Studying CPT with Neutral Mesons - Standard Model Extension Approach (SME)

Mateusz Kmieć

Outline

1. Basic concepts (mesons?, discrete sym. ?).
2. Neutral meson oscillations phenomenological description.
3. CPT, Lorentz invariance and SME.
4. SME description of CPTV in meson mixing.
5. Analysis steps of CPTV measurement in charm.

Discrete Symmetries

- C: $\hat{\boldsymbol{C}}\,|c,\vec{p},t\rangle = e^{i\alpha_C}\,|\bar{c},\vec{p},t\rangle$, charge conjugation transformation
- P: $\hat{\boldsymbol{P}}\,|c,\vec{p},t\rangle = e^{i\alpha_P}\,|c,-\vec{p},t\rangle$, parity transformation
- T: $\hat{\boldsymbol{T}}\,|c,\vec{p},t\rangle = e^{i\alpha_T}\,\langle c,\vec{p},-t|$, time reversal transformation

  where $e^{i\alpha_C}$, $e^{i\alpha_P}$, $e^{i\alpha_T}$ are phase factors
- when $[H,X]=0$ then X is conserved
- CPT symmetry represented by $\hat{\boldsymbol{C}}\hat{\boldsymbol{P}}\hat{\boldsymbol{T}}$
- QFT+(Locality, Unitarity, Lorentz Invariance) $\Rightarrow$ CPT invariant

CPT theorem

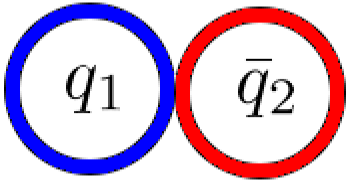
- CPT theorem states that local quantum field theories with Lorentz symmetry and hermitian Hamiltonian also have CPT symmetry [arXiv:1204.4674, R. Jost, Hel. Phys. Acta, 30:409–416, 1957.].

- Greenberg: An interacting theory that violates CPT invariance necessarily violates Lorentz invariance.” [PRL 89 (2002) 231602]

Hence: We can study CPT with Lorentz Invariance

Neutral Mesons

1. meson = quark + antiquark:



2. neutral meson => charge = 0;

3. Flavour is not conserved in weak interactions.

4. This enables oscillations.

Neutral meson $Q = 0$	Flavor F
$\mathbf{K^0}$ $d\bar{s}$	Strangeness $S = 1$
$\mathbf{D^0}$ $c\bar{u}$	Charm $C = 1$
$\mathbf{B^0}$ $d\bar{b}$ $s\bar{b}$	Beauty $B = 1$ $B = 1, S = -1$

Flavour roughly tells us how massive our particles are.
Heavy quark content.

Credits: Agnes Roberts,
Presentation IUCSS CPT 21

Neutral Meson Oscillations

- In the SM full Hamiltonian can be written as: $H = H_{st} + H_{em} + H_{wk}$
- We can treat weak interactions as a perturbation to strong Hamiltonian.
- Flavour states e.g.$|P^0 >, |\bar{P}^0 >$ are not eigenvectors of the full Hamiltonian.
- Flavour states are eigenstates of the strong Hamiltonian.
- Due to neutral el. charge $H_{em} = 0$.
- $H = H_{st} + H_{wk}$

https://arxiv.org/pdf/hep-ph/0104120.pdf

Weisskopf-Wiger Approx. (WWA)

What happens to our Hamiltonian H?

WWA=>We get an effective 2x2 Hamiltonian H^{eff}.

- We assume times longer than strong interaction scale.
- Space resticted to 2-dim P^0-$\overline{P}^0$.
- Eff. Hamiltonian is non-hermitian (possiblity of decays).
- Eff. Hamiltonian is time-independent.

V. Weisskopf and E. P. Wigner. Z. Phys. 63, 54 (1930); Z. Phys. 65, 18 (1930).

We can express the eff. Hamiltonian as a sum of to 2x2 hermitian matrices **M** and **Γ** (mass and decay matrix respectively).

Neutral Meson Math. Description

Neutral meson system in the (P^0, $\overline{P}^0$) basis can be described by the 2x2 effective hamiltonian H^{eff}:

$$H^{eff} = \left[\begin{pmatrix} M_{11} & M_{12} \\ M_{21}^* & M_{22} \end{pmatrix} - \frac{i}{2} \begin{pmatrix} \Gamma_{11} & \Gamma_{12} \\ \Gamma_{21}^* & \Gamma_{22} \end{pmatrix} \right]$$

CPT $(M_{11} - M_{22}) - \frac{i}{2}(\Gamma_{11} - \Gamma_{22}) = 0 \Longleftrightarrow M_{11} = M_{22}; \Gamma_{11} = \Gamma_{22}$

T $\frac{|H_{12}|}{|H_{21}|} = 1 \Longleftrightarrow H_{12} = e^{2i\eta_{CP}} H_{21}$

CP Conserved when both of the above are fulfilled.

https://arxiv.org/pdf/hep-ph/0104120.pdf

Let's find H^{eff} eigenvalues

Eigen vectors of the eff. Hamil.

$$|P_H>, |P_L>$$

mass eigenstates

Interpretation of the coefficients will come later!

$$|P_L>= c_1|P^0> + c_2|\bar{P}^0>$$
$$|P_H>= d_1|P^0> - d_2|\bar{P}^0>$$

Mass eigenstates are linear combinations of flavour eigenstates!

$$H^{eff}|P_{H/L}>= \left(M - \frac{i}{2}\Gamma\right)|P_{H/L}>= \left(m_{H/L} - \frac{i}{2}\Gamma_{H/L}\right)|P_{H/L}>$$

Uff!

Let’s try to visualise how these oscillations occur.

Neutral Meson Oscillations

$$H^{eff}$$

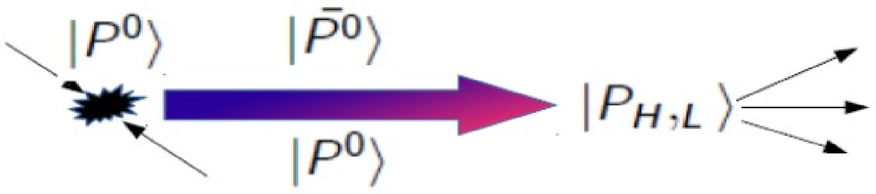
described by 2x2 effective hamiltonian – accuracy up to the second order in weak interactions

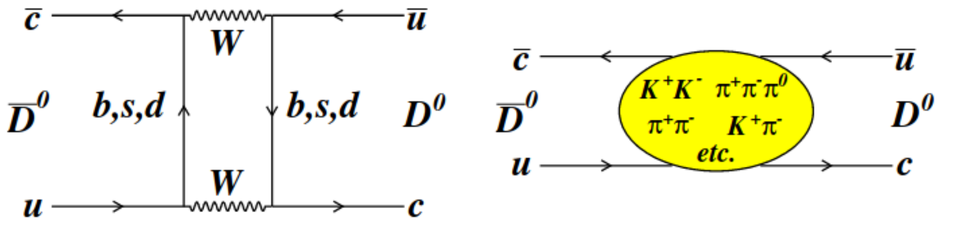
$$P_H - P_L$$

mass eigenstates
→ propagation

$$P^0 - \bar{P}^0$$

flavour eigenstates
→ production, decay





Credits: Fernando Martinez Vidal arXiv:0910.5061

Fig. 1. SM processes contributing to D^0-$\bar{D}^0$ mixing: (Left) Short-range box diagram and (Right) long-range interactions with intermediate states.

