2015/Jul/23 EPS HEP, VIENNA

NEW

Searches for the $\mathrm{B}^0 \to \eta\pi^0$ at Belle

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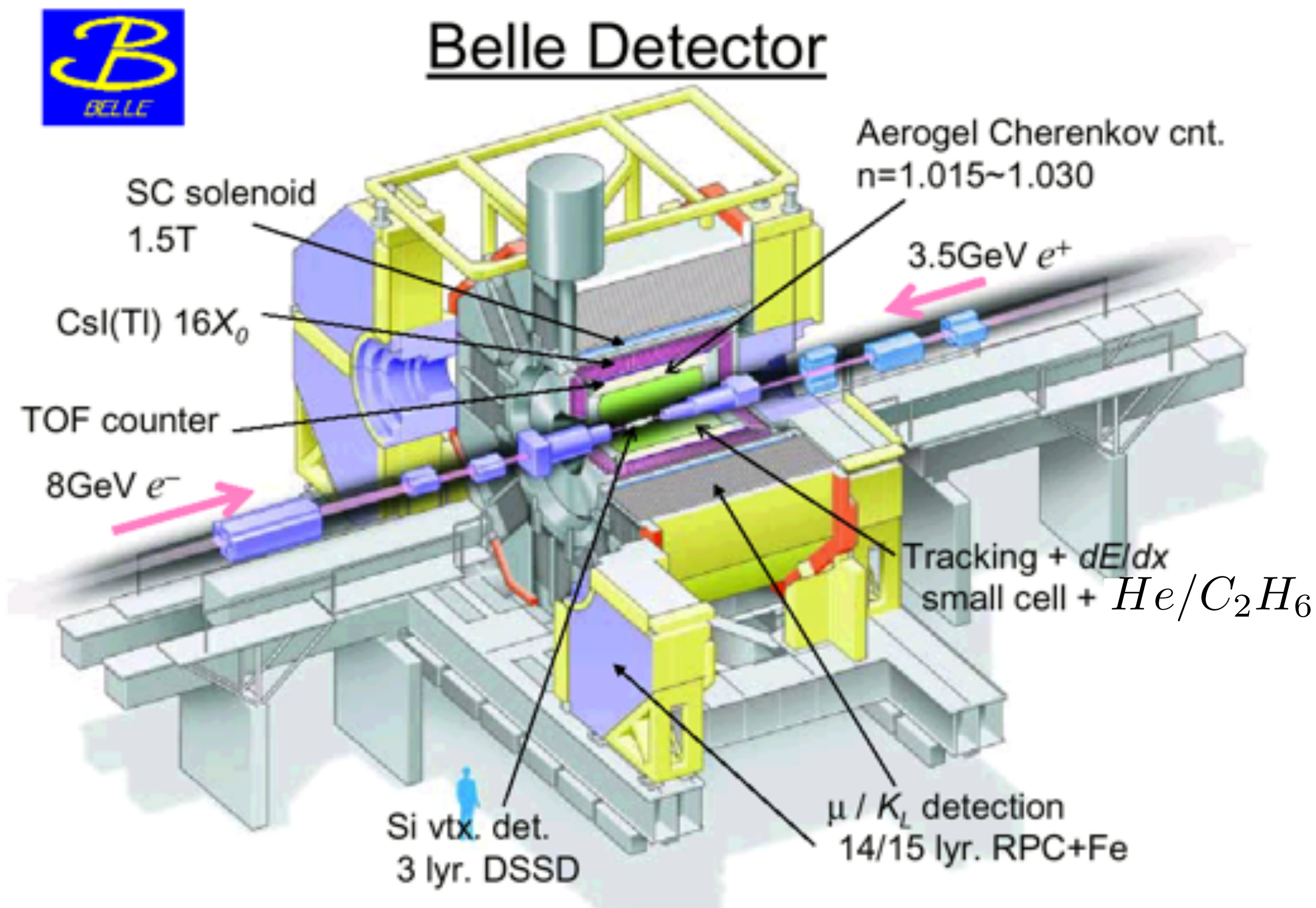
Use Full Belle Data set

