Measurement of Ξ^- Hyperons produced in (K^-, K^+) reaction at 1.8 GeV/c

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for the E42 Collaboration

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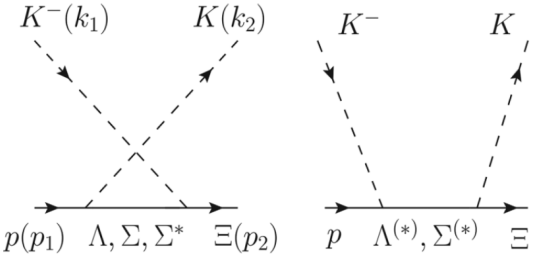
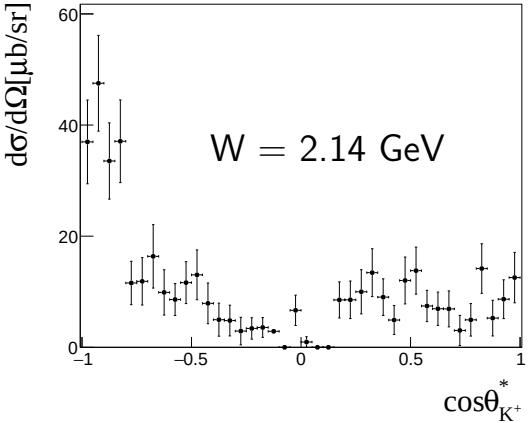
Properties of $K^- p \to K^+ \Xi^-$ Reaction



- In the absence of $S = 2$ meson, $t-$channel exchange is forbidden



Burgun et al., Nucl. Phys. B8, 447(1968)

Why Polarization?

$$\hat{M} = \begin{pmatrix} M_{++} & M_{+-} \\ M_{-+} & M_{--} \end{pmatrix}$$

$$\frac{d\sigma}{d\Omega} = \frac{1}{2}\mathrm{Tr}[\hat{M}\hat{M}^{\dagger}];$$

$$P_y \frac{d\sigma}{d\Omega} = \frac{1}{2}\mathrm{Tr}[\hat{M}\sigma_y\hat{M}^{\dagger}]$$

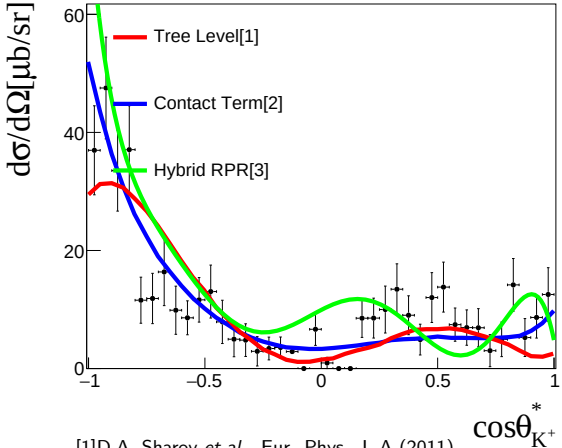
$$= 2\mathrm{Im}[M_{++}M_{+-}^{*} + M_{-+}M_{--}^{*}]$$

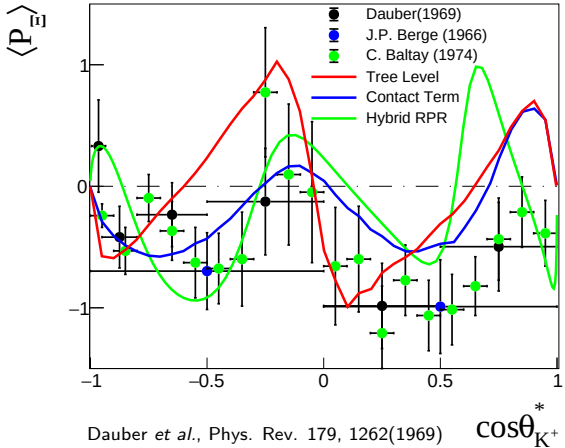
$$M_{++} = M_{--}; \quad M_{+-} = -M_{-+};$$

- Parity conservation in a strong process forbids polarization in x or z direction.
- Polarization shows the interaction of spin-flip and non-flip amplitude[1]

[1] BC Jackson. *et al*, Phys. Rev. C89, 025206(2014)

