UNIVERSITY OF
South Carolina

Feasibility Study of Λd Elastic Scattering in Data From Photoproduction Off Deuteron

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Introduction

Goal: investigate Λd elastic scattering from photoproduction data off deuteron

Motivation: provide novel hyperon-nucleon-nucleon (YNN) scattering data for the hyperon puzzle

Hyperon Puzzle: "… the difficulty to reconcile the measured masses of neutron stars (NSs) with the presence of hyperons in their interiors …" (Bombaci, 2016)

Introduction

NS equations of state not consistent with NS mass measurements of ~$2M_{sun}$

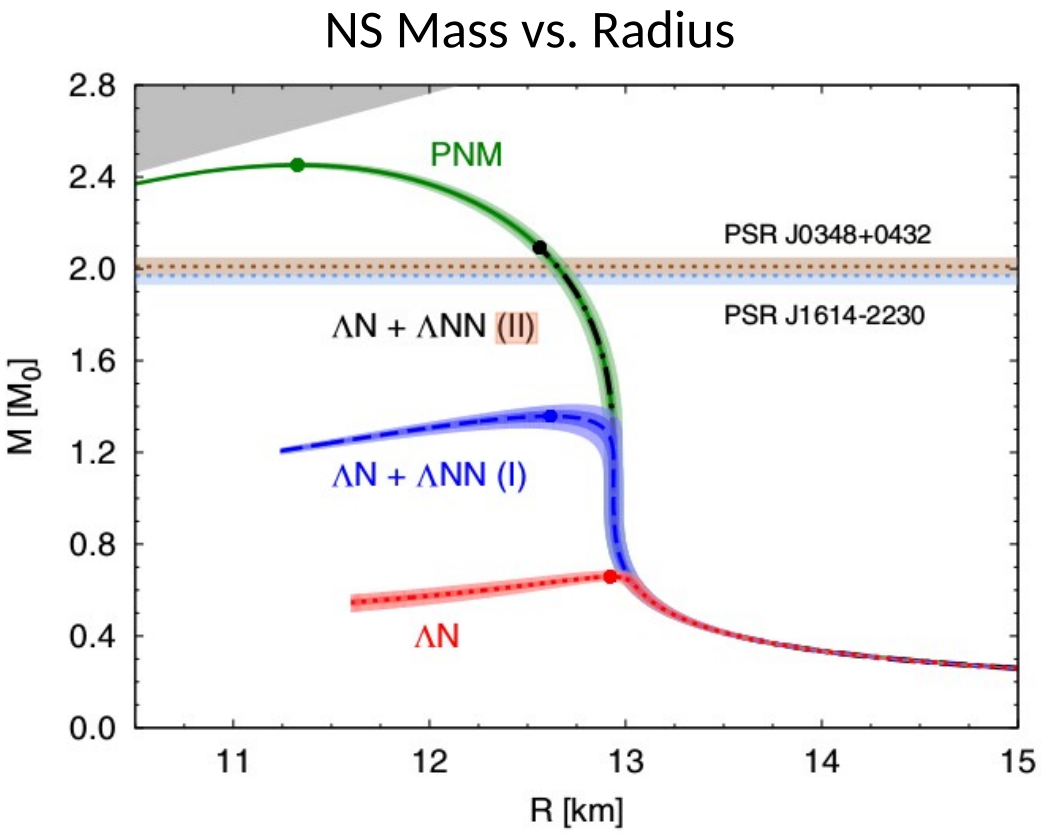
- NN, NNN, YN forces included
- YNN 3-body contribution needs improvement
- Need more YN interaction constraints to improve YNN 3-body contribution

Hypernuclear spectroscopy provides YN interaction constraints

- Nuclear medium effects limit constraint determinations

YN scattering is cleanest method to constrain constants in potentials

- No nuclear medium effects → bare YN interaction
- Existing YN scattering data limited due to short hyperon lifetimes
- No YNN scattering data exists



[Lonardoni et al., 2015]

Introduction

Want to investigate feasibility of analyzing Λd elastic scattering to supply YNN scattering data

How do we look for Λd elastic scattering?

