CP violation in B→hhh @ LHCb

Gabriel Guerrer

Centro Brasileiro de Pesquisas Fisicas
Rio de Janeiro, Brazil

on behalf of the LHCb Collaboration

5th International Workshop on the CKM Unitary Triangle
September 9-13 2008
Roma, Italy

outline

- motivation
- LHCb
  - trigger
  - selection strategy
  - yields, S/B
- CKM γ measurements
- CPV: Dalitz anisotropy

motivation

- hhh corresponds to the following decays

  BR - O(10^{-5} - 10^{-6})

  B+- → π+- π+- π+-
  B+- → K+- π+- π+-
  B+- → K+- K+- π+-
  B+- → K+- K+- K+-
  B+- → p+- p+- π+-
  B+- → p+- p+- K+-

- contain CKM Vub transitions
  - presence of CP Violation (CPV)
  - possibility of γ measurement

- rare decays B+ → K- π+ π+ , B+ → K+ K+ π-
  - could be enhanced by new physics

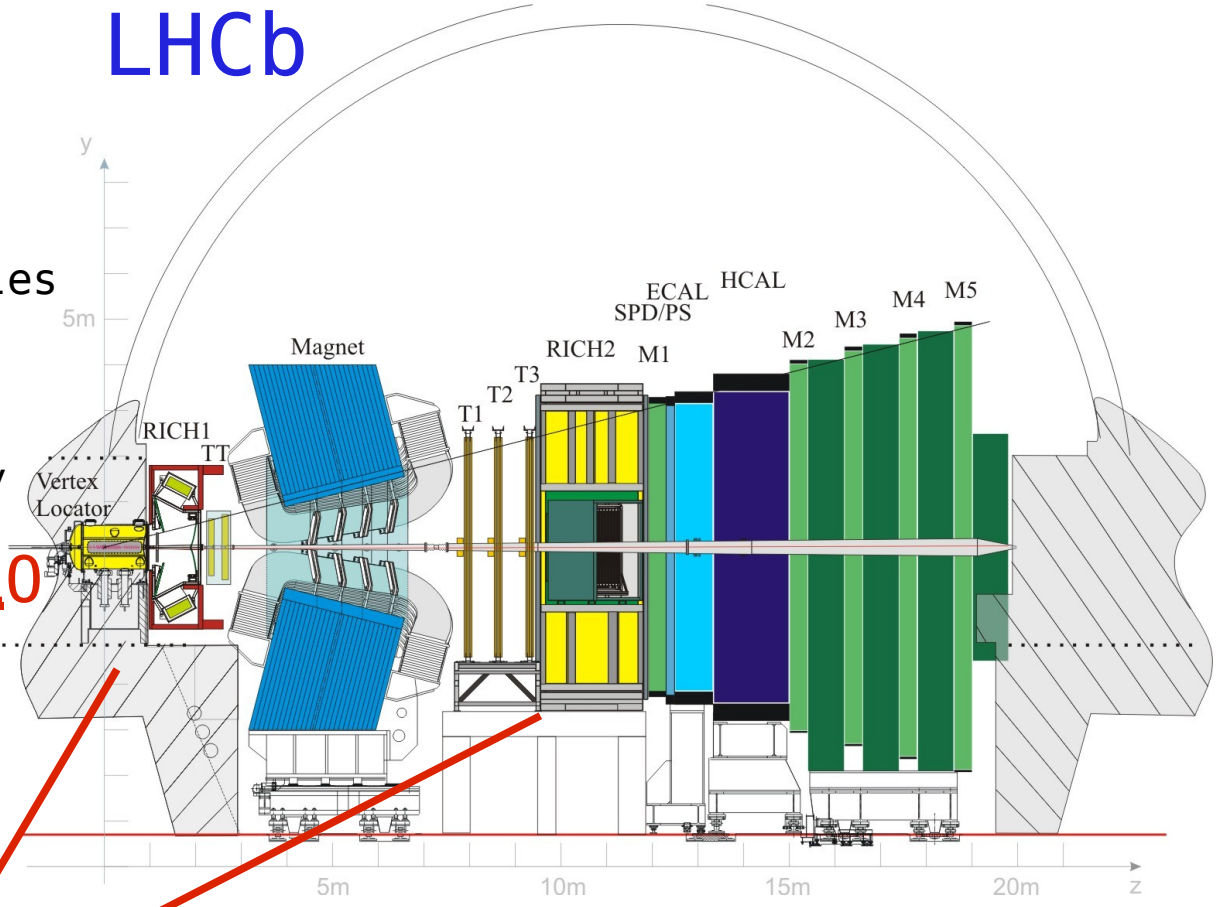
- 3 body amplitude analysis: measure resonant states magnitudes and phases
  - access to additional CPV information

LHCb

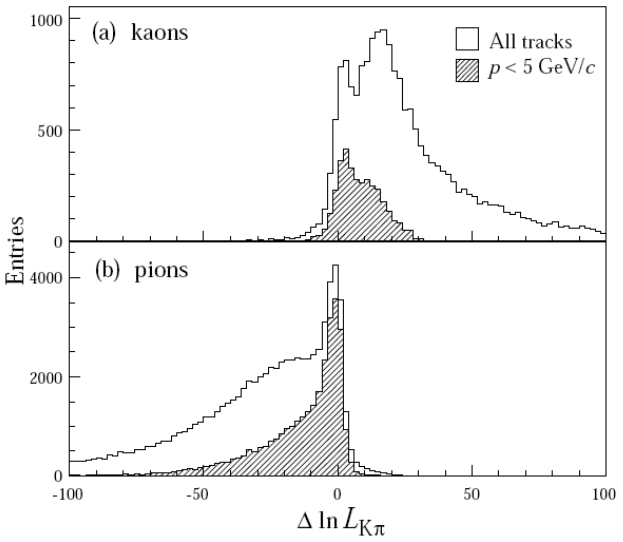
1 nominal year = 2fb^{-1}
~10^{12} bb pairs produced

goals
- precise measure of CKM angles
- Bs mixing parameters
- NP in loop processes

characteristics
- good resolution for primary and secondary vertices
- PV res ~ 50 μm
- SV res ~ 200 μm in beam direction



