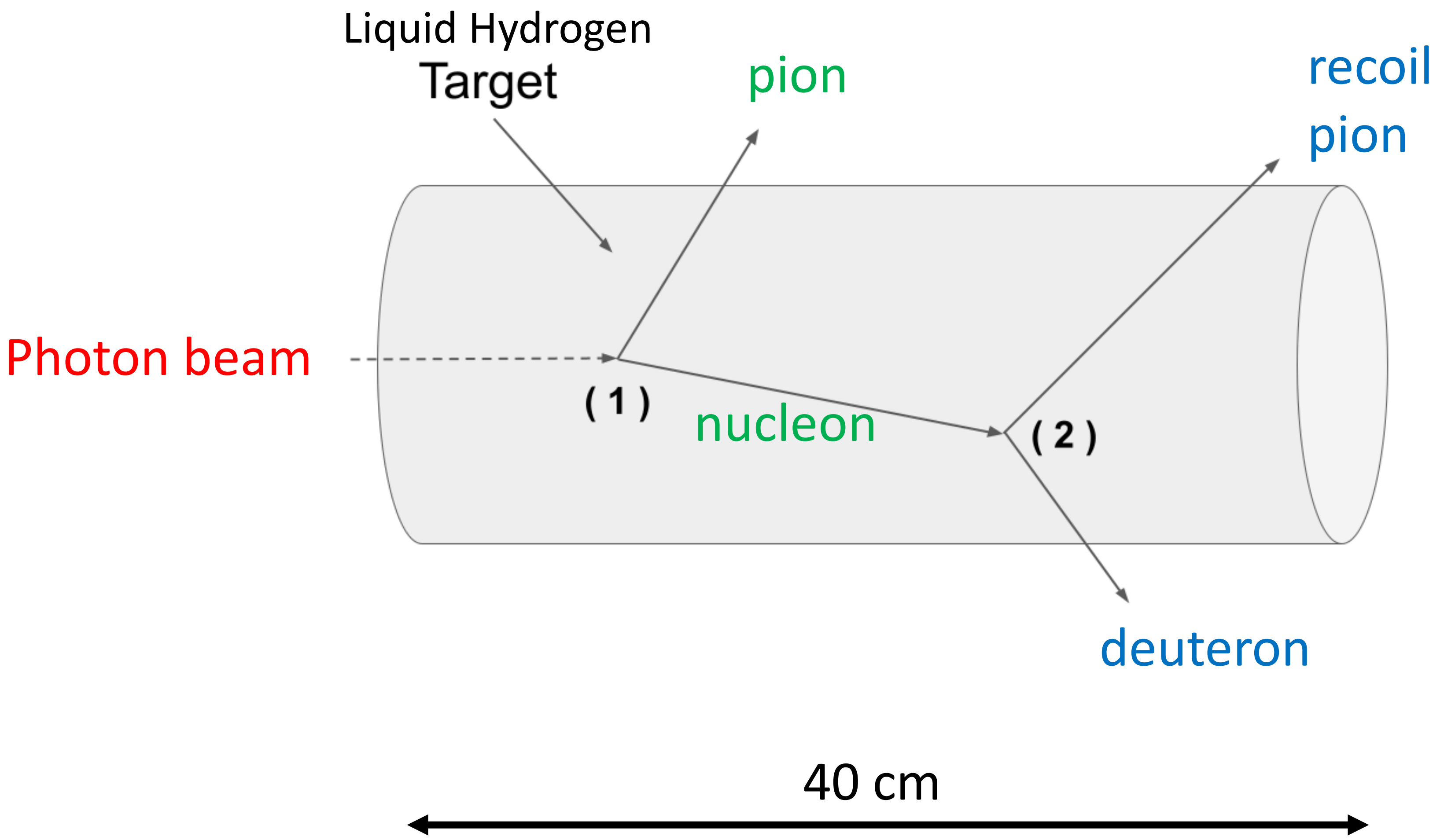
The d* dibaryon measured via NN rescattering at CLAS

