A Study of Λ-N Scattering using the CLAS Detector at Jefferson Lab

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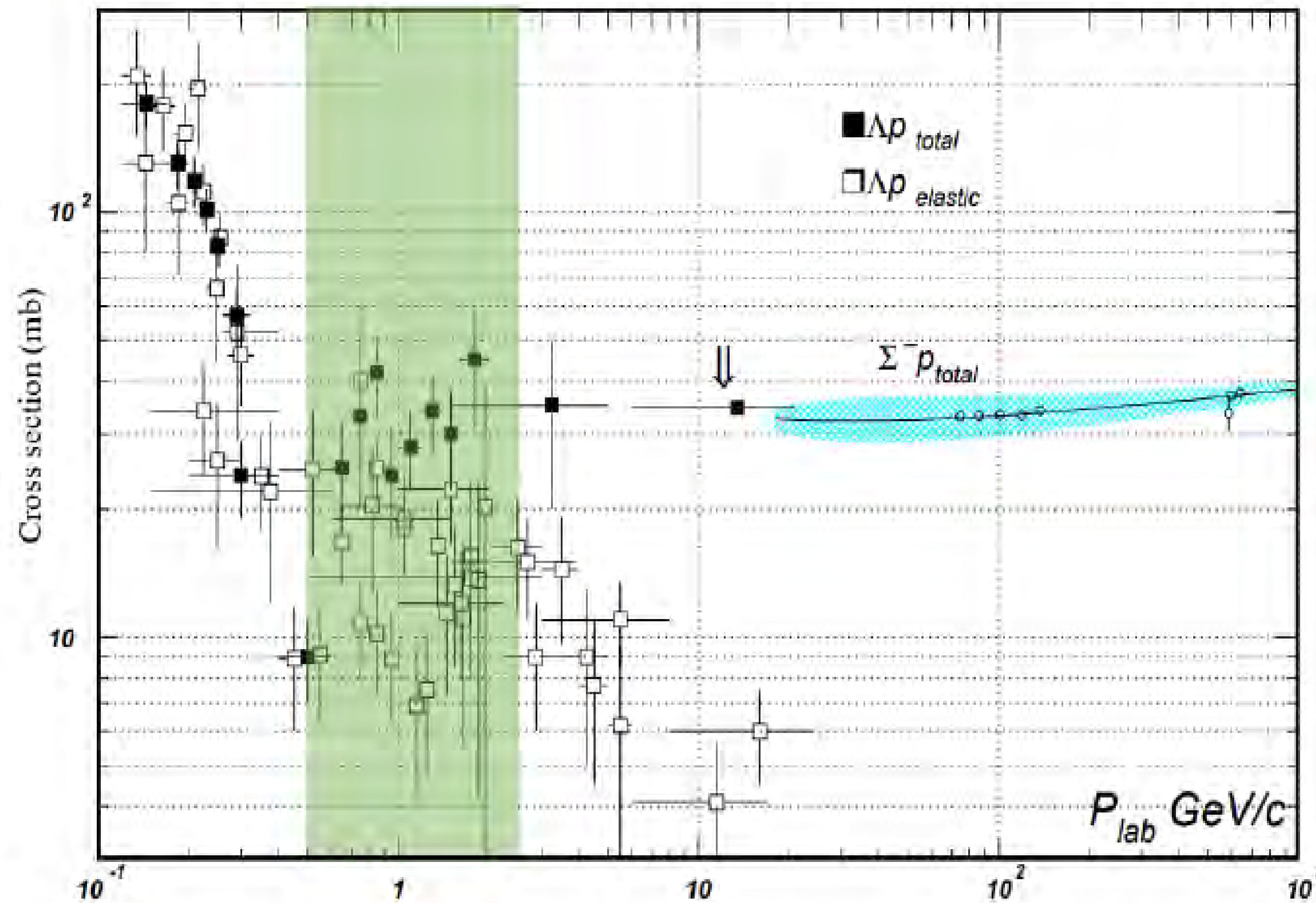
NNPSS 2019

Motivation

- Currently very little data for ΛN scattering compared to other elastic scattering processes (NN, KN or πN).

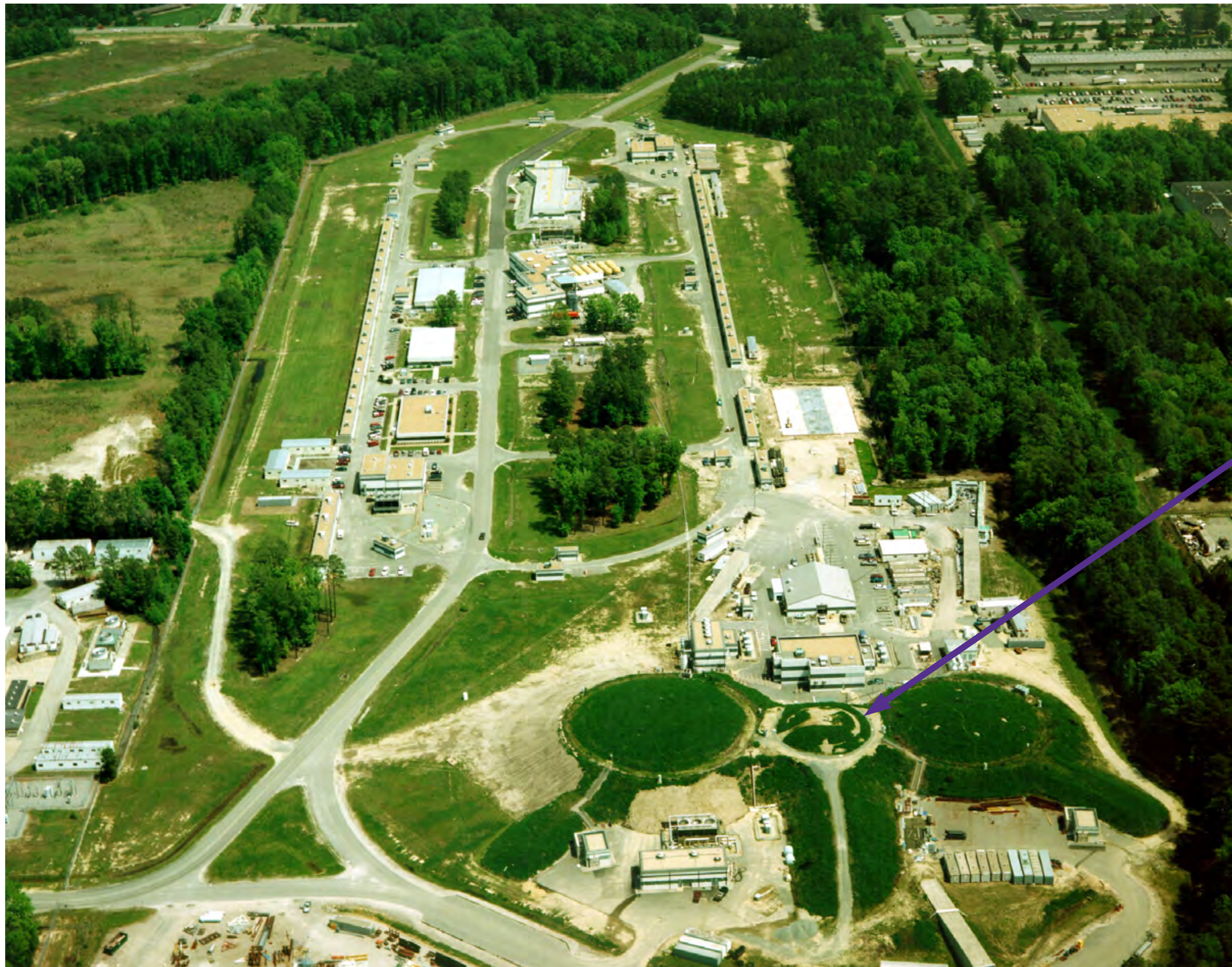
    * **< 1300 events**

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



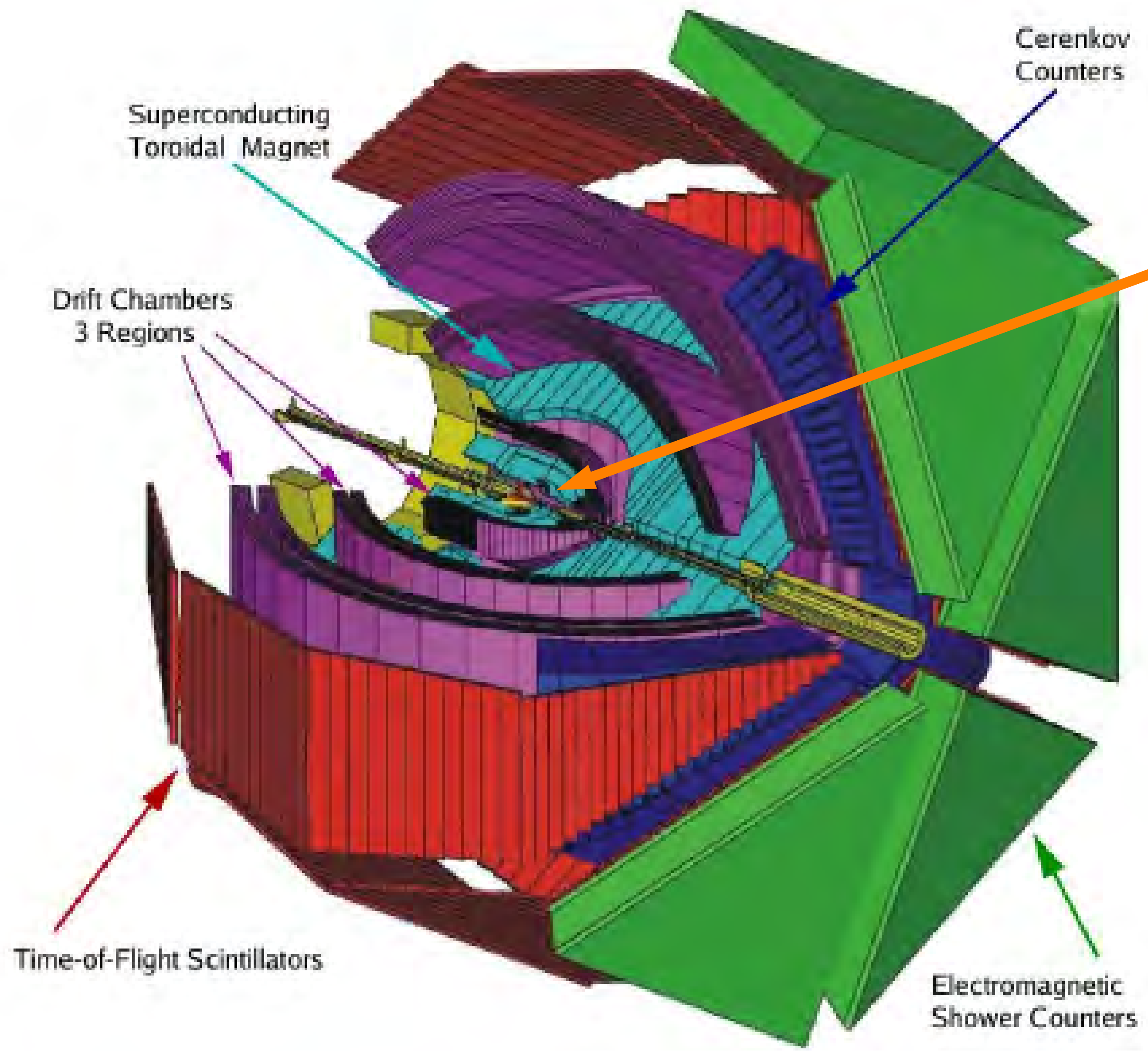
C. Patrignani et al. (Particle Data Group), Chin. Phys. C, **40**, 100001 (2016) and 2017 update.

