Hunting Dibaryons: A study of the $\gamma d \rightarrow \pi^+\pi^- d$ reaction

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GHP Meeting
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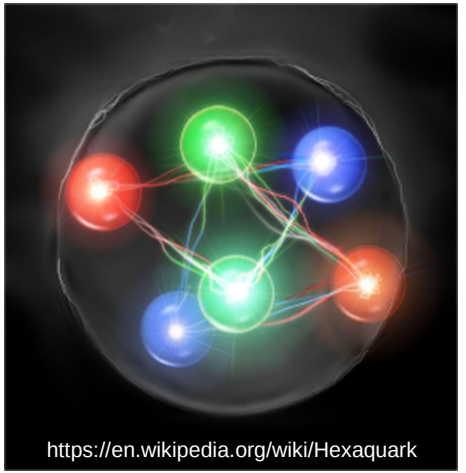
Dibaryons

- Dibaryon: Particle with baryon number B = 2.
- Composed of six valence quarks
  - Six quarks in a bag.
- Theoretically expected and long sought resonances.


https://en.wikipedia.org/wiki/Hexaquark

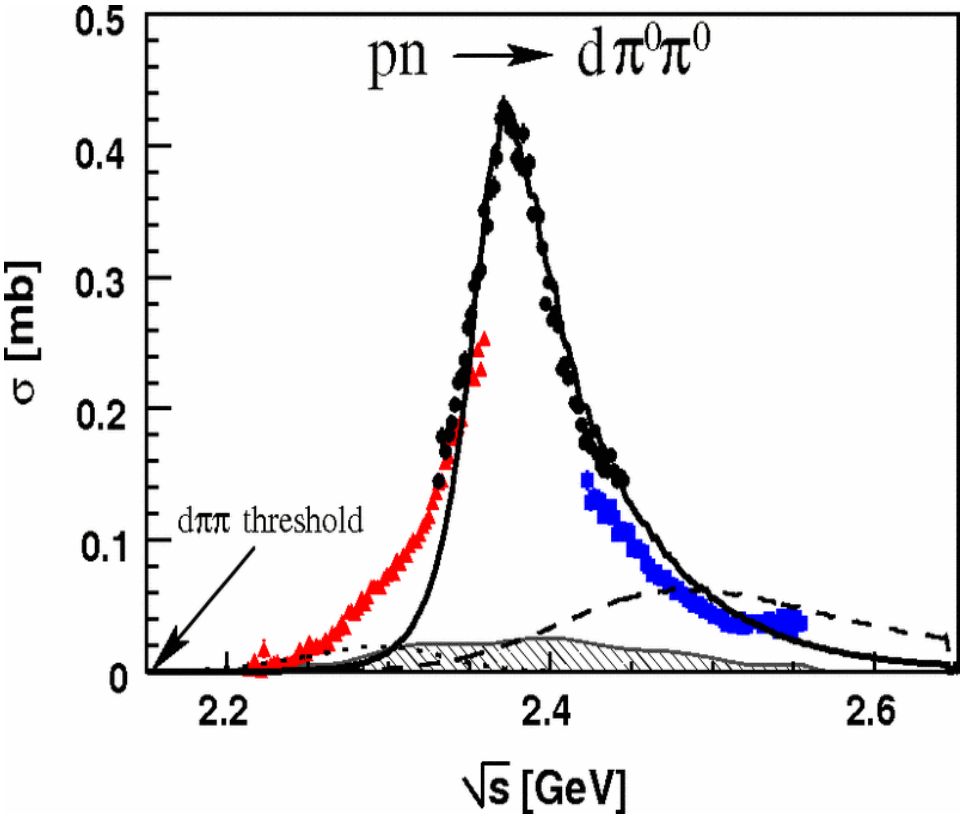
Dibaryon	I	J	*BB* configuration	Mass formula	Predicted Mass [MeV]
D_{01}	0	1	deuteron	A	1876
D_{10}	1	0	NN virtual state	A	1876
D_{12}	1	2	$N\Delta$	$A + 6B$	2160
D_{21}	2	1	$N\Delta$	$A + 6B$	2160
D_{03}	0	3	$\Delta\Delta$	$A + 10B$	2350
D_{30}	3	0	$\Delta\Delta$	$A + 10B$	2350

Freeman J. Dyson and Nguyen-Huu Xuong
Phys. Rev. Lett. 13, 815 – Published 28 December 1964

- Dyson-Xuong mass formula:
  - $M_{N\Delta} \approx 2160$ MeV
  - $M_{\Delta\Delta} \approx 2350$ MeV
- A. Gal, H Garcilazo, “3-body model calculations of N Δ and ΔΔ dibaryon resonances” Nuclear Physics A 928 (2014) 73-88
- H. Clement, “On the History of Dibaryons and their Final Observation”, Progress in Particle and Nuclear Physics 93 (2017) 195-242

$d^*(2380)$

- The WASA@COSY result for ΔΔ by studying: $pn \rightarrow d\pi^0\pi^0$
- $M \sim 2370$ MeV, $\Gamma \sim 70$ MeV
- $I(J^P) = 0(3^+)$: Fact arrived from the reaction is purely isoscalar.



P. Adlarson *et al*
Phys Rev Lett 106, 242302 (2011)

P. Adlarson, et al., Phys. Lett. B 721 (2013) 229

P. Adlarson, et al., Phys. Rev. C 88 (2013) 055208

P. Adlarson, et al., Phys. Lett. B 743 (2015) 325

P. Adlarson, et al., Phys. Rev. Lett. 112 (2014) 202301

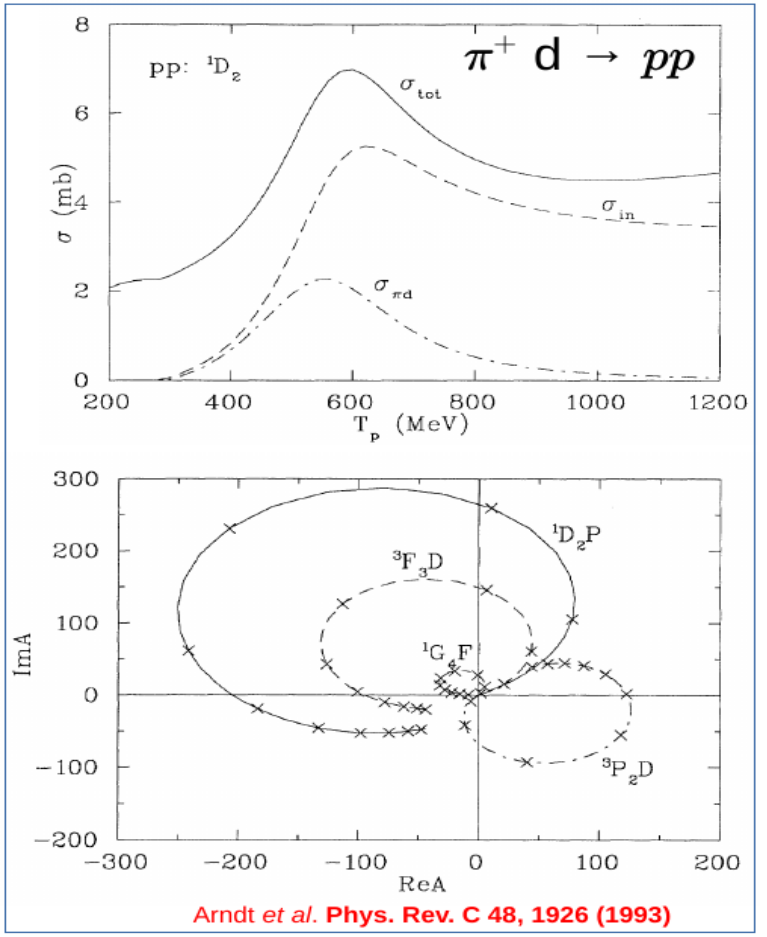
P. Adlarson, et al., Phys. Rev. C 90 (2014) 035204

