

# Measurement of the $\bar{B}^0 \rightarrow D^{*-} \pi^+ \pi^- \pi^+$ decay branching fraction

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## 38th INTERNATIONAL CONFERENCE ON HIGH ENERGY PHYSICS

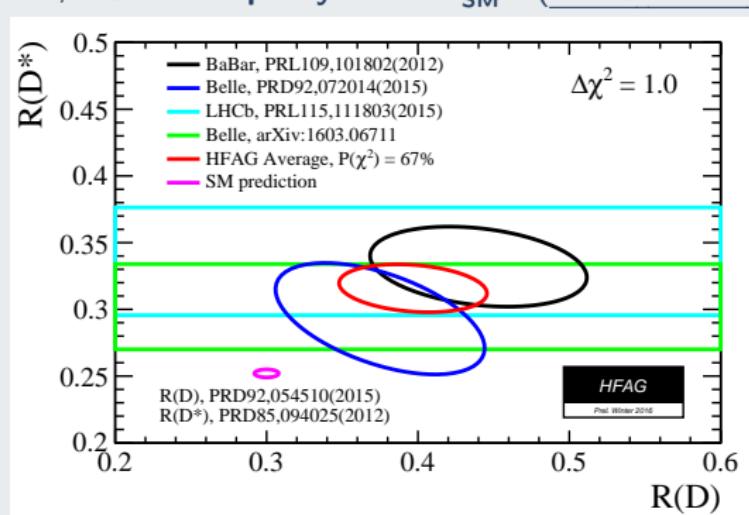
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CHICAGO

## Introduction

experimental discrepancy on  $\mathcal{B}(\bar{B} \rightarrow D^{(*)}\tau^-\bar{\nu}_\tau)$  w.r.t. SM prediction

- *BABAR*, *Belle* and *LHCb* have measured  $R[D^{(*)}] = \frac{\mathcal{B}(\bar{B} \rightarrow D^{(*)}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(\bar{B} \rightarrow D^{(*)}\ell^-\bar{\nu}_\ell)}$
  - combining all results,  $4.0\sigma$  discrepancy w.r.t.  $R_{SM}^{(*)}$  (HFAG Winter 2016)



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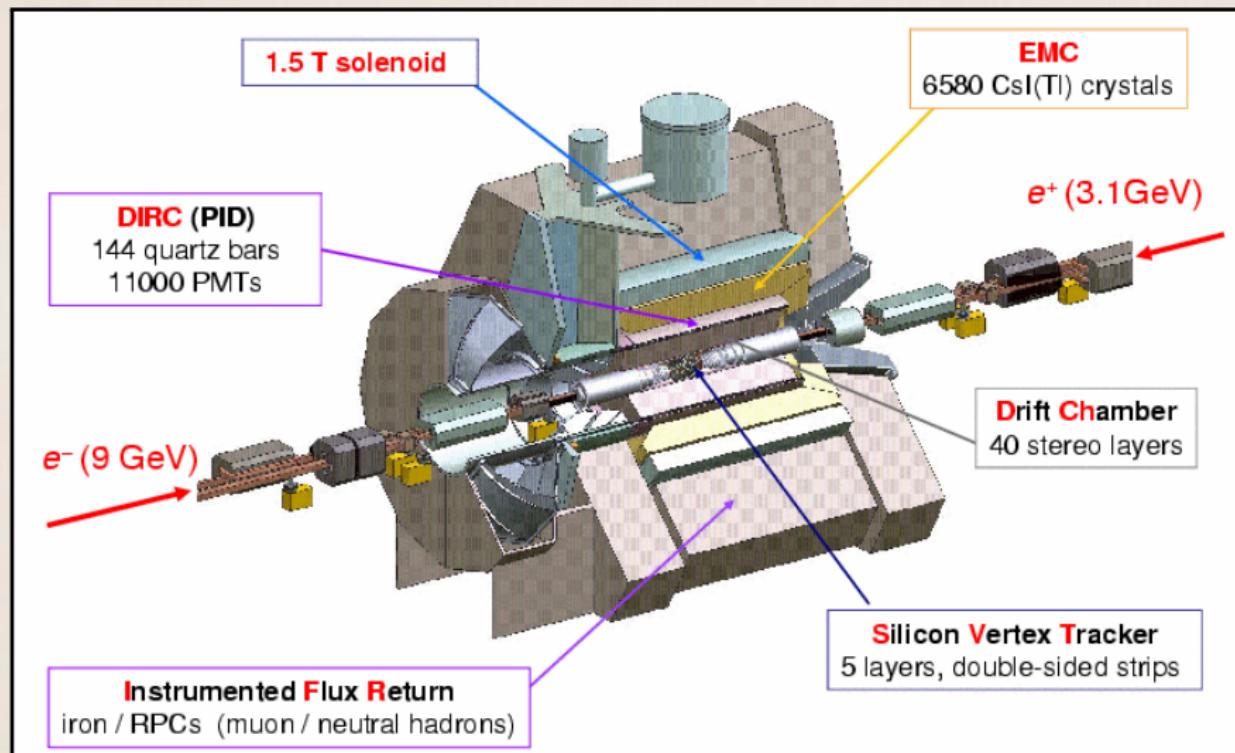
## Introduction, continued

