Measurements of Λ_c Branching Fractions of Cabibbo-Suppressed Decays

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For
Babar Collaboration

(DPF 2004, UC Riverside)

Outline

- Physics motivation
- BABAR detector and data samples
- Analysis method & Λ_c reconstruction
- Branching Fraction Measurements
- Results & Conclusions

Physics Motivations

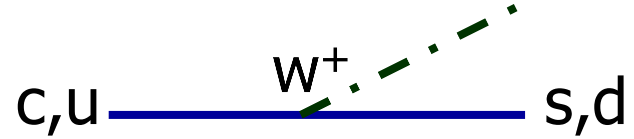
- Until now charm Baryon sector is not well explored for the Cabibbo-suppressed decays.

  High luminosity is needed.

- Singly charm Baryon Λ_c (lowest mass charm Baryon) contains ***cud***.

  (Mass$_{PDG}$: 2284.9MeV/c^2)

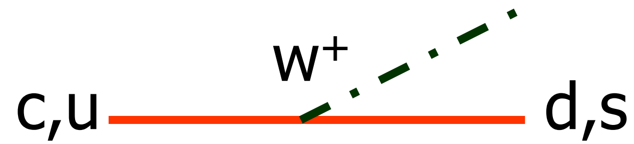
- c quark decays under weak interactions to s or d quark.



$A \propto \cos\theta_c$

$\Gamma \,\alpha\, \cos^2\theta_c$

Cabibbo Favored(C.F.)



$A \propto \sin\theta_c$

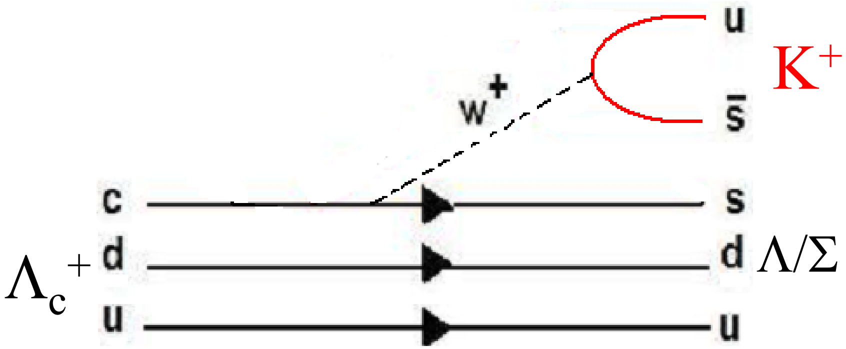
$\Gamma \,\alpha\, \sin^2\theta_c$

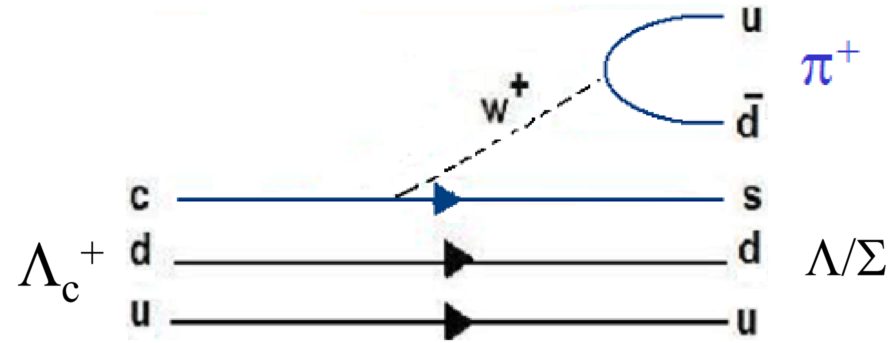
Cabibbo suppressed(C.S)

- $\Gamma_{C.F.} / \Gamma_{C.S.} \approx 1/20$

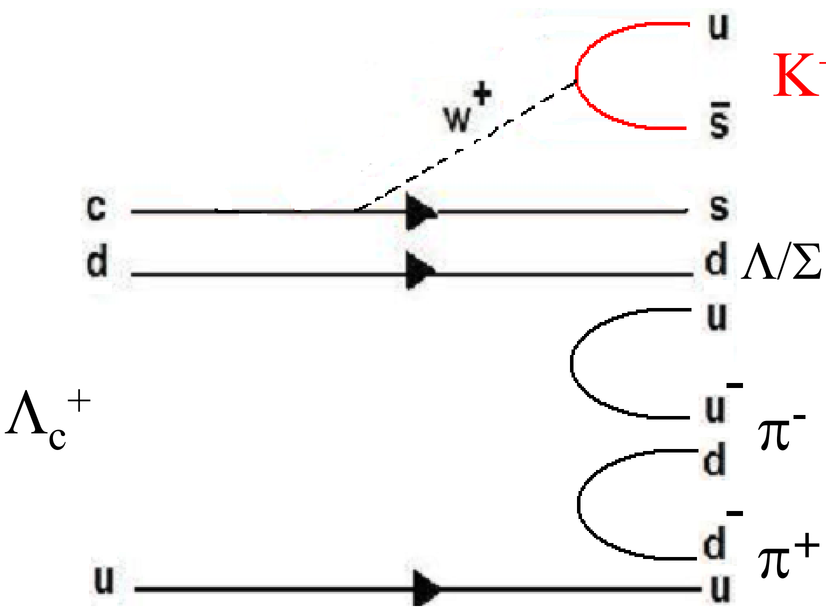
- $\theta_c \cong 0.23$ *(Cabibbo Angle)*

