Search for CPV in $D^0 \to K_S^0 K_S^0$ decays at LHCb

Giulia Tuci,
on behalf of the LHCb collaboration
giulia.tuci@cern.ch

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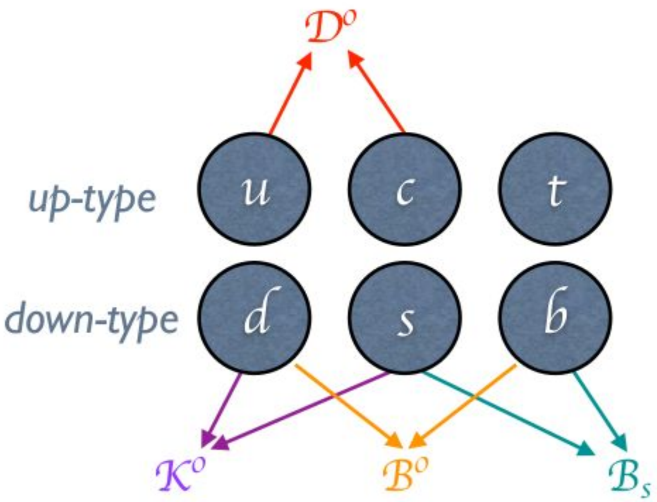
LHCb

UNIVERSITÀ DI PISA

INFN Istituto Nazionale di Fisica Nucleare

CPV in charm

- Charm transitions are a unique portal for obtaining a novel access to flavor dynamics
  - complementarity with K^0 and $B^0_{(S)}$
  - expected CPV in charm $\lesssim 10^{-3} \rightarrow$ difficult to observe it experimentally

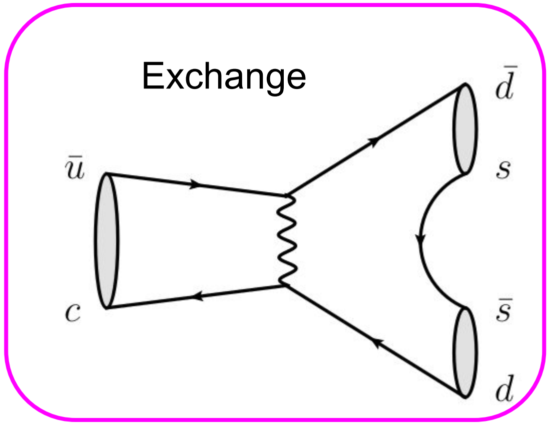


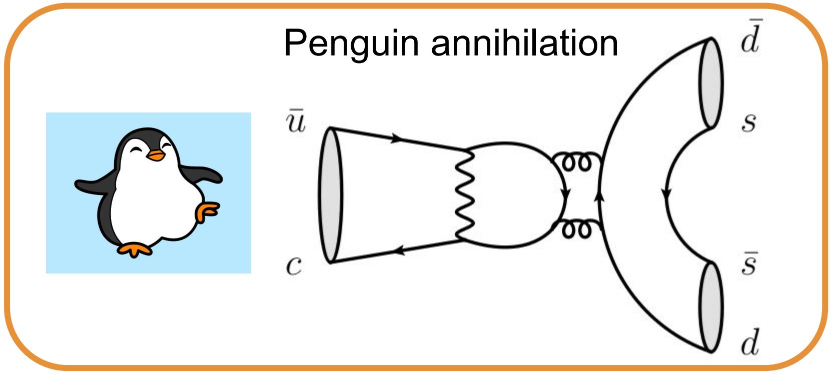
- **Finally CPV in charm has been observed!** PRL 122 (2019) 211803
- It's the moment to start a systematic exploration of all the charm hadrons decay channels to do a quantitative study of CPV
- **$D^0 \rightarrow K_S^0 K_S^0$ decay channel** is a perfect candidate due to the significant size of the expected effect

A^{CP} in $D^0 \to K_S^0 K_S^0$

- In $D^0 \to K_S^0 K_S^0$ decay channel **A^{CP} could be as large as ~1%**

Brod et al. 2011, Nierste & Schacht 2015, Buccella et al. 2019, Cheng & Chiang 2019



