Λ_c decays and its CPV

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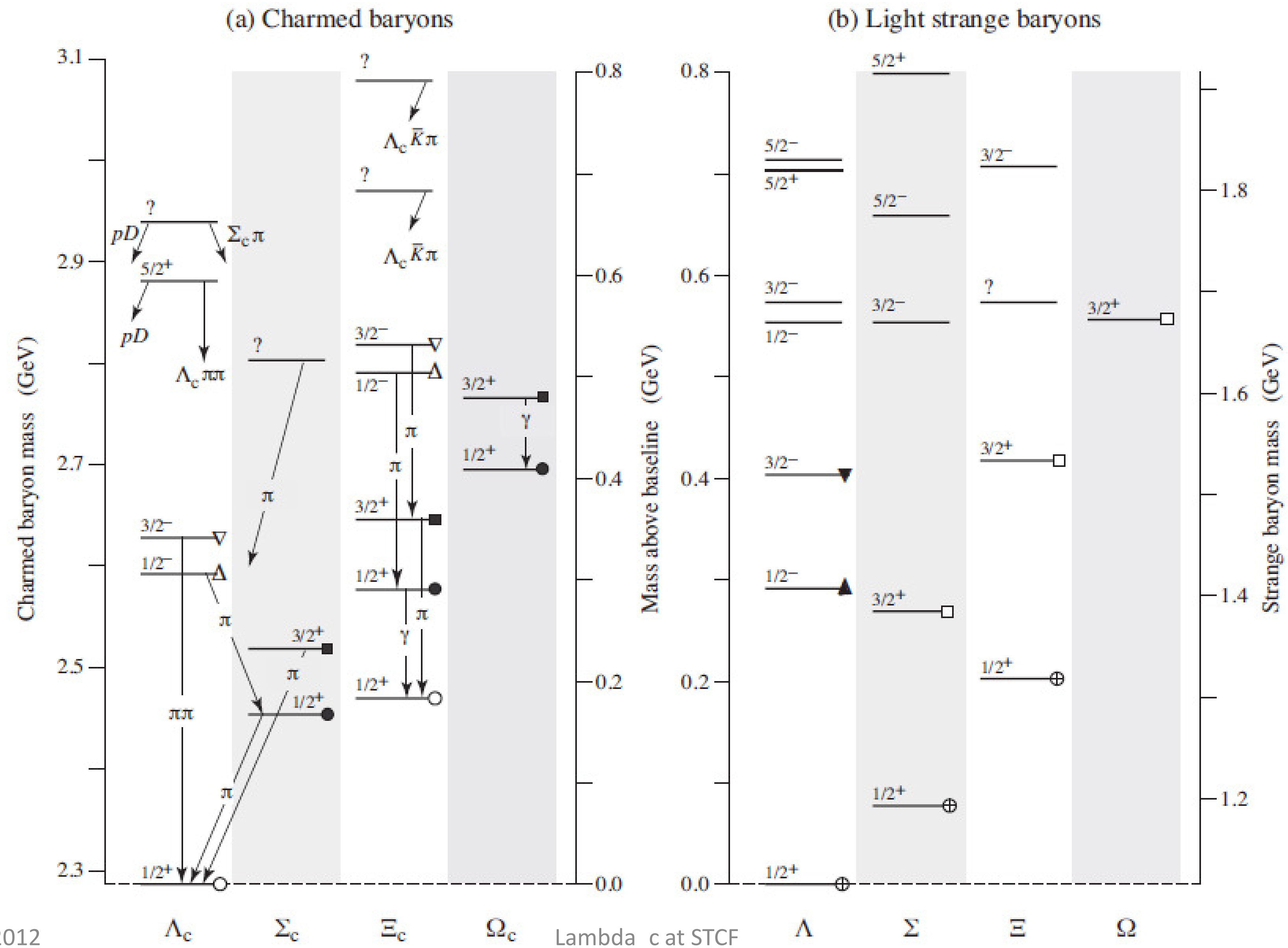
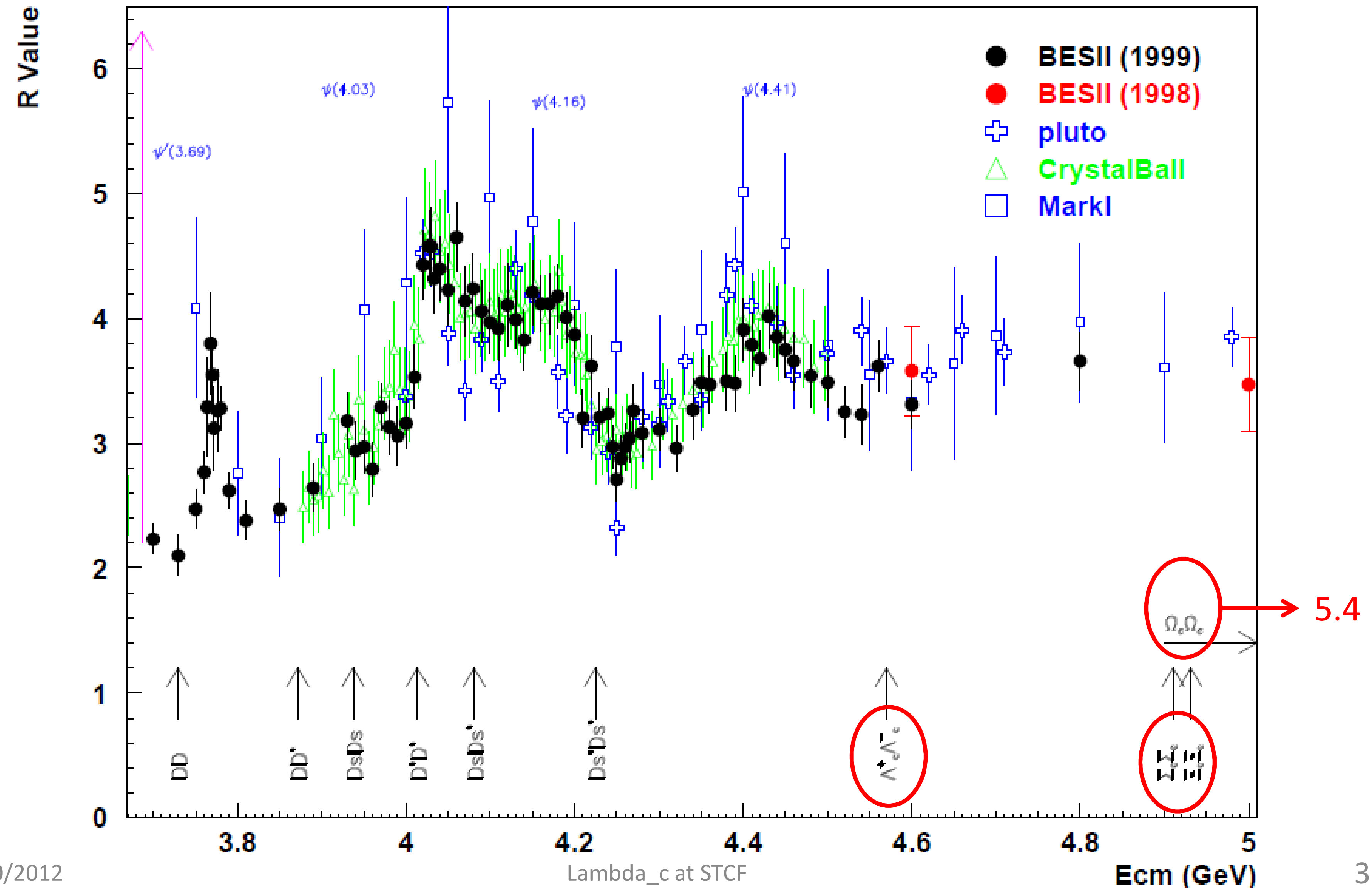
Charm baryon vs. strange baryon



