Λ-p Elastic Scattering with the CLAS Detector

CLAS Collaboration Meeting

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clas

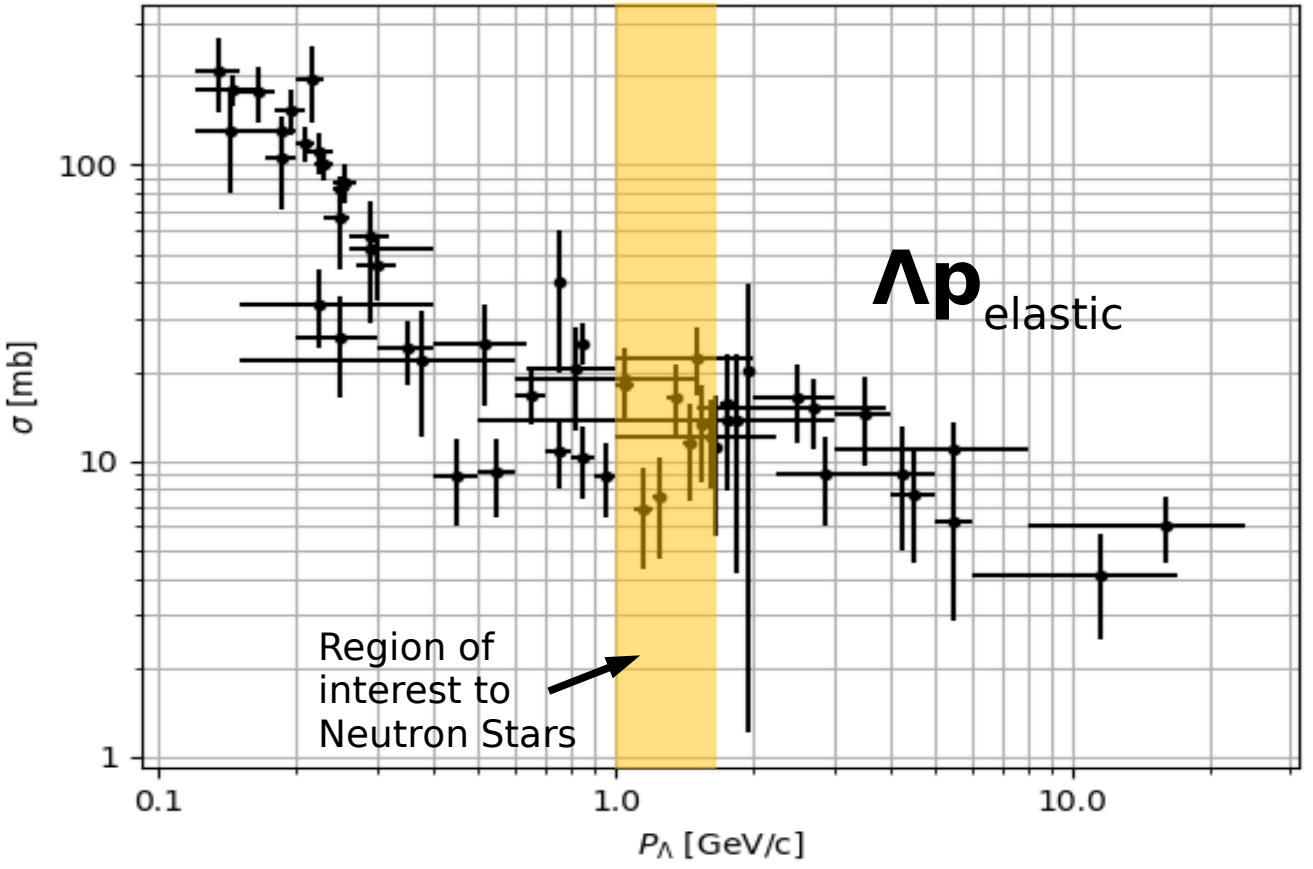
CEBAF Large Acceptance Spectrometer

Motivation

- Currently very little data for ΛN

  < 1300 events

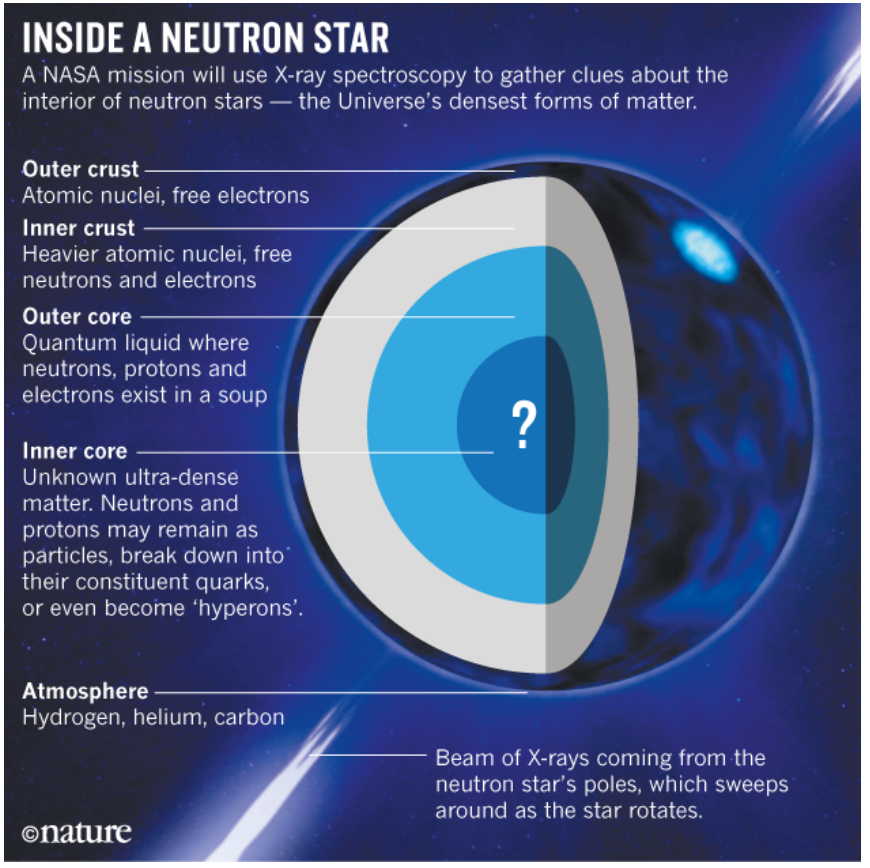
- Entirely from Bubble Chamber
- ΛN scattering is important to understand the interior of neutron stars. (Haidenbauer and Meissner, PRC 72, 044005 (2005).)



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

Neutron Stars and the Hyperon Puzzle

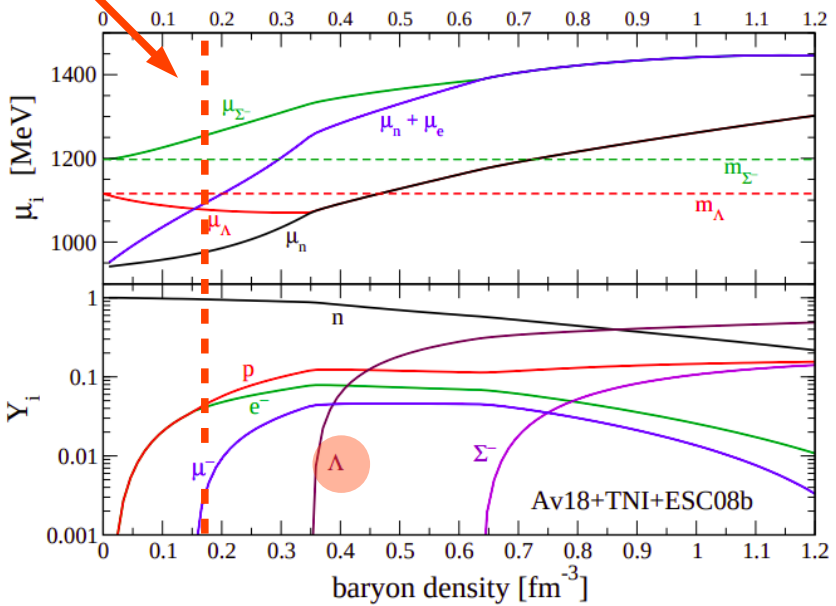
- Hyperons **may** exist inside neutron stars
  - results in a softened Equation of State (EOS)
- EOS must be able to predict the highest mass NS observed (~2 solar masses)
- One would expect Hyperons based on simple Fermi momentum kinematics and conservation principles



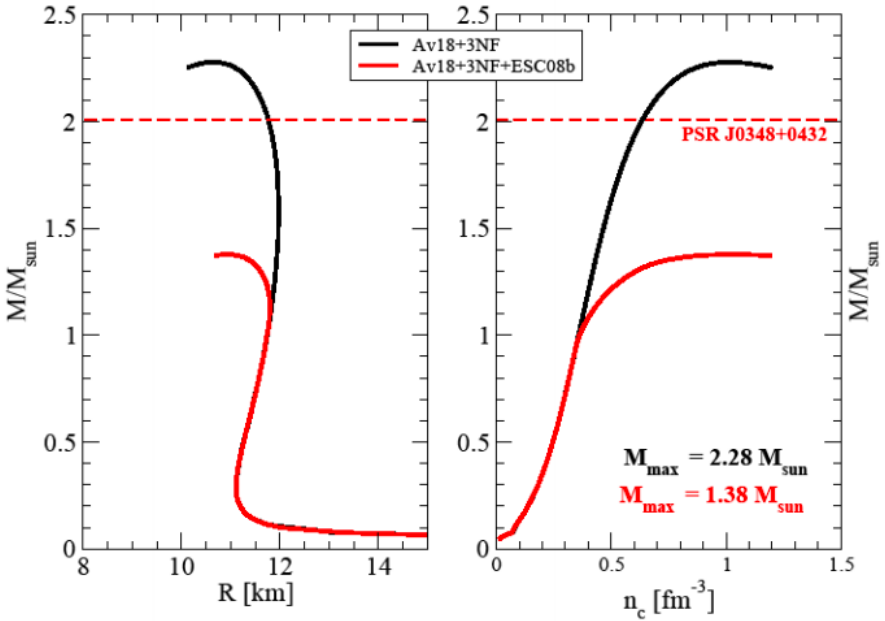
E. Gibney, Nature **546**, 18 (2017)

