CSUDH CALIFORNIA STATE UNIVERSITY, DOMINGUEZ HILLS

# Hyperon Beams in Modern Baryon Spectroscopy


*John Price*

*California State University, Dominguez Hills*


*HAW 2023*

*27 November 2023*

U.S. DEPARTMENT OF ENERGY | Office of Science

# Outline

- Motivation
- Feasibility
- Data Mining with CLAS
- $\Lambda p$ Elastic Scattering
  - Analysis details
  - Cross section calculation plans
- Physics with “tertiary” beams
- Conclusion

# The Group

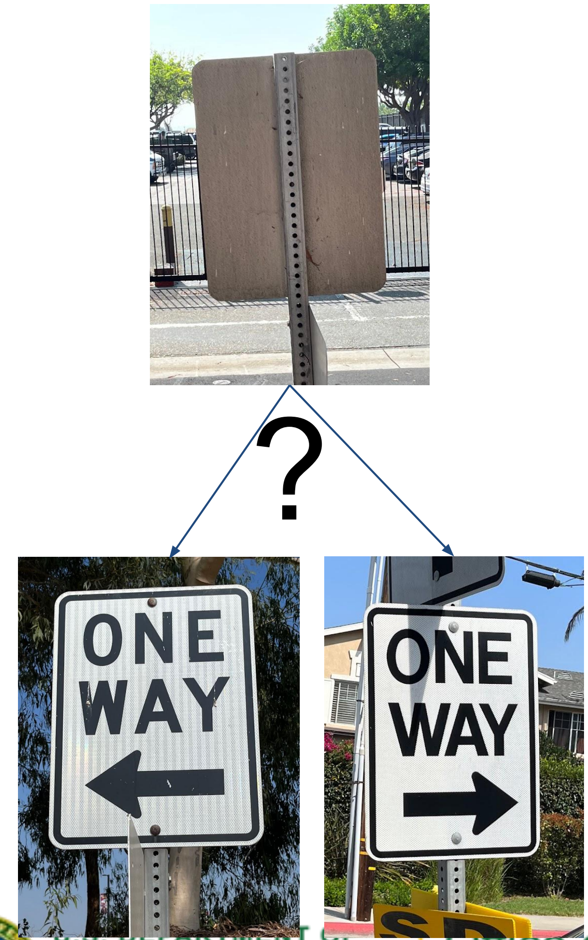
- JWP (PI)
- Current UG students
  - Jose Fabian Rodriguez ($pp \to pp$)
  - Matthew Kuljis ($\Lambda p \to \Lambda p$)
  - Anthony Scott ($K_S p \to K_S p$)
  - Athena Tran (simulations)
- Recent graduates
  - Dylan Nicholas (MS)
  - Gania Figueroa
  - Reina Morales
  - Noraim Nuñez ($\Lambda p$ poster at HYP18)

# Introduction

- Why hyperon beams?
  - Different beam-target combinations look at the particles from a different “view”
  - Imagine the proton is a traffic sign

# Introduction

- Why hyperon beams?
  - Different beam-target combinations look at the particles from a different "view"
  - Imagine the proton is a traffic sign
  - The wrong view can lead to very bad results
  - We don't know which beam particle will give us the view we need
    - We need to try everything we can



# Motivation

- “Because it’s there”
  - So many people told me it was impossible

# Motivation

- “Because it’s there”
  - So many people told me it was impossible
- Hyperon puzzle
- $SU(3)_F$ symmetry

# Channeling George Mallory

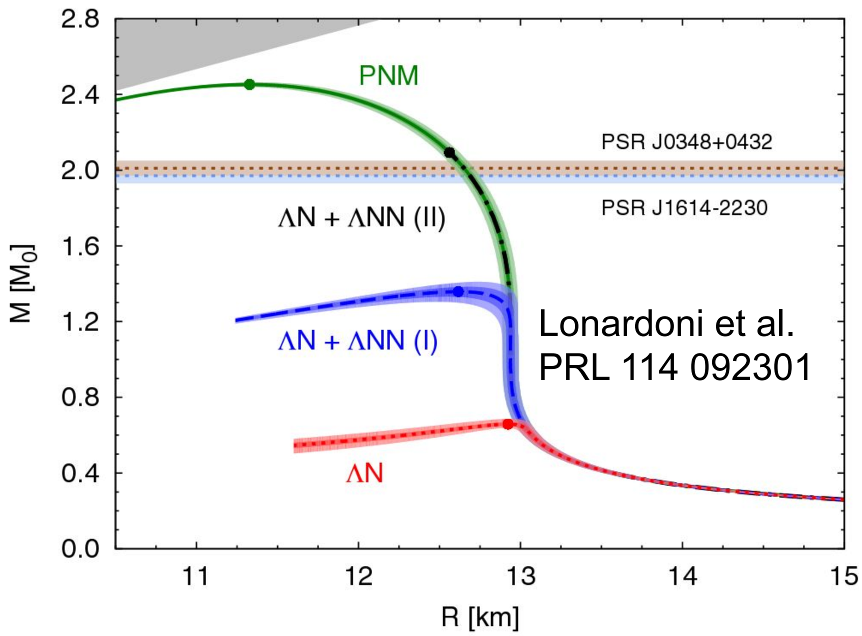
- We do this “because it’s there”
- There’s a value to “stunts”
  - Push the boundary of what we can and can’t do
  - Even if there were no good reason to look
- Today’s analysis “techniques” were yesterday’s “tricks”
  - Tomorrow, it will be a background we’ll have to suppress...

