

**Measurement of the α Decay Parameters in
 $\Omega^- \rightarrow \Lambda K^-$ and $\bar{\Omega}^+ \rightarrow \bar{\Lambda} K^+$**

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Why We Measure Decay Parameters?

- A nonleptonic hyperon decay, $B_i \rightarrow B_f X$, is described by three decay parameters (B and X represent a baryon and a spin-zero meson respectively):

$$\alpha_H = \frac{2\text{Re}(A_{J-\frac{1}{2}}^* A_{J+\frac{1}{2}})}{|A_{J-\frac{1}{2}}|^2 + |A_{J+\frac{1}{2}}|^2}, \quad \beta_H = \frac{2\text{Im}(A_{J-\frac{1}{2}}^* A_{J+\frac{1}{2}})}{|A_{J-\frac{1}{2}}|^2 + |A_{J+\frac{1}{2}}|^2}, \quad \gamma_H = \frac{|A_{J-\frac{1}{2}}|^2 - |A_{J+\frac{1}{2}}|^2}{|A_{J-\frac{1}{2}}|^2 + |A_{J+\frac{1}{2}}|^2}.$$

- $\Omega \rightarrow \Lambda K$ decay: $J = 3/2$

$A_{J-\frac{1}{2}}$ and $A_{J+\frac{1}{2}}$ are amplitudes of P -wave and D -wave, corresponding to parity-conserving and parity-violating states respectively;

- Decay parameter: $\alpha_\Omega = \frac{2\text{Re}(P^* D)}{|P|^2 + |D|^2}.$

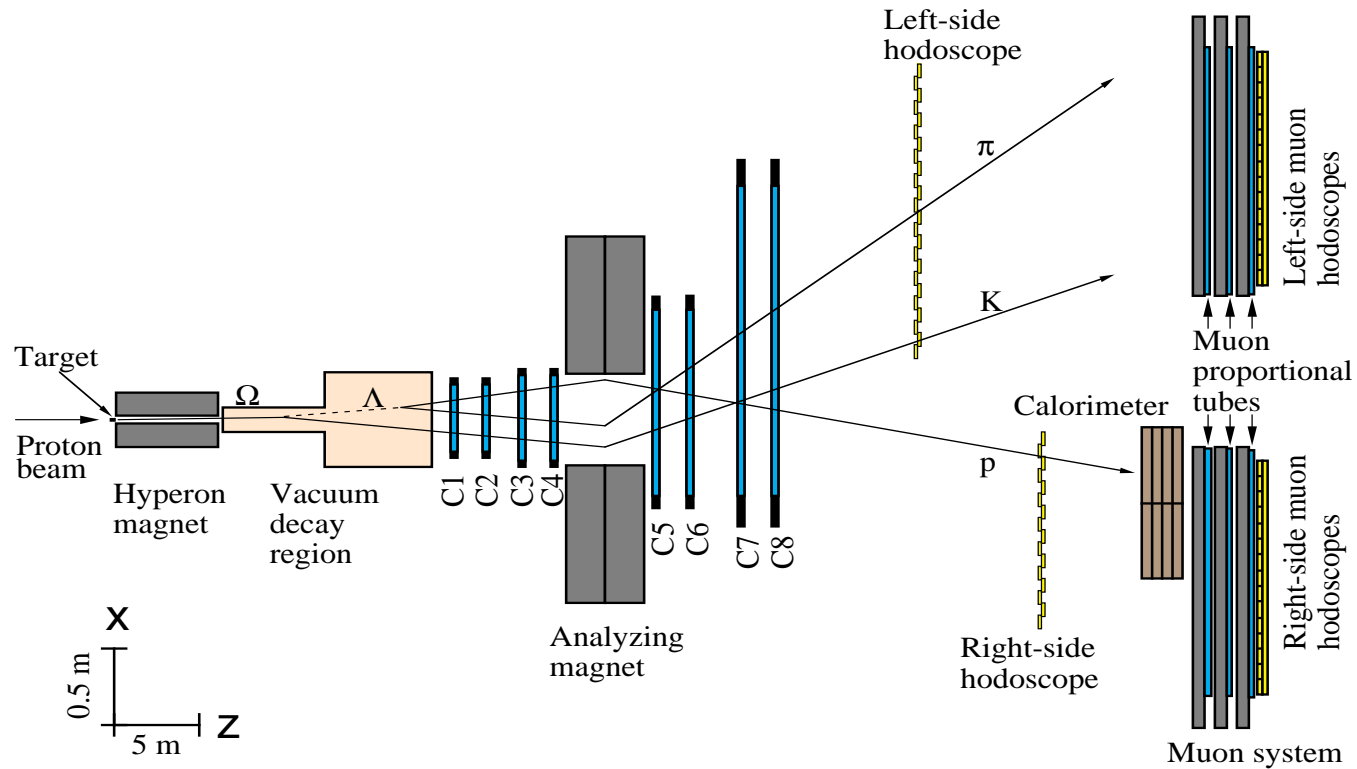
- Theoretically, D -wave is kinematically suppressed and hence α_Ω is expected nearly to be zero (M. Suzuki, 1964). Non-zero α_Ω indicates parity violation in this decay.
- A difference between $|\alpha_\Omega|$ and $|\alpha_{\bar{\Omega}}|$ would be evidence of CP violation.
- Previous experimental results for α_Ω and $\alpha_{\bar{\Omega}}$ are **consistent with zero**.