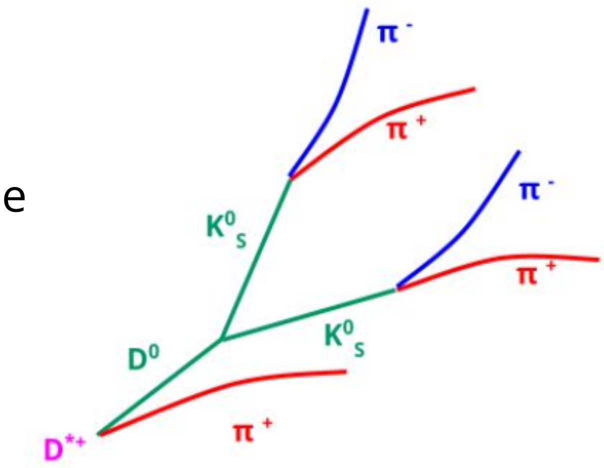


Previous measurements

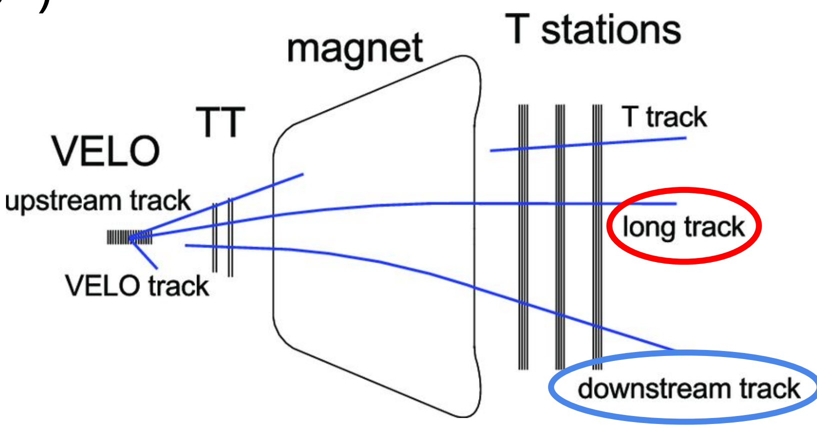
$A^{CP}(K_S^0 K_S^0)$ (%)	Yield	Collaboration	
$-23. \pm 19.$	65 ± 14	CLEO	PRD 63 (2001) 071101
$-2.9 \pm 5.2 \pm 2.2$	635 ± 74	LHCb Run 1	JHEP 10 (2015) 055
$-0.02 \pm 1.53 \pm 0.17$	5399 ± 87	Belle	PRL 119(2017)171801
$4.3 \pm 3.4 \pm 1.0$	1067 ± 41	LHCb 2015+2016	JHEP 11 (2018) 048

$D^0 \to K_S^0 K_S^0$ @ LHCb

- K_S^0 are difficult to select at trigger level
  - $\tau(K^0_S) = 0.9 \times 10^{-10}$ s , $<\beta\gamma>\sim 80 \to \beta\gamma c\tau \sim 120$ cm
  - K_S^0 decays often outside vertex detector acceptance



- Data samples collected in 2015-2018 (~6fb^{-1})
  - **LL** sample: both K_S^0 reconstructed from **Long** tracks
  - **LD** sample: one K_S^0 is **Long** and the other one is **Downstream**
  - **DD** sample: both K_S^0 reconstructed from **Downstream** tracks



Methodology

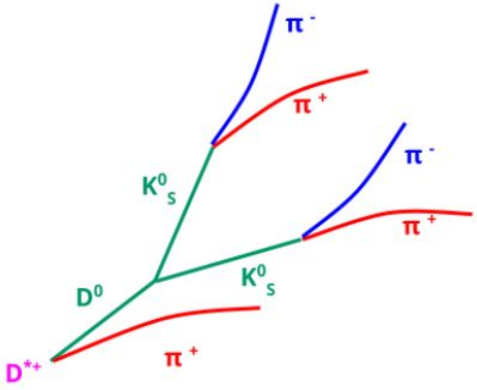
- Time-integrated measurement. Quantity to be measured:

$$\mathcal{A}^{CP}(f) = \frac{\Gamma(D \to f) - \Gamma(\bar{D} \to f)}{\Gamma(D \to f) + \Gamma(\bar{D} \to f)}$$

- Experimentally

$$\mathcal{A}^{raw} \equiv \frac{N_{D^0} - N_{\bar{D}^0}}{N_{D^0} + N_{\bar{D}^0}}$$