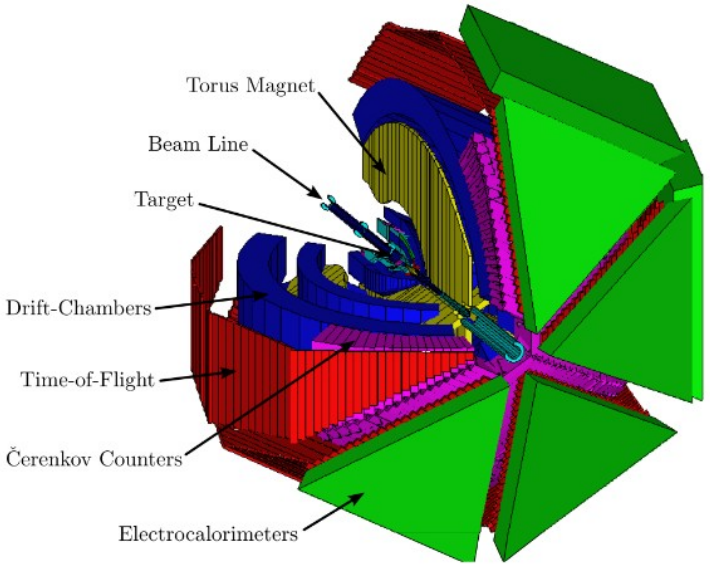
- Produce hyperons (Λ) off target (deuteron), which scatter off other target (deuteron) in same target cell
- Done in:
  - Λp elastic scattering at Jlab [Price, 2019 and Rowley 2022]
  - $\Sigma^{\pm}$p elastic scattering at J-PARC [Yoshiyuki Nakada et al., 2019]

Method two sequential nuclear reactions

- Need high luminosity in primary experimental beam
- Need detector with large acceptance
- g13: very high statistics (50 bn triggers)
- Reaction process: $\gamma d \rightarrow X\Lambda$, $\Lambda d' \rightarrow \Lambda d'$, $\Lambda \rightarrow p\pi^-$
- CLAS → Large acceptance, especially for charged particles (~2.8π solid angle coverage)

Experimental Facility

CEBAF Large Acceptance Spectrometer (CLAS)



CLAS is optimized to detect multiple-charged particle final states

Large acceptance of ~2.8π

Δp/p ~ 0.5-1 %

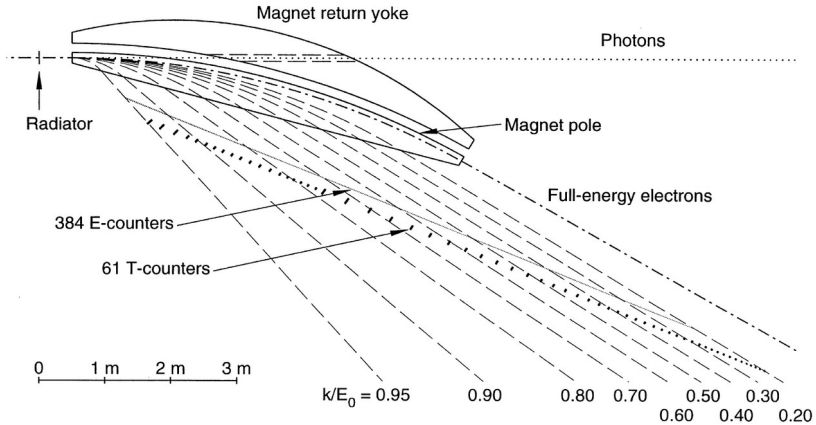
Bremsstrahlung Photon Tagger ($\Delta E_\gamma/E_\gamma \sim 10^{-3}$)

JLab Experiment E06-103 (g13)

Circularly Polarized Photons (g13a)
- E_e = 2 GeV, 2.65 GeV
- electron polarization ~ 80%
- ~ 20×10^9 triggers

