Study of Charmless Hadronic B decays at *BABAR*

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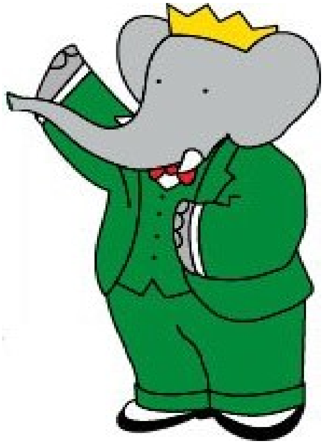
Representing
the *BABAR* Collaboration



July 23rd 2010
ICHEP 2010, Paris

Motivations

- Charmless hadronic *B* decays are sensitive probes to investigate potential effects of new physics:
  - shift of time-dependent *CP*-asymmetries;
  - suppression/enhancement of branching fractions;
  - … ;
- "Polarization puzzle": in several *VV* decays (such as ϕK^* or ρK^*) the longitudinal polarization fraction f_L is ~0.5, contrary to the prediction of $f_L \sim 0.9$ based on simple helicity arguments. Still to be fully explained;
- We can investigate new/poorly known resonances through the Dalitz Plot analysis of charmless three-body *B* decays;

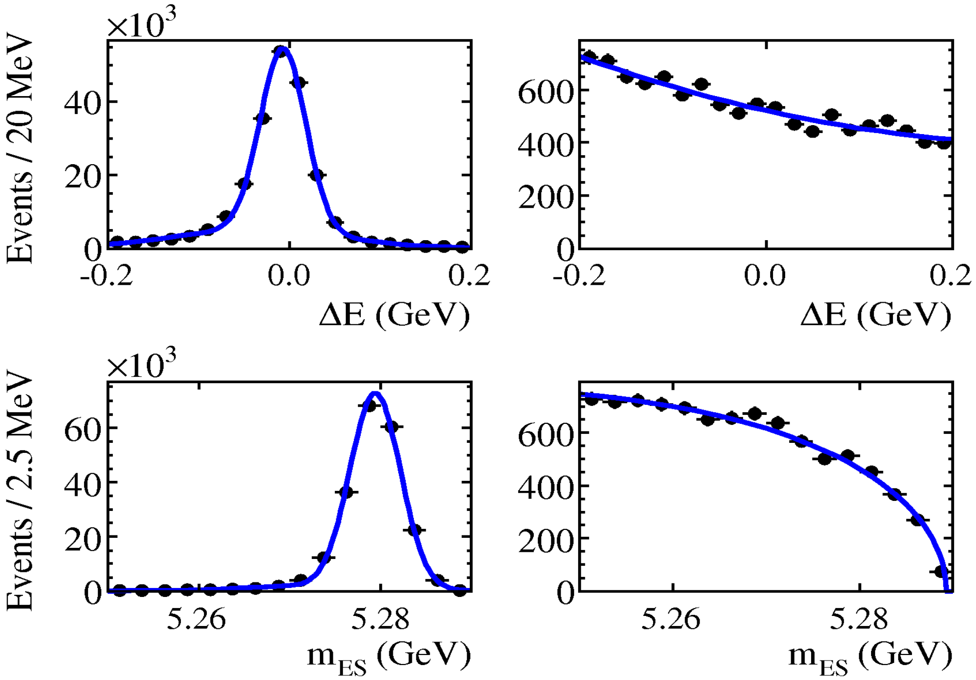
The measurements I will present today exploit the full BaBar dataset (~465 x 10^6 $B\bar{B}$ pairs).

Kinematics of *B* decays

- Fully reconstructed *B* mesons: two variables are commonly used (exploiting the precise knowledge of the beam energy):

$$\boxed{\Delta E = E_{meas} - E_{beam}}$$

$$\boxed{m_{ES} = \sqrt{E_{beam}^2 - \mathbf{p}_{meas}^2}}$$



Signal Background

- Dominant background: $q\bar{q}$ ($q = u, d, s, c$). Reduced by means of a Fisher discriminant / Neural Network exploiting event shape variables ($B\bar{B}$ events are spherical, $q\bar{q}$ jet-like)

Two-body Decays

- Search for $B \to \eta' \rho, \eta' f_0, \eta' K^*$;

arXiv:1004.0240 [hep-ex] – Accepted by PRD-RC

- Search for $B^+ \to a_1^+ K^{*0}$;

arXiv:1007.2732 [hep-ex] – Submitted to PRD-RC

Two-body: motivations

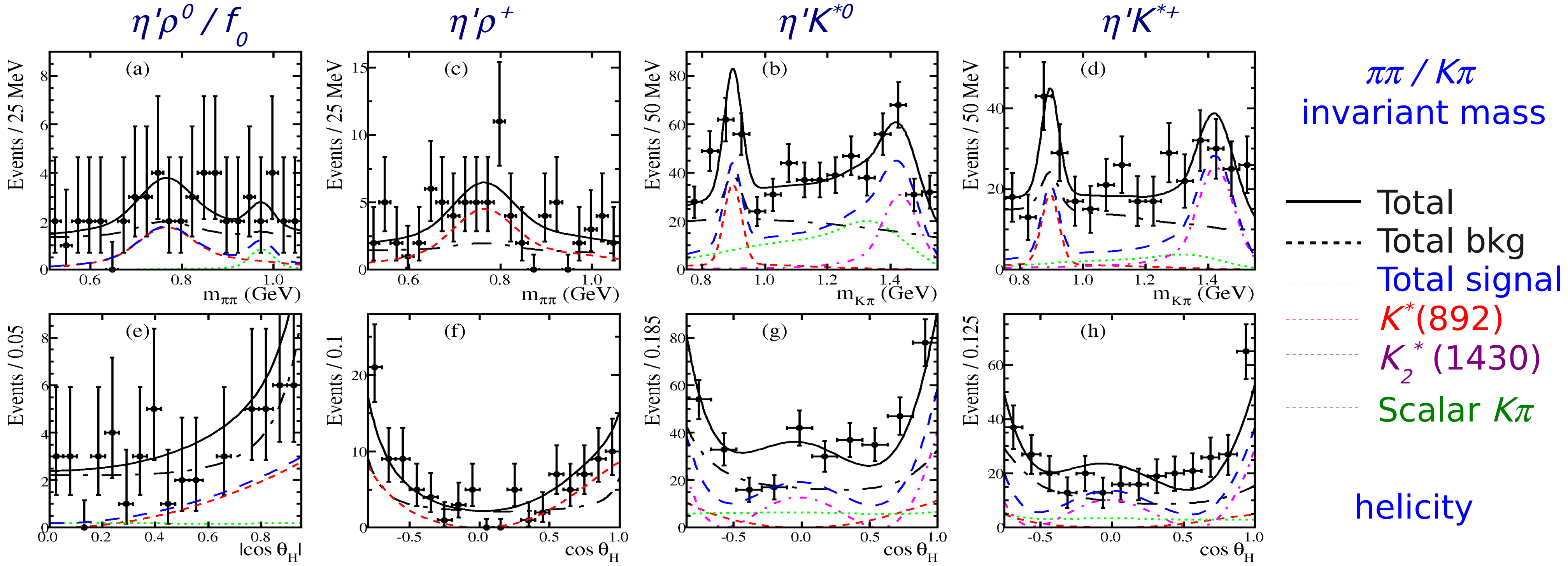
- Search for $B \to \eta' \rho, \eta' f_0, \eta' K^*$:
  - Confirm the predicted pattern of interference for $B \to \eta/\eta' X$ decays;
  - Discrepancies among theory models in the predicted BF of $B \to \eta'\rho^+$. Also poor agreement between Belle's result and previous BaBar analysis;

$B^+ \to \eta'\rho^+$	Predicted $\mathcal{B}(10^{-6})$
SCET	$0.4^{+3.2}_{-0.2}$
QCDF	$6.3^{+2.8}_{-3.3}$
pQCD	$8.7^{+3.3}_{-2.5}$

  - We fit simultaneously for three K^* components: $K^*(892)$, $K_2^*(1430)$, and the scalar $K_0^*(1430)$ + non-resonant $K\pi$ (we use the LASS parameterization) ;

- Search for $B^+ \to a_1^+ K^{*0}$:
  - Verify and constrain theory models: QCDF predicts a BF ~ 11 x 10^{-6}, while naïve factorization predicts ~10^{-6};
  - Investigate the polarization puzzle.