# Hyperon Puzzle

- Ask the theorists/ astrophysicists for the “real” answer

# Hyperon Puzzle

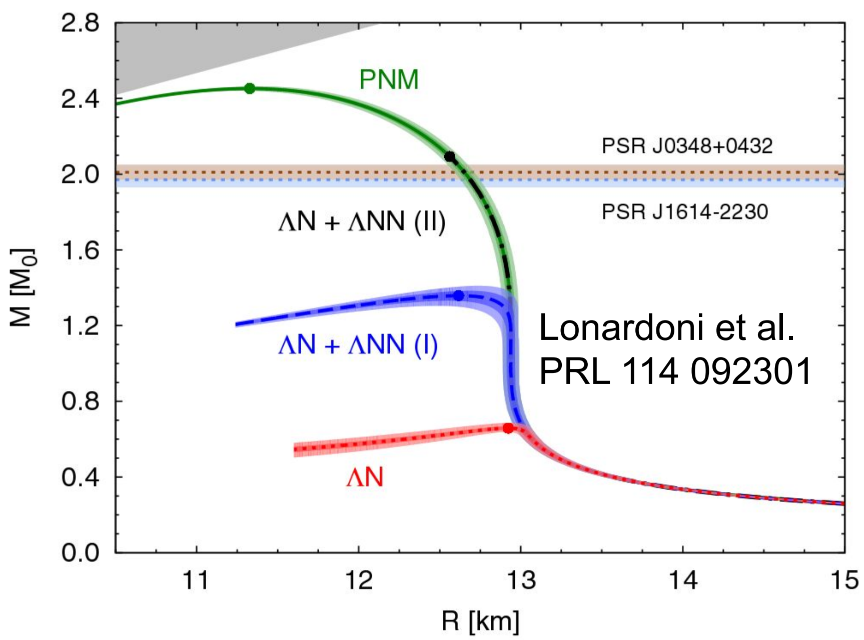
- Ask the theorists/ astrophysicists for the “real” answer



CSUDH CALIFORNIA STATE UNIVERSITY, DOMINGUEZ HILLS

# Hyperon Puzzle

- Ask the theorists/ astrophysicists for the “real” answer
- From the experimentalist’s point of view, though...

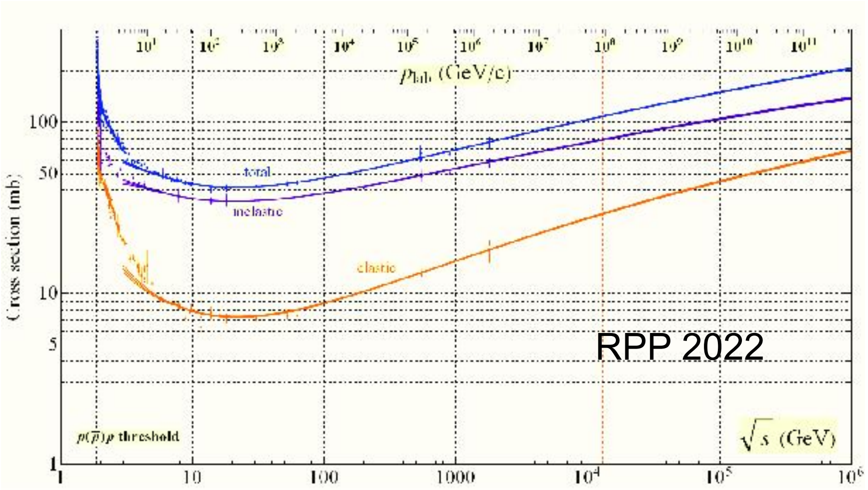



Lonardoni et al.
PRL 114 092301

U.S. DEPARTMENT OF ENERGY Office of Science

# Hyperon Puzzle

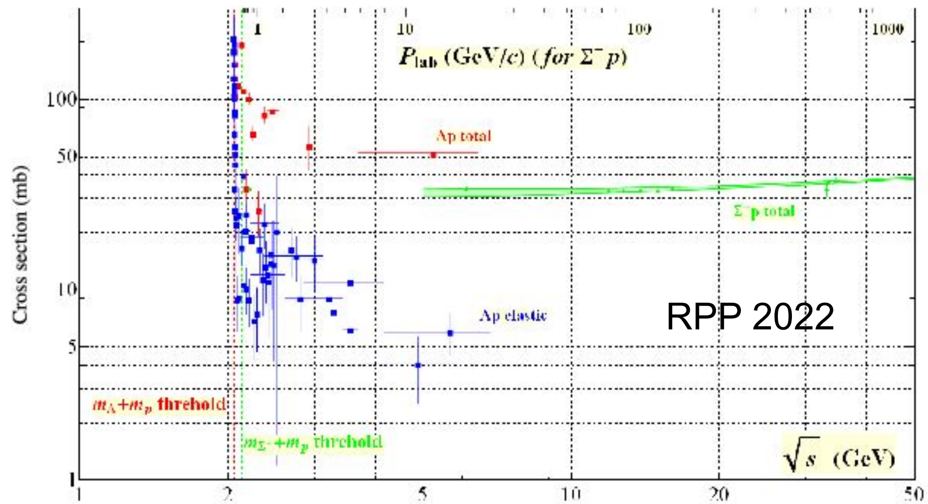
- Ask the theorists/ astrophysicists for the “real” answer
- From the experimentalist’s point of view, though...