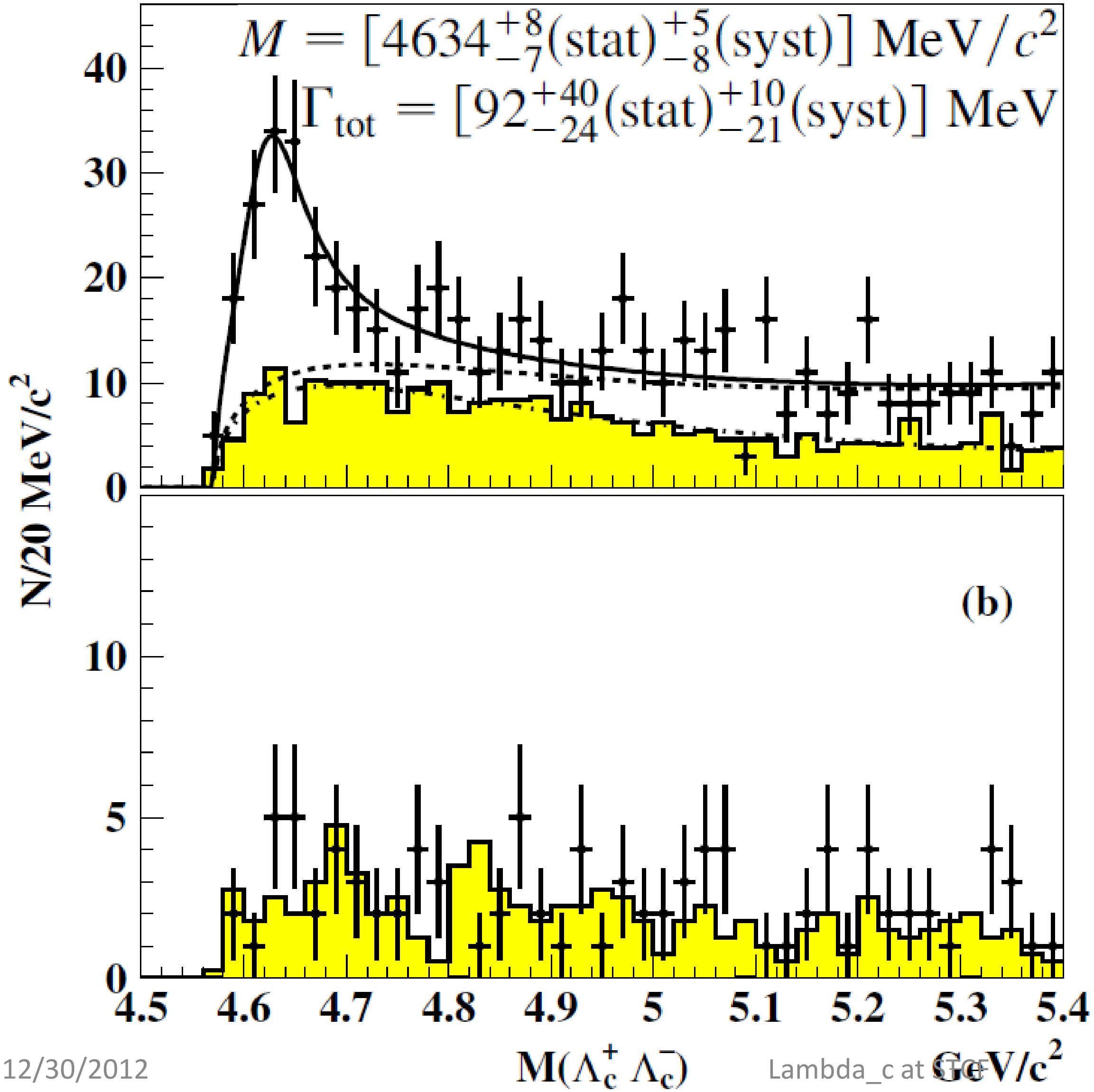
Charmed baryon thresholds around 4.6 – 5.5 GeV