VELO



RICH: K, π identification

- good separation between pion and kaon
- B mass resolution ~ 15 MeV (2 body decays)
- trigger dedicated to select b events

trigger

$b\bar{b}$ production @ 14 TeV
- intense boost in beam direction, average B momentum p ~ 80 GeV
- signature: high transverse momentum (p_t) tracks

L0 (hardware trigger) : 40 MHz → 1 MHz
- searches for high E_t (p_t) calo clusters (muon segments)

HLT1 (software trigger) : 1 MHz → 30 kHz
- confirm seeds by finding matching long tracks

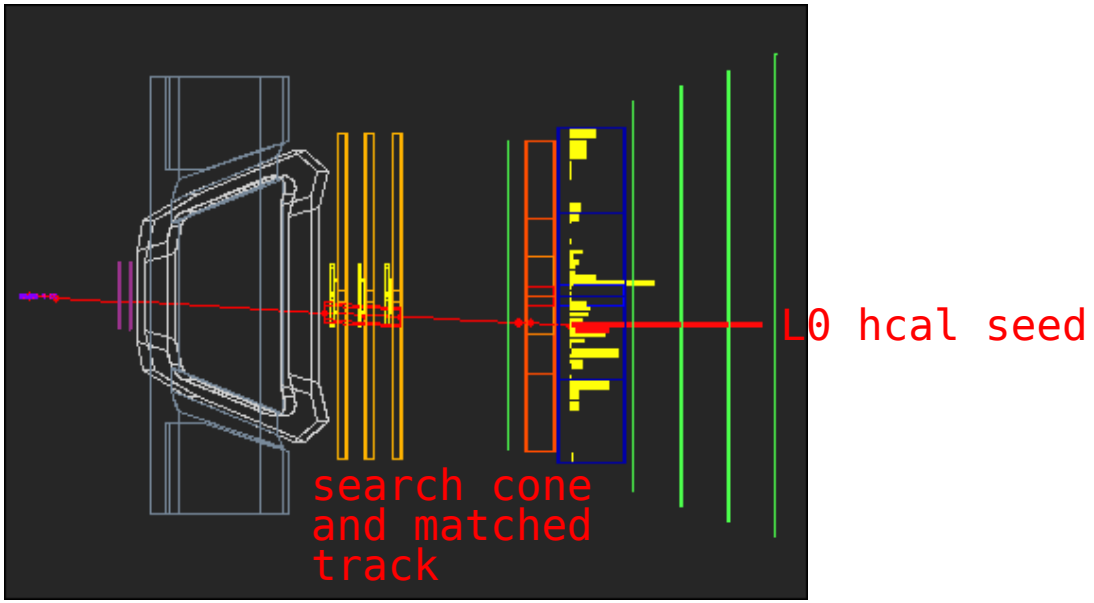
HLT2 (software trigger) : 30 kHz → 2 kHz
- at lower rate, tries to make specific B candidates with broad cuts

hhh efficiencies

L0 ~ 45%

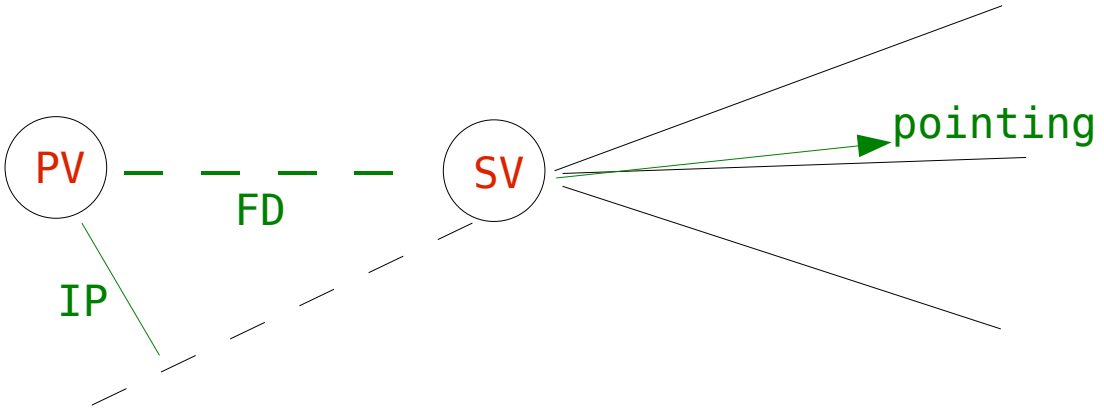
HLT1 ~ 80%

HLT2 > 90%



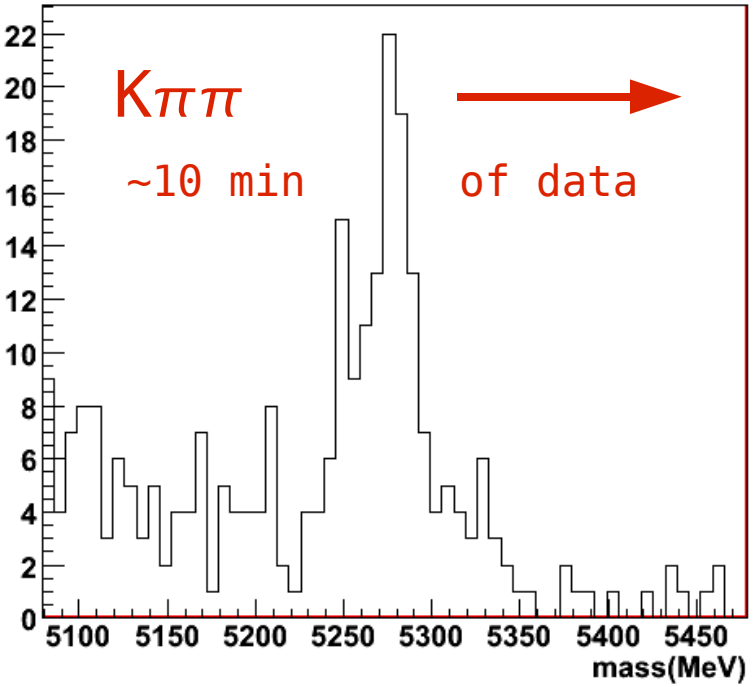
hhh selection strategy

- primary vertex (PV) charged track multiplicity ~ 70
  - 1st task : minimize combinatorics background
- identification cuts to id kaons, pions and protons
  - RICH detector
- looks for 3 charged particles with high p_t
- use IP to select tracks not originated from PV
- fit a good chi2 vertex (SV)
- which has some flight distance (FD) from PV
  - good resolution provided by VELO
- sum of 3 daughter momentum must be colinear to FD - pointing
- invariant mass inside a reasonable window Δm