- $D^{*+} \to D^0\pi^+$ decay used to tag D^0

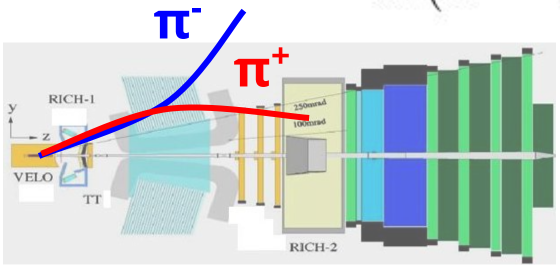


Production asymmetry: initial state pp is not CP symmetric

$$N(D^0 \to K^0_S K^0_S) \propto \sigma(D^{*+})\epsilon(\pi^+)\Gamma(D^0 \to K^0_S K^0_S)$$

$$\neq \qquad \neq$$

$$N(\bar{D}^0 \to K^0_S K^0_S) \propto \sigma(D^{*-})\epsilon(\pi^-)\Gamma(\bar{D}^0 \to K^0_S K^0_S)$$



Asymmetric detector acceptance + material interaction different for particles/antiparticles

Methodology (2)

- $D^0 \rightarrow K^+K^-$ is used as a calibration channel
  - CP asymmetry known with high precision ($O(10^{-3})$) PLB 767 (2017) 177
- To remove production and detection asymmetries, each signal candidate is weighted by:

$$w^{\pm}(\vec{p}_0) = \frac{n_C^+(\vec{p}_0) + n_C^-(\vec{p}_0)}{2n_C^{\pm}(\vec{p}_0)}\left[1 \pm \mathcal{A}^{CP}(K^+K^-)\right]$$

D^0 momentum

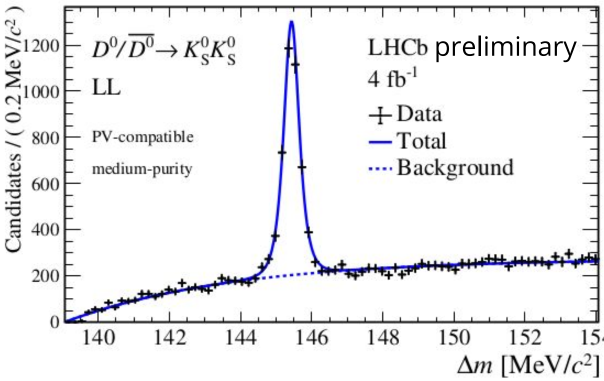
Local density of $D^0/\overline{D}^0 \rightarrow K^+K^-$ events (estimated via multivariate classifier)

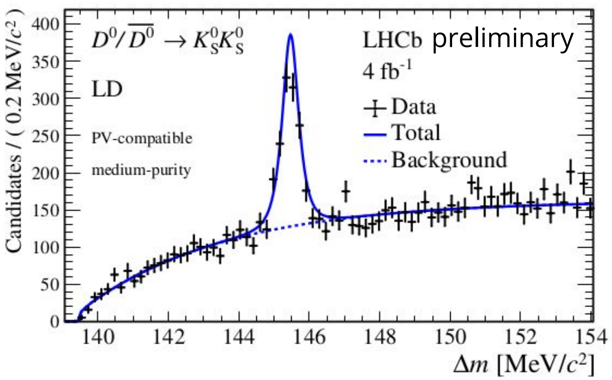
- A^{CP} extracted via a multidimensional weighted fit to $\Delta m = m(D^{*+})-m(D^0)$ and the two $m(K^0_S)$ distributions

