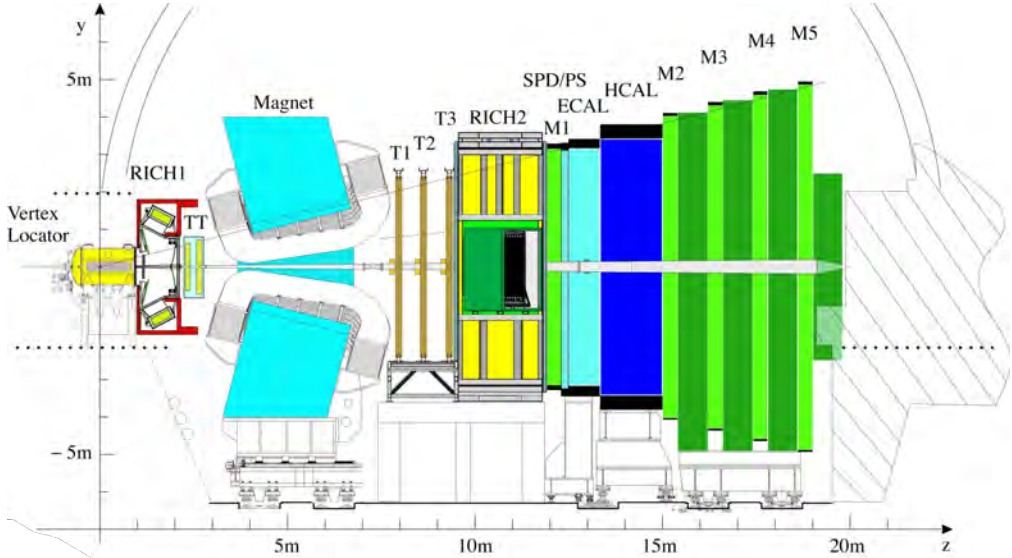
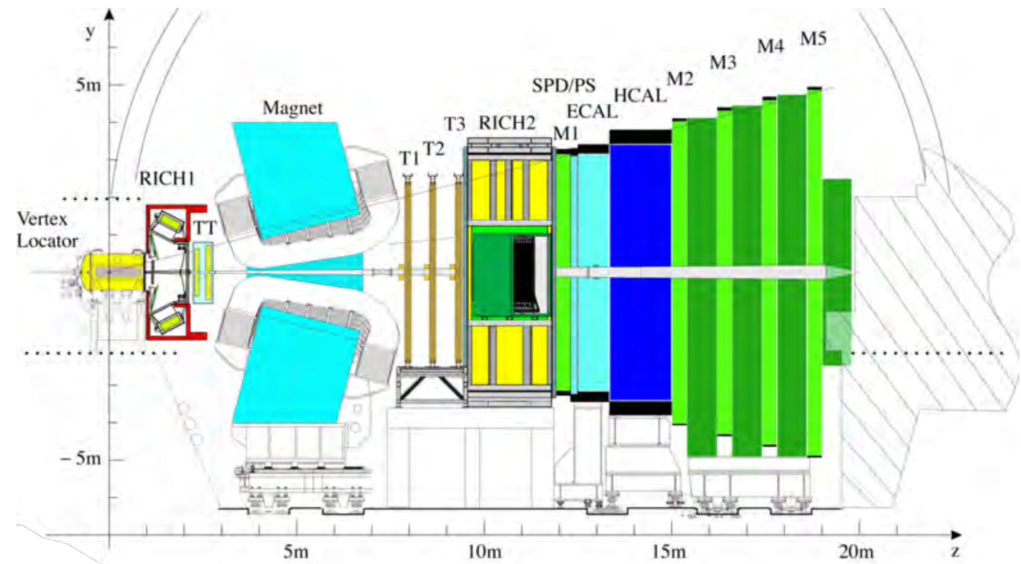
CP Violation in charm and other LHCb charm results



Jonas Rademacker (Bristol) on behalf of the LHCb collaboration.

CP Violation in charm and other LHCb charm results



Jonas Rademacker (Bristol) on behalf of the LHCb collaboration.

I'll try to keep this part of the slides, which most of you cannot see, empty

(with occasional exceptions, such as this one)

Charm as a tool for New Physics searches

- LHCb has huge charm samples (c x-section ≈ 20× b cross section)

- The theme of this talk is precision searches for new Physics in charm at LHCb - studying loop-sensitive processes with a precise Standard Model prediction.

- This includes CP violation (which should be tiny* in charm), but also other loops.

* until recently most calculations suggested SM CPV in charm of < ~10^{-3}
although sometimes with important qualifications such as: "Direct CP asymmetries in partial widths could be 'as large as' 10^{-3}. There is no theorem, though, ruling out SM effects [in SCS decays] of 1%" [6]
However, most were less cautious and a widespread consensus was that CPV O(1%) would indicate New Physics.

[5] Y. Grossman, A. L. Kagan, and Y. Nir, New physics and CP violation in singly Cabibbo suppressed D decays, Phys. Rev. D75 (2007) 036008, [arXiv:hep-ph/0609178].
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[7] M. Bobrowski, A. Lenz, J. Riedl, and J. Rohrwild, How large can the SM contribution to CP violation in $D^0-\bar{D}^0$ mixing be?, JHEP 1003 (2010) 009, [arXiv:1002.4794].
[8] A. A. Petrov, Searching for New Physics with Charm, PoS BEAUTY2009 (2009) 024, [arXiv:1003.0906].

Charm as a tool for New Physics searches

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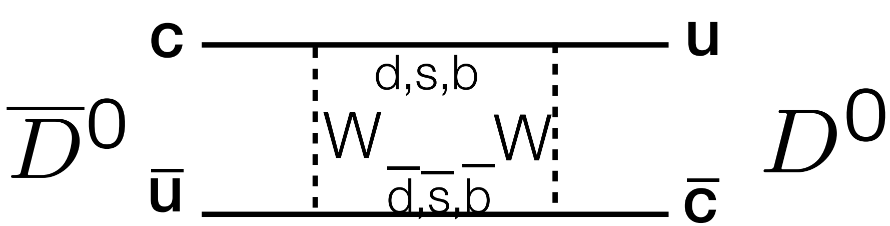
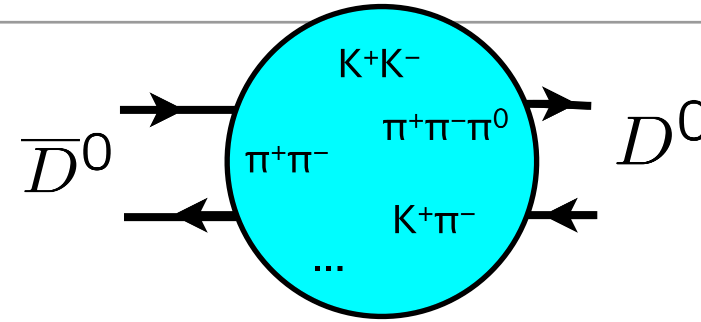
Charm Mixing (differences to the B mixing world in red)



Box diagram - FCNC between up type quarks -> loop with down-type quarks.



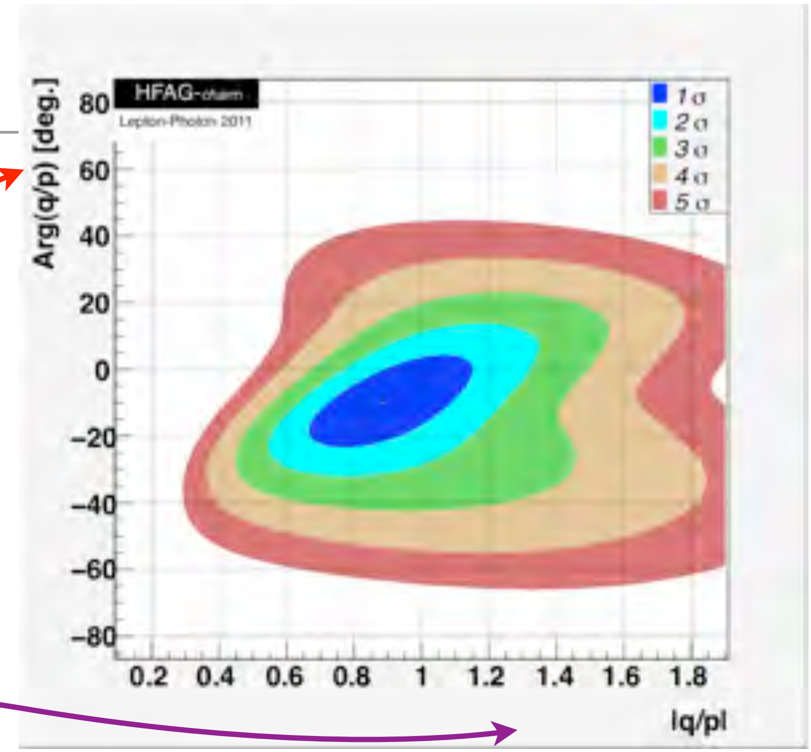
long-distance effects important/dominant, but difficult to calculate

- Two mass eigenstates (= CP eigenstates if no CPV) $|D_{1,2}\rangle = p|D^0\rangle \pm q|\overline{D}^0\rangle$
- Δm = mass difference ~ mixing frequency. $x = \Delta m/\Gamma$
  $\Delta\Gamma$ = width difference. $y = \frac{1}{2}\,\Delta\Gamma/\Gamma$
- D mixing now well established (~10σ)

CP Violation in mixing and interference of mixing and decay.

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

$$\frac{q}{p} = \left|\frac{q}{p}\right| e^{i\phi_D}$$



- $\varphi_D \equiv \mathrm{Arg}(q/p)$ equivalent to 2β in B_d system (i.e. CPV in the interference between mixing and decay)
- $(1 - |q/p|)$ equivalent to A_{sl} or ε_K, CPV in mixing.
- $\varphi_D \equiv \mathrm{Arg}(q/p) = 0$, $|q/p| = 1$ in SM. Plot shows current constraints.

Time-dependent CPV and mixing at LHCb

- Define

$$y_{CP} \equiv \frac{\tau\left(D^0 \to K^-\pi^+\right)}{\tau\left(D^0 \to KK\right)} - 1$$

$$= y\cos\phi - \frac{1}{2}\left(\left|\frac{q}{p}\right| - \left|\frac{p}{q}\right|\right) x\sin\phi$$

(this could be any other CP eigenstate such as ππ)

- W/o CP violation (and to 1st order even with CPV): $y_{CP} = y$

Time-dependent CPV and mixing at LHCb

tag the D flavour using

$D^{*-} \rightarrow \overline{D}^{0}\pi^{-}$ $D^{*+} \rightarrow D^{0}\pi^{+}$

- Define:

$$A_\Gamma \equiv \frac{\tau\left(\overline{D}^0 \to K^+K^-\right) - \tau\left(D^0 \to K^+K^-\right)}{\tau\left(\overline{D}^0 \to K^+K^-\right) + \tau\left(D^0 \to K^+K^-\right)}$$

$$= \frac{1}{2}\left(\left|\frac{q}{p}\right| - \left|\frac{p}{q}\right|\right)\cos\phi - x\sin\phi$$

- A_Γ sensitive especially to CPV in mixing ($|q/p| \neq 1$)

Time-dependent CPV and mixing at LHCb

- Define:

$$A_{\Gamma} \equiv \frac{\tau\left(\overline{D}^0 \to K^+K^-\right) - \tau\left(D^0 \to K^+K^-\right)}{\tau\left(\overline{D}^0 \to K^+K^-\right) + \tau\left(D^0 \to K^+K^-\right)}$$

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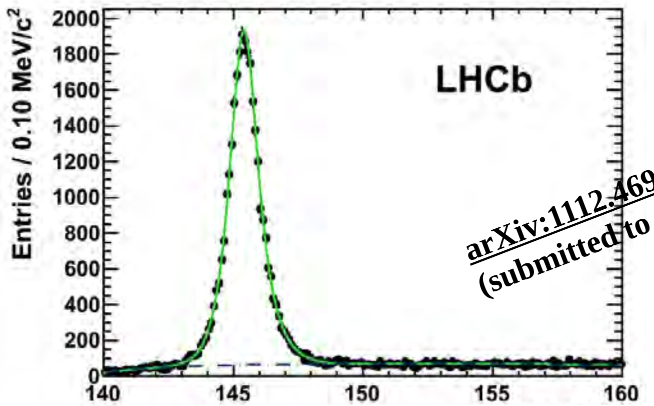
- A_Γ sensitive especially to CPV in mixing ($|q/p| \neq 1$)

tag the D flavour using

$D^{*-} \to \overline{D}{}^0\pi^-$ $D^{*+} \to D^0\pi^+$

38k $D \to KK$ in 29/pb



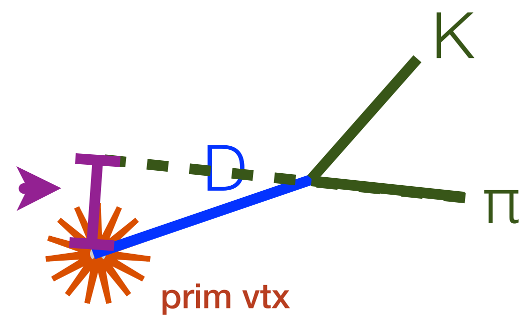
m(D*)-m(D) [MeV]

Time-dependent charm at LHCb

arXiv:1112.4698 [hep-ex]
(submitted to JHEP)

$$y_{CP} \equiv \frac{\tau\left(D^0 \to K^-\pi^+\right)}{\tau\left(D^0 \to KK\right)} - 1$$

$$A_\Gamma \equiv \frac{\tau\left(\overline{D}^0 \to K^+K^-\right) - \tau\left(D^0 \to K^+K^-\right)}{\tau\left(\overline{D}^0 \to K^+K^-\right) + \tau\left(D^0 \to K^+K^-\right)}$$

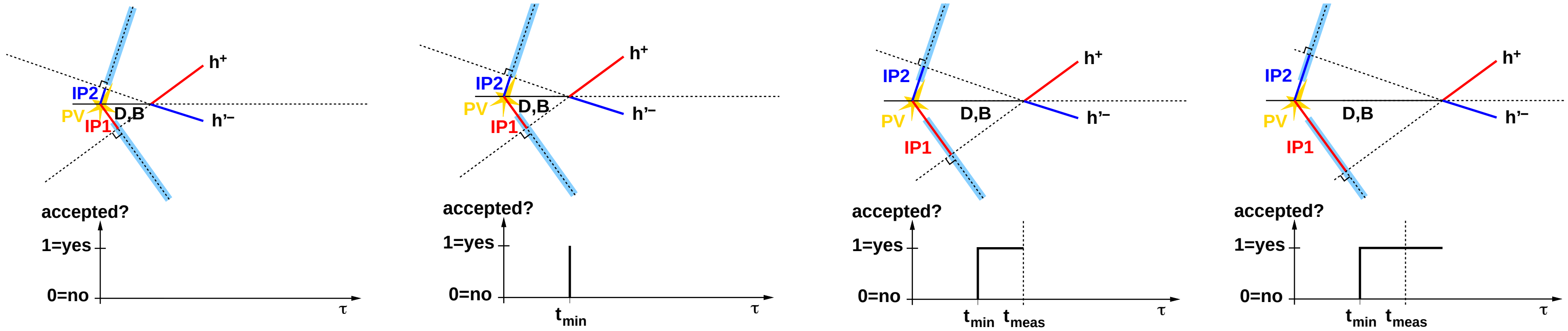


- Trigger relies on impact parameters to identify tracks from long-lived particles - this biases the lifetime distribution; does not completely cancel in ratio.

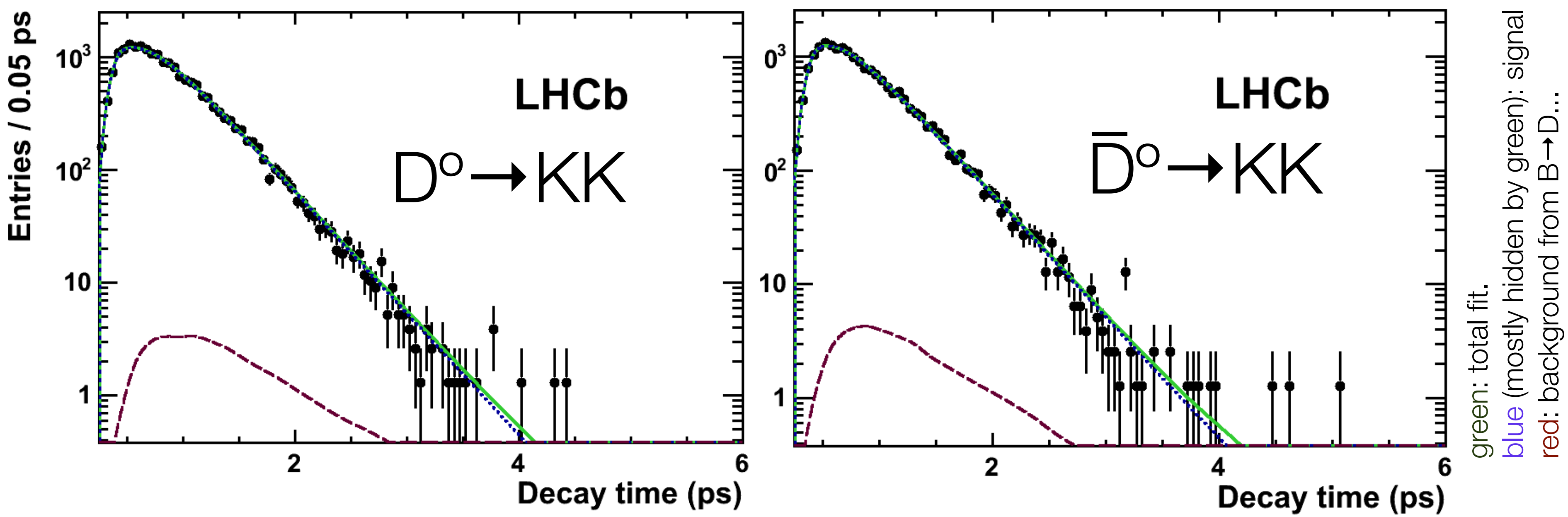
Time-dependent charm at LHCb

arXiv:1112.4698 [hep-ex]
(submitted to JHEP)

- We calculate (not simulate) the acceptance function for each event, by re-evaluating the trigger response for every possible decay time this event could have had. (see CDF's analysis: Phys.Rev. D83 (2011) 032008 and also Nucl.Instrum.Meth. A570 (2007) 525-528)



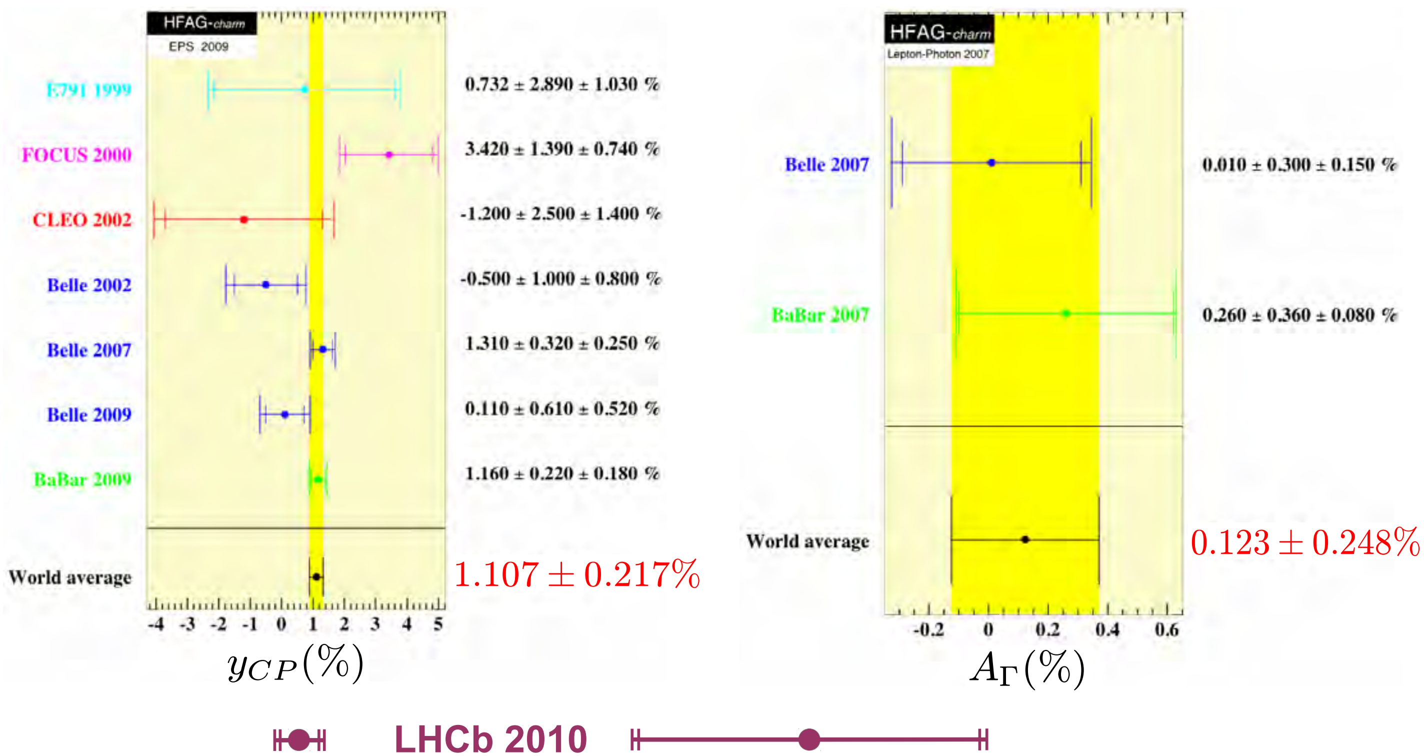
y_{CP} and A_{Γ} results



arXiv:1112.4698 [hep-ex] (submitted to JHEP)

y_{CP} and A_Γ results (2010 data)

$$y_{CP} = (5.5 \pm 6.3_{\text{stat}} \pm 4.1_{\text{syst}}) \times 10^{-3} \qquad A_\Gamma = (-5.9 \pm 5.9_{\text{stat}} \pm 2.1_{\text{syst}}) \times 10^{-3}$$