yields, S/B

	eff (%)	Yield (10^3)	S/B	BR (10^{-5})
$\pi\ \pi\ \pi$	1.1	141.7	1.4	1.62 ± 0.15
K $\pi\ \pi$	1.1	494.4	3.1	5.6 ± 0.7
K K π	1	38.8	0.3	0.50 ± 0.07
K K K	1	236.4	21.5	3.01 ± 0.22
p p~ π	0.9	22.5	0.2	0.31 ± 0.02
p p~ K	0.8	39.2	1.5	0.59 ± 0.05



events used to calculate S/B on bb inclusive sample

- B mass resolution = 19 MeV
- eff includes reconstruction, selection cuts and L0 (hardware trigger) effects
- results for 100% efficient HLT (software trigger)
  - expect HLT eff ~ 70% for hhh

comparing with B factories

- K$\pi\pi$: BaBar (Belle) published their analysis for ~ 2100 (4300) signal events taken from 226 (386) M BB pairs

  hep-ex/0507004 (hep-ex/0512066)

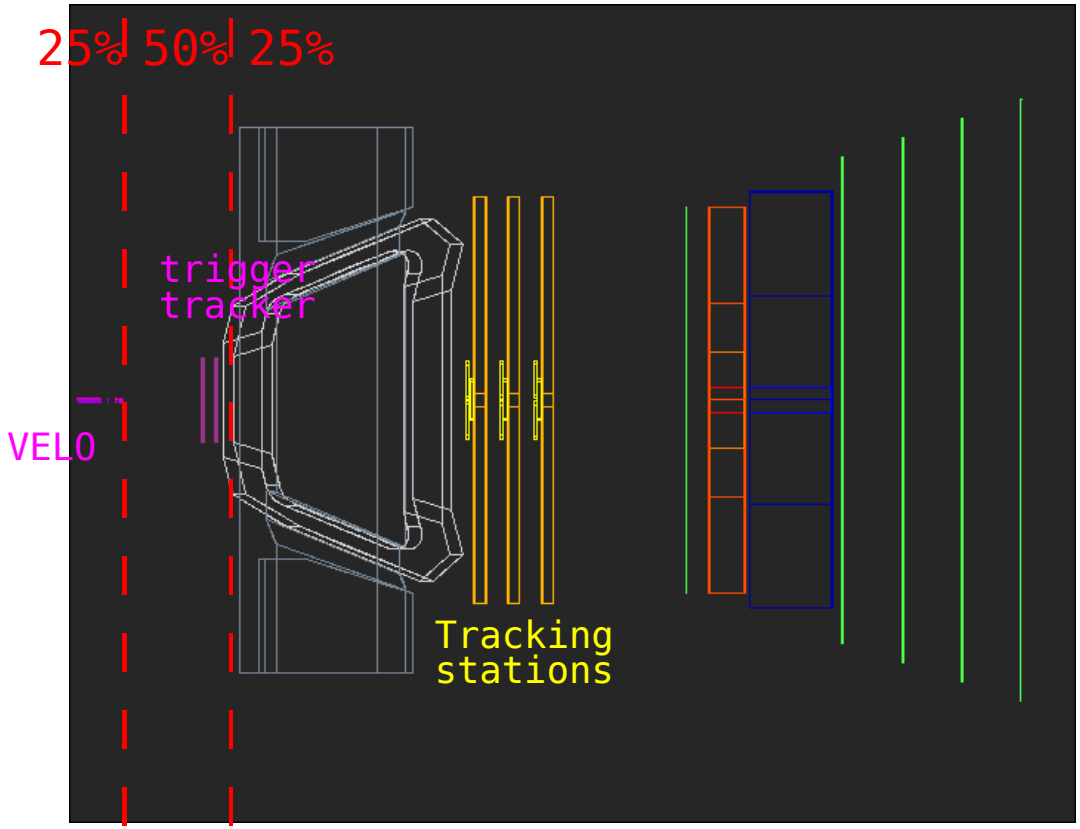
- statistics: 2 order of magnitude above in 1st nominal year
  - many possibilities!
  - example: new physics search on rare B+ $\rightarrow$ K- π+ π+ , K+ K+ π-
    - SM BR : O (10^{-14}), O (10^{-11})
    - enhanced by Minimal Supersymmetric SM : O (10^{-9}), O (10^{-6})
    - current limits: < 9.5 x 10^{-7}, < 1.6 x 10^{-7}, 90% CL
      Babar: hep-ex/08080900
  - other examples: CPV in baryon sector, baryonic number violation, ...

CKM γ measurements

- There are studies showing the possibility of extracting γ at LHCb using the decay B+ → K+ π+ π-
  - G. Gilles, CERN-THESIS-2007-050
- On this talk I'm going to focus in an approach which combines B+ → K+ π+ π- and B0 → K_s π+ π- based on the possibility of untagged analysis on neutral B
  - I. Bediaga, G. Guerrer, J. Miranda, Phys. Rev. D **76**, 073011 (2007)

LHCb : B0 → K_s π+ π-

- similar selection strategy to hhh
- eff = 0.5% (1.1% in B+)
  - 25% Ks decays after trigger tracker straight lines at T stations, no p → event lost
  - 50% decay after VELO but before trigger tracker, having worse defined tracks
- BR = 2.24 x 10^{-5} (5.6×10^{-5} in B+)
- Yield = 90k / $2fb^{-1}$ (494k in B+)



Dalitz plot analysis

- decay amplitude is a complex function of the Dalitz plot variables (s_{12},s_{23}) parametrized as a coherent sum of resonant and non-resonant contributions

$$A(s_{12},s_{23}) = \sum_k (a_k \; e^{i\delta_k} M_k) + a_{NR} \; e^{i\delta_{NR}} M_{NR}$$