Oscillations – diff. species

$$x = \frac{\Delta m}{\Gamma} = \frac{m_H - m_L}{\Gamma}$$

controls freq. of oscillations

$$y = \frac{\Delta \Gamma}{2\Gamma} = \frac{\Gamma_H - \Gamma_L}{2\Gamma}$$

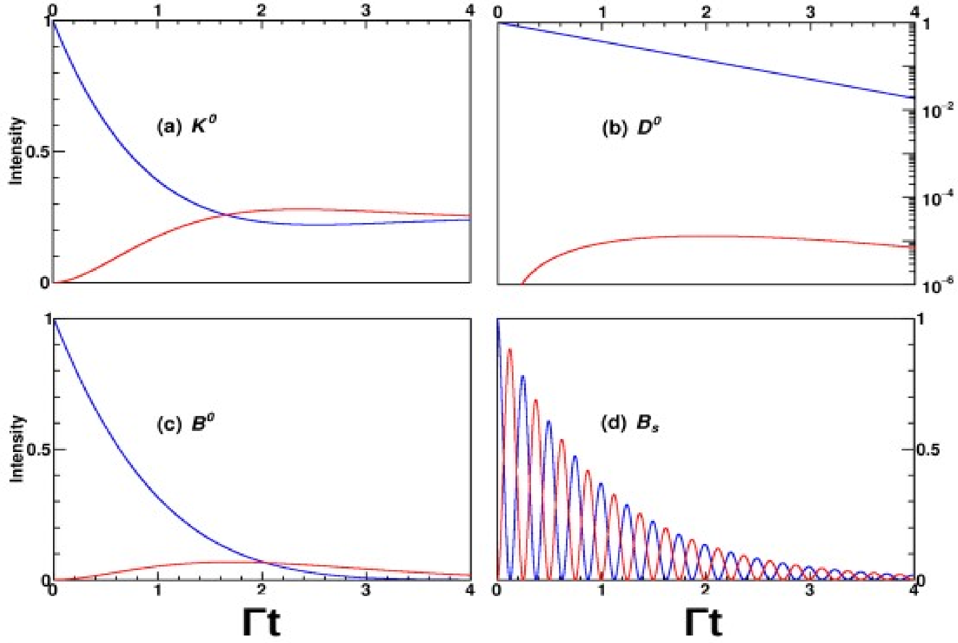
influences the shape

$$\boxed{\begin{aligned} \Gamma &= \frac{\Gamma_H + \Gamma_L}{2} \\ \Delta m &= m_H - m_L \\ \Delta\Gamma &= \Gamma_H - \Gamma_L \end{aligned}}$$

	B_s^0	B^0	D^0	K^0
x	25.194	0.773	0.006	-0.946
y	0.046	0.005	0.008	0.997

$Pr[P^0 \to P^0] \sim e^{-\Gamma t} (\cosh(y\Gamma t) + \cos(x\Gamma t))$

$Pr[P^0 \to \overline{P}^0] \sim e^{-\Gamma t} |q/p|^2 (\cosh(y\Gamma t) - \cos(x\Gamma t))$



PDF distributions for diff. meson species. No non-direct transitions and CPV assumed.

CPT parametrisation in mixing

$$|P_L >= p\sqrt{1-z}|P^0 > +q\sqrt{1+z}|\bar{P}^0 >$$
$$|P_H >= p\sqrt{1+z}|P^0 > -q\sqrt{1-z}|\bar{P}^0 >$$

$$z = \frac{H_{11}^{eff} - H_{22}^{eff}}{\Delta m - i\Delta\Gamma/2} = \frac{\delta m - i\delta\Gamma/2}{\Delta m - i\Delta\Gamma/2}$$

$$\delta m = M_{11} - M_{22}; \delta\Gamma = \Gamma_{11} - \Gamma_{22}$$
$$\Delta m = m_H - m_L; \Delta\Gamma = \Gamma_H - \Gamma_L$$

T is conserved then $\left|\frac{p}{q}\right| = 1$.

CPT is conserved then $z = 0$.

CP is conserved then $z = 0$ and $|p| = |q|$.

$0 \le |p| \le 1$; $0 \le |q| \le 1$; $0 \le |z| \le 1$.

When $z = 0$ then $|p|^2 + |q|^2 = 1$.

CPT conserved => z=0 !!!

Lorentz Symmetry

(in this presentation: arbitrary rotation or boost invariance violation)

- Foundational assumption of both the SM and GR.
- Continually tested since Einstein (many potential LV sources untested)
- Theory predictions => possibility of LV at Planck scale.
- Resurgence of interest due to searches of physics at the Planck scale.
- In interacting theories CPTV necessitates LV.

[Rep. Prog. Phys. 77, 062901 (2014)]

Standard Model Extension (SME)

- SME – effective field theory, which includes all possible Lorentz violating terms that can be constructed from the associated fields [V.A.Kostelecky, PRD55 (1997), 6760].

- During the last 50 years the SM was established.

- We are interested in the small deviations from the SM using tools of the effective field theory.

- Planck-scale physics using Planck sensitivity rather than Planck energy.

[Rep. Prog. Phys. 77, 062901 (2014)]

Structure of the SME

1. LV terms of the SME are constructed by coupling observer vector or tensor coefficients for Lorentz violation to SM operators.

2. Generality of the SME => LV could exist in nature associated with one particle but not another.

3. Lagrange density includes: LV terms that are CPT invariant + terms that violate both CPT and Lorentz symmetries.

4. SME is not a model => test framework designed for a broad search [Data tables: arXiv:0801.0287]

[Rep. Prog. Phys. 77, 062901 (2014)]

Classical vs SME for mesons

- Classical approach: purely phenomenological description of neutral meson mixing (p,q,z).

- Alternative (EFT) approach: SME framework where Lorentz Violation and CPT violation are treated as small deviations to the SM.
- “z” can be associated with CPTV parameters in the SME.
- In the SME “z” equivalent depends on meson species boost and 3-momenta.

Sidereal Modulations

- Search for LV => study a system that is symmetric in conventional physics and changes in SME when rotated.
- LV effects are correlated to the background vacuum.
- Earth based LV effects are correlated with sidereal days.

What are sidereal days?

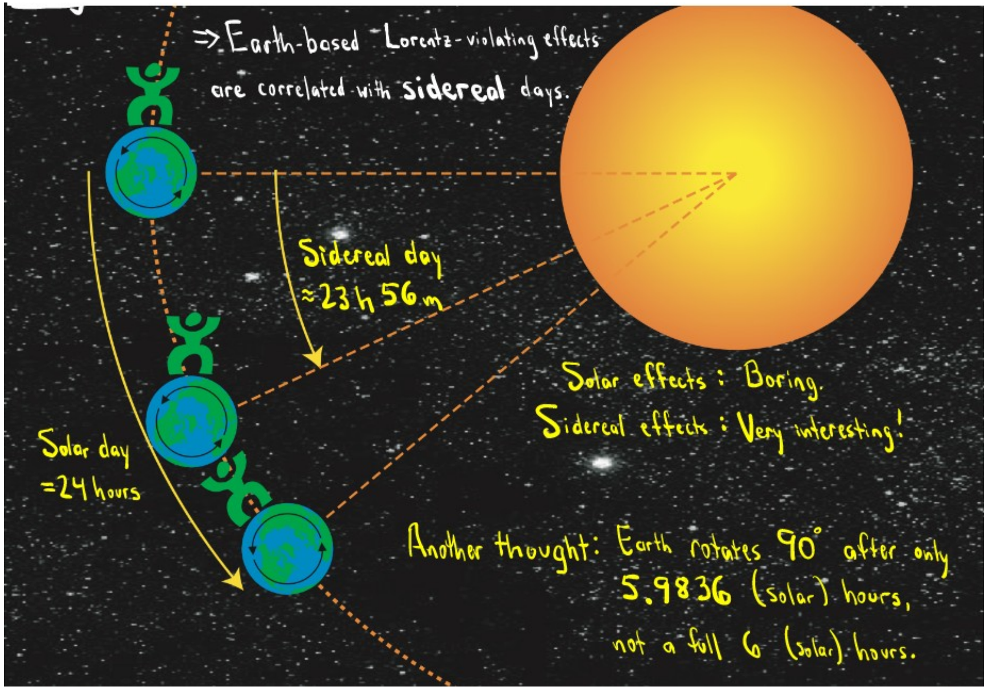
1. Karl Jansky 1930 built a resonant electric circuit sensitive to 20.5 MHz.

