The NN -> d π^0 reaction: secondary scattering at CLAS

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Motivation

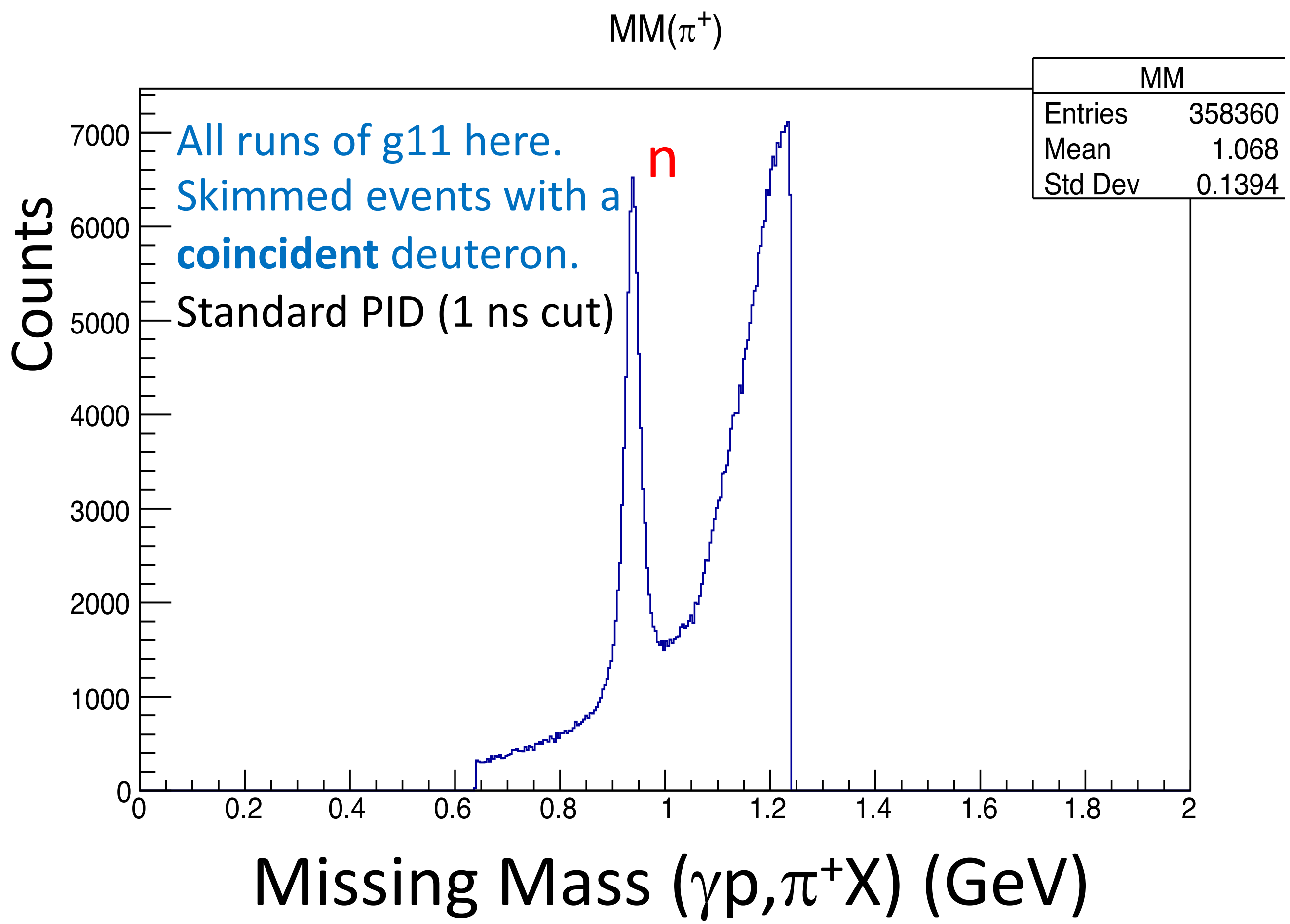
- We want to demonstrate that secondary-scattering reactions are possible to measure with CLAS
  - Some new hadronic reactions could be measured (such as Λ-p scattering).
  - To demonstrate it, we need to show we can **reproduce a known reaction**.
- Additionally, neutron reactions are hard to measure
  - There are few existing data for the np -> d π^0 reaction.
  - There is existing data on pp -> d π^+, for validation of the technique.
- Physics goal: evidence for a N-Δ resonance (d*, I=1) at M=2140 MeV.
  - This d* resonance is also seen in photoproduction γd -> $\pi^+\pi^-$d. (T. Chetry)

What do we measure

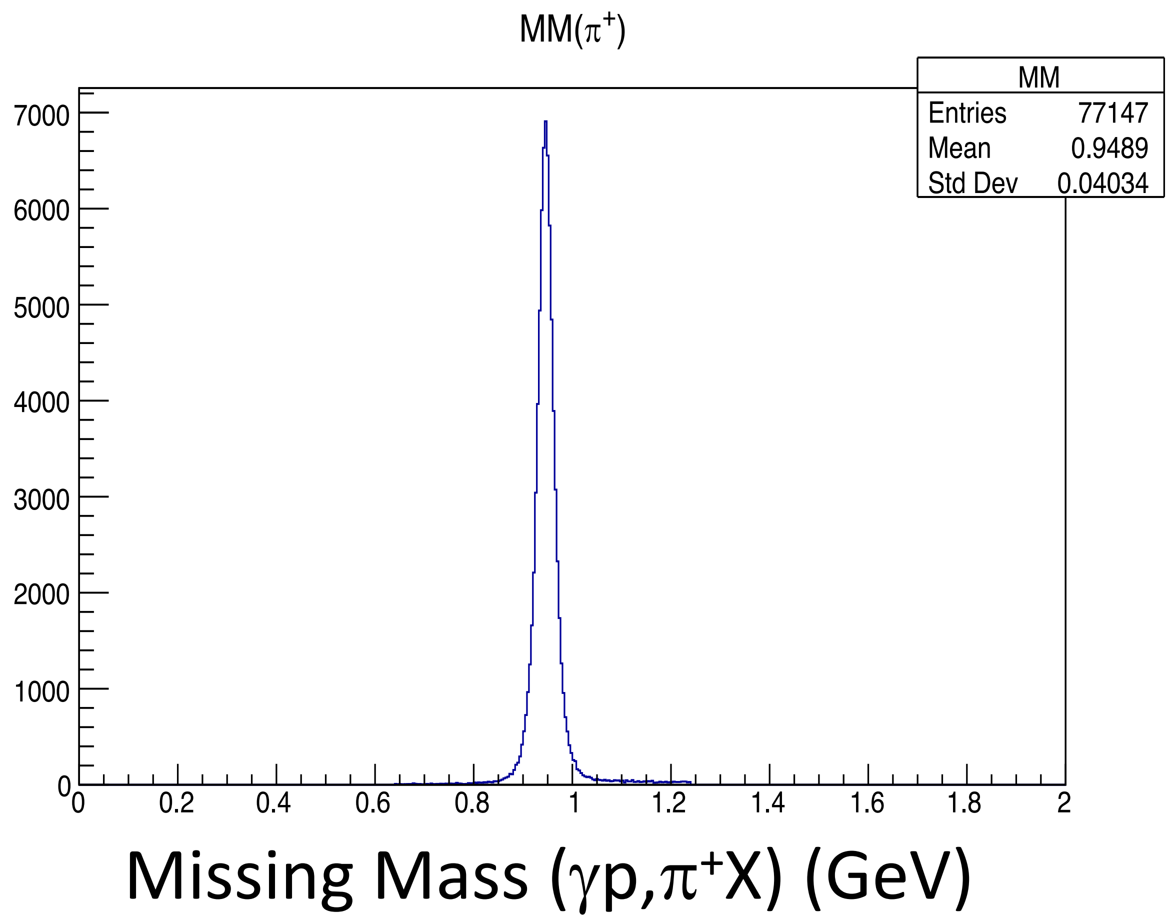
- Incident beam/target: g11 has GeV photons on 40-cm LH2 target
- Detected particles: coincidence of π^+ and deuteron.
  - At first, this sounds ridiculous: $\gamma p \dashrightarrow d\ \pi^+$ violates: baryon #, charge conserv.
- Two-step process:
  - Step 1: produce a neutron: γp --> π^+ n
  - Step 2: neutron rescatters: np --> d π^0
- Do this with missing masses:
  - Step 1: neutron 4-vector from MM(γp,π^+X) for X = neutron mass.
  - Step 2: π^0 4-vector from MM(np,dX) for X=pion mass.

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

G11 data: lots of background!