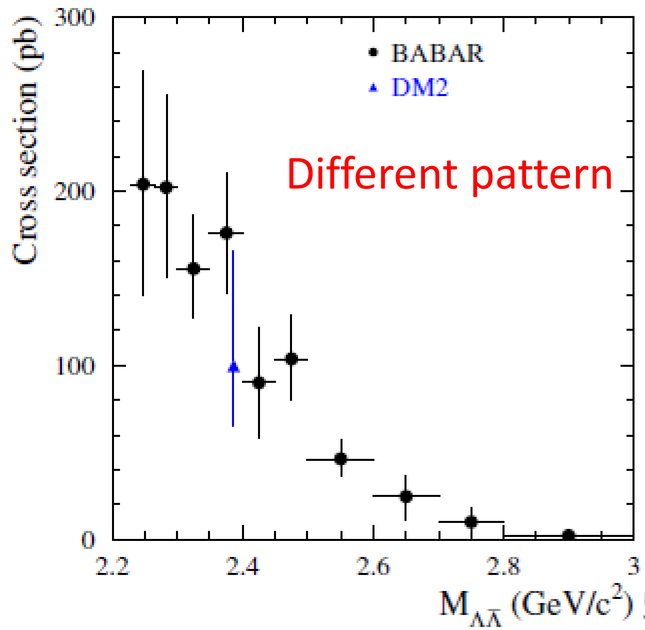
Λ_c^+ branching fractions

- Most Λ_c^+ branching fractions are measured relative to $B(\Lambda_c^+ \to pK^-\pi^+)$, which itself is not a model-independent measurement:
  - $(4.14\pm0.91)\%$ from $B(B \to \Lambda_c^+ X)\cdot B(\Lambda_c^+ \to pK^-\pi^+)$;
  - $(7.3\pm1.4)\%\cdot fF$ from $B(\Lambda_c^+ \to pK^-\pi^+)/B(\Lambda_c^+ \to \Lambda l^+\nu_l)$;
  - PDG average $(5.0\pm1.3)\%$;
  - Same result from CLEO $e^+e^- \to DpX$, $X = \Lambda_c^+ + \ldots$;
- Any change in $B(\Lambda_c^+ \to pK^-\pi^+)$ will affect most of the Λ_c^+ decay width;
- An absolute measurement is absolutely needed.

