A rather informal speech on the LHCb contribution to the τ-Charm Factory Physics

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on behalf of the LHCb collaboration

2009-2010 learning phase years

2011	$\sqrt{s}$=7TeV	maxL=4*10^{32}	Int(L)=1fb^{-1}
2012	$\sqrt{s}$=8TeV	maxL=4*10^{32}	Int(L)=2fb^{-1}
2015-2018	$\sqrt{s}$=13TeV	maxL=4*10^{32}	Int(L)=6fb^{-1}
2020-2030(?)	$\sqrt{s}$=14TeV	maxL=1-2*10^{33}	Int(L)=50fb^{-1}

σ(ccbar) linear with $\sqrt{s}$; σ(Tau) also linked to σ(c) (80% from Ds)

Outline

- Introduction to LHCb and its upgrade
- Charm Physics
- τ Physics
- Some competitive X,Y,Z physics from B decays

Projections for mixing and CPV for the upgrade I leave to Mike's talk on Thursday

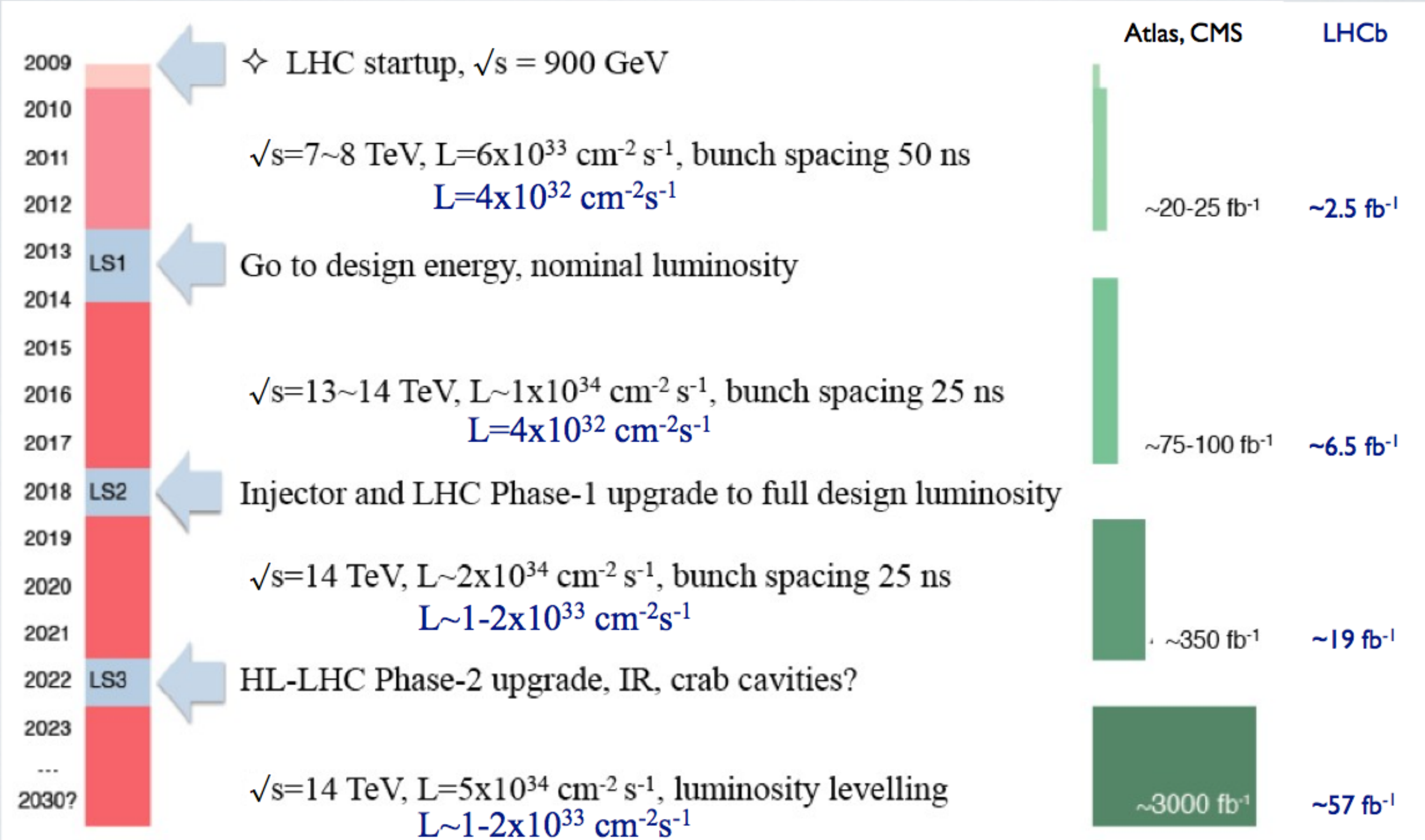
Some news first

- The LHCb experiment has recently increased significantly the number of collaborators and collaborating institutes (you know why…)
- Upgrade is well on track: framework TDR submitted in June 2012
  - It defines cost, milestones and institutes scientific interest:

  →The LHCC endorsed the upgrade plans of the Collaboration

  →the CERN Research Board approved the upgrade of LHCb to be part of the long-term exploitation of the LHC
- approval given by some funding agencies (Italy not yet, but almost ready to go to the Scientific Committee), large part of the international funding reasonably guaranteed
  - Some major detector choices to be made very soon (e.g. VELO, RICH)
  - TDR's of various subsystems to come during 2013
  - production and QA in 2014-2017
- Publications so far: above 100! but we have a huge potential to increase the yield, so far mostly based on 2011 data

THE LHC SCHEDULE

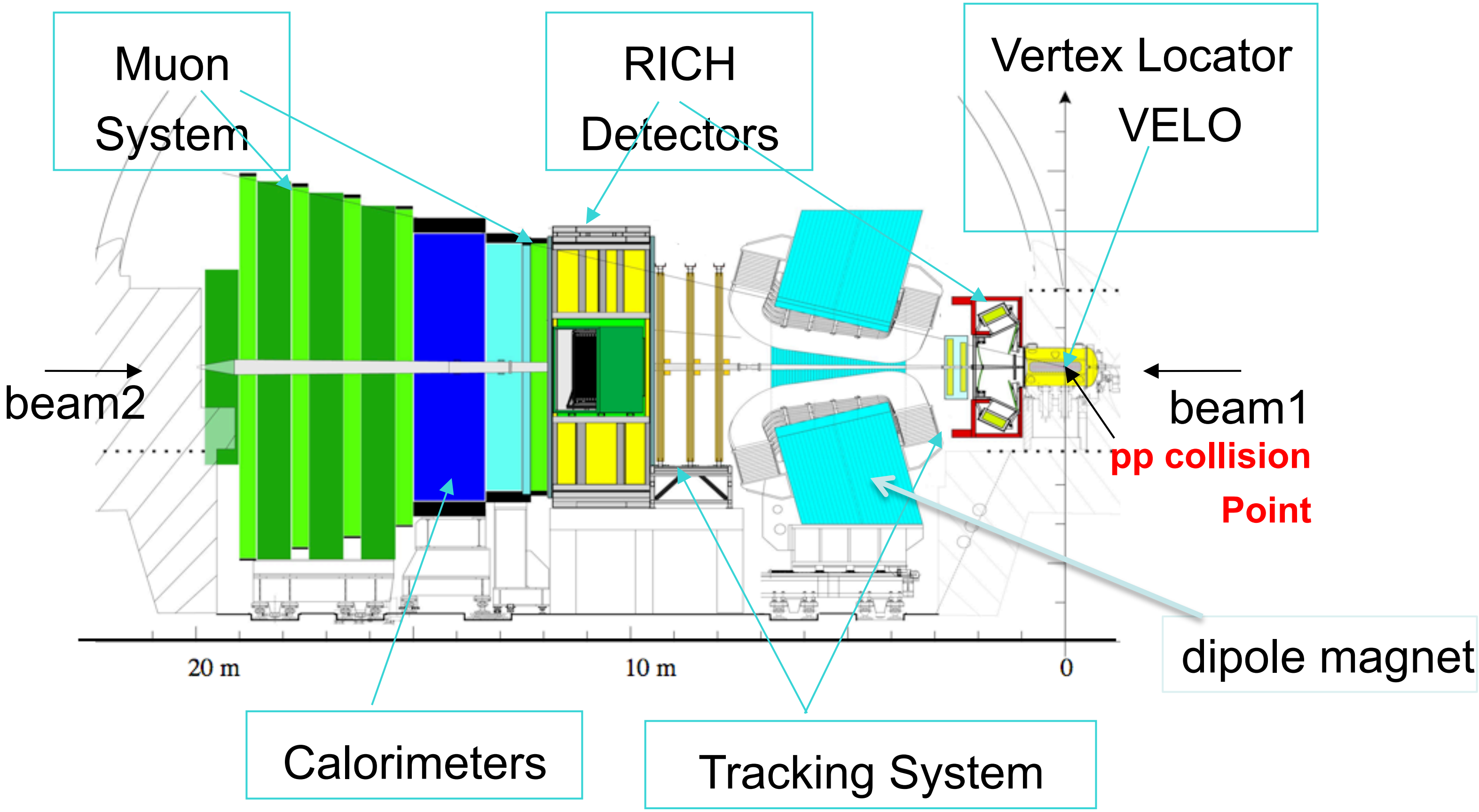


adapted from M. Nessi, Chamonix 2012

Context

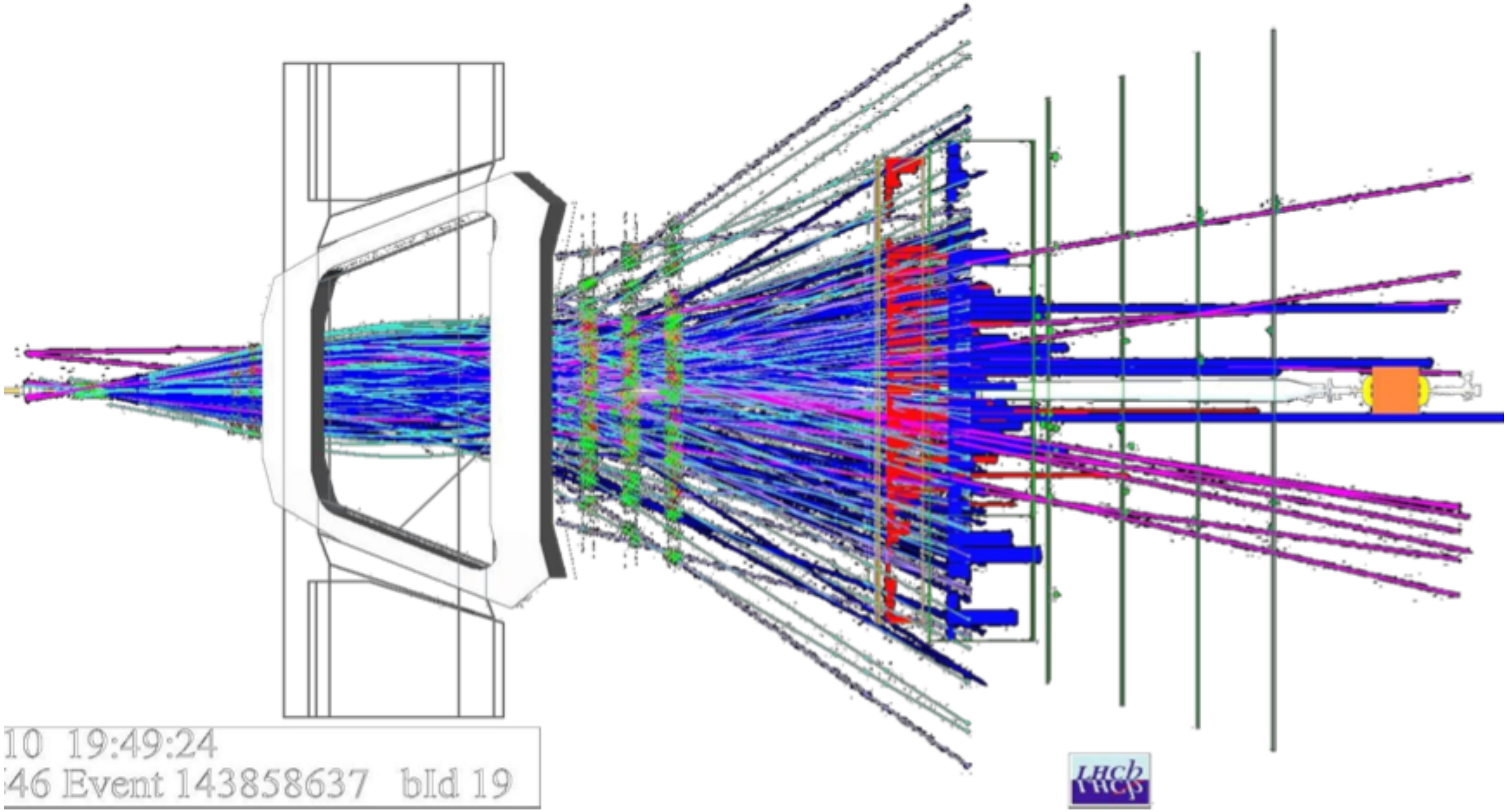
- LHCb is a multi-purpose experiment
- Charm and Tau Physics in LHCb are only a small part of the whole program which includes
  - **b hadron decays**
  - b hadron spectroscopy
  - quarkonia, X,Y and Z spectroscopy
  - K^0_S rare decays
  - W and Z production in the forward region
  - jet and associated EWB+jet production in the forward region
  - search for (some) NP in the forward region (decaying with displaced vertexes, such as Hidden Valley, $H \rightarrow \tau\tau$)
  - pp interaction dynamics
- Still, in charm physics we are already able to make measurement which are world best, at least when only charged tracks are involved in the decay
  - but analyses with one π^0 are starting to be attacked
- With Tau Physics it is tougher to compete: our main Tau source is Ds (we don't have the e+e- equivalent process!); so far only restricted to charged LFV decays with μ in final state

