Search for B-meson decays to four baryons at BABAR and future prospects at Belle II

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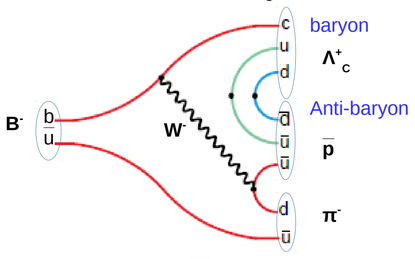
B-meson baryonic decays: measurement of the BF($B^0(\bar{B}^0) \to p\,p\,\bar{p}\,\bar{p}$)

Motivation for baryonic decay searches

Theory



Investigate $q\bar{q}$ production and hadronization into baryons

The ***baryon puzzle***

Inclusive BF(B→ *baryons*) = **(6.8 ± 0.6) %**

Σ exclusive BF(B→ *baryons*) < **1 %**

Peculiarities observed in baryonic decays:

- Multiplicity effect
- Threshold enhancement

Why B → p p $\bar{p}$ $\bar{p}$

NEW : **4-baryon** final-state, **no Upper Limit** on PDG!

Start point: UL for B($\bar{B}^0 \to \Lambda_c^+$ p $\bar{p}$ $\bar{p}$) = 2.8×10^{-6} @ 0.90 CL *(Gruenberg et al., 2014)*

Mode	$\bar{B}^0 \to \Lambda_c^+$ p $\bar{p}$ $\bar{p}$	B → p p $\bar{p}$ $\bar{p}$
Weak coupling	$V_{cb} = (41.1 \pm 1.3) \times 10^{-3}$	$V_{ub} = (4.13 \pm 0.49) \times 10^{-3}$
Phase space (*Q-value*)	$Q(m_B - m_\Lambda - 3m_p) = 0.19$ GeV/c²	$Q(m_B - 4m_p) = 1.52$ GeV/c²

Working hypothesis: **BF(B → p p $\bar{p}$ $\bar{p}$) =**

$BF_{UL}(\bar{B}^0 \to \Lambda_c^+ \; p\,\bar{p}\,\bar{p}) \times |V_{ub}|^2/|V_{cb}|^2 \times Q_{pppp}/Q_{\Lambda_c^+ ppp} \sim \mathbf{10^{-7}}$

PEP II and the BABAR experiment

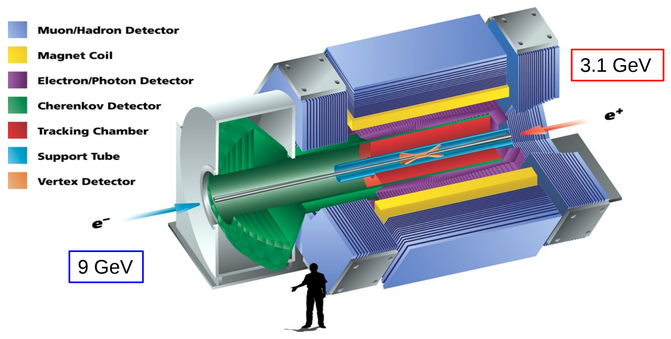
B-factories: dedicated experiments at *e^+e^- asymmetric colliders* for the production of quantum coherent $B\bar{B}$ pairs → **CPV studies** and **NP indirect** searches.

$e^+e^- \to \Upsilon(4S) \to B\bar{B}$

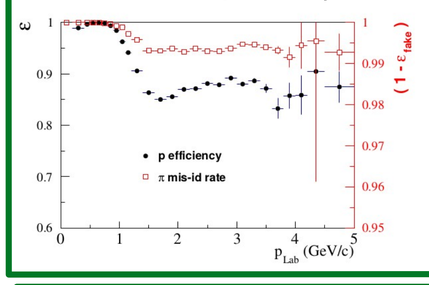
- $\beta\gamma = 0.56$

In its 9-year operation (1999-2008):

- 424 fb^{-1} *on-peak* ($\sqrt{s} = 10.58$ GeV, 471 billion $B\bar{B}$ pairs)
- 44 fb^{-1} *off-peak* ($\sqrt{s} = 10.54$ GeV)



Hermeticity and **asymmetry** are necessary for optimum acceptance and tagging performances

