Threshold π^- production/Compton scattering on the deuteron

Bruno Strandberg
The University Of Glasgow
Nuclear Physics Group
June 6, 2016

Outline

Introduction

Why measure $\gamma + {}^2\mathrm{H} \to \pi^- + 2\mathrm{p}$ $(\gamma + \mathbf{n} \to \pi^- + \mathrm{p})$?

University of Glasgow

Why measure $\gamma + {}^2\mathrm{H} \to \pi^- + 2\mathrm{p}$ ($\gamma + \mathbf{n} \to \pi^- + \mathrm{p}$)?

- Provides a test for various low-energy QCD models.
  - Dispersion Theory
  - Effective Field Theories
  - SAID/MAID models

Why measure $\gamma + {}^2\mathrm{H} \to \pi^- + 2\mathrm{p}$ ($\gamma + \mathbf{n} \to \pi^- + \mathrm{p}$)?

- Provides a test for various low-energy QCD models.
  - Dispersion Theory
  - Effective Field Theories
  - SAID/MAID models
- Available cross-section data points below $\mathrm{E}_\gamma = 200\,\mathrm{MeV}$ [1]:
  - π^0: 1524
  - π^+: 92
  - π^-: 51

Why measure $\gamma + {}^2\mathrm{H} \to \pi^- + 2\mathrm{p}$ ($\gamma + \mathbf{n} \to \pi^- + \mathrm{p}$)?

- Provides a test for various low-energy QCD models.
  - Dispersion Theory
  - Effective Field Theories
  - SAID/MAID models
- Available cross-section data points below $\mathrm{E}_\gamma = 200\,\mathrm{MeV}$ [1]:
  - π^0: 1524
  - π^+: 92
  - π^-: 51
- No π^- data below $\mathrm{E}_\gamma = 158\,\mathrm{MeV}$.
- Last known π^- measurement in 1994 by Liu (PhD thesis, unpublished).

University of Glasgow

Why measure $\gamma + {}^2\mathrm{H} \rightarrow \gamma' + {}^2\mathrm{H}$?

University of Glasgow

Why measure $\gamma + {}^2\mathrm{H} \rightarrow \gamma' + {}^2\mathrm{H}$?

- Access neutron polarisabilities.

Why measure $\gamma + {}^2\mathrm{H} \rightarrow \gamma' + {}^2\mathrm{H}$?

- Access neutron polarisabilities.
- Test for HBχPT.

University of Glasgow

Why measure $\gamma + {}^2\mathrm{H} \rightarrow \gamma' + {}^2\mathrm{H}$?

- Access neutron polarisabilities.
- Test for HBχPT.
- No data close above pion threshold.

Experiment - setup

The experiment was performed at Maxlab in Lund, Sweden.

University of Glasgow

The experiment was performed at Maxlab in Lund, Sweden.

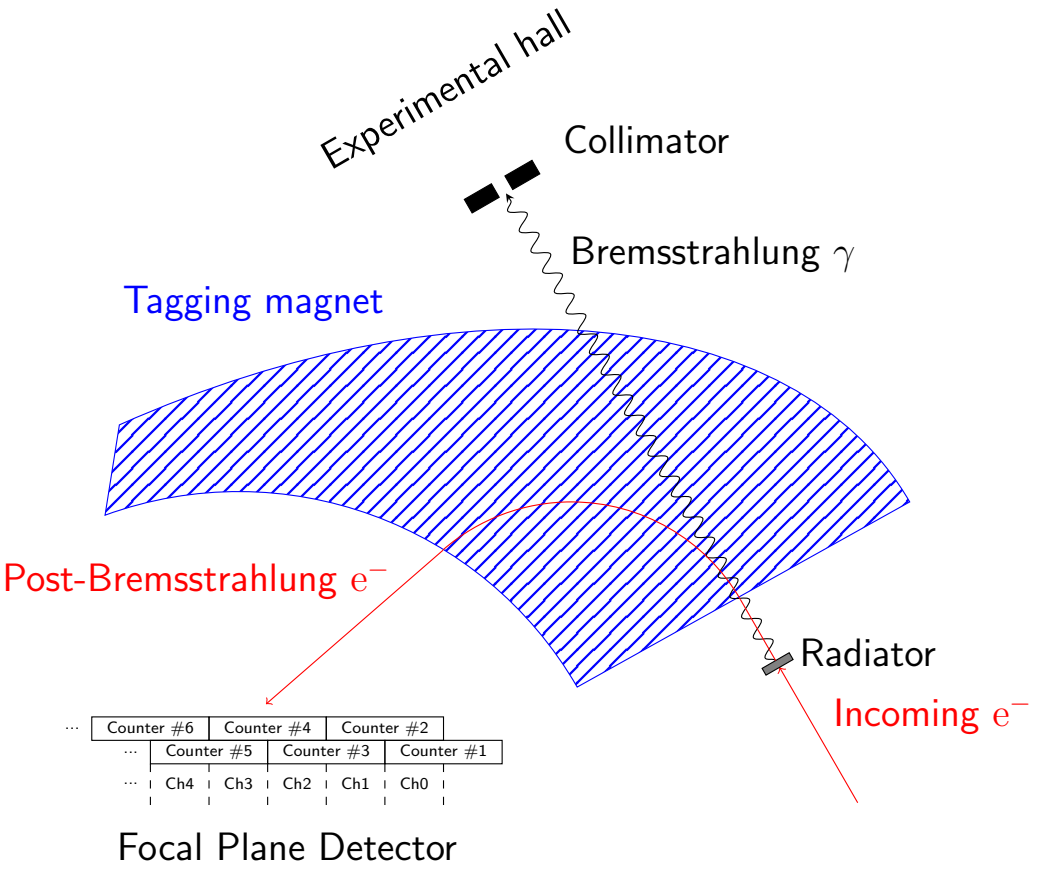
University of Glasgow

- Mainly a synchrotron radiation facility.
- For nuclear physics: electron beam with $E_e = 190\,\mathrm{MeV}$

The experiment was performed at Maxlab in Lund, Sweden.

- Mainly a synchrotron radiation facility.
- For nuclear physics: electron beam with $E_e = 190\,\mathrm{MeV}$

Create tagged Bremsstrahlung photon beam from electron beam, E_γ from 140 to 160 MeV.



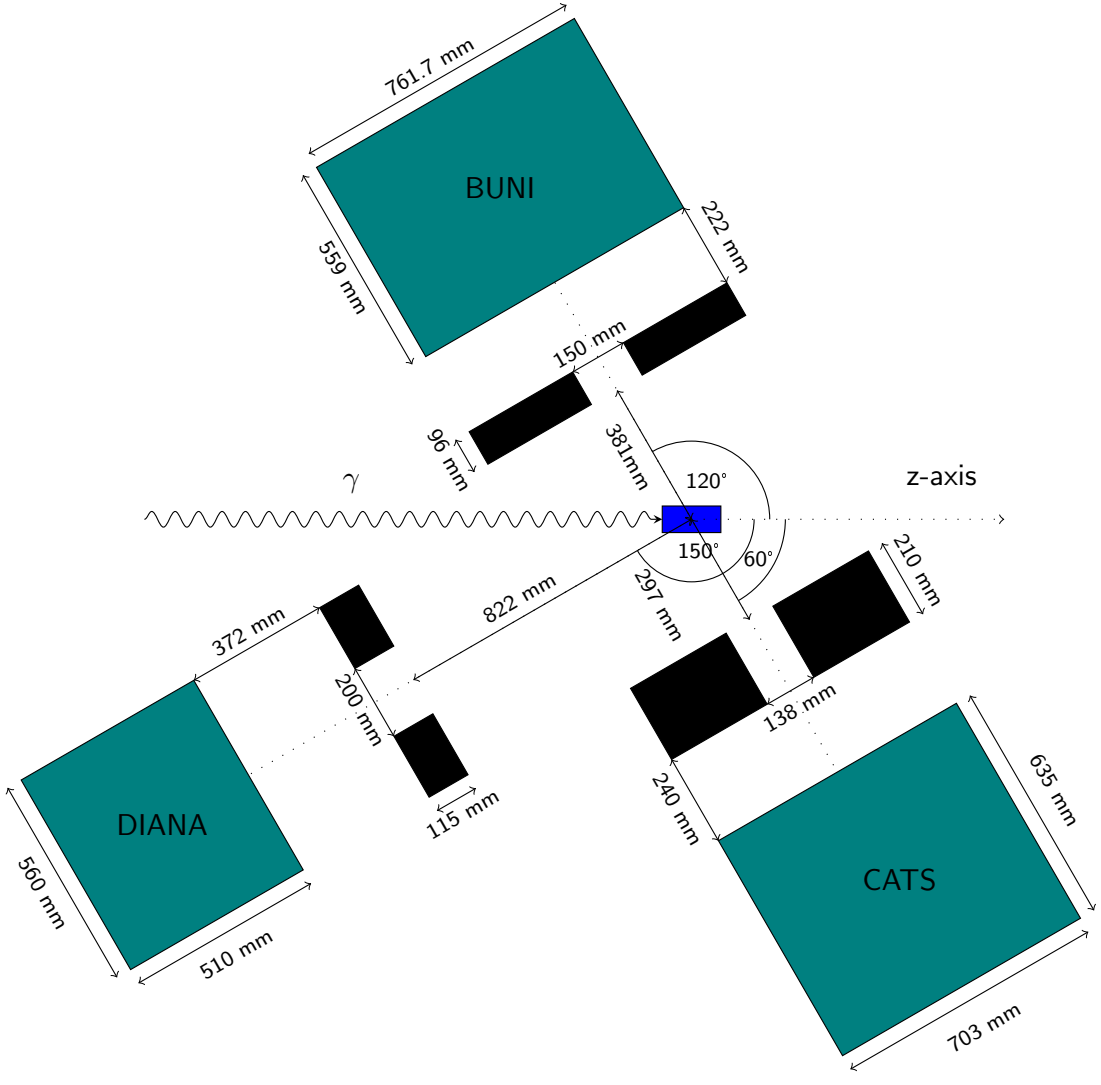


Figure : Floor plan of the experiment at Maxlab in Lund, Sweden.