N. Compton, K. Hicks and N. Zachariou

For the CLAS Collaboration

April 14, 2021

The Reaction to be measured at CLAS

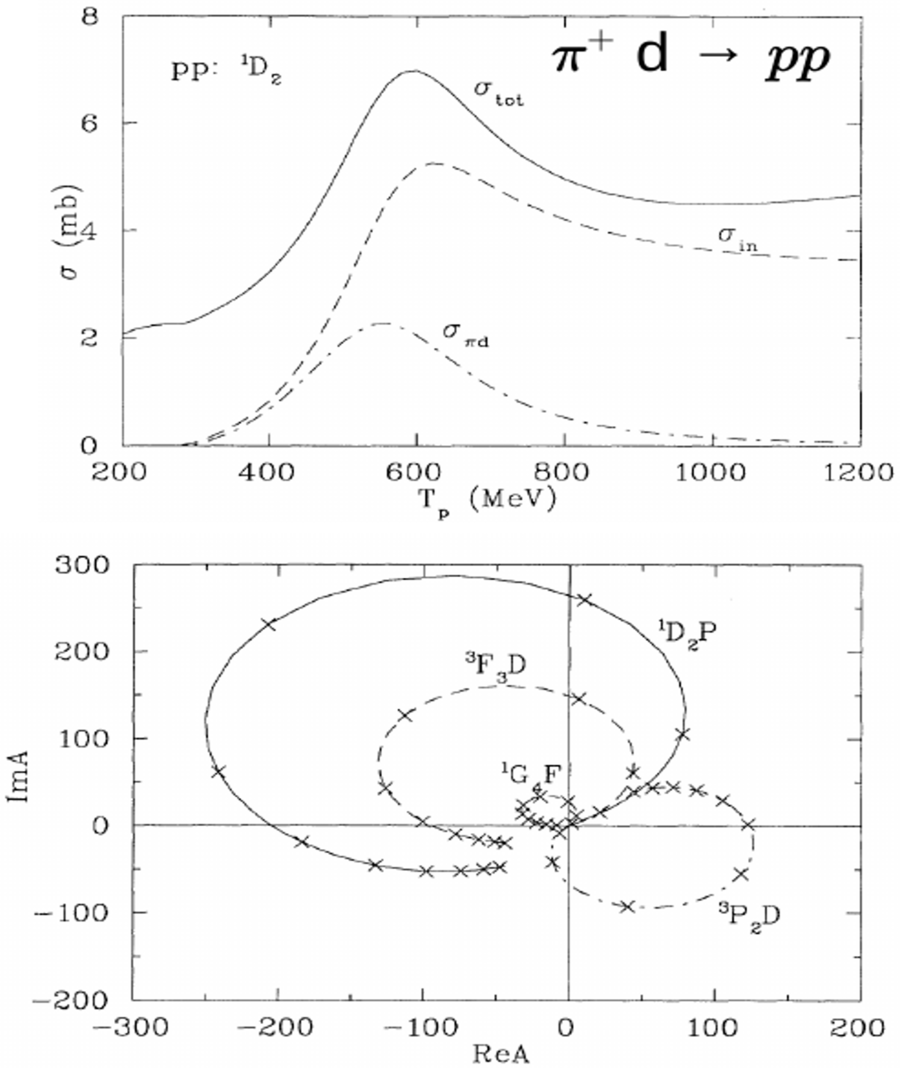


Overview

- What is already known:
  - The reaction pp -> $d\pi^+$ reaction (and its inverse) cross sections are known.
  - A resonance with mass about 2150 MeV extracted from PWA ($^1D_2$, I=1).
    - See SAID group PWA in Phys. Rev. C 56, 635 (1997) and references therein.
  - This resonance is close to the combined $N\Delta$ mass (~2170 MeV).
  - Other data (WASA@COSY) see a higher-mass resonance near $\Delta\Delta$ mass.
  - These resonances were predicted in 1964 by F.J. Dyson and N-H Xuong.
- What is not known:
  - The reaction np -> $d\pi^0$ reaction is poorly known (but related by isospin).
  - What is the interference of the $^1D_2$ resonance with quasifree $N\Delta$ production?

$\pi^+ d$ Scattering

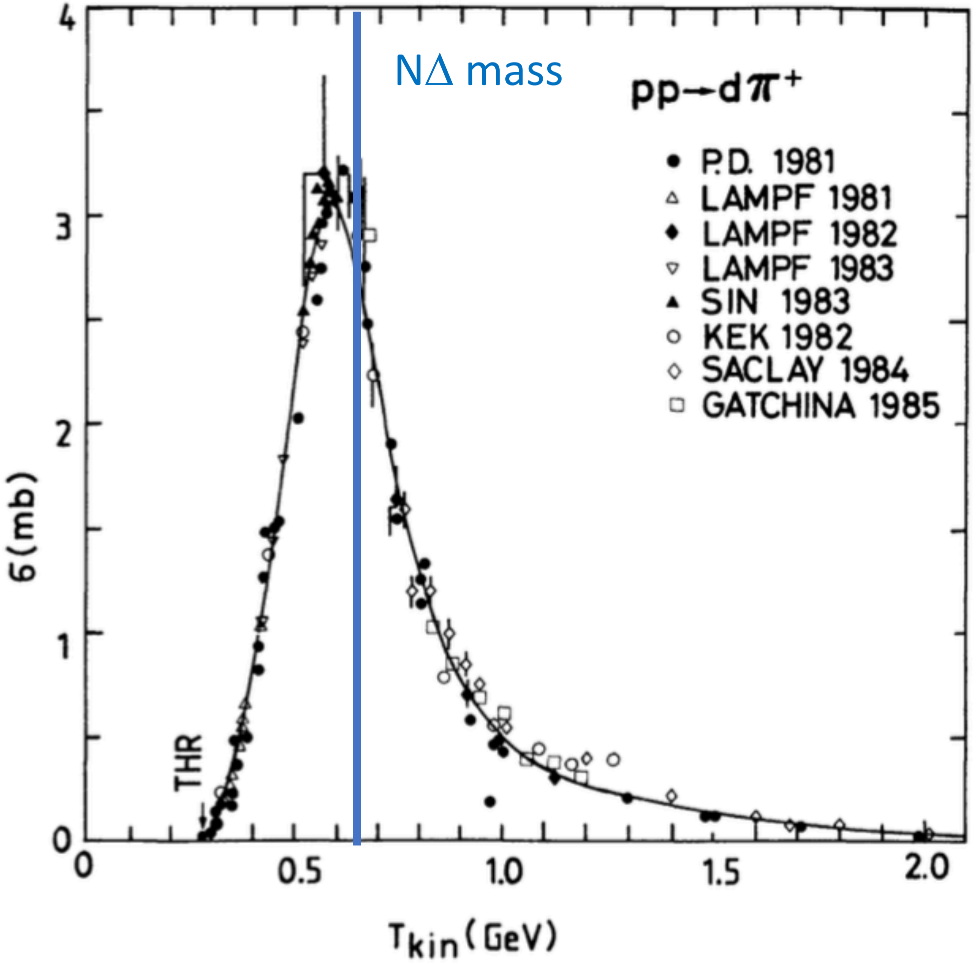
- Partial Wave Analysis.
- Prominent "resonance pole" seen in the SAID analysis.
- $^1D_2$ wave in pp dibaryon system
- Pole mass and width: 2148 – i 63 MeV.



Arndt *et al.* **Phys. Rev. C 48, 1926 (1993)**

Previous data: pp -> d π^+

Plot from: J. Bystricky et al., J. Physique 48 (1987) 1901.