The LHCb detector

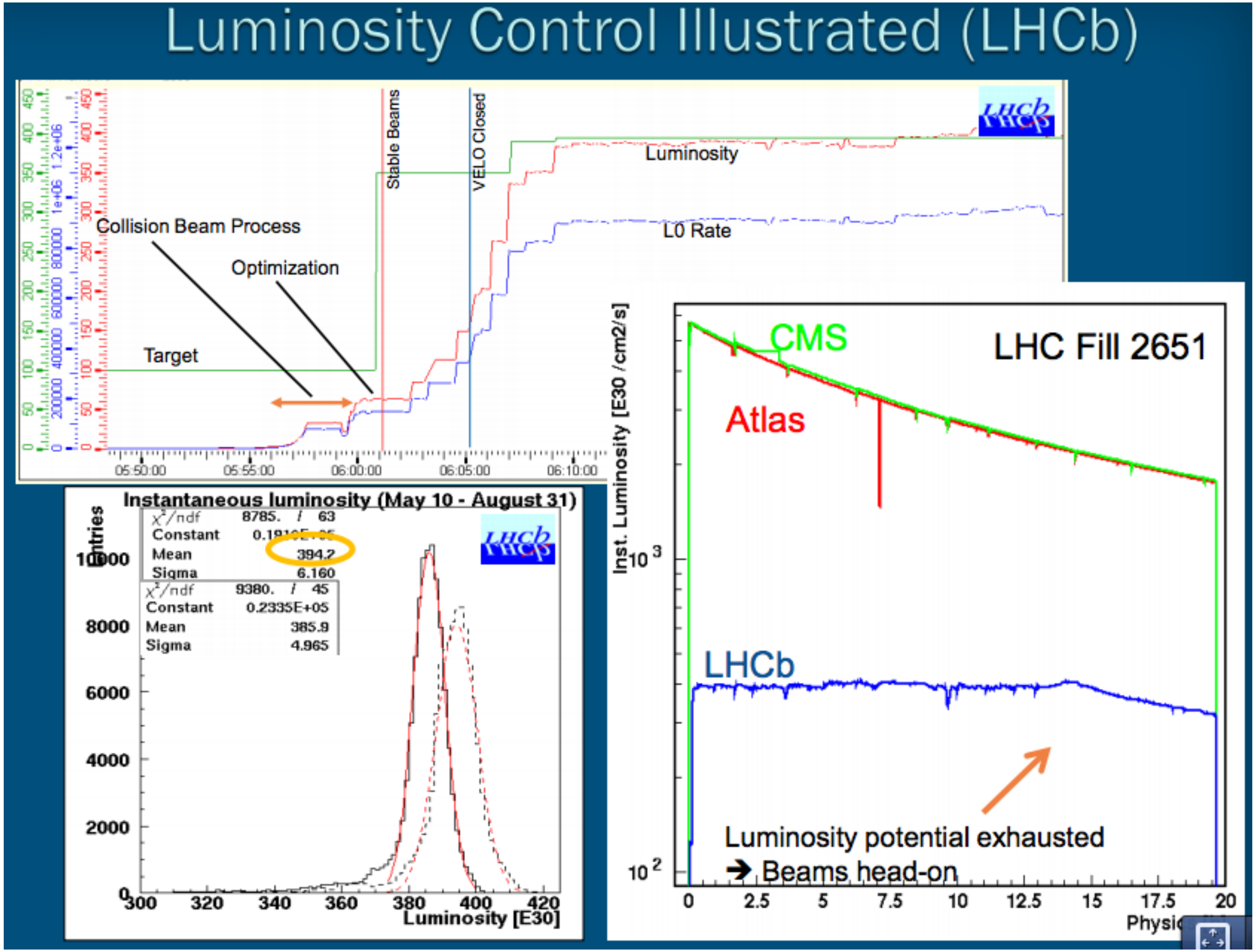


Pseudo-rapidity coverage → 1.9-4.9

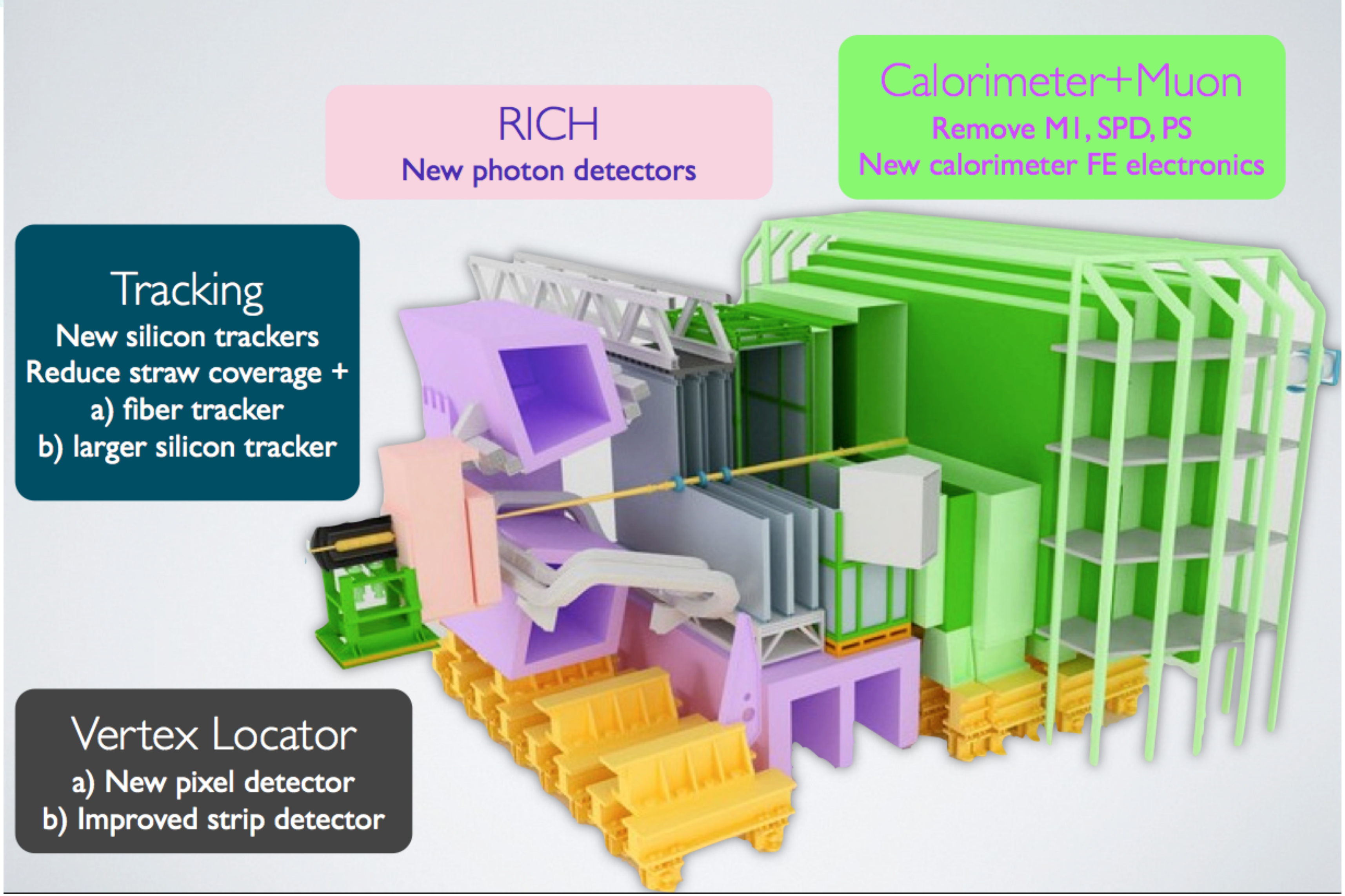
A typical event at 7 TeV!



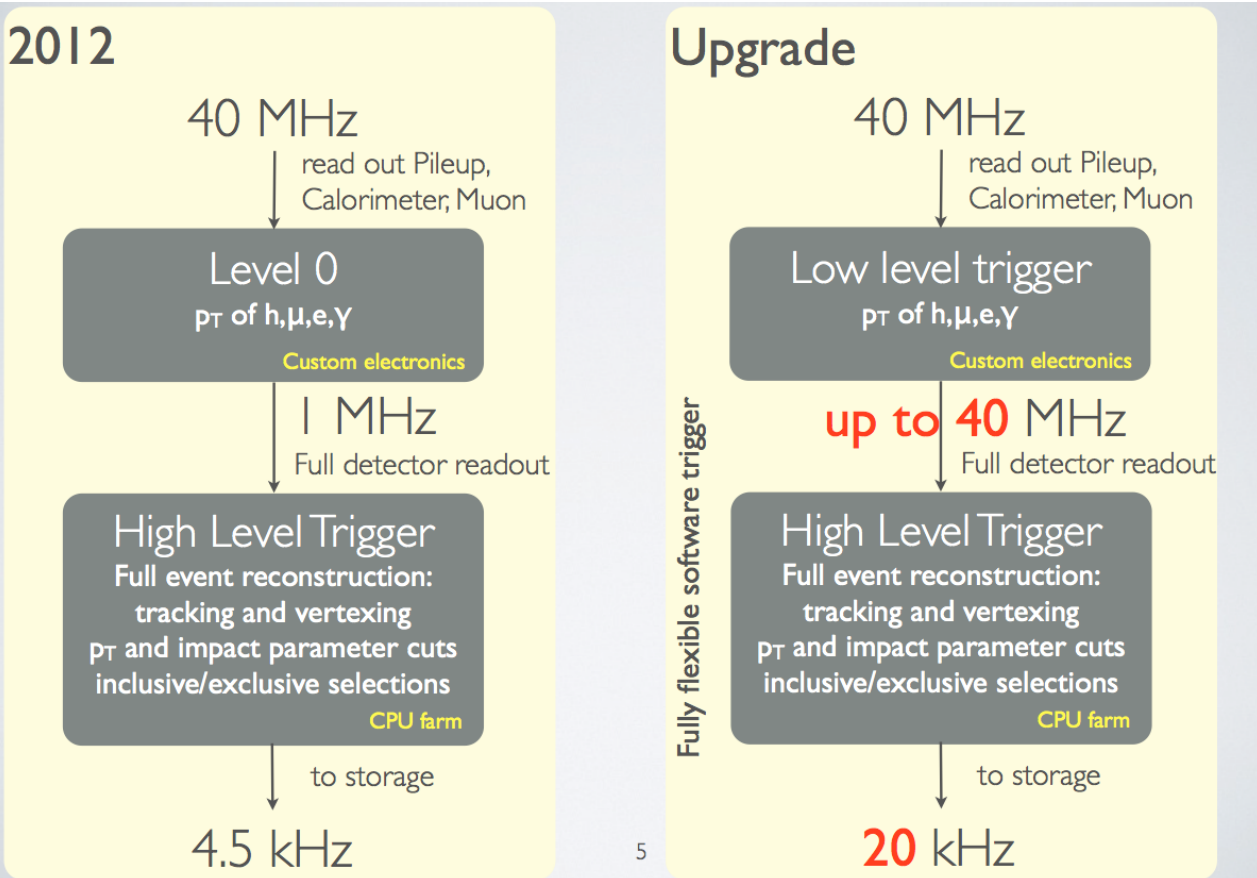
The LHCb running conditions

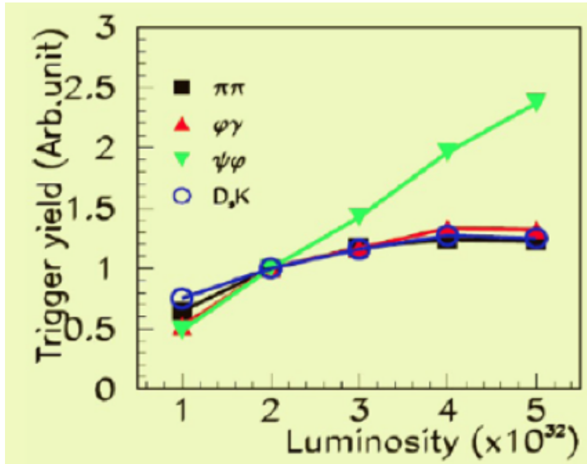


The LHCb upgraded detector



Trigger upgrade





for charm even worse (it goes down)

ε(L0)<10%
for hadronic charm

→ increase hadronic prompt charm ε by factors…(in the calculations we assumed conservatively a factor 2)

Open charm

Seen from yesterday!

