Measuring A_{LR} with polarization at Belle II via $c\bar{c}$ production

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The problem *(my understanding)*

$$A_{LR} = \frac{\sigma(e^+e^-_L \to \bar{c}c) - \sigma(e^+e^-_R \to \bar{c}c)}{\sigma(e^+e^-_L \to \bar{c}c) + \sigma(e^+e^-_R \to \bar{c}c)} \equiv \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}$$

$$= \frac{N(\bar{c}c)_L/\mathcal{L}_L \; - \; N(\bar{c}c)_R/\mathcal{L}_R}{N(\bar{c}c)_L/\mathcal{L}_L \; + \; N(\bar{c}c)_R/\mathcal{L}_R}$$

$$\equiv \frac{N_L/\mathcal{L}_L \; - \; N_R/\mathcal{L}_R}{N_L/\mathcal{L}_L \; + \; N_R/\mathcal{L}_R}$$

[NOTE: for N = D^0 decays, the fragmentation factor divides out. For N_L, N_R being the yield of a single decay mode, the efficiency divides out]

$$\Rightarrow \quad \delta A_{LR} = \frac{2(N_L/\mathcal{L}_L)(N_R/\mathcal{L}_R)}{(N_L/\mathcal{L}_L \; + \; N_R/\mathcal{L}_R)^2}\sqrt{\left(\frac{\delta N_L}{N_L}\right)^2 + \left(\frac{\delta N_R}{N_R}\right)^2 + \left(\frac{\delta \mathcal{L}_L}{\mathcal{L}_L}\right)^2 + \left(\frac{\delta \mathcal{L}_R}{\mathcal{L}_R}\right)^2}$$

$$\approx \frac{1}{2}\sqrt{\left(\frac{\delta N_L}{N_L}\right)^2 + \left(\frac{\delta N_R}{N_R}\right)^2 + \left(\frac{\delta \mathcal{L}_L}{\mathcal{L}_L}\right)^2 + \left(\frac{\delta \mathcal{L}_R}{\mathcal{L}_R}\right)^2}$$

[if $N_L/\mathcal{L}_L \approx N_R/\mathcal{L}_R$]

$$\Rightarrow \quad \frac{\delta A_{LR}}{A_{LR}} = \frac{2(N_L/\mathcal{L}_L)(N_R/\mathcal{L}_R)}{(N_L/\mathcal{L}_L)^2 - (N_R/\mathcal{L}_R)^2}\sqrt{\left(\frac{\delta N_L}{N_L}\right)^2 + \left(\frac{\delta N_R}{N_R}\right)^2 + \left(\frac{\delta \mathcal{L}_L}{\mathcal{L}_L}\right)^2 + \left(\frac{\delta \mathcal{L}_R}{\mathcal{L}_R}\right)^2}$$

What are these factors?

Assumptions

$$\delta A_{LR} = \frac{2(N_L/\mathcal{L}_L)(N_R/\mathcal{L}_R)}{(N_L/\mathcal{L}_L + N_R/\mathcal{L}_R)^2}\sqrt{\left(\frac{\delta N_L}{N_L}\right)^2 + \left(\frac{\delta N_R}{N_R}\right)^2 + \left(\frac{\delta \mathcal{L}_L}{\mathcal{L}_L}\right)^2 + \left(\frac{\delta \mathcal{L}_R}{\mathcal{L}_R}\right)^2}$$

Take $\mathcal{L}_L = \mathcal{L}_R = 40\ ab^{-1}$ *(from p.14 of M. Roney's TAU 2021 talk, September 2021)*

Note that $(\delta\mathcal{L}_L/\mathcal{L}_L) = (\delta\mathcal{L}_R/\mathcal{L}_R) \approx 1.4\%$ (Belle) or 1.1% (BaBar); Belle II would need to do much better

For negligible background, take $(\delta N_L/N_L) \approx 1/\sqrt{N_L}$, $(\delta N_R/N_R) \approx 1/\sqrt{N_R}$

But: what are N_L, N_R?