Linearly Polarized Photons (g13b)
- Ee = 3.3 - 5.2 GeV
- photon polariztion ~ 70% - 90%
- ~30×10^9 triggers

Photon Tagger



P. Nadel-Turonski, B. Berman, YI, D. Ireland, A. Tkabladze et al., E06-103: "Kaon Production on the Deuteron Using Polarized Photons"

Experimental Method

Access to Λd → Λd by means of two sequential reactions

γd → ΛX (1st vertex)

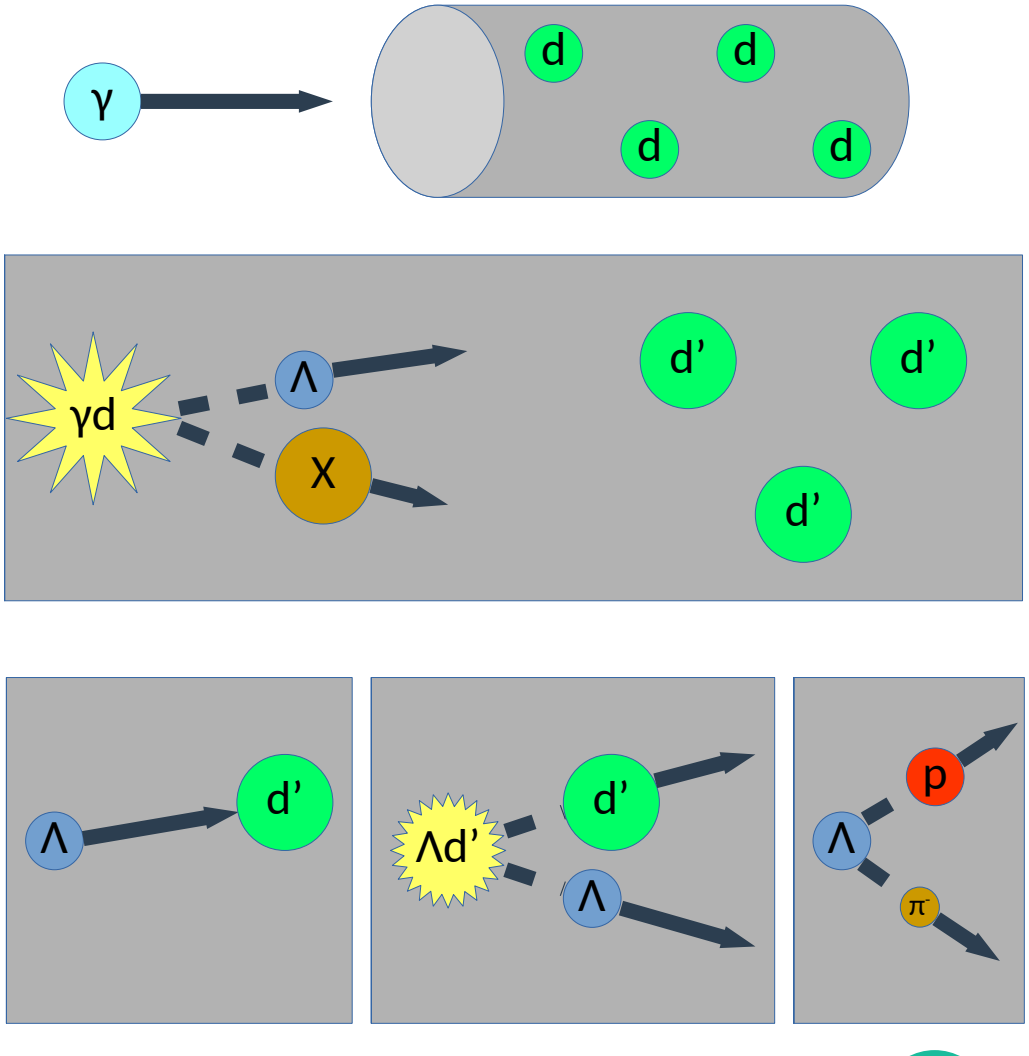
Λd' → Λd' (2nd vertex)