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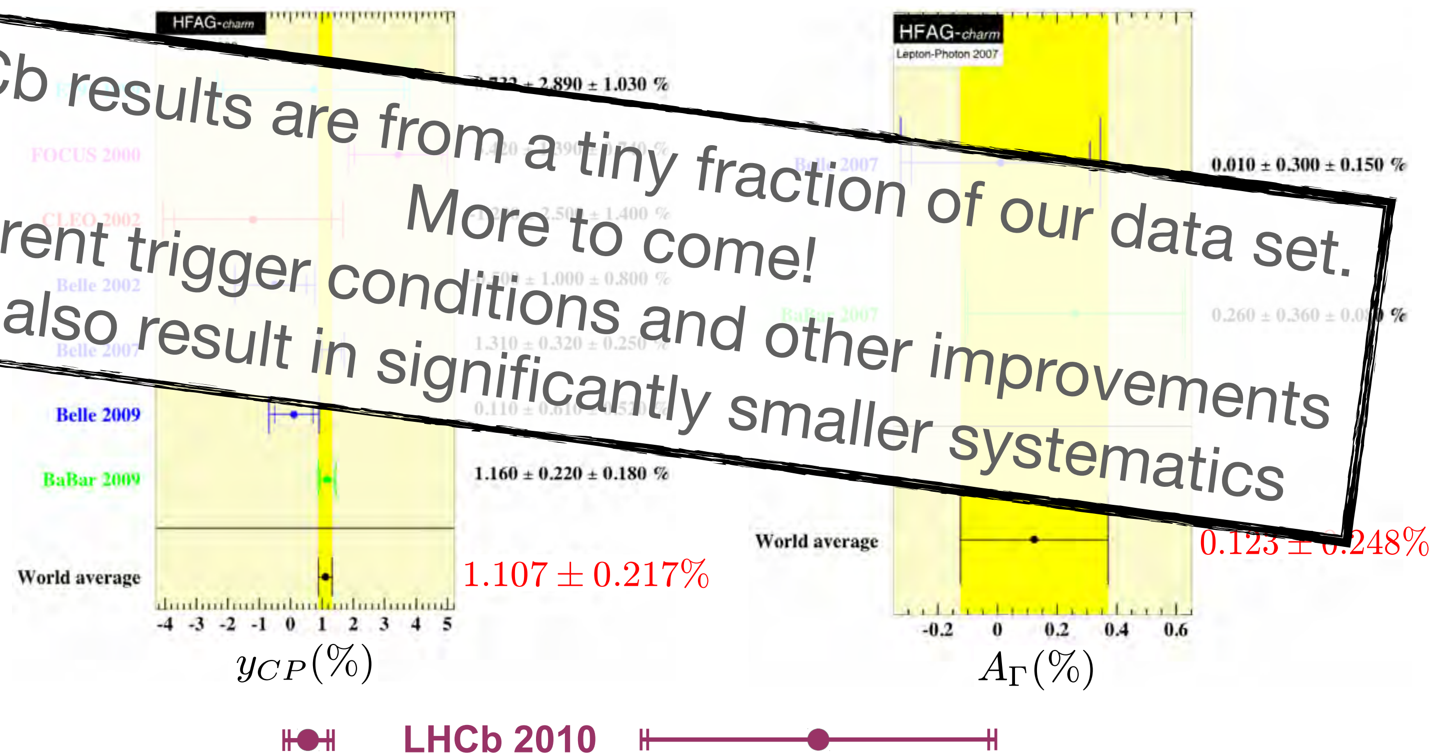
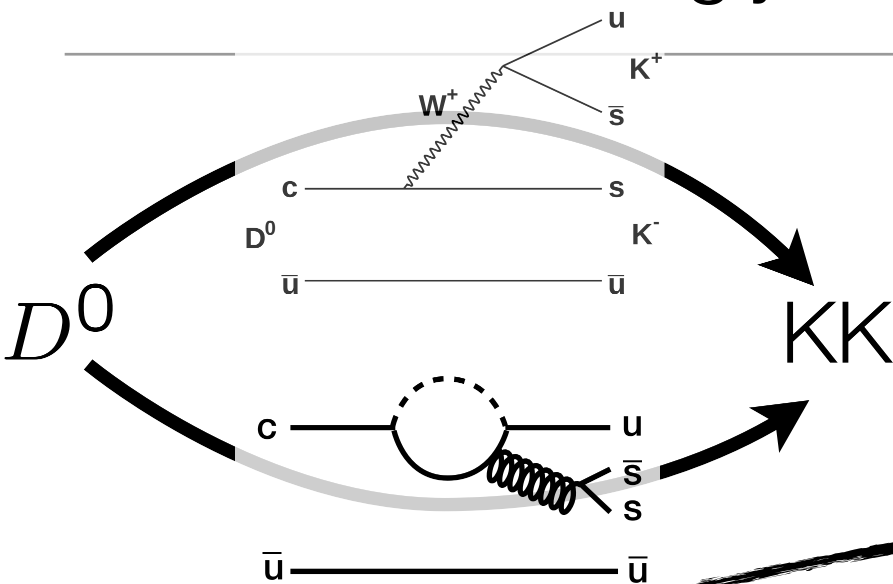


LHCb results are from a tiny fraction of our data set.
More to come!
Different trigger conditions and other improvements will also result in significantly smaller systematics

Direct CPV in Singly Cabibbo Suppressed Decays



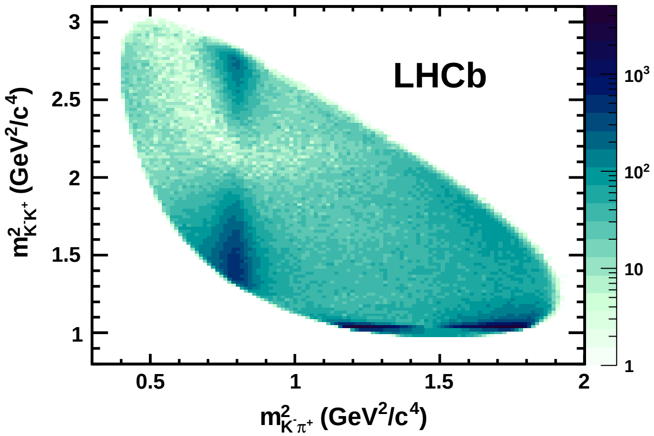
Earlier this session, Till Moritz Karbach discussed direct CPV in B decays, which can be **large**. Here, at least according to the SM, it should be **tiny**.

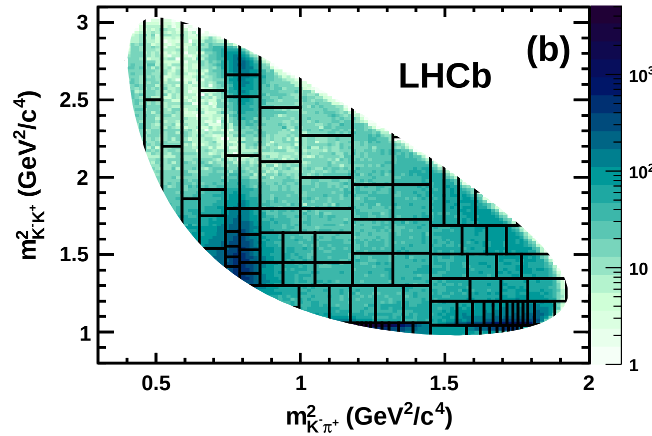
- Measure absolute decay rate differences between $D^o \rightarrow f$ and $\overline{D}^o \rightarrow \overline{f}$.
- Tag initial state with D*:
  $D^{*-} \rightarrow \overline{D}^0 \pi_s^-$ $D^{*+} \rightarrow D^0 \pi_s^+$
- Worry about production and detection asymmetries.

Searches for direct CPV $D^+ \to K^- K^+ \pi^+$

35/pb, PhysRevD.84.112008

- Kinematics of 3-body decays can be parameterised with 2 parameters and represented as a Dalitz plot.



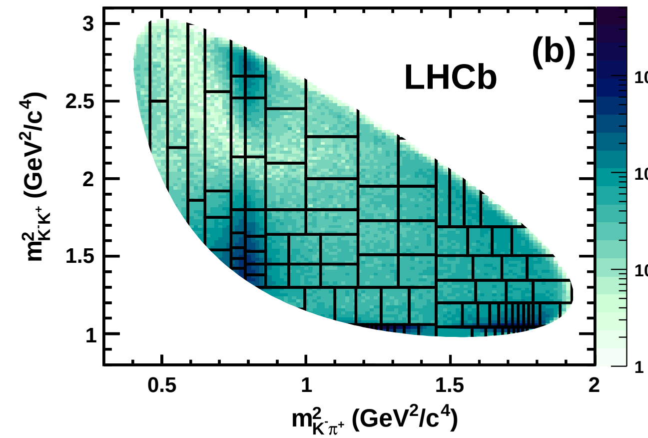


- Analysis based on splitting the D^+ and D^- Dalitz plot into bins and comparing yields bin-by-bin as suggested in Bediaga et al, Phys.Rev.D80:096006,2009

Searches for direct CPV $D^+ \to K^- K^+ \pi^+$

- Compare yields in CP-conjugate bins

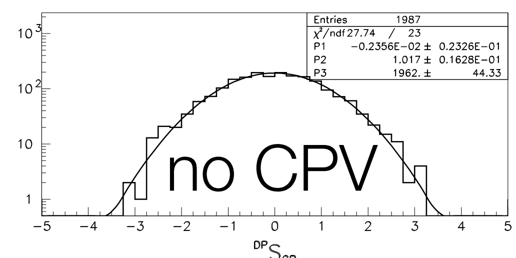
$$S_{CP} = \frac{N_i - \alpha \bar{N}_i}{\sqrt{N_i + \alpha^2 \bar{N}_i}} \qquad \alpha = \frac{N_{\text{total}}}{\bar{N}_{\text{total}}}$$

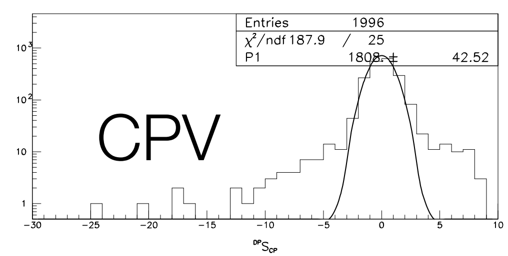


35/pb, PhysRevD.84.112008

- Model independent. Due to normalisation, many production and detection effects cancel.

- Plot this for all bins - expect Gaussian with μ=0, σ=1





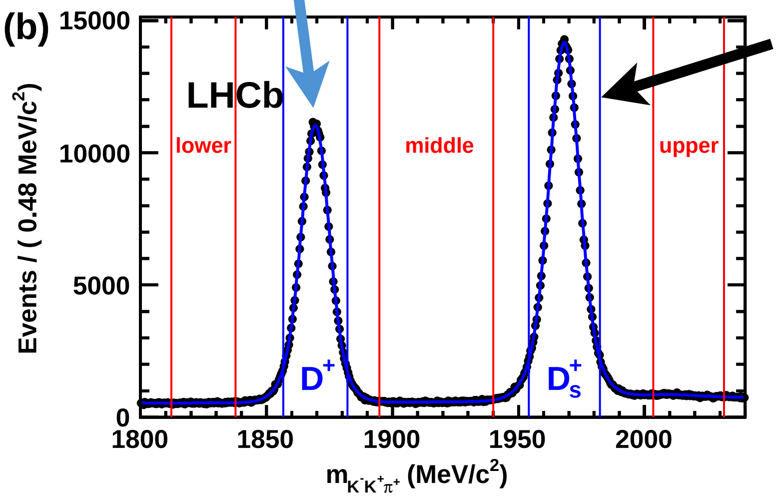
Plots: Simulation by Bediaga et al, Phys.Rev.D80:096006,2009

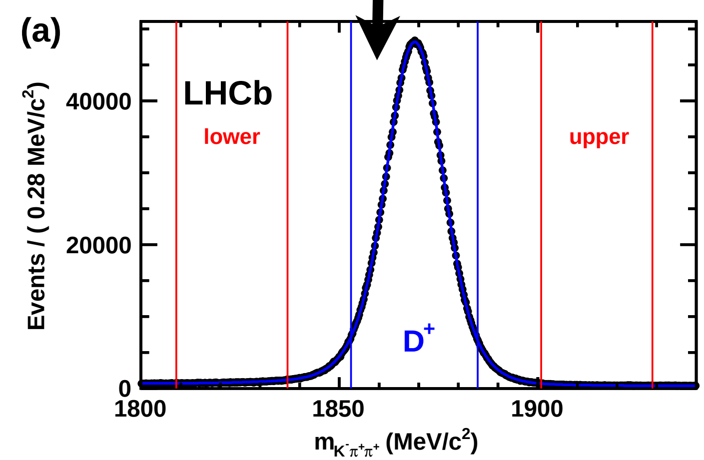
$D^+ \to K^- K^+ \pi^+$ and control modes at LHCb

SCS Signal: 0.33M $D^+ \to K^- K^+ \pi^+$

CF control: 0.46M $D_s^+ \to K^- K^+ \pi^+$

CF Control: 3.38M $D^+ \to K^- \pi^+ \pi^+$





Expect no CPV in tree-dominated Cabibbo-favoured (CF) control channels

35/pb, PhysRevD.84.112008

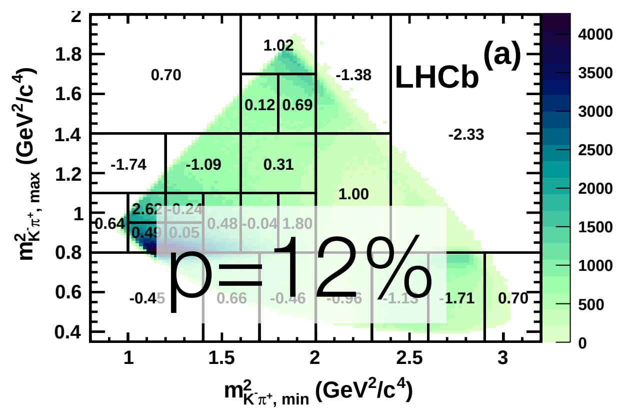
Searches for direct CPV in $D^+ \to K^- K^+ \pi^+$

35/pb, PhysRevD.84.112008

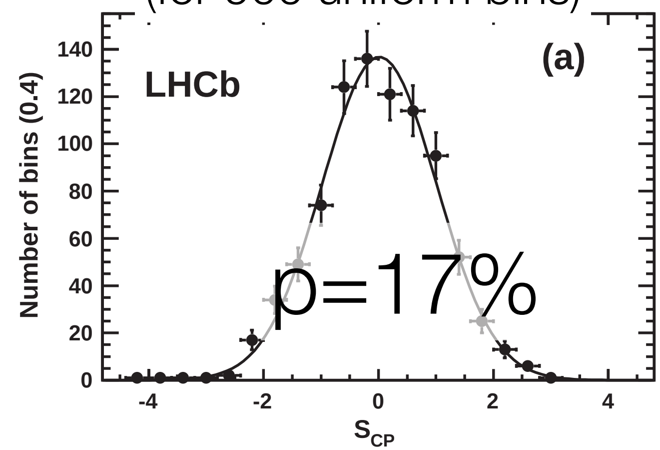
$D^+ \to K^- \pi^+ \pi^+$

Control channel

adaptive binning



(for 900 uniform bins)

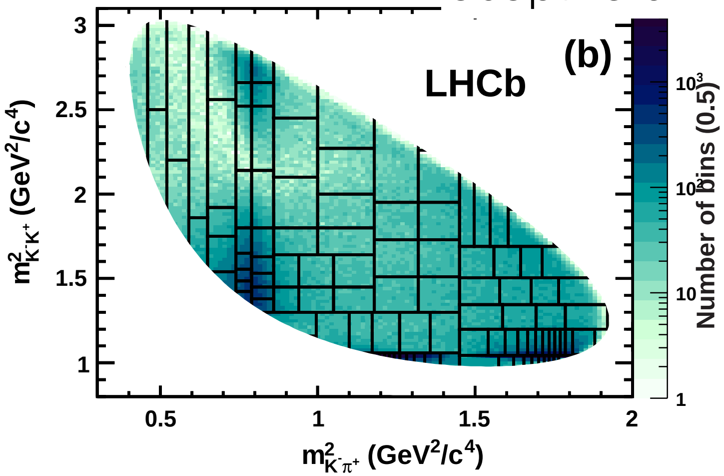


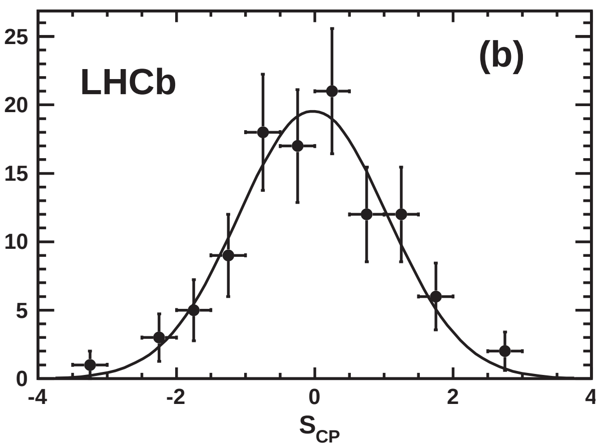
Searches for direct CPV in $D^+ \to K^- K^+ \pi^+$

35/pb, PhysRevD.84.112008

Search channel

adaptive binning (106 bins)





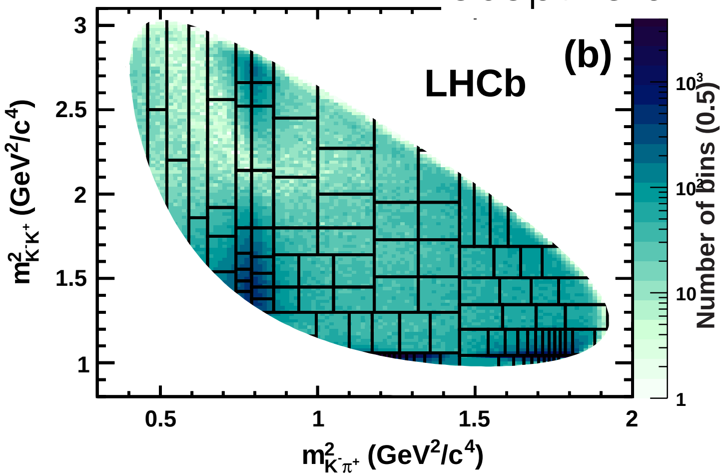
p=11%

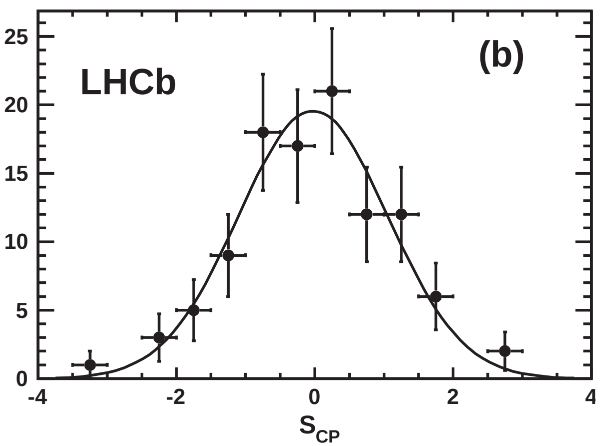
Searches for direct CPV in $D^+ \to K^- K^+ \pi^+$

35/pb, PhysRevD.84.112008

Search channel

adaptive binning (106 bins)





p=11%

(Investigated several alternative binnings in all 3 channels – no signs of CPV)

Direct CPV in D→KK, D→ππ

0.62/fb, arXiv:1112.0938 [hep-ex] (accepted by PRL)

$$A_{CP}(K^+K^-) \equiv \frac{\Gamma(D^0 \to K^+K^-) - \Gamma(\overline{D}^0 \to K^+K^-)}{\Gamma(D^0 \to K^+K^-) + \Gamma(\overline{D}^0 \to K^+K^-)} \quad A_{CP}(\pi^+\pi^-) \equiv \frac{\Gamma(D^0 \to \pi^+\pi^-) - \Gamma(\overline{D}^0 \to \pi^+\pi^-)}{\Gamma(D^0 \to \pi^+\pi^-) + \Gamma(\overline{D}^0 \to \pi^+\pi^-)}$$

Tag initial state with D*: $D^{*-} \to \overline{D}^0 \pi_s^-$, $D^{*+} \to D^0 \pi_s^+$

Direct CPV in D→KK, D→ππ

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Tag initial state with D*: $D^{*-} \to \overline{D}^0 \pi_s^-$, $D^{*+} \to D^0 \pi_s^+$

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

what we want

f's detection asymmetry.

