Secondary scattering analysis using g11 data

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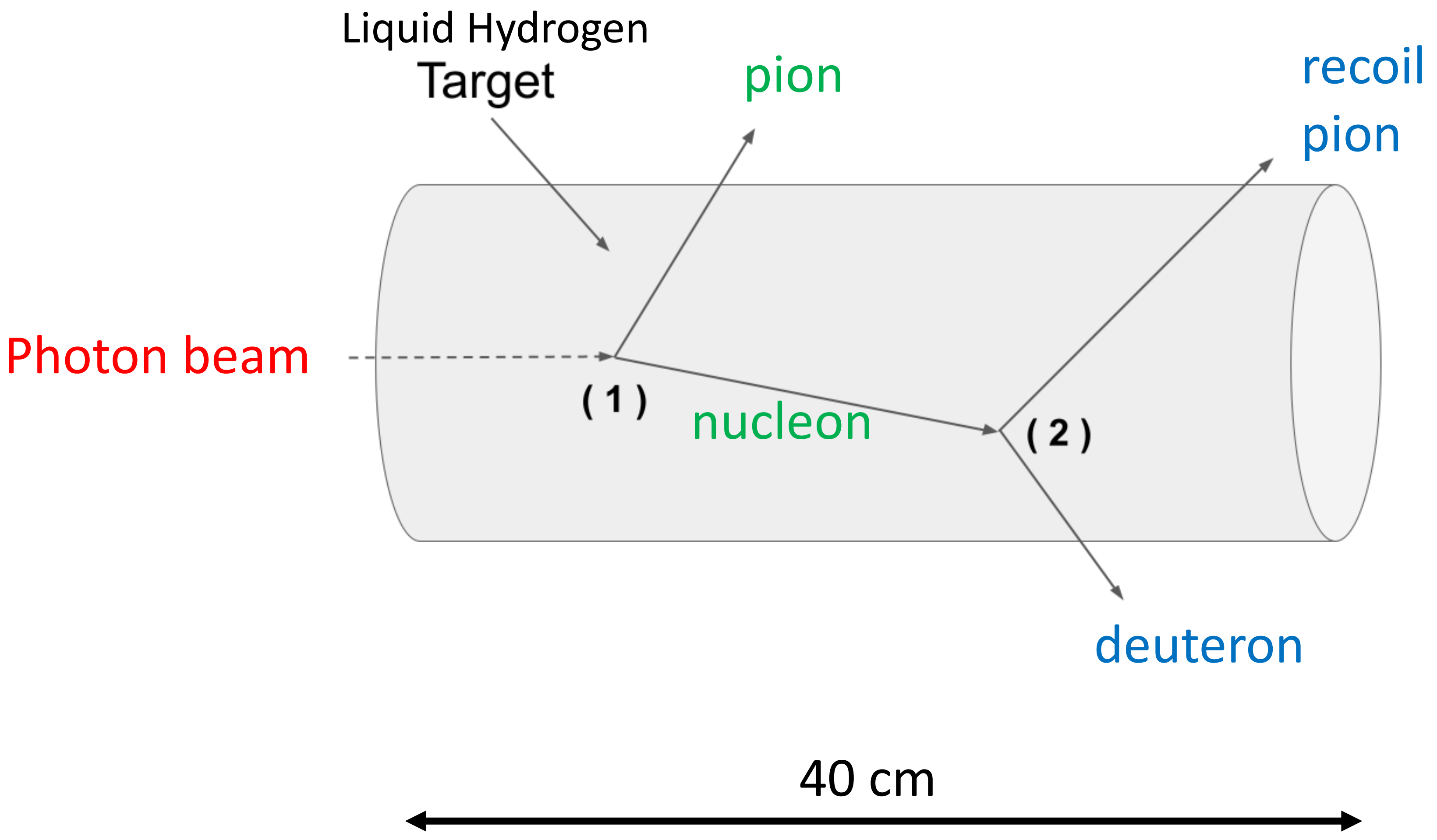
CLAS Collaboration Meeting, HSWG Session