- a : magnitude, δ: strong + weak phase

- Dalitz plot fit to $|A(s_{12},s_{23})|^2$ returns a's and δ's

- usual CPV

$$A_{CP}(k) = (a_k^+ - a_k^-) / (a_k^+ + a_k^-)$$

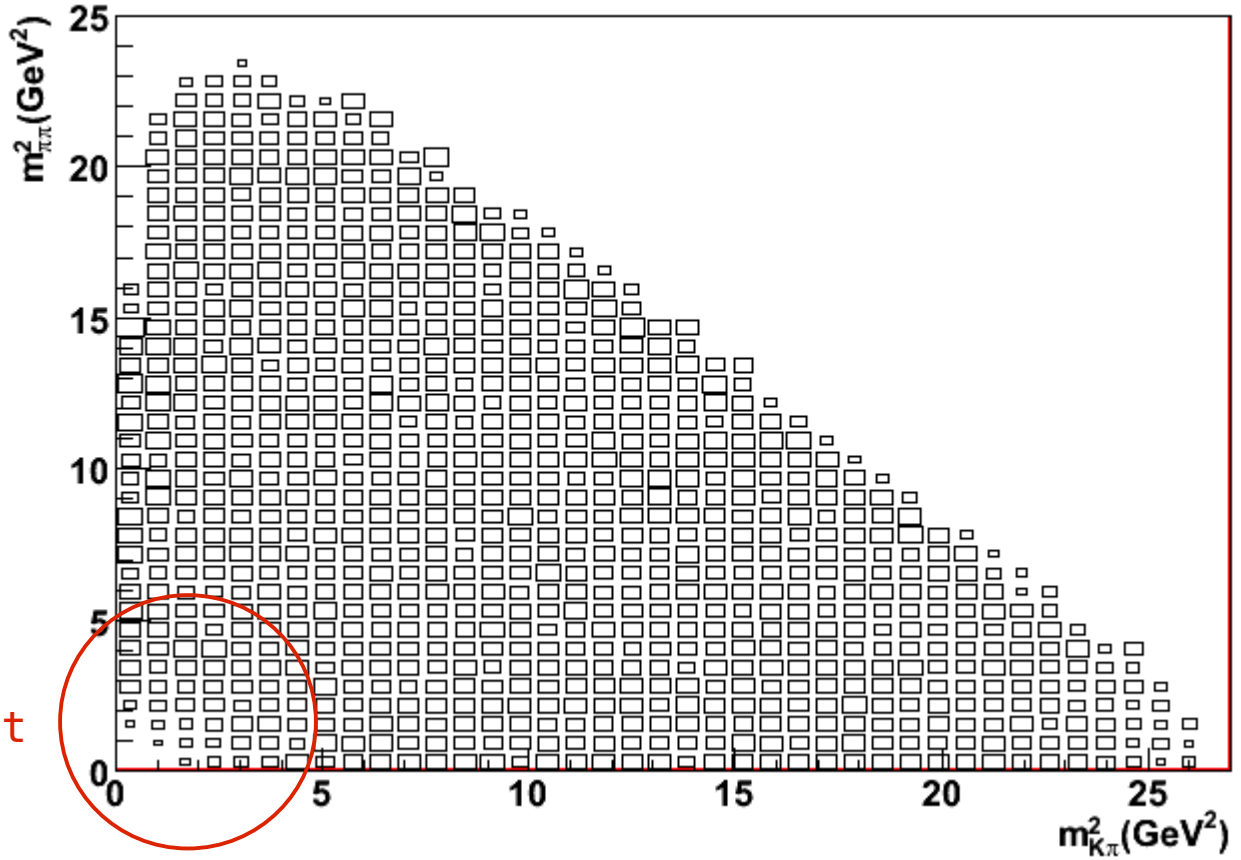
  - inspired by 2 body idea of difference in num of events
  - model dependent
  - ignores information on δ !!!

ex: BaBar Kpipi analysis, Phys. Rev. D **72**, 072003 (2005)

Belle Kpipi analysis, Phys. Rev. Lett. **96**, 251803 (2006)

LHCb Dalitz plot acceptance: K$\pi\pi$

- no significant difference between regions
- low at corners due to p_t cuts
  - kept small as possible to reduce combinatorics