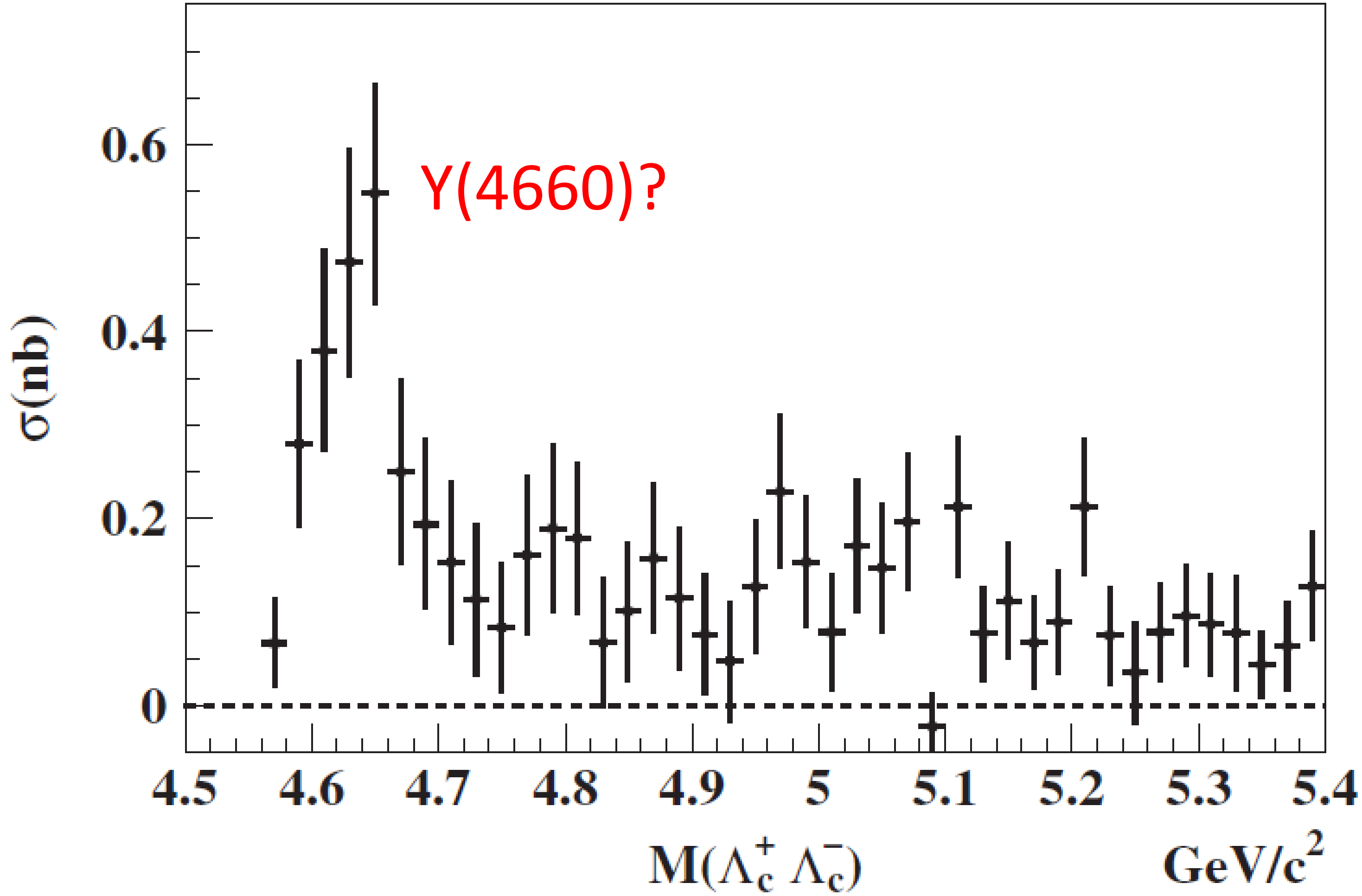
$e^+e^- \to \Lambda_c^+\Lambda_c^-$ from ISR (Belle)



- 695 fb^{-1} data
- 8.2σ
- PRL 101, 172001 (2008)



Cross section for $e^+e^- \to \Lambda_c^+\Lambda_c^-$



$$\sigma(e^+e^- \to X(4630)) \times \mathcal{B}(X(4630) \to \Lambda_c^+\Lambda_c^-)$$

$$= [0.47^{+0.11}_{-0.10}(\text{stat})^{+0.05}_{-0.08}(\text{syst}) \pm 0.19(\text{syst})]\ \text{nb}$$

Scan around 4.60GeV

1600 pb^{-1} @ 9 energy points ($3*10^{32}\ cm^{-2}s^{-1}$)

4.55	4.60	4.61	4.62	4.63	4.64	4.65	4.70	4.75	GeV
50	270	350	420	470	420	360	180	100	pb
300,	200,	150,	100,	100,	100,	150,	200,	300	pb^{-1}

Λ^+_c can be fully reconstructed and antiproton are used
As tag to suppress backgrounds.

First absolute measurements of Λc decays may be available at BES-III.

(Haibo's slide in 2009)

But unfortunately BEPCII does not have the energy reach.