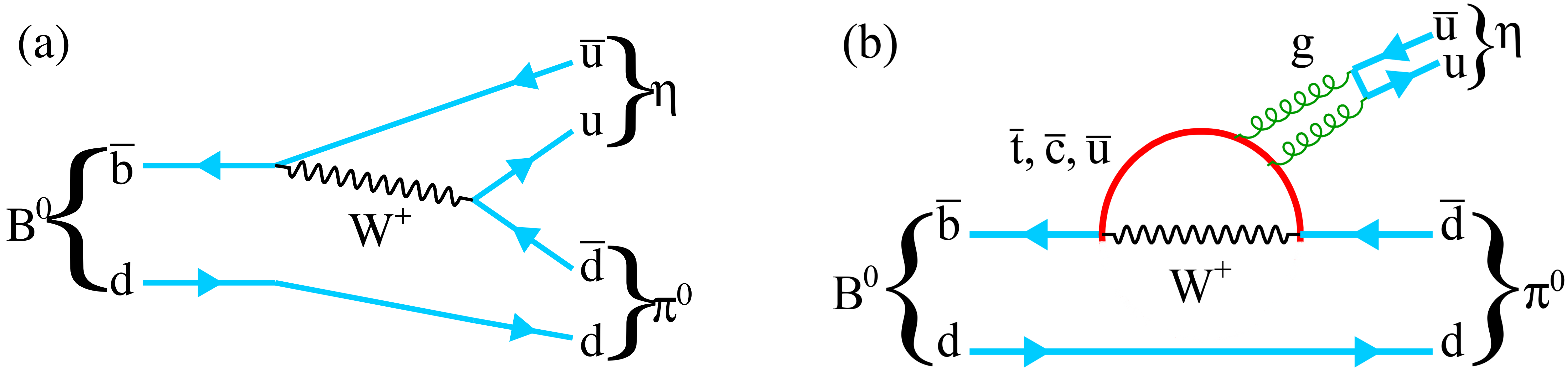


$$B^0 \to \eta\pi^0$$

694 fb^{-1} at $\Upsilon(4S)$ resonances

753M $B\overline{B}$ pairs

Previous studies of $B^0 \to \eta\pi^0$



Tree Diagram

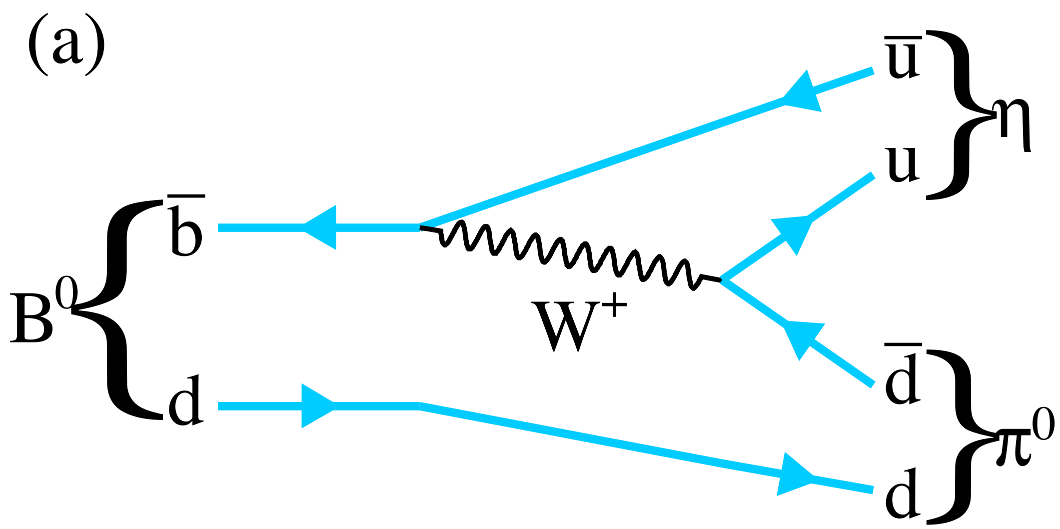
Penguin Diagram

QCD factorization (theory) expectation: $(2 - 12) \times 10^{-7}$

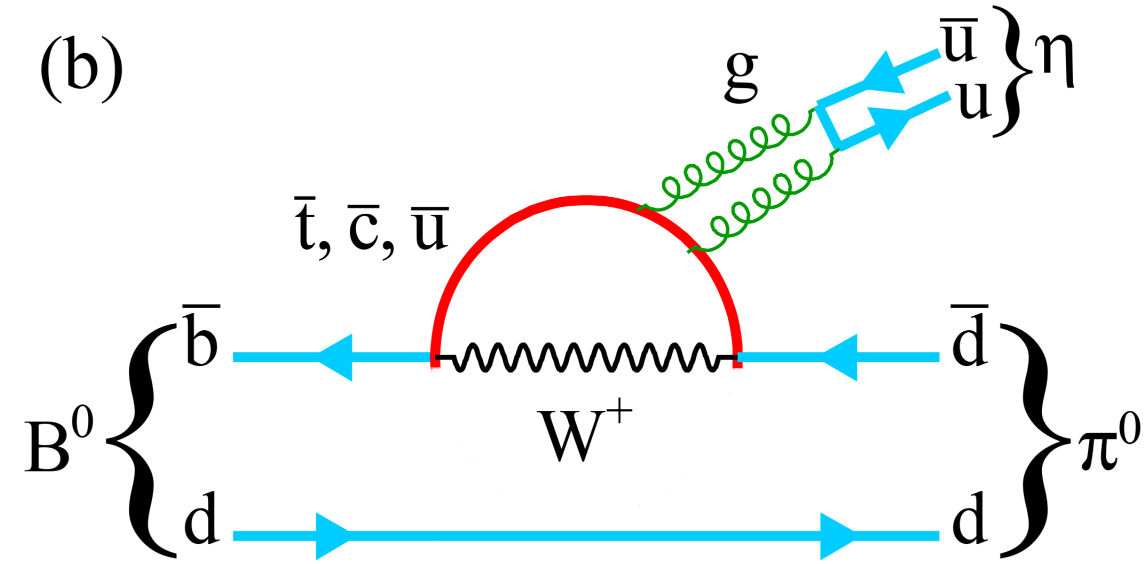
The best upper limit by BaBar: $< 1.5 \times 10^{-6}$,

by Belle: $< 2.5 \times 10^{-6}$

Implication of the results



Tree Diagram



Penguin Diagram

Constrain the contribution of isospin-breaking effects on the value of $\sin 2\alpha$ in $B^0 \to \pi^+\pi^-$ decays

Event selections

Use EVTGEN event generator to generate 1 Million MC events.

Charged Particles

$\mathrm{Impact\ Parameters}: |\mathrm{dr}| < 0.3\ \mathrm{cm},\ |\mathrm{dz}| < 3.0\ \mathrm{cm}$

$\mathrm{KID} < 0.4$ for pion, $\mathrm{eID} < 0.95$, $\mu\mathrm{ID} < 0.95$

π^0

$\mathrm{Mass-constraint\ Fit},\ 115 < m_{\pi^0} < 155\ \mathrm{MeV}$

$E_\gamma > 100\ \mathrm{MeV} (> 50\ \mathrm{MeV})$ in end cap(barrel) region

$\eta \to \gamma\gamma$

$\pi^0\ \mathrm{veto},\ E_\gamma > 50\ \mathrm{MeV},\ \frac{|E_{\gamma 1} - E_{\gamma 2}|}{E_{\gamma 1} + E_{\gamma 2}} < 0.9$

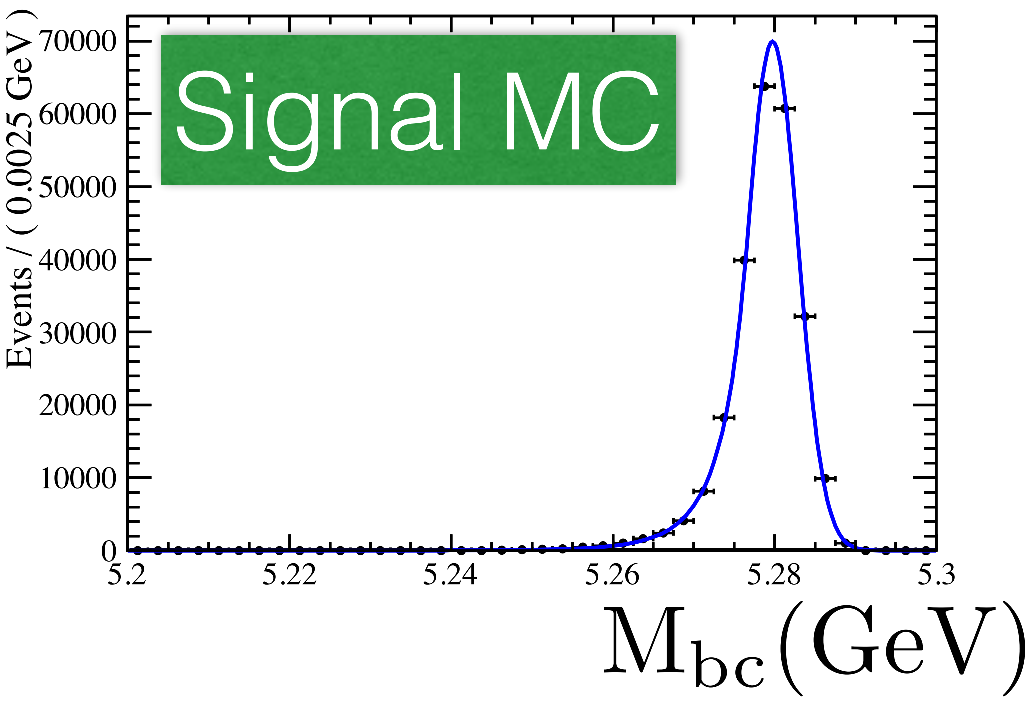
$\mathrm{Mass-constraint\ Fit},\ 500 < m_{\gamma\gamma} < 575\ \mathrm{MeV}$

