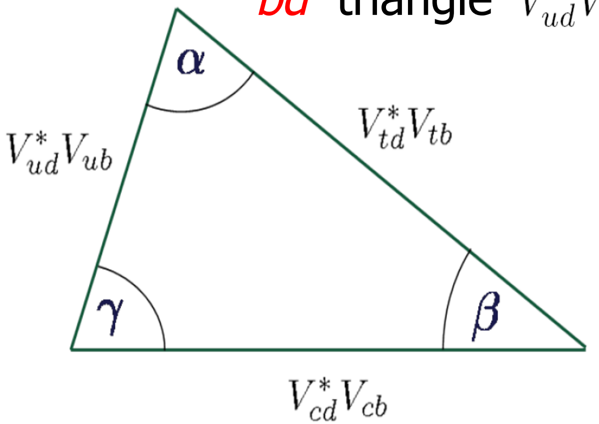
(Dated: October 13, 2011)

We examine measurements of time-dependent CP asymmetries that could be made in new and future flavour facilities. In charm decays, where they can provide a unique insight into the flavor changing structure of the Standard Model, we examine a number of decays to CP eigenstates and describe a framework that can be used to interpret the measurements. We make a preliminary assessment, based on statistical considerations, of the relative capabilities of LHCb with data from pp collisions, with Belle II and Super$B$ using data from B_d, B_s and charm thresholds. We discuss the measurements required to perform direct and indirect tests of the charm unitarity triangle and its relationship with the usual B_d triangle. We find that, while theoretical and experimental systematic uncertainties may limit their interpretation, useful information on the unknown charm mixing phase, and on the possible existence of new physics can be obtained. We point out that, for B_d decays, current experimental bounds on $\Delta\Gamma_{B_d}$ will translate into a significant systematic uncertainty on future measurements of $\sin 2\beta$ from $b \to c\bar{c}s$ decays. The possibilities for simplified B_s decay asymmetry measurements at Super$B$ and Belle II are also reviewed.

ArXiv: 1106.5075v2

Constraint on cu Triangle ?

bd triangle $V_{ud}^*V_{ub} + V_{cd}^*V_{cb} + V_{td}^*V_{tb} = 0$

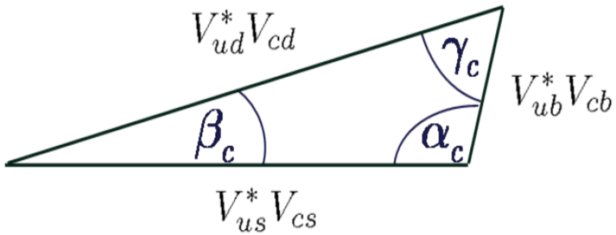


$$\alpha = [V_{td}V_{tb}^*/V_{ud}V_{ub}^*] = (89.4 \pm 4.3)^\circ$$
$$\beta = [V_{cd}V_{cb}^*/V_{cd}V_{cb}^*] = (22.1 \pm 0.6)^\circ$$
$$\gamma = [V_{ud}V_{ub}^*/V_{cd}V_{cb}^*] = (68.4 \pm 3.7)^\circ$$

NOTE that

- [illegible]$_c$ is equal to [illegible]
- [illegible]$_c$ + [illegible]$_c$ ~90^0

cu triangle $V_{ud}^*V_{cd} + V_{us}^*V_{cs} + V_{ub}^*V_{cb} = 0$



$$\alpha_c = [V_{ub}^*V_{cb}/V_{us}^*V_{cs}] = (111.5 \pm 4.2)^\circ$$
$$\beta_c = [V_{ud}^*V_{cd}/V_{us}^*V_{cs}] = (0.0350 \pm 0.0001)^\circ$$
$$\gamma_c = [V_{ub}^*V_{cb}/V_{ud}^*V_{cd}] = (68.4 \pm 0.1)^\circ$$

Decays to CP Eigenstates

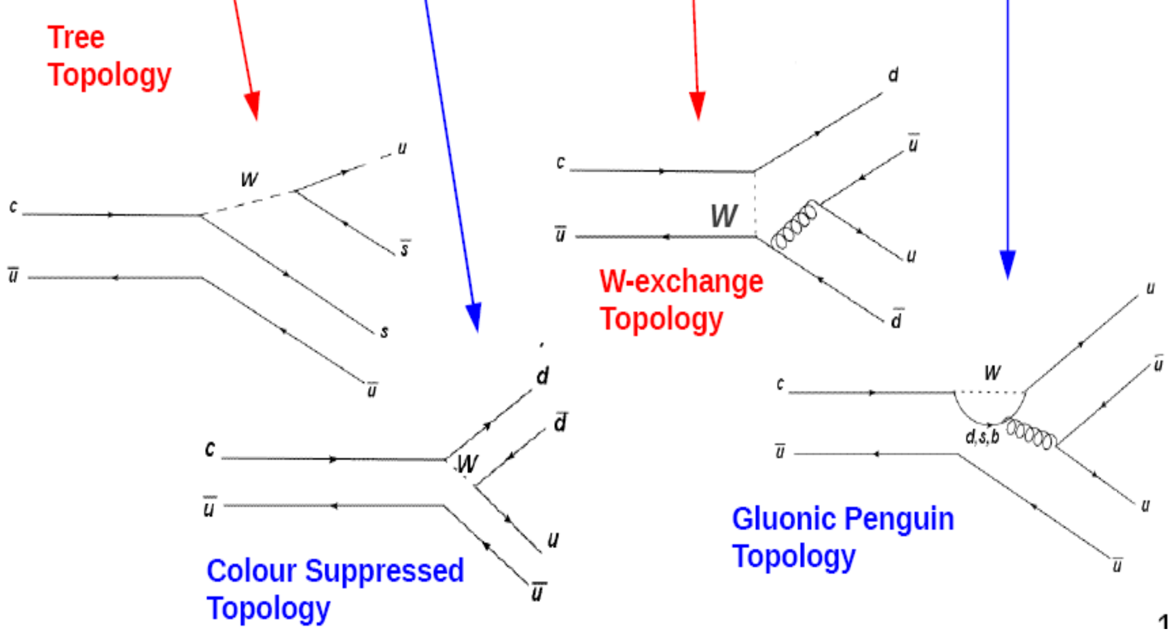
- For decays to CP eigenstates, strong phase □ in □$_f$ is zero

