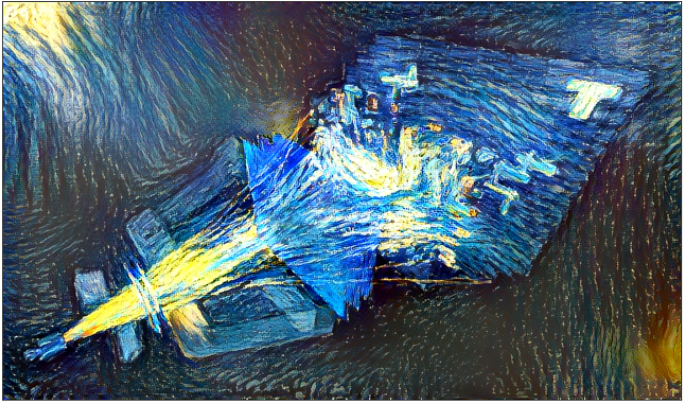

Search for the decay $D_s^*(2317)^\pm \to D_s^{*\pm}\gamma$

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LHCb Summer Student Presentations,
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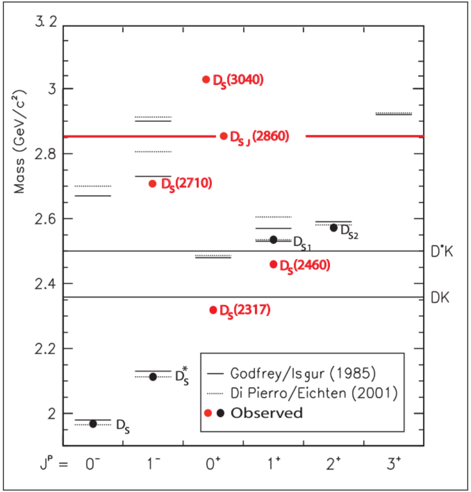
Who am I?

- Master student at TU Dortmund, Germany
- Bachelor thesis in LHCb Group of Dortmund
  → likelihood-based test statistics
  for upper limit setting
- Besides physics: collecting jazz records,
  playing trumpet, pool and snooker

Motivation for strange-charmed meson spectroscopy

- most heavy-light meson states successfully predicted by quark potential models in HQET limit
- expectation of ${}^{j}P_J$-wave states doubly degenerated in spin of the heavy quark
- HQET calculations expect width of the ${}^{1/2}P_J$-states to be broad and above the DK/D^*K threshold
- conventional excited states are expected to decay with large BR via radiative transitions
- $D_s^*(2317)^\pm$ and $D_s^*(2460)^\pm$ were a surprising discovery

[2]



[2] P. Gianotti: *Results and perspectives in hadron spectroscopy*, Phys. Scr. (2012) 014014, doi:10.1088/0031-8949/2012/T150/014014

Current Status of $D_s^*(2317)^+$ measurements

- $D_s^*(2317)^+$ first seen by the BABAR Collaboration in the channel $D_s^+\pi^0$[3]
- confirmation by CLEO Collaboration, search for $D_s^*(2317)^+ \to D_s^{*+}\gamma$

$$R = \frac{BR(D_s^*(2317)^+ \to D_s^{*+}\gamma)}{BR(D_s^*(2317)^+ \to D_s^+\pi^0)} < 0.059^{[4]}$$

- confirmed by BELLE Collaboration, compatible with mass measured by BABAR and CLEO

$$R = \frac{BR(D_s^*(2317)^+ \to D_s^{*+}\gamma)}{BR(D_s^*(2317)^+ \to D_s^+\pi^0)} < 0.18^{[5]}$$

- theory predictions on R give 0.06-0.16

Open questions

- Why can't we measure the radiative transition?
- How are the low masses explainable?