2. Observed signal around noon each day. Sounds like the Sun is triggering it…?

3. Minor detail: it occurred 4 minutes earlier each day.

4. Interpretation => signal coming from outside of the solar system.

5. Strong radio source in the center of the Milky way.

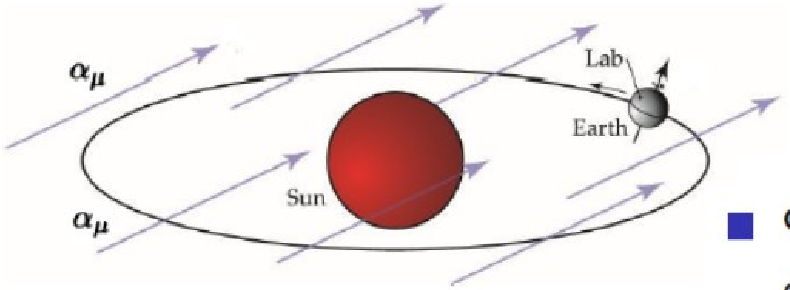


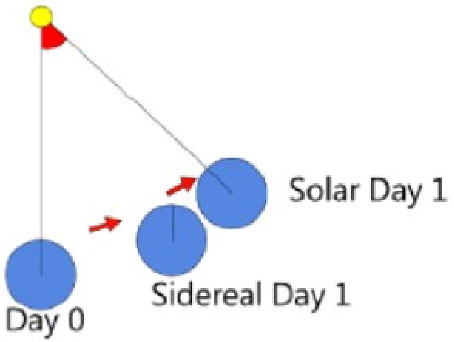
https://iucss.sitehost.iu.edu/sme2021/lectures/Lane.pdf

Credits: Charles Lane (Berry)

Sidereal Modulations

CPTV z undergoes sidereal modulations, which depend on the geographical location of the lab.





- $\Phi_{sid} = \Omega\hat{t} = \Omega t_{GPS} + \Phi^0_{sid}$
- Sidereal angular frequency: $\Omega = \frac{2\pi}{T_{sid}} = 7.292 \times 10^{-11}$ rad μs^{-1}
- $T_{sol} = 86400s$
- $T_{sid} \approx \frac{365.25}{366.25} T_{sol} = 86164.1s$

mSME for mesons (coupling to LV)

- CPTV and LV terms operator mass dim. < 4 (mSME):
  are introduced for fermions with coupling coefficients a_{μ}.
- All components of a “good” QFT remain (renormalisation, locality, spin-statistics etc.).
- Observable effect determined by the contribution from the coupling of the two valence quarks q_1, $\bar{q}_2$ with the LV field:

$$\boxed{\Delta a_\mu \simeq a_\mu^{q_1} - a_\mu^{q_2}}$$

[Phys.Rev.D61:016002,2000; Phys. Lett. B 730 (2014) 89-94]

CPT violating parameter z

Phys.Rev.D61:016002,2000

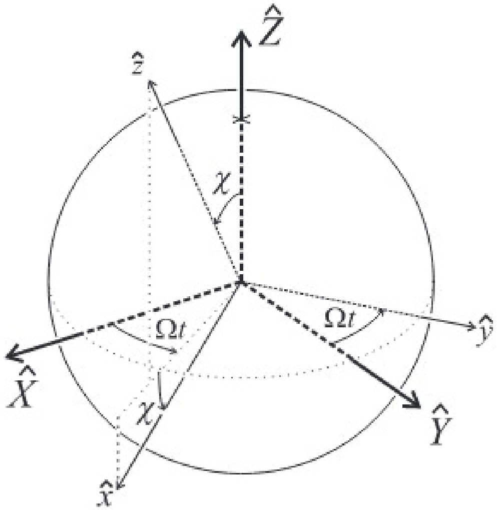
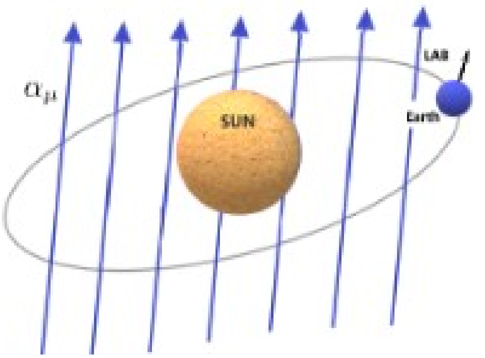


FIG. 1. Bases in the laboratory and nonrotating frames.

$$z \simeq \frac{\beta^{\mu} \Delta a_{\mu}}{\Delta m - i\Delta\Gamma/2}$$

$$\beta^{\mu} = \gamma\left(1, \vec{\beta}\right)$$

four-velocity (lab frame)



blue arrows-LV/CPTV field

sidereal modulations

$$\beta^{\mu} \Delta a_{\mu} = \gamma[\Delta a_0 + \beta \Delta a_Z \cos\chi + \beta \sin\chi(\Delta a_Y \sin\Omega\hat{t} + \Delta a_X \cos\Omega\hat{t}\,)]$$

lab frame

fixed stars frame

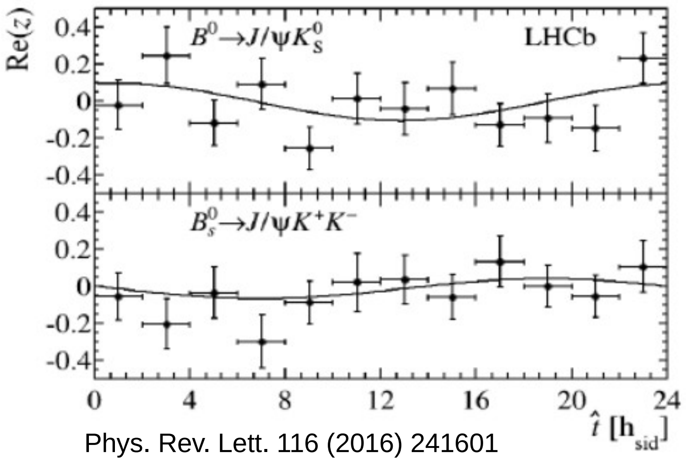
Sidereal Modulations at LHCb

$$Re(z) = \frac{\gamma}{\Delta m}[\Delta a_0 + \beta \Delta a_Z \cos\chi + \beta \sin\chi (\Delta a_Y \sin\Omega\hat{t} + \Delta a_X \cos\Omega\hat{t})].$$

- Ω and $\hat{t}$ - sidereal frequency and time respectively,
- Due to the LHCb geographical location: $\cos\chi = -0.38$ (const term), $\sin\chi = 0.92$ (sidereal modulated term)

At CERN site these modulations are close to being maximal!

Re(z) as a function of sidereal phase



Phys. Rev. Lett. 116 (2016) 241601

Current Limits on CPTV

- KLOE: $K^0 : \Delta a_0, \Delta a_{X,Y,Z} \approx 10^{-18}$ GeV
- FOCUS: $D^0 : \Delta a_0, \Delta a_{X,Y,Z} \approx 10^{-13}$ GeV
- LHCb: $B^0 : \Delta a_0, \Delta a_Z \approx 10^{-15}$ GeV, $\Delta a_X, \Delta a_Y \approx 10^{-15}$ GeV
- LHCb: $B_s^0 : \Delta a_0, \Delta a_Z \approx 10^{-12}$ GeV, $\Delta a_X, \Delta a_Y \approx 10^{-14}$ GeV

Measurements in different sectors are complementary [Data tables: arXiv:0801.0287].

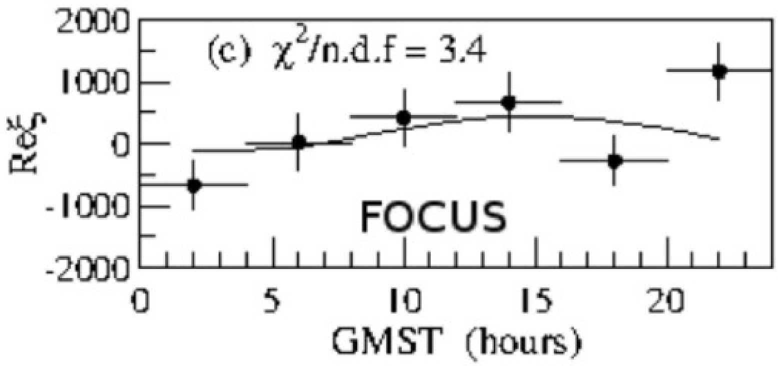
LHCb – good place to study CPTV in charm, 10^4 greater statistics compared to FOCUS and excellent decay time resolution 45fs.