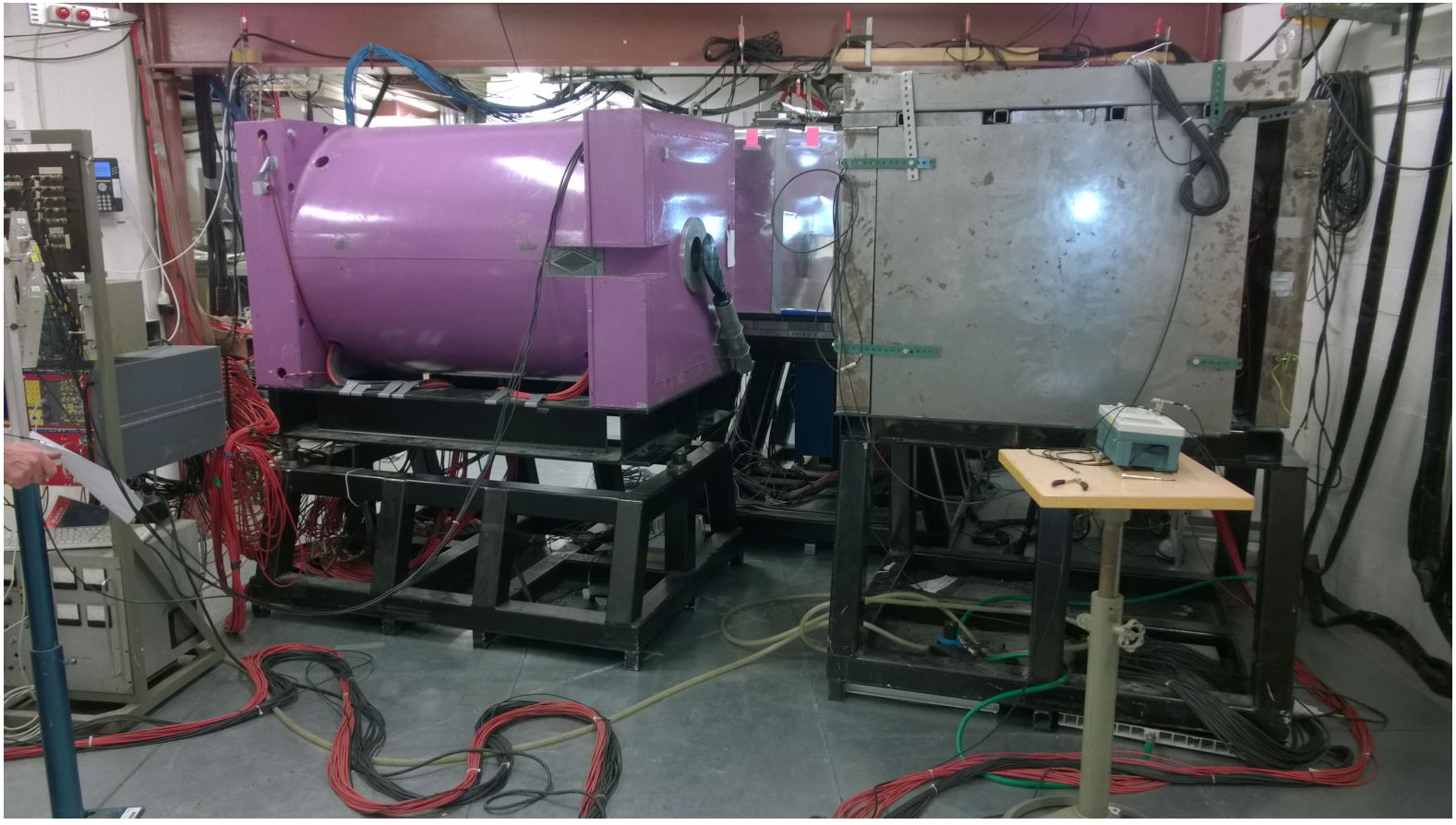
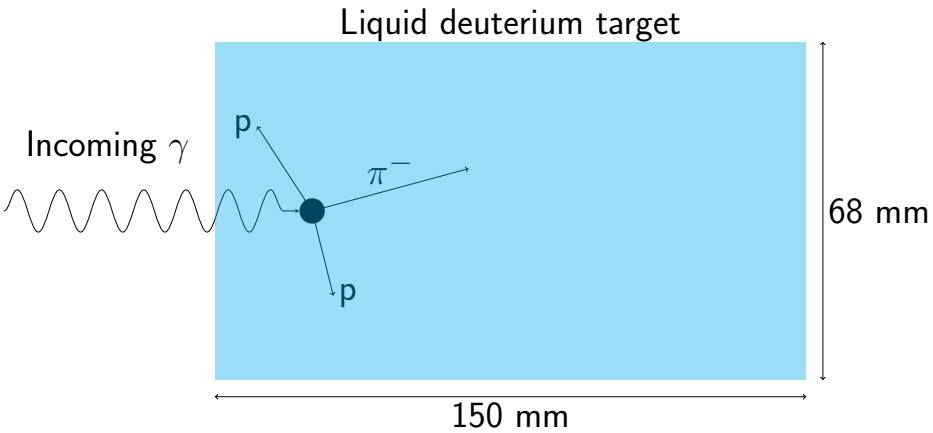


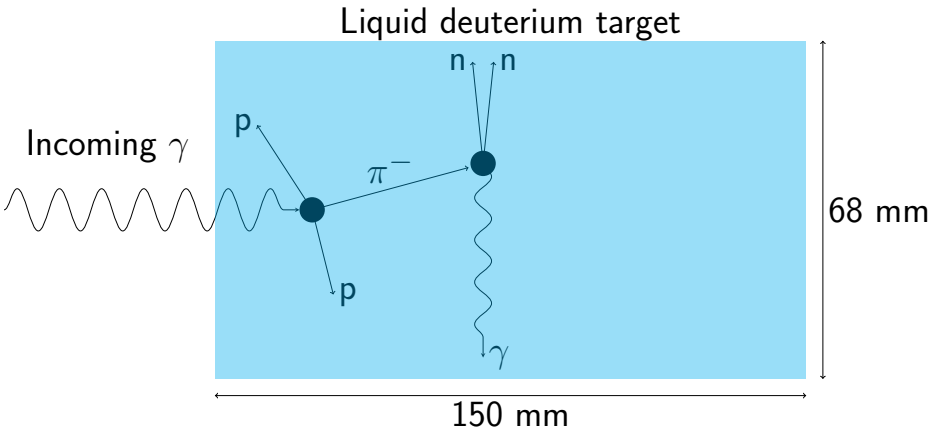
Figure : Experimental hall at Maxlab in Lund, Sweden.

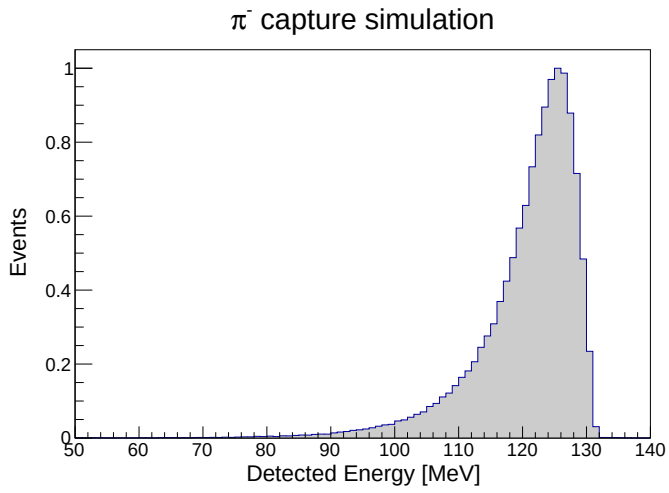
Experiment - event counting

Reaction $\gamma + {}^2\mathrm{H} \rightarrow \pi^- + 2\mathrm{p}$, pion produced on the neutron.



Reaction $\gamma + {}^2\mathrm{H} \rightarrow \pi^- + 2\mathrm{p}$, pion produced on the neutron.

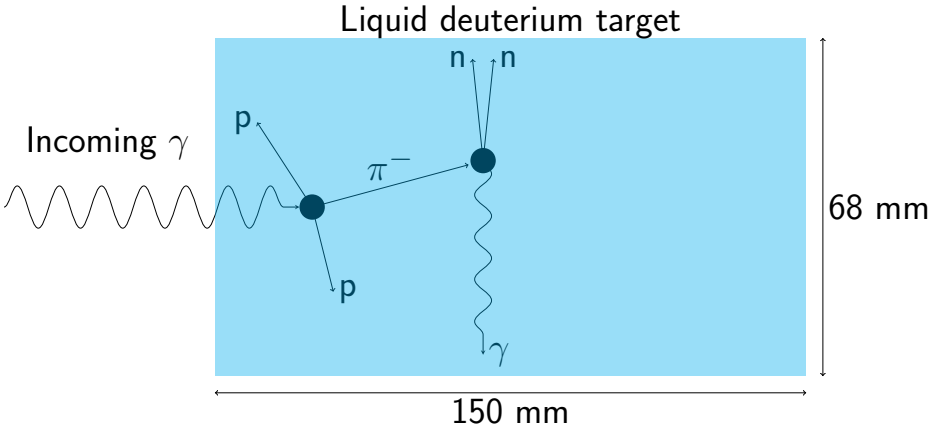


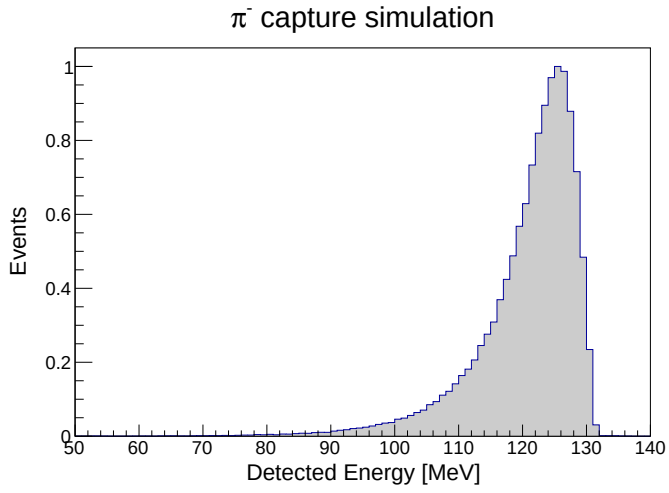


Radiative capture reaction $\pi^- + {}^2\mathrm{H} \rightarrow \gamma + 2\mathrm{n}$, pion captured on the proton.

Identify pions through counting radiative capture photons.

Reaction $\gamma + {}^2\mathrm{H} \rightarrow \pi^- + 2\mathrm{p}$, pion produced on the neutron





Radiative capture reaction $\pi^- + {}^2\mathrm{H} \rightarrow \gamma + 2\mathrm{n}$, pion captured on the proton.