$$pp \rightarrow pp$$

# Hyperon Puzzle

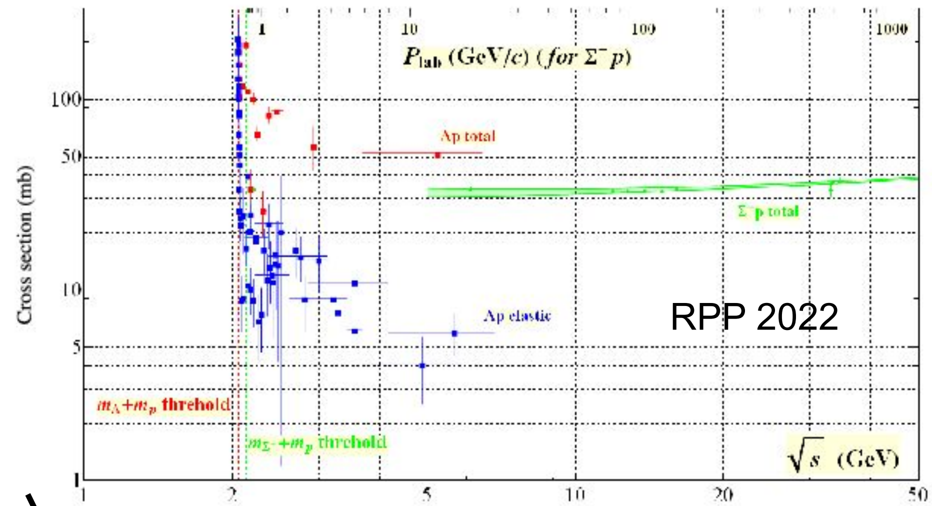
- Ask the theorists/ astrophysicists for the “real” answer
- From the experimentalist’s point of view, though…
- 13 measurements, ~1500 total events




$$\Lambda p \rightarrow \Lambda p$$

# Hyperon Puzzle

- Ask the theorists/ astrophysicists for the “real” answer
- From the experimentalist’s point of view, though…
- 13 measurements, ~1500 total events




$\Lambda p \rightarrow \Lambda p$

We need more/better data!

# $SU(3)_F$ Symmetry

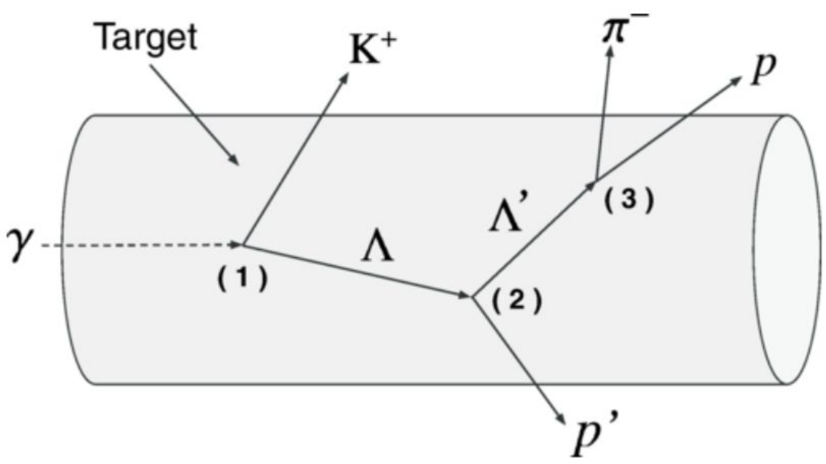
- $\sigma(\Lambda p \rightarrow \Lambda p)$ "should be" related to $\sigma(pp \rightarrow pp)$
- "Additive Quark Model" ca. 1965 (Levin & Frankfurt)

$$\sigma_{\Lambda p} = \frac{1}{2}\left(\sigma_{pp} + \sigma_{\Xi p}\right)$$

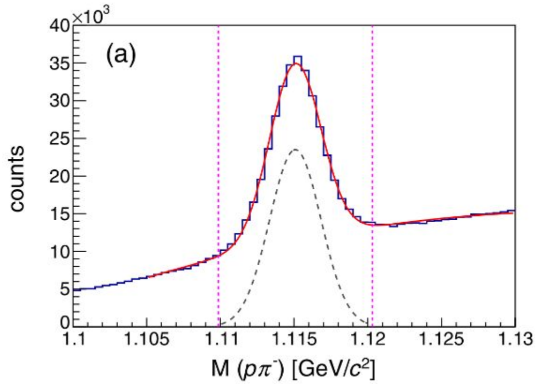
- We don't really have sufficient data to test
- Probably not "right"; just as probably not "wrong"
  - Useful as a starting point, at least...