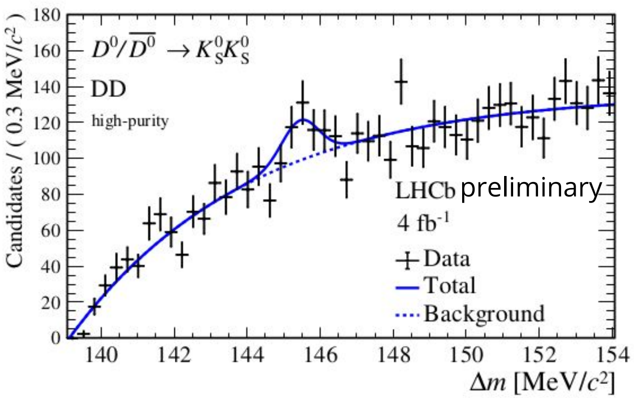
Results

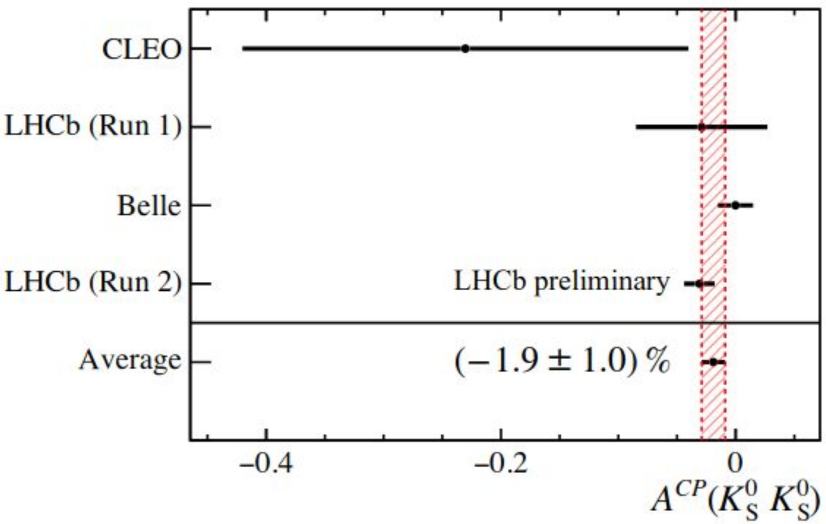
- **$A^{CP}(D^0 \to K_S^0 K_S^0)_{\text{Run2}}$ = (-3.1 ± 1.2 (stat.) ± 0.4 (syst.) ± 0.2 (ext.))%**
- Yields: 8102 ± 136

LHCb-PAPER-2020-047, in preparation









World's best measurement up to now.

Consistent with no-CPV hypothesis and previous results.

Statistically limited.

