Observation of Parity Violation in the $\Omega^- \to \Lambda K^-$ Decay

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(Representing the *HyperCP* Collaboration)

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Why Are We Interested In The $\Omega \to \Lambda K$ Decay?

- Ω is a particle of spin $\frac{3}{2}$ predicted by the quark model. Angular momentum conservation allows the ΛK system to be P-wave and D-wave, corresponding to parity conserving and parity violating decays respectively.

- Parity violation is characterized by the parameter α_Ω defined as:

$$\alpha_\Omega = \frac{2Re(P^*D)}{|P|^2 + |D|^2}.$$

  Non-zero α_Ω indicates parity violation in this decay.

- *HyperCP* has collected about 19 million Ω^- and $\bar{\Omega}^+$ in RUN-I (1997) and RUN-II (1999), which allows us to measure α_Ω for both Ω^- and $\bar{\Omega}^+$ at the 10^{-3} level.

- A difference between $|\alpha_\Omega|$ and $|\alpha_{\bar{\Omega}}|$ would be evidence of CP violation.

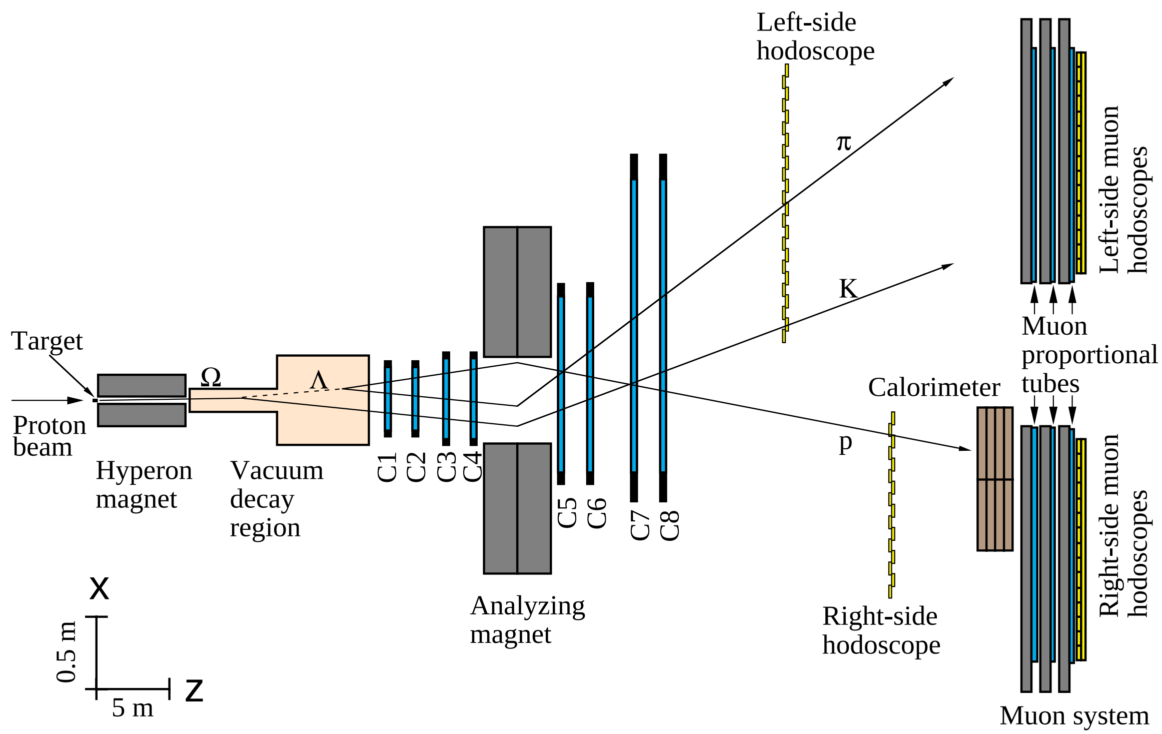
Existing Experimental Results for α_Ω

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

$\Longrightarrow$ **consistent with** $\alpha_\Omega = 0$ **at** 10^{-2} **level**

The *HyperCP* (E871) Spectrometer

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



HyperCP Yields

RUN	I	II	Total
Triggers (10^9)	58	173	231
Data Volume (TB)	38	82	120
Tapes (Exabyte, 5GB)	8,980	20,421	29,401