Proposed solutions

- hadronic DK molecule supported by absence of large total width and radiative transitions
- multiquark compound

[3] BABAR Collaboration, B. Aubert et. al., Phys. Rev. Lett. 90 (2003) 242001, arXiv:hep-ex/0304021
[4] CLEO Collaboration, D. Besson et al., Phys. Rev D68 (2003) 032002, arXiv:hep-ex/0305100
[5] BELLE Collaboration, Y. Mikami et al. , Phys. Rev. Lett. 92 (2004) 012002, arXiv:hep-ex/0307052

Strategy for search

- goal is to measure radiative decay
- search via measurement of

$$R = \frac{\text{BR}(D_s^*(2317)^\pm \to D_s^{*\pm}\gamma, D_s^{*\pm} \to D_s^\pm\gamma)}{\text{BR}(D_s^*(2317)^\pm \to D_s^\pm\pi^0, \pi^0 \to \gamma\gamma)}$$

- performing a common $D_s^\pm \to K^+K^-\pi^\pm$ selection
- select neutrals by profiting from small phase space and studying narrow cone around $D_s^\pm$ flight direction to reduce background
- using resolved π^0 to build $D_s^*(2317)^\pm \to D_s^\pm\pi^0$
- build $D_s^{*\pm}$, fit the peak and performing SPlot to extract sweights
- build $D_s^*(2317)^\pm \to D_s^{*\pm}\gamma$ with weights
- taking advantage from the similarity of the selections to cancel uncertainties

$$\frac{N(D_s^*(2317)^\pm \to D_s^{*\pm}\gamma)}{N(D_s^*(2317) \to D_s^\pm\pi^0)} = \frac{\text{BR}(D_s^*(2317)^\pm \to D_s^{*\pm}\gamma)}{\text{BR}(D_s^*(2317)^\pm \to D_s^\pm\pi^0)} \frac{\varepsilon_{\text{sel}}{}^{\pi^0}}{\varepsilon_{\text{sel}}{}^{2\gamma}} \underbrace{\frac{\varepsilon_{\text{rec}}{}^{\gamma_0}\varepsilon_{\text{rec}}{}^{\gamma_1}}{(\varepsilon_{\text{rec}}{}^{\gamma})^2}}_{\approx 1} \frac{\varepsilon_{\text{trig}}\varepsilon_{\text{rec}}^{KK\pi}\varepsilon_{\text{sec}}^{KK\pi}}{\varepsilon_{\text{trig}}\varepsilon_{\text{rec}}^{KK\pi}\varepsilon_{\text{sec}}^{KK\pi}} \frac{\mathcal{L}\sigma(pp \to c\bar{c})f_{Ds(2317)}}{\mathcal{L}\sigma(pp \to c\bar{c})f_{Ds(2317)}}$$

Reconstruction of the $D_s^\pm$ mesons

- using data collected in 2016 and 2017 in StrippingD2hhhFTCalib_KKPLine
- Reconstruction in the channel

$$D_s^\pm \to \phi(1020)\pi^\pm, \phi(1020) \to K^+K^-$$

- from stripping S28r1 to S29r2 change based on Dalitz structure[6]:

$$m(K^+K^-) \in [1012.461, 1026.461]\text{MeV}$$

→ within ± 7 MeV of the $\phi(1020)$-mass

- exluding background from $\Lambda_c^\pm \to (p \overset{\text{misid.}}{\to} K^+)K^-\pi^\pm$ by assigning m_p to K^+ and recalculating energy

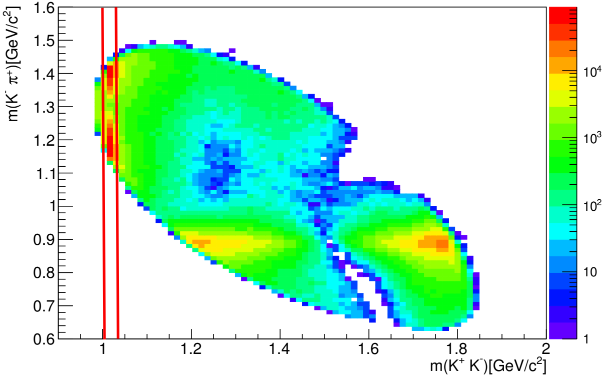


Figure: Dalitz plot of $D_s^+ \to K^+K^-\pi^+$ on RapidSim[7][8] simulation with 5 million events.