Several amplitudes could, however, contribute to the decays.

- Some information on the magnitude of **P**, the penguin contribution can be obtained from an isospin analysis if all charge modes have well measured **BF**'s, including neutralmodes □^{0}□^{0}, □^{0}□^{0} and all the □□ modes too.

This is best done at the electron machines.

$$A=\boxed{|T|}\,e^{i(\phi_T+\delta_T)}+\boxed{|CS|}\,e^{i(\phi_{CS}+\delta_{CS})}+\boxed{|W|}\,e^{i(\phi_W+\delta_W)}+\sum_{q=d,s,b}\boxed{|P_q|}\,e^{(i\phi_q+\delta_q)}$$



Results – “as good as (they) get”

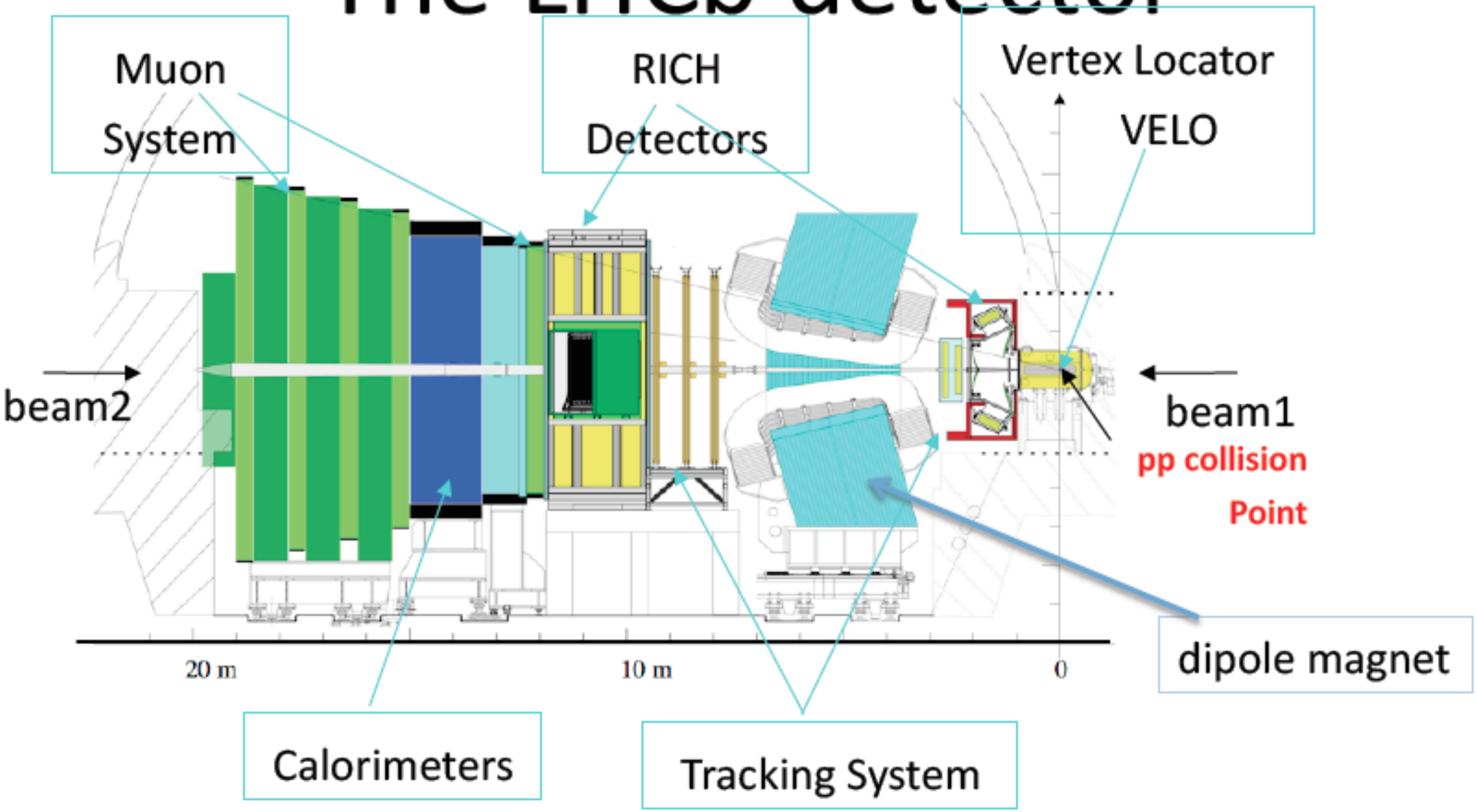
- The K^+K^- mode is dominated by a tree diagram that is real.

