Zerfälle von B- und D-Mesonen in Endzustände aus neutralen Kaonen bei LHCb

B- and D-meson decays to two neutral kaons at LHCb

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Outline

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Decays into two neutral kaons

Measure *CP* violation (*CP*V) and search for new physics (NP)

- $B_d^0, B_s^0, D^0 \to K_s^0 K_s^0, K_s^0 K^{*0}, K_s^0 \bar{K}^{*0}$ and $K^{*0} \bar{K}^{*0}$
- can be detected via $K_s^0 \to \pi^+ \pi^-$ and $K^{*0} \to K^+ \pi^-$
- most of these decays have not yet been observed before
  $\to$ make first observations and measure branching ratios

In this introduction I will

- show the current experimental status
- briefly remind you about *CP* violation
- give you a short overview of the LHCb experiment

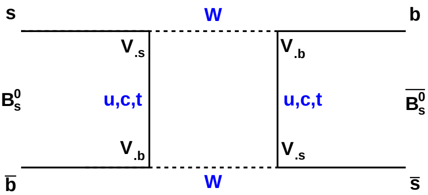
Experimental status

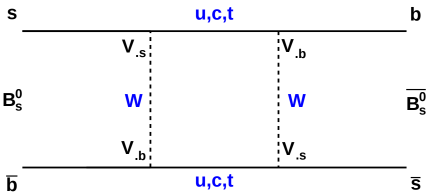
decay	BR $[10^{-5}]$ (PDG live)	CPV measurements
$B_s^0 \to K^{*0}\bar{K}^{*0}$	(2.8 ± 0.7)	–
$B_s^0 \to K_s^0 K^{*0}$	—	–
$B_s^0 \to K_s^0 \bar{K}^{*0}$		–
$B_s^0 \to K_s^0 K_s^0$	< 6.6 $(K^0\bar{K}^0)$	–
$B_d^0 \to K^{*0}\bar{K}^{*0}$	0.08 ± 0.05	–
$B_d^0 \to K_s^0 K^{*0}$	< 0.19 $(\bar{K}^{*0}K^0 + K^{*0}\bar{K}^0)$	–
$B_d^0 \to K_s^0 \bar{K}^{*0}$		–
$B_d^0 \to K_s^0 K_s^0$	$0.096^{+0.020}_{-0.018}$	first meas. exist[1]
$D^0 \to K^{*0}\bar{K}^{*0}$	7 ± 5	–
$D^0 \to K_s^0 K^{*0}$	< 28	–
$D^0 \to K_s^0 \bar{K}^{*0}$	< 50	–
$D^0 \to K_s^0 K_s^0$	17 ± 4	$\mathcal{A}_{CP}^{\mathrm{dir}} = (-23 \pm 19)\ \%$[2]

[1] PRL 97 (2006) 171805, PRL 100 (2008) 121601

[2] CLEO, Phys. Rev. D63 (2008) 071101

Flavor mixing





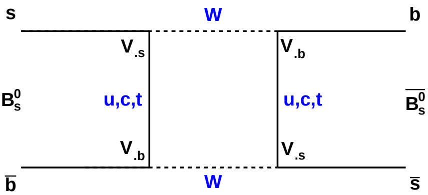
- similar for B_d^0, K^0, D^0
- new physics could come in, replacing u, c, t, W-propagators

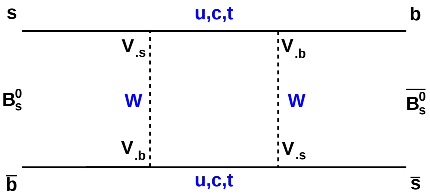
The CKM-matrix:

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

where:
d, s, b – mass eigenstates
d', s', b' – weak eigenstates

Flavor mixing





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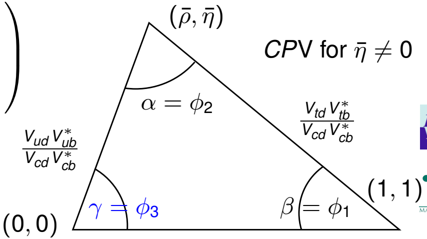
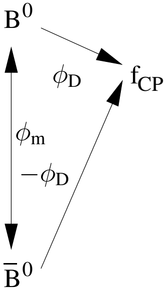
Standard unitarity triangle:

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$



*CP*V in interference between mixing and decay

$B^0 \to f_{CP}$ and $B^0 \to \overline{B^0} \to f_{CP}$, if f_{CP} is *CP*-eigenstate.