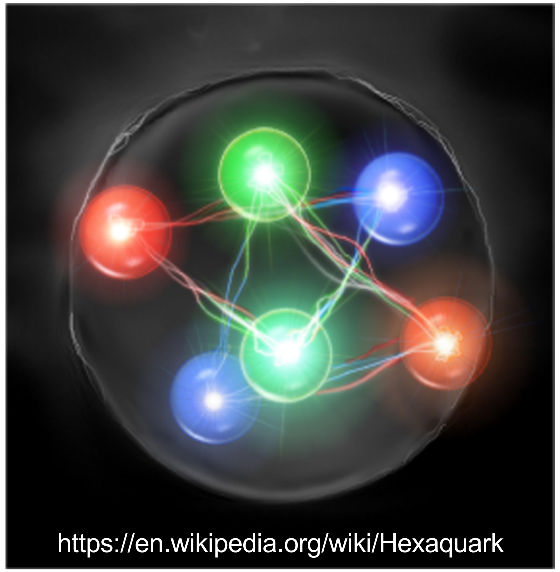
Data from a variety of facilities, shown by the legend.

Peak at T_{kin} = 0.55 GeV
Convert to W = 2.137 GeV

Full width (W) = 100 MeV

Dibaryons

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



dibaryon	I	S	SU(3)	legend	mass
$\mathcal{D}_{01}$	0	1	$\overline{\mathbf{10}}$	deuteron	A
$\mathcal{D}_{10}$	1	0	$\mathbf{27}$	nn	A
$\mathcal{D}_{12}$	1	2	$\mathbf{27}$	$N\Delta$	$A+6B$
$\mathcal{D}_{21}$	2	1	$\mathbf{35}$	$N\Delta$	$A+6B$
$\mathcal{D}_{03}$	0	3	$\overline{\mathbf{10}}$	$\Delta\Delta$	$A+10B$
$\mathcal{D}_{30}$	3	0	$\mathbf{28}$	$\Delta\Delta$	$A+10B$

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” Nucl. Phys. 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

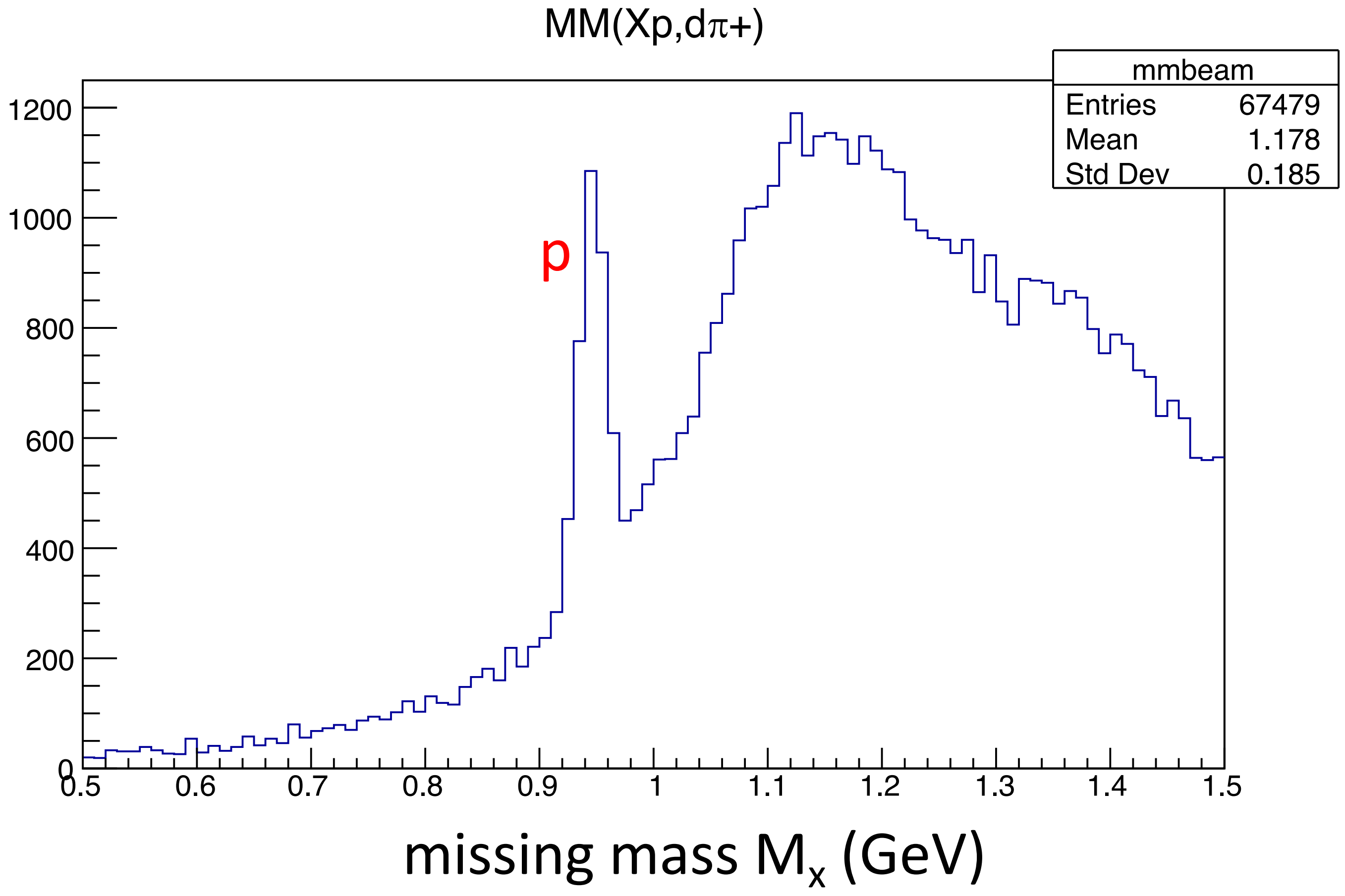
Why remeasure this at CLAS?