Physics Motivations



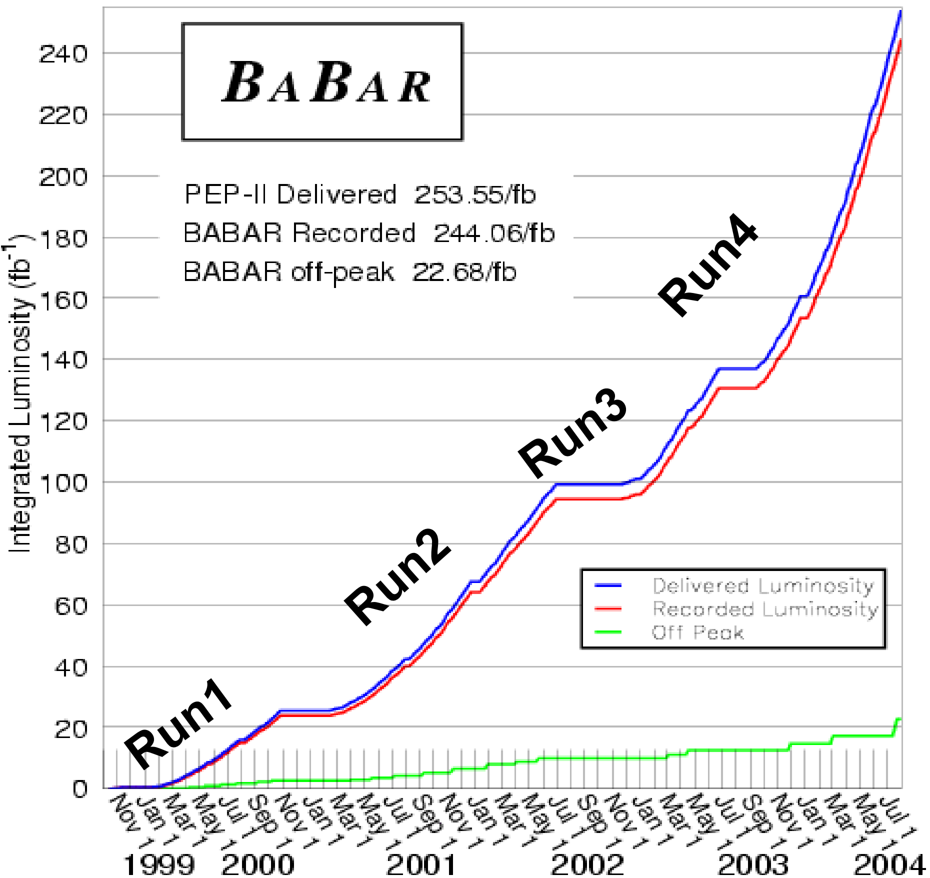


$\frac{B(\Lambda_c^+ \to \Lambda K^+)}{B(\Lambda_c^+ \to \Lambda \pi^+)}$	$0.074 \pm 0.010 \pm 0.012$ PLB524,33(2002) Belle	0.039 -0.056 PRD49,3417(3417) Theory
$\frac{B(\Lambda_c^+ \to \Sigma K^+)}{B(\Lambda_c^+ \to \Sigma \pi^+)}$	$0.056 \pm 0.014 \pm 0.008$ PLB524,33(2002) Belle	0.033 -0.036 PRD49,3417(1994) Theory
$\frac{B(\Lambda_c^+ \to \Lambda K^+ \pi^+ \pi^-)}{B(\Lambda_c^+ \to \Lambda \pi^+)}$	----	----
$\frac{B(\Lambda_c^+ \to \Sigma K^+ \pi^+ \pi^-)}{B(\Lambda_c^+ \to \Sigma \pi^+)}$	----	----



- All are statistically limited
- With a large amount of data from BABAR, we can make precise measurements & search for new decays.

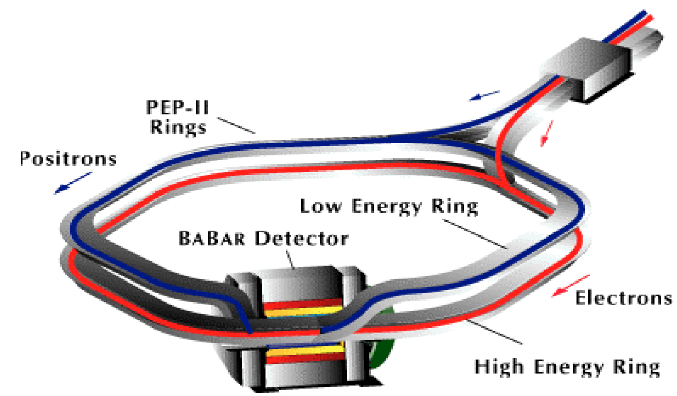
Integrated Luminosity and PEP-II



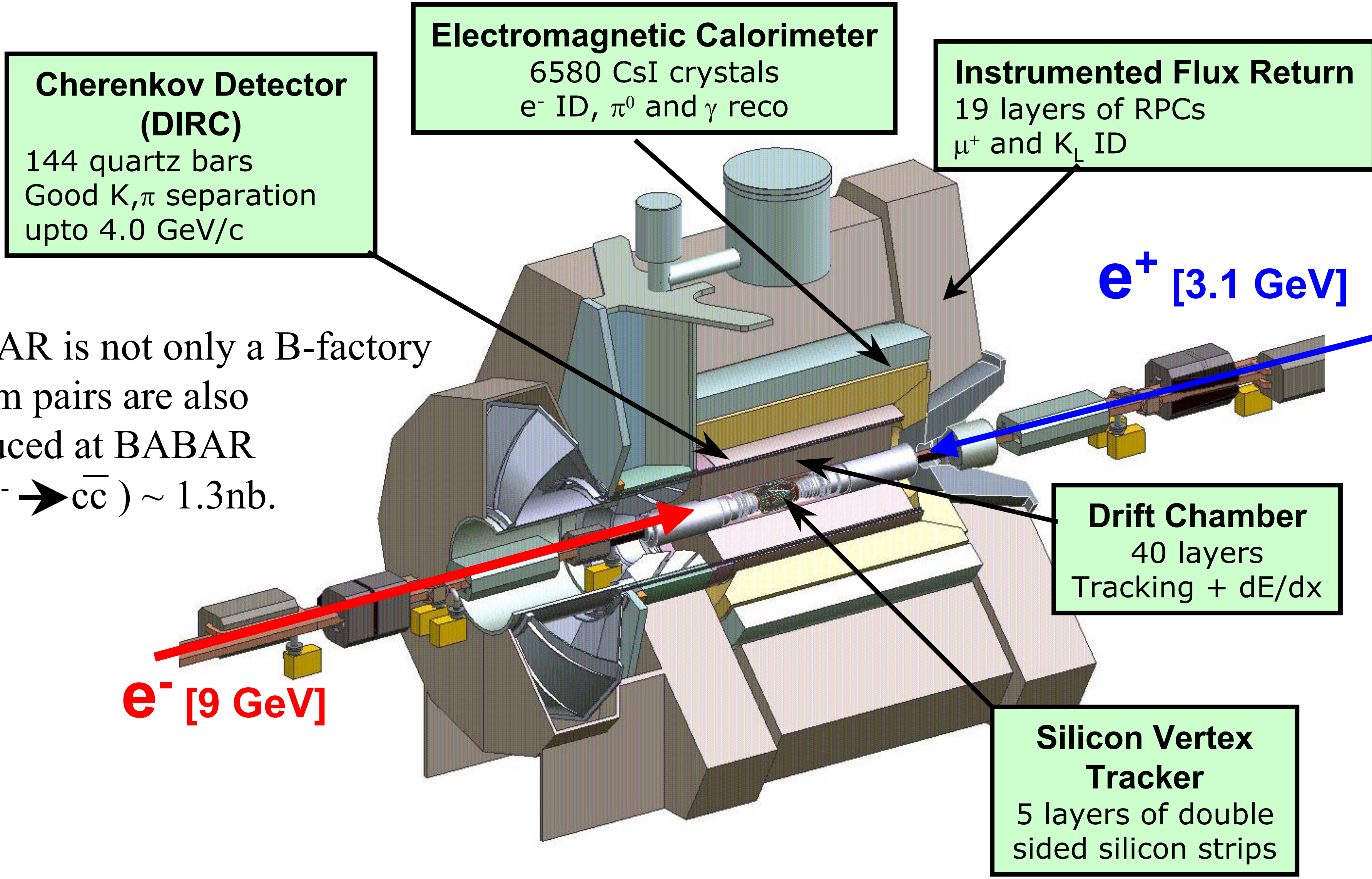
PEP-II top luminosity:
$9.2 \times 10^{33} cm^{-2}s^{-1}$
(more than 3x design goal 3.0×10^{33})

PEP-II delivered 254 fb^{-1}
BaBar recorded 244 fb^{-1}

In this analysis: Run1-3 data: 125 fb^{-1}
On peak at $\Upsilon(4S)$ 112 fb^{-1}
Off peak 13 fb^{-1}
[40 MeV below $\Upsilon(4S)$]



The BaBar detector



BABAR is not only a B-factory
Charm pairs are also produced at BABAR
$\sigma(e^+e^- \rightarrow c\bar{c}) \sim 1.3\text{nb}$.