Λ_c Decays

- Λ_c^+ decays through weak interaction only, poorly measured precision 30~40%;
- Normalization mode $\Lambda_c^+ \to pK^-\pi^+$, (5.0±1.3)%;
- Hadronic modes: $\Lambda_c^+\to\Lambda\pi^+$, $\Sigma^+\pi^0$, …, to measure decay asymmetry parameters;
- Semileptonic modes: $\Lambda_c^+\to\Lambda e^+\nu_e$, $\Lambda e^+\nu_e$;
- Search for rare decays:
  - radiative $\Lambda_c^+\to\Sigma^+\gamma$, predicted rate 10^{-4};
  - FCNC $\Lambda_c^+\to pl^+l^-$, 10^{-5}~10^{-6};
  - LFV $\Lambda_c^+\to pe\mu$, 10^{-5}~10^{-6};
  - ……

Single tag efficiencies of Λ_c^+

- Produced in pairs: $e^+e^- \to \Lambda_c^+\Lambda_c^-$;
- 15 singly tagging modes give an overall efficiency of 4.89%.

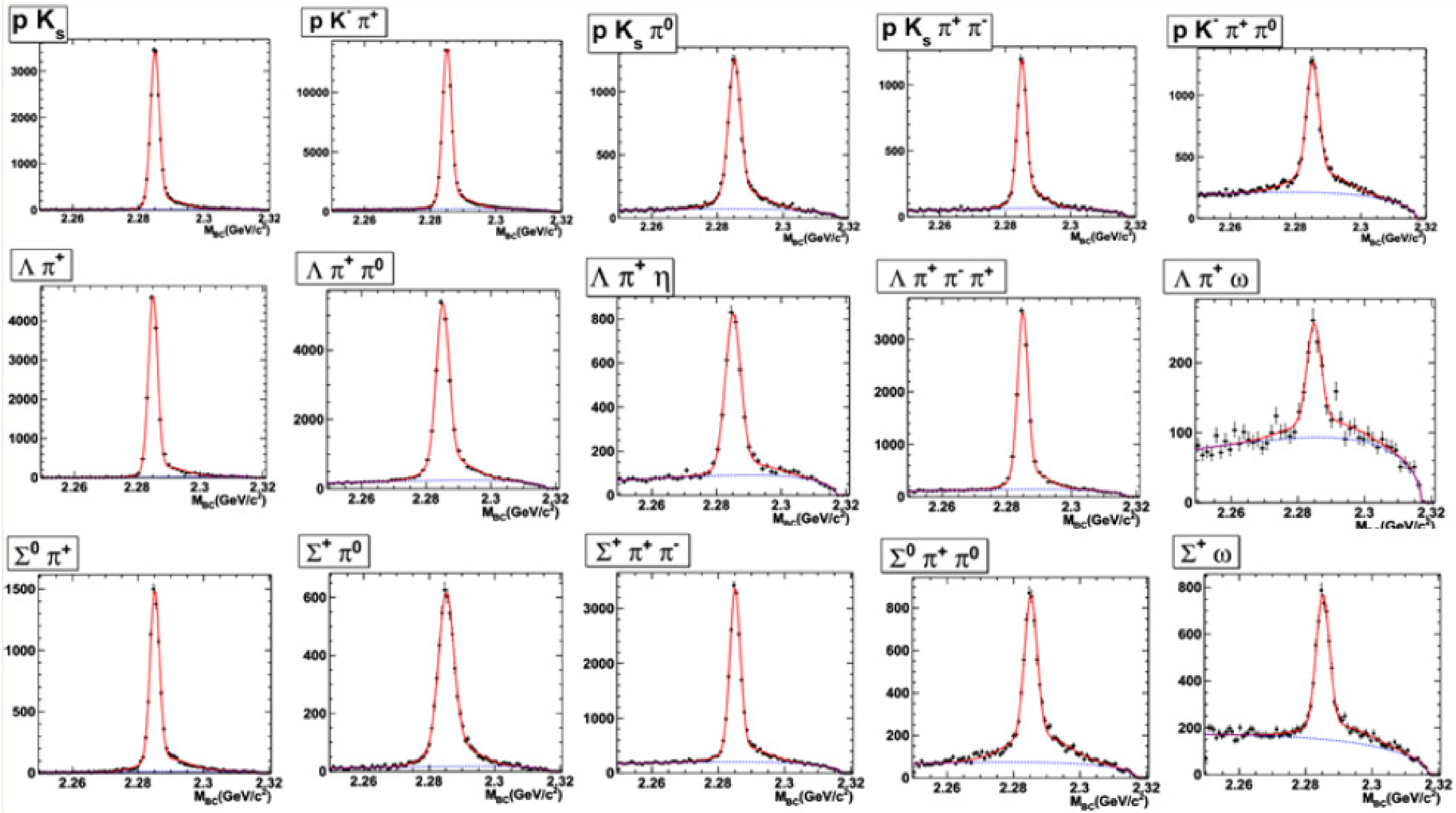
ST Mode	$B_i(\%)$	$\varepsilon_i(\%)$	$\varepsilon_i B_i(\%)$	ST Mode	$B_i(\%)$	$\varepsilon_i(\%)$	$\varepsilon_i B_i(\%)$
pK_s	1.15 ± 0.3	34.9	0.39 ± 0.10	$\Lambda\pi^+\eta$	1.8 ± 0.6	4.2	0.08 ± 0.03
$pK^-\pi^+$	5.0 ± 1.3	35.7	1.78 ± 0.46	$\Lambda\pi^+\pi^+\pi^-$	2.6 ± 0.7	10.2	0.27 ± 0.08
$pK_s\pi^0$	1.65 ± 0.5	12.0	0.20 ± 0.06	$\Lambda\pi^+\omega$	1.2 ± 0.5	1.7	0.02 ± 0.01
$pK_s\pi^+\pi^-$	1.3 ± 0.35	15.5	0.20 ± 0.05	$\Sigma^0\pi^+$	1.05 ± 0.28	16.2	0.17 ± 0.05
$pK^-\pi^+\pi^0$	3.4 ± 1.0	7.4	0.25 ± 0.07	$\Sigma^+\pi^0$	1.00 ± 0.34	10.8	0.11 ± 0.04
$\Lambda\pi^+$	1.07 ± 0.28	27.6	0.30 ± 0.08	$\Sigma^+\pi^+\pi^-$	3.6 ± 1.0	11.0	0.40 ± 0.11
$\Lambda\pi^+\pi^0$	3.6 ± 1.3	13.3	0.48 ± 0.18	$\Sigma^0\pi^+\pi^0$	1.8 ± 0.8	7.6	0.14 ± 0.16
				$\Sigma^+\omega$	2.7 ± 1.0	3.8	0.10 ± 0.04
single tag efficiency: $\sum_i \varepsilon_i B_i = (4.89 \pm 0.55)\%$							