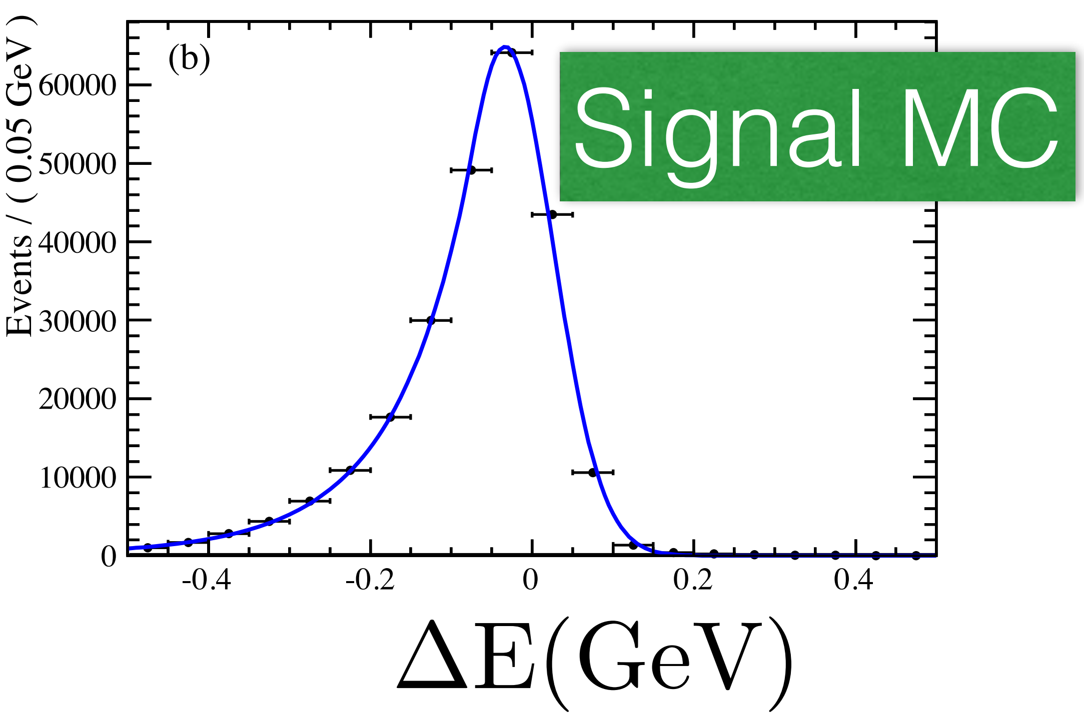
$\eta \to \pi^+\pi^-\pi^0$

$\mathrm{Mass-constraint\ Fit},\ 538 < m_{\pi^+\pi^-\pi^0} < 557\ \mathrm{MeV}$

B^0

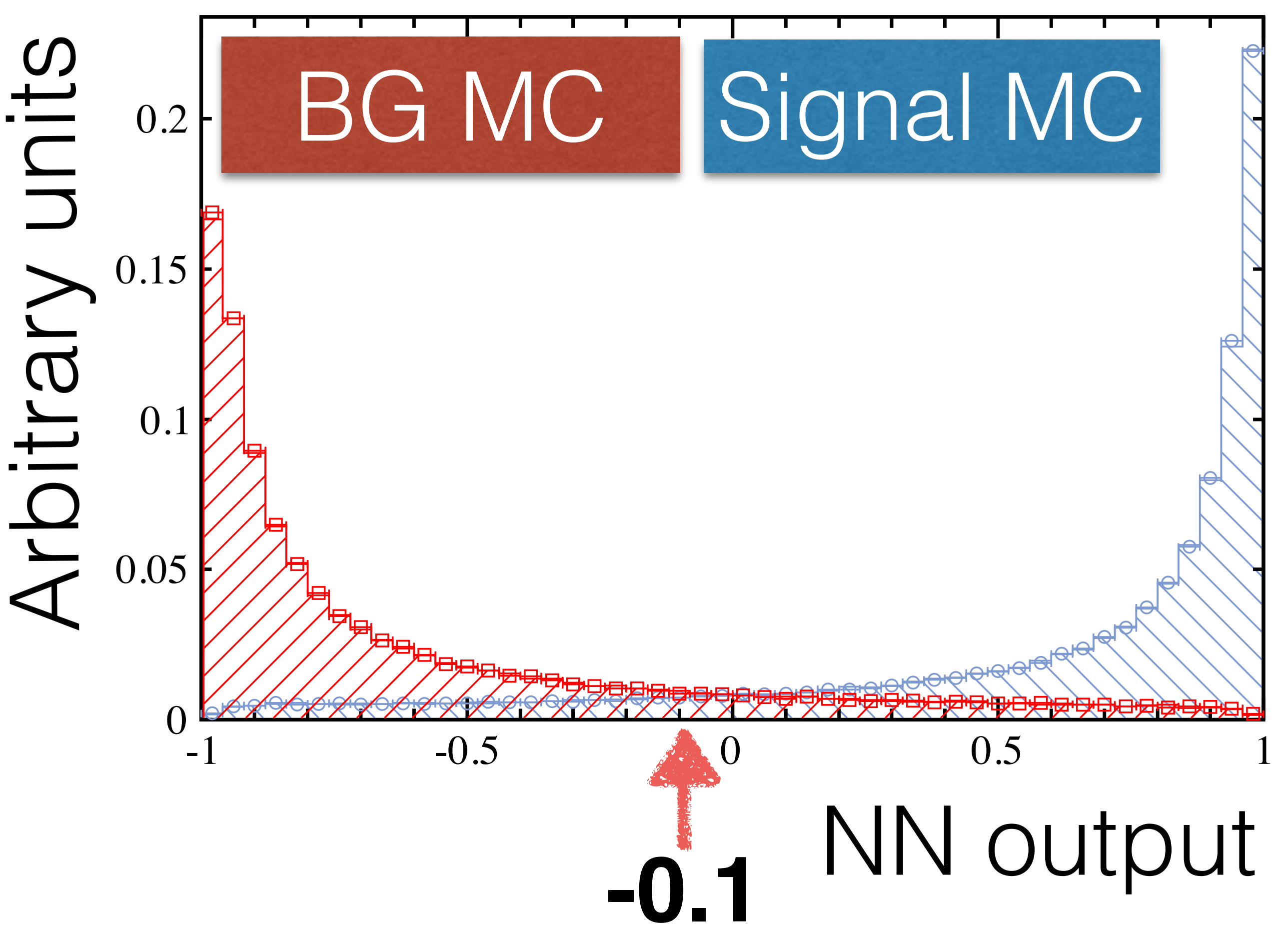
$M_{bc} > 5.2\ \mathrm{GeV},\ |\Delta E| < 0.5\ \mathrm{GeV}$