Λ decays into pπ⁻

(or nπ⁰, but CLAS is optimized for charged particles)

Final particles detected and selected:

d', p, π⁻



This method has also been used in:

Λp elastic scattering at JLab (CLAS g11) [Price, 2019 and Rowley, 2022]

$\Sigma^{\pm}$p elastic scattering at J-PARC [Yoshiyuki Nakada et al., 2019]

Particle Identification

$\beta_{meas} = L/c\Delta t$

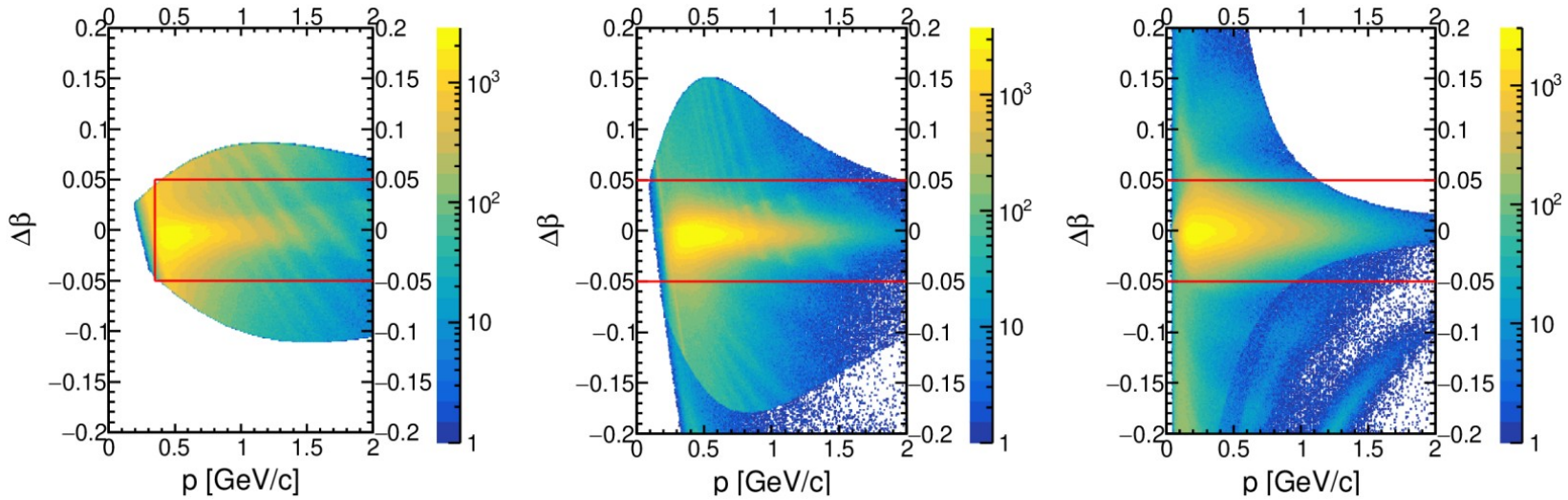
$\beta_{calc} = p/\sqrt{(p^2 + m^2)}$

- m: mass hypothesis

$\Delta\beta = \beta_{meas} - \beta_{calc}$

- m → deuteron, proton, or pion mass

Δβ vs p



Event distribution of Δβ vs. p for (**left**) deuterons, (**middle**) protons, and (**right**) π^-

Reaction Selection

How do we ensure the detected $dp\pi^-$ originated in $\Lambda d \rightarrow \Lambda d$ scattering?