Differences in accuracy stem from different masses!

FOCUS experiment (1996-1997)

- Upper limit in the charm sector from FOCUS (PLB 556 (2003)7),
- Experiment @FERMILAB (γ beam with energy of $\approx$ 180 GeV on fixed BeO target),
- $D^{*+} \to D^0\pi^+$, $D^0 \to K^-\pi^+$, both in classical and SME approach,
- $\mathrm{Re}(z) - \mathrm{Im}(z) \approx O(1)$,
- $\Delta a_\mu \approx 3 \times 10^{-13}$ GeV,

[Phys. Lett. B 556, 7 (2003)]



Expected from statistics:
N_{FOCUS}: ~ 10^4 events
N_{LHCb}: ~ 10^8
sqrt(N_{LHCb}/N_{FOCUS}) ~ 100

Goal of my analysis

- 1. Upper limits on CPTV parameters in the charm sector using LHCb data (10^4 greater statistics + excellent decay time resolution).

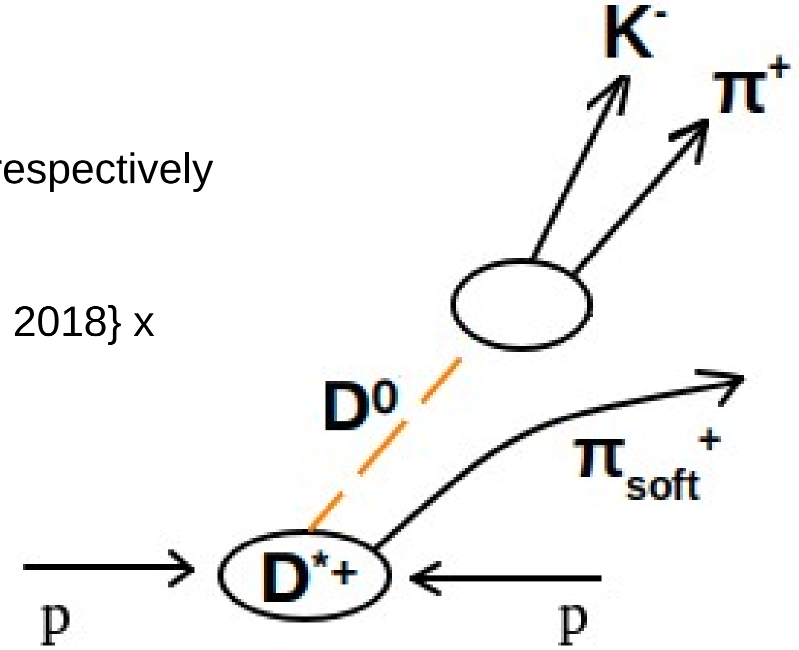
  2. The search is performed in $D^* \rightarrow \pi^+_{soft} D^0(K^- \pi^+)$ prompt channel (D^* produced in pp vertex)

Data sample

- $D^0 \rightarrow K\,\pi$ candidates from prompt
- $D^{*+/-} \rightarrow D^0\,\pi_{soft}^{+/-}$, $\pi_{soft}^{+/-}$ used to tag the flavour => $D^0/\overline{D}^0$ respectively

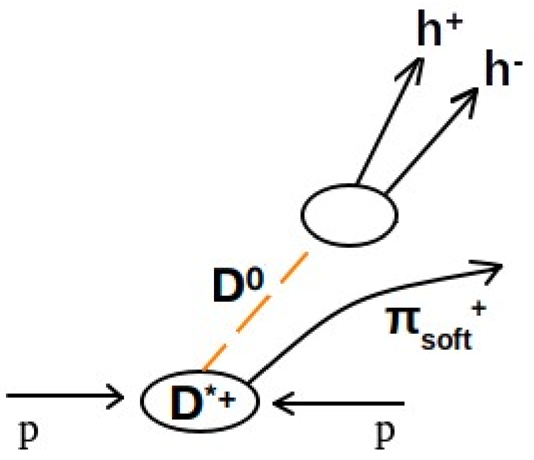
- Analysis performed with Run 2 data: {2015, 2016, 2017, 2018} x {MagUp, MagDown} (today only 2015+2016)

- L ~6 fb^{-1} @13 TeV p-p collision in Run 2

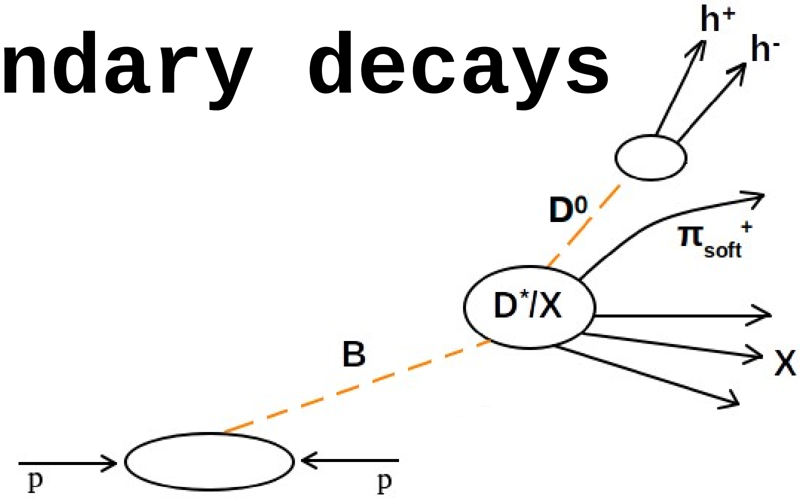


This selected mode was used as a control channel in other LHCb analyses.

Secondary decays



Primary vertex (PV)



reco. decay time

$$t = \frac{d}{c\beta\gamma} = d \cdot \frac{m}{p},$$

Displacement from PV

Fraction of registered D^0 are produced in the secondary decays of B
→ on average larger decay times

Analysis done with the assumption that all D^0 come from PV.

D0 lifetime ~= 0.41 ps
B hadrons ~= 1.5 ps

Analysis Steps

1) Trigger and offllline selection (done)

2) Combinatorial background estimation with m(D*) distribution

3) Kinematic weighting to reduce the second-order effect of detector-induced time-depend asymmetry

4) D^0 secondary decays contamination estimation

5) Control of Misreconstructed $D^0/\overline{D}^0 \rightarrow K^-\pi^+ (K^+\pi^-)$ background

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6) Formation of time-dependent right-sign A_{CPT} asymmetry (ongoing)

7) Extraction of bounds on CPT violation parameter z from asymmetry fit.

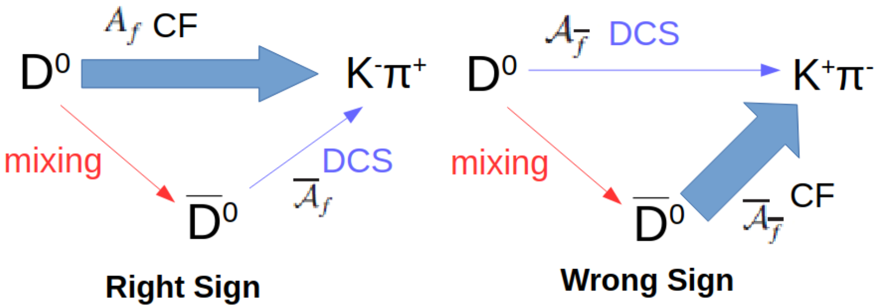
8) Analysis and systematic studies of observables and errors in sidereal time.