  So we expect that no direct CPV will be found here

- Therefore, this mode can be used to find arg (q/p) = [illegible]$_M$
- Then [illegible]$^+$[illegible]$^-$ mode (for which arg([illegible]$_f$} = [illegible]$_M$-2[illegible]$_{C,eff}$) can give [illegible]$_{C,eff}$

Parameter	SuperB SL	SuperB SL + K	SuperB $\Upsilon(4S)$	LHCb
$\phi(\pi\pi) = \arg(\lambda_{\pi\pi})$	8.0°	3.4°	2.2°	2.3°
$\phi(KK) = \arg(\lambda_{KK})$	4.8°	2.1°	1.3°	1.4°
$\phi_{CP} = \phi_{KK} - \phi_{\pi\pi}$	9.4°	3.9°	2.6°	2.7°
$\beta_{c,eff}$	4.7°	2.0°	1.3°	1.4°

The LHCb detector



CERN LHC: pp machine with $\sqrt{s}$=7TeV (due to the 2008 accident)
Pseudo-rapidity coverage → 1.9-4.9
Originally designed for b physics, but now is pursuing a wide charm physics program (out of 4 physics WGs, one is Charm)

Challenges and goodies of charm physics in LHCb (1)

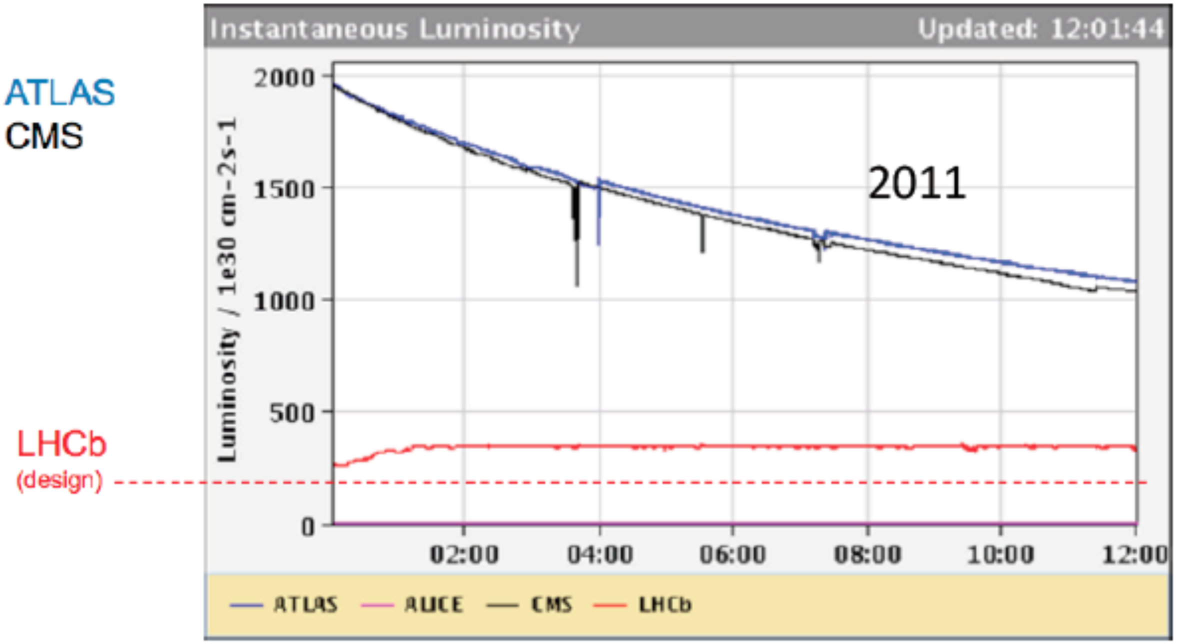
- at 7TeV σ(ccbar) ≈ 6mb, σ(bbar) ≈ 0.3mb, σ(pp inelastic)≈60mb
  - huge σ(ccbar); background from secondary charm from b already low from the start of the selection
  - and very favorable ratio to inelastic σ (only a factor of 10!)
  - → high purity selections with few and soft IP, displaced vertex and p_T cuts
  - → very large yields (the highest on the market)
- however due to lower D meson daughter p_T and IP wrt B mesons, trigger thresholds have to be kept low
  - → tough requirements for trigger, tracking, online and offline reconstruction, both for bandwidth and timing, and last but not least storage!

Challenges and goodies of charm physics in LHCb (2)

- yields (and competition with other experiments) decrease with # of tracks in the final state due to tracking efficiency (a factor/track) and to trigger efficiency (the meson p_T is divided among the n---tracks)
  - the competition with the B factories for channels with ≥4 tracks is tough
- we mostly concentrate on channels with charged tracks in the final state (due to the large number of π^0 in the event and to the modest resolution EM Calorimeter)
- the large data yields are also a problem for MC → very tough to get equivalent MC statistics of full simulation (to test for e.g. detector effects in CPV asymmetries)
    - toy studies need to be extensively used
- Charm physics at hadron colliders has been successfully pioneered by the Tevatron experiments!