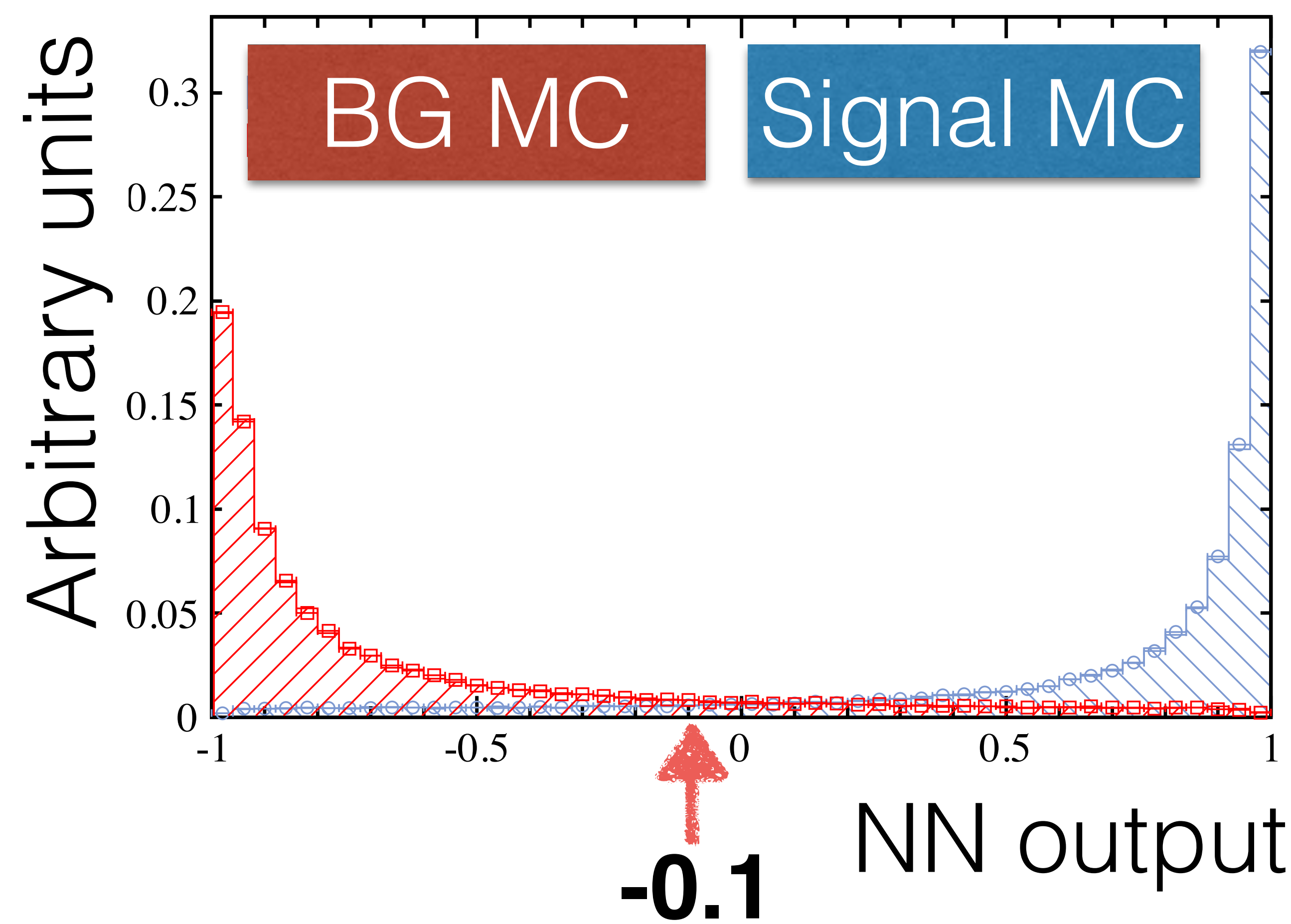


Background Suppression 1/2

$B^0 \to \eta_{\gamma\gamma}\pi^0$

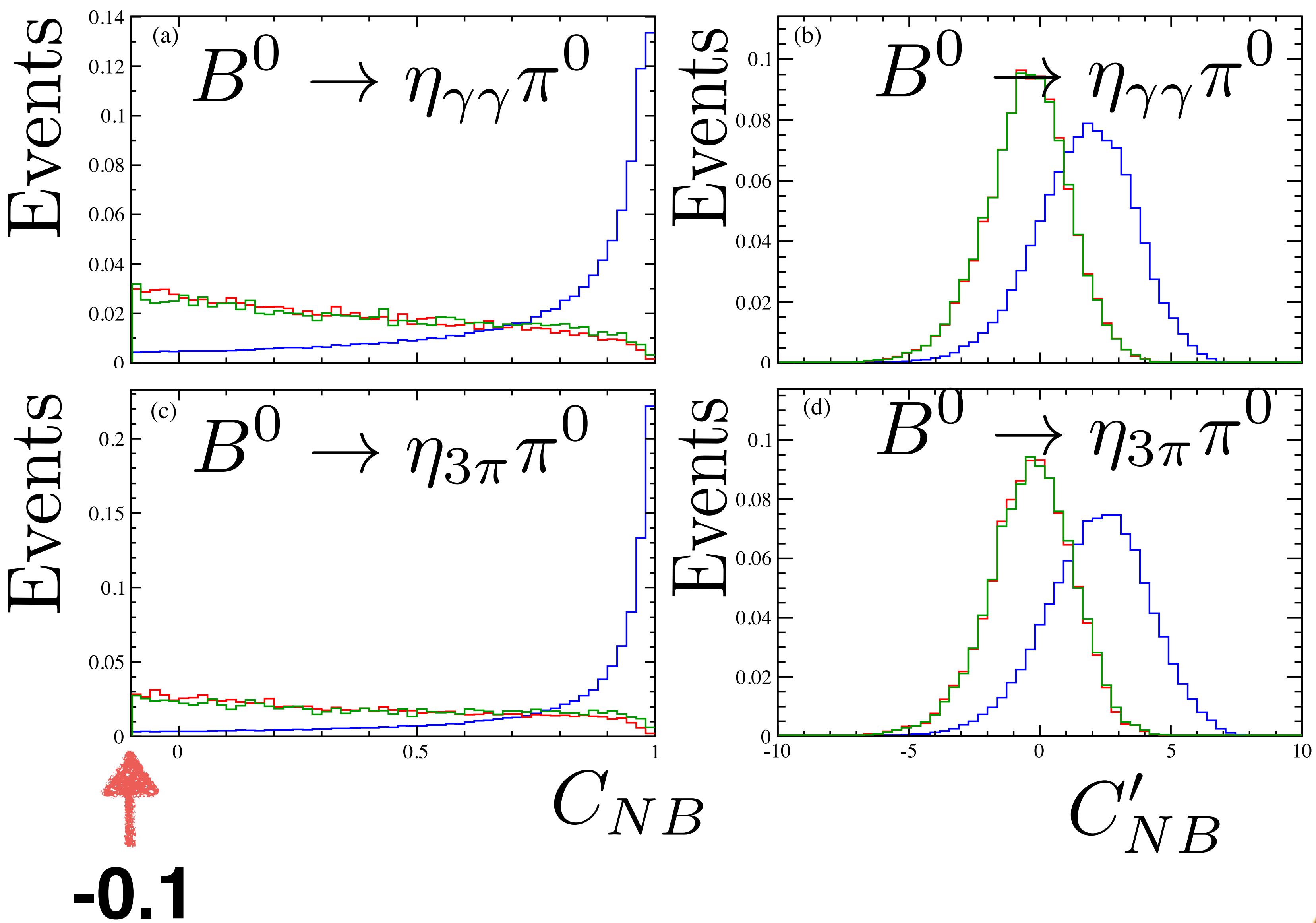


$B^0 \to \eta_{3\pi}\pi^0$



Using **neural networks (NN) technique** and choosing 19 useful variables, we distinguish signals from **continuum backgrounds**.

Background Suppression 2/2



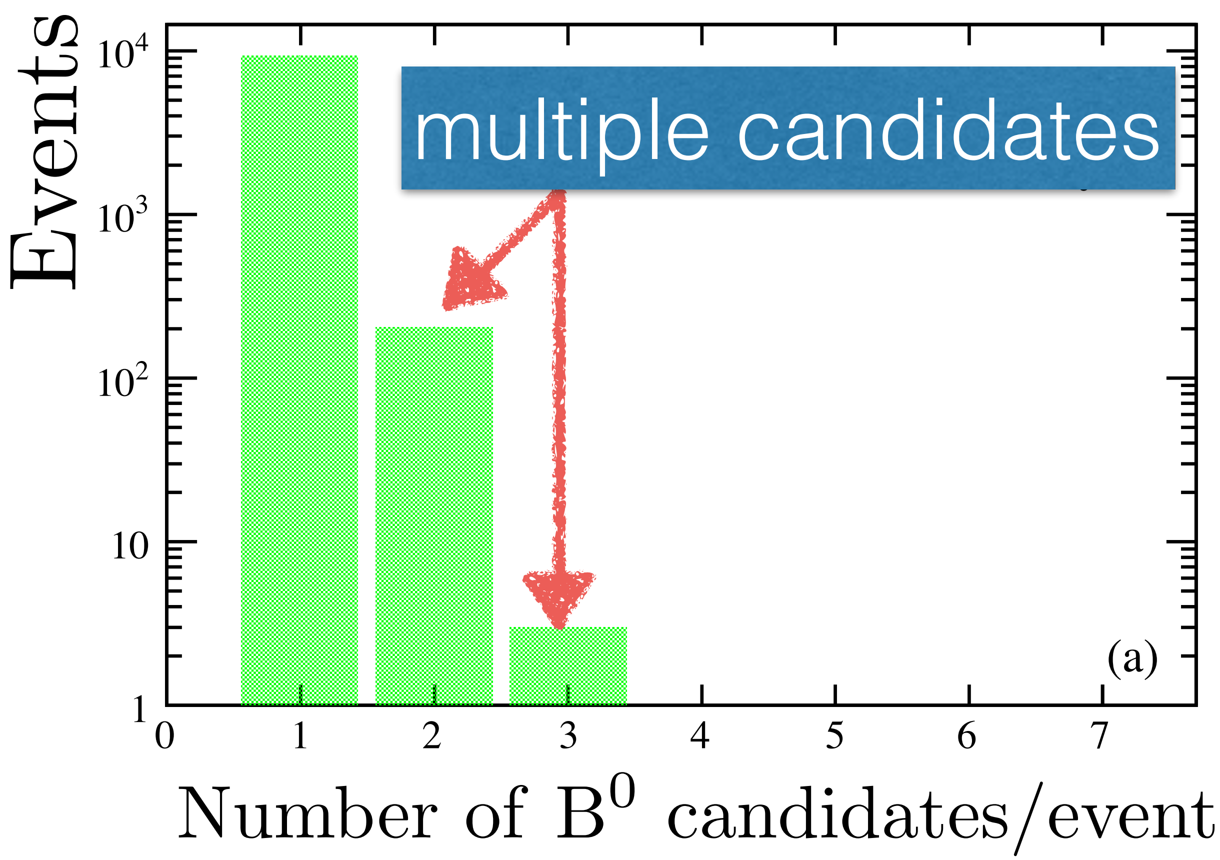
blue: signal MC,
red: continuum MC,
green: data side band

The **NN output = $\mathbf{C_{NB}}$, $\mathbf{C_{NB} > -0.1}$,** rejects 85% continuum backgrounds and contains 90% signal events.

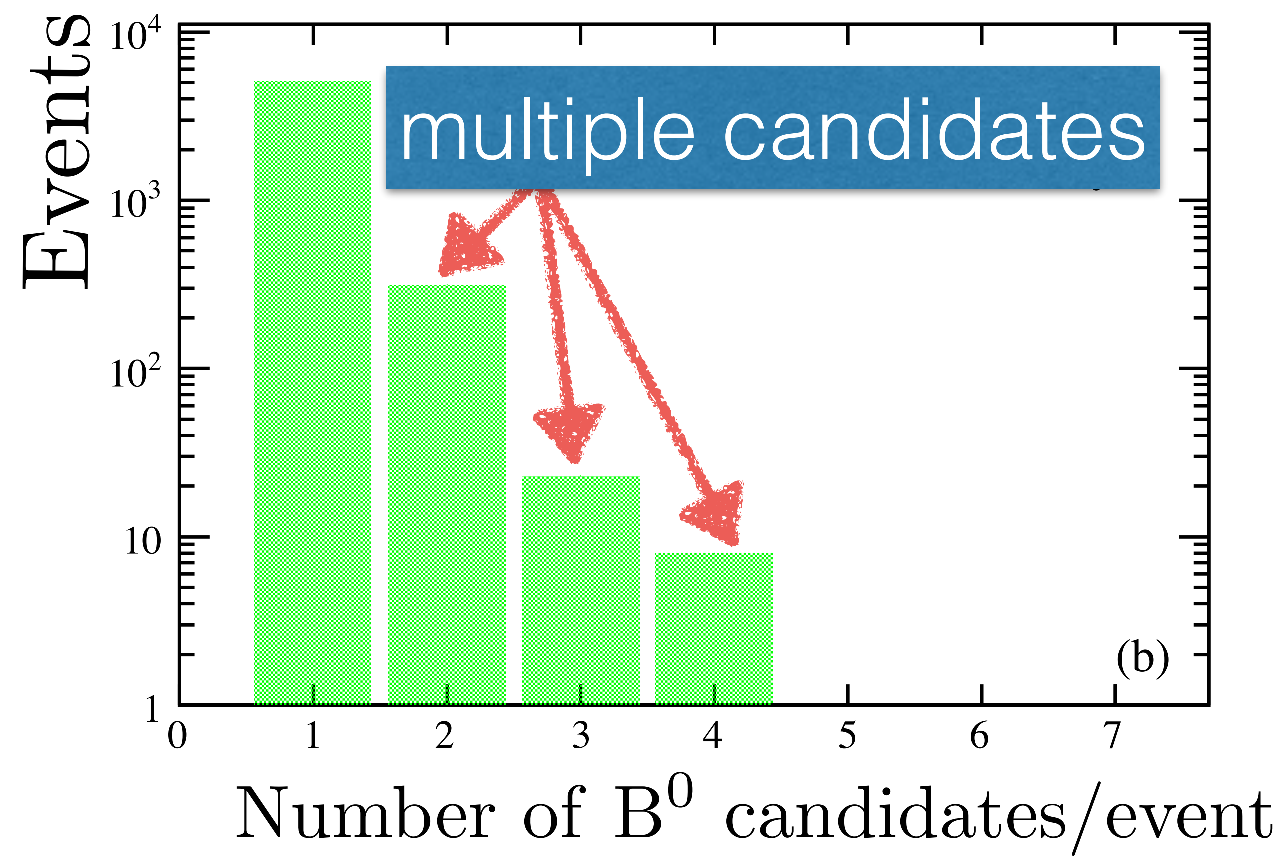
$$C'_{NB} = \ln\left(\frac{C_{NB} - C_{NB}^{\min}}{C_{NB}^{\max} - C_{NB}}\right)$$