Observable

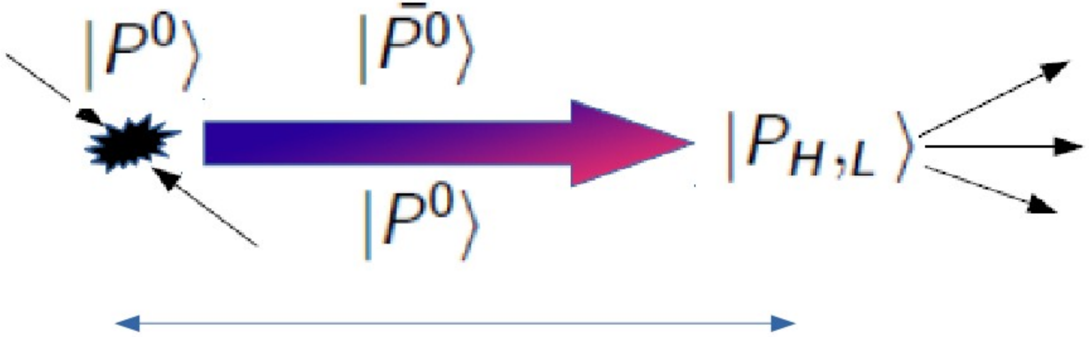
right-sign time-dependent CPT asymmetry

$$A_{CPT}(t) = \frac{\Gamma\left(\bar{P}^0 \to \bar{f}\right)(t) - \Gamma\left(P^0 \to f\right)(t)}{\Gamma\left(\bar{P}^0 \to \bar{f}\right)(t) + \Gamma\left(P^0 \to f\right)(t)}$$

$P^0 = D^0; f = K^+\pi^-$



General Experimental Idea



1. determine flavour in the initial state
2. determine decay time
3. determine flavour in the final state
4. construct (time-dependent) asymmetry $A_{CPT}(t)$
5. extract (mixing/CP/CPT) parameters from the fit

Naturally, the analysis can be performed in the time-bins enabling SME parameter extraction and sidereal modulations analysis.

τ_{D^0} ~= 0.41 ps

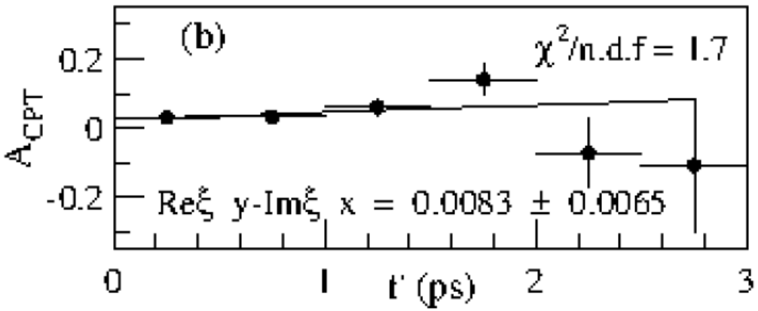
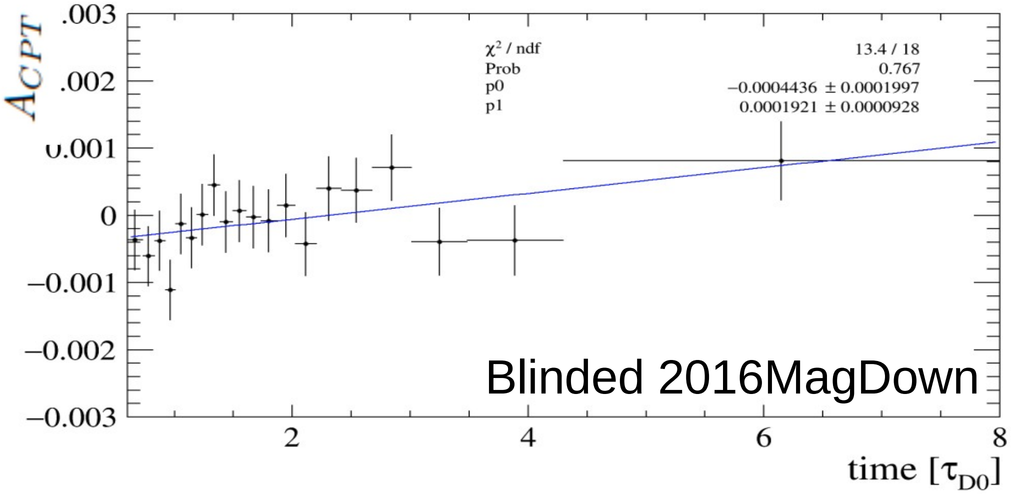


Figure: *J. Link et al., Phys. Lett. B 556, 7 (2003)*



FOCUS: Re(z)*y – Im(z)*x = [8.3 +- 6.5] *10^{-3}

LHCb expected: Re(z) * y – Im(z) *x ~ 10^{-5}

For convenience let's denote slope as:
p1= Re(z)*y – Im(z)*x

Expected from statistics:
N_{FOCUS}: ~ 10^4 events
N_{LHCb}: ~ 10^8
sqrt(N_{LHCb}/N_{FOCUS}) ~ 100

Run 2: 15-16

Bounds on z:
x,y ~ O(10^{-3}) in charm → z bound ~ O(10^{-2})

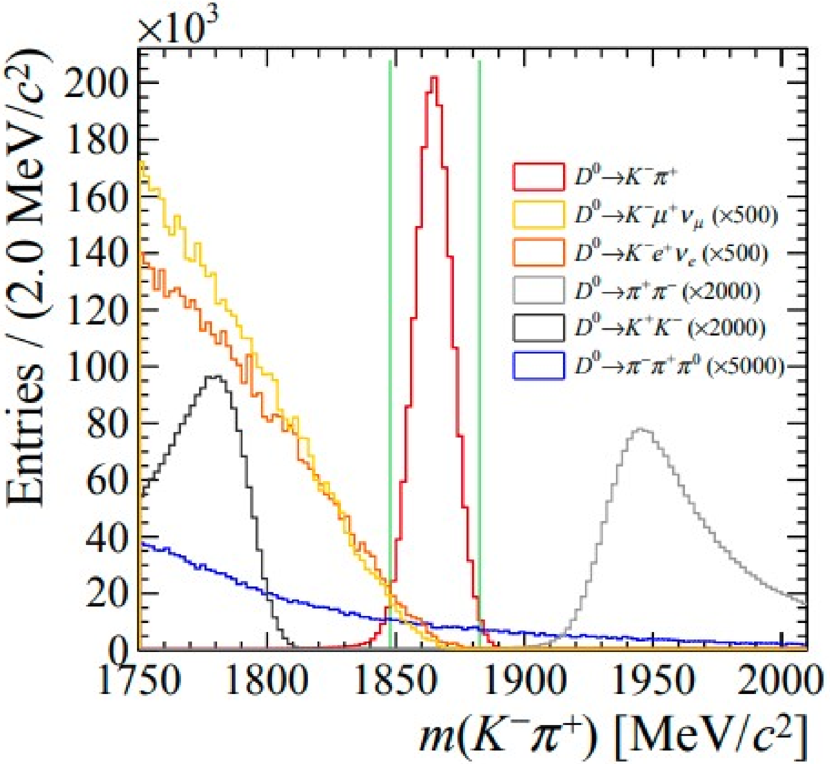
Compared with the best strange sector (KLOE, KteV) :
z bound ~O(10^{-4})

Misidentification BKG sources

- $\boxed{D^0 \to K^-\pi^+ \quad \text{SIGNAL!}}$
- $D^0 \to K^-\pi^+\pi^0$ (π^0 not rec.)
- $D^0 \to \pi^+\pi^-$ (K^- instead of π^-)
- $D^0 \to \pi^-\pi^+\pi^0$ (K^- instead of π^- + π^0 not rec.)
- $D^0 \to K^-e^+\nu_e$ (π^+ instead of e^+)
- $D^0 \to K^-\mu^+\nu_\mu$ (π^+ instead of μ^+)

Misidentification background

Sum of (weighted) misid bkgs/signal ~ 10^{-4}



Note! Mis-PID bkg. histograms scaled with scaling factors – see legend.

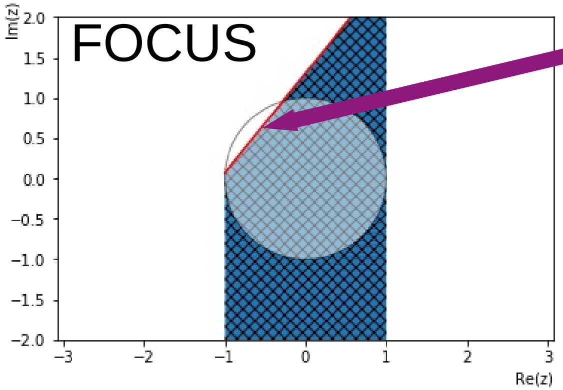
Produced using RapidSim simulated samples.