Theoretical Expectations for Elementary $K^- p \to K^+ \Xi$

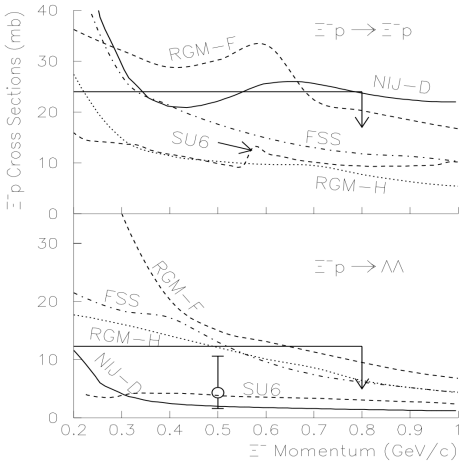




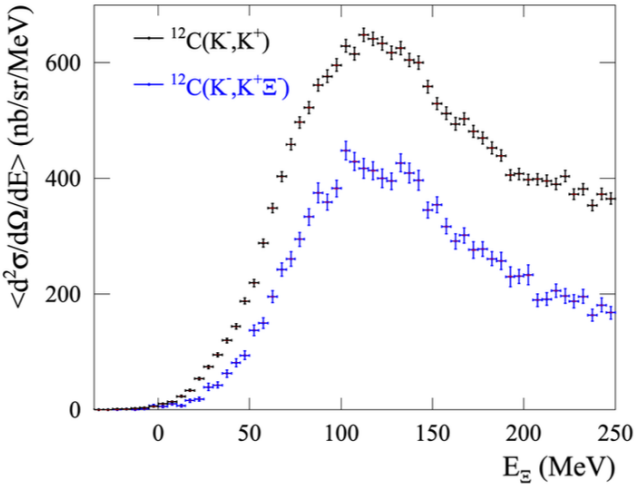
[1]D.A. Sharov *et al.*, Eur. Phys. J. A (2011)
[2]BC Jackson. *et al*, Phys. Rev. C91, 065208(2015)
[3]S. H. Kim *et al.*, Phys. Rev. C107, 065202(2023)

Dauber *et al.*, Phys. Rev. 179, 1262(1969)
J.P. Berge *et al.*, Phys. Rev. 147, 945 (1966)
C. Baltay *et al.*, Phys. Rev. D9, 49(1974)

Ξp Scattering

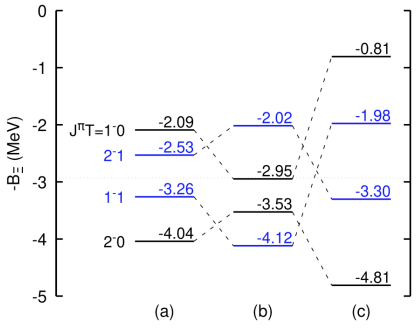


J.K. Ahn *et al.*, Phys. Lett. 633, 214-218 (2006)



W.S. Jung *et al.*, Prog. Theor. Exp. Phys., 9, ptaf064(2025)

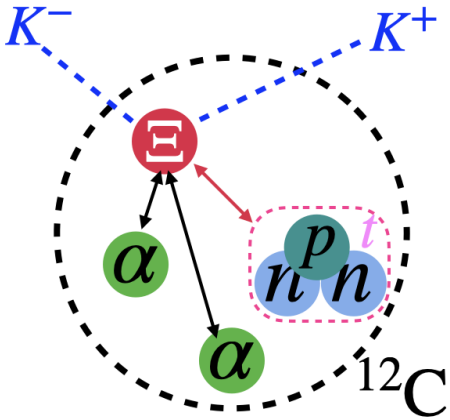
Spin Structure of $^{12}\mathrm{Be}_{\Xi}$



- Level structure of $^{12}\mathrm{Be}_{\Xi}$ arises from spin-isospin dependent term[1]

[1] Y Tanimura. *et al*, Phys. Rev. C105, 044324(2022)

$$V_{\Xi N} = V_0 + \sigma \cdot \sigma V_{\sigma\sigma} + \tau \cdot \tau V_{\tau\tau} + \sigma \cdot \sigma\tau \cdot \tau V_{\sigma\tau}$$