Search for $B \to \eta'\rho$ / $\eta' f_0$ / $\eta' K^*$



- First observation of: $\eta'\rho^+$, $\eta' K_0^*(1430)^0$, $\eta' K_2^*(1430)^+$, $\eta' K_2^*(1430)^0$;
- Evidence of: $\eta' K^*(892)^+$, $\eta' K^*(892)^0$, $\eta' K_0^*(1430)^+$;
- Our result on $\eta'\rho^+$ favors the predictions of pQCD and QCDF, confirmed suppression of $\eta' K^*$ with respect to ηK^*;
- Enhancement of the tensor component $K_2^*(1430)$ over the vector $K^*(892)$ not anticipated by the theory. This was observed also in ωK^*, but not in ηK^*.

Search for $B^+ \to a_1^+ K^{*0}$

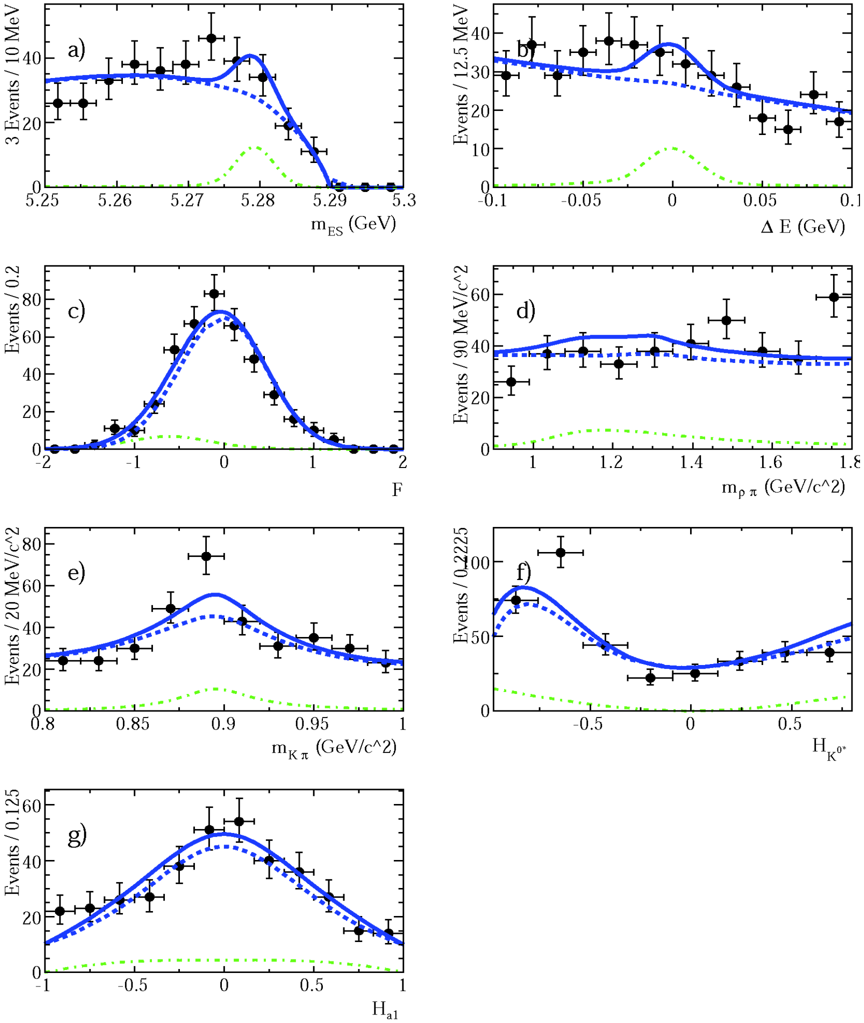
- Maximum likelihood fit to the variables:

m_{ES}, ΔE, Fisher, $m(\rho\pi)$, $m(K\pi)$, $H(a_1)$, $H(K^*)$

- No significant signal found, we set the upper limit:

$$BF(B^+ \to a_1^+ K^{*0}) \times BF(a_1^+ \to \pi^+\pi^-\pi^+)$$

$$< (1.8 \times 10^{-6}) \text{ (at 90\% CL)}$$



- Naïve factorization predictions favored over QCDF;
- Dominant systematic uncertainty from ignorance about f_L (nominal fit with $f_L = 1$ to get the most conservative upper limit).

Three-body Decays

- Inclusive branching fraction of $B^+ \rightarrow K^+ \pi^0 \pi^0$;

arXiv:1005.3717 [hep-ex] – Presented at FPCP 2010

- Observation of the rare decay $B^0 \rightarrow K_S^0 K \pi$;

arXiv:1003.0640 [hep-ex] – Submitted to PRD-RC

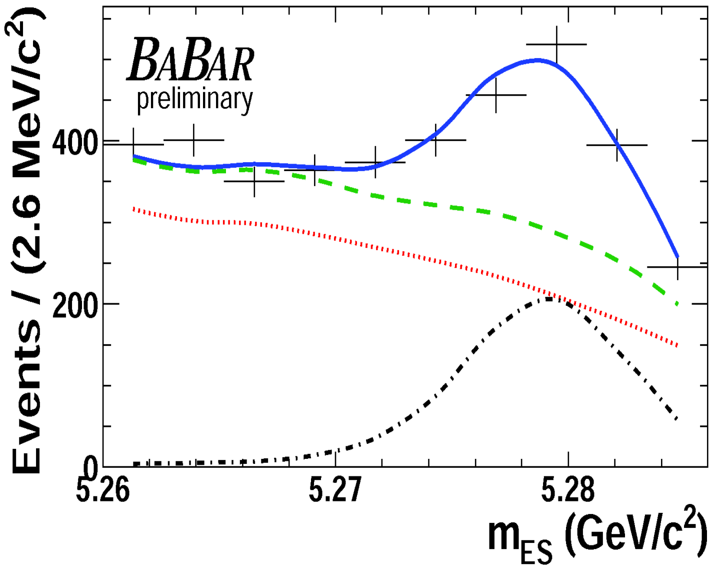
- Amplitude analysis of $B^0 \rightarrow K_S^0 K_S^0 K_S^0$;