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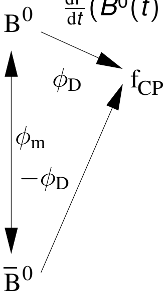
$$\frac{\frac{\mathrm{d}\Gamma}{\mathrm{d}t}(\overline{B^0}(t) \to f_{CP}) - \frac{\mathrm{d}\Gamma}{\mathrm{d}t}(B^0(t) \to f_{CP})}{\frac{\mathrm{d}\Gamma}{\mathrm{d}t}(\overline{B^0}(t) \to f_{CP}) + \frac{\mathrm{d}\Gamma}{\mathrm{d}t}(B^0(t) \to f_{CP})} = \mathcal{A}^{\mathrm{mix}}_{f_{CP}} \sin(\omega t) + \mathcal{A}^{\mathrm{dir}}_{f_{CP}} \cos(\omega t) + \ldots$$



$\mathcal{A}^{\mathrm{mix}}_{f_{CP}} = \mathcal{A}^{\mathrm{mix}}_{f_{CP}}(\phi_m, \phi_D)$ function of unitary triangle angles

CPV in interference between mixing and decay

$B^0 \to f_{CP}$ and $B^0 \to \overline{B^0} \to f_{CP}$, if f_{CP} is CP-eigenstate.

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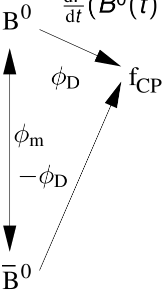

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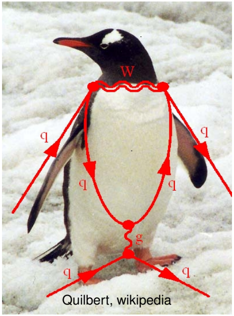
NP also in decay through penguin diagrams (diagrams with loops)

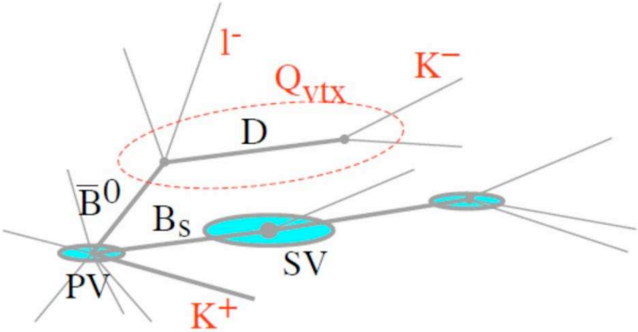


Quilbert, wikipedia

Flavor tagging

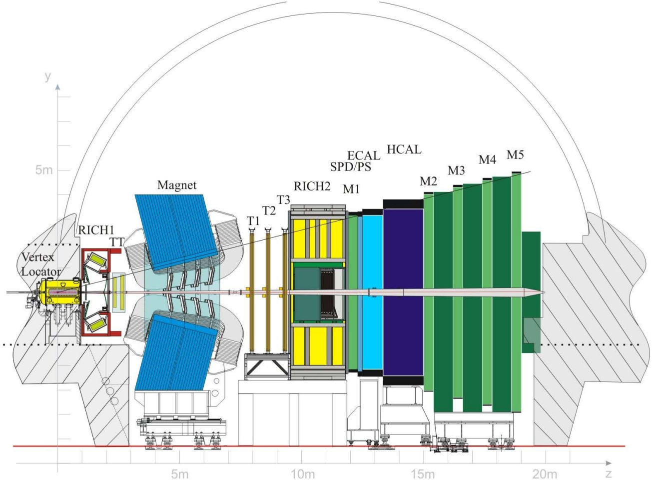
Deduce if a B/D or $\overline{B}/\overline{D}$ meson was created $\rightarrow$ flavor tagging

- D^0 can be tagged very efficiently:
  $D^{*+} \rightarrow D^0\pi^+$ versus $D^{*-} \rightarrow \overline{D}^0\pi^-$
- for B more involved



- tagging power D: effective tagging capability
- typical values for B-tagging at LHCb are $D \sim 2$ %
  (Eur. Phys. J. C 72 (2012) 2022) – could become 3 % for B_s^0