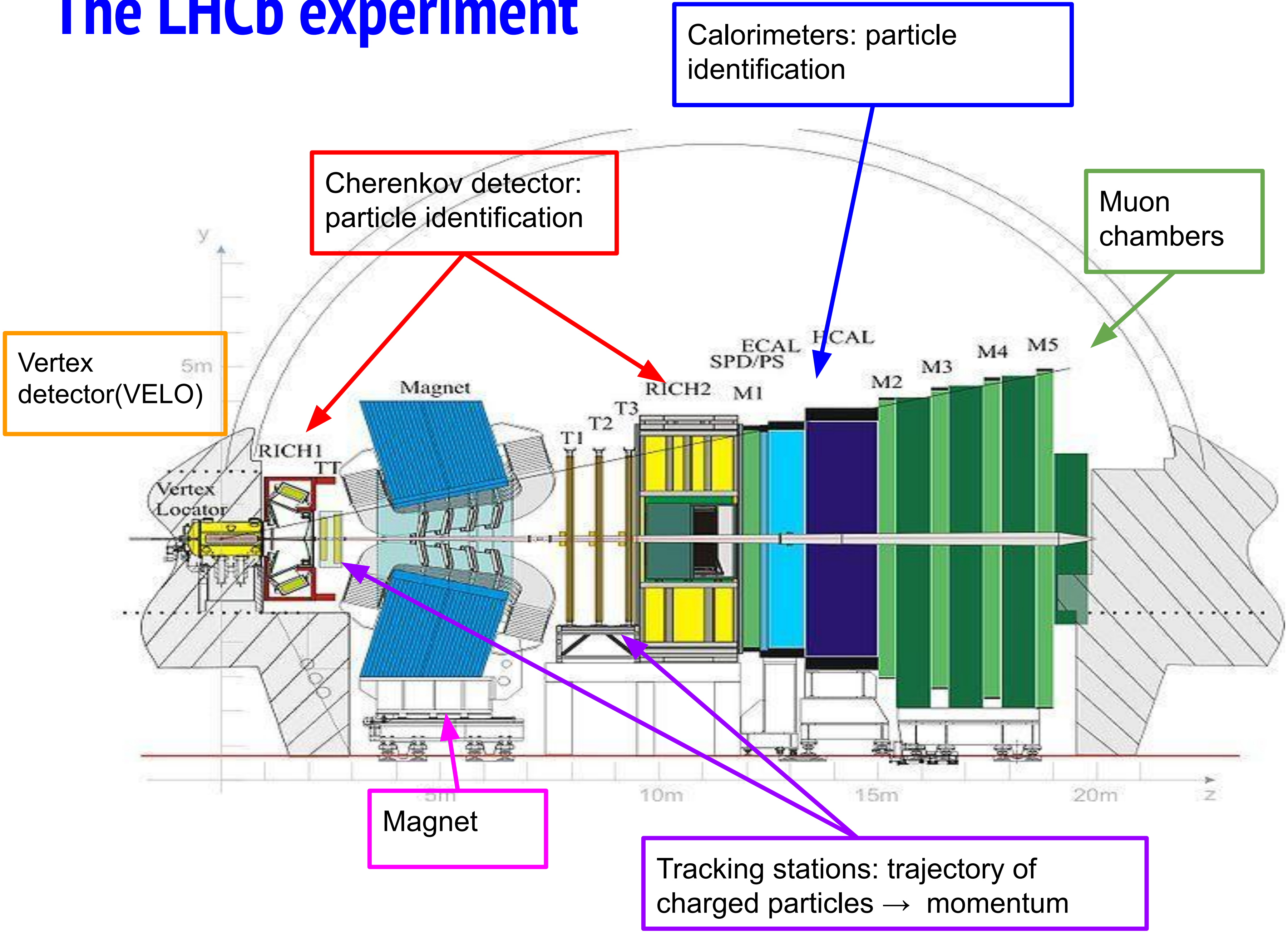
Prospects with future runs

- New data will arrive in 2022 with an almost completely new detector and trigger system
  - Instantaneous luminosity will increase by 5x (2 x 10^{33} $cm^{-2}s^{-1}$)
- Effort is being made to keep high efficiency for K_S^0 reconstruction despite the higher luminosity
- As an example, R&D work to realize a dedicated downstream tracking unit that can be integrated in the DAQ architecture and act as an “embedded track-detector” CERN-LHCC-2017-003

- **LHCb has the potential to further improve this measurement in the years to come → Stay tuned!**