[6]LHCb StrippingD2hhhFTCalib_KKPLine stripping lines: stripping28r1 stripping29r2

Simulations with RapidSim

RapidSim[7][8]

- Framework to generate Monte Carlo for heavy-quark hadrons rapidly
- predefined LHCb geometry for acceptance but no interaction with detector

Tasks

- studying kinematics for $D_s^*(2317)^\pm \to D_s^\pm \pi^0$ and $D_s^*(2317)^\pm \to (D_s^{*\pm} \to D_s^\pm \gamma_0)\gamma_1$
- verify that cone size $\Delta R = 0.4$ around the $D_s^\pm$ flight direction covers both photons
- calculating selection efficiencies

- using RapidSim simulation because real Monte Carlo not available
- cone size described by angular separation

$$\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\varphi)^2}$$

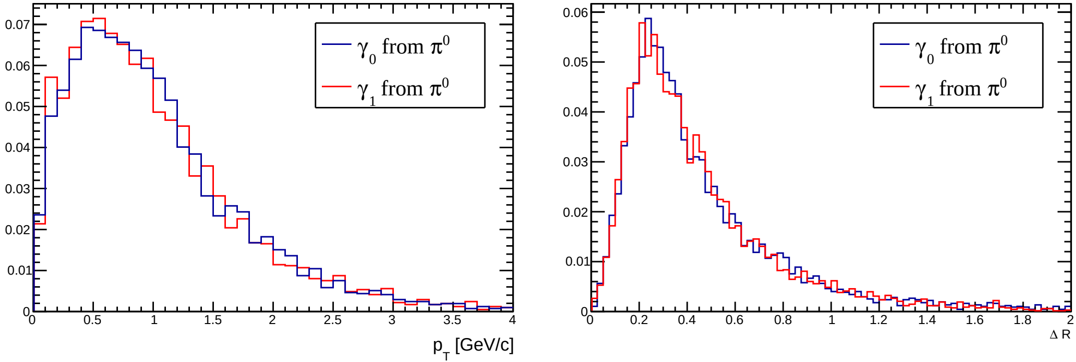
- looking for a p_T cutoff value and asymmetry between the two photons

$$A_{\mathrm{PT}}(\gamma_0, \gamma_1) = \frac{p_{\mathrm{T}}(\gamma_0) - p_{\mathrm{T}}(\gamma_1)}{p_{\mathrm{T}}(\gamma_0) + p_{\mathrm{T}}(\gamma_1)}$$

[7] G. A. Cowan, D. C. Craik and M. D. Needham, Comput. Phys. Commun. 214 (2017) 239-246, arXiv:1612.07489
[8] https://github.com/gcowan/RapidSim

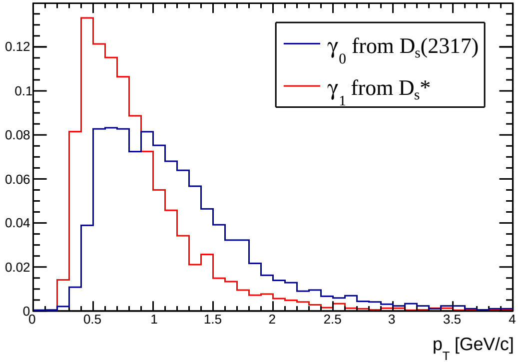
Results for $D_s^*(2317)^\pm \to D_s{}^\pm\pi^0, \pi^0 \to \gamma\gamma$