<table>
<tr><th colspan="6">Number of Reconstructed Events (10^6)</th></tr>
<tr><th rowspan="2">Type</th><th colspan="4">Channeled beam polarity</th><th rowspan="2">Total</th></tr>
<tr><th colspan="2">+</th><th colspan="2">−</th></tr>
<tr><td>$\Xi \longrightarrow \Lambda\pi$</td><td colspan="2">460</td><td colspan="2">2000</td><td>2460</td></tr>
<tr><td>$K \longrightarrow \pi\pi\pi$</td><td colspan="2">390</td><td colspan="2">160</td><td>550</td></tr>
<tr><td rowspan="3">$\Omega \longrightarrow \Lambda K$</td><td>RUN−I</td><td>RUN−II</td><td>RUN−I</td><td>RUN−II</td><td rowspan="3">19</td></tr>
<tr><td>1.54</td><td>3.32</td><td>5.71</td><td>8.41</td></tr>
<tr><td colspan="2">5</td><td colspan="2">14</td></tr>
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Analysis Method

The angular distribution of the proton from unpolarized Ω decays

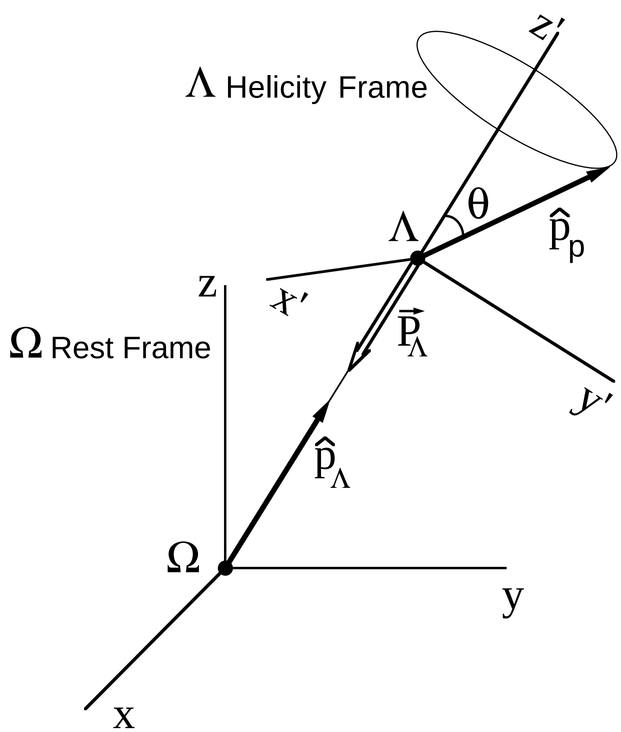
$$\Omega \to \Lambda K, \Lambda \to p\pi$$

is expressed as

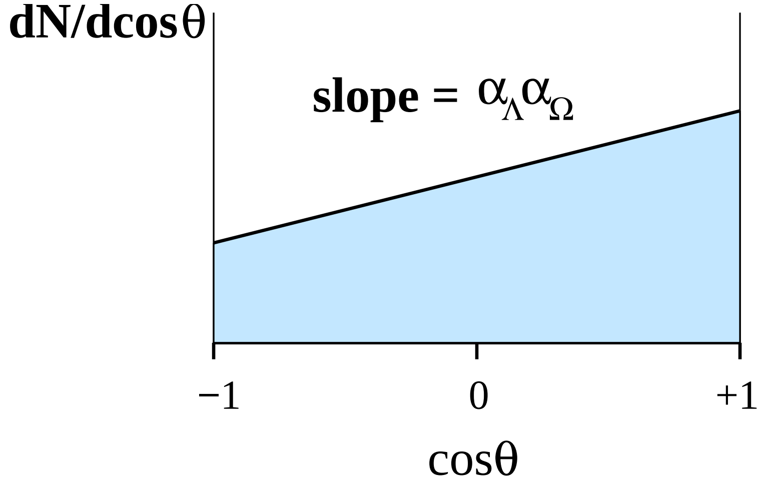
$$\frac{dN}{d\cos\theta} = \frac{N_0}{2}(1 + \alpha_\Lambda \alpha_\Omega \cdot \cos\theta), \quad (1)$$

where:

θ is the polar angle of the proton in the Λ helicity frame.



- Slope of the proton $\cos\theta$ distribution in Λ helicity frame given by $\alpha_\Lambda \alpha_\Omega$



- The parameter α_Λ of the $\Lambda \rightarrow p\pi$ decay defined as

$$\alpha_\Lambda = \frac{2Re(S^*P)}{|S|^2 + |P|^2} \quad \Longrightarrow \text{ well measured !!!}$$

$$\Downarrow$$

$$\alpha_\Lambda = 0.642 \pm 0.013$$

$$\Downarrow$$

allowing α_Ω to be extracted

- In reality, the proton $\cos\theta$ distribution is distorted by the spectrometer acceptance