The LHCb detector at the LHC



optimized for *b*-and *c*-physics

unique kinematic range: $2 < \eta < 5$, down to $p_T \approx 0$

- excellent vertex resolution and tracking
- good particle identification (RICH: $\pi/K/p$, ECAL: e/γ, MUON)
- trigger: L0 (hardware: HCAL,ECAL,MUON: high p_T particles)
  HLT (software: global event reconstruction and selection)

LHCb *pp*-data at $\sqrt{s} = 7$ TeV and 8 TeV

Integrated luminosity altogether: $\mathcal{L} \sim 3\ \text{fb}^{-1}$

2010:

- $\sqrt{s} = 7$ TeV
- $\mathcal{L} = 38\ \text{pb}^{-1}$

2011:

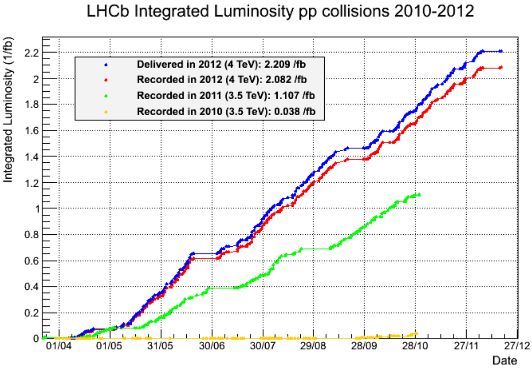
- $\sqrt{s} = 7$ TeV
- $\mathcal{L} = 1\ \text{fb}^{-1}$

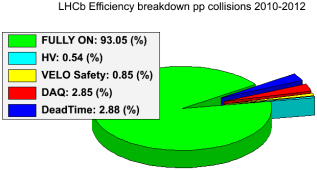
2012:

- $\sqrt{s} = 8$ TeV
- $\mathcal{L} = 2\ \text{fb}^{-1}$

Future:

- 2015 – 2017: 4 fb^{-1}
- Upgrade (2020 –): 50 fb^{-1}



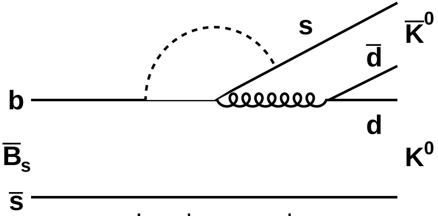


Data taking efficiency: 93 %

Outline

$B \to K^{(*)0}\bar{K}^{(*)0}$ diagrams

Decay dominated by this diagram:



gluonic penguin

For $B_d^0 \to K^{(*)0}\bar{K}^{(*)0}$: $s \leftrightarrow d$
$\Rightarrow$ U-spin symmetry in flavor-$SU(3)$

*CP*V-predictions difficult due to strong (QCD) phases.
Constrain free parameters by U-spin or isospin.
Issue: both can be broken.

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- $\mathcal{B}(B_s^0 \to K_s^0 K_s^0)$ for measurement of CKM-angle γ:

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  - possible time dependent analysis to get γ: $B_s^0 \to K^+K^-$ and $B_d^0 \to \pi^+\pi^-$ using their U-spin symmetry but: U-spin breaking
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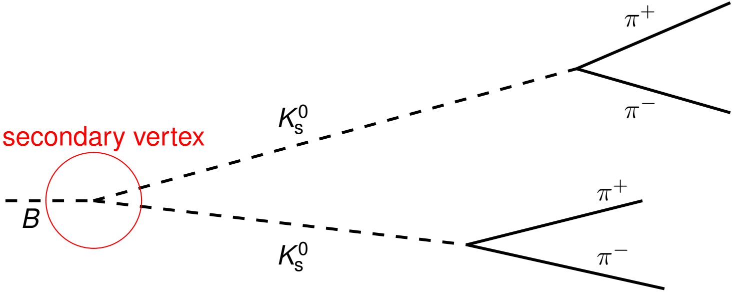
  (*e.g.*, Eur. Phys. J. C 38 (2004) 251)
- $\Rightarrow$ $B_{s(d)}$ time dependent asymmetry: (almost) null test for SM
- $D^0 \to K^{(*)0}\bar{K}^{(*)0}$ time integrated CP violation
  e.g., $D^0 \to K_s^0 K_s^0$ could be O(1 %) in SM, enhanced in NP

  (Phys. Rev. D87 (2013) 014024)