1. Events reweighted with: mis-PID efficiency (obtained with PIDCalib) and branching fractions (kinematic weights will be added soon).

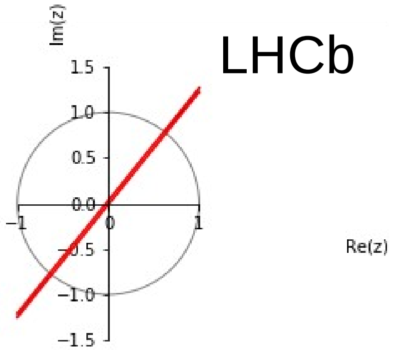
2. Calculation based on the comparison between integrals of signal and backgrounds within D* signal region.

	raw	weights applied
$K^-\pi^+$	1	1
$K^-\mu^+\nu_\mu$	$4.81 \cdot 10^{-4}$	$1.07 \cdot 10^{-4}$
$K^-e^+\nu_e$	$9.70 \cdot 10^{-4}$	$1.55 \cdot 10^{-4}$
$\pi^-\pi^+$	$4.32 \cdot 10^{-3}$	$2.18 \cdot 10^{-6}$
K^-K^+	0	0
$\pi^-\pi^+\pi^0$	$2.99 \cdot 10^{-2}$	$1.81 \cdot 10^{-5}$

Circles in the graphics below mark 0<|z|<1

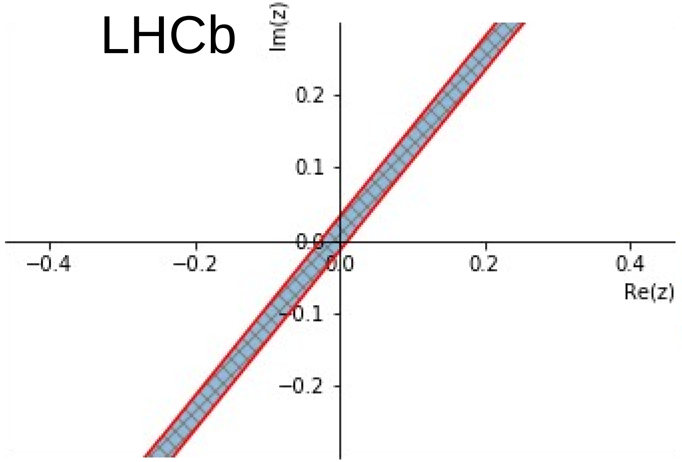


Only this bit can be excluded



Reminder:
CPT conserved =>z=0

External params from HFLAV:
X_{NoCPV} = 0.43 + 0.13 - 0.14 %
Y_{NoCPV} = 0.65 +- 0.02 %
$X_{CPVAllowed}$ = 0.407 +- 0.044 %
$Y_{CPVAllowed}$ = 0.68 +- 0.024 %



For convenience let's denote slope as:

$$p1 = Re(z) \cdot y - Im(z) \cdot x$$

The read lines in the plots are given with the following system of equations:

$$\begin{cases} p1^{up}@95\%CL = Re(z) \cdot y - Im(z) \cdot x \\ p1^{down}@95\%CL = Re(z) \cdot y - Im(z) \cdot x. \end{cases}$$

Phys. Lett. B 742, 236 (2015)

Summary

- Due to large statistics and excelent decay time resulution at LHCb in $D^* \rightarrow \pi^+_{soft} D^0(K^- \pi^+)$ prompt channel =>

  => we might expect improvement on the limits on FOCUS results by the factor of 100.

- Control of systematic and statistical errors constitute a significant part of my work (not fully covered here).
- We conseqently move the precision to CPTV in the direction of the Planck scale.
- We expect to achieve the highest sensitivity to SME target CPTV parameters in the charm sector.

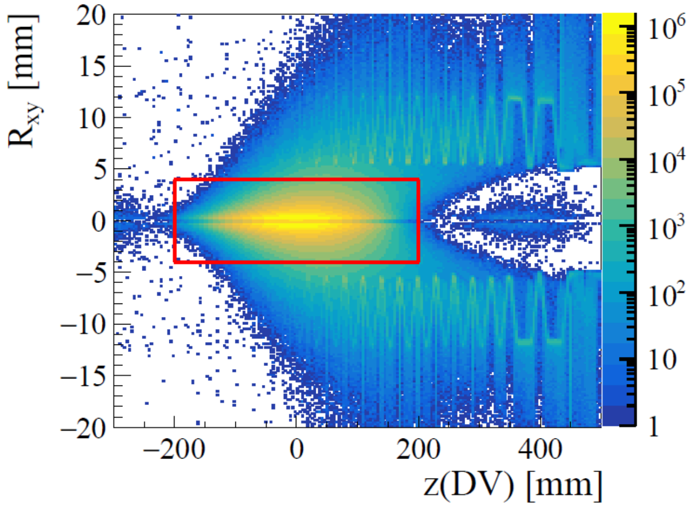
BACK UP

Trigger requirements

- $D^0 \rightarrow h^+h^-$ candidates from prompt $D^{*+} \rightarrow D^0 \pi_{soft}^+$, π_{soft}^+ used for D^0 flavour tagging
- L0 trigger: **D0_L0HadronDecision_TOS || Dst_L0Global_TIS**
- HLT1: **D0_Hlt1TrackMVADecision_TOS || D0_Hlt1TwoTrackMVADecision_TOS**

Event Selection - Offline

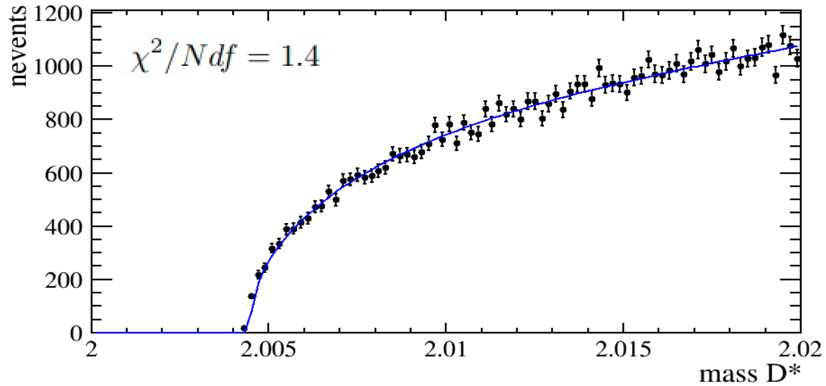
Name	Offline
$m(D^0)$	$\in [1840.84, 1888.84]$ MeV
$\mathrm{DLL}(K^\pm)$	$<= -5$
$\mathrm{DLL}(\pi^\pm)$	$>= 5$
Rxy	$<= 4$ mm
$\lvert z(DV)\rvert$	$\in [-200, 200]$ mm
track-based ghost probabiliy $(\pi_s^\pm)$	$<= 0.15$
D^{*+} vertex-fit χ^2/ndf	$<= 25$
$p_T(\pi_s^\pm)$	$>= 200$ MeV
D^0 proper decay time	$\in [0.45, 8]\ \tau(D^0)$
$IP(D^0)$	< 9