Experiment	Year	Events	α_Ω	$\alpha_{\bar{\Omega}}$
CERN-SPS	1984	12,000	-0.025 ± 0.028	N/A
FNAL E620	1988	1,743	-0.034 ± 0.079	N/A
FNAL E756	1998	6,953/1,823	-0.028 ± 0.047	$+0.017 \pm 0.077$
PDG Average			-0.026 ± 0.023	N/A

- *HyperCP* has collected the largest samples of $\Omega \rightarrow \Lambda K$ decays in the world which allows precise measurements of decay parameters and search for CP violation.

The *HyperCP* (E871) Spectrometer

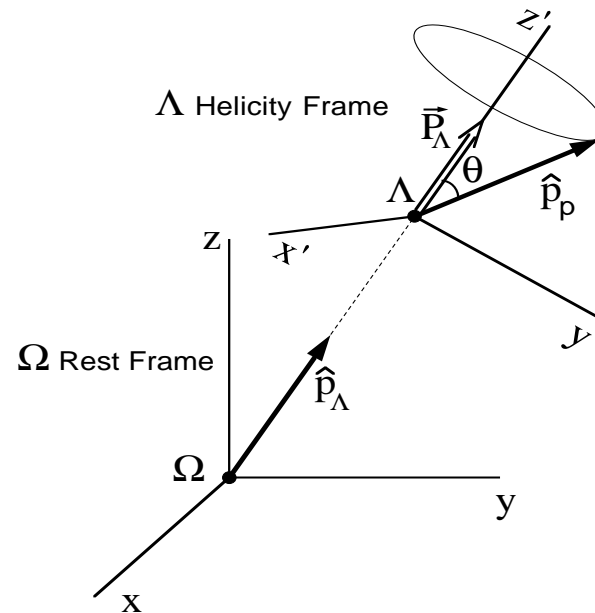
- Protons on target = (7 ~ 8) GHz
- Secondary beam intensity = (10 ~ 15) MHz
- Trigger rate = (50 ~ 80) KHz
- Charge of Sec. beam selected by the sign of Hyperon magnet



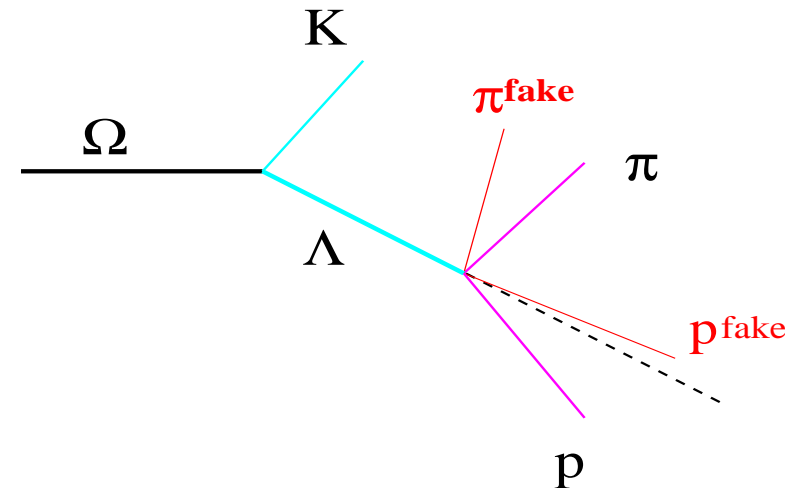
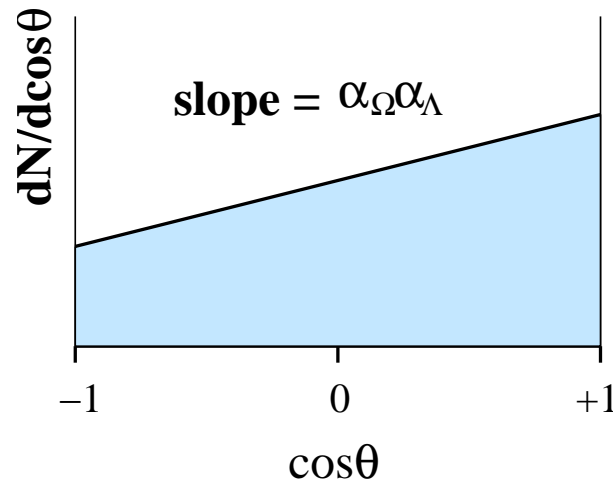
Hybrid Monte-Carlo Method (HMC)

