CSUDH CALIFORNIA STATE UNIVERSITY, DOMINGUEZ HILLS

Λp Elastic Scattering in CLAS

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Outline

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

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The Group

- CSUDH: JWP, Noraim Nunez
  - recent graduates: Marcos Guillen, Juan Cardenas, Hector Carranza
- Ohio University: Ken Hicks, Joey Rowley
- Always looking for more...

Motivation

- Hyperon puzzle
- $SU(3)_F$ symmetry

Motivation

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

Hyperon Puzzle

- Ask the theorists/ astrophysicists for the "real" answer

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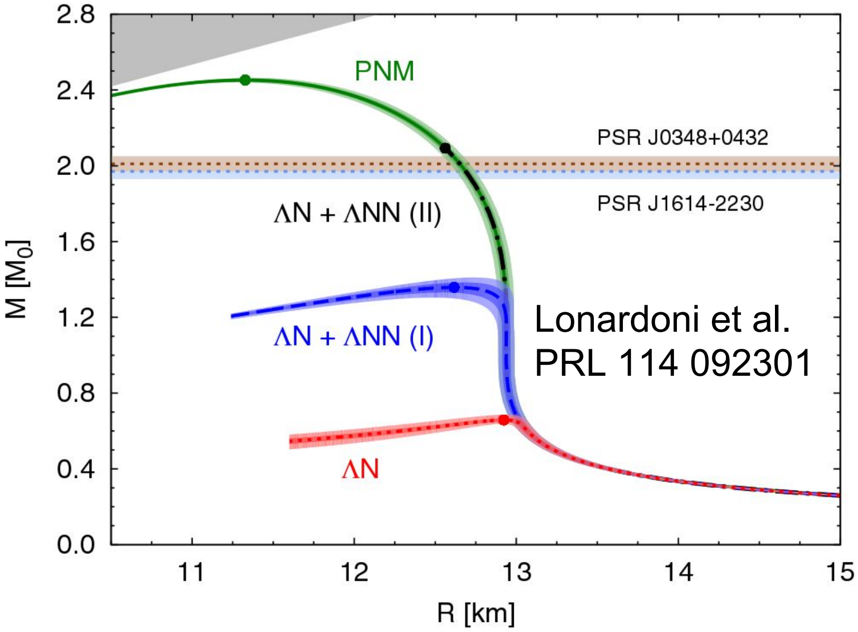
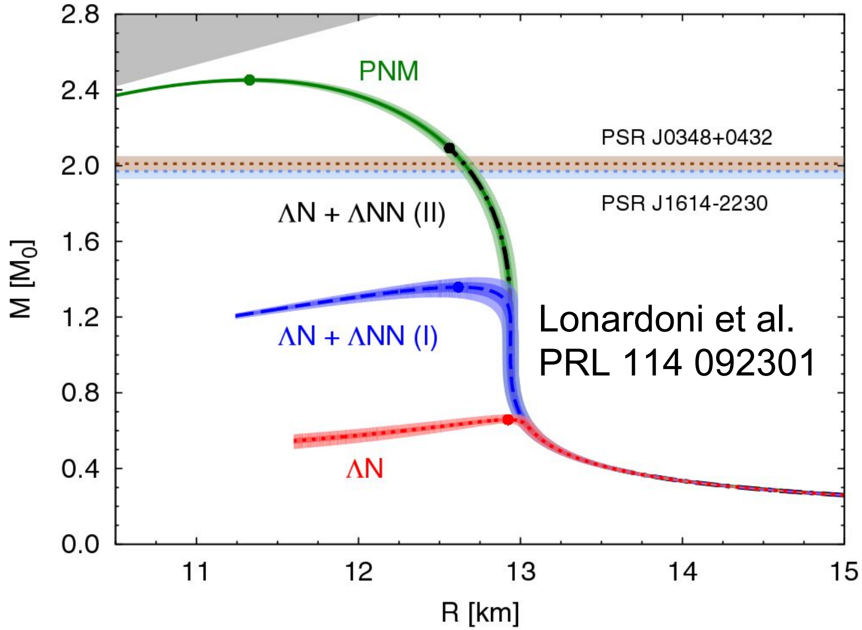