$\bar{D}^0$-D^0 mixing and CPV:

	CDF		Belle	CLEO	LHCb	Belle II	
√		√	√	√	√	√	• **Wrong-sign semileptonic $D^0(t) \to K^+ l^- \nu$** measures x^2+y^2, no DCS contamination
√	√	√	√		√	√	• **Wrong-sign hadronic $D^0(t) \to K^+ \pi^-$** measures $x' = x \cos\delta + y \sin\delta$, $y' = y \cos\delta - x \sin\delta$
√		√	√	√	√	√	• **Decays to CP eigenstates: $D^0(t) \to K^+K^-, \pi^+\pi^-$** measures y_{CP} , A_K, A_π
		√	√			√	• **Dalitz plot analysis of $D^0(t) \to K^0 \pi^+\pi^-$** measures x, y
		√				√	• **Dalitz plot analysis of $D^0 \to K^+\pi^-\pi^0$** measures x", y"
		√	√			√	• **Dalitz plot analysis of $D^0 \to K^0 K^+ K^-$** measures y_{CP} (CLEO, Belle)
				√			• **Quantum correl. in $e^+e^- \to \psi(3770) \to D^0\bar{D}^0(n\pi^0)$** measures x^2, y, R_D, $\cos\delta$. $\sin\delta$

A. J. Schwartz   Workshop on Tau-Charm, Isola D'Elba   Belle II Physics Prospects   13

As always happened in the past,
people from the other experiments underestimate the LHCb potential!

Challenges and goodies: two sources of charm

- Two sources of charm: prompt and from semi-leptonic b decays
- Both can be used for tagged D0 CPV and mixing analyses:
  - tag with soft π from D*+ for the prompt (efficiency about 30% due to π reconstruction)
  - tag with μ charge in SL
- **Prompt charm** at 7 TeV (at 8 is 15% more):
  - σ(ccbar) ≈ 6mb, σ(bbar) ≈ 0.3mb, σ(pp inelastic)≈60mb
  - → **huge σ(ccbar) cross section**
    - 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)
- need low threshold due to low D meson daughter p_T and IP wrt B mesons

  → tough requirements for trigger, tracking, online and offline reconstruction, both for bandwidth and timing, and last but not least storage!

  → L0 efficiency low (max 10%) → main driver for the upgraded trigger
- **Secondary charm** at 7 TeV:
  - high trigger efficiency (muon)
  - BR(b→D0μX)=7%

Spectroscopy

Hunting for the production of excited states and new particles

Basically: **the art of** combining charm hadrons with other particles promptly produced **and of understanding the resulting spectra**

→ main issue reflections + background of course (purity, by miracle and ability of the analysts, not much worse than b-factory) ;

also play with angular distributions to enhance natural/unnatural parity

On top of what we show here, other (2body) combinations under active study

Excited D_{sJ} mesons

JHEP 10, 151 (2012)

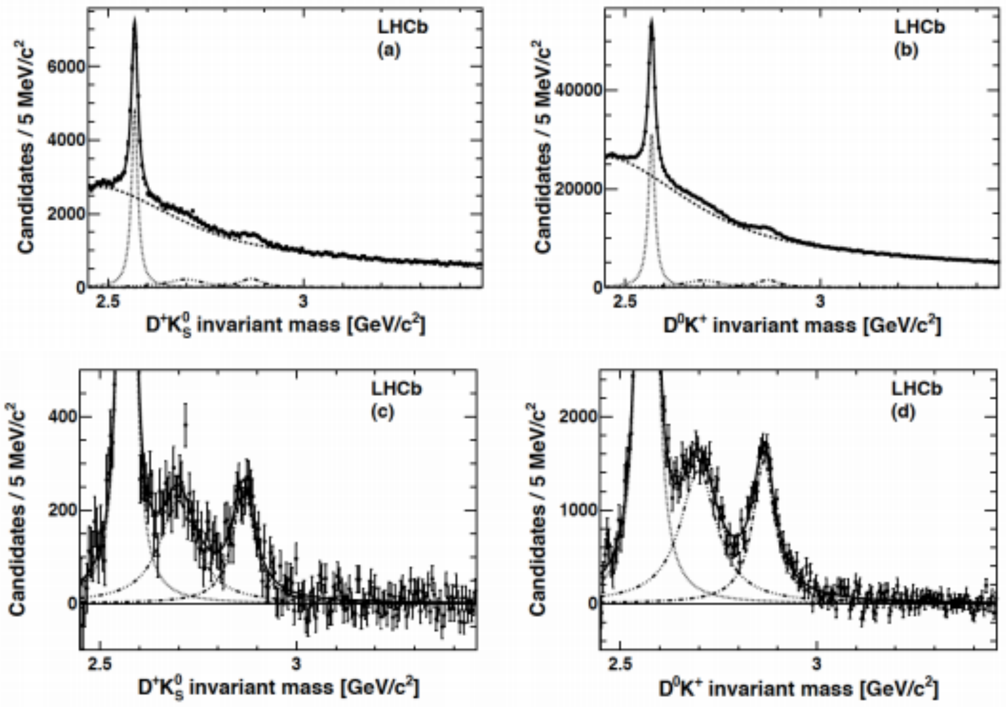
Observe the same structures in both final states, plus some feed-through from partially reconstructed $D_{sJ} \to D^* K$ decays

Simultaneous fit to smooth background plus

- $D^*_{s2}(2573)^+$ — spin 2
- $D^*_{s1}(2700)^+$ — spin 1
- $D^*_{sJ}(2860)^+$ — spin 0?

constraining the resonance parameters to be the same in both spectra

No evidence for states above 3 GeV



$$
\begin{aligned}
m(D^*_{s1}(2700)^+) &= 2709.2 \pm 1.9(\mathrm{stat}) \pm 4.5(\mathrm{syst})\ \mathrm{MeV}/c^2,\\
\Gamma(D^*_{s1}(2700)^+) &= 115.8 \pm 7.3(\mathrm{stat}) \pm 12.1(\mathrm{syst})\ \mathrm{MeV}/c^2,\\
m(D^*_{sJ}(2860)^+) &= 2866.1 \pm 1.0(\mathrm{stat}) \pm 6.3(\mathrm{syst})\ \mathrm{MeV}/c^2,\\
\Gamma(D^*_{sJ}(2860)^+) &= 69.9 \pm 3.2(\mathrm{stat}) \pm 6.6(\mathrm{syst})\ \mathrm{MeV}/c^2.
\end{aligned}
$$

First observation of these states in inclusive hadronic production

Excited D_J mesons

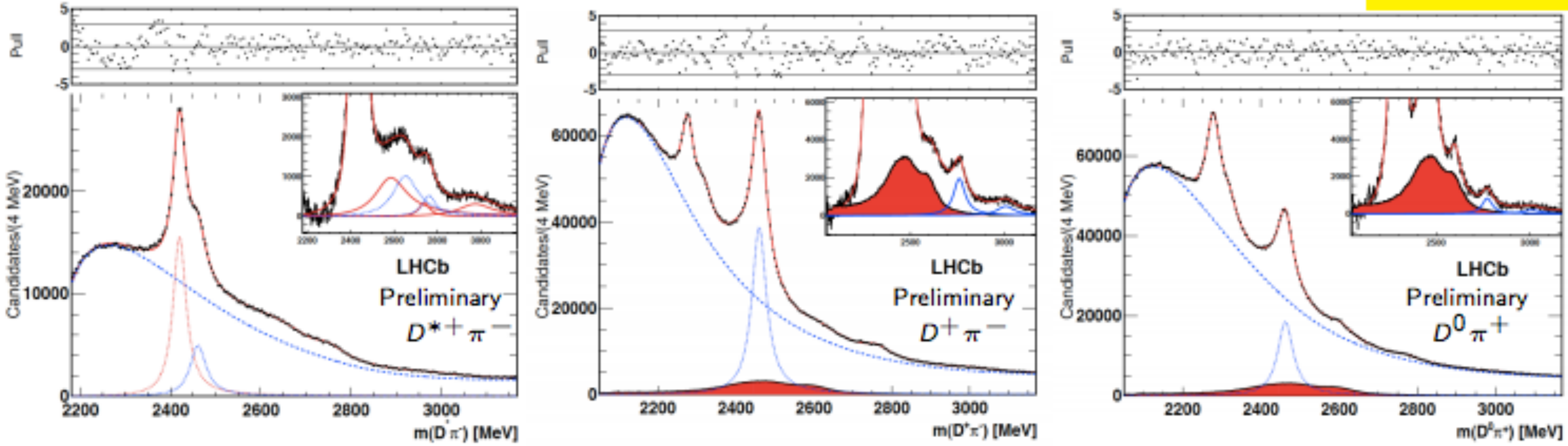
NEW

LHCb-PAPER-2013-026

Exploit differences in π^- helicity angle distribution for natural/unnatural spin-parity states to selectively enhance/suppress some of them in $D^{*+}\pi^-$ spectrum to determine the needed signal components and initialize the final fit

Final fit to total sample includes smooth background and reflections

Preliminary



Final state	Mass (MeV)	Width (MeV)	Yields	Significance
$D^{*+}\pi^-$	2419.6 ± 0.1 ± 0.7	35.2 ± 0.4 ± 0.9	210200 ± 1900 ± 700	
$D^{*+}\pi^-$	2460.4 ± 0.4 ± 1.2	43.2 ± 1.2 ± 3.0	81900 ± 1200 ± 900	
$D^{*+}\pi^-$	2649.2 ± 3.5 ± 3.5	140.2 ± 17.1 ± 18.6	50700 ± 2200 ± 2300	24.5 (15.9)
$D^{*+}\pi^-$	2761.1 ± 5.1 ± 6.5	74.4 ± 3.4 ± 37.0	14400 ± 1700 ± 1700	10.2 (6.0)
$D^{*+}\pi^-$	2579.5 ± 3.4 ± 5.5	177.5 ± 17.8 ± 46.0	60300 ± 3100 ± 3400	18.8 (13.1)
$D^{*+}\pi^-$	2737.0 ± 3.5 ±11.2	73.2 ± 13.4 ± 25.0	7700 ± 1100 ± 1200	7.2 (4.7)
$D^{*+}\pi^-$	2971.8 ± 8.7	188.1 ± 44.8	9500 ± 1100	9.0 (3.7)
$D^+\pi^-$	2460.4 ± 0.1 ± 0.1	45.6 ± 0.4 ± 1.1	675000 ± 9000 ± 1300	
$D^+\pi^-$	2760.1 ± 1.1 ± 3.7	74.4 ± 3.4 ±19.1	55800 ± 1300 ± 10000	17.3 (5.5)
$D^+\pi^-$	3008.1 ± 4.0	110.5 ± 11.5	17600 ± 1100	21.2 (12.4)
$D^0\pi^+$	2463.1 ± 0.2 ± 0.6	48.6 ± 1.3 ± 1.9	341600± 22000 ± 2000	
$D^0\pi^+$	2771.7 ± 1.7 ± 3.8	66.7 ± 6.6 ±10.5	20100 ± 2200 ± 1000	18.8 (8.3)
$D^0\pi^+$	3008.1 (fixed)	110.5 (fixed)	7600 ± 1200	6.6 (5.1)