Neutron Stars and the Hyperon Puzzle

Nuclear Density



Stellar mass

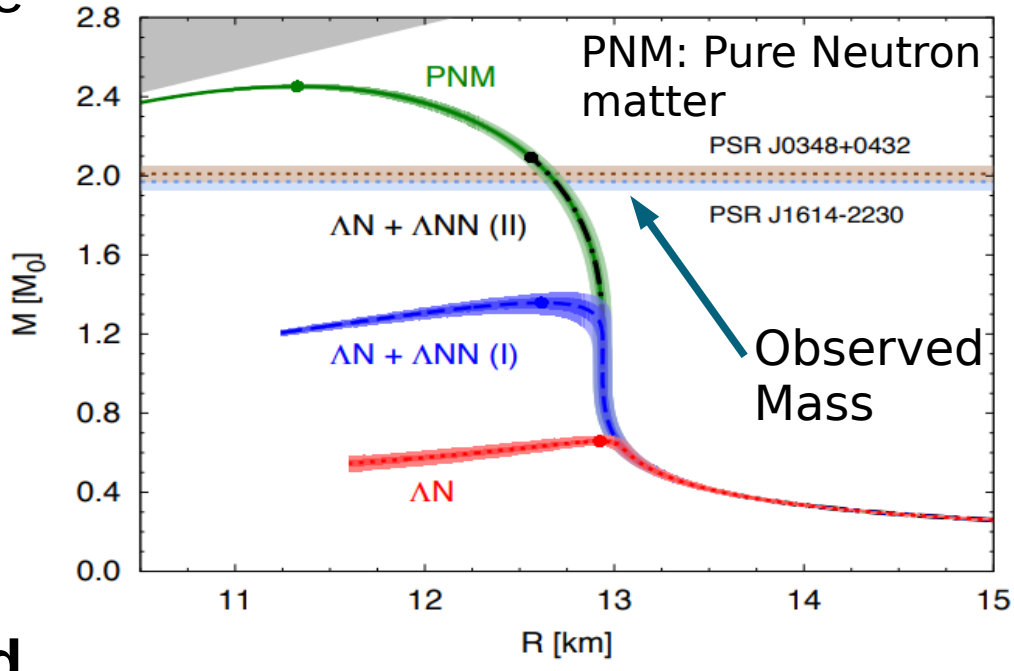


- Λ start appearing at densities of ~2 x nuclear density
- The core of a NS can reach densities of 5 x nuclear density (or more!)
- EOS get significantly softened and can not reach 2 solar masses.

I. Bombaci, JPS Conf. Proc. **17**, 101002 (2017)

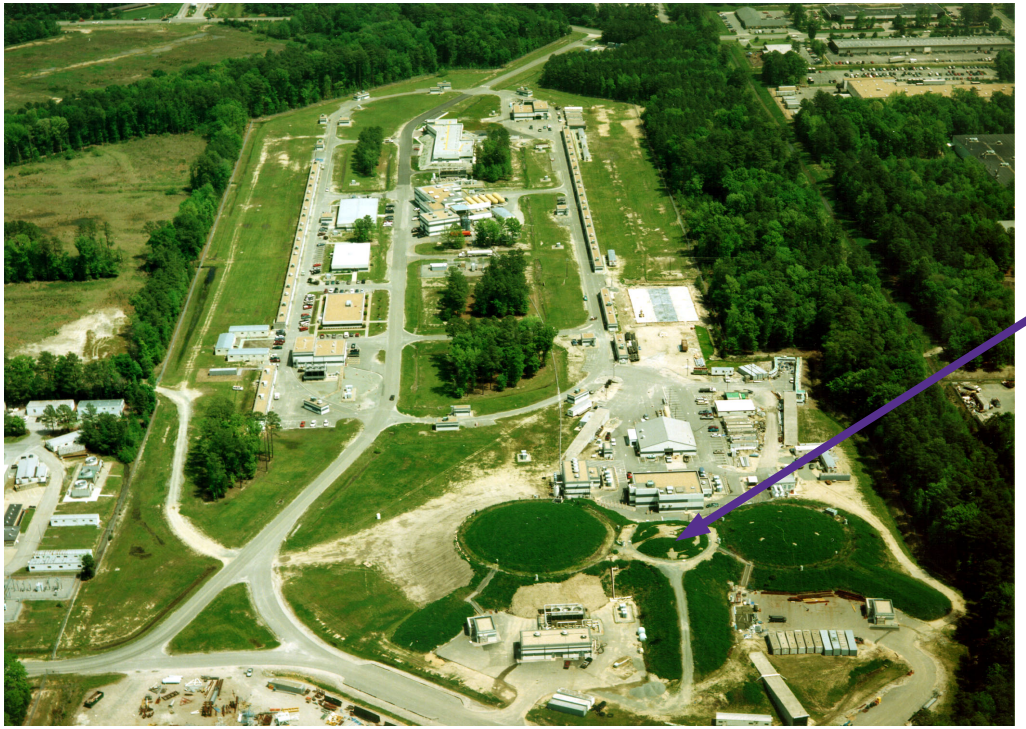
Neutron Stars and the Hyperon Puzzle

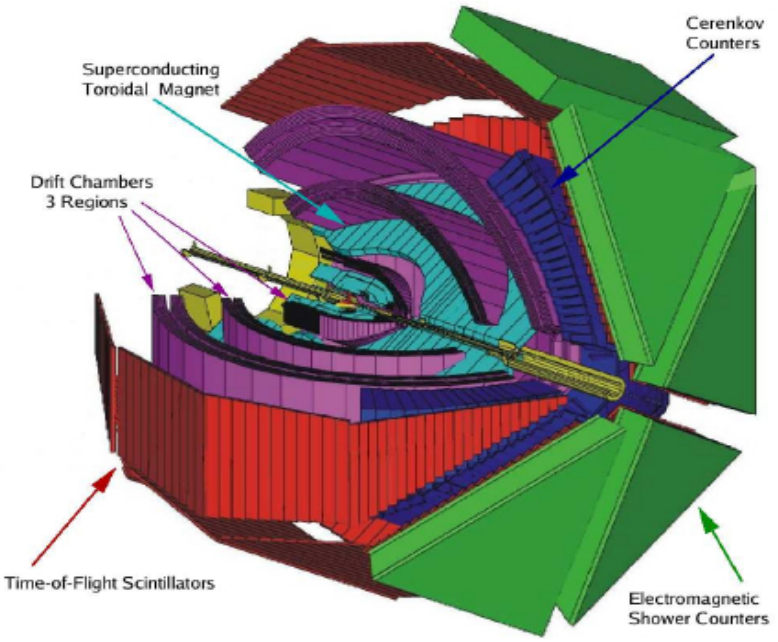
- Three body interactions can resolve this issue!
- ΛN + ΛNN can create a NS EOS which reaches above 2 solar masses.
- Currently focusing on Λp but these techniques can be extended to future experiments.
- **Takeaway: Better data for ΛN and ΛNN interactions are needed.**



D. Lonardoni *et al.*, Phys. Rev. Lett. **114**, 092301 (2015)

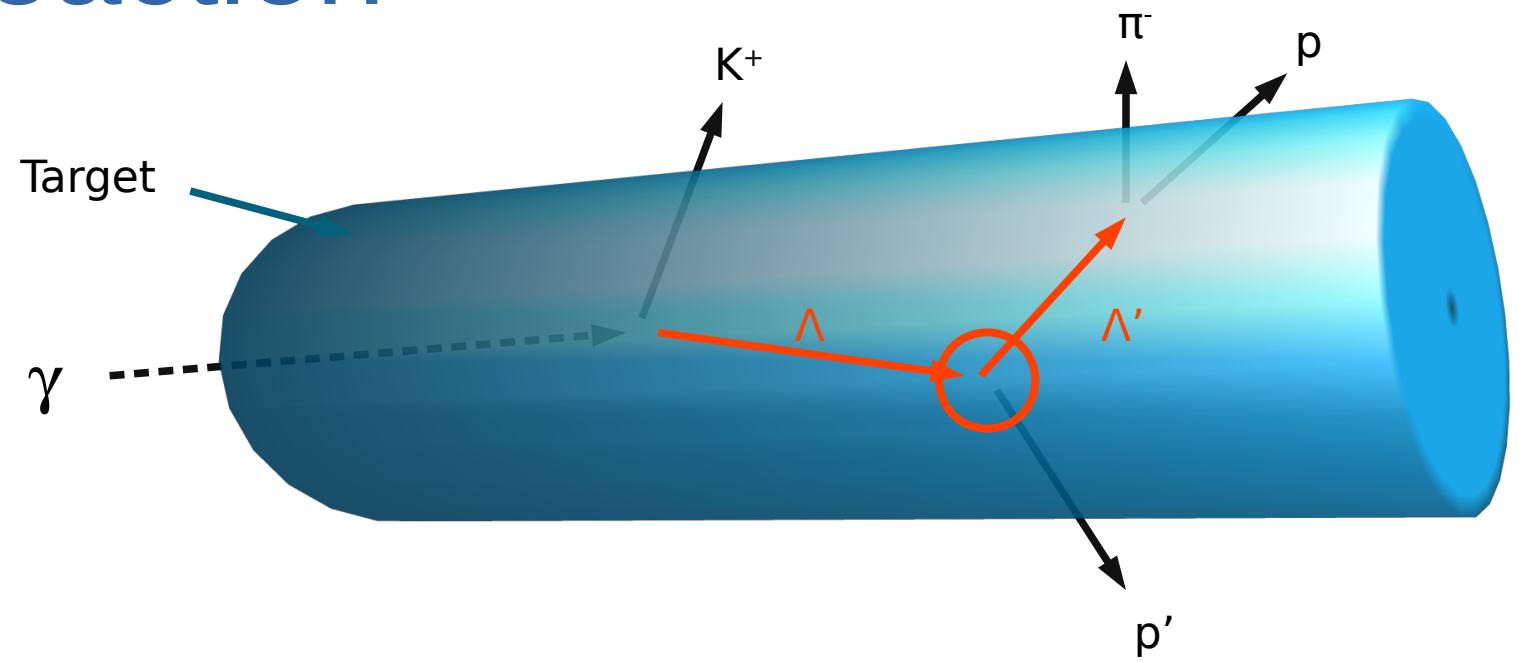
g12 at Jefferson Lab





- LH_2 target
- Length: 40 cm
- Width: 4 cm
- -90 cm from center of detector

Reaction



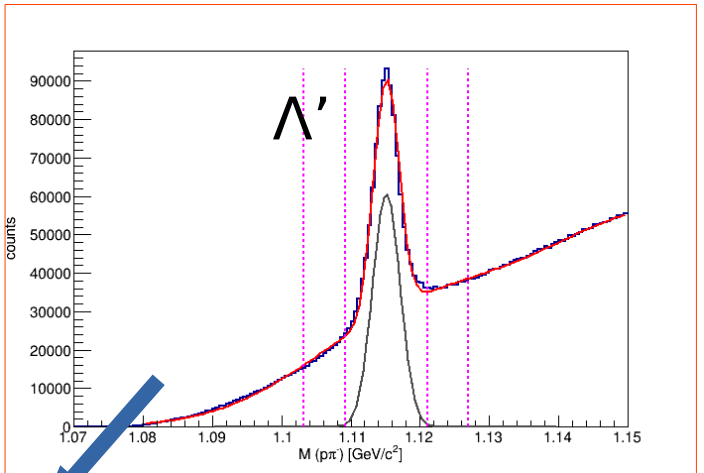
- Liquid Hydrogen Target
- p, p', π^- detected
- Λp scatter elastically