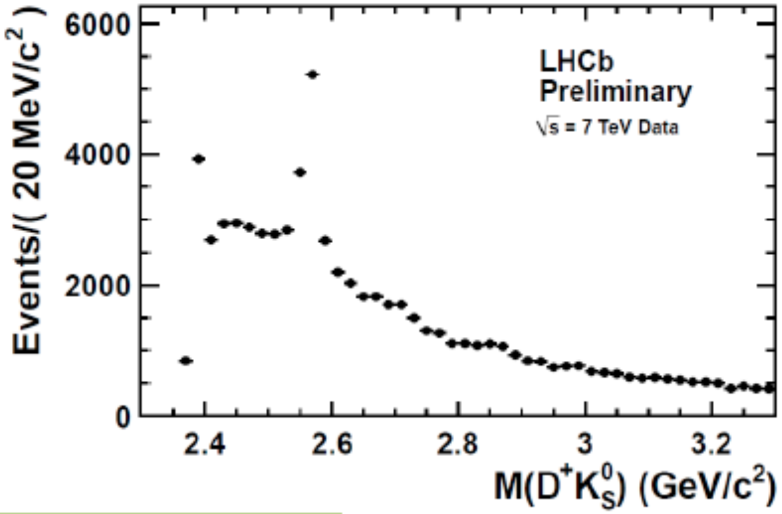
The LHCb running conditions

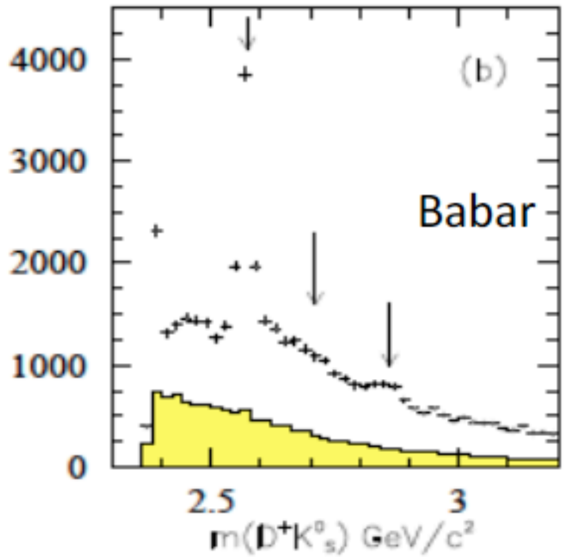
2010 was a "learning phase" year with fast varying running conditions and luminosity at the end of it we collected $37pb^{-1}$ and we were running at a pile-up of up to 2.5 collisions/event in average (with the design being 0.4) but we coped well with it!



In 2011 we've been running with more steady conditions of ≈1.5collisions/event with $L=3.5\bullet10^{-32}\ cm^{-1}s^{-1}$ (1.5x the design value) with luminosity leveling collecting up to more than $1fb^{-1}$ by now (while GPE collected about $5pb^{-1}$)

$D^+K_s^0$





Preliminary: 2011 data
$320pb^{-1}$

Thank to the excellent performances of LHC and LHCb detector, D_J and D_{sJ} spectroscopy feasible with the same sensitivity of the B-factories

Phys.Rev.D 80, 092003(2009)

Resonance	Mass (MeV/c²)	Width (MeV)
$D_{s1}^*(2700)$	$2710 \pm 2\ ^{+12}_{-7}$	$149 \pm 7\ ^{+39}_{-52}$
$D_{sJ}^*(2860)$	$2862 \pm 2\ ^{+5}_{-2}$	$48 \pm 3 \pm 6$

Experimental issues of time integrated CPV in LHCb

- Experimentally, we have to cope with fake asymmetries:
  - production asymmetries (pp collider)
  - detection asymmetries (different K+/K- interaction lengths, soft pion efficiency asymmetry)
  - backgrounds
- Moreover the dipole magnet makes the detector left-right asymmetric for + charge and – charge particles
  - a localized detector inefficiency translates into a fake CPV asymmetry

  1) we developed robust observables:
     - Miranda technique for SCS decay $D^+ \rightarrow K^+K^-\pi^-$
     - difference of two CPV asymmetries in SCS decays into CP eigenstates $D^0 \rightarrow KK$ and $D^0 \rightarrow \pi\pi$

  2) swap the magnetic field from time to time

- signal purity is a must → excellent detector performance

D->KKπ: the method

- Model-independent search for CPV in Dalitz plot distribution
- Compare binned, normalized Dalitz plots for D^+ and D^-
  - Production asymmetry cancels completely after normalization.
  - Efficiency asymmetries that are flat across Dalitz plot also cancel.

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

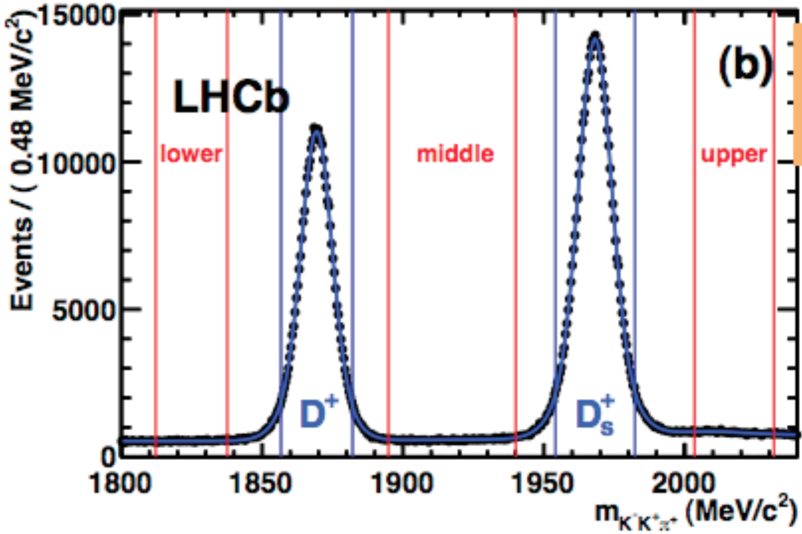
- Method based on “Miranda” (*)approach -- asymmetry significance
  - In absence of asymmetry, values distributed as Gaussian(μ=0, σ=1)
  - Figure of merit for statistical test: sum of squares of S^i_{CP} is a $\chi 2$