- For the *unpolarized* $\Omega \rightarrow \Lambda K \rightarrow p\pi K$ decay, the proton angular distribution is found to be

$$\frac{dN}{d \cos \theta} = \frac{1}{2} (1 + \underbrace{\alpha_{\Omega} \alpha_{\Lambda}}_{S_m} \cos \theta). \quad (1)$$



- Measuring the slope of the proton $\cos \theta$ distribution gives us $\alpha_\Omega \alpha_\Lambda$.

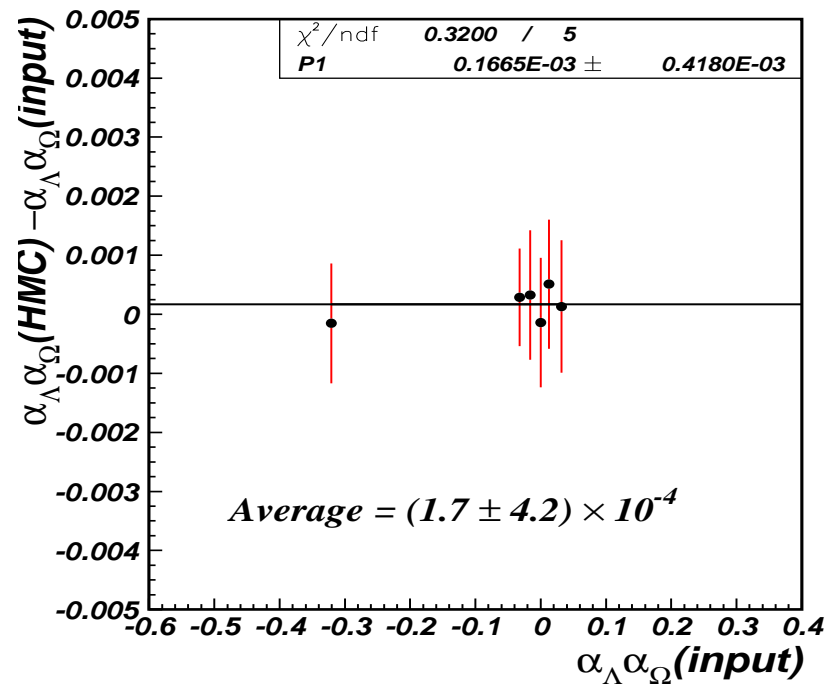


- α_Ω can be extracted by using the parameter α_Λ of $\Lambda \rightarrow p\pi$ decays from PDG, $\alpha_\Lambda = 0.642 \pm 0.013$.
- **In reality**, $\cos \theta$ distribution is distorted by the spectrometer acceptance, which can be measured by **Monte-Carlo**.

- Take all variables from each real event except $\cos \theta$.
- Generate **HMC events** with uniform $\cos \theta$.
- Let all the **HMC events** go through the software spectrometer, triggers, etc.; hence determine the acceptance.
- Weight **HMC events** to match the angular distributions of real and HMC events to obtain $\alpha_{\Omega}\alpha_{\Lambda}$.