June 3, 2021

The Reaction to be measured at CLAS

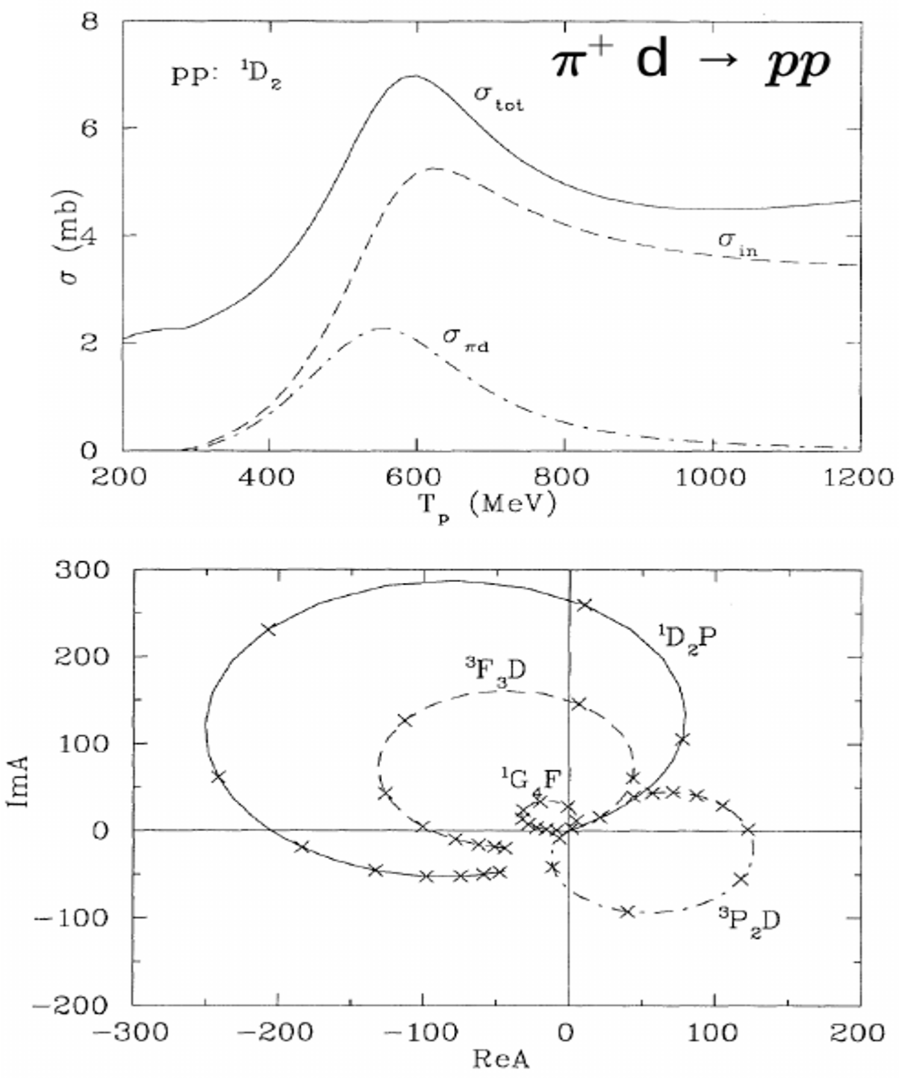


Overview

- 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

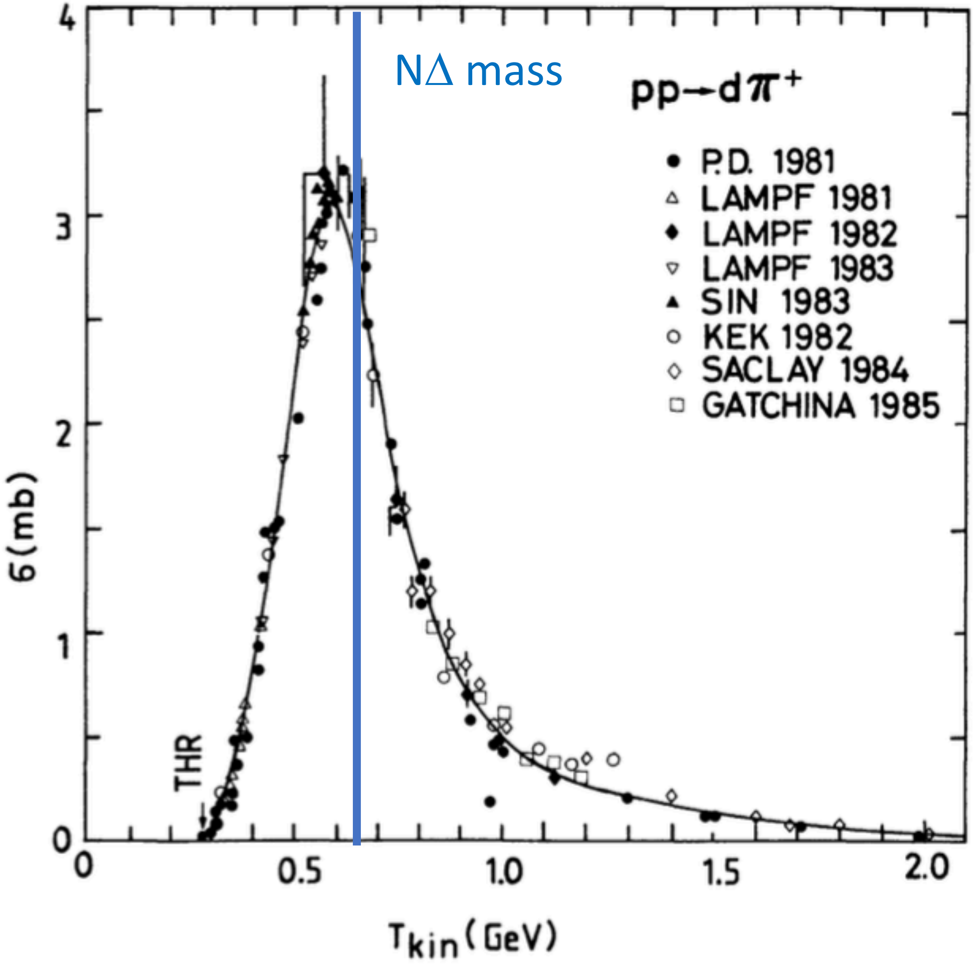
- Partial Wave Analysis.
- Prominent "resonance pole" seen in the SAID analysis.
- $^1D_2$ wave in pp dibaryon system
- Pole mass and width: 2148 – i 63 MeV.



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.