CP violation measurements

- $\mathcal{B}(B_s^0 \to K_s^0 K_s^0)$ (see previous slide)
- $B_s^0/B_d^0 \to K^{*0}\bar{K}^{*0}$, time dependent, tagged
  - vector–vector final state
  - no CP eigenstate, spin eigenstates are CP eigenstates
- $B_s^0 \to K_s^0 K_s^0$, time dependent, tagged:
  issue: vertex resolution – maybe possible at LHCb



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- $B_s^0 \to K_s^0 K_s^0$, time dependent, tagged:
  issue: vertex resolution – maybe possible at LHCb
- $B_s^0/B_d^0 \to K_s^0 K^{*0}$, $B_s^0/B_d^0 \to K_s^0 \bar{K}^{*0}$ time dependent, tagged:
  - possible at LHCb
  - no spin decomposition needed
  - no *CP* eigenstate, *CP*V measurement possible due to similar decay rates

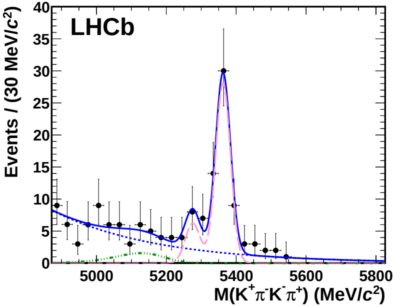
    (*e.g.*, PRL 100 (2008) 031802 and references therein)
- D^0 decays: tagged, time integrated measurement
  $\to$ direct *CP*V ($\mathcal{A}^{\mathrm{dir}}$) – slow D^0 oscillation yields the cosine term only

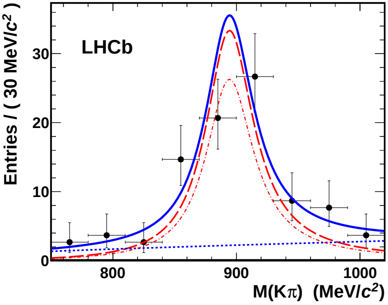
Outline

$B_s^0 \to K^{*0}\bar{K}^{*0}$ branching fraction measurement

- first observation with 35 pb^{-1} of 2010 data
- very good signal to background ratio
- $K^*(1430)$ component in ±150 MeV window around K^{*0} mass < 12 %

$$\mathcal{B}(B_s^0 \to K^{*0}\bar{K}^{*0}) = (2.81 \pm 0.46(\text{stat.}) \pm 0.45(\text{syst.}) \pm 0.34(f_s/f_d)) \cdot 10^{-5}$$





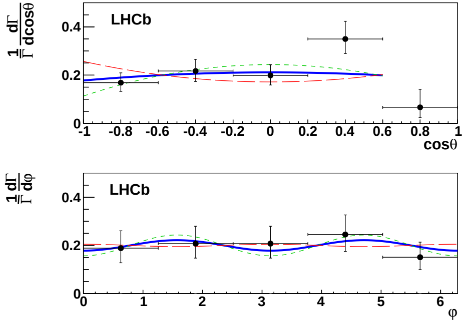
Phys. Lett. B709 (2012) 50 (arXiv:1111.4183)

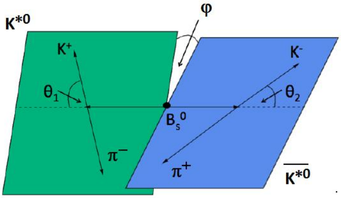
$B_s^0 \to K^{*0}\bar{K}^{*0}$ polarization measurement

- pseudoscalar decay into two vector particles:
  three polarization amplitudes A_L, $A_\parallel$ (CP-even), $A_\perp$ (CP-odd)
- untagged, time integrated angular fit to helicity angles

$$f_L = \frac{|A_L|^2}{|A_L|^2 + |A_\parallel|^2 + |A_\perp|^2} = 0.31 \pm 0.12(\text{stat.}) \pm 0.04(\text{syst.})$$

- remarkable: difference to its U-spin partner $B_d^0 \to K^{*0}\bar{K}^{*0}$,
  BaBar: $f_L = 0.8 \pm 0.12(\text{stat.}) \pm 0.04(\text{syst.})$ (Phys. Rev. Lett. 100 (2008) 081801)