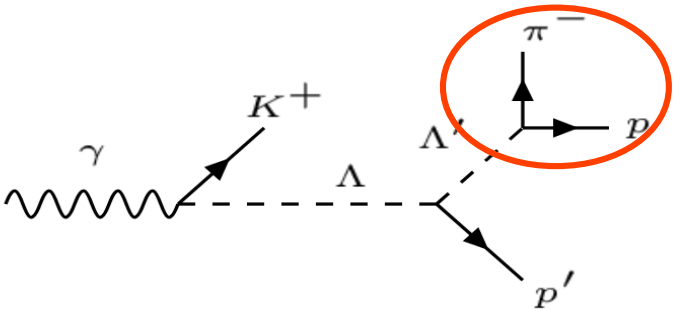
Procedure Analysis

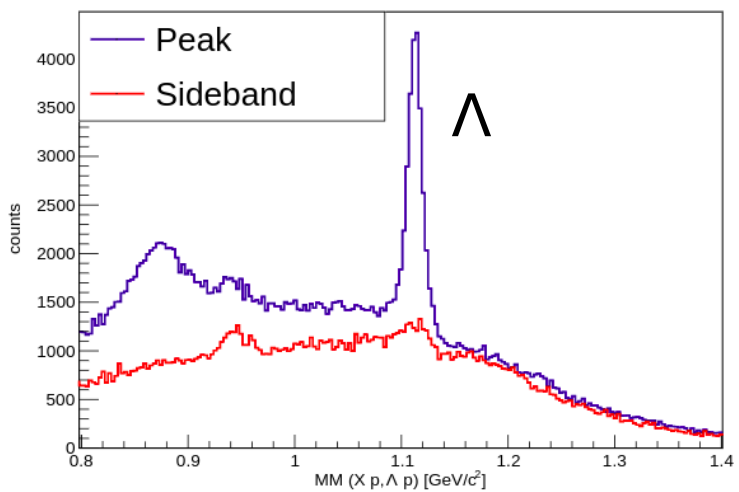
$$\gamma p \rightarrow K^{+}\Lambda \longrightarrow \Lambda \mathrm{p} \rightarrow \Lambda' p' \rightarrow p' p \pi^{-}$$

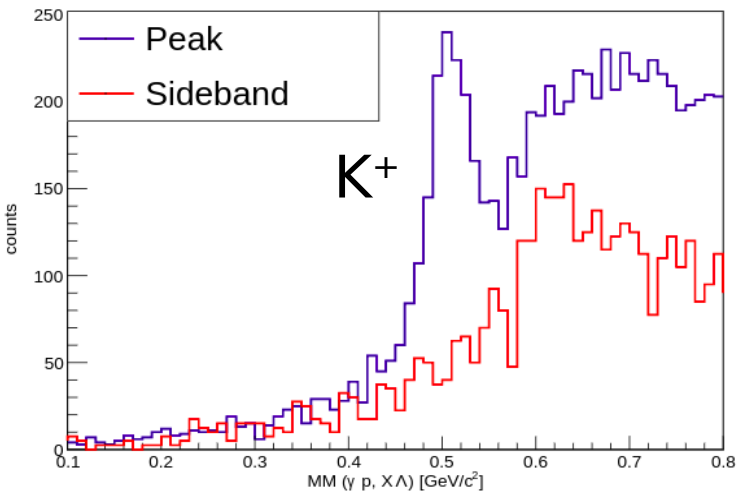
- Standard procedures are applied (PID, Fiducial, etc…)
- Reconstruct the Λ’ mass: M(Λ’) = M(pπ^{-})
- Reconstruct incident Λ: MM(Xp$\rightarrow$Λp)
- Identify K^{+} by missing mass: MM(γp$\rightarrow$XΛ)