Jefferson Lab



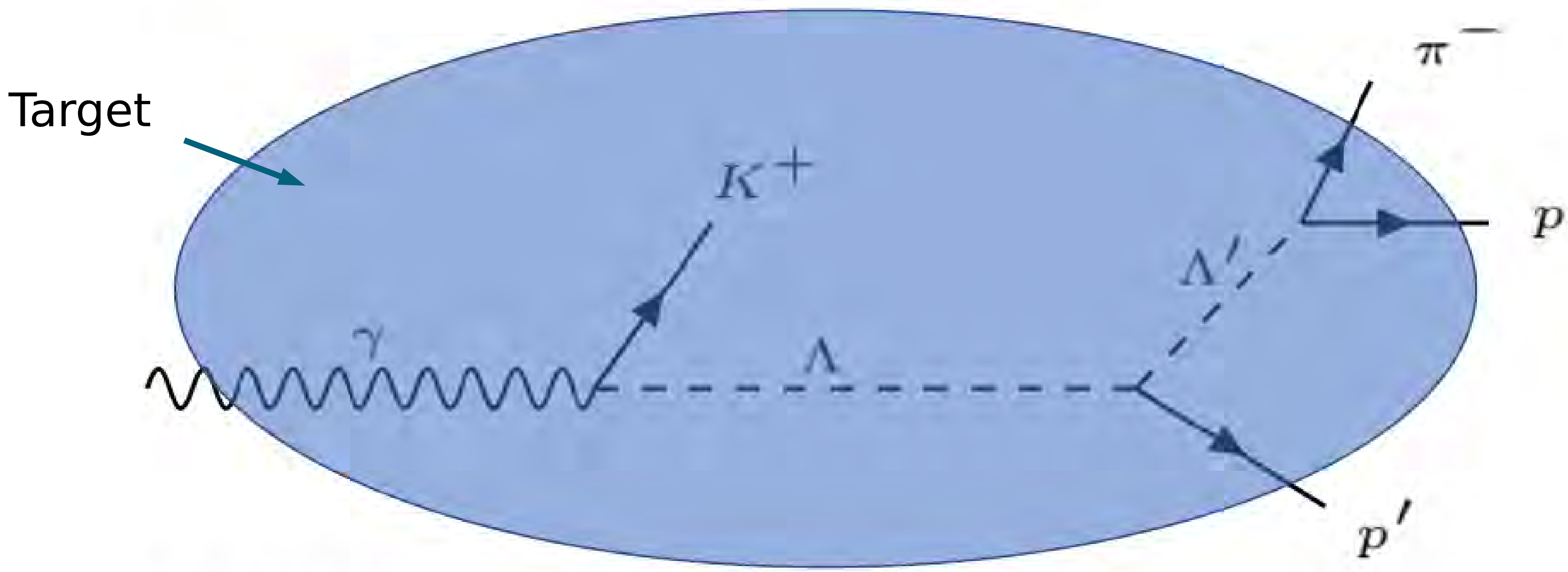
Hall B

CLAS Detector



- 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

* NOT a Feynman Diagram

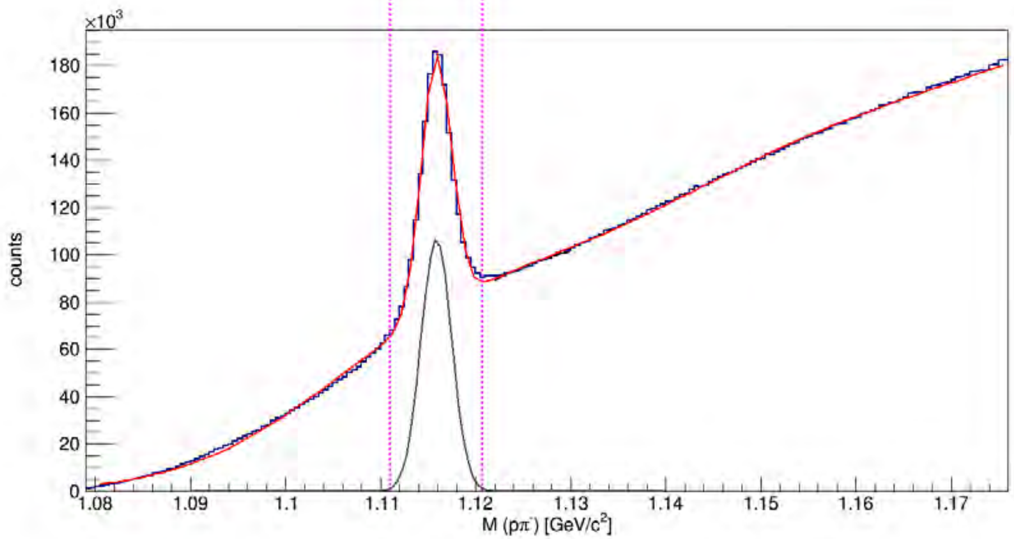
Procedure Analysis

$$\gamma p \to K^{+}\Lambda$$

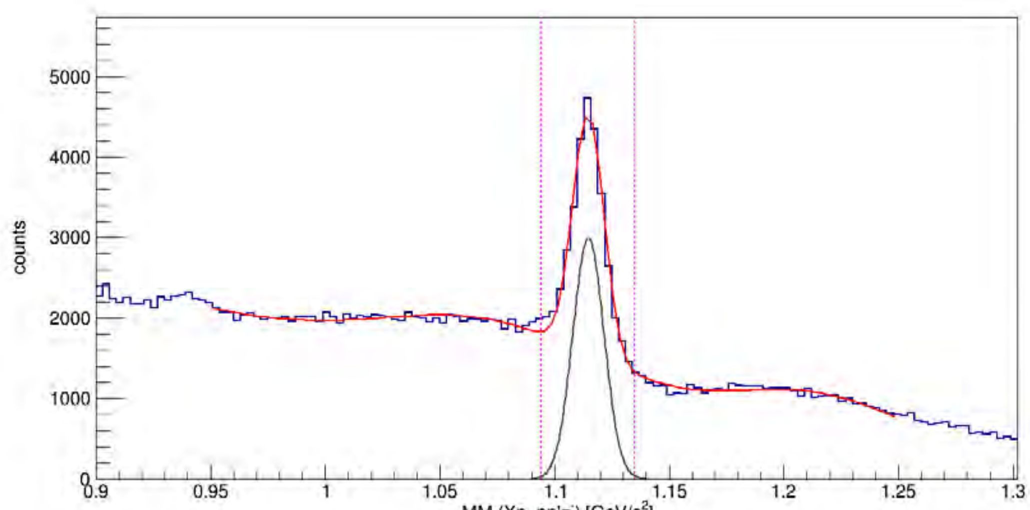
$$\hookrightarrow \Lambda \mathrm{p} \to \Lambda' p' \to p' p \pi^{-}$$

- Data from g12
- Reconstruct the Λ' mass: M(Λ') = M($p\pi^-$)
- Reconstruct incident Λ
- Identify K^+ by missing mass

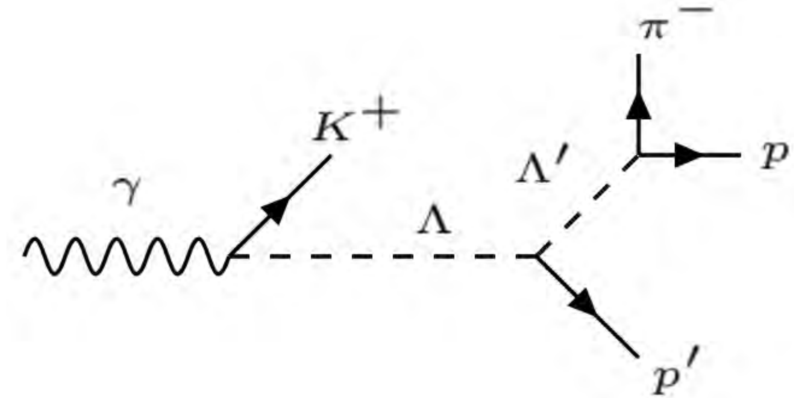
Data



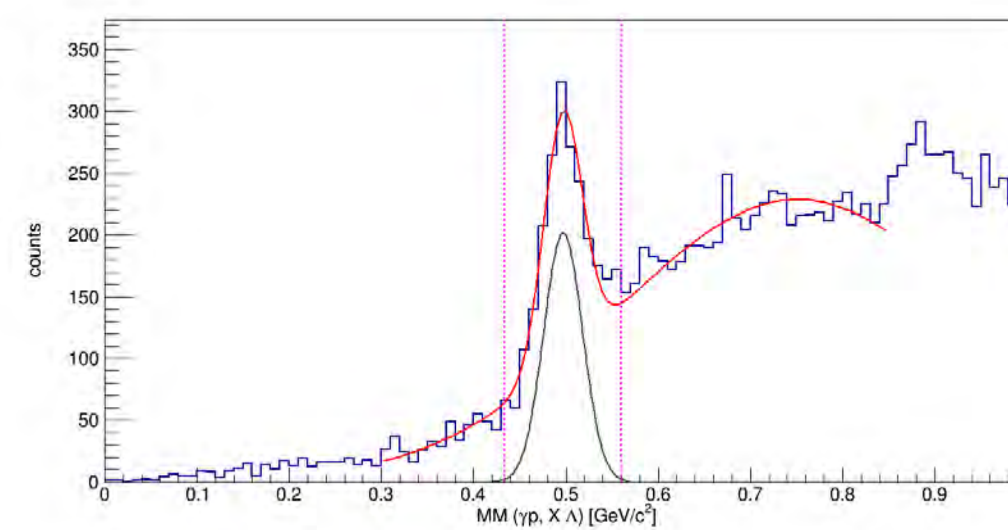
×10^3
counts
180
160
140
120
100
80
60
40
20
0
1.08 1.09 1.1 1.11 1.12 1.13 1.14 1.15 1.16 1.17
M (pπ⁻) [GeV/c²]



counts
5000
4000
3000
2000
1000
0
0.9 0.95 1 1.05 1.1 1.15 1.2 1.25 1.3
MM (Xp, pp'π⁻) [GeV/c²]

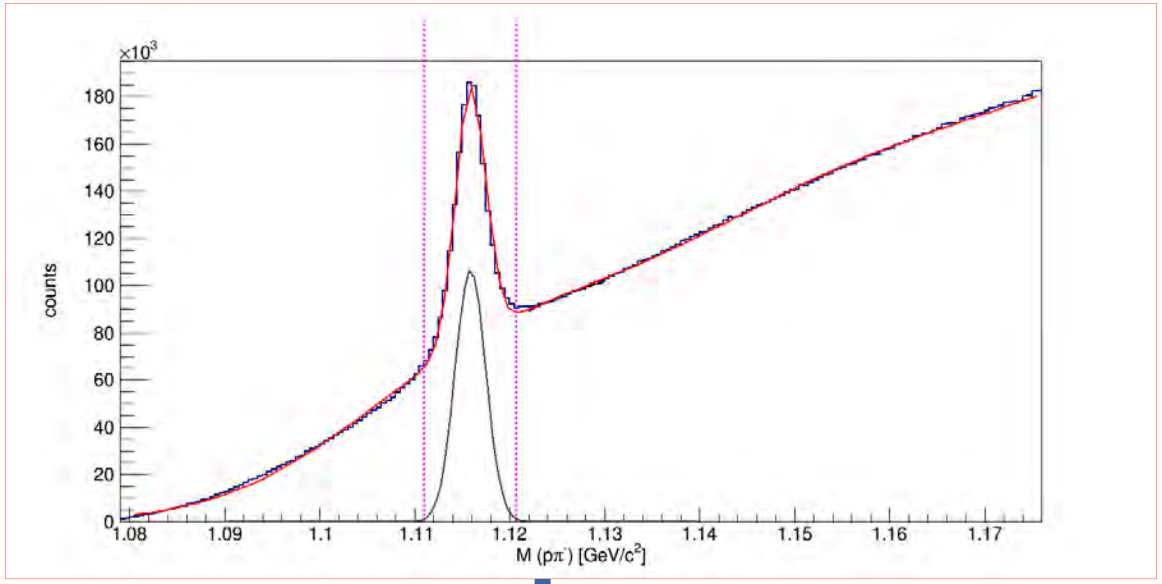


γ
K^+
Λ
Λ'
π^-
p
p'

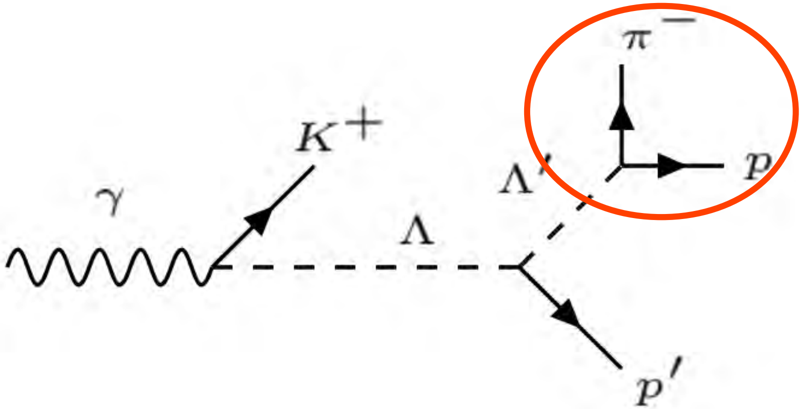


counts
350
300
250
200
150
100
50
0
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1
MM (γp, X Λ) [GeV/c²]

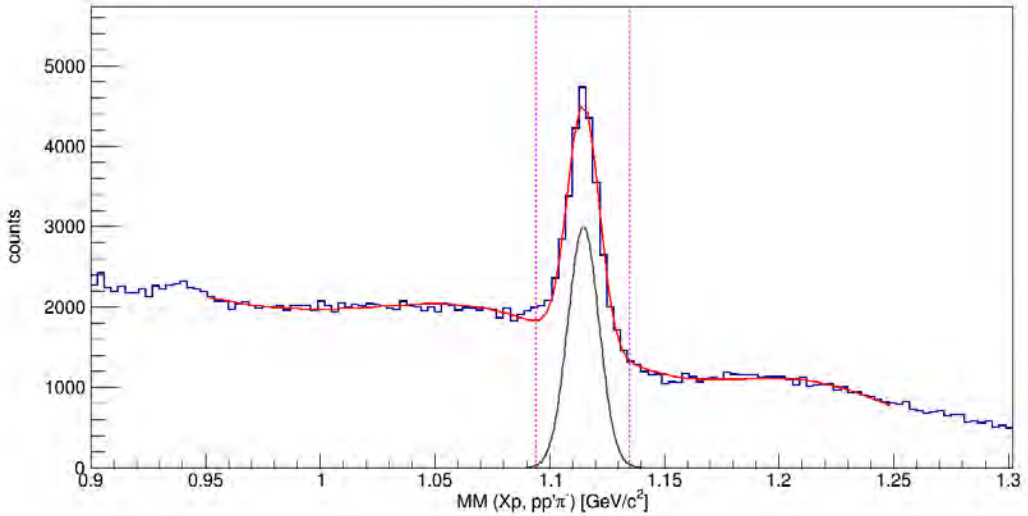
Data



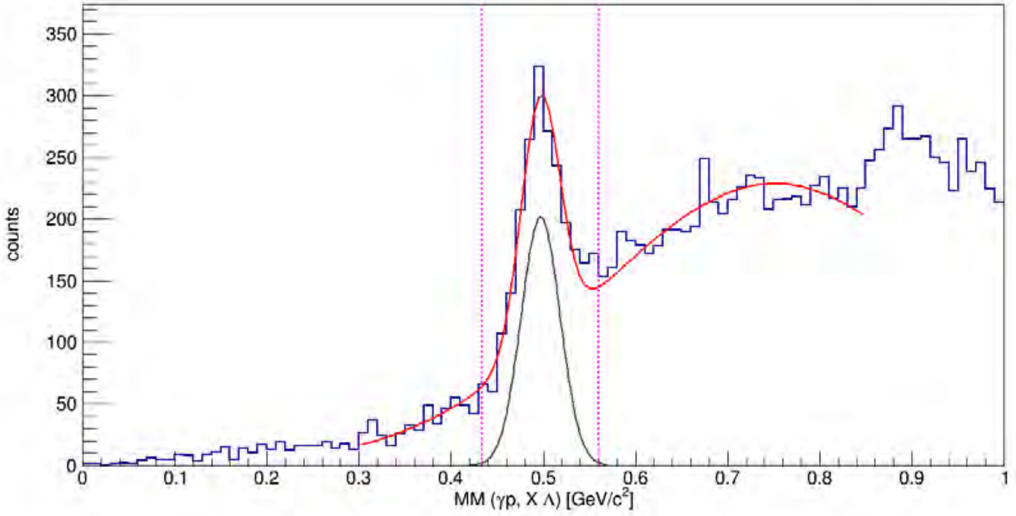
$\times 10^3$
counts
M (pπ⁻) [GeV/c²]