pp Elastic Scattering

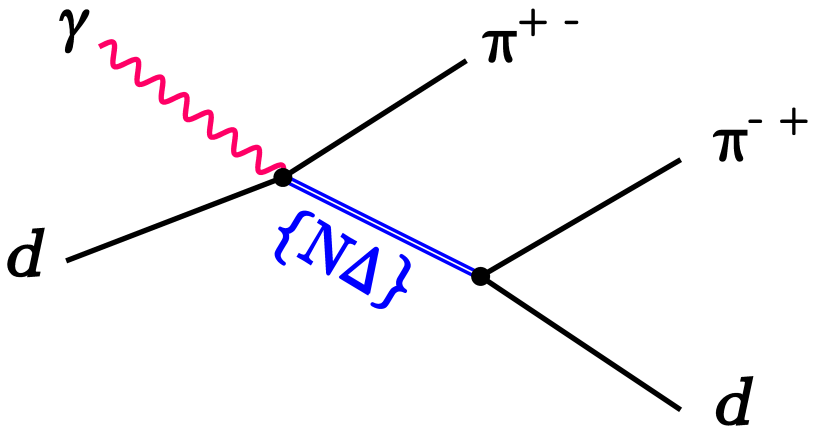
- Partial Wave Analysis.
- $^1D_2$ wave in pp elastic scattering:

  structure at 2148 – i 63 MeV.
- Prominent "resonance pole" seen in the SAID analysis.
- The total partial wave strength is consistent with the sum of its parts

Follow K. Hicks' talk for more motivation
Hadronic Interactions I



Goal



- Spin:
  1 + 1 → J = {0, 1, **2**}
- Isospin:
  {0, 1} + 1 → {0, 1}

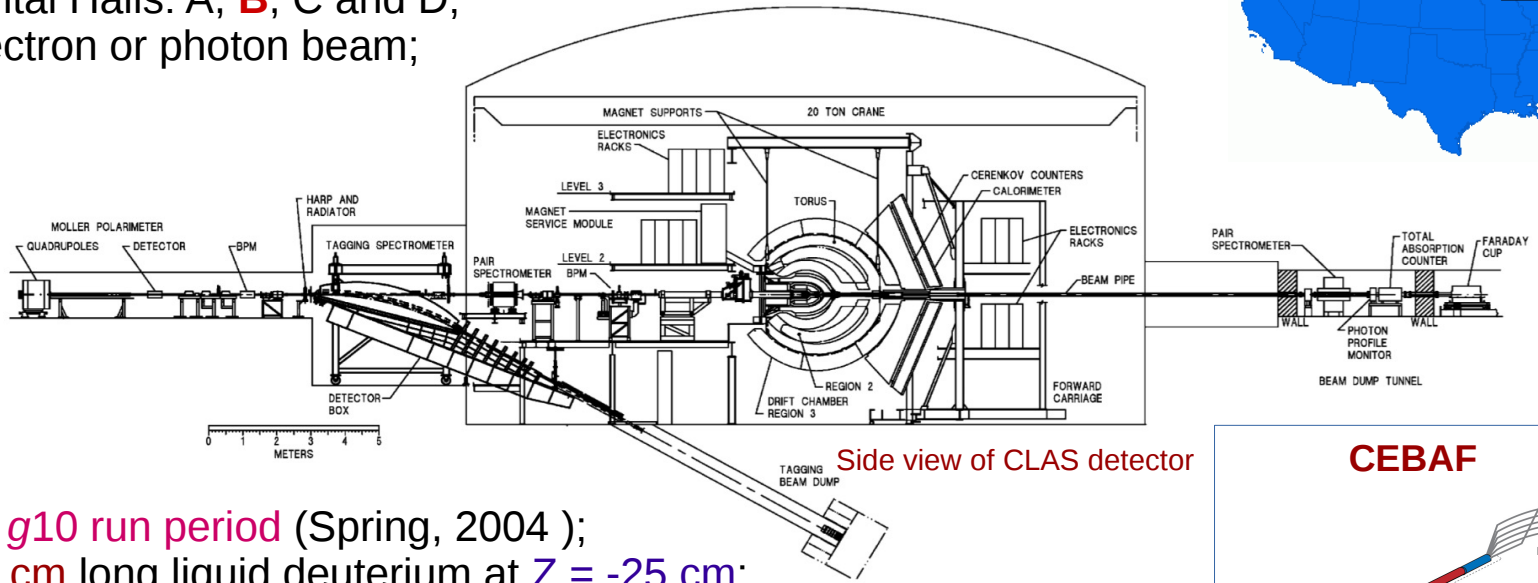
Investigate NΔ using dππ in the final state.

- $d\pi^+$ channel → d^{*++}
- $d\pi^0$ channel → d^{*+}
- $d\pi^-$ channel → d^{*0}

Verify the resonance and extract the differential cross section.

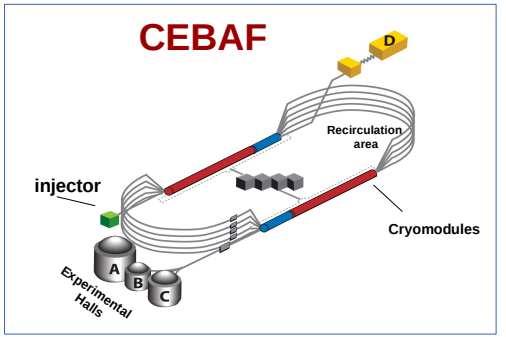
CLAS @ JLab

- JLAB: Newport News, VA;
- CEBAF: accelerated electrons up to 6 GeV;
- Experimental Halls: A, **B**, C and D;
- Hall B: electron or photon beam;



Side view of CLAS detector

- Data from *g*10 run period (Spring, 2004);
- Target: 24 cm long liquid deuterium at Z = -25 cm;
- Electron beam energy 3.778 GeV;
- Tagged photon beam in [0.8, 3.59] GeV range;
- Trigger: At least two charged particles in any of 2 six sectors of CLAS.