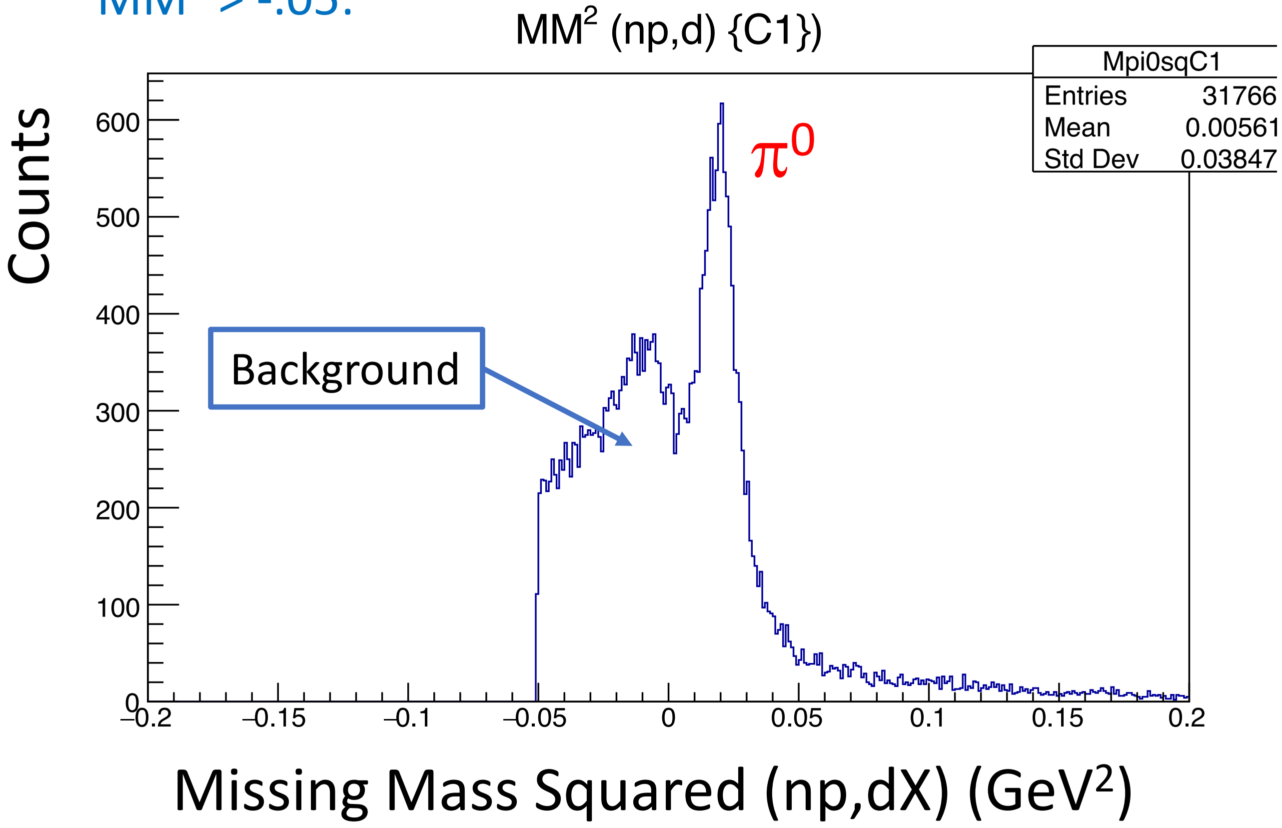
MC using N.Z.'s event generator



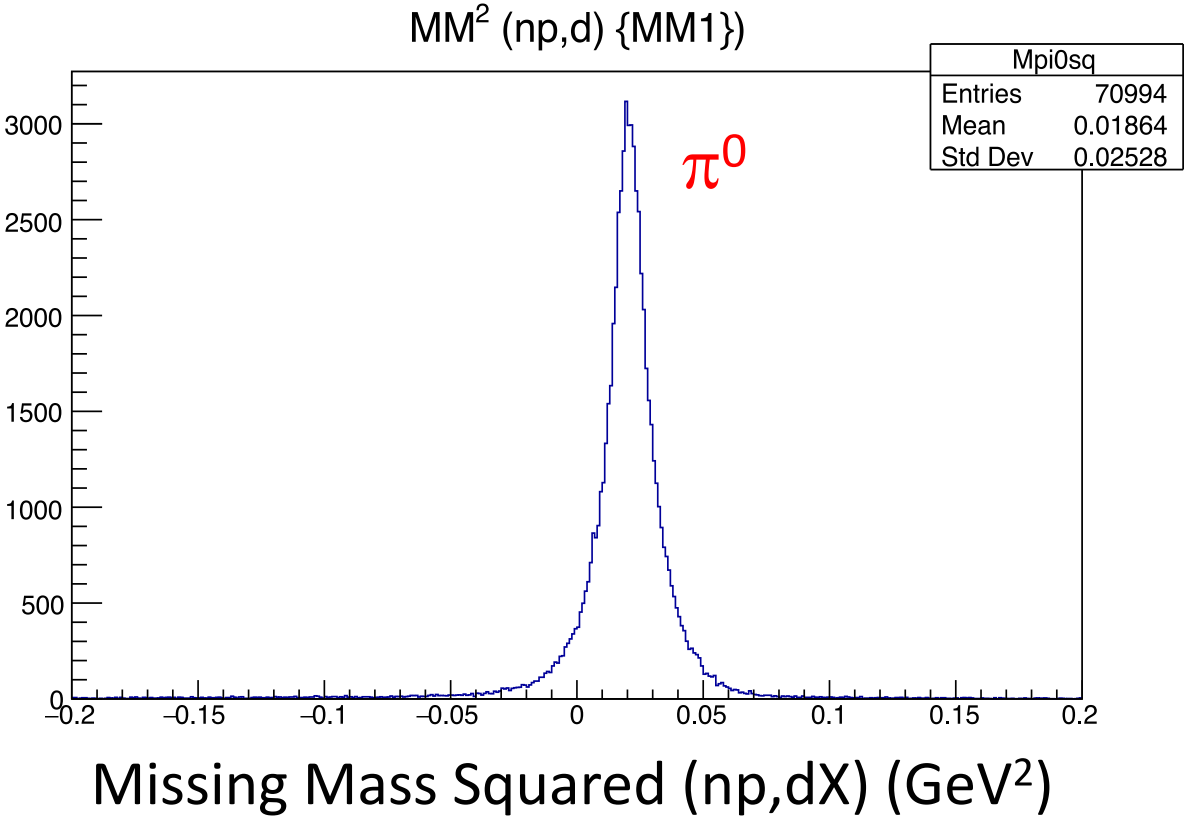
Step 2: Missing mass of np -> d π^0.

Cut on the Neutron & $MM^2 > -.05$:

G11 data: lots of background!

