# Observation of Rare Baryonic B Decays

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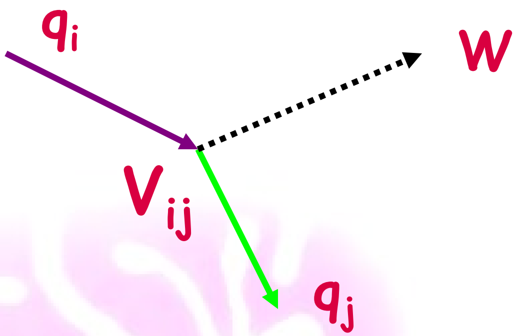
- Introduction
- Apparatus
- Analysis Procedure
- Rare Baryonic B decays
- Summary

# CP violation in Standard Model

2008 Nobel Prize

- In 1973, M. Kobayashi and T. Maskawa realized:
  CP violation $\rightarrow$ third generation of quarks
- In SM, CPV can be accommodated via the CKM matrix, which relates quark mass eigenstates to weak eigenstates:

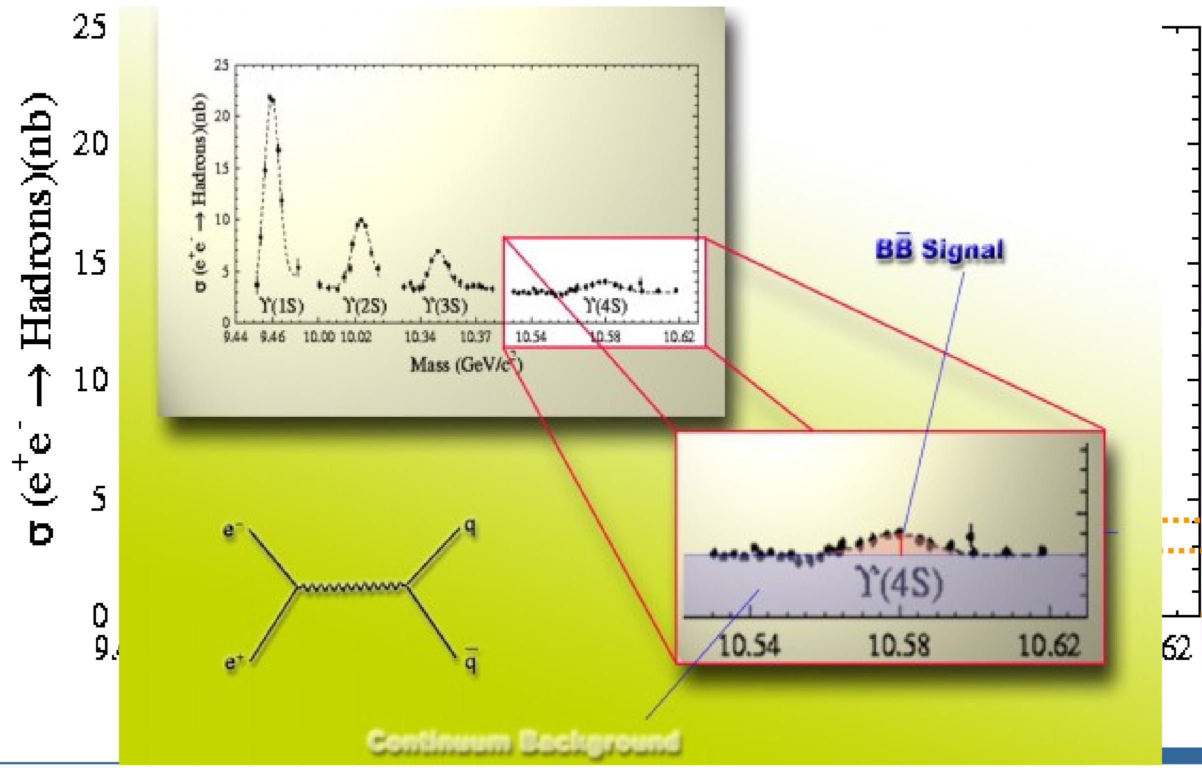
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$




- With 3 quark generations, there is 1 phase in the CKM matrix which is physical (can't be absorbed in redefinition of the fields)
  - ➔ allows possibility of CP violation

# B Meson Production

- Electron-Positron collider: $e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\bar{B}$
  - 4S resonance above the B meson pair threshold
  - Low B production cross-section: ~1 nb
  - Clean environment, coherent $B^0\bar{B}^0$ production




$$M_{\Upsilon(4S)} = 10.58\text{GeV}$$
$$M_B = 5.28\text{GeV}$$

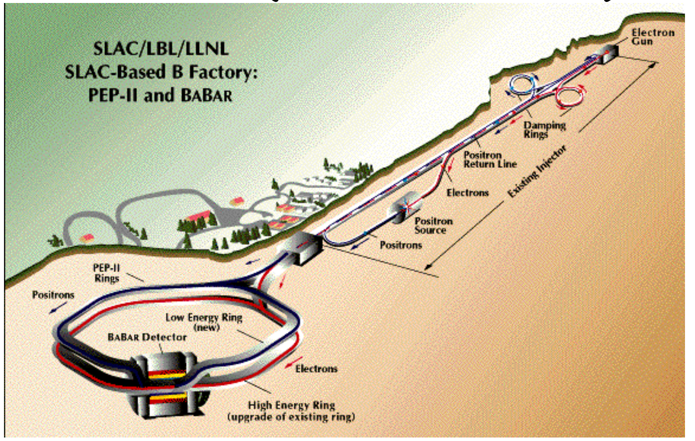
$1fb^{-1} \sim 1$ M $B\bar{B}$pairs

$$\frac{\sigma(b\bar{b})}{\sigma(\text{hadr})} = 0.28$$

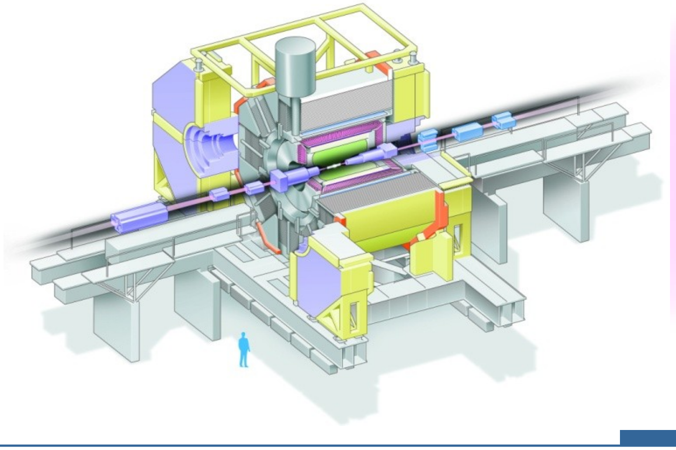
# Two B Factories

KEK (日本)

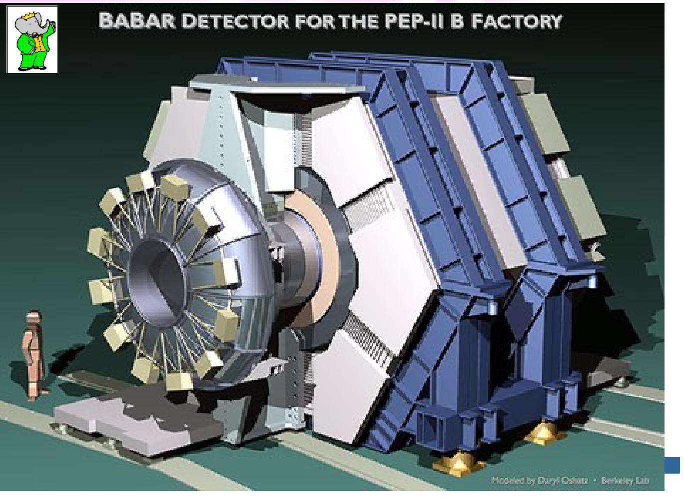
SLAC (史丹福大學)




Belle

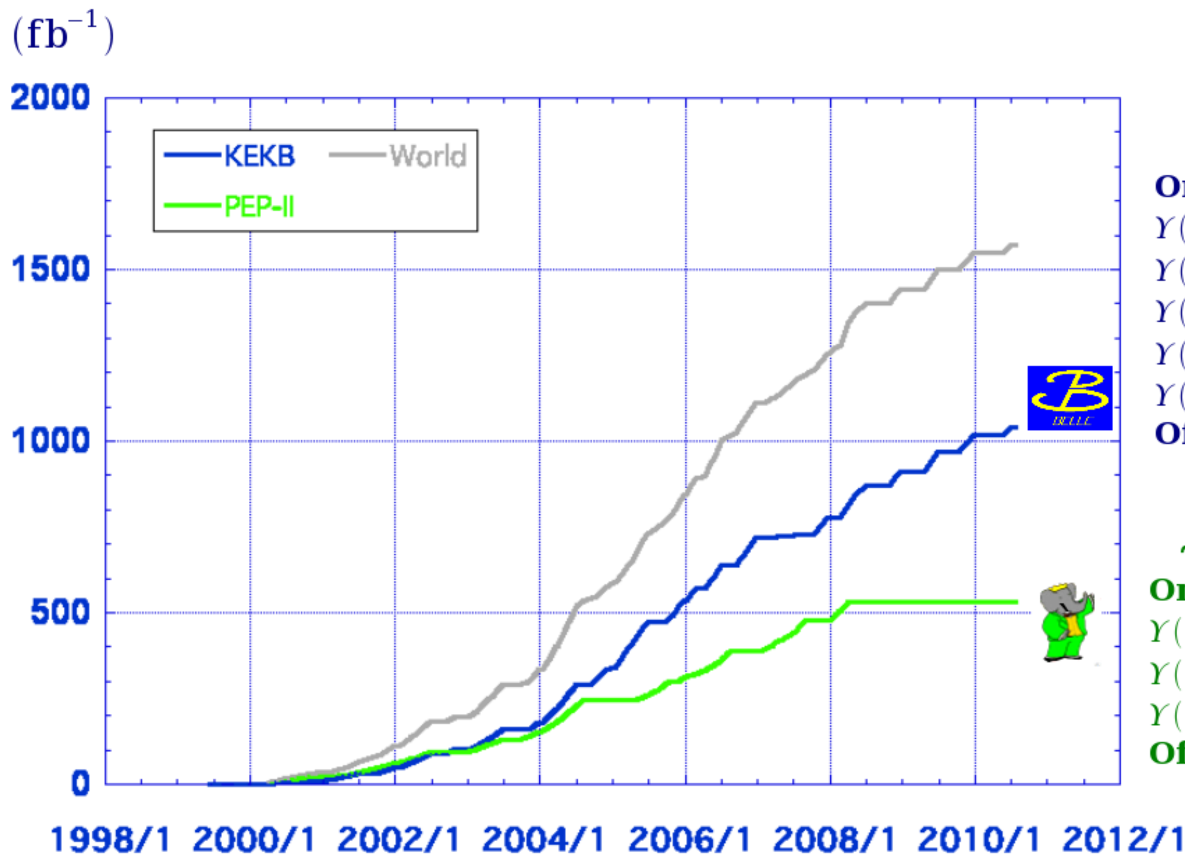


BaBar



# Integrated Luminosity

## Luminosity at B factories




**> 1 ab$^{-1}$**

**On resonance:**

$\Upsilon(5S)$: 121 fb$^{-1}$

$\Upsilon(4S)$: 711 fb$^{-1}$

$\Upsilon(3S)$: 3 fb$^{-1}$

$\Upsilon(2S)$: 24 fb$^{-1}$

$\Upsilon(1S)$: 6 fb$^{-1}$

**Off reson./scan:**

~ 100 fb$^{-1}$

**~ 550 fb$^{-1}$**

**On resonance:**

$\Upsilon(4S)$: 433 fb$^{-1}$

$\Upsilon(3S)$: 30 fb$^{-1}$

$\Upsilon(2S)$: 14 fb$^{-1}$

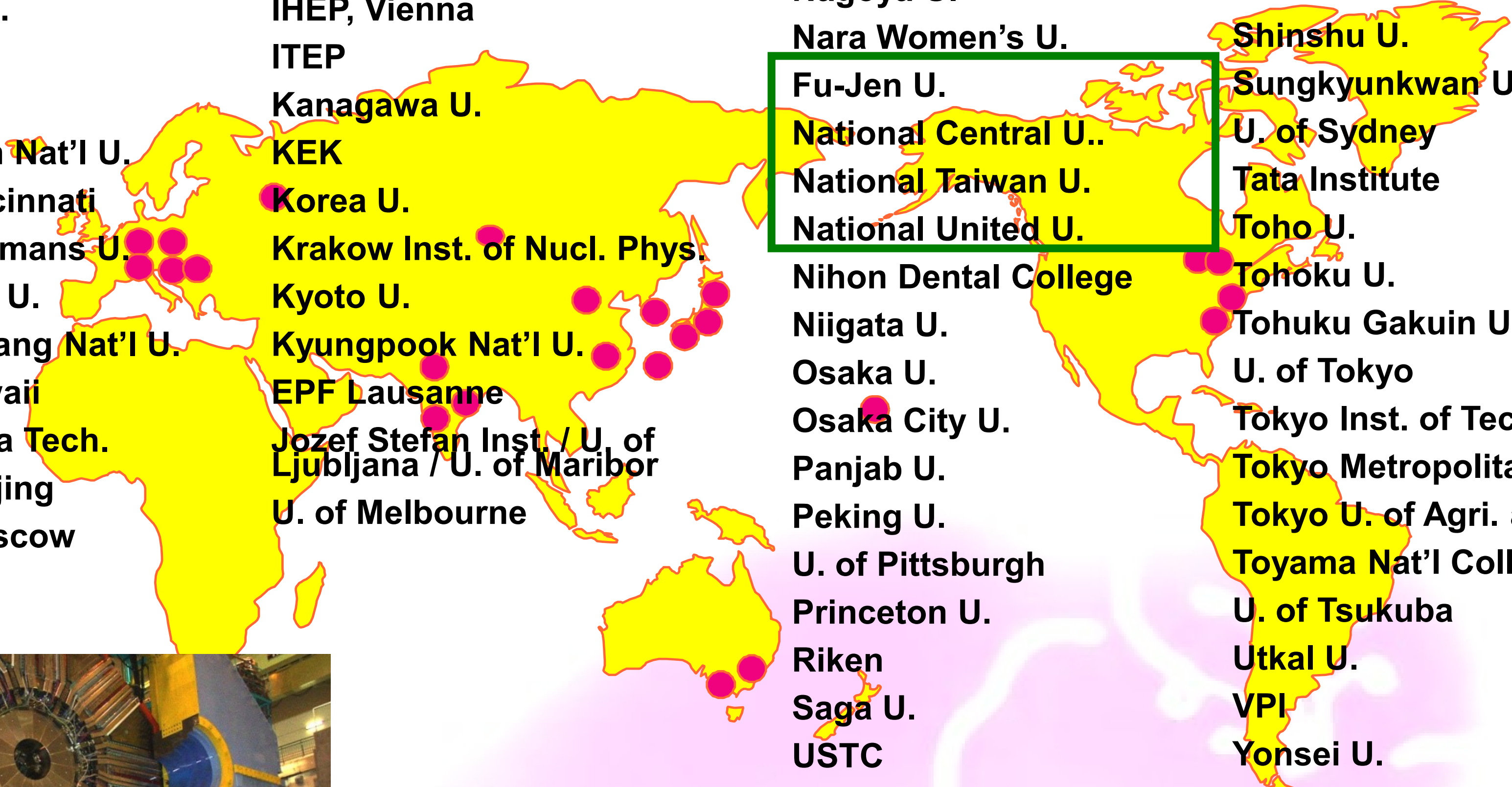
**Off resonance:**

~ 54 fb$^{-1}$

# KEK View

日本　茨城県　つくば市

# International Collaboration: Belle



Aomori U.
BINP
Chiba U.
Chonnam Nat'l U.
U. of Cincinnati
Ewha Womans U.
Frankfurt U.
Gyeongsang Nat'l U.
U. of Hawaii
Hiroshima Tech.
IHEP, Beijing
IHEP, Moscow

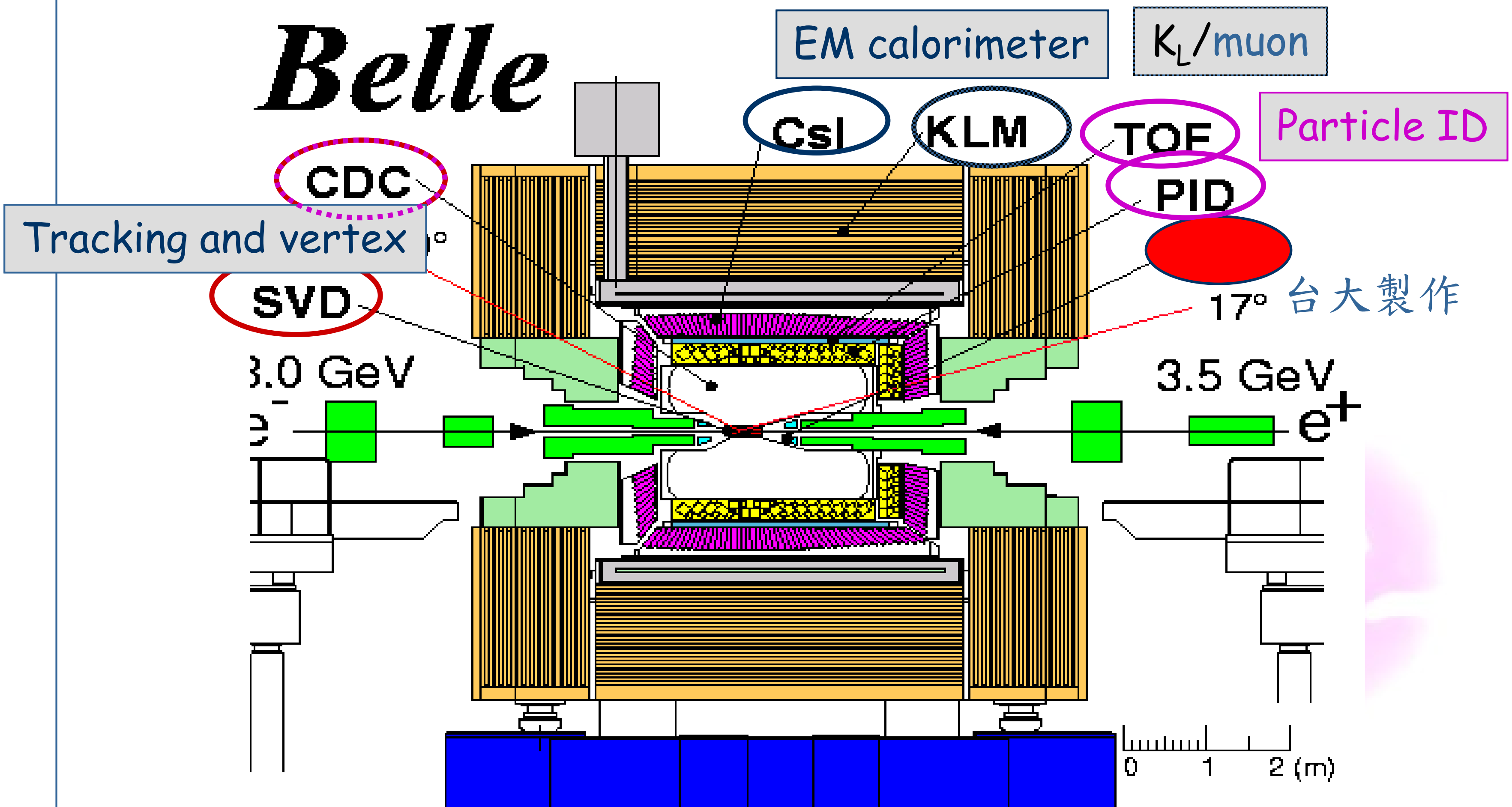
IHEP, Vienna
ITEP
Kanagawa U.
KEK
Korea U.
Krakow Inst. of Nucl. Phys.
Kyoto U.
Kyungpook Nat'l U.
EPF Lausanne
Jozef Stefan Inst. / U. of Ljubljana / U. of Maribor
U. of Melbourne