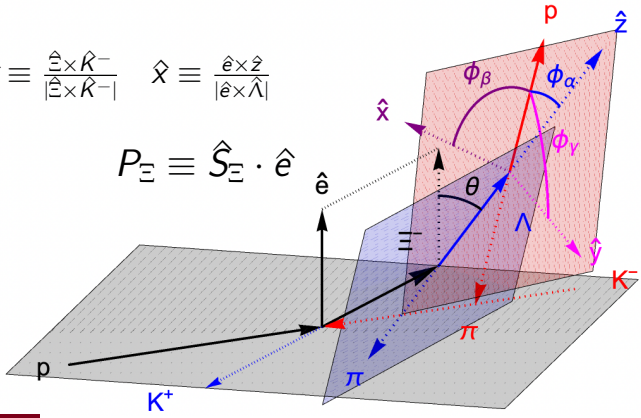


The Polarization Angles

$$I = 1 + \alpha_\Xi \vec{P}_\Xi \cdot \hat{\Lambda} + \alpha_\Lambda \hat{p} \cdot [(\alpha_\Xi + \vec{P}_\Xi \cdot \hat{\Lambda})\hat{\Lambda} + \beta_\Xi (\vec{P}_\Xi \times \hat{\Lambda}) + \gamma_\Xi \hat{\Lambda} \times (\vec{P}_\Xi \times \Lambda)]$$
$$= 1 + \alpha_\Xi P_\Xi \cos\theta + \alpha_\Lambda [(\alpha_\Xi + P_\Xi \cos\theta)\hat{p} \cdot \hat{z} + \beta P_\Xi \sin\theta \hat{p} \cdot \hat{x} + \gamma_\Xi P_\Xi \sin\theta \hat{p} \cdot \hat{y}]$$

$\hat{e} \equiv \frac{\hat{\Xi} \times \hat{K}^-}{|\hat{\Xi} \times \hat{K}^-|}$ $\quad \hat{x} \equiv \frac{\hat{e} \times \hat{z}}{|\hat{e} \times \hat{\Lambda}|}$

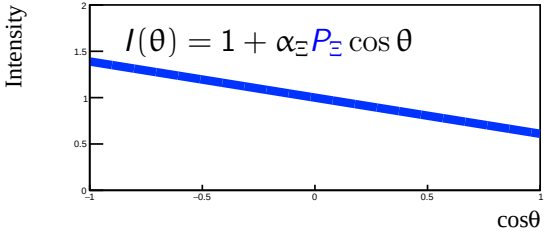
$P_\Xi \equiv \hat{S}_\Xi \cdot \hat{e}$

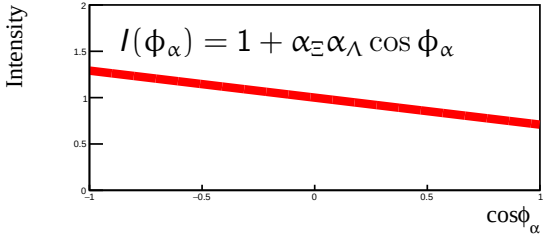


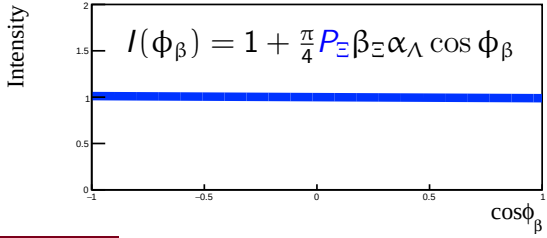
We need to measure...

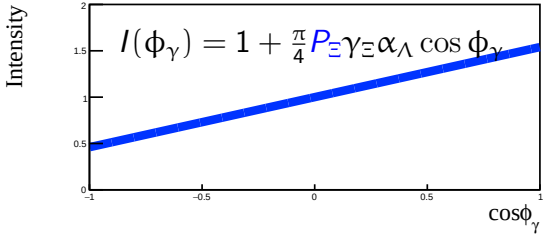
- θ, the angle between the reaction plane and Λ
- $\phi_{\alpha,\beta,\gamma}$, the proton angle in Λ rest frame.