Sideband Subtraction

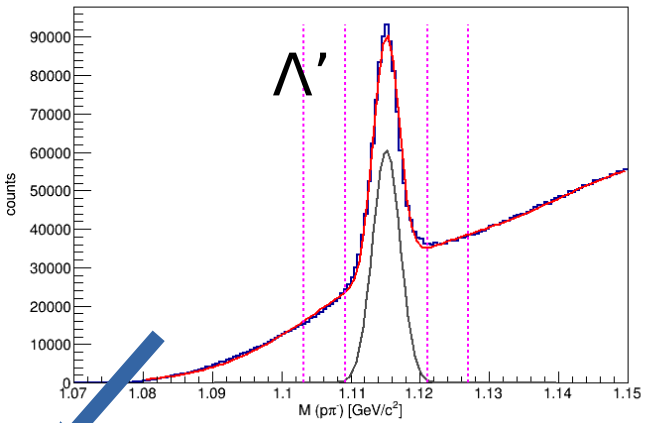


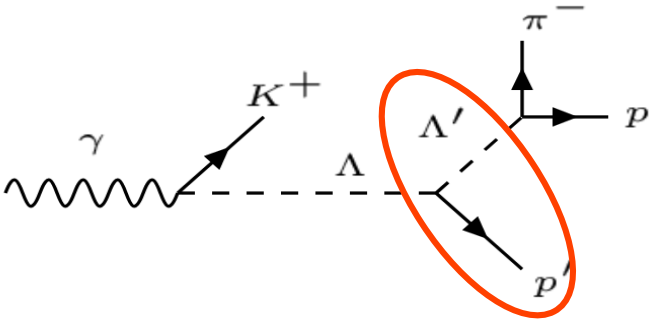


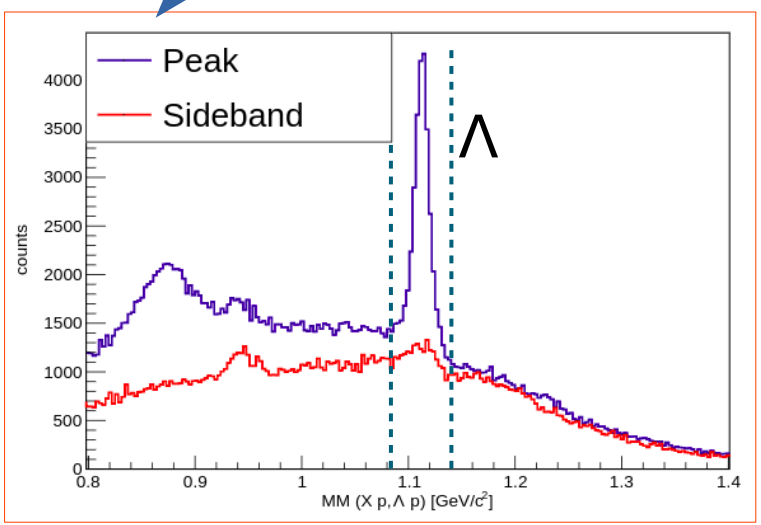


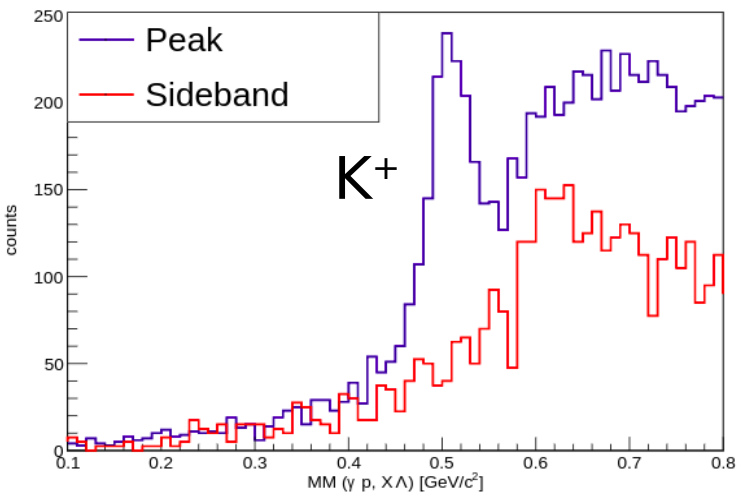


Sideband Subtraction

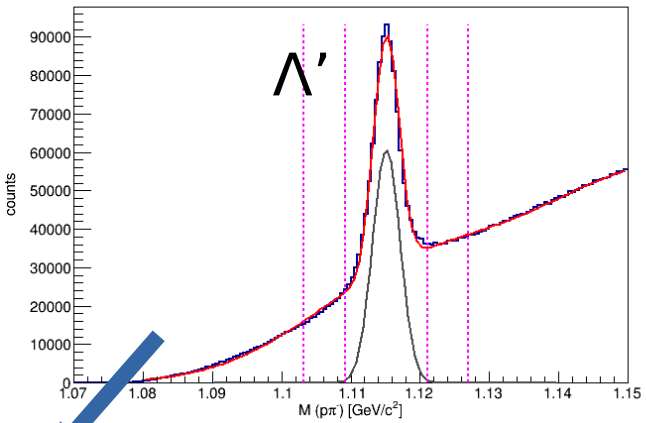


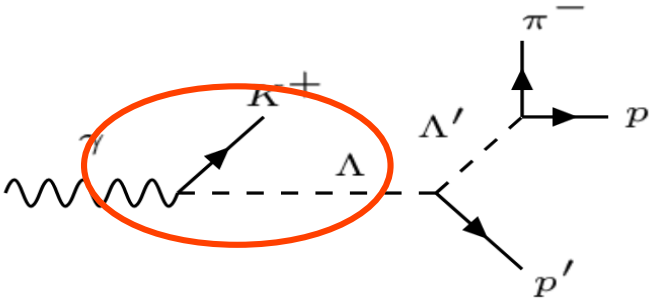


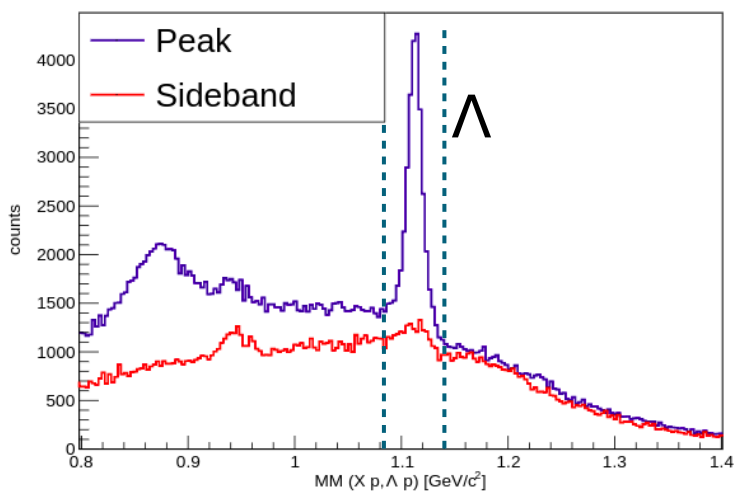


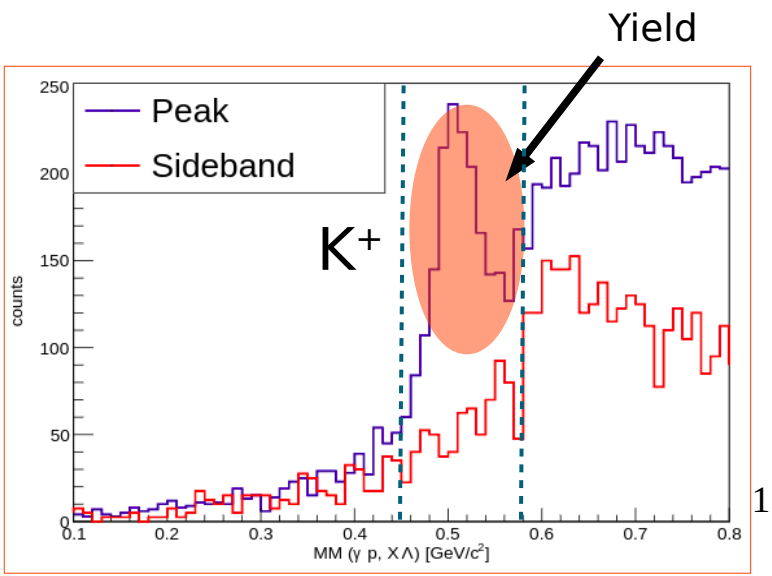


Sideband Subtraction

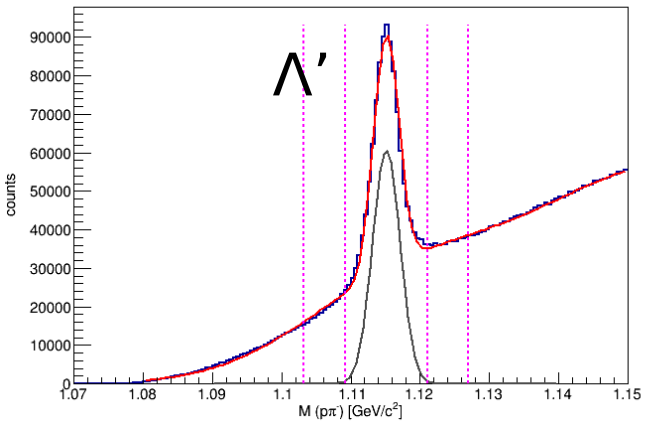


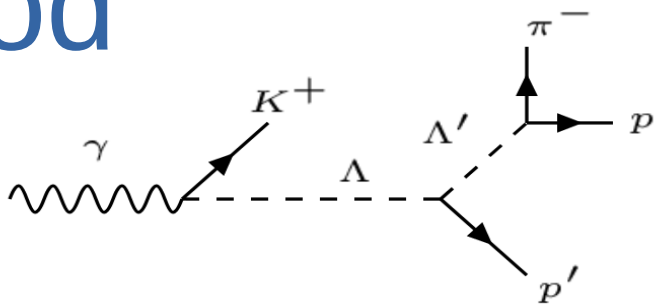




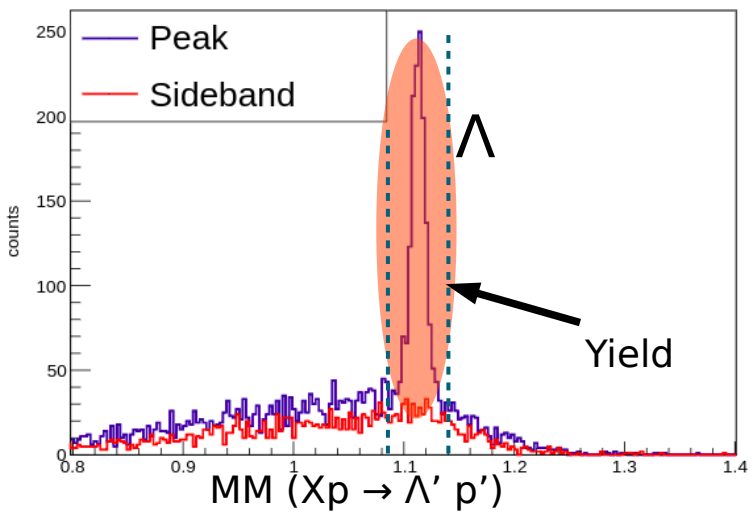


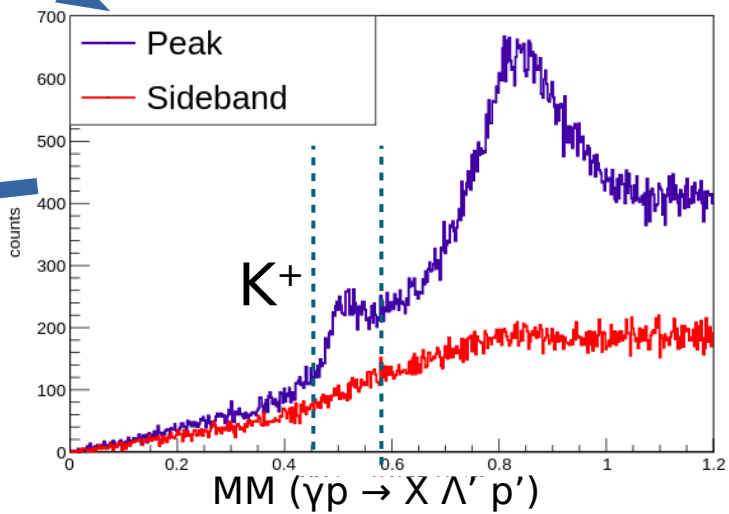
Incident Λ Fitting Method



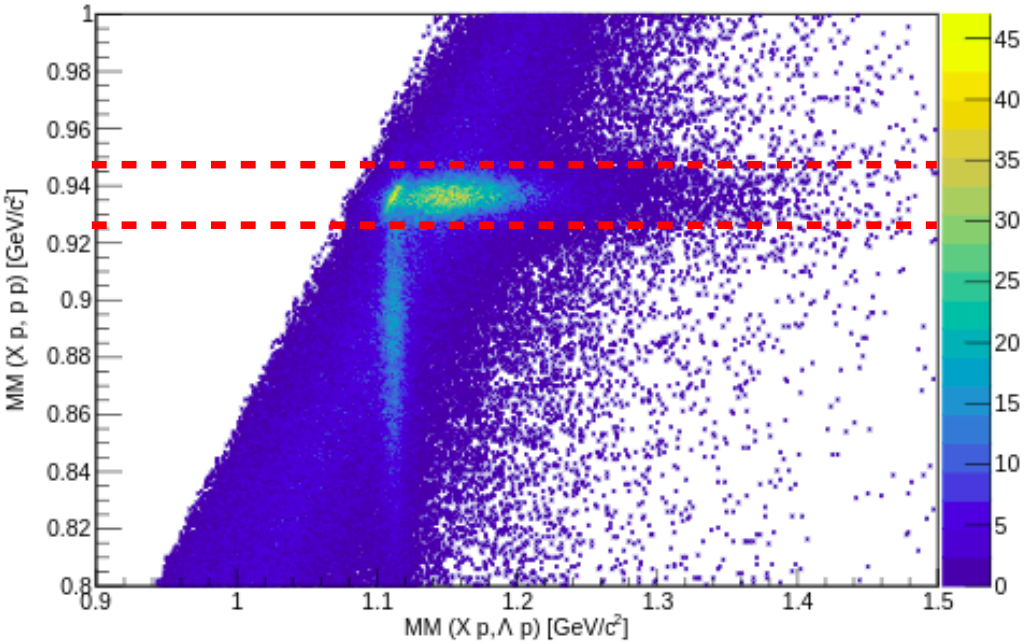


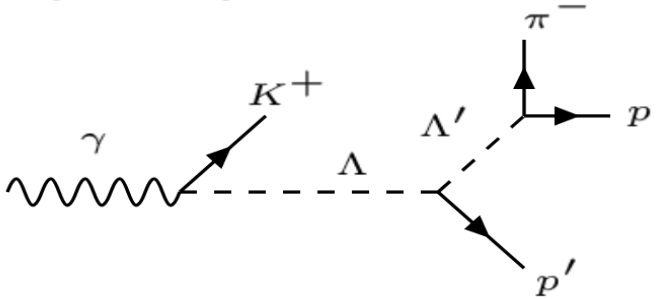
- Significant reduction in background
- Sideband subtraction almost completely removes background