Improve experimental precision on  $\mathcal{B}(\bar{B}^0 \rightarrow D^{*+} \tau^- \bar{\nu}_\tau)$  at hadronic collider

- existing LHCb measurement selects  $\bar{B}^0 \rightarrow D^{*+} \tau^- (\rightarrow \mu \bar{\nu}_\mu \nu_\tau) \bar{\nu}_\tau$
- can improve measuring  $\mathcal{B}(\bar{B}^0 \rightarrow D^{*+} \tau^- (\rightarrow \pi \pi \pi \nu_\tau) \bar{\nu}_\tau)$  at hadronic collider

Normalization branching fraction  $\mathcal{B}(B^0 \rightarrow D^{*-} \pi^+ \pi^- \pi^+)$ 

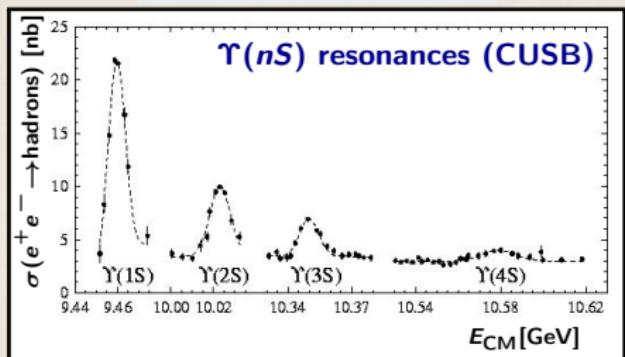
- hadronic collider  $\Rightarrow$  normalization branching ratio needed to reach required precision
  - similar topology
  - well measured in absolute value
- $\mathcal{B}(B^0 \rightarrow D^{*-} \pi^+ \pi^- \pi^+)$ 
  - $\mathcal{B} = (7.0 \pm 0.8) \cdot 10^{-3}$  PDG 2015 (11.4% precision)
  - $\mathcal{B} = (7.27 \pm 0.50) \cdot 10^{-3}$  LHCb, PRD 87 092001 (2013): (8.8% precision)
    - not in PDG average
    - [actually, LHCb measures  $\mathcal{B}(B^0 \rightarrow D^{*-} \pi^+ \pi^- \pi^+) / \mathcal{B}(B^0 \rightarrow D^{*-} \pi^+)$ ]
- cannot get competitive result with present uncertainties on  $\mathcal{B}(B^0 \rightarrow D^{*-} \pi^+ \pi^- \pi^+)$
- $\Rightarrow$  improved precision measurement of  $\mathcal{B}(B^0 \rightarrow D^{*-} \pi^+ \pi^- \pi^+)$  by *BABAR*