γ
K^+
Λ
Λ′
π^-
p
p′

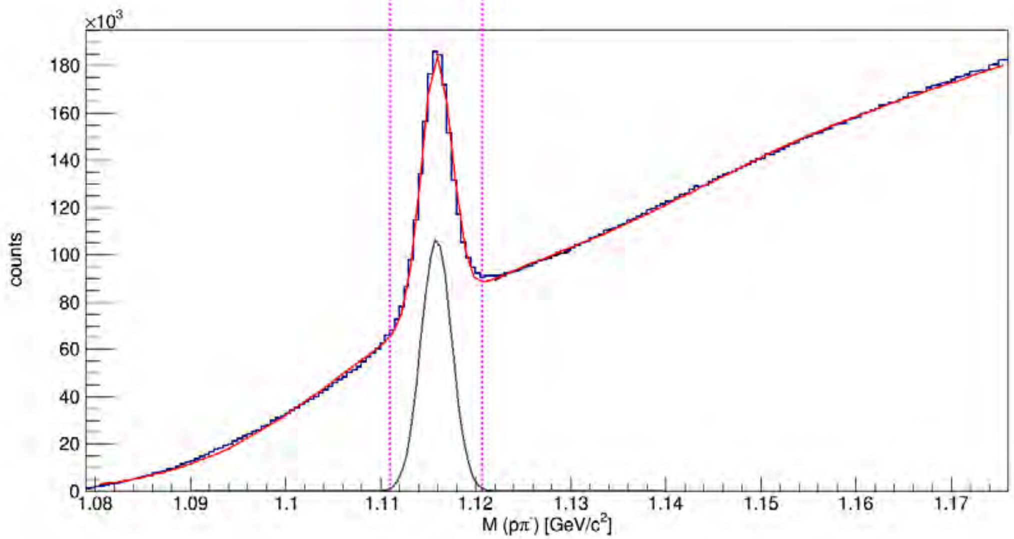


counts
MM (Xp, pp'π⁻) [GeV/c²]

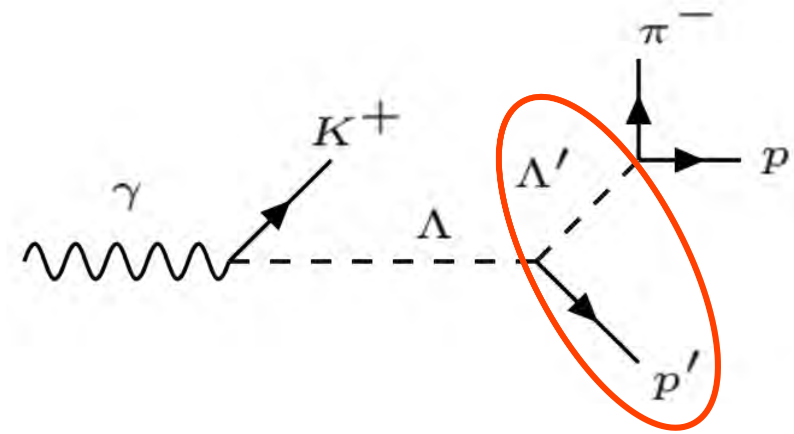


counts
MM (γp, X Λ) [GeV/c²]

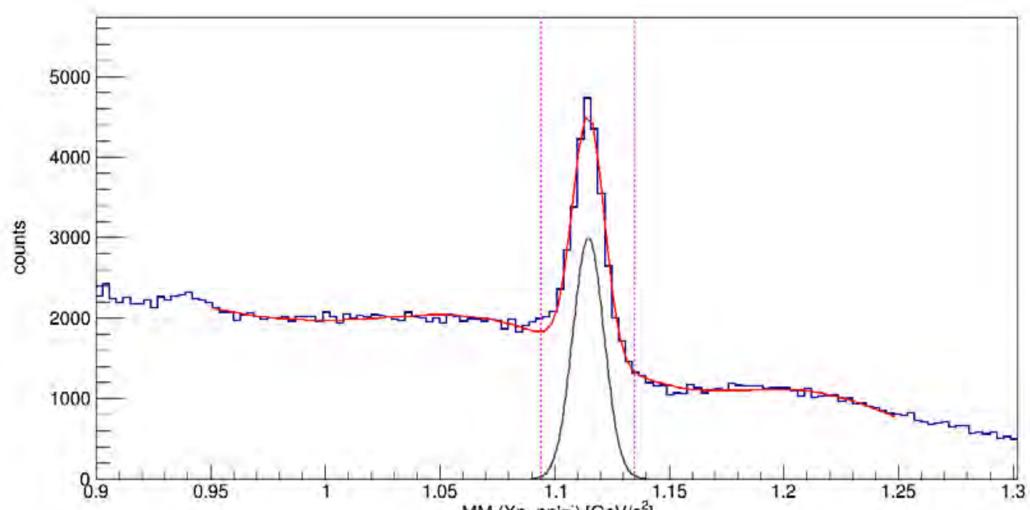
Data



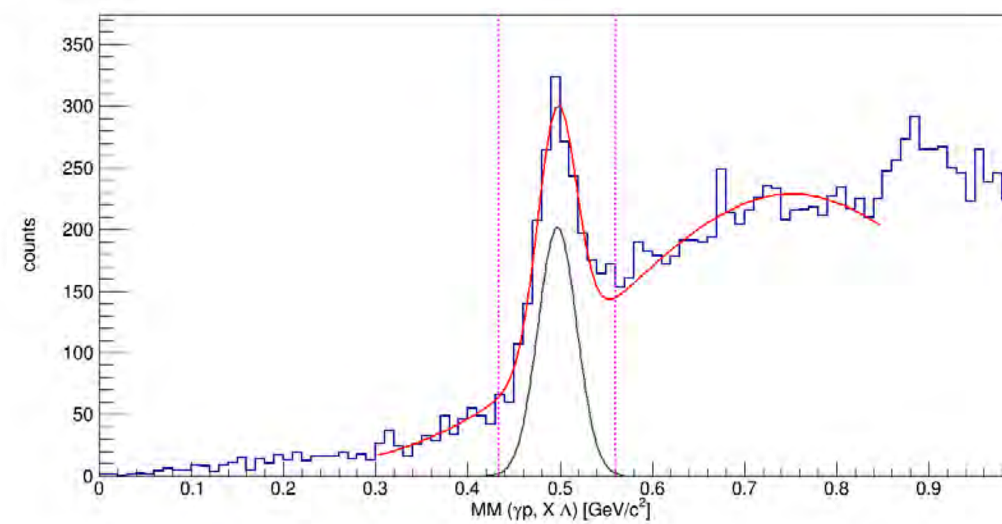
×10^3
counts
M (pπ⁻) [GeV/c²]



γ
K+
Λ
Λ′
π−
p
p′

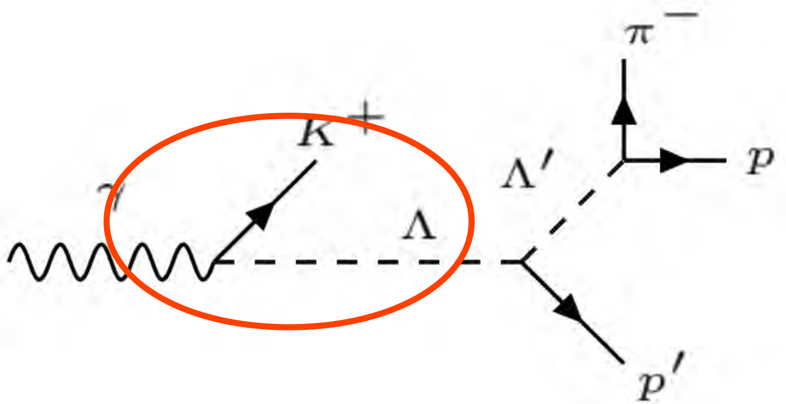


counts
MM (Xp, pp′π⁻) [GeV/c²]

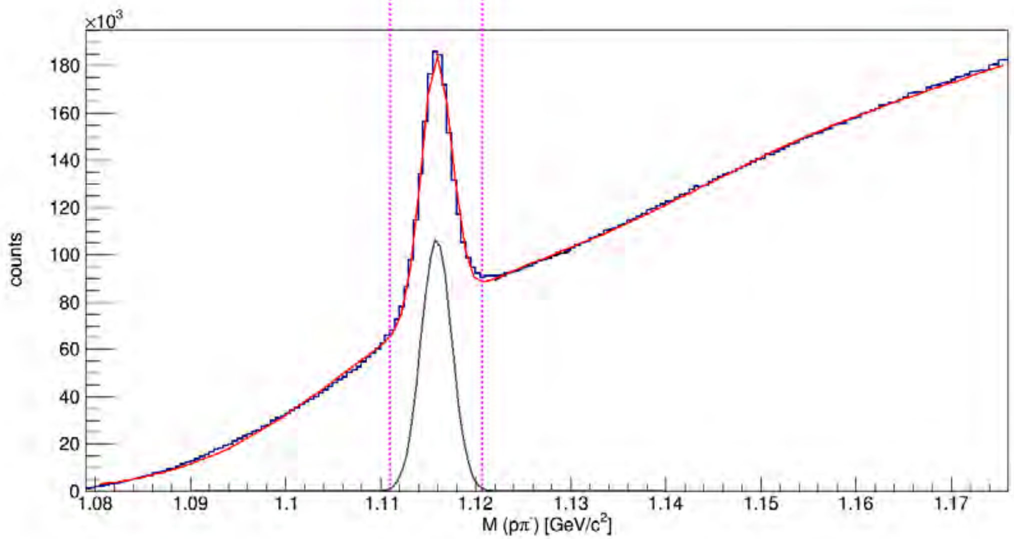


counts
MM (γp, X Λ) [GeV/c²]

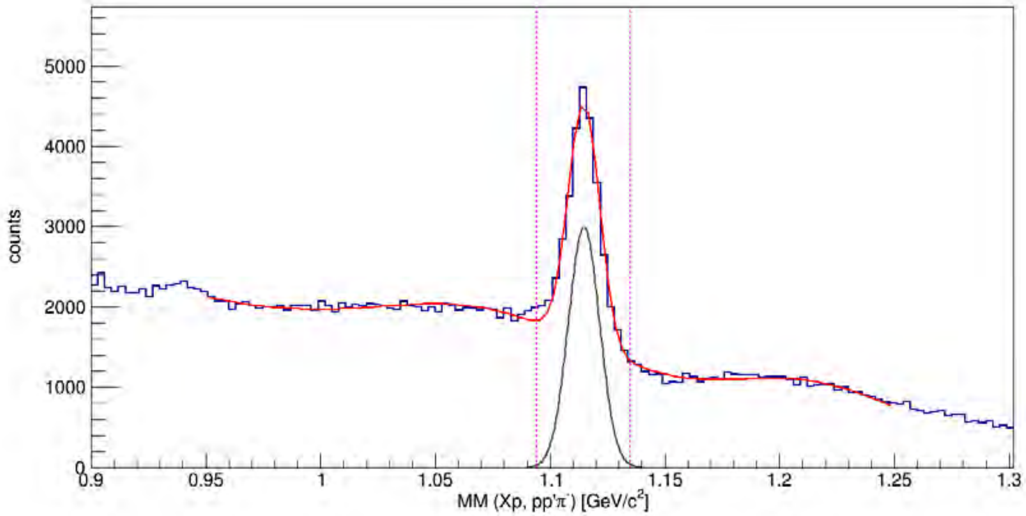
Data



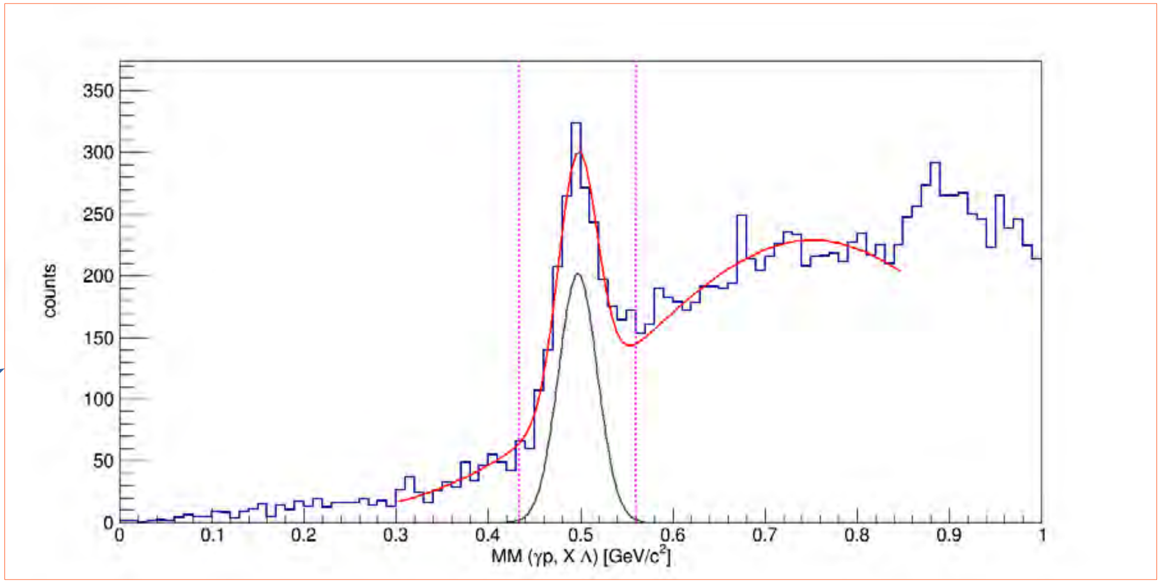
π⁻
K⁺
γ
Λ′
p
Λ
p′



×10³
counts
M (pπ⁻) [GeV/c²]



counts
MM (Xp, pp′π⁻) [GeV/c²]



counts
MM (γp, X Λ) [GeV/c²]

Cross Section

$$\frac{d\sigma}{d\cos(\theta)}(E) = \frac{Y}{A * \mathcal{L} * \mathrm{b.r.} * \Delta\cos(\theta)}$$