4-Momentum Conservation

Identification of the scattered Λ:

$$P_{\Lambda,scat} = P_p + P_\pi$$

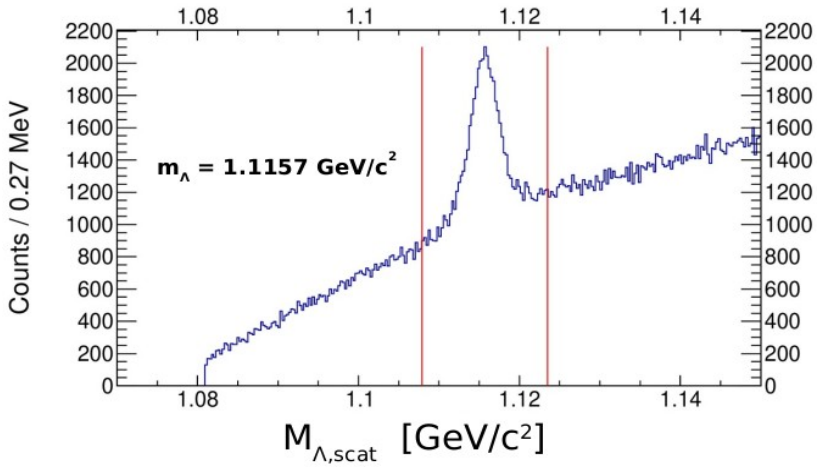
$$M_{\Lambda,scat} = \sqrt{(P_{\Lambda,scat})^2}$$

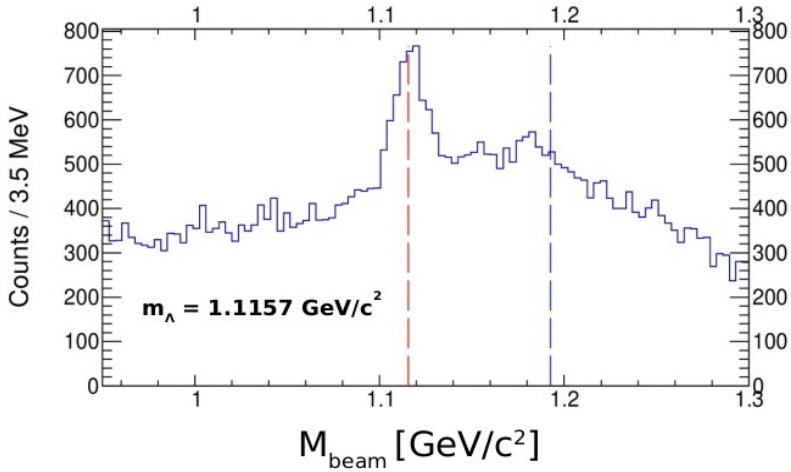
Identification of Λ beam:

$$P_{beam} = P_{\Lambda\text{-}scat} + P_{d\text{-}meas} - P_T$$

where $P_T = (m_d , 0)$ is the 4-vector of the target at the 2nd vertex

$$M_{beam} = \sqrt{(P_{beam})^2}$$





Results

Analysis performed on g13a subset of g13 data

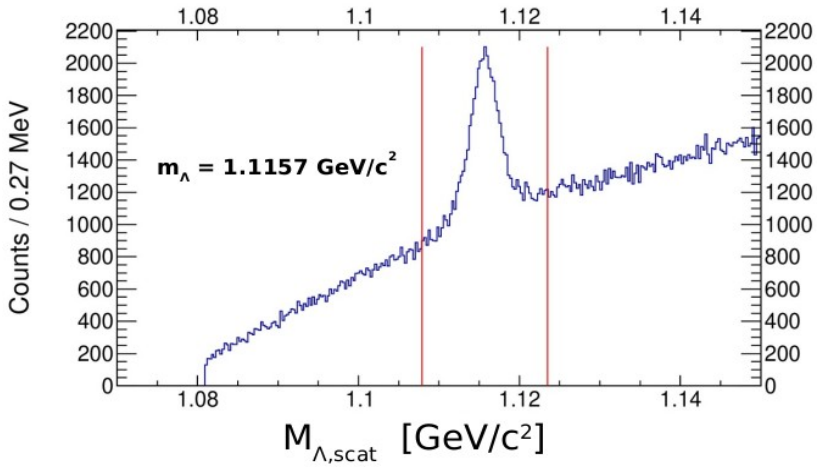
~ 2000 Λd elastic scattering events in g13a