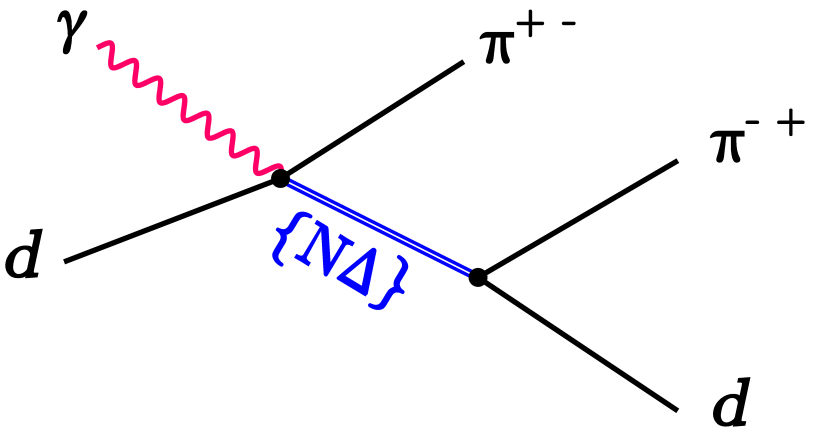


g10 @ CLAS

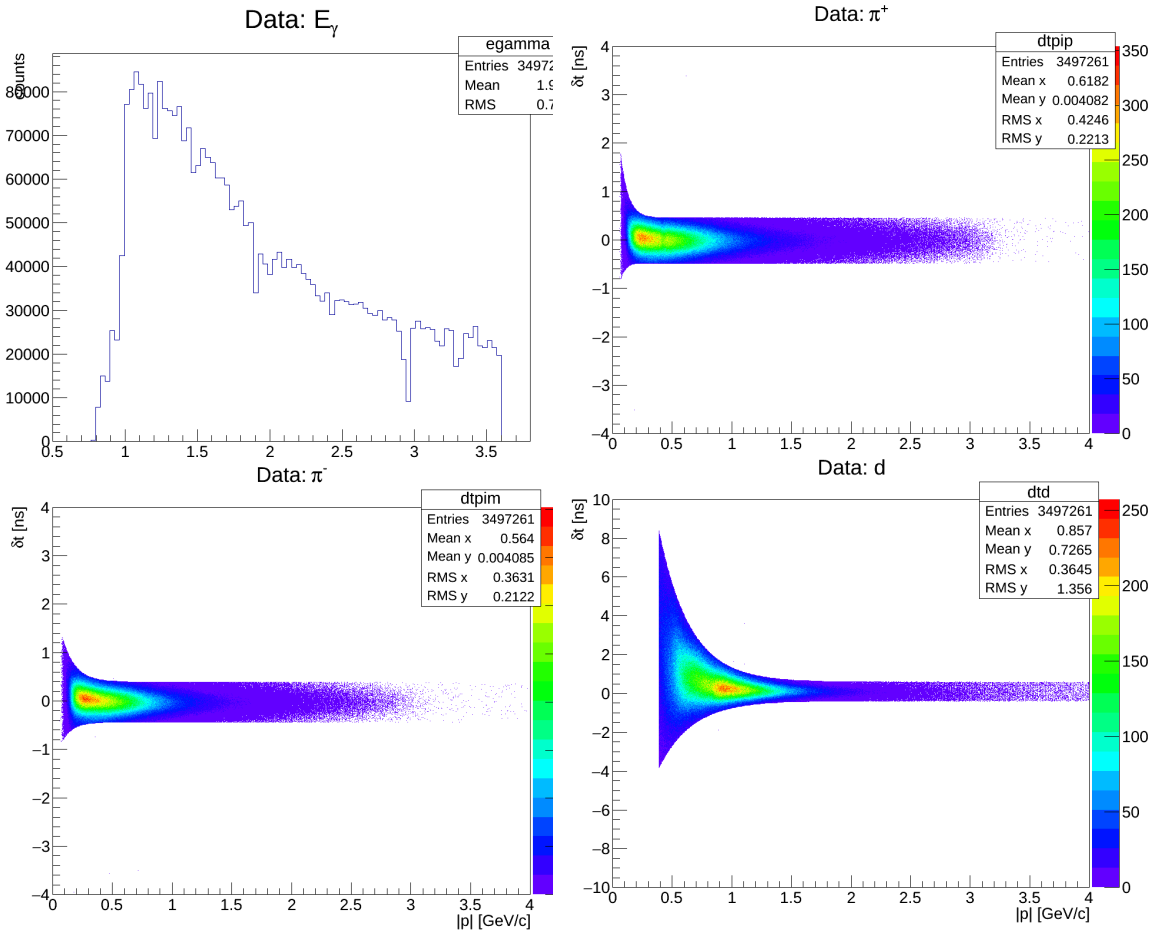
- Photons on deuteron target
- Spin:

  $1 + 1 \rightarrow J = \{0, 1, \mathbf{2}\}$
- Isospin:

  $\{0, 1\} + 1 \rightarrow \{0, 1\}$
- Coherent production removes complicated partial waves for nucleon mixtures.



Event Selection

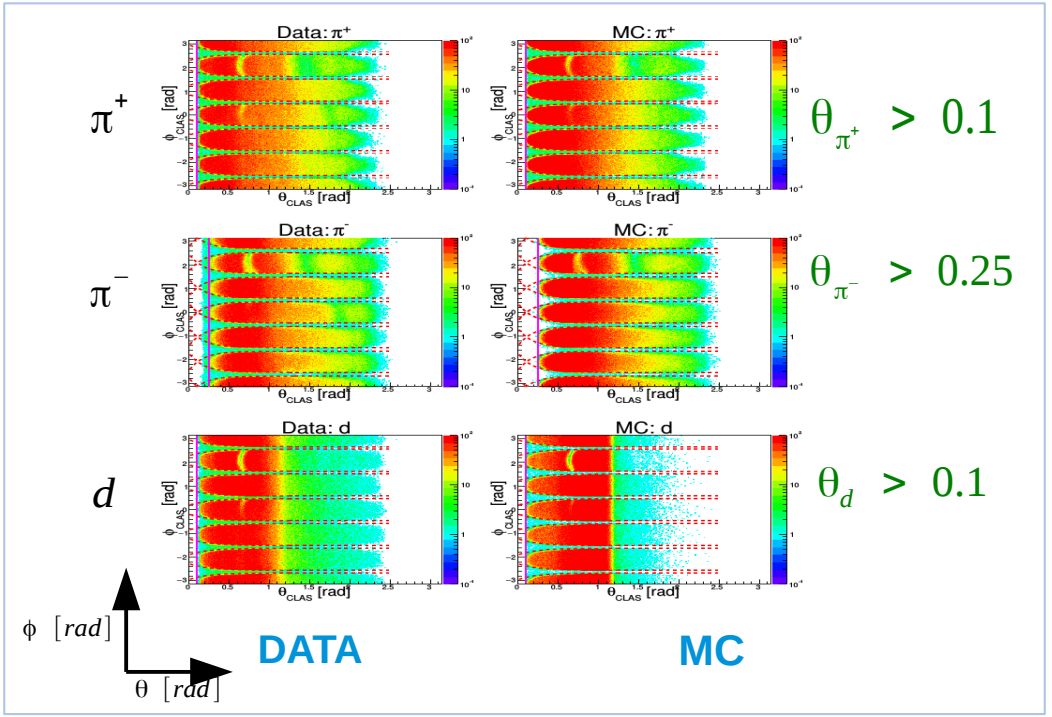


- Final state particles detected: two charged pions and a coherent deuteron.
- Particle identification is done based on momentum-dependent timing analysis.