Lonardoni et al. PRL 114 092301

Hyperon Puzzle

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



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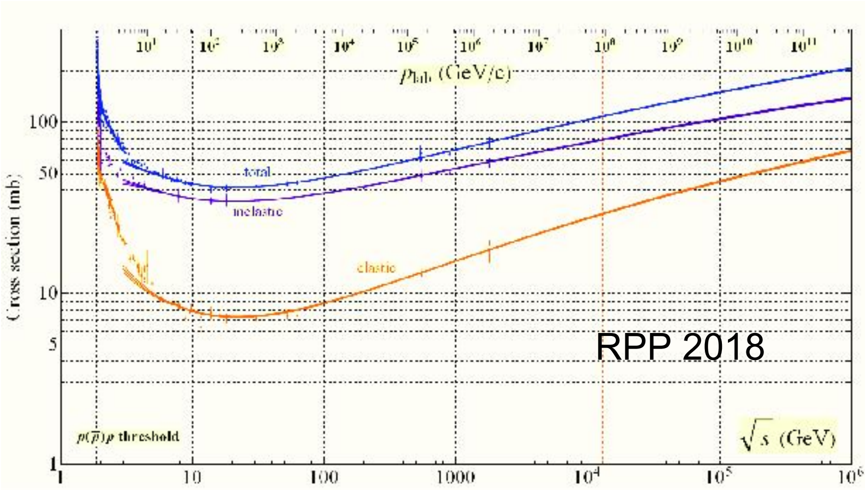
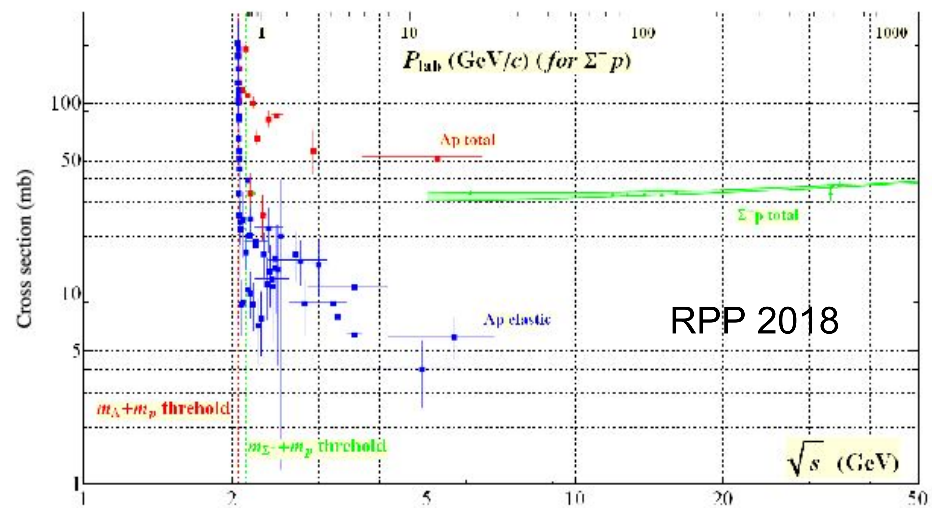


pp→pp

Hyperon Puzzle

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



Λp→Λp

Hyperon Puzzle

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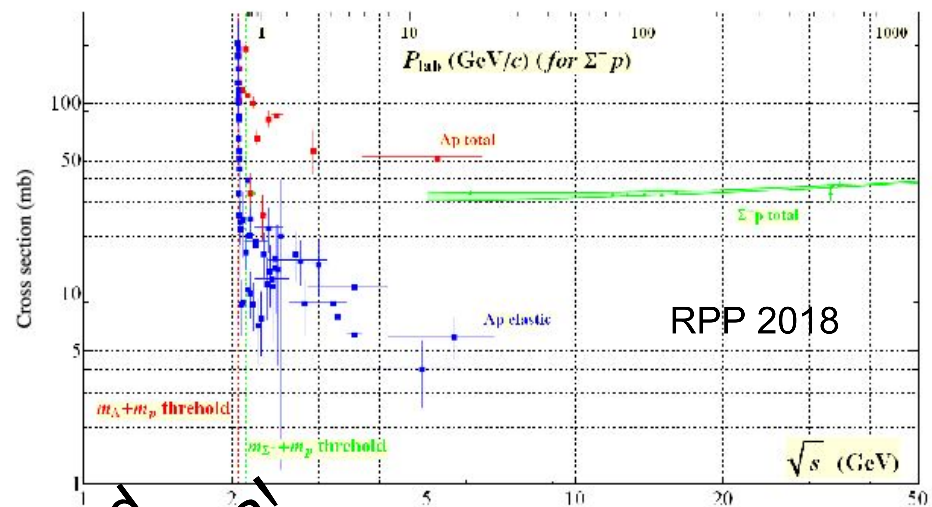

$\Lambda p \rightarrow \Lambda p$

We need more/better data!