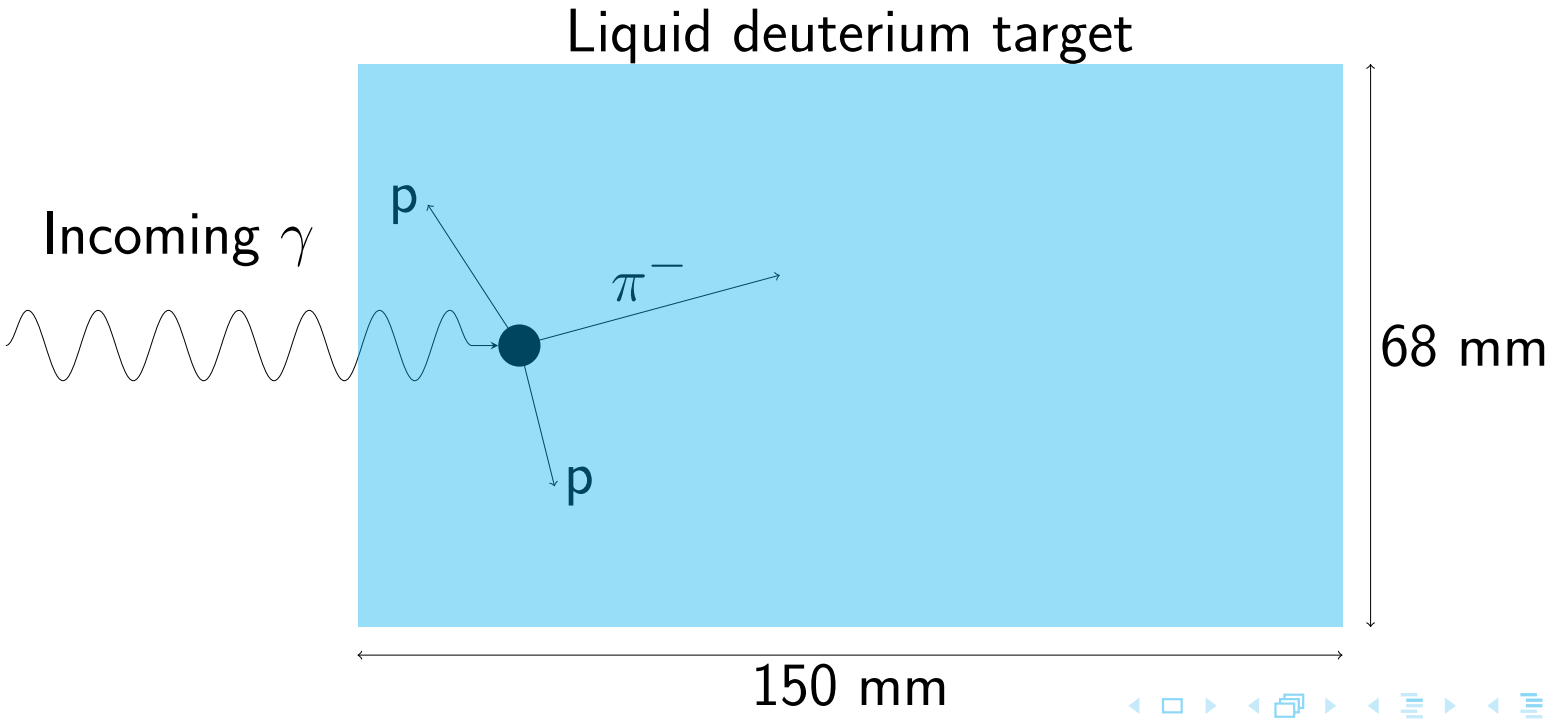
Identify pions through counting radiative capture photons.

Assumption: radiative photons emitted isotropically, effectively we do 3 simultaneous σ measurements.

University of Glasgow

Competing scenarios to radiative capture

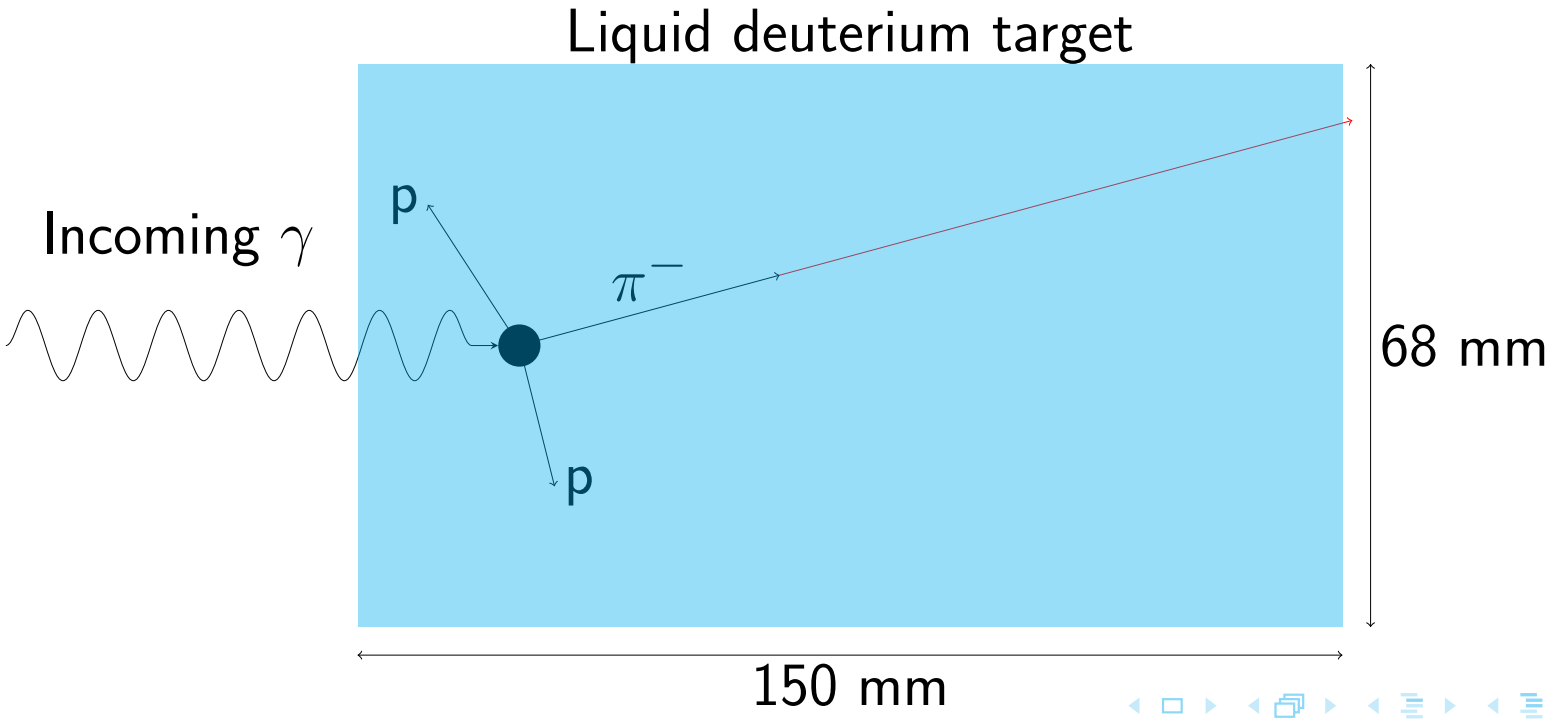
$\pi^- + {}^2\mathrm{H} \rightarrow \gamma + 2\mathrm{n}$?



University of Glasgow

Competing scenarios to radiative capture $\pi^- + {}^2\mathrm{H} \rightarrow \gamma + 2\mathrm{n}$?

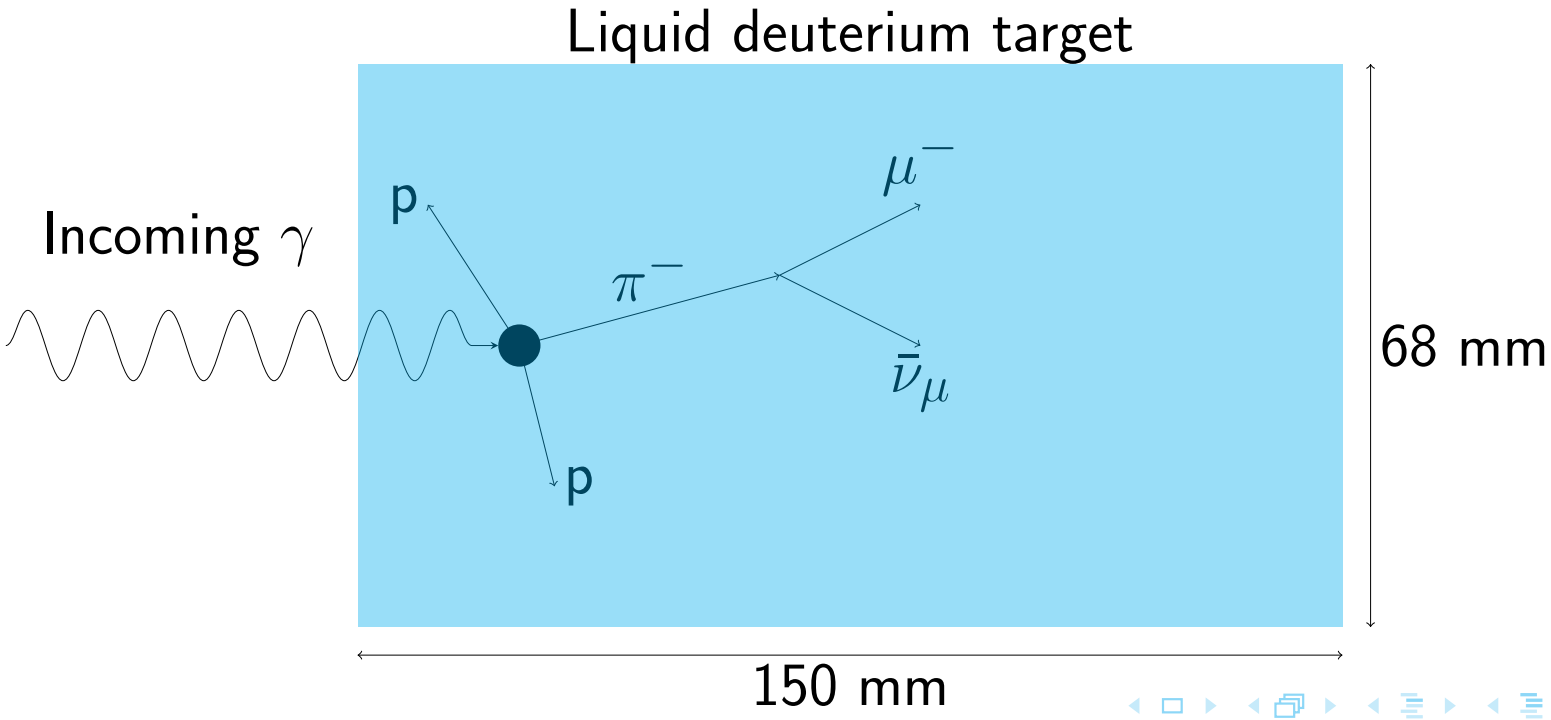
- Escape from target volume - *Geant4 simulation*.