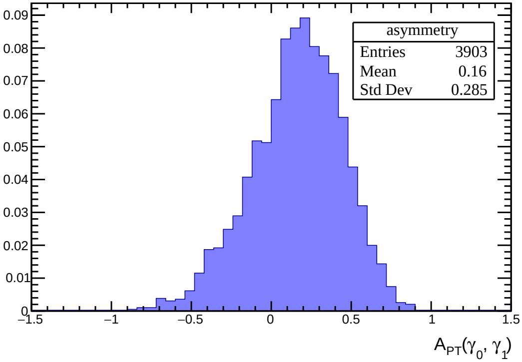
- transverse momenta identical, because photons indistinguishable
- π^0 are mainly resolved → cut on $p_\mathrm{T} \in [0.2, 1.5]$**GeV** to exclude merged π^0
- cone size of $\Delta R = 0.4$ contains most of the signal



Results for $D_s^*(2317)^\pm \to {D_s}^{*\pm}\gamma_0, {D_s}^{*\pm} \to {D_s}^{\pm}\gamma_1$

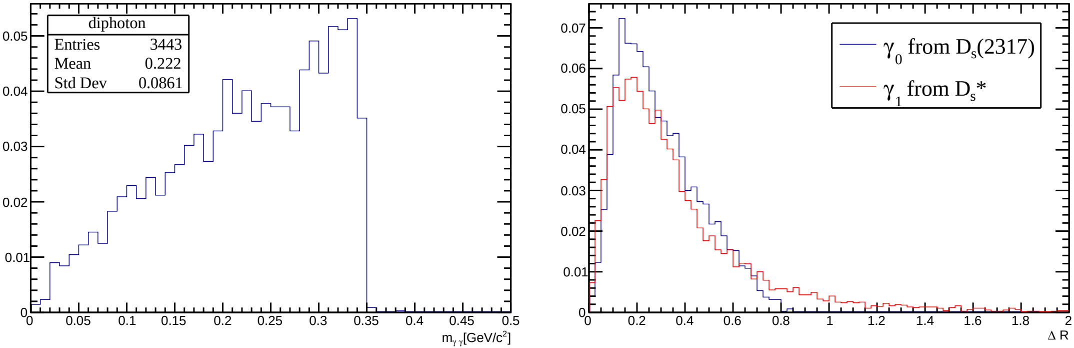
- cuts on p_T between **0.2 GeV** and **1.5 GeV** reasonable to exclude background from merged π^0
- transverse momentum distributions slightly different, asymmetry tends to $p_\mathrm{T}(\gamma_0) > p_\mathrm{T}(\gamma_1)$





Results for $D_s^*(2317)^\pm \to {D_s}^{*\pm}\gamma_0, {D_s}^{*\pm} \to {D_s}^\pm\gamma_1$

- mass veto in π^0 mass range possible without losing much signal
- $m_{\gamma\gamma}$ limited by available phase space → cut on $m_{\gamma\gamma}$ can reduce background from random photons
- cut on cone size at $\Delta R = 0.4$ covers most of the photons



Conclusion of results from simulation

For both channels

- narrow cone size of $\Delta R = 0.4$ covers most of the photons, so that the small phase space can be used to reduce background
- cut on p_{T} between 0.2 GeV and 1.5 GeV can be applied to exclude high energetic and very low energetic photons
- selection efficiencies ${\varepsilon_{\mathrm{sel}}}^{\pi^0} = 45.56\,\%$ and ${\varepsilon_{\mathrm{sel}}}^{2\gamma} = 27.49\,\%$

$D_s^*(2317)^\pm \to D_s^\pm \pi^0$

- resolved pions expected, no asymmetry in transverse momentum

$D_s^*(2317)^\pm \to D_s^{*\pm} \gamma$

- small asymmetry between the p_{T} of the two photons → $p_{\mathrm{T}}(\gamma_0) > p_{\mathrm{T}}(\gamma_1)$, identify γ_0 as photon with maxPT inside the cone, and γ_1 as the one with secPT