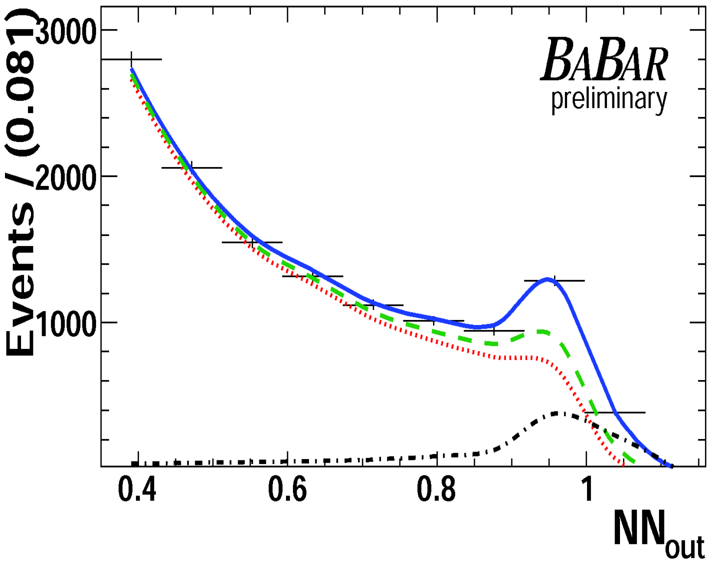
Presented at FPCP 2010

Three-body: motivations

- $B^+ \rightarrow K^+ \pi^0 \pi^0$:
  - help solving the *"Kπ puzzle"* looking at the similar $K^*\pi$;
  - Investigate the poorly known $f_X(1300)$, seen to decay to $\pi^+\pi^-$;
- $B^0 \rightarrow K_S^0 K \pi$:
  - Decay proceeding through $b \rightarrow u$ tree and $b \rightarrow d$ penguin amplitudes;
  - Search for an isospin partner of the $f_X(1500)$ seen decaying to K^+K^- in $B^+ \rightarrow K^+K^-\pi^+$, but not in $B^+ \rightarrow K_S^0 K_S^0 \pi^+$;
- $B^0 \rightarrow K_S^0 K_S^0 K_S^0$:
  - First amplitude analysis of this mode;
  - Investigate the nature of the $f_X(1500)$.

Inclusive BF of $B^+ \to K^+ \pi^0 \pi^0$





Fit results:

N_{slg} = 1220 ± 85

f_{SCF} = 9.7 %

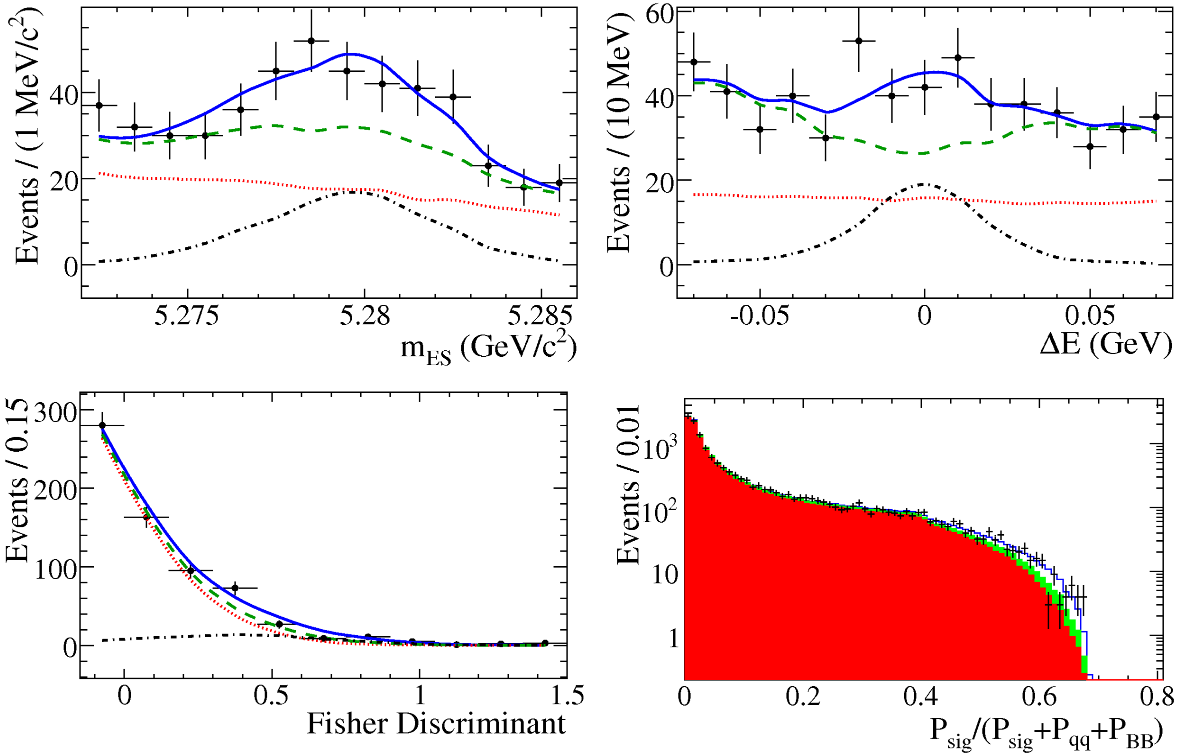
Significance 10σ (15.6σ stat only)

- We measure the branching fraction:

$$BF(B^+ \to K^+ \pi^0 \pi^0) = (15.5 \pm 1.1 \pm 1.6) \times 10^{-6}$$

- Dominant systematic uncertainties: π^0 reconstruction efficiency (6.0%), NN_{out} PDF shape (4.9%), ΔE cut efficiency (4.0%).

Observation of $B^0 \to K_S^0 K \pi$

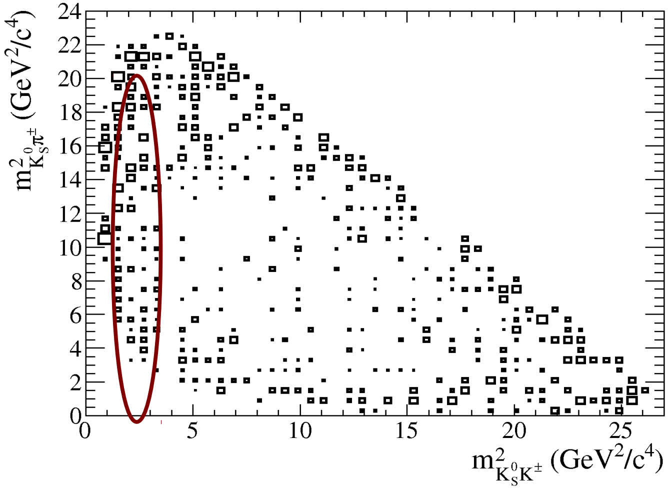


Fit results:

$N_{sig} = 262 \pm 47$

Significance 5.2σ
(6.0σ stat only)

No evidence of an isospin partner of the $f_X(1500)$



$$BF(B^0 \to K_S^0 K \pi) = (3.2 \pm 0.5 \pm 0.3) \times 10^{-6}$$

- Dominant systematic uncertainties: signal PDF's (5.2%), corrections due to vetoes (4.1%), self-crossfeed fraction (3%).