Cuts Applied

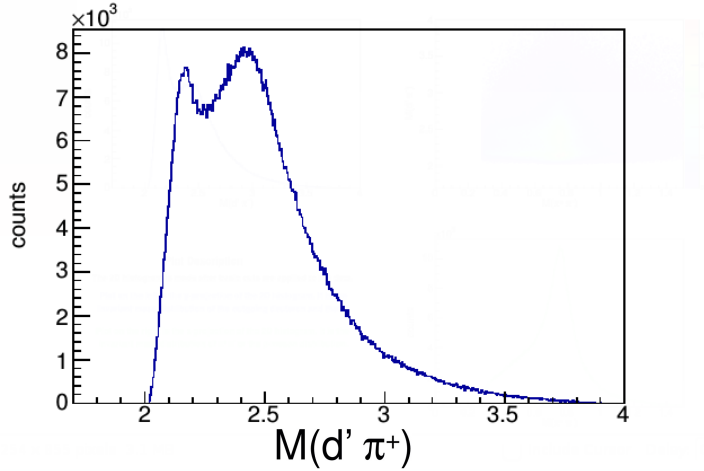
- Timing cuts made using momentum-dependent analysis
  - One “good photon”, |Δt|<1 ns
- -37 cm < z_{vertex} < -13 cm
- Fiducial cuts applied
  - Minimum Theta Cut
- Minimum Momentum Cuts
- $-0.01 < MM^2(\pi^+\pi^-d) < 0.005$ [GeV^2]
- Bad SC Paddles removed.

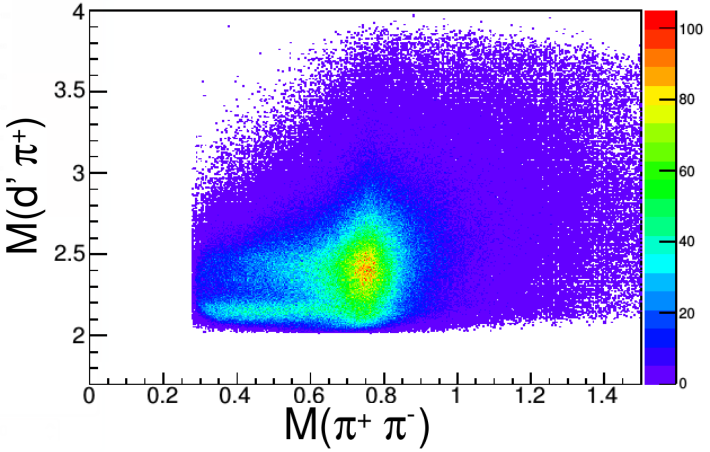
Particle	Sector 1	Sector 2	Sector 3	Sector 4	Sector 5	Sector 6
π^+	23, 27 ≥ 43	≥ 45	11, 13, 23, 31 ≥ 40	23, 33, 35 ≥ 46	23, 29 ≥ 46	23 ≥ 45
π^-	23, 27 ≥ 41	≥ 41	11, 15, 16, 23, 31 34-36, ≥ 41	23, 27, 35 ≥ 43	20, 23, 29 ≥ 43	23 ≥ 42
d	23, 27 ≥ 35	23 ≥ 35	11, 22, 23, 31 ≥ 35	23 ≥ 35	23, 29 ≥ 35	23 ≥ 35

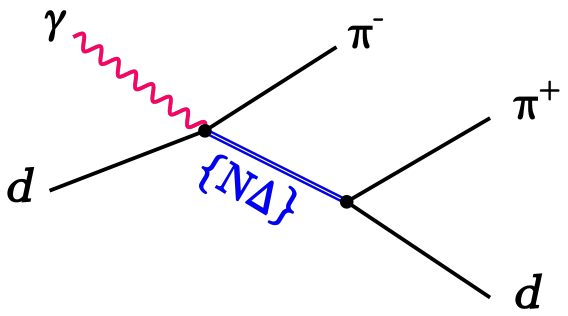


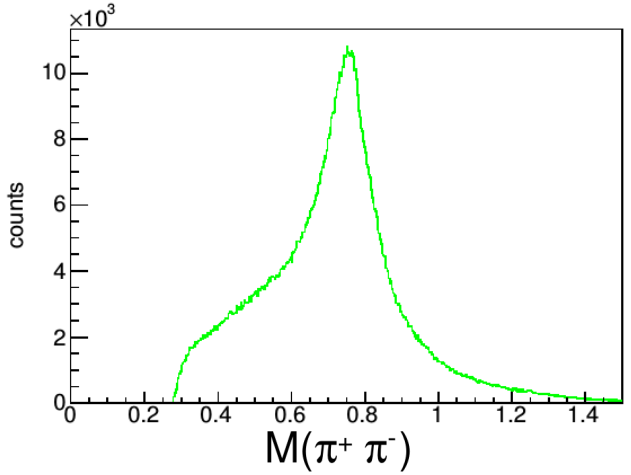
- Tagger energy corrections
- Momentum corrections

What we see?