Y: Yield

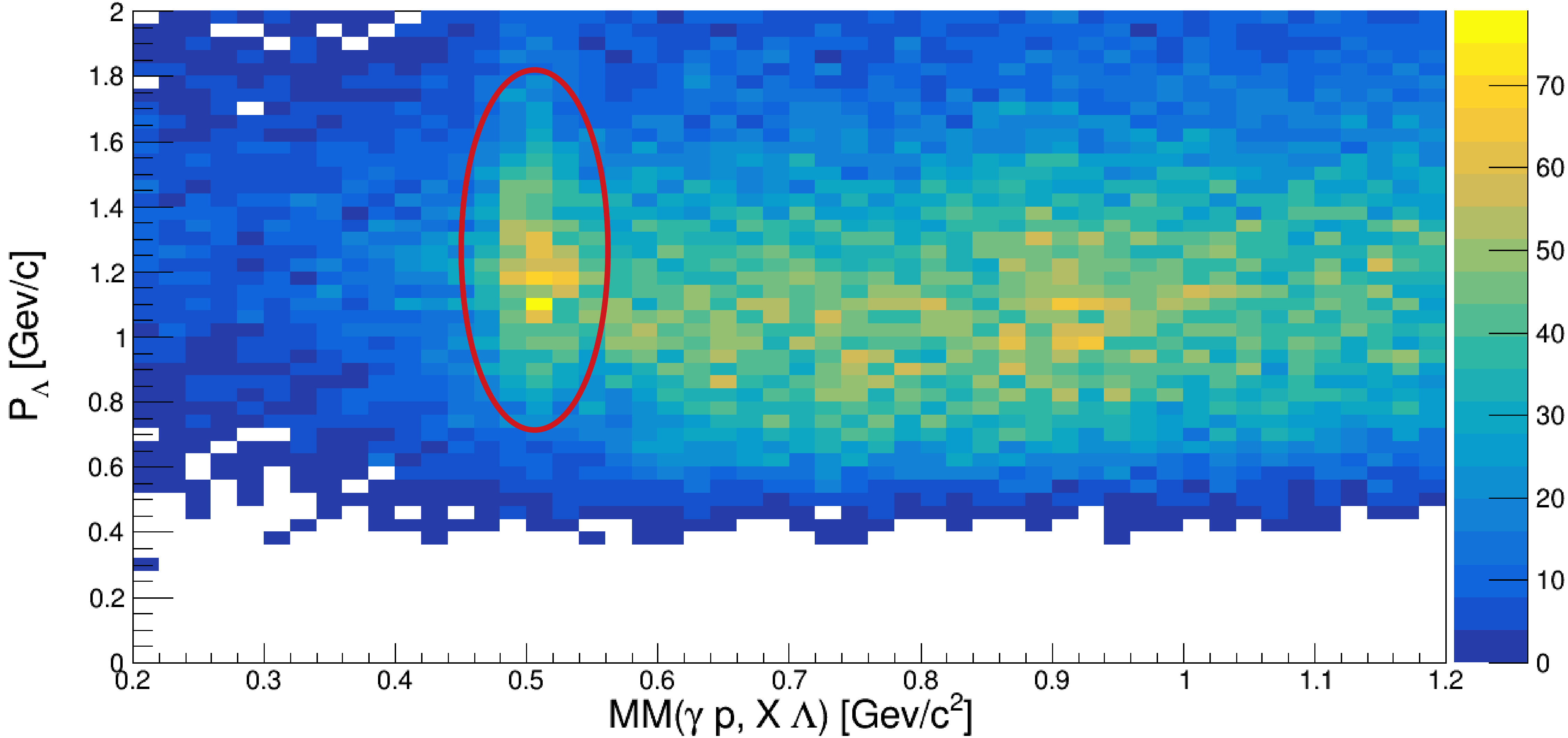
A: Acceptance

$\mathcal{L}$: Luminosity

b.r: Branching ratio (for $p\pi^-$)

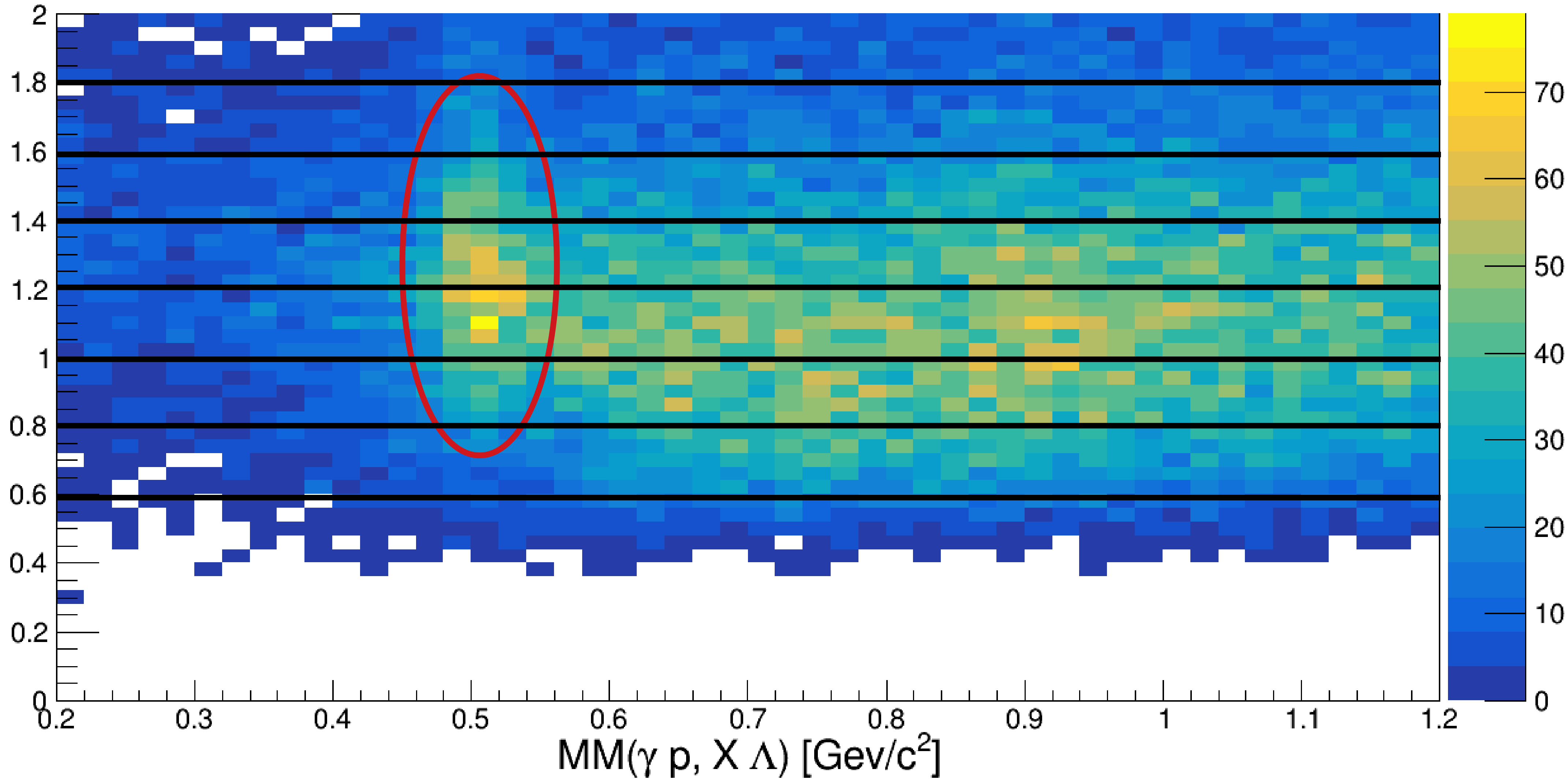
$\frac{d\sigma}{d\cos(\theta)}(E)$: Energy dependent cross section

