Not a summary of

Implications of LHCb measurements and future prospects

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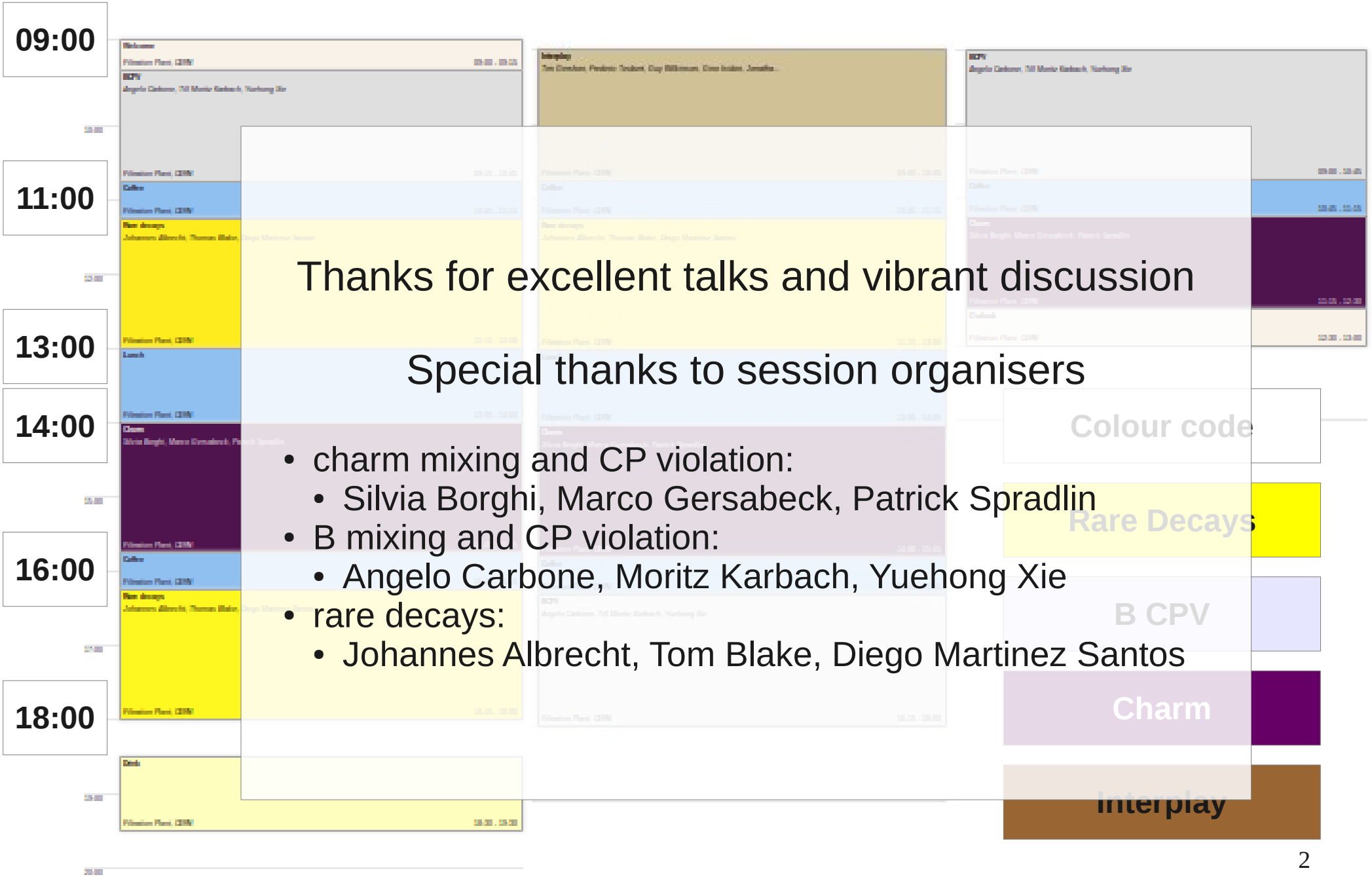
G. Perez, F. Teubert, G. Wilkinson

18 April 2012



Thanks for excellent talks and vibrant discussion

Special thanks to session organisers

- charm mixing and CP violation:
  - Silvia Borghi, Marco Gersabeck, Patrick Spradlin
- B mixing and CP violation:
  - Angelo Carbone, Moritz Karbach, Yuehong Xie
- rare decays:
  - Johannes Albrecht, Tom Blake, Diego Martinez Santos

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

LHCb-PUB-2012-YYY
April 17, 2012

Implications of LHCb measurements and future prospects

The LHCb collaboration
and
various theorists[1]

Abstract

During 2011 the LHCb experiment at CERN collected 1.0fb^{-1} of $\sqrt{s} = 7\text{TeV}$ pp collisions. Due to the large production cross-sections, these data provide unprecedented samples of heavy flavoured hadrons. The first results from LHCb have made a significant impact on the flavour physics landscape and have definitively proved the concept of a dedicated experiment in the forward region at a hadron collider. This document discusses the implications of these first measurements on classes of extensions to the Standard Model, bearing in mind the interplay with the results of direct searches at ATLAS and CMS. The physics potential of an upgrade to the LHCb detector, which would allow an order of magnitude more data to be collected, is emphasised.