(From Xiaorui Lv)

- *Efficiencies are estimated based on MC simulation in BOSS663*
- *Secondary decay rates are included in the efficiencies.*
- *Selection criteria not optimized*

Distributions of M_{BC} for 15 ST modes in Λ_c^+ generic decays

(From Xiaorui Lv)



good signal-to-background ratios

Estimation of event rate

- For $\Lambda_c^+\Lambda_c^-$ pair, if peak cross section is 0.47 nb around 4.63 GeV, at a luminosity of 10^{35} $cm^{-2}s^{-1}$ at a STCF, the production rate would be 47 Hz, which is equivalently 4 M events per day. Assuming the single/double tagging efficiency 4.89%/0.24%, this gives 391k singly tagged $\Lambda_c^\pm$, or 9.6k doubly tagged $\Lambda_c^+\Lambda_c^-$;
- A ~1% statistical uncertainty for $Br(\Lambda_c^+ \to pK^-\pi^+)$ measurement!
- Unprecedent potential to study Λ_c decays.

CP Violation in Λ_c^+ Decay

- In $\Lambda_c^+ \to$ BP and $\Lambda_c^+ \to$ BV decays (B: spin ½ baryon, P: pseudoscalar, V: vector), one may examine the T odd CP violating triple-product (TP) correlation – $\mathbf{v_1} \cdot \mathbf{v_2} \times \mathbf{v_3}$, where $\mathbf{v_i}$ can be spin or momentum;
- FOCUS measured $\Lambda_c^+ \to \Lambda\pi^+$ with an asymmetry parameter α=-0.91$\pm$0.15, leads to the CP violation parameter A=-0.07$\pm$0.19$\pm$0.12, however the errors are large;
- The TP asymmetries in Λ_c^+ decays is estimated to be negligible in the Standard Model, so the processes are an excellent place to look for new physics.