Yield



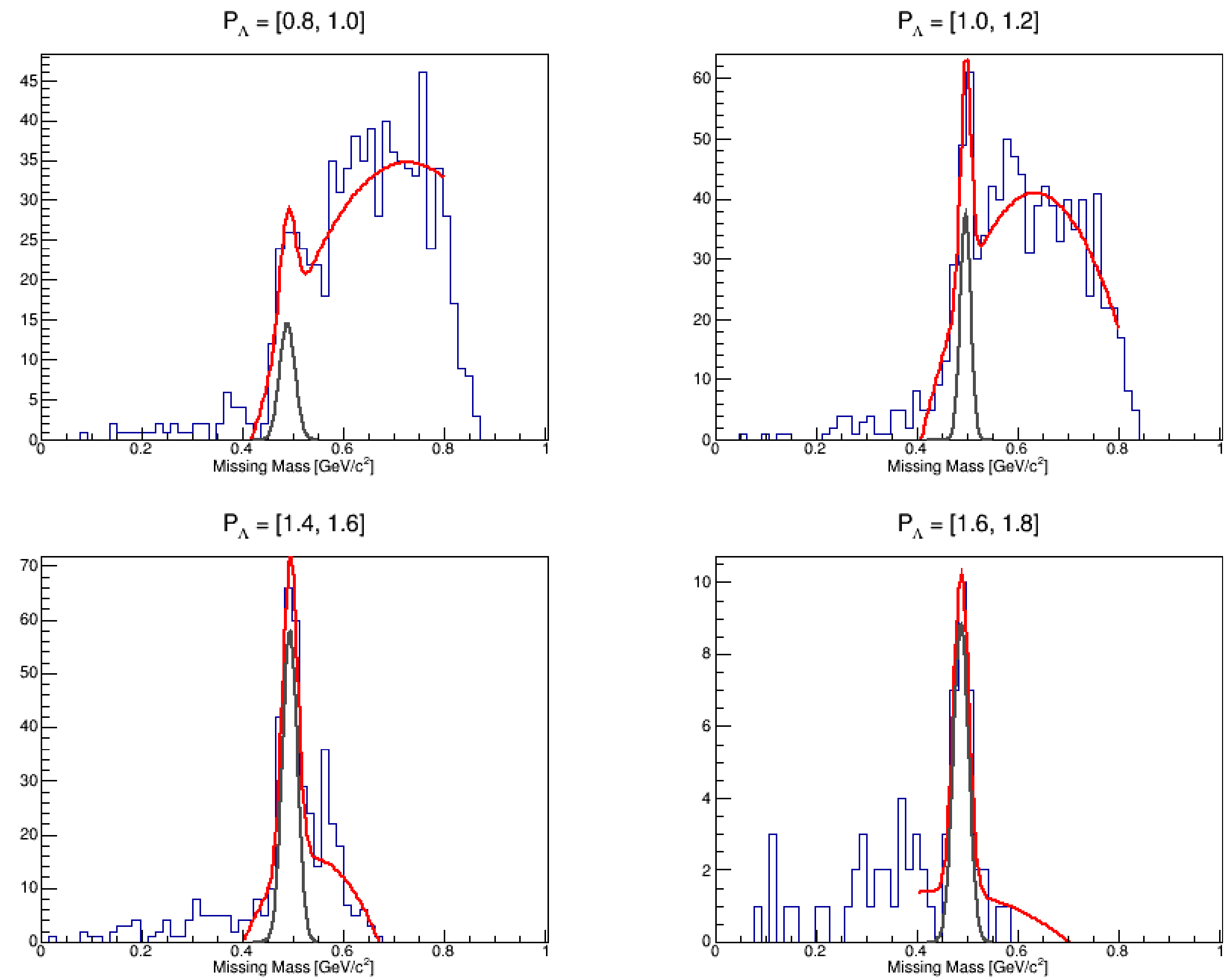
~2622
events

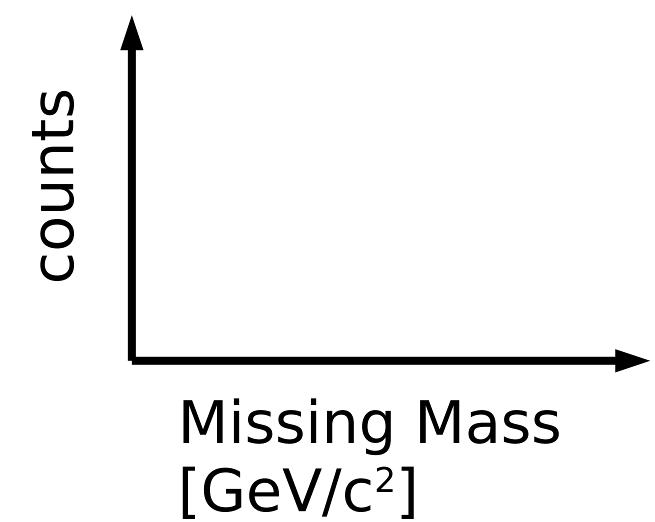
Yield



~2622
events

Yields

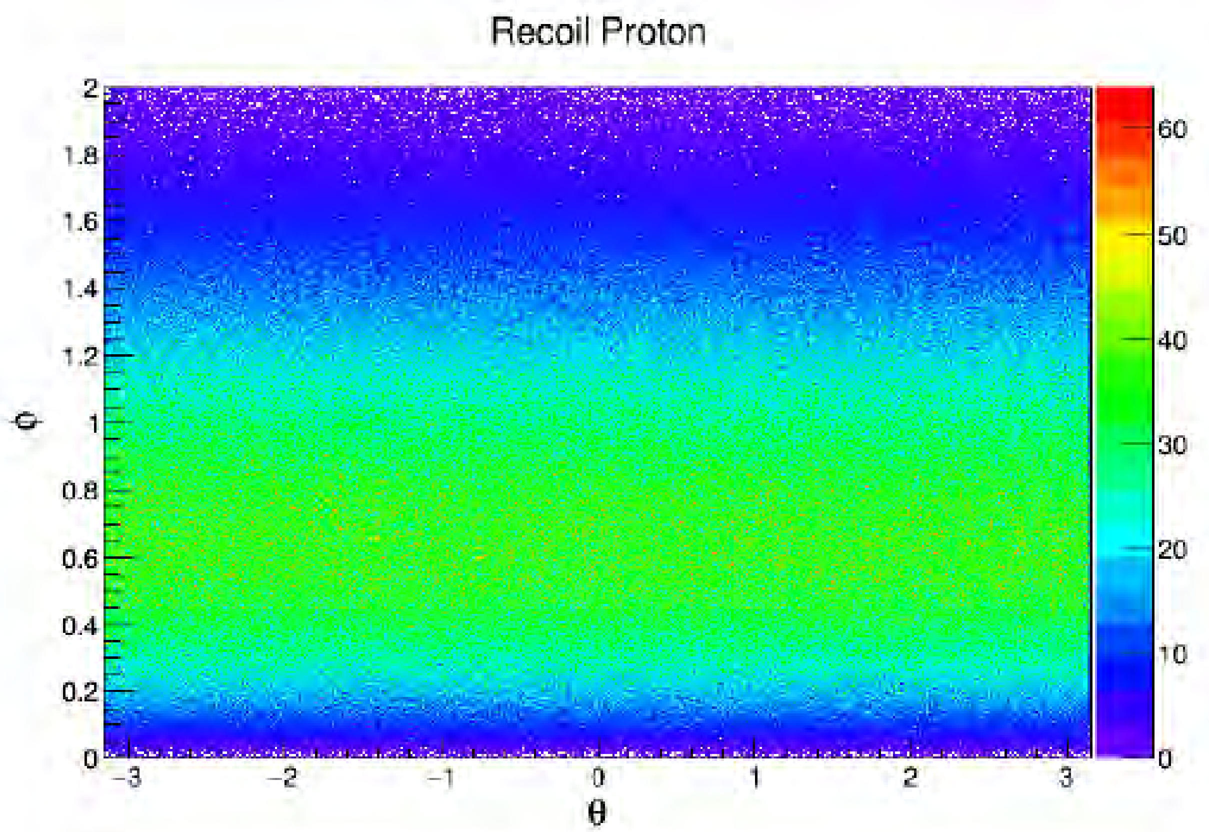


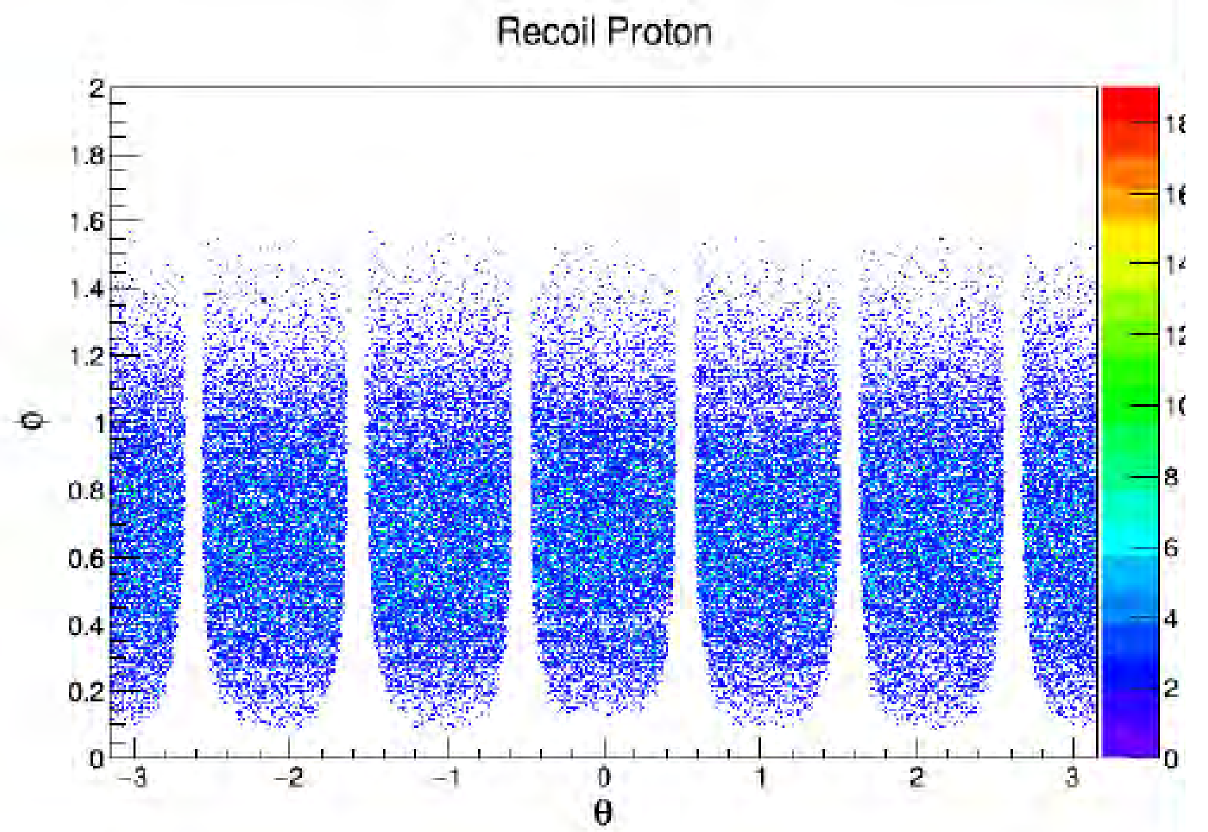


- Yield is taken from Missing Mass (K+ peak)
- Binned in Λ Momentum

Acceptance

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

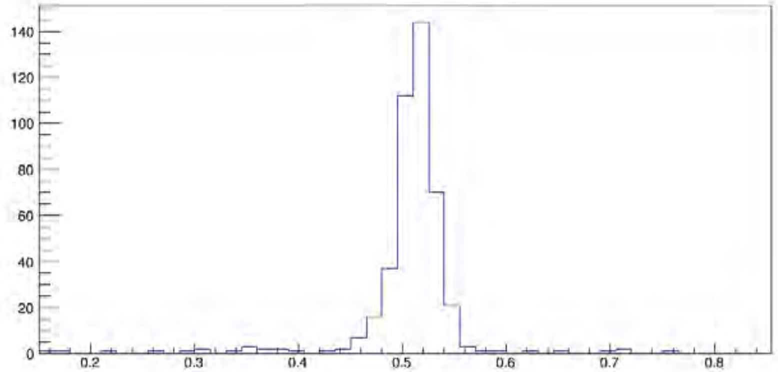




Acceptance

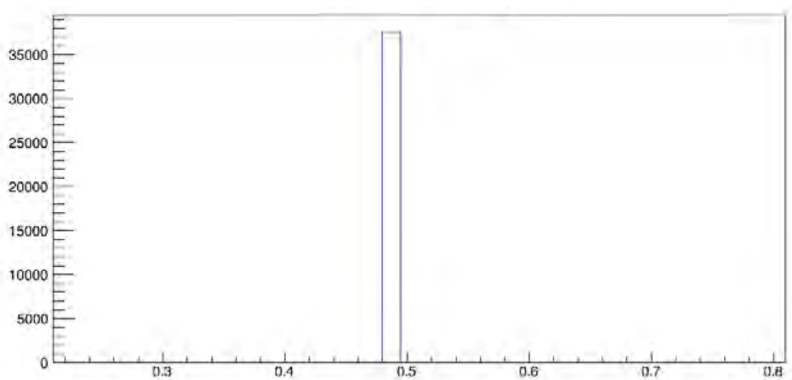
$$Acceptance = \frac{Accepted\ pp\pi^{-}}{Generated\ \Lambda p\ scattering}$$

Accepted Events:

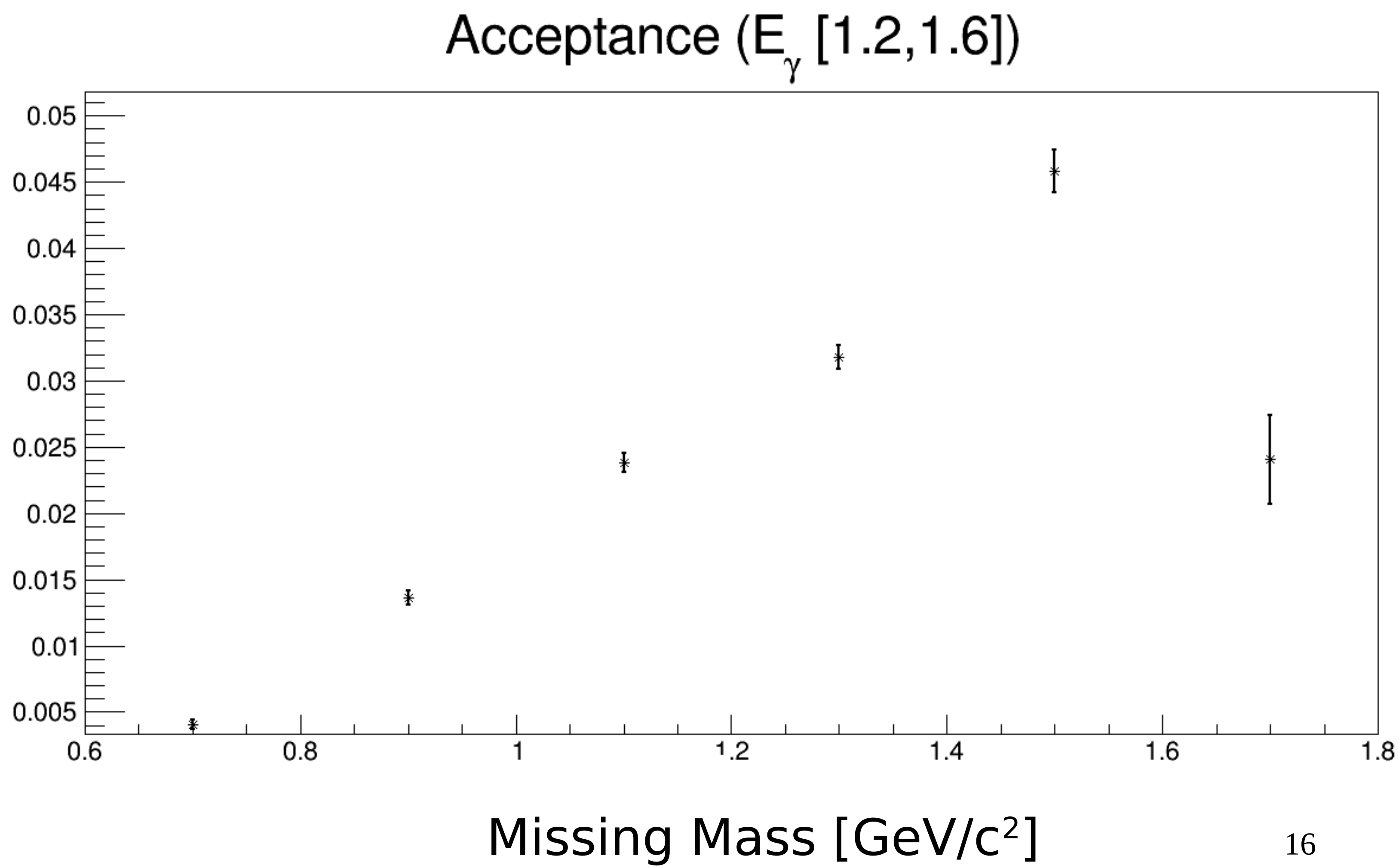


Missing Mass [GeV/c^2]

Generate Events:



Missing Mass [GeV/c^2]



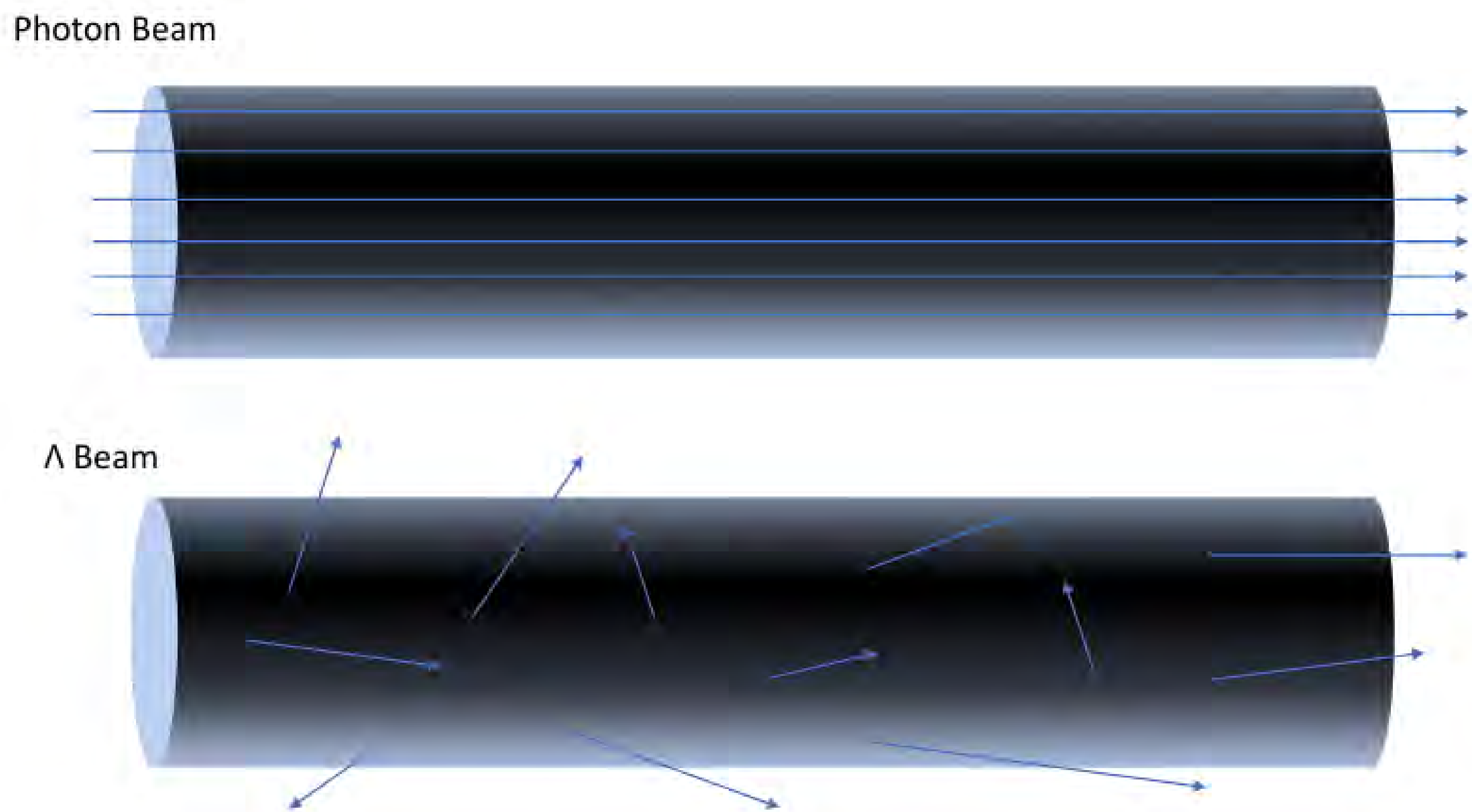
Luminosity

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

- 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

Problem: How do we find l and $N_\Lambda(E_\Lambda)$?