[1]Still need to decide exactly how the author list should appear.

Reminder

Outcome of the workshops will be a document to form the basis of a submission to the European Strategy Preparatory Group

Please discuss with session organisers how to contribute (and beware that fast turnaround is needed)

What is $BR(B_s \to \mu^+\mu^-)$?

- Several different numbers mentionned in the talks this week (and even more came up during discussion):

	$BR(B_s \to \mu^+\mu^-) \times 10^{-9}$
Alexey Petrov	3.3 ± 0.2
David Straub	3.2 ± 0.2
Nazila Mahmoudi	3.58 ± 0.36
UTFIT	3.54 ± 0.28
CKMFITTER	$3.63^{+0.18}_{-0.32}$

but what is the SM value . . . ?

. . . and should we assume there is no NP in Δm_s to calculate it?

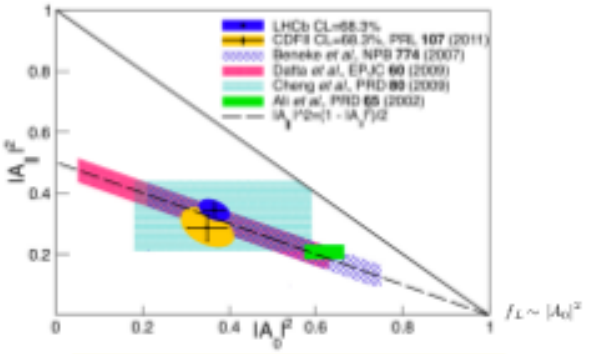
Rare decays

- Bs → μμ – need to aim to observe 20% deviation from SM prediction(!)
  - Important role of lattice input – must be properly acknowledged
- Bs → μμγ
  - Lots to discuss
  - Hard/soft gamma: different regimes, different issues
- LFV searches
  - Many interesting channels, not only tau decays
- K(*)μμ isospin asymmetries
  - Further theoretical scrutiny well motivated
- K*μμ angular analysis
  - Inexhaustible supply of observables?
  - CPV certainly interesting – make sure to measure right thing
- Baryonic decays offer new potential
  - Quantum numbers should be measured, not just assumed?

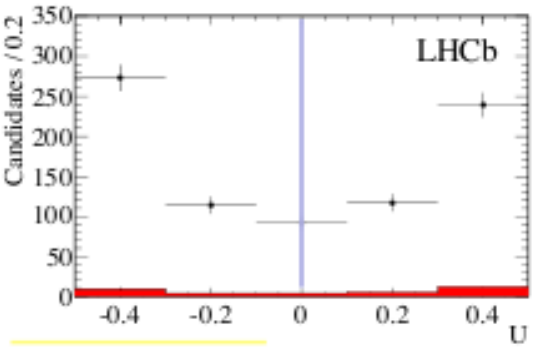
NP in hadronic B decay

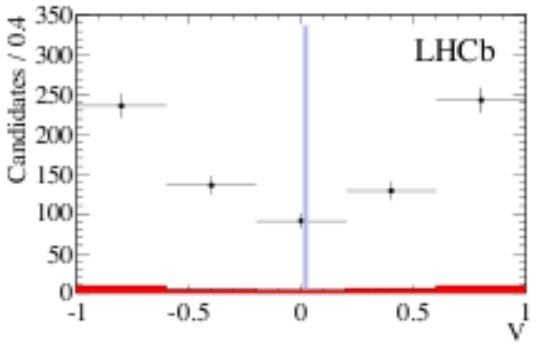
- LHCb report (Matt)
  - First observation of $B_s \to K^*K^{*0bar}$
  - Measurements of polarizations and TPA in $B_s \to \phi\phi$
  - CPV and more modes in future
- NP in $B \to VV$? (Alakhaba)
  - $B \to VV$ good place to probe NP
  - Polarizaion puzzle: NP explanation constrained by polarization and TPA measurements
  - Time dependent analysis to measure ϕ_s needed
  - May separate NP in mixing and decay