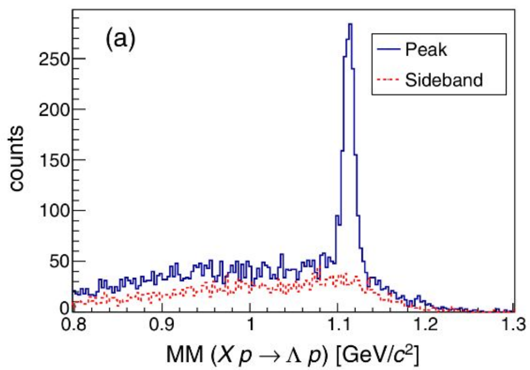
# Event Topology

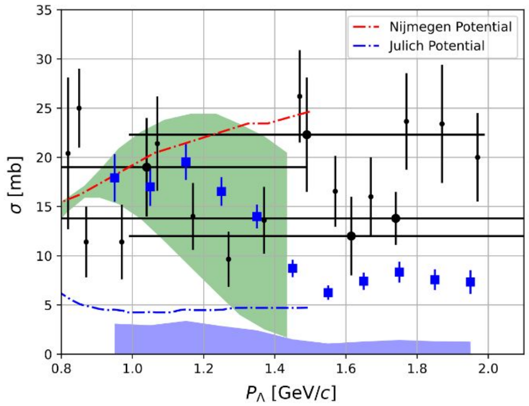
- Basic process:
  - $\gamma p \to K^+\Lambda$;
    $\Lambda p \to \Lambda p$;
    $\Lambda \to \pi^- p$
  - Final state: $K^+\pi^- pp$
- Can reconstruct $K^+$
- Helps to reduce the background



# Recent Results: $\Lambda p \rightarrow \Lambda p$



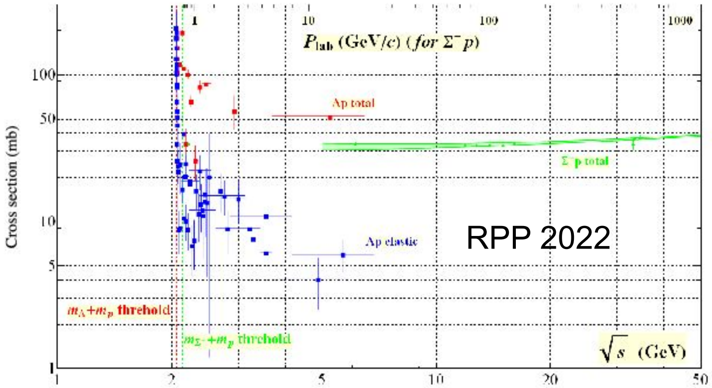

- Results from CLAS g12 run
- J. Rowley *et al.*, PRL 127, 272303 (2021).
- Used $K^+$ to aid in detection of beam $\Lambda$

# Inclusively-produced short-lived beams

- $\Lambda p \rightarrow \Lambda p$; $\Lambda \rightarrow \pi^{-} p$ is kinematically overdetermined
  - We don't "need" the initial $\gamma p \rightarrow K^{+} \Lambda$ process
- Cross section determination is complicated
  - Beam normalization must be done *in situ*
  - Target thickness requires some work

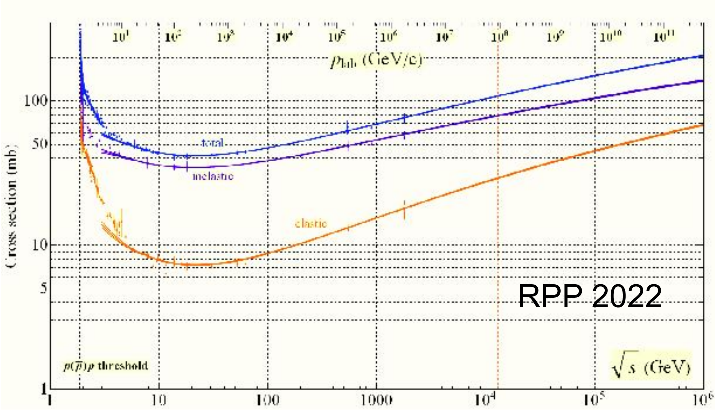
# Inclusively-produced short-lived beams

- $\Lambda p \to \Lambda p$; $\Lambda \to \pi^- p$ is kinematically overdetermined
  - We don't "need" the initial $\gamma p \to K^+ \Lambda$ process
- Cross section determination is complicated
  - Beam normalization must be done *in situ*
  - Target thickness requires some work
- Need to verify method using high-quality data
  - $\Lambda p \to \Lambda p$ data sample insufficient



# Inclusively-produced short-lived beams

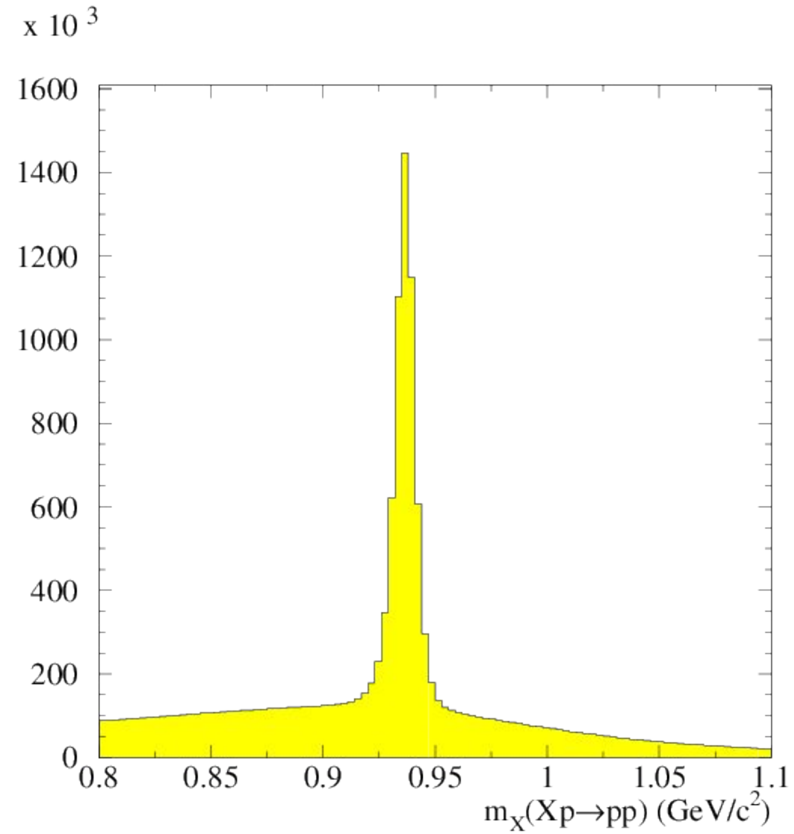
- $\Lambda p \to \Lambda p$; $\Lambda \to \pi^- p$ is kinematically overdetermined
  - We don't "need" the initial $\gamma p \to K^+ \Lambda$ process
- Cross section determination is complicated
  - Beam normalization must be done *in situ*
  - Target thickness requires some work
- Need to verify method using high-quality data
  - $\Lambda p \to \Lambda p$ data sample insufficient
  - use $pp \to pp$ instead