Joint Decay Spectrum of a Polarized Ξ^-

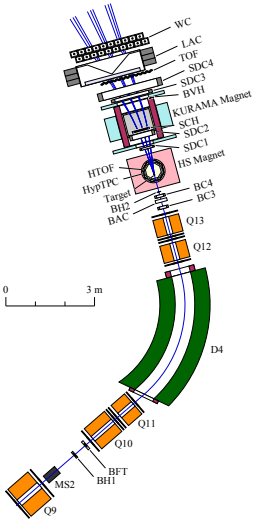








J-PARC E42 Experiment



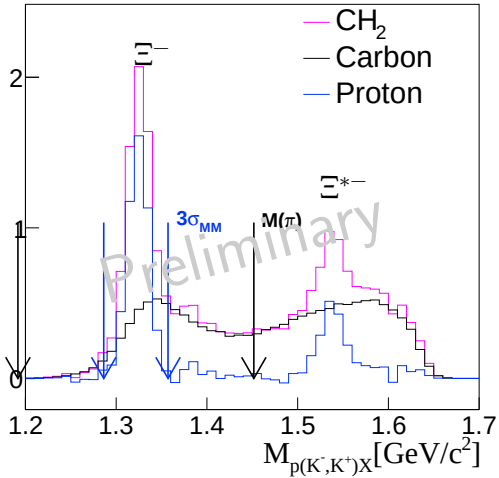
Ξ^- Polarization measurement requires...

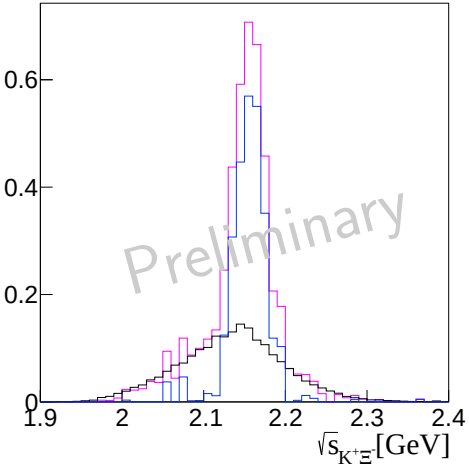
- Precise momentum measurement for all decay products in $p(K^-, K^+)\Xi^-$ event.
- Wide angular acceptance for decaying particles
- Good statistics to override previous data

	P_{K^-}	Target	Detector	$N_\Xi(\cos\theta^*_{K^+} > 0.85)$
Berge	1.7 GeV/c	LH_2	BC	13
Dauber	1.7 GeV/c	LH_2	BC	~20
Baltay	1.75 GeV/c	LH_2	BC	~ 200
E42	1.8 GeV/c	CH_2	TPC	~ 800
E42	1.8 GeV/c	^{12}C	TPC	~ 32,000

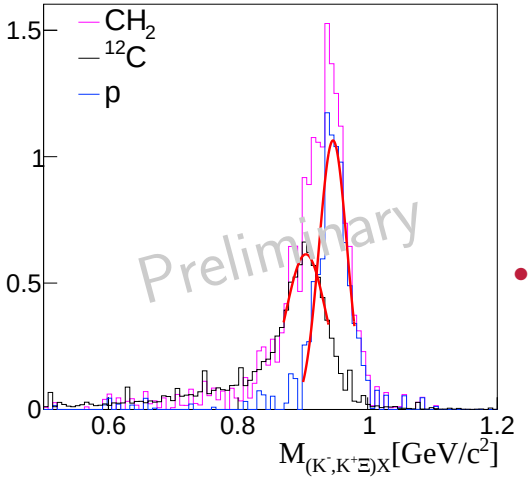
J-PARC E42 meets the requirement!

$(K^-, K^+\Xi)$ Events


CH2
Carbon
Proton
Ξ−
Ξ*−
3σMM
M(π)
Preliminary
2
1
0
1.2
1.3
1.4
1.5
1.6
1.7
M p(K-,K+)X [GeV/c2]


Preliminary
0.6
0.4
0.2
0
1.9
2
2.1
2.2
2.3
2.4
√s K+Ξ- [GeV]