π_s detection asymmetry

Production asymmetry

Direct CPV in D→KK, D→ππ

0.62/fb, arXiv:1112.0938 [hep-ex] (accepted by PRL)

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

what we want ($A_{CP}(f)$)

~~f's detection asymmetry.~~ ($A_D(f)$, crossed out)

π_s detection asymmetry ($A_D(\pi_s)$)

Production asymmetry ($A_P(D^{*+})$)

Direct CPV in D→KK, D→ππ

0.62/fb, arXiv:1112.0938 [hep-ex] (accepted by PRL)

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

what we want

~~f's detection asymmetry.~~

π_s detection asymmetry

Production asymmetry

Direct CPV in $D \to KK$, $D \to \pi\pi$

0.62/fb, arXiv:1112.0938 [hep-ex] (accepted by PRL)

Tag initial state with D*: $D^{*-} \to \overline{D}^0 \pi_s^-$, $D^{*+} \to D^0 \pi_s^+$

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

what we want

f's detection asymmetry.

π_s detection asymmetry

Production asymmetry

- Initial state subject to production and π_s detection asymmetry. Cancel in the difference: $\Delta A_{CP} \equiv A_{CP}(KK) - A_{CP}(\pi\pi)$

Direct CPV in D→KK, D→ππ

0.62/fb, arXiv:1112.0938 [hep-ex] (accepted by PRL)

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

what we want

f's detection asymmetry.

π_s detection asymmetry

Production asymmetry

- Initial state subject to production and π_s detection asymmetry.
  Cancel in the difference: $\Delta A_{CP} \equiv A_{CP}(KK) - A_{CP}(\pi\pi)$
- Nice: U-spin suggests that $A_{CP}(KK) \approx -A_{CP}(\pi\pi)$ (Grossmann Kagan Nir Phys.Rev.D75:036008,2007)
- Measures CPV in decay only, other forms of CPV cancel (to very good approx)

Direct CPV in D→KK, D→ππ

0.62/fb, arXiv:1112.0938 [hep-ex] (accepted by PRL)

Tag initial state with D*: $D^{*-} \to \overline{D}^0 \pi_s^-$, $D^{*+} \to D^0 \pi_s^+$

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what we want

~~f's detection asymmetry.~~

π_s detection asymmetry

Production asymmetry

- Initial state subject to production and π_s detection asymmetry. Cancel in the difference: $\Delta A_{CP} \equiv A_{CP}(KK) - A_{CP}(\pi\pi)$
- Caveat: Correlations between the D/D production kinematics and the KK/ππ detection efficiencies can destroy exact cancellations.

Direct CPV in D→KK, D→ππ

0.62/fb, **arXiv:1112.0938 [hep-ex]** (accepted by PRL)

Tag initial state with D*: $D^{*-} \rightarrow \overline{D}^0 \pi_s^-$, $D^{*+} \rightarrow D^0 \pi_s^+$

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

what we want

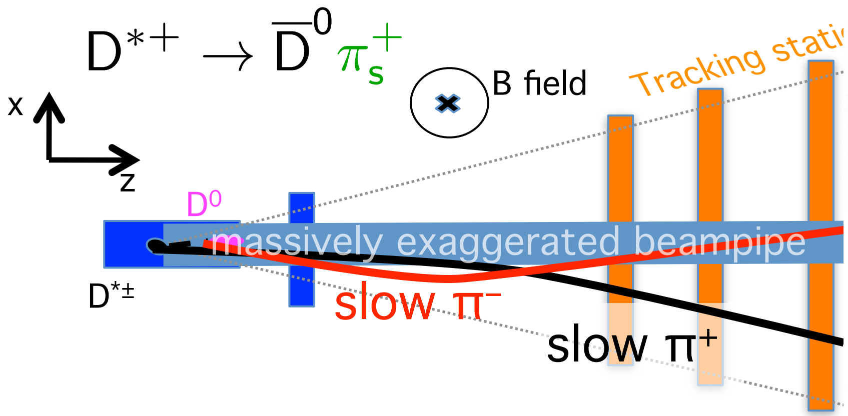
~~f's detection asymmetry.~~

π_s detection asymmetry

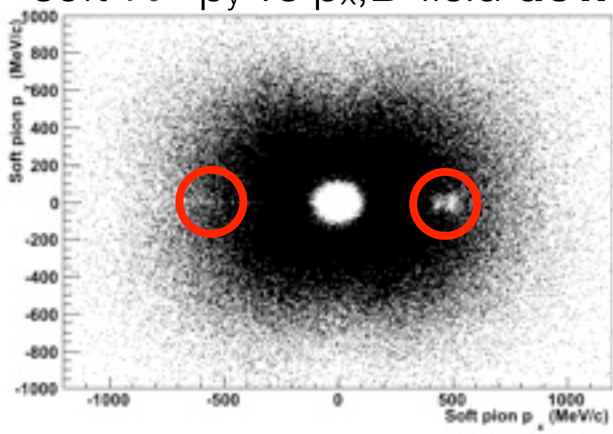
Production asymmetry

- Initial state subject to production and π_s detection asymmetry.
  Cancel in the difference: $\Delta A_{CP} \equiv A_{CP}(KK) - A_{CP}(\pi\pi)$
- We remove correlations with kinematic binning - analyse in bins of (p_T, η) of D* and p of pion. Additionally split by detector hemisphere and run conditions.

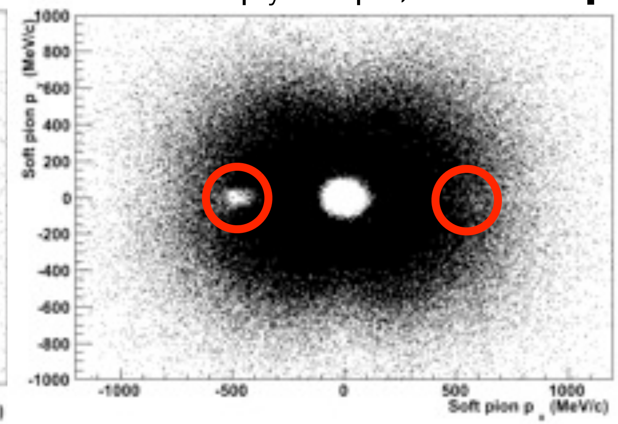
Direct CPV in D→KK, D→ππ: field reversal and fiducial cuts



soft π+ p_y vs p_x, B-field **down**

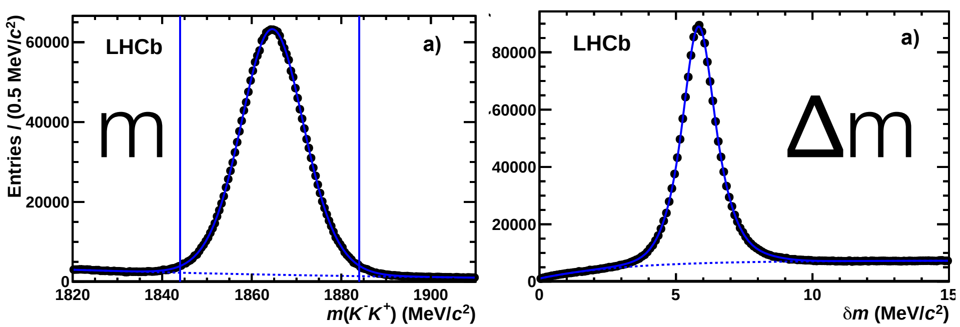


soft π+ p_y vs p_x, B-field **up**

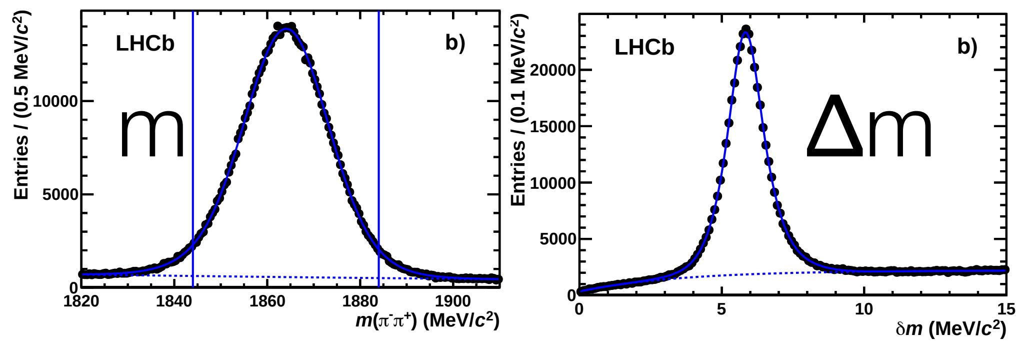


Acceptance effects cancel in this measurement - however, to ensure that we rely only on cancellations of ***small*** numbers, we regularly reverse the B field and remove kinematic regions with large asymmetries.

Direct CPV in D→KK, D→ππ: Mass spectra



K⁺K⁻ Yield: (1436 ± 2) x 10³



π⁺π⁻ Yield: (381 ± 1) x 10³

0.62/fb, arXiv:1112.0938 [hep-ex] (accepted by PRL)

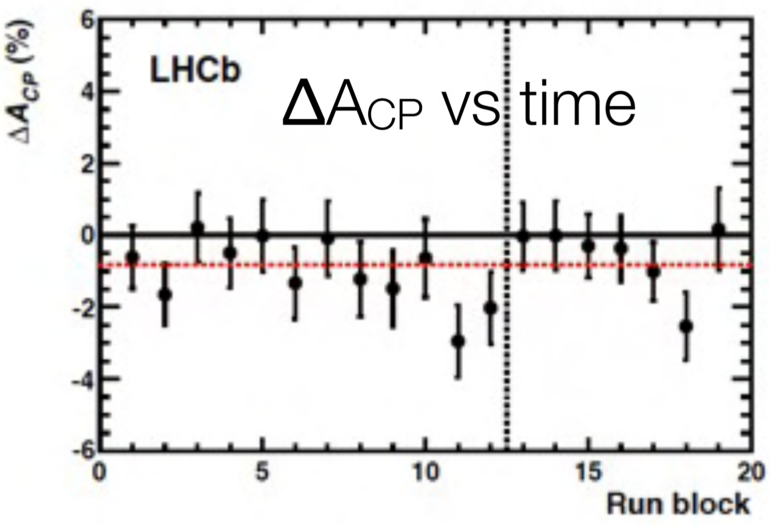
Direct CPV in D→KK, D→ππ: Result for 0.62 fb^{-1}

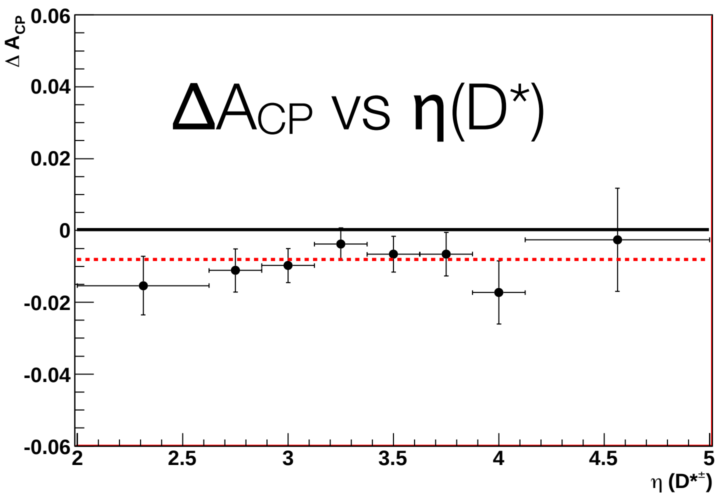
$$\Delta A_{CP} = (-0.82 \pm 0.21 \pm 0.11)\%$$

Significance: 3.5 σ

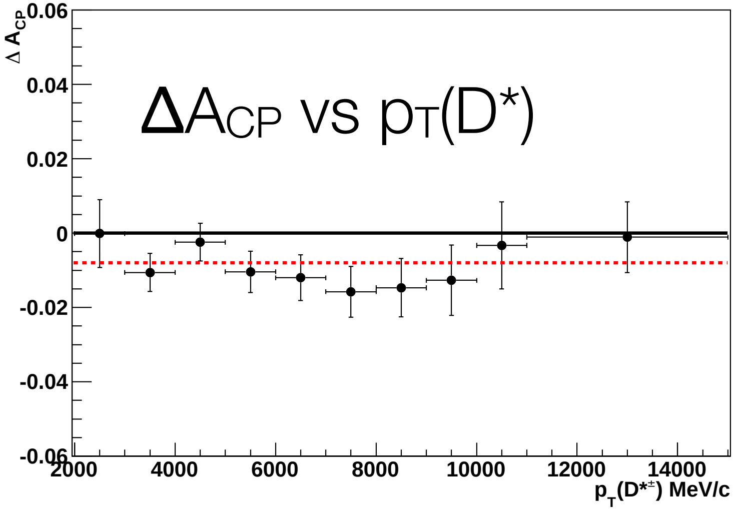
arXiv:1112.0938 [hep-ex] (accepted by PRL)

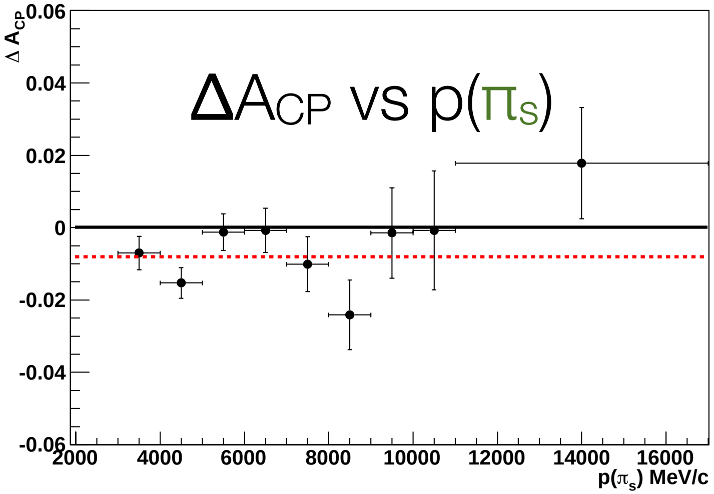
Many, many cross checks. Here 2 of them:





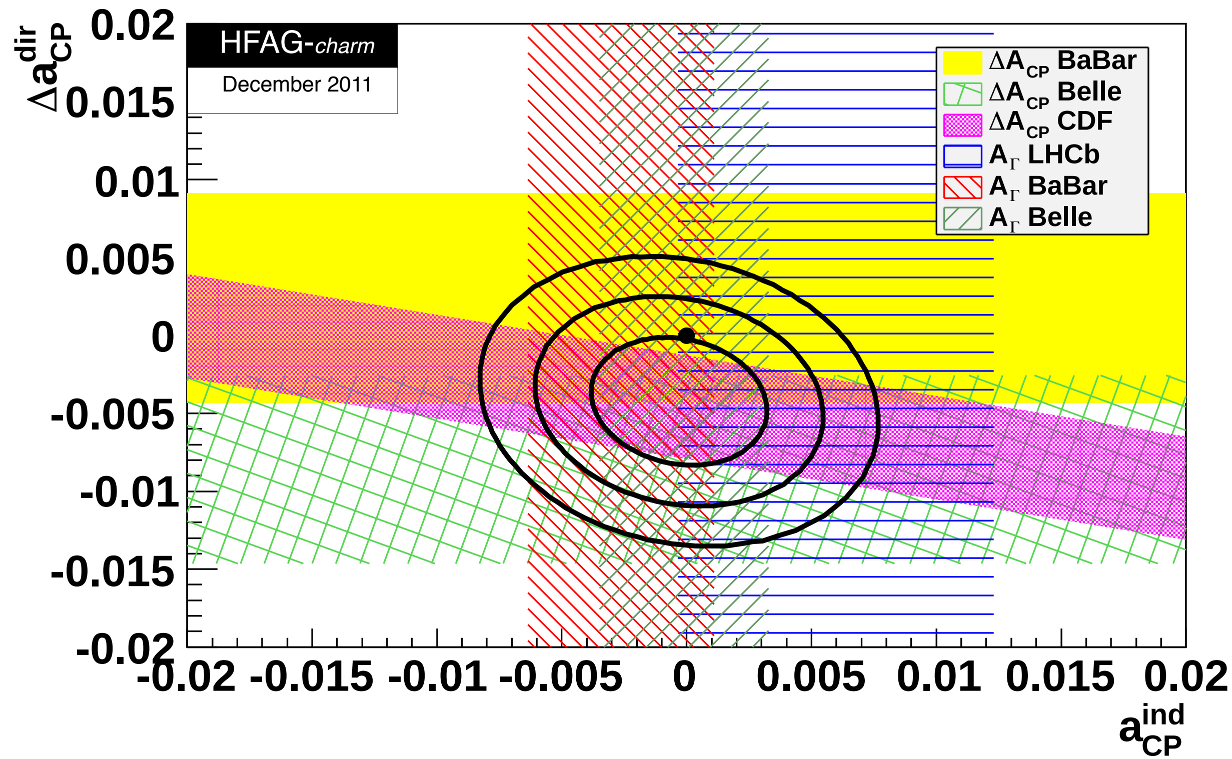
Many, many cross checks. Here are another 2:





Direct CPV in D→KK, D→ππ: Result

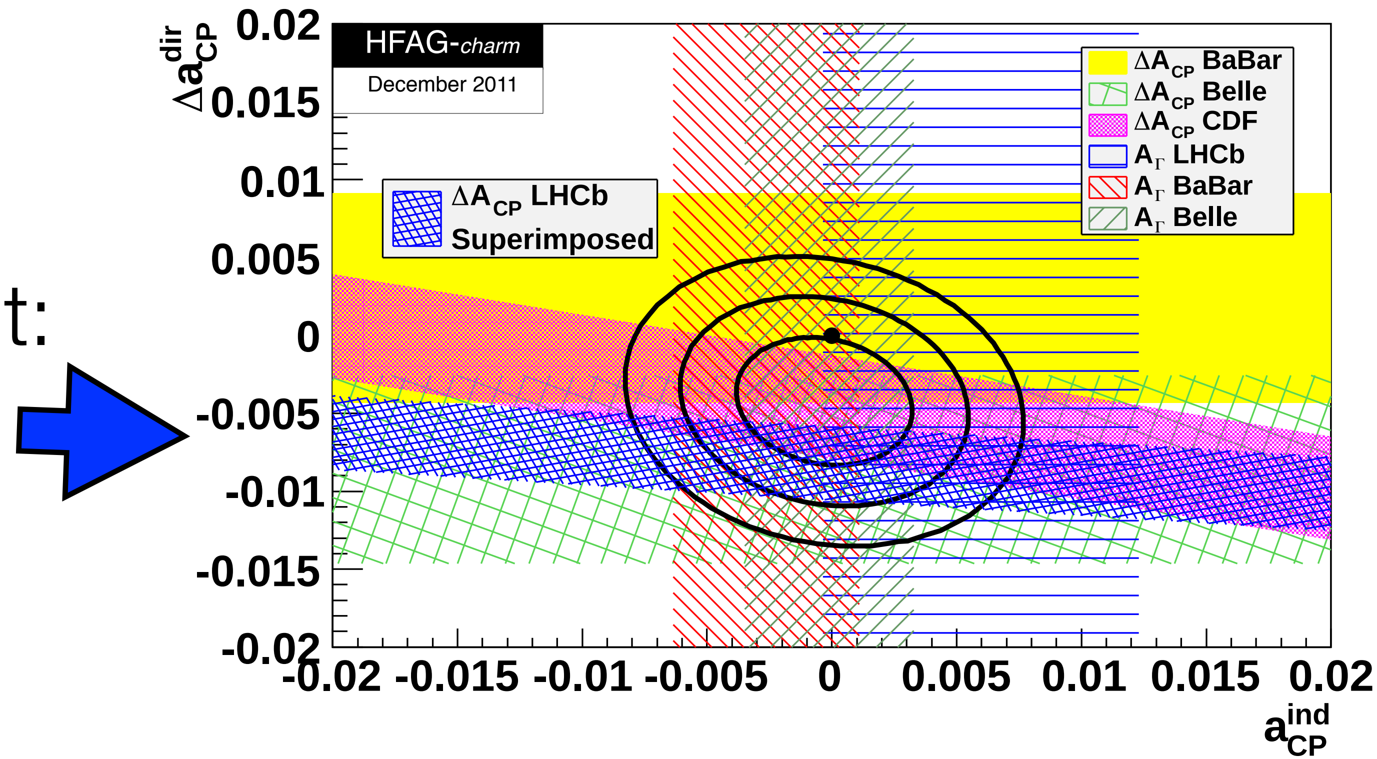
Before this measurement:



Direct CPV in D→KK, D→ππ: Result

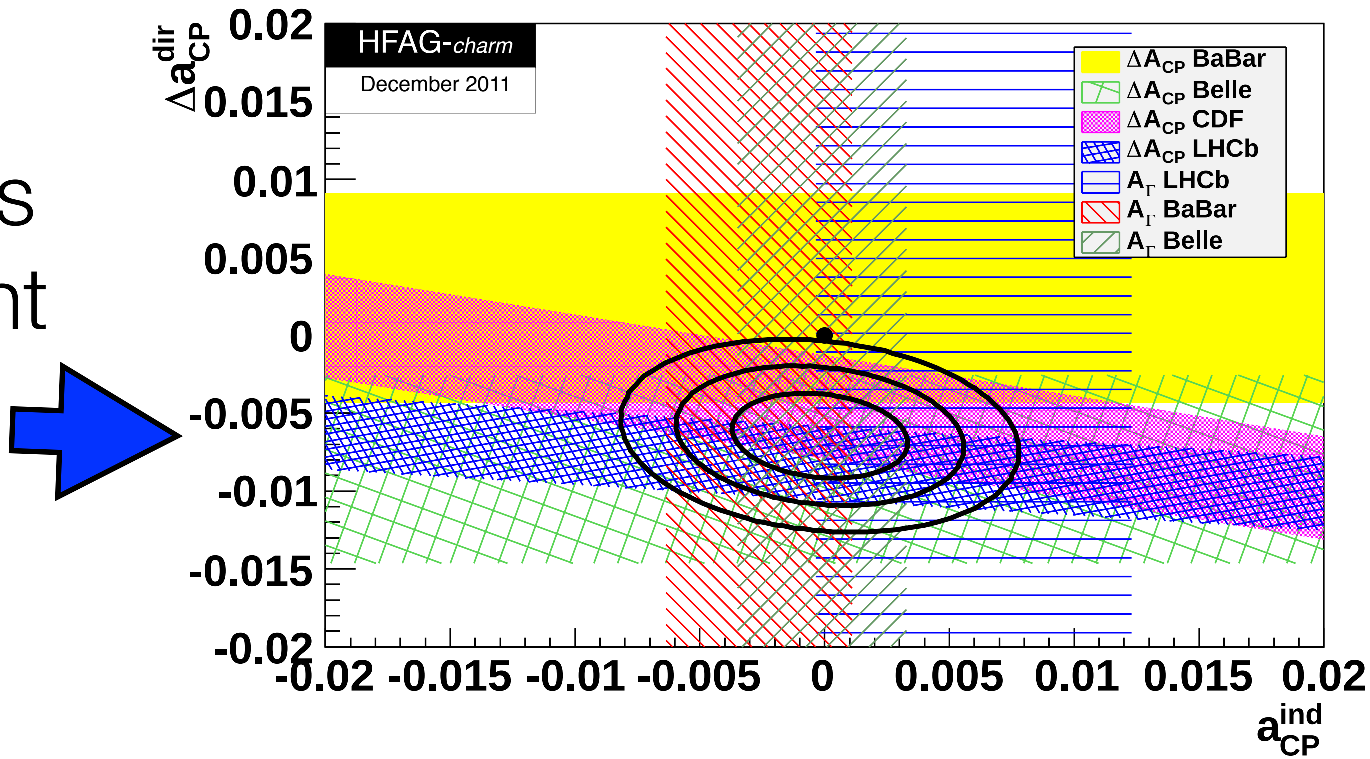
Before this measurement:

LHCb's result superimposed, not included:



Direct CPV in D→KK, D→ππ: Result

Average including this measurement



Combining more numbers

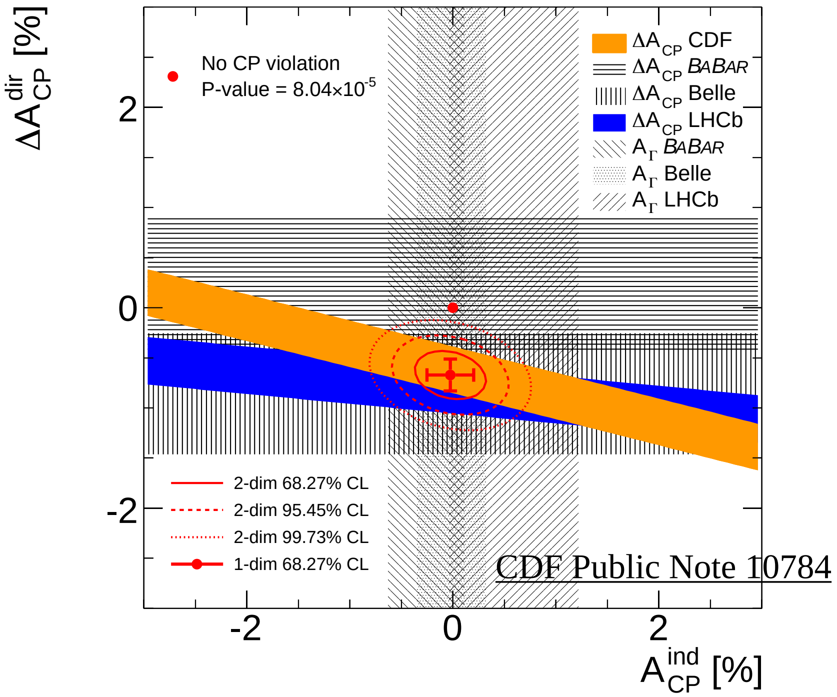
See also Guennadi Borissov's talk earlier today

- CDF have recently published a similar result:
  ΔA_{CP} (CDF) = (-0.62 ± 0.21 ± 0.10)% CDF Public Note 10784
  ΔA_{CP} (LHCb) = (-0.82 ± 0.21 ± 0.11)% (ca ½ the data on tape)

world average (by CDF):

ΔA_{CP}^{dir} = (-0.67 ± 0.16)%

(3.8σ from 0)



Reactions

Clearly larger than the widely assumed SM level of up to 10^{-3}
Is this therefore NP?

arXiv:1202.3795: Repercussions of Flavour Symmetry Breaking on CP Violation in D-Meson Decays (Feldmann, Nandi, Soni)
arXiv:1202.5038: On the Universality of CP Violation in Delta F = 1 Processes (Gedalia, Kamenik, Ligeti, Perez)
arXiv:1202.3300: CP violation in D0 -> K+K-, pi+pi- from diquarks(Chen, Geng, Wang)
arXiv:1202.2866: New Physics Models of Direct CP Violation in Charm Decays (Altmannshofer, Primulando, Yu, Yu)
arXiv:1201.6204: Direct CP violation in charm and flavor mixing beyond the SM (Giudice, Isidori, Paradisi)
arXiv:1201.2565: LHCb Delta A_CP of D meson and R-Parity Violation (Chang, Du, Liu, Lu, Yang)
arXiv:1201.2351: CP asymmetries in singly-Cabibbo-suppressed D decays to two pseudoscalar mesons (Bhattacharya, Gronau, Rosner)
arXiv:1201.0785: Direct CP violation in two-body hadronic charmed meson decays (Cheng, Chiang)
arXiv:1112.5268: Relating direct CP violation in D decays and the forward-backward asymmetry in ttbar production (Hochberg, Nir)
arXiv:1112.5451: CP Violation and Flavor SU(3) Breaking in D-meson Decays (Pirtskhalava, Uttayarat)
arXiv:1111.6949: (ΔA_{CP})_{LHCb} and the fourth generation (Rozanov, Vysotsky)
arXiv:1111.5196: Can Up FCNC solve the $ΔA_{CP}$ puzzle? (Wang, Zhu)
arXiv:1111.5000: On the size of direct CP violation in singly Cabibbo-suppressed D decays (Brod, Kagan, Zupan)
arXiv:1111.4987: Implications of the LHCb Evidence for Charm CP Violation (Isidori, Kamenik, Ligeti, Perez)
hep-ph/0609178: New Physics and CP Violation in Singly Cabibbo Suppressed D Decays (Grossman, Kagan, Nir)

Alexander Lenz, yesterday, about Christmas:

LHCb

Theorist

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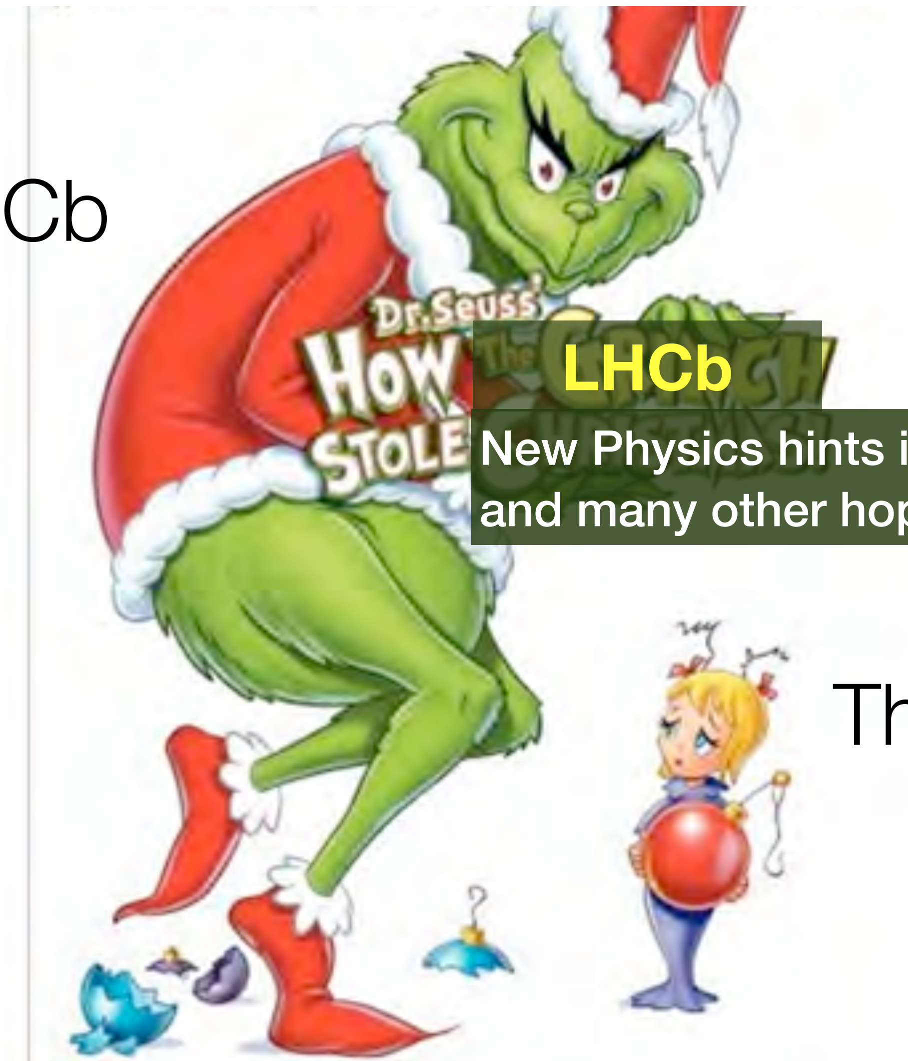
LHCb



LHCb

New Physics hints in B_s mixing and many other hopes for NP.

Theorist

What happend later that Christmas:

quote from: Thorsten Feldmann, Soumitra Nandi, Amarjit Soni: “Repercussions of Flavour Symmetry Breaking on CP Violation in D-Meson Decays”, arXiv:1202.3795v1, Feb 2012

What happend later that Christmas:

Ebenezer Scrooge in A Christmas Carol, by Charles Dickens. Illustration by John Leech, 1843.

quote from: Thorsten Feldmann, Soumitra Nandi, Amarjit Soni: “Repercussions of Flavour Symmetry Breaking on CP Violation in D-Meson Decays”, arXiv:1202.3795v1, Feb 2012

What happend later that Christmas:

Bah Humbug!

Ebenezer Scrooge in A Christmas Carol, by Charles Dickens. Illustration by John Leech, 1843.

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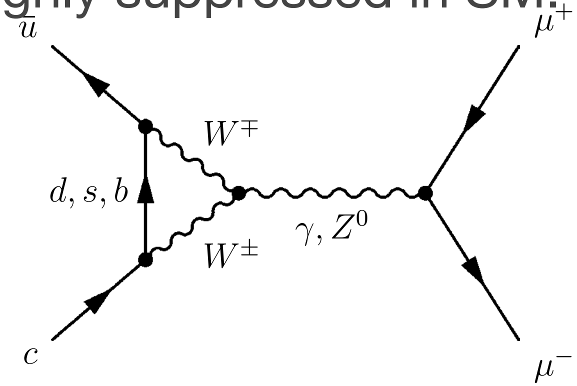
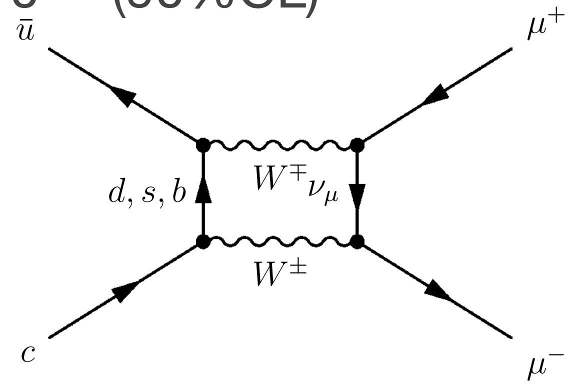
Rare decays: D→μμ

- Highly suppressed in SM. BF< $6\cdot10^{-11}$ (90%CL)





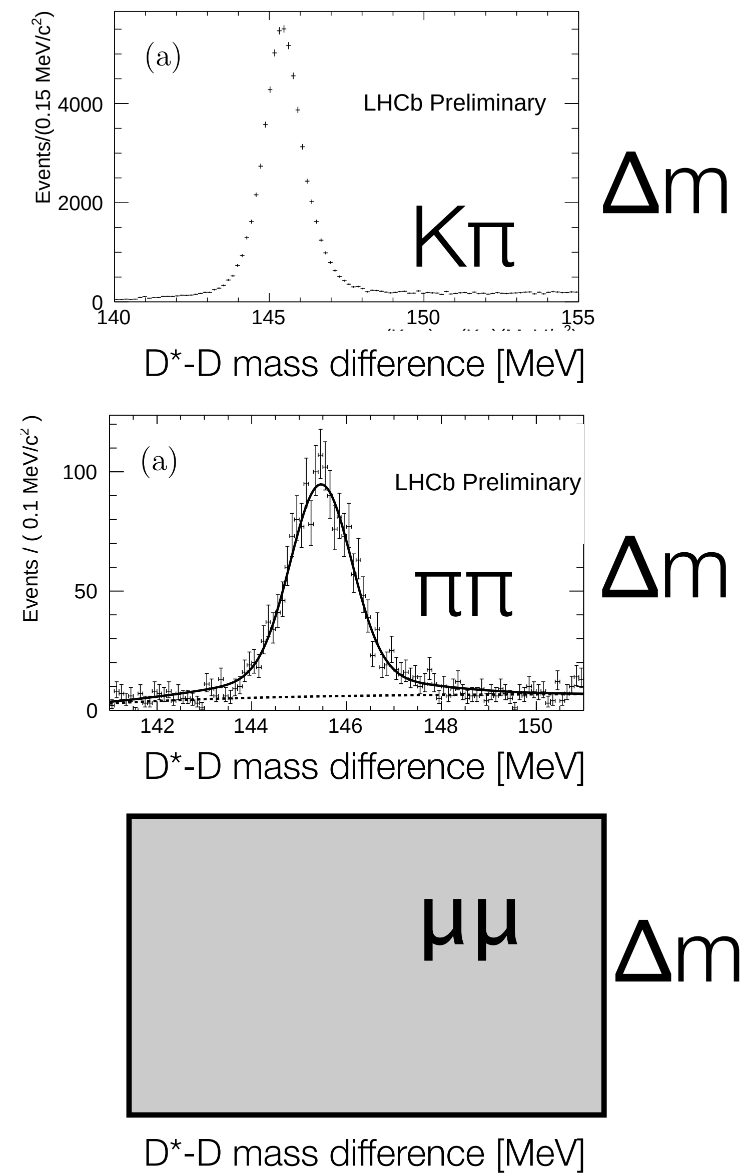
- Several orders of magnitude enhancements possible in NP models such as $\not{R}$ SUSY*

See J. Angel Hernando Morata's talk yesterday evening for our latest SUSY-challenging results on rare B decays

* G. Burdman, E. Golowich, J. L. Hewett, and S. Pakvasa, Phys. Rev. D66 (2002) 014009, arXiv:hep-ph/0112235.
G. Burdman and I. Shipsey, Ann. Rev. Nucl. Part. Sci. 53 (2003) 431–499, arXiv:hep-ph/0310076.

Rare decays: D→μμ

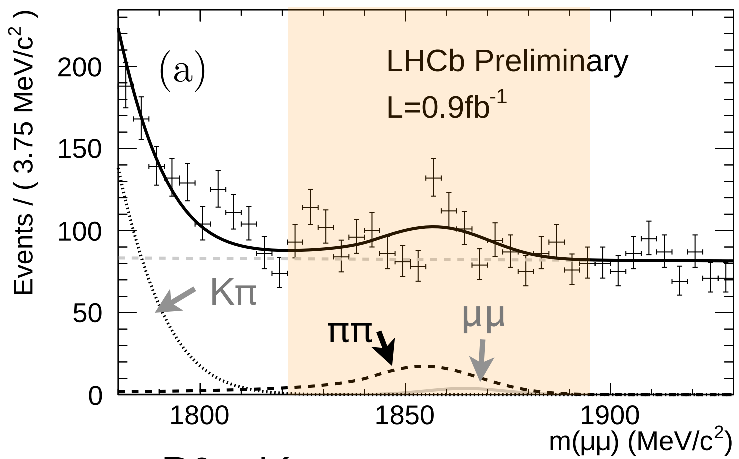
- Strategy: Search for D→μμ in D*→D(μμ) π. “D* trick” gives very clean data samples.
- Use D→ππ from D*→D(ππ)π as normalisation mode - same kinematics.
- Use clean and extremely prolific D*→D(Kπ)π for a variety of cross checks, including μ/π mis-ID



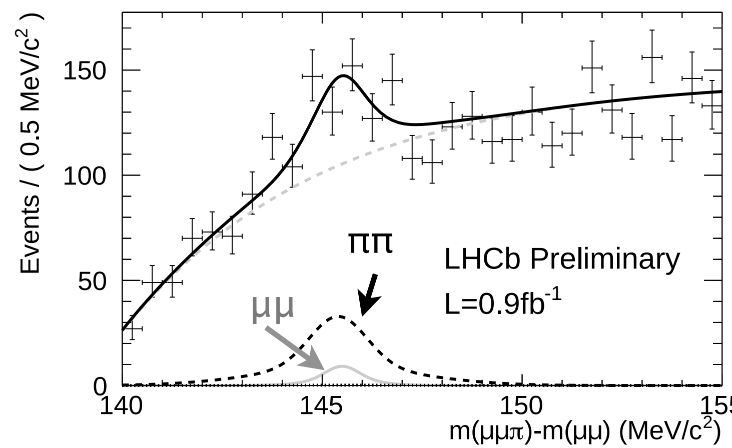
new result

Rare decays: $D\to\mu\mu$ LHCb 0.9/fb:

m(μμ)



Δm for m(μμ)∈[1820, 1880] MeV



$D^o\to K^-\pi^+$

$D^o\to \pi^-\pi^+$

combinatorial

'μμ signal', compatible with 0

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

(compare prev best limit (BELLE*) $\mathcal{B}(D^0\to\mu^+\mu^-) < 1.4\cdot 10^{-7}$)

*) Phys. Rev. D 81, 091102(R) (2010)

Summary

- LHCb's enormous charm samples are beginning to pay off. Amongst many exciting results, for using ½ our data, we find $\Delta A_{CP} = (-0.82 \pm 0.21 \pm 0.11)\%$
- This is 3.5σ evidence of CP violation in charm. CDF confirmed this result and together we push the world average to 3.8σ. Is this New Physics?
- CPV is not the only way to study charm loops! $\mathcal{B}(D^0 \to \mu^+\mu^-) < 1.3 \cdot 10^{-8}$ at 95%CL

new result

Outlook

- Clearly need to study charm system in detail. A lot more to do for LHCb:

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  - Continue to investigate charm loops a variety of ways, such as rare decays.
- Lots of precision charm results to come. Will calculations match this precision?