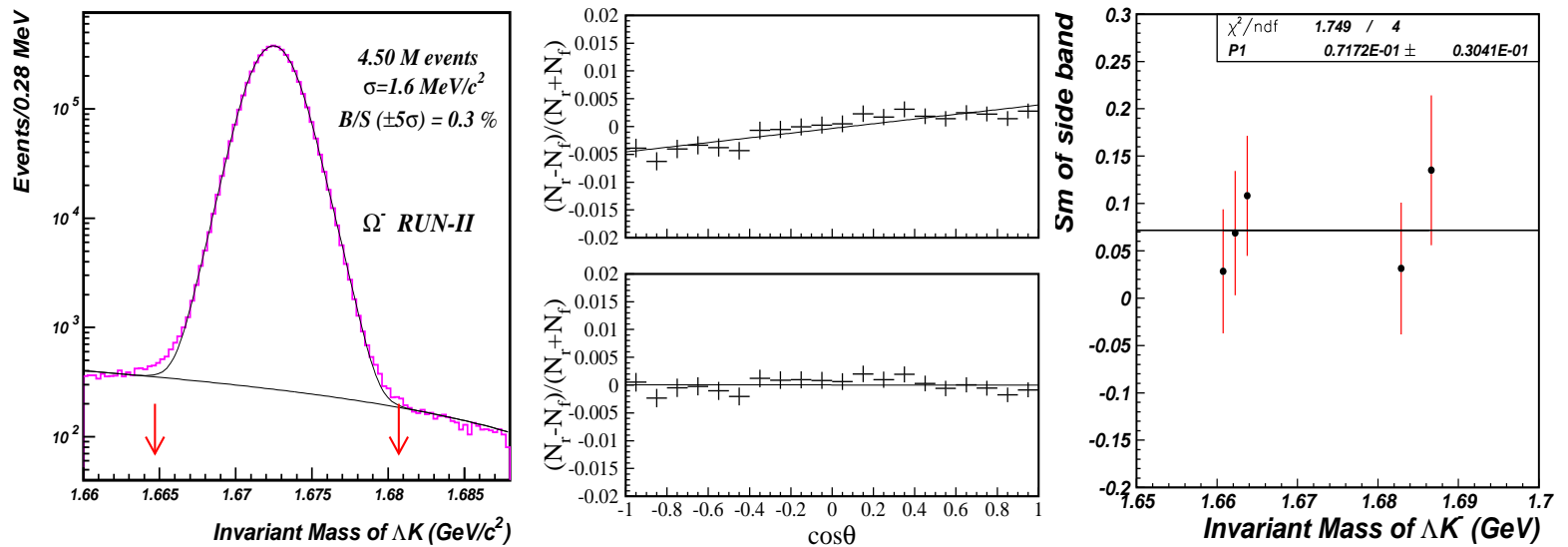
Validation of HMC

- Generated Monte-Carlo samples with different input values of $\alpha_\Omega \alpha_\Lambda$.
- Analyzed these Monte-Carlo samples with HMC to obtain the measurement values of $\alpha_\Omega \alpha_\Lambda$, and compared the difference between measurement and input values.



Preliminary Results of α_Ω

- After all event selection cuts, 4.5 million from RUN-II $\Omega^- \rightarrow \Lambda K^-$ events were used to measure α_Ω .



- Slope of proton angular distribution S_m was extracted using HMC,

$$S_m = (1.16 \pm 0.12) \times 10^{-2}, \quad \chi^2 = 23 \text{ for } 20 \cos\theta \text{ bins.}$$

- **Background slope S_b was measured from mass sidebands,**

$$S_b = (7.17 \pm 3.04) \times 10^{-2}.$$

- **Using $\alpha_\Omega \alpha_\Lambda = \frac{N_m}{N_s} S_m - \frac{N_b}{N_s} S_b$ to subtract background, we get**

$$\alpha_\Omega \alpha_\Lambda = [1.14 \pm 0.12(stat)] \times 10^{-2}.$$

- **Systematic Errors**

Systematic Study	$ \alpha_\Omega \alpha_\Lambda - (\alpha_\Omega \alpha_\Lambda)_{basic} $
π_Λ decays in flight	negligible
Event selection cuts	$0.09 \times 10^{-2} (0.73\sigma)$
Inefficiencies of spectrometer	negligible
BM109 field	negligible
HMC validation	$0.04 \times 10^{-2} (0.33\sigma)$
Total	0.10×10^{-2}

- **Preliminary Results of $\alpha_\Omega\alpha_\Lambda$ and α_Ω**

Together with the results from the analysis of 1 million events on RUN-I data, our results are:

$$\alpha_\Omega\alpha_\Lambda = [1.18 \pm 0.29(\text{stat})] \times 10^{-2} \text{ (RUN-I),}$$

$$\alpha_\Omega\alpha_\Lambda = [1.14 \pm 0.12(\text{stat}) \pm 0.10(\text{syst})] \times 10^{-2} \text{ (RUN-II).}$$