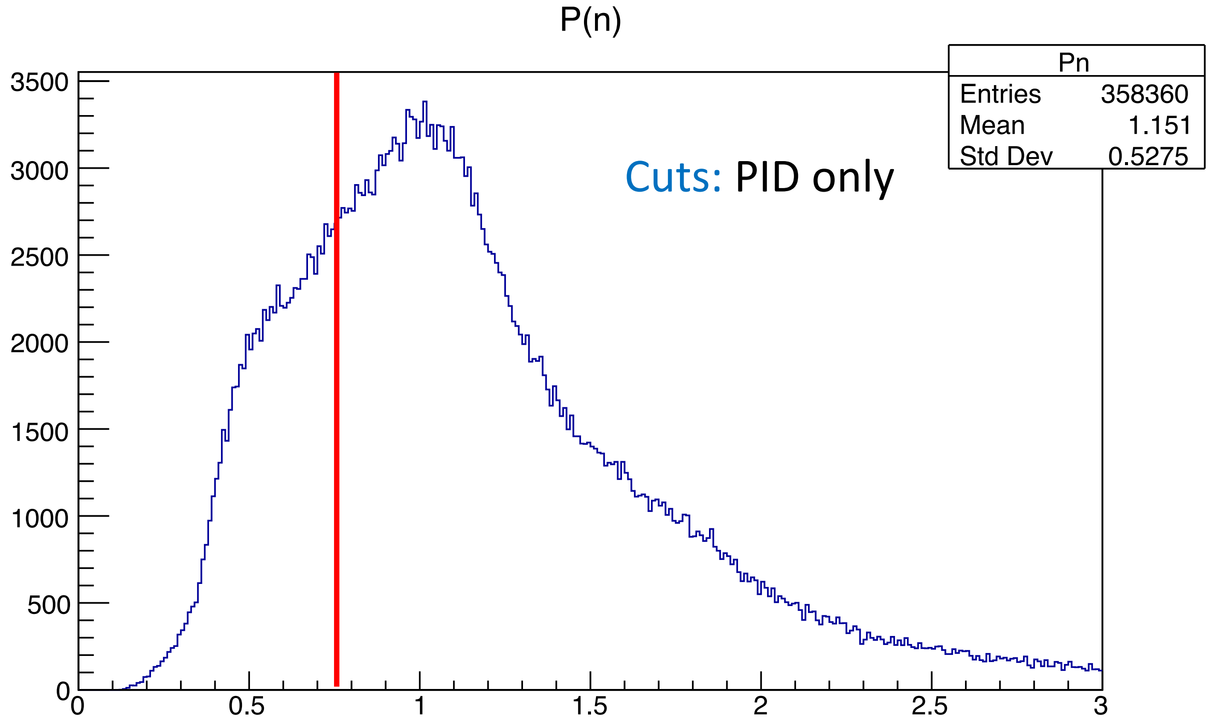


MC using N.Z.'s event generator



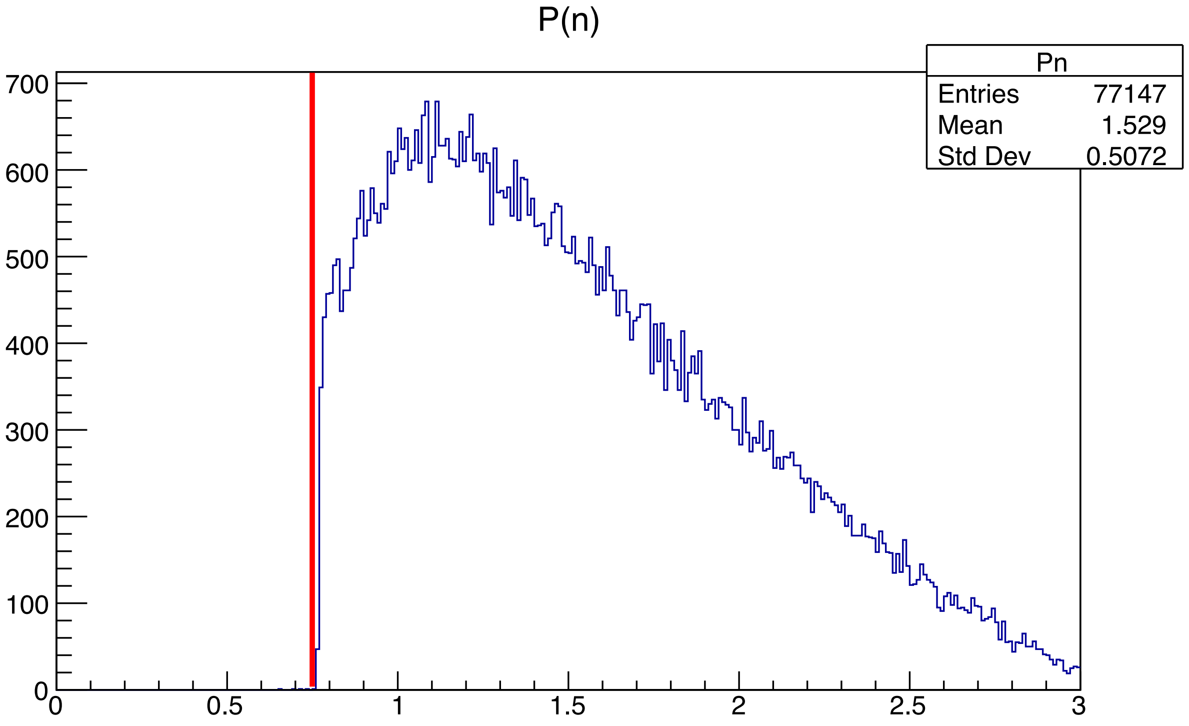
Kinematic threshold cut added

G11 data: lots of background!



Neutron momentum (GeV/c)

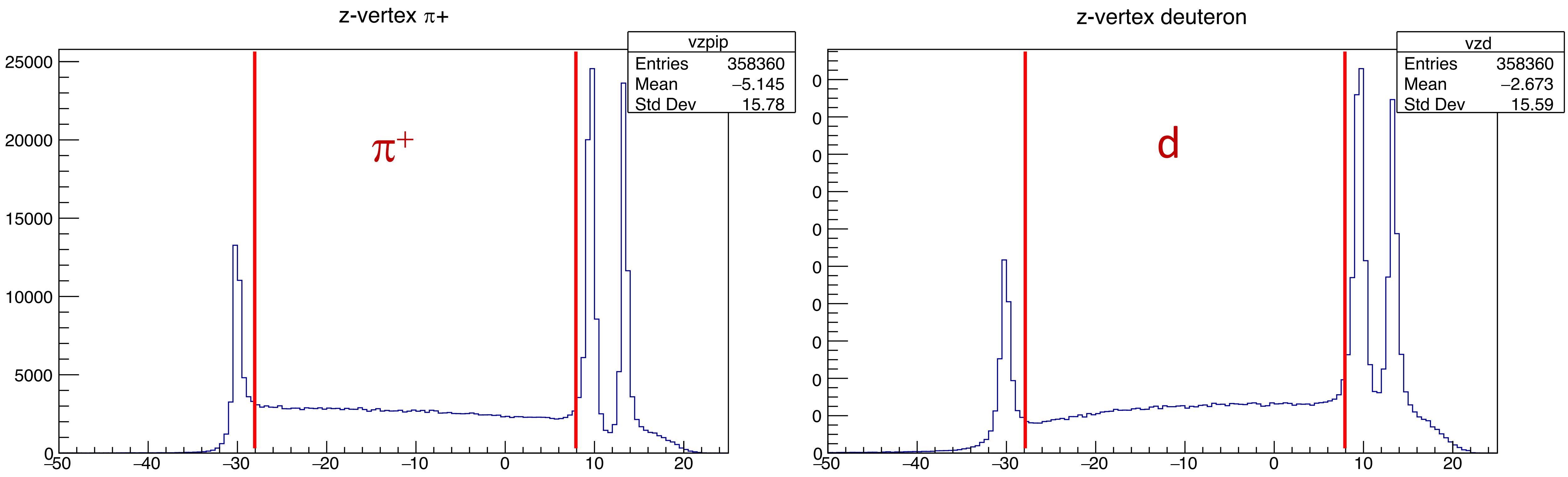
MC using N.Z.'s event generator



$p_n > 0.75$ GeV/c

Threshold for $np \rightarrow d\pi^0$

Z-vertex cuts added: both detected particles



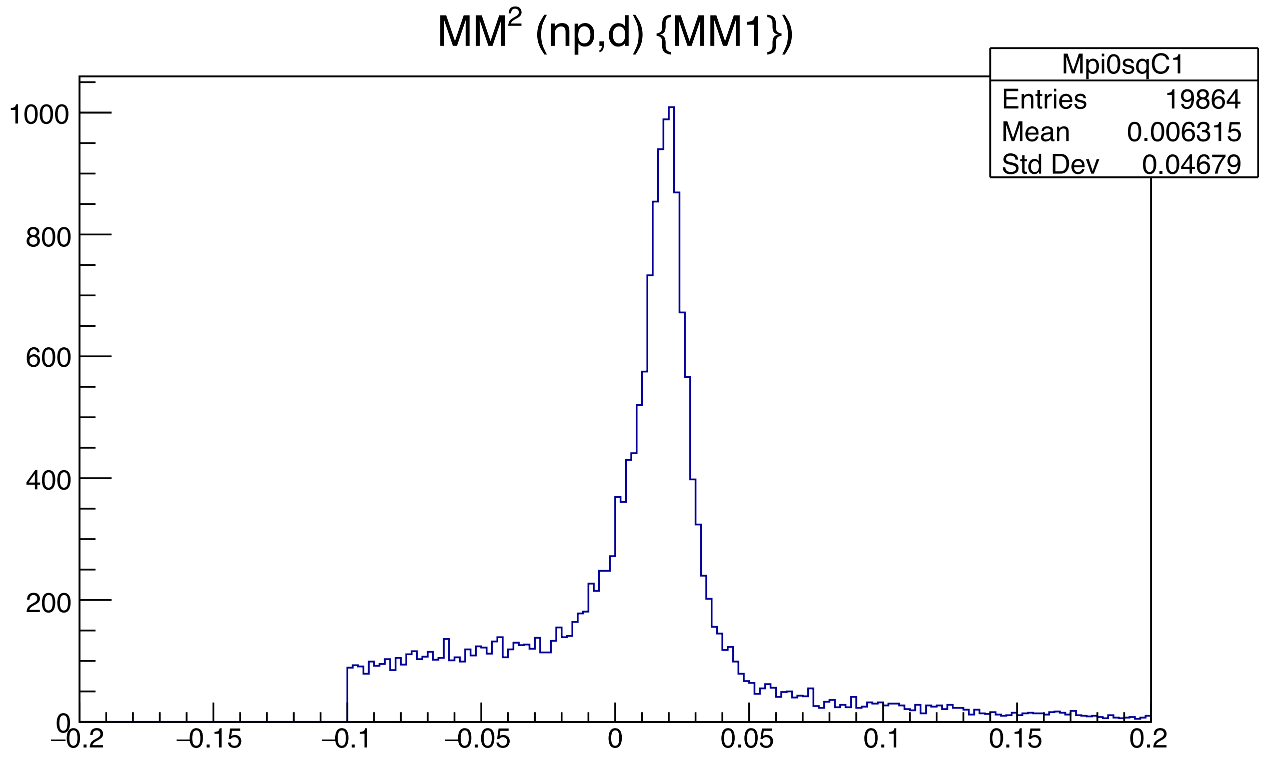
Summary of cut level 1:

- $MM^2(np,dX) > -0.1\ GeV^2$ = physical threshold (and a bit below)
- abs($MM(\gamma p,\pi^+X) - M_n$) < 0.06 = neutron peak
- abs(z-vertex – center) < 18 (cm) = target cut (both particles)
- n-momentum > 0.75 GeV/c = threshold for $(np,d\pi^0)$

All of the next plots shown are with cut level 1.

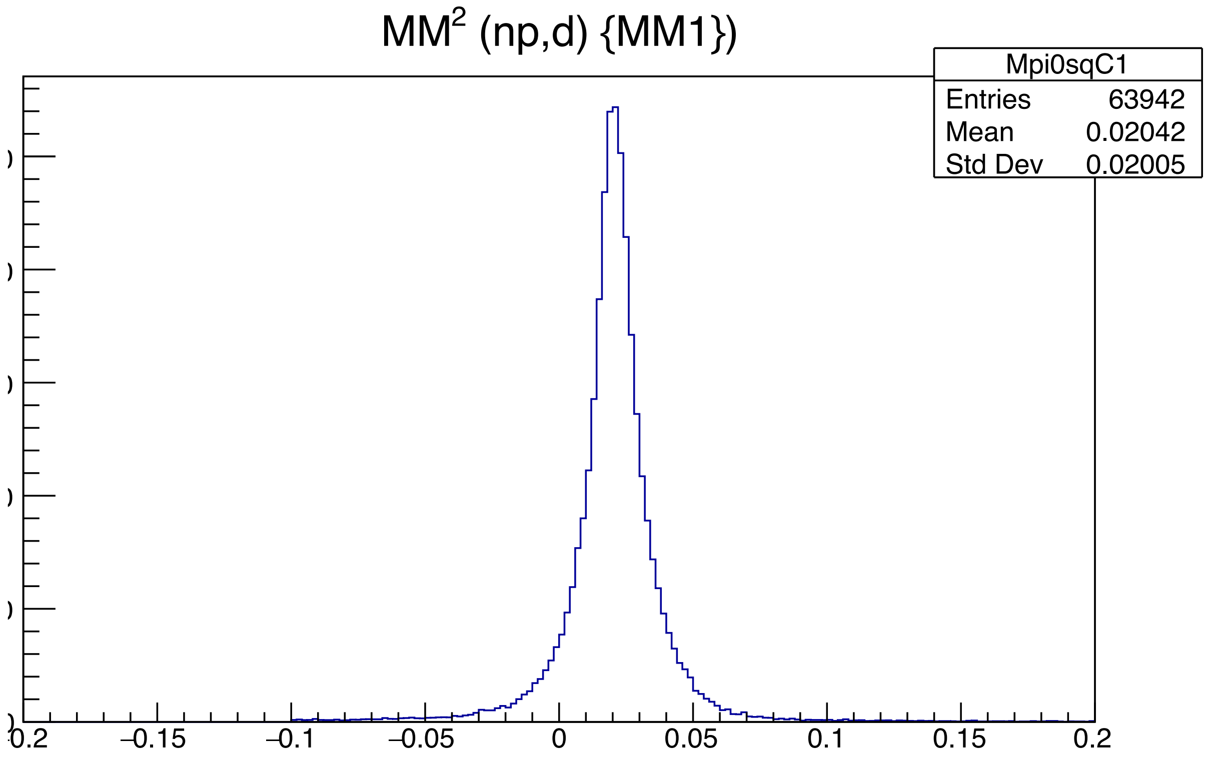
After cut level 1:

g11: less background!



Missing Mass Squared (np,dX) (GeV^2)