(*) Phys. Rev. D80 (2009) 096006

See also BaBar: Phys.Rev. D78:051102 (2008); our dataset contains 10x more events and is of comparable size of Belle analysis of D→ϕπ:(arXiv:0807.4545)

D→KKπ: mass and Dalitz plot

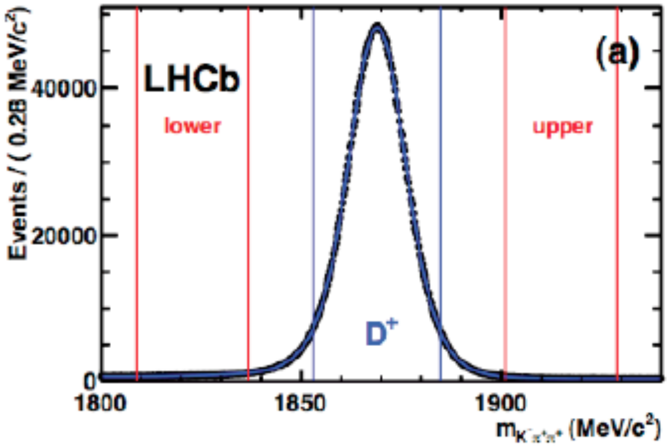
Yield of 400k in window
Purity of ≈91%



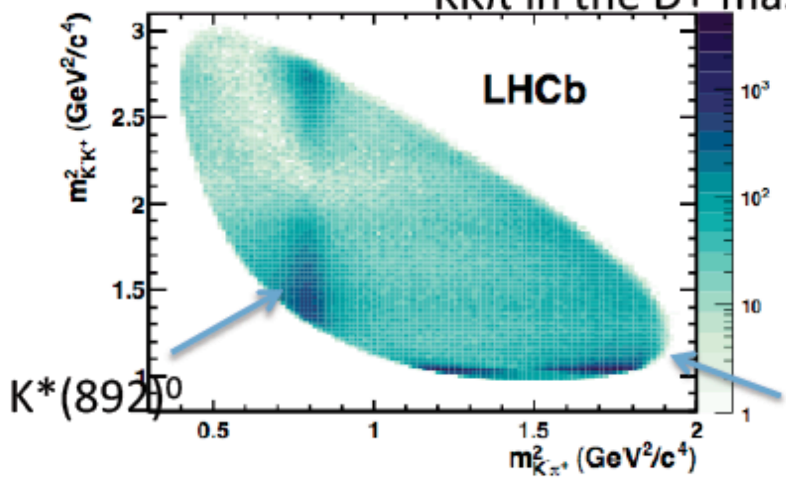
http://arxiv.org/abs/1110.3970
LHCb 35pb^{-1}

KKπ signal (D^+) and control mode (D_s^+)

Kππ control mode (D^+) purity ~ 98%



KKπ in the D+ mass window



$\Delta A_{CP} = A_{CP}(D^0 \rightarrow KK) - A_{CP}(D^0 \rightarrow \pi\pi)$

$$A_{RAW}(f) \equiv \frac{N(D^0 \to f) - N(\overline{D}^0 \to \bar{f})}{N(D^0 \to f) + N(\overline{D}^0 \to \bar{f})}$$

$$A_{RAW}(f)^* \equiv \frac{N(D^{*+} \to D^0(f)\pi^+) - N(D^{*-} \to \overline{D}^0(\bar{f})\pi^-)}{N(D^{*+} \to D^0(f)\pi^+) + N(D^{*-} \to \overline{D}^0(\bar{f})\pi^-)}$$

$$A_{RAW}(f) = \boxed{A_{CP}(f)} + \boxed{A_D(f)} + \boxed{A_P(D^0)}$$

$$A_{RAW}(f)^* = \boxed{A_{CP}(f)} + \boxed{A_D(f)} + \boxed{A_D(\pi_s)} + \boxed{A_P(D^{*+})}$$

physics CP asymmetry

Detection asymmetry of D^0

Detection asymmetry of soft pion

Production asymmetry

For a two-body decay of a spin-0 particle to a self-conjugate final state, no D^0 detector efficiency asymmetry, $A(K^-K^+) = A(\pi^-\pi^+) = 0$

Look at difference in CP asymmetry between KK and ππ: very robust against systematics

$$A_{RAW}(K^-K^+)^* - A_{RAW}(\pi^-\pi^+)^* = A_{CP}(K^-K^+) - A_{CP}(\pi^-\pi^+)$$

A_{CP}(KK) and A_{CP}(ππ) receive contributions from both indirect CPV (universal) and direct CPV (final state dependent) → taking the difference we are sensitive (almost) only to the direct CPV contribution

Systematics and preliminary result

Effect	Uncertainty
Modeling of lineshapes	0.06%
D^0 mass window	0.20%
Multiple candidates	0.13%
Binning in (p_t, η)	0.01%
Total systematic uncertainty	0.25%
Statistical uncertainty (for comparison)	0.70 %