- To demonstrate a <u>new technique</u>: secondary scattering
  - First vertex: photoproduction of hadrons (well-known cross sections)
    - Using liquid hydrogen (LH2) or liquid deuterium (LD2) targets
  - Second vertex: hadron-nucleon scattering
  - We can measure various <u>hadron-proton reactions</u> at CLAS!
    - For example: Λ-p elastic scattering, which is poorly known.
- First, we must show we can reproduce a known cross section
  - If this works, we can apply it to other reactions.
    - Another example: πp -> $\pi\pi$p which is also poorly known.

What do we measure?

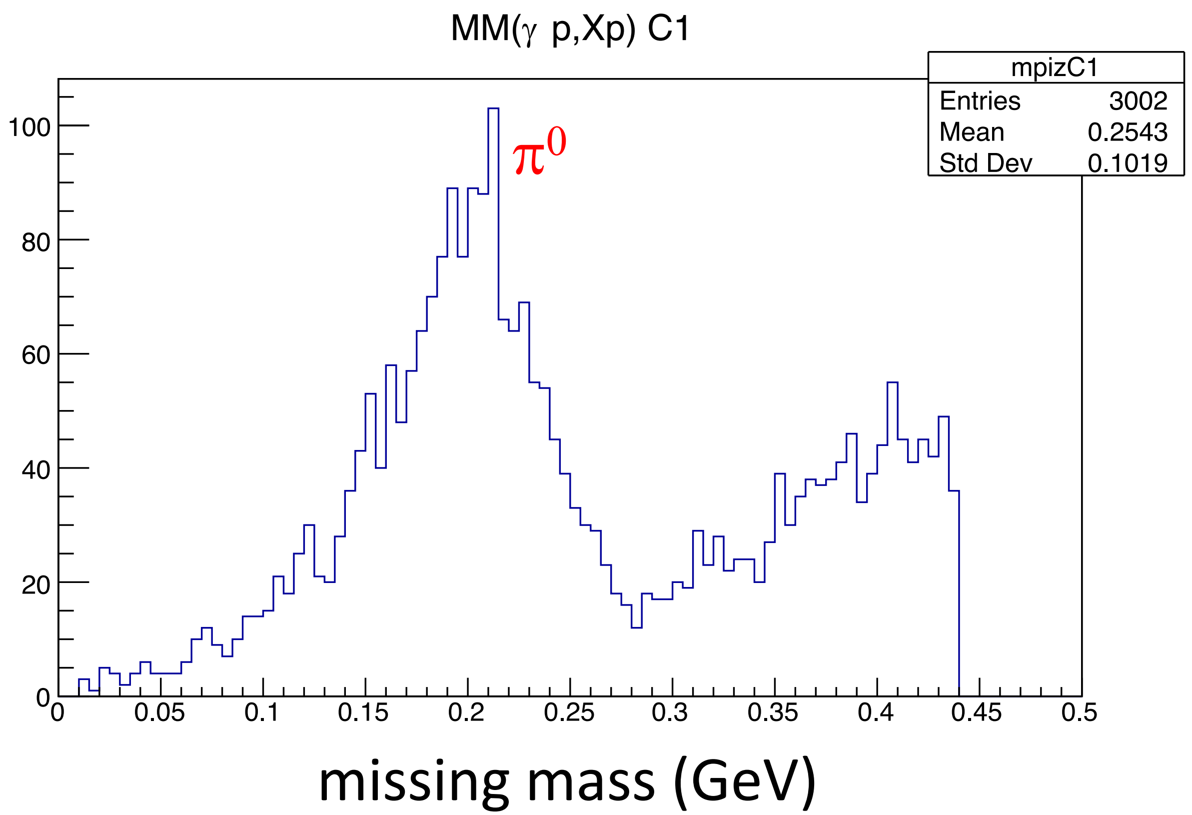
- Incident beam/target: GeV photons on 40-cm LH2 target
- Detected particles: coincidence of π^+ and deuteron.
  - At first, this sounds ridiculous: $\gamma p \dashrightarrow d\ \pi^+$ violates: baryon #, charge conserv.
- Two-step process:
  - Step 1: produce a neutron: γp --> π^0 p
  - Step 2: proton re-scatters: pp --> d π^+
- Do this with missing masses (in reverse order):
  - Step 2: proton 4-vector from $MM(Xp, d\pi^+)$ for X=proton mass.
  - Step 1: pion 4-vector from $MM(\gamma p, pX)$ for X = pion mass.