Using PDG value $\alpha_\Lambda = 0.642 \pm 0.013$, we get

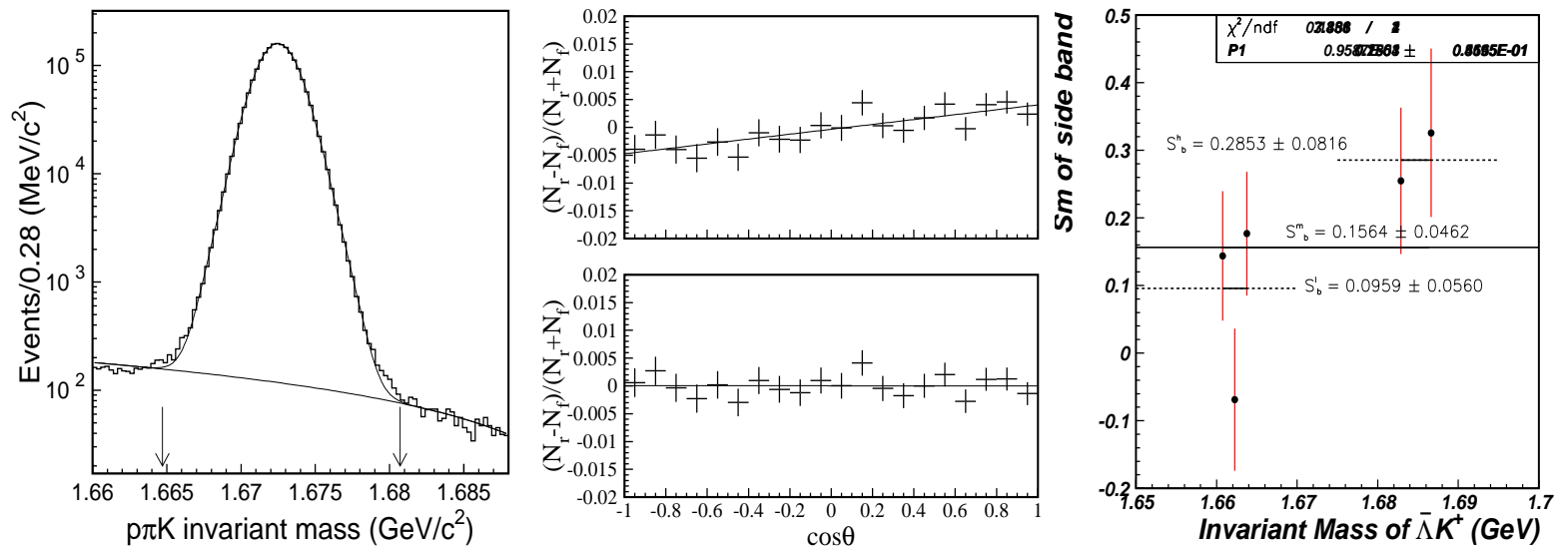
$$\alpha_\Omega = [1.84 \pm 0.46(\text{stat})] \times 10^{-2} \text{ (RUN-I),}$$

$$\alpha_\Omega = [1.78 \pm 0.19(\text{stat}) \pm 0.16(\text{syst})] \times 10^{-2} \text{ (RUN-II).}$$

Note: RUN-I systematic error is still under study.

Measurement of $\alpha_{\bar{\Omega}}$ and Search for CPV

- Using the same code and event selection cuts, we have analyzed 1.9 million $\bar{\Omega}^+ \rightarrow \bar{\Lambda}K^+$, $\bar{\Lambda} \rightarrow \bar{p}\pi^+$ events.



- **Preliminary Results of $\alpha_{\bar{\Omega}}\alpha_{\bar{\Lambda}}$ and $\alpha_{\bar{\Omega}}$**

$$\alpha_{\bar{\Omega}}\alpha_{\bar{\Lambda}} = [1.16 \pm 0.18(\text{stat}) \pm 0.16(\text{syst})] \times 10^{-2}, \quad \chi^2 = 22 \text{ for } 20 \cos \theta \text{ bins.}$$

Using the PDG value of $\alpha_{\bar{\Lambda}} = -0.642 \pm 0.013$, $\alpha_{\bar{\Omega}}$ was extracted:

$$\alpha_{\bar{\Omega}} = [-1.81 \pm 0.28(\text{stat}) \pm 0.25(\text{syst})] \times 10^{-2}.$$