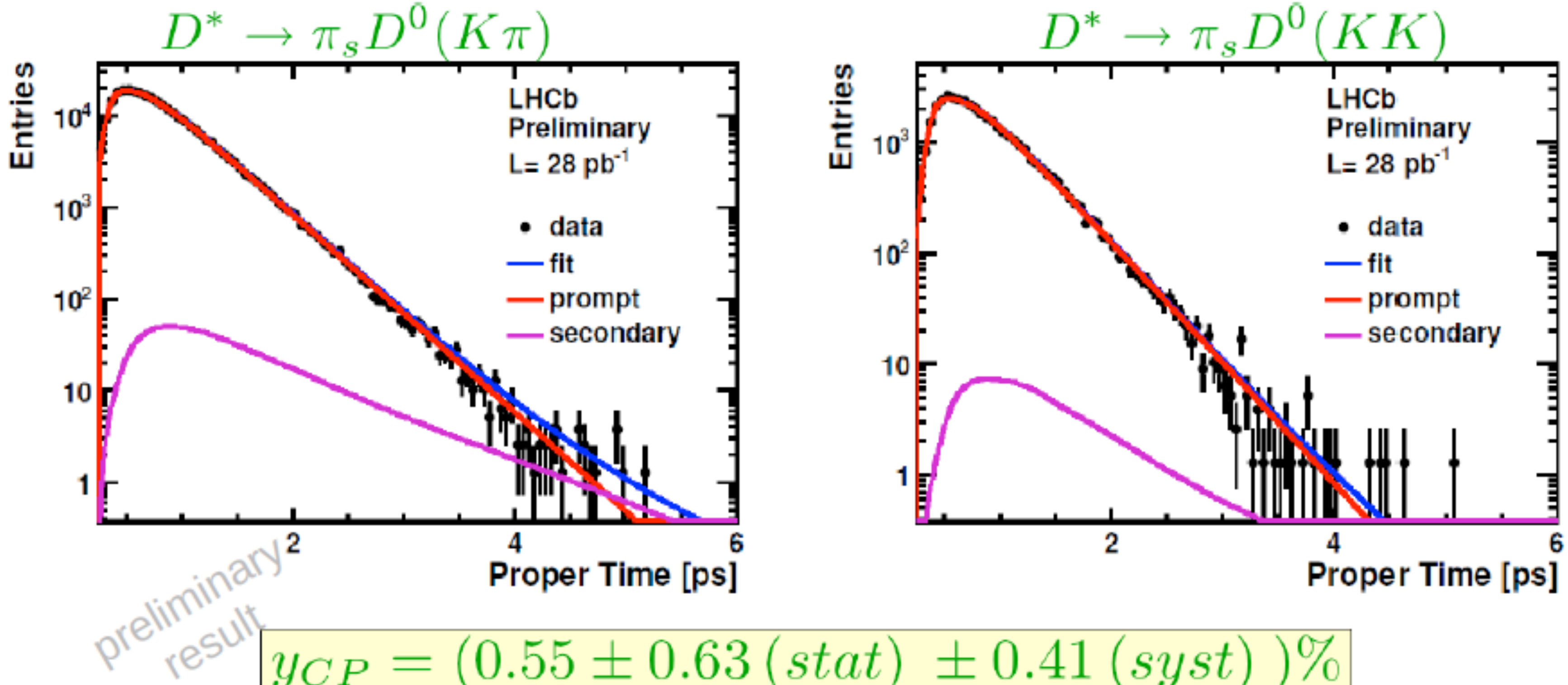
Preliminary: 2010 data
38pb-1

$$A_{CP}(KK) - A_{CP}(\pi\pi) = (-0.275 \pm 0.701 \pm 0.25)\%$$

Note: already competitive with the B-factories!
Statistical error for BABAR 0.62%, Belle 0.60%
But for CDF: 0.33%
Expect systematic error to scale well with integrated lumi.
Estimates very conservative, with large statistical component.

Result for y_{CP} with 2010 data

y_{CP} measures the ratio of lifetimes between CP eigenstates $D^0 \to K\pi$ and CP-mixed states $D^0 \to \pi\pi$.