Best Candidate per event selection

$B^0 \to \eta_{\gamma\gamma}\pi^0$



$B^0 \to \eta_{3\pi}\pi^0$



choose smallest χ^2 among the multiple candidates

$$\chi^2 = \chi^2_{\eta} + \chi^2_{\pi 0},\ \mathrm{mass-constraint\ fits}$$

Signal Efficiency

$$\epsilon = \frac{N_{fit}}{N_{gen}}$$

$$\epsilon(\mathrm{B}^0 \to \eta_{\gamma\gamma}\pi^0) = (18.43 \pm 0.04)\%$$

$$\epsilon(\mathrm{B}^0 \to \eta_{3\pi}\pi^0) = (14.21 \pm 0.04)\%$$

Calculate the expected number of signal yields

$$\mathrm{N_s}(\mathrm{B}^0 \to \eta_{\gamma\gamma}\pi^0) = 54.6(\mathrm{Fit\ Region}) = 49.2(\mathrm{Signal\ Region})$$

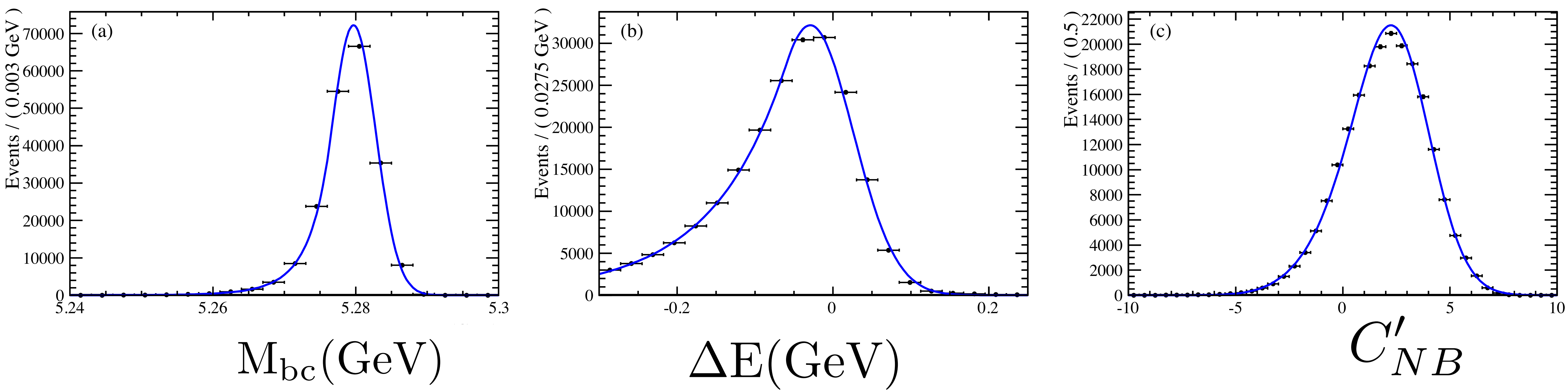
$$\mathrm{N_s}(\mathrm{B}^0 \to \eta_{3\pi}\pi^0) = 22.8(\mathrm{Fit\ Region}) = 21.1(\mathrm{Signal\ Region})$$

Fitting Procedure 1/2

3D Unbinned maximum likelihood fit

$$\mathcal{L} = e^{-\sum_j Y_j} \cdot \prod_i^N \left(\sum_j Y_j \mathcal{P}_j(M_{\mathrm{bc}}^i, \Delta E^i, C'^i_{NB}) \right)$$

Signal PDF

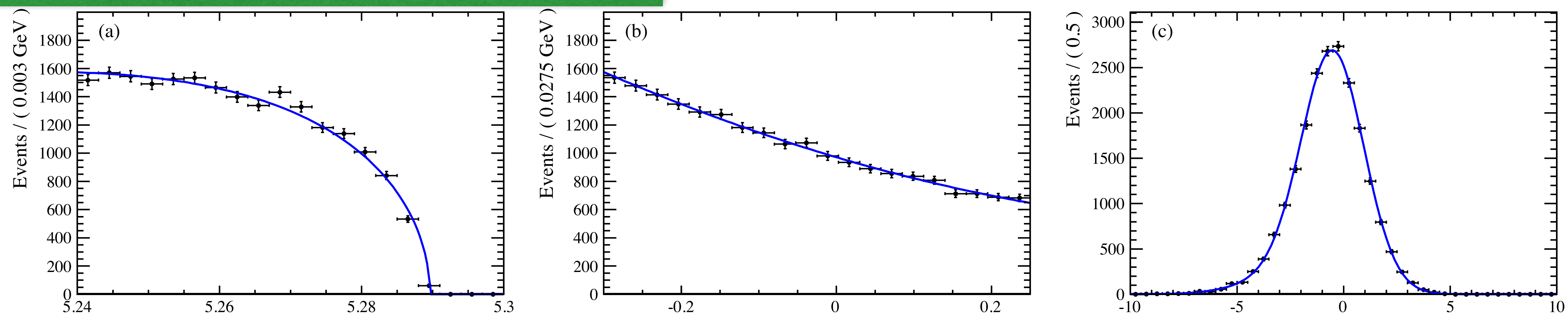


$$\mathcal{P}_j(M_{\mathrm{bc}}, \Delta E, C'_{NB}) = \mathcal{P}_j(M_{\mathrm{bc}}) \cdot \mathcal{P}_j(\Delta E) \cdot \mathcal{P}_j(C'_{NB})$$