Overview of the applied cuts

$D_s^{\pm} \to K^+K^-\pi^{\pm}$	$D_s^*(2317)^{\pm} \to D_s^{\pm}\pi^0$	$D_s^*(2317)^{\pm} \to D_s^{*\pm}\gamma$

$D_s^{\pm} \to K^+K^-\pi^{\pm}$

- kinematics

$$p_{\mathrm{T}}(K^+, K^-, \pi^{\pm}) > 1.5\,\text{GeV}$$
$$p_{\mathrm{T}}(D_s^{\pm}) > 5\,\text{GeV}$$

- ϕ mass range

$$|m(K^+K^-) - m_{\phi}| \leq 7\,\text{MeV}$$

- Particle identification

$$\text{ProbNNk}(K^+, K^-) > 0.8$$

- exclude $\Lambda_c^{\pm}$

$$|m((K^+ \to p)K^-\pi^{\pm}) - m(\Lambda_c^{\pm})| > 33\,\text{MeV}$$

$D_s^*(2317)^{\pm} \to D_s^{\pm}\pi^0$

- photon likelihood

$$CL(\gamma) > 0.6$$

- exclude merged pions

$$p_{\mathrm{T}}(\gamma_{1/2}) < 1.5\,\text{GeV}$$

- π^0 mass range

$$|m(\gamma\gamma) - m_{\pi^0}| \leq 25\,\text{MeV}$$

- cone around D_s

$$\Delta R(D_s, \gamma) < 0.4$$

$D_s^*(2317)^{\pm} \to D_s^{*\pm}\gamma$

- photon likelihood

$$CL(\gamma) > 0.6$$

- exclude merged pions and low energetic photons

$$p_{\mathrm{T}}(\gamma_{1/2}) \in [0.2, 1.5]\,\text{GeV}$$

- exlude pions and random photons

$$|m(\gamma\gamma) - m_{\pi^0}| > 25\,\text{MeV}$$
$$m(\gamma\gamma) < 0.5\,\text{GeV}$$

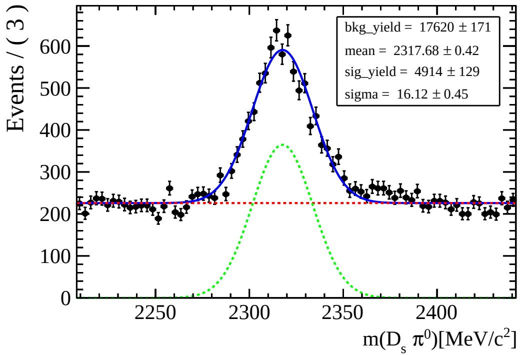
- cone around D_s

$$\Delta R(D_s, \gamma) < 0.4$$

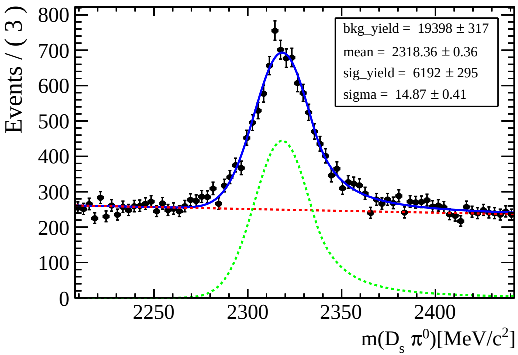
$D_s^*(2317)^\pm$ yield in $D_s^\pm \pi^0$ channel

- $m(D_s^\pm \pi^0) - m(D_s^\pm) + 1968.27$ MeV $- m(\pi^0) + 134.9766$ MeV to get a better peak resolution
- signal peak modelled with Crystall Ball and background with Exponential
- combining data from 2016 and 2017 yields in approximately 11000 events →largest yield ever observed in this channel

(2016)