p in ^{12}C

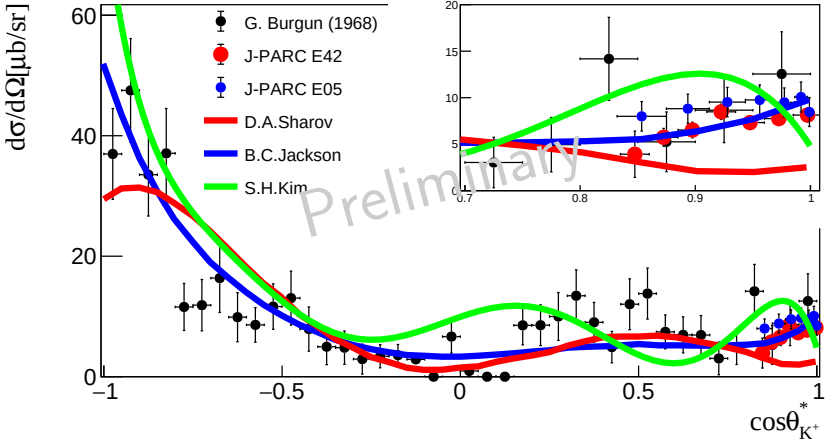


Target	Mass [MeV/c^2]	σ [MeV/c^2]
Free Proton	946.0 ± 1.8	16.3 ± 2.5
Proton(^{12}C)	904.55 ± 0.40	29.20 ± 0.64

c.f. $m_p = 938.272$ MeV/c^2

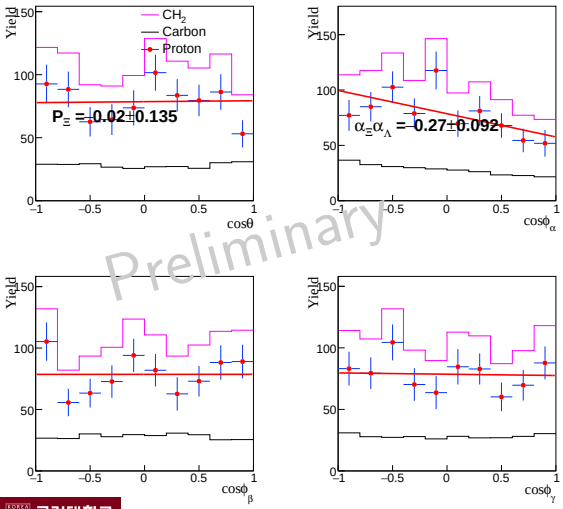
- Proton mass can be extracted from the missing mass of $X(K^-, K^+\Xi)$.

Preliminary Results on $p(K^-, K^+)\Xi^-$ Differential Cross Section



[1] Y. Ichikawa et al., Prog. Theor. Phys. **2024** 091D01 (2024).

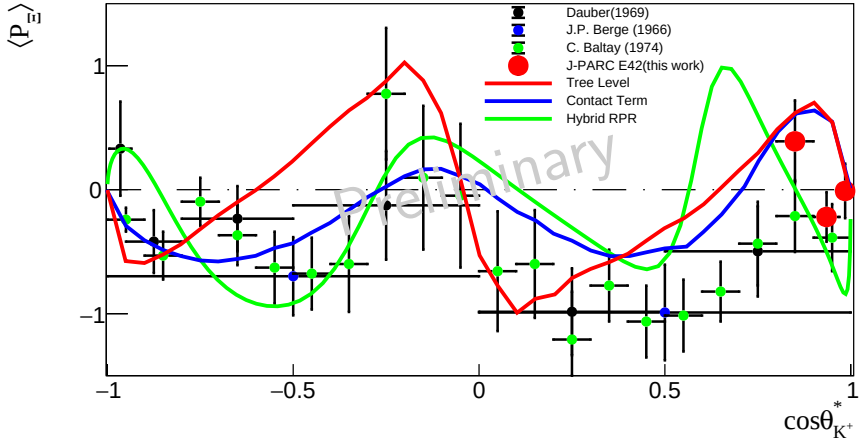
Preliminary Results on P_Ξ in $p(K^-, K^+)\Xi$