Luminosity



Decay Length (*l*)

$$P(z) = e^{-\left(\frac{M}{p}\right)\left(\frac{z-z0}{c\tau}\right)}$$

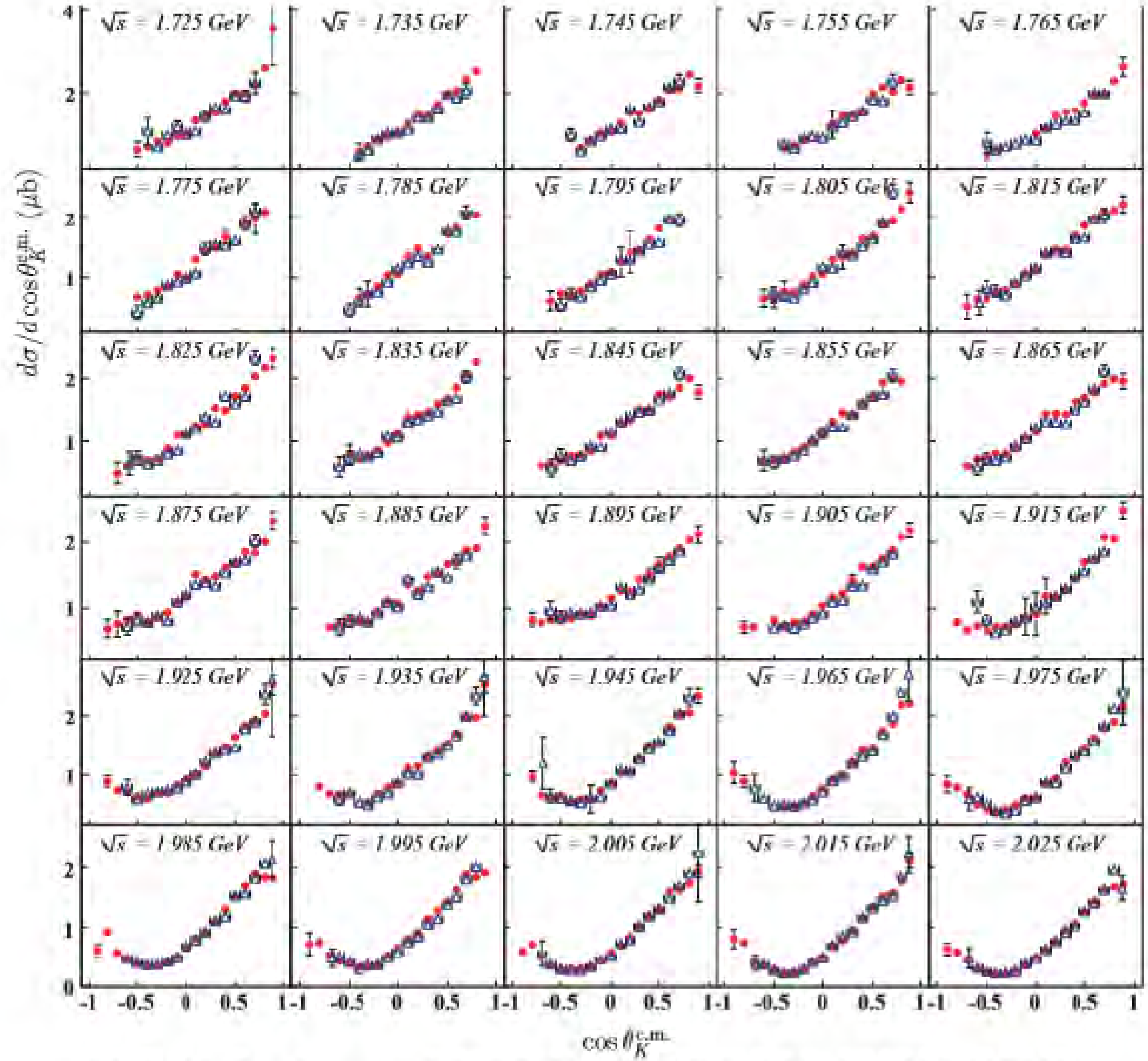
- 10,000 Generated Λ
- Step Size: 1 mm
- P_{Λ} = 1000 MeV/c

- P(z): probability of Λ decay
- M: mass of Λ (1.115 GeV/c²)
- p: momentum of Λ
- z0: starting position
- $c\tau$: mean proper life (7.89cm)

Z Vertex (cm)	Cos(Θ)	Avg. Pathlength (cm)
0.0	1.0	7.5
20	1.0	7.2
20	.707	2.4
Random	Random	2.2

$N_\Lambda(E_\Lambda)$

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



M. E. McCracken *et al.* PHYSICAL REVIEW C 81, 025201 (2010)

Luminosity

Simulation

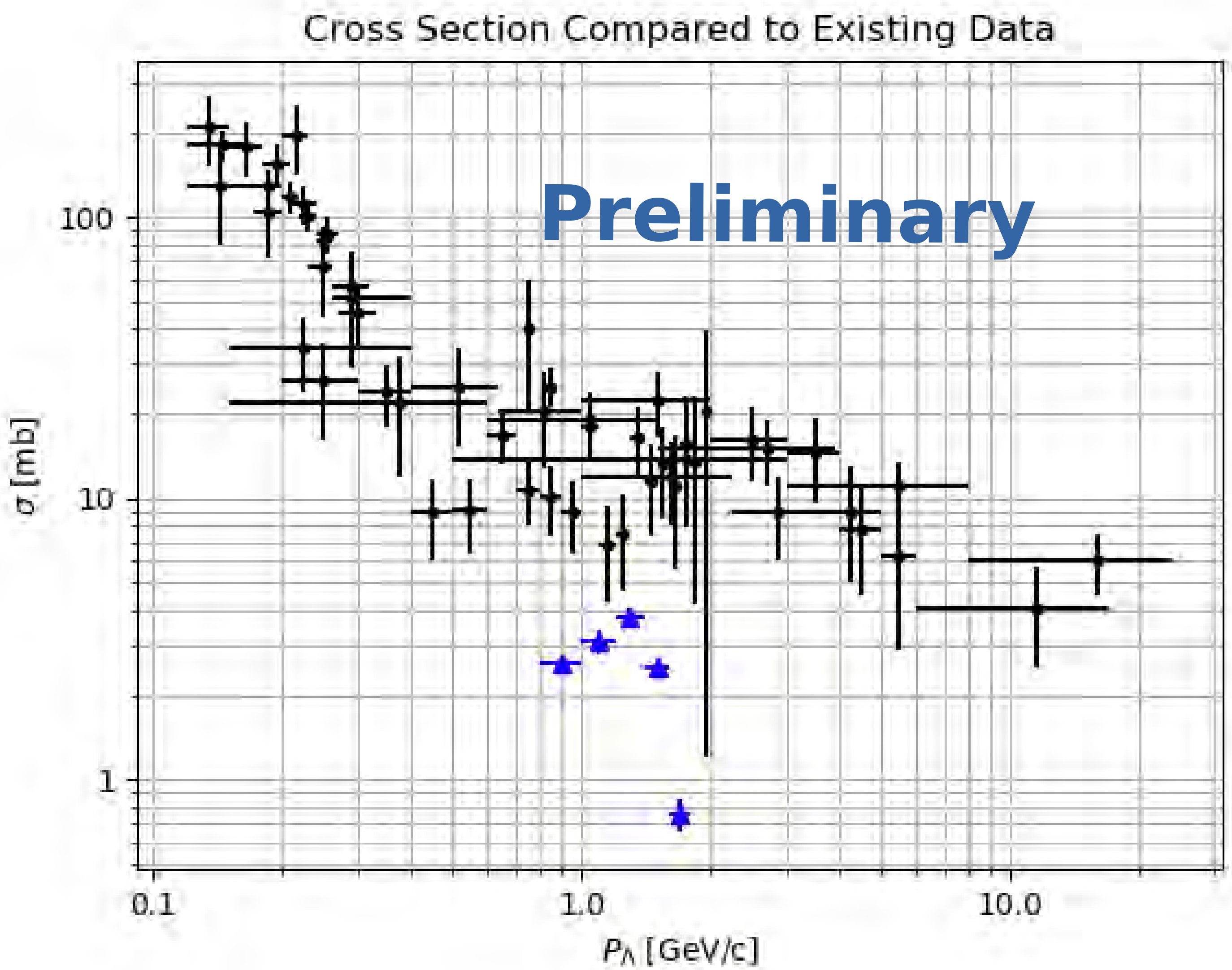
$$L_\Lambda(E_\Lambda) = \frac{\rho_T * N_A * l}{M} * N_\Lambda(E_\Lambda)$$

K+ Λ cross sections

Results to Come

- ✔ Yields
- ✔ Acceptance
- ✔ Luminosity

Preliminary Results



- Black: Existing world data
- Blue: Measurements from this study

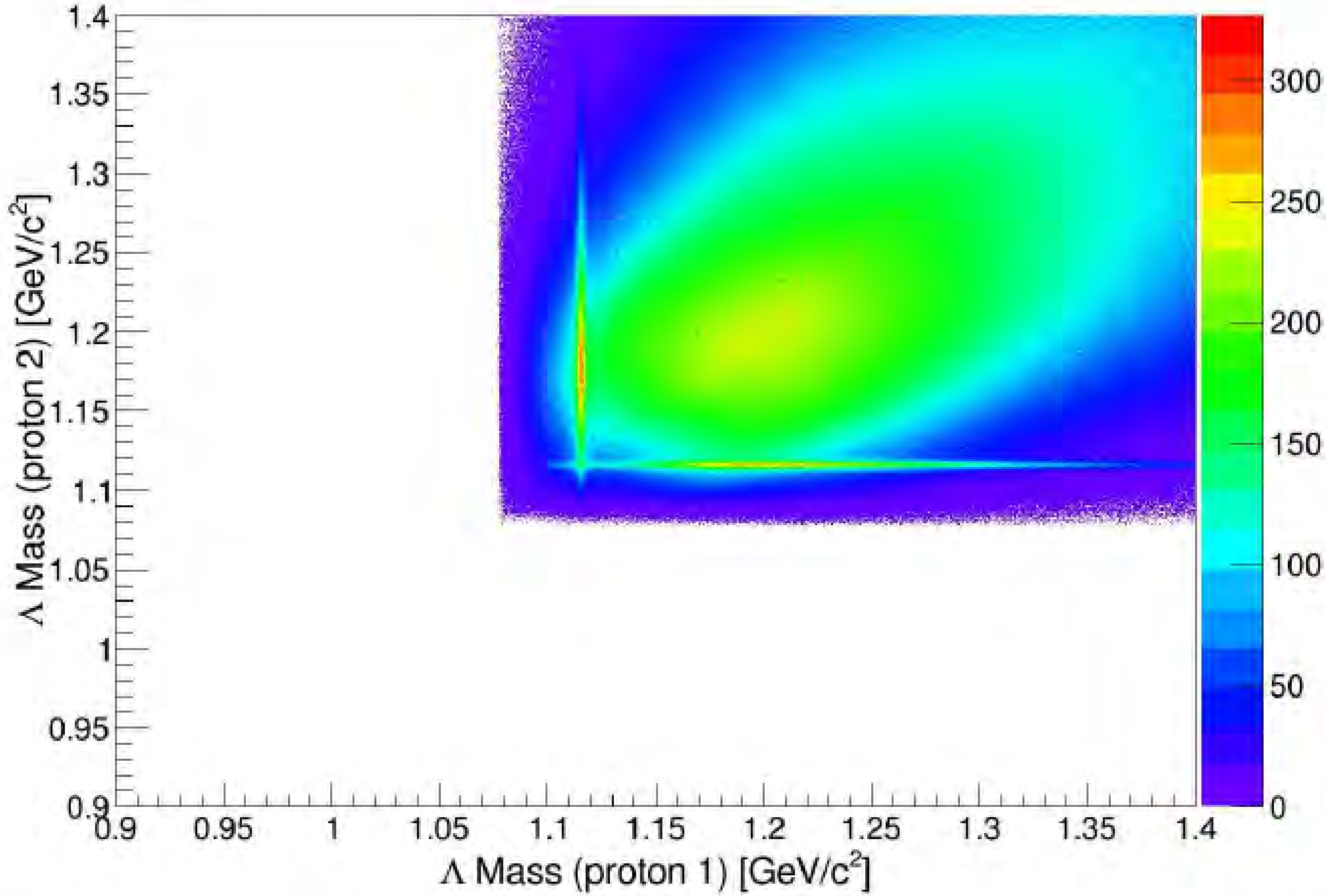
- Error only from statistical uncertainty

Summary and Future Work

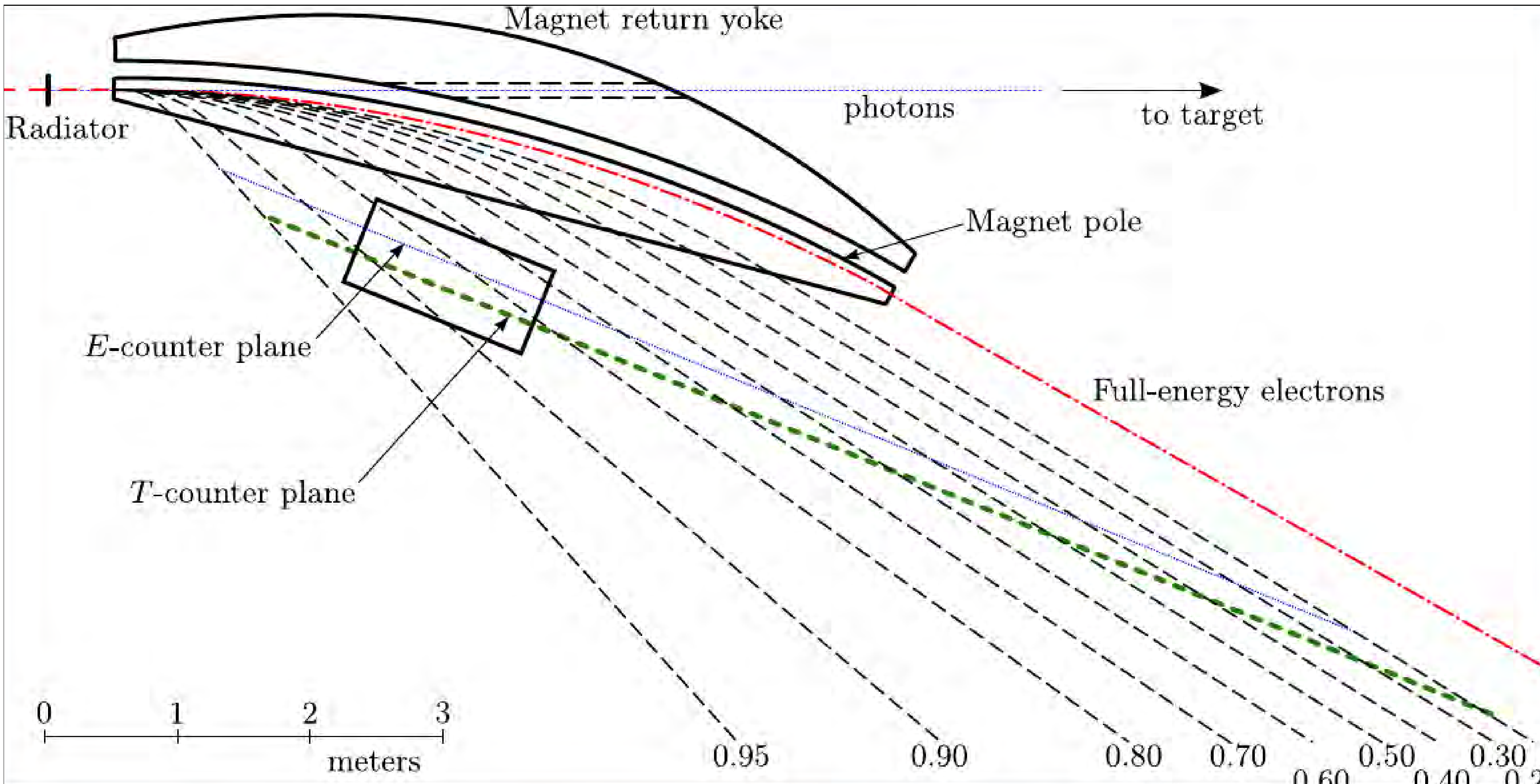
- Many Λp events in the g12 data.
- This method opens up possibility to study other reactions with “difficult” beams.
- Various corrections still need to be made but all the mechanisms are in place.