# *pp* Elastic Scattering

$$\gamma p \to Xp;\ pp \to pp$$

Many available events in g11



# Luminosity Calculation

Start with generic cross section equation

$$\sigma = \frac{N_e}{N_b N_t A\eta} = \frac{N_e}{\mathcal{L} A\eta}$$

$N_b$ usually provided by accelerator

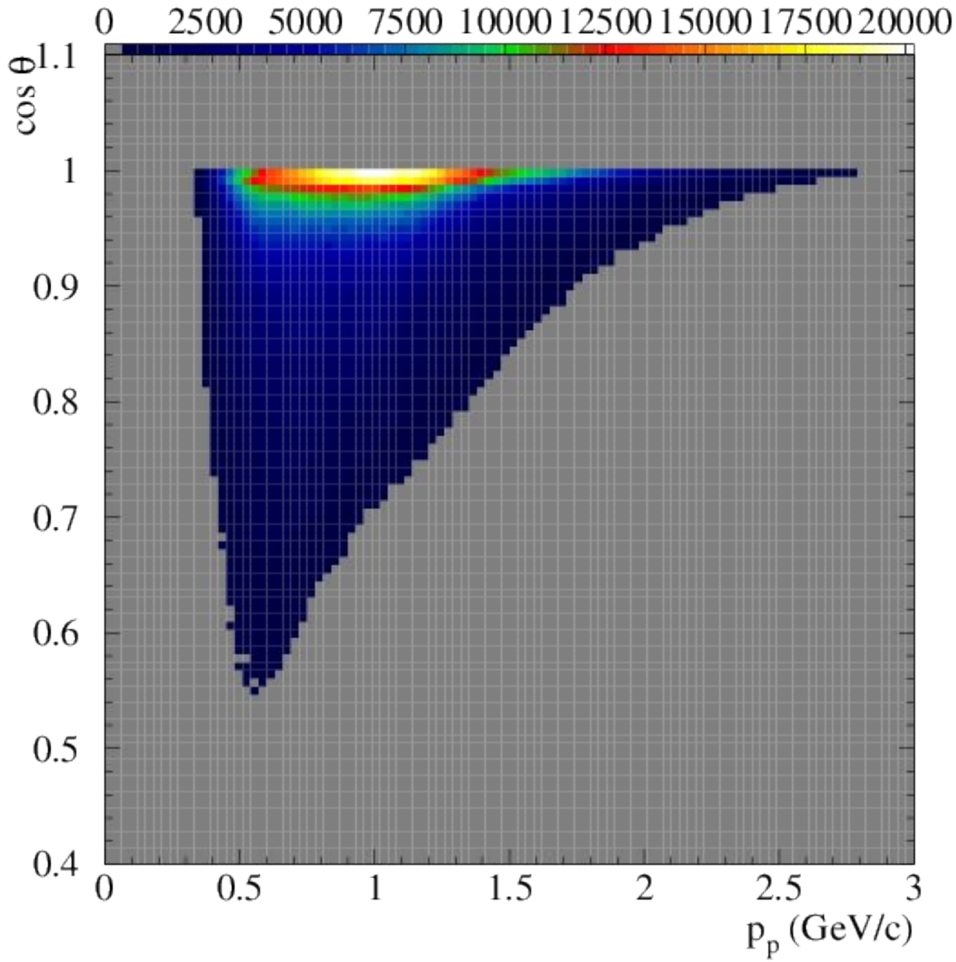
- Not valid for our “tertiary” beam
  - Electron -> Photon -> Proton

$N_t$ given by target length

- Not valid for particles not traveling along beamline
- ...or particles that decay (but that’s later…)

# Calculating $N_b$

- Plot proton angle vs. momentum
- Determine bins to get decent statistics in beam mass plot
- Produce same plot with single-proton events
- Events in each bin is $N_b$