University of Glasgow

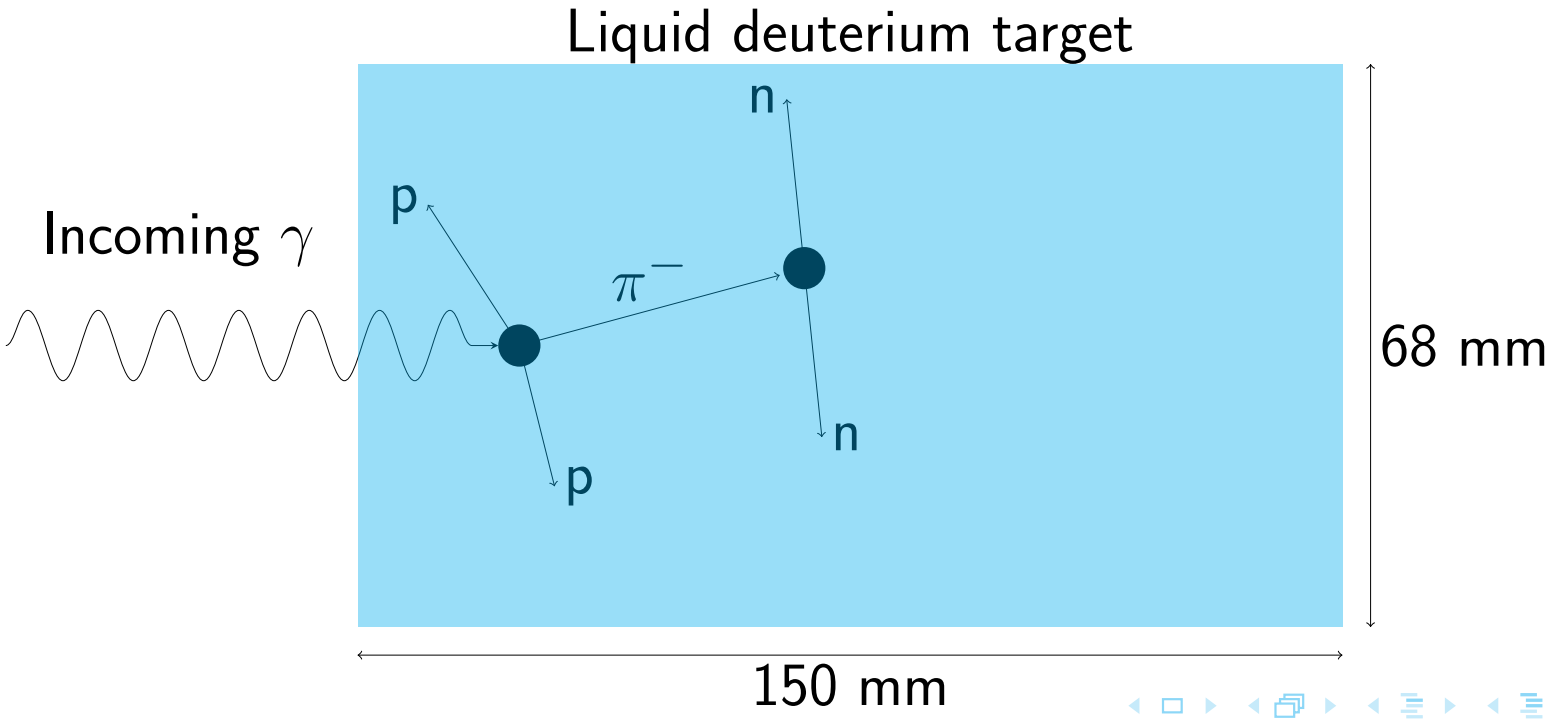
Competing scenarios to radiative capture
$\pi^- + {}^2\mathrm{H} \rightarrow \gamma + 2\mathrm{n}$?

- Escape from target volume - *Geant4 simulation*.
- Decay - *Geant4 simulation*.



Competing scenarios to radiative capture $\pi^- + {}^2\mathrm{H} \rightarrow \gamma + 2\mathrm{n}$?

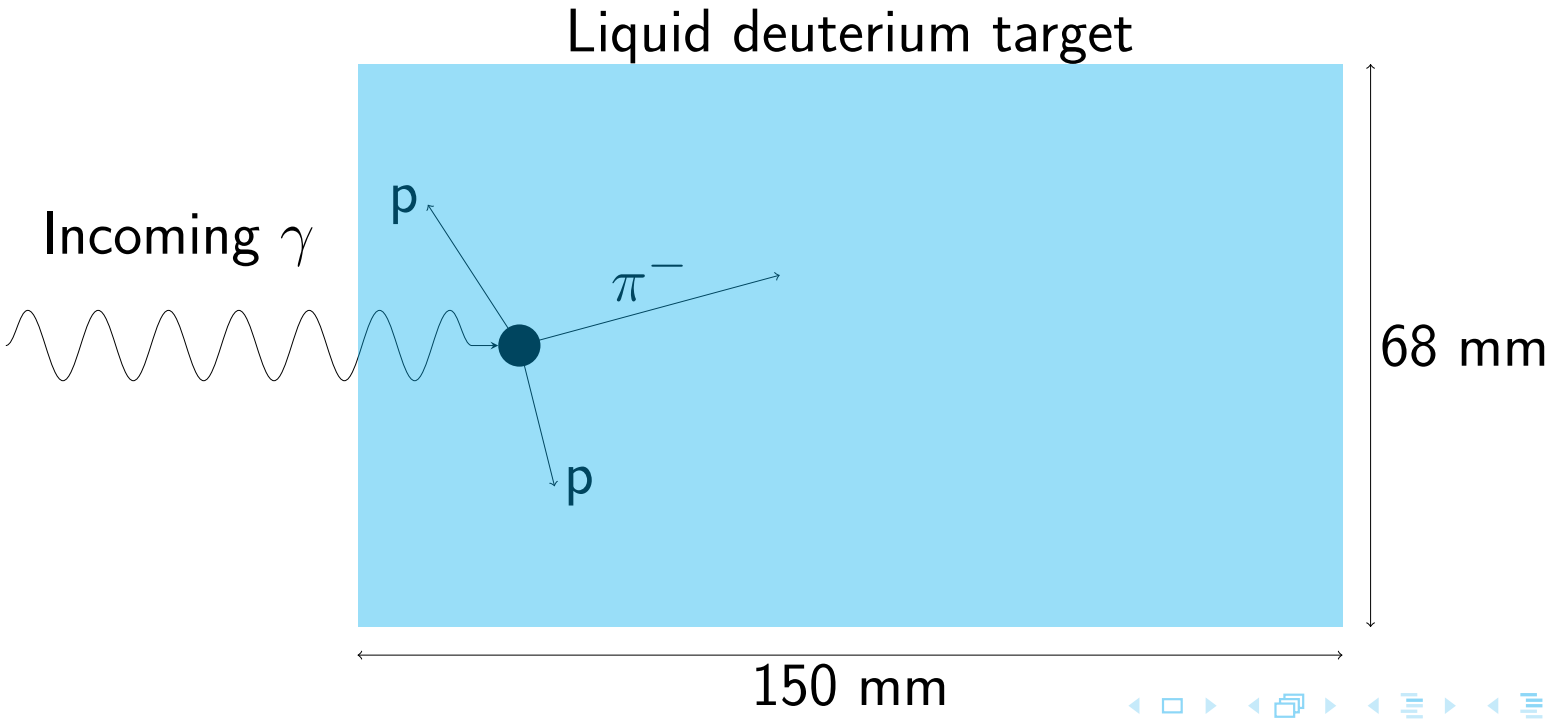
- Escape from target volume - *Geant4 simulation*.
- Decay - *Geant4 simulation*.
- Non-rad capture $\pi^- + {}^2\mathrm{H} \rightarrow 2\mathrm{n}$ - *Branching ratio known* $\frac{\pi^- + {}^2\mathrm{H} \rightarrow 2\mathrm{n}}{\pi^- + {}^2\mathrm{H} \rightarrow \gamma 2\mathrm{n}} = 2.83 \pm 0.04$ *[2]*



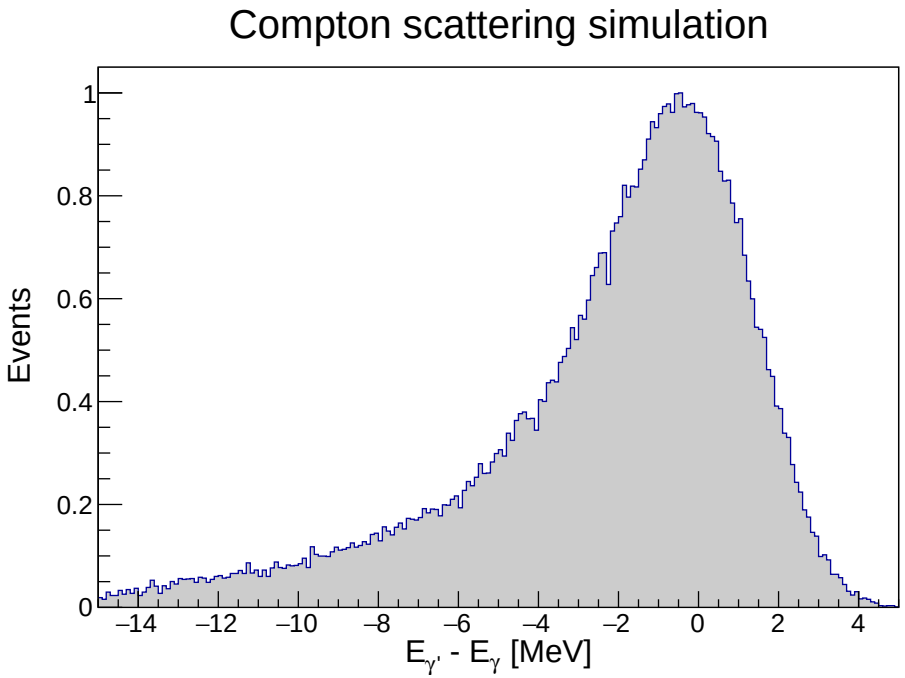
University of Glasgow

Competing scenarios to radiative capture $\pi^- + {}^2\mathrm{H} \to \gamma + 2\mathrm{n}$?