1/fb, LHCb-CONF-2012-004



Good agreement with CDF measurements and Latest pQCD predictions



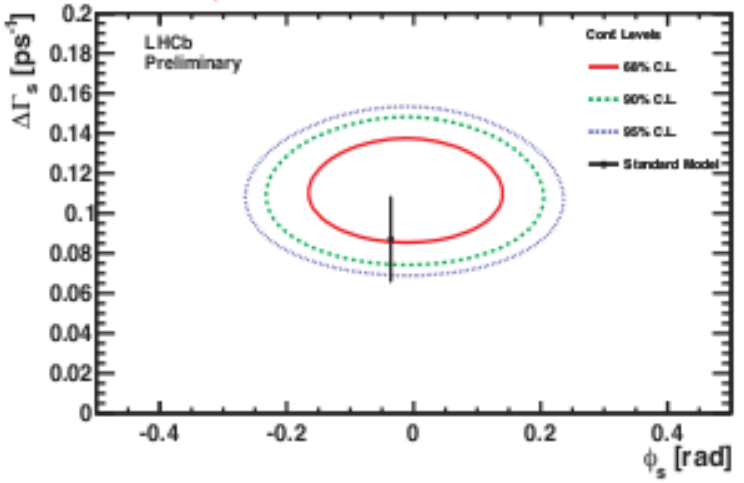


New physics in B mixing

- LHCb report (Franz)
  - World best ϕ_s and $\Delta\Gamma_s$ measurements, compatible with SM
  - ΔM_s very well measured
  - A_{sl}^s expected soon
  - $\Delta\Gamma_d$ to come, limited precision

- NP in mixing? (Christoph, Alex)
  - SM / NP in M_{12}^q only: difficult to reconcile D0 A_{sl}^b with others
  - Large NP in Γ_{12}^s? strong constraints
  - Large NP in Γ_{12}^d less constrained
  - Need better measuremetns of A_{sl}^s, A_{sl}^d, $\Delta\Gamma_d$ to clarify

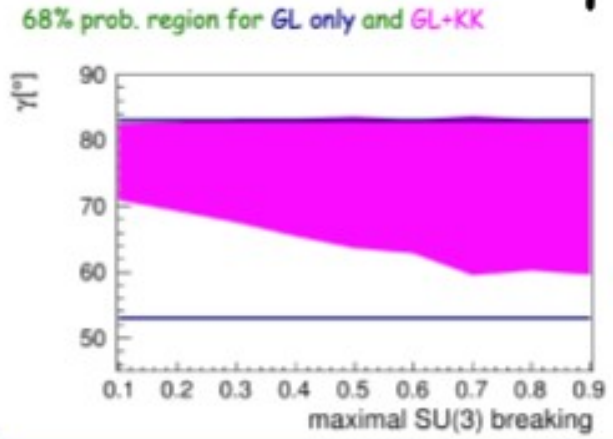
1/fb, LHCb-CONF-2012-002



- Penguin pollutions (Martin, Alex)
  - Very important issue
  - Size small but no precise estimate
  - Need full SU(3) analysis
- Lifetimes (Alex): more for test of SM calculations?

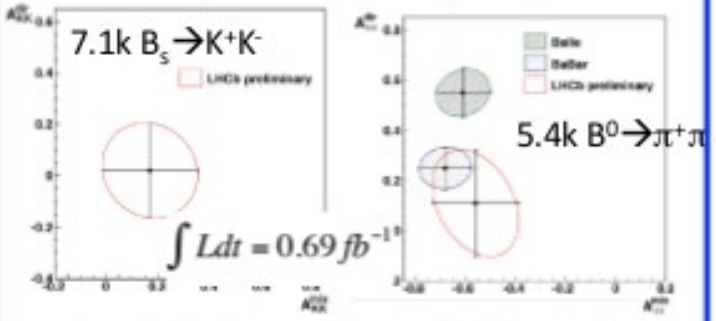
γ from loops

L. Silvestrini



LHCb results

Time-dependent CP asymmetries



- A_{mix} is the first evidence of mixing-induced CP violation at an hadron collider (3.2σ)
- First measurement ever of time-dependent CP asymmetries of the $B_s \to K^+K^-$ decay

S. Perazzini

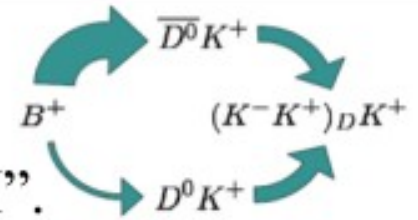
Two-body

- $B_s \to K^+K^-$ can be combined with standard GL analysis to improve considerably the determination of γ, even allowing for sizable SU(3) breaking effects
- The consistency of GL with $B_s \to K^+K^-$ is a test of NP in b → s penguins

Three-body

- Tree-level amplitudes can be successfully isolated in $B_{(s)} \to K^*\pi$ decays using Dalitz analyses
- While optimal strategies require Dalitz plots with π^0s, first attempts could be made with $K^\pm\pi^+\pi^-$ and $K_S\pi^+\pi^-$ only