Questions?

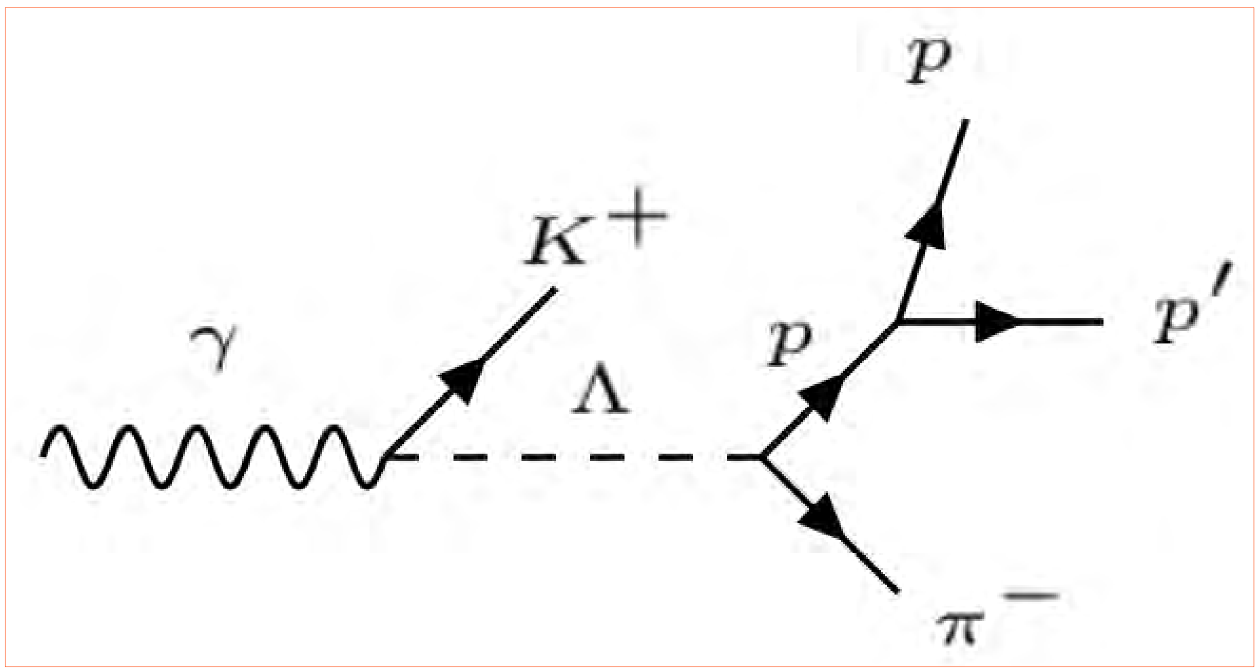
Extra (proton identification)

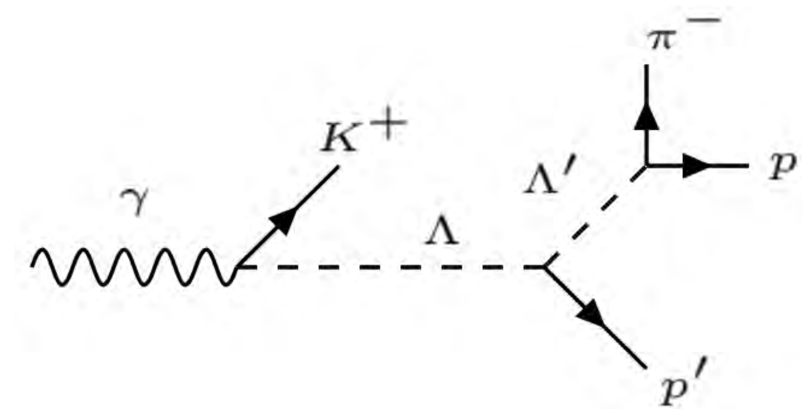


Tagger


Magnet return yoke
Radiator
photons
to target
Magnet pole
E-counter plane
T-counter plane
Full-energy electrons
0
1
2
3
meters
0.95
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20

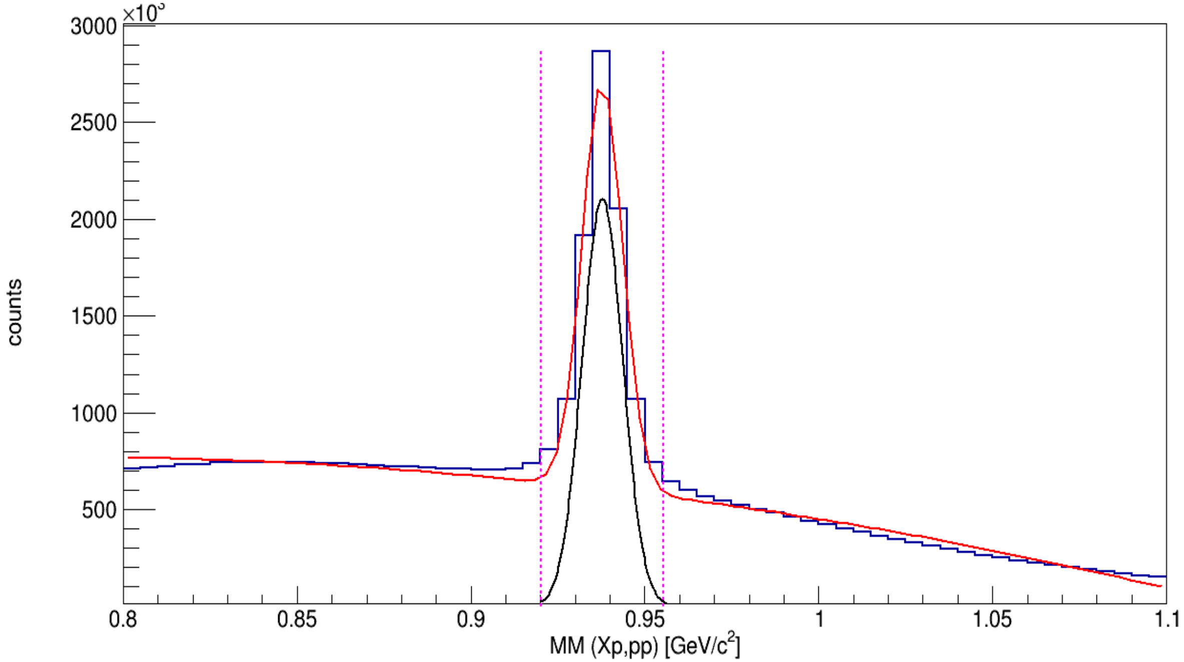
pp → pp events



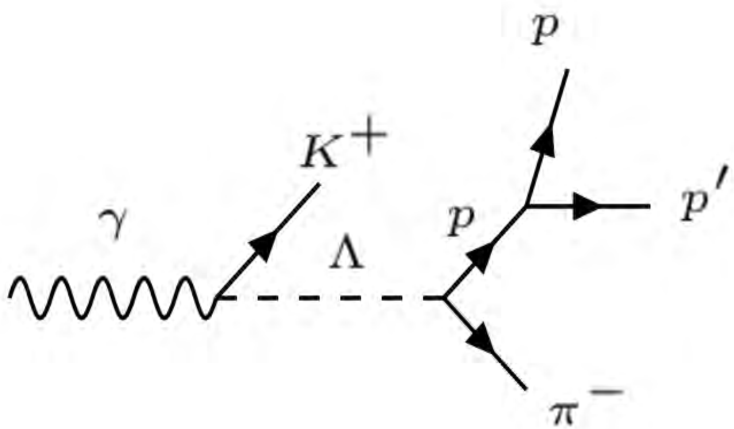


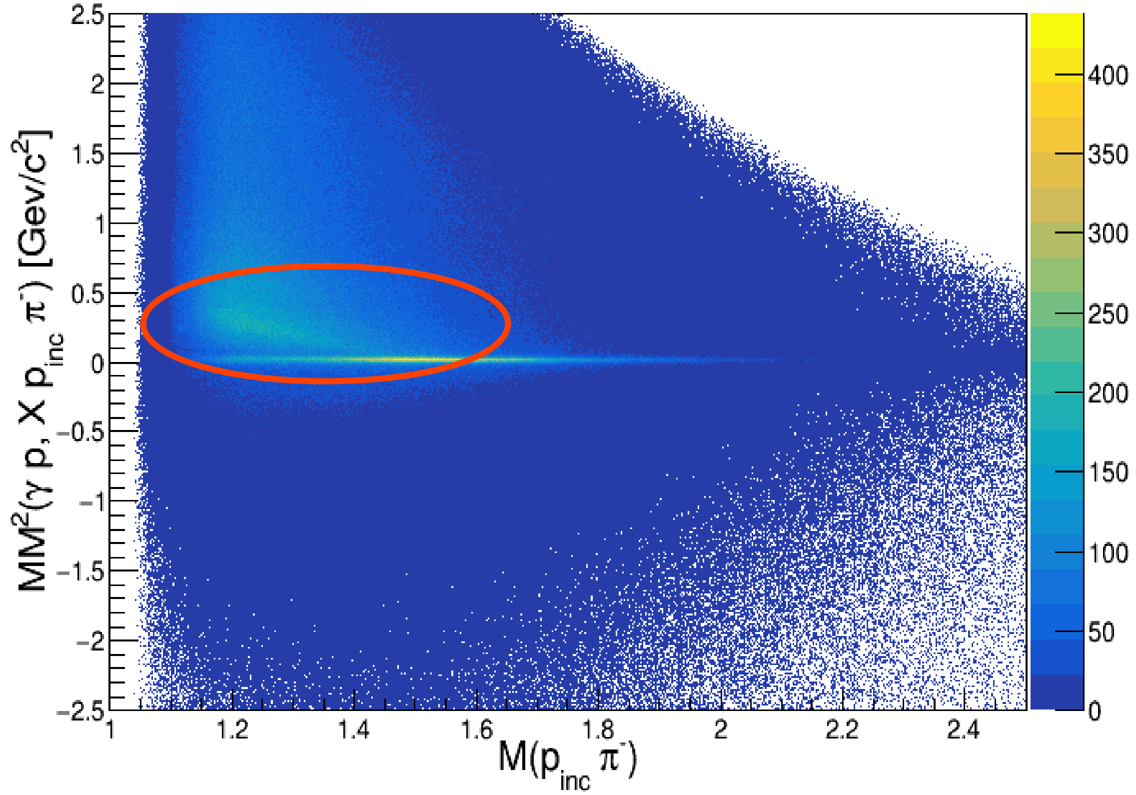
- pp → pp events can also result in the same final state.