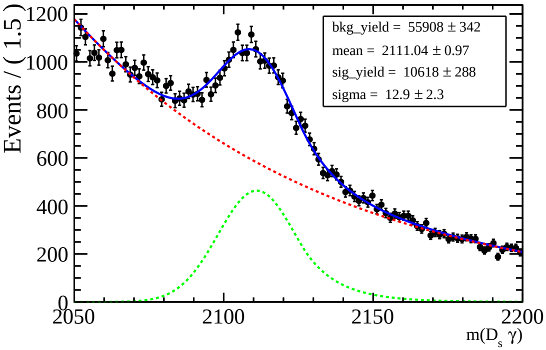
(2017)



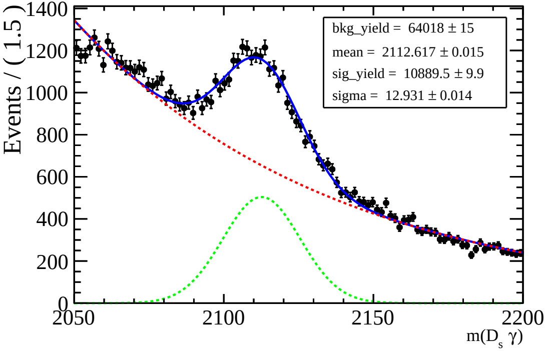
SPlot for the $D_s^{*\pm}$

- $m(D_s^\pm\gamma) - m(D_s^\pm) + 1968.27$ MeV to get a better peak resolution
- performing an SPlot[9] of the reconstructed $D_s^{*\pm}$ to weigh each event's likelihood of being signal

(2016)



(2017)

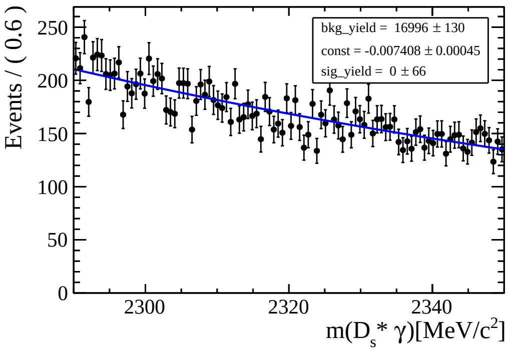


[9] M. Pivk and F. Le Diberder, Nucl. Instrum. Meth. A555 (2005) 356-369, arXiv:physics/0402083

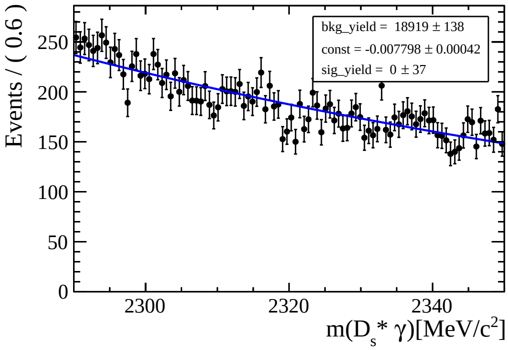
Yield for $D_s^*(2317)^\pm \to D_s^{*\pm}\gamma$

- reconstruction with sweighted $D_s^{*\pm}$
- $m(D_s^{*\pm}\gamma) - m(D_s^{*\pm}) + 2112.1$ MeV to get a better peak resolution

(2016)



(2017)



- considering theory predictions for the decay rate (6-16 %) at least 1000 events are expected

Conclusion and outlook

- evolved common $D_s^\pm \to K^+ K^- \pi^\pm$ selection and developed a selection for the $D_s^*(2317)^\pm$ decay channels
- existence of $D_s^*(2317)^\pm \to D_s^\pm \pi^0$ confirmed with largest ever observed yield in this channel
- no hint for the decay $D_s^*(2317)^\pm \to D_s^{*\pm}\gamma$

- setting expected upper limit on BR$(D_s^*(2317)^\pm \to D_s^{*\pm}\gamma)$/BR$(D_s^*(2317)^\pm \to D_s^\pm \pi^0)$ with the CL$_s$ method
- requesting real Monte Carlo to evaluate and determine efficiencies and systematic uncertainties