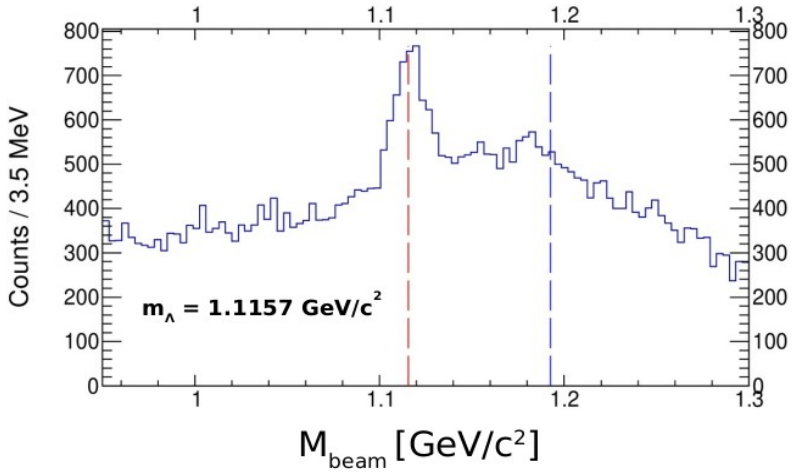
~ 4000 expected in all of g13

Possible enhancement around Σ^0 mass in M_{beam}

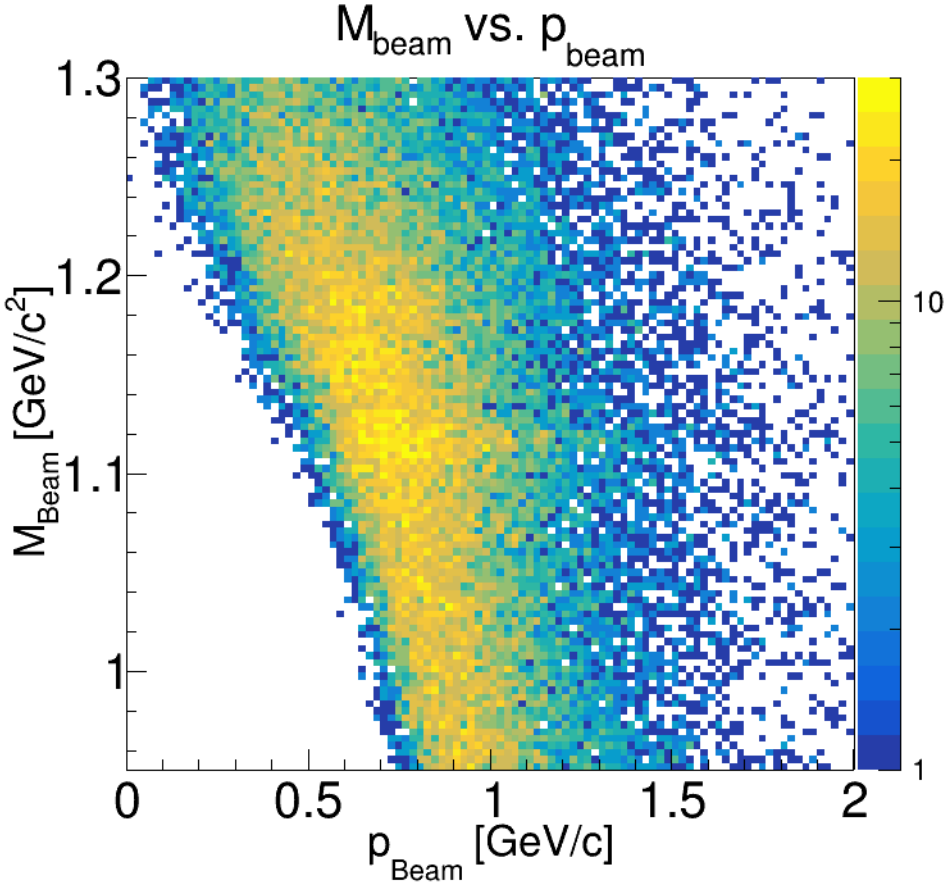
m_Σ = 1.1926 GeV/c^2

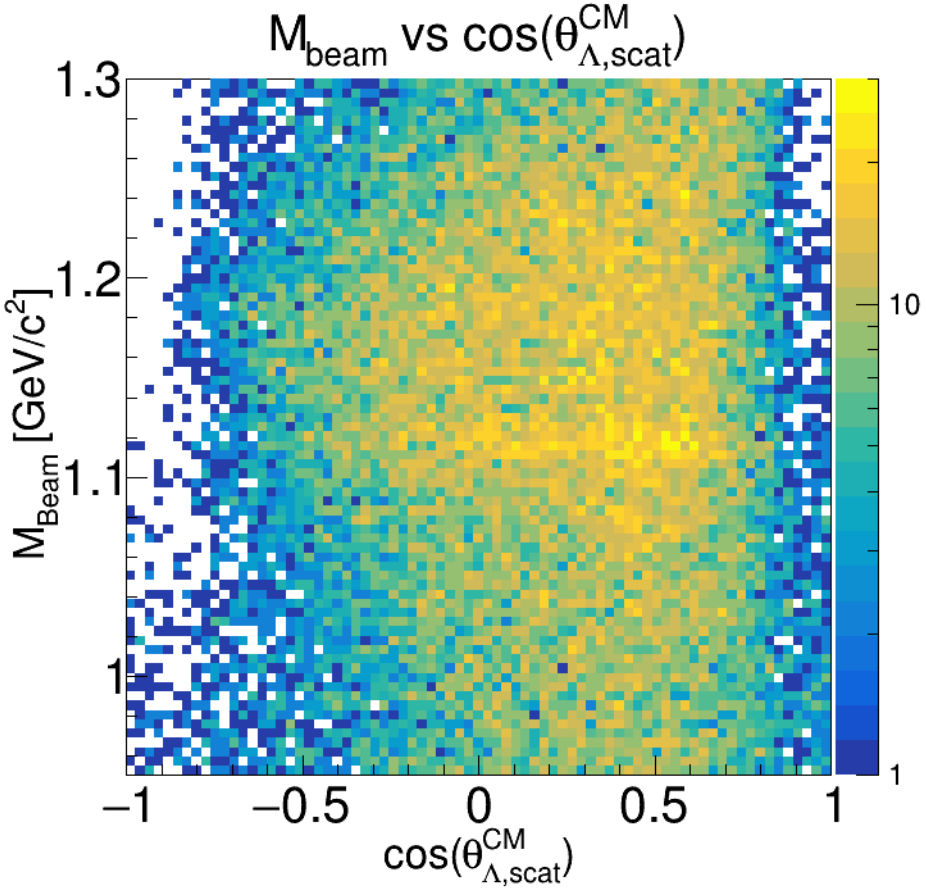