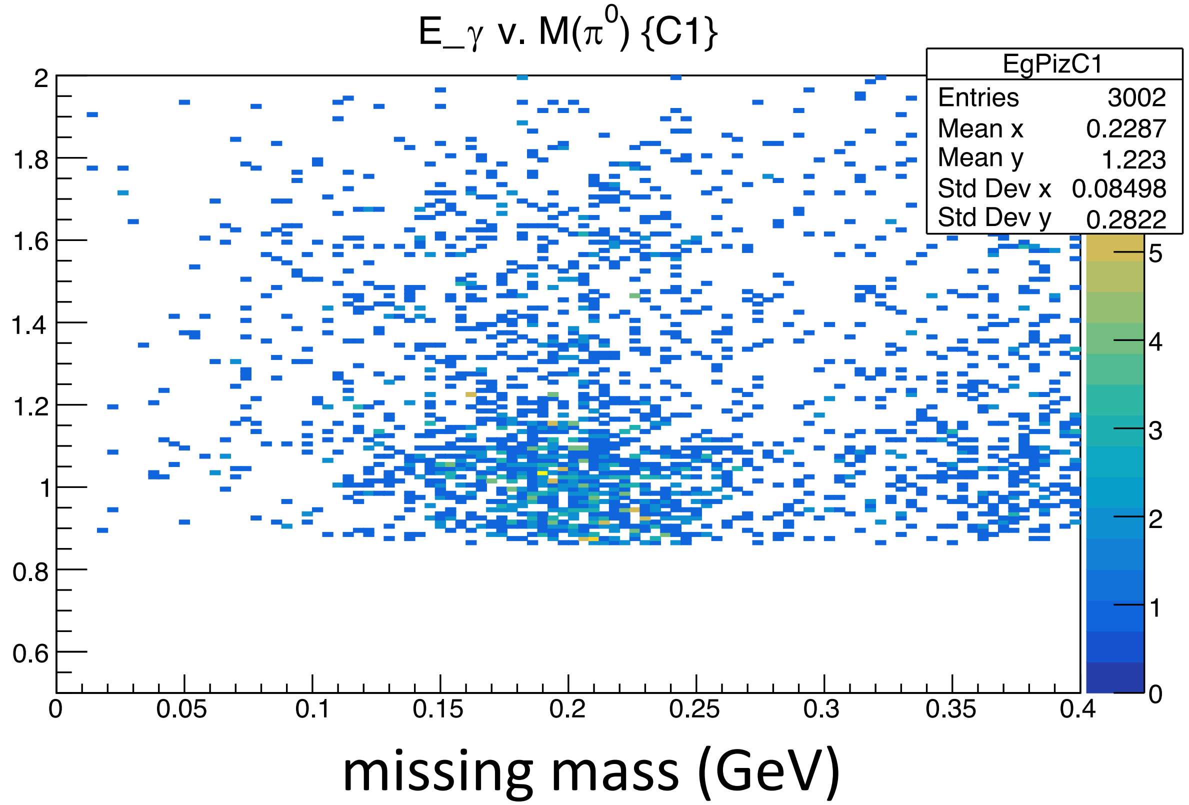
Now look for Xp->$d\pi^+$ (X=p)



Clear peak at the proton mass. Lots of background, but most of it can be removed with kinematical cuts.

Cut on proton: look for π^0 in Missing Mass





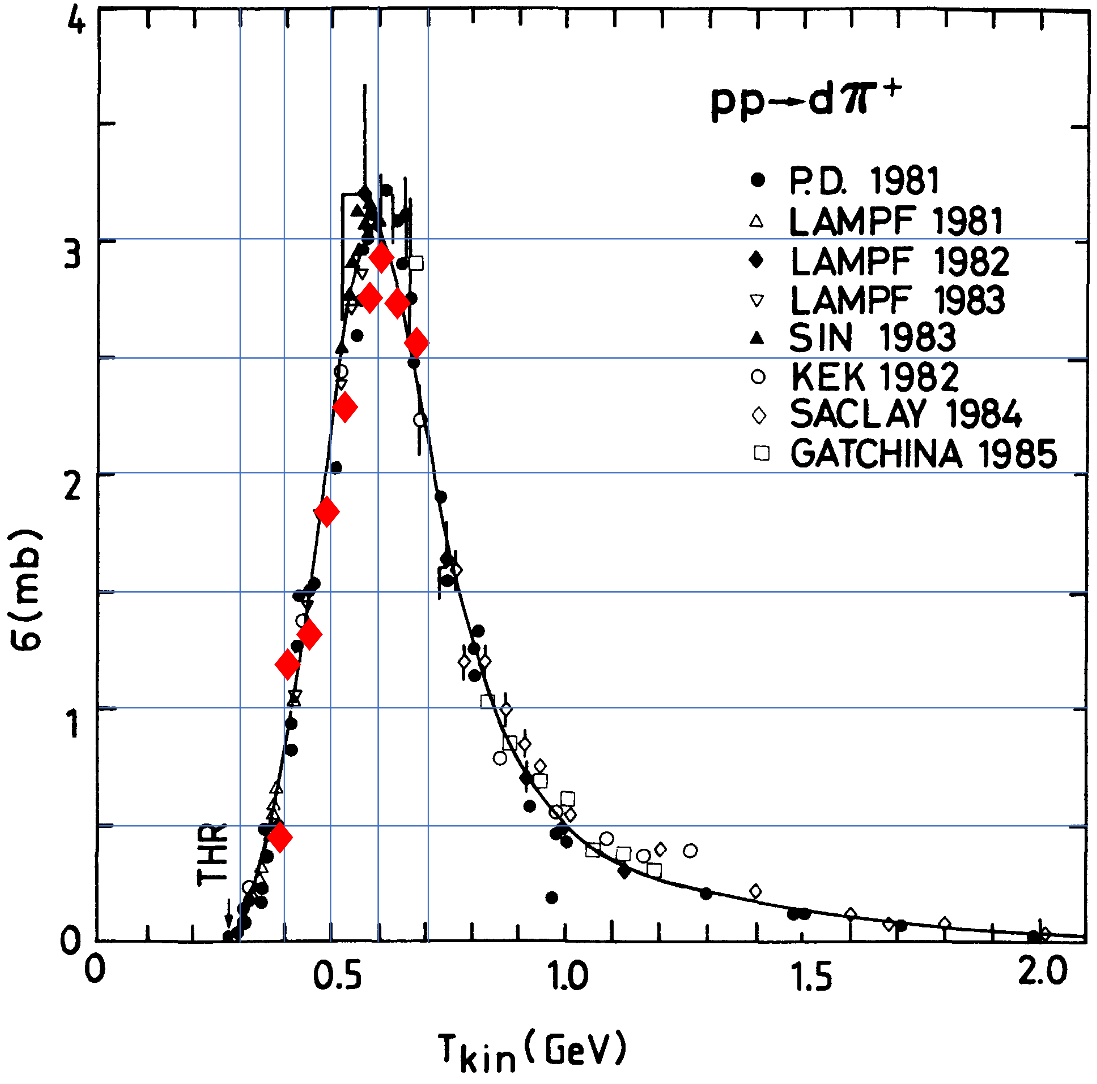
Pion mass comes out high (energy-loss).