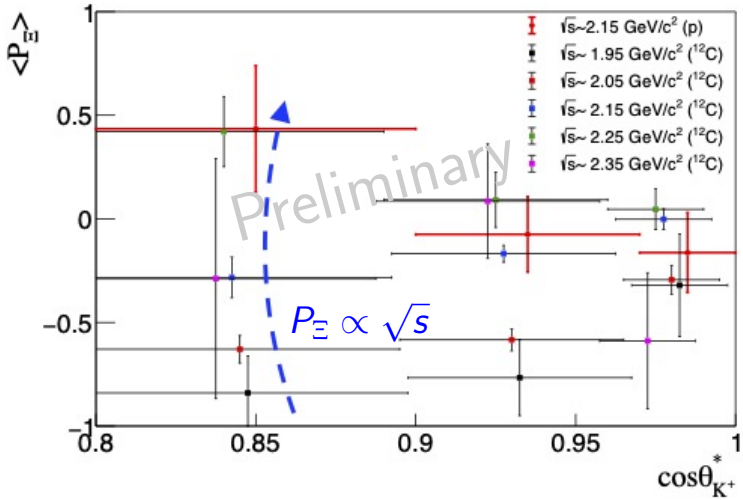
$$\begin{cases} I(\theta) = 1 + \alpha_\Xi P_\Xi \cos\theta \\ I(\phi_\alpha) = 1 + \alpha_\Xi \alpha_\Lambda \cos\phi_\alpha \\ I(\phi_\beta) = 1 + \frac{\pi}{4} P_\Xi \beta_\Xi \alpha_\Lambda \cos\phi_\beta \\ I(\phi_\gamma) = 1 + \frac{\pi}{4} P_\Xi \gamma_\Xi \alpha_\Lambda \cos\phi_\gamma \end{cases}$$

- Measured $\alpha_\Xi \alpha_\Lambda = -0.27 \pm 0.092$(cf. PDG value = -0.291 $\pm$ 0.0063).

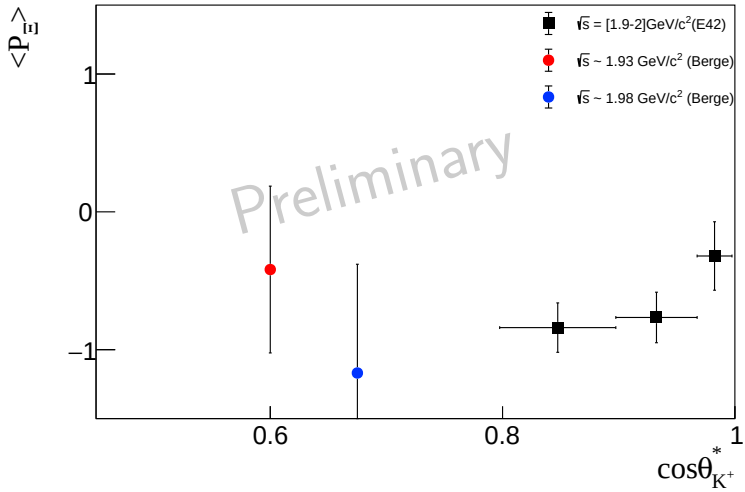
Preliminary Results on P_Ξ in $p(K^-, K^+)\Xi$



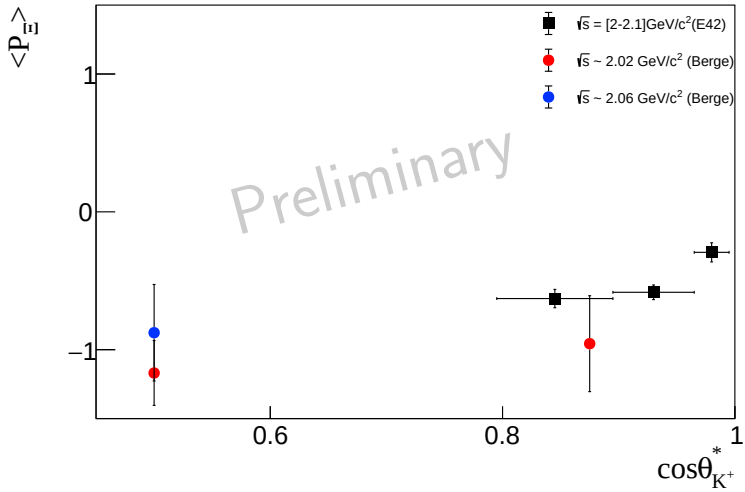
Preliminary Results on P_Ξ in $^{12}\mathrm{C}(K^-, K^+\Xi)$