Amplitude analysis of $B^0 \to K_s^0 K_s^0 K_s^0$

- Three identical particles in the final state: the analysis can be done only in 1/6th of the Dalitz Plot. We use the variables s_{max} and s_{min}, and we move to the Squared Dalitz Plot formalism:

Standard DP

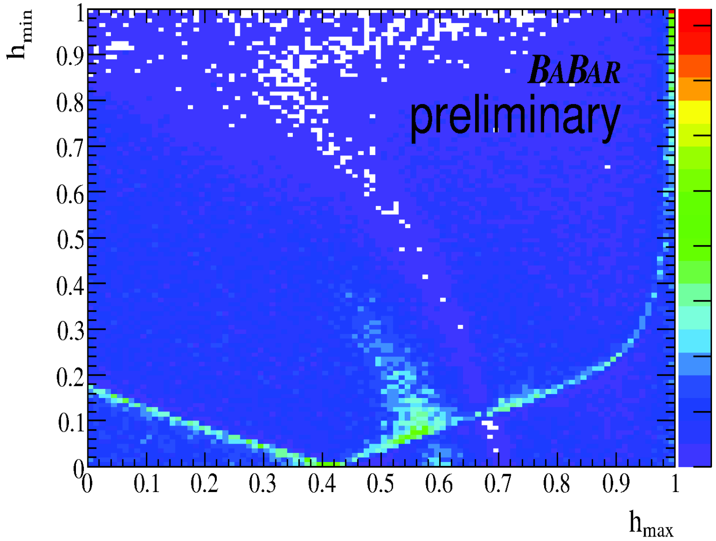
$$\begin{aligned} s_{min} &= \min(s_{12}, s_{23}, s_{13}) \\ s_{max} &= \max(s_{12}, s_{23}, s_{13}) \\ s_{xy} &= m^2_{xy} \end{aligned}$$

Squared DP

$$\begin{aligned} s_{min} &\to \cos\theta_{min} \equiv h_{min} \\ s_{max} &\to \cos\theta_{max} \equiv h_{max} \\ ds_{min} ds_{max} &\to |\det J| dh_{min} dh_{max} \end{aligned}$$

- The isobar model is used to describe the DP structure:

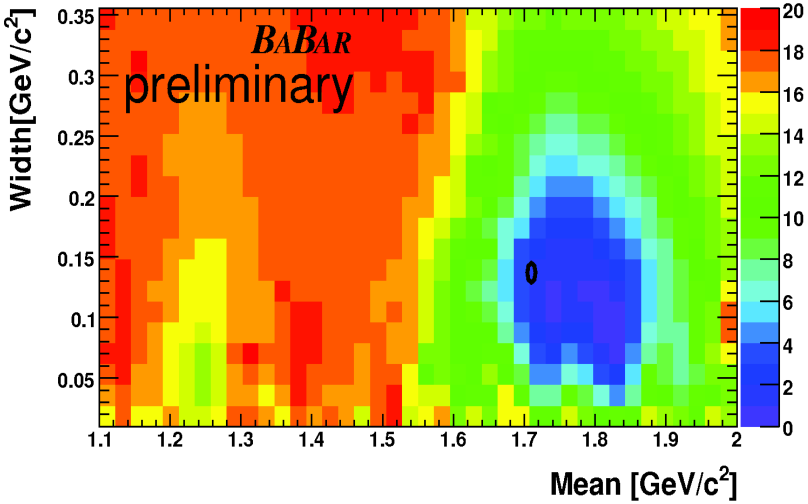
$$\mathcal{A}(s_{\rm min}, s_{\rm max}) = \sum_{j=1}^{N} c_j F_j(s_{\rm min}, s_{\rm max})$$



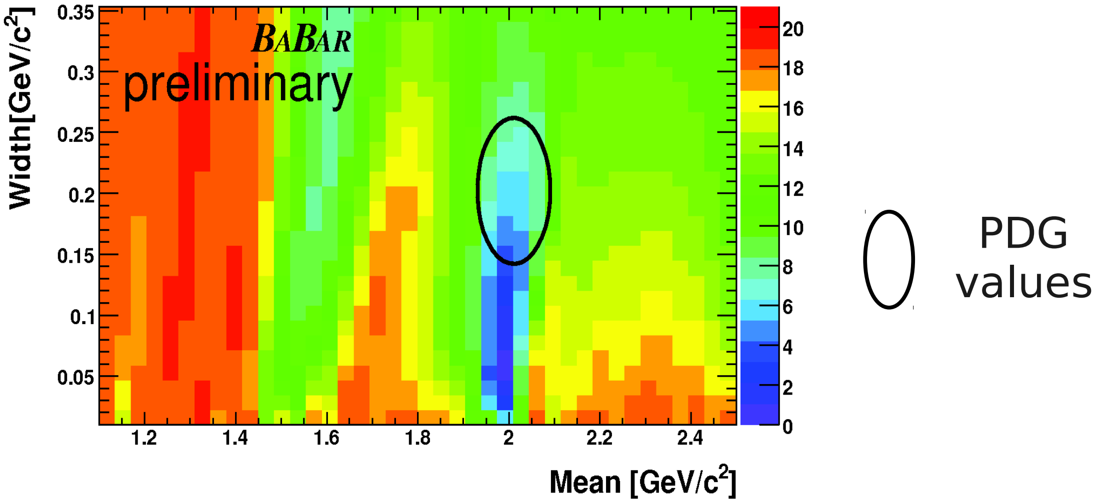
Amplitude analysis of $B^0\to K_s^0K_s^0K_s^0$

- 200 ± 15 signal events (305 ± 18 $q\bar{q}$);
- We start with a baseline model with f_0 (980), χ_{c0} , and non-resonant. We add a resonance and scan the likelihood varying its mass and width;

Scan for a scalar resonance



Scan for a tensor resonance



- We only find significant contributions from f_0 (1710) and f_2 (2010), no evidence of the f_X (1500);
- We measure the inclusive branching fraction:

BF($B^0 \to K_sK_sK_s$) = (6.5 ± 0.5 ± 0.4) x 10^{-6}

Conclusions

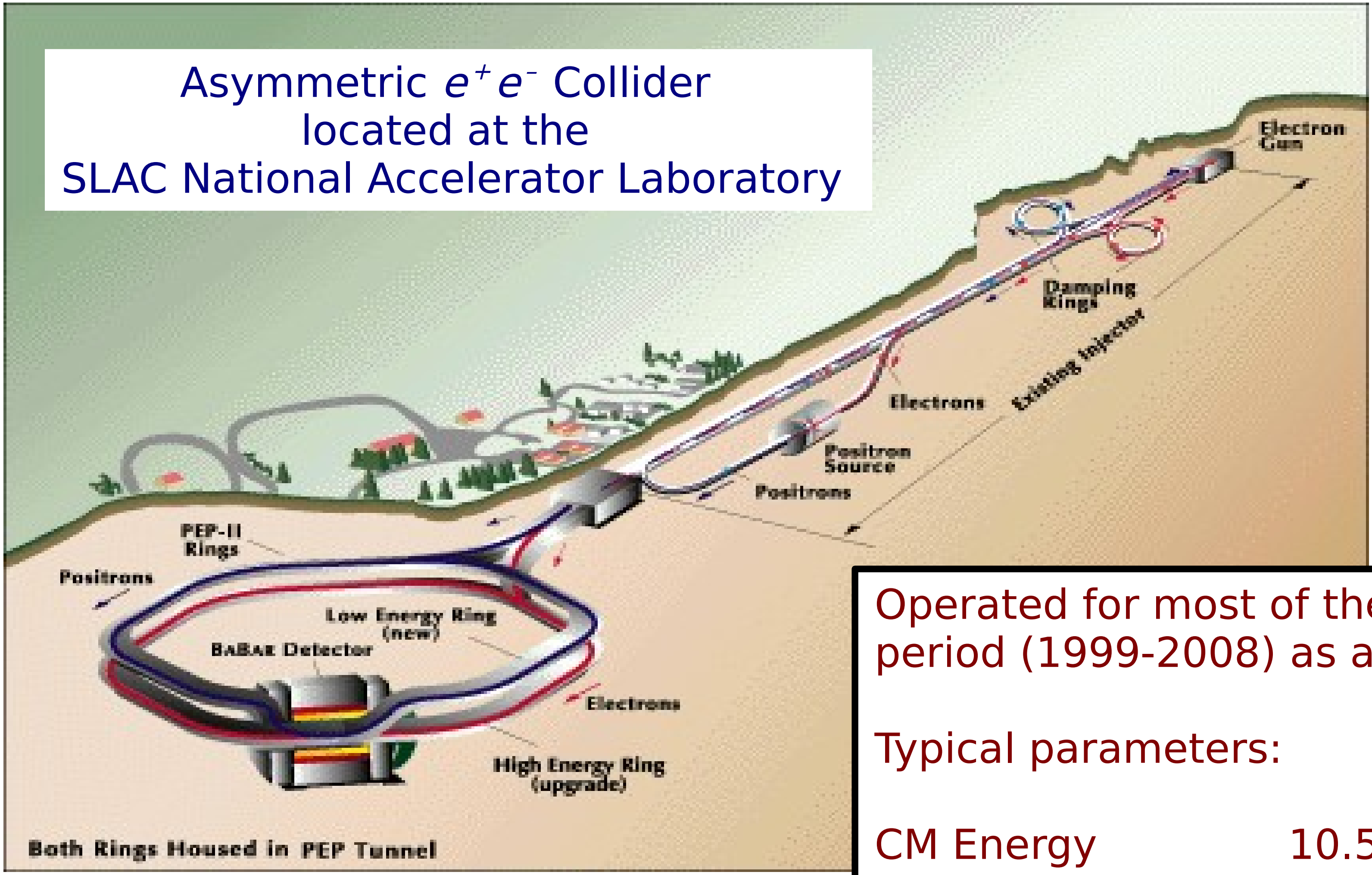
Search for $B \to \eta' \rho, \eta' f_0, \eta' K^*$	Four first observations (>5σ) and evidence (>3σ) for three more modes. Unexpected enhancement of the tensor component over the vector in $\eta' K^*$
Search for $B^+ \to a_1^+ K^{*0}$	No signal found: upper limit sets useful constraints for theoretical models
Inclusive BF of $B \to K^+ \pi^0 \pi^0$	First measurement of the inclusive mode, next we will measure the $K^* \pi$ branching fraction
Measurement of $B^0 \to K_S^0 K \pi$	No evidence of an isospin partner of the f_X (1500)
Amplitude analysis of $B^0 \to K_S K_S K_S$	First amplitude analysis of this mode, no evidence of the f_X (1500) decaying to $K_S K_S$

- Two years after the end of the data taking, BaBar continues to exploit its rich dataset, more results will be coming...

Backup Slides

The PEP-II Collider

Asymmetric e^+e^- Collider
located at the
SLAC National Accelerator Laboratory

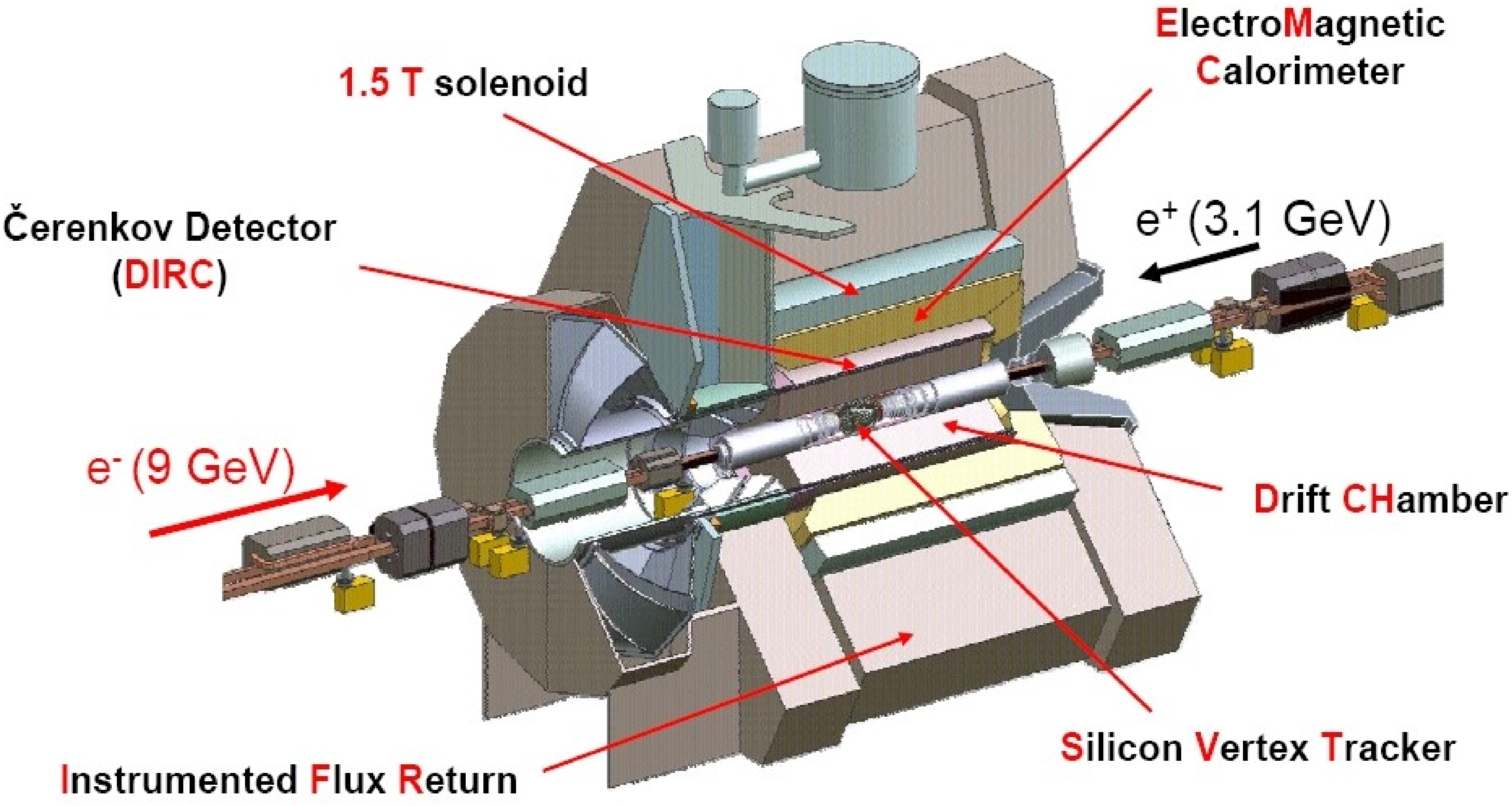


Operated for most of the data-taking period (1999-2008) as a B-factory.