Nagoya U.
Nara Women's U.
Fu-Jen U.
National Central U..
National Taiwan U.
National United U.
Nihon Dental College
Niigata U.
Osaka U.
Osaka City U.
Panjab U.
Peking U.
U. of Pittsburgh
Princeton U.
Riken
Saga U.
USTC

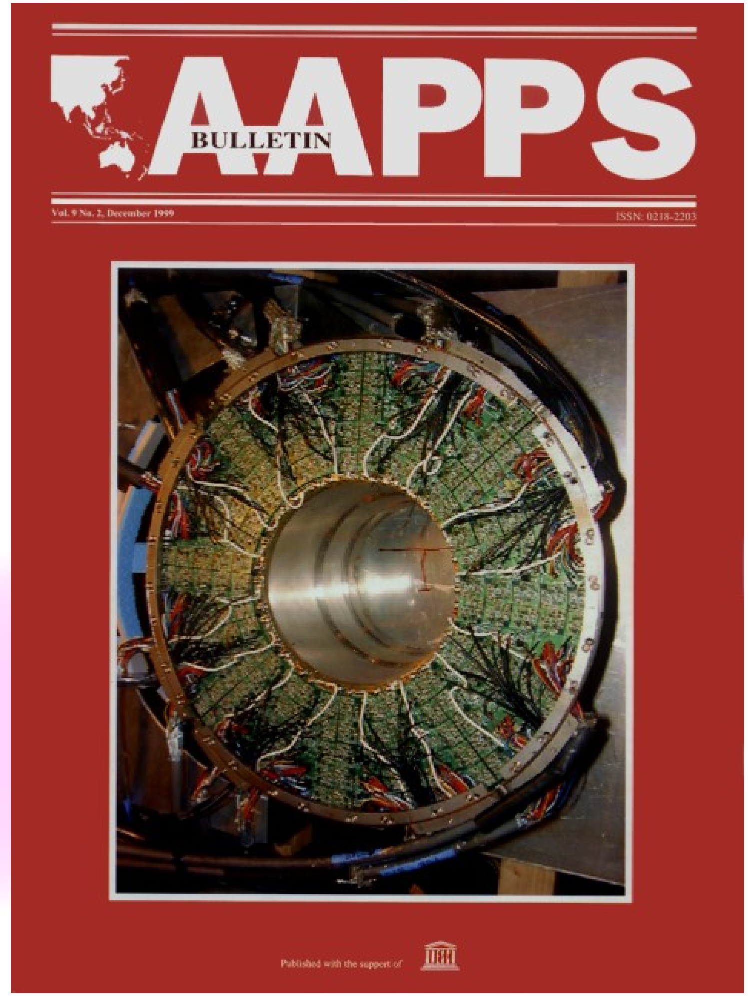
Seoul National U.
Shinshu U.
Sungkyunkwan U.
U. of Sydney
Tata Institute
Toho U.
Tohoku U.
Tohuku Gakuin U.
U. of Tokyo
Tokyo Inst. of Tech.
Tokyo Metropolitan U.
Tokyo U. of Agri. and Tech.
Toyama Nat'l College
U. of Tsukuba
Utkal U.
VPI
Yonsei U.

**13 countries, 54 institutes, ~400 collaborators**

# Belle Detector – Side View

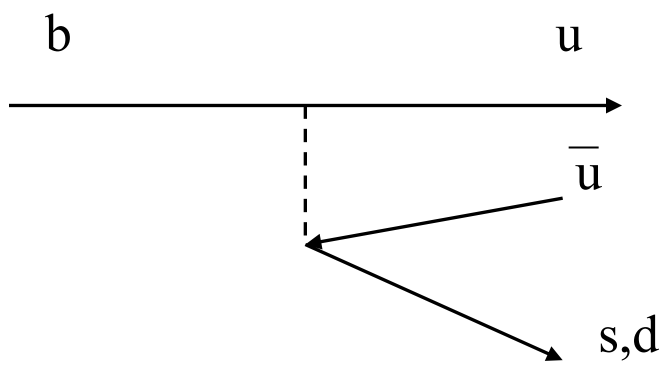


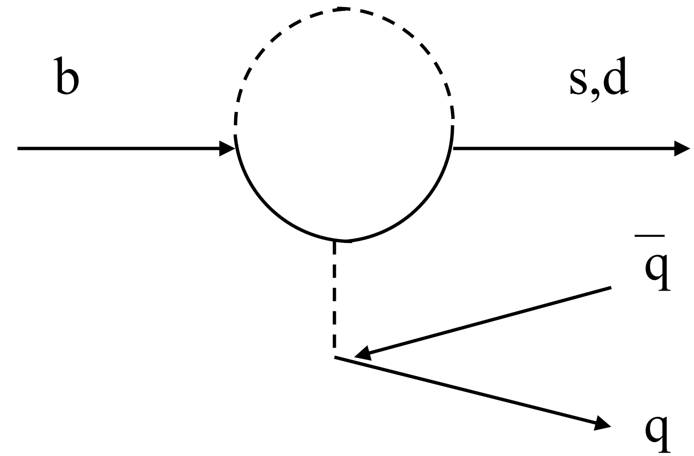
# EFC disassembled on 10/25, 2010


EFC saw First Bhabha events at B Factory!

# Quark Diagrams for Charmless B Decays

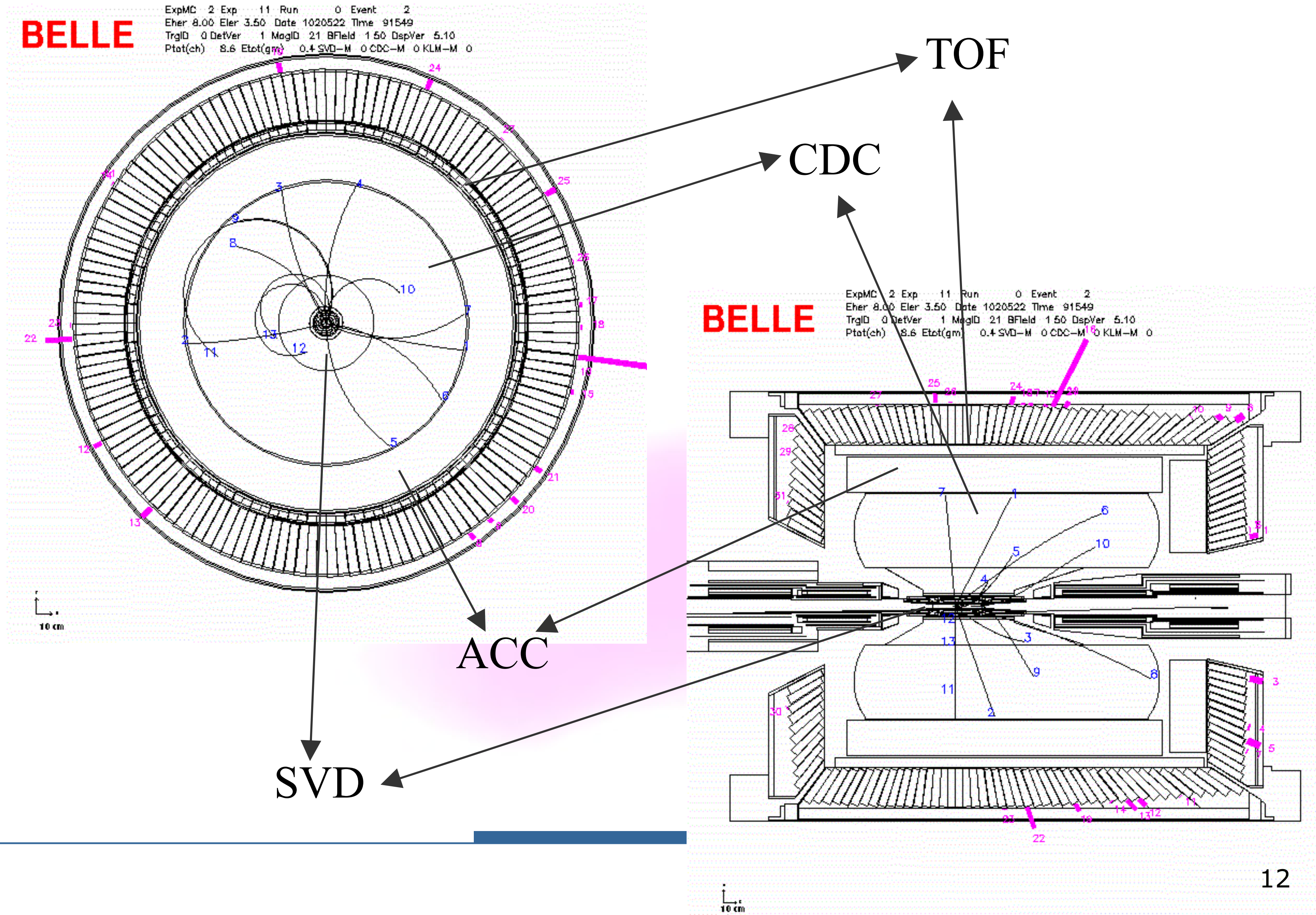



# Motivations

- Charmless decays: a good searching ground for large Direct CP Violation
  due to tree-penguin interference
- $b \rightarrow s$ (d) FCNC loop process: sensitive to new physics
- Unexpected large rates/CPV: new physics
- Charmless two-body decays: useful to constrain CKM unitary triangle

# B→$p\bar{p}K$ example



# Particle Selection

- We use the PID (ACC+CDC+TOF) system to identify the charged particles.

- Proton: $\frac{L_p}{L_p + L_K} > 0.6 \quad \frac{L_p}{L_p + L_\pi} > 0.3$

- Kaon: $\frac{L_K}{L_K + L_\pi} > 0.6$

- Pion: $\frac{L_K}{L_K + L_\pi} < 0.4$

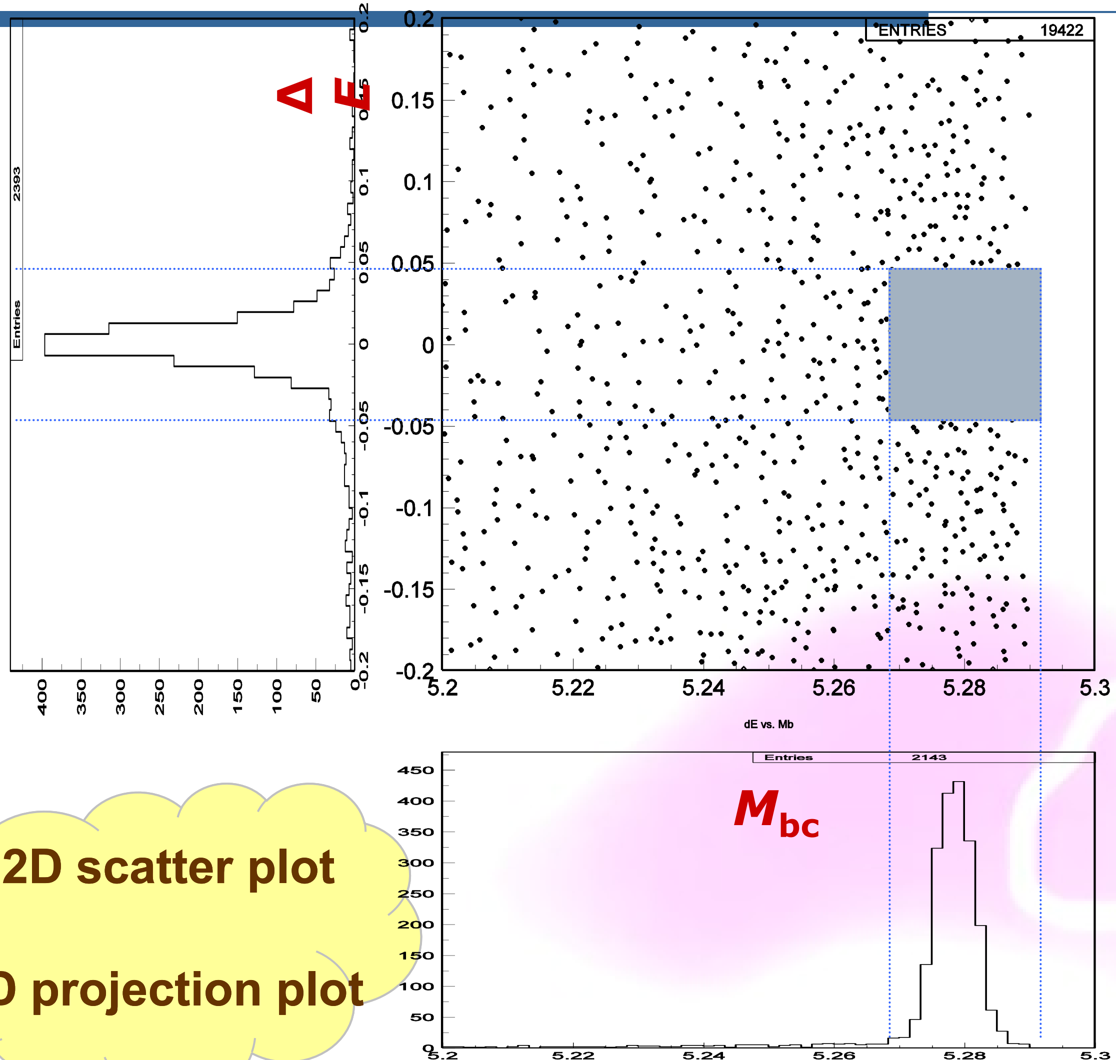
TO

| From | p | K | $\pi$ |
|---|---|---|---|
| (p) | | | |
| (K) | ~9% | | ~10% |
| ( $\pi$ ) | ~4% | ~8% | |

**Fake rate**

- $\Lambda$: reconstructed from $\Lambda \to p \pi^-$

# B Signal Reconstruction



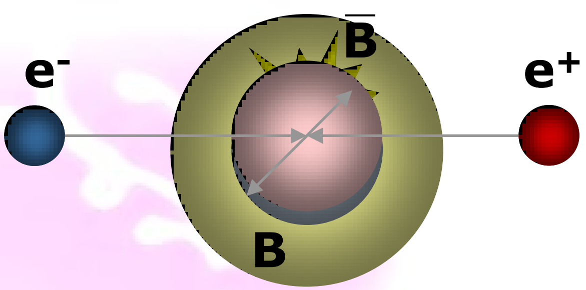

2D scatter plot

1D projection plot

In $\Upsilon(4S)$ rest frame:

$$M_{bc} = \sqrt{E_{beam}^2 - p_B^2}$$

$$\Delta E = E_B - E_{beam}$$

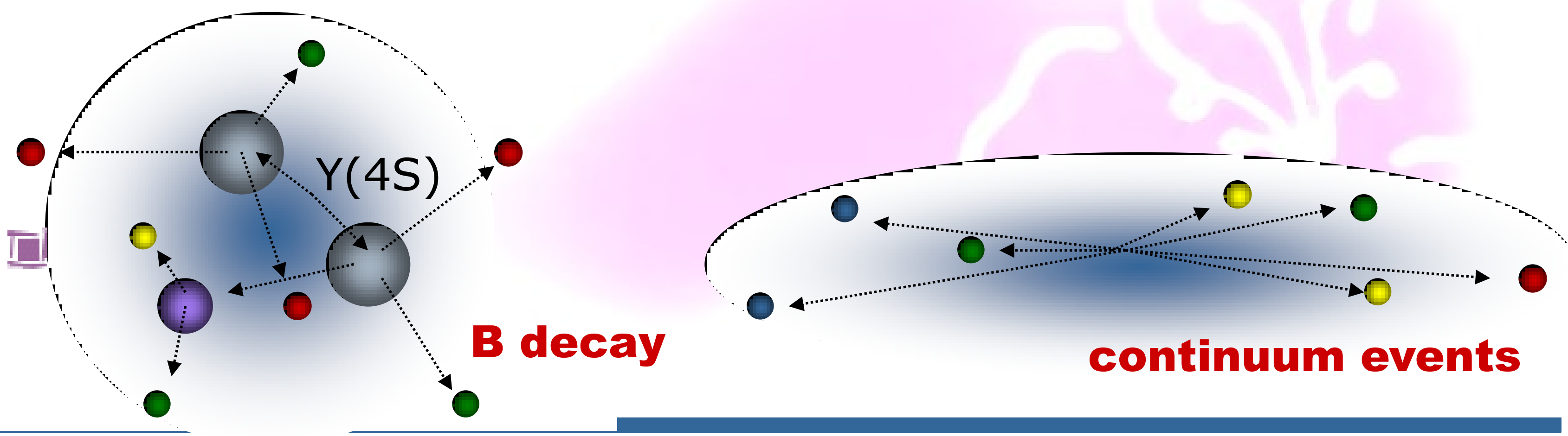


# Background suppression

- The main background is continuum qq events (q=u,d,s,c).
- The Topology of continuum events and B decays are different. We choose $|\cos\theta_{Thrust}|$ $S_\perp$ $R_2^{so}$ $R_4^{so}$ $R_2^{oo}$ $R_3^{oo}$ $R_4^{oo}$ as the fisher input and combine it with **$\cos\theta_B$** to calculate the likelihood ratio.
- We define the Super-fox wolfram moment (F) like:

$$F = \sum_{i=2,3,4} \alpha_i R_i^{oo} + \sum_{i=2,4} \beta_i R_i^{so} + \gamma |\cos\theta_{Thrust}| + \delta S_\perp$$

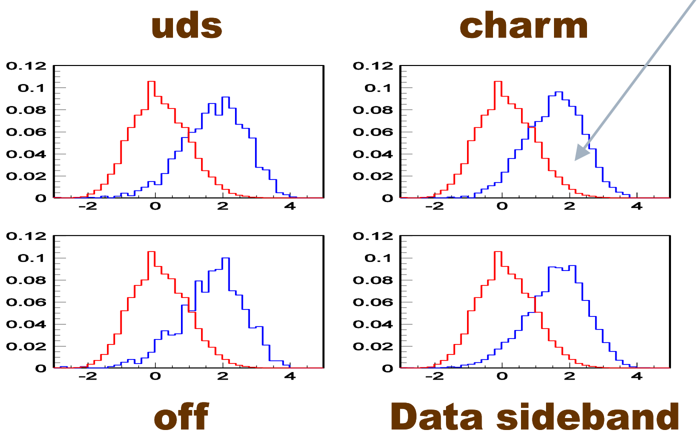
We use Fisher's discriminant to optimize the coefficients.