TP asymmetry quantity:

$$A_T = \frac{N(\mathbf{v}_1 \cdot \mathbf{v}_2 \times \mathbf{v}_3 > 0) - N(\mathbf{v}_1 \cdot \mathbf{v}_2 \times \mathbf{v}_3 < 0)}{N_{\rm total}}$$

Or equivalently,

$$A_T = \frac{\Gamma(\mathbf{v}_1 \cdot \mathbf{v}_2 \times \mathbf{v}_3 > 0) - \Gamma(\mathbf{v}_1 \cdot \mathbf{v}_2 \times \mathbf{v}_3 < 0)}{\Gamma(\mathbf{v}_1 \cdot \mathbf{v}_2 \times \mathbf{v}_3 > 0) + \Gamma(\mathbf{v}_1 \cdot \mathbf{v}_2 \times \mathbf{v}_3 < 0)}$$

The true CP violating asymmetry:

$$\mathcal{A}_T = \frac{1}{2}(A_T + \bar{A}_T)$$

Promising modes to look for

Sensitivity estimated based on 2.5x10^6 $\Lambda_c^+\Lambda_c^-$ pairs (one year @BESIII).

BP	Br	Eff. (ϵ)	Expected errors at BES-III ($\times 10^{-2}$)
$\Lambda\pi^+ \to (p\pi^-)\pi^+$	6.8×10^{-3}	0.82	0.85
$\Lambda K^+ \to (p\pi^-)K^+$	3.2×10^{-4}	0.75	4.08
$\Lambda(1520)\pi^+ \to (pK^-)\pi^+$	8.1×10^{-3}	0.75	0.81
$\Sigma^0\pi^+ \to (\Lambda\gamma)\pi^+$	1.0×10^{-2}	0.62	0.80
$\Sigma^0 K^+ \to (\Lambda\gamma)K^+$	4.0×10^{-4}	0.56	4.23
$\Sigma^+\pi^0 \to (p\pi^0)\pi^0$	5.0×10^{-3}	0.60	1.15
$\Sigma^+\eta \to (p\pi^0)(\pi^+\pi^-\pi^0)$	8.2×10^{-4}	0.52	3.06
$\Xi^0 K^+ \to (\Lambda\pi^0)K^+$	2.6×10^{-4}	0.57	5.20

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BV	Br	Eff. (ϵ)	Expected errors at BES-III ($\times 10^{-2}$)
$\Lambda\rho^+ \to (p\pi^-)(\pi^+\pi^0)$	$3.2\times10^{-2*}$	0.65	0.44
$\Sigma(1385)^+\rho^0 \to (\Lambda\pi^+)(\pi^+\pi^-)$	2.4×10^{-3}	0.69	1.55
$\Sigma^+\rho^0 \to (p\pi^0)(\pi^+\pi^-)$	$0.7\times10^{-2*}$	0.62	0.96
$\Sigma^+\omega \to (p\pi^0)(\pi^+\pi^-\pi^0)$	1.4×10^{-2}	0.49	0.76
$\Sigma^+\phi \to (p\pi^0)(K^+K^-)$	0.8×10^{-3}	0.52	3.10
$\Sigma^+K^{*0} \to (p\pi^0)(K^-\pi^+)$	0.7×10^{-3}	0.57	3.17

Summary

- There have been no improvements in the Λ_c^+ branching fraction measurements since 1998;
- A super tau-charm factory will provide unique opportunity for charmed baryon study if it operates in 4.6 – 5.5 GeV;
- $\Lambda_c^+ \to pK^-\pi^+$ mode can be measured precisely;
- Access to rare decays at $\sim 10^{-6}$ level can be expected;
- CP violation in Λ_c^+ decay can be studied.