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$SU(3)_F$ Symmetry

- Motivated by QCD Lagrangian

$$\mathcal{L} = \underbrace{\left(\sum_q \overline{\psi}_{q,a}(i\gamma^\mu \partial_\mu \delta_{ab} - g_s \gamma^\mu t^C_{ab} A^C_\mu)\psi_{q,b} - \frac{1}{4} F^A_{\mu\nu} F^{A\mu\nu}\right)}_{\mathcal{L}_0} - \underbrace{\sum_q \overline{\psi}_{q,a} m_q \delta_{ab} \psi_{q,b}}_{\mathcal{L}_m}$$

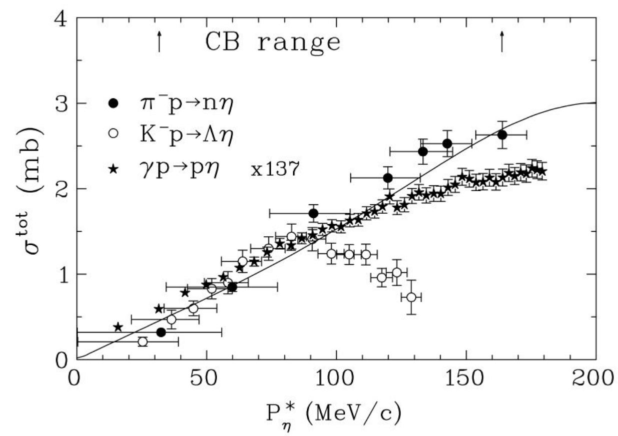
- Leads to expectation that $\mathcal{L}_0$ sets the overall mass scale of each SU(3) multiplet
- $\mathcal{L}_m$ sets the mass splitting within the multiplet

$SU(3)_F$ Symmetry

- Works surprisingly well
  - $m_{N(1440)} - m_{N(940)} \simeq 500\ MeV$
  - $m_{\Lambda(1600)} - m_{\Lambda(1115)} \simeq 485\ MeV$

SU(3)$_F$ Symmetry

- Works surprisingly well
  - $m_{N(1440)} - m_{N(940)} \simeq 500\ MeV$
  - $m_{\Lambda(1600)} - m_{\Lambda(1115)} \simeq 485\ MeV$
- Also works for cross sections



S. Prakhov et al. (Crystal Ball), PRC 72 015203 (2005)

$SU(3)_F$ Symmetry

- $\sigma(\Lambda p \to \Lambda p)$ "should be" related to $\sigma(pp \to pp)$
- "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...

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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...

Feasibility

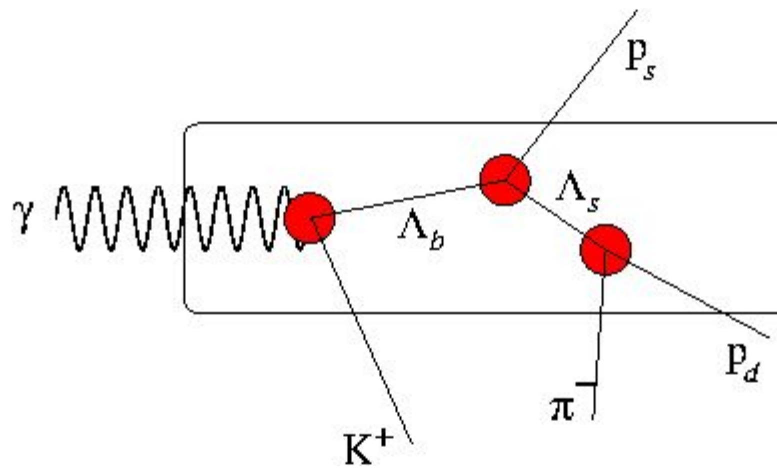
- Is it possible to measure $\Lambda p \rightarrow \Lambda p$?
  - Can we see a signal?
    - Can we produce a Λ "beam"?
    - How many events do we produce?
    - How well can we identify this process?
  - Can we determine the cross section?
    - Can we determine the luminosity?
    - Can we determine the acceptance?

Feasibility

- Is it possible to measure Λp→Λp?
  - Can we see a signal?
    - Can we produce a Λ "beam"? *yes*
    - How many events do we produce? *"lots"*
    - How well can we identify this process? *surprisingly well*
  - Can we determine the cross section?
    - Can we determine the luminosity? *probably yes*
    - Can we determine the acceptance? *almost certainly*

Event Topology

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



Experiment Design

- The ideal experiment for this process will have
  - A large number of Λs
  - A large target
  - Ability to resolve multiple detached vertices
  - Good invariant/missing mass resolution
- Proposal "should" be able to show real results
  - Better see what we have with existing data...