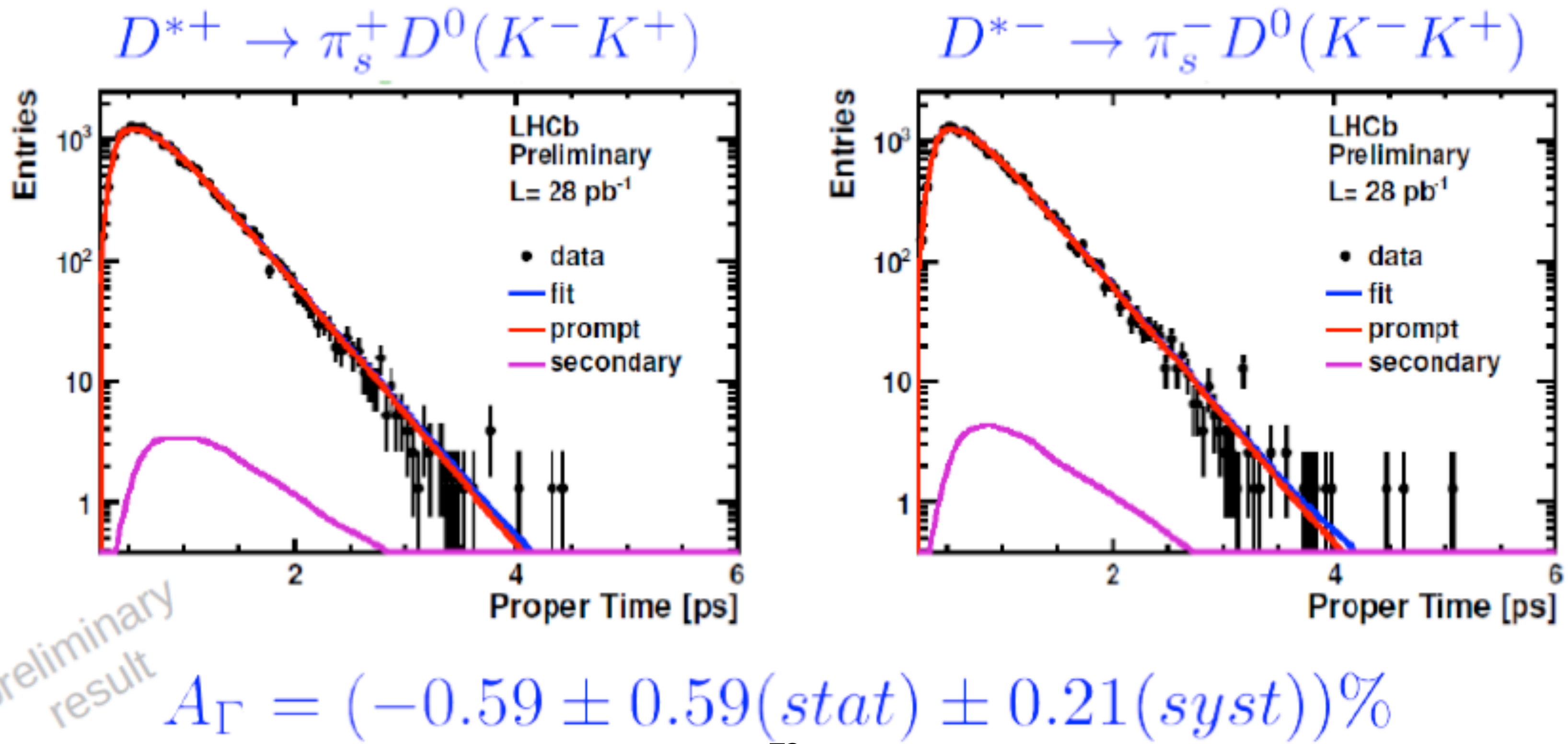
$$y_{CP} = (0.55 \pm 0.63\,(stat)\ \pm 0.41\,(syst)\ )\%$$

- **Budget for systematic error:**
  - Contribution from Combinatorical BG: $\pm 0.08\%$
  - Fit model: $\pm 0.08\%$
  - Impact of secondary charm: $\pm 0.39\%$

Measurement of A_Γ with 2010 data

A_Γ measures the lifetime difference between D^0 and $\overline{D^0}$ into CP-eigenstates K^+K^-

- Mistag rate determined from sidebands in $\Delta m(D^* - D^0(hh))$
- Systematic error mainly from combinatorical and secondary charm BG



$$A_\Gamma = (-0.59 \pm 0.59(stat) \pm 0.21(syst))\%$$

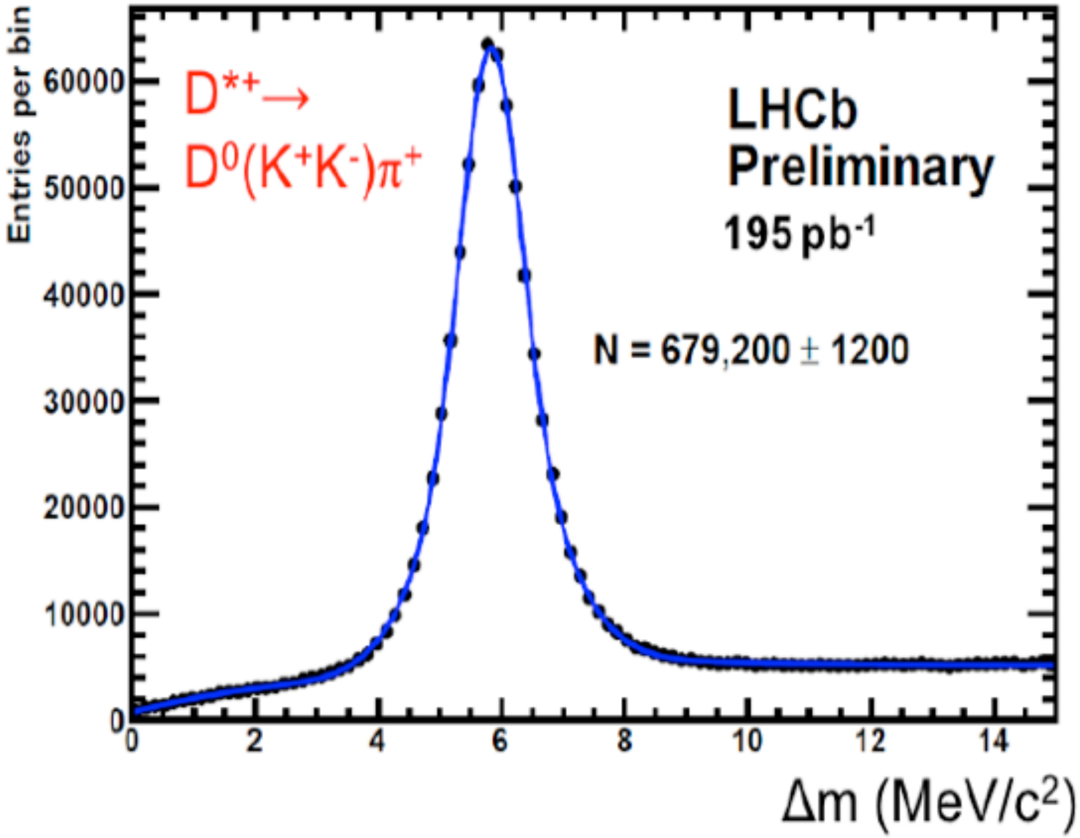
Prospects for 2011

In 2011 we increased already now the amount of data by a factor 30! (i.e. already now the world highest statistics for many channels)

Signal yield per pb^{-1} approximately the same or even improved (e.g. $3x10^5$ untagged $D0 \rightarrow K\pi$ decays per pb^{-1})

Trigger settings have been improved And more channels have been added To the trigger..