Fitting Procedure 2/2

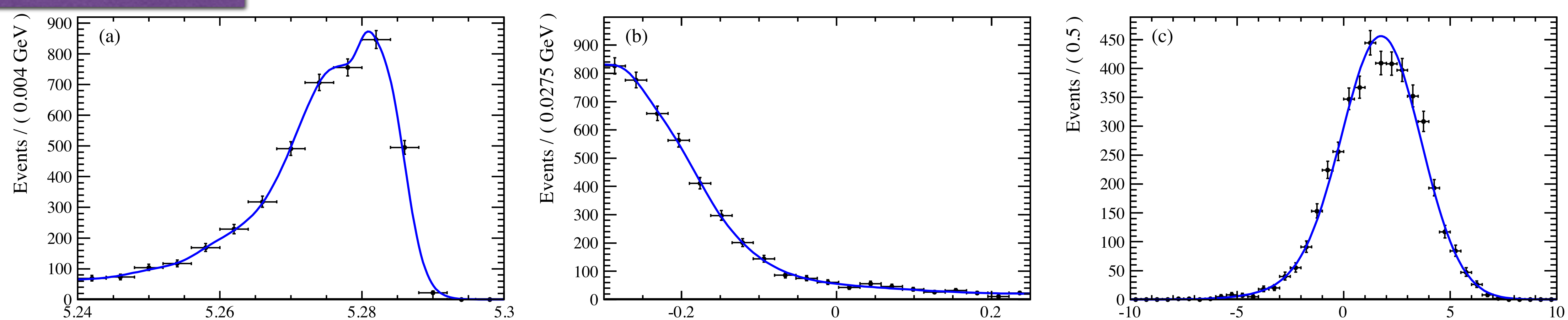
3D Unbinned maximum likelihood fit

Continuum BG PDF



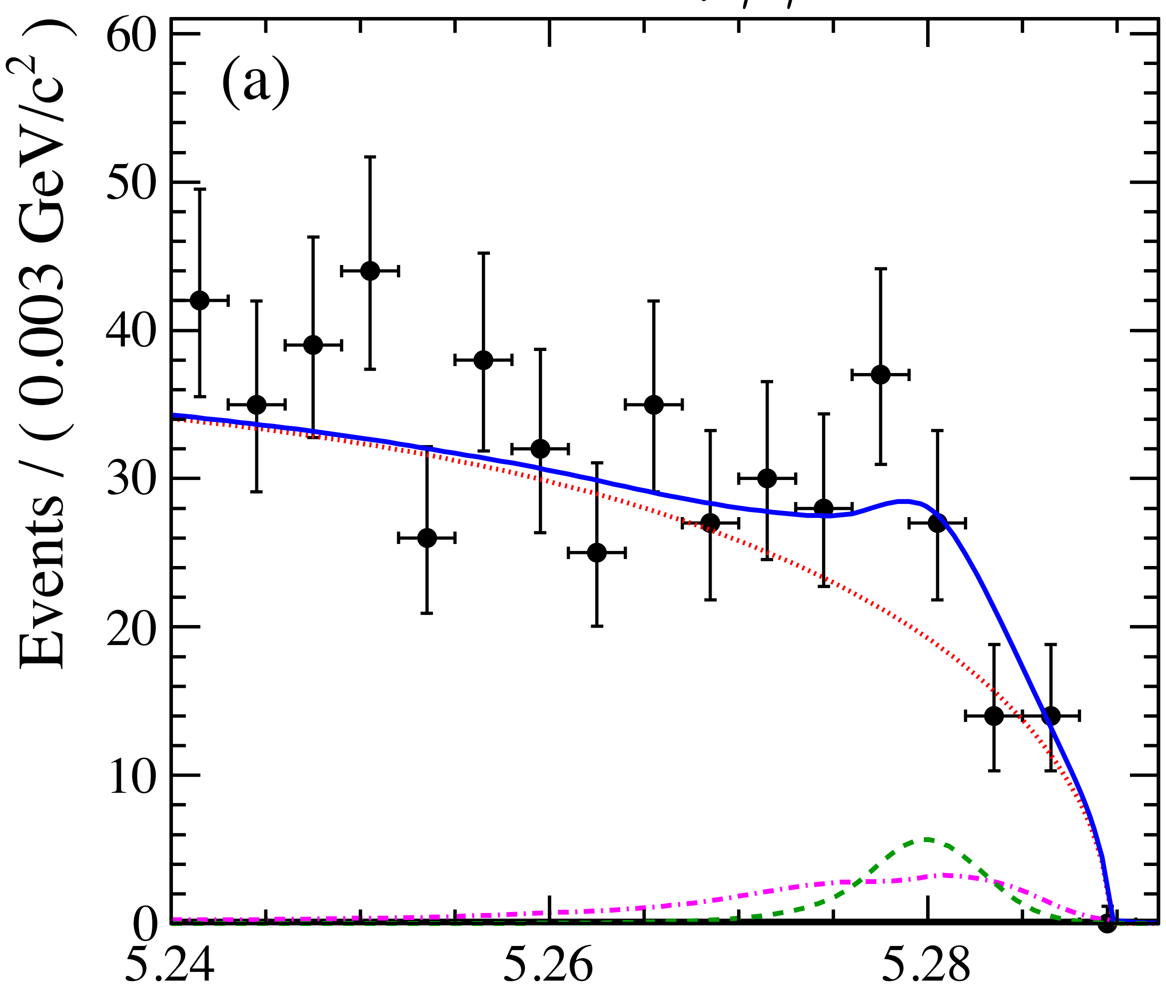
Rare B PDF

$\mathrm{M_{bc}(GeV)}$ $\Delta\mathrm{E(GeV)}$ C'_{NB}



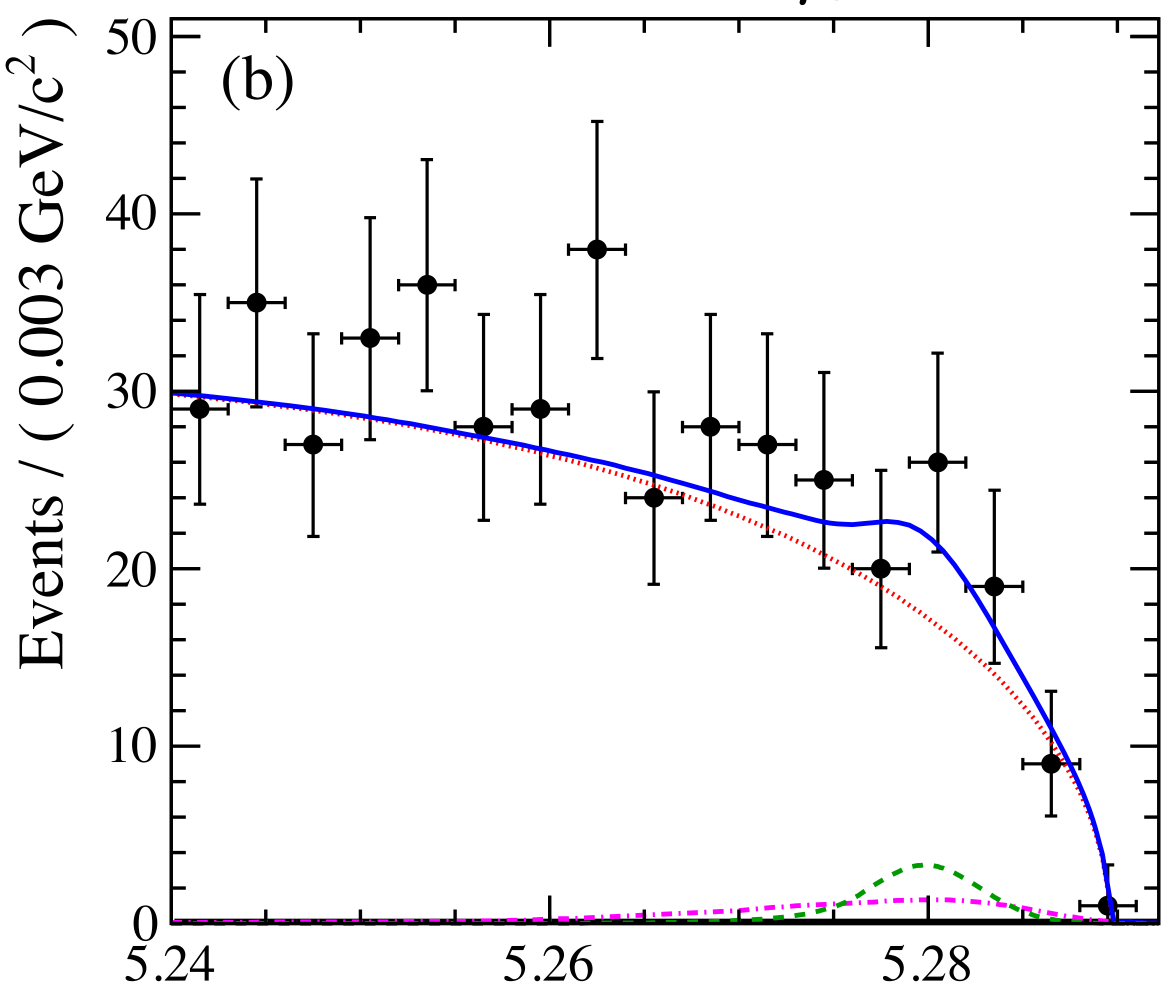
Simultaneous Fit Results 1/3

$B^0 \to \eta_{\gamma\gamma}\pi^0$



$M_{bc}(GeV)$

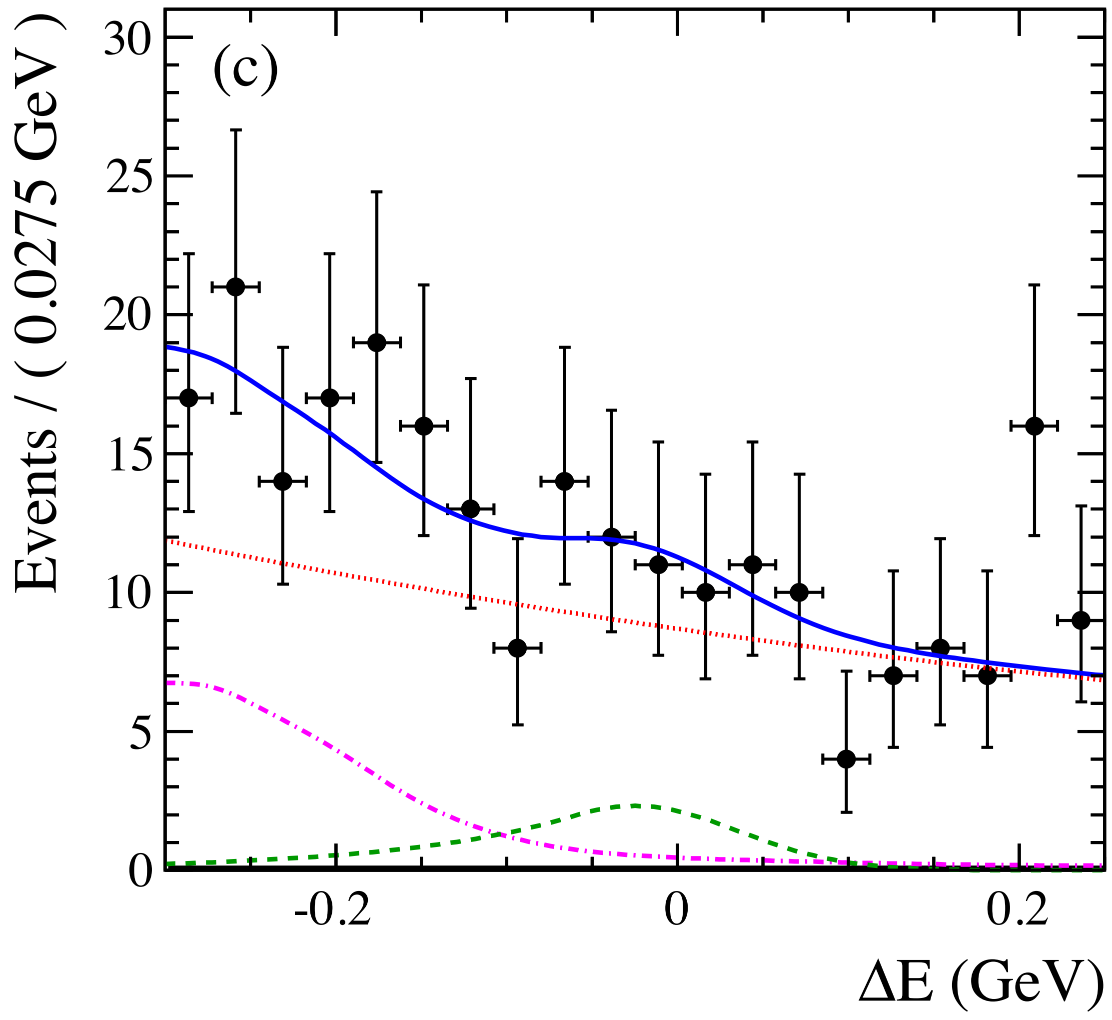
$B^0 \to \eta_{3\pi}\pi^0$



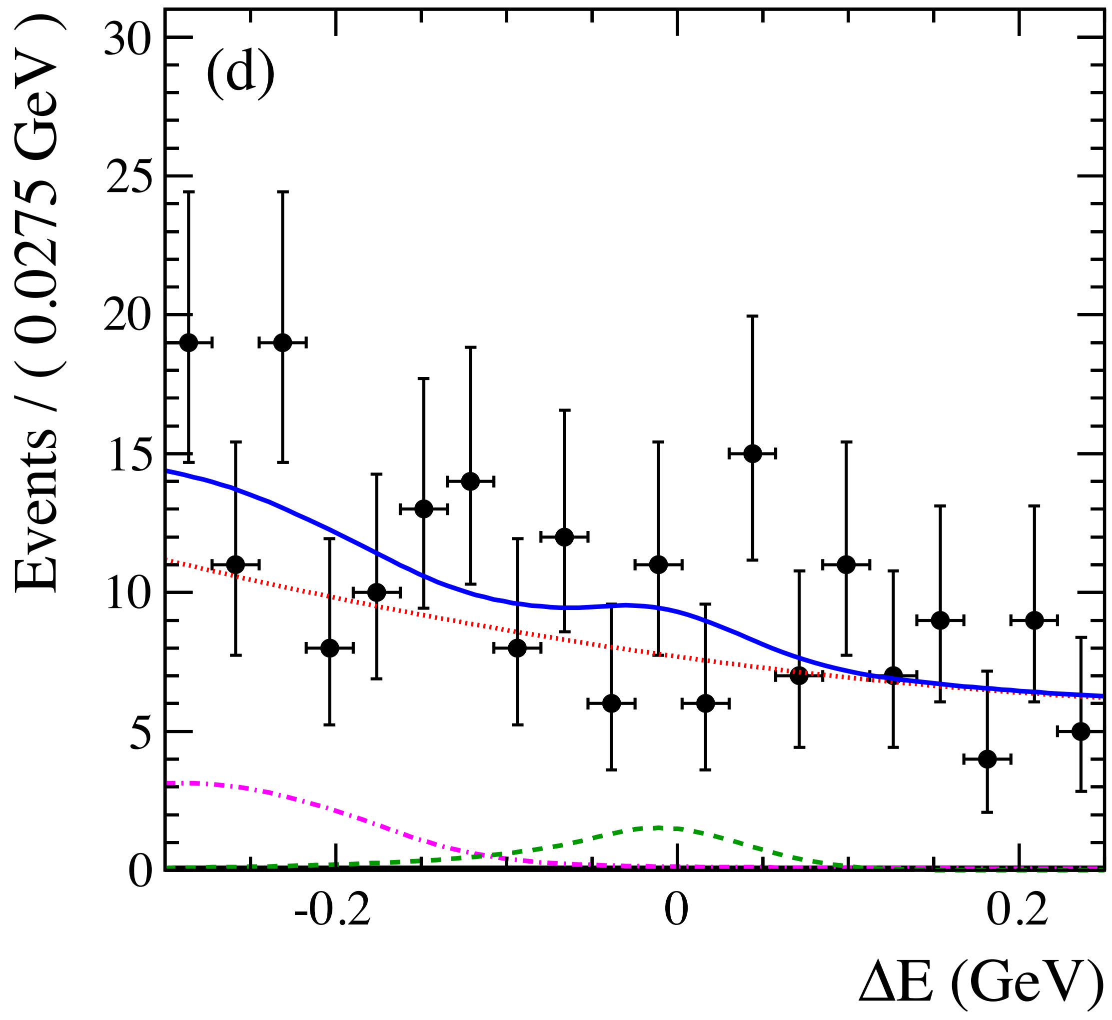
$M_{bc}(GeV)$

Simultaneous Fit Results 2/3

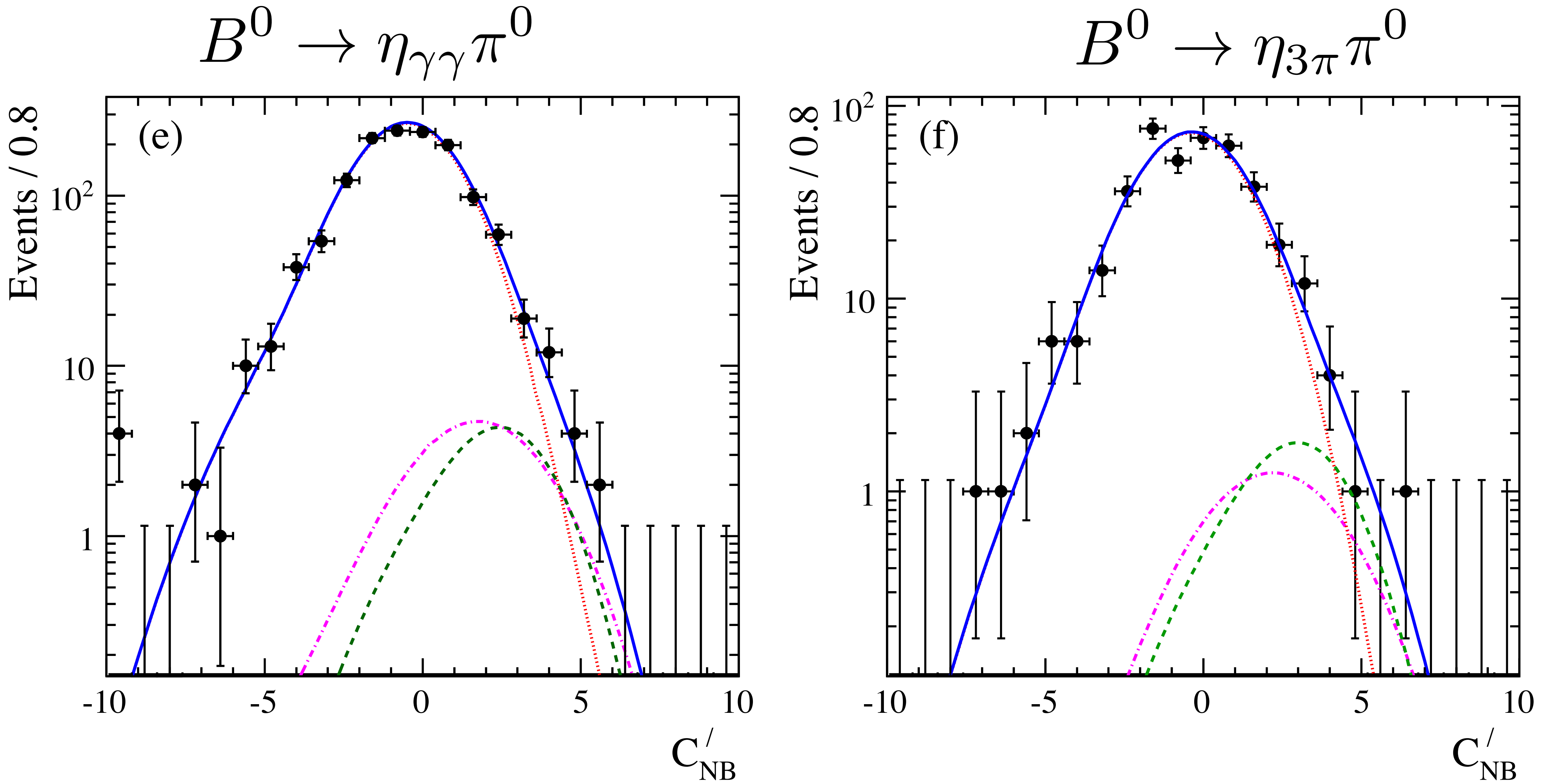
$B^0 \to \eta_{\gamma\gamma}\pi^0$



$B^0 \to \eta_{3\pi}\pi^0$



Simultaneous Fit Results 3/3



Branching Fractions

Mode	Y_{sig}	$\epsilon(\%)$	$\mathcal{B}_\eta(\%)$	Significance	$\mathcal{B}(10^{-7})$
$B^0 \to \eta_{\gamma\gamma}\pi^0$	$30.6^{+12.2}_{-10.8}$	18.4	39.41	3.1	$5.6^{+2.2}_{-2.0}$
$B^0 \to \eta_{3\pi}\pi^0$	$0.5^{+6.6}_{-5.4}$	14.2	22.92	0.1	$0.2^{+2.8}_{-2.3}$