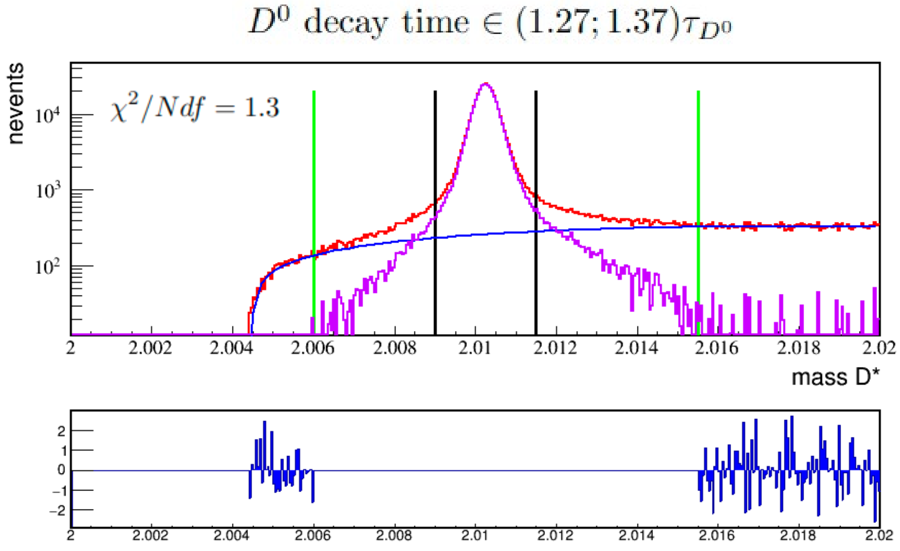


$$R_{xy} = \mathrm{sgn}[x(\mathrm{DV}) - x(\mathrm{PV})]\sqrt{(x(\mathrm{DV}) - x(\mathrm{PV}))^2 + (y(\mathrm{DV}) - y(\mathrm{PV}))^2}$$

Selection criteria analogous to LHCb-ANA-2020

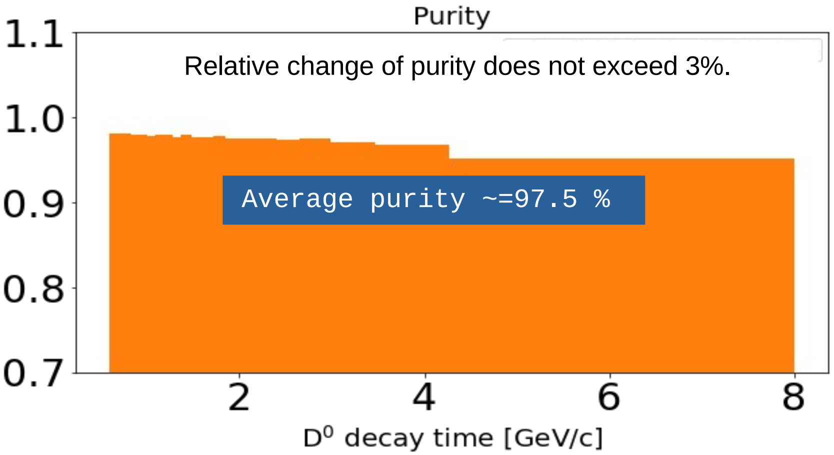
Combinatorial background

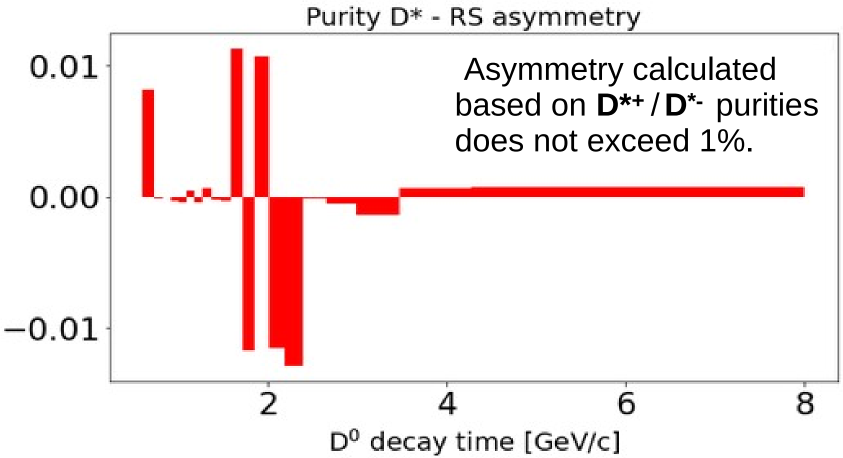




$$P_{\text{bkg}}(m) = \theta_H\left(m^2 - m_0^2\right) N\left[1 + \alpha(m - m_0) + \beta(m - m_0)^2\right]\sqrt{m^2 - m_0^2}$$

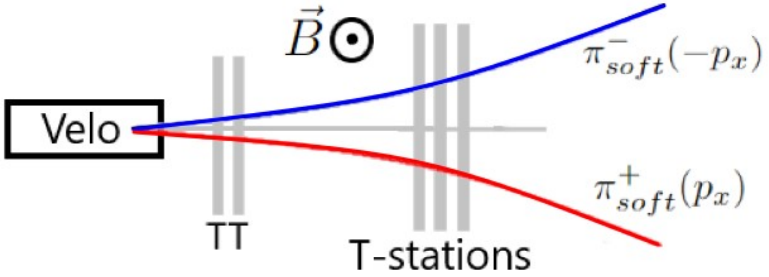
$$m_0 = D^0 \text{ PDG mass} + \pi^+ \text{ PDG mass}$$

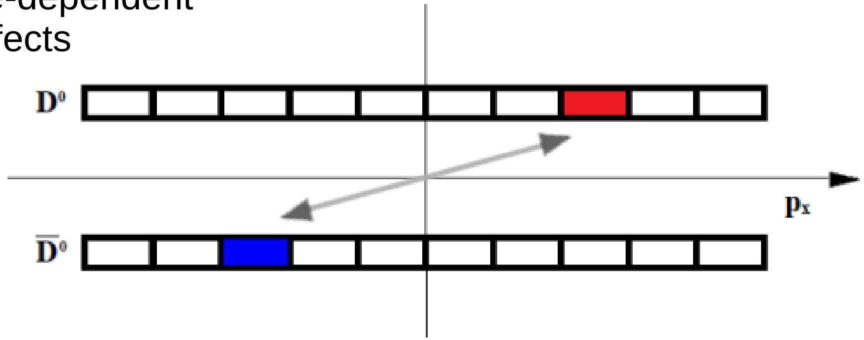




Kinematic Weighting

Equalisation of time-dependent detector effects





Inspired by: Agamma - LHCb-ANA-2018-030

- Detection should be symmetric with respect to the transformation:
  $x \rightarrow -x$ && $q_s \rightarrow -q_s$
- Currently one-step procedure used reweigh the events in 3-D bins of D^0 momenta
- Geometric mean with additional fiducial cuts
- Weighing performed separately for Run periods and Magnet positions

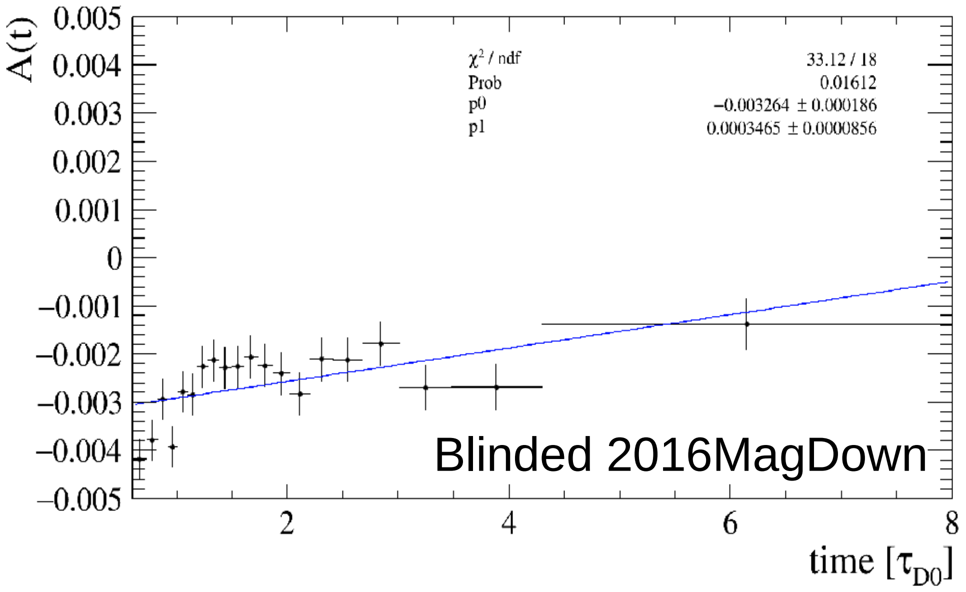
Representation of D^0:

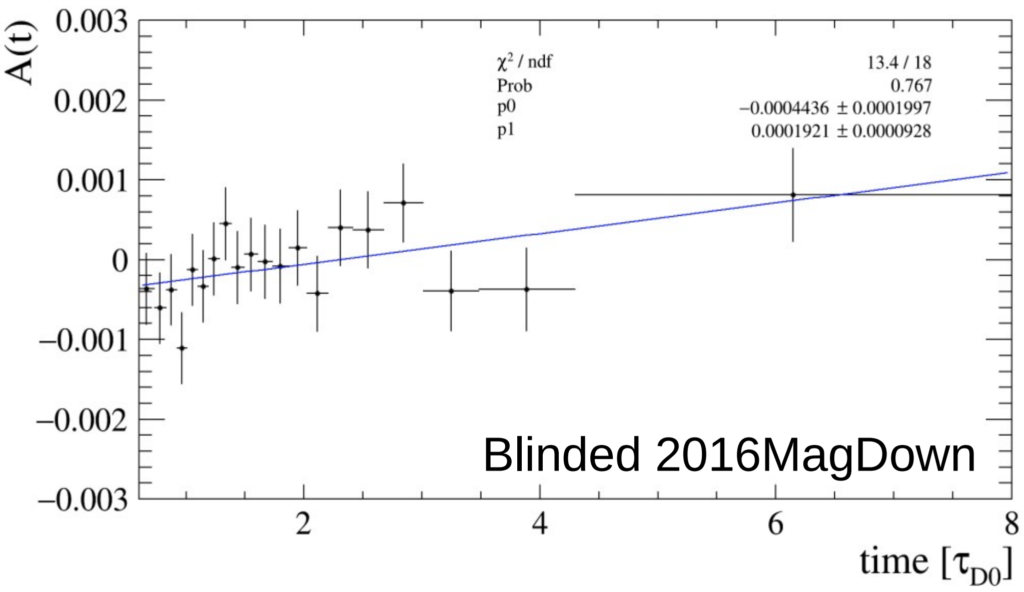
- θ_x = atan2(Px/P_z)*sgn(π_{soft})
- θ_y = atan2(P_y/P_z)
- k = 1/sqrt($P_x^2 + P_z^2$)

Method taken from [**Agamma - LHCb-ANA-2020-040**]

Kinematic weighting

$$p1 = Re(z) \cdot y - Im(z) \cdot x$$





Before kin. weighting After kin. weighting

Secondary decays

$$N_{\text{prim}}(t) = N^{+}_{\text{prim}}(t) + N^{-}_{\text{prim}}(t)$$
$$N_{\text{sec}}(t) = N^{+}_{\text{sec}}(t) + N^{-}_{\text{sec}}(t)$$
$$f_{\text{sec}}(t) = N_{\text{sec}}(t) / \left[N_{\text{prim}}(t) + N_{\text{sec}}(t)\right]$$

$$A_{\text{sec}}(t) = \frac{N^{+}_{\text{sec}}(t) - N^{-}_{\text{sec}}(t)}{N^{+}_{\text{sec}}(t) + N^{-}_{\text{sec}}(t)}$$

$$A_{\text{prim}}(t) = \frac{N^{+}_{\text{prim}}(t) - N^{-}_{\text{prim}}(t)}{N^{+}_{\text{prim}}(t) + N^{-}_{\text{prim}}(t)}$$

$$\boxed{\begin{aligned} A_{\text{raw}}(t) &= \left[1 - f_{\text{sec}}(t)\right] \cdot A_{\text{prim}}(t) + f_{\text{sec}}(t) \cdot A_{\text{sec}}(t) \\ &= A_{\text{prim}}(t) + \boxed{f_{\text{sec}}(t) \cdot \left[A_{\text{sec}}(t) - A_{\text{prim}}(t)\right]} \end{aligned}}$$

For the analysis we need to estimate the values of N_{prim} and N_{sec}:

→ next presentation

Fitting Strategy

$$A_{CPT}(t) = \frac{\frac{d\Gamma_{\bar{M}^0\to\bar{f}}(t)}{dt} - \frac{d\Gamma_{M^0\to f}(t)}{dt}}{\frac{d\Gamma_{\bar{M}^0\to\bar{f}}(t)}{dt} + \frac{d\Gamma_{M^0\to f}(t)}{dt}} \qquad A^{\text{dir}} \equiv (|\bar{A}_{\bar{f}}|^2 - |A_f|^2)/(|\bar{A}_{\bar{f}}|^2 + |A_f|^2)$$

$$A_{CPT}(t) = A^{\text{dir}} + \frac{2\mathrm{Re}(z)\sinh\Delta\Gamma t/2 - 2\mathrm{Im}(z)\sin\Delta m t}{(1+|z|^2)\cosh\Delta\Gamma t/2 + (1-|z|^2)\cos\Delta m t}$$

$$A_{CPT}(t) = A^{dir} + [Re(z)y - Im(z)x]\,\Gamma t$$ (Linear term Taylor expansion in t.)

$$A_{CPT}(t) = \frac{Re(z)\,(x^2+y^2)}{2x}(\Gamma t)^2\left[\frac{xy}{3}\left(\Gamma t + \sqrt{R_{DCS}}\,(x\cos\delta + y\sin\delta)\right)\right]$$ (Second non zero term in Taylor)

Term responsible for doubly cabibbo supressed.

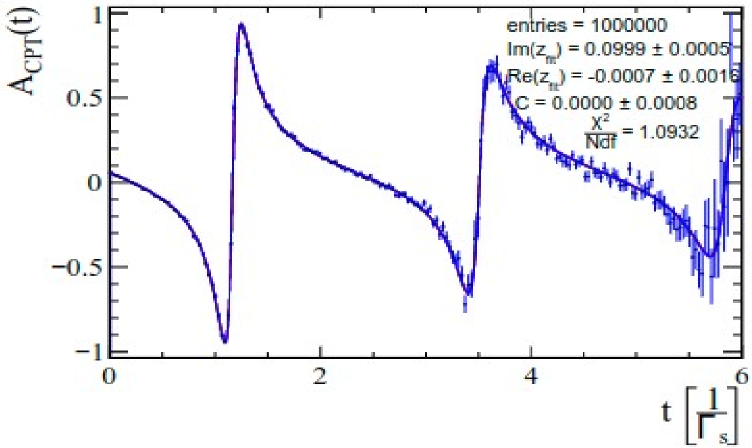
Sensitivity studies based toy MC generator

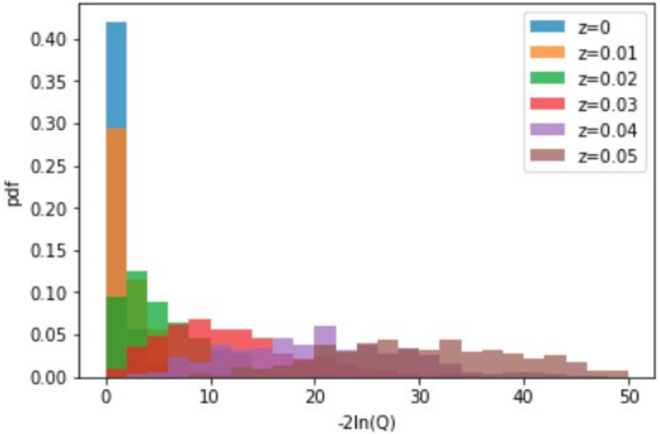
1. MC generator of neutral meson decays. We can set CP/CPT violation scale before simulation through the choice of CPV/CPTV parameter values (p,q,z).

2. It can be used to generate times of decay of any meson.

3. Generated times of decay can be used to build right-sign asymmetry histogram.

4. Finally, CPTV parameters can be extracted from fits of the phenomenolgical/SME model to the aforementioned right-sign asymmetry.





-2ln(Q) => test-statistic

We're testing z=0 hypothesis vs z≠0. Likelihood based tastes possible e.g. CLs.