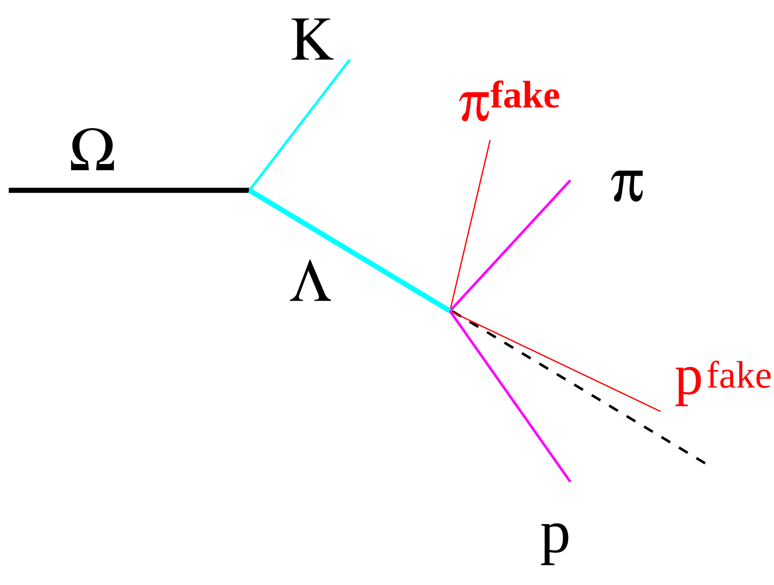
- Use Hybrid Monte-Carlo Method (HMC) to handle the acceptance

  - Take all variables from each real event except $\cos\theta$

  - Generate HMC events (**fake events**) with uniform $\cos\theta_f$

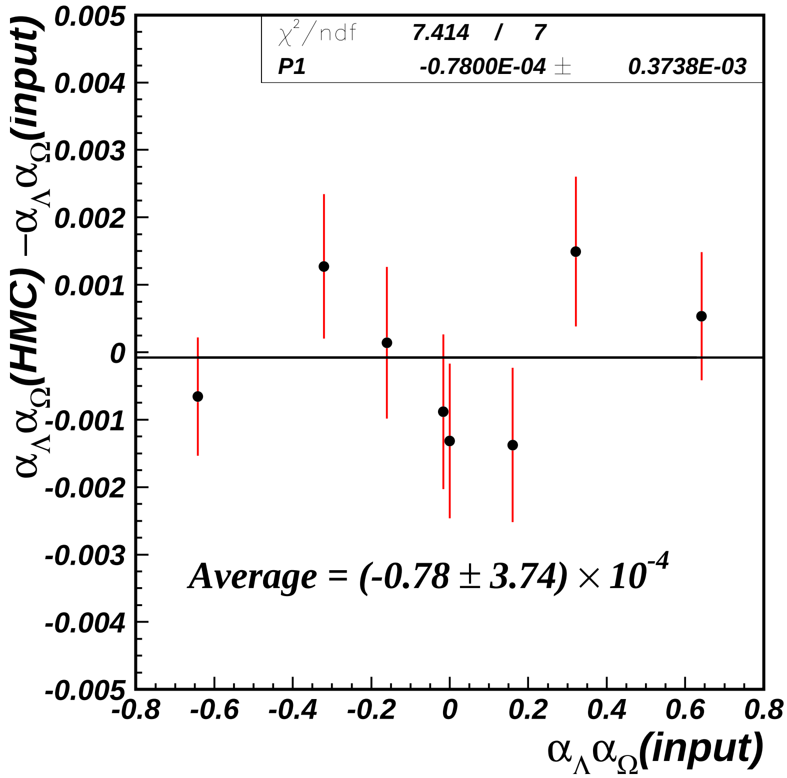
  - Let all the **fake events** go through the software spectrometer, triggers, etc. to simulate the behavior of real events in the experiment; hence determine the acceptance

  - Weight **fake events** by a function $W(\alpha_\Lambda\alpha_\Omega)$ so as to match $\cos\theta$ distributions of real and fake events to obtain $\alpha_\Lambda\alpha_\Omega$