**BABAR detector at PEP-II, SLAC National Accelerator Laboratory**

main focus: study of  $CP$  violation in  $B$  mesons

**BABAR: CM energy, collected luminosity**

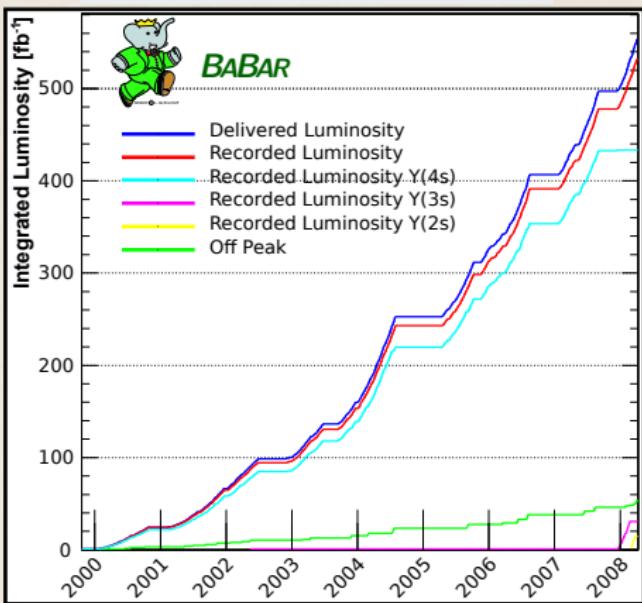
center-of-mass energies



	$\mathcal{L}(\text{fb}^{-1})$	events
$\Upsilon(4S)$	424	$471 \cdot 10^6$
$\Upsilon(3S)$	28	$121 \cdot 10^6$
$\Upsilon(2S)$	14	$99 \cdot 10^6$
off-peak	48	
$e^+e^- \rightarrow c\bar{c}$		$\sim 650 \cdot 10^6$
$e^+e^- \rightarrow \tau^+\tau^-$		$\sim 450 \cdot 10^6$

large clean data sample

integrated luminosity over time



data-taking ended in April 2008

## Decay chain reconstruction

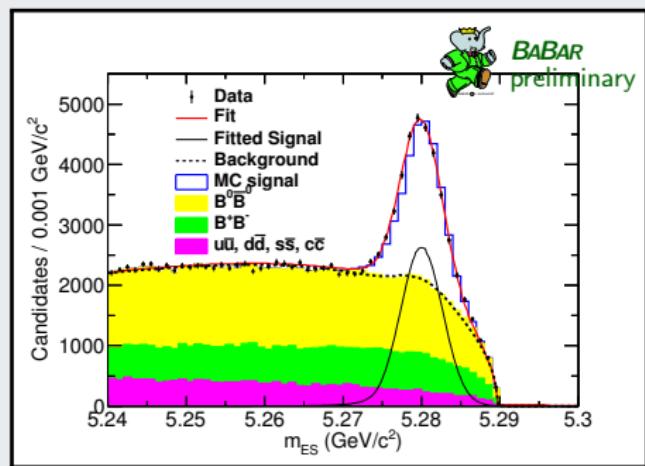
- data sample:  $e^+e^-$  collisions,  $424.2 \pm 1.8 \text{ fb}^{-1}$  luminosity,  $(470.9 \pm 2.8) \cdot 10^6 B\bar{B}$  pairs
- reconstruct  $\bar{D}^0 \rightarrow K^+\pi^-$  candidates from
  - ▶ 1 positive-charged identified  $K$
  - ▶ 1 negative-charged track, assumed to be a  $\pi$  (no pion identification)
  - ▶ candidate  $m(K\pi)$  must match nominal  $m(D^0)$  within 20 MeV
- reconstruct  $D^{*-} \rightarrow \bar{D}^0\pi^-$  candidates from
  - ▶ 1  $\bar{D}^0$  candidate
  - ▶ 1 negative-charged track with  $p < 0.45 \text{ GeV}$
  - ▶  $D^{*-} - \bar{D}^0$  candidates mass difference must lie between 0.1435 and 0.1475 GeV
- reconstruct  $\bar{B}^0 \rightarrow D^{*-}\pi^+\pi^-\pi^+$  candidates from
  - ▶ 1  $D^{*-}$  candidate
  - ▶ 3 tracks with total charge +1 (no pion identification)
  - ▶ candidate  $E(\bar{B}^0)$  must match  $\sqrt{s}/2$  within 90 MeV
- all remaining objects: rest-of-event (ROE)