- **CPV Test for $\Omega \rightarrow \Lambda K$ Decays**

Using the measured values of $\alpha_{\Omega}\alpha_{\Lambda}$ and $\alpha_{\bar{\Omega}}\alpha_{\bar{\Lambda}}$, asymmetries are determined to be

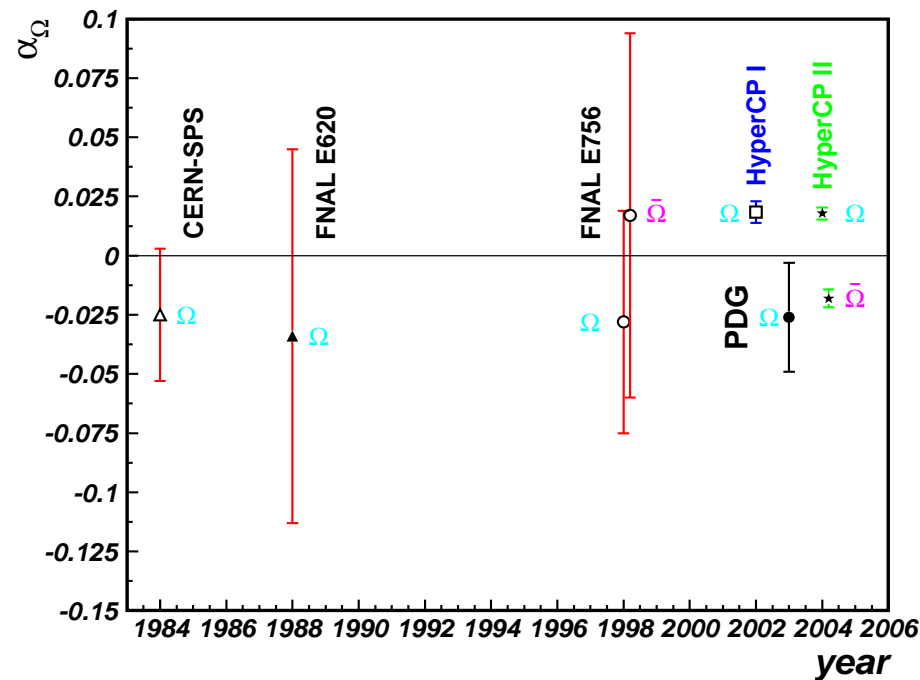
$$\delta_{\Omega\Lambda} \equiv \alpha_{\Omega}\alpha_{\Lambda} - \alpha_{\bar{\Omega}}\alpha_{\bar{\Lambda}} = [-0.02 \pm 0.22(\text{stat}) \pm 0.19(\text{syst})] \times 10^{-2},$$

$$A_{\Omega\Lambda} \equiv \frac{\alpha_{\Omega}\alpha_{\Lambda} - \alpha_{\bar{\Omega}}\alpha_{\bar{\Lambda}}}{\alpha_{\Omega}\alpha_{\Lambda} + \alpha_{\bar{\Omega}}\alpha_{\bar{\Lambda}}} = [-0.87 \pm 9.41(\text{stat}) \pm 8.20(\text{syst})] \times 10^{-2}.$$