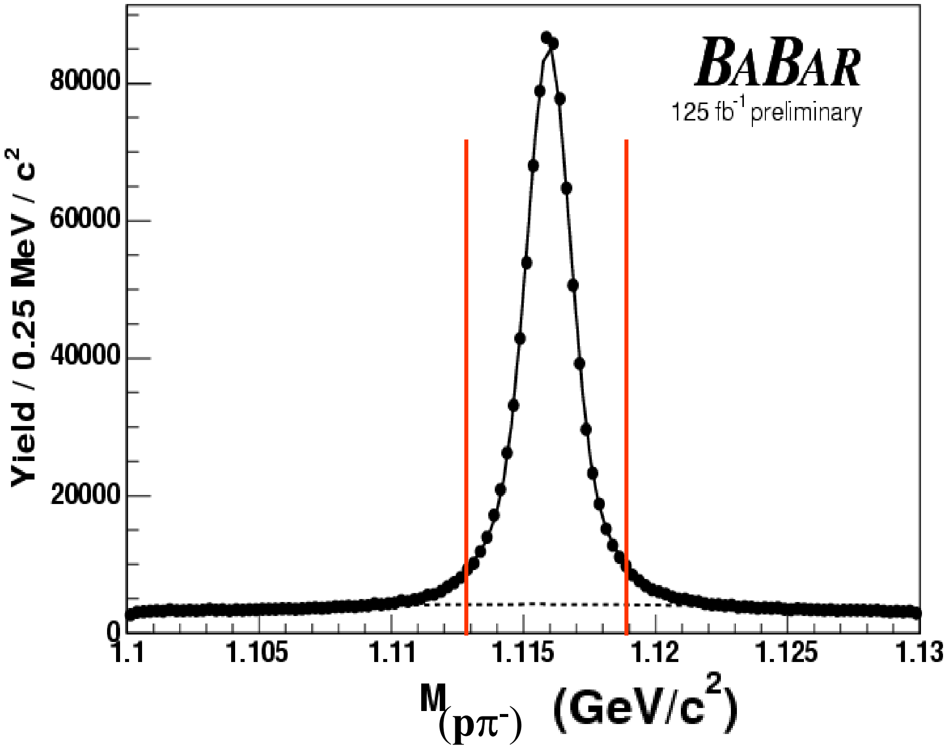
Analysis Method

❑ Λ Reconstruction

- ❑ $\Lambda \longrightarrow p\,\pi^-$ (64 %)
- ❑ **Require a common vertex**

  $P\left(\chi^2_{\Lambda_{Veretex}}\right) > 0.1\ \%$
- ❑ **Flight cut (3d) > 0.2 cm**
- ❑ **Mean:1115.90 ± 0.01 (stat.) MeV/c²**

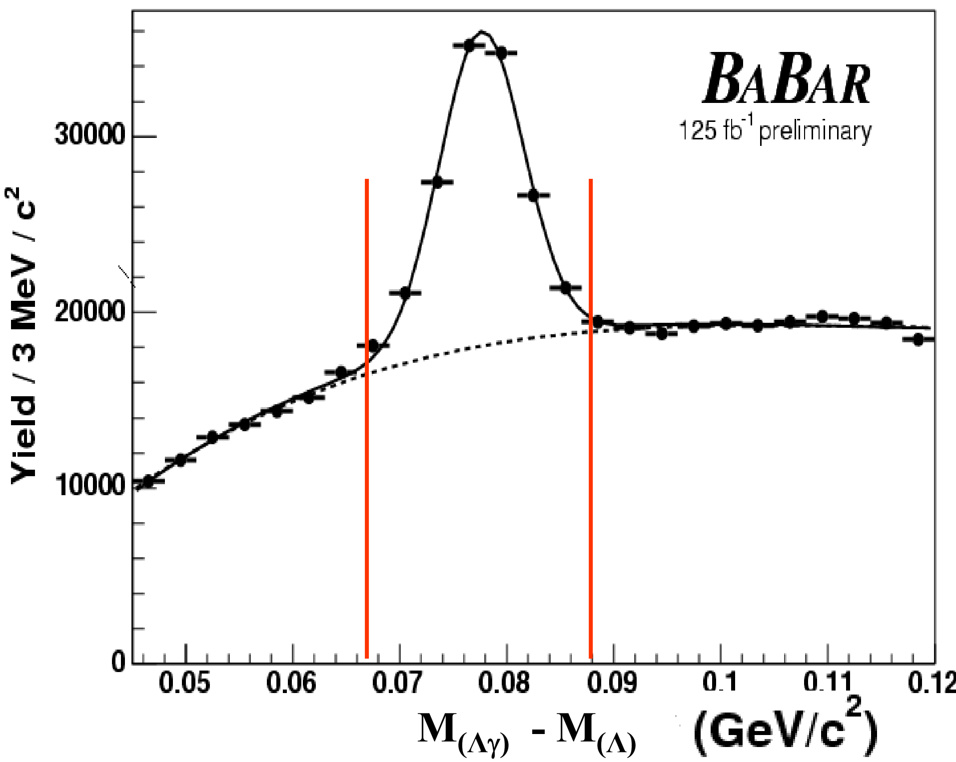
  σ_{RMS} : 1.50 ± 0.01 (stat.) MeV/c²
- ❑ **Yield : 845300 ± 1286 (stat.)**
- ❑ **Λ Mass window: ± 3 MeV/c²**



Analysis Method

- Σ Reconstruction
  - $\Sigma \longrightarrow \Lambda\gamma$ (100 %)
  - Use same reconstructed Λ
  - Photon with E_γ > 100 MeV
  - Mean: 77.64 ± 0.04 (stat.) MeV/c^2

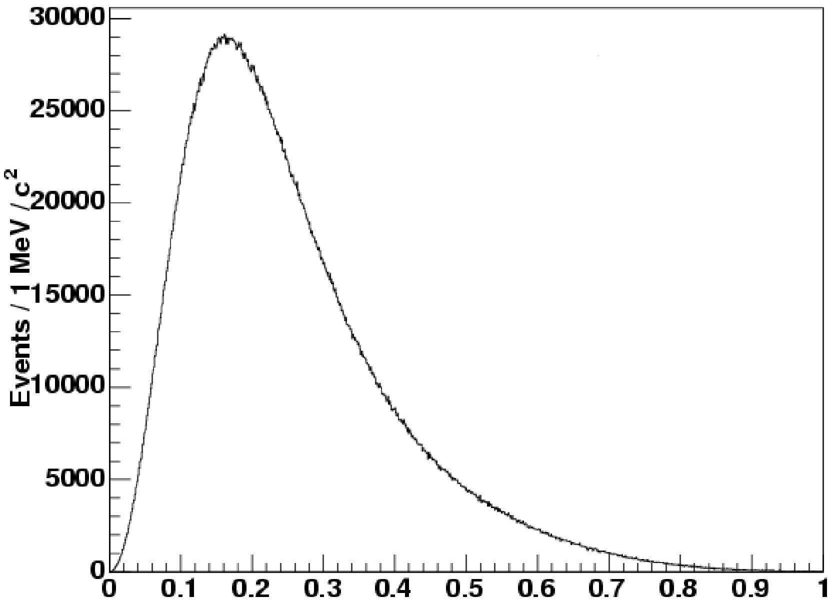
    σ_{RMS} : 4.0 ± 0.4 (stat.) MeV/c^2
  - Yield : 58070 ± 159 (stat.)
  - $(\Sigma - \Lambda)$ Mass window: ± 10.0 MeV/c^2