Data Mining with CLAS

- CLAS is well-suited to data mining studies
  - Good angular resolution
  - Good momentum resolution
  - Good angular acceptance
  - Good efficiency for multiparticle final states
- If CLAS wasn't made for this type of process, what detector was?

Data Mining parameters

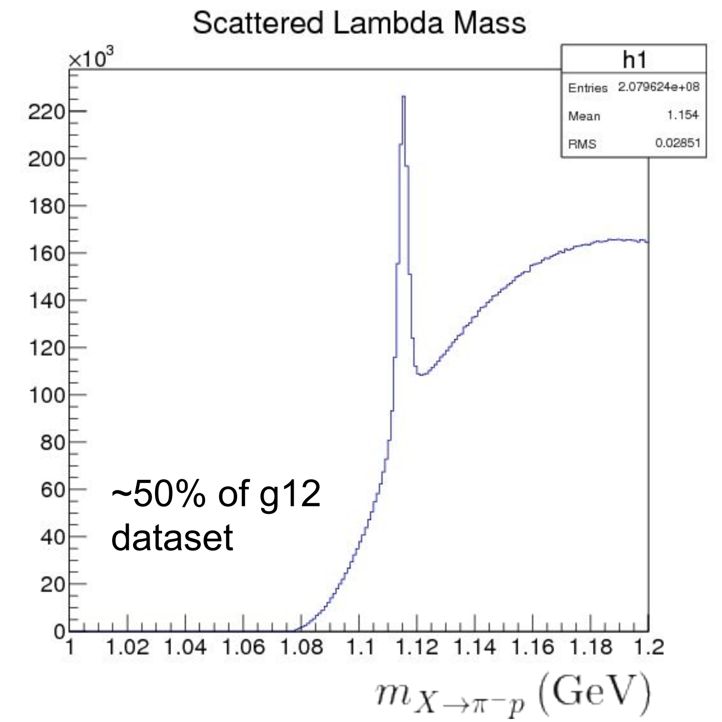
- For Λp scattering, we need
  - High E_γ
  - High Luminosity (many photons)
  - Long target (for rescattering)
- g12 run a good candidate
  - E_γ up to 5.4 GeV
  - 52 pb^{-1} γp data
    - ~0.5μb cross section ⇒ 26M Λ_b!
  - 40 cm LH_2 target - lots of available targets

Data skim

- Start by skimming data for two protons in the final state -- limits the possibilities
  - Rescattering on two target protons
  - Baryon nonconservation
- Looking for the former; won't be too upset if I see the latter

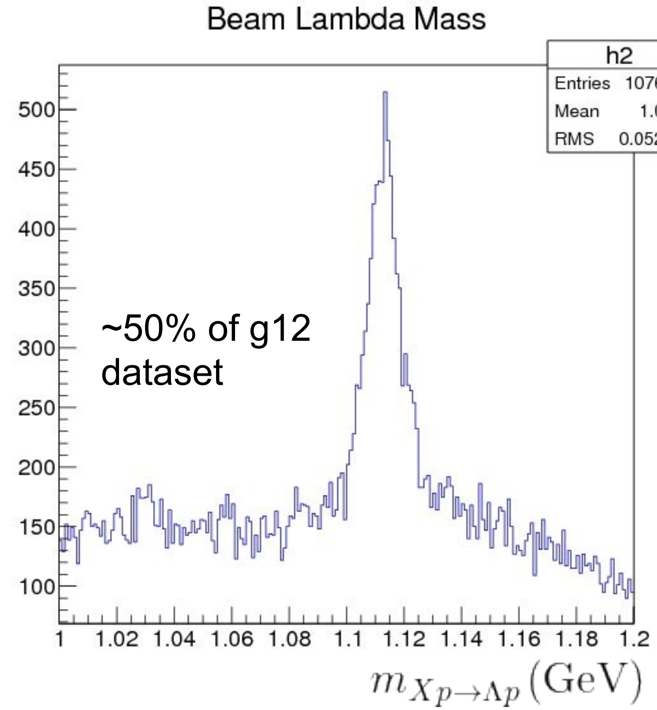
Scattered Λ Detection

- Calculate $\pi^- p$ invariant mass
    - Take pair closest to Λ mass
- Λ_s peak clearly seen above background
- No attempt (yet) to reduce background