Typical parameters:

CM Energy	10.58 GeV
e^+ Energy	3.1 GeV
e^- Energy	9.0 GeV
Max Luminosity	1.2×10^{34} cm^{-2}s^{-1}

The *BABAR* detector



Search for $B \rightarrow \eta'\rho$ / $\eta' f_0$ / $\eta' K^*$

Mode	Y (events)	Y_0 (events)	ϵ (%)	$\prod \mathcal{B}_i$ (%)	S (σ)	$\mathcal{B}$ (10^{-6})	$\mathcal{B}$ U.L. (10^{-6})	$\mathcal{A}_{\rm ch}$
$\eta'\rho^0$	37±15	9±5	23.4	17.5	2.0	$1.5 \pm 0.8 \pm 0.3$	2.8	–
$\eta' f_0$	8±8	4±2	25.9	17.5	0.5	$0.2^{+0.4}_{-0.3} \pm 0.1$	0.9	–
$\eta'\rho^+$	128±22	15±8	14.3	17.5	5.8	$9.7^{+1.9}_{-1.8} \pm 1.1$	–	$0.26 \pm 0.17 \pm 0.02$
$\eta' K^*(892)^0$					4.0	$3.1^{+0.9}_{-0.8} \pm 0.3$	4.4	$0.02 \pm 0.23 \pm 0.02$
$\eta'_{\eta\pi\pi} K^*(892)^0$	28±10	4±2	18.9	11.7	2.7	$2.4^{+1.1}_{-0.9} \pm 0.3$		-0.04 ± 0.35
$\eta'_{\rho\gamma} K^*(892)^0$	61±18	9±5	13.3	19.6	3.1	$4.3^{+1.6}_{-1.5} \pm 0.5$		0.06 ± 0.29
$\eta' K^*(892)^+$					3.8	$4.8^{+1.6}_{-1.4} \pm 0.8$	7.2	$-0.26 \pm 0.27 \pm 0.02$
$\eta'_{\eta\pi\pi} K^*(892)^+_{K^+\pi^0}$	14±8	2±1	11.5	5.8	2.0	$3.9^{+3.1}_{-2.1} \pm 0.5$		-1.00 ± 0.78
$\eta'_{\rho\gamma} K^*(892)^+_{K^+\pi^0}$	26±19	6±3	9.7	9.8	1.1	$4.7^{+4.5}_{-4.1} \pm 1.3$		0.05 ± 0.66
$\eta'_{\eta\pi\pi} K^*(892)^+_{K^0_S\pi^+}$	23±10	3±2	19.1	4.0	2.6	$5.5^{+2.9}_{-2.4} \pm 0.7$		-0.47 ± 0.37
$\eta'_{\rho\gamma} K^*(892)^+_{K^0_S\pi^+}$	34±15	10±5	16.2	6.8	1.6	$4.8^{+3.2}_{-2.8} \pm 1.2$		0.24 ± 0.44
$\eta'(K\pi)^{*0}_0$					5.6	$7.4^{+1.5}_{-1.4} \pm 0.6$	–	$-0.19 \pm 0.17 \pm 0.02$
$\eta'_{\eta\pi\pi}(K\pi)^{*0}_0$	106±21	12±6	20.2	11.7	4.9	$8.5^{+2.0}_{-1.9} \pm 1.0$		-0.39 ± 0.20
$\eta'_{\rho\gamma}(K\pi)^{*0}_0$	115±36	21±11	17.6	19.6	2.7	$5.8^{+2.3}_{-2.2} \pm 1.0$		0.32 ± 0.31
$\eta'(K\pi)^{*+}_0$					2.9	$6.0^{+2.2}_{-2.0} \pm 0.9$	9.3	$0.06 \pm 0.20 \pm 0.02$
$\eta'_{\eta\pi\pi}(K^+\pi^0)^{*+}_0$	36±15	2±1	13.9	5.8	2.4	$8.8^{+4.2}_{-3.8} \pm 1.3$		0.00 ± 0.41
$\eta'_{\rho\gamma}(K^+\pi^0)^{*+}_0$	185±51	31±15	12.8	9.8	2.8	$26.4^{+9.0}_{-8.5} \pm 5.9$		0.23 ± 0.27
$\eta'_{\eta\pi\pi}(K^0_S\pi^+)^{*+}_0$	18±12	1±1	18.6	4.0	1.6	$5.1^{+3.5}_{-3.2} \pm 0.9$		0.13 ± 0.59
$\eta'_{\rho\gamma}(K^0_S\pi^+)^{*+}_0$	-29±22	-8±4	17.4	6.8	–	$-3.8^{+4.0}_{-3.9} \pm 1.5$		-0.40 ± 1.48
$\eta' K^*_2(1430)^0$					5.3	$13.7^{+3.0}_{-2.9} \pm 1.2$	–	$0.14 \pm 0.18 \pm 0.02$
$\eta'_{\eta\pi\pi} K^*_2(1430)^0$	42±13	2±1	15.1	5.8	3.7	$9.8^{+3.4}_{-3.2} \pm 0.9$		0.58 ± 0.32
$\eta'_{\rho\gamma} K^*_2(1430)^0$	125±26	20±10	10.6	9.8	4.1	$21.7^{+5.4}_{-5.3} \pm 3.0$		-0.05 ± 0.20
$\eta' K^*_2(1430)^+$					7.2	$28.0^{+4.6}_{-4.3} \pm 2.6$	–	$0.15 \pm 0.13 \pm 0.02$
$\eta'_{\eta\pi\pi} K^*_2(1430)^+_{K^+\pi^0}$	42±11	5±3	9.9	2.9	3.5	$27.1^{+8.8}_{-8.1} \pm 4.5$		0.29 ± 0.25
$\eta'_{\rho\gamma} K^*_2(1430)^+_{K^+\pi^0}$	115±28	20±10	8.5	4.9	2.9	$46.2^{+14.4}_{-13.8} \pm 12.2$		-0.33 ± 0.24
$\eta'_{\eta\pi\pi} K^*_2(1430)^+_{K^0_S\pi^+}$	42±10	5±2	15.3	2.0	4.5	$25.9^{+7.8}_{-7.1} \pm 2.7$		0.44 ± 0.23
$\eta'_{\rho\gamma} K^*_2(1430)^+_{K^0_S\pi^+}$	62±16	14±7	12.4	3.4	3.0	$24.1^{+8.7}_{-8.0} \pm 4.1$		0.22 ± 0.25

Search for $B \to \eta'\rho$ / $\eta' f_0$ / $\eta' K^*$

Previous results (x 10^{-6})

Mode	BABAR	Belle
$B^+ \to \eta'\rho^+$	$8.7^{+3.1+2.3}_{-2.8-1.3}$	<5.8
$B^0 \to \eta'\rho^0$	< 3.7	<1.3
$B^0 \to \eta' K^{*0}$	$3.8 \pm 1.1 \pm 0.5$	<2.6
$B^+ \to \eta' K^{*+}$	$4.9^{+1.9}_{-1.7} \pm 0.8$	<2.9

232M $B\bar{B}$ pairs
PRL 98, 051802 (2007)

535M $B\bar{B}$ pairs
PRD 75, 092002 (2007)