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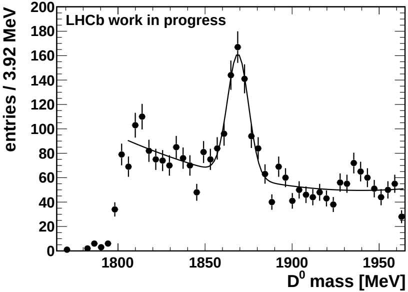
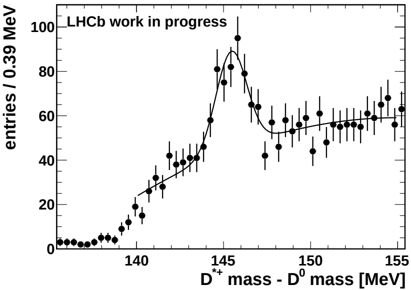
Estimates: expected reconstructed yields for 3 fb^{-1} (current data)

- for $B_s^0 \to K^{*0}\bar{K}^{*0}$ directly extrapolate from 35 pb^{-1}
- for $D^0 \to K_s^0 K_s^0$ use LHCb yields from work in progress

Tagged $D^0 \to K_s^0 K_s^0$ in part of 2012 data





[3] NuPhB 675 (2003) 333

[4] IEEE (2010) 1155; J. of Phys.: Conf. Ser. 331 (2011) 032023

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- for others take branching ratio from theory[3] (experiment)
- based on MC study using the LHCb MC setup[4]
- take trigger and reconstruction efficiency from MC
- is yield enough for time dependent tagged analysis?
  (taking tagging power into account)

Mind: MC for 2011, new trigger with higher K_s^0 yield in 2012
$\Rightarrow$ numbers are conservative for modes containing a K_s^0

[3] NuPhB 675 (2003) 333
[4] IEEE (2010) 1155; J. of Phys.: Conf. Ser. 331 (2011) 032023

Expectations for 3 fb^{-1} and beyond

decay	O($N_{\rm exp}$) 3 fb^{-1}	time dep., tagged current data	time dep. tagged upgrade
$B_s^0 \to K^{*0}\bar{K}^{*0}$	4500	YES	YES
$B_s^0 \to K_s^0 K^{*0}$	100	no	YES
$B_s^0 \to K_s^0 \bar{K}^{*0}$	100	no	YES
$B_s^0 \to K_s^0 K_s^0$	100	no	following slides
$B_d^0 \to K^{*0}\bar{K}^{*0}$	300	no	YES
$B_d^0 \to K_s^0 K^{*0}$	30	no	possibly
$B_d^0 \to K_s^0 \bar{K}^{*0}$	30	no	possibly
$B_d^0 \to K_s^0 K_s^0$	15	no	no
$D^0 \to K_s^0 K_s^0$	1000†	time integrated	time integrated

Other D^0 decay modes: same order of magnitude as $D^0 \to K_s^0 K_s^0$

†tagged, untagged number: 5000

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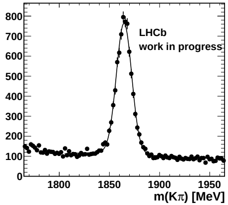
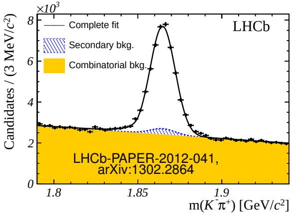
MVA



cuts based



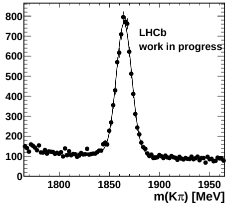
same selection quality as cuts based analysis using powerful RICH cuts

- $\to$ very robust and powerful algorithm!

MVA to select $B_s^0 \to K_s^0 K_s^0$

- expect huge combinatorial background
  – RICH does not help much with pions, which are legion
- use MVA proposed in Britsch et al., PoS(ACAT2010)047 and PoS(ACAT08)086: rule based
- method includes MVA-preselections
  $\to$ fits perfectly LHCb analysis model requiring central preselection
- test on $D^0 \to K^-\pi^+$ whithout using RICH information:
  training done on 2006 MC, never redone!
- one of the first selections to give open charm peak at LHCb!