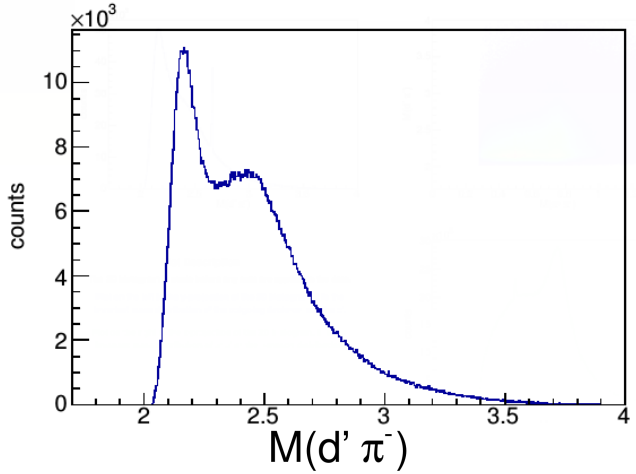


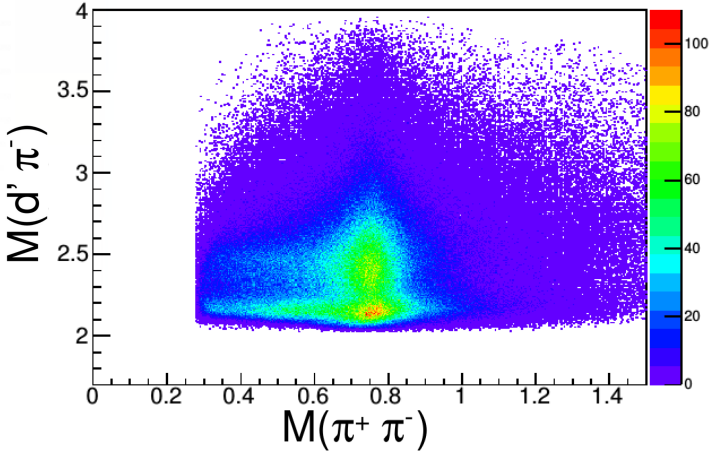


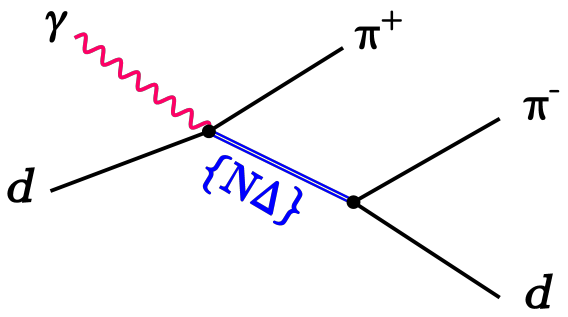


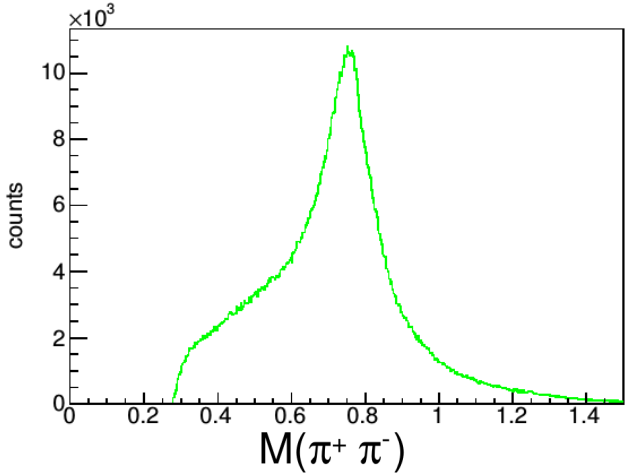
- dπ⁺ mass distribution.
- Basic cuts applied.
- Structure at about 2150 MeV.

What we see?





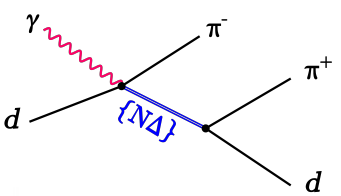


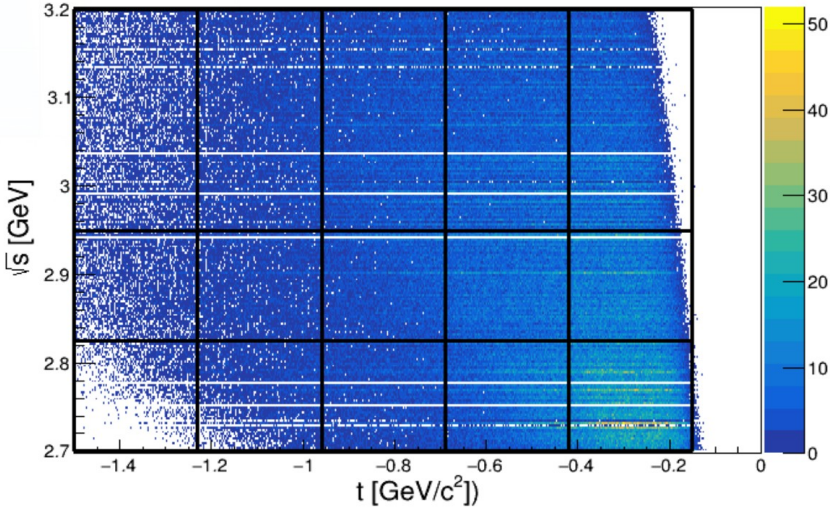


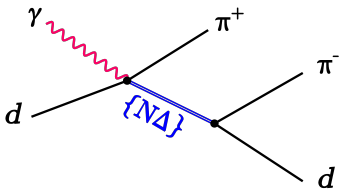
- $d\pi^-$ mass distribution.
- Basic cuts applied.
- Structure at about 2150 MeV.
- $d\pi^-$ distribution has prominent peak than $d\pi^+$ mass distribution.