Analysis Method

❑ Λ_c^+ Reconstruction

- ❑ $\Lambda_c^+ \longrightarrow \Lambda(K^+ / K^+\pi^+\pi^- / \pi^+)$
- ❑ $\Lambda_c^+ \longrightarrow \Sigma\,(K^+ / K^+\pi^+\pi^- / \pi^+)$



(x_p For $\Lambda_c^+ \longrightarrow \Lambda\,\pi^+$)

❑ Background Suppression:

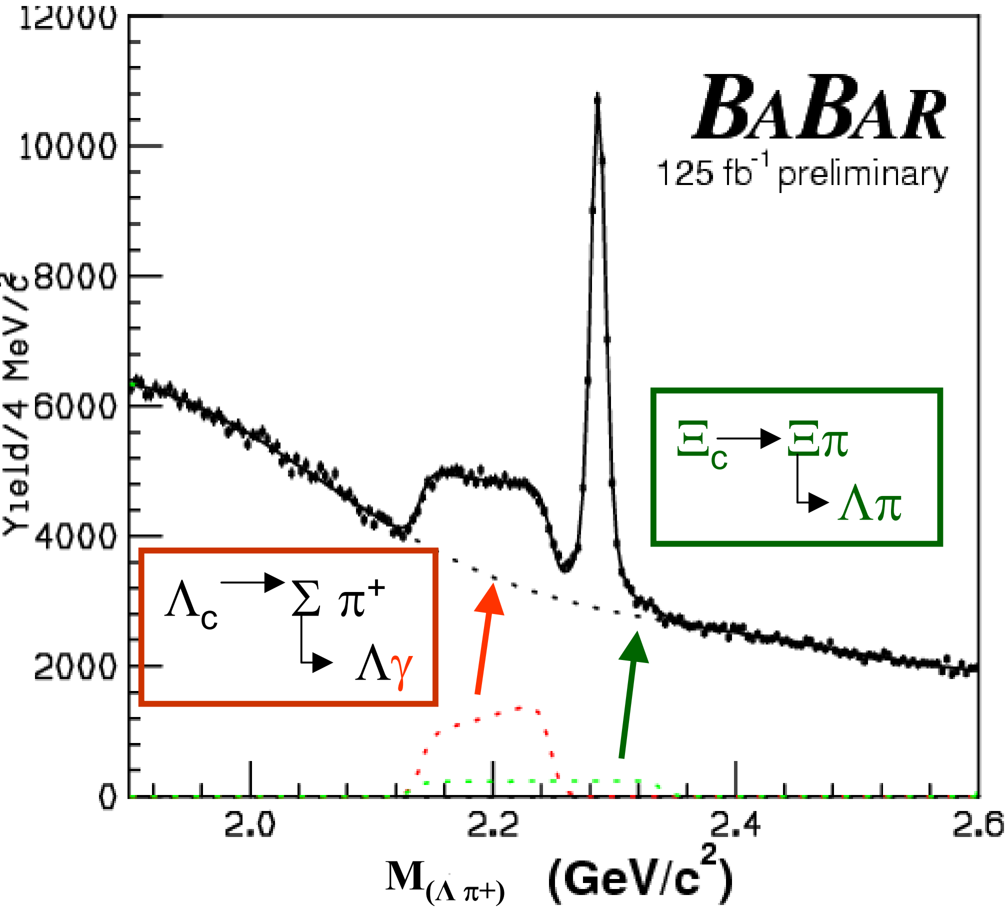
- ❑ Combinatorial + $B\bar{B}$

$$\boxed{x_p = p^* / \sqrt{(s/4 - M_{\Lambda_c}^2)} > 0.5}$$

- ❑ $\sqrt{s}$:Total center of mass Energy
- ❑ p^* : C.o.M Momentum of reconstructed Λ_c^+