MVA



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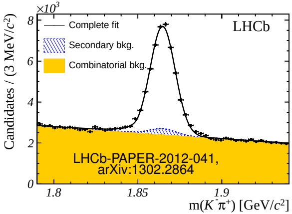


same selection quality as cuts based analysis using powerful RICH cuts

- $\to$ very robust and powerful algorithm!
- $B_s^0/B_d^0 \to K_s^0 K_s^0$: central preselection implemented and running

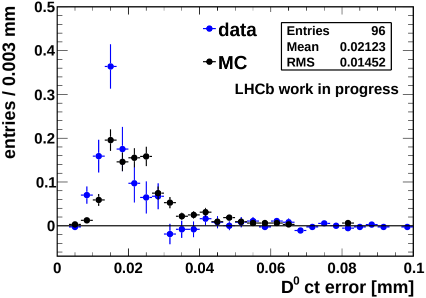
$B_s^0 \to K_s^0 K_s^0$ time dependent measurement

- use only highest quality category K_s^0
- upgrade, with tagging efficiency: effectively O(10) candidates
- $\Rightarrow$ enough? But mind comment about trigger
- an untagged analysis also an option
- what about the time resolution?

$B_s^0 \to K_s^0 K_s^0$ time dependent measurement

- use only highest quality category K_s^0
- upgrade, with tagging efficiency: effectively O(10) candidates
- $\Rightarrow$ enough? But mind comment about trigger
- an untagged analysis also an option
- what about the time resolution?
- look at $D^0 \to K_s^0 K_s^0$ to get the error on the decay length σ_{ct}

- find time resolution: $85\text{ fs} \approx \frac{1}{4} \cdot T_{\mathrm{mix}}$
- B_s^0 has higher mass
  $\to$ larger opening angle
  $\to$ smaller σ_{ct}
- $\Rightarrow$ should be enough to do $B_s^0 \to K_s^0 K_s^0$ time dependent



Outline

Conclusions

- status and potential of *B* & *D* meson decays to two neutral kaons at LHCb
- first observation and f_L of $B_s^0 \to K^{*0}\bar{K}^{*0}$ with 2010 data
- with the current data the following should be possible
  - (first) observation and branching ratios for all decay modes
  - first *CP* measurements are possible for $B_s^0 \to K^{*0}\bar{K}^{*0}$
  - world best *CP* measurements for all these D^0 modes
- with the upgrade
  - time dependent *CP*V measurements for $B_s^0 \to K_s^0 K^{*0}, K_s^0 \bar{K}^{*0}$
  - though tough, time dependent *CP* measurement of $B_s^0 \to K_s^0 K_s^0$ within reach
- this will increase our knowledge of $\mathcal{A}^{\mathrm{dir}}_{D^0 \to K^{(*)0}\bar{K}^{(*)0}}$, β_s, and γ
- more important: good potential for the observation of NP

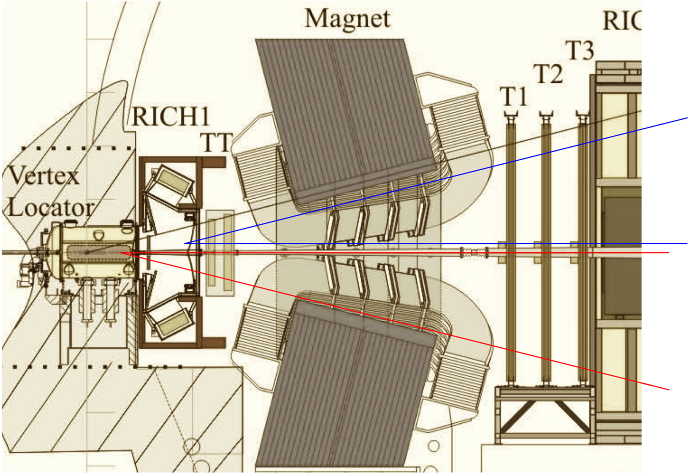
Start backup slides

Backup

Outline

Track types

- L – long tracks: track segment in Vertex Locator (VELO)
- D – downstream tracks: no track segment in VELO
- K_s^0: typically two tracks of same kind: K_s^0LL or K_s^0DD
- of course K_s^0LL are of higher quality



Outline

What are rule learner?

- supervised (*i.e.*, learning from a test sample) classifier
- classifying events according to a rule set,
  i.e., a collection of "if…then…" rules.

Example for a rule set:

```
(IPpi >= 1.039316) and (DoCA <= 0.307358) and
(IP <= 0.270767) and (IPp >= 0.800645)
=> class=Lambda

(IPpi >= 0.637403) and (DoCA <= 0.159043) and
(IP <= 0.12081) and (ptpi >= 149.2332) and
(IP >= 0.003371)
=> class=Lambda

=> class=BG
```