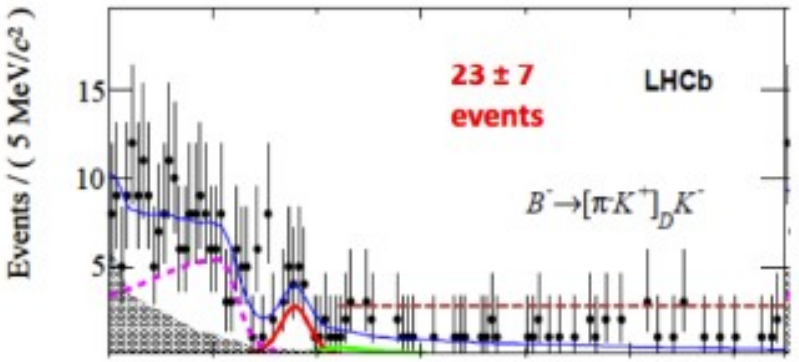
γ from trees



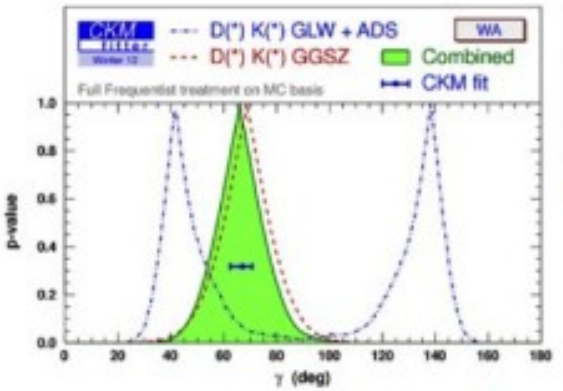
- Theoretically **very clean**, "standard candle of the CKM".
- Irreducible theoretical relative error on γ at **O(10^{-6})**.
- **New Physics** effects, if allowed for, can only be **very small**.
- LHCb sensitivity to γ from trees from **many measurements**, no single one dominating.

  Pipelined: $K_S\pi\pi$ GGSZ, Bs → D_sK time dependent, many more GLW/ADS modes, multi-body modes (B → DKππ), baryonic modes (Λ_b → DpK), ...

LHCb GLW/ADS:

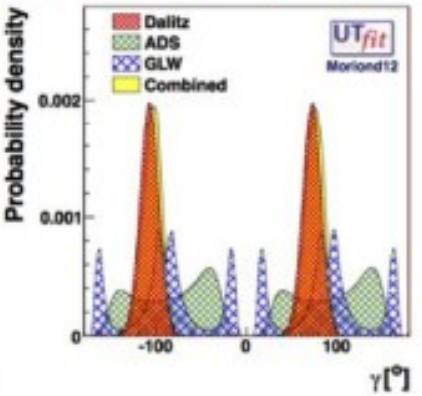


slightly different results of combination groups



$\gamma_{comb} = (66 \pm 12)°$*

$\gamma_{SM} = (67.1^{+4.6}_{-3.7})°$



$\gamma_{comb} = (75.5 \pm 10.5)°$*

$\gamma_{SM} = (68.5 \pm 3.2)°$

BCPV

- CKM fit tension (sin2β vs. εK vs. B → τν) – could suggest few degree shift in φs
  - Keep reducing experimental uncertainty!
- Lifetime ratios not yet at theory limit
  - Better measurements help better theory (Lb lifetime particularly needed – also Ξb & Ωb?)
  - Large NP in Γ12 now very unlikely (but Bs->ττ BF limit still needed)
- Possible penguin pollution to phi_s & beta
  - Small, but how small? Aim for measurements of complete SU(3) set of B(u,d,s) → J/ψP & J/ψV
- Charmless decays: PP, VV, PV
  - Many observables.
  - Best combinations to test SM (I-spin/U-spin/SU(3))?

SCS D→multibody studies & CPV searches

Mode	Recent Study	# events	Comment
$D^+ \to K^+K^-\pi^+$	LHCb , PRD 84 (2011) 112008	370k	2010 data; binned CPV search.
	Belle, PRL 108 (2012) 071801	237k	Φπ specific study
$D^+ \to \pi^+\pi^-\pi^+$	E791, PLB 403 (1997) 377	1.5k	CPV search with inclusive final state
$D^+ \to K_S K^+\pi^+\pi^-$	BABAR, PRD 84 (2011) 031103	21k	T-odd moments CPV search
$D^+ \to \pi^+\pi^-\pi^+\pi^0$	Belle, PRL 107 (2011) 221801	6.5k	πη specific study
$D^0 \to K^+K^-\pi^0$	BABAR, PR		l dep. & indep. CPV search
$D^0 \to \pi^+\pi^-\pi^0$	BABAR, PR		l dep. & indep. CPV search
$D^0 \to K_S K^{+-}\pi^{-+}$	CLEO, arXiv:1203.3804	1.3k	Coherence factor + amplitude model study
$D^0 \to K^+K^-\pi^+\pi^-$	CLEO, arXiv:1201.5726	3k	Amplitude model CPV search
	BABAR, PRD 81 (2010) 111103 (R)	47k	T-odd moments CPV search
$D^0 \to \pi^+\pi^-\pi^+\pi^-$	FOCUS, PRD 75 (2007) 052003	6.4k	Amplitude model study
$D_s \to K^+\pi^-\pi^+$	CLEO, PRL 100 (2008) 161804	~1k	CPV search with inclusive final state

no CPV signal yet

Lots and lots to do!