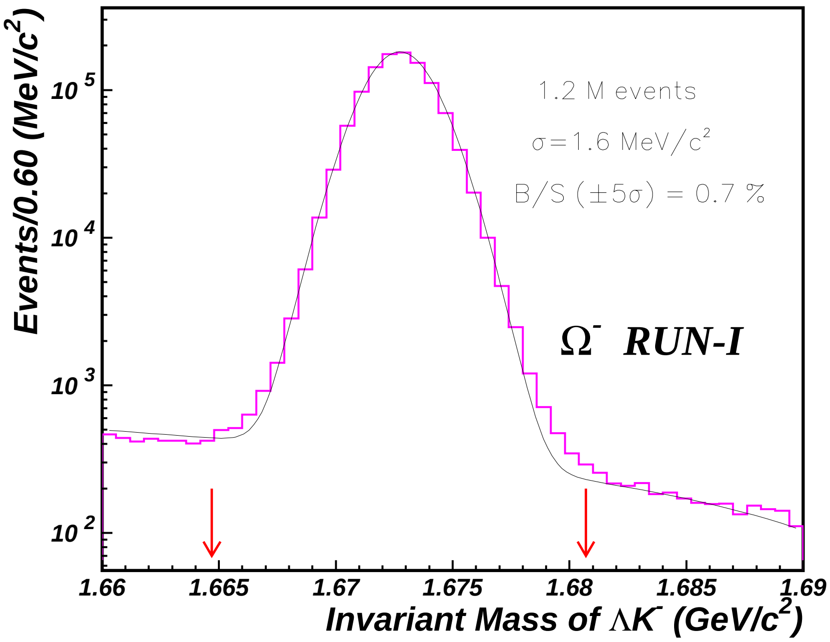
Validation of HMC

- Generate Monte-Carlo data samples with different input $\alpha_\Lambda \alpha_\Omega$
- Analyze these Monte-Carlo data samples with HMC



Results from RUN-I Data

- ΛK **Invariant Mass**

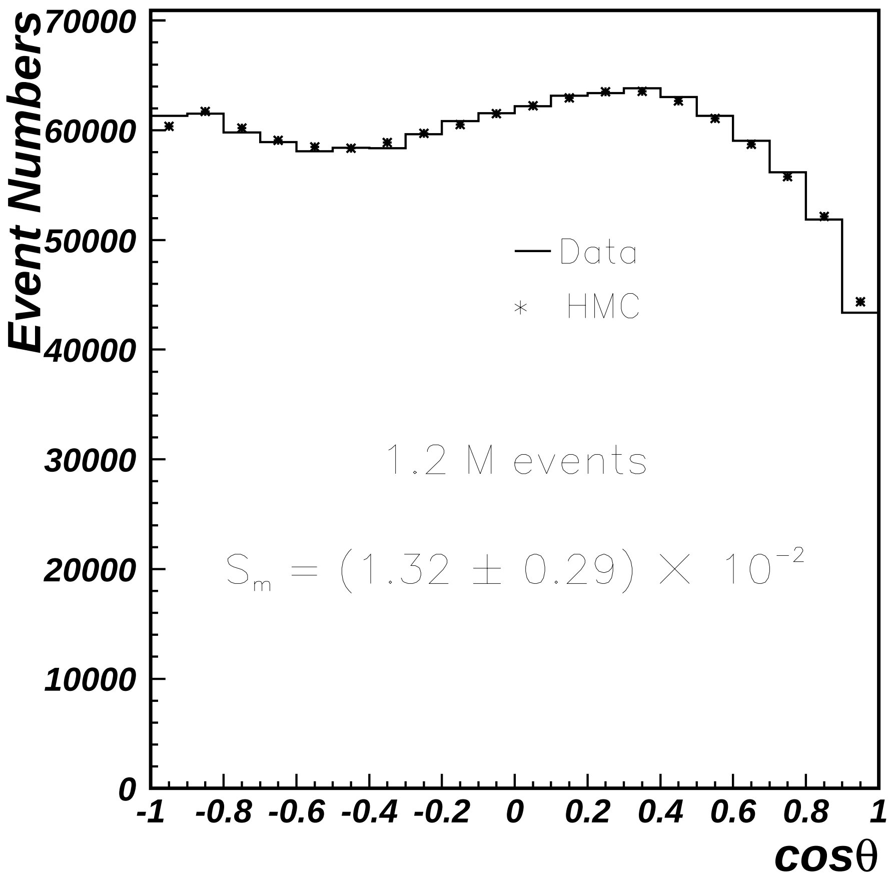


- Background: 0.7% $\Rightarrow$ will affect $\alpha_\Lambda \alpha_\Omega$ measurement
- Measure $\cos\theta$ slope: $\frac{dN}{d\cos\theta} = \frac{N_0}{2}(1+S_m \cdot \cos\theta)$, where

  $S_m = f(\alpha_\Lambda \alpha_\Omega, S_b)$

  S_b is the slope of background angular distribution.
- Estimate background slope S_b from side bands.