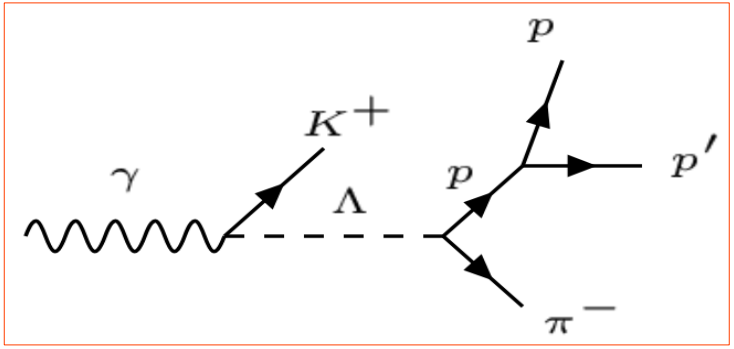




Other Cuts: *pp* → *pp* events

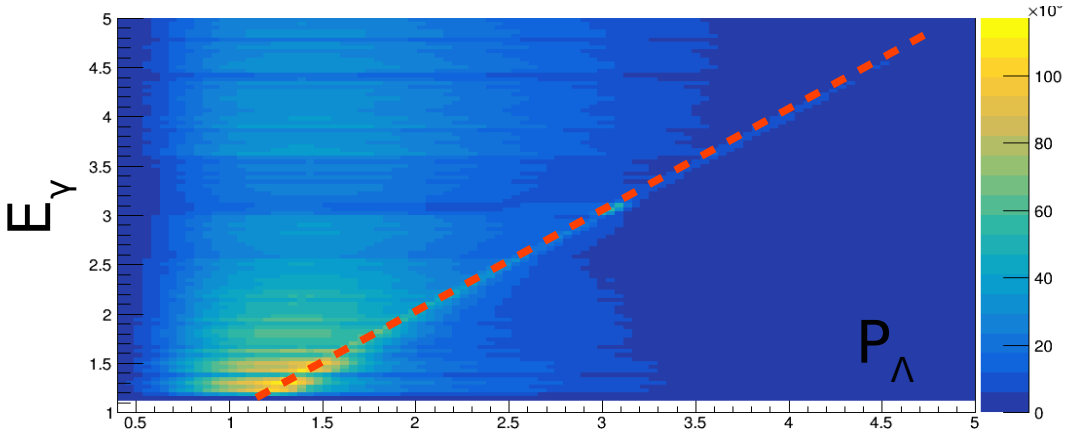


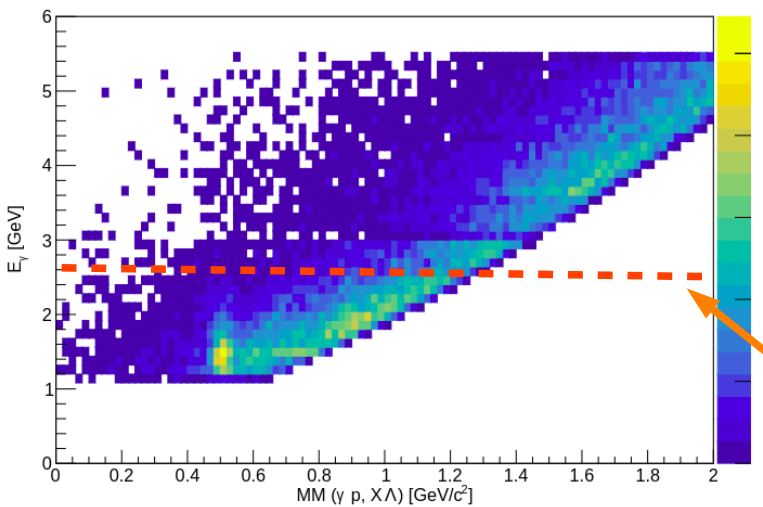




- *pp* → *pp* events can also result in the same final state.

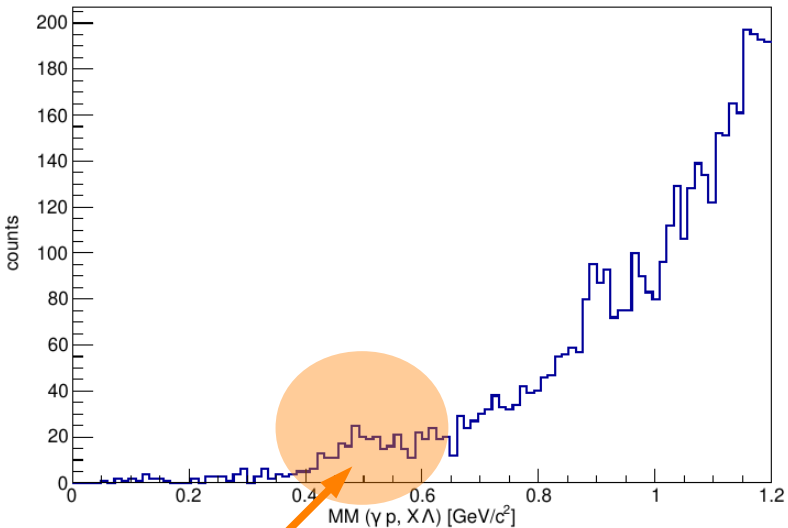
Other Cuts: E_γ Cut





E_γ<2.3

MM (γp → XΛ) for events outside the E_γ cut region

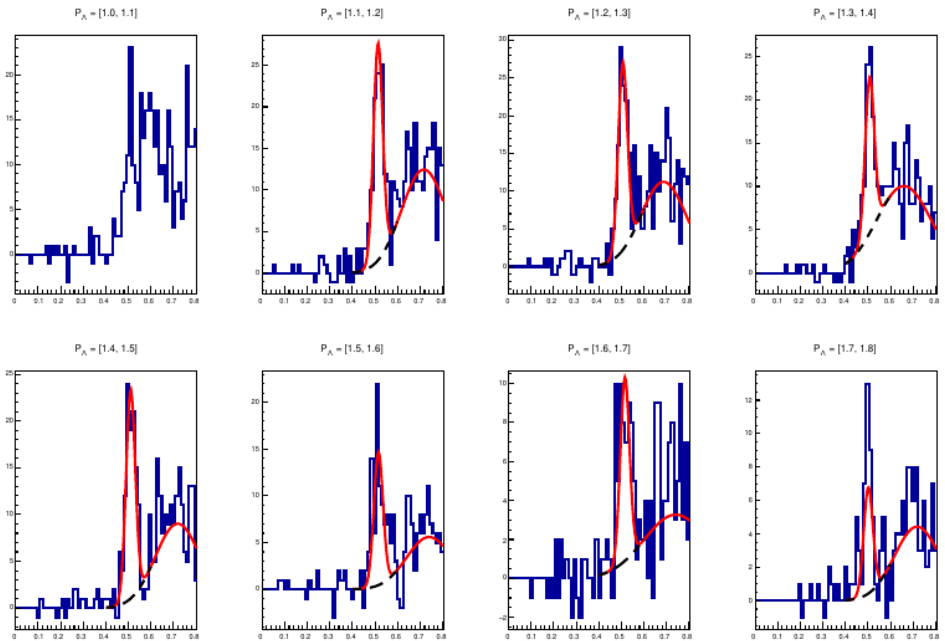


No prominent K^+ peak

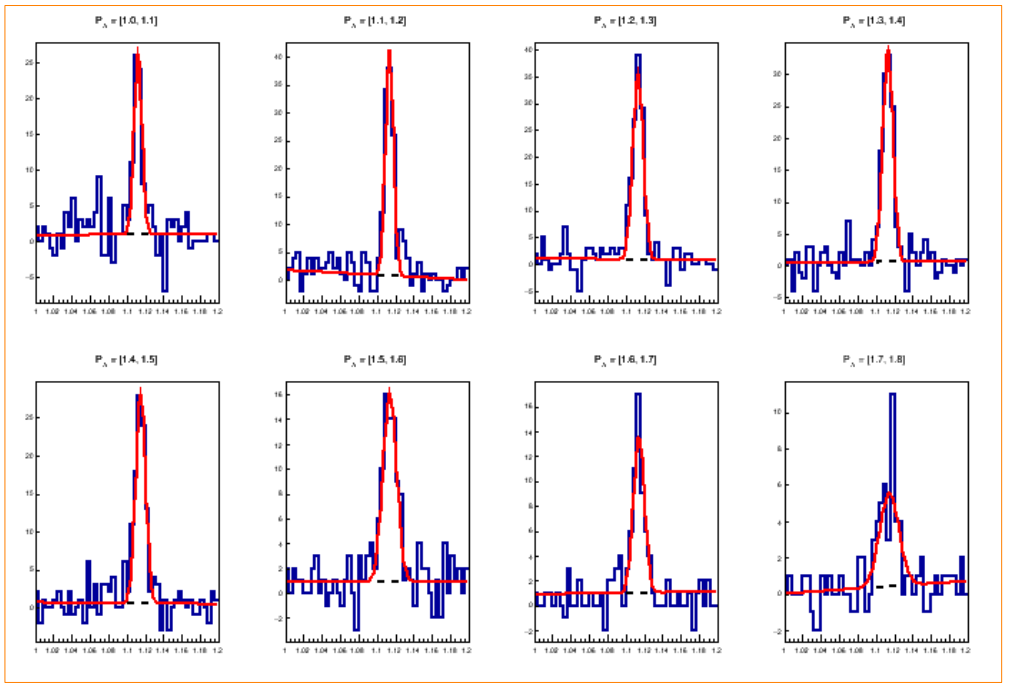
***Other standard cuts are applied**

Comparison of Methods

K^+ Extraction



Λ_{inc} Extraction



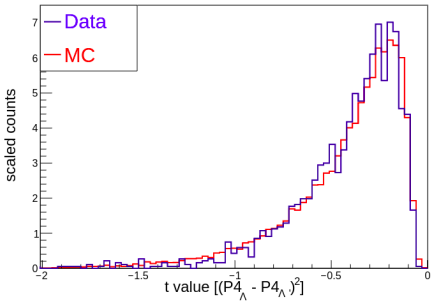
Λ_{inc} binning shows significant reduction in background