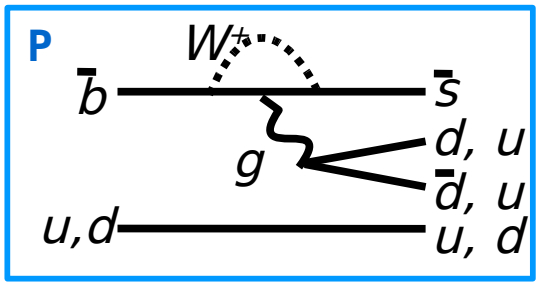


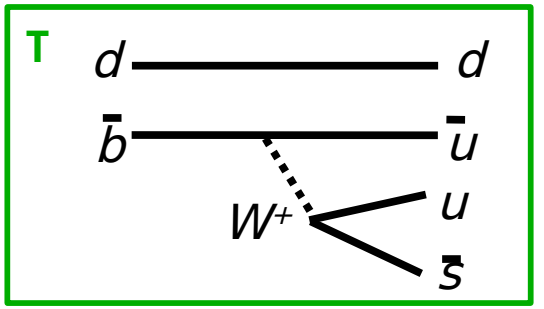
γ : B+ → K+π+π- and B0 → $K_s\pi$+π-

dominant contributions for K* resonance

B+ → K*0 π+ : Vbt V*ts **P**

B0 → K*+ π- : Vbt V*ts **P** + Vbu V*us **T**



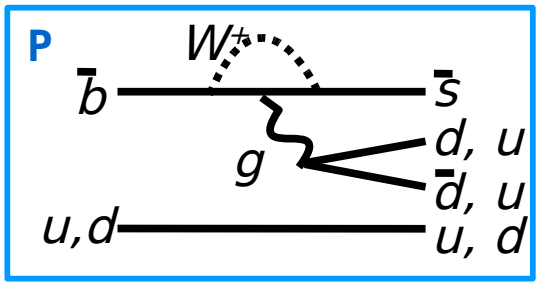


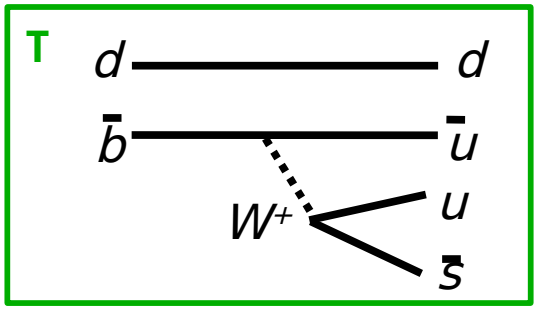
γ : B+ → K+π+π- and B0 → $K_s\pi$+π-

dominant contributions for K* resonance

B+ → K*0 π+ : **Vbt V*ts P**

B0 → K*+ π- : Vbt V*ts **P** + Vbu V*us **T**





1st step: amplitude analysis of charged B

- extracts B+ : Vbt V*ts $\propto a\, e^{i\delta}$
  B- : V*bt Vts $\propto a\, e^{i\delta}$
  which should be equal in absence of weak phase

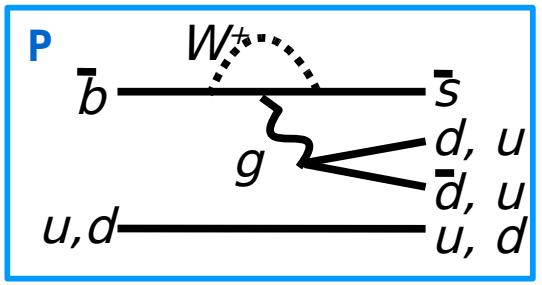
- parameters are extracted relative to
  B+ → χc0 K+
  which should have same contribution in neutral decay, allowing comparison of parameters

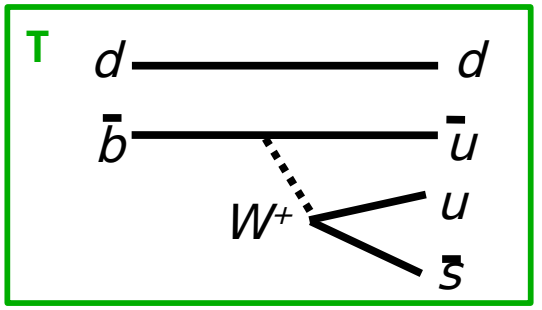
γ : B+ → K+π+π- and B0 → $K_S\pi$+π-

dominant contributions for K* resonance

B+ → K*0 π+ : Vbt V*ts **P**

B0 → K*+ π- : Vbt V*ts **P** + **Vbu V*us T**



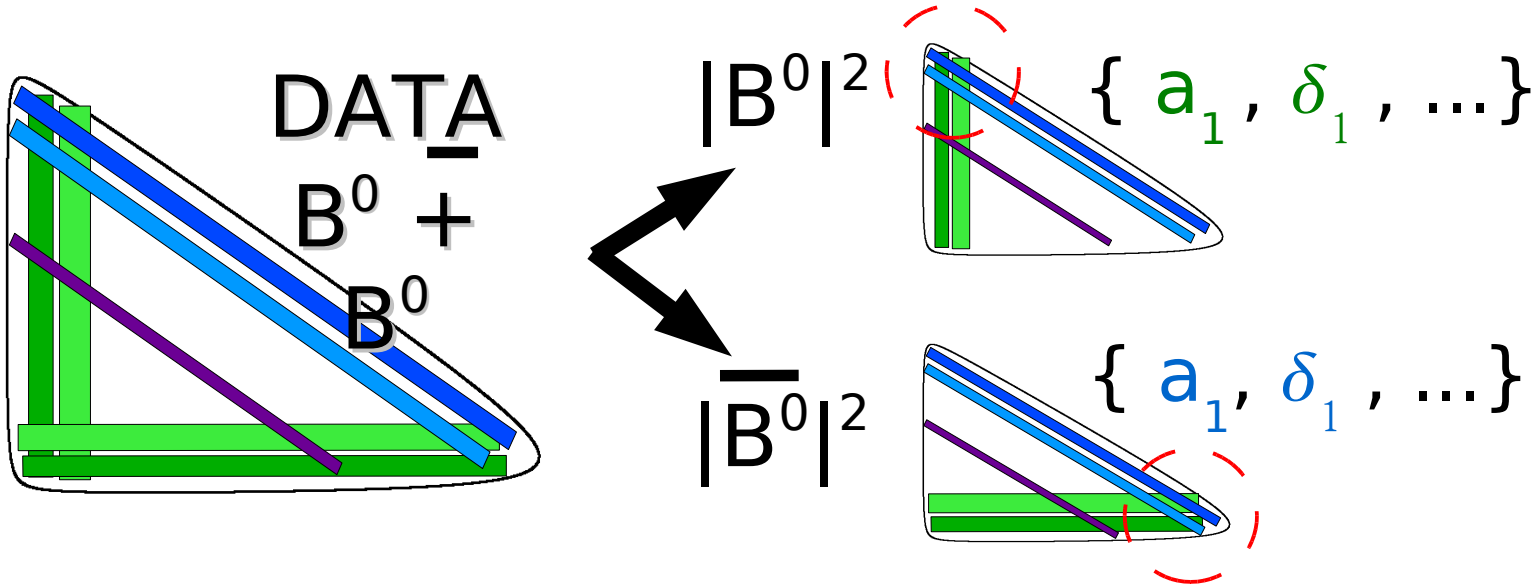


2nd step: amplitude analysis of neutral B

- inputs P from B+
- extracts $B0 : Vbu\ V^*us \propto a\ e^{i\delta}$
  $\bar{B}0 : V^*bu\ Vus \propto \bar{a}\ e^{i\bar{\delta}}$
- **$\gamma = (\delta - \bar{\delta}) / 2$**

amplitude analysis of neutral B

- reconstructing K_S $\pi+$ $\pi-$ without tagging for B0 or anti-B0 leads to a joint DP. In a single fit procedure it's possible to extract parameters from B0 and anti-B0. The intuition behind is the non-overlap of interference regions – the identity of each DP



$$PDF = B^0 \leftarrow |M_0 + a_1 e^{i\delta 1} M_1 + \ldots|^2 + |s\, M_0 + a_1 e^{i\delta 1} M_1 + \ldots|^2 \rightarrow \overline{B}^0$$