Most of the events in range of E_γ = 0.9-1.1 GeV

Cross section calculation

- Step 1: calculate the proton "beam" flux (or luminosity)
  - This is not trivial but can be done using simulations.
- Step 2: get the detector acceptance
  - A two-vertex generator was coded (N. Zachariou) specially for this.
  - The GSIM code, based on CERN's geant, is well documented for CLAS.
  - The hardware trigger and run-time conditions are also simulated.
- Step 3: get the counts for a specific beam-momentum bin
  - For now, restrict photon beam energy to $0.9 < E_\gamma < 1.1$ GeV.
  - Take bins in proton-momentum, *e.g.*, $1.00 < p_{prot} < 1.05$ GeV/c.
- Step 4: calculate!

Preliminary results (red diamonds):

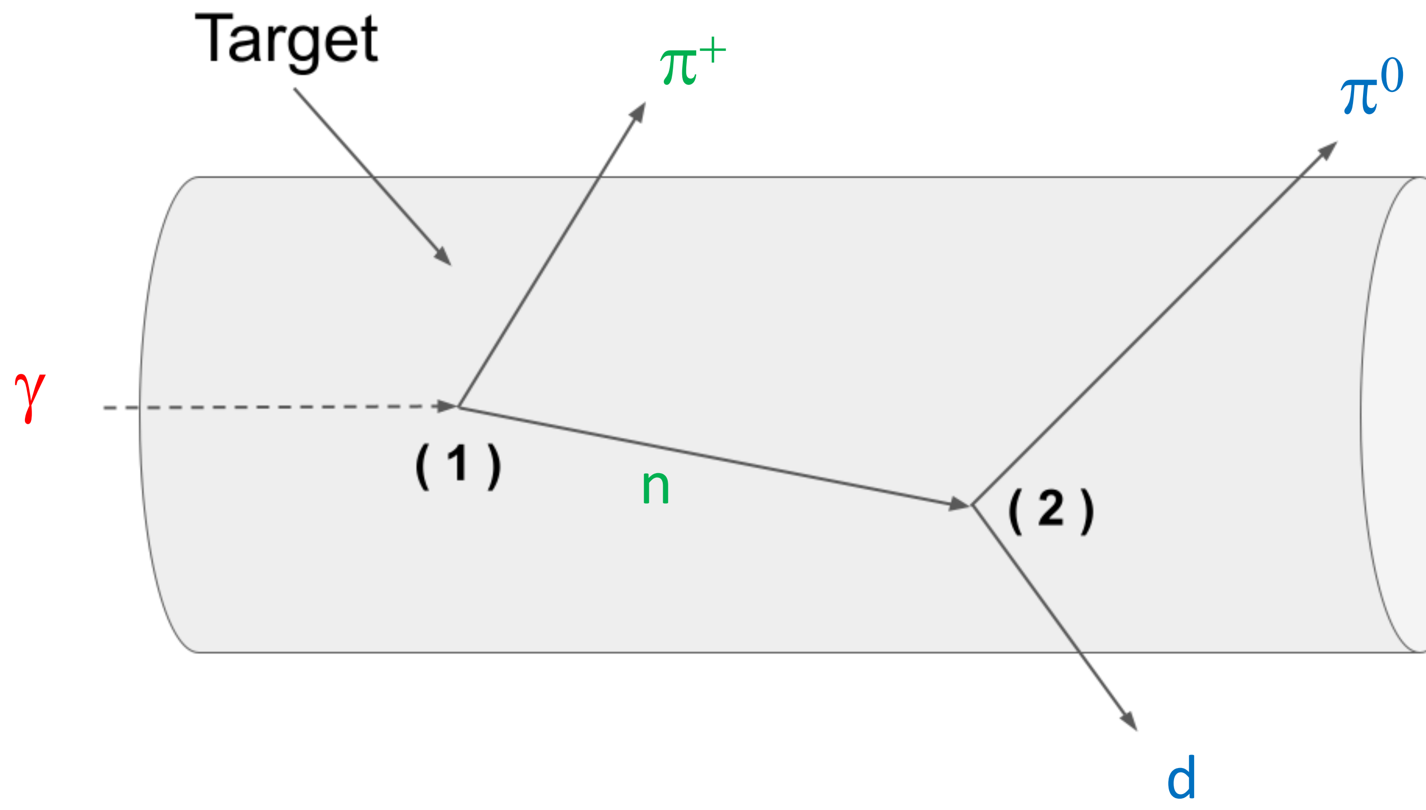


Note: statistical errors are about the size of the points.

Systematic uncertainties are of the order of 10%, mainly due to the global normalization uncertainty.

Points at higher beam energy can be extracted, given time.

Bonus: get np -> dπ^0 for free!