Comparison With Old HBC Data



Comparison with old HBC data



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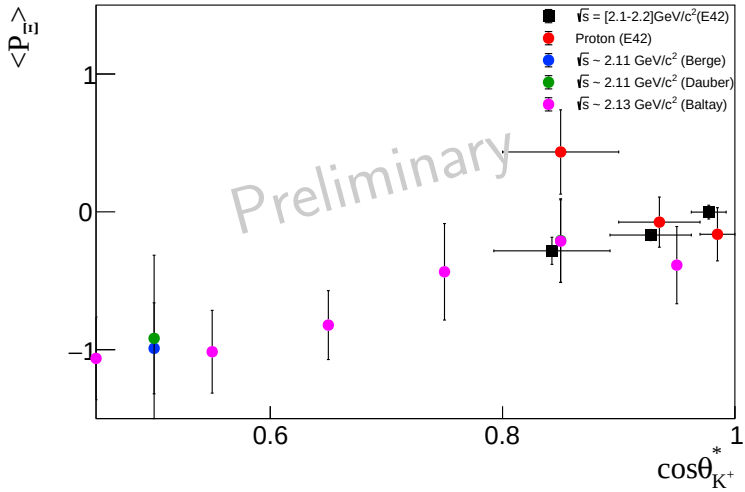
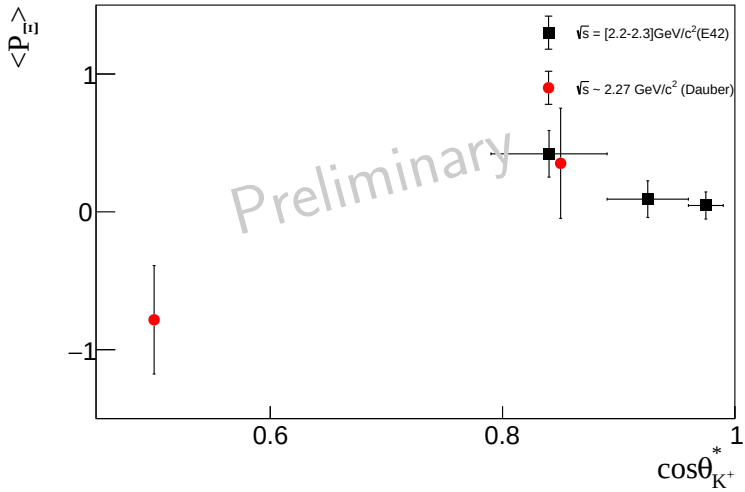
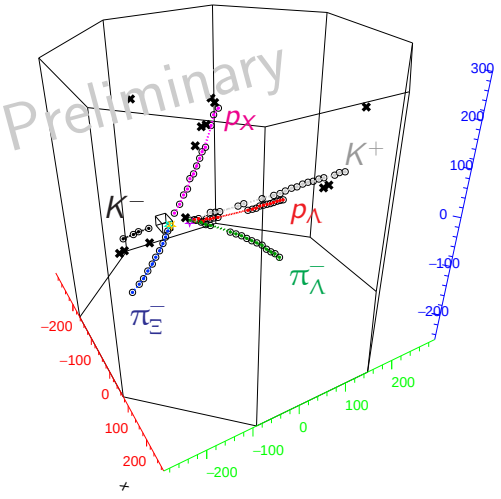
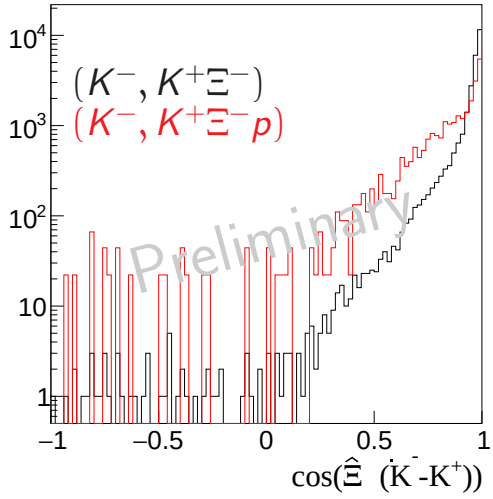