Strategy I

- To minimize backgrounds, we need to use $D^{*+} \to D^0\pi^+$ decays
- To maximize statistics, we need to use Cabibbo-favored (CF) D^0 decays, i.e.,

  $D^0 \to K^-\pi^+$ (branching fraction = 4.0 %)

  $D^0 \to K^-\pi^+\pi^0$ (branching fraction = 14.4 %, but notable backgrounds due to π^0)

  $D^0 \to K^-\pi^+\pi^+\pi^-$ (branching fraction = 8.2 %)

What are the yields of these decays at Belle II?

only one charm paper published so far:

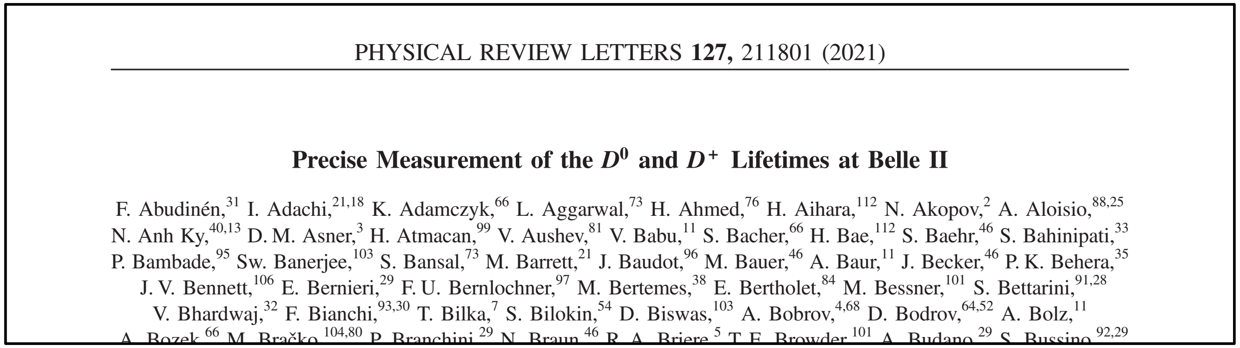
72 fb^{-1}

PHYSICAL REVIEW LETTERS **127,** 211801 (2021)

Precise Measurement of the D^0 and D^+ Lifetimes at Belle II

F. Abudinén,[31] I. Adachi,[21,18] K. Adamczyk,[66] L. Aggarwal,[73] H. Ahmed,[76] H. Aihara,[112] N. Akopov,[2] A. Aloisio,[88,25] N. Anh Ky,[40,13] D. M. Asner,[3] H. Atmacan,[99] V. Aushev,[81] V. Babu,[11] S. Bacher,[66] H. Bae,[112] S. Baehr,[46] S. Bahinipati,[33] P. Bambade,[95] Sw. Banerjee,[103] S. Bansal,[73] M. Barrett,[21] J. Baudot,[96] M. Bauer,[46] A. Baur,[11] J. Becker,[46] P. K. Behera,[35] J. V. Bennett,[106] E. Bernieri,[29] F. U. Bernlochner,[97] M. Bertemes,[38] E. Bertholet,[84] M. Bessner,[101] S. Bettarini,[91,28] V. Bhardwaj,[32] F. Bianchi,[93,30] T. Bilka,[7] S. Bilokin,[54] D. Biswas,[103] A. Bobrov,[4,68] D. Bodrov,[64,52] A. Bolz,[11] A. Bozek,[66] M. Bračko,[104,80] P. Branchini,[29] N. Braun,[46] R. A. Briere,[5] T. E. Browder,[101] A. Budano,[29] S. Bussino,[92,29] M. Campajola,[88,25] L. Cao,[11] G. Casarosa,[91,28] C. Cecchi,[90,27] D. Červenkov,[7] M.-C. Chang,[15] P. Chang,[65] R. Cheaib,[11] V. Chekelian,[57] C. Chen,[42] Y.-T. Chen,[65] B. G. Cheon,[20] K. Chilikin,[52] K. Chirapatpimol,[8] H.-E. Cho,[20] K. Cho,[48] S.-J. Cho,[118] S.-K. Choi,[19] S. Choudhury,[34] D. Cinabro,[116] L. Corona,[91,28] L. M. Cremaldi,[106] S. Cunliffe,[11] T. Czank,[113] F. Dattola,[11] E. De La Cruz-Burelo,[6] G. de Marino,[95] G. De Nardo,[88,25] G. De Pietro,[29] R. de Sangro,[24] M. Destefanis,[93,30] S. Dey,[84] A. De Yta-Hernandez,[6] A. Di Canto,[3] F. Di Capua,[88,25] J. Dingfelder,[97] Z. Doležal,[7] I. Domínguez Jiménez,[87] T. V. Dong,[13] M. Dorigo,[31] K. Dort,[45] D. Dossett,[105] S. Dubey,[101] S. Duell,[97] G. Dujany,[96] P. Ecker,[46] D. Epifanov,[4,68] T. Ferber,[11] D. Ferlewicz,[105] G. Finocchiaro,[24] K. Flood,[101] A. Fodor,[58] F. Forti,[91,28] B. G. Fulsom,[72] A. Gabrielli,[94,31] N. Gabyshev,[4,68] A. Gaz,[89,26] A. Gellrich,[11] G. Giakoustidis,[97] R. Giordano,[88,25] A. Giri,[34] A. Glazov,[11] B. Gobbo,[31] R. Godang,[110] P. Goldenzweig,[46] B. Golob,[102,80] W. Gradl,[44] E. Graziani,[29] D. Greenwald,[83] T. Gu,[108] Y. Guan,[99] K. Gudkova,[4,68] J. Guilliams,[106] C. Hadjivasiliou,[72] S. Halder,[82] K. Hara,[21,18] T. Hara,[21,18] O. Hartbrich,[101] K. Hayasaka,[67] H. Hayashii,[63] S. Hazra,[82] C. Hearty,[98,39] I. Heredia de la Cruz,[6,10] M. Hernández Villanueva,[11] A. Hershenhorn,[98] T. Higuchi,[113] E. C. Hill,[98] H. Hirata,[60] M. Hoek,[44] M. Hohmann,[105] C.-L. Hsu,[111] T. Humair,[57] T. Iijima,[60,62] K. Inami,[60]