*both methods are consistent

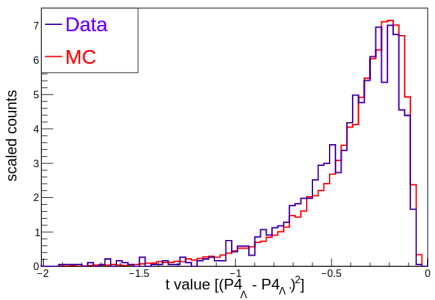
Acceptance

$$Acceptance = \frac{Accepted\ pp\pi^-}{Generated\ \Lambda p\ scattering}$$

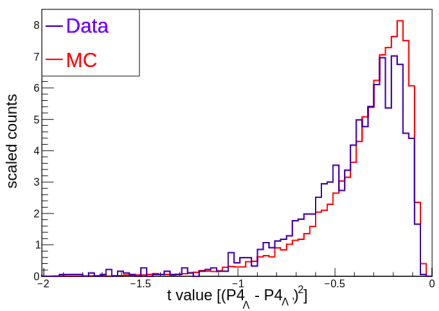
t-slope =1.0

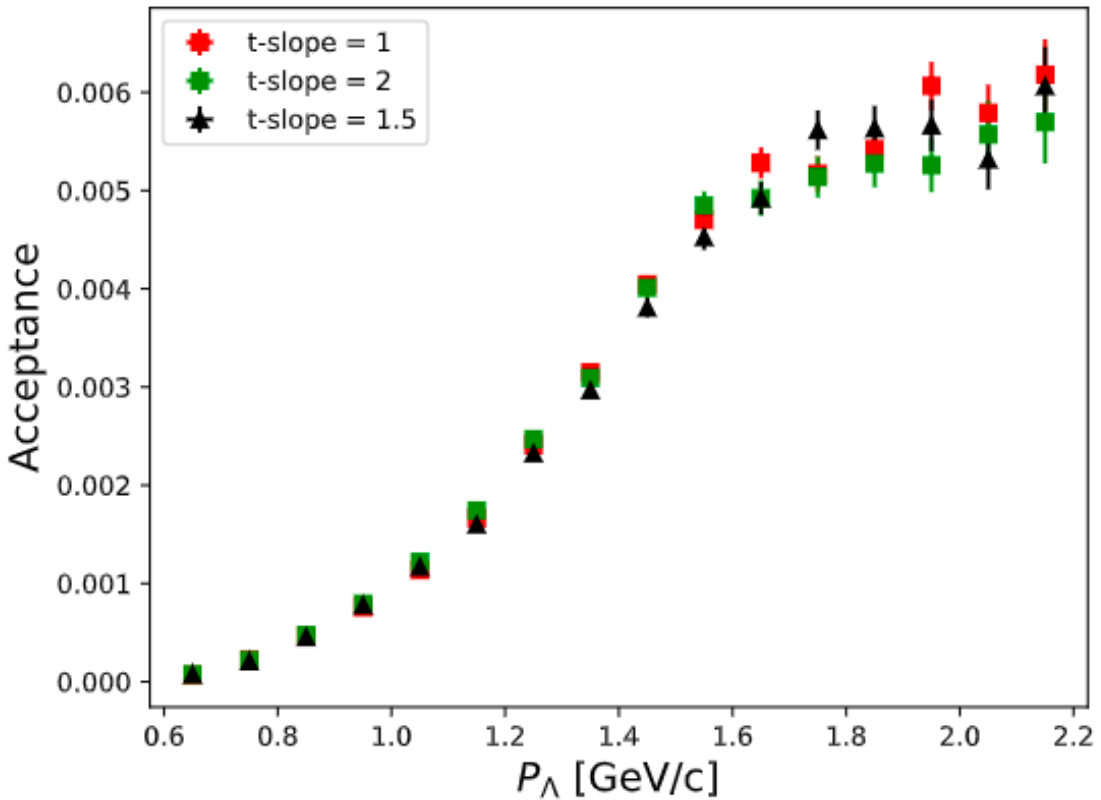


t-slope =1.5



t-slope =2.0





Luminosity

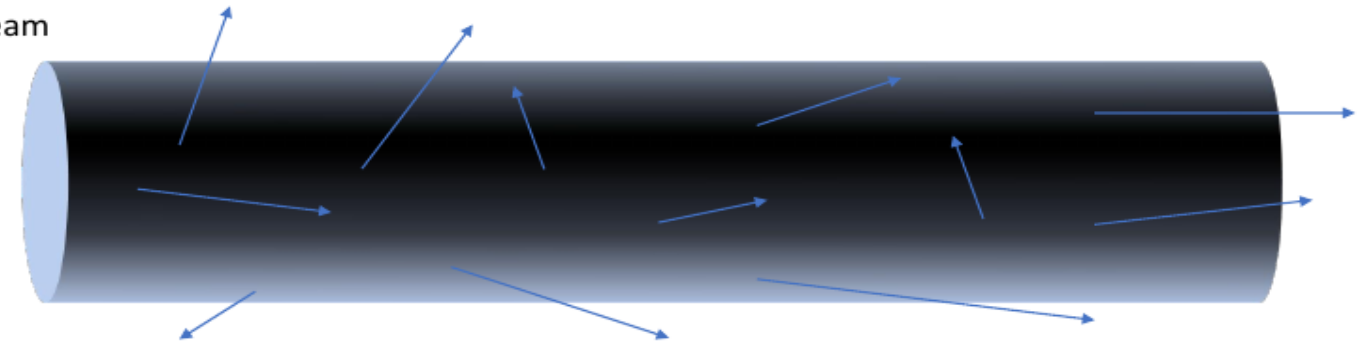
$$L_\Lambda(E_\Lambda) = \frac{\rho_T * N_A * l}{M} * N_\Lambda(E_\Lambda)$$

- ρ_T: density of the target
- N_A: Avogadro's number
- M: molar mass of Hydrogen
- l: travel distance of Λ
- $N_\Lambda(E_\Lambda)$: yield in a certain energy range

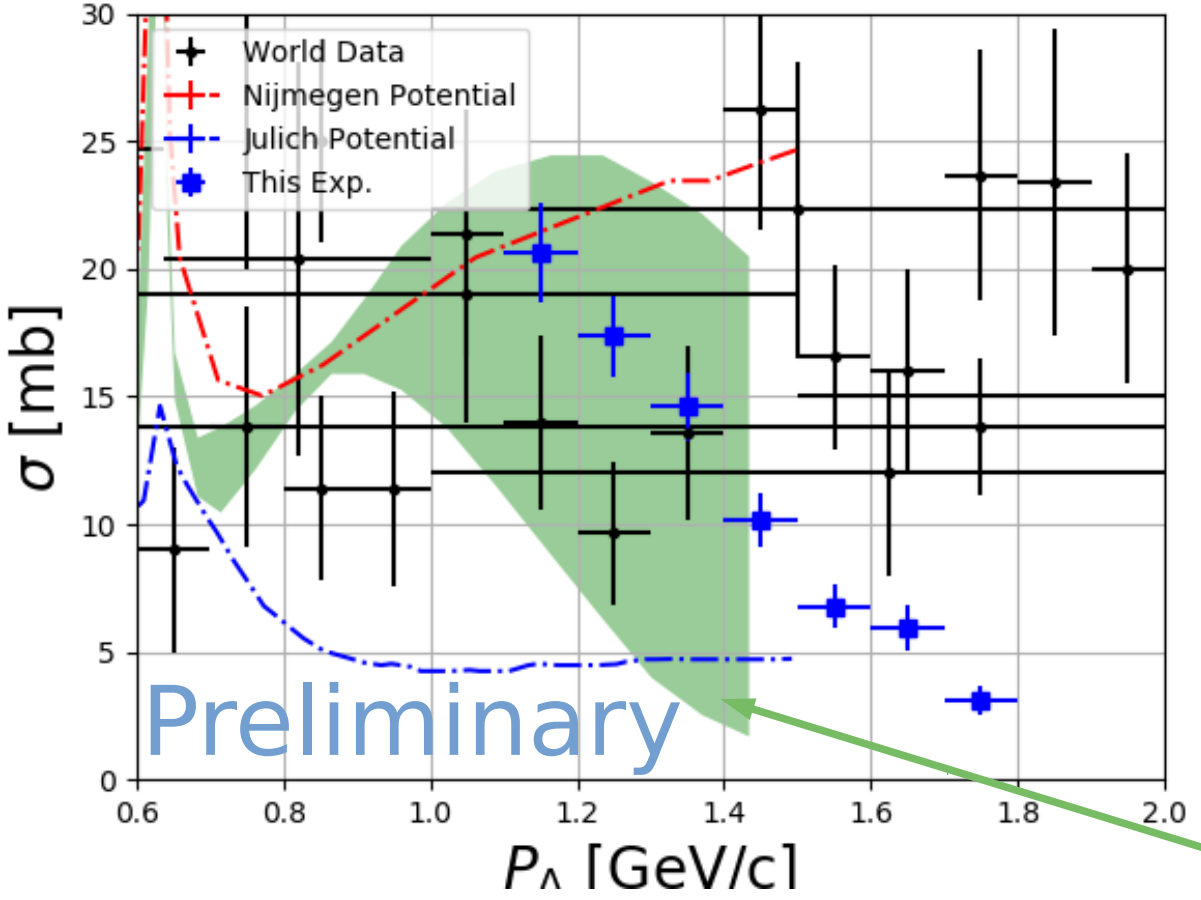
Photon Beam

$$\frac{d\sigma}{d\Omega} = \frac{N_\Lambda}{2\pi * L_\gamma * \Delta\cos(\theta)}$$

Λ Beam



Preliminary Results



- Results are consistent with theoretical prediction at lower momentum. measurements
- At higher momentum, our results drop which will effect the EOS.

Theoretical prediction based on chiral EFT from Haidenbauer extended to our momentum range (unpublished).