Modelling of combinatorical BG and BG from B-decays will be improved.



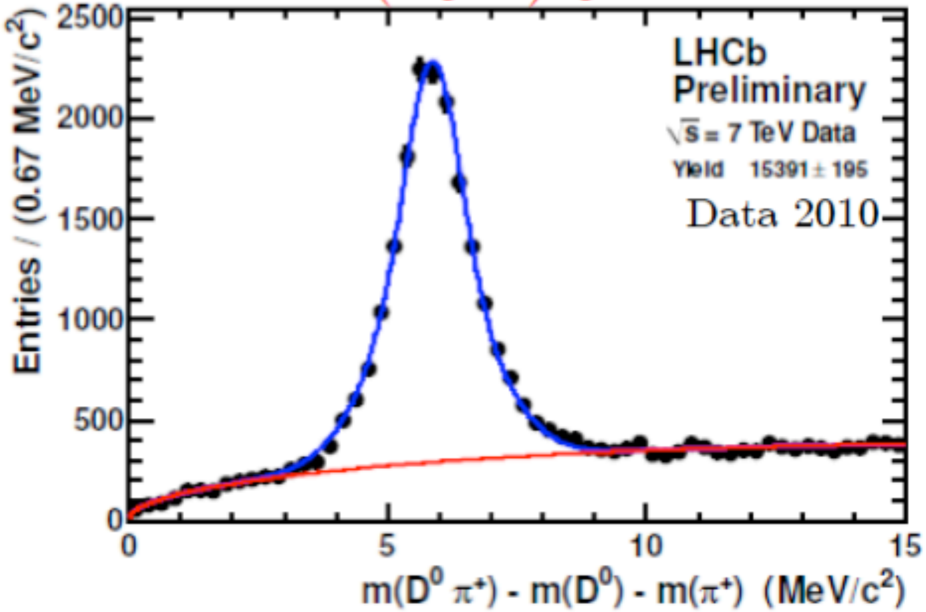
→ Larger data sample + improved trigger allow to reduce systematic error significantly.

Prospects for $D^0 \to K_s hh$

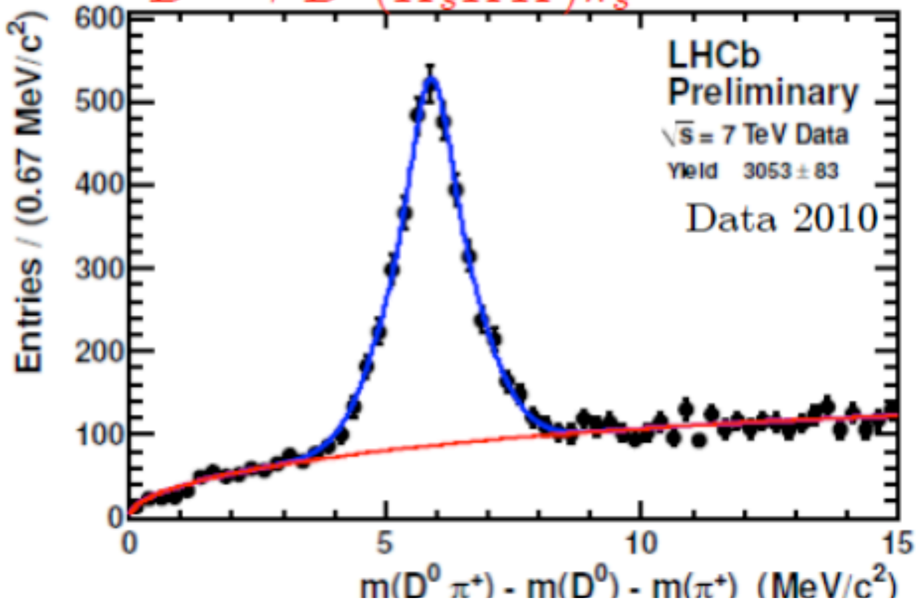
- LHCb was running in 2010 without a dedicated trigger for $D^0 \to K_s hh$
  - → despite that a nice signal in $35 pb^{-1}$ is seen!
- In 2011 LHCb is running with a dedicated trigger for that channel.

This offers LHCb a method to measure x, y and CPV parameters complementary to the decay channel $D^0 \to hh$!

$D^* \to D^0(K_s\pi\pi)\pi_s$



$D^* \to D^0(K_sKK)\pi_s$



Conclusion(1)

- LHCb has a very rich charm physics program ranging from mixing/CPV to rare decays and spectroscopy, mostly with decays to charged particles in the final state
- With 2011 data ($1fb^{-1}$)we already have the world highest statistics in many channels
- We expect to collect $5fb^{-1}$ up to 2017 (phase 1) and $50fb^{-1}$ (2019-2029?) with the upgrade
- For many years to come, at least until 2018, LHCb will be (together with BES3) the leading experiment in the field: statistical sensitivity to many observables such to rule out NP contributions (e.g. some channels of direct CPV)
- Still systematics such as production asymmetries in CPV and lifetime acceptance have to be treated with care and more new ideas on that need to be developed