$\Lambda^+_c \rightarrow \Lambda \pi^+$

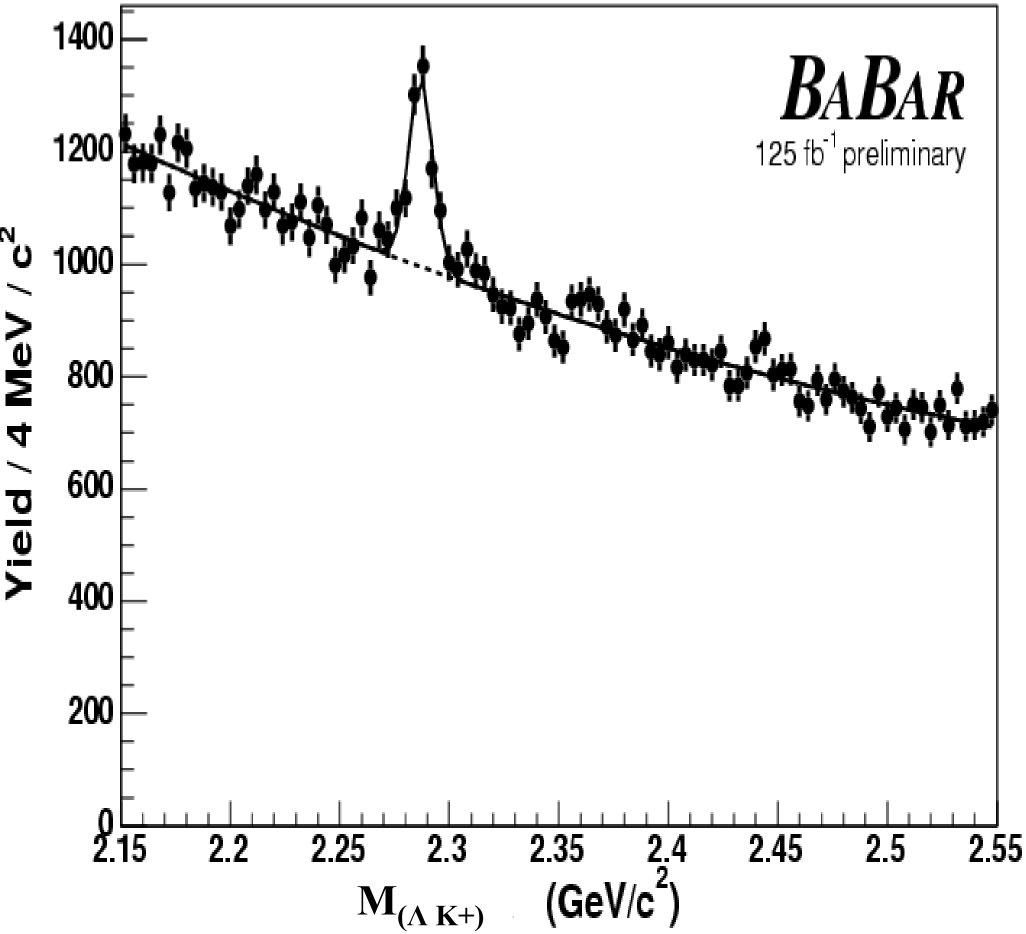
$x_p > 0.5$



- $\varepsilon = 31.4 \pm 0.3$ (stat.) %
- $N_{signal} = 33594 \pm 367$ (stat.)
- Mean $= 2286.6 \pm 0.1$ (stat.) MeV/c^2
- $\sigma_{RMS} = 8.0 \pm 0.3$ (stat.) MeV/c^2

$\Lambda^+_c \to \Lambda K^+$

$x_p > 0.5$



- $\varepsilon = 25.0 \pm 0.2$ **(stat.) %**
- $N_{signal} = 1164.0 \pm 106.5$ **(stat.)**
- **Mean** $= 2287 \pm 1.0$ **(stat.) MeV/c²**
- $\sigma = 5.5 \pm 0.7$ **(stat.) MeV/c²**

Measurement of $\Lambda_c^+ \rightarrow \Lambda K^+$

$N_{\Lambda\pi^+}$ = 33594 ±367(stat.)

$N_{\Lambda K^+}$ = 1164 ± 106.5 (stat.)

$\Big\} \; x_p > 0.5$

$$\langle \varepsilon_{K/\pi} \rangle = \frac{\varepsilon\left(\Lambda_c^+ \to \Lambda K^+\right)}{\varepsilon\left(\Lambda_c^+ \to \Lambda \pi^+\right)} = 0.781 \pm 0.004 \text{ (stat.)}$$

$$\frac{B\left(\Lambda_c^+ \to \Lambda K^+\right)}{B\left(\Lambda_c^+ \to \Lambda \pi^+\right)} = \left(1/\langle \varepsilon_{K/\pi} \rangle\right) * \left(N_{\Lambda K^+} / N_{\Lambda\pi^+}\right)$$

$= 0.044 \pm 0.004$ **(stat.)** $\pm\, 0.002$ **(syst.)** (BABAR preliminary)

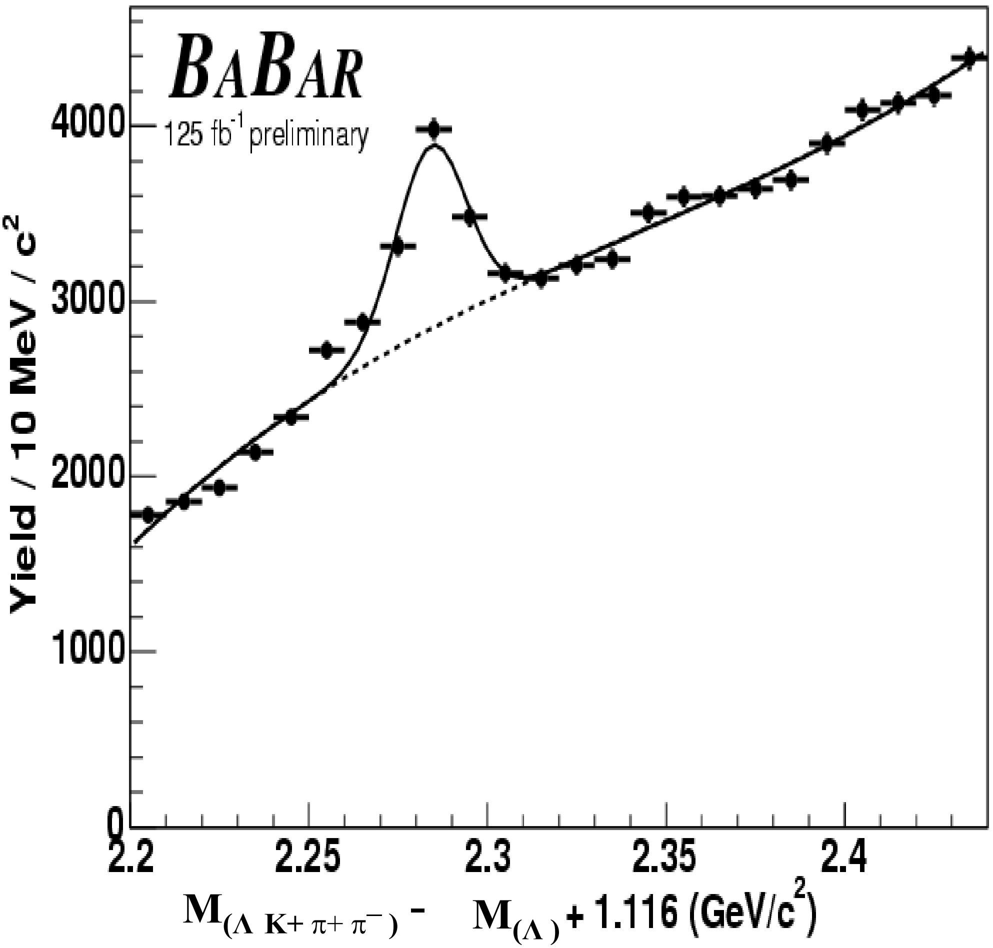
$= 0.074 \pm 0.010 \pm 0.012$ (Belle) ; **0.039 - 0.056** (Theory Predicts)

PLB524, 33(2002)

PRD 49, 3417(1994)

$\Lambda^+_c \rightarrow \Lambda K^+ \pi^+ \pi^-$

$x_p > 0.6$



- **ε = 15.8 $\pm$ 0.2 (stat.) %**
- **N_{signal} = 2591 $\pm$ 258 (stat.)**
- **Mean = 2284 $\pm$ 1.0 (stat.) MeV/c^2**
- **σ = 9.9 $\pm$ 1.0 (stat.) MeV/c^2**

Measurement of $\Lambda_c^+ \rightarrow \Lambda K^+ \pi^+ \pi^-$

$N_{\Lambda\pi^+}$ = 22173 ±287(stat.)

$N_{\Lambda K^+\pi^+\pi^-}$ = 2591 ± 258 (stat.)