Backup

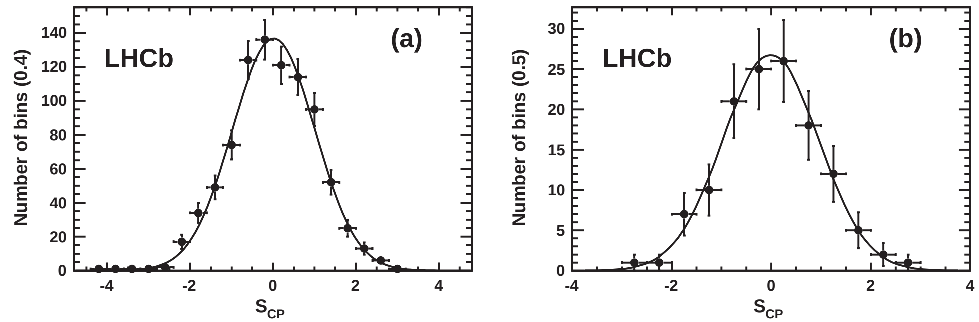


FIG. 5. (a) Distribution of $\mathcal{S}_{CP}$ values from $D^+ \to K^-\pi^+\pi^+$ from a test with 900 uniform bins. The mean of the fitted Gaussian distribution is 0.015 ± 0.034 and the width is 0.996 ± 0.023. (b) Distribution of $\mathcal{S}_{CP}$ values from $D_s^+ \to K^-K^+\pi^+$ with 129 bins. The fitted mean is -0.011 ± 0.084 and the width is 0.958 ± 0.060.

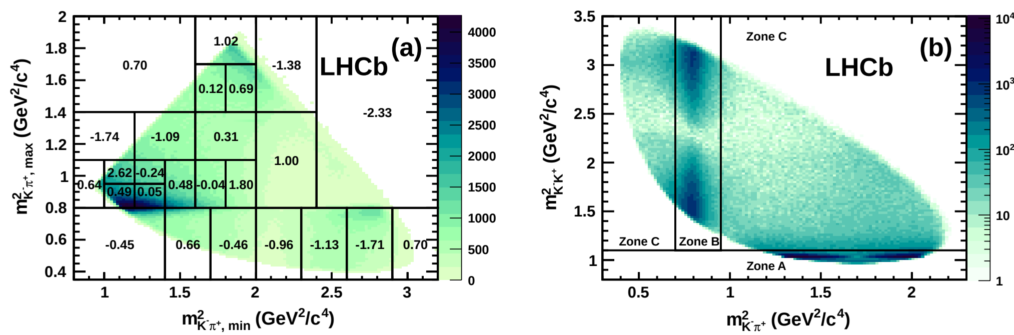


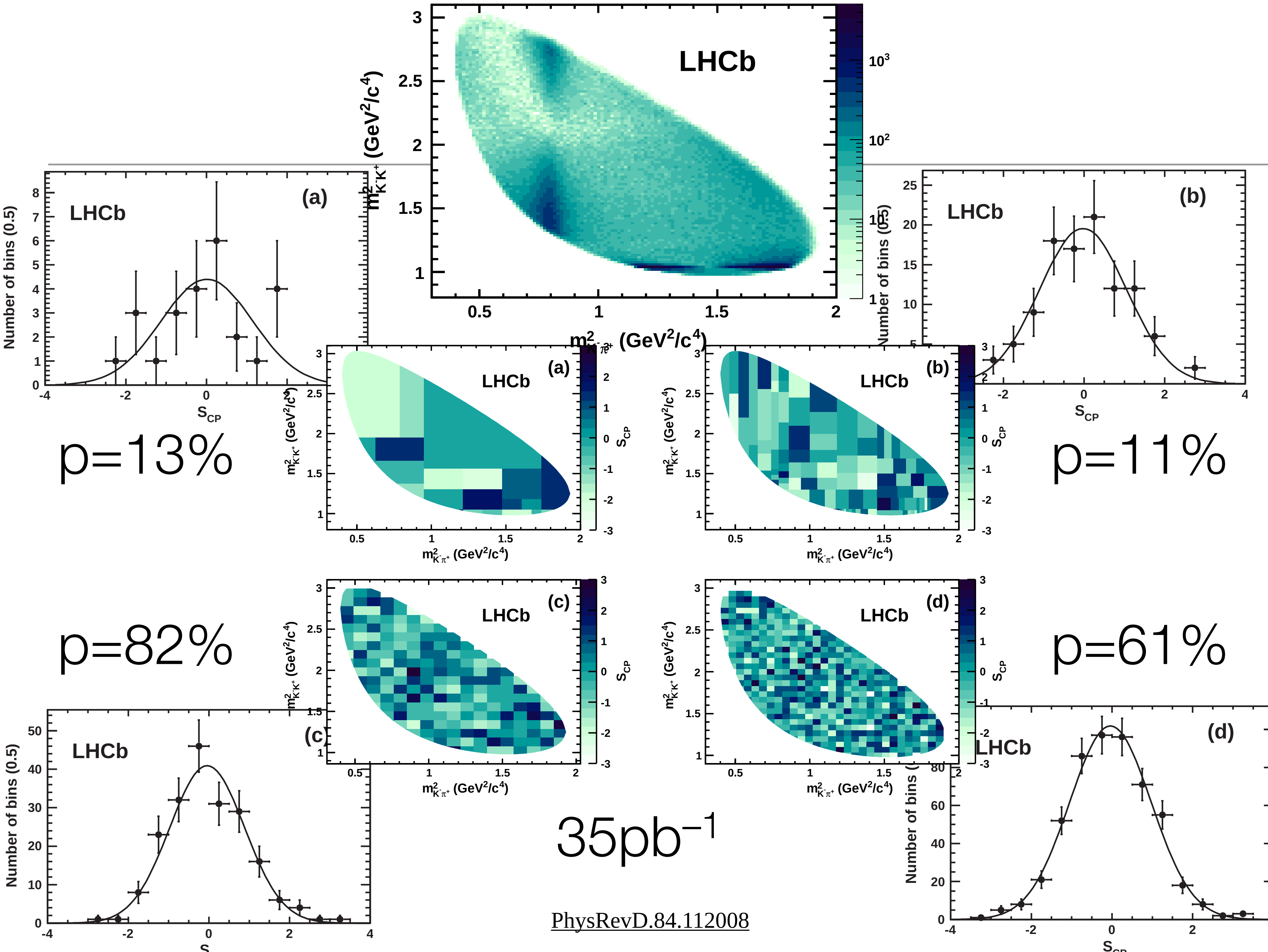
FIG. 6 (color online). Dalitz plots of (a) $D^+ \to K^-\pi^+\pi^+$, showing the 25-bin adaptive scheme with the $\mathcal{S}_{CP}$ values, and (b) $D_s^+ \to K^-K^+\pi^+$, showing the three regions referred to in the text. The higher and lower $K^-\pi^+$ invariant mass combinations are plotted in (a) as there are identical pions in the final state.

TABLE VI. Results (p-values, in %) from tests with the $D^+ \to K^-\pi^+\pi^+$ control channel using the uniform and adaptive binning schemes. The values correspond to tests performed on the whole data set in the mass windows defined in Sec. II.

	1300 bins	900 bins	400 bins	100 bins	25 bins
Uniform	73.8	17.7	72.6	54.6	1.7
Adaptive	81.7	57.4	65.8	30.0	11.8

Systematic uncertainties

- Kinematic binning: 0.02%
  - Evaluated as change in ΔA_{CP} between full 54-bin kinematic binning and "global" analysis with just one giant bin.
- Fit procedure: 0.08%
  - Evaluated as change in ΔA_{CP} between baseline and not using any fitting at all (just sideband subtraction in m for KK and modes)
- Peaking background: 0.04%
  - Evaluated with toy studies injecting peaking background with a level and asymmetry set according to D^0 mass sidebands (removing signal tails).
- Multiple candidates: 0.06%
  - Evaluated as mean change in ΔA_{CP} when removing multiple candidates, keeping only one per event chosen at random.
- Fiducial cuts: 0.01%
  - Evaluated as change in ΔA_{CP} when cuts are significantly loosened.
- Sum in quadrature: 0.11%



p=13%

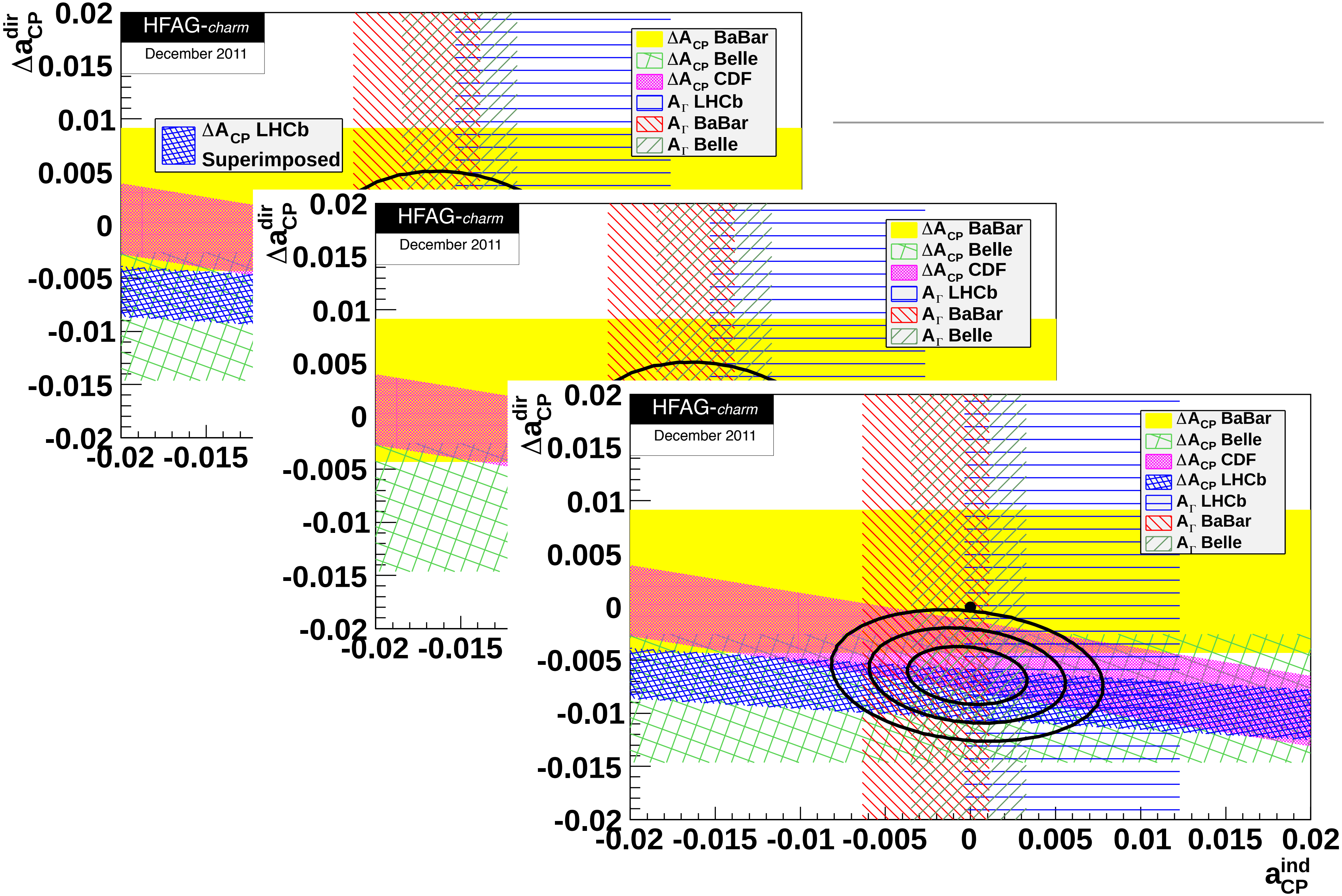
p=11%

p=82%

p=61%

$35pb^{-1}$

PhysRevD.84.112008


HFAG-charm
December 2011
ΔA_CP LHCb Superimposed
ΔA_CP BaBar
ΔA_CP Belle
ΔA_CP CDF
ΔA_CP LHCb
A_Γ LHCb
A_Γ BaBar
A_Γ Belle
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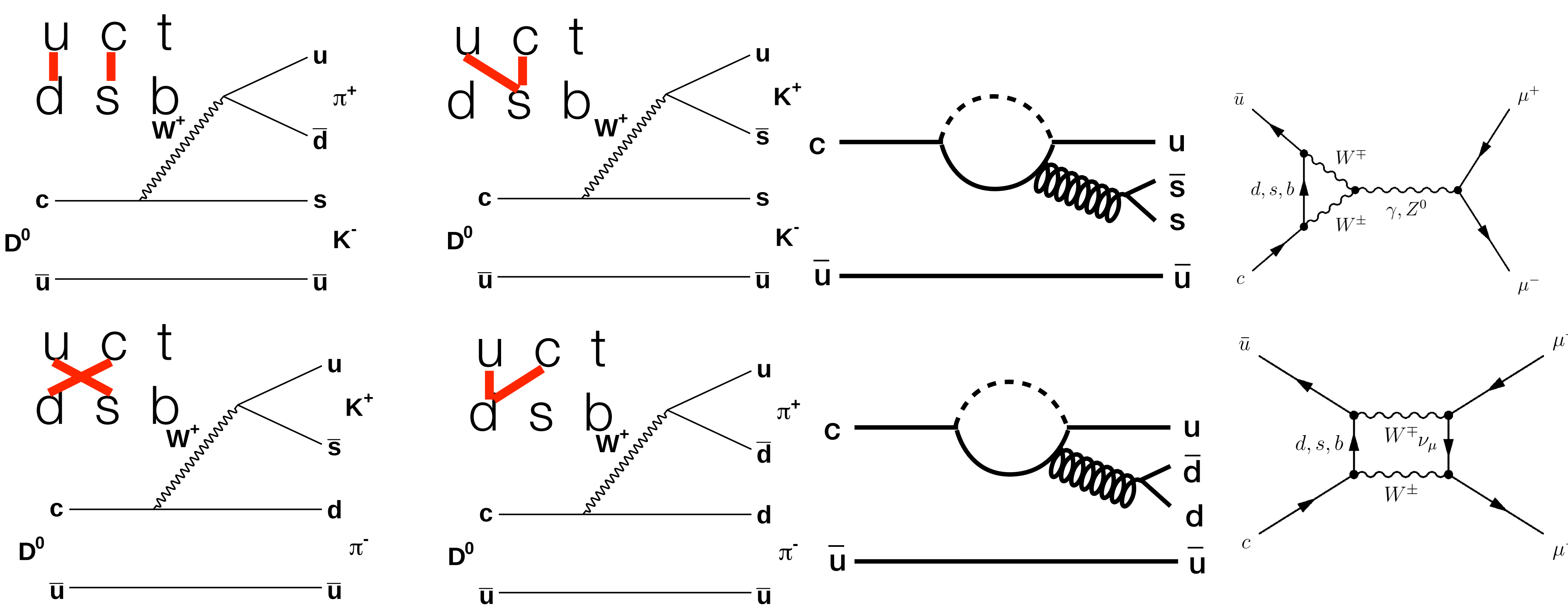
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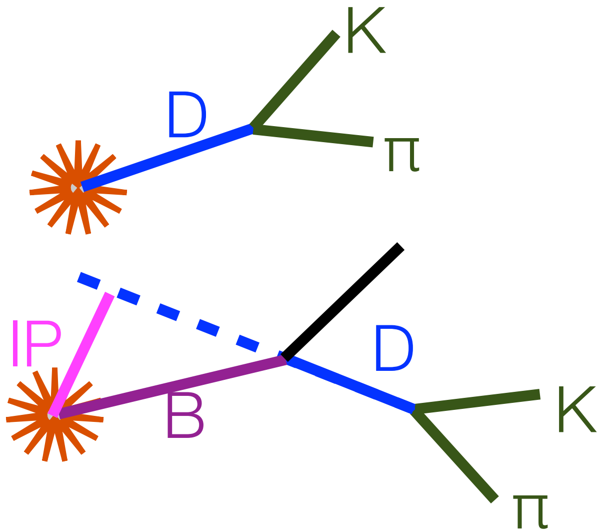
Time-dependent charm at LHCb: y_{CP}

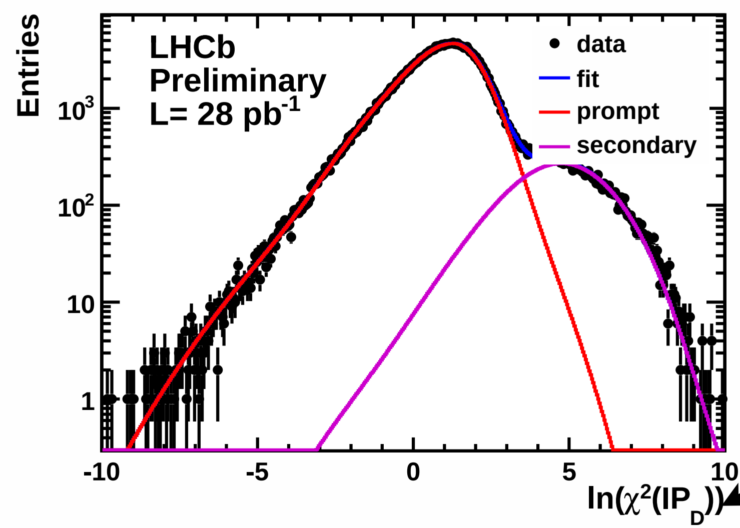
arXiv:1112.4698 [hep-ex] (submitted to JHEP)

- Define
$$y_{CP} \equiv \frac{\tau\left(D^0 \to K^-\pi^+\right)}{\tau\left(D^0 \to KK\right)} - 1$$
$$= y\cos\phi - \frac{1}{2}\left(\left|\frac{q}{p}\right| - \left|\frac{p}{q}\right|\right) x\sin\phi$$
(or any other CP eigenstate such as ππ)

- W/o CP violation (and to 1st order even with CPV): $y_{CP} = y$

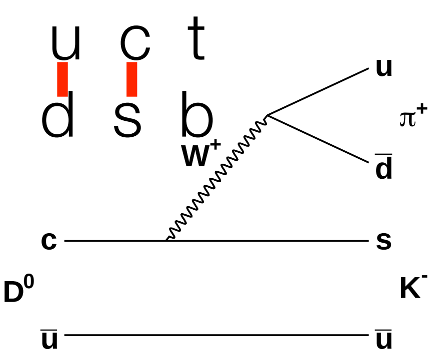
Challenge 1: prompt/secondary separation



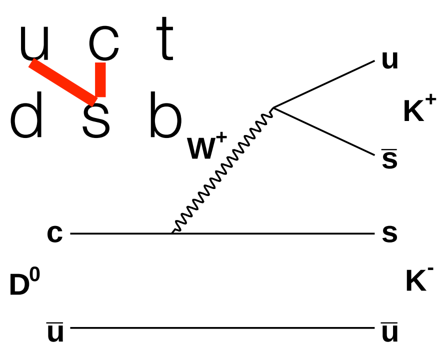


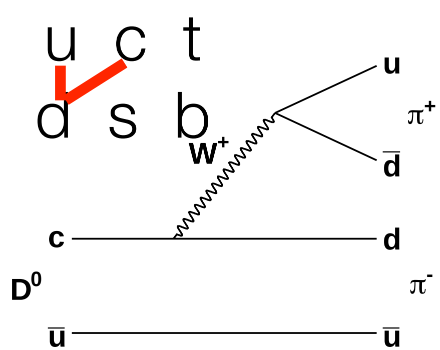
effectively log(IP significiance)

Cabbibo favoured (CF)

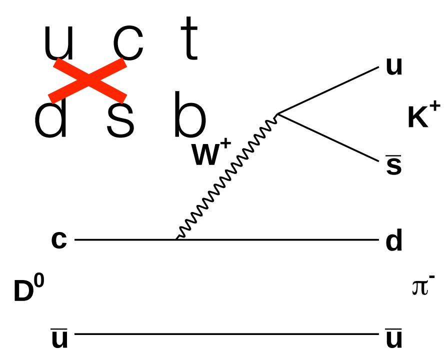


Singly Cabibbo Supressed (SCS)