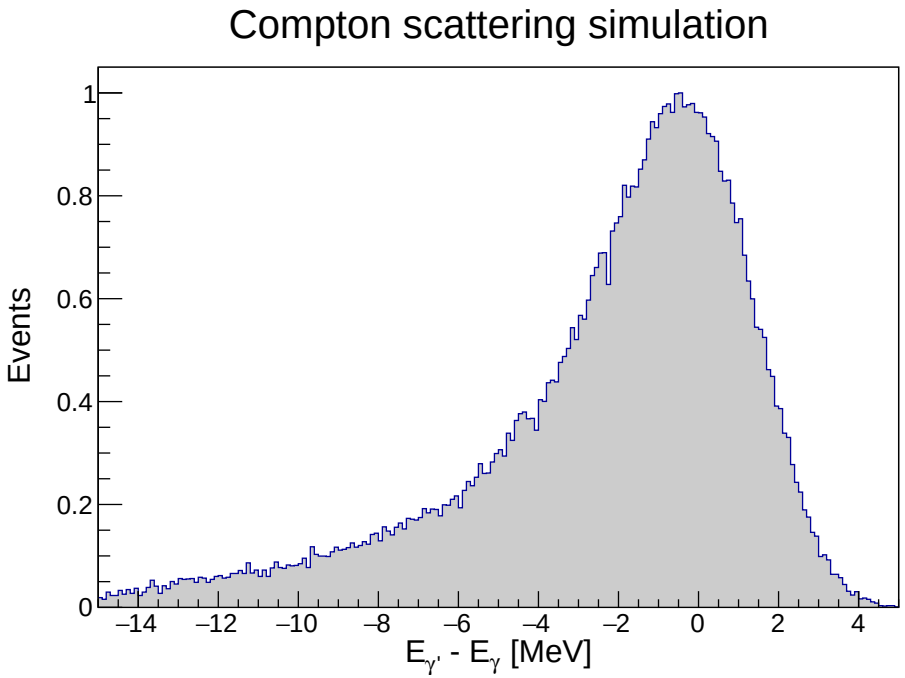
- Escape from target volume - *Geant4 simulation*.
- Decay - *Geant4 simulation*.
- Non-rad capture $\pi^- + {}^2\mathrm{H} \to 2\mathrm{n}$ - *Branching ratio known* $\frac{\pi^- + {}^2\mathrm{H} \to 2\mathrm{n}}{\pi^- + {}^2\mathrm{H} \to \gamma 2\mathrm{n}} = 2.83 \pm 0.04$ *[2]*
- Other scenarios $\sim<$ 1% [3, 4, 5]



The Compton events $\gamma + {}^2\mathrm{H} \rightarrow \gamma' + {}^2\mathrm{H}'$ are identified through $E_\gamma - E_{\gamma'} = 0$.

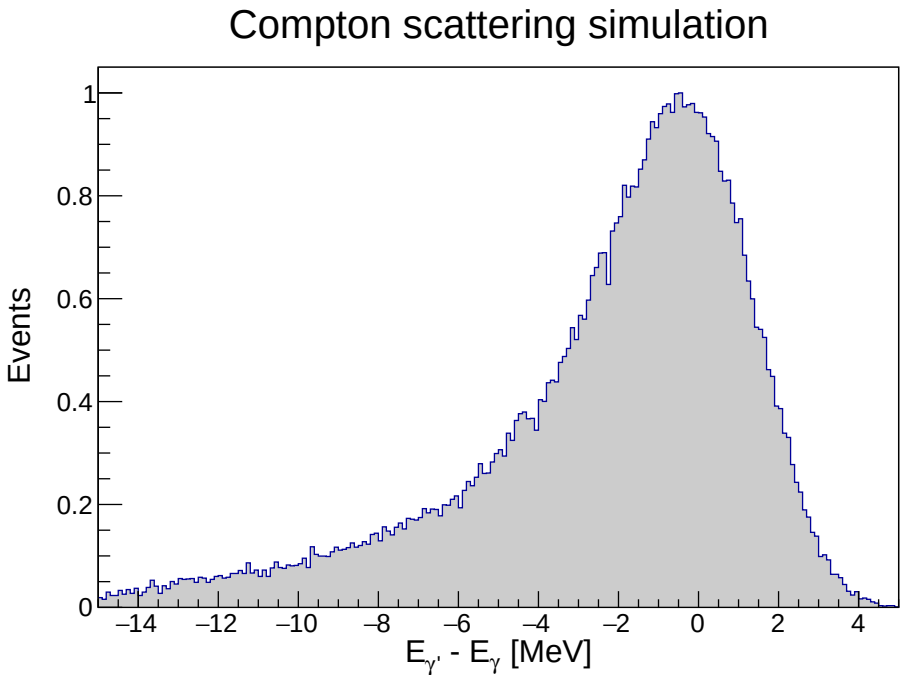


The Compton events $\gamma + {}^2\mathrm{H} \rightarrow \gamma' + {}^2\mathrm{H}'$ are identified through $E_\gamma - E_{\gamma'} = 0$.



Note the difference compared to π^- measurement:

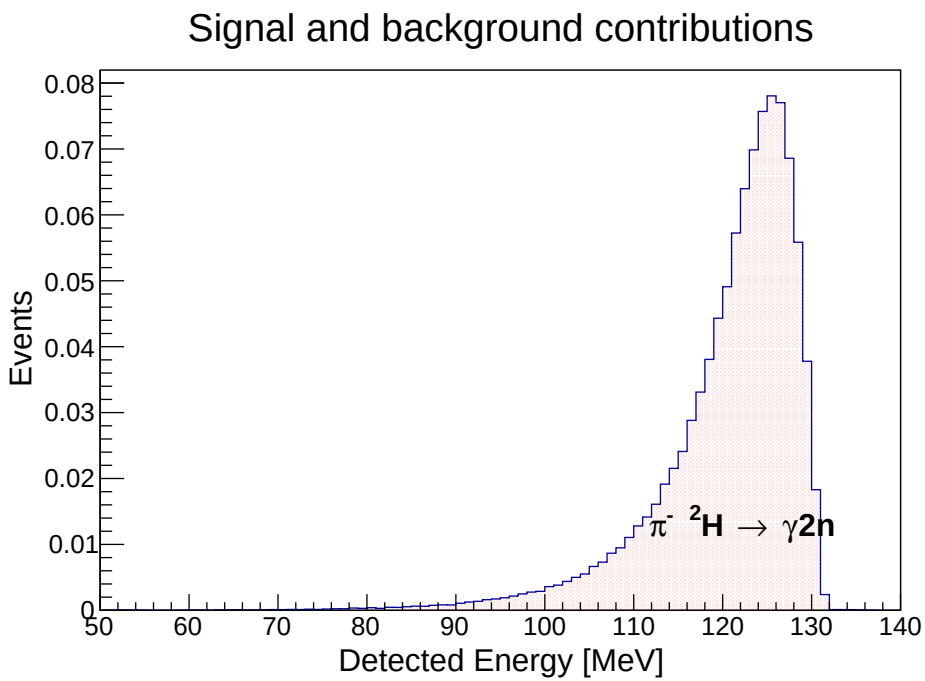
The Compton events $\gamma + {}^2\mathrm{H} \rightarrow \gamma' + {}^2\mathrm{H}'$ are identified through $E_\gamma - E_{\gamma'} = 0$.



Note the difference compared to π^- measurement:
For π^- we measure σ **VS** For Compton we measure $\frac{d\sigma}{d\Omega}$ points.

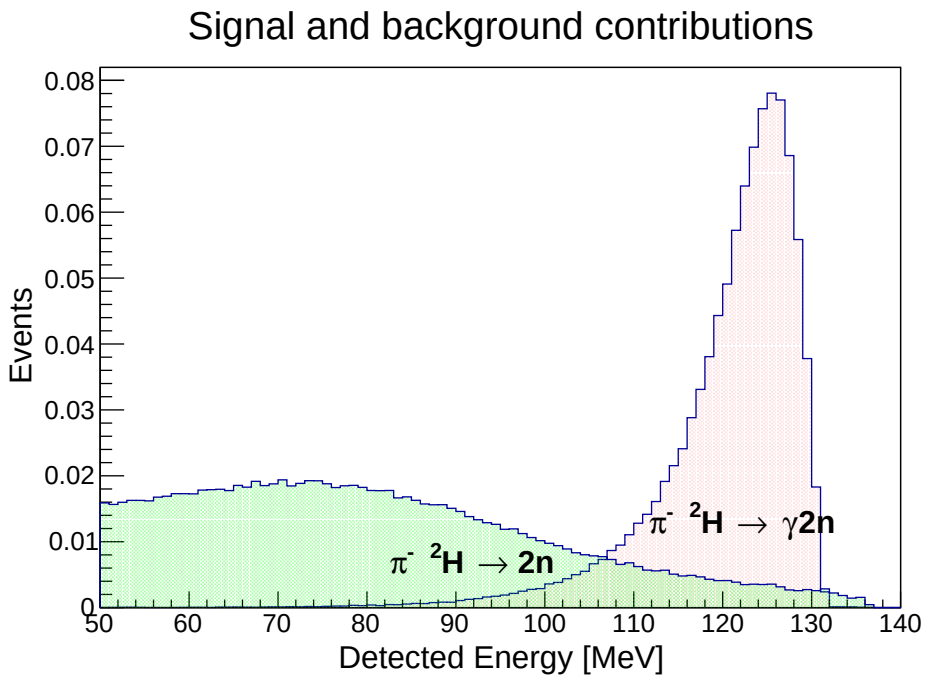
Analysis - backgrounds

Neutron background channels:



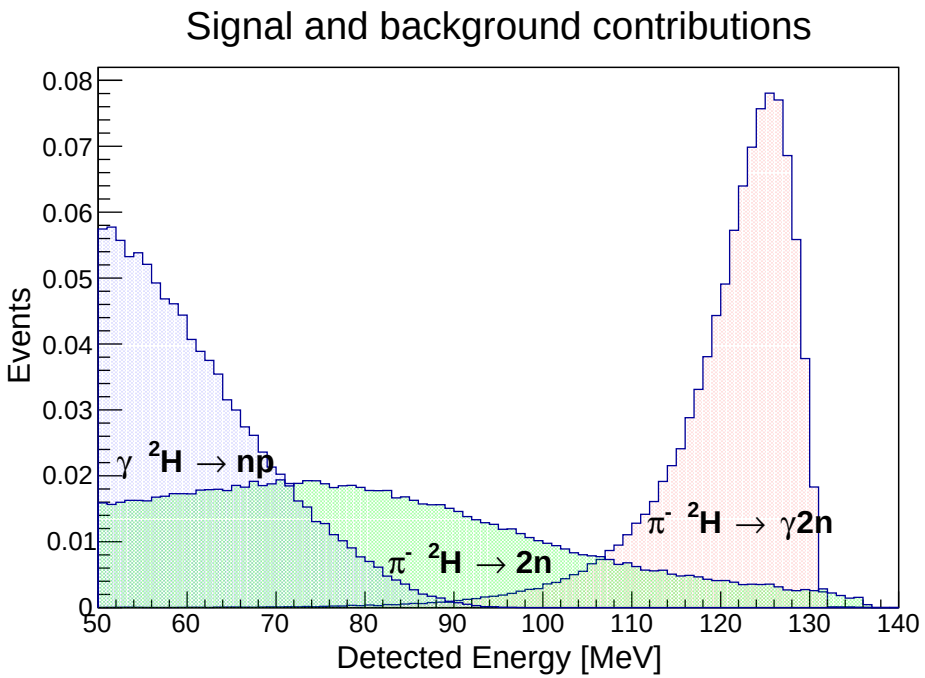
Neutron background channels:

1. Non-rad. capture $\pi^- + {}^2\mathrm{H} \rightarrow 2\mathrm{n}$, $2.83 \times \sigma_{\gamma 2\mathrm{n}}$ (Geant4)



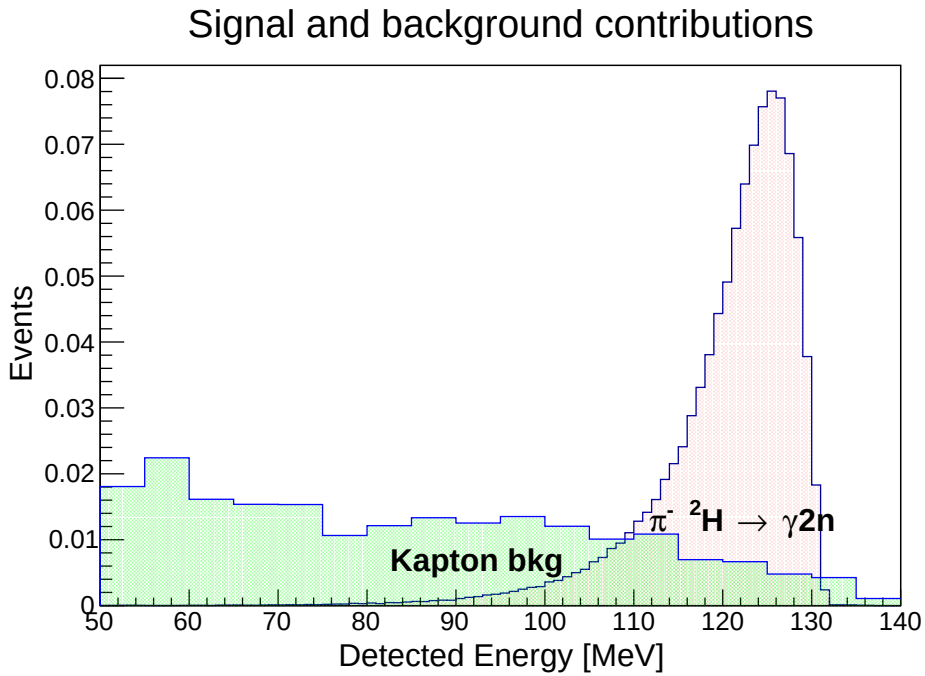
Neutron background channels:

1. Non-rad. capture $\pi^- + {}^2\mathrm{H} \rightarrow 2\mathrm{n}$, $2.83 \times \sigma_{\gamma 2\mathrm{n}}$ (Geant4)
2. Photodisinteg. $\gamma + {}^2\mathrm{H} \rightarrow \mathrm{np}$, $\sigma_{\mathrm{np}} \sim \sigma_{\pi^- 2\mathrm{p}}$ (Geant4, [6])



Neutron background channels:

1. Non-rad. capture $\pi^- + {}^2\mathrm{H} \rightarrow 2\mathrm{n}$, $2.83 \times \sigma_{\gamma 2\mathrm{n}}$ (Geant4)
2. Photodisinteg. $\gamma + {}^2\mathrm{H} \rightarrow \mathrm{np}$, $\sigma_{\mathrm{np}} \sim \sigma_{\pi^- 2\mathrm{p}}$ (Geant4, [6])

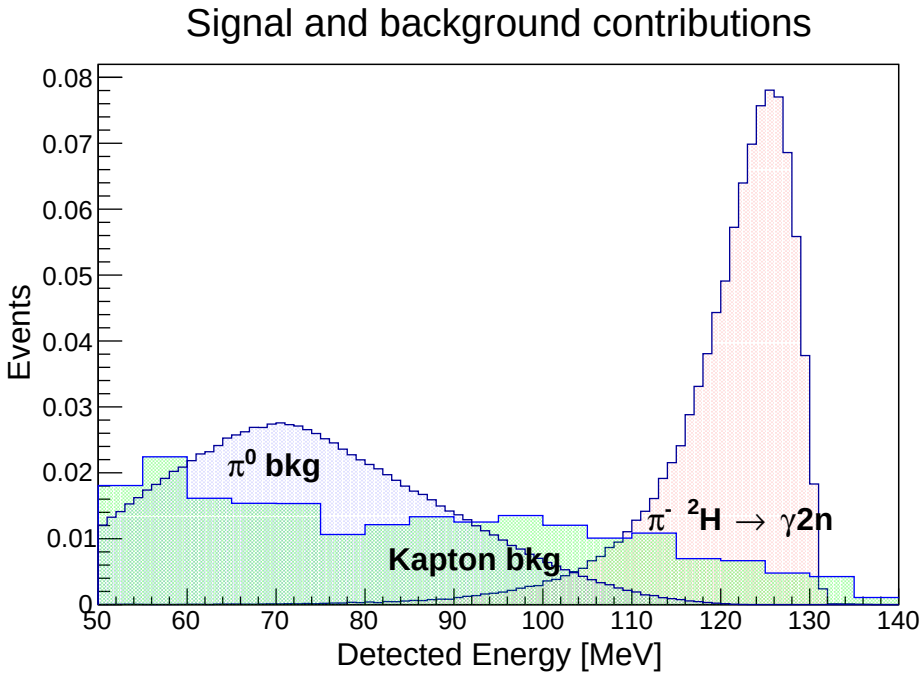


Other background channels:

1. Kapton container background, measured (dummy target run).

Neutron background channels:

1. Non-rad. capture $\pi^- + {}^2\mathrm{H} \rightarrow 2\mathrm{n}$, $2.83 \times \sigma_{\gamma 2\mathrm{n}}$ (Geant4)
2. Photodisinteg. $\gamma + {}^2\mathrm{H} \rightarrow \mathrm{np}$, $\sigma_{\mathrm{np}} \sim \sigma_{\pi^- 2\mathrm{p}}$ (Geant4, [6])

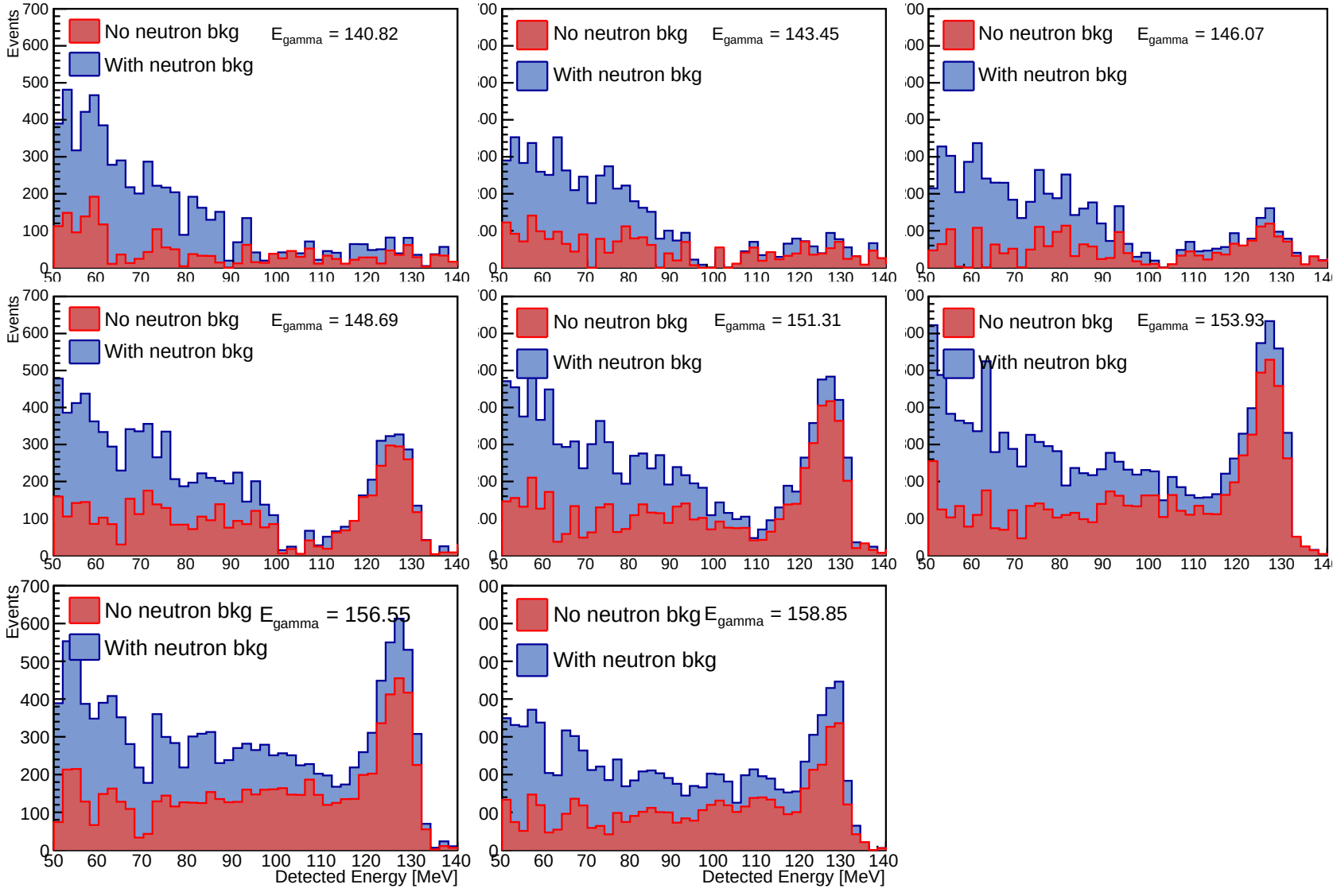


Other background channels:

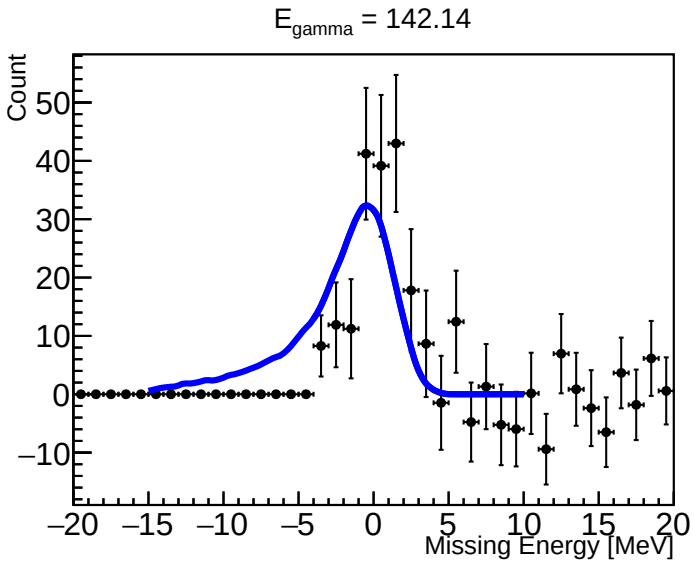
1. Kapton container background, measured (dummy target run).
2. Pi0 single photon background, $\sigma_{\pi^0 \mathrm{np}} < \sigma_{\pi^- 2\mathrm{p}}$ (Geant4).