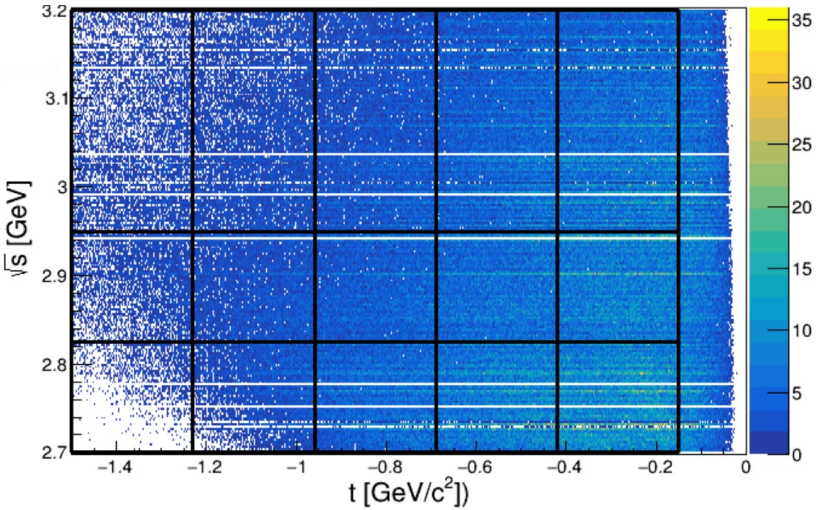
Binning

Distribution









$t_{d\pi^+} = (P_\gamma - P_{\pi^-})^2$

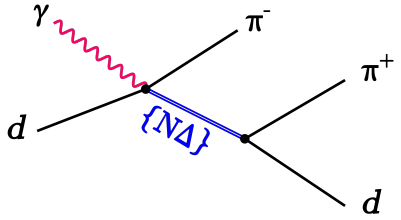
2.7 < √s < 3.2 GeV

0.2 < |t| < 1.5 GeV/c²

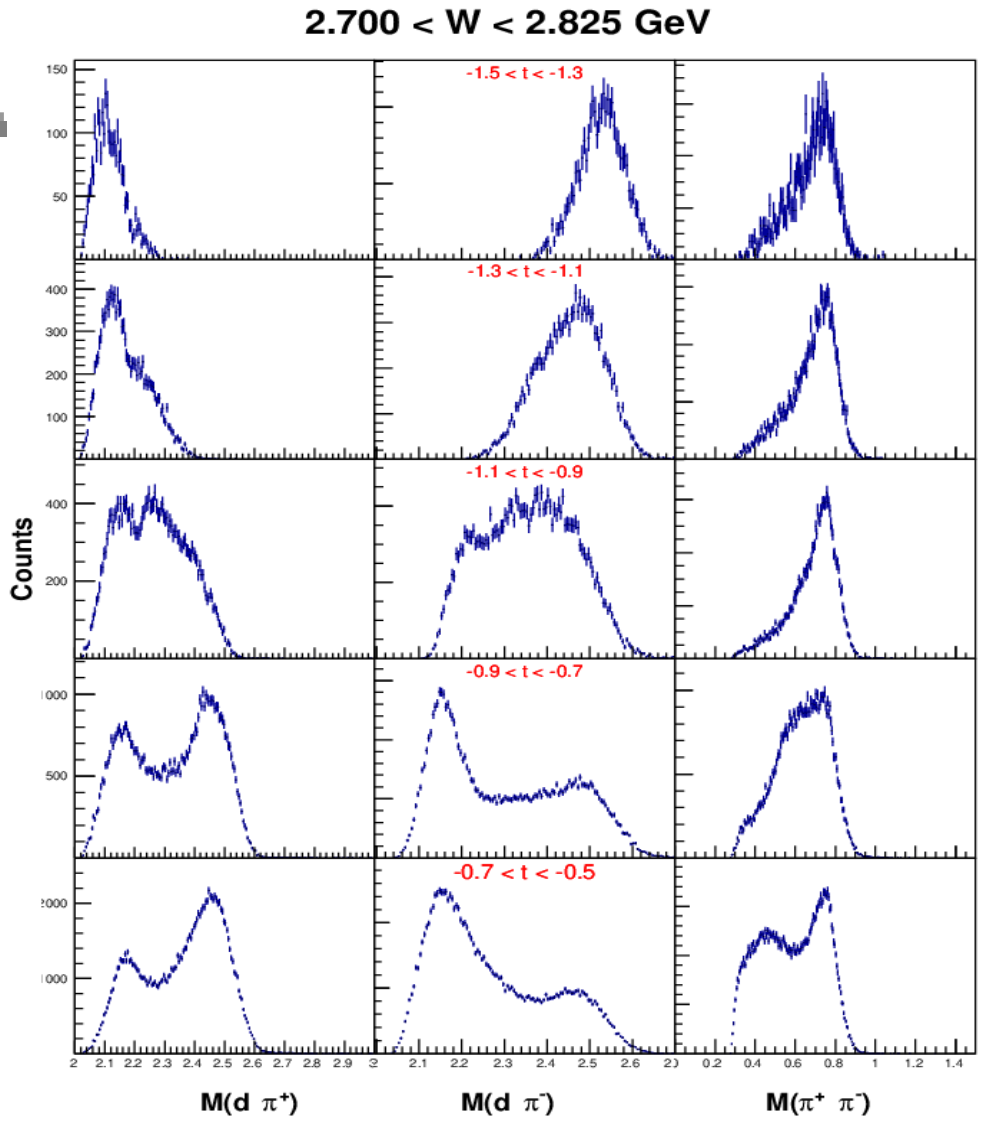
$t_{d\pi^-} = (P_\gamma - P_{\pi^+})^2$

4 CM bins and 5 |t| bins are considered

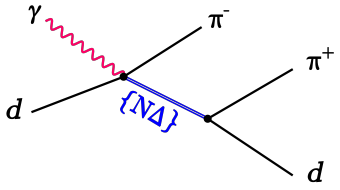
Backgrounds

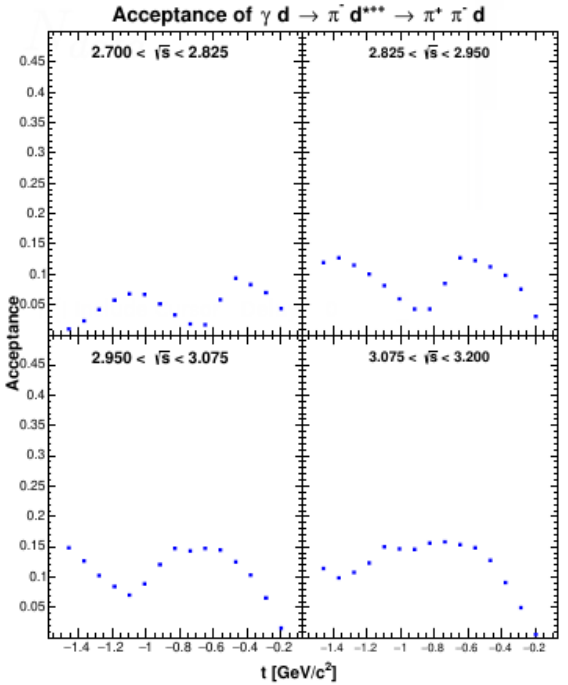


- Major Backgrounds:
  - Phase Space: $d\pi^+\pi^-$
  - Rho meson: $\pi^+\pi^-$
  - Reflection: $d\pi^+/d\pi^-$
  - Assuming no other background.
- MC Generated for each case.

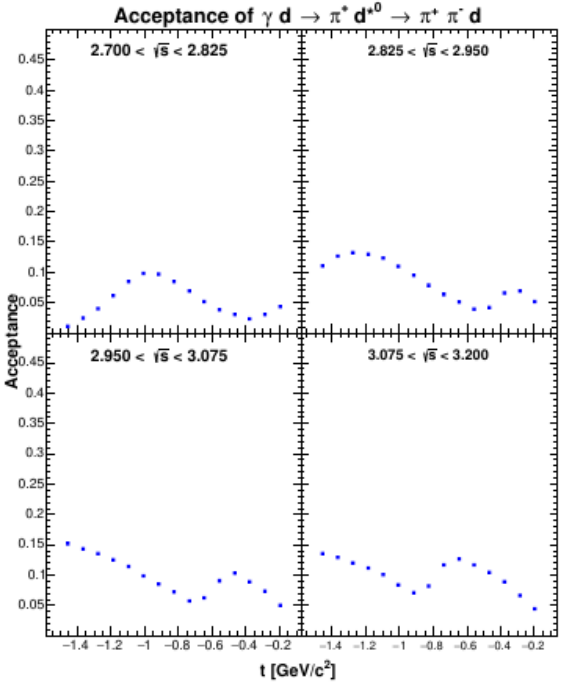


Acceptance

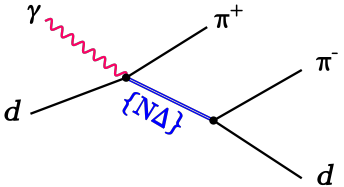




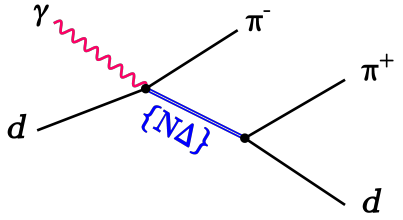
(a) Acceptance of $\gamma d \to d^{*++}\pi^- \to \pi^+\pi^- d$.



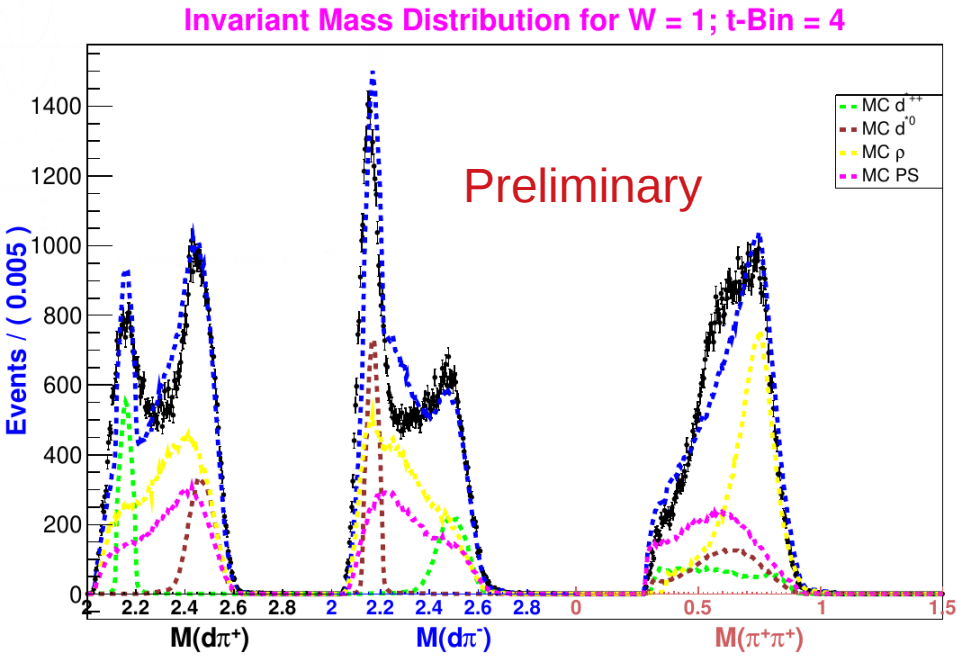
(b) Acceptance of $\gamma d \to d^{*0}\pi^+ \to \pi^+\pi^- d$.