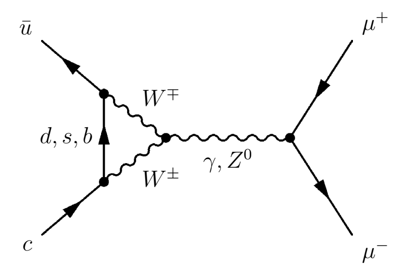


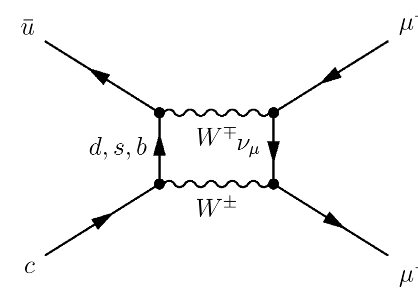


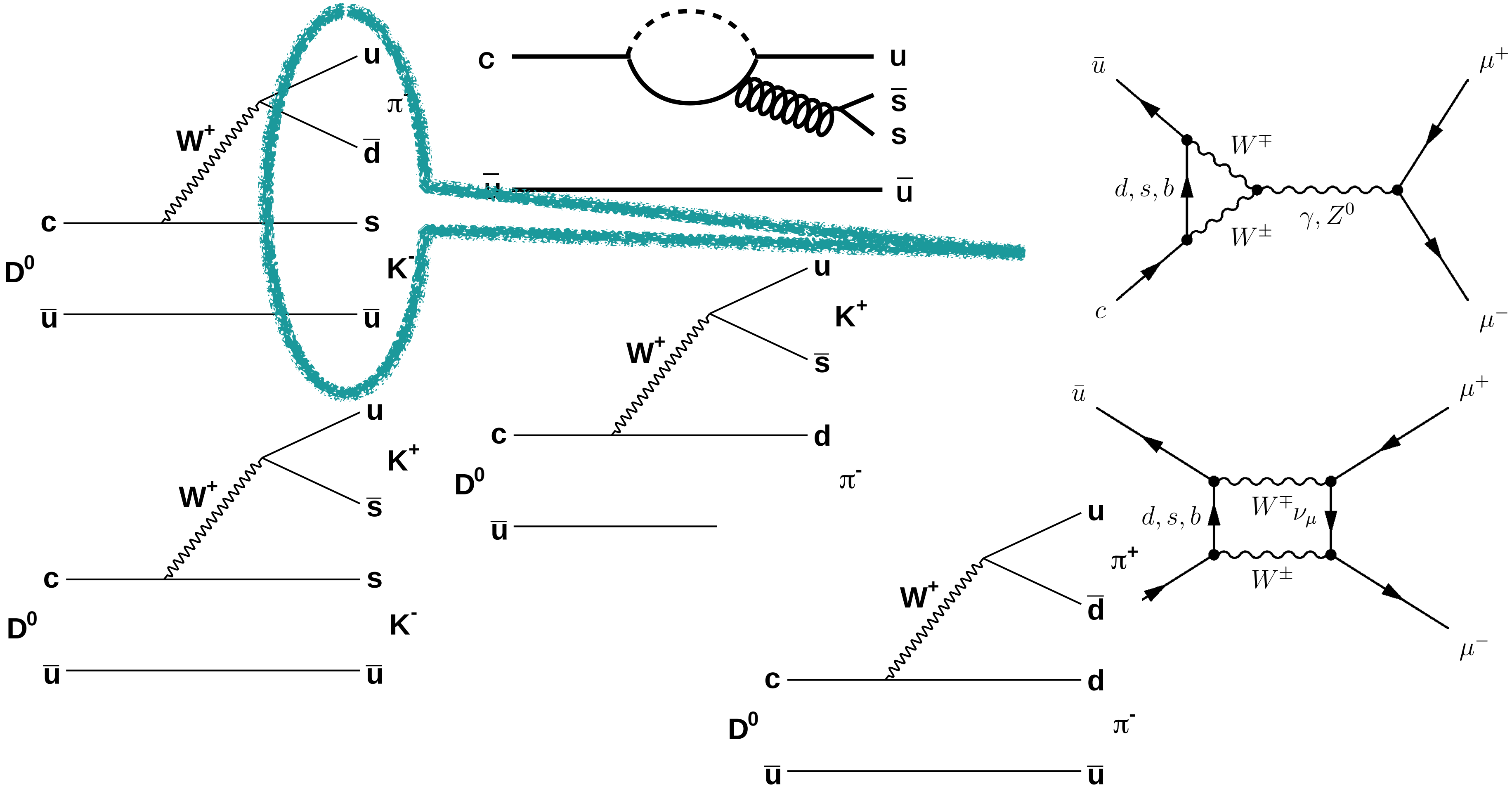
Doubly Cabibbo Supressed (DCS)



Near Impossible (rare)







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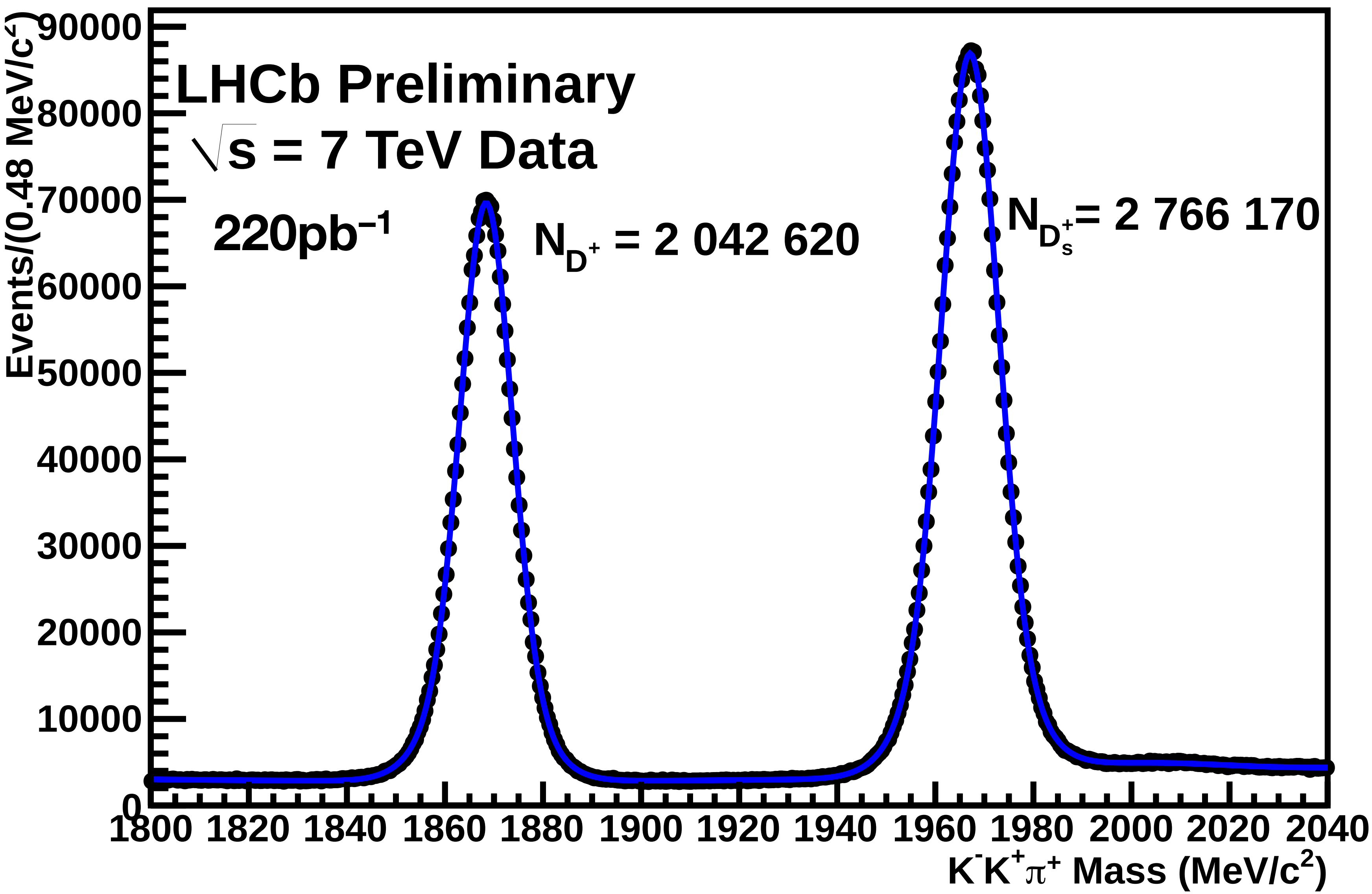
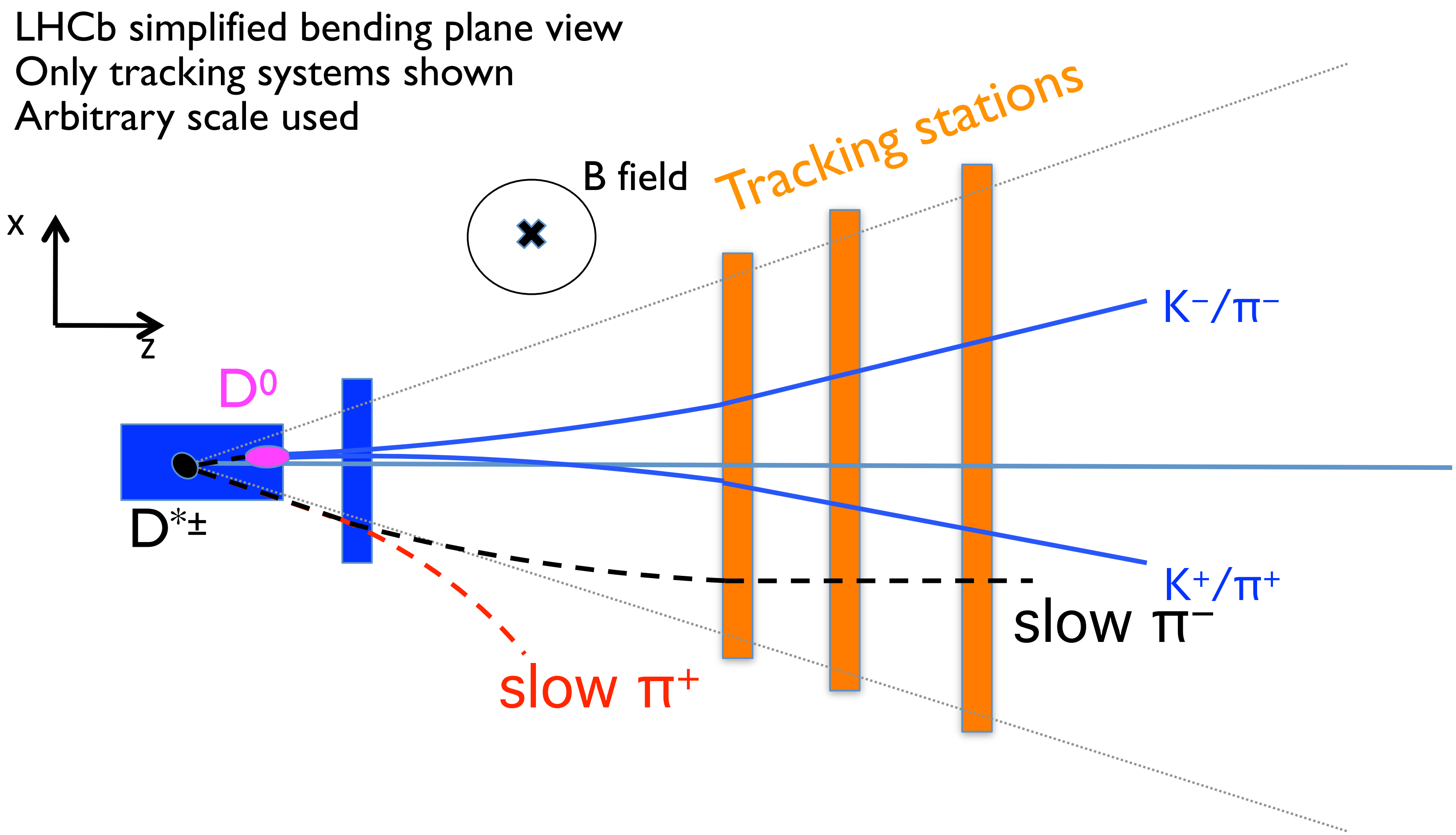
$W^\pm$
μ^-

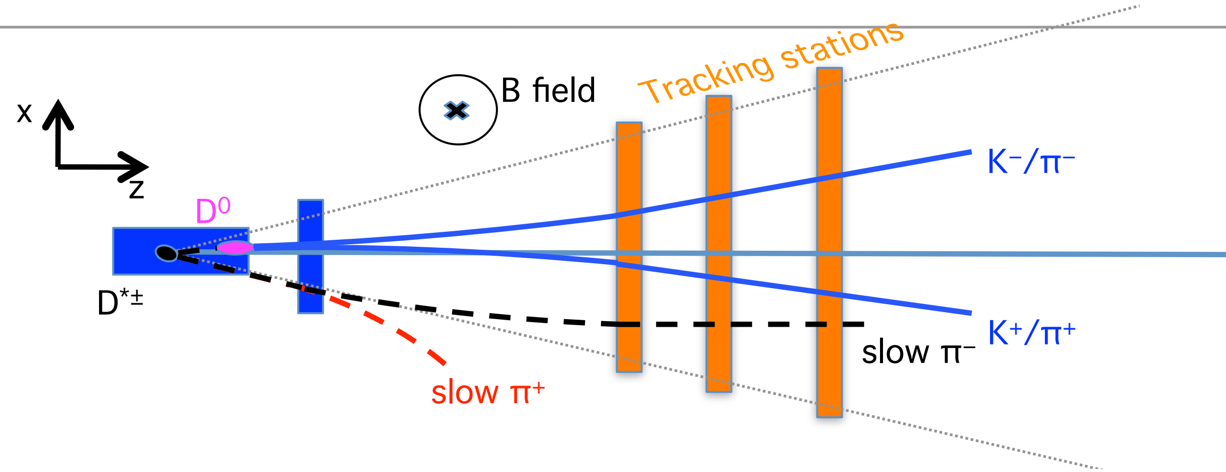
Searches for direct CPV in Dalitz plots: More to come!



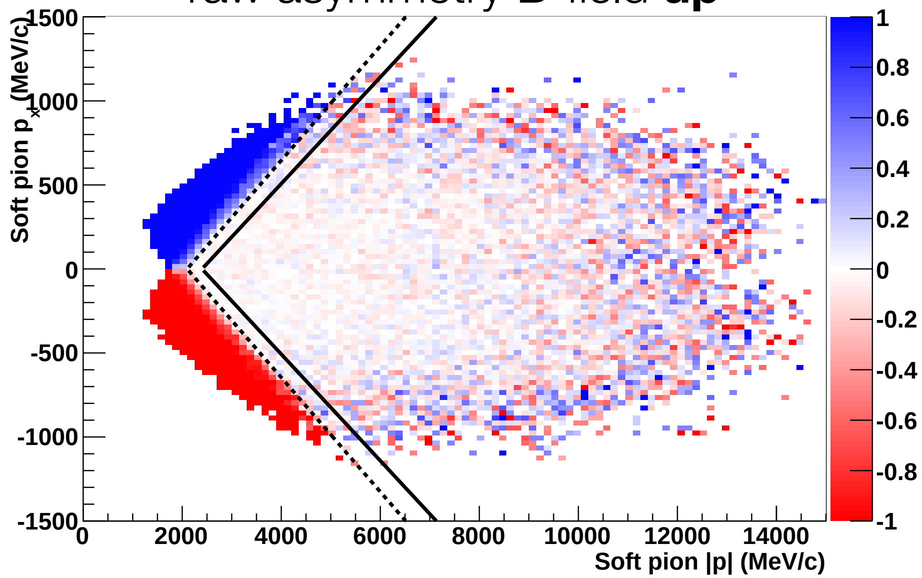
Direct CPV in D→KK, D→ππ: fiducial cuts



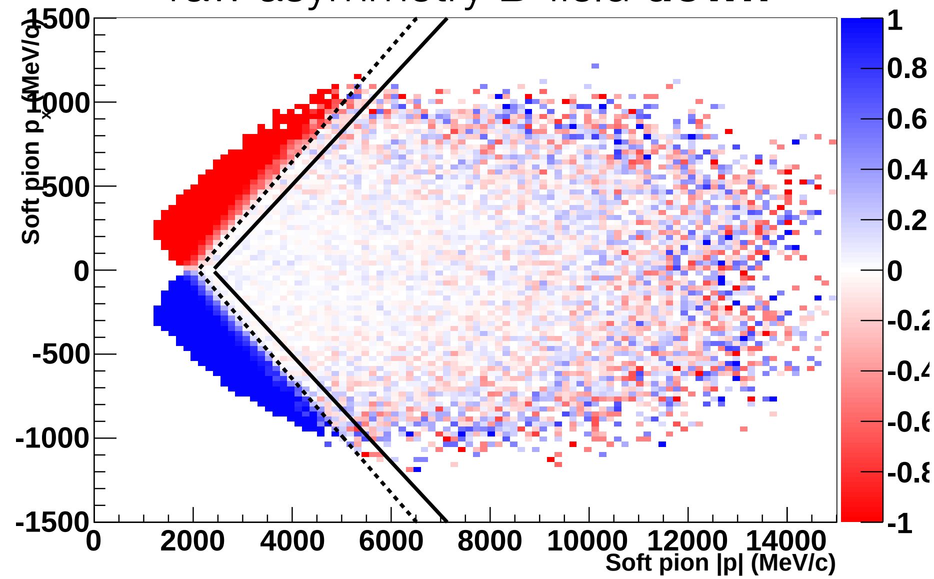
Direct CPV in D→KK, D→ππ: fiducial cuts



raw asymmetry B-field **up**



raw asymmetry B-field **down**



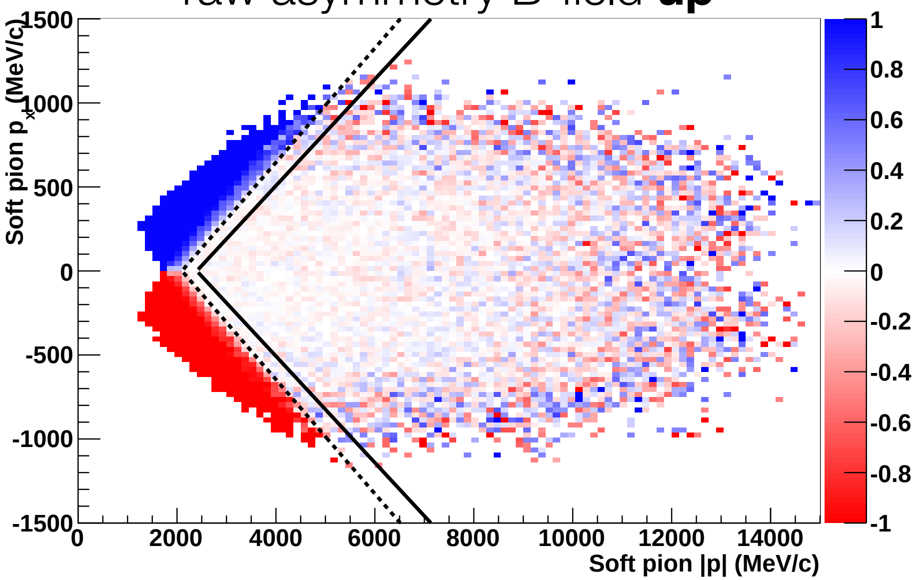
arXiv:1112.0938 [hep-ex]

Direct CPV in D→KK, D→ππ: fiducial cuts

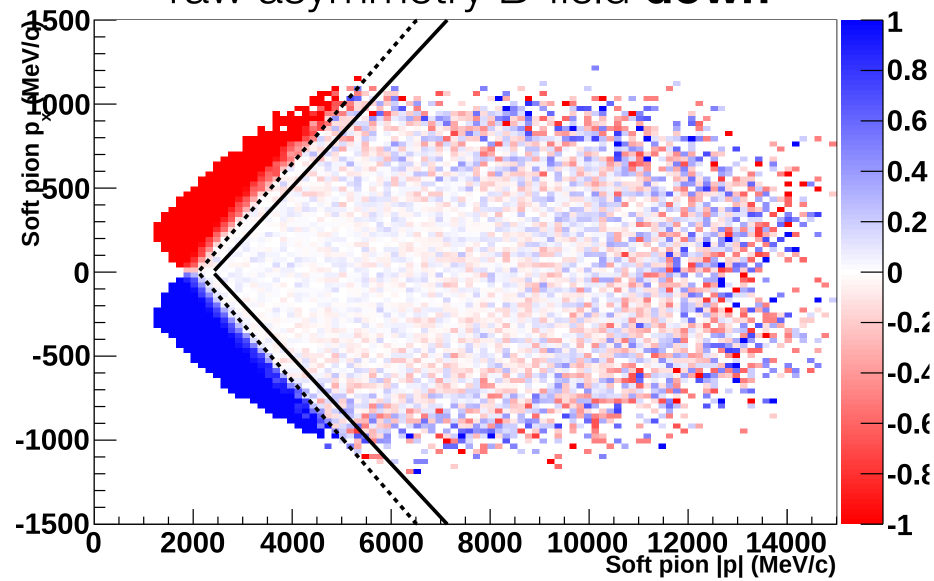
In this analysis, detection asymmetries cancel. For formalism to work, and to be save against 2nd order effects, we want to make sure that those cancelling asymmetries are themselves *small* - therefore we apply fiducial cuts.

slow π⁺

raw asymmetry B-field **up**

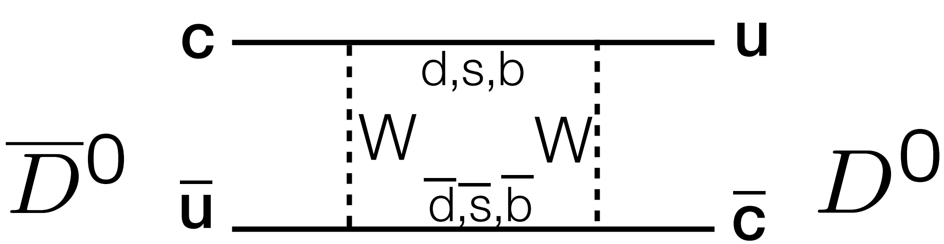


raw asymmetry B-field **down**

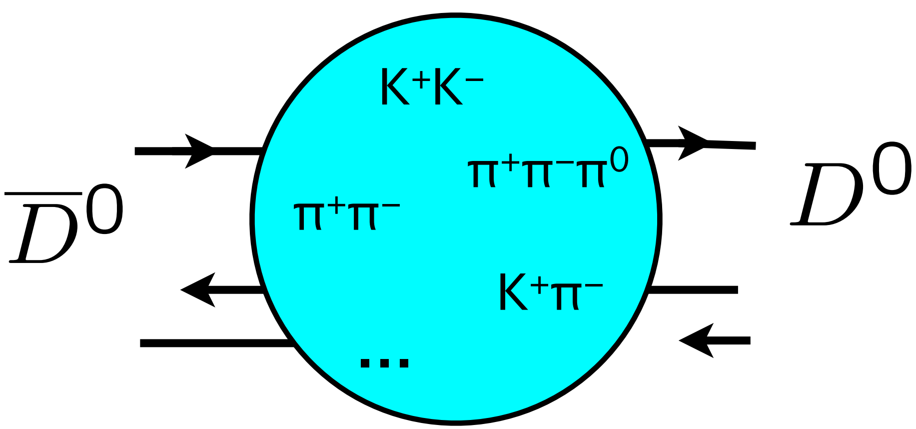


arXiv:1112.0938 [hep-ex]

Mixing



Loop mediated – new CPV phases could enter here.