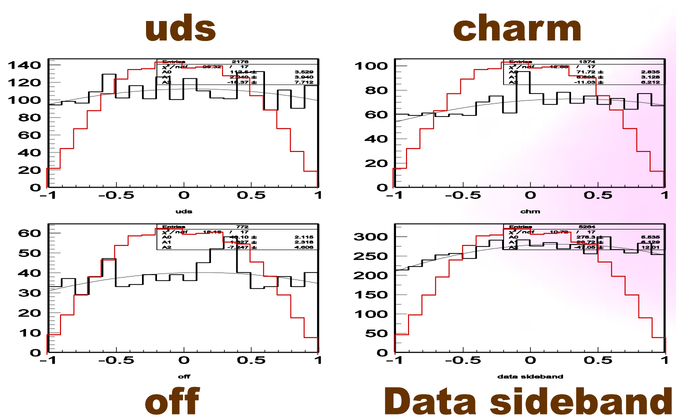
# Background Suppression

## SFW Moment (F)

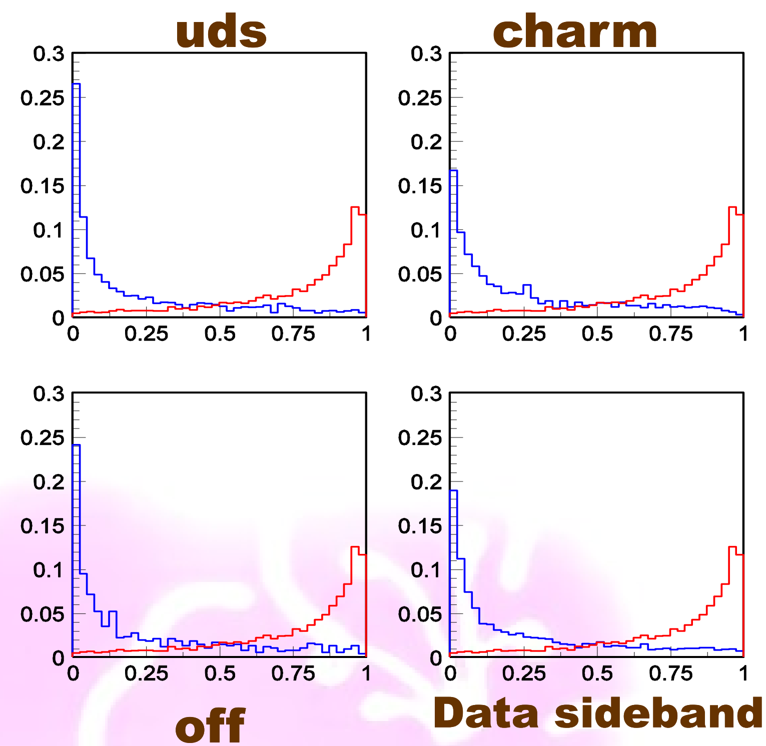
Signal MC




## $\cos\theta_B$ distribution




## Likelihood Ratio (LR)




$$LR = \frac{L_s}{L_s + L_b}$$

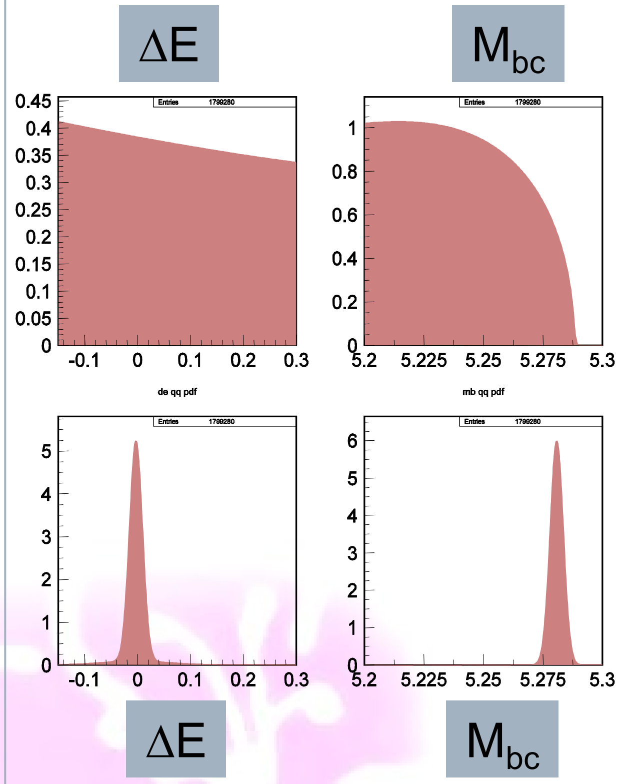
Optimized by $\frac{s}{\sqrt{s+b}}$ study

# Signal Extraction

- PDFs:
  - Background modeling: a line (curve) to represent the $\Delta$E and the following parametrization first suggested by ARGUS group to represent the $M_{bc}$.

    $$f(M_{bc}) \propto M_{bc}\sqrt{1-(M_{bc}/E_{beam})^2}\exp[-\xi(1-(M_{bc}/E_{beam})^2]$$

  - Signal modeling: a double Gaussian for $\Delta$E and a Gaussian for $M_{bc}$.




- 1D-binned fit: maximum Likelihood fit
  - Branching fraction are calculated by $\Delta$E fit
  - $M_{bc}$ fit for cross-check.
- 2D-unbinned fit ($\Delta$E$-M_{bc}$): Extended maximum likelihood fit.

$$L = e^{-(S+B)}\prod_{i=1}^{N}[SP_s(M_{bci},\Delta E_i)+BP_b(M_{bci},\Delta E_i)]$$

# Cited from PPP7 opening talk (by Professor H.Y. Cheng)

Extensive studies of baryonic B decays in Taiwan both experimentally and theoretically

| Expt. | Theory |
|---|---|
| Belle group at NTU | Chen, Chua, Geng, Hou, Hsiao, Tsai, Yang, HYC,… |

**Expt.**

Belle group at NTU

$B^- \to p\bar{p}K^-$ : first observation of charmless baryonic B decay ('01)

$B \to p\bar{p}(K, K^*, \pi)$

$\to \Lambda\bar{p}(\pi, K)$

$\to \Lambda\bar{\Lambda}K$

$B \to p\bar{p}$, $\Lambda\bar{\Lambda}$, $p\bar{\Lambda}$ (stringent limits)

$B \to p\bar{\Lambda}\gamma$: first observation of $b \to s\gamma$ penguin in baryonic B decays ('04)

Publication after 2002: (hep-ex)

0302024, 0310018, 0406068, 0408143,

0503046, 0503047, 0703048

**Theory**

Chen, Chua, Geng, Hou, Hsiao, Tsai, Yang, HYC,…

Publication after 2000: (hep-ph)

0008079, 0107110, 0108068, 0110263, 0112245, 0112294, 0201015, 0204185, 0204186, 0208185, 0210275, 0211240, 0302110, 0303079, 0306092, 0307307, 0311035, 0405283, 0503264, 0509235, 0511305, 0512335, 0603003, 0603070, 0606036, 0606141, 0607061, 0607178, 0608328, 0609133, 0702249, PRD(05,not on hep-ph)

Taiwan contributes to 87% of theory papers

4

There are total 15 papers so far
7 PRL, 2 PLB, 6PRD

# First Observation of Charmless Baryonic B Decays

**With charmonium veto**

PRL **88**, 181803 (2002)

♣ Large 3-body $p\bar{p}K^+$ signal observed

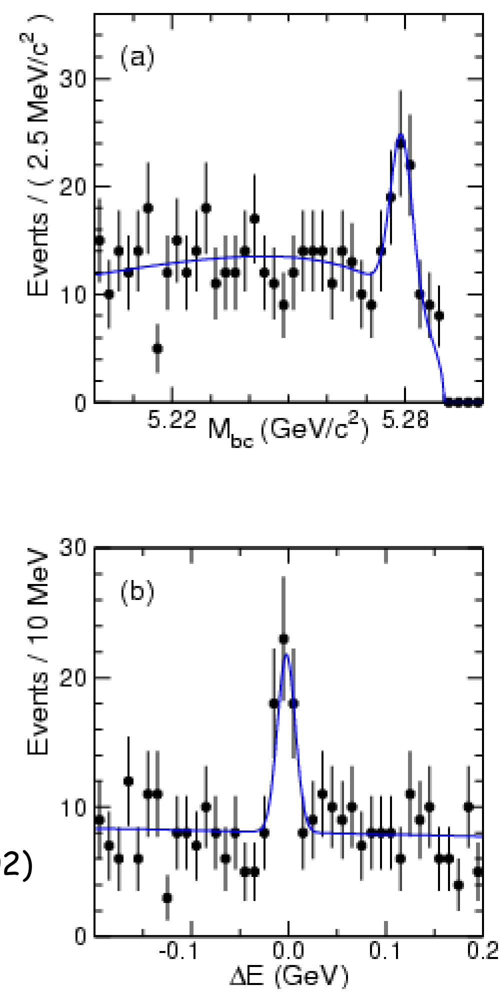
(31.7M $B\overline{B}$, PRL **88**, 181803 (2002))

- $B^+ \to p\bar{p}K^+$
  - $42.8^{+10.8}_{-9.6}$ events, 5.6 $\sigma$
  - $\mathcal{B} = 4.3^{+1.1}_{-0.9} \pm 0.5 \times 10^{-6}$
- $B^+ \to p\bar{p}\pi^+$
  - $16.2^{+8.6}_{-8.0}$ events, 2.1 $\sigma$
  - $\mathcal{B} < 3.7 \times 10^{-6}$
- $B^0 \to p\bar{p}K^0_S$
  - $6.4^{+4.4}_{-3.7}$ events
  - $\mathcal{B}(B^0 \to p\bar{p}K^0) < 7.2 \times 10^{-6}$

♣ Prefer to decay to 3 body PRD 65, 091103 (2002)

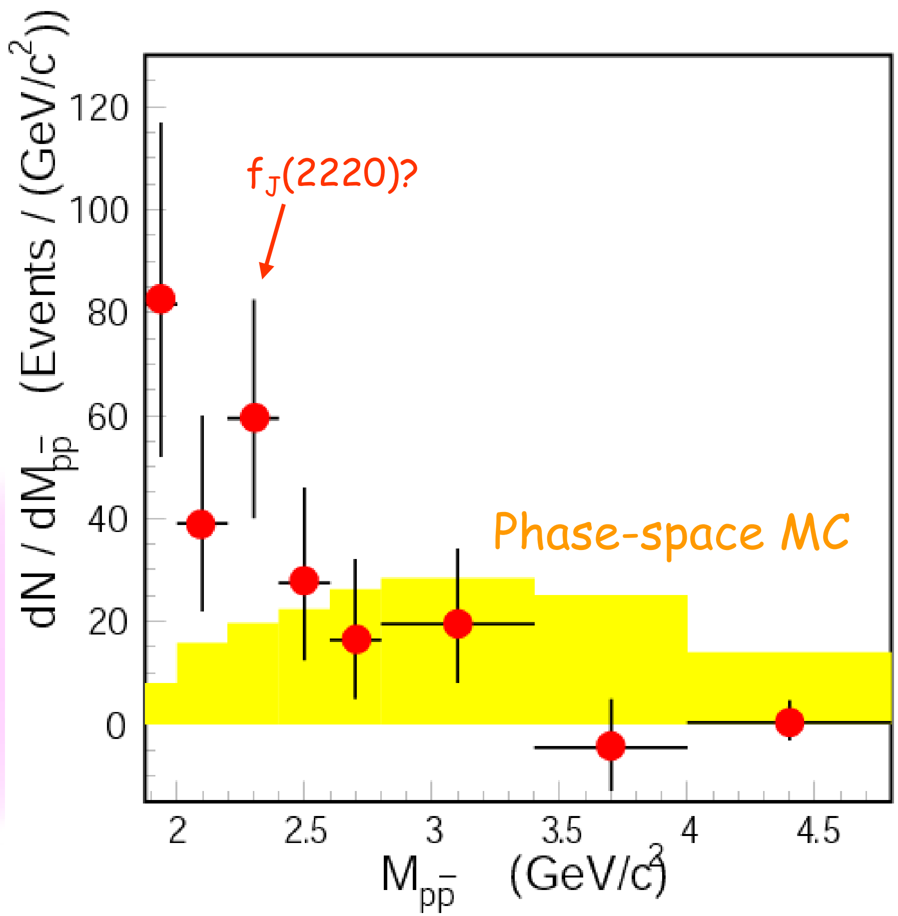
BF(3-body) >> BF(2-body)

$p\bar{p}K^+$



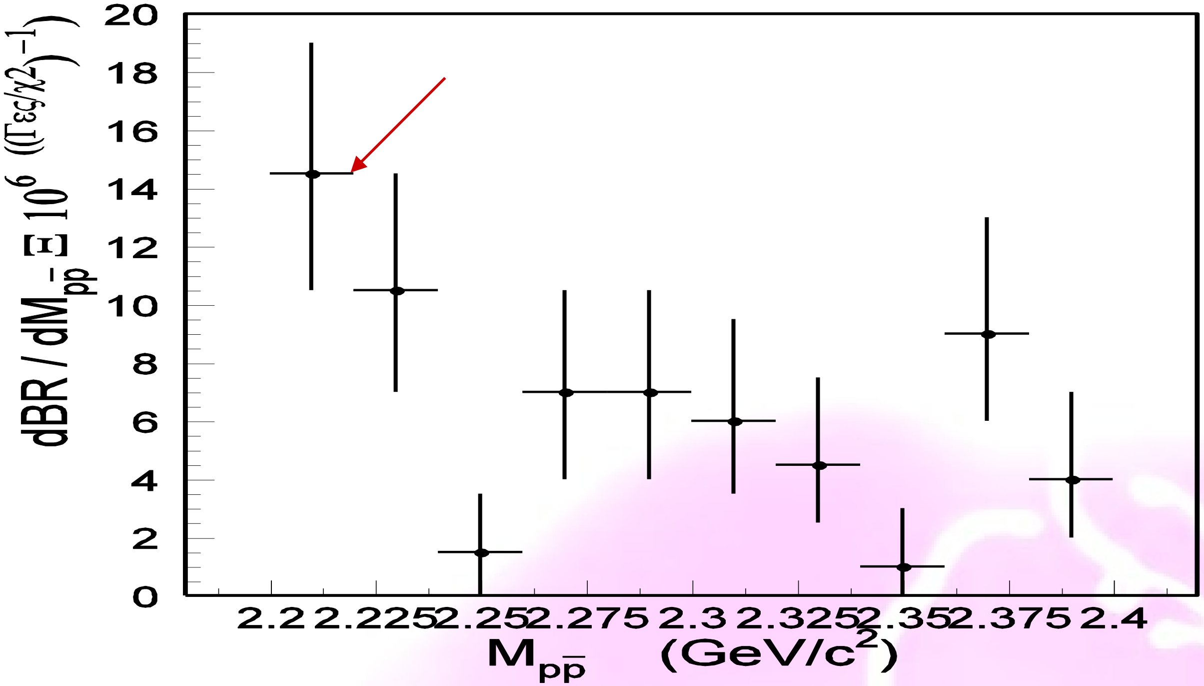
# New type of B Decays: $B^{\pm} \to p\bar{p}K^{\pm}$

- Peak at Low Mass
- Baryon form factor?
  - Cheng & Yang PRD **66** 014020 ('02)
  - Chua, Hou, Tsai PRD **66** 054004 ('02)
- Quasi 2-body Decay?
  - Chua, Hou, Tsai PLB **544** 139 ('02)
  - Glueball?
- Baryonium
- Fragmentation
- Final state interaction



# Glueball Search

**Search for glue-ball Production in rare B decays PLB544, 139 (2002)**




Scanning through the mass region from 2.2 to 2.4 GeV region

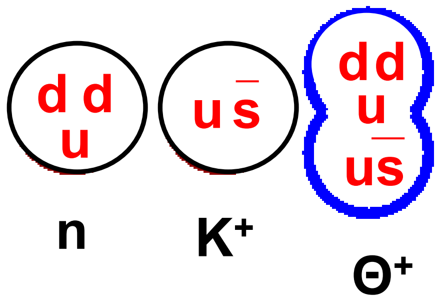
No significant signal is found.