- s : free parameter for scale, allows to measure number of events of both samples
- unambiguous extraction of a's and δ's

γ measurement: K$\pi\pi$

- the ability of measuring γ is related to it's own value and the ratio **r** = **T** / **P** in B0 $\rightarrow$ K* π
- we can measure **r**
- conflicting theoretical predictions
  Beneke,Neubert Nucl. Phys **B675**, 333(2003)
  Buras et al, Phys. Rev.Lett **92** 101804 (2004)

Monte Carlo test

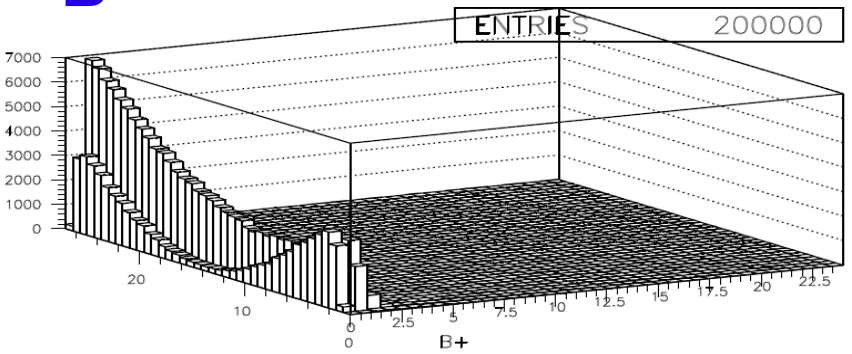
- 100 samples of 100k B0 events
- no background nor acceptance included
- inputs inspired by BaBar
- input γ = 69° , r = 0.45
- extracts $\gamma = 69^\circ \pm 5^\circ$

phase role in CPV

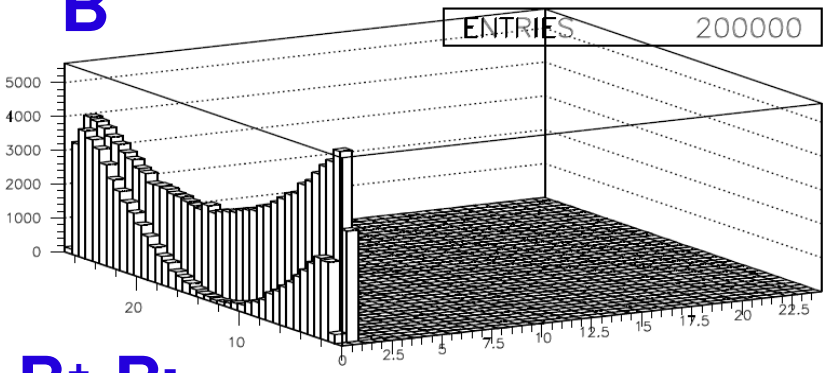
- example: pure phase effect

mode	DP+: 200K		DP-: 200K	
	a+	δ+	a-	δ–
ρ(770)K	0.874	0.00	0.874	2.44
f0(980)K	1.02	2.29	1.02	2.29

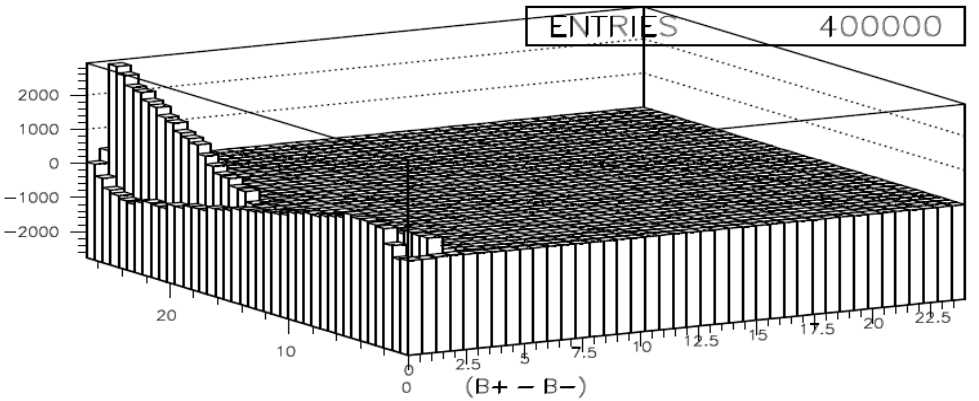
B^+



B^-



B^+-B^-



- $A_{CP}(\rho) = 0$
- but evident CPV
- need a new quantity to measure asymmetries which takes phase into account

Dalitz anisotropy

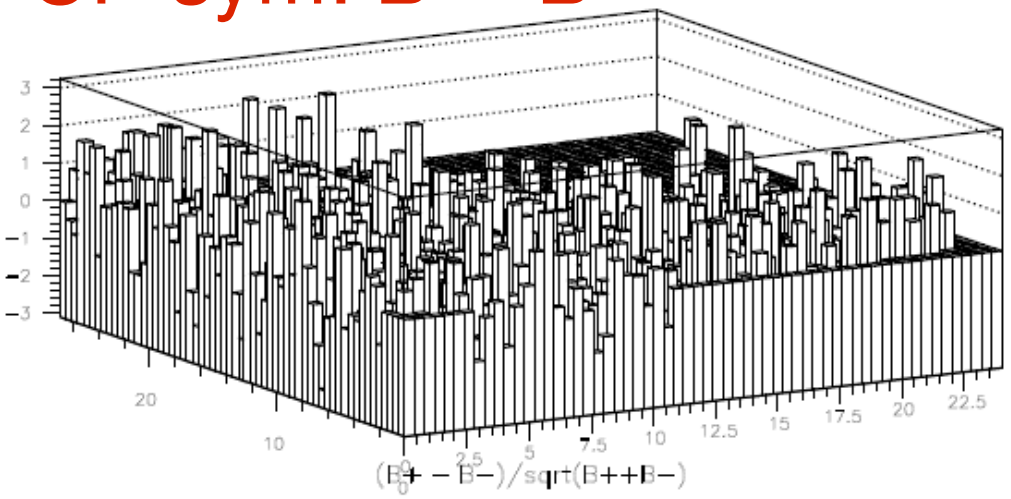
Ti-Pei Li and Yu-qian Ma, Astr.Jour. 272:317-324(1983)