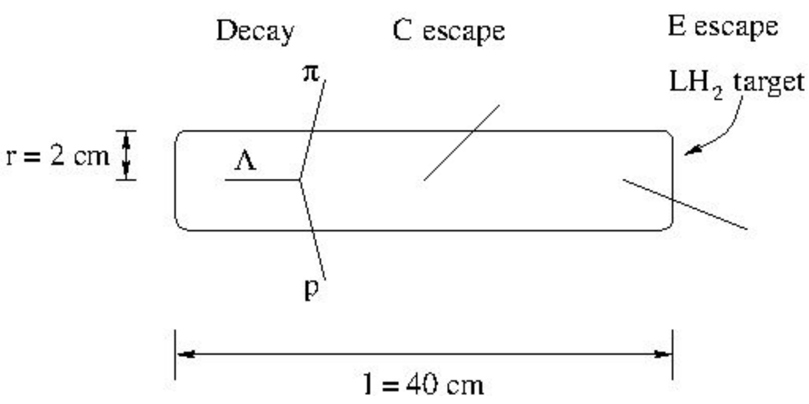
# Calculating $N_t$

Based on the “effective” target length

Primary beam particles see the whole target

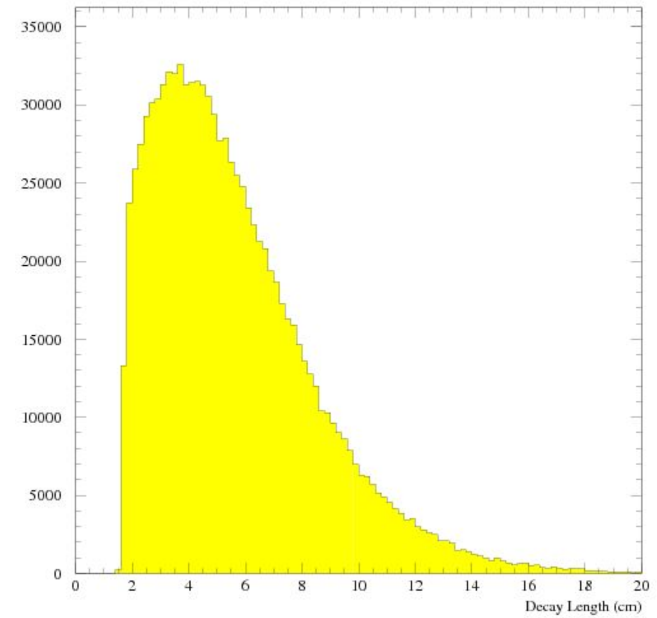
Our particles don’t

- decay $\ell_d$ (for short-lived particles)
- escape out cylindrical wall $\ell_c$
- escape out endcap $\ell_e$



# Calculating $\ell_d$

- Mean path given by $\ell_d = \beta\gamma c\tau$
- Faster-moving $\Lambda$s live longer in the lab frame
  - Contribute to a higher luminosity
  - Typically at smaller angles
- Here, assume target is infinite in extent