CP is conserved within statistics

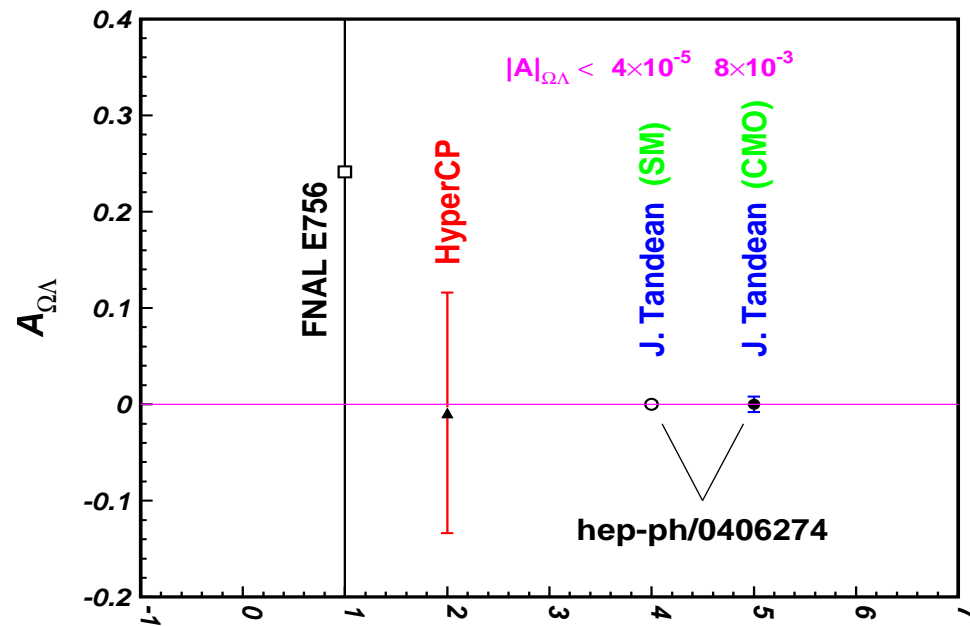
Comparison With Other Results

- α_Ω and $\alpha_{\bar{\Omega}}$
 - α_Ω ($\alpha_{\bar{\Omega}}$) from *HyperCP* has a **positive** (**negative**) sign, which is different from PDG value and other experiments.
 - The values of α_Ω and $\alpha_{\bar{\Omega}}$ from *HyperCP* are **nonzero**.



- **Asymmetry $A_{\Omega\Lambda}$**

- $A_{\Omega\Lambda}$ for **FNAL E756** in the plot is extrapolated from their measurements, $\alpha_{\Omega} = -0.028 \pm 0.047$ and $\alpha_{\bar{\Omega}} = +0.017 \pm 0.077$.
- In Tandean's predictions, **SM** stands for the standard model, and **CMO** stands for chromomagnetic-penguin operators which includes possible physics beyond the standard model.

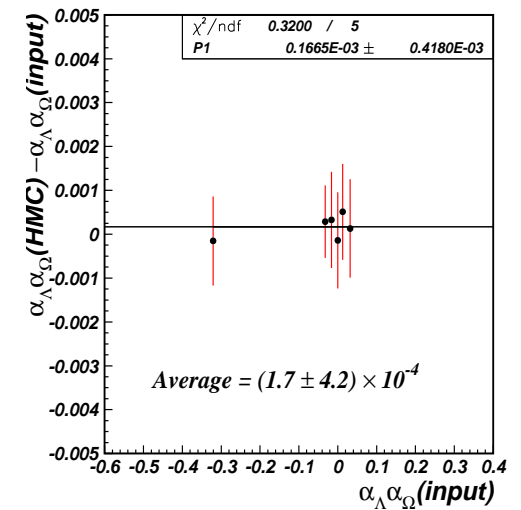
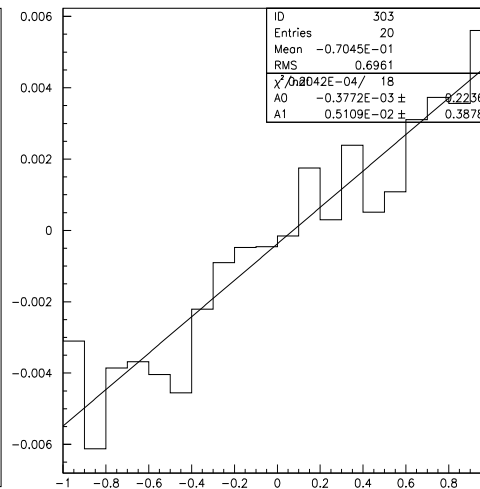
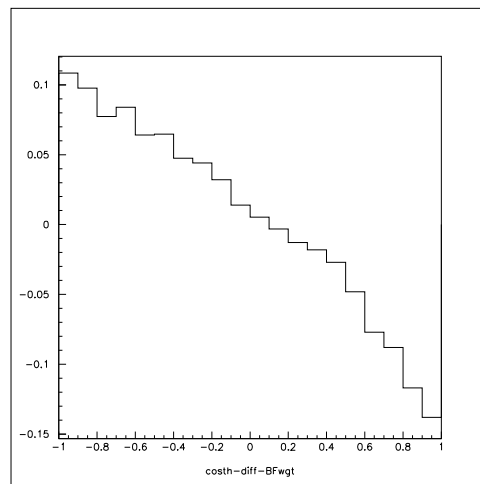


Conclusions

- With the largest samples of $\Omega^- \rightarrow \Lambda K^-$ and $\bar{\Omega}^+ \rightarrow \bar{\Lambda} K^+$ decays ever recorded, HyperCP has precisely measured the decay parameters of α_Ω and $\alpha_{\bar{\Omega}}$.
- We find the first evidence of nonzero α_Ω and $\alpha_{\bar{\Omega}}$, and hence parity violation in $\Omega \rightarrow \Lambda K$ decays.
- No *CP*-violation is observed in the joint decays of $\Omega \rightarrow \Lambda K \rightarrow p\pi K$ at the statistical level of 0.22×10^{-2} for $\delta_{\Omega\Lambda}$ and 9.41×10^{-2} for $A_{\Omega\Lambda}$.