Confirm the states observed by BABAR

Resonance parameters in reasonable agreement, some discrepancy for $D_J^*(2650)^0$

Three new states at 3000 MeV/c^2

Decays: i.e. searching for NP

Direct CPV (i)

Here we look at SCS decays assuming no CPV in CA decays: the reason is that CPV comes from the interference between the tree and the $\Delta C=1$ penguin (e.g. chromo-magnetic dipole) diagram and this can only happen in the SCS decays (Grossman)

either we compare binned Dalitz distributions (>2 body decays!!) or build ΔA_{CP}'s (for all 2 body decays) to get rid of production/detection asymmetries

- either 2 SCS decays (hoping the asymmetry does not exactly cancels)
- or 1 SCS and one CF

DCS modes also potentially interesting (Bigi)

T-odd distributions is another possibility (T violation)

Quite a controversial subject in terms of NP reach: after some experimental excitement that you know about, theorist realized that effects of few 10^{-3} in the SM are possible and in practice cannot be distinguished from NP

Effects at 10^{-2} level would be a clear sign of NP

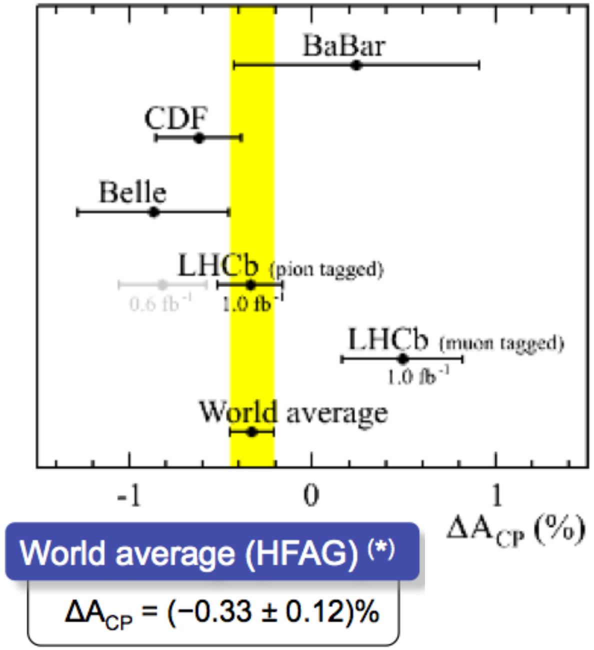
We should check many channels at 10^{-3} level, both CP eigenstates and non CP eigenstates

Direct CPV (ii)

ΔA_{CP}(KK/ππ) of D^0 from both B→lX and prompt 2011 done: a rather … story (…=put your preferred adjective)
→<u>bottom line : no CPV at the level that can be distinguished from the SM</u>

we of course should clarify the situation (i.e. understand the systematics) but if the central value stays the same it becomes less interesting in itself for the search of NP

However for indirect CPV this looks as a very important systematics and needs to be done at 0.1% precision



SIC TRANSIT GLORIA MUNDI

Direct CPV(iii)

Here we build a

ΔA_{CP} with $D^+ \rightarrow \varphi\pi$ and $D^+ \rightarrow K^0_S\pi$ and measure: (-0.04±0.14±0.13)%

(systematics mainly due to difference up-down)

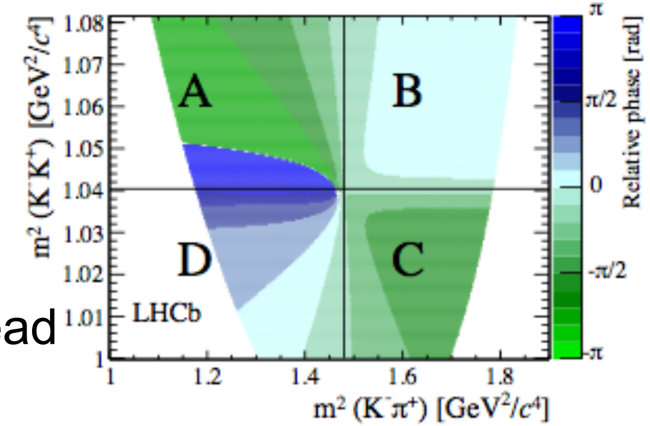
and for $D_s^+ \rightarrow K^0_S\pi$ we measure: (0.6±0.8±0.1)%

One big advantage w.r.t. the B factories: CPV due to K^0_S is negligible in LHCb due to the boost

Moreover we also measured :

$$A_{CP} = \left| Im\left(\frac{V_{ub}V_{cb}^*}{V_{us}V_{cs}^*}\right)\right| R\sin\delta_S$$

but the strong phase varies a lot across $\varphi(1020) \rightarrow$ may lead to vanishing A_{CP}



define $$A_{CP}|_S = \frac{1}{2}\left(A^A_{\text{raw}} + A^C_{\text{raw}} - A^B_{\text{raw}} - A^D_{\text{raw}}\right)$$ =-(0.18±0.17±0.18)%

Direct CPV: the other analyses (1)

- $D^+ \rightarrow K^0_S K^+$:
  - this shares the same diagrams as $D^0 \rightarrow KK$ exchanging the spectator quark q<->s and therefore the same CPV
  - Belle: (+0.08 ± 0.28 ± 0.14)%
  - LHCb 3fb-1 underway

- Dalitz analysis $D^+ \rightarrow 3\pi$ 2011 underway
- Dalitz $D^0 \rightarrow KK\pi\pi$ and $D^0 \rightarrow 4\pi$ 2011 underway($D^0 \rightarrow 4\pi$ preliminary Moriond 2012)
- T-odd moments $D^0 \rightarrow KK\pi\pi$ going to be done for 2012+2011
- these two analysis are complementary since
  - $A_T \approx \sin\varphi \cos\delta$
  - $A^{CP}_{dir} \approx \sin\varphi \sin\delta$ with φ weak phase and δ strong phase

Direct CPV: other measurements

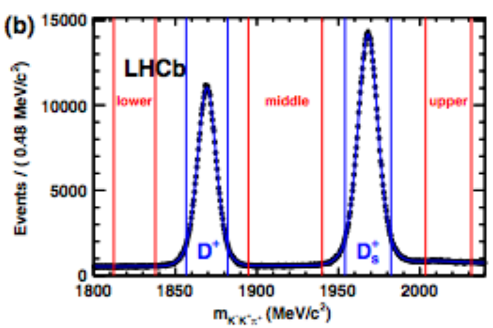
PhysRevD.84.112008

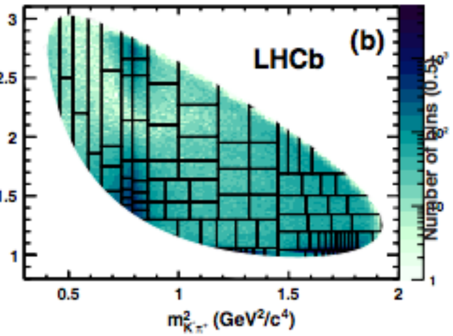
- Compare yields in CP-conjugate bins

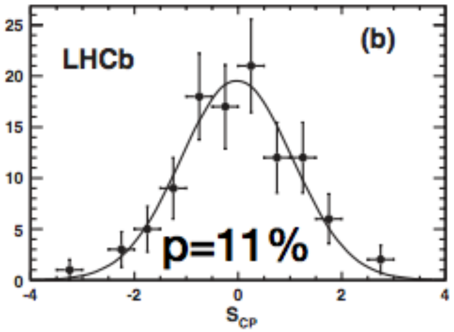
$$S_{CP} = \frac{N_i - \alpha \bar{N}_i}{\sqrt{N_i + \alpha^2 \bar{N}_i}}$$

$$\alpha = \frac{N_{\text{total}}}{\bar{N}_{\text{total}}}$$

330k $D^+ \to K^- K^+ \pi^+$ in 35/pb





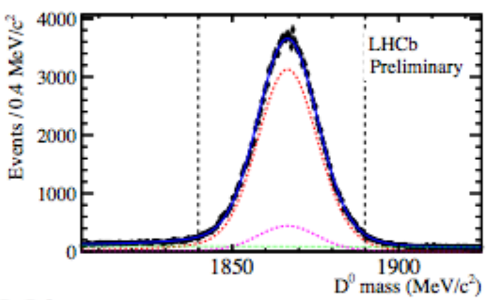


- Calculate p-value for no-CPV hypothesis based on

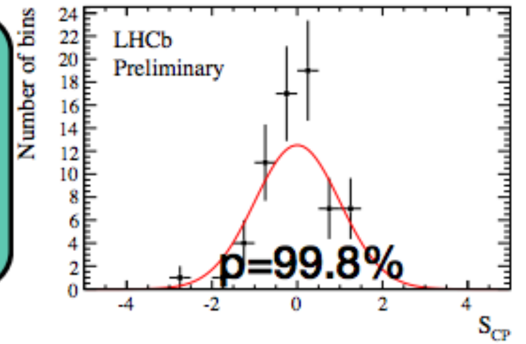
$$\chi^2 = \sum_i (S^i_{CP})^2$$

- Model independent. Many production and detection effects cancel.

~180k $D^{*+} \to D^0 \pi$, $D^0 \to \pi\pi\pi\pi$ in 1/fb



5-dim. "Dalitz" plot, binned.



LHCb-CONF-2012-019

Mixing and indirect CPV: 1 formulae page

$$R(t) = R_D + \sqrt{R_D}\, y' t + \frac{x'^2 + y'^2}{4} t^2$$

mixing with WS

$$x'_D = x_D \cos\delta + y_D \sin\delta$$
$$y'_D = y_D \cos\delta - x_D \sin\delta$$

now δ≈20±10° (don't expect much improvement from BES3

for CPV analysis

$$R^+(t) = R_D^+ + \sqrt{R_D^+}\, y'^+ t + \frac{(x'^+)^2 + (y'^+)^2}{4} t^2,$$
$$R^-(t) = R_D^- + \sqrt{R_D^-}\, y'^- t + \frac{(x'^-)^2 + (y'^-)^2}{4} t^2.$$

$$x'^\pm = \left(\frac{1 \pm A_M}{1 \mp A_M}\right)^{1/4} (x' \cos\phi \pm y' \sin\phi)$$
$$y'^\pm = \left(\frac{1 \pm A_M}{1 \mp A_M}\right)^{1/4} (y' \cos\phi \mp x' \sin\phi),$$

$$y_{CP} = \frac{\hat{\Gamma} + \hat{\bar{\Gamma}}}{2\Gamma} - 1 \approx \eta_{CP}\left[\left(1 - \frac{1}{8}A_m^2\right) y_D \cos\phi - \frac{1}{2}(A_m) x_D \sin\phi\right]$$

$$(|\bar{A}_f / A_f|^{\pm 2} \approx 1 \pm A_d)$$

$$A_\Gamma = \frac{\hat{\Gamma} - \hat{\bar{\Gamma}}}{\hat{\Gamma} + \hat{\bar{\Gamma}}} \approx \eta_{CP}\left[\frac{1}{2}(A_m + A_d) y_D \cos\phi - x_D \sin\phi\right]$$