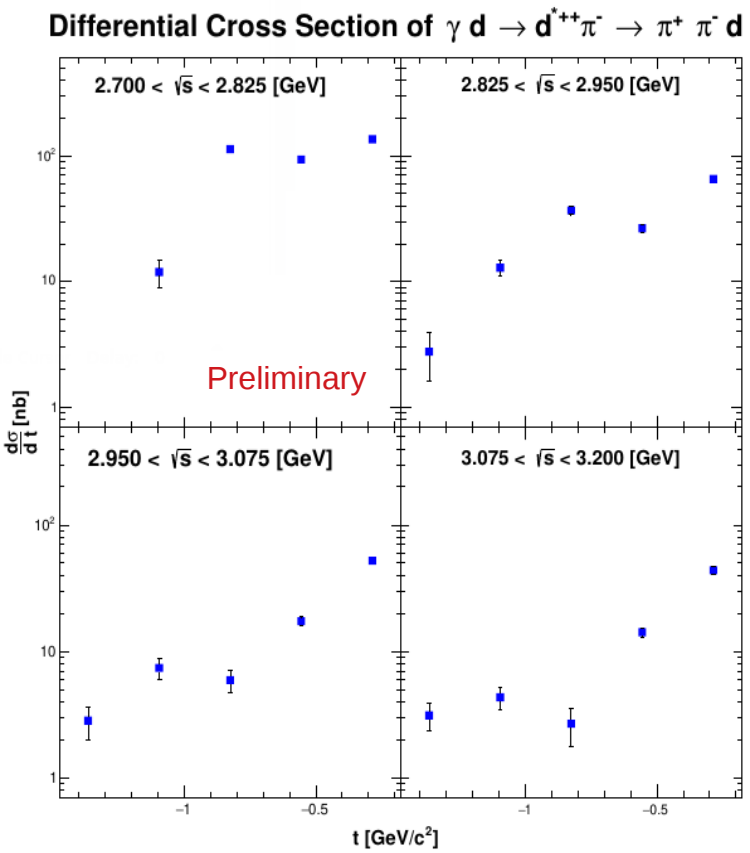
Yield Extraction



- Template fitting of all projections using simulation of signal and major backgrounds.
- Extract yield for the peak.
  - $Y = N_{signal} = f_{signal} \times N_{data}$
  - $\sigma_Y = \sqrt{\left(\frac{\sigma_{f_{signal}}}{f_{signal}}\right)^2 + \frac{1}{N_{data}}}$
- Extracted the signal for both channels separately.



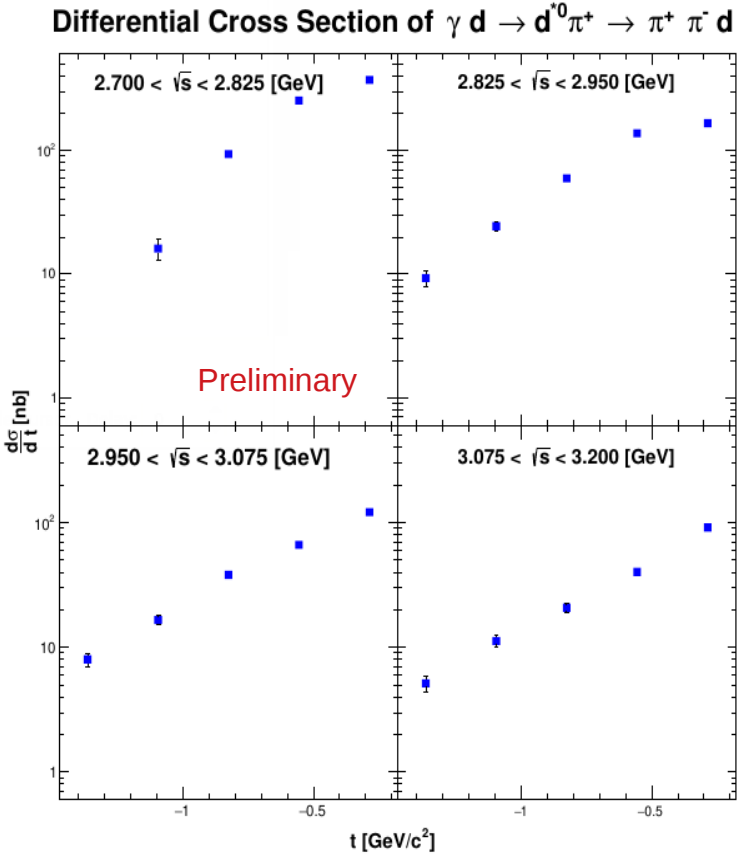
Differential Cross Section



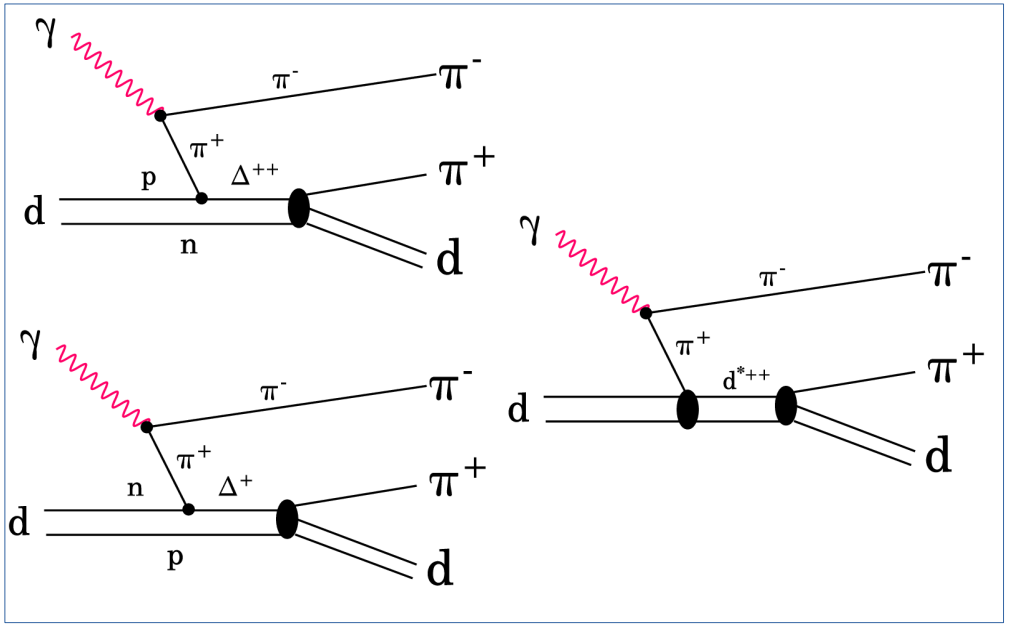
$$\frac{d\sigma}{dt} = \frac{Y_D}{\Delta t A \mathscr{L}}$$