- inspired by astrophysics statistical methods, we use the significance calculated in each bin (i) of the Dalitz plot

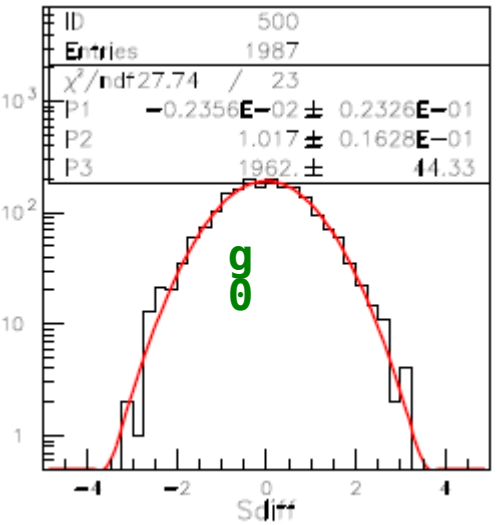
$$\mathcal{S}_{CP}(i) = \frac{N^+(i) - N^-(i)}{\sqrt{N^+(i) + N^-(i)}}$$

- it returns a gaussian **g0**, centered at 0 and width=1 in case of CP symmetry

CP sym: $B^+ - B^-$



$\mathcal{S}_{CP}$

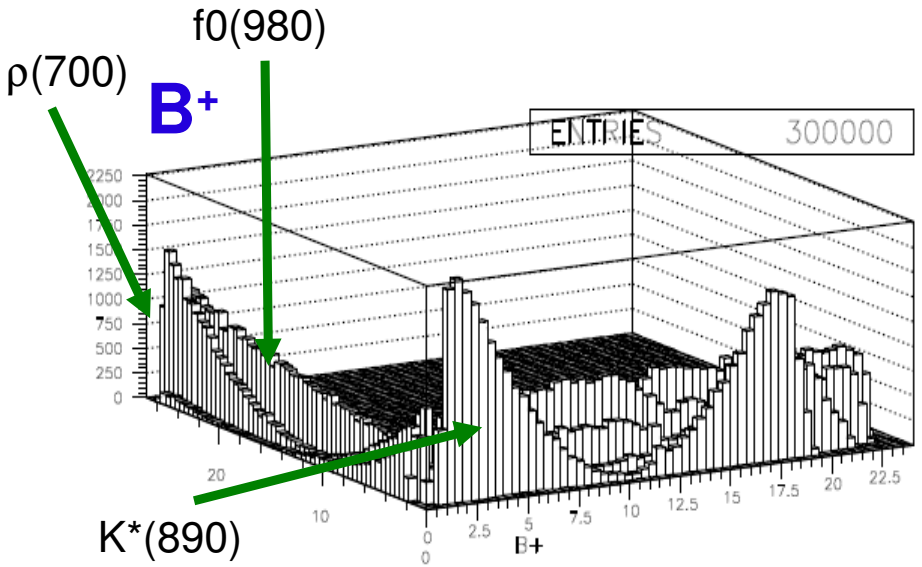


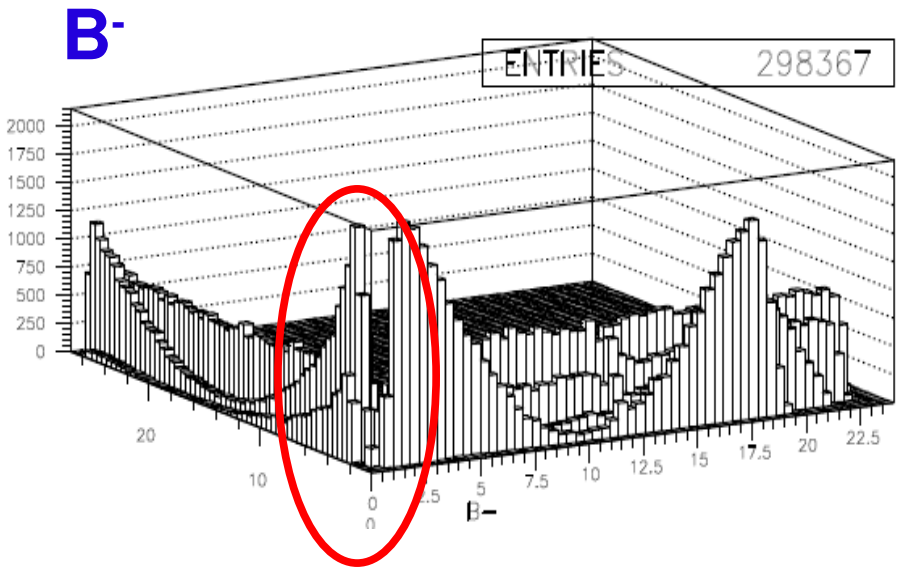
- possible to isolate CPV effects from statistical fluctuations by visual inspection

Dalitz anisotropy: Kππ example

- fast MC sample inspired by BaBar parameters and 1 nominal year of LHCb statistics (~300k)

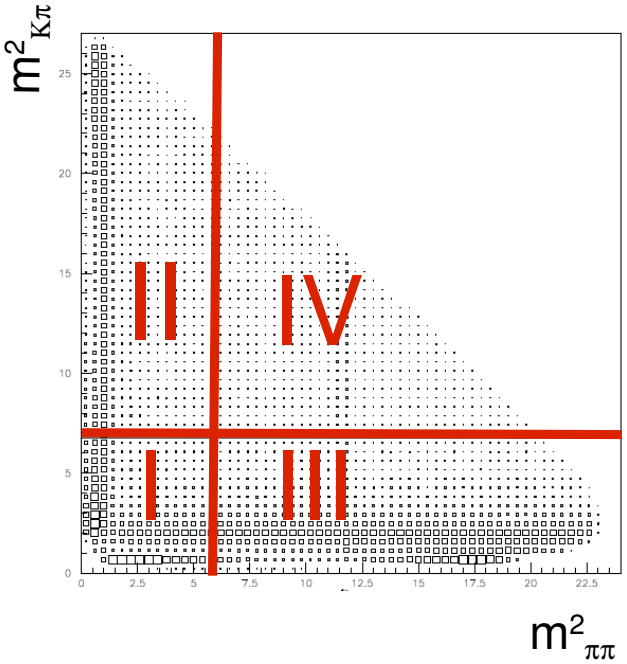
mode	B+		B-	
	a+	δ+	a-	δ−
K*(890)Π	1.00	0.00	1.00	0.00
K(1430)Π	2.08	0.1	2.08	0.1
ρ(770)K	0.874	-0.55	0.874	0.49
f0(980)K	1.02	2.29	1.02	2.29
χK	0.3	-2.52	0.3	-2.52
NR	0.6	-1.85	0.6	-1.85