$x_p > 0.6$

$$\langle \varepsilon_{K\pi\pi/\pi} \rangle = \frac{\varepsilon(\Lambda_c^+ \rightarrow \Lambda K^+ \pi^+ \pi^-)}{\varepsilon(\Lambda_c^+ \rightarrow \Lambda \pi^+)} = 0.442 \pm 0.004 \text{ (stat.)}$$

$$\frac{B(\Lambda_c^+ \rightarrow \Lambda K^+ \pi^+ \pi^-)}{B(\Lambda_c^+ \rightarrow \Lambda \pi^+)} = (1/\langle \varepsilon_{K\pi\pi/\pi} \rangle) * (N_{\Lambda K^+\pi^+\pi^-}/N_{\Lambda\pi^+})$$

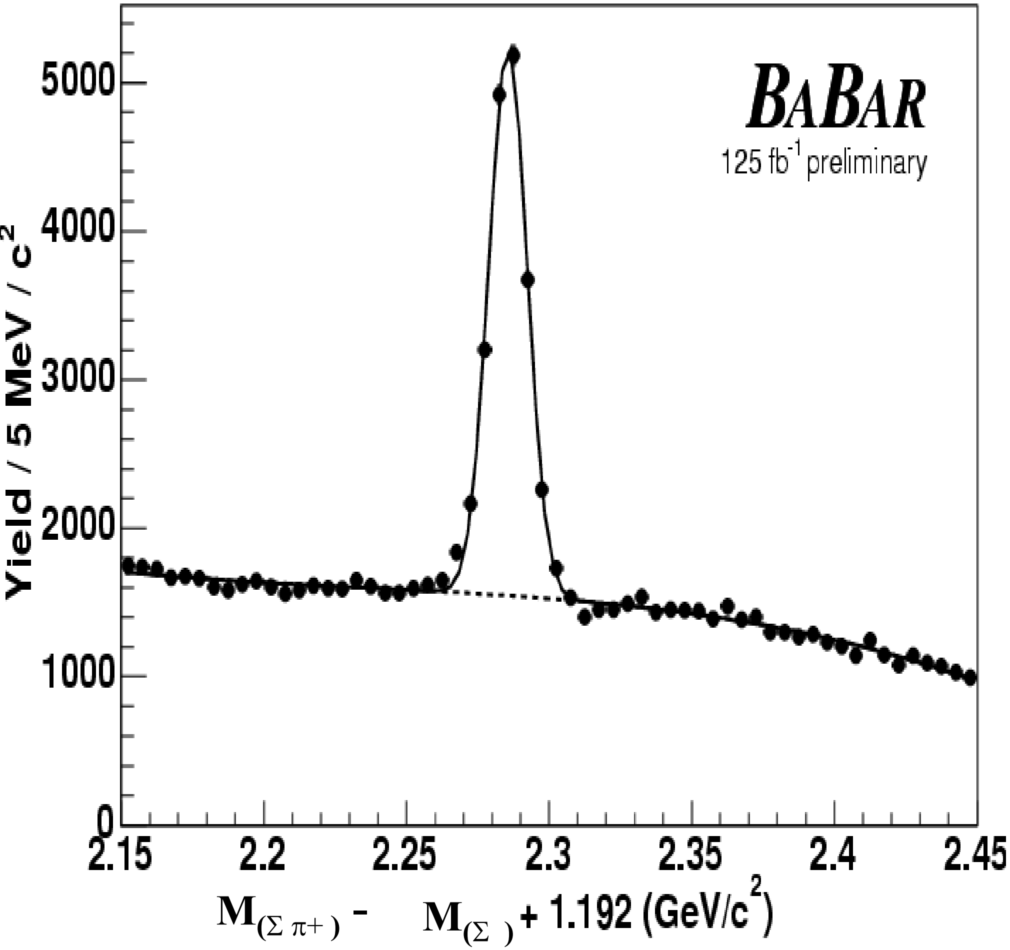
$= 0.266 \pm 0.027$**(stat.)** $\pm\ 0.032$**(syst.)**

(First Measurement)

(BABAR preliminary)

(No Theoretical Prediction)

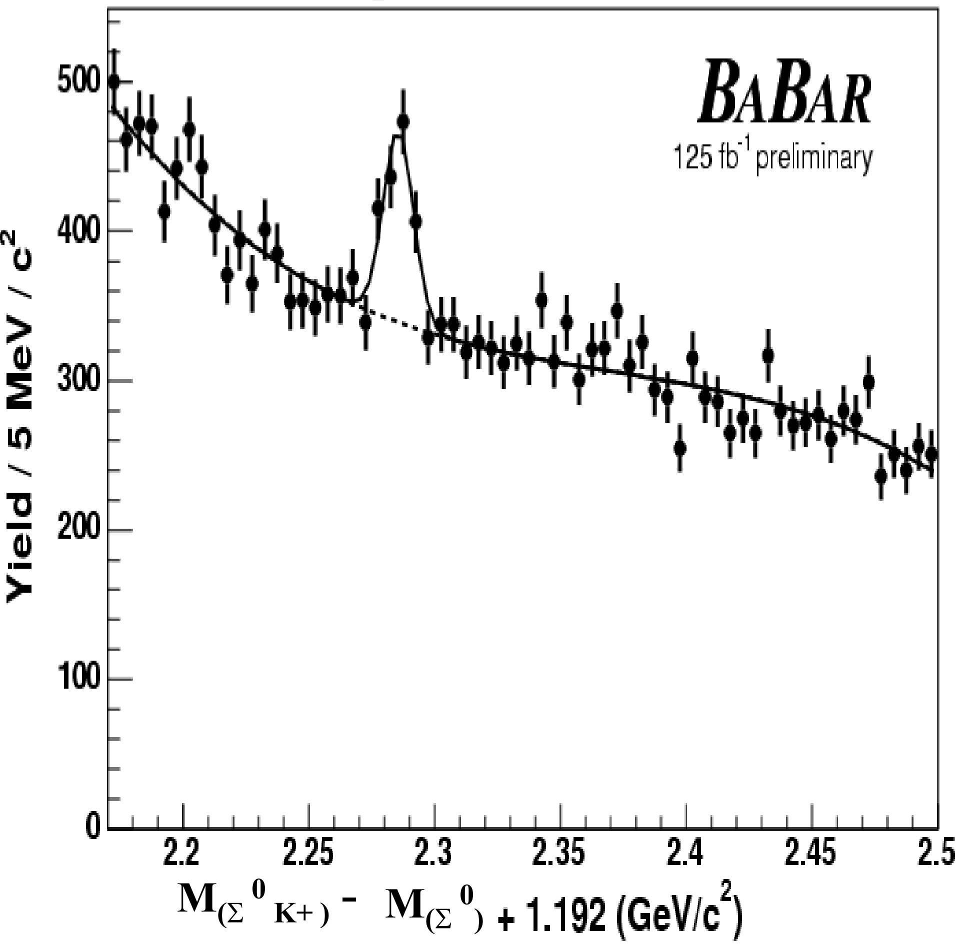
$\Lambda_c^+ \rightarrow \Sigma \pi^+$



- ε = 11.9 ± 0.1 (stat.) %
- N_{signal} = 12450 ± 171 (stat.)
- Mean = 2286.0 ± 0.1 (stat.) MeV/c^2
- σ = 6.7 ± 0.1 (stat.) MeV/c^2

$\Lambda_c^+ \longrightarrow \Sigma K^+$

$x_p > 0.5$



- **ε = 9.5 ± 0.1 (stat.) %**
- **N_{signal} = 387 ± 45 (stat.)**
- **Mean = 2286.0 ± 1.0 (stat.) MeV/c^2**
- **σ = 6.0 MeV/c^2 (Fixed to MC Value)**