- Many analyses based on small samples (c.f. LHCb ΔA_{CP} which used 1.4M / 0.4M KK / ππ) decays). *Much* larger samples are now available.
- Not so many analyses exploit full power of Dalitz plane
- Very little activity with D_s studies. Presumably even less with baryons...

Rare charm decays

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

LHCb Preliminary

One order of magnitude below Belle.

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

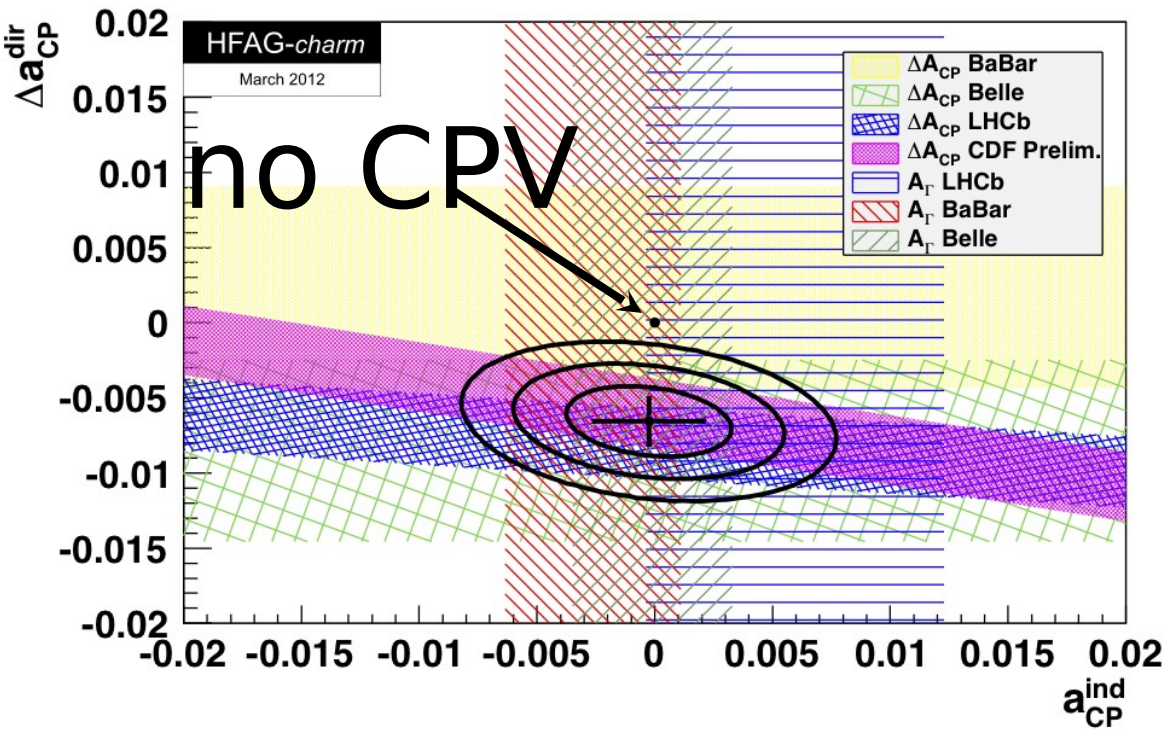
- **$D^+ \to (\pi,K)^+\mu^+\mu^-$ & $D^+ \to (\pi,K)^-\mu^+\mu^+$: few 10^{-8}**
- **$D_S \to (\pi,K)^+\mu^+\mu^-$ & $D^+ \to (\pi,K)^-\mu^+\mu^+$: few 10^{-7}**

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

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

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

- ΔA_{CP} “confirmed” by CDF
- Further measurements ongoing in e.g. $D^+ \to K_S h$, $D_{(s)}^+ \to 3h$, $D^0 \to 4h$



- Indirect CPV measurement via A_Γ ongoing (NP in mixing process?)
- Expect additional input from $D^0 \to K_S hh$
- Mixing measurements WS K(3)π, y_{CP}

Theory & ΔACP

- Estimate U-spin breaking effects in $D^0 \to \pi\pi/KK$
- Large effects needed but conceivable within SM
- More information needed, e.g. from $D \to PV$
- Expect similar effects in $D_{(s)}^+ \to K_S h^+$
  - NB. CPV effect from eps_K
- NP interpretations: see today's session