We set a 90% confidence-level upper limit:

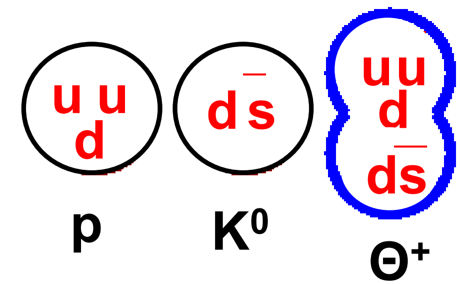
$BF(B^+ \to \text{glueball } K^+) \times BF(\text{glueball} \to p\bar{p}) < 4.1\times10^{-7}$

# Pentaquark search in $p\bar{p}K_s$

- $\Theta^+(1540)$ : $uudd\bar{s}$
- $\Theta^+ \rightarrow K^+ n$




**$\Theta^+ \rightarrow K^0 p$**

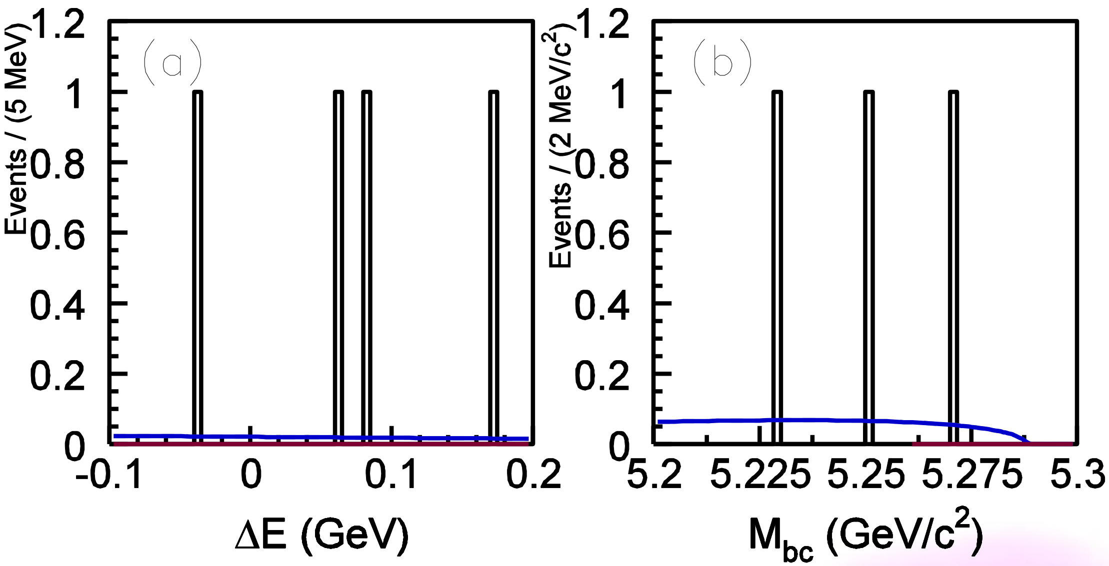



- **$B^0 \rightarrow \Theta^+ \bar{p}$**

  $B^0 \rightarrow p\bar{p}K^0$, $B \rightarrow p\bar{p}K_s$

  Search for B signal with a 20 MeV pKs mass window cut at 1540MeV

# Pentaquark search in $p\bar{p}K_s$




Fixed background shape from sideband data

Count the events in signal region and compare with background estimation

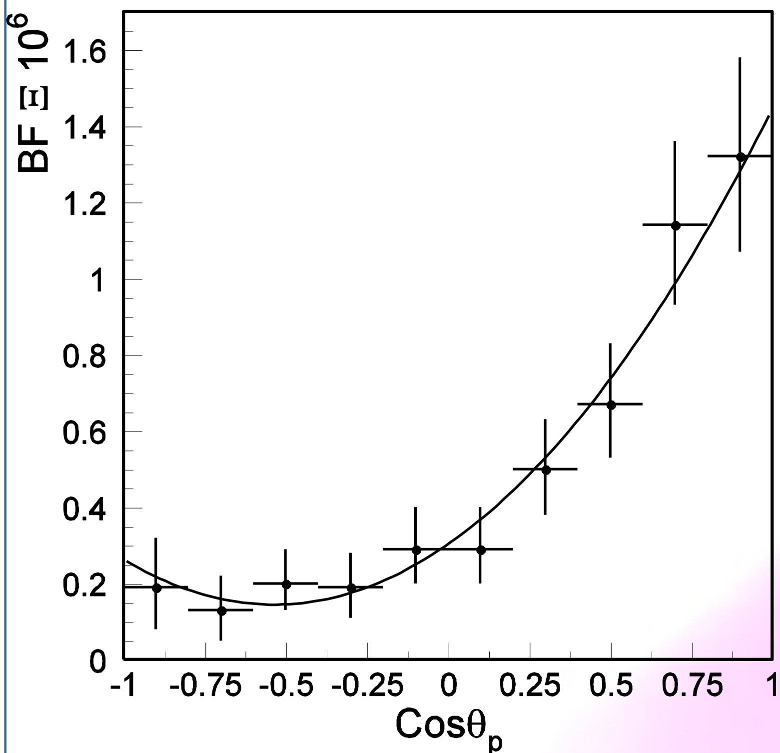
BF product upper limit < $2.3 \times 10^{-7}$ at 90% C.L.

PLB 617, 141 (2005)

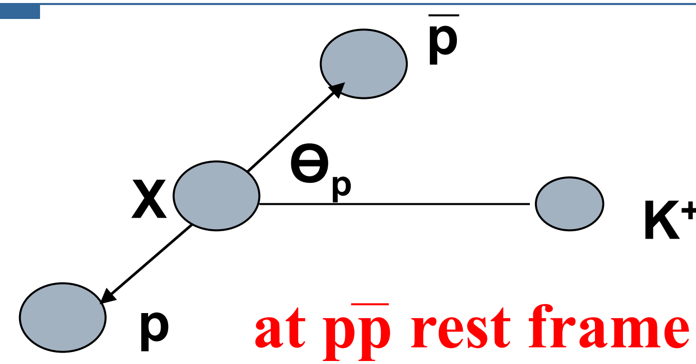
# Angular distribution: $p\bar{p}K^+$

**$140 fb^{-1}$**

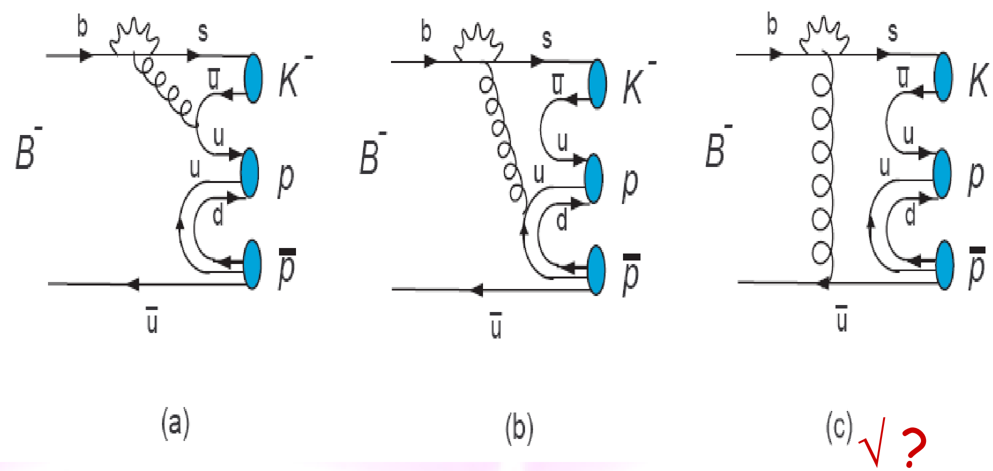
**$p\bar{p}K$ signal**




PLB617:141(2005)




**at $p\bar{p}$ rest frame for threshold peak**

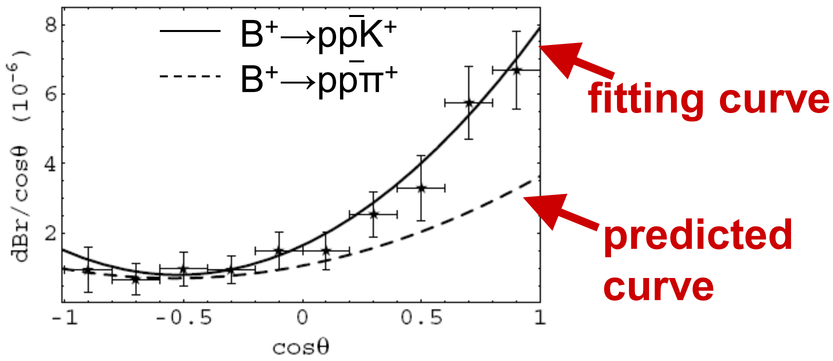



**Proton against $K^-$ ($\bar{p}$ against $K^+$) : flavor dependence!**

# Theoretical Predictions for $p\bar{p}\pi^+$

- Angular distribution
  - Perturbative QCD(PQCD): Geng and Hsiao, Phys.Rev.D74,
  - Final-State Interaction (FSI): M.Suzuki, J.Phys.G34, 2007

hep-ph/0606141




- Upper limit
  - BF of $B^+ \to \bar{p}\Delta^{++}$ was predicted to be
    - $2.9\times10^{-7}$ (QCD sum rules, Chernyak and Zhitnitsky Nucl.Phys.B345,1990)
    - $3.2\times10^{-4}$ (pole model, M.Jafri,Phys.Rev.D43,1991)
    - $1.4\times10^{-6}$ (pole model, Cheng and Yang,Phys.Rev.D66,2002)

# Dalitz plot of $B^+ \to p\bar{p}\pi^+$ 414fb$^{-1}$

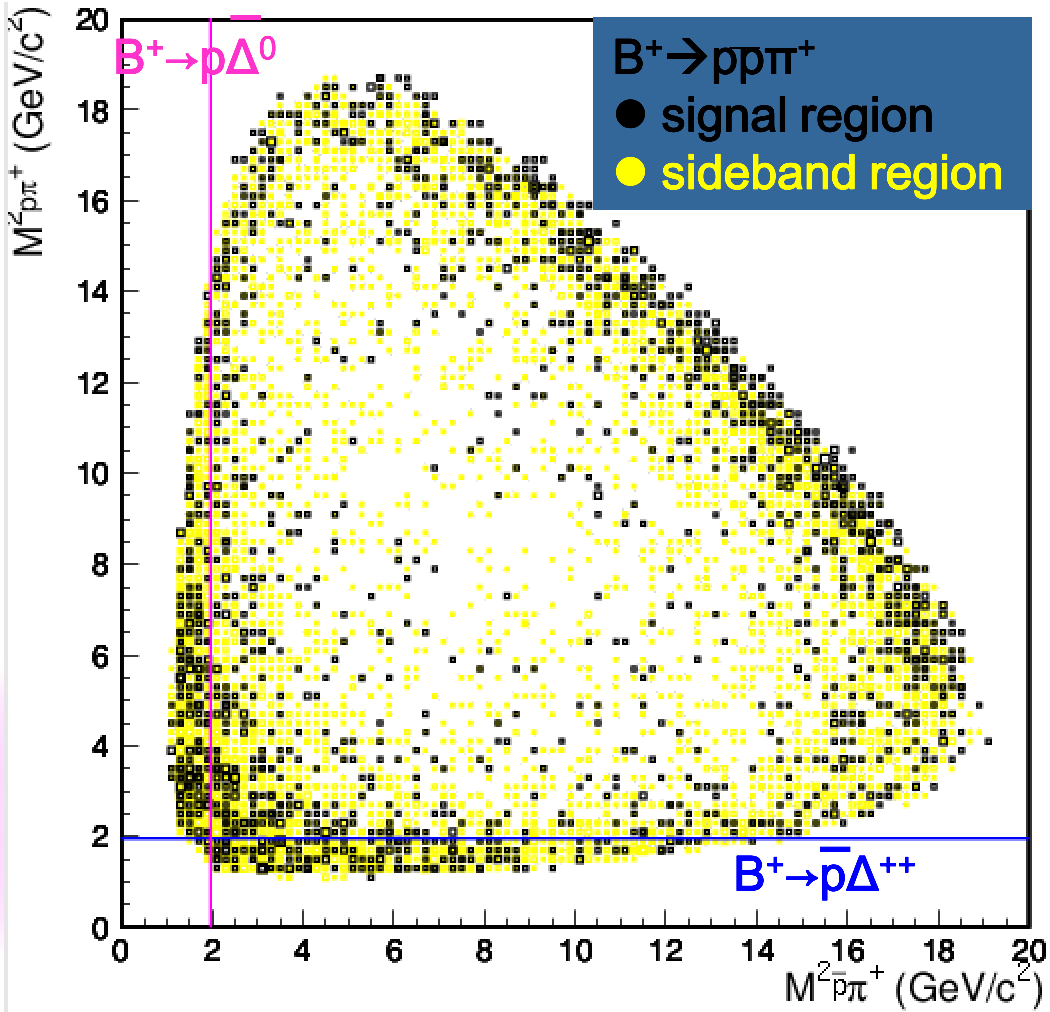
PLB 659:80 (2008)

- **$B^+ \to p\bar{\Delta}^0$**
  Expected background: 81.4
  Background uncertainty: 2.0%
  Observed event: 86
  Systematic error: 7.3%
  Yield upper-limit: 28.3

**BF($B^+ \to p\bar{\Delta}^0$)< $1.38\times10^{-6}$**

- **$B^+ \to \bar{p}\Delta^{++}$**
  Expected background: 73.0
  Background uncertainty: 2.1%
  Observed event: 59
  Systematic error: 7.3%
  Yield upper-limit: 9.1

**BF($B^+ \to \bar{p}\Delta^{++}$)< $1.4\times10^{-7}$**



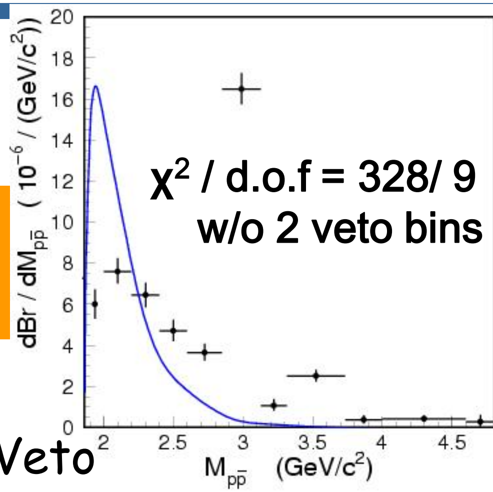
# Results for B→pp̄h

465M $B\bar{B}$ pairs

PLB 659:80 (2008)

## B→pp̄K

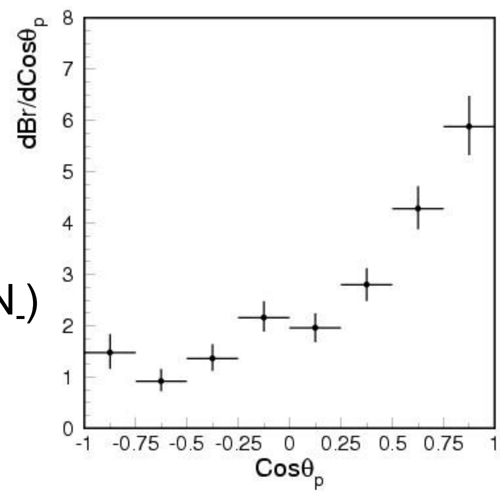
● data point
predicted curve
(hep-ph/0204185)




With Charm Veto

$BF(B^+ \to p\bar{p}K^+) = (5.54^{+0.27}_{-0.25} \pm 0.36) \times 10^{-6}$

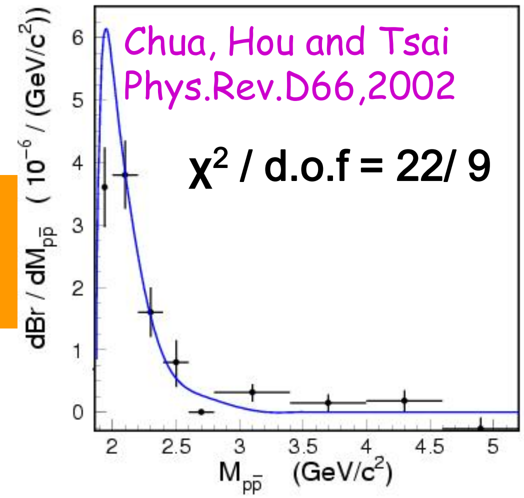
Threshold peak




$A_\theta = (N_+ - N_-)/(N_+ + N_-)$
$= 0.45 \pm 0.05$

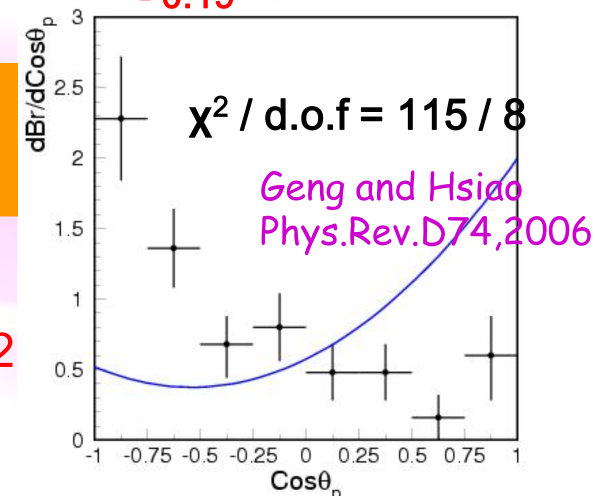
## B→pp̄π

● data point
—predicted curve
(hep-ph/0204185)




$BF(B^+ \to p\bar{p}\pi^+) = (1.60^{+0.22}_{-0.19} \pm 0.12) \times 10^{-6}$

● data point
—predicted curve
(hep-ph/0606141)