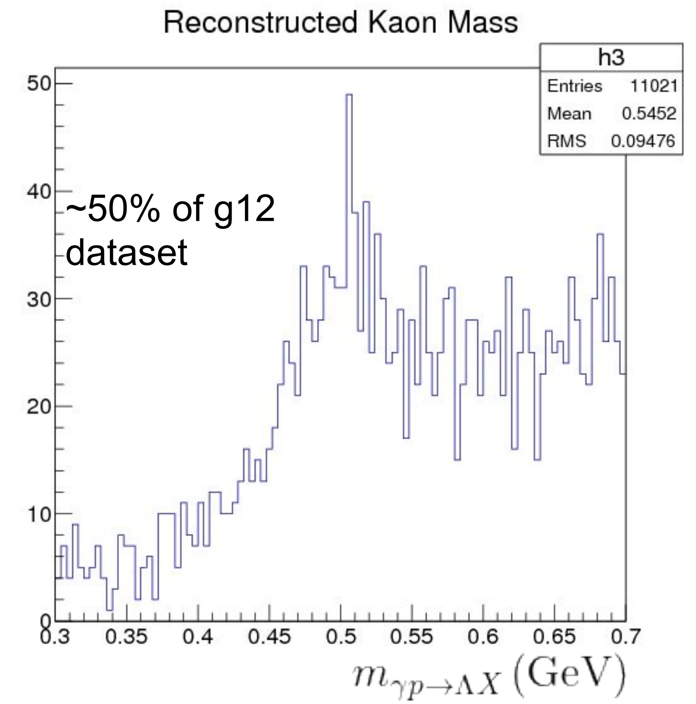
Beam Λ Detection

- Require m_{Λ_s} within 5 MeV of known Λ mass
- K^+ detected (no kinematic conditions)
- More events than the entire published world data sample



Reconstructed K^+

- Require m_{Λ_s} within 5 MeV, m_{Λ_b} within 20 MeV of the “right” value
- Not as pretty; still working on background suppression etc.
- Still, definitely some K^+ there



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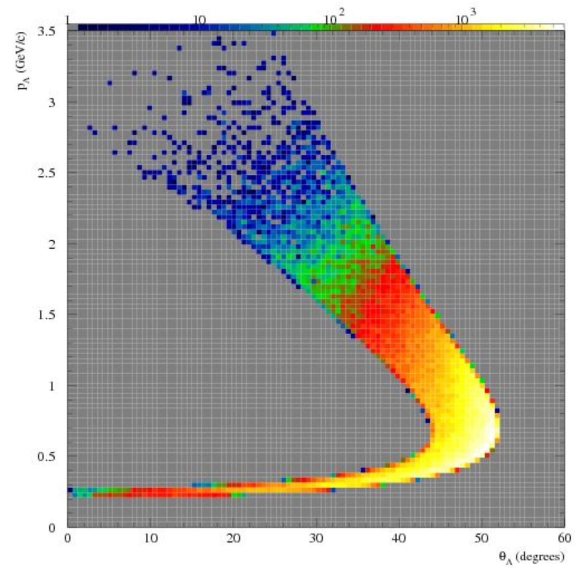
Luminosity Calculation

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

- Start with generic cross section equation
- N_b usually provided by accelerator
  - Not valid for our “tertiary” beam
    - Electron -> Photon -> Lambda
- N_t given by target length
  - Not valid for particles not traveling along beamline
  - ...or particles that decay...

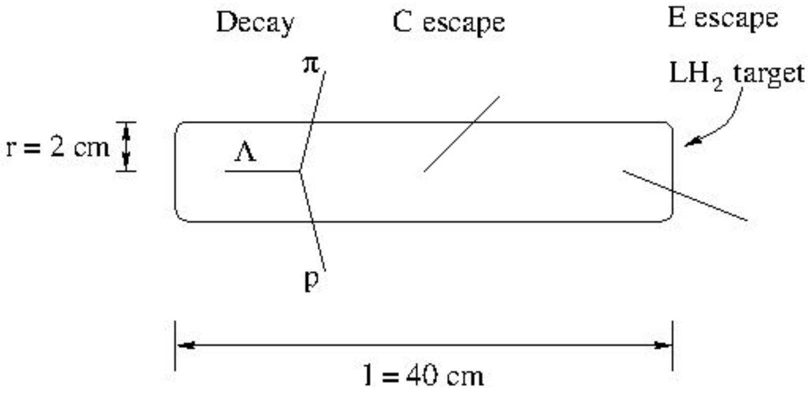
Beam Λ Kinematics

- Look at the kinematics of Λ_b in simulation
  - Don't need to run simulation
- Convert $(p_\Lambda, \theta_\Lambda)$ to $(E_\gamma, \theta^*_{K^+})$
- Use published cross section for $\gamma p \rightarrow K^+ \Lambda$ to get N_b