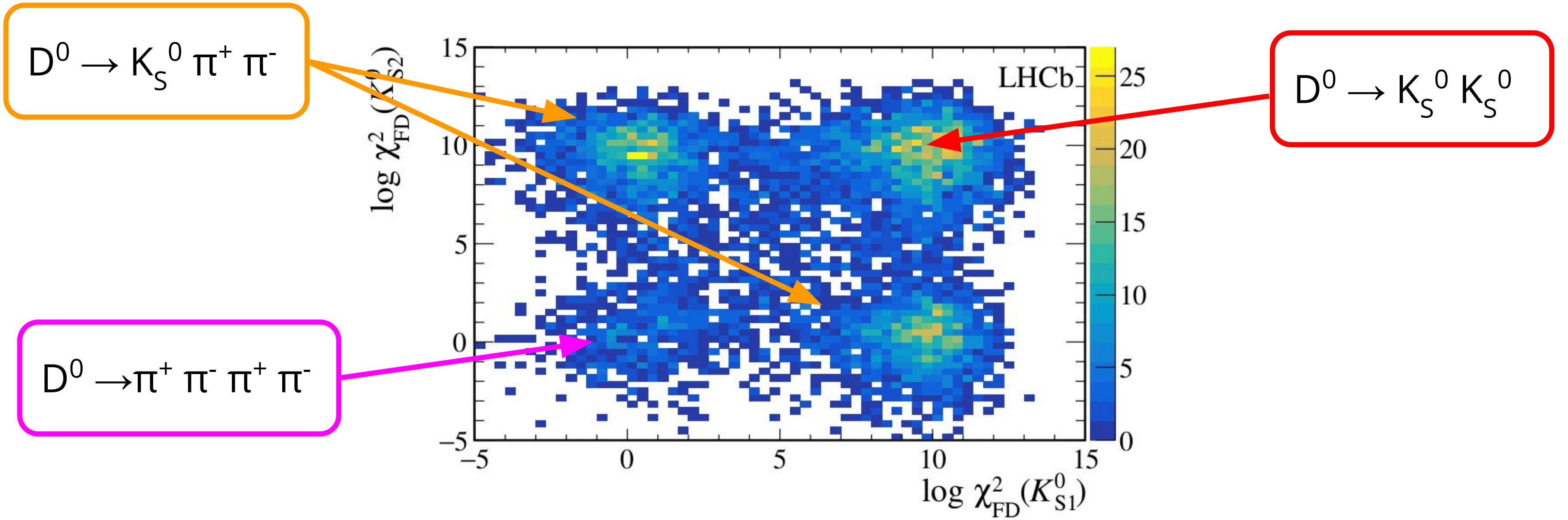
Backup slides

The LHCb experiment



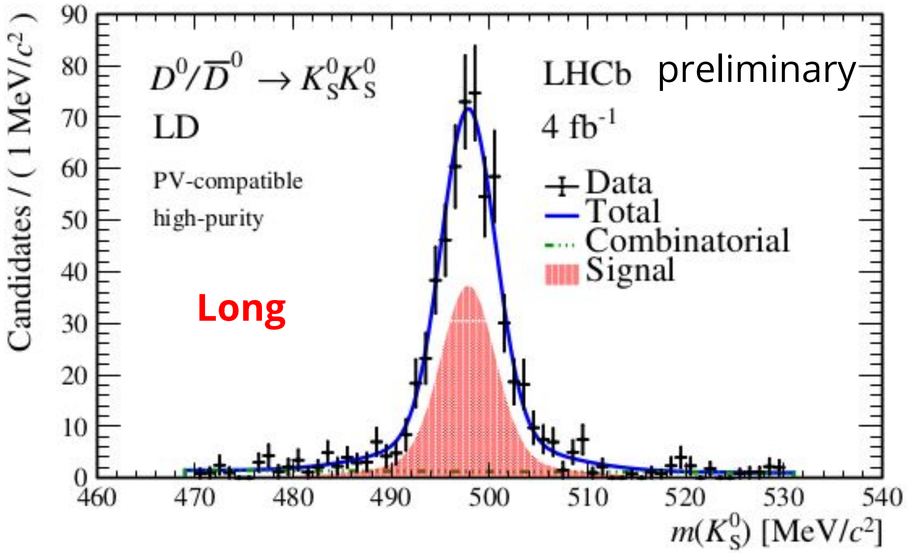
Background

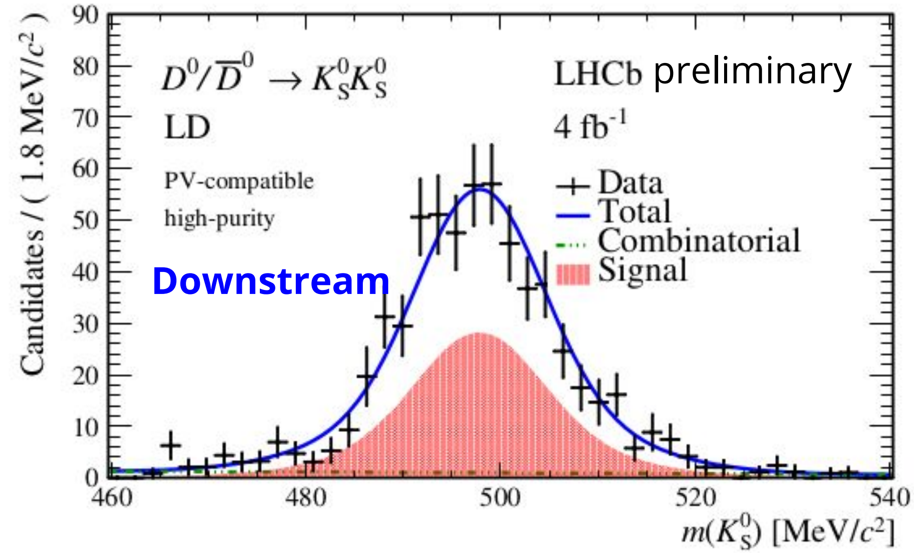
- Peaking background reduced with cut based selection, e.g.
  - $D^0 \to K_S^0 \pi^+ \pi^-$, reduced performing selections on flight distance