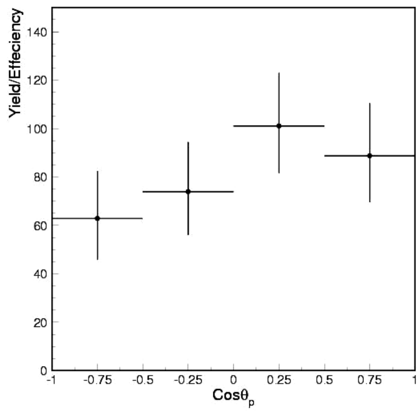

$A_\theta = -0.47 \pm 0.12$

# Angular asymmetry in fine bins

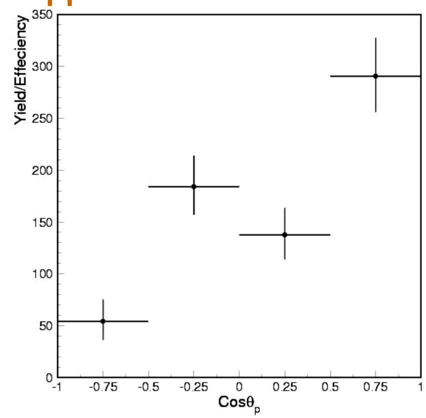
**414fb$^{-1}$**

## The binned angular distributions of $B \to p\bar{p}K$:

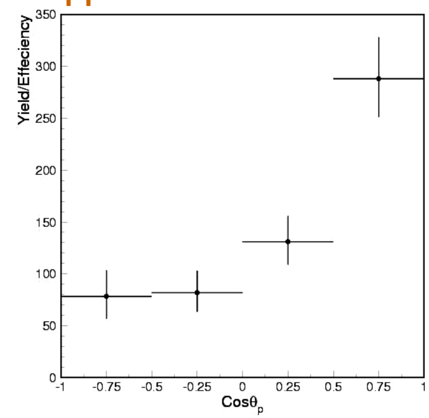
$M_{pp}$<2.0 GeV/c²



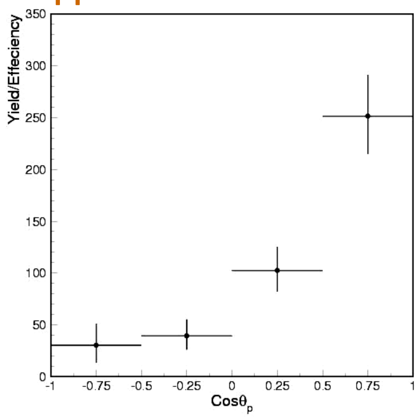

$M_{pp}$=2.0~2.2 GeV/c²



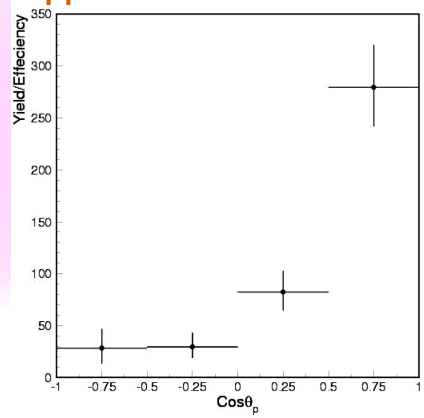

$M_{pp}$=2.2~2.4 GeV/c²

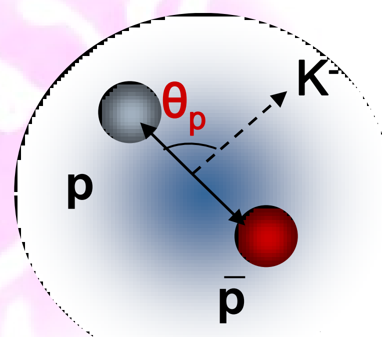



$M_{pp}$=2.4~2.6 GeV/c²



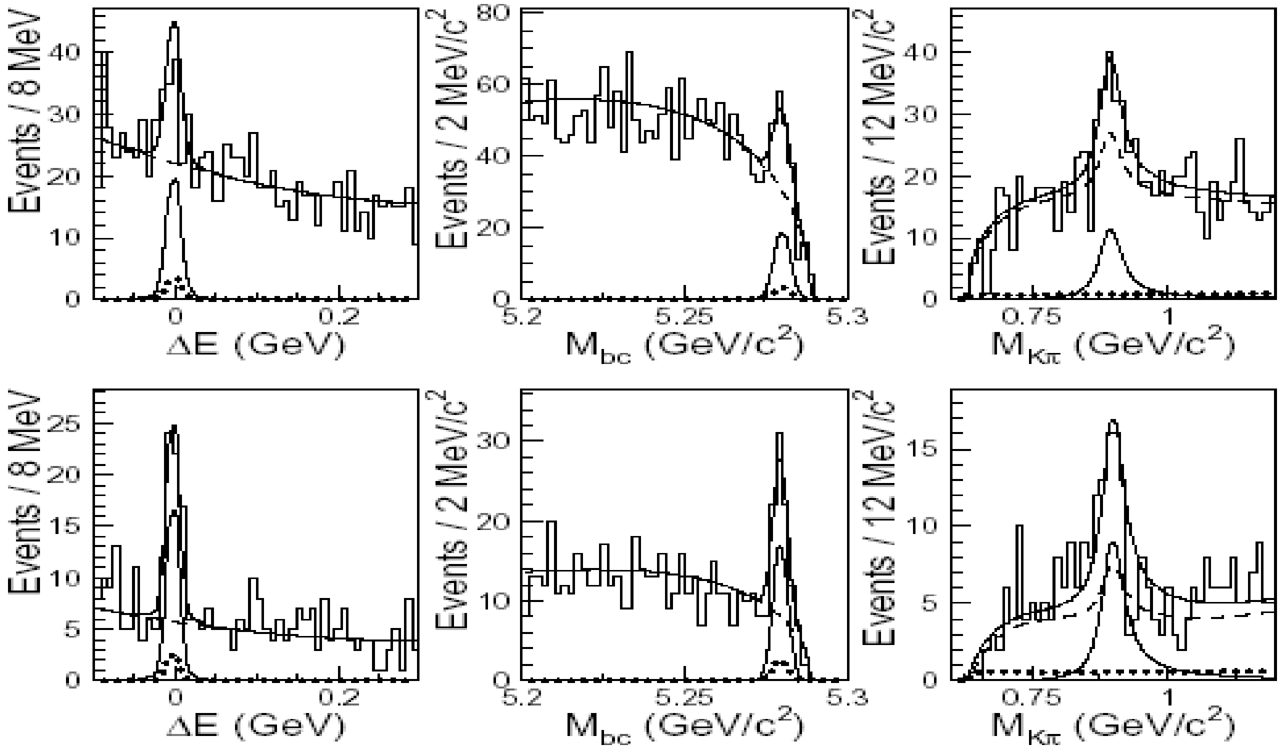

$M_{pp}$=2.6~2.85 GeV/c²




PLB 659:80 (2008)

# Observation of $B^0 \to p\bar{p}K^{*0}$




$K^{*0}$

535M $B\bar{B}$ pairs

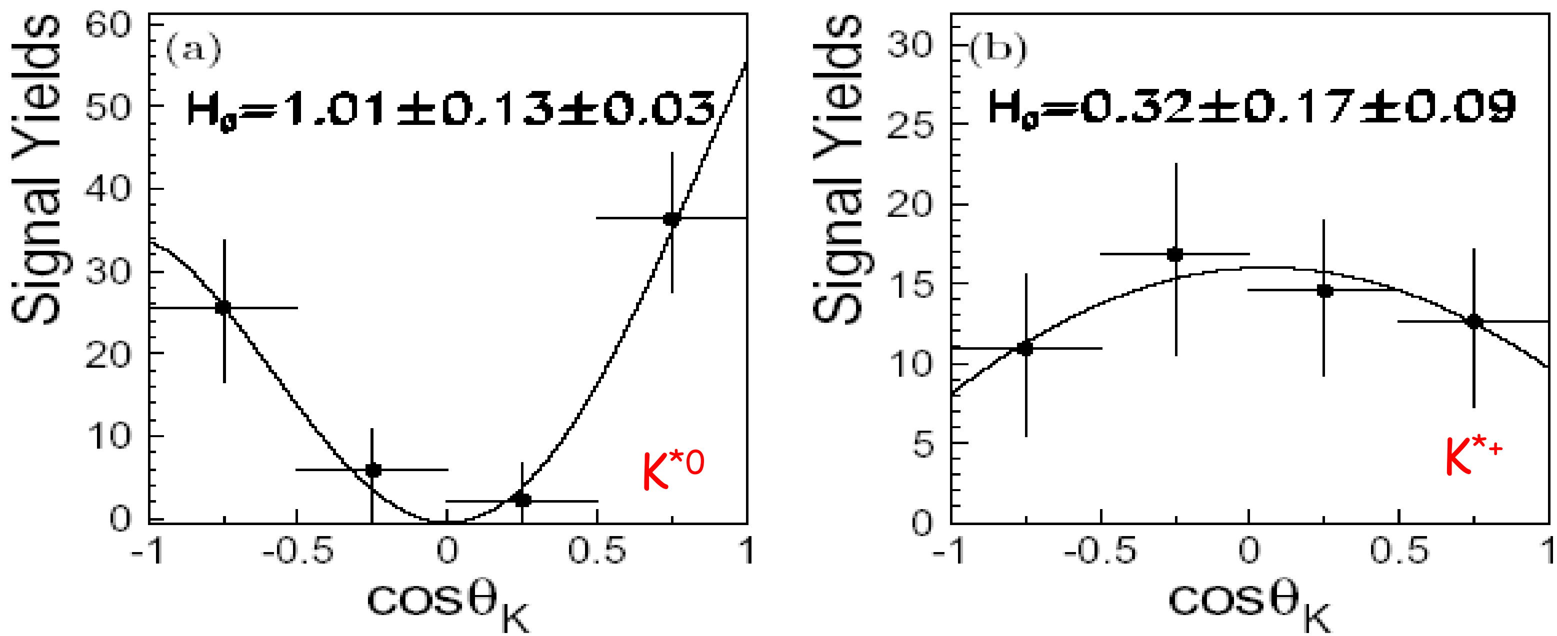
$K^{*+}$

$BF(B^+ \to p\bar{p}K^+)$ =(5.54 )x10-6
>$BF(B^+ \to p\bar{p}K^{*+})$ =(3.38 )x10-6
>$BF(B^0 \to p\bar{p}K^0)$ =(2.51 )x10-6
>$BF(B^0 \to p\bar{p}K^{*0})$ =(1.18 )x10-6

PRL100:251801 (2008)

**Pattern agrees with Pole model Predictions, Cheng & Yang, PRD66:014020 (2002)**

# Decay angular distributions of $K^*$



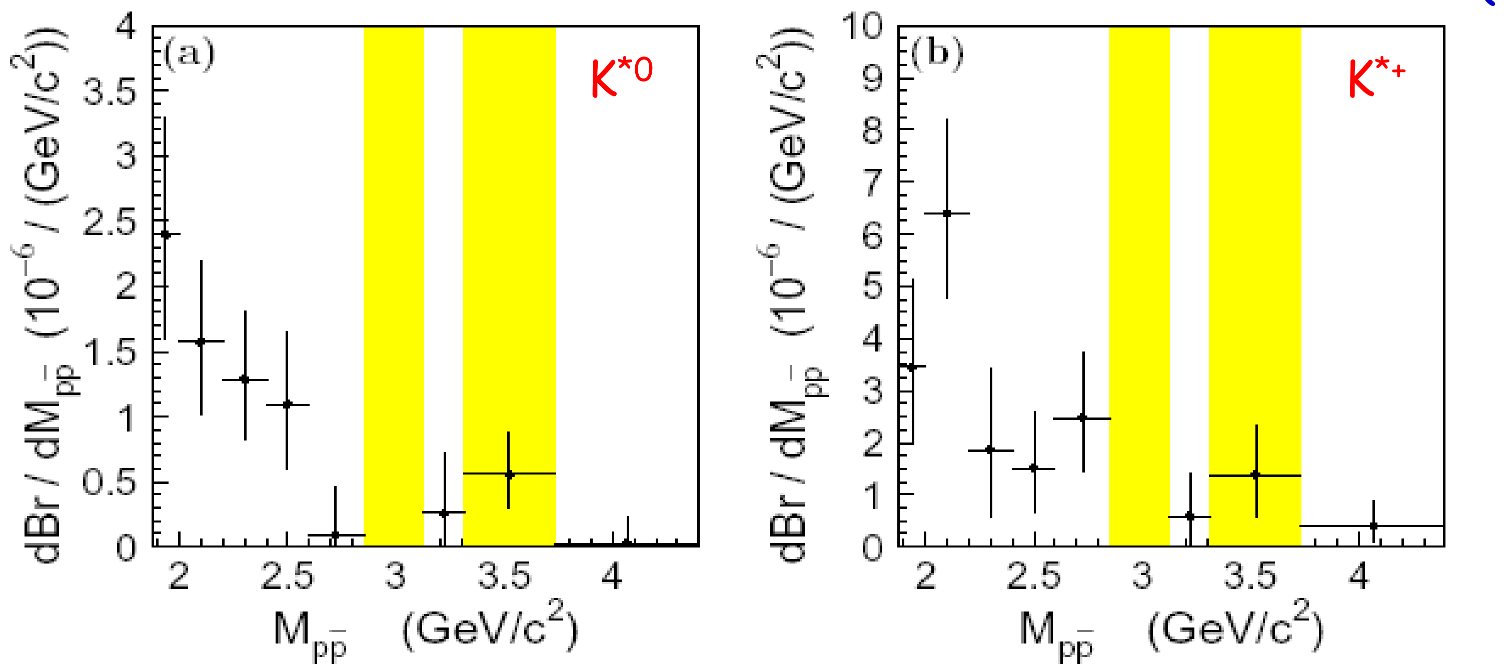

**$K^{*0}$ is almost 100% longitudinally polarized**
**Consistent with the $b \rightarrow s$ picture for two-body decays**

**$K^{*+}$ has non helicity zero amplitude**
**e.g. eternal W emission diagram**

PRL100:251801 (2008)

# Threshold enhancements and $A_{cp}$

PRL100:251801 (2008)

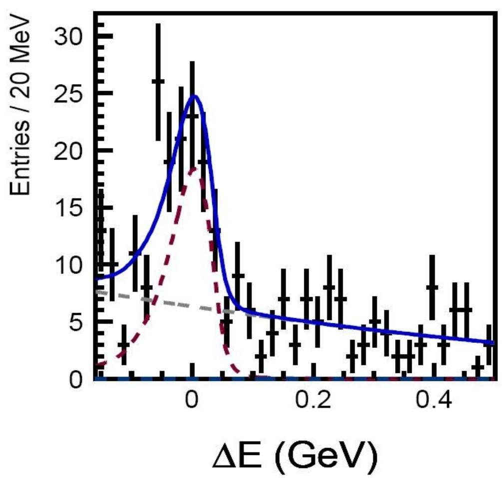


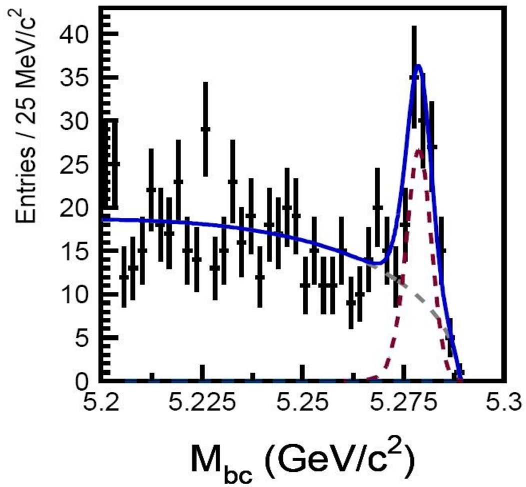

Threshold enhancements persist in all charmless baryonic B decays

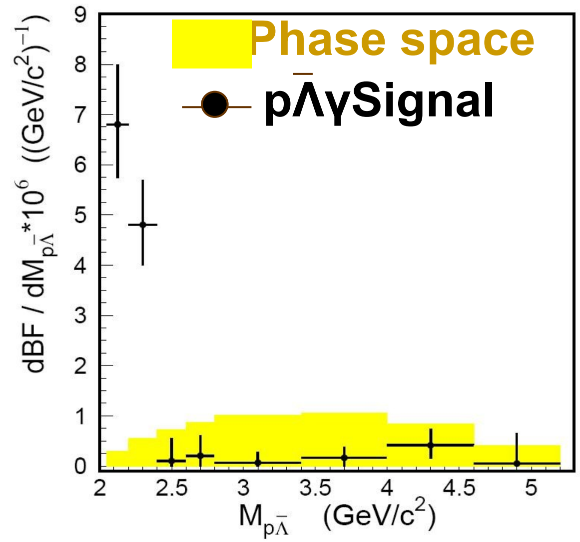
**Acp(B+→pp$K^{*+}$)= -0.01±0.19**
still need more statistics to check the theoretical prediction
(~20% from Geng, Hsiao &, Ng, PRL98:011801 (2007)).

# Study of $B^+ \to p\bar{\Lambda}\gamma$

**414fb$^{-1}$**




PRD76:052004 (2007)

**Signal yield:**

Signal Yield for $B \to p\bar{\Lambda}\gamma$ with $M_{p\bar{\Lambda}}$<2.4GeV/c$^2$: 95.3

Statistical Significance: 14.5σ

Full mass range:

BF($B \to p\bar{\Lambda}\gamma$ ): $(2.45^{+0.44}_{-0.38} \pm 0.22)\times 10^{-6}$

**Theoretical prediction:**

***Pole Model**: Cheng and Yang Phys.Lett. B533 (2002)

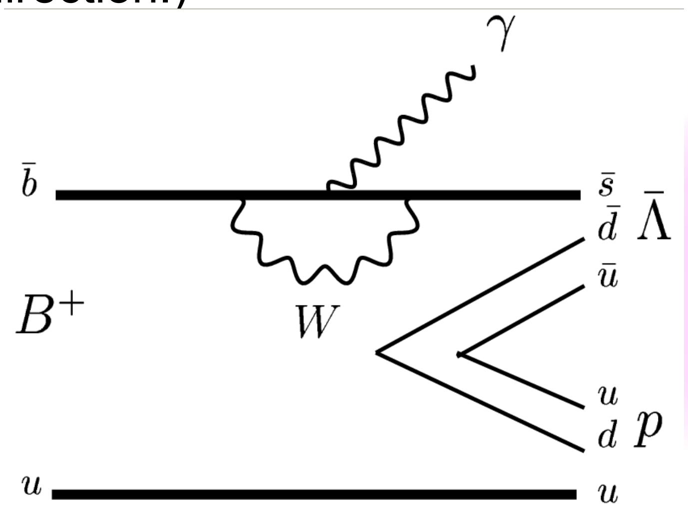
BF($B \to p\bar{\Lambda}\gamma$ ) ~ $1.2 \times 10^{-6}$

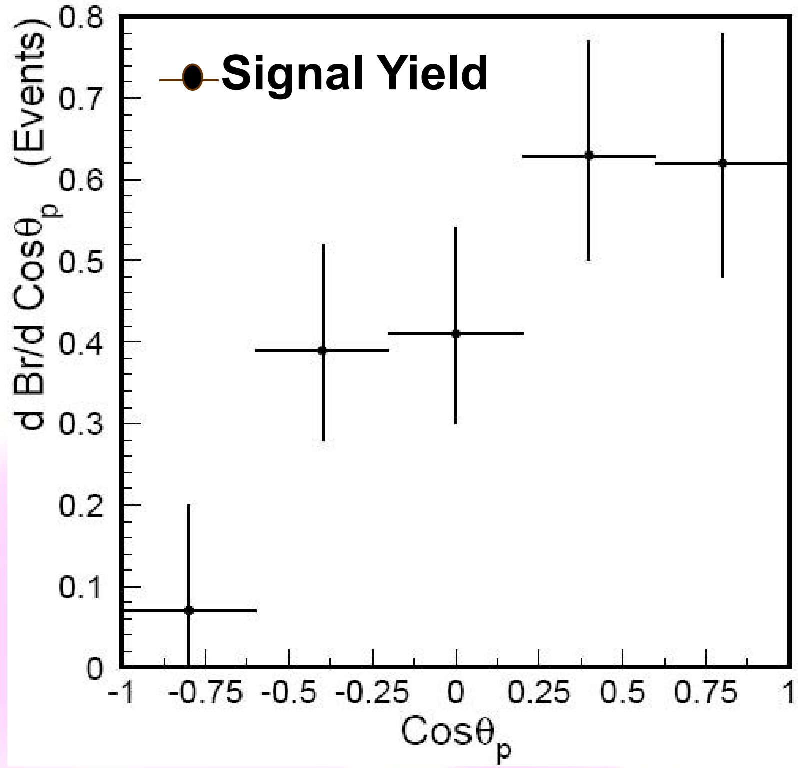
***QCD counting rules**: Geng and Hsiao Phys.Lett. B610 (2005)

BF($B \to p\bar{\Lambda}\gamma$ ) ~ $1 \times 10^{-6}$

# Angular distribution

Fit results in bins of $\cos\theta_p$ with $M_{p\bar{\Lambda}}$<4.0GeV/$c^2$ (Assuming $X \rightarrow p\bar{\Lambda}$, calculated in X rest frame. $\theta_p$ is defined as the angle between the proton direction and the meson/photon direction.)