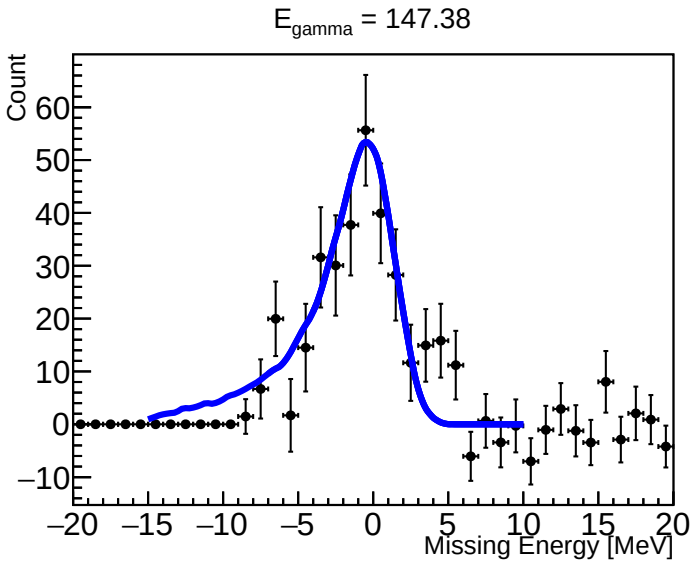
Analysis - signals

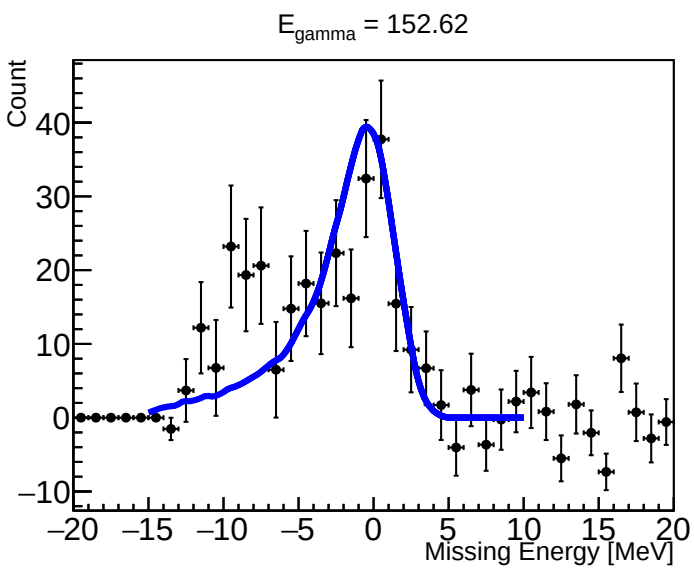
π^- production signal by incident E_γ (prelim)

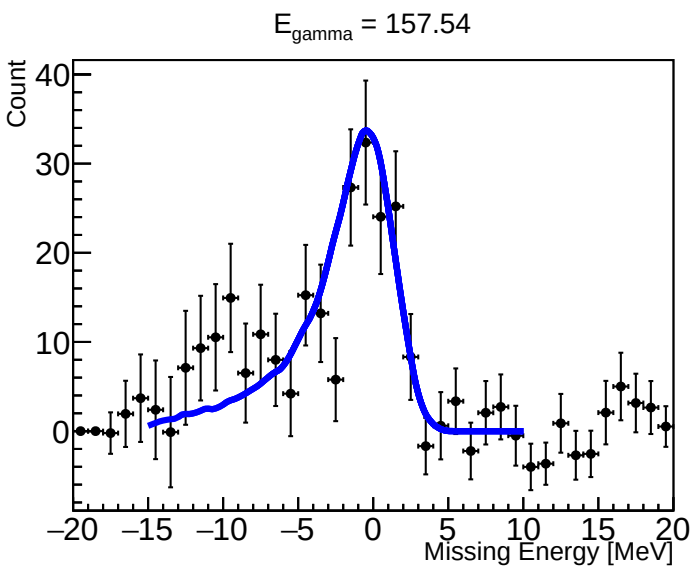


Compton signal by incident E_γ at $\theta = 60°$ (prelim)



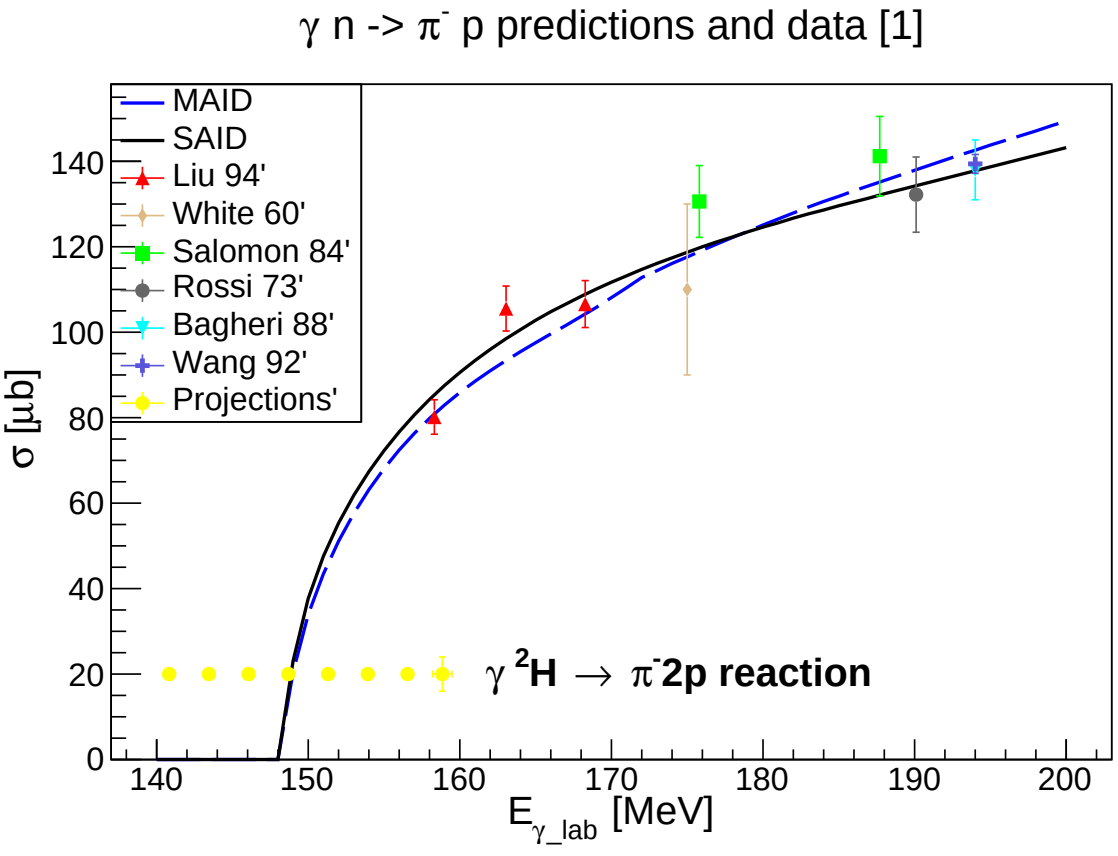




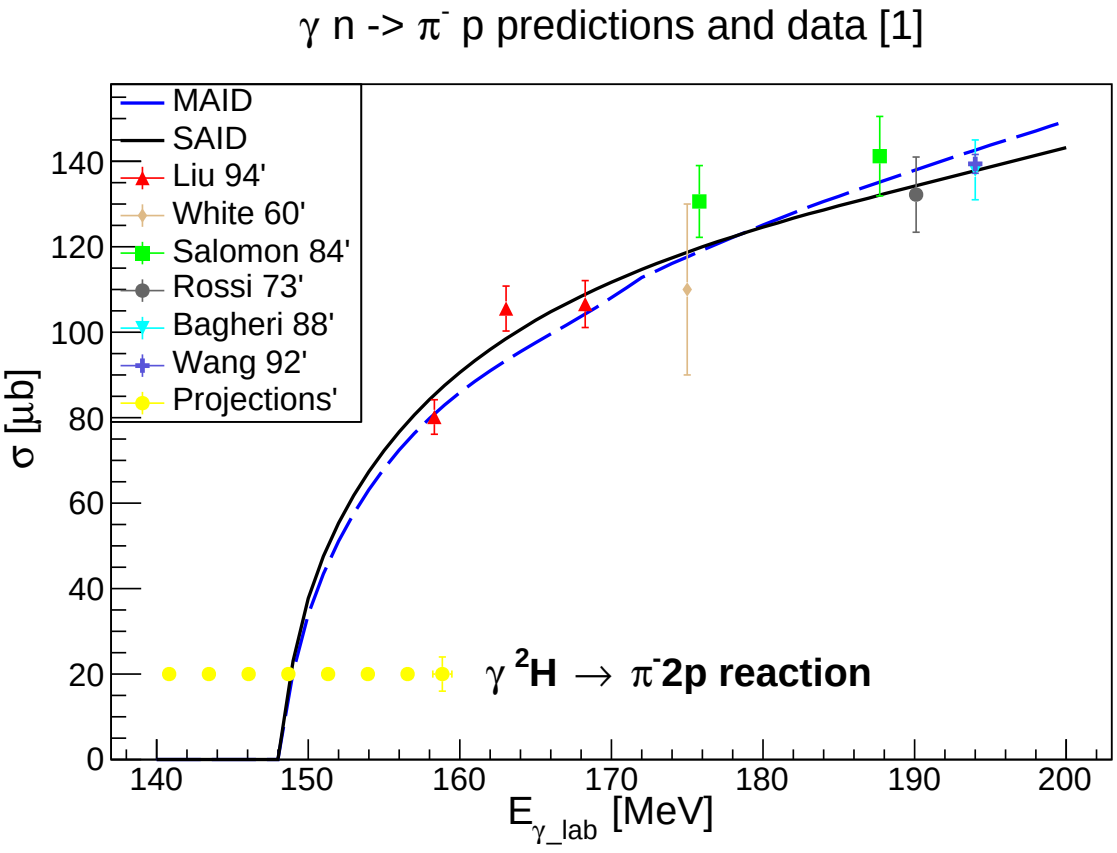


Analysis - π^- expected results

π^- on deuteron: σ at eight E_γ values from 140 to 160 MeV in $\sim$ 2 MeV bins.