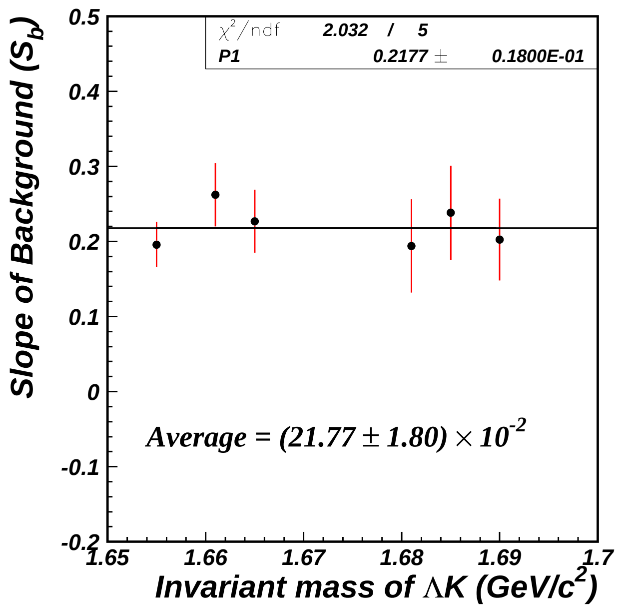
• Proton Angular Distribution in Λ Helicity Frame

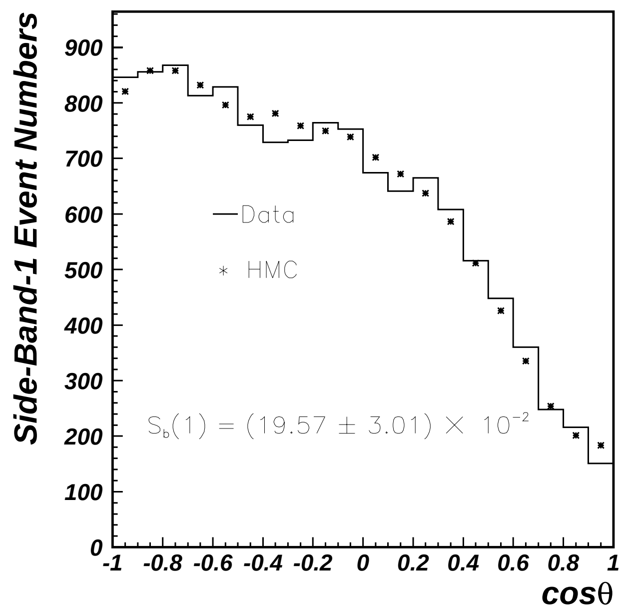


The measured slope:

$$S_m = (1.32 \pm 0.29) \times 10^{-2}, \quad \chi^2/\mathrm{ndf} = 3.0$$

- **Slope of Side Bands**





$$S_b = (21.77 \pm 1.80) \times 10^{-2}, \quad \chi^2/\mathrm{ndf} = 0.41$$

- **Background Correction**

Assuming background under the mass peak has the same shape as side bands, we use

$$\alpha_\Lambda \alpha_\Omega = \frac{N_m}{N_s} S_m - \frac{N_b}{N_s} S_b$$

where

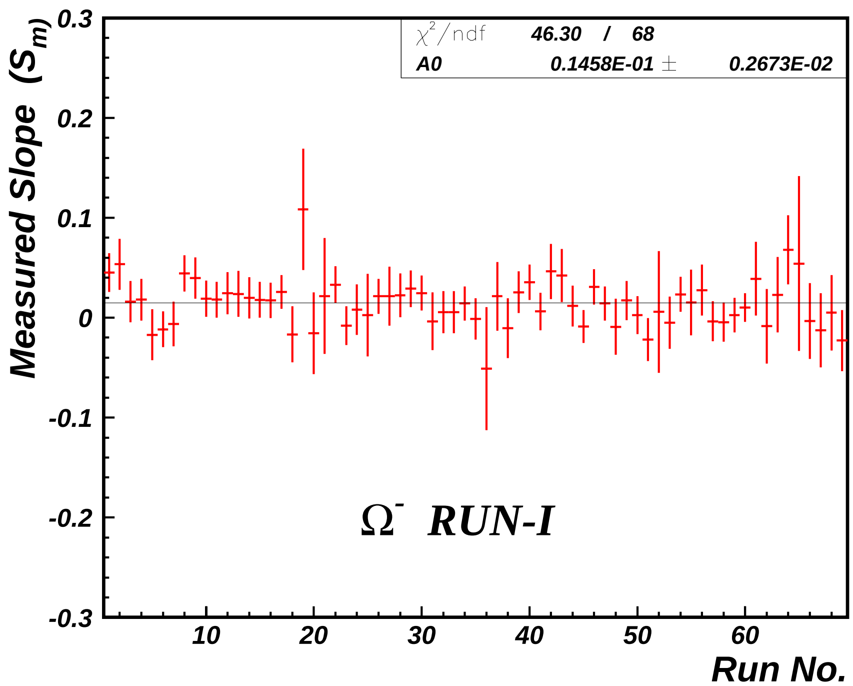
N_m: number of measured events

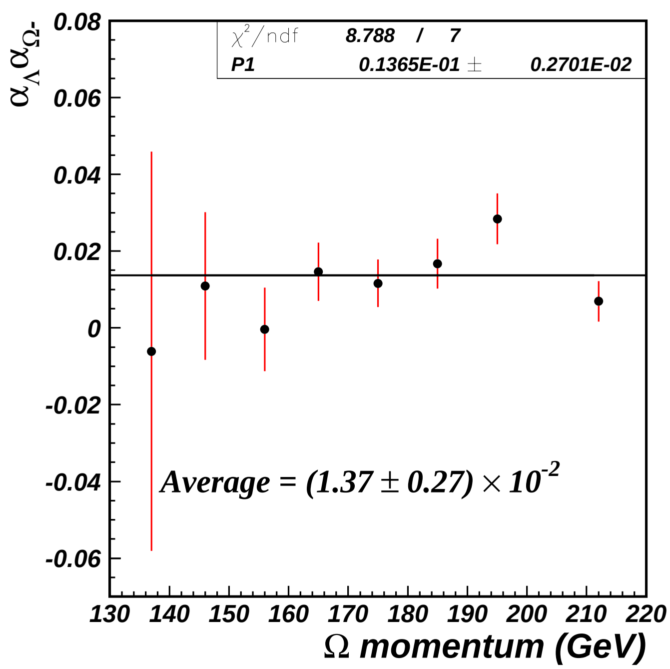
N_s: number of signal events

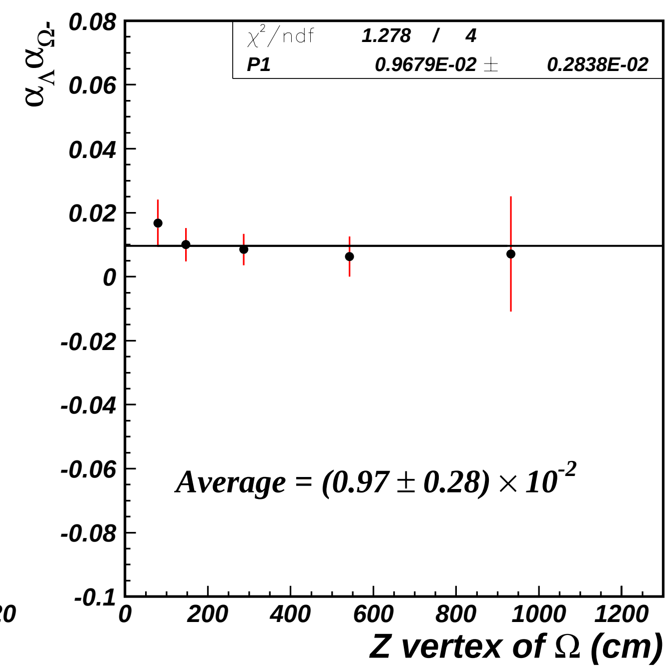
N_b: number of background events

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

- **Stability of $\alpha_\Lambda \alpha_\Omega$**







Preliminary Result

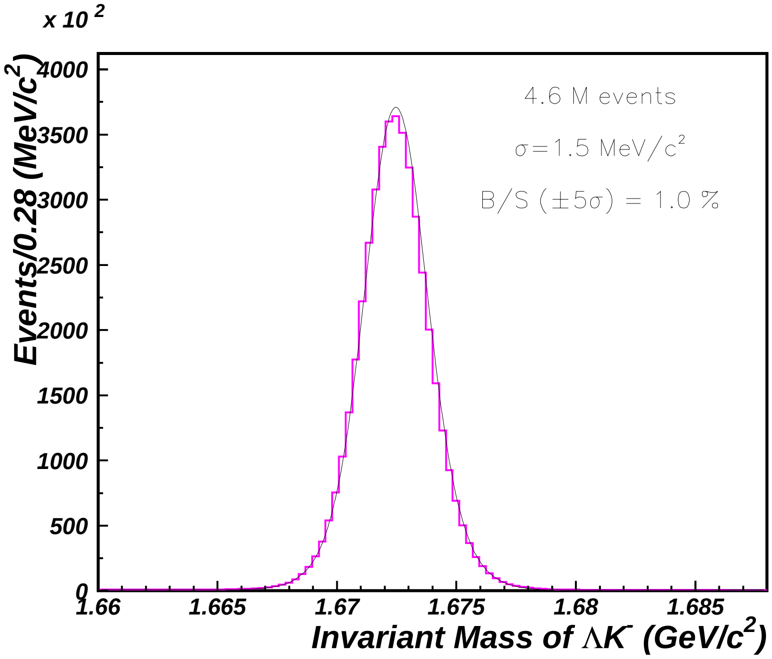
- $\alpha_\Lambda \alpha_\Omega = (1.18 \pm 0.29) \times 10^{-2}$