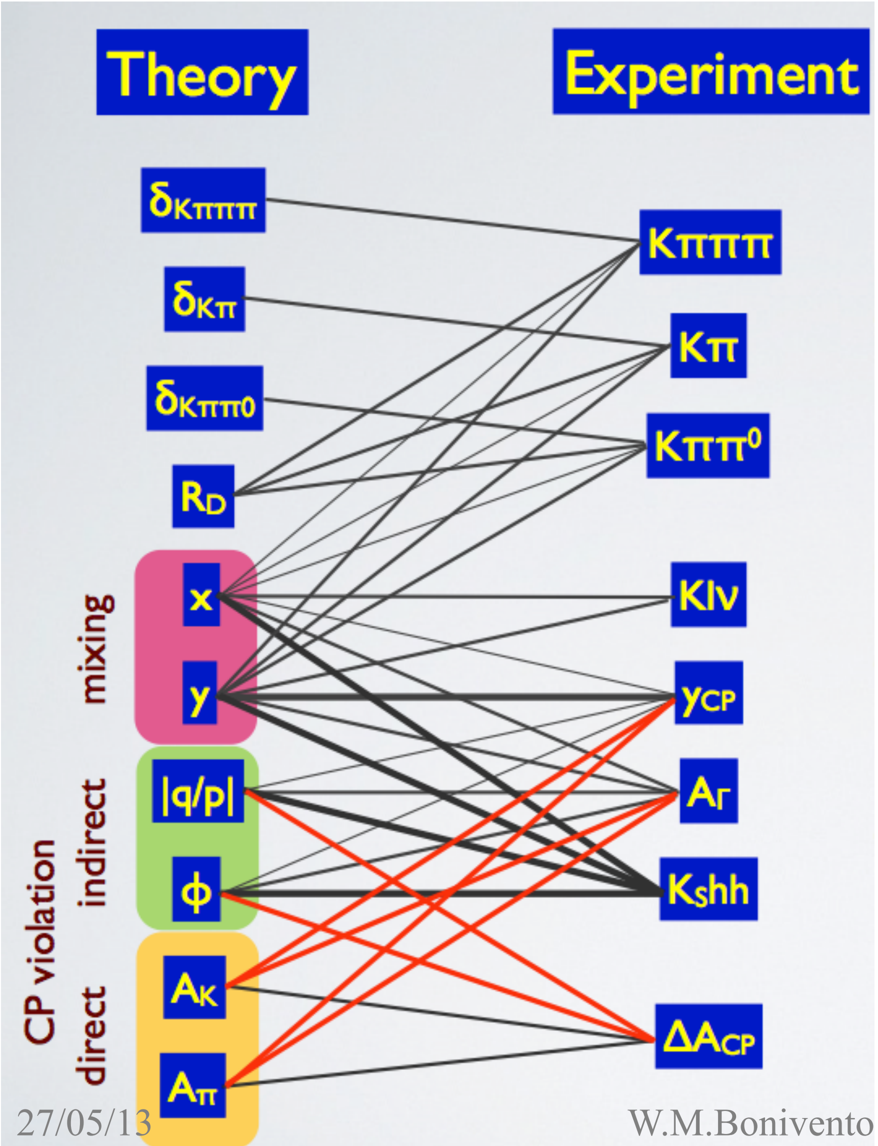
$$a_{CP}^{dir} \equiv \frac{|A_f|^2 - |\bar{A}_f|}{|A_f|^2 + |\bar{A}_f|} \approx -\frac{1}{2} A_d$$

$$|q/p|^{\pm 2} \approx 1 \pm A_m \qquad \phi = \arg\left(\frac{q}{p}\right)$$

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

CPV in the mixing CPV in the interference between mixing and decay

Our view of the network…



Mixing and indirect CPV: on disk

Sample	Observable	Sensitivity ($1.0\,\text{fb}^{-1}$)	Sensitivity (~~2~~3$.5\,\text{fb}^{-1}$)
Tagged KK	y_{CP}	5×10^{-4}	4×10^{-4}
Tagged $\pi\pi$	y_{CP}	10×10^{-4}	7×10^{-4}
Tagged KK	A_Γ	7 ~~5~~ $\times10^{-4}$	4×10^{-4}
Tagged $\pi\pi$	A_Γ	10×10^{-4}	7×10^{-4}
Tagged WS/RS $K\pi$	$x_D'^2$	10×10^{-5}	7 ~~5~~ $\times10^{-5}$
Tagged WS/RS $K\pi$	y_D'	20×10^{-4}	12 ~~10~~ $\times10^{-4}$
Tagged $K_S^0\pi\pi$	x_D	5×10^{-3}	3×10^{-3}
Tagged $K_S^0\pi\pi$	y_D	3×10^{-3}	2×10^{-3}
Tagged $K_S^0\pi\pi$	$\|q/p\|$	0.5	0.3
Tagged $K_S^0\pi\pi$	ϕ	25°	15°

absolute !!
relative is
30-40%

WA present uncertainty on A_Γ is O(2 10^{-3}) from various sources

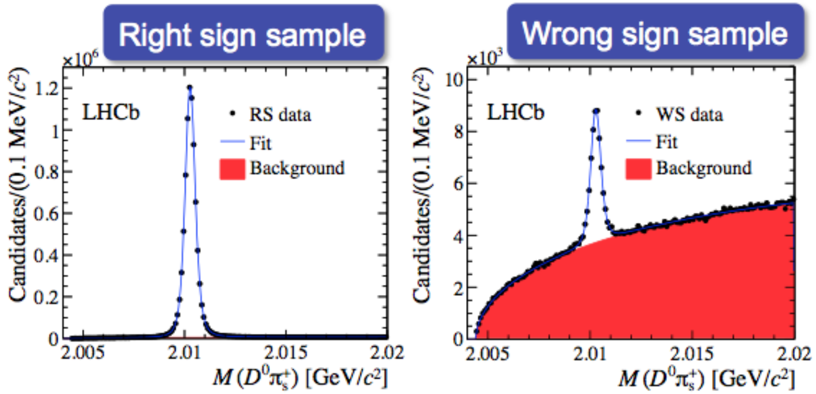
Mixing and indirect CPV: upgrade

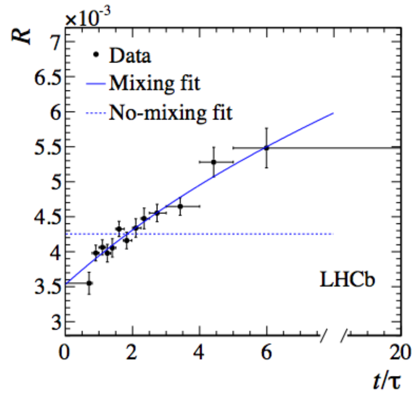
see Mike's talk on Thursday

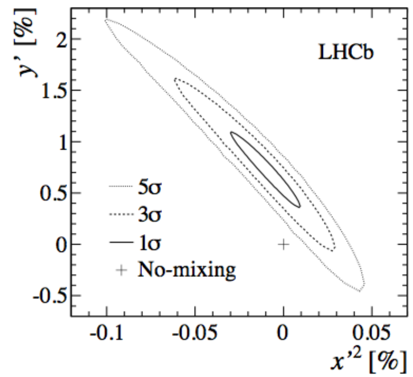
on x and y → 2% relative uncertainty (statistical)

Beautiful observation of D^0 mixing!

First observation of charm mixing (>9σ)
with WS D0→Kπ →2011 data







R_D	3.52 ± 0.15
y'	7.2 ± 2.4
x'^2	-0.09 ± 0.13

x10^{-3}

From this we get x' and y' →no way to get precise x and y due to 50% error on $\delta_{K\pi}$

Now, mixing is clearly established: from the point of view of QM this certainly a very important result, but what about our search for NP?

- **in itself the SM LD allows for x and y up to 1% so these measurements do not allow to distinguish SM from NP (but allow to put upper bounds on some NP models). Maybe one day lattice…**
- **but precision measurement of x and y (from $D^0 \rightarrow K^0_S \pi\pi$) important for indirect CPV**

Our main roads to indirect CPV

1. With WS/RS $D^0 \to K\pi$ 2011+2012 upcoming
   – follows the mixing analysis with the noticeable addition of the K interaction asymmetry measured
2. A_Γ 2010 published; 2011 upcoming

If these quantities are different from 0 then we have evidence of indirect CPV (if DCPV in 0 in A_Γ) but what about determining |q/p| and φ?

sensitivity to φ, |q/p| from these 2 measurements being reassessed

3. $D^0 \to K^0_S\pi\pi$ ($D^0 \to K^0_S KK$)

Provide access to both mixing parameters x and y directly and in particular to the relative sign of them; and to extract directly |q/p| and arg(q/p)

– Need swimming
– time-dependent Dalitz plot analysis
  - both model dependent and model independent being pursued
  - both prompt and from $B \to \mu DX$
– very good precision in prospect

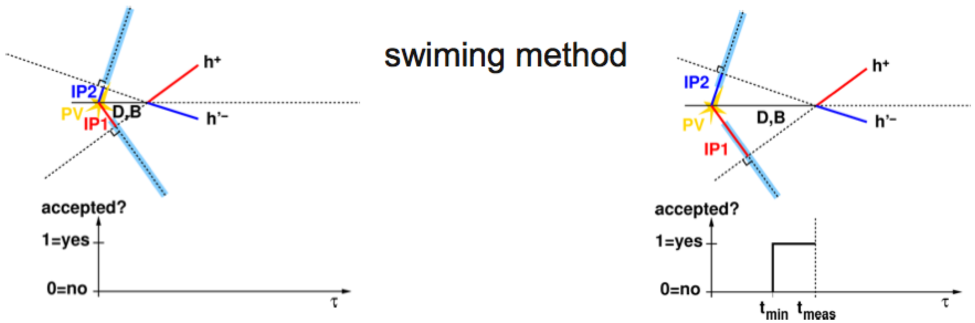
Parameter	Ψ(3770)	Ψ(4040)	LHCb	Belle-II
$x(\%)$	0.02-0.05	0.03	0.015	0.08
$y(\%)$	0.02-0.03	0.03	0.010	0.04
$\|q/p\|(\%)$	2-5	0.9	1	5
$\arg(q/p)(^\circ)$	2-3	0.8	3	2.6

Numbers presented yesterday are only a fraction of our sensitivity! (e.g. |q/p| and φ can be extracted from 2. with high precision with some (reasonable) assumption)

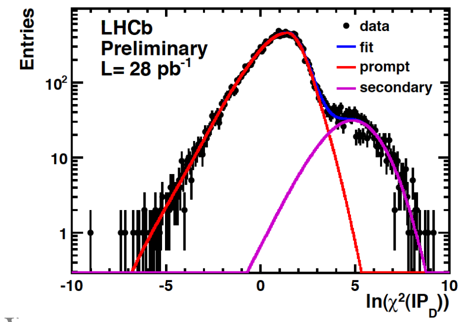
y_{CP} and A_Γ: 2 main experimental issues

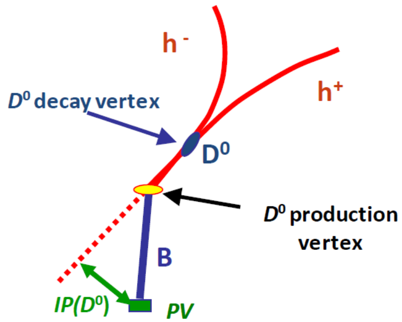
- **Need to determine lifetime acceptance in real data**
  - Key ingredient to the method is an event by event based lifetime acceptance which takes trigger and selection into account: this is possible in LHCb since the lifetime bias is in the software trigger
  - results are used in the normalization of the PDF in the fitting procedure