Search for $B^+ \to a_1^+ K^{*0}$

Y	Y_b	$\mathcal{B}(10^{-6})$	S	UL (10^{-6})
61^{+23}_{-21}	34 ± 17	$0.7^{+0.5+0.6}_{-0.5-1.3}$	0.5	1.8

$$\mathcal{B}(B^+ \to a_1^+ K^{*0}) \times \mathcal{B}(a_1^+ \to \pi^+\pi^-\pi^+) = (0.7^{+0.5+0.6}_{-0.5-1.3}) \times 10^{-6}$$

Source of systematic uncertainty	
Additive errors (events)	
PDF parametrization	4
a_1 meson parametrization	6
ML Fit Bias	17
Non resonant charmless $B\overline{B}$ background	3
$B^+ \to a_2^+ K^{*0}$ charmless background	6
Remaining charmless $B\overline{B}$ background	7
Total additive (events)	22
Multiplicative errors (%)	
Tracking efficiency	1.2
Determination of the integrated luminosity	1.1
MC statistics (signal efficiency)	0.6
Differences in selection efficiency for a_1 decay	3.3
Particle identification (PID)	1.4
Event shape restriction ($\cos\theta_{\mathrm{T}}$)	1.0
Total multiplicative (%)	4.1
Variation on f_L [$\mathcal{B}(10^{-6})$]	$^{+0.0}_{-1.2}$
Total systematic error [$\mathcal{B}(10^{-6})$]	$^{+0.6}_{-1.3}$

Inclusive BF of $B^+ \rightarrow K^+ \pi^0 \pi^0$

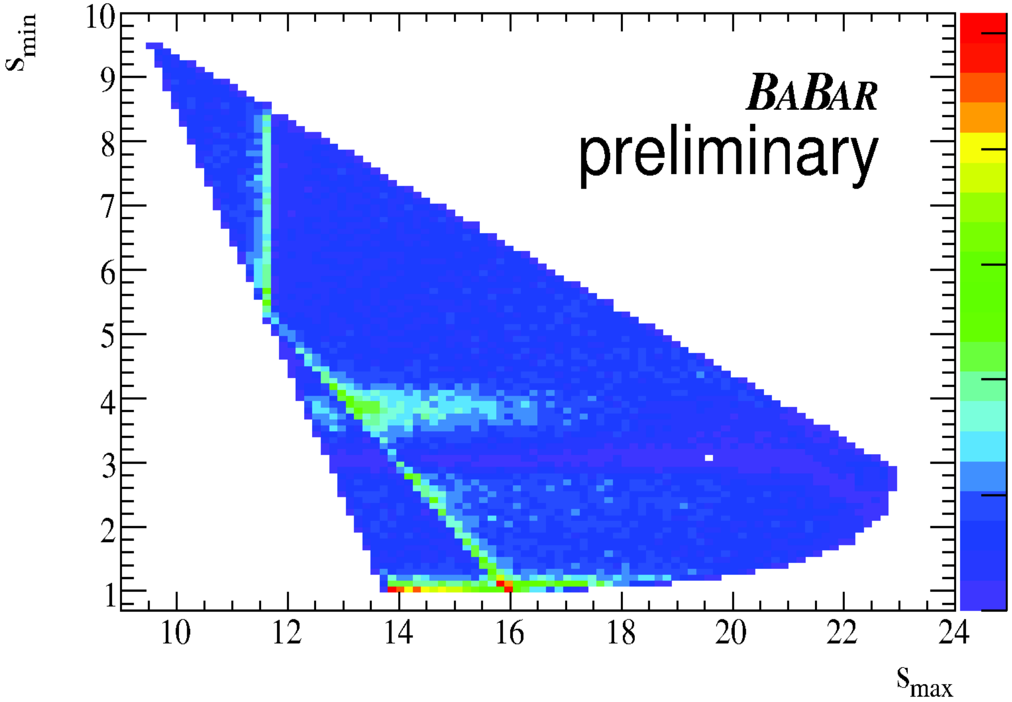
$$\mathcal{P}_j^i \equiv \mathcal{P}_j({m_{\rm ES}}^i)\mathcal{P}_j({\rm NN_{out}}^i)$$

$$\begin{aligned}\mathcal{P}^i_{\rm sig} \;\equiv\; & (1-f_{\rm SCF})\mathcal{P}_{\rm CR}({m_{\rm ES}}^i)\mathcal{P}_{\rm CR}({\rm NN_{out}}^i)+ \\ & f_{\rm SCF}\mathcal{P}_{\rm SCF}({m_{\rm ES}}^i)\mathcal{P}_{\rm SCF}({\rm NN_{out}}^i)\,,\end{aligned}$$

Source	Uncertainty
CR signal $m_{\rm ES}$ PDF	0.8 %
CR signal and $B\overline{B}$ background $\rm NN_{out}$ PDFs	4.9 %
SCF signal $m_{\rm ES}$ PDF	1.7 %
SCF signal $\rm NN_{out}$ PDF	0.7 %
SCF fraction	2.5 %
$B\overline{B}$ background PDFs (MC statistics)	0.8 %
$B\overline{B}$ background $m_{\rm ES}$ PDFs	1.6 %
$B\overline{B}$ background yields	1.4 %
Fit bias	1.8 %
Subtotal	6.5 %
Tracking efficiency	0.4 %
Particle identification	1.0 %
Neutral pion efficiency	6.0 %
ΔE cut efficiency	4.0 %
$\rm NN_{out}$ cut efficiency	3.0 %
K_S^0 veto	2.0 %
$N_{B\overline{B}}$	0.6 %
Total	10.4 %

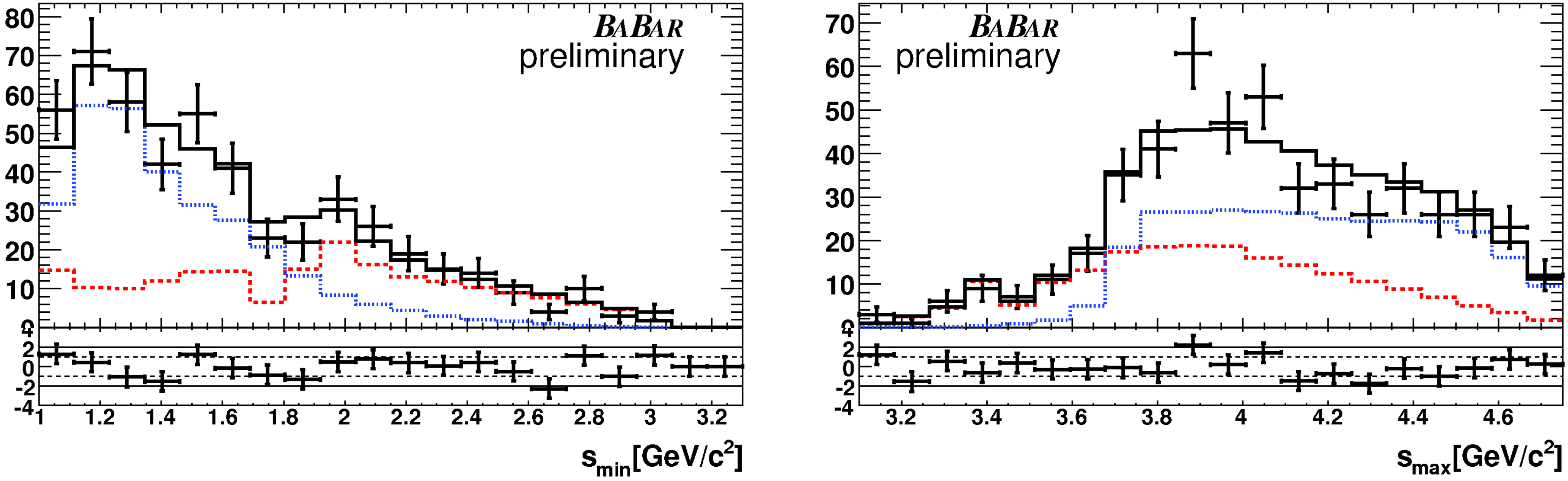
Amplitude analysis of $B^0 \to K_S^0 K_S^0 K_S^0$