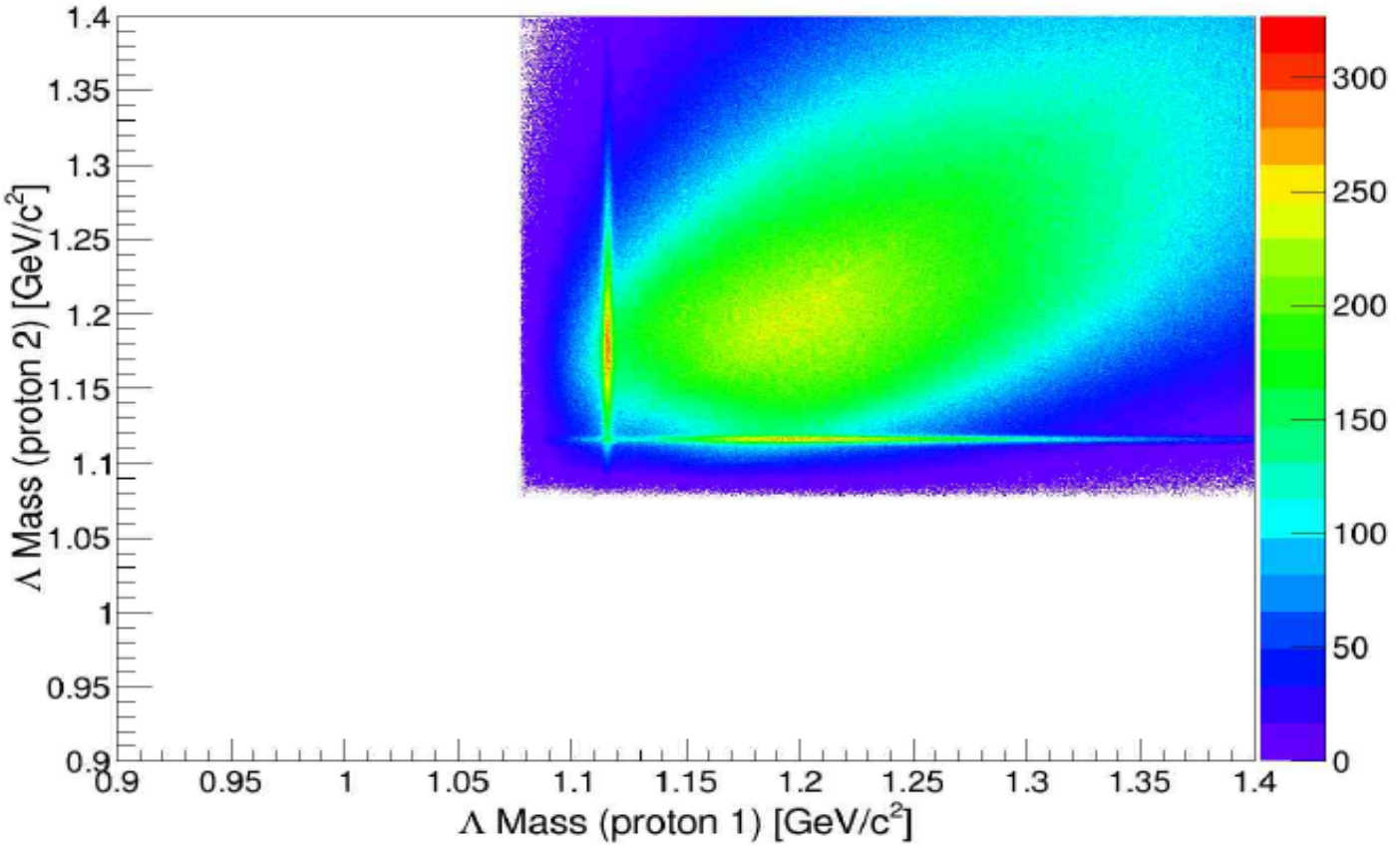
Outlook

- Results are being finalized.
- Submitted for CLAS review.
  - Currently going through the process.
- Plans to publish after review is finished.

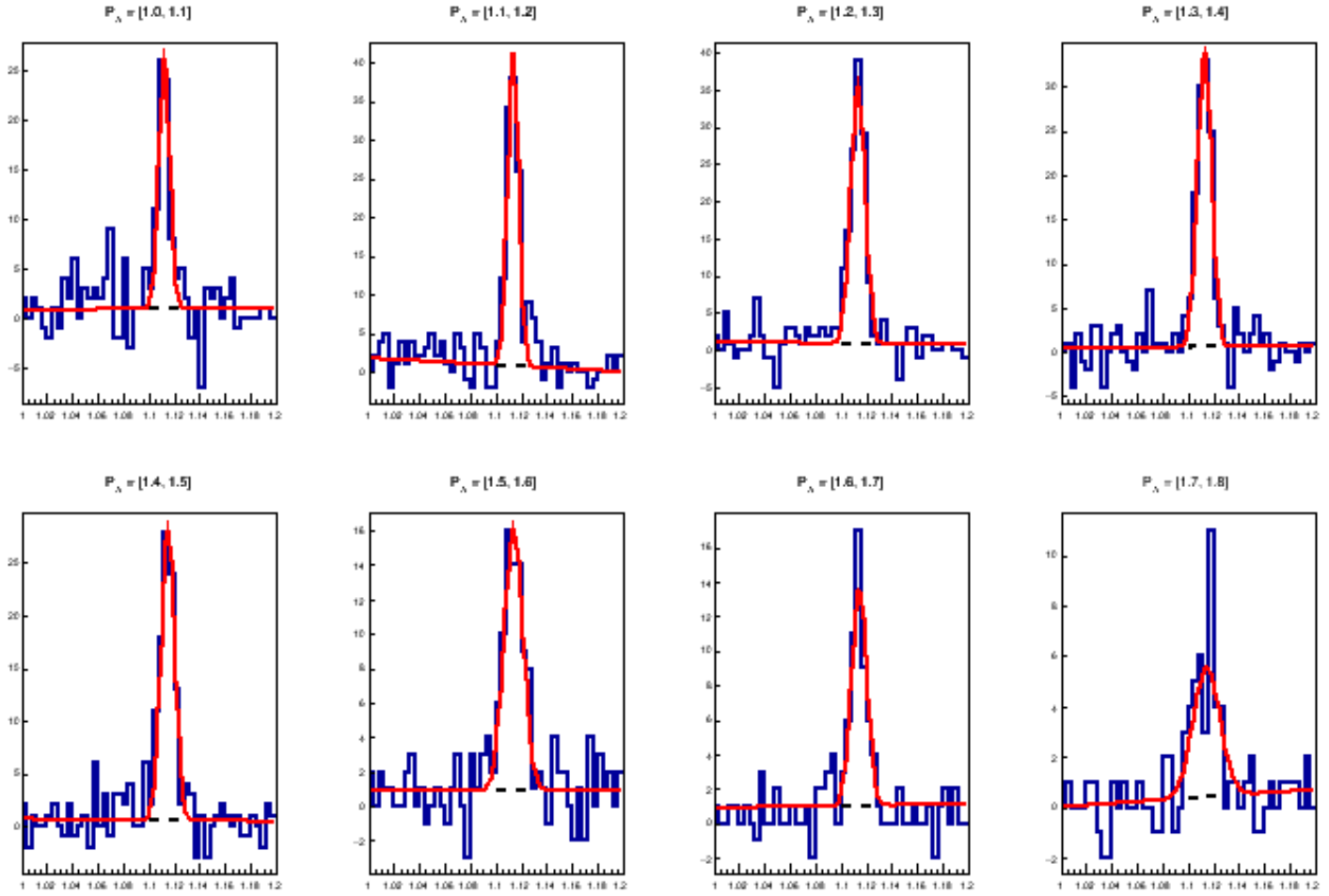
Questions?

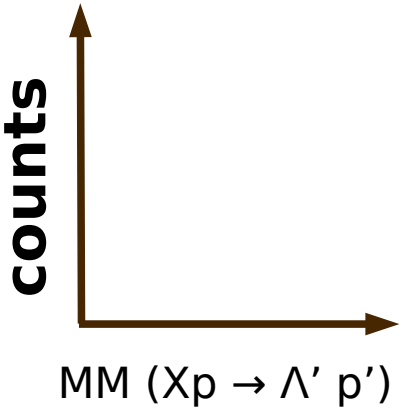
Extra Slides

Proton Distinction

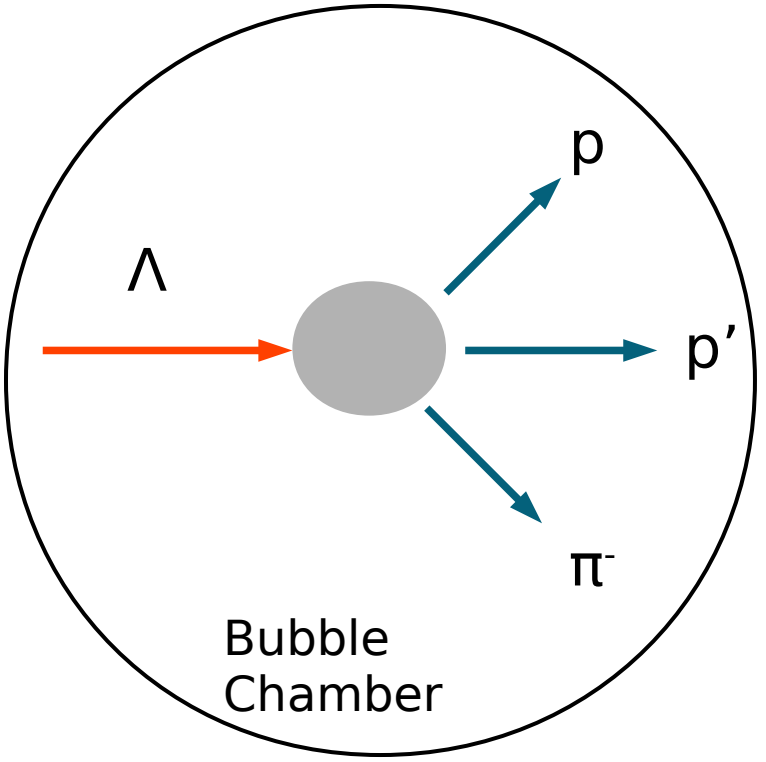


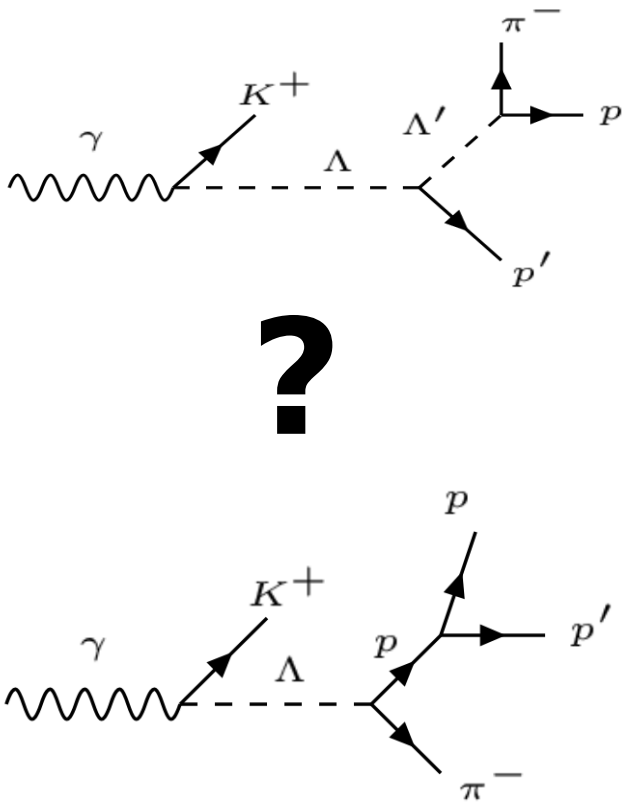
Yield (Incident Λ Fitting Method)