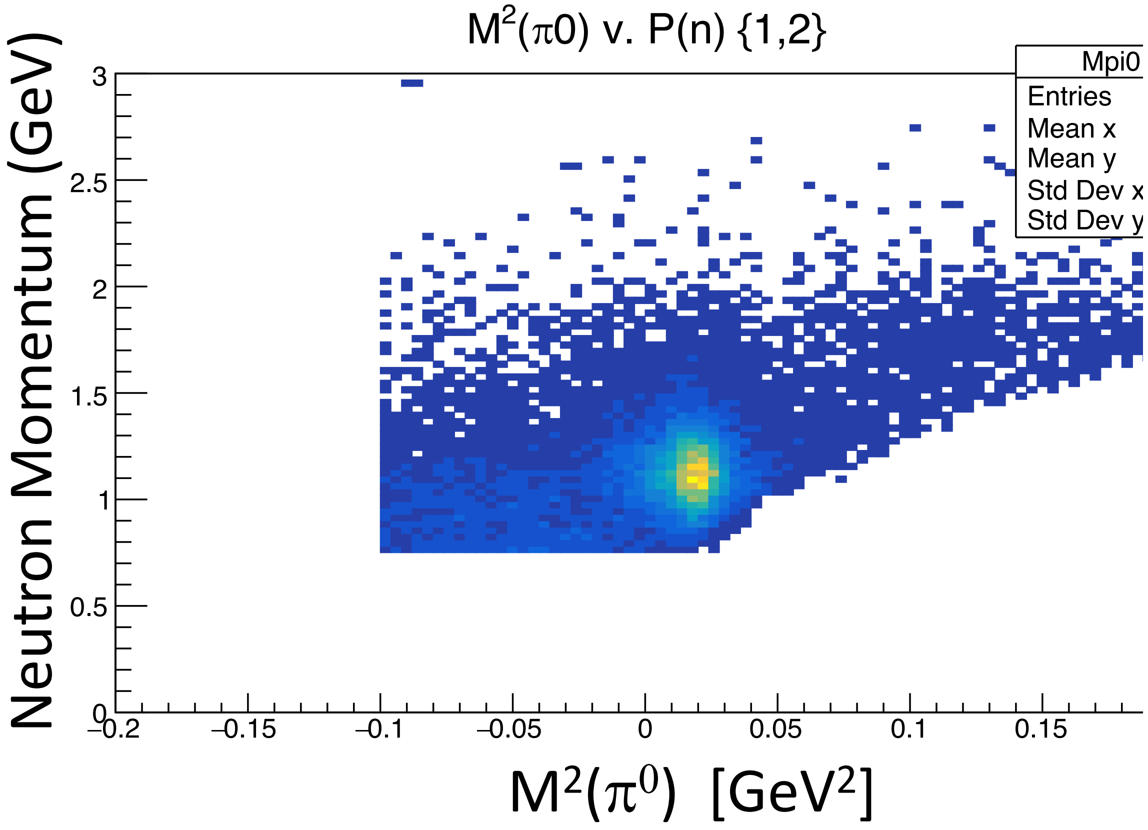
MC: ~17% loss of events



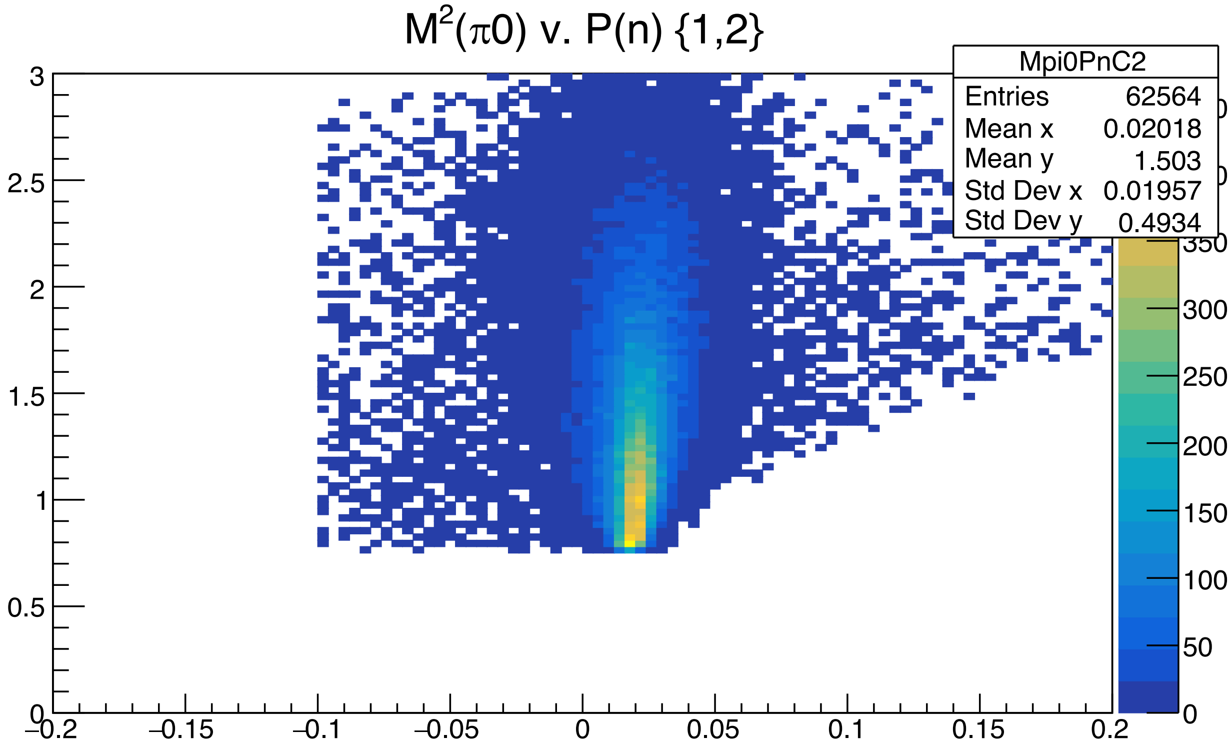
Missing Mass Squared (np,dX) (GeV^2)

2D correlation: π^0-peak vs. n-momentum

g11: P_n-dependence shows resonance!

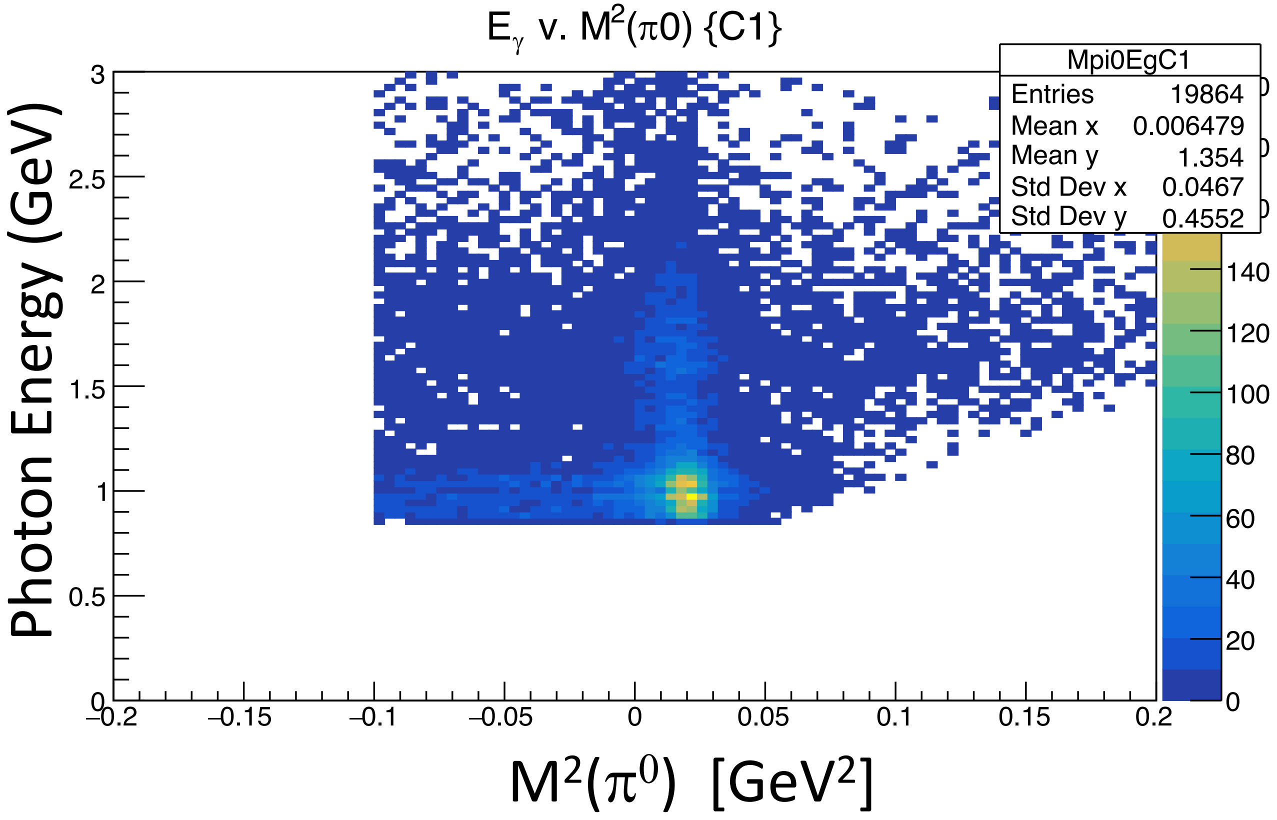


MC: (phase space) x (acceptance)