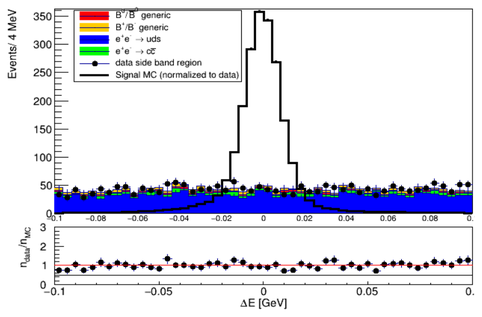


Clean environment allows **outstanding tracking** and **vertex** reconstruction; dE/dx, $\cos\theta_C$ measurements provide **excellent PID** performance: high efficiency with pion misID below 1% at any momentum.

Event Reconstruction

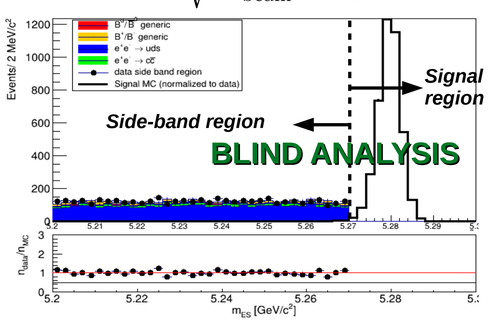
Energy difference

$\Delta E = E^*_B - E^*_{\rm beam}$ * = CM frame



Beam energy substituted mass

$m_{ES} = \sqrt{(E^*_{\rm beam})^2 - |\vec{p_B}^*|^2}$



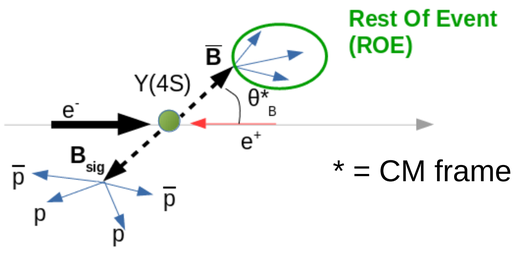
Fit to **common vertex** + kinematic cuts

4 protons from the same vertex: **$\varepsilon_{reco} \sim 40$ %**

Event Selection and Validation: MC-data comparison

Optimal background rejection with the **Boosted Decision Tree (BDT)** method. **INPUT VARIABLES**: kinematic (ΔE), angular ($\cos\theta^*_B$) and **event shape** variables (2nd and 0th *FoxWolfram* moment ratio R_2, and the *Thrust* angle θ_{TH}).

- $B\bar{B}$ Event

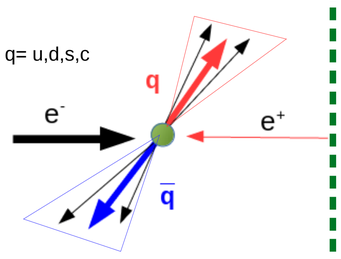


* = CM frame

Spherical shape

Vs.