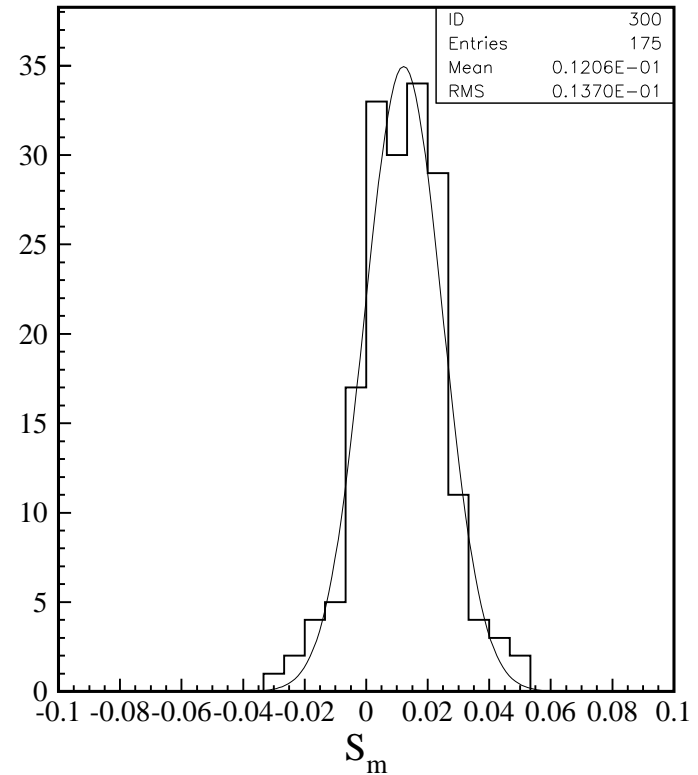
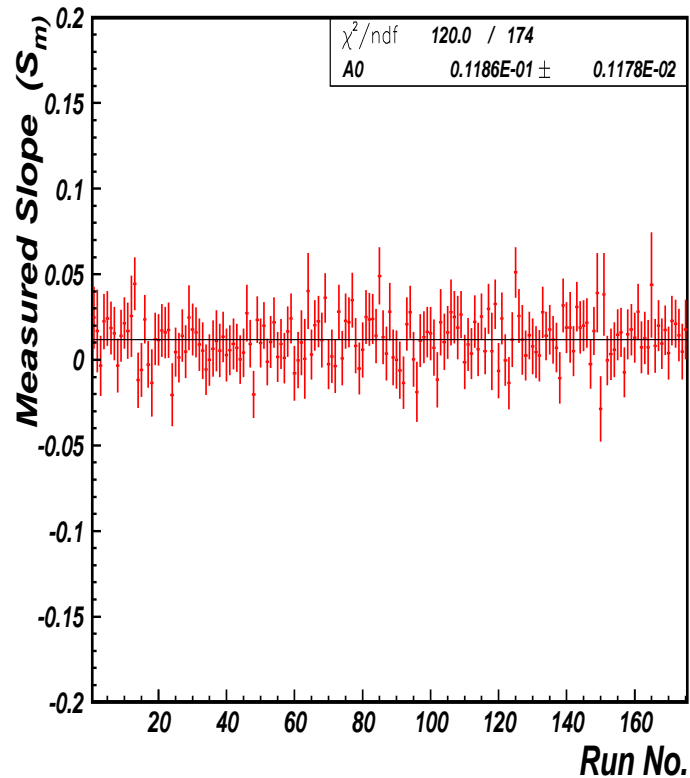
The Sign of α_Ω

- The same analysis code was used to analyze 78,000 events of the $\Xi^- \rightarrow \Lambda\pi^-$ decay, $\alpha_\Xi\alpha_\Lambda = -0.286 \pm 0.007$, both the sign and value are consistent with PDG.



- Monte-Carlo Study: HMC results consistent with input values both on the sign and value.

- Individual run by run analysis shows only 29 out of 175 runs have negative $\alpha_{\Omega}\alpha_{\Lambda}$ values but all with very large statistical errors compared with their values.



- Individual run by run analysis for $\bar{\Omega}^+ \rightarrow \bar{\Lambda}K^+$ Decays