swiming method



•prompt-secondary D separation

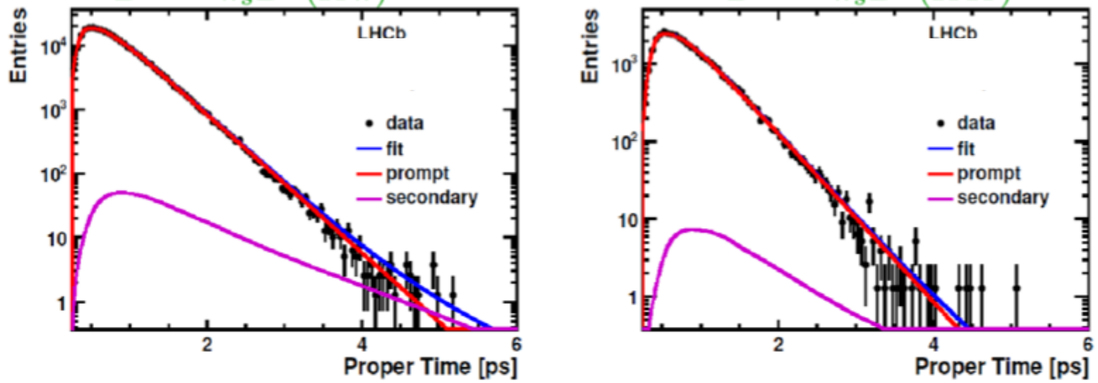




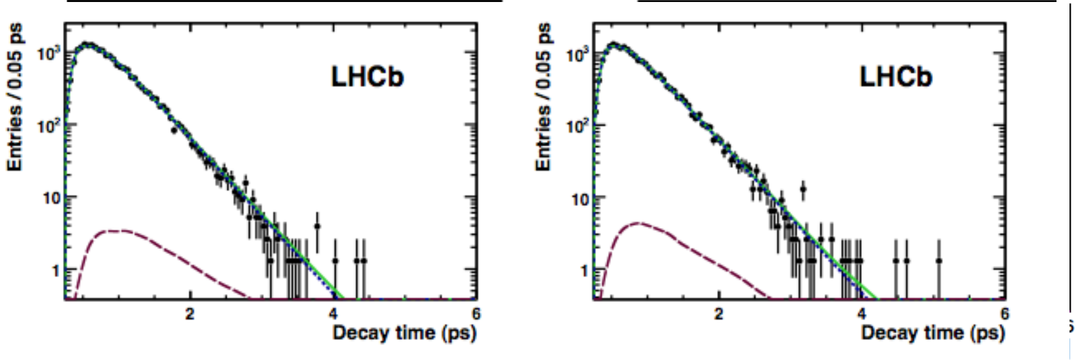
y_{CP} and A_Γ: the 2010 measurement

Measurement of y_{CP}
with 2010 data L=28pb^{-1}
arXiv:1112.4698

y_{CP}=y cosΦ-R_Mx sinΦ



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



A_Γ = (- 5.9 ± 5.9 ± 2.1) x 10^{-3}

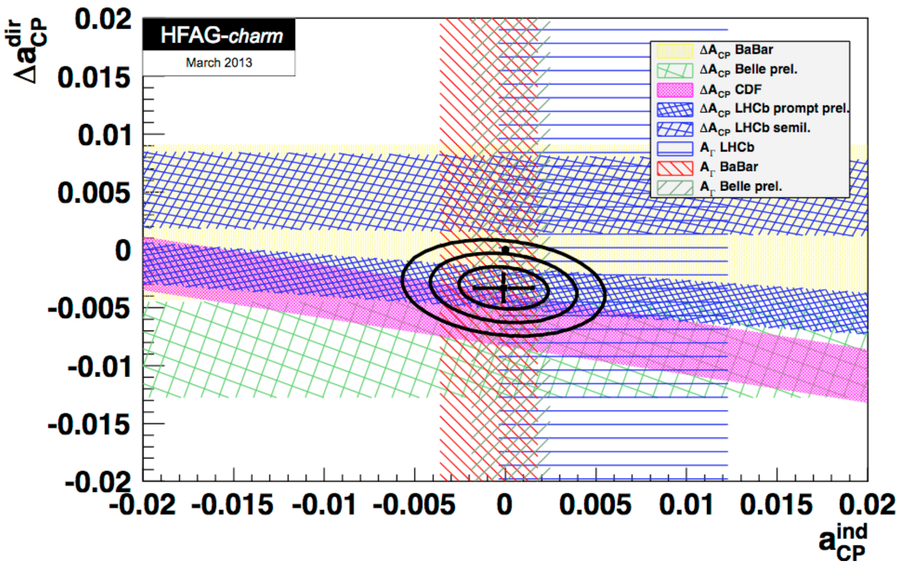
WA_{HFAG} A_Γ = (0.12±0.25)%
(w/o LHCb)

The latest CPV averages

Courtesy M. Gersabeck, HFAG 21 March 2013

Without assuming DCPV=0

$$\Delta A_{CP} = \Delta a_{CP}^{dir} (1 + y_{CP} \overline{\langle t \rangle}/\tau) - \Delta\langle t \rangle/\tau \, a_{CP}^{ind}$$



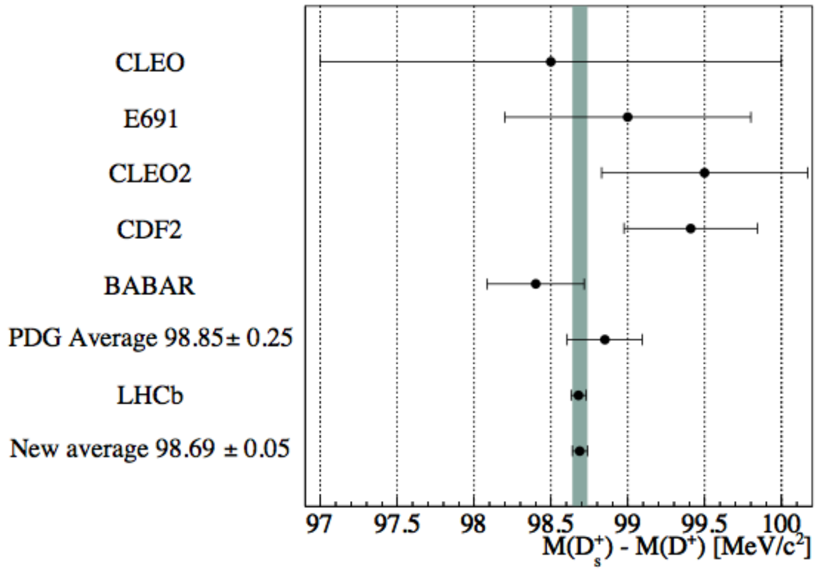
data is consistent with no CPV at 2.1% CL

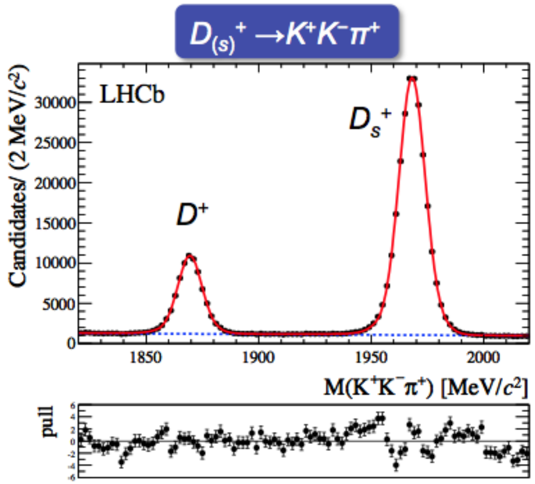
a_{CP}^{ind} = (-0.010 ± 0.162)%

Δa_{CP}^{dir} = (−0.329 ± 0.121)%

Charm meson masses

- Use low Q-value modes
- Main systematics from momentum scale and energy loss correction
  - calibration from $B^+ \to J/\Psi\, K^+$
- Measured D^0 mass (with precision ≈ the world average)
- Measured $m(D^+)-m(D^0)$ and $m(D_s^+)-m(D^+)$
- huge improvement over WA

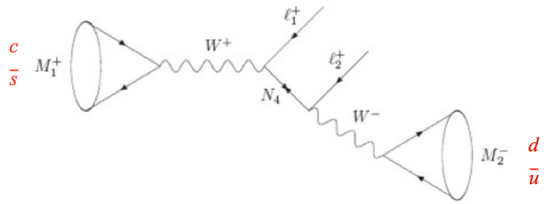




Quantity	LHCb measurement	Best previous measurement	PDG fit
$M(D^0)$	1864.75 ± 0.19	1864.85 ± 0.18 [5]	1864.86 ± 0.13
$M(D^+) - M(D^0)$	4.76 ± 0.14	4.7 ± 0.3 [7]	4.76 ± 0.10
$M(D_s^+) - M(D^+)$	98.68 ± 0.05	98.4 ± 0.3 [10]	98.88 ± 0.25

The charm RD measurements

- **LHCb is well suited for measurements with muons in the final state**, a bit less with e-, though we are doing some measurements su as B→K*e+e- (bremsstrahlung, modest resolution ECAL)
- High efficiency triggering on muons in LHCb
- **Three main channels were analyzed**:
  - D→μμ FCNC, best limit Belle 1.7*10^{-7} @ 90% C.L.
    - SM predicts, even including a long range term O(10^{-13})
    - Very interesting NP, WED and SUSY with RPV, starts at around few 10^{-10}
  - $D_{(s)}^{+}$→πμμ with SS muons → forbidden in SM, sensitive to Majorana neutrinos



present limits on the order of 10^{-6} for D^+ modes and 10^{-5} for D_s^+ modes

  - $D_{(s)}^{+}$→πμμ with OS muons →FCNC, sensitive to RPV SUSY →need to study μμ invariant mass distribution to exclude regions of long range contributions
- Analyses with 2011 data submitted to journals
- D^0→ππμμ, D^0->K*μμ and KKμμ under study

$D^0 \to \mu\mu$

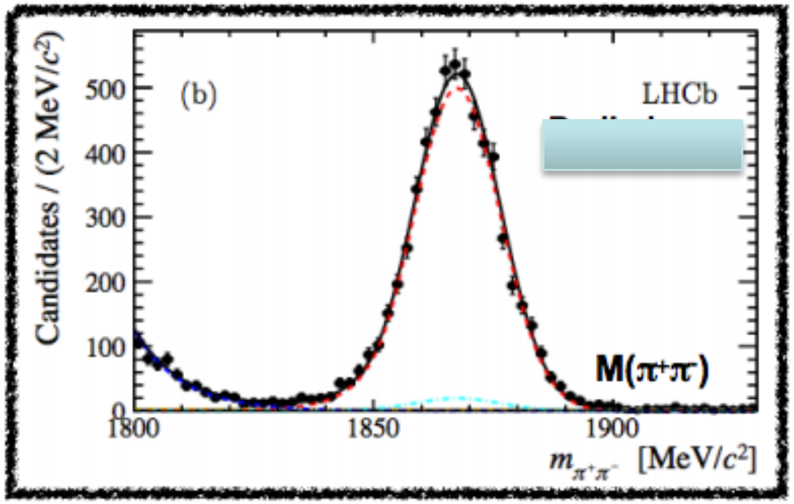
1/fb 2011 data
LHCb-PAPER-2013-013
$D^{*+} \to D^0(\to \mu^+\mu^-)\pi^+$

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

PDG

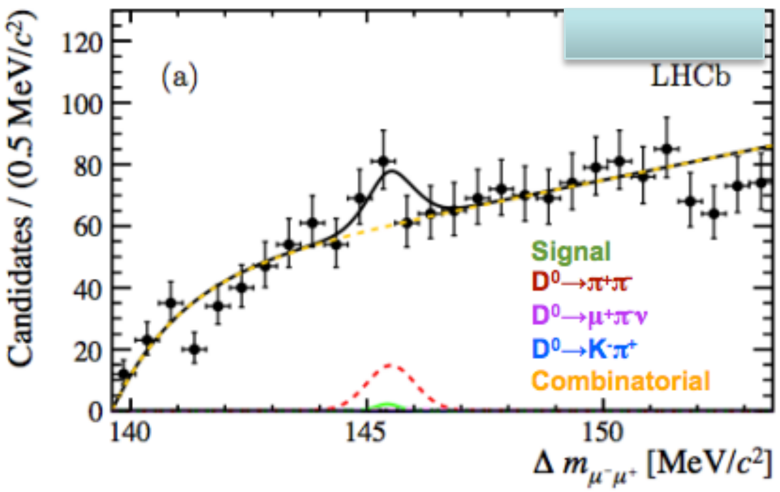
→ Large efficiency from di-muon specific trigger
→ Good track and vertex quality
→ Tracks from D^0 detached from PV
→ D^0 produced in the PV
→ Tight μID and multivariate discrimination for semileptonic D decays and random background reduction, using signal MC and data from the signal sidebands