Combined				3.0	$4.1^{+1.7}_{-1.5}$

$$\mathcal{B}(B^0 \to \eta\pi^0) = \frac{Y_{\mathrm{sig}}}{N_{B\bar{B}} \times \epsilon \times \mathcal{B}_\eta}$$

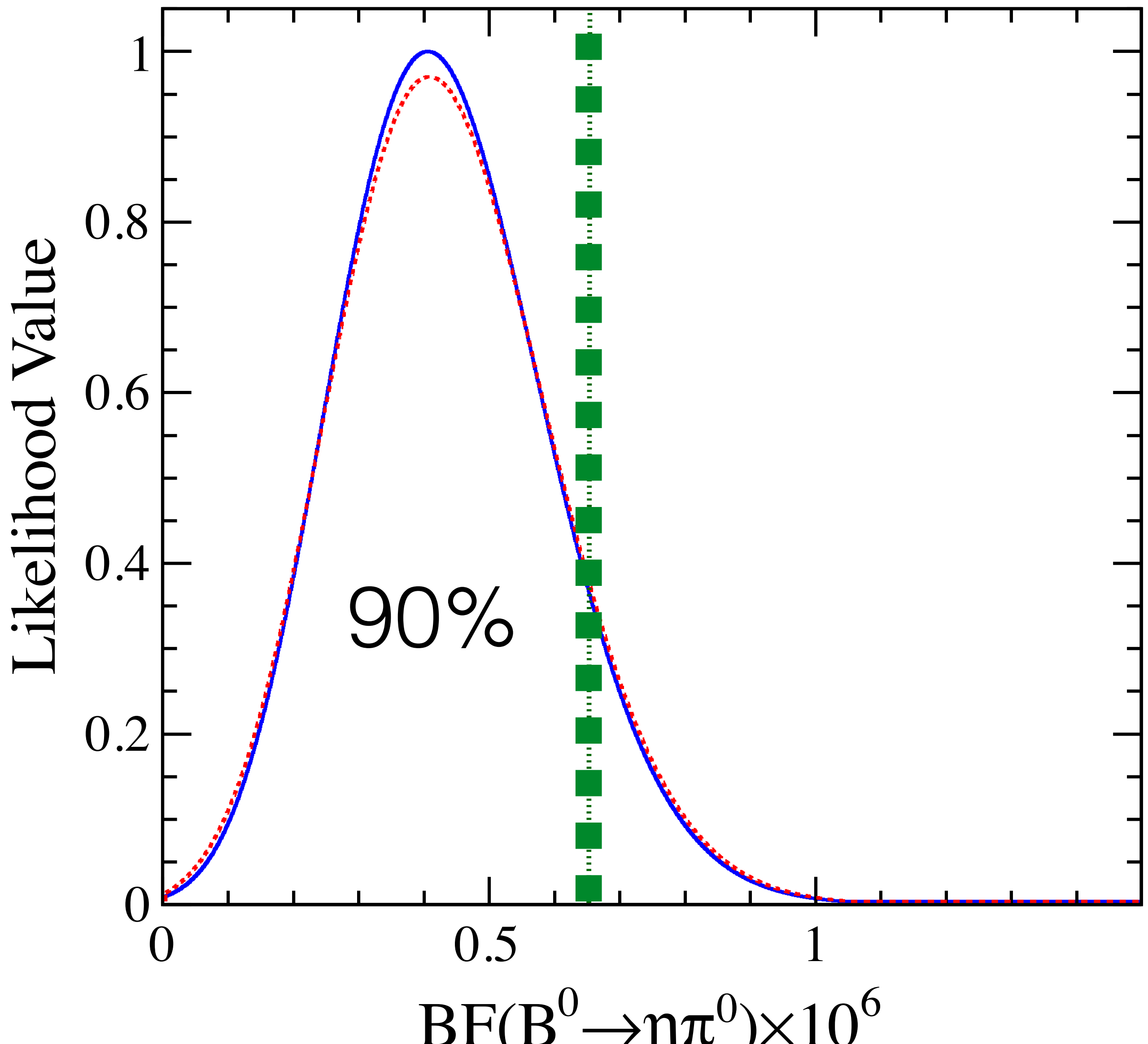
Systematic Uncertainties

Source	Uncertainty (%)
PDF parametrization	$^{+10.2}_{-\ 9.2}$
Fit bias	$^{+0.0}_{-2.6}$
$\pi^0/\eta \to \gamma\gamma$ reconstruction	6.0
Tracking efficiency	0.3
PID efficiency	0.6
C_{NB} selection efficiency	$^{+2.1}_{-2.2}$
MC statistics	0.4
Nonresonant contributions	$^{+\ 0.0}_{-10.8}$
$\mathcal{B}(\eta \to \gamma\gamma)$	0.5
$\mathcal{B}(\eta \to \pi^+\pi^-\pi^0)$	1.2
Number of $B\overline{B}$ pairs	1.3
Total	$^{+12.2}_{-15.9}$

$$Br(B^0 \to \eta\pi^0) = (4.1 \pm^{1.7}_{1.5} \pm^{0.5}_{0.7}) \times 10^{-7}$$

Upper Limits

$$Br(B^0 \rightarrow \eta\pi^0) < 6.5 \times 10^{-7} \text{ @ } 90\% \; C.L.$$



Integrate the likelihood function from zero to infinity; take the value corresponding to 90% of the total area as the 90% C.L. upper limit.