Measurement of $\Lambda_c^+ \rightarrow \Sigma K^+$

$N_{\Sigma\pi}^+ = 12450 \pm 171(\text{stat.})$

$N_{\Sigma K}^+ = 387 \pm 45 \quad (\text{stat.})$

$x_p > 0.5$

$$\langle \varepsilon_{K/\pi} \rangle = \frac{\varepsilon(\Lambda_c^+ \rightarrow \Sigma K^+)}{\varepsilon(\Lambda_c^+ \rightarrow \Sigma \pi^+)} = 0.780 \pm 0.001(\text{stat.})$$

$$\frac{B(\Lambda_c^+ \rightarrow \Sigma K^+)}{B(\Lambda_c^+ \rightarrow \Sigma \pi^+)} = (1/\langle\varepsilon_{K/\pi}\rangle) * (N_{\Sigma K}^+ / N_{\Sigma\pi}^+)$$

$= 0.040 \pm 0.005$ **(stat.)** ± 0.004 **(syst.)** (BABAR preliminary)

$= 0.056 \pm 0.014 \pm 0.008$; 0.033 - 0.036

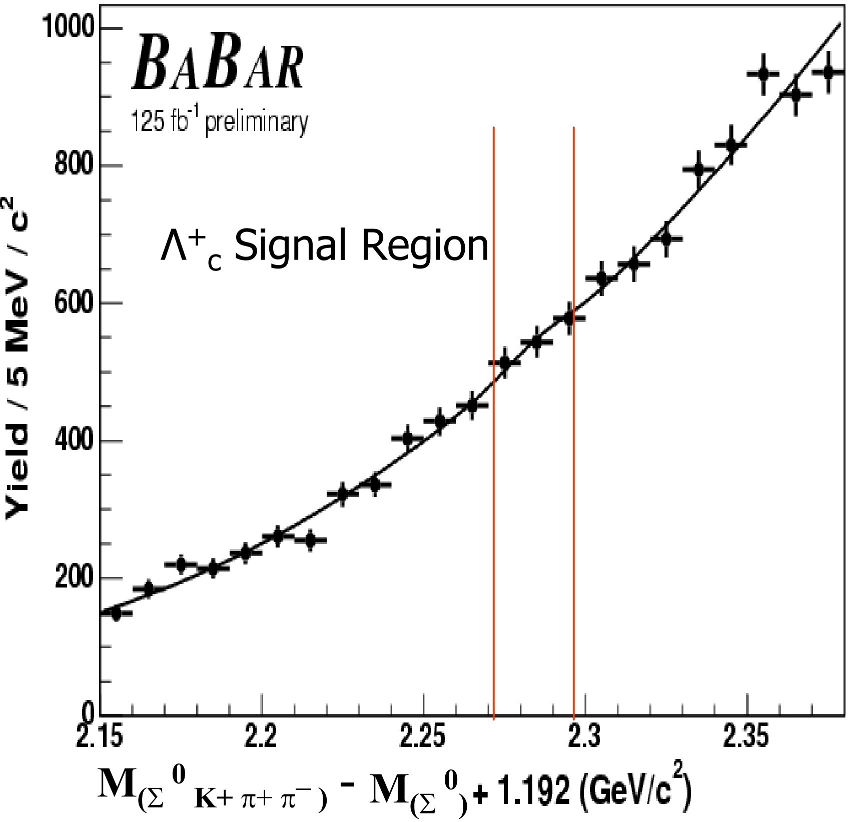
(Belle) (Theory Predicts)

PLB524, 33(2002) **PRD 49, 3417(1994)**

Search for $\Lambda^+_c \longrightarrow \Sigma^0 K^+ \pi^+ \pi^-$

ε = 5.4 $\pm$ 0.1 (stat.) %

N_{signal} = 41$\pm$ 51 (stat.)
σ = 10.0 MeV/c^2
Mean = 2285 MeV/c^2



$$\left.\begin{array}{l} N_{\Sigma\pi^+} = 8785 \pm 131 \text{ (stat.)} \\ N_{\Sigma K^+ \pi^+ \pi^-} = 41 \pm 51 \text{ (stat.)} \end{array}\right\} x_p > 0.6$$

$$\frac{\varepsilon(\Lambda_c^+ \to \Sigma\ K^+ \pi^+ \pi^-)}{\varepsilon(\Lambda_c^+ \to \Sigma\ \pi^+)} = 0.390 \pm 0.002 \text{(stat.)}$$

$$\frac{\mathrm{B}(\Lambda_c^+ \to \Sigma\ K^+ \pi^+ \pi^-)}{\mathrm{B}(\Lambda_c^+ \to \Sigma\ \pi^+)}$$

< 3.9×10^{-2} @ 90% CL
(Upper Limit)
(First time search)

(Using Feldmans and Cousins Method)

Puzzle: why so suppressed ?

Conclusions

- We report on the measurements of the Cabibbo-suppressed decays :

$$\frac{B\left(\Lambda_c^+ \rightarrow \Lambda K^+\right)}{B\left(\Lambda_c^+ \rightarrow \Lambda \pi^+\right)} = 0.044 \pm 0.004(\text{stat.}) \pm 0.002(\text{syst.})$$

$$\frac{B\left(\Lambda_c^+ \rightarrow \Sigma\ K^+\right)}{B\left(\Lambda_c^+ \rightarrow \Sigma\ \pi^+\right)} = 0.040 \pm 0.005(\text{stat.}) \pm 0.004\ (\text{syst.})$$

  with improved accuracy.

- We also report the First Observation of the Cabibbo-suppressed mode:

$$\frac{\mathrm{B}(\Lambda_c^+ \rightarrow \Lambda\ K^+ \pi^+ \pi^-)}{\mathrm{B}(\Lambda_c^+ \rightarrow \Lambda\ \pi^+)} = 0.266 \pm 0.027(\text{stat.}) \pm 0.032(\text{syst.})$$

Conclusions

- We set an upper Limit at 90% CL on:

$$\frac{B(\Lambda_c^+ \to \Sigma \;\; K^+ \pi^+ \pi^-)}{B(\Lambda_c^+ \to \Sigma \;\; \pi^+)} < 3.9 \times 10^{-2} \text{ @ } 90\% \text{ CL}$$

(**First Limit**)

- **These results have been reported in ICHEP 2004, Beijing.**
- **hep-ex/0408024**

BACK UP SLIDES

Measurement of $\Lambda^+_c \rightarrow \Lambda K^+$

Source of Systematic Error	
MC Stat.	1.1 %
Λ Mass Cut	0.6 %
$P_{\chi}{}^2$ Λ Vertex Cut	1.1 %
Λ Flight Cut(r)	0.2 %
X_p Cut	1.1 %
Fitting	5.1 %
Total Syste. Error	5.5 %

$$\left.\begin{aligned} N_{\Lambda\pi^+} &= 33594 \pm 367 \text{ (stat.)} \\ N_{\Lambda K^+} &= 1164 \pm 106.5 \text{ (stat.)} \end{aligned}\right\} x_p > 0.5$$