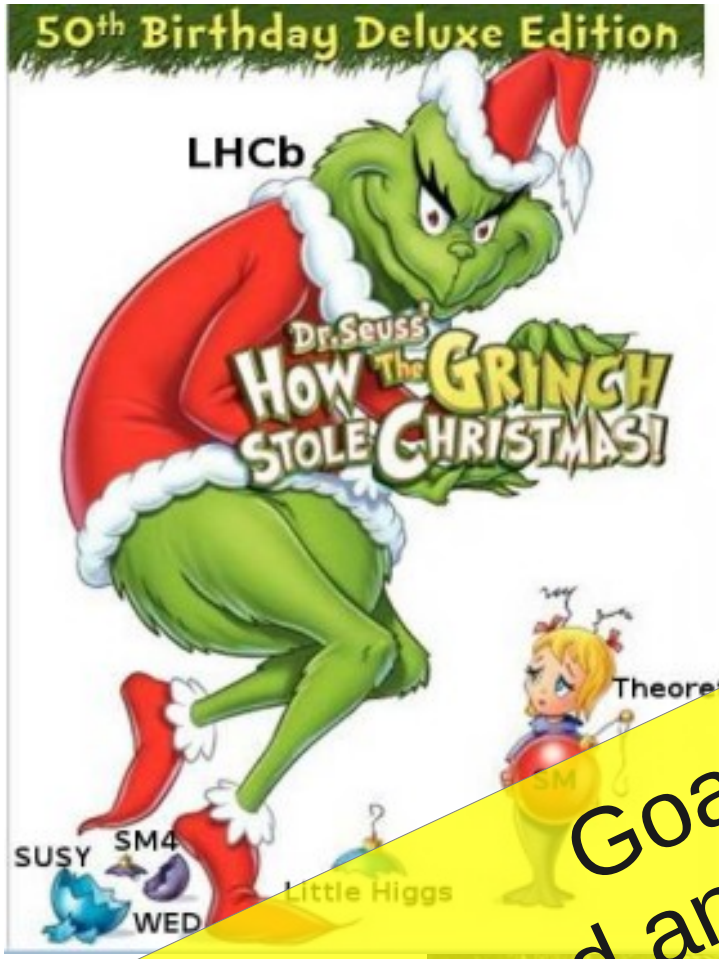
Physics Questions

- The projected levels of charm allow mixing and CPV measurements with sensitivity in ranges below 10^{-4}.
  - What are the SM predictions?
  - What are NP model predictions?
  - How will SM and NP amplitudes interfere?
- Assuming we have discovered New Physics via direct observation of high mass states, how will mixing and flavor measurements improve our understanding of the underlying physics?
  - If something like the simplest SM Higgs is discovered in the next 5 years, can charm measurements help us understand what else there is?
  - If some sort of SUSY is discovered in the next 5 years, how does studying charm mixing and CPV help us understand its flavor couplings?
- What other questions should we be asking?

Charm

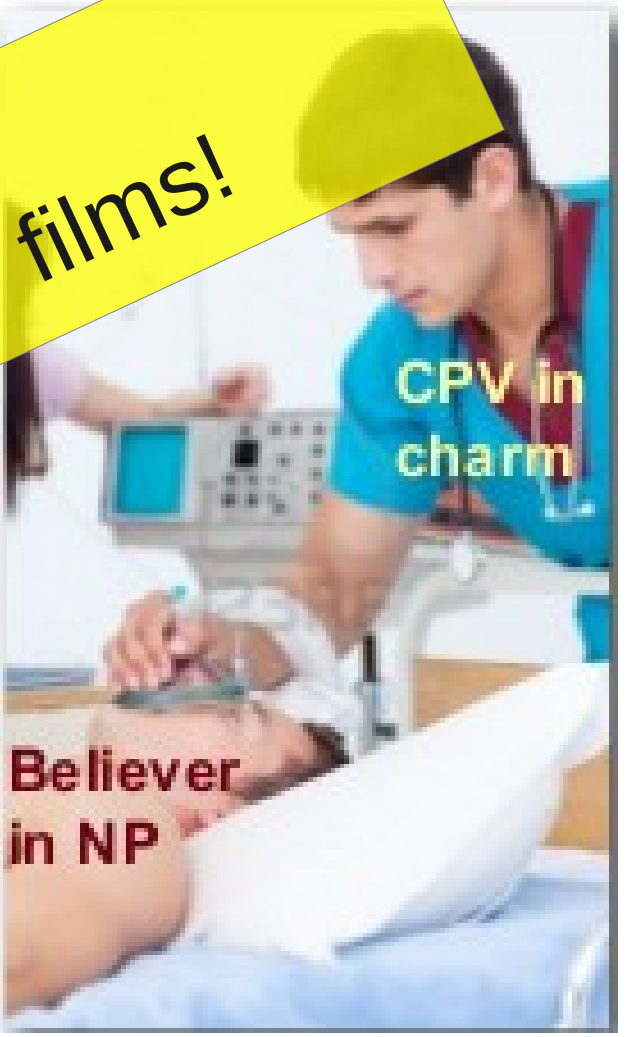
- ΔA_CP can maybe be accommodated in SM
  - But it still looks a bit of a stretch
  - More measurements of CPV helpful (multibody modes, D+ → φπ+, D0 → KsKs, D0 → π0π0, etc. – not all easy for LHCb!)
- Rare decays such as D → “φ”γ very interesting
  - D → ργ also interesting but harder for LHCb
  - D → “φ”μμ also interesting – very rare, but if we can observe it, CPV searches mandatory
- Excellent progress in lattice QCD
  - Ds → φμν accessible at LHCb?
- CPV in charm baryons
  - which comes first: the chicken (theory) or the egg (measurement)?