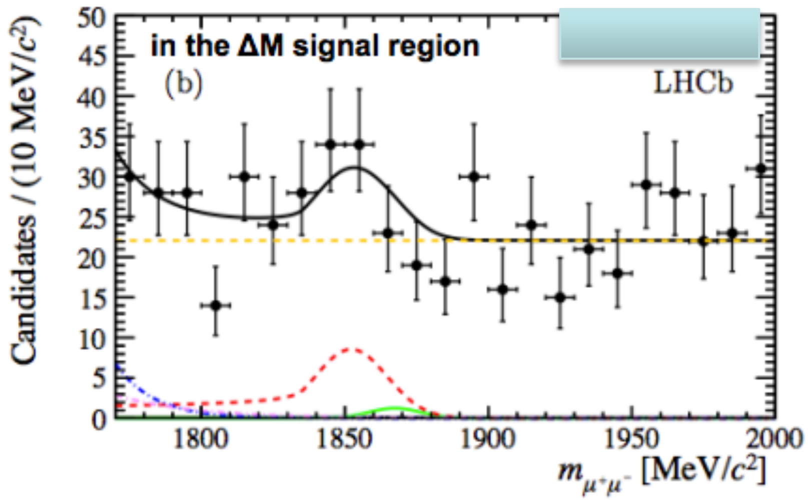
→ Main source of peaking background corresponds to double misID.
→ $D \to K\pi$ used to control $\pi \to \mu$ ID rate in data
→ MisID $D^0 \to \pi^+\pi^-$, contribution yield floated in the fit, with 45±19 as gaussian constraint
→ Stability check using twice looser constraint

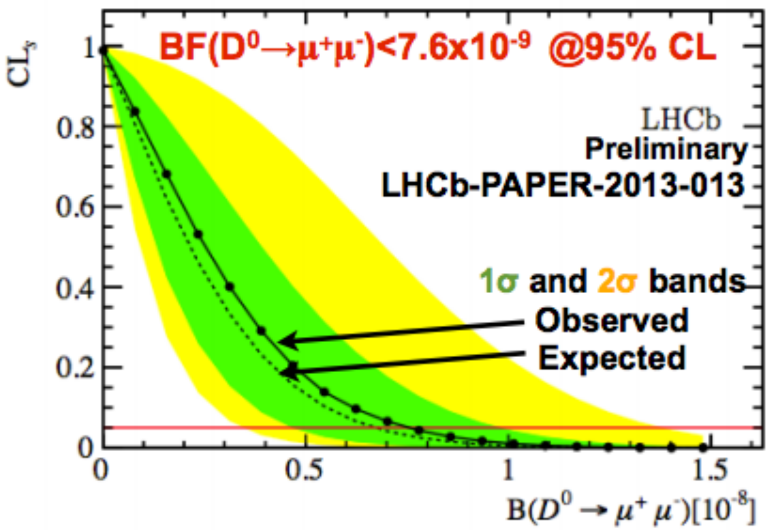


Efficiency ratio
→ Trigger and PID
→ $J/\psi \to \mu^+\mu^-$ to control trigger and PID efficiency of the signal
→ $D^0 \to K^-\pi^+$ tagged and untagged as control sample for the normalization mode

$D^0 \to \mu\mu$ (2)







Source	relative uncertainty(%)
Material interactions	6.0
Muon identification efficiency	2.6
Hadronic trigger efficiency	4.9
Muon trigger efficiency	2.7
$\mathcal{B}(D^0 \to \pi^+\pi^-)$	1.9
Total systematic uncertainty	8.8

No significant excess of signal wrt the expected background

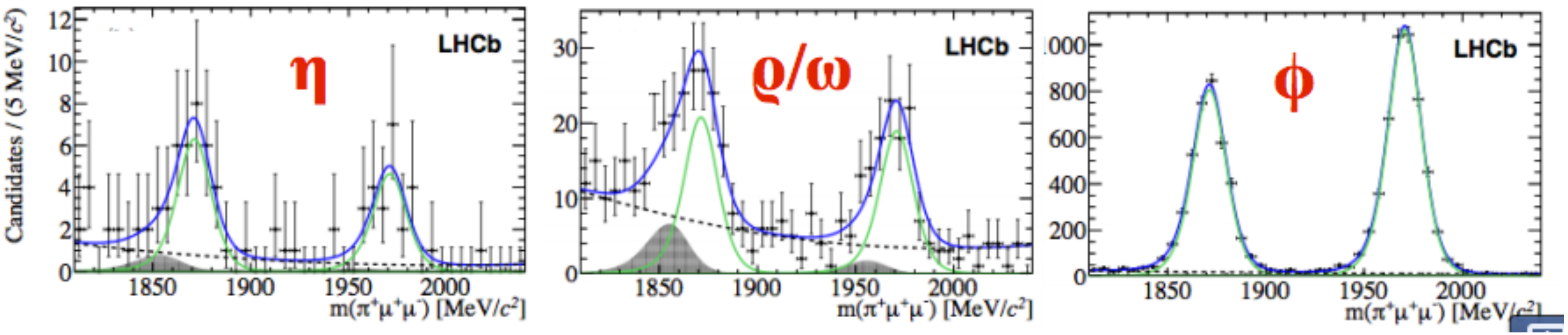
Most stringent limit up to date

D→πμμ

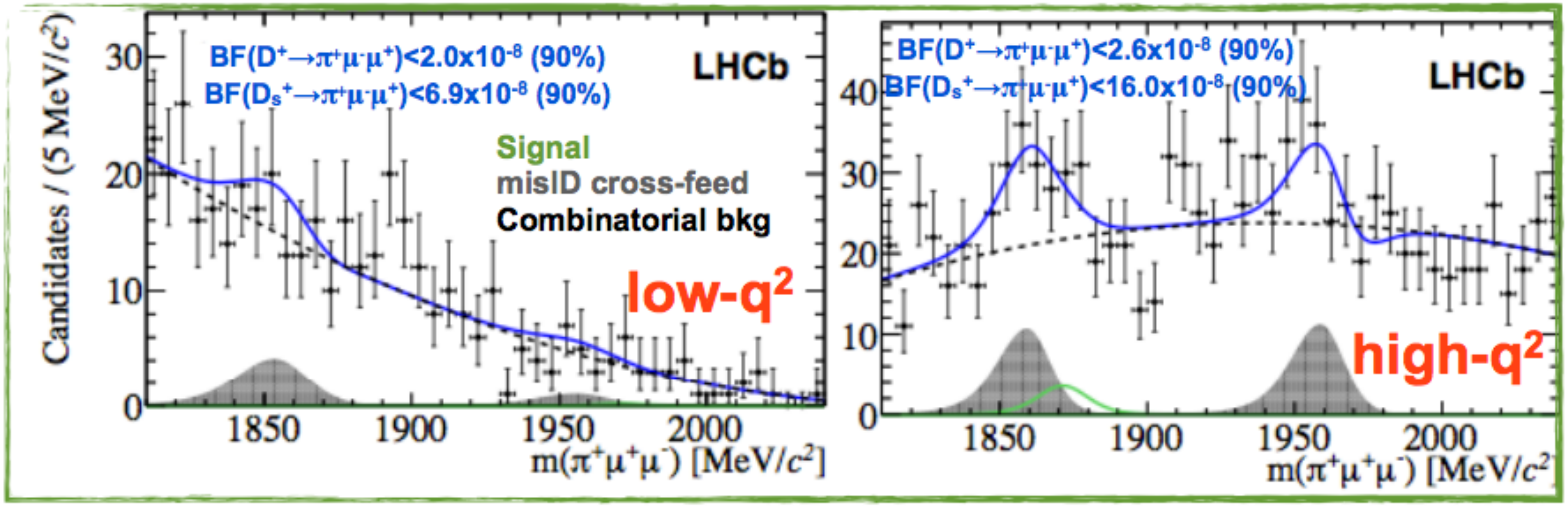
1/fb @√s=7TeV arXiv:1304.6365. Submitted to PLB

→ Selection criteria similar to the one used in $D^0 \to \mu^+\mu^-$ analysis.
→ Additionally, isolation variables exploited at selection
→ Main source of background is the final state with 3 pions
→ $D_{(s)}^+ \to \pi^+\phi(\mu^+\mu^-)$ mode used for normalization and as control sample
→ Analysis performed in regions of $q^2=M^2(\mu^+\mu^-)$
→ Double misID peaking background extracted from the fit. Shape extracted from $D_{(s)}^+ \to \pi^+\pi^+\pi^-$ sample with looser PID requirement and reconstructed with the μ mass hypothesis

Signal
misID cross-feed
Combinatorial bkg



$D \to \pi\mu\mu$ (2)



FCNC contributions sensitive to NP constrained to regions far from the resonances: low and high q^2 values
Consistent with no signal observation and limit is ~2 orders of magnitude improved wrt previous measurements*

*D0 PRL100(2008)101801
BaBar PRD84(2011)072006

$$\mathcal{B}(D^+ \to \pi^+\mu^+\mu^-) < 7.3\,(8.3) \times 10^{-8}$$
$$\mathcal{B}(D_s^+ \to \pi^+\mu^+\mu^-) < 4.1\,(4.8) \times 10^{-7}$$

@90(95)% CL

arXiv:1304.6365

D→πμμ (3)

LNV decay forbidden in the SM

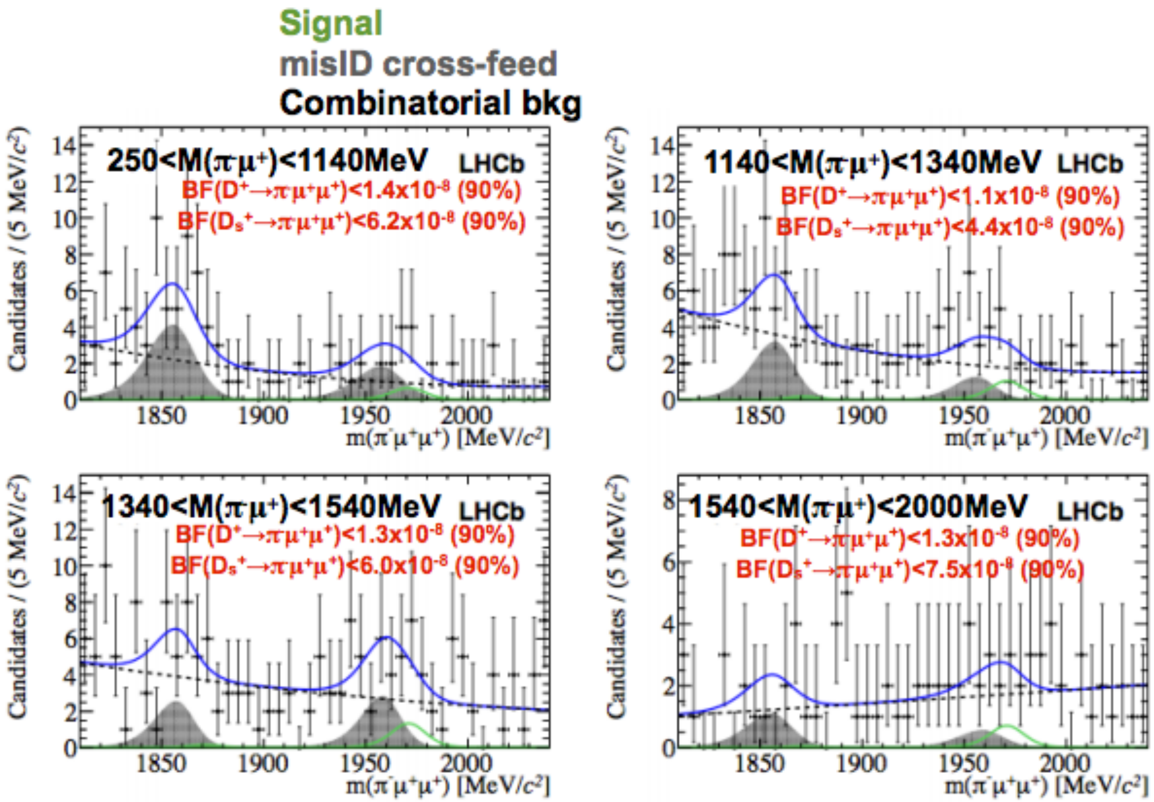
Split in 4 bins in M(πμ⁺) to improve sensitivity to the signals

Peaking bkg dominated by 3π final state

No evidence of LNV

Limit ~2 orders of magnitude improved wrt previous measurements*

*BaBar PRD84(2011)072006



$$\mathcal{B}(D^+ \to \pi^- \mu^+ \mu^+) < 2.2\,(2.5) \times 10^{-8},$$
$$\mathcal{B}(D_s^+ \to \pi^- \mu^+ \mu^+) < 1.2\,(1.4) \times 10^{-7}$$

@90(95)% CL

arXiv:1304.6365

Other Physics

Tau decays

- Large τ cross section (~ 10^{11} τ per 1 fb^{-1})
- Inclusive τ cross-section:~80μb−1
  - ~80%fromDs
- So far two analyses, about CLFV:
  - τ→3μ
    - normalized to Ds→Φ(μμ)π
    - dominated by combinatorial background
    - U.L. with 2011 data : 8.3×10^{-8} @90%C.L.
      - Belle 2.1×10^{-8} @ 90%C.L.
    - prospects for the upgrade
  - τ-→anti-p μ+μ- and τ-→p μ-μ-
    - CLFV and BNV but B-L conserved
    - overlooked by FF
    - exploits RICH PID
    - U.L. with 2011 data: 4.6×10^{-8} and 5.4×10^{-8}@90%C.L.