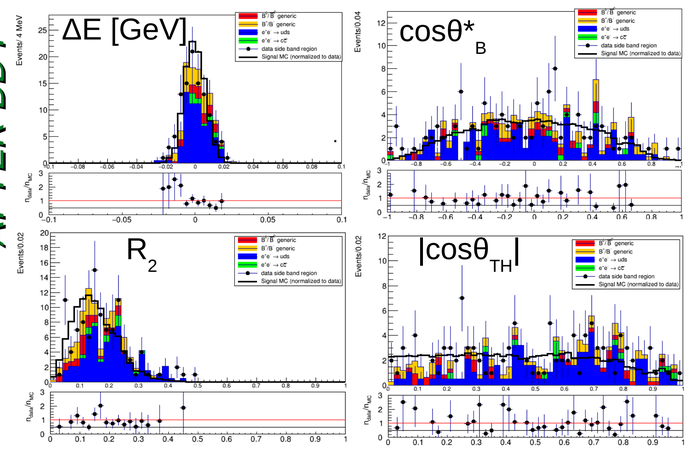
- *Continuum* Event



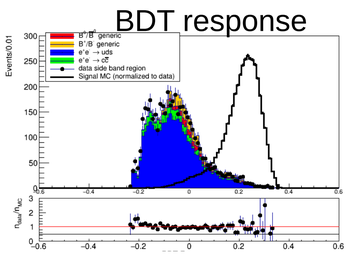
Jet-like shape

Continuum suppression

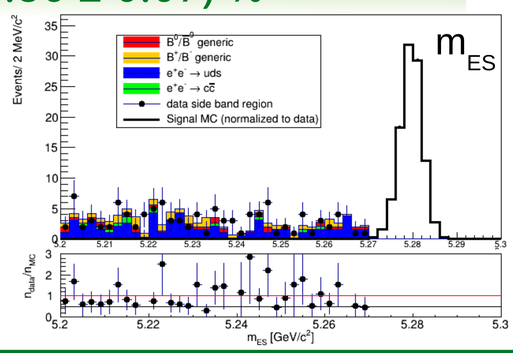
AFTER BDT



Selection efficiency on Signal MC:
$\varepsilon = (20.86 \pm 0.07)$ %



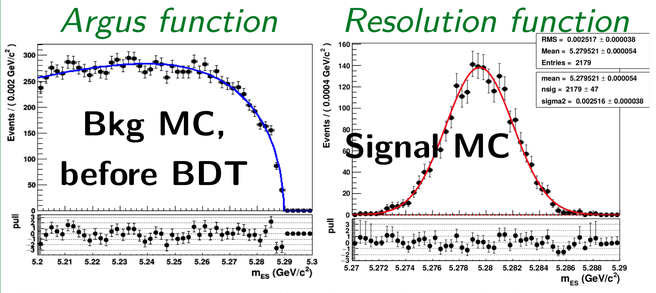
ε^{BDT} on Signal MC = 60 %



Fit, Signal yield extraction, BF calculation

m_{ES} shape modeled on MC and side-band data to define the total *pdf*

Argus function *Resolution function*



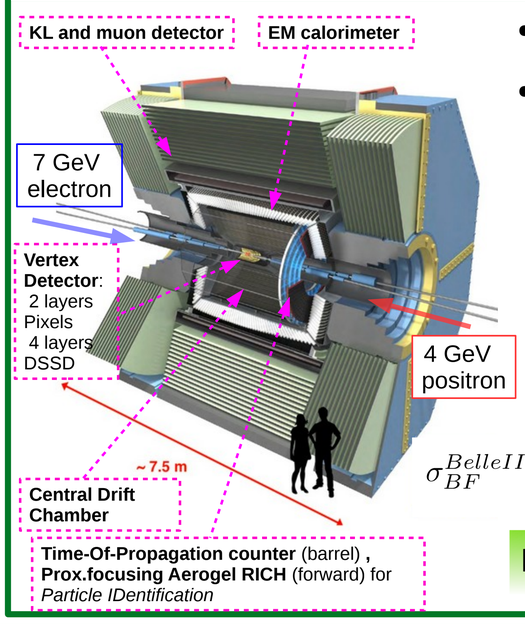
$$BF = \frac{N^{obs}_{sig}}{2 \cdot \epsilon \cdot N_{B^0\bar{B}^0}}$$

- 3 experimental input: N_{sig}, ε, $N_{B\bar{B}}$
- Statistics-dominated measurement: **45%** uncertainty from expected N_{sig}
- Not unblinded yet, currently **under review**

Shape parameters fixed → *Extended unbinned maximum likelihood* fit to m_{ES} distribution in the range [5.2-5.3] GeV/c² → N_{sig}, N_{bkg}

Within the working hypothesis, expected $N_{sig} = 10.0 \pm 4.5$ → UL @ 90% CL **2×10^{-7}**

Prospects at Belle II



- $\beta\gamma = 0.28$
- *Nano-beam*

Max. peak luminosity: 8×10^{35} cm^{-2}s^{-1} → **50 ab^{-1} by 2024**

100 x statistics + improved detector performances (improved vertex reconstruction due to the **2 times** better resolution on impact parameter)

$$\sigma^{BelleII}_{BF}/\sigma^{BaBar}_{BF} = \sqrt{k'/k} \cdot \sqrt{\frac{L_{BaBar}}{L_{BelleII}}}$$

$k'/k \sim (\varepsilon_{BABAR}/\varepsilon_{BelleII}) < 1$

Belle II

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