$<\varepsilon_{K/\pi}> = 0.78$(relative efficiency)

$$\frac{B(\Lambda_c^+ \to \Lambda K^+)}{B(\Lambda_c^+ \to \Lambda \pi^+)} = (1/<\varepsilon_{K/\pi}>) * (N_{\Lambda K^+} / N_{\Lambda\pi^+})$$

$= 0.044 \pm 0.004_{\text{(stat.)}} \pm 0.002_{\text{(syst.)}}$

(Our Measurement)

$= 0.074 \pm 0.010 \pm 0.012$

(Belle Measured)

$= 0.039 - 0.056$ PRD 49, 3417(1994)

(Theory Predicts)

Measurement of $\Lambda_c^+ \rightarrow \Lambda K^+ \pi^+ \pi^-$

Sources of Systematic Error	
MC Stat.	1.6 %
Λ Mass Cut	0.3 %
P_{χ^2} Λ Vertex Cut	0.7 %
Λ Flight Cut(r)	1.2 %
X_p Cut	1.6 %
Fitting	10.1 %
MC Modeling	5.4 %
Tracking	2.8 %
Total Syste. Error	12.1 %

$$\left.\begin{array}{l} N_{\Lambda\pi^+} = 22173 \pm 287 \text{ (stat.)} \\ N_{\Lambda K^+\pi^+\pi^-} = 2591 \pm 258 \text{ (stat.)} \end{array}\right\} x_p > 0.6$$

$\langle \varepsilon_{K\pi\pi/\pi} \rangle = 0.44$(relative efficiency)

$$\frac{B(\Lambda_c^+ \rightarrow \Lambda\ K^+\pi^+\pi^-)}{B(\Lambda_c^+ \rightarrow \Lambda\ \pi^+)}$$

$$= (1/\langle \varepsilon_{K\pi\pi/\pi} \rangle) * (N_{\Lambda K^+\pi^+\pi^-}/N_{\Lambda\pi^+})$$

$$= 0.266 \pm 0.027_{\text{(stat.)}} \pm 0.032_{\text{(syst.)}}$$

(First Measurement)

(No theoretical Prediction)

Measurement of $\Lambda_c^+ \to \Sigma K^+$

Sources of Systematic Error	
MC Stat.	1.8 %
Λ Mass Cut	0.8 %
P_{χ}^{2} Λ Vertex Cut	1.3 %
Λ Flight Cut(r)	1.8 %
$M_{\Sigma\text{-}\Lambda}$ Cut	1.6 %
X_p Cut	1.5 %
E_γ Cut	2.8 %
Fitting	8.0 %
Total Syste. Error	9.2 %

$$\left.\begin{array}{ll} N_{\Sigma\pi}^{+} & = 12450 \pm 171 \text{ (stat.)} \\ N_{\Sigma K}^{+} & = 387 \pm 45 \text{ (stat.)} \end{array}\right\} x_p > 0.5$$

$\langle \varepsilon_{K/\pi} \rangle$ = 0.78(relative efficiency)

$$\frac{B(\Lambda_c^+ \to \Sigma\ K^+)}{B(\Lambda_c^+ \to \Sigma\ \pi^+)} = 1/\langle \varepsilon_{K/\pi} \rangle) * (N_{\Sigma K}^{+} / N_{\Sigma\pi}^{+})$$

$= 0.040 \pm 0.005_{\text{(stat.)}} \pm 0.004\ _{\text{(syst.)}}$

(*BABAR* **priliminary**)

$= 0.056 \pm 0.014 \pm 0.008$

(Belle)

=0.033 - 0.036 PRD 49, 3417(1994)

(Theory Predicts)

$\Lambda_c^+ \rightarrow \Lambda\,\pi^+$

Belle : **hep-ex/0108003**

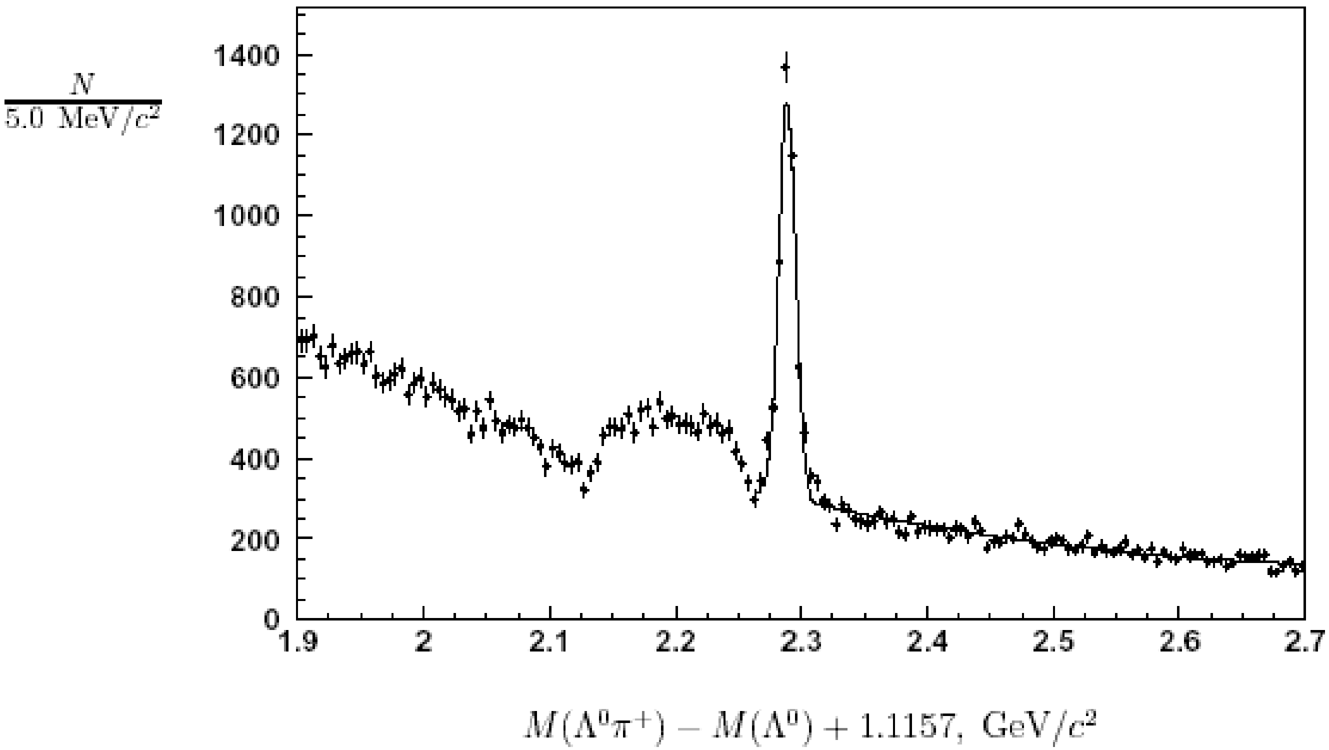


FIG. 2. The invariant mass spectrum for the normalization mode $\Lambda_c^+ \to \Lambda^0\pi^+$. The selection requirements and fit are described in the text. The broad feature below the Λ_c^+ mass is due to $\Lambda_c^+ \to \Sigma^0\pi^+$ decays.