Summary 1/2

NEW

Phys. Rev. D 92, 011101(R)-Published 9 July 2015

3.0σ

$$Br(B^0 \to \eta\pi^0) = (4.1 \pm^{1.7}_{1.5} \pm^{0.5}_{0.7}) \times 10^{-7}$$

evidence!

$$Br(B^0 \to \eta\pi^0) < 6.5 \times 10^{-7} \ @ \ 90\% \ C.L.$$

Good agreement with QCD factorization (theory) expectation:

$$(2 - 12) \times 10^{-7}$$

Summary 2/2

NEW Phys. Rev. D 92, 011101(R)-Published 9 July 2015

3.0σ

$$Br(B^0 \to \eta\pi^0) = (4.1 \pm^{1.7}_{1.5} \pm^{0.5}_{0.7}) \times 10^{-7}$$ evidence!

$$Br(B^0 \to \eta\pi^0) < 6.5 \times 10^{-7} \text{ @ } 90\% \ C.L.$$

Constrain the contribution of isospin-breaking effects on the value of $\sin 2\alpha$ in $\mathrm{B}^0 \to \pi^+\pi^-$ decays

Inserting our measured Br value into a theory paper*, $\pi^0 - \eta - \eta'$ mixing is less than 0.97^o at 90% C.L.

* M. Gronau and J. Zupan, Phys. Rev. D **71**, 074017 (2005).