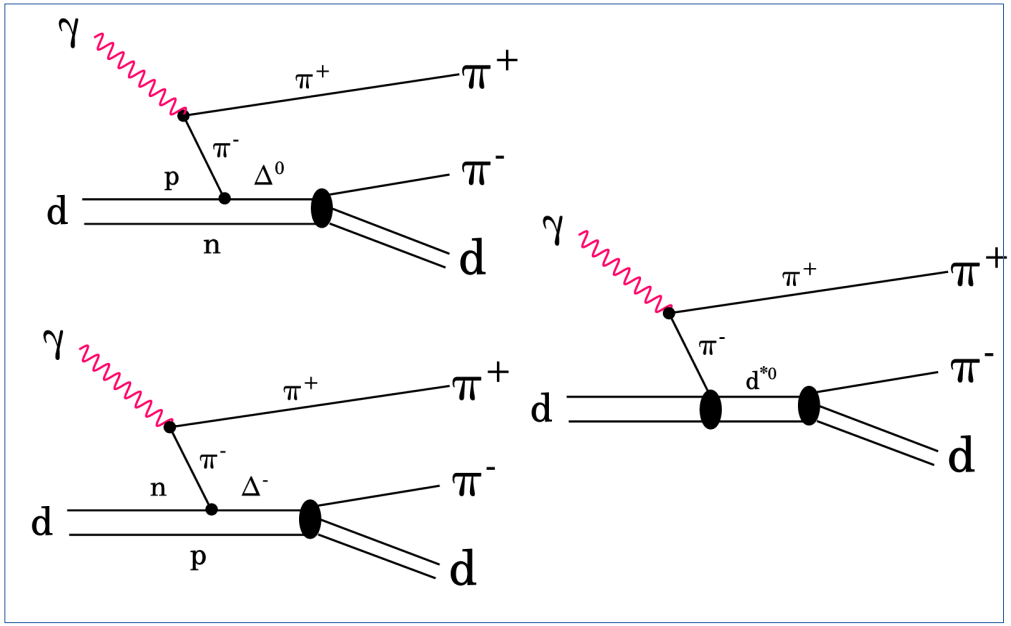
$\mathscr{L}$ is the target luminosity

d^{*0} production is favored by an order of magnitude compared to d^{*++}



Why is one channel favored than the other?





- Just from the Clebsch-Gordan coefficients, the amplitudes of the NΔ resonances have opposite signs.
- For Δ^{++} and Δ^{+} (left diagrams): $\sqrt{(3/4)} - \sqrt{(1/12)} = +0.577$
- For Δ^{0} and Δ^{-} (right diagrams): $-\sqrt{(3/4)} + \sqrt{(1/12)} = -0.577$
- Deuteron asymmetry (?)
- If d^* resonance cancels in one channel, it should add up in the other.

Courtesy: M. Sargsian, FIU

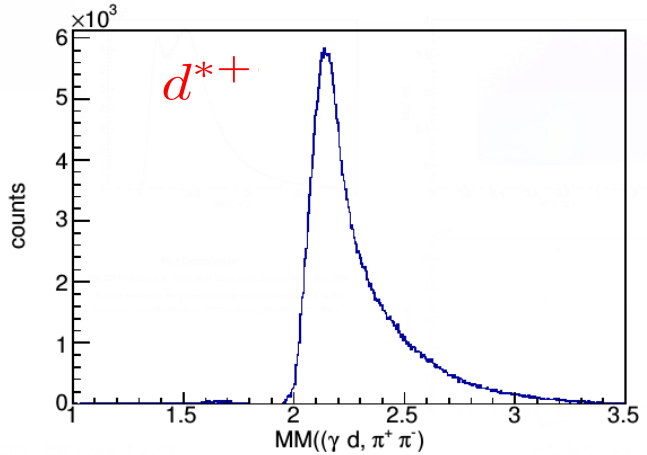
Summary

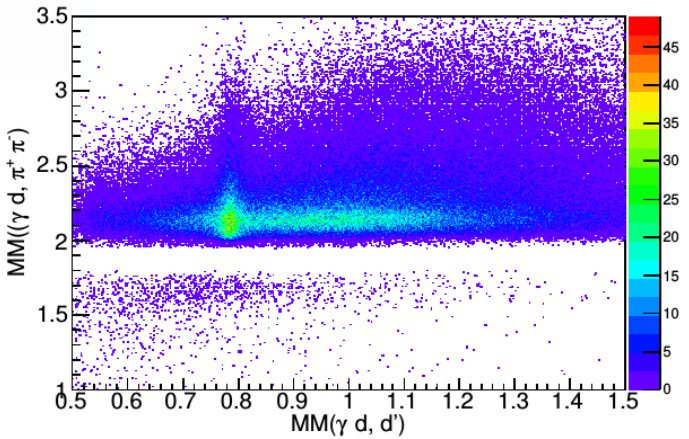
- Resonance peaks seen: three charge states are possible using the same detection sample.
- Template fitting procedure using reconstructed sample of signal and major backgrounds.
- Preliminary diff. cross section of two channels are presented.
- The probability of d^{*++} production is an order of magnitude different than that of d^{*0} → Calls for theory interpretation.

Thank you for your attention!

Extras

What we see?



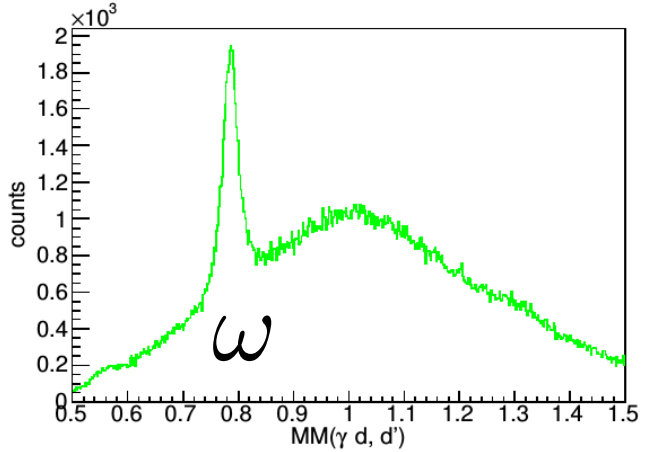


Plot Description

The 2D histogram is made after basic cuts are applied to the data.

Plot on the left is the y-projection of the 2D histogram. It is the mass distribution for the π^0 and the outgoing d.

Plot on the right is the x-projection of the 2D histogram. It is the mass distribution for $\pi^+ \pi^- \pi^0$ or the ω-meson distribution.



- $d\pi^0$ mass distribution.
- Basic cuts applied.
- Structure at about 2150 MeV.
- Will investigate this channel later!