Strategy II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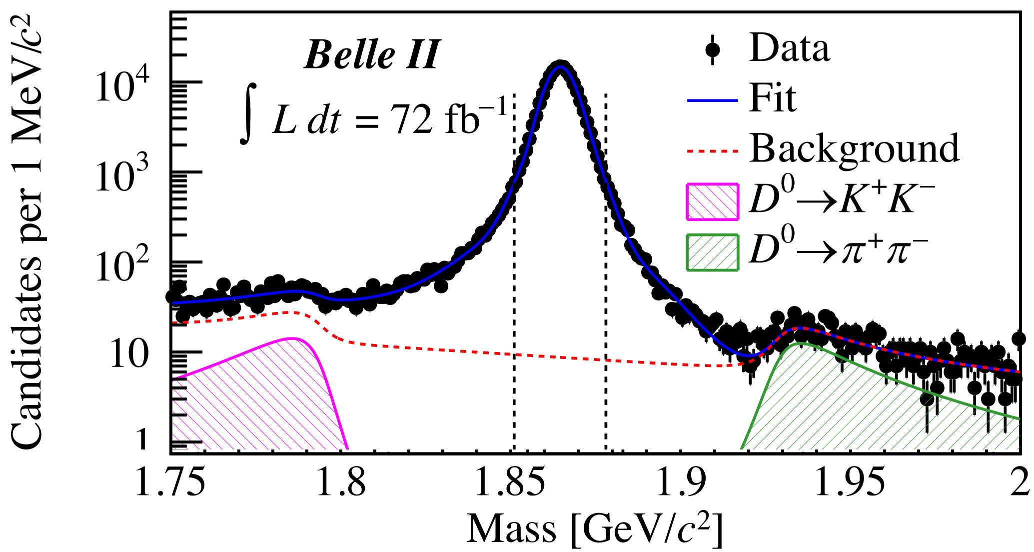
$D^{*+} \to D^0\pi^+$, $D^0 \to K^-\pi^+$



From this analysis, we have:

- $\mathcal{L}$ = 72 fb^{-1}
- N_{signal} = 171 x 10^3
- *Purity = 0.998*

⇒ *in 40 ab^{-1}, we would reconstruct (171000)(40/0.072) = 95 x 10^6 decays*

⇒ $(\delta N_L/N_L)$ = 1.0 x 10^{-4}

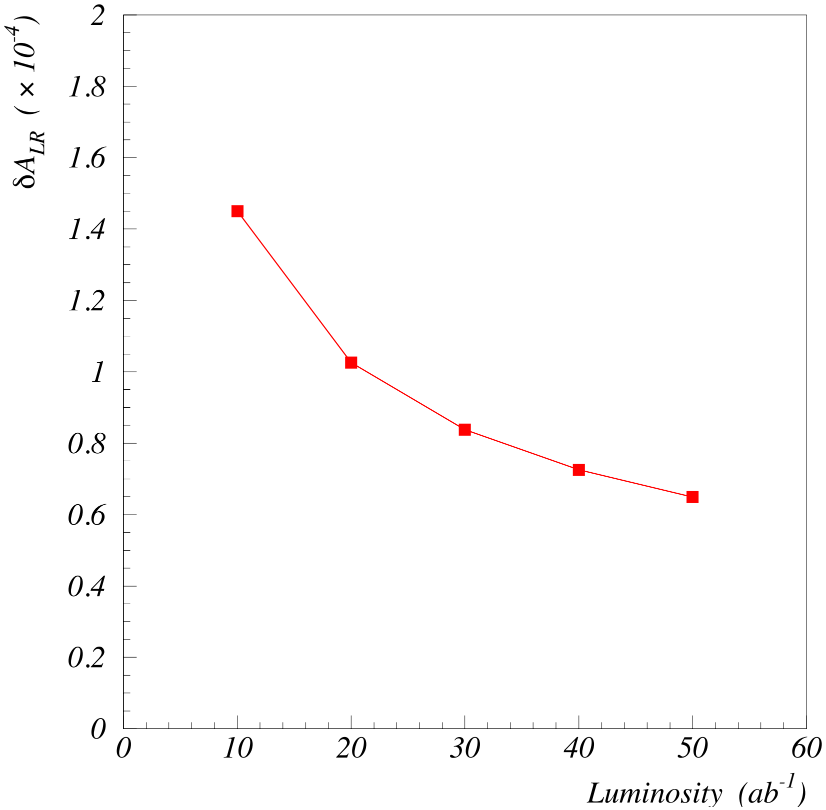
Note that $\delta L/\mathcal{L}$ = 0.011 (Belle/Babar precision) would dominate

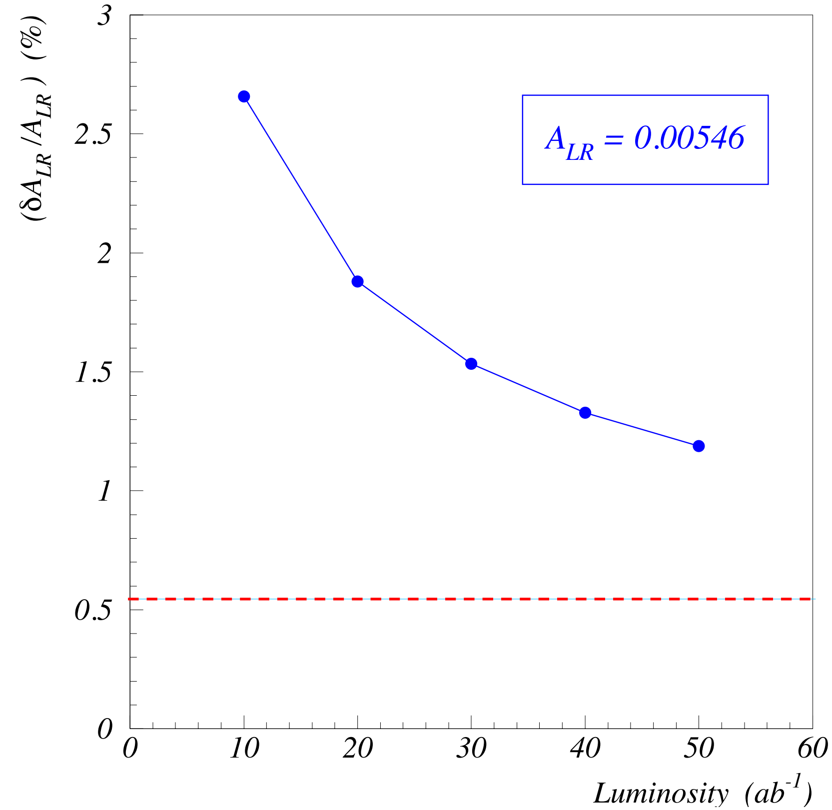
Sensitivity

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

(take to be 0 for now)

$$\delta A_{LR} = \frac{2(N_L/\mathcal{L}_L)(N_R/\mathcal{L}_R)}{(N_L/\mathcal{L}_L + N_R/\mathcal{L}_R)^2} \sqrt{\left(\frac{\delta N_L}{N_L}\right)^2 + \left(\frac{\delta N_R}{N_R}\right)^2 + \left(\frac{\delta \mathcal{L}_L}{\mathcal{L}_L}\right)^2 + \left(\frac{\delta \mathcal{L}_R}{\mathcal{L}_R}\right)^2}$$