May allow for $\Sigma^0 d \rightarrow \Lambda d$ reaction measurements





Results





Can expect cross-sections determined in the regions:

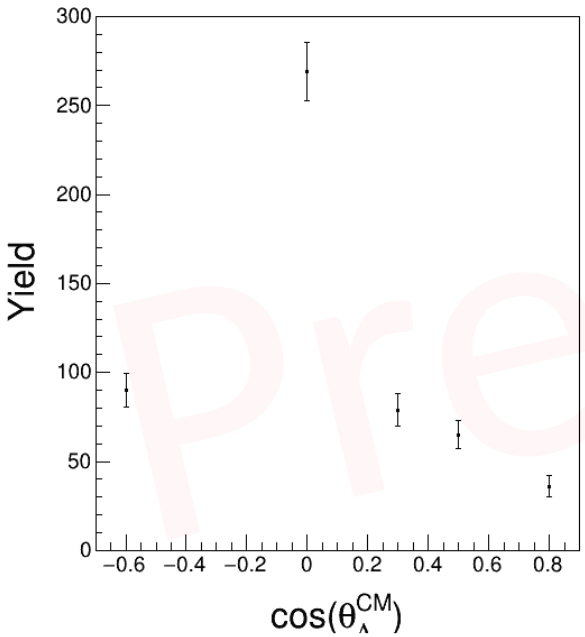
p_Λ: > 0.7 GeV/c, $\cos(\theta_\Lambda^{CM})$: (−0.6, 0.9), $W_{d\Lambda} = \sqrt{s_{d\Lambda}}$: (3.0, 3.8) GeV