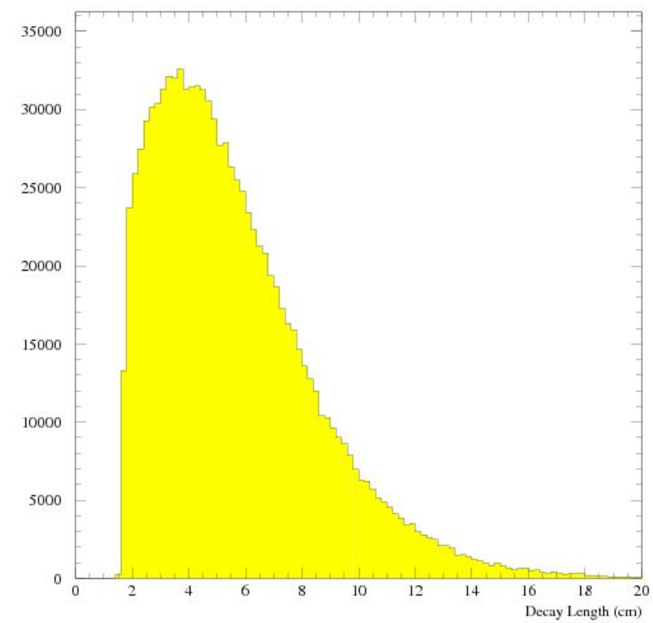
Calculating N_t

- Based on the "effective" target length
- Primary beam particles see the whole target
- Λs don't
  - decay
  - escape out cylindrical wall
  - escape out endcap



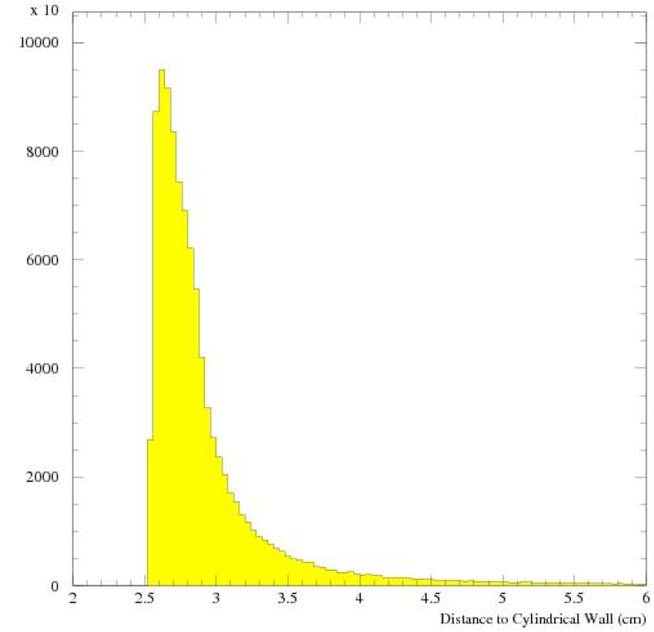
Calculating ℓ_d

- Mean path given by $\ell_d = \beta\gamma c\tau$
- Faster-moving Λs live longer in the lab frame
    - Contribute to a higher luminosity
    - Typically at smaller angles



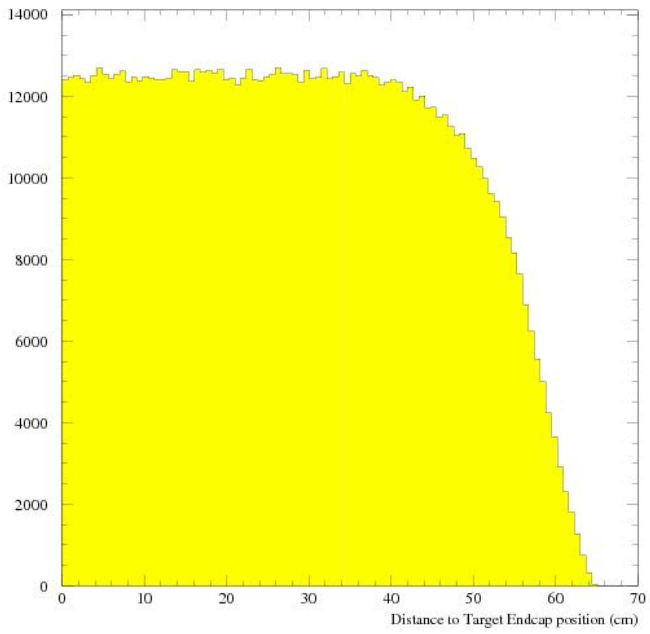
Calculating ℓ_c

- Mean path given by
  $$\ell_c = r_{tgt}/\sin\theta_\Lambda$$
- In g12 run, most Λs at large angles
  - up to ~50°
  - shortest path length is about 30% longer than target radius