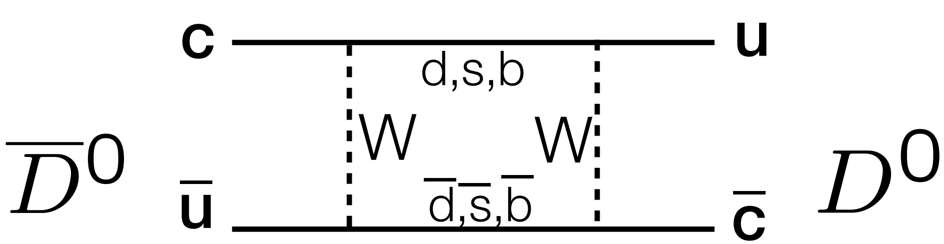
long-distance effects important but are difficult to calculate

- Two mass eigenstates (= CP eigenstates if no CPV)

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

- Δm = mass difference between mass eigenstates ~ mixing frequency. x = Δm/Γ
- ΔΓ = width difference. y = ½ ΔΓ/Γ

Mixing



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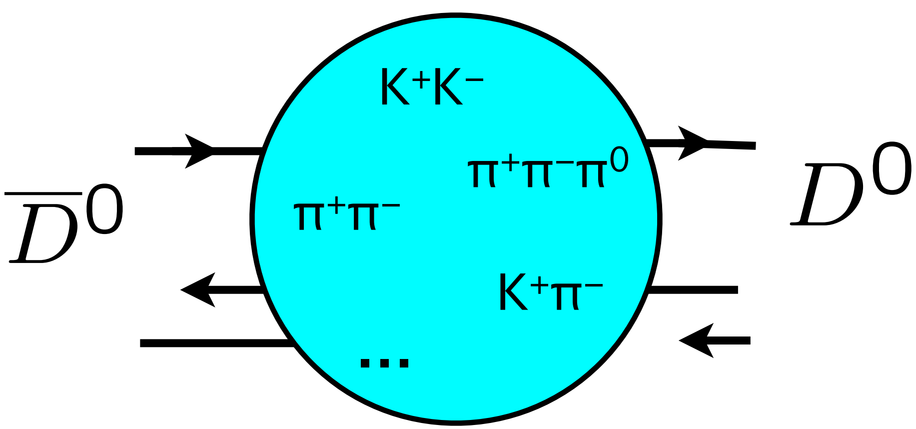

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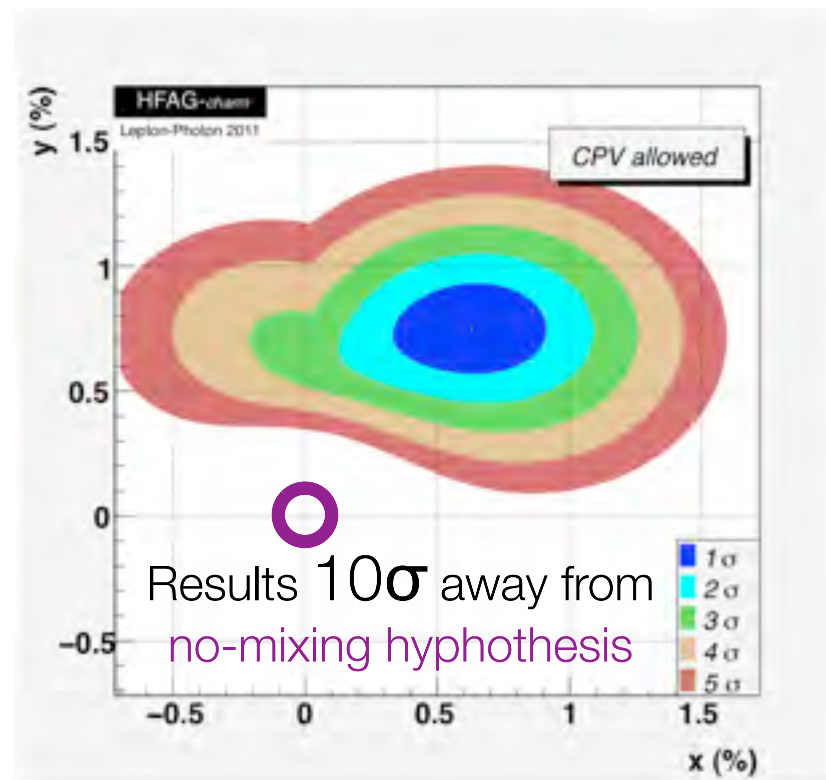


- Δm = mass difference between mass eigenstates ~ mixing frequency. $x = \Delta m/\Gamma$
- ΔΓ = width difference. $y = ½\ \Delta\Gamma/\Gamma$

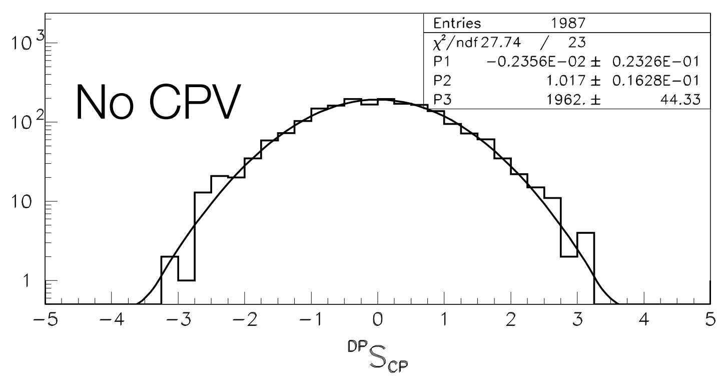
Searches for direct CPV in Dalitz plots

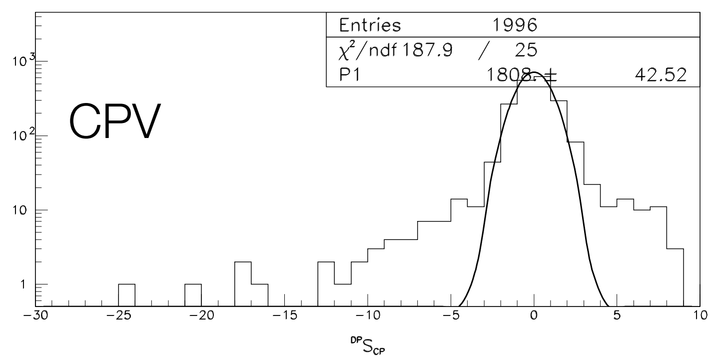
- Divide Dalitz plots into CP-conjugate bins

Bediaga et al, Phys.Rev.D80:096006,2009

$$S_{CP} = \frac{N_i - \alpha \bar{N}_i}{\sqrt{N_i + \alpha^2 \bar{N}_i}} \qquad \alpha = \frac{N_{\text{total}}}{\bar{N}_{\text{total}}}$$

- Plot this for all bins - expect Gaussian of width 1, centred at 0:



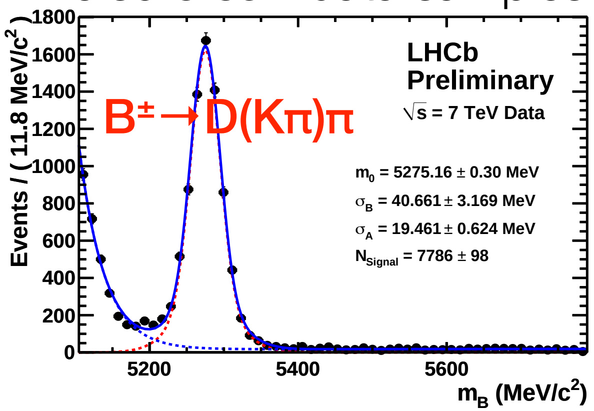


- Model independent. Overall production and detection asymmetries cancel (although some differences depending on kinematics can remain).

Plots = Simulation from Bediaga et al, Phys.Rev.D80:096006,2009

LHCb Myths-Buster

Hadron collider flavour physics can not only provide huge, but also **clean** data samples



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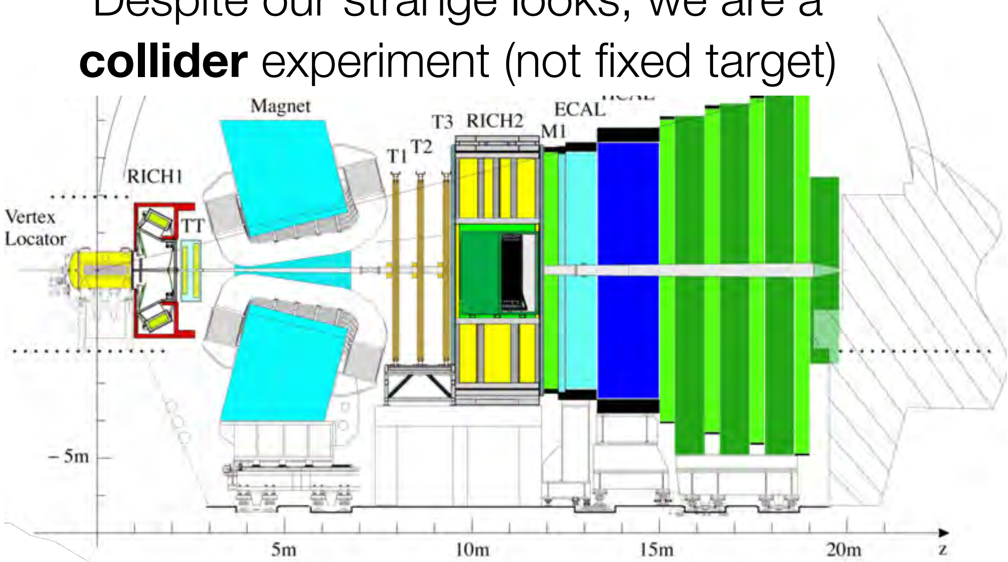

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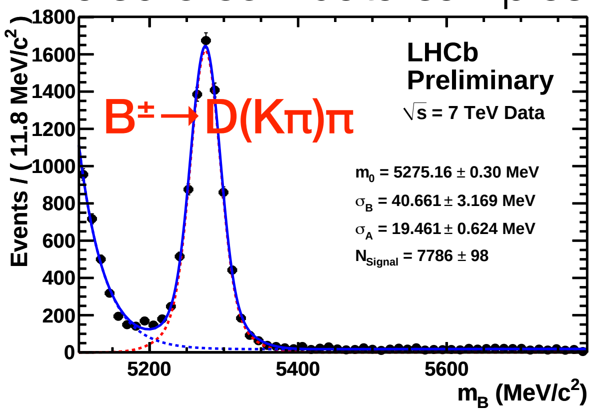

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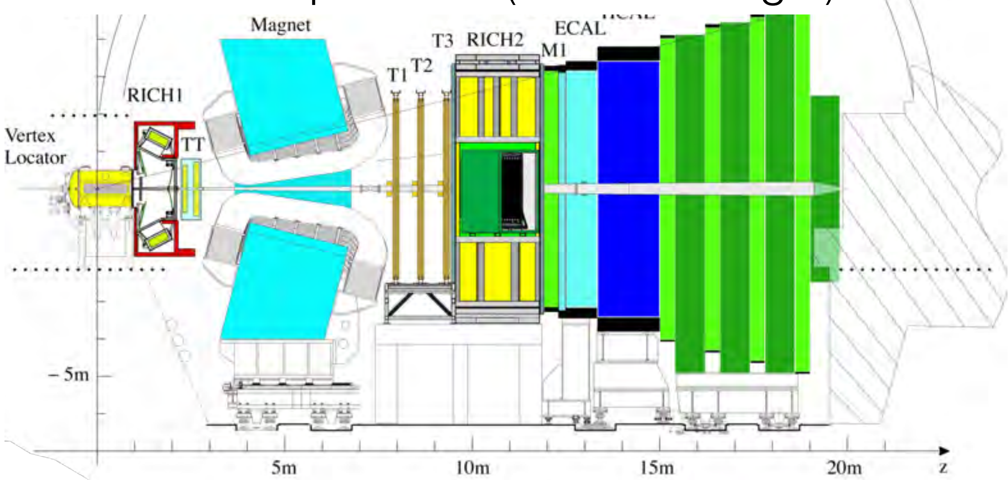

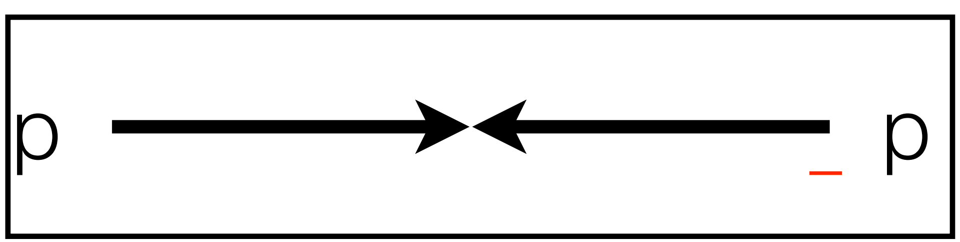

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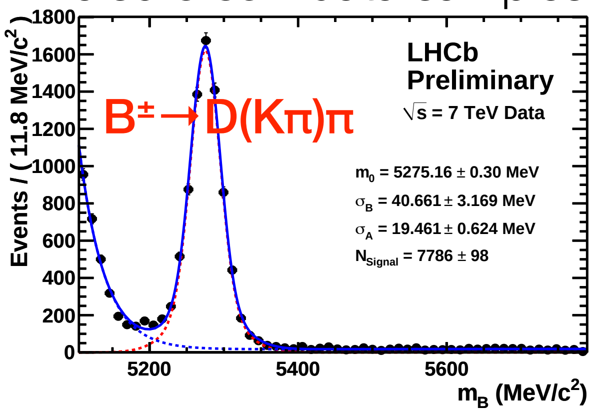

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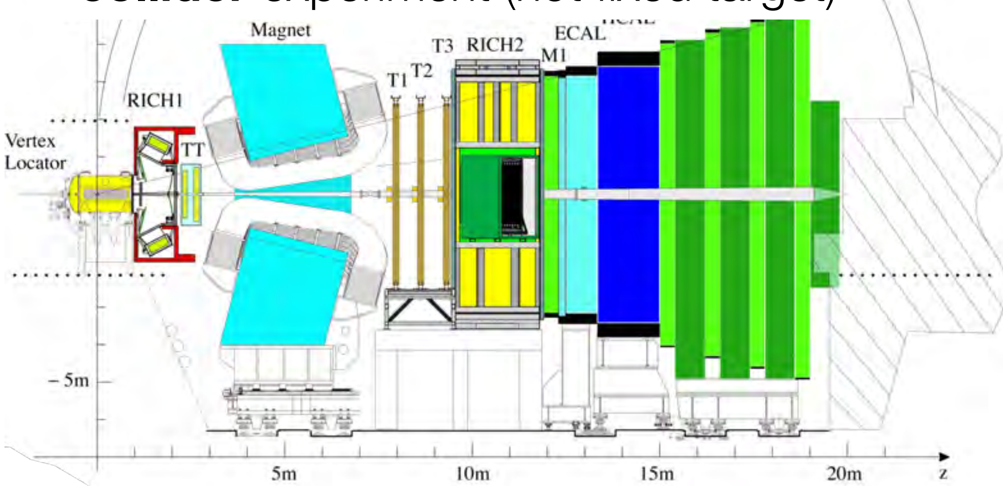

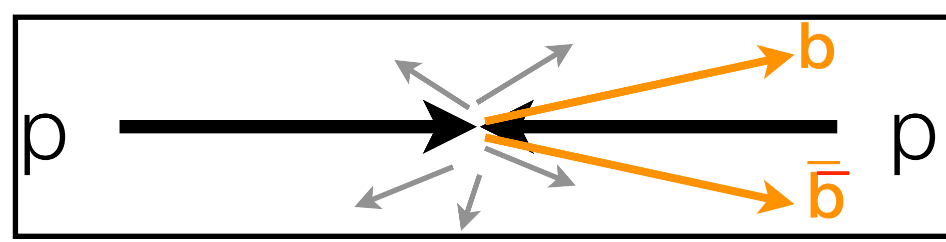

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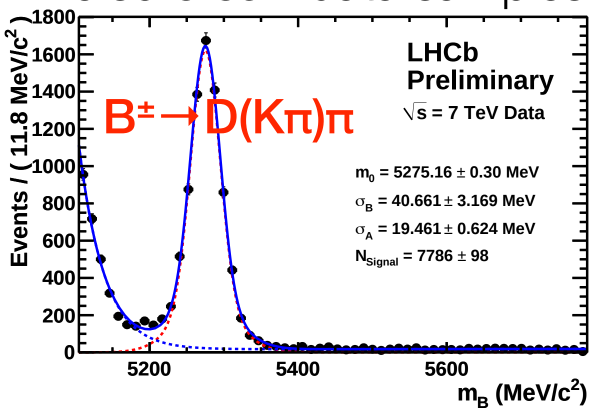

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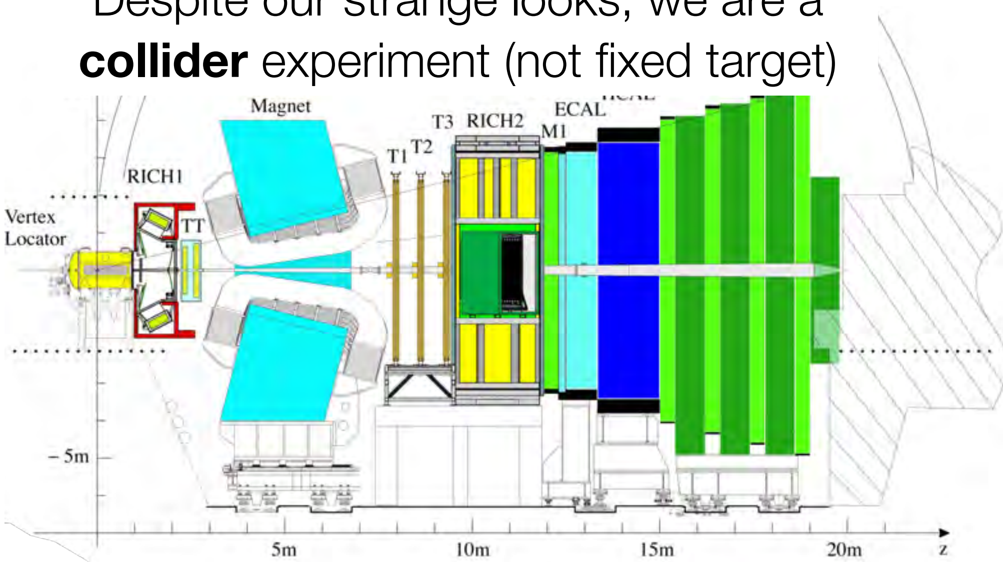

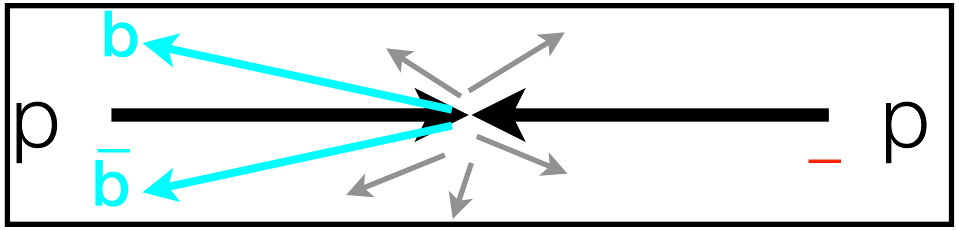

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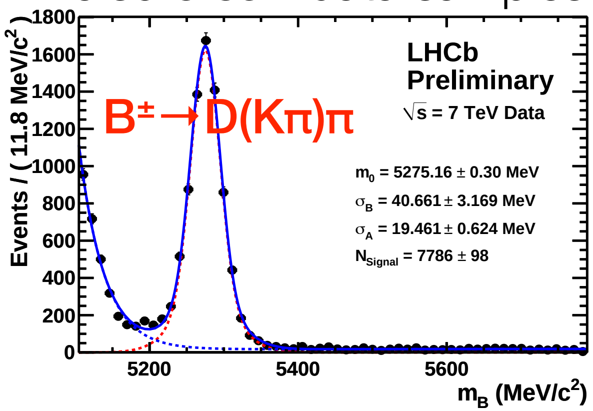