Results

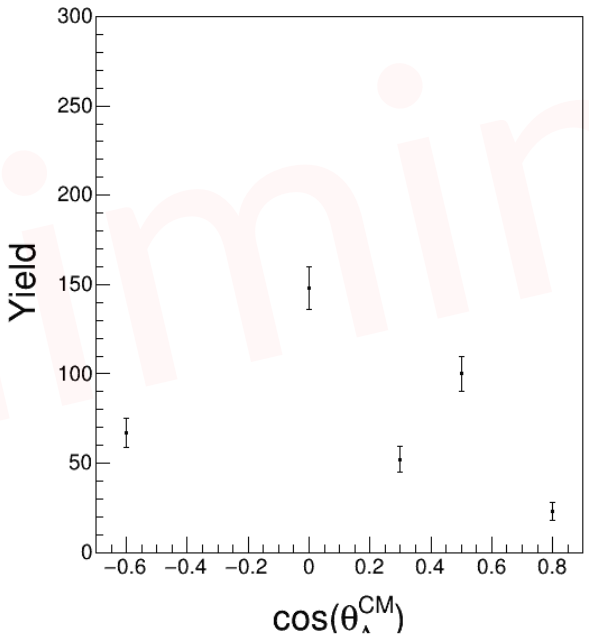
Yield estimates made using polynomial + gaussian fits to beam mass distributions

Only statistical uncertainties shown

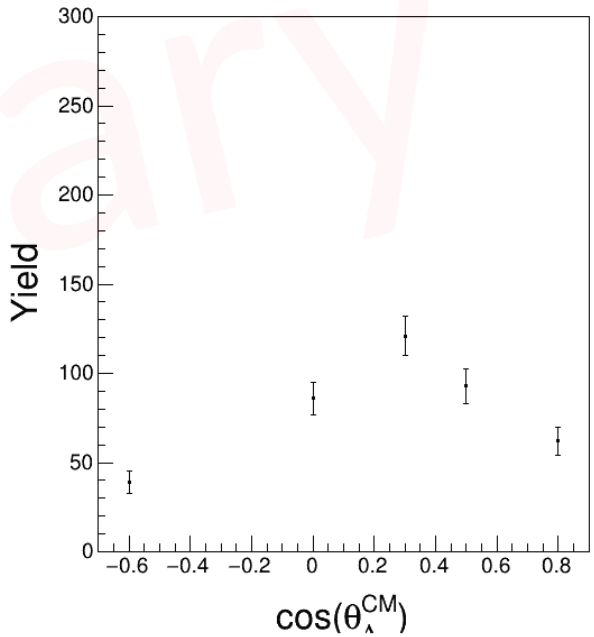
$p_{beam} \in [0.6,0.8]$ GeV/c



$p_{beam} \in [0.8,1.0]$ GeV/c



$p_{beam} > 1.0$ GeV/c



Preliminary

Summary and Outlook

Goal: investigate feasibility of analyzing Λd elastic scattering from photoproduction off deuteron

Conclusion: analyzing Λd elastic scattering from photoproduction off deuteron is feasible. Can expect approx. 4000 events

Total and differential cross sections for Λd elastic scattering can be determined:

For Λ beam momentum above 0.7 GeV/c

For $\cos(\theta_{\Lambda}^{CM})$ between −0.6 and 0.9

For $W_{d\Lambda}$ between 3 GeV and 3.8 GeV