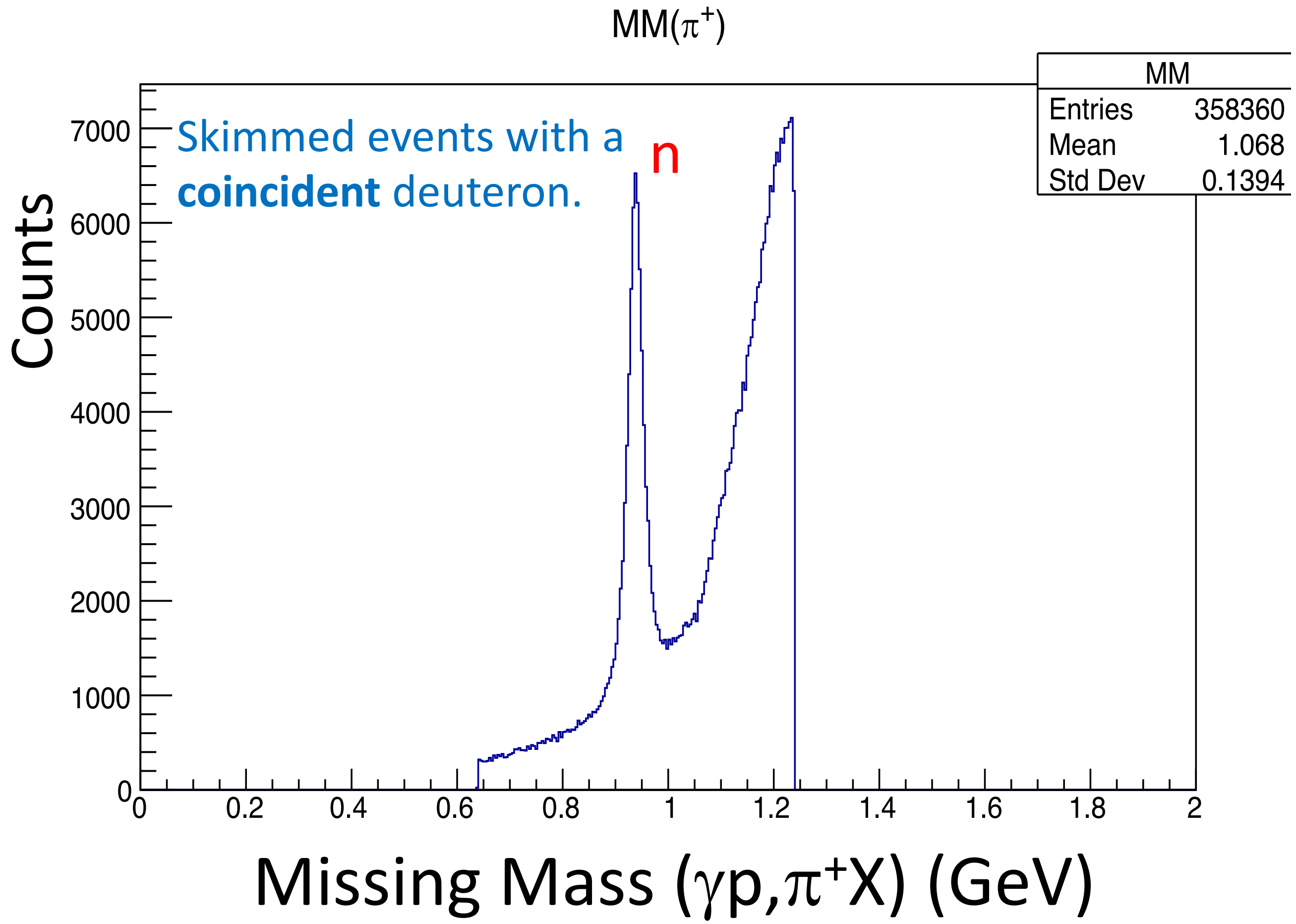


What do we measure?

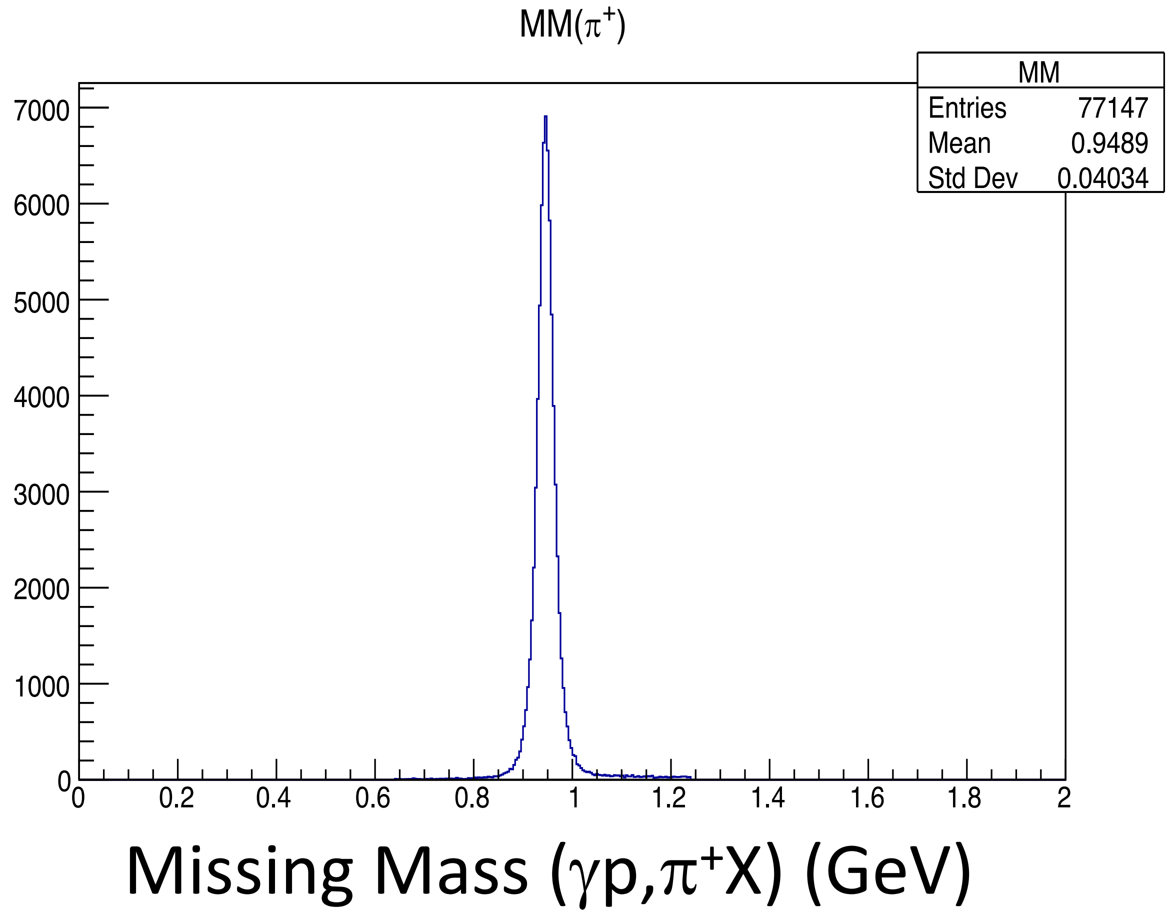
- The g11 experiment at CLAS has GeV photons on 40-cm LH2 target
- Detected particles: coincidence of π^+ and d.
- Two-step process:
  - Step 1: produce a neutron: $\gamma p \dashrightarrow \pi^+ n$
  - Step 2: neutron rescatters: $np \dashrightarrow d\, \pi^0$
- Do this using missing masses:
  - Step 1: neutron 4-vector from $MM(\gamma p, \pi^+ X)$ for X = neutron mass.
  - Step 2: π^0 4-vector from MM(np,dX) for X=pion mass.