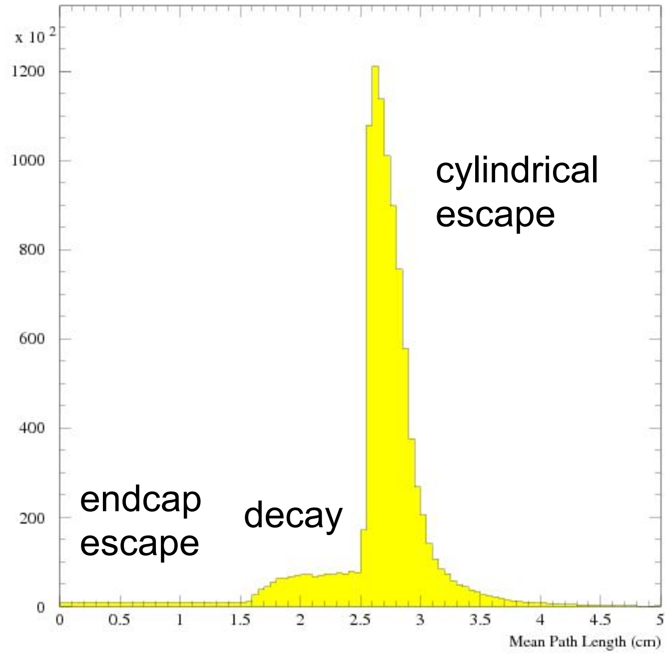
Calculating ℓ_e

- Mean path given by
  $$\ell_e = r_{tgt}/\cos\theta_\Lambda$$
- Happens when Λ is produced near the end of the target
- Distance represents path length to z-position of target endcap
  - not taking cylindrical escape into account
  - leads to distances larger than target size



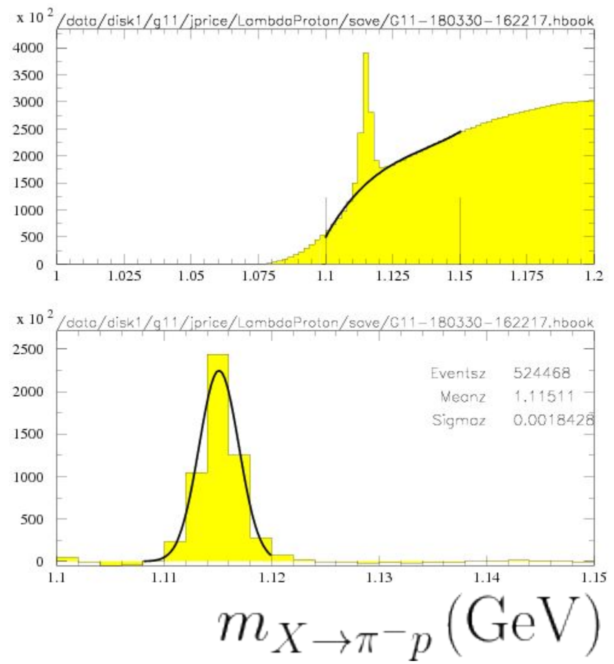
Mean Λ Path Length

- 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



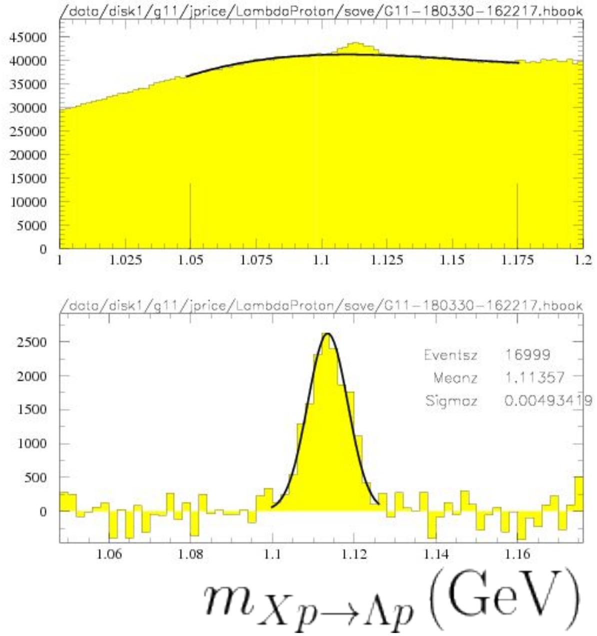
Confirmation with g11 dataset

- Same target; further downstream
- Lower beam energy
- Λ_s peak strongly seen above background
    - 500,000 events...