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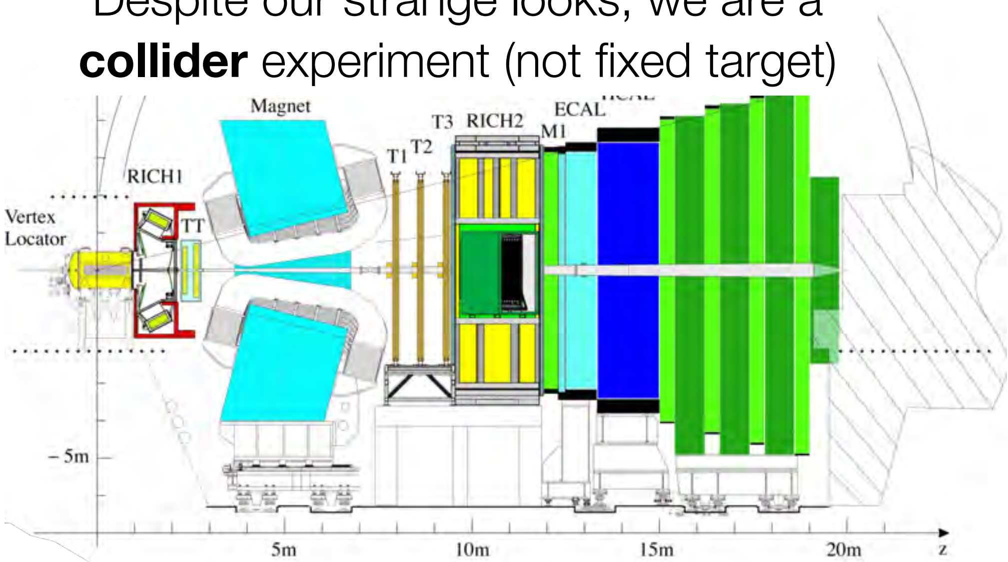

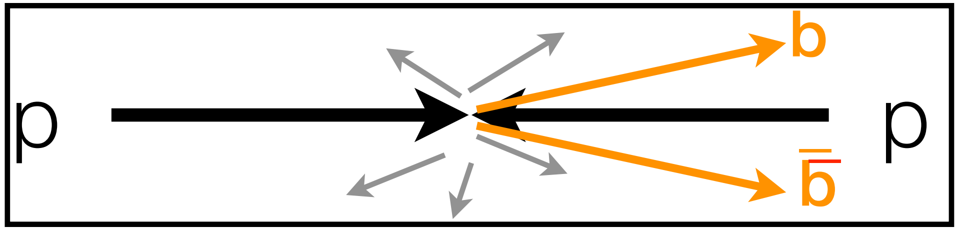

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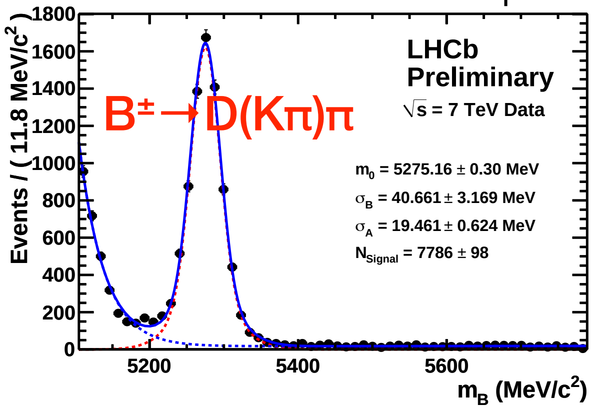

B-physics experiment?

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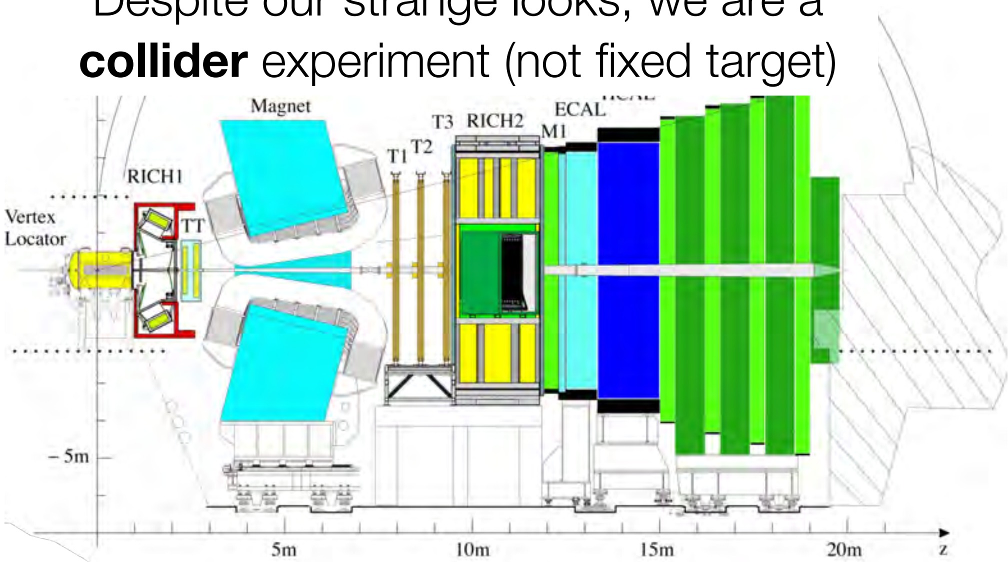

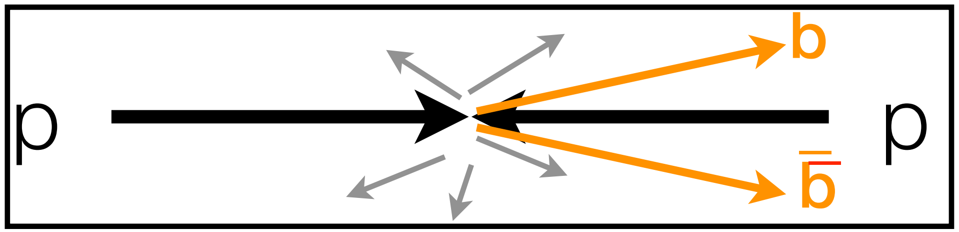

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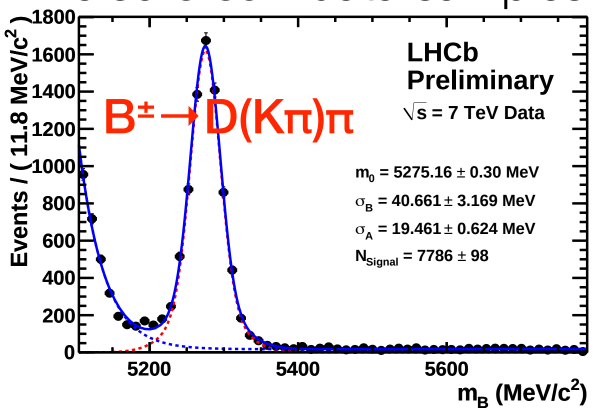

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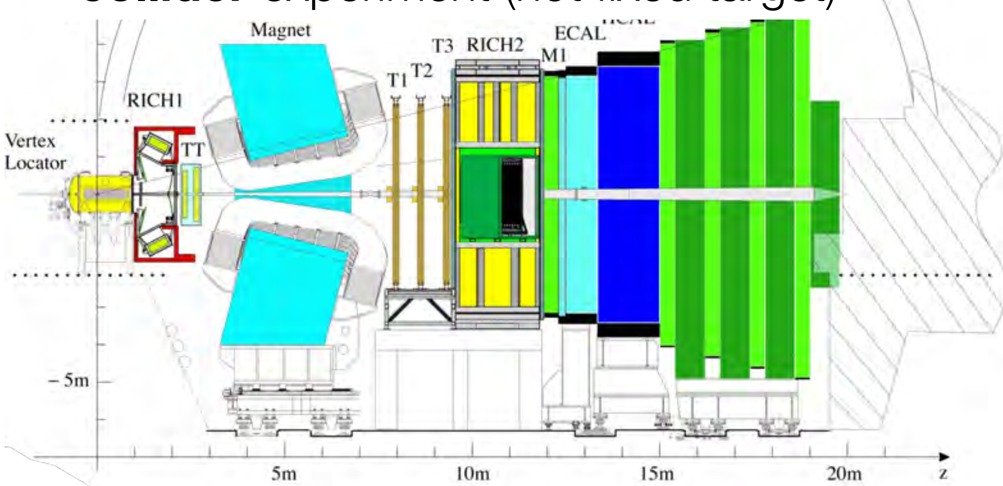

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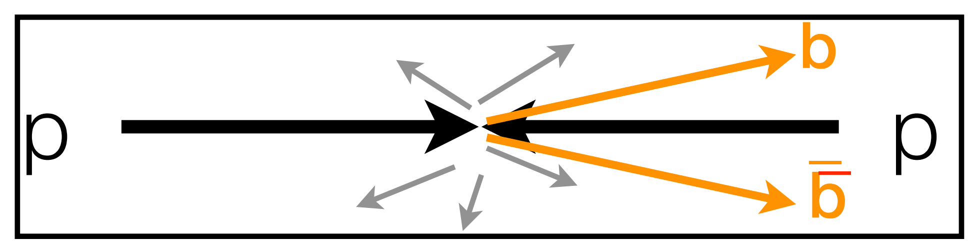

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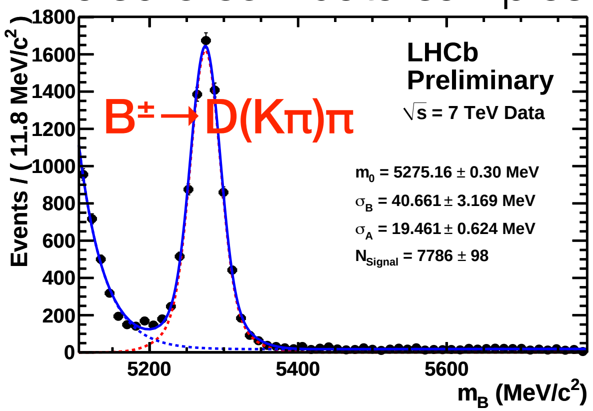

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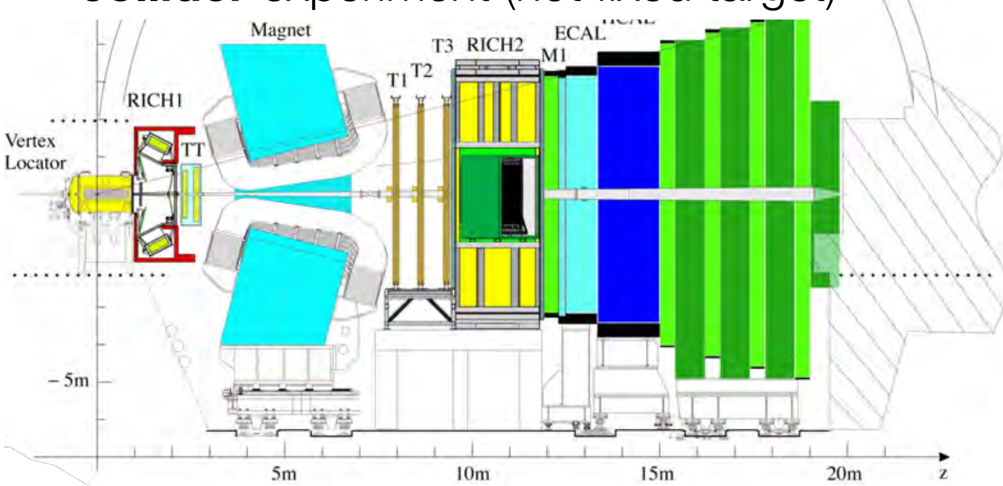

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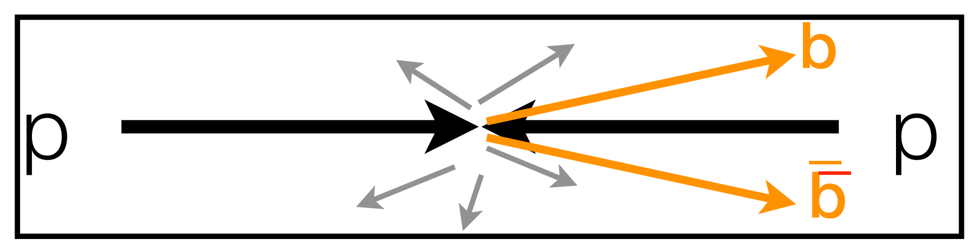
- charm x-section ≈ 20× b cross section
- Most features that optimise the experiment for b, are also very powerful for charm (RICH, IP resolution, hadronic trigger, ...)



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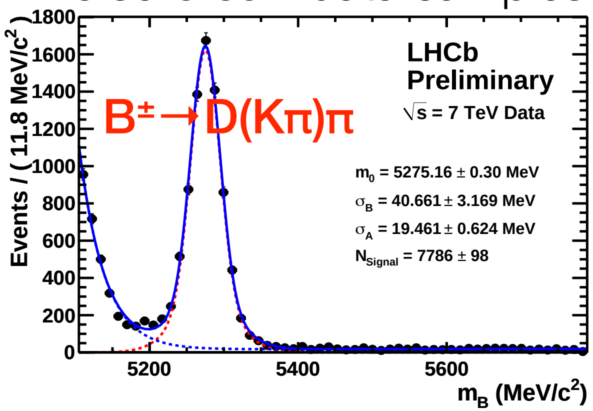

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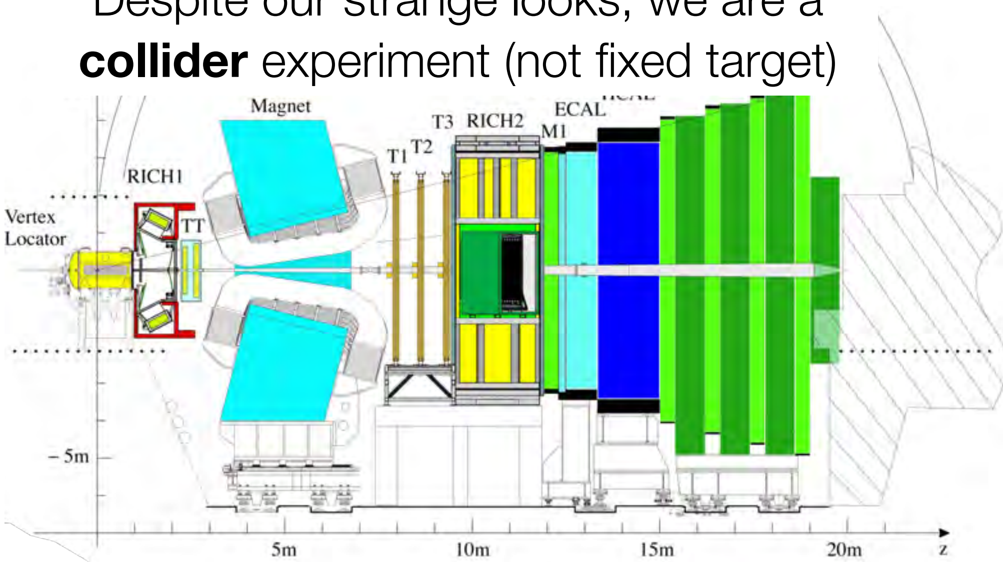

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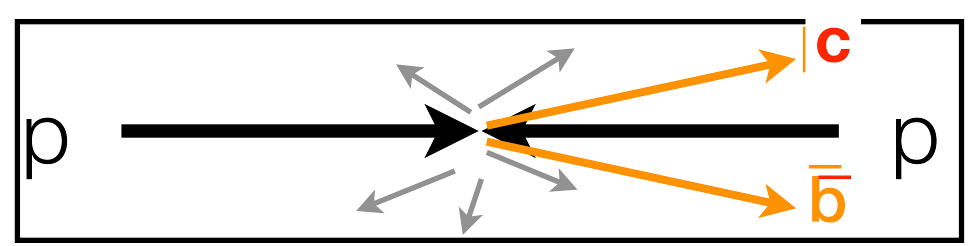

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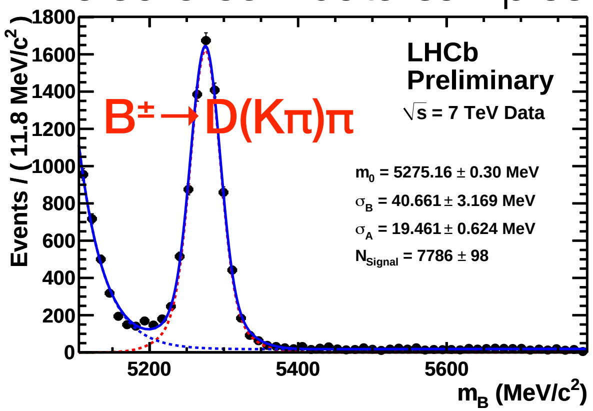

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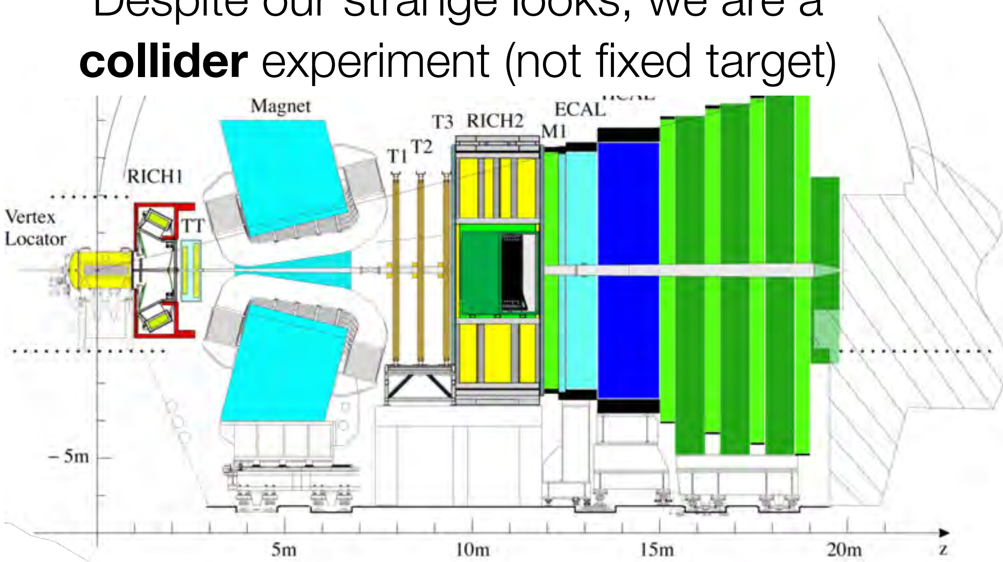

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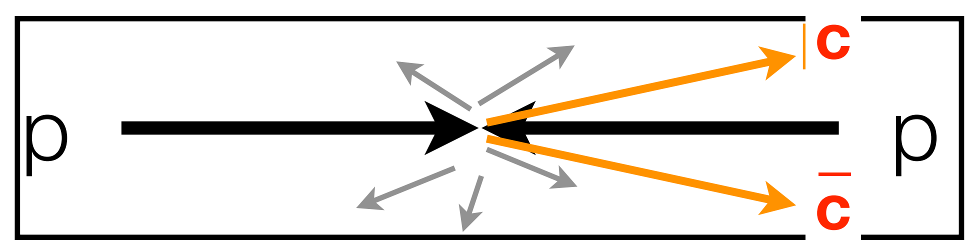
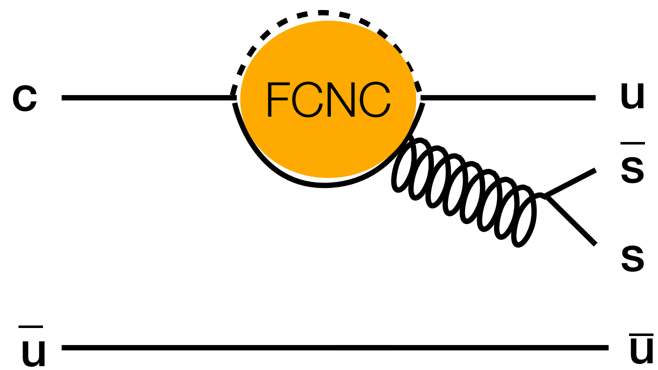


Charm as a tool for New Physics searches

- New physics is most likely to enter in loop diagrams, such as flavour changing neutral currents:



with charm we study FCNC's between up-type quarks (in contrast to Kaons and B mesons where it's down type quark)