## Suppression of non- $B\bar{B}$ backgrounds

- multilayer perceptron (MLP) classifier with 9 variables, in center-of-mass (CM) frame
  - ▶ cosine of angle  $B^0$  decay products thrust axis w.r.t. beam axis
  - ▶ sphericity of  $B^0$  decay products
  - ▶ thrust of the ROE
  - ▶  $\sum p_i$  in ROE
  - ▶  $\sum(3 \cos^2 \theta_i - 1)p_i$  in ROE
  - ▶ cosine of angle of  $B^0$  decay products thrust axis w.r.t. ROE thrust axis
  - ▶ cosine of angle of  $B^0$  decay products sphericity axis w.r.t. ROE thrust axis
  - ▶ 2nd-order Fox-Wolfram moment using all re-constructed particles
  - ▶ cosine of the angle of the event thrust axis w.r.t. the beam axis
- cut on MLP output, retains 80% of  $B\bar{B}$  events and rejects 69% of non- $B\bar{B}$  events

Signal yield and fit on  $m_{ES} = \sqrt{s/4 - p_B^2}$

### $m_{ES}$ : data, simulation and fit on data



### Unbinned extended max. likelihood fit

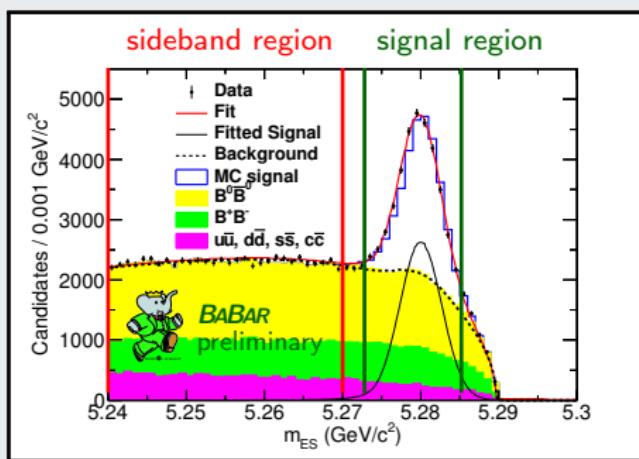
- signal: Crystal Ball function
  - ▶ shape parameters from MC
  - ▶ fit mean, width & normalization
- non-peaking background: ARGUS f.
  - ▶ fit normalization & curvature param.
- peaking backgrounds: 2 Gaussians
  - ▶ all parameters fixed on MC
  - ▶  $1445 \pm 1272$  from  $B^0 \bar{B}^0$
  - ▶  $592 \pm 121$  from  $B^+ B^-$

### Fit results

- number of signal events:  $17767 \pm 324$  candidates

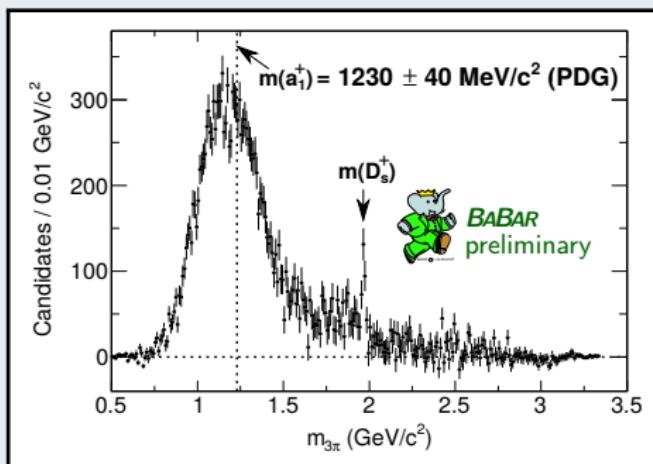
## Background-subtracted 3 pion invariant mass distribution

- background-subtracted 3 pion mass distribution:
  - ▶ distribution of events in signal region
  - ▶ subtracted with distribution of events in sideband region  
normalized to the events in the fitted background in the signal region
- regions: signal  $5.273 < m_{ES} [\text{GeV}] < 5.285$     sideband  $5.240 < m_{ES} [\text{GeV}] < 5.270$

Background subtraction region (on the  $m_{ES}$  plot of previous page)