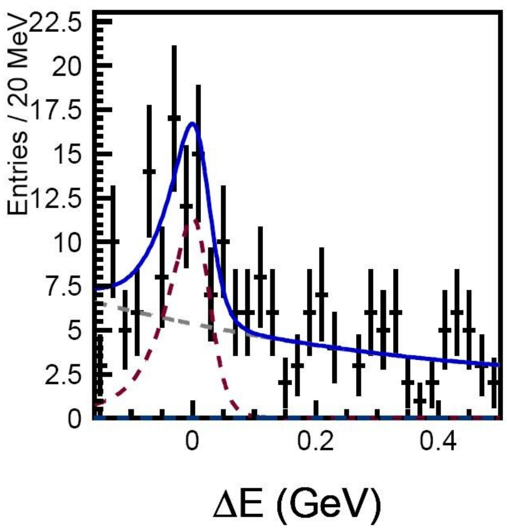


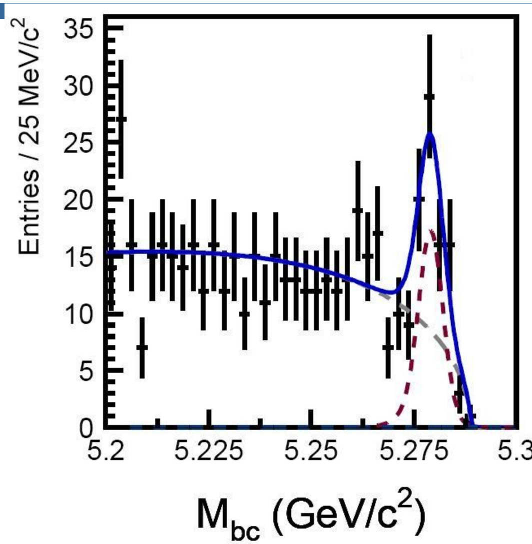



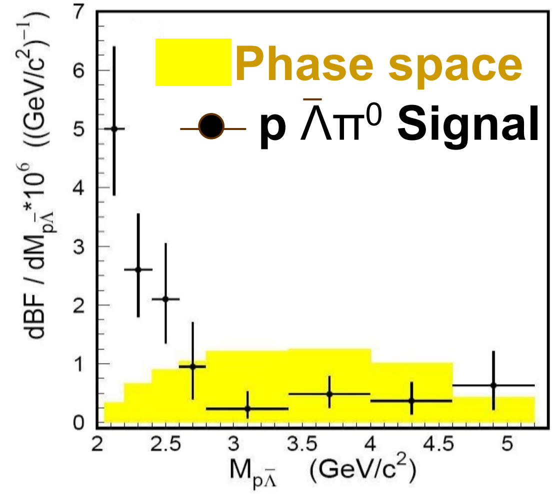

PRD76:052004 (2007)

# Study of $B^+ \to p\overline{\Lambda}\pi^0$

PRD76:052004 (2007)



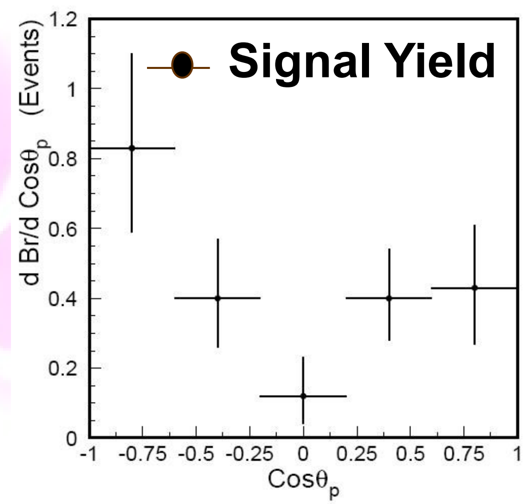

**Signal yield:**

Signal Yield for $B \to p\overline{\Lambda}\pi^0$ with $M_{p\overline{\Lambda}} < 2.8 GeV/c^2$: 56.1

Statistical Significance: $10.2\sigma$

$BF(B \to p\overline{\Lambda}\pi^0)$: $(3.00\,^{+0.61}_{-0.53} \pm 0.33) \times 10^{-6}$

First observation!



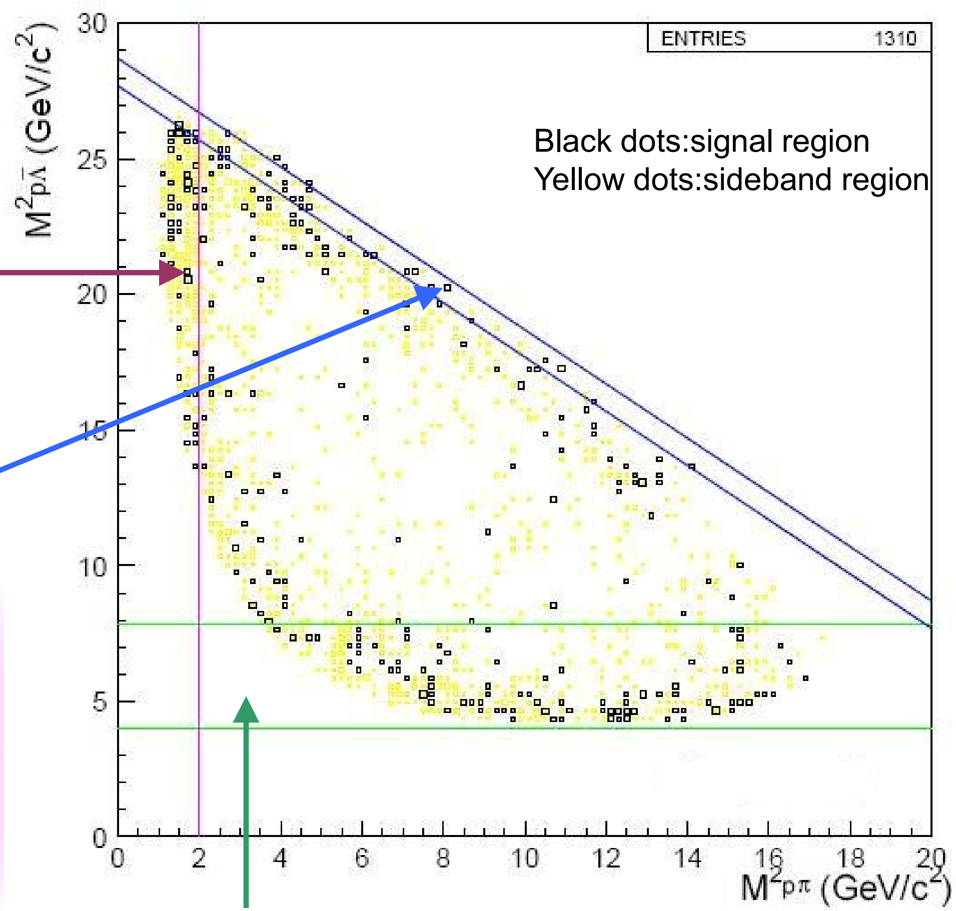
# Dalitz plot $B^+ \to p\bar{\Lambda}\pi^0$ PRD76:052004 (2007)

BELLE

**The studies of intermediate two-body decays:**

We apply $M_{p\pi}<1.40$ GeV/$c^2$ for $B^- \to \Lambda\bar{\Delta}^-$.
BF($B^- \to \Lambda\bar{\Delta}^-$) < $8.2\times10^{-7}$

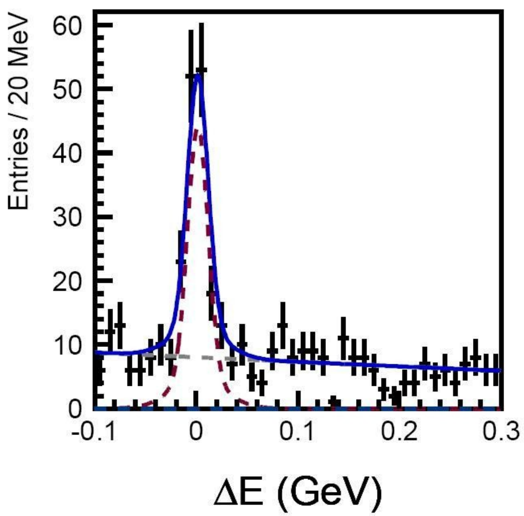
We apply $1.30<M_{\Lambda\pi}<1.45$ GeV/$c^2$ for $B^- \to \Sigma^{*0}\bar{p}$.
BF($B^- \to \Sigma^{*0}\bar{p}$) < $4.7\times10^{-7}$

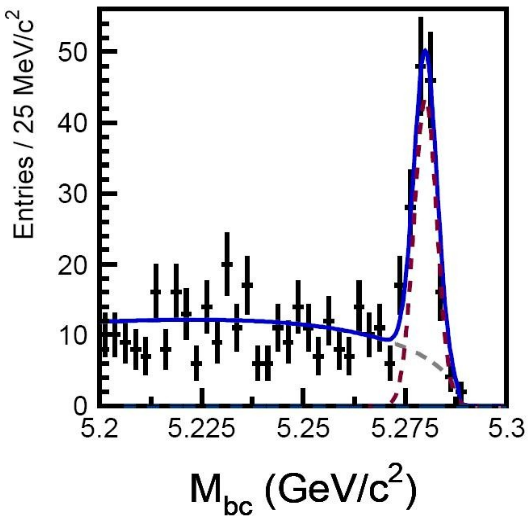


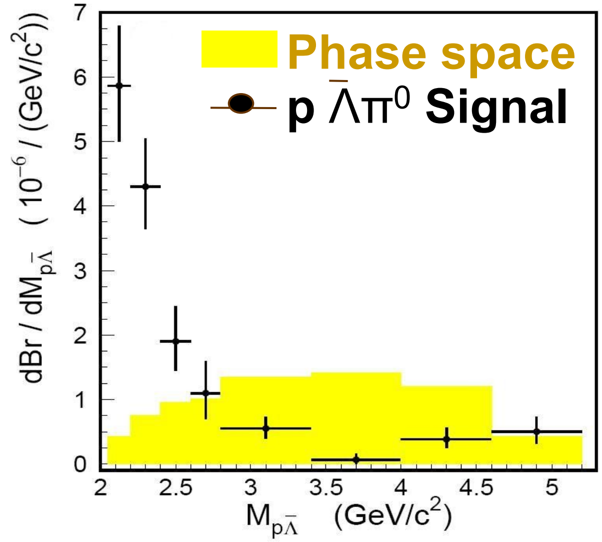

Threshold enhancement

# Study of $B^+ \to p\bar{\Lambda}\pi^-$

PRD76:052004 (2007)



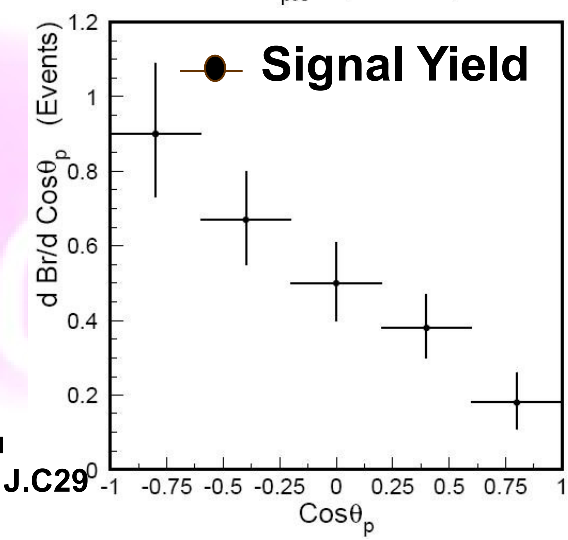

**Signal yield:**

Signal Yield for $B \to p\bar{\Lambda}\pi^-$ with $M_{p\bar{\Lambda}}$<2.8GeV/$c^2$: 129.4

Statistical Significance: 20.0σ

BF($B \to p\bar{\Lambda}\pi^-$): $(3.23^{+0.33}_{-0.29} \pm 0.29) \times 10^{-6}$

$$\frac{BF(B^+ \to p\bar{\Lambda}\pi^0)}{BF(B^+ \to p\bar{\Lambda}\pi^-)} = \boxed{0.93 \pm 0.21}$$ ≠1/2?




Chua&Hou
Eur. Phys. J.C29
(2003)

# Dalitz plot $B^+ \to p\bar{\Lambda}\pi^-$ PRD76:052004 (2007)

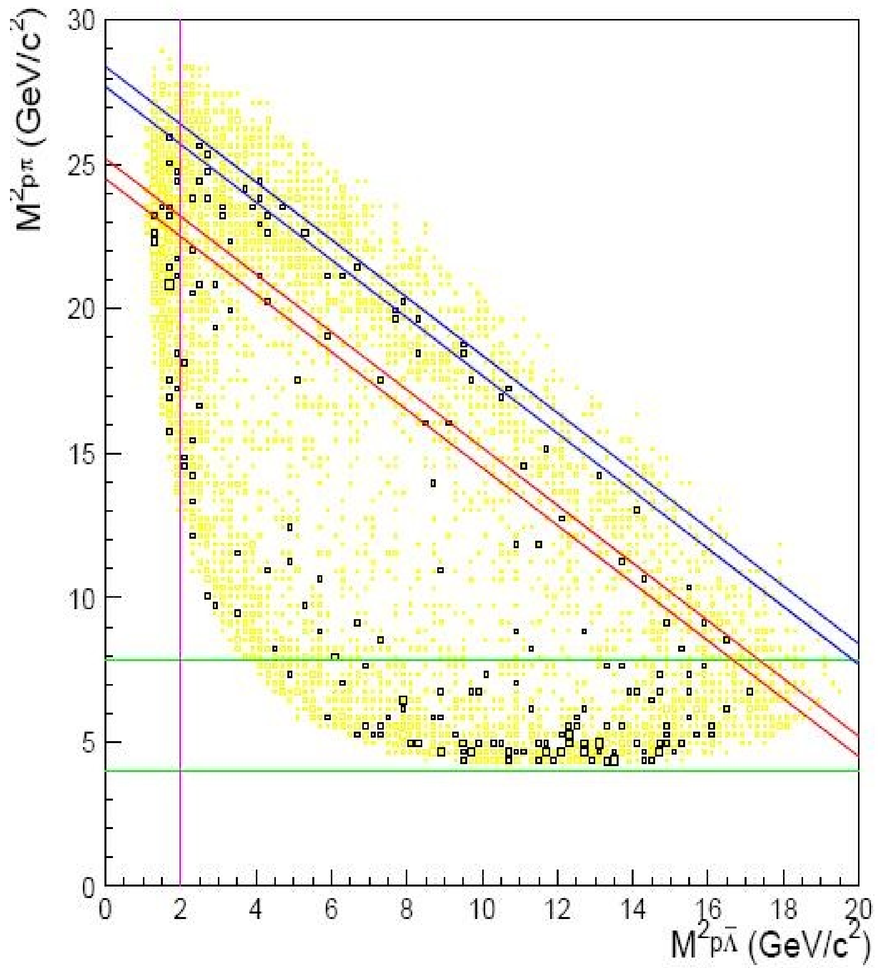
**The studies of intermediate two-body decays:**

We apply $2.262 < M_{\Lambda\pi} < 2.310$ GeV/c$^2$ for $B^0 \to \Lambda_c \bar{p}$.
BF($B^0 \to \Lambda_c \bar{p}$): $(1.43^{+0.77}_{-0.56} \pm 0.45) \times 10^{-5}$

BF($B^0 \to \Lambda_c \bar{p}$): $(2.19^{+0.56}_{-0.49} \pm 0.32 \pm 0.57) \times 10^{-5}$ (PRL 90 121802)

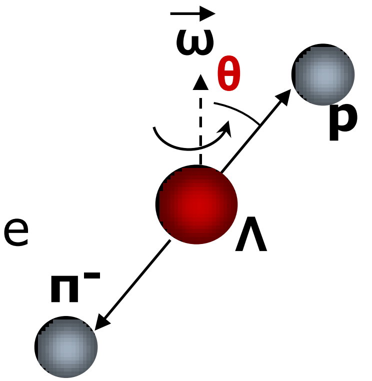
We apply $M_{p\pi} < 1.40$ GeV/c$^2$ for $B^0 \to \Lambda\bar{\Delta}^0$.
BF($B^0 \to \Lambda\bar{\Delta}^0$) < $9.3 \times 10^{-7}$

We apply $1.30 < M_{\Lambda\pi} < 1.45$ GeV/c$^2$ for $B^- \to \Sigma^{*0}\bar{p}$.
BF($B^0 \to \Sigma^{*+}\bar{p}$) < $2.6 \times 10^{-7}$



# Introduction to Λ polarization

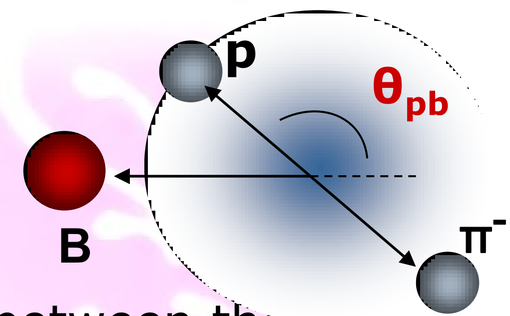
- **Decay parameter α:**
  - Transition rate R is proportional to (1+αcosθ).
  - θ is defined as the angle between the initial hyperon polarization and the momentum of the final baryon.
  - $\alpha_\Lambda$=0.642±0.013 **(PDG, Journal of Phys. G33, 1 (2006))**




- **The effective angular asymmetry parameter $\bar{\alpha}$ :**
  - For the cascade decay B→ΛX→π⁻pX :

$$\frac{d^2\Gamma}{dE_\Lambda \cos\theta_{pb}} = \frac{1}{2}\frac{d\Gamma}{dE_\Lambda}(1+\bar{\alpha}\cos\theta_{pb})$$

  - $\theta_{pb}$ is defined as the supplementary angle between the emitted proton momentum and the B momentum in the Λ rest frame.