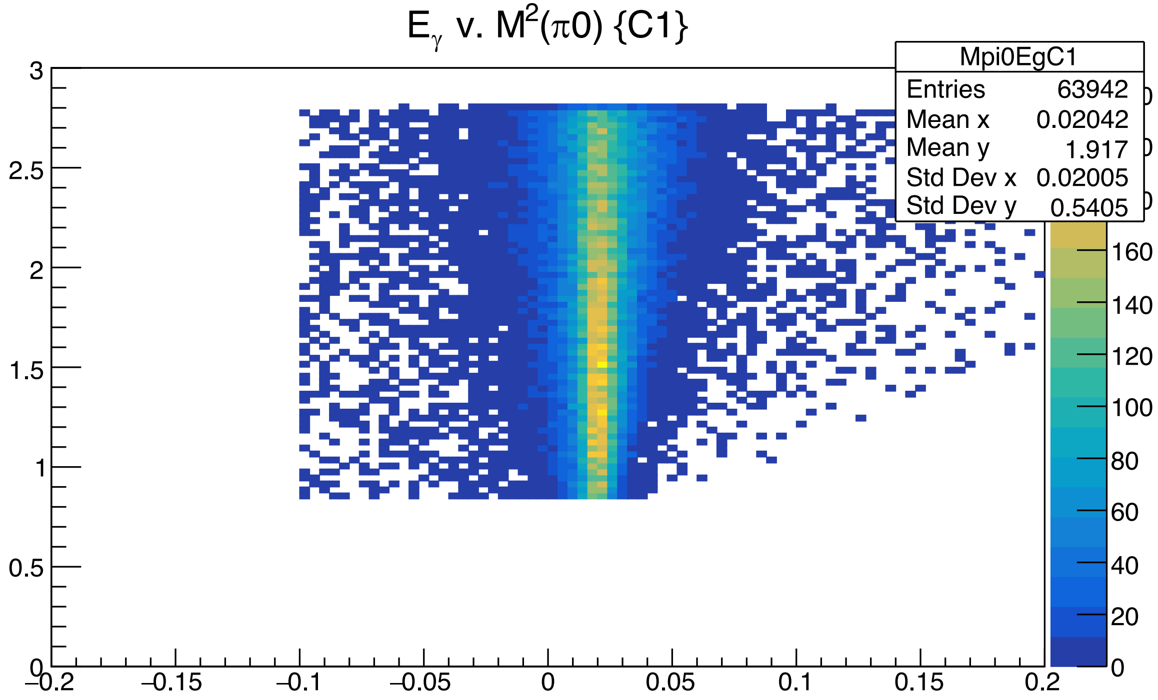


2D correlation: π^0-peak vs. E_γ

g11: limited to low Eγ

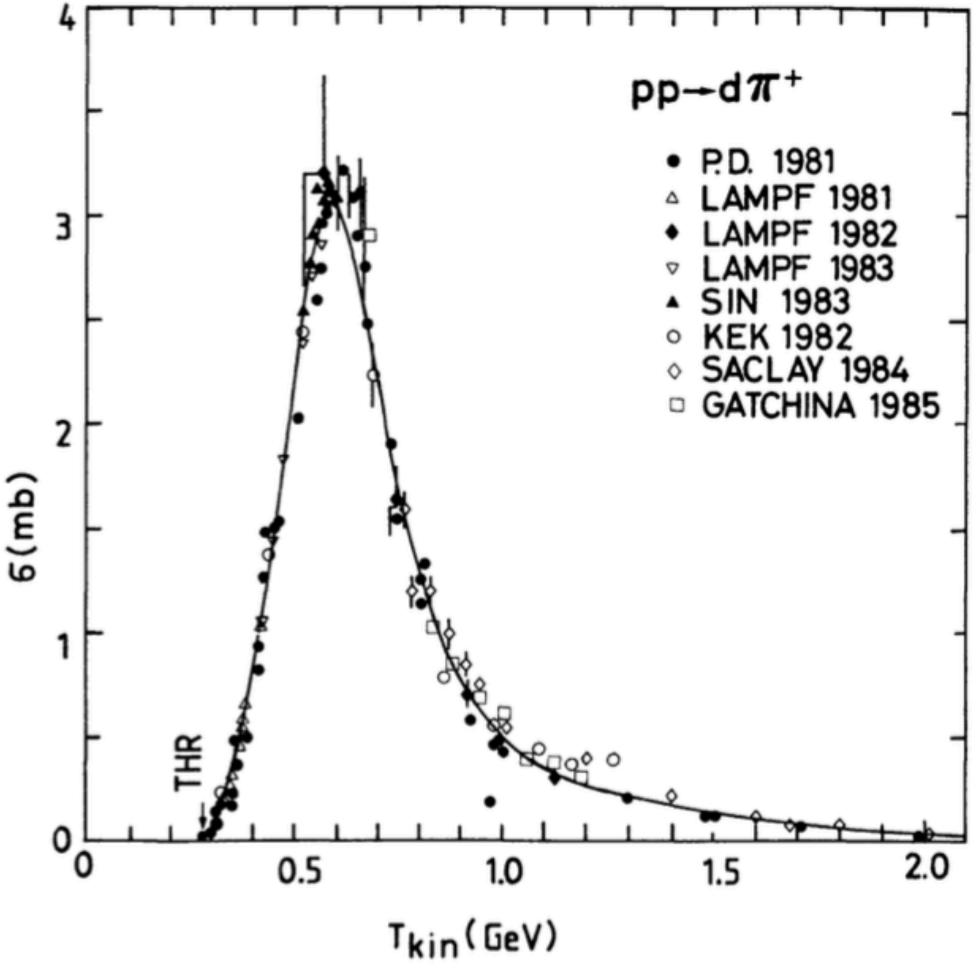


MC: (phase space) x (acceptance)



Previous data: pp -> d π^+

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



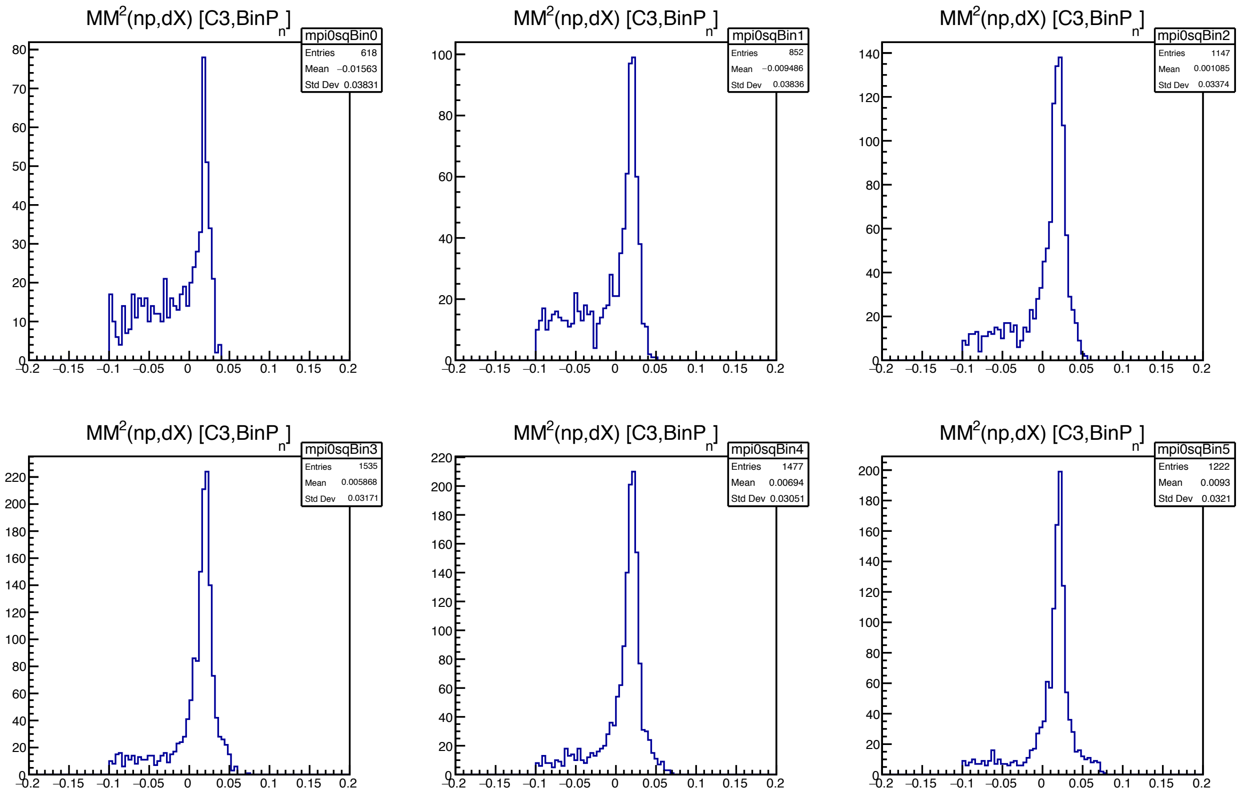
Data from a variety of facilities, shown by the legend.

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

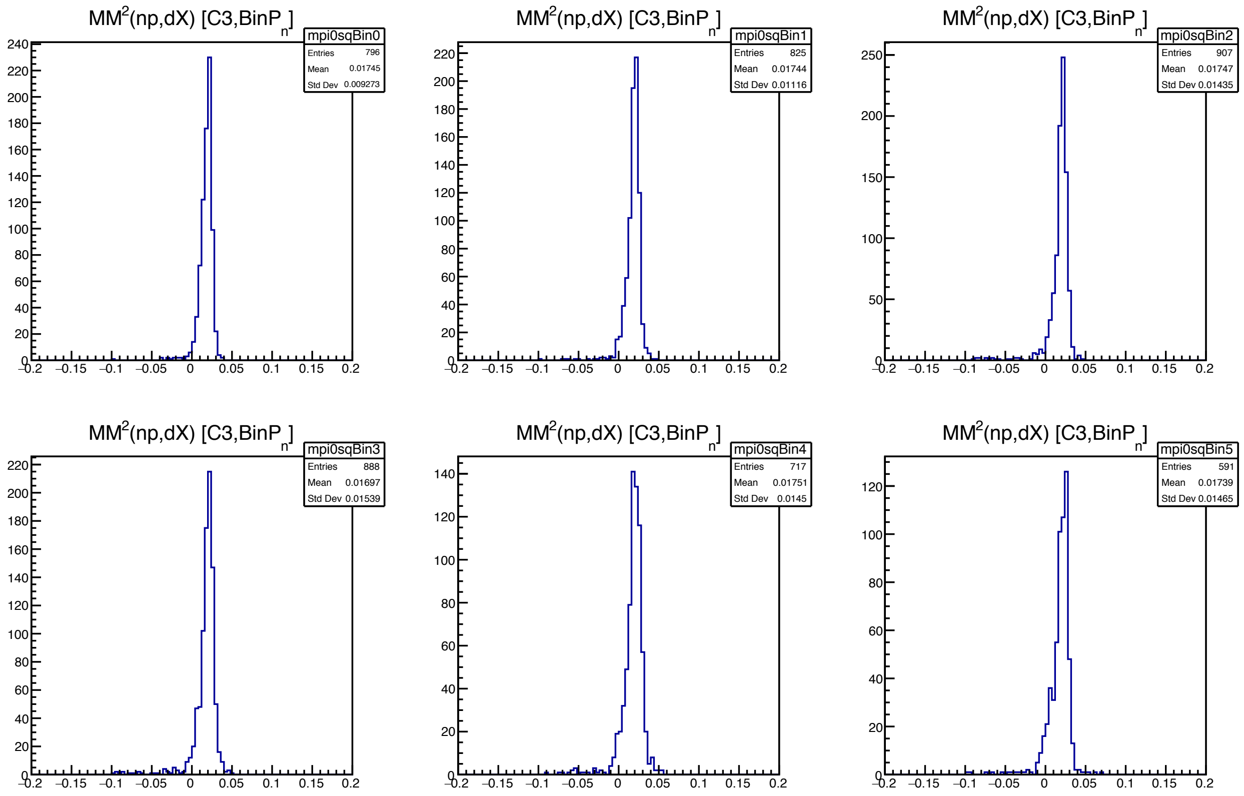
Full width (W) = 100 MeV

Binning in p_n: 0.90-0.95, 0.95-1.00, etc.