# Calculating $\ell_c$

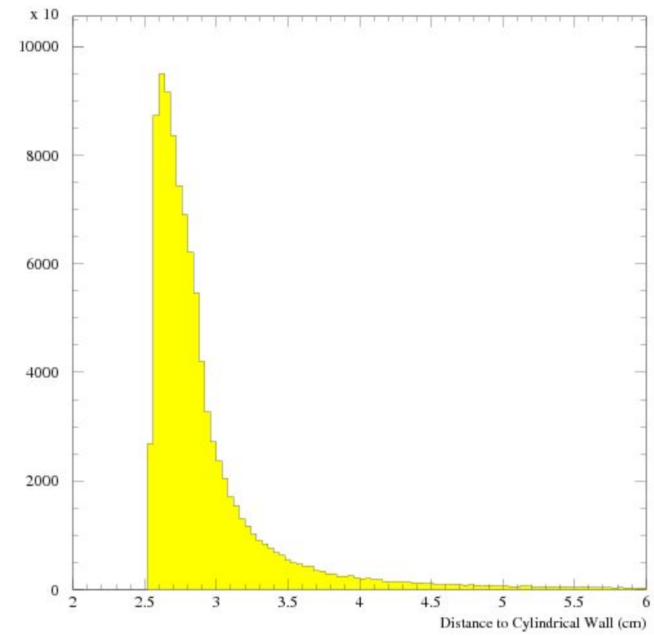
Mean path given by

$$\ell_c = r_{tgt} / \sin\theta_\Lambda$$

In $g11$ run, few particles at "large" angles

- up to ~50°
- shortest path length is about 30% longer than target radius

Here, assume particle does not decay, target is infinitely long



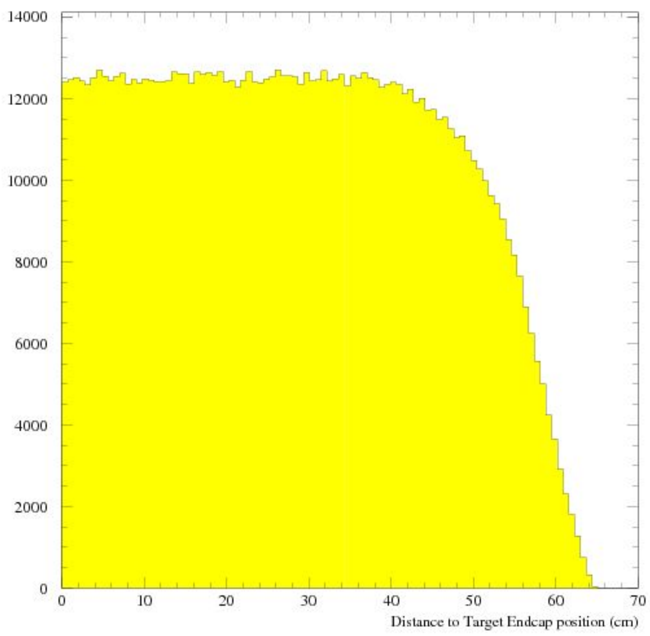
# Calculating $\ell_e$

Mean path given by

$$\ell_e = r_{tgt} / \cos\theta_\Lambda$$

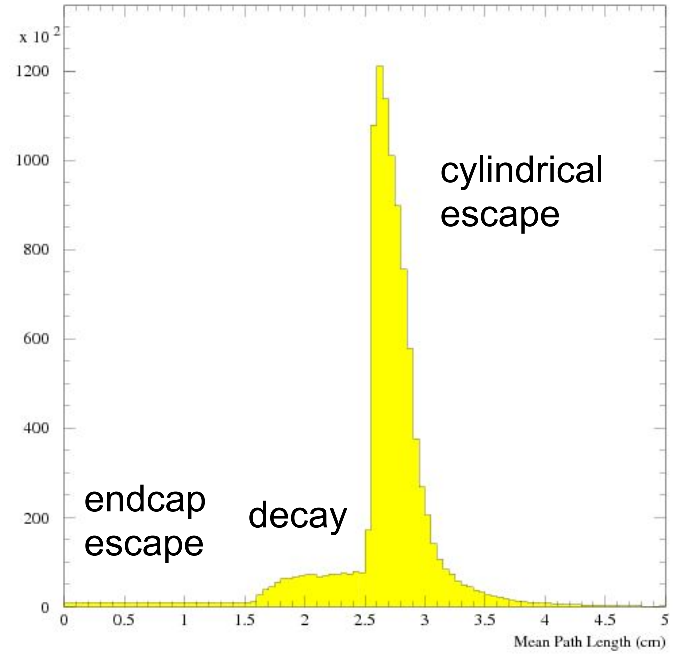
Happens when beam particle is produced near the end of the target

Here, assume particle does not decay, target has infinite radius (leads to lengths longer than target size)



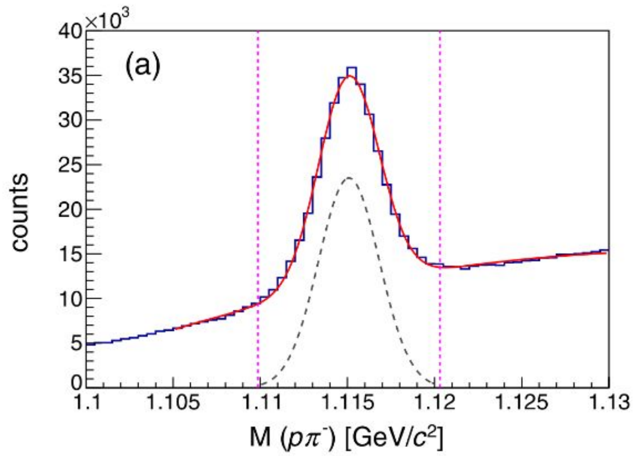
# Mean Beam Path Length

- Plot $min(\ell_d, \ell_c, \ell_e)$
- Determine mean path length event by event
- Sum over all events to get total path length through target
  - Use to calculate $N_t$

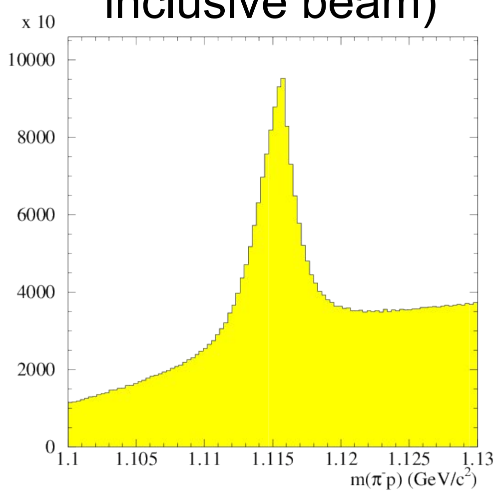


# $\Lambda p$ Scattering Progress

Rowley *et al.* ($g12$)

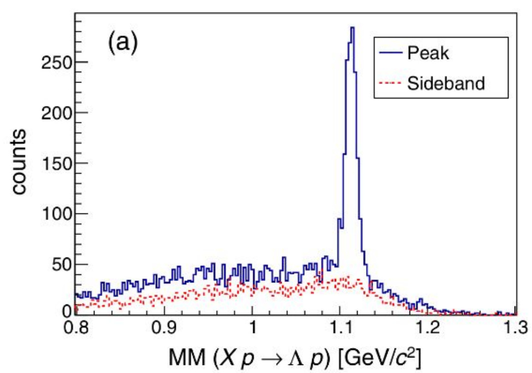



This work ($g11$, inclusive beam)

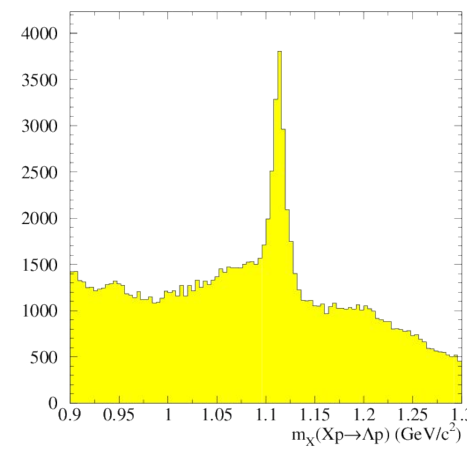


# $\Lambda p$ Scattering Progress

Rowley *et al.* ($g12$)
(required $K^+$)