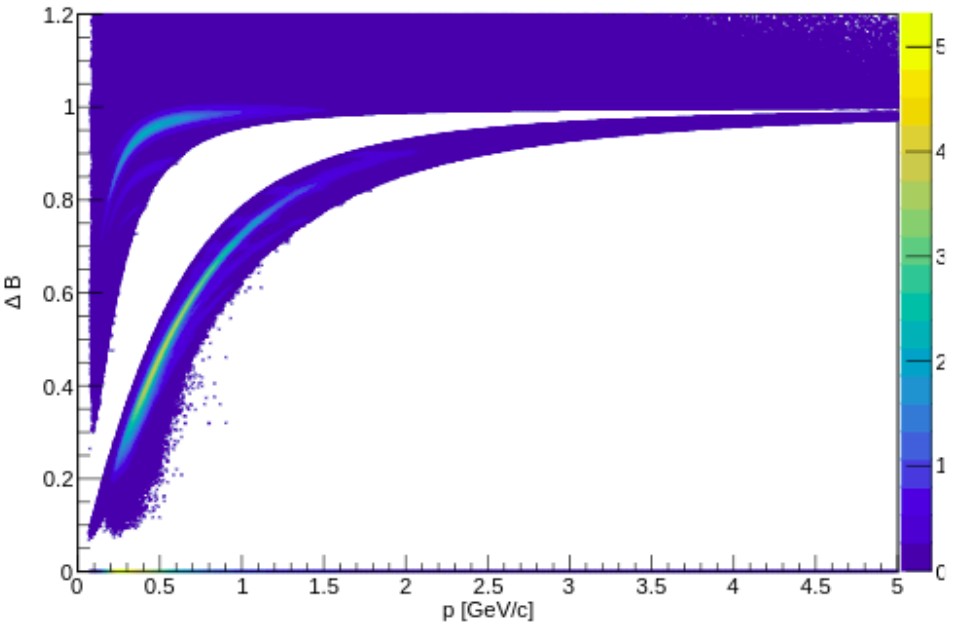


pp → pp events

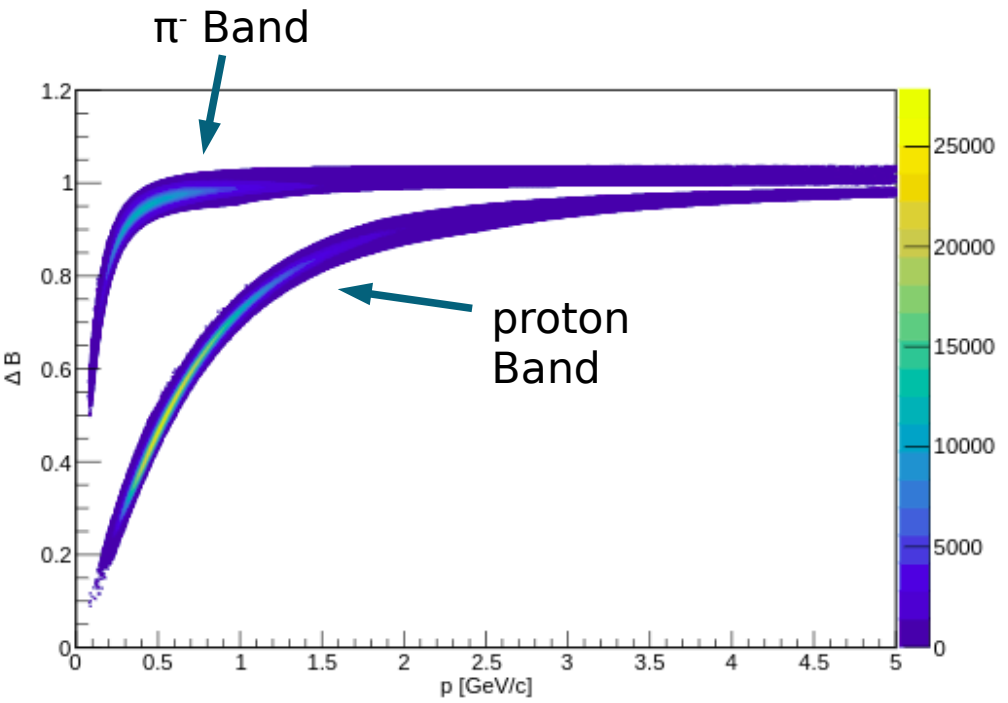




PID Selection



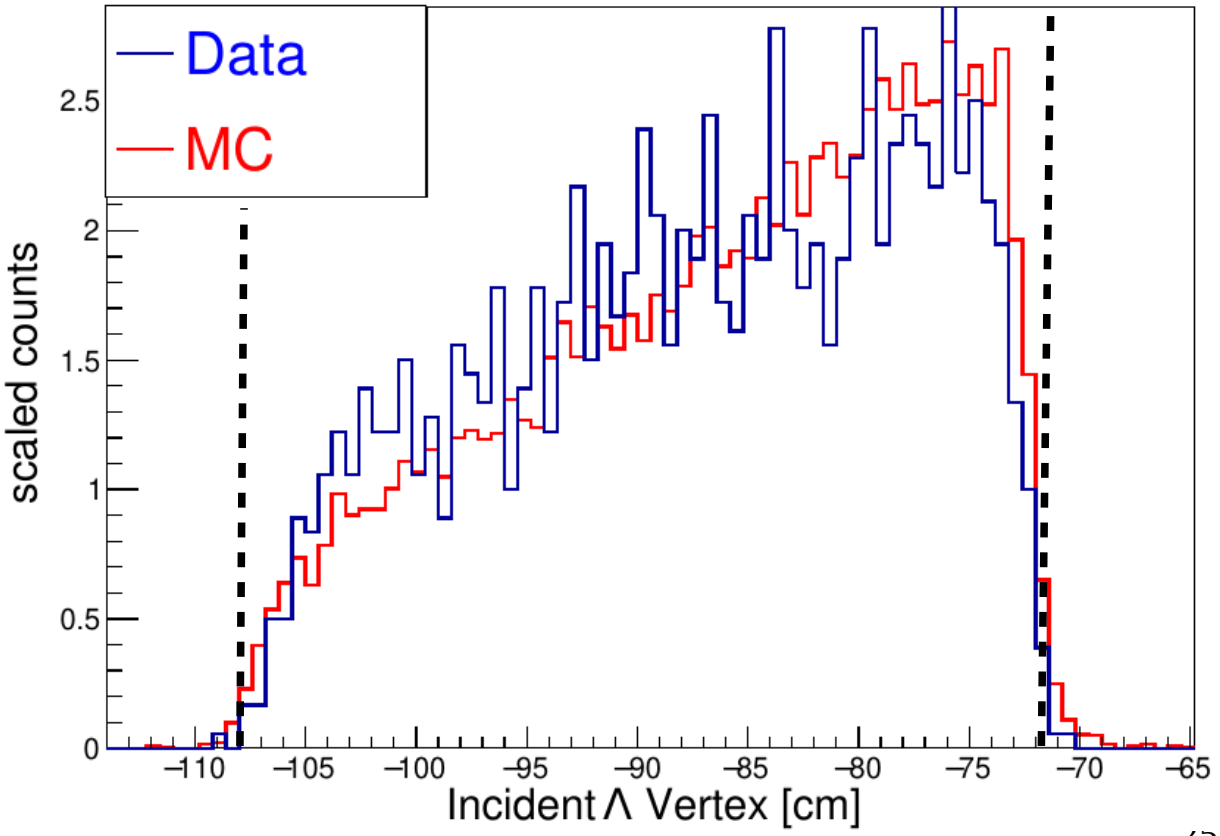
Before Selection



After Selection

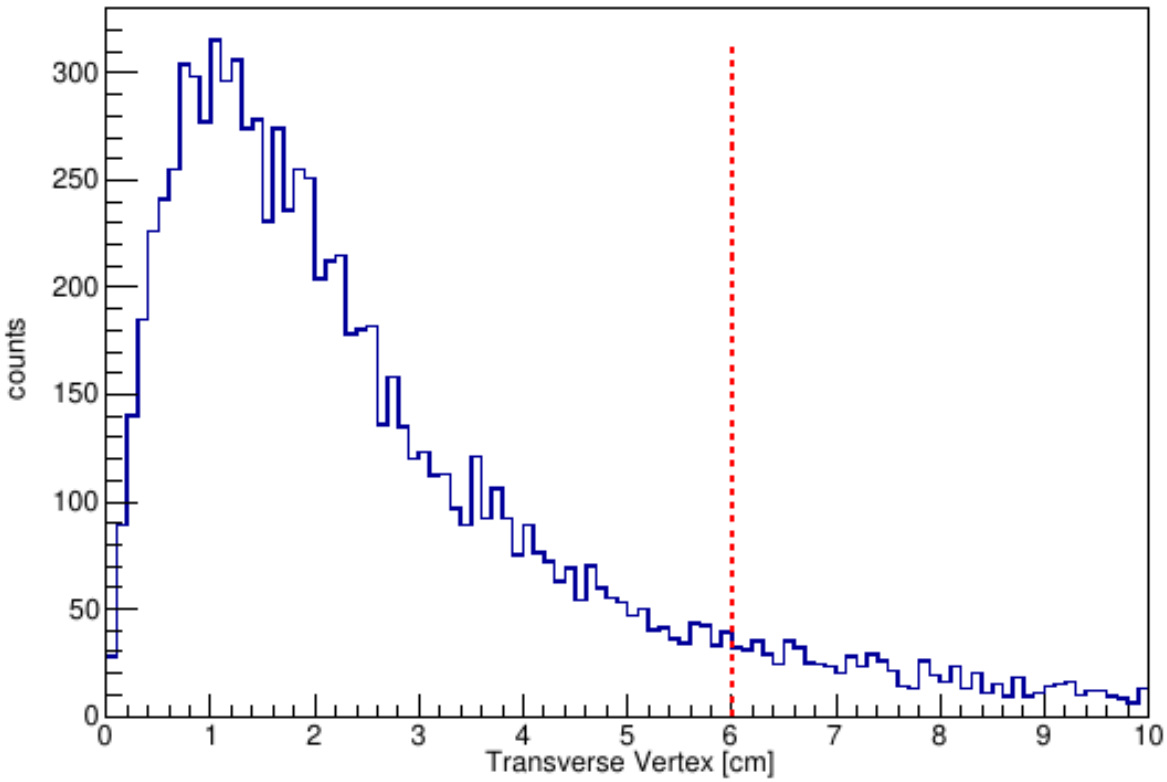
z-Vertex Cuts

- z-vertex is measured from DOCA calculations
- Comparison at “inner most” level of cuts
- Good agreement between data and simulation



Transverse Vertex Cuts

- Unlike a photon beam, the secondary nature of the Λ beam can have a transverse vertex outside the target.
- 6 cm cut is a non-physical region but represents the fact that not all tracks trace well.



Systematic Study Results

Cuts	Error (%)
Vertex	0.9
M ($p\ \pi^-$) (Scattered proton)	0.03
MM (Xp, Λp) (Incident proton)	4.3
PID	1.8
Fit Function	9.6

Total Systematic = 14.4%

***Not an inclusive list**

Trigger Efficiency