G11: peak yield (Counts)



MC: after GSIM (acceptance)



Missing Mass Squared (np,dX) (GeV^2)

Neutron Luminosity

L_n = (# n's)(target number density)(average n-pathlength)

where:

(# n's) = (L_γ)(average integrated cross section)

target density = 4.26e22 / cm^2 (as before)

average n-pathlength = from generator (for given bin)

Note: A CLAS Note is in preparation to explain the details.

Table of values to get cross section

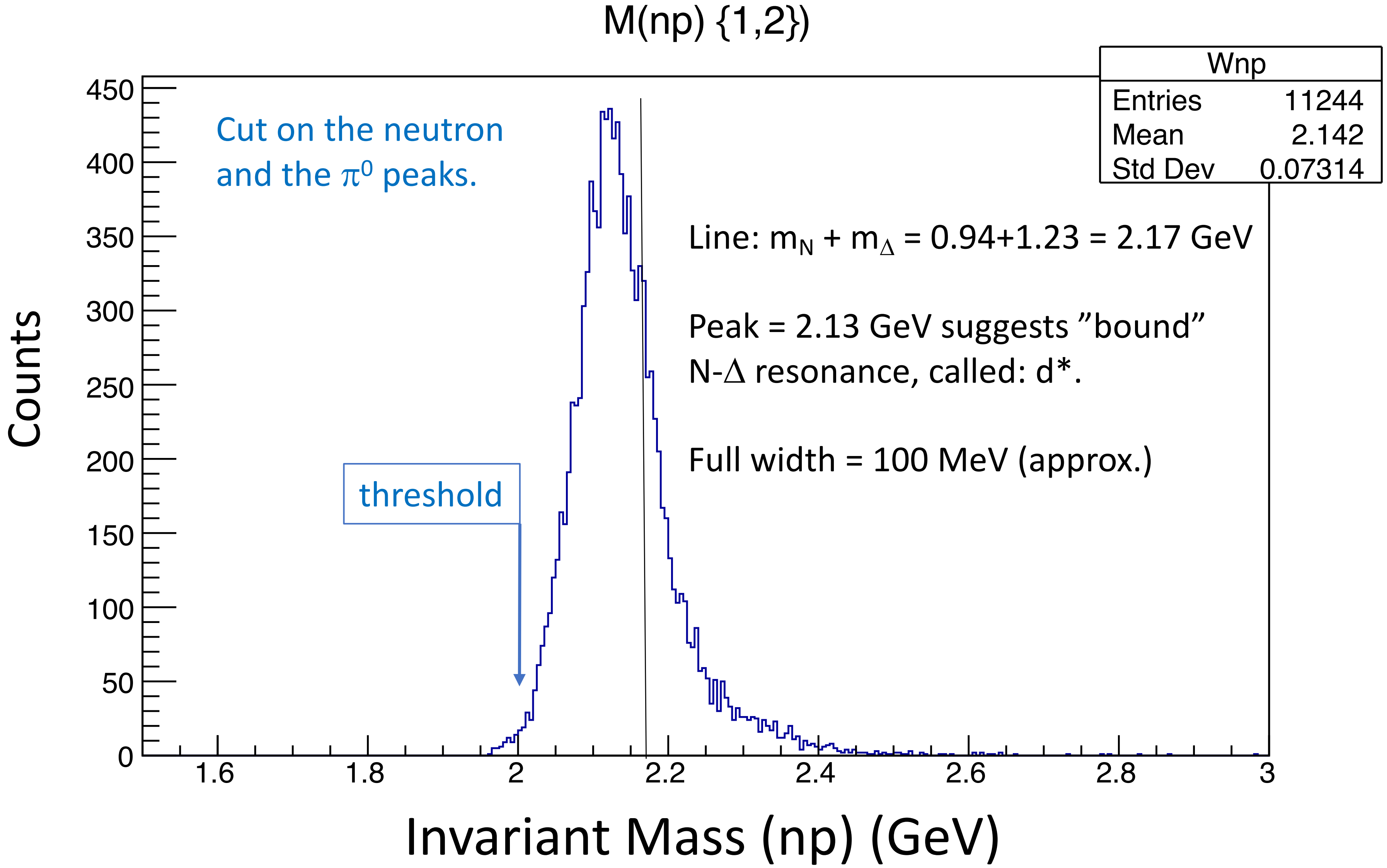
N-momentum	Yield	Acceptance	Luminosity(n) x e29	Cross section (mb)
0.90 – 0.95	35	0.269	3.38	1.01
0.95 – 1.00	65	0.306	4.04	1.37
1.00 – 1.05	94	0.294	4.93	1.69
1.05 – 1.10	130	0.288	5.94	1.98
1.10 – 1.15	120	0.268	7.03	1.66
1.15 – 1.20	106	0.178	8.97	1.73

σ = Yield/(Accep.)(Lumin.)(effic.)

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

Uncertainties: (~10-20% error bars)