Comparison With Old HBC Data



$^{12}\mathrm{C}(K^-, K^+\Xi X)$



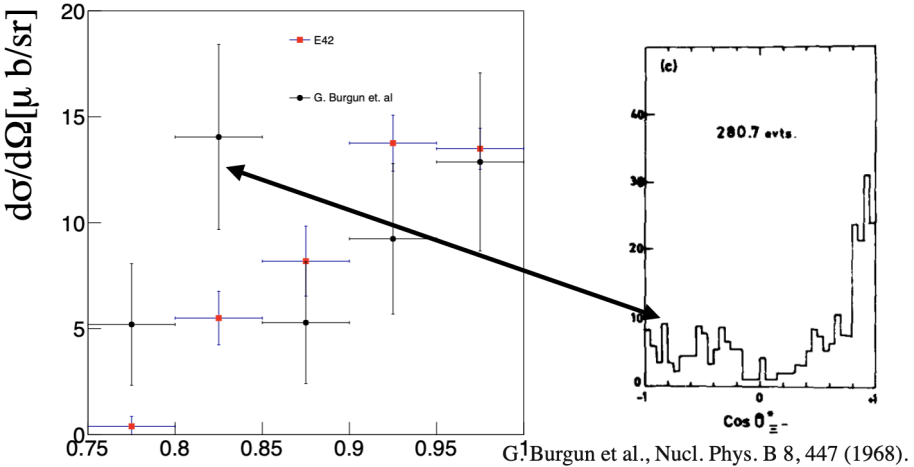


Summary

- Ξ^- production reaction is an excellent test bench to study strange hyperons in KY^*N and $KY^*\Xi$ vertices
- Polarization measurement is essential to investigate the nuclear structure and potential of Ξ hypernuclei.
- Drastic $\sqrt{s}$ dependence of P_Ξ in the forward region is observed in the Ξ produced in $^{12}\mathrm{C}$
- ΞN Scattering can be investigated through E42 data

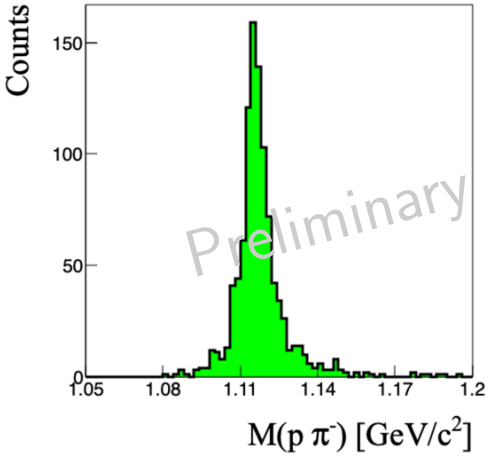
BACKUP

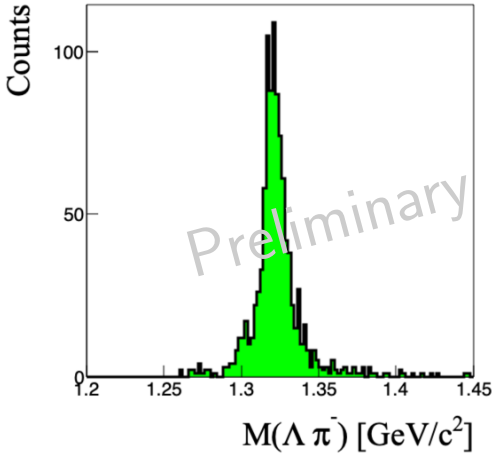
Diffrential CrossSection from Previous Data



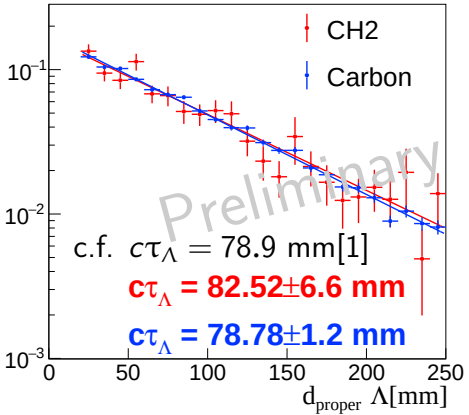
G. Burgun et al., Nucl. Phys. B 8, 447 (1968).

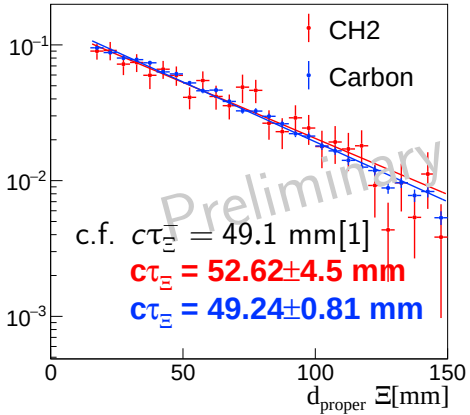
Ξ^- and Λ Invariant Mass





Lifetime Measurements





[1] P.A. Zyla et al. (Particle Data Group), Prog. Theor. Exp. Phys. 2020, 083C01 (2020)