Viewpoints



A.Lenz

G.Dissertori



Goal of the workshop:
Need analogies with better films!

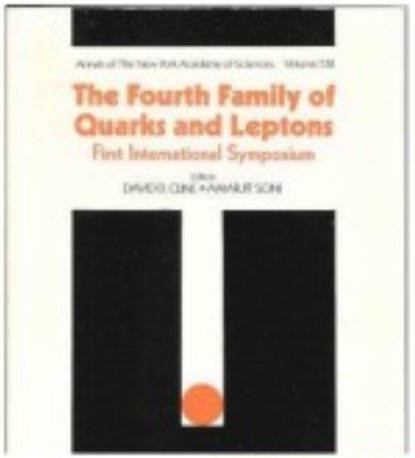
H. Murayama

Sticking to his guns – Alexander Lenz

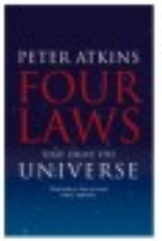
Alexander Lenz

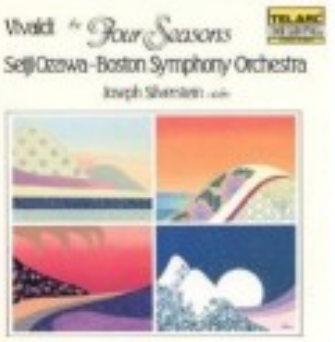
CERN, Theory Division

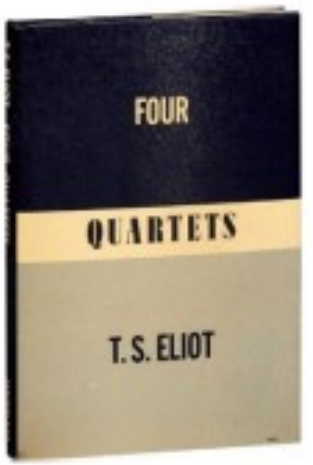
Highbrow – Guy Wilkinson



$$\begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

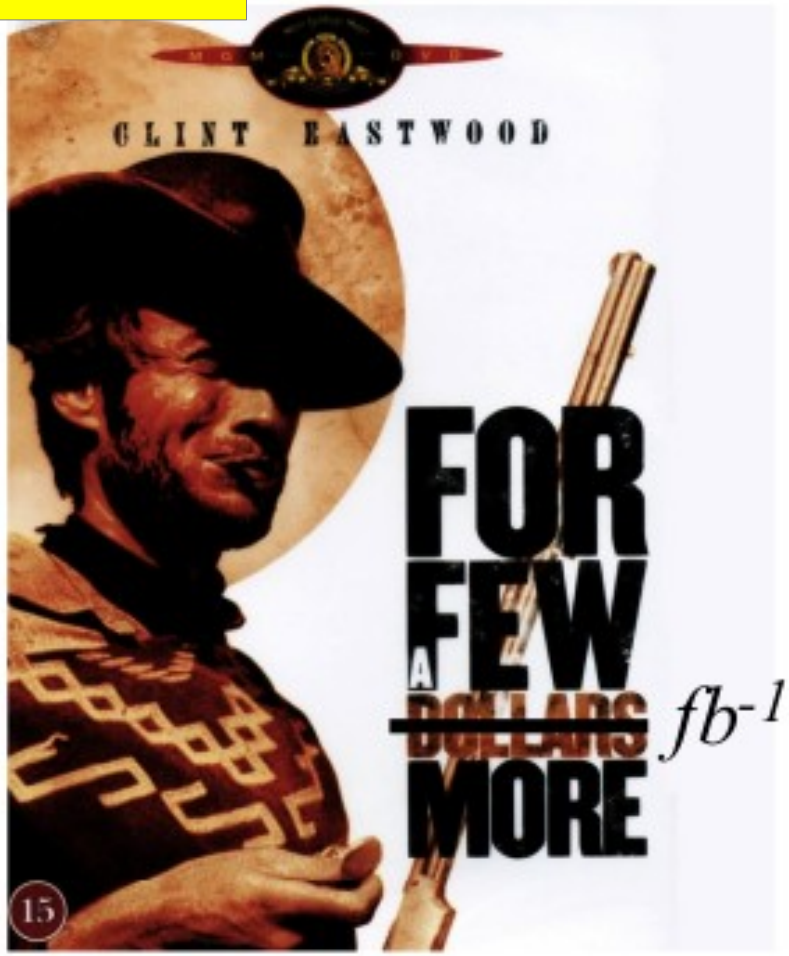






Spaghetti – Gino Isidori

THE GOOD THE BAD AND THE UGLY



fb^{-1}

news:
NP could hide in Δa_{CP} & $B \to \mu\mu$

news:
could all be SM...