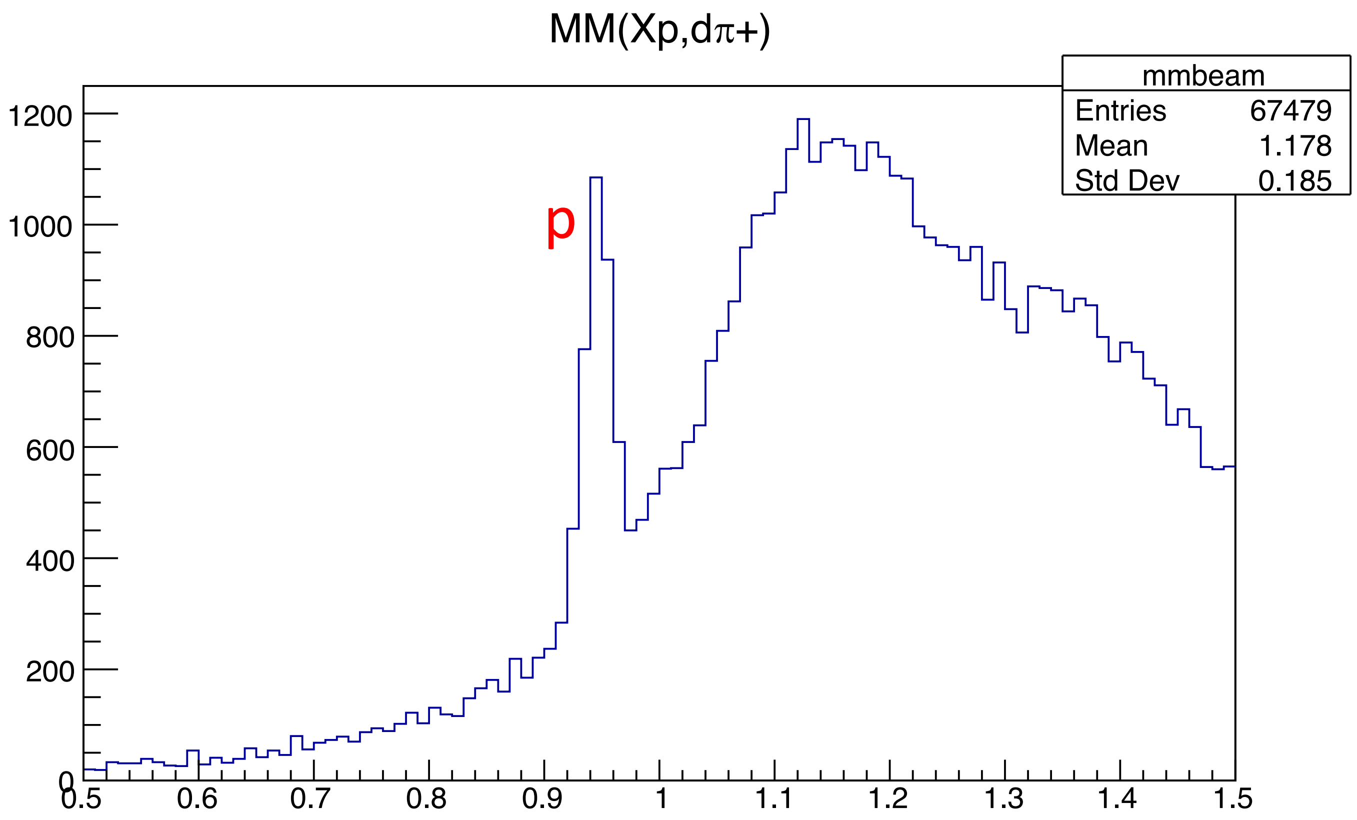
W-dependence: strong resonance shape



Proton-proton scattering at CLAS

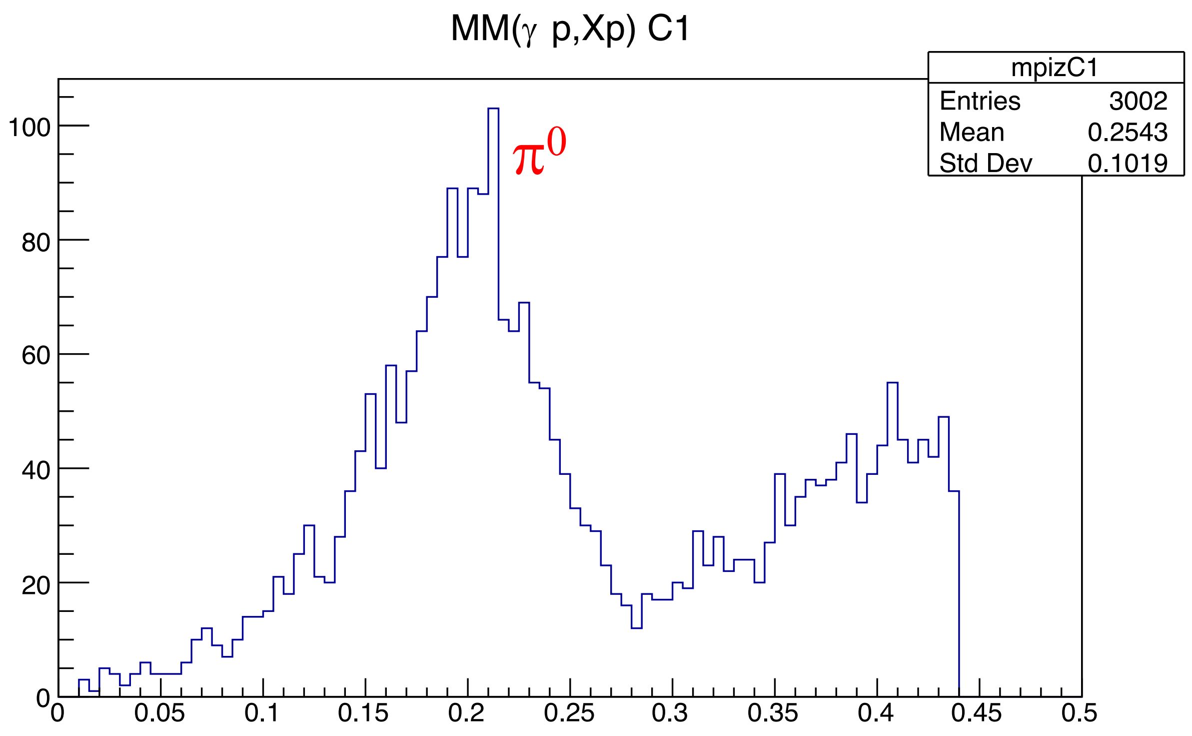
- Two-step process:
  - Step 1: produce a neutron: $\gamma p \rightarrow \pi^0 p$
  - Step 2: neutron re-scatters: pp --> d π^+
- Do this with missing masses (reverse order):
  - Step 2: proton 4-vector from MM(Xp,dπ^+) for X=proton mass.
  - Step 1: pion 4-vector from MM(γp,pX) for X = pion mass.
- Note: this can be extracted from the same skim
  - detect charged particles: d, π^+ only (plus tagged γ)

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

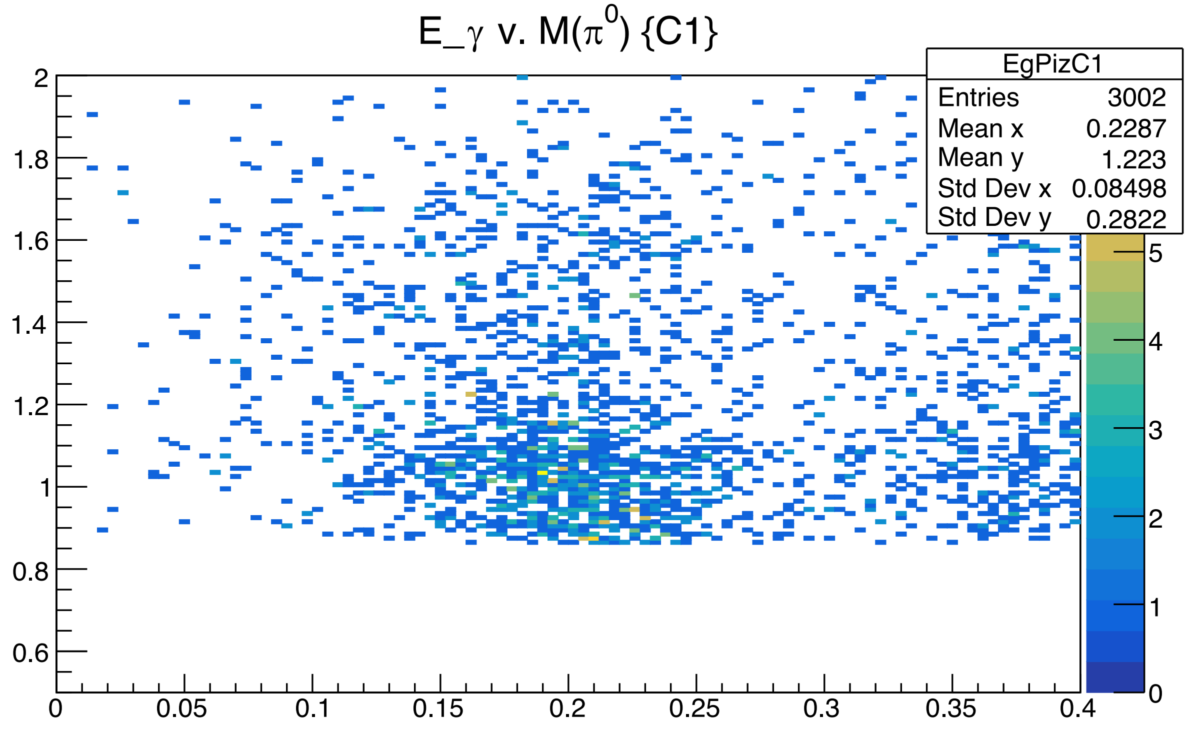


Clear peak at the proton mass. Lots of background, some goes away with z-vertex cuts (remove target ends).

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



Pion mass comes out high (fix with Eloss?).



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

Table to get cross sections:

N-momentum	Yield	Acceptance	Luminosity(n) x e29	Cross section (mb)
1.05 – 1.10 (n)	130	0.288	5.94	1.98 (np -> $d\pi^0$)
1.05 – 1.10 (p)	~90	0.219	4.92	~2.2 (pp -> $d\pi^+$)

σ = Yield/(Accep.)(Lumin.)(effic.)
where effic. = (trigger factor)(trigger efficiency) = (0.467)(0.82)

Note: for np scattering, single-sector events are negligible.
For pp scattering, need correction for single-sector events.

Summary

- We have demonstrated that $np \rightarrow d\pi^0$ can be seen at CLAS.
  - This can establish the validity of the secondary scattering technique.
  - Also validated by $pp \rightarrow d\pi^+$ in the same data skim.
- There are ~10,000 events for $np \rightarrow d\pi^0$ over a range of W.
  - This is sufficient to show a resonance near the N-Δ mass.
  - Probably enough events to get angular distributions.
- We expect to finalize the analysis soon.
  - A full analysis note will be ready about summer 2021.

Backup slides

Isospin Invariance

- The reaction pp --> d π^+ is isospin I=1, I_3 = +1.
  - This would be the same as nn --> d π^-, which we can't measure.
- Now, using Clebsch-Gordon coefficients:
  - Matrix elements: $< d\pi^- | M | nn > = \sqrt{2} < d\,\pi^0 | M | np >$.
  - **If no resonances**: cross sections $\sigma_{pp\to d\pi+} = 2\,(\sigma_{np\to d\pi 0})$.
- We can use "world data" to validate our "secondary scattering" measurements at CLAS.