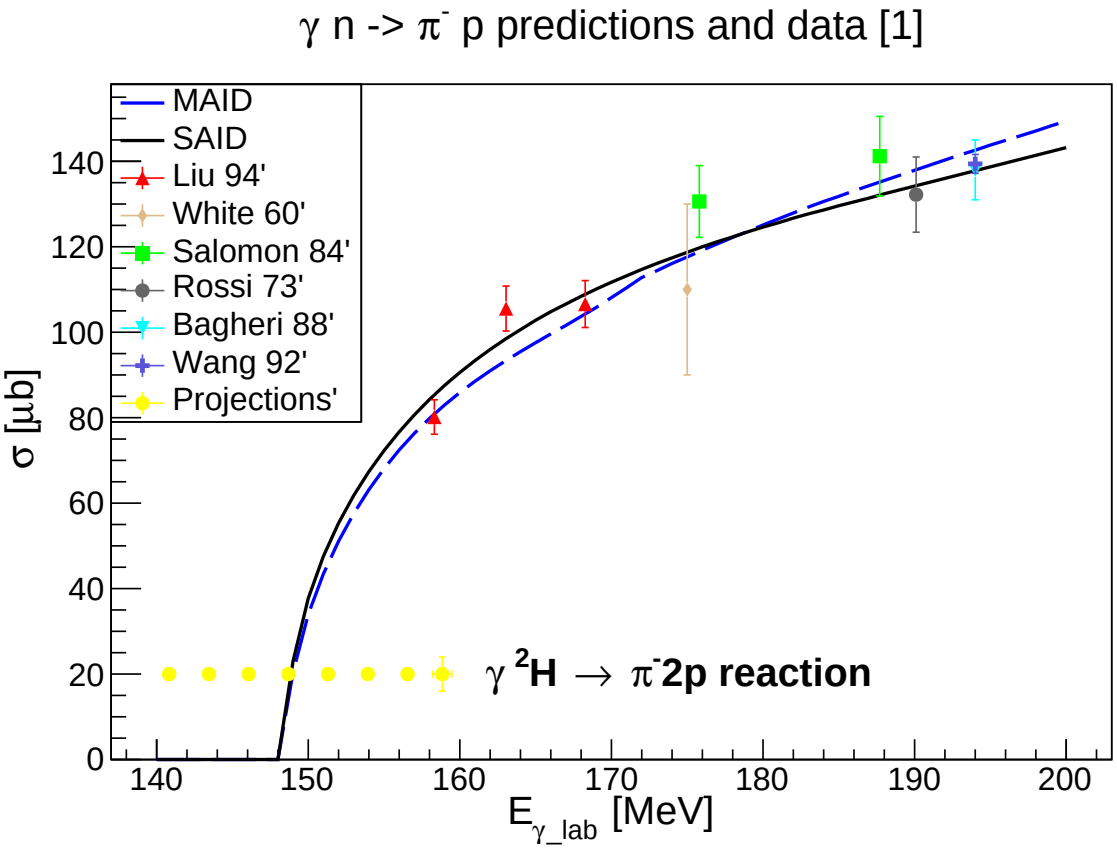


π^- on deuteron: σ at eight E_γ values from 140 to 160 MeV in $\sim$ 2 MeV bins.



- Shown signals include roughly 50-60% of data, with all data statistical uncertainty $< 5\%$.

π^- on deuteron: σ at eight E_γ values from 140 to 160 MeV in $\sim$ 2 MeV bins.

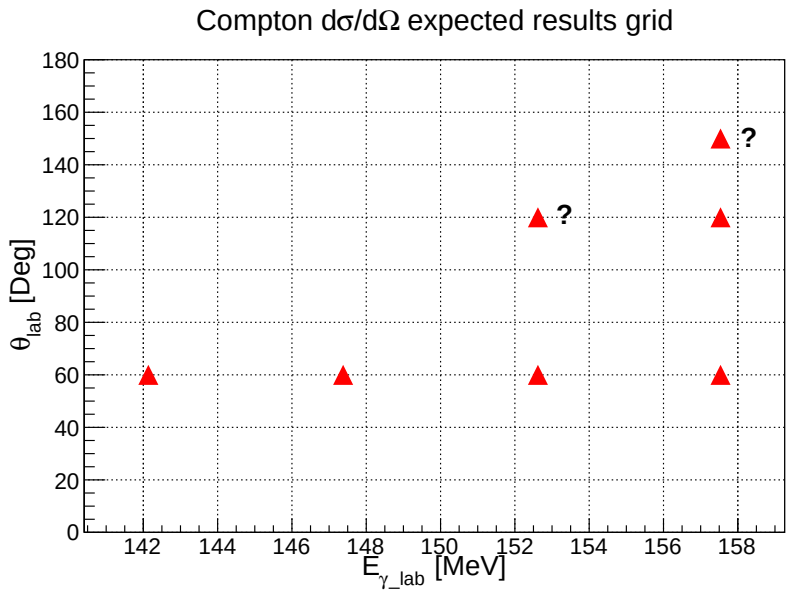


- Shown signals include roughly 50-60% of data, with all data statistical uncertainty $< 5\%$.
- This will be first good statistics threshold data.

Analysis - Compton expected results

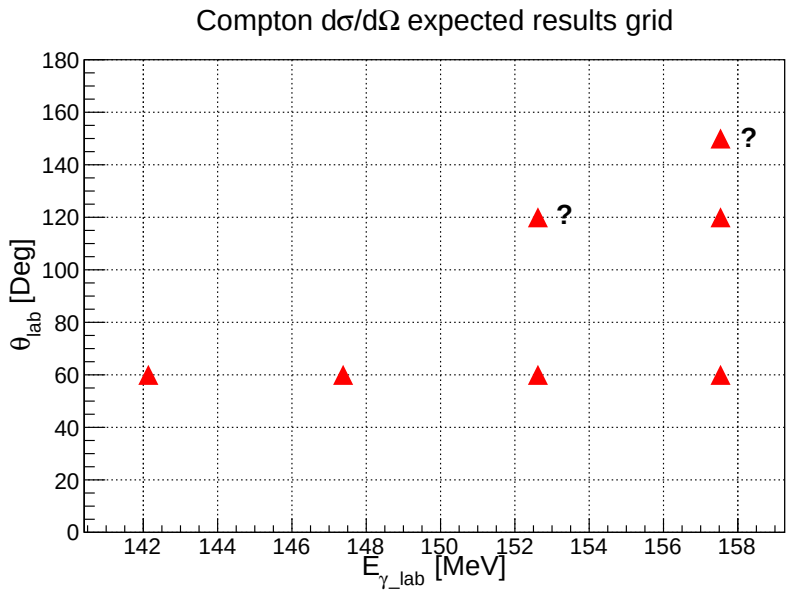
Analysis - Compton expected results

Compton on deuteron: differential cross-section $d\sigma/d\Omega$ values in 4 energy bins at 2(3?) angles.



Analysis - Compton expected results

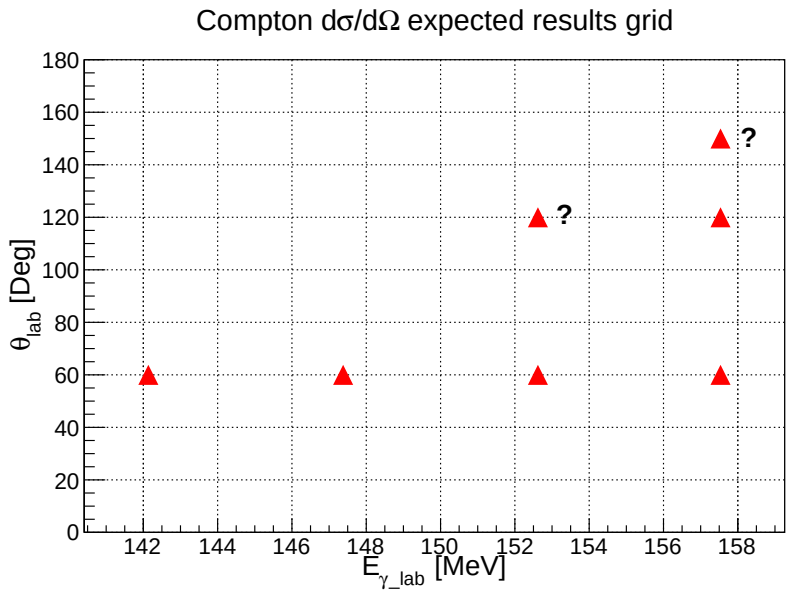
Compton on deuteron: differential cross-section $d\sigma/d\Omega$ values in 4 energy bins at 2(3?) angles.



- Shown signals include roughly 50-60% of data, with all data statistical uncertainty $\sim$ 10%.

Analysis - Compton expected results

Compton on deuteron: differential cross-section $d\sigma/d\Omega$ values in 4 energy bins at 2(3?) angles.



- Shown signals include roughly 50-60% of data, with all data statistical uncertainty $\sim$ 10%.
- This will be first Compton measurement in above threshold region.

Summary

Summary

π^-/Compton on deuteron measurement motivation:

- Provide test for low-energy QCD models.
- No previous measurement.

Summary

π^-/Compton on deuteron measurement motivation:

- Provide test for low-energy QCD models.
- No previous measurement.

Experiment and analysis:

- Analysis components and procedures well understood.
- Preliminary results show promise.

Summary

π^-/Compton on deuteron measurement motivation:

- Provide test for low-energy QCD models.
- No previous measurement.

Experiment and analysis:

- Analysis components and procedures well understood.
- Preliminary results show promise.

Expected results:

- π^- σ on deuteron: value at 8 energies.
- Compton $d\sigma/d\Omega$ on deuteron: 5(7?) points.

Summary

π^-/Compton on deuteron measurement motivation:

- Provide test for low-energy QCD models.
- No previous measurement.

Experiment and analysis:

- Analysis components and procedures well understood.
- Preliminary results show promise.

Expected results:

- π^- σ on deuteron: value at 8 energies.
- Compton $d\sigma/d\Omega$ on deuteron: 5(7?) points.

I would like to thank the MAXTagg collaboration and the MESONS2016 conference.

Thank you for listening!

References I

- http://gwdac.phys.gwu.edu
- V.L. Highland *et. al.*, Branching Ratios For Stopped Pions In Deuterium, 1981.
- D.W. Joseph, Electron Pair Production in $\pi^- + d$ Capture, 1960.
- S. Tripathi *et al.* Double radiative pion capture on hydrogen and deuterium and the nucleons pion cloud, 2007.
- R. MacDonald *et al.* Charge Exchange of Stopped π^- in Deuterium: Experiment and Theory, 1977.
- D.A. Jenkins *et al.* $^2\mathrm{H}(\gamma, \mathrm{p})\mathrm{n}$ cross section between 20 and 440 MeV, 1994.