# Theoretical prediction

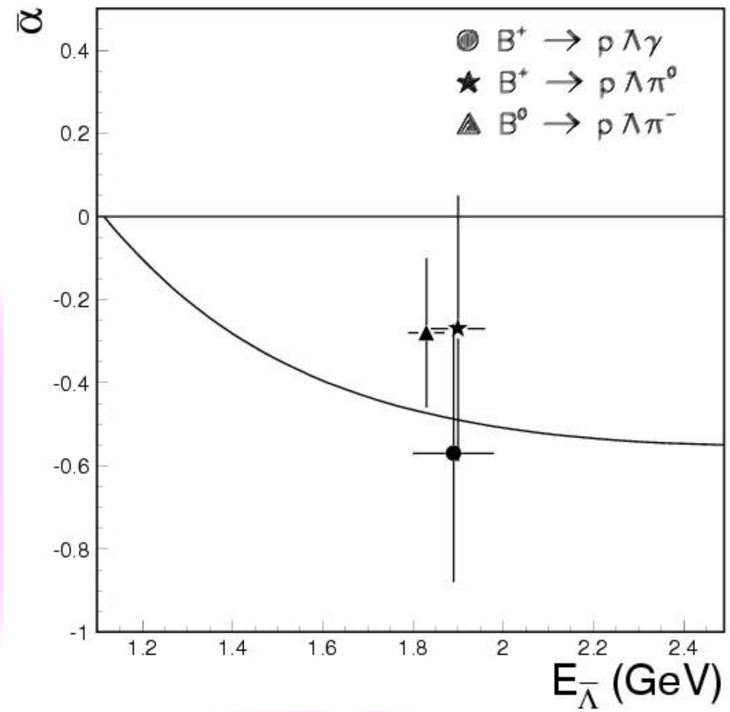
- **Predicted $\bar{\alpha}$ of $B \rightarrow \Lambda X \rightarrow p\pi X$ cascade decays**
  **Chua and Hou,J. Phys. G: Nucl. Part. Phys. 29 (2003)**
  - The relation between $\alpha$ and $\bar{\alpha}$ can be written in the form:
    $$\overline{\alpha}_{\Lambda}(E_{\Lambda}) = \mathcal{P}_{\Lambda}(E_{\Lambda})\,\alpha_{\Lambda}$$
  - For $\Lambda$ and $\overline{\Lambda}$, both the polarization function $\mathbf{P}_{\Lambda}(\mathbf{E}_{\Lambda})$ and decay parameter $\boldsymbol{\alpha}$ have different sign, with the same absolute value. (i.e. $\bar{\alpha}_{\Lambda}=\bar{\alpha}_{\overline{\Lambda}}$)

# Theoretical curves & Data 414fb$^{-1}$

- $\overline{\alpha}_\Lambda$ ($B^+ \to p\overline{\Lambda}\gamma$) = -0.57 ±0.33 ±0.10
- $\overline{\alpha}_\Lambda$ ($B^+ \to p\overline{\Lambda}\pi^0$) = -0.27 ±0.33±0.10
- $\overline{\alpha}_\Lambda$ ($B^0 \to p\overline{\Lambda}\pi^-$) = -0.28 ±0.21±0.10

**B→ΛX** PRD76:052004 (2007)

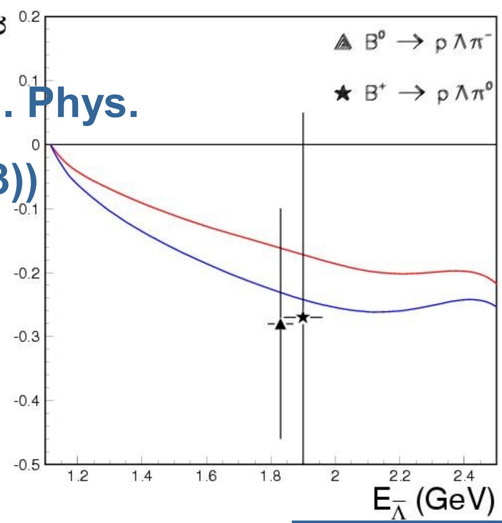
**M. Suzuki, J. Phys. G: Nucl. Part. Phys. 29 (2003)**




- Theoretical curves:

**B→pΛπ**

**Chua and Hou, Eru. Phys. J. C 29, 27-35 (2003))**



# $B \to \Lambda \bar{\Lambda} h$ Fitting Results 605fb$^{-1}$

PRD79:052006 (2009)

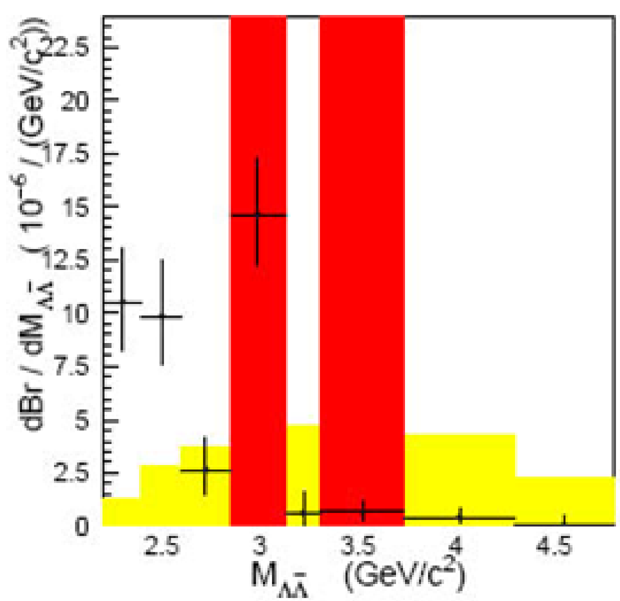
| Charmless branching fractions. | | | |
|---|---|---|---|
| Mode | Yield | $\mathcal{B}(10^{-6})$ | Significances ($\sigma$) |
| $B^0 \to \Lambda\bar{\Lambda}K^0$ | $49.1^{+8.6}_{-7.1}$ | $4.76^{+0.84}_{-0.68} \pm 0.61$ | 12.5 |
| $B^0 \to \Lambda\bar{\Lambda}K^{*0}$ | $25.3^{+9.4}_{-7.8}$ | $2.46^{+0.87}_{-0.72} \pm 0.34$ | 9.0 |
| $B^+ \to \Lambda\bar{\Lambda}K^+$ | $103.4^{+12.9}_{-11.2}$ | $3.38^{+0.41}_{-0.36} \pm 0.41$ | 16.5 |
| Results in the threshold-mass-enhanced region. | | | |
| Mode | Yield | $\mathcal{B}(10^{-6})$ | Significances ($\sigma$) |
| $B^+ \to \Lambda\bar{\Lambda}\pi^+$ | $7.76^{+4.49}_{-3.72}$ | $< 0.94$ at 90% C.L. | 2.5 |
| $B^+ \to \Lambda\bar{\Lambda}K^{*+}$ | $6.54^{+3.37}_{-2.63}$ | $2.19^{+1.13}_{-0.88} \pm 0.33$ ( $< 4.98$ at 90% C.L. ) | 3.7 |
| Related search. | | | |
| Mode | Yield | $\mathcal{B}(10^{-5})$ | Significances ($\sigma$) |
| $B^0 \to \Lambda\bar{\Lambda}\bar{D}^0$ | $5.53^{+3.04}_{-2.35}$ | $1.05^{+0.57}_{-0.44} \pm 0.14$ ( $< 2.60$ at 90% C.L. ) | 3.4 |

First observation!

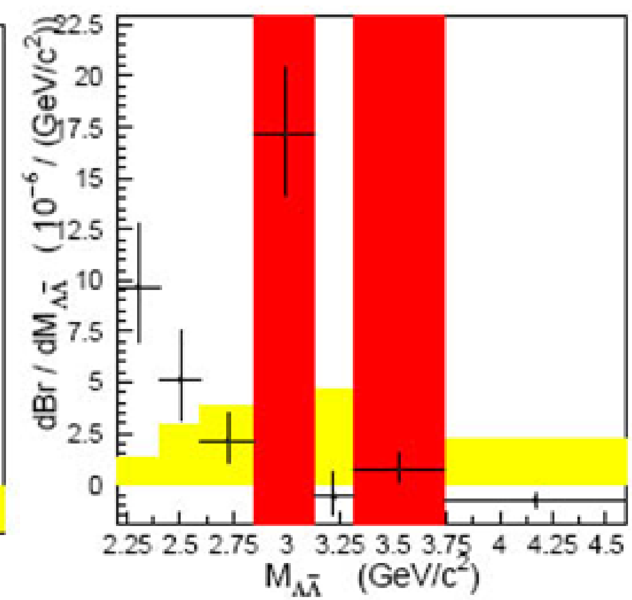
# $M_{\Lambda\bar{\Lambda}}$ Distribution

- The threshold enhancement is still there for the two newly observed modes

**PRD79:052006 (2009)**




$B^0 \rightarrow \Lambda\bar{\Lambda}K^0$

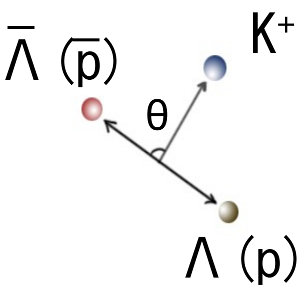



$B^0 \rightarrow \Lambda\bar{\Lambda}K^{*0}$

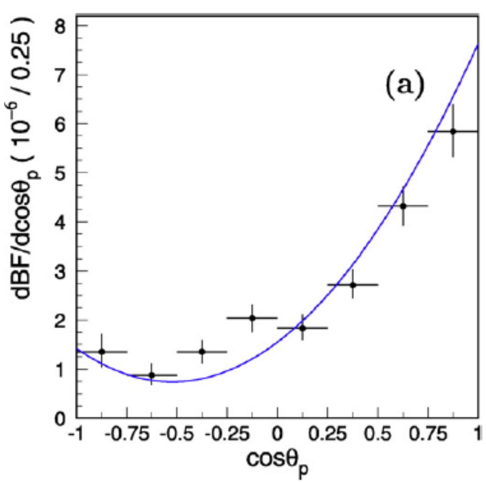
# Dibaryon Angular Distribution

- Fit results in bins of $\cos\theta_{\Lambda}$ with $M_{\Lambda\bar{\Lambda}}<2.85\mathrm{GeV}/c^2$

**PRD79:052006 (2009)**

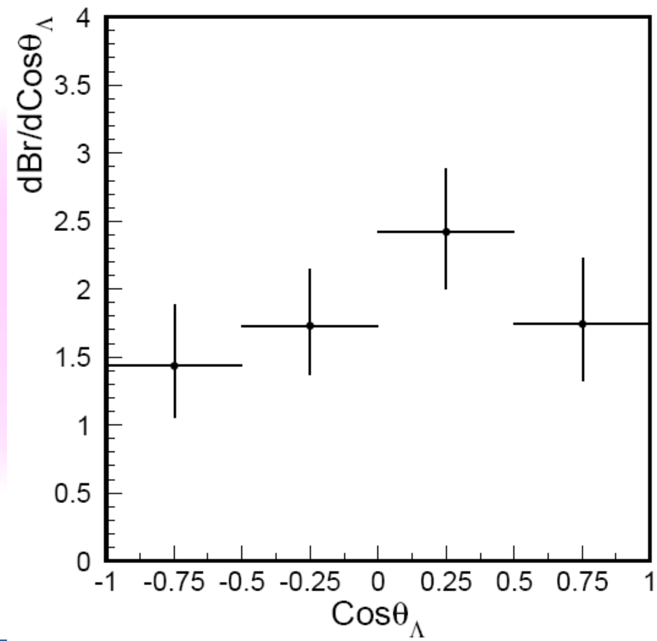



Angular distribution of $B^+ \rightarrow p\bar{p}K^+$

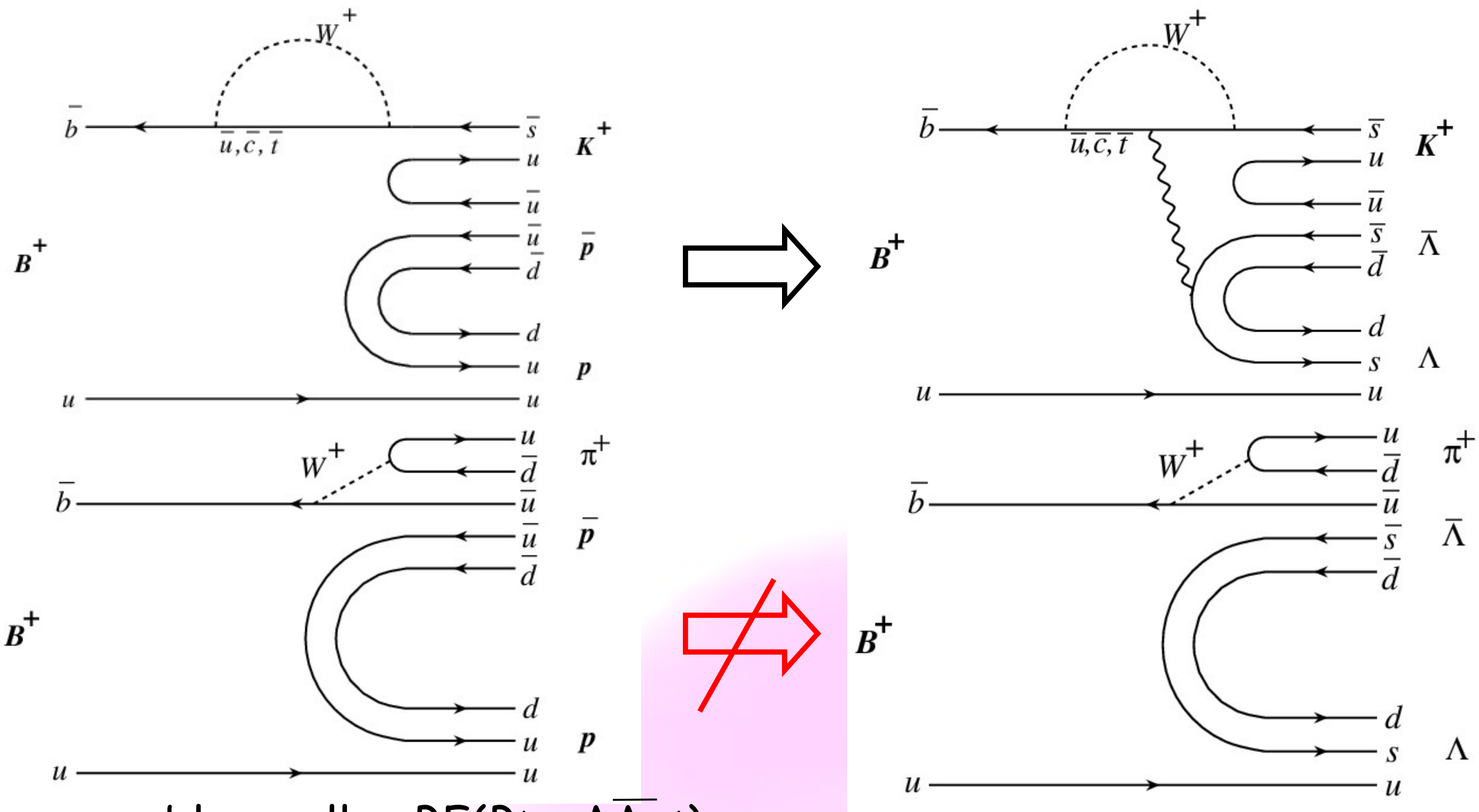



Phys. Lett. B659, 80-86 (2008)

Angular distribution of $B^+ \rightarrow \Lambda\bar{\Lambda}K^+$

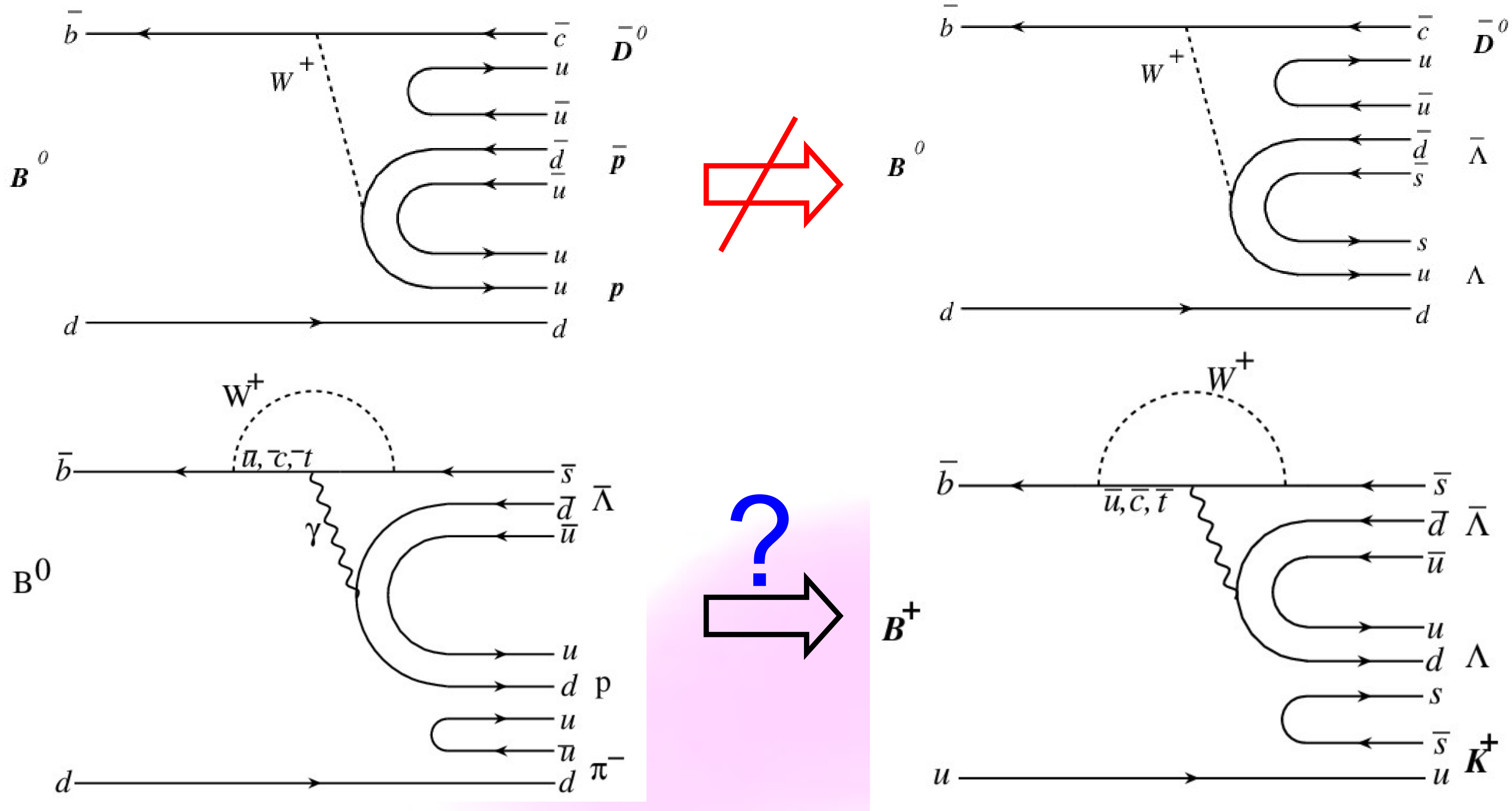


# Discussion based on quark diagrams




comparably smaller BF($B^+ \to \Lambda\bar{\Lambda}\pi^+$)
considerably larger BF($B^0 \to \Lambda\bar{\Lambda}K^0$)
lack of peaking feature in $\cos\theta_\Lambda$ distribution for $B^+ \to \Lambda\bar{\Lambda}K^+$
$\to$ **$B \to \Lambda\bar{\Lambda}h \neq B \to p\bar{p}h$** ?