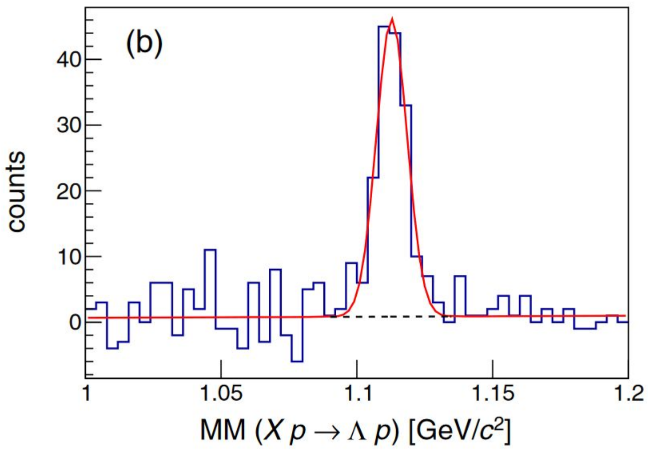



This work ($g11$,
inclusive beam)

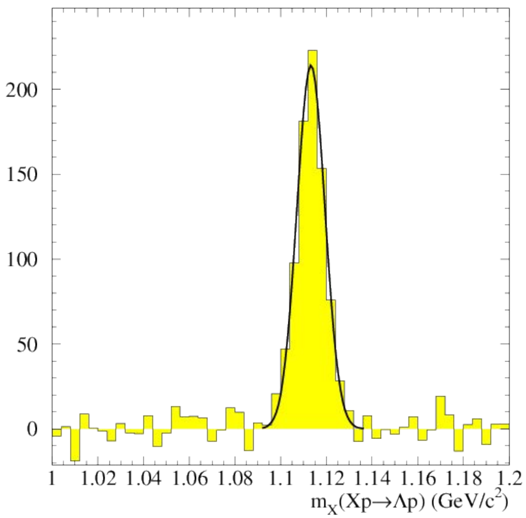


# $\Lambda p$ Scattering Progress

Rowley *et al.* ($g12$)




This work ($g11$, inclusive beam)



# $K_s p$ Scattering Progress

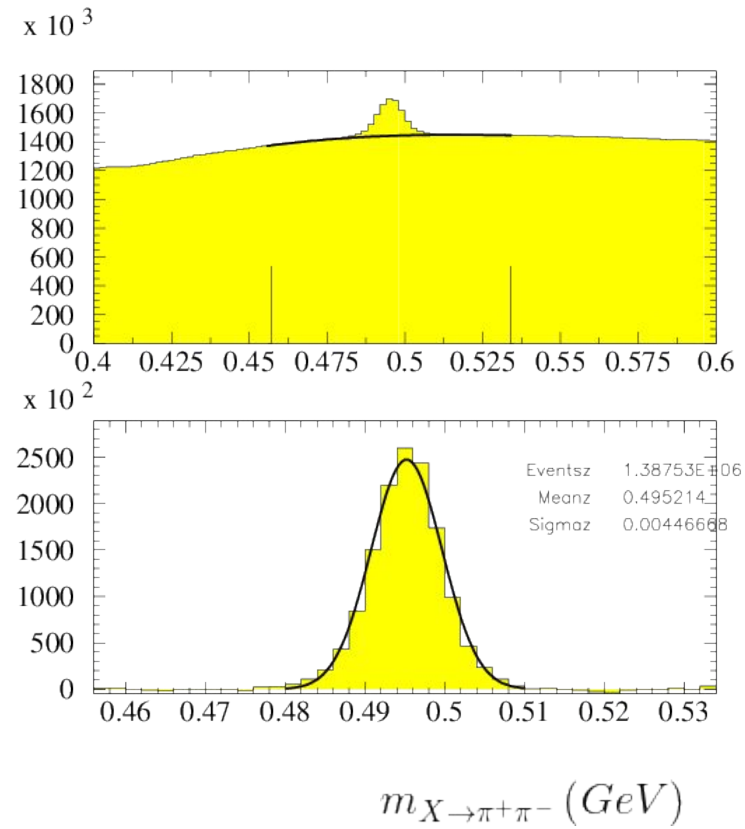
$$\gamma p \to K^0 \Sigma^+;$$

$$K^0 p \to K^0_s p$$

Final state: $\pi^+\pi^- pp(\pi^0)$

Harder; need to subtract $K^0_L$ contribution, many backgrounds

Only 1 previous expt.



# Other possibilities

This technique is not limited to $\Lambda$, $K_S$ studies

Any particle produced in sufficient quantities can (in principle) be used

- Having a second proton in the event reduces the background considerably

# Future work

Basically, "calculate the cross section"...

- Bin the events by $p_{beam}$ and $\theta_{beam}$
- Get $N_b$, $N_t$
- Simulate the acceptance

Currently underway for $pp$, $\Lambda p$ processes

Still isolating signal for $K_S p$

# Conclusion

We have observed $\Lambda p \rightarrow \Lambda p$ in two independent CLAS datasets

There are many more that we can look at…

We are making good progress at understanding the luminosity

We have observed a strong signal for $pp \rightarrow pp$

We are well on our way to demonstrating the feasibility of using secondary (tertiary) beams in CLAS