$$\begin{aligned}\mathcal{A}[B^0 &\to K_S^0(1)K_S^0(2)K_S^0(3)] \\ &= \frac{1}{2}^{3/2}\{\mathcal{A}_1[B^0 \to \overline{K}^0(1)K^0(2)K^0(3)] \\ &+ \mathcal{A}_2[B^0 \to \overline{K}^0(2)K^0(3)K^0(1)] \\ &+ \mathcal{A}_3[B^0 \to \overline{K}^0(3)K^0(1)K^0(2)]\}\ ,\end{aligned}$$

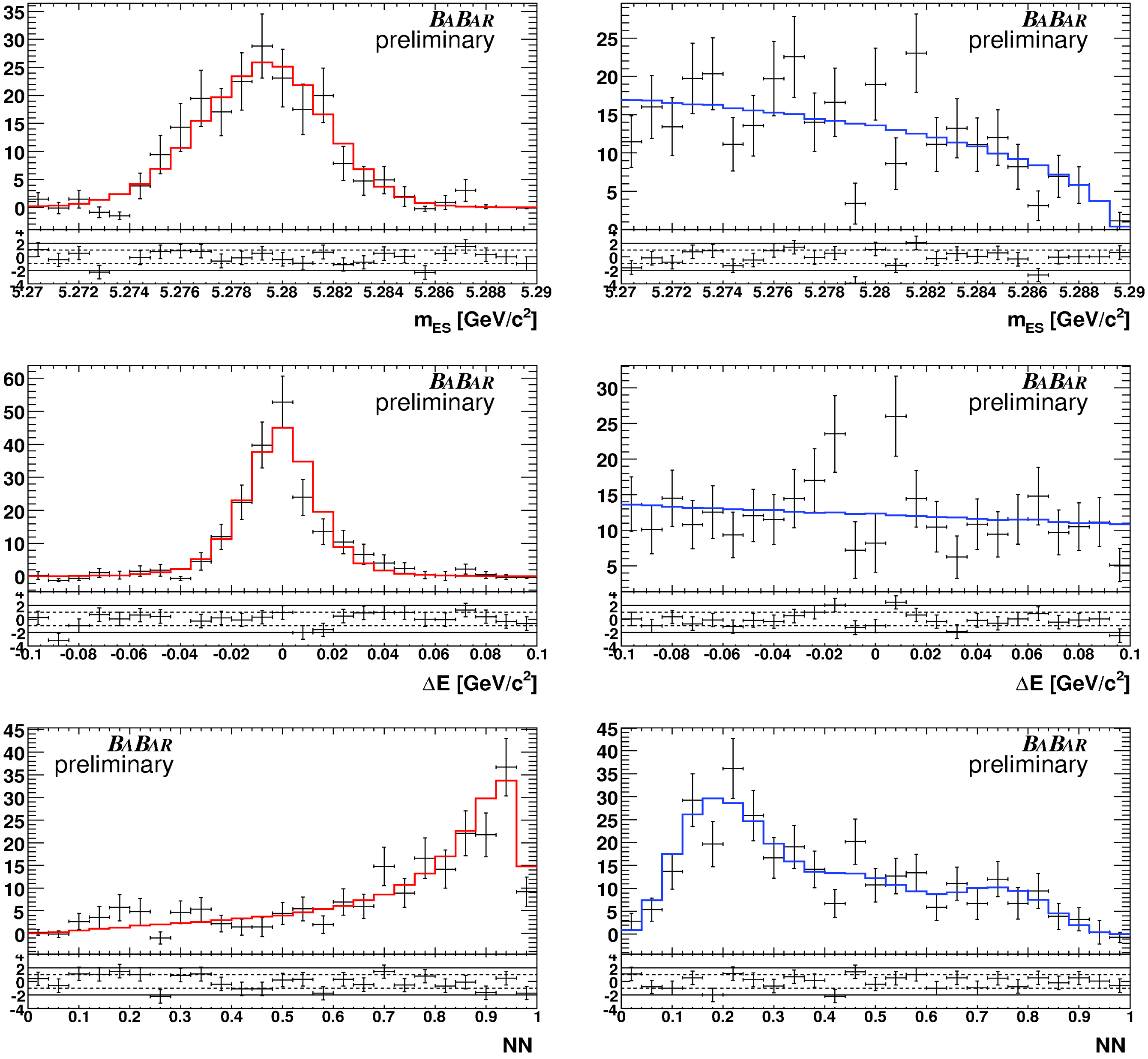


$$d\Gamma(B^0 \to K_S^0 K_S^0 K_S^0) = \frac{1}{(2\pi)^3}\frac{|\mathcal{A}|^2}{32m_{B^0}^3}\, ds_{\min} ds_{\max}$$

Amplitude analysis of $B^0 \to K_s^0 K_s^0 K_s^0$



Amplitude analysis of $B^0 \to K_S^0 K_S^0 K_S^0$



Amplitude analysis of $B^0 \rightarrow K_s^0 K_s^0 K_s^0$

Mode	Solution 1	Solution 2
FF $f_0(980)K_S^0$	$0.44^{+0.20}_{-0.19}$	$1.03^{+0.22}_{-0.17}$
Phase [rad] $f_0(980)K_S^0$	0.09 ± 0.16	1.26 ± 0.17
Significance [σ] $f_0(980)K_S^0$	3.3	-
FF $f_0(1710)K_S^0$	$0.07^{+0.07}_{-0.03}$	$0.09^{+0.05}_{-0.02}$
Phase [rad] $f_0(1710)K_S^0$	1.11 ± 0.23	0.36 ± 0.20
Significance [σ] $f_0(1710)K_S^0$	3.7	-
FF $f_2(2010)K_S^0$	$0.09^{+0.03}_{-0.03}$	0.10 ± 0.02
Phase [rad] $f_2(2010)K_S^0$	2.50 ± 0.20	1.58 ± 0.22
Significance [σ] $f_2(2010)K_S^0$	3.3	-
FF $\chi_{c0}K_S^0$	$0.07^{+0.04}_{-0.02}$	0.07 ± 0.02
Phase [rad] $\chi_{c0}K_S^0$	0.63 ± 0.47	-0.24 ± 0.52
Significance [σ] $\chi_{c0}K_S^0$	4.2	-
FF NR	$2.15^{+0.36}_{-0.37}$	$1.37^{+0.26}_{-0.21}$
Phase [rad] NR	0.0	0.0
Significance [σ] NR	8.2	-
Total FF	$2.84^{+0.71}_{-0.66}$	$2.66^{+0.35}_{-0.27}$