(from p.14 of M. Roney's TAU 2021 talk)

Some improvement

Add another mode: $D^{*+} \to D^0\pi^+$, $D^0 \to K^-\pi^+\pi^+\pi^-$

Belle:

- $\mathcal{L}$ = 281 fb^{-1}
- Nsig = 525900
- Purity = very good

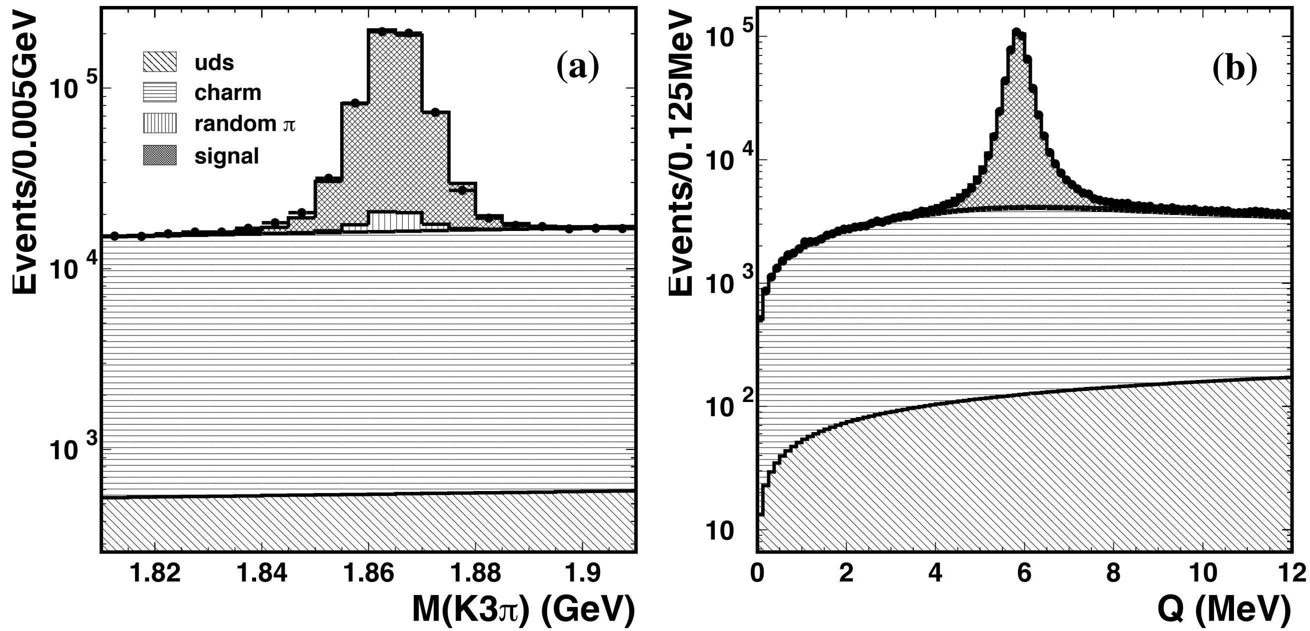
⇒ in 40 ab^{-1}, we would reconstruct (525900)(40/0.281) = 74.9 x 10^6 decays

⇒ $(\delta N_L/N_L)$ = 1.2 x 10^{-4}

This would almost double the statistics

⇒ reduce statistical error on δA_{LR} by ~30%, but a systematic from the ratio of efficiencies $\varepsilon_{K\pi}/\varepsilon_{K\pi\pi\pi}$ would enter

X.C.Tian et al. (Belle), PRL 95, 231801 (2005)



Summary

- *Measurement is feasible: there will be large, ~background-free charm samples. Most promising modes are $D^{*+} \to D^0 \pi^+$, $D^0 \to K^- \pi^+$, $D^0 \to K^- \pi^+ \pi^+ \pi^-$. The $K^- \pi^+$ final state is expected to provide somewhat better sensitivity.*
- *But uncertainty on integrated luminosity could dominate the measurement (?)*
- *Assuming it does not, the first charm result from Belle II indicates that the precision ($\delta A_{LR}/A_{LR}$) would be perhaps a factor of 2 worse than initial (rough) estimates*