- Combinatorial background reduced using kNN classifier

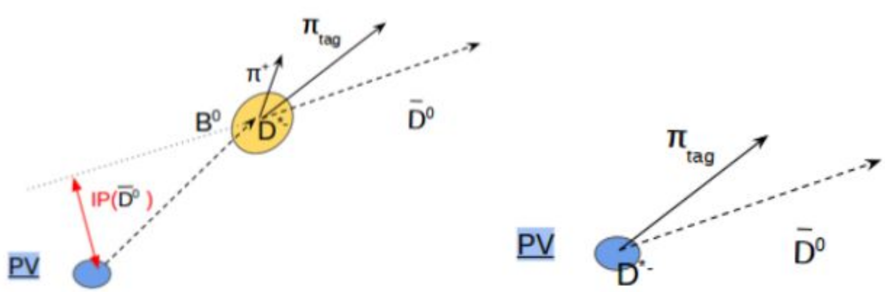
K_S^0 mass distributions

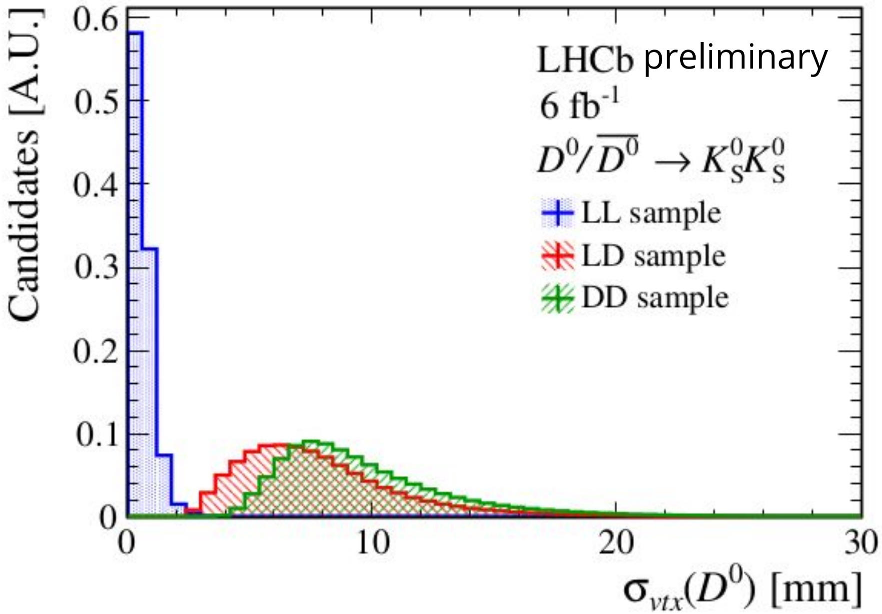




Secondary decays

- D^{*+} could originate from a b-hadron decay
  - Same CP asymmetry, but different production asymmetry





- Standard approach: remove them using information on D^0 vertex displacement
  - Not effective in the $D^0 \to K_S^0 K_S^0$ decay channel
  - Unlike in 2015-16 measurement, secondary decays are treated as signal and their different production asymmetry is corrected for

Results

Sample	2015 + 2016 ($2\ \text{fb}^{-1}$)		2017 + 2018 ($4\ \text{fb}^{-1}$)	
	Yield	$\mathcal{A}^{CP}$ [%]	Yield	$\mathcal{A}^{CP}$ [%]
LL PV-comp.	1388 ± 41	$0.3 \pm 2.5 \pm 0.6$	4056 ± 77	$-4.3 \pm 1.6 \pm 0.4$
LL PV-incomp.	178 ± 31	$-11 \pm 17 \pm 2$	430 ± 41	$-3.0 \pm 7.9 \pm 1.1$
LD PV-comp.	411 ± 25	$-7.2 \pm 5.8 \pm 1.1$	1145 ± 49	$-2.9 \pm 3.8 \pm 0.7$
LD PV-incomp.	58 ± 18	$-10 \pm 31 \pm 4$	349 ± 64	$-5 \pm 17 \pm 2$
DD	–	–	87 ± 28	$-35 \pm 47 \pm 6$

Sample split into different categories:

- ➢ LL,LD, DD samples;
- ➢ output of kNN classifier (2 categories);
- ➢ compatibility of the D^{*+} with coming from the primary pp vertex (PV);
- ➢ 2015–2016 vs. 2017–2018