## Background-subtracted 3 pion invariant mass distribution (2)

## 3 pion mass distribution



- dominated by  $a_1$  resonance
- peak at  $\sim 2 \text{ GeV}$  from  $\bar{B}^0 \rightarrow D^{*-} D_s^+ (\rightarrow 3\pi)$  (expected dominant exclusive contribution)
- hint of  $\pi(1800)$  contribution
- (this study does not aim at studying the structure of this distribution)

## Branching fraction determination

$$\bullet \mathcal{B} = \frac{N_{\text{signal}}}{\epsilon \cdot \mathcal{B}(D^{*-} \rightarrow \bar{D}^0 \pi^-) \cdot \mathcal{B}(\bar{D}^0 \rightarrow K^+ \pi^-)}$$

- efficiency  $\epsilon$ 
  - ▶ estimated in Monte Carlo as function of  $m(3\pi)$
  - ▶ corrected for data  $m(3\pi)$  distribution

Measurement / subtraction of exclusive contribution  $\bar{B}^0 \rightarrow D^{*-} D_s^+ (\rightarrow 3\pi)$ 

- the yield of  $\bar{B}^0 \rightarrow D^{*-} D_s^+ (\rightarrow 3\pi)$  is measured by computing the excess of candidates in the interval 1.9–2.0 GeV of the  $3\pi$  mass distribution over the extrapolation of the neighbouring bins

## Systematics

- 2.4% Fit algorithm and peaking backgrounds subtraction
  - ▶ normalization, mean & width of the two Gaussians for  $B^0 \bar{B}^0$  and  $B^+ B^-$  peaking backgrounds, determined by Monte Carlo
  - ▶ signal's Crystal Ball PDF cutoff and power parameters (fixed on Monte Carlo)
- 2.0% Track-finding
  - ▶ uncertainty on track efficiency from *BABAR* studies on data control samples
- 1.7%  $3\pi$  invariant mass modeling
  - ▶ 100% of the shift in efficiency when going from MC to data for the  $3\pi$  mass distribution
- 0.7%  $3\pi$  invariant mass sideband subtraction
  - ▶ background subtraction uncertainty, estimated in Monte Carlo
- 1.3%  $D^{*+}$  and  $\bar{D}^0$  branching fractions uncertainties (PDG 2015)
- 1.2%  $\mathcal{B}(\Upsilon(4S) \rightarrow B^0 \bar{B}^0)$  uncertainty (PDG 2015)
- 1.1%  $K$  identification, as estimated by *BABAR* using data control samples
- 0.9% signal efficiency Monte Carlo statistics
- 0.6% estimate of the number of  $\Upsilon(4S) \rightarrow B\bar{B}$  decays
- **4.3% total**

## Results

- $\mathcal{B}(\bar{B}^0 \rightarrow D^{*-} \pi^+ \pi^- \pi^+) = (7.37 \pm 0.11 \pm 0.31) \cdot 10^{-3}$ 
  - ▶ total uncertainty 4.5%, to be compared with 11.4% in PDG 2015
  - ▶ includes exclusive contributions like  $B^0 \rightarrow D^{*-} D_s^+ (\rightarrow \pi^+ \pi^- \pi^+)$
- $\mathcal{B}(\bar{B}^0 \rightarrow D^{*-} \pi^+ \pi^- \pi^+ \text{ (ex. } D_s^+ \rightarrow \pi^+ \pi^- \pi^+)) = (7.26 \pm 0.11 \pm 0.31) \cdot 10^{-3}$
- to be submitted to PRD

Thanks for your attention

## Backup Slides

## References

- measurements of  $R^{(*)} = \frac{\mathcal{B}(B \rightarrow D^{(*)}\tau^-\bar{\nu}_\tau)}{\mathcal{B}(B \rightarrow D^{(*)}\ell^-\bar{\nu}_\ell)}$ 
  - ▶ *BABAR*, Phys. Rev. D 88, 072012 (2013)
  - ▶ *Belle*, Phys. Rev. D 92, 072014 (2015)
  - ▶ *LHCb*, Phys. Rev. Lett. 115, 111803 (2015)
  - ▶ HFAG Winter 2016 averages,  
[http://www.slac.stanford.edu/xorg/hfag/semi/winter16/winter16\\_dtaunu.html](http://www.slac.stanford.edu/xorg/hfag/semi/winter16/winter16_dtaunu.html)