pp → pp events

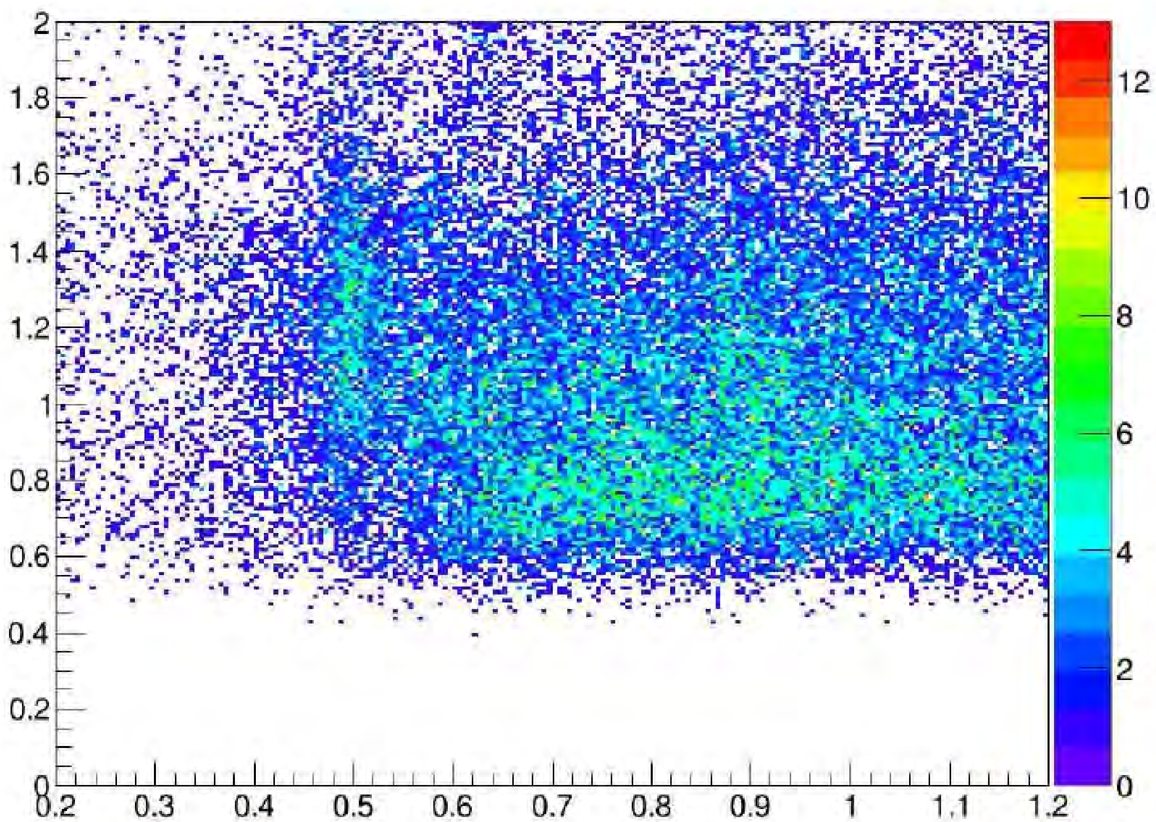


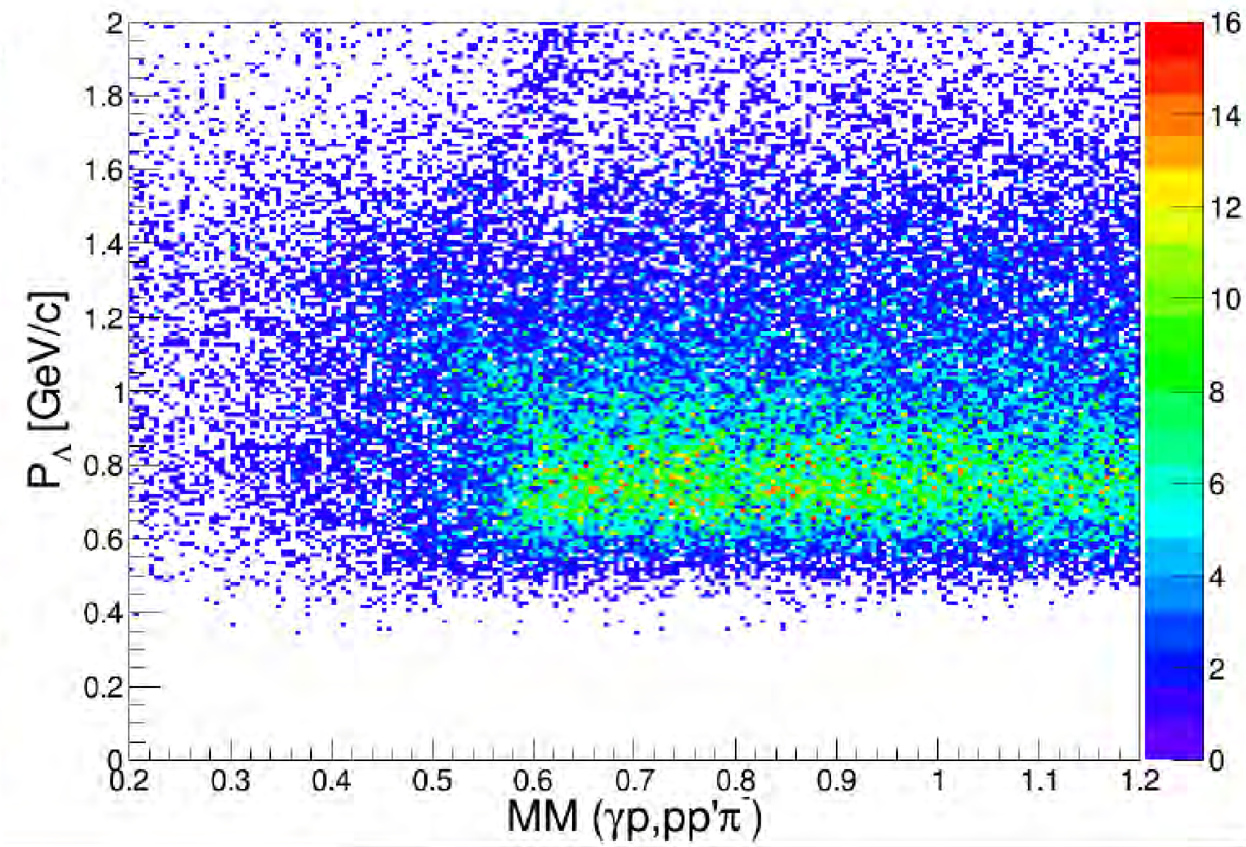
Events need to be removed for incident p events but not for incident π^-





Extra (Sideband Subtraction)





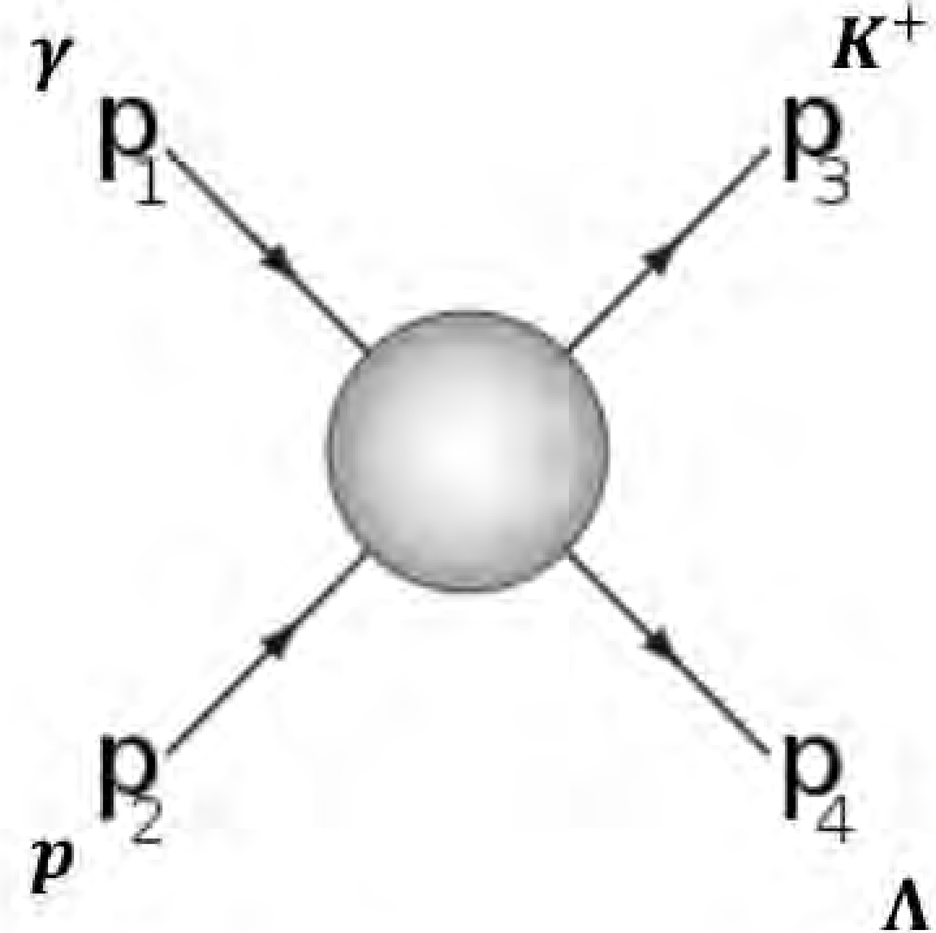
Extra (Mandelstam Variables)

$$\boldsymbol{t = (p_1 - p_3)^2 = (p_4 - p_2)^2}$$

$$\cos(\theta)_{K^+} = \frac{t + 2E_\gamma E_{K^+} - m_{K^+}^2}{2E_\gamma \sqrt{E_{K^+}^2 - m_{K^+}^2}}$$

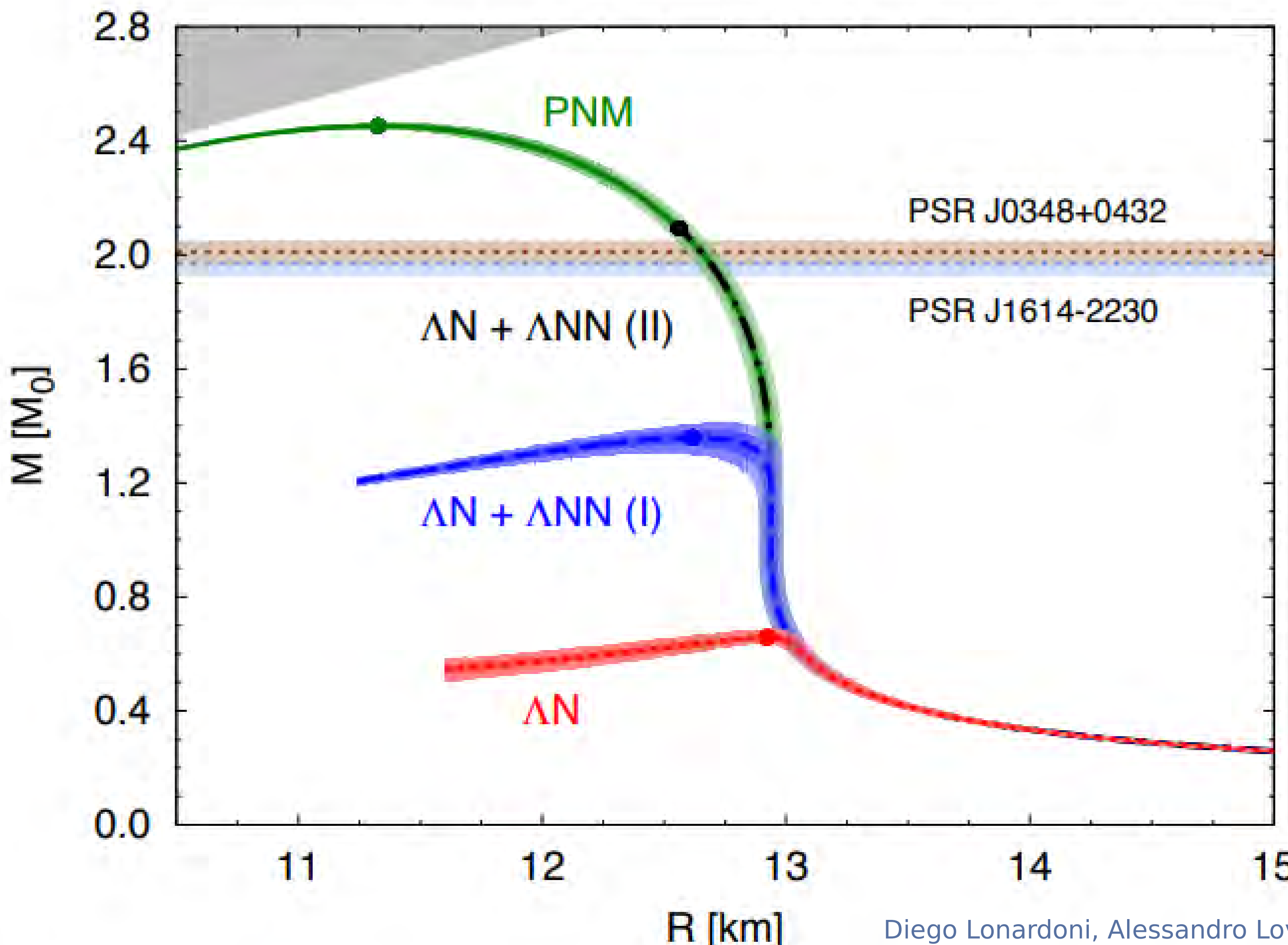
$$E_{K^+} = E_\gamma + m_p - E_\Lambda$$

$$E_\Lambda = -\frac{t - m_p^2 - m_\Lambda^2}{2m_p}$$



$$\cos(\theta)_{K^+\,CM} \rightarrow \cos(\theta)_{\Lambda\,LAB}$$

Motivation

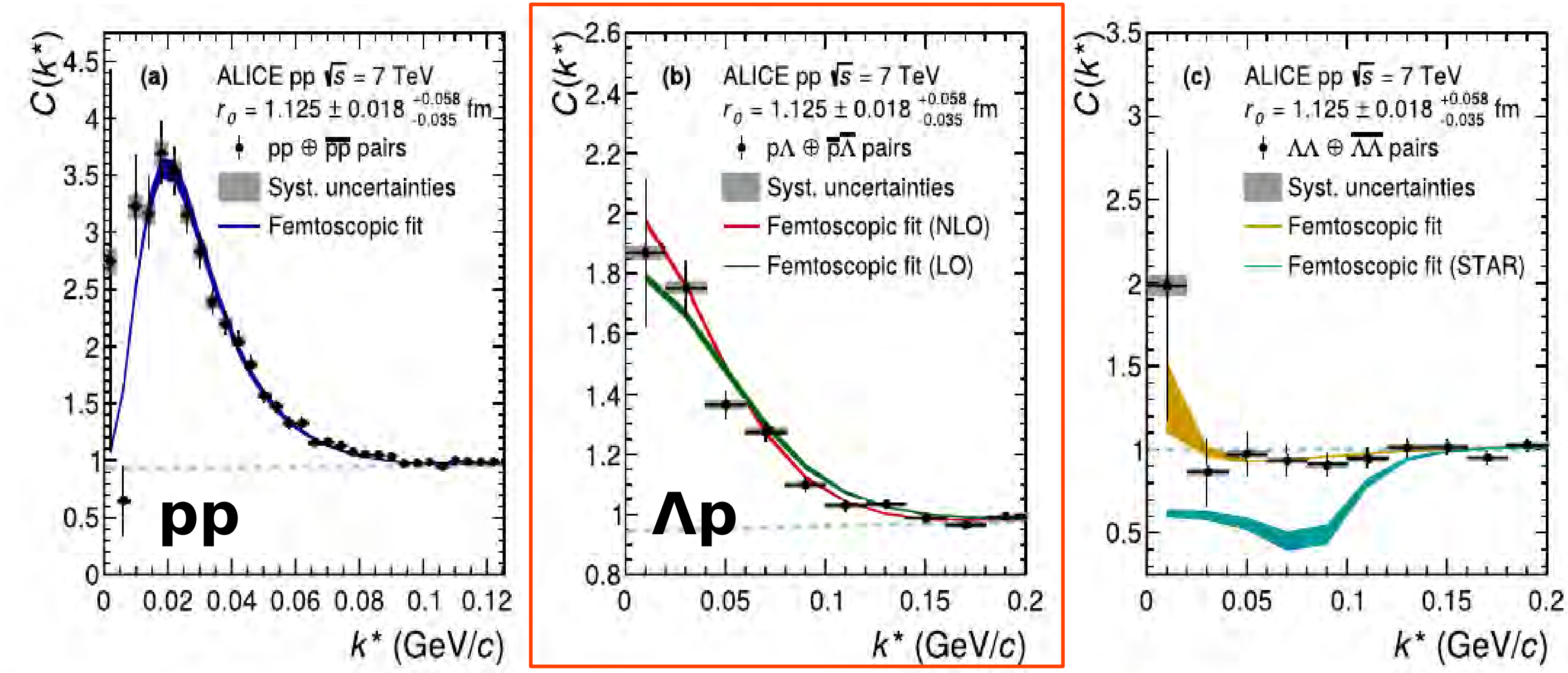


PNM: Pure Neutron matter

Observed mass of pulsars

Diego Lonardoni, Alessandro Lovato, Stefano Gandolfi, and Francesco Ped-eriva. PRL, **114**, 092301 2015.

Motivation



$$C(\mathbf{p}_1, \mathbf{p}_2) \equiv \frac{P(\mathbf{p}_1, \mathbf{p}_2)}{P(\mathbf{p}_1) \cdot P(\mathbf{p}_2)}$$

k* : relative momentum of pair

S. Acharya *et al.* (ALICE Collaboration), Phys Rev C, **99**, 024001 (2019).

- Correlation function relies on the cross section of Λp
- Our analysis will help improve these results