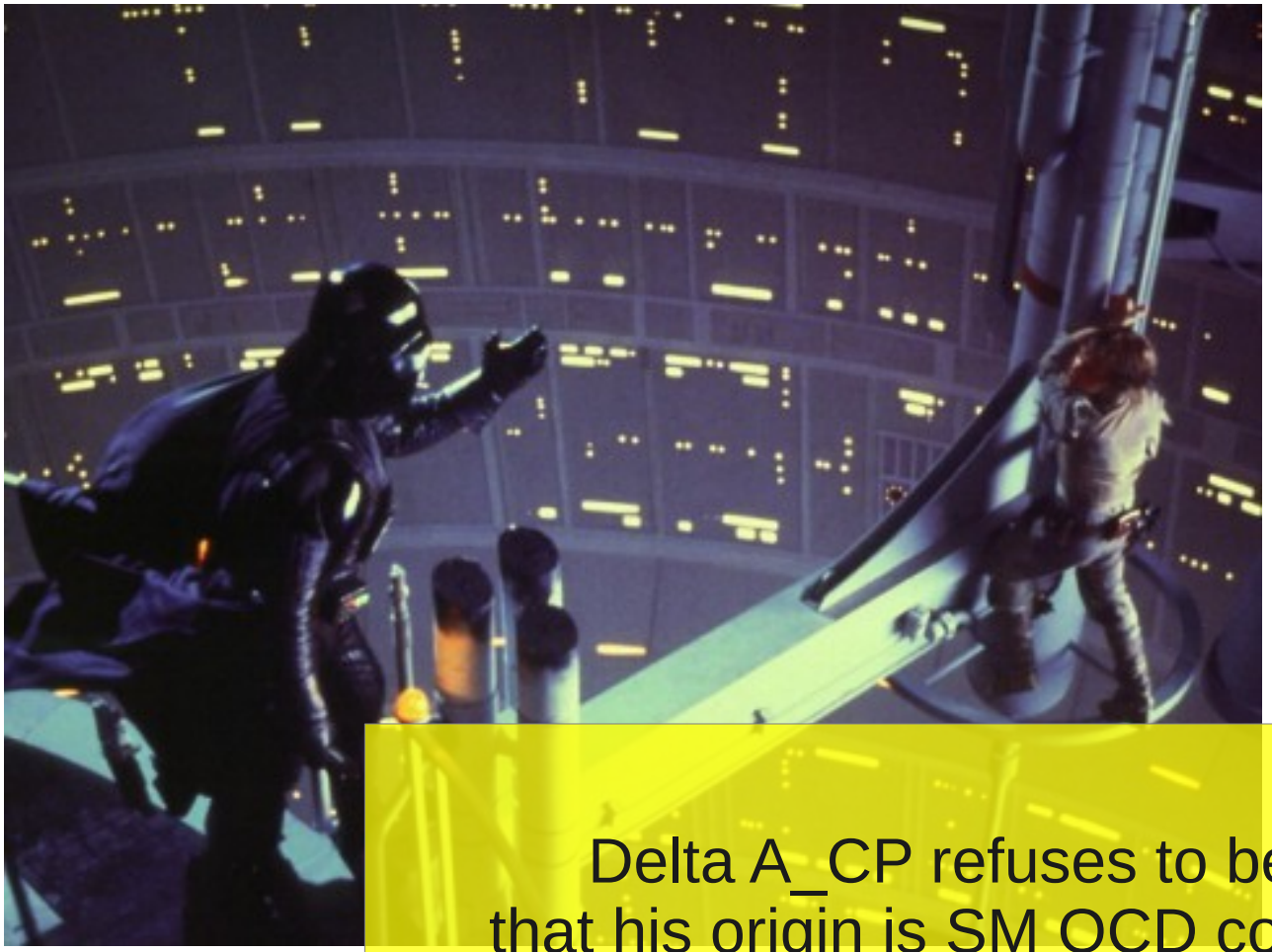
news:
so far QCD and stat. errors prevent us to understand...

That's why we need the LHCb upgrade!

Which is better:
US/Italian version or Japanese version?

Yojimbo

Sanjuro



Delta A_CP refuses to believe
that his origin is SM QCD corrections

Delta A_CP refuses to believe
that his origin is SM QCD corrections

Coming soon(ish)

Higher-dimensional analysis of multibody charm decays will add new information

… an upbeat ending

(see also Kurosawa's Ikiru)

LHCb spokesperson realises that (even if it is not unambiguous NP discovery) evidence of CP violation in charm is still one of most interesting LHC results