X(3872)

Determination of the $X(3872)$ quantum numbers

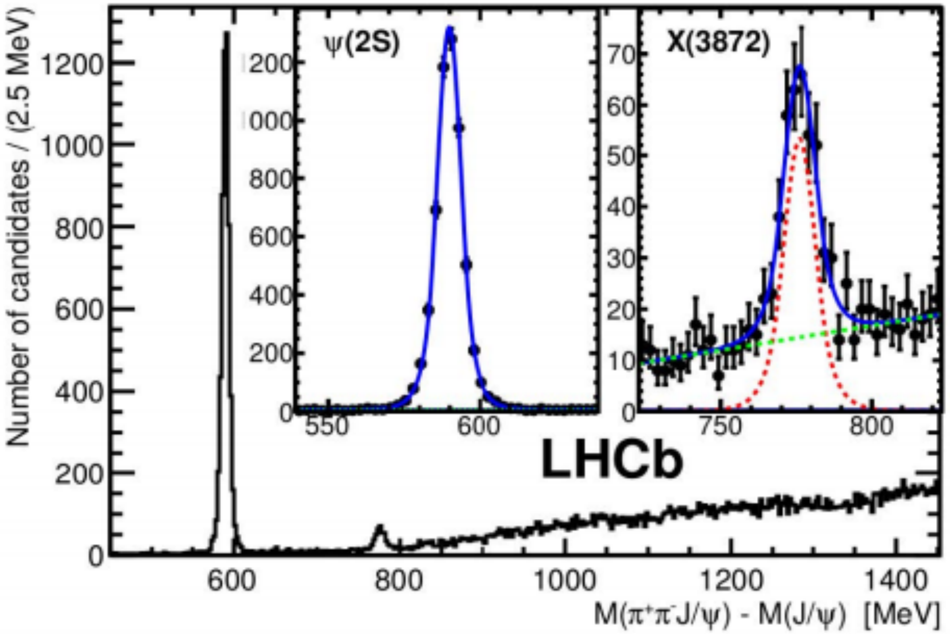
arXiv:1302.6269

The analysis uses 1 fb^{-1} of data collected in 2011

- 313 ± 26 $B^+ \to X(3872) K^+$ (568 ± 31 background events)
- 5642 ± 76 $B^+ \to \psi(2S) K^+$ (control sample)

with $X(3872)$ and $\psi(2S)$ decaying to

$$J/\psi \pi^+ \pi^- \to (\mu^+ \mu^-) \pi^+ \pi^-$$



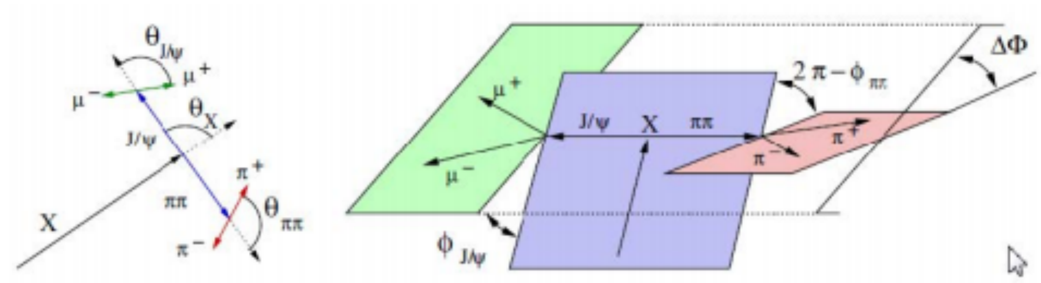
Angular correlations in the B^+ decay chain carry information on the J^{PC} of the $X(3872)$

X(3872)

arXiv:1302.6269

Analysis performed in 5D exploiting all angular correlations

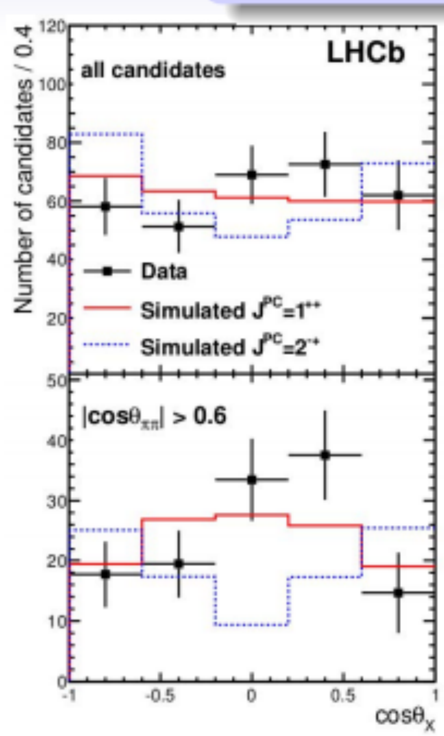
$$\Omega = (\cos\theta_X, \cos\theta_{\pi\pi}, \Delta\phi_{X,\pi\pi}, \cos\theta_{J/\psi}, \Delta\phi_{X,J/\psi})$$



Matrix elements in the helicity formalism

- 1^{++}: no free parameter
- 2^{-+}: one complex parameter α

Data favors 1++ over 2+ at 8.4σ



marginal differences in 1D distributions

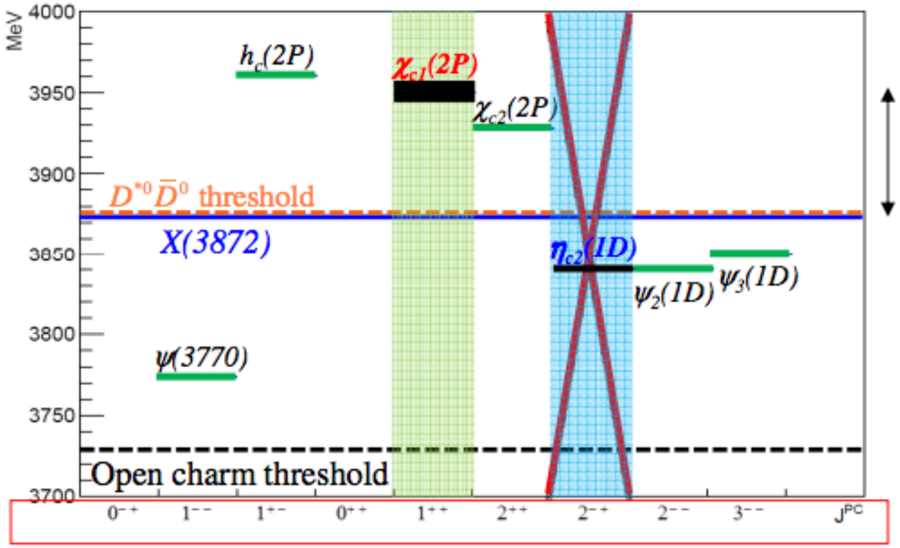
discrimination relies on correlations in specific phase-space regions

X(3872) interpretations

J^{PC} of X(3872) has been determined to be 1^{++}

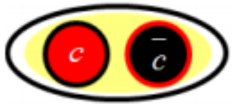
$\eta_{c2}(1^1D_{2-+})$ is now ruled out!

Charmonium spectrum



$\chi_{c1}(2^3P_{1++})$ possible but disfavored by mass

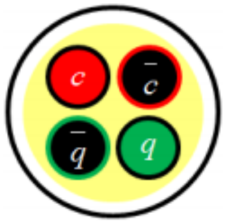
Charmonium



1^{++} was expected in both tetra-quark and molecular models

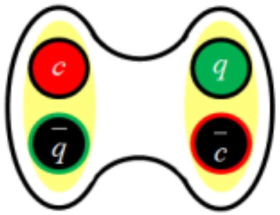
The four-quark models also favored by the coincidence of X(3872) mass with the $D^{*0}\bar{D}^0$ threshold

Tetra-quark



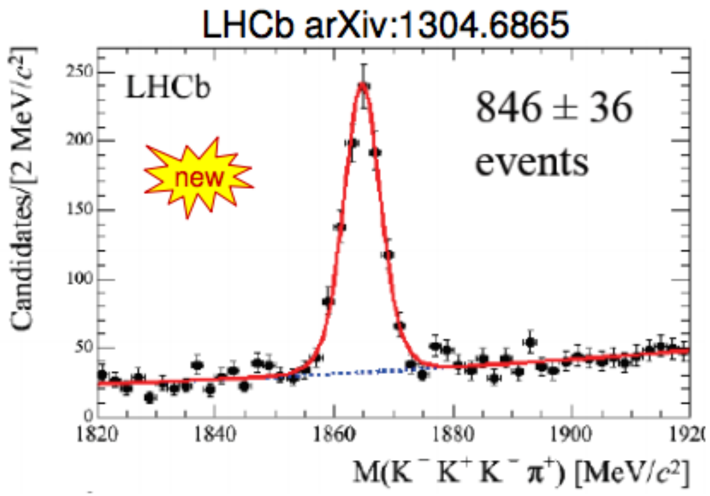
Nearly degenerate charged partners expected but not observed.

$D^{*0}\bar{D}^0$ molecule



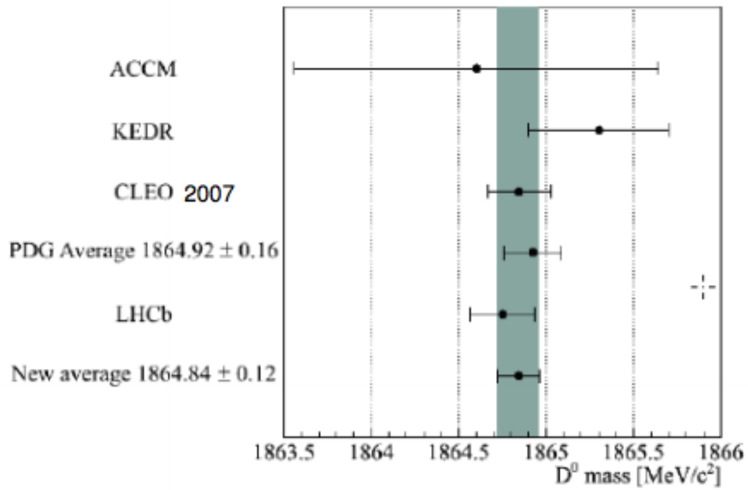
Binding energy requires mass to be below $M(D^0)+M(D^{*0})$. Satisfied? (see next)

from the D^0 mass measurement



M(D^0) = 1864.85±0.15±0.11 MeV

- Use $D^0 \to K^-K^+K^-\pi^+$ decays
- Low energy release $\to$ low systematic error
- Use D^0s produced in semileptonic b decays for good background suppression and high trigger efficiency



New average: M(D^0)=1864.84±0.12 MeV

+ using PDG averages:
ΔM(D^{*0}-D^0) =142.12±0.07 MeV
M[X(3872)] =3871.68±0.17 MeV

M[X(3872)] – M(D^0+D^{*0})= –0.12±0.30 MeV

If molecule then very loosely bound
$\to$ large in size (>6 fm at 90% CL)

Conclusion

- LHCb has a very rich physics program which also covers many subjects related to a tau-charm factory
- In charm physics, subjects range from mixing/CPV to rare decays and spectroscopy, mostly with decays to charged particles in the final state, using both promptly produced charmed hadrons and from B decays
- Also can perform some tau physics and competitive X,Y,Z spectroscopy manly from B decays
- **With 2011 and 2012 data (3fb^{-1}) we already have the world highest statistics in many channels**
- **For many years to come, at least until BElle2 will run at full speed, LHCb will be (together with BES3) the leading experiment in the charm sector**: statistical sensitivity to many observables such to rule out NP contributions (e.g. some channels sensitive 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
- Things are progressing also for some channels including one **π^0**.
- **Most channels with neutrinos and π^0's remain peculiar to the e^+e^- machines**