Step 1: Missing mass of $\gamma p \rightarrow \pi^+ n$.

G11 data: lots of background!



MC using N.Z.'s event generator



Step 2: Missing mass of np -> d π^0.

g11: after kinematical cuts

MC: ~17% loss of events

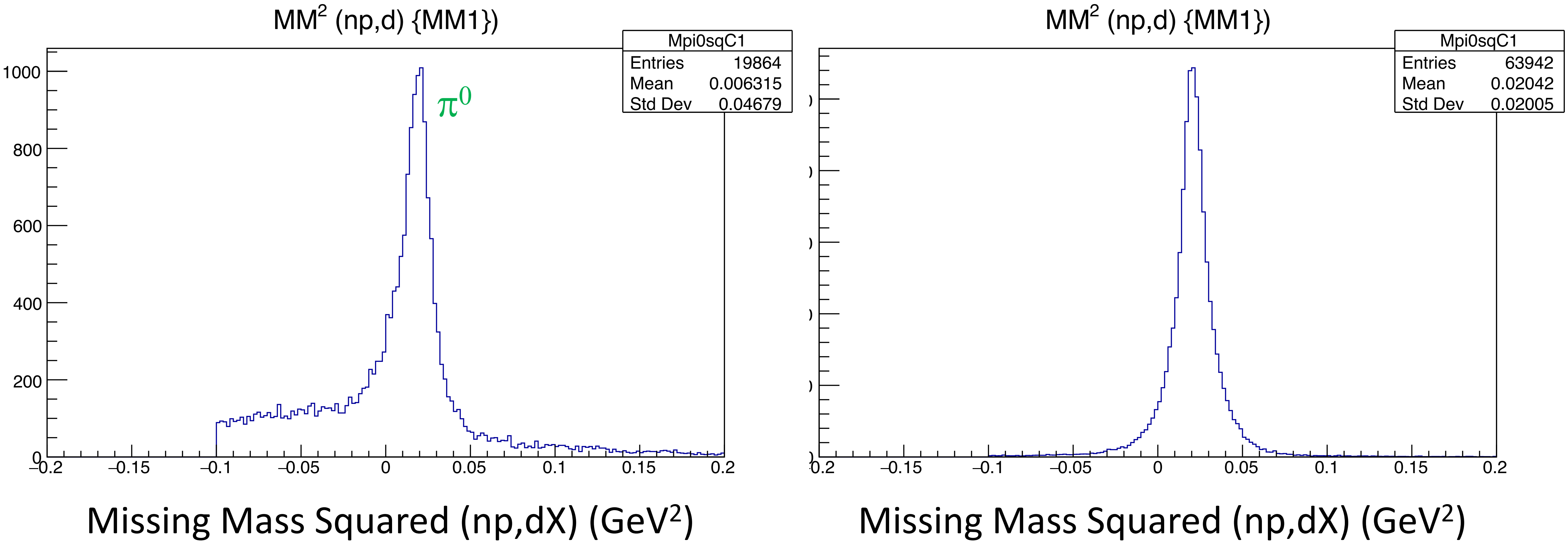


Table of cross sections

N-momentum	Yield (uncert.)	Acceptance	n-Luminosity (e27)	Cross section (mb)
0.90 – 0.95	35 (16%)	0.292	338.	0.93
0.95 – 1.00	65 (12%)	0.278	405.	1.51
1.00 – 1.05	94 (10%)	0.294	495.	1.69
1.05 – 1.10	120 (9%)	0.285	595.	1.85
1.10 – 1.15	120 (9%)	0.250	703.	1.78
1.15 – 1.20	106 (10%)	0.166	896.	1.86
1.20 – 1.25	72 (12%)	0.115	1009	1.62
1.25 – 1.30	41 (15%)	0.0876	732	1.67
1.30 – 1.35	10 (30%)	0.0443	502	1.17

σ = Yield/(Accep.)(Lumin.)(effic.)

where effic. = (trigger factor)(trigger efficiency) = (0.467)(0.82)

Refs.: trigger factor [M. Williams], trigger effic. [INFN]

Notes: 1) Luminosity from $\gamma p \to \pi^+ n$ has ~10% systematic uncert.

Summary

- These results are still preliminary!
  - Systematic uncertainties are still being evaluated.
  - This represents only 15% of the full data set.
- This new technique gives cross sections that agree with world data.
  - This give confidence that we can measure other hadron-beam reactions.
  - One advantage here: both pp->$d\pi^+$ and np->$d\pi^0$ in the same data set.
- The expected ratio (isospin symmetry) of (pp->$d\pi^+$)/(np->$d\pi^0$) = 2.
  - Assumes no isospin-breaking in the interference of resonance & background.
  - Note: only a single absolute cross section for np->$d\pi^0$ in the past.
    - Ref.: V.B. Fliagin, et al., JEPT 35, 592 (1959). All other papers assume isospin symmetry.
  - Our preliminary results give a lower ratio, especially near threshold.