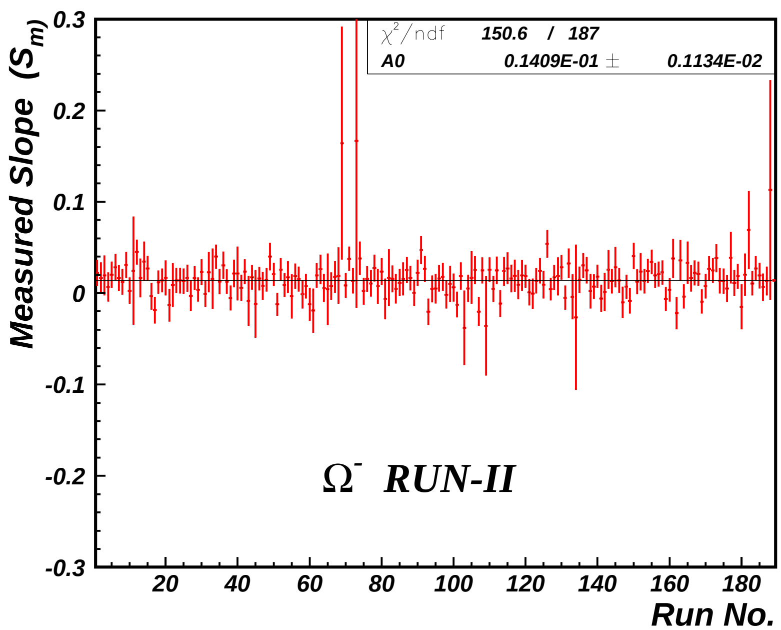
- Using PDG value $\alpha_\Lambda = 0.642 \pm 0.013$,
  $\alpha_\Omega = [1.84 \pm 0.46 \text{ (stat)} \pm 0.04 \text{ (sys PDG)}] \times 10^{-2}$

- The systematic error study is underway and is expected to yield an uncertainty less than the statistical error.