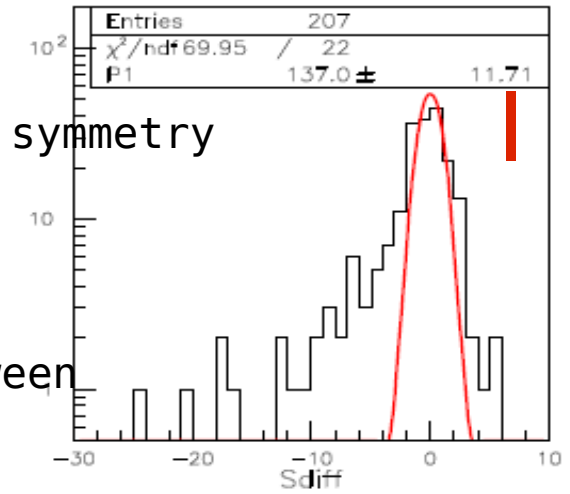


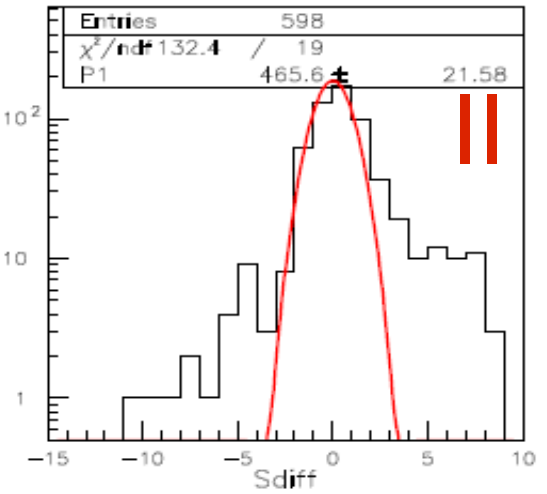


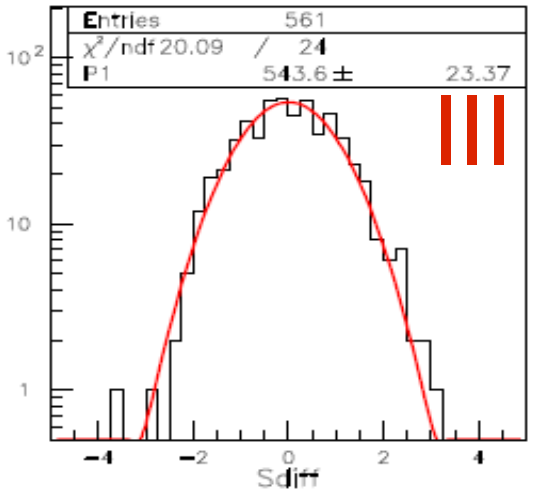
Dalitz anisotropy: K$\pi\pi$ example

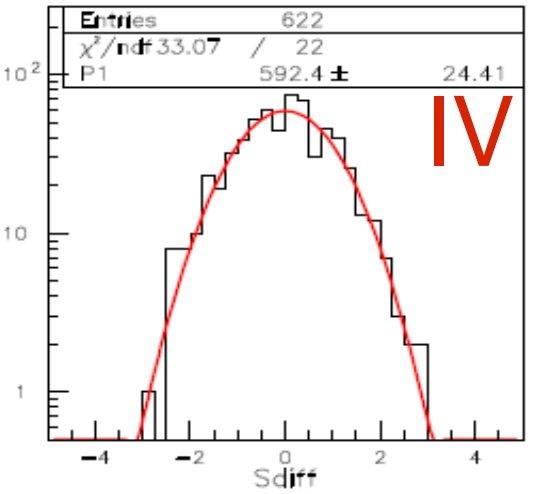
- divide DP in 4 regions
  region I and II → CPV
  region III and IV → CP symmetry
- any contrib out g0 is signature of CPV
- reg I and II show clear 5-sigma difference between B+ and B-











conclusion

LHCb

- large statistics, ~2 orders of magnitude more than B factories → many possibilities and a rich environment for physics, stay tuned for exciting results!

γ measurement

- possibility of measuring γ in $K\pi\pi$ channels

- idealized fast MC study points to 5° error in 1 nominal year of LHCb data ($2fb^{-1}$)

amplitude analysis of B neutral

- possibility of extracting parameters from B0 and anti-B0 in an untagged joint sample

Dalitz anisotropy

- model independent, fast approach to spot regions of CPV before full amplitude analysis

- sensible to phase difference

- it can be used to steer amplitude analysis
  - pick a 3 body channel X
  - check if different regions have CPV as expected in SM
    - move to long term detailed analysis

- work ongoing to define a quantitative measurement

extra

hhh selection cuts

- PID cuts + Δm = 200 MeV
- similar distributions, only pt is slightly different

tracks	pt (MeV)	> 200
	Σpt (MeV)	> 3800
	IPS	> 4
	Σtrack chi2ndof i	< 12
B	vertex chi2	< 15
	cosp	> 0.99994
	IPS	< 3
	FS	> 20
	Σip i (SV) (mm)	< 0.15
	vi_ip1 (mm)	> 0.5

- IPS – impact parameter significance
- FS – flight distance significance
- cosp – pointing cut, dot product of tracks momentum sum and SV-PV
- ip (SV) – ip with regards to B vertex
- vi_ip1 is a vertex isolation cut which allows 1 extra track inside sphere of radius 0.5 mm centered at SV