# More Comparisons



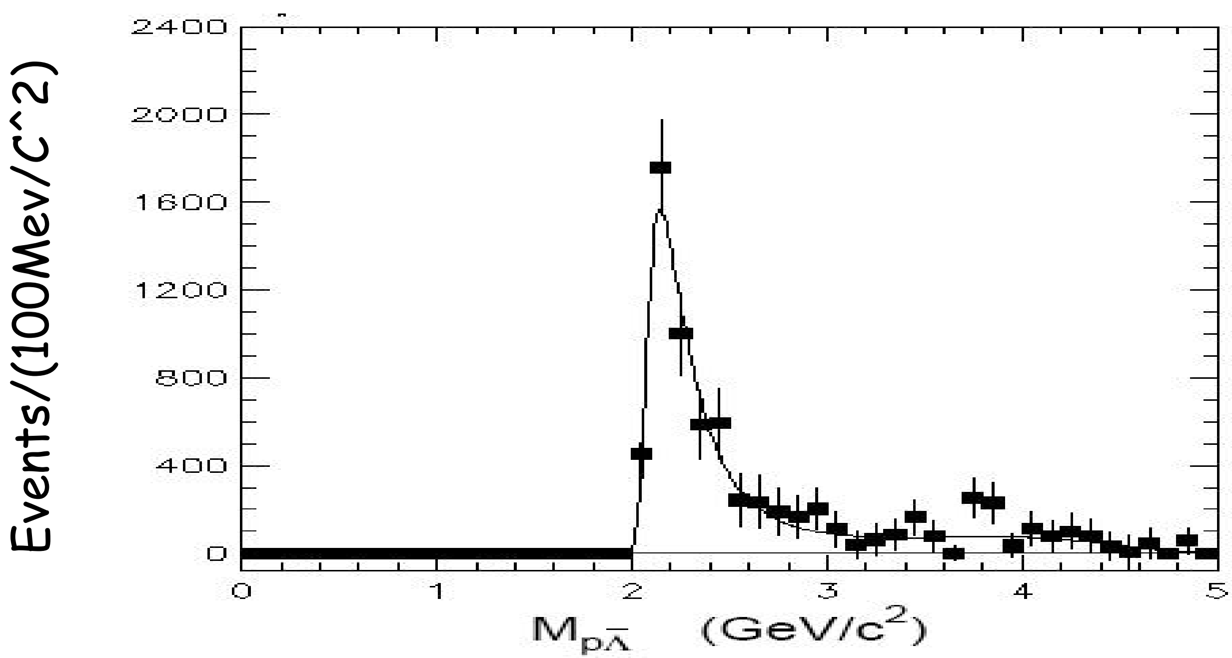

- B to $\bar{\Lambda}\Lambda K$ mode might behave like B to $p\bar{\Lambda}\pi$ mode?

# Threshold enhancement in $B^+ \to p\,\overline{\Lambda}\,\pi^+\pi^-$

# of B/eff. in $M_{p\overline{\Lambda}}$ spectrum

Fit with threshold function

Phys.Rev.D80:111103 (2009)

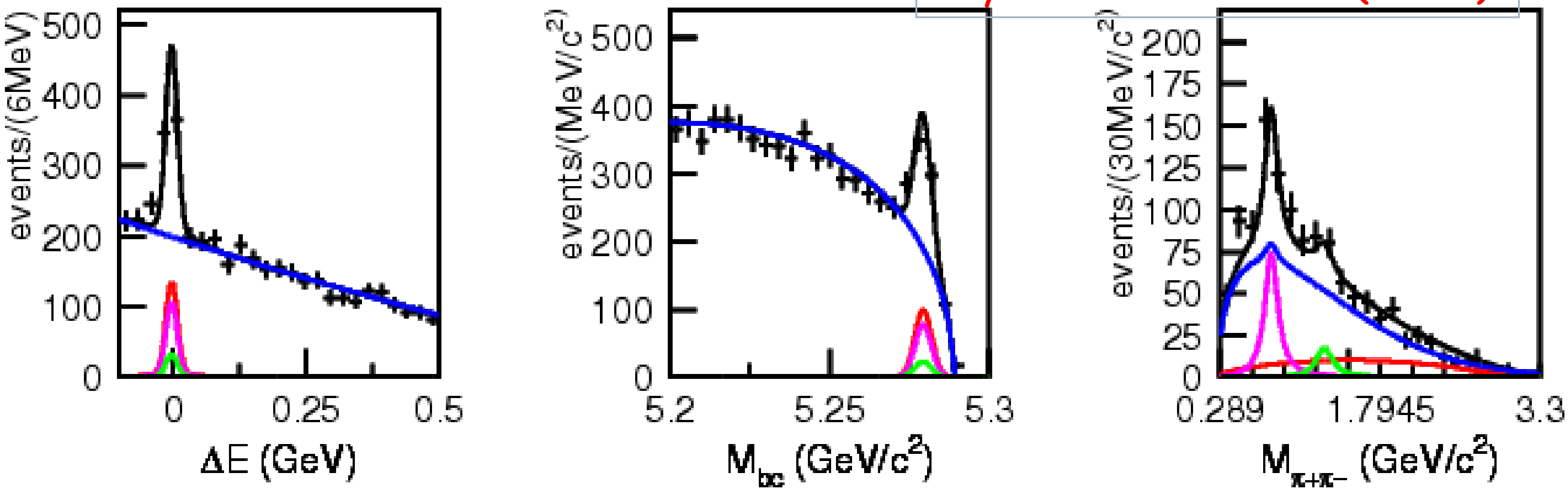



605 $fb^{-1}$

First observed in 4-body B decay

# Intermediate 3-body decay study

Phys.Rev.D80:111103 (2009)




| 605 fb$^{-1}$ | | | | | |
|---|---|---|---|---|---|
| Decay | BF ($10^{-6}$) | Stat. Err. | Sys. Err. | Eff.(%) | Significance |
| $p\bar{\Lambda}\pi\pi$ | 5.92 | $^{+0.88}_{-0.84}$ | ±0.69 | 4.32 | 9.1 |
| $p\bar{\Lambda}\rho$ | 4.78 | $^{+0.67}_{-0.64}$ | ±0.60 | 4.17 | 9.5 |
| $p\bar{\Lambda}f_2$ | 2.03 | $^{+0.77}_{-0.72}$ | ±0.27 | 2.94 | 3.0 |

$B \to p\bar{\Lambda}\pi\pi$

$B \to p\bar{\Lambda}\rho$

$B \to p\bar{\Lambda}f_2$

Continuum

# $B^- \to \bar{p}\Lambda D^0$, $D^0 \to K^-\pi^+$

Chen, Cheng, Geng&Hsiao, PRD78

**b → c can be useful to understand the charmless decays** since the penguin contribution should be small

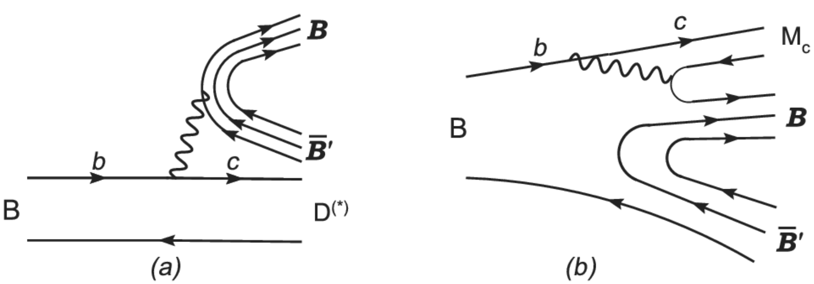
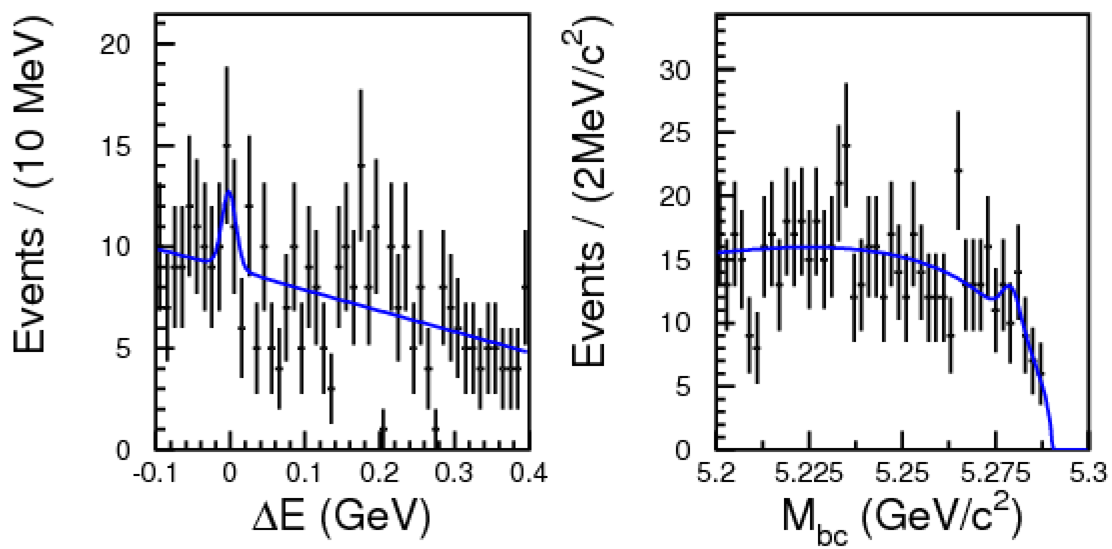
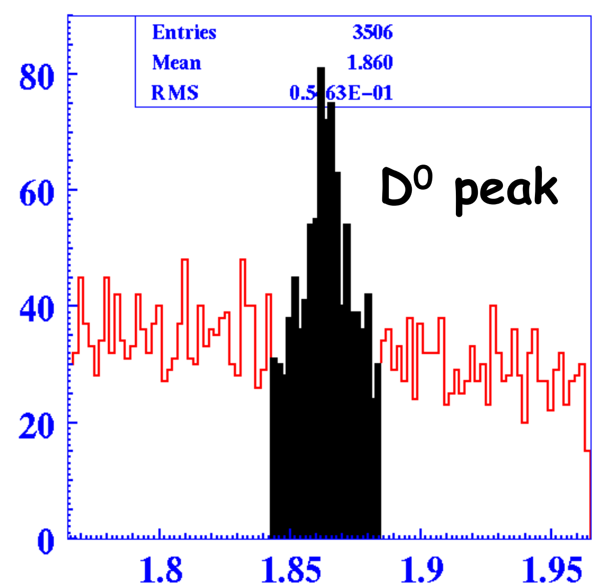



FIG. 1. Two types of the $B \to \mathbf{B}\bar{\mathbf{B}}'M_c$ decay process: (a) current type and (b) transition type.

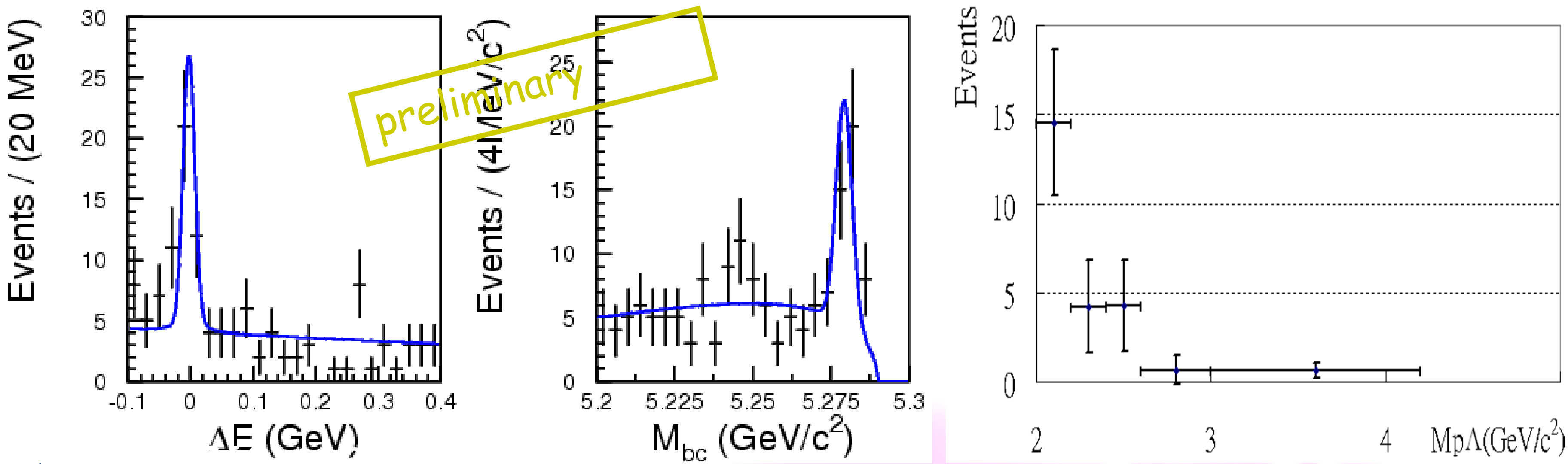



Small signal yield from $D^0$ sideband

# $B^- \to p\Lambda D^0$, $D^0 \to K^-\pi^+$

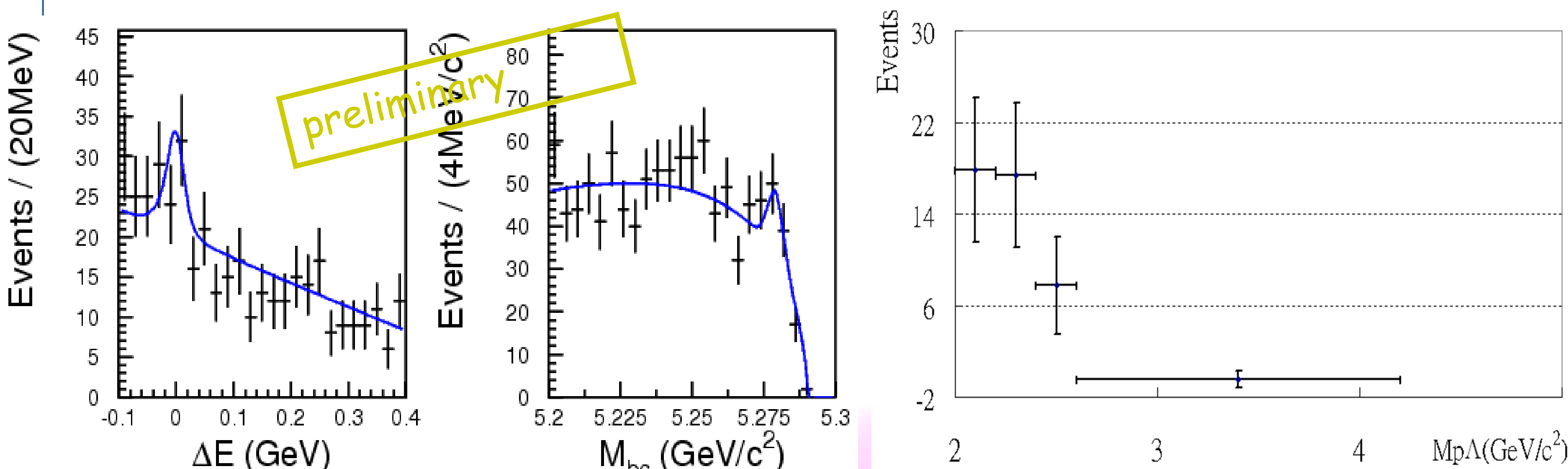
605 $fb^{-1}$




Measured BF = $(14.3 + 3.4 - 3.0 \pm 1.8) \times 10^{-6}$
Significance = 7.7

**Threshold enhancement persists in $b \to c$**

# $B^- \to p\Lambda D^0$, $D^0 \to K^-\pi^+\pi^0$ $605\ fb^{-1}$




Measured Br = (13.47 +4.40 -4.03 ± 1.84 )X$10^{-6}$
Significance = 3.85
Prediction = 11 X $10^{-6}$ Chen, Cheng, Geng&Hsiao, PRD78 (2008)

Combined BF = (14.01 +2.67 -2.40 ± 1.58 )X$10^{-6}$

# Summary

- Baryonic decays: Well established after a few years of B-factory running
- BF(2-body) < BF(3-body)
- Threshold enhancement in the baryon-antibaryon system:

  Puzzle of angular distribution!
- Searching ground for exotic states
- More results will be shown this winter

# Acknowledgement


- Thanks to NSC for strong supports in past years
- Special thanks to the co-1st authors of these published papers: Yen-Jie Lee, Ping-Han Chu, Tze-Ling Kuo, Cheng-Hsun Wu, Jheng-Hao Chen, Jui-Te Wei, Yu-Wei Chang, Poyuan Chen