The First Look at Ω from RUN-II Data

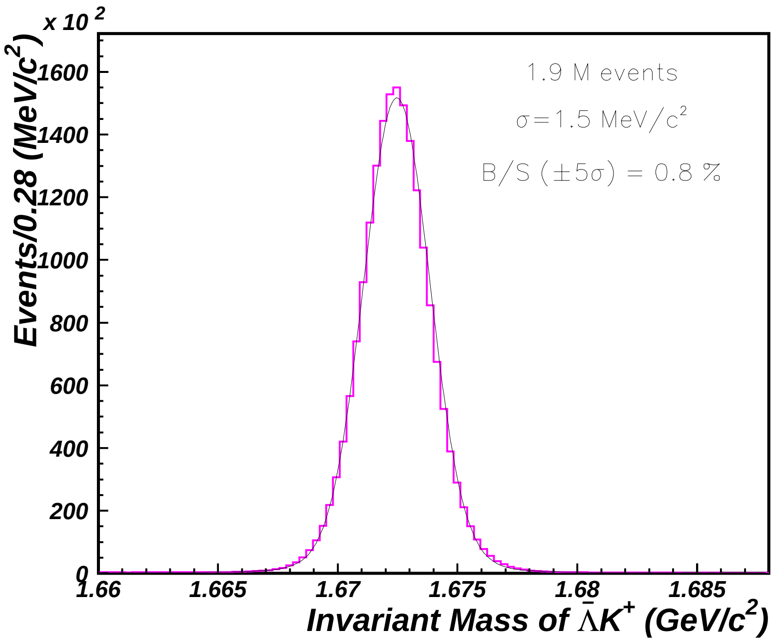
- Ω^- from RUN-II

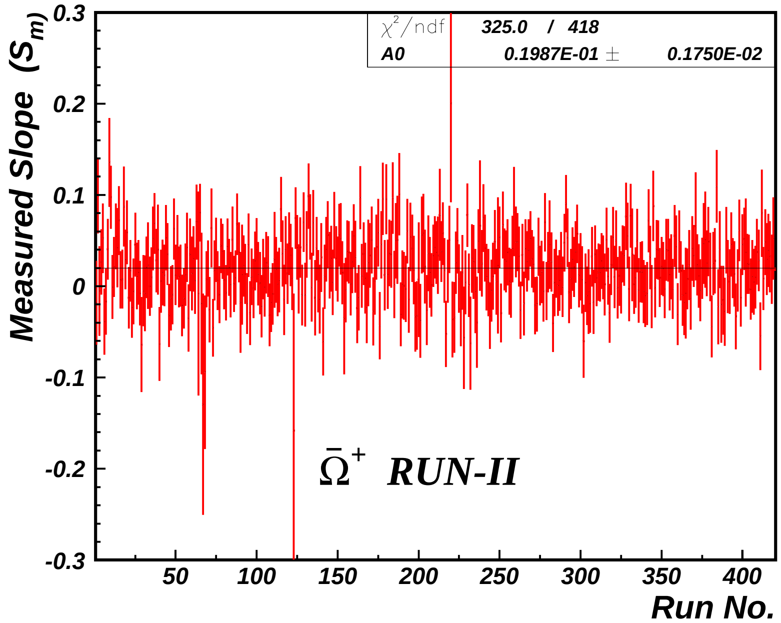




$$S_m = (1.41 \pm 0.11) \times 10^{-2}$$

- **$\bar{\Omega}^+$ from RUN-II**





$$S_m = (1.99 \pm 0.18) \times 10^{-2}$$

- **Anticipated Statistical Error from RUN-II Data**

- Ω^-: ~ 4.6 M events

$$\sigma(\alpha_\Lambda \alpha_\Omega) \approx 1.2 \times 10^{-3}$$
$$\sigma(\alpha_\Omega) \approx 1.9 \times 10^{-3}$$
$$\Downarrow$$

A factor of 2 better than RUN-I !!!

- $\bar{\Omega}^+$: ~ 1.9 M events

$$\sigma(\alpha_{\bar{\Lambda}} \alpha_{\bar{\Omega}}) \approx 1.8 \times 10^{-3}$$
$$\sigma(\alpha_{\bar{\Omega}}) \approx 2.8 \times 10^{-3}$$

- Will allow us to measure $\Delta(\alpha_\Lambda \alpha_\Omega)$ and asymmetry $A_{\Lambda\Omega}$

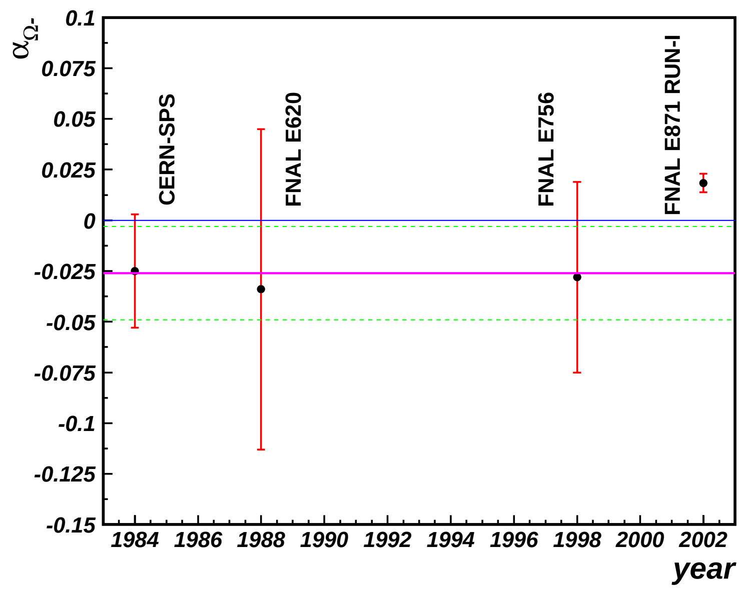
$$\Delta(\alpha_\Lambda \alpha_\Omega) \equiv \alpha_\Lambda \alpha_\Omega - \alpha_{\bar{\Lambda}} \alpha_{\bar{\Omega}}$$

$$A_{\Lambda\Omega} \equiv \frac{\alpha_\Lambda \alpha_\Omega - \alpha_{\bar{\Lambda}} \alpha_{\bar{\Omega}}}{\alpha_\Lambda \alpha_\Omega + \alpha_{\bar{\Lambda}} \alpha_{\bar{\Omega}}} \approx A_\Lambda + A_\Omega$$

at precisions of 2×10^{-3} and 9×10^{-2} respectively.

Conclusion

- With RUN-I data sample, our preliminary measurement of α_Ω is $\alpha_\Omega = [1.84 \pm 0.46\ (\mathrm{stat}) \pm 0.04\ (\mathrm{sys\ PDG})] \times 10^{-2}$. This is a significant improvement over previous results.



- First evidence that α_Ω is non-zero and hence of parity violation exists in $\Omega \to \Lambda K$ decays.

- A first look of RUN-II data indicates that α_Ω is consistent with the result from RUN-I data. RUN-II analysis will significantly improve the precision of the α_Ω measurement.

- We expect the precision of the measurement of $\Delta(\alpha_\Lambda \alpha_\Omega)$ in $\Omega \to \Lambda K$ decays to be $\sim 2 \times 10^{-3}$ (stat).