Confirmation with g11 dataset

- Λ_b peak also seen well
  - didn't require K^+ -- higher background
  - 17,000 events

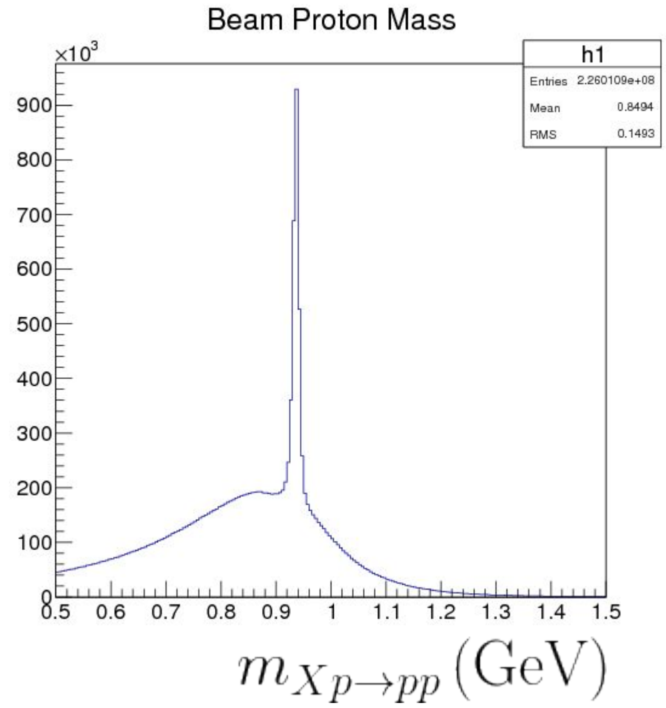


Other possibilities

- This technique is not limited to Λ studies
- Any particle produced in sufficient quantities can (in principle) be used
  - Having a second proton in the event reduces the background considerably

pp Elastic Scattering

- $\gamma p \to Xp;\ pp \to pp$
- 3-particle trigger prevents us from using $\gamma p \to \pi^0 p$
- Instead, use $\gamma p \to \omega p$
  - Final state: $\pi^+\pi^- pp(\pi^0)$
  - Still get lots of events…



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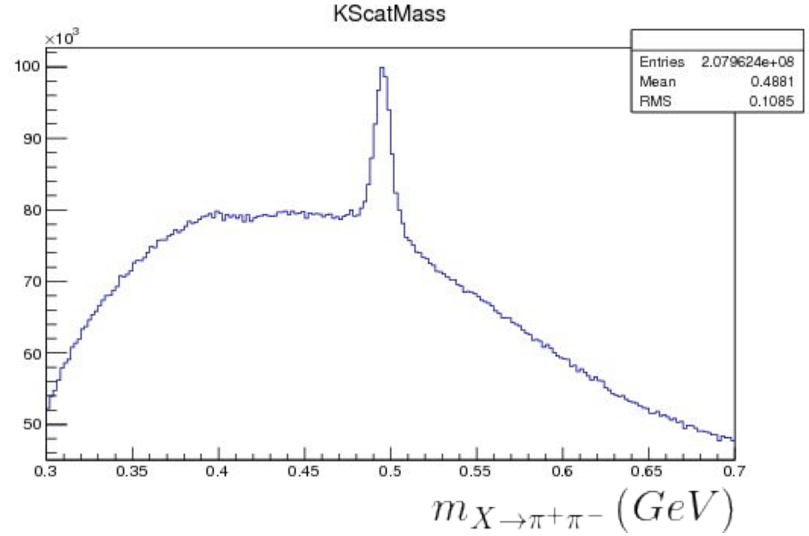
$K_s p$ Elastic Scattering

- $\gamma p \rightarrow K^0 \Sigma^+;$
  $$K^0 p \rightarrow K_s^0 p$$
  - Final state: $\pi^+\pi^- pp(\pi^0)$
- Harder; need to subtract K_L^0 contribution
- Only 1 previous expt.



Future work

Basically, "calculate the cross section"...

- Bin the events by p_Λ and $\theta^*_{p_s}$
- Determine the bin-by-bin luminosity for the g12 dataset
- Simulate the acceptance

Repeat as needed for other channels, datasets

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Future work

Aside from “calculate the cross section”...

- $\sigma(\gamma p \rightarrow \Lambda X)$: at higher energy, most of the Λ cross section is in other channels
- Look for other processes that can utilize this technique
  - Need to find unique signatures that we can normalize

Conclusion

- We have observed $\Lambda p \to \Lambda p$ 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 $pp \to pp$
- We have demonstrated the feasibility of using secondary (tertiary) beams in CLAS

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