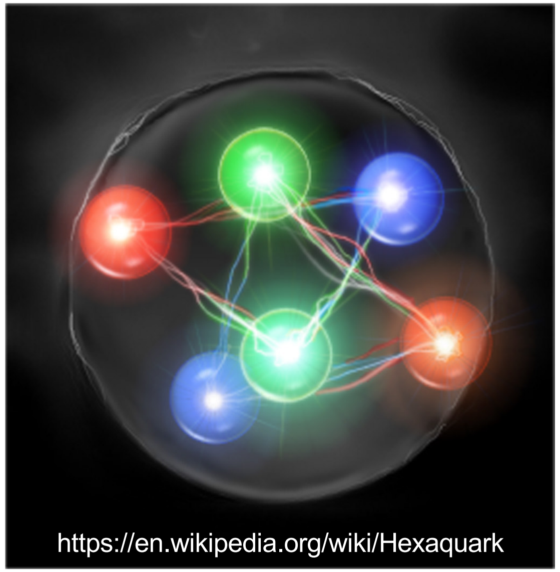
Data from a variety of facilities, shown by the legend.

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	**27**	nn	A
$\mathcal{D}_{12}$	1	2	**27**	$N\Delta$	$A+6B$
$\mathcal{D}_{21}$	2	1	**35**	$N\Delta$	$A+6B$
$\mathcal{D}_{03}$	0	3	$\overline{\mathbf{10}}$	$\Delta\Delta$	$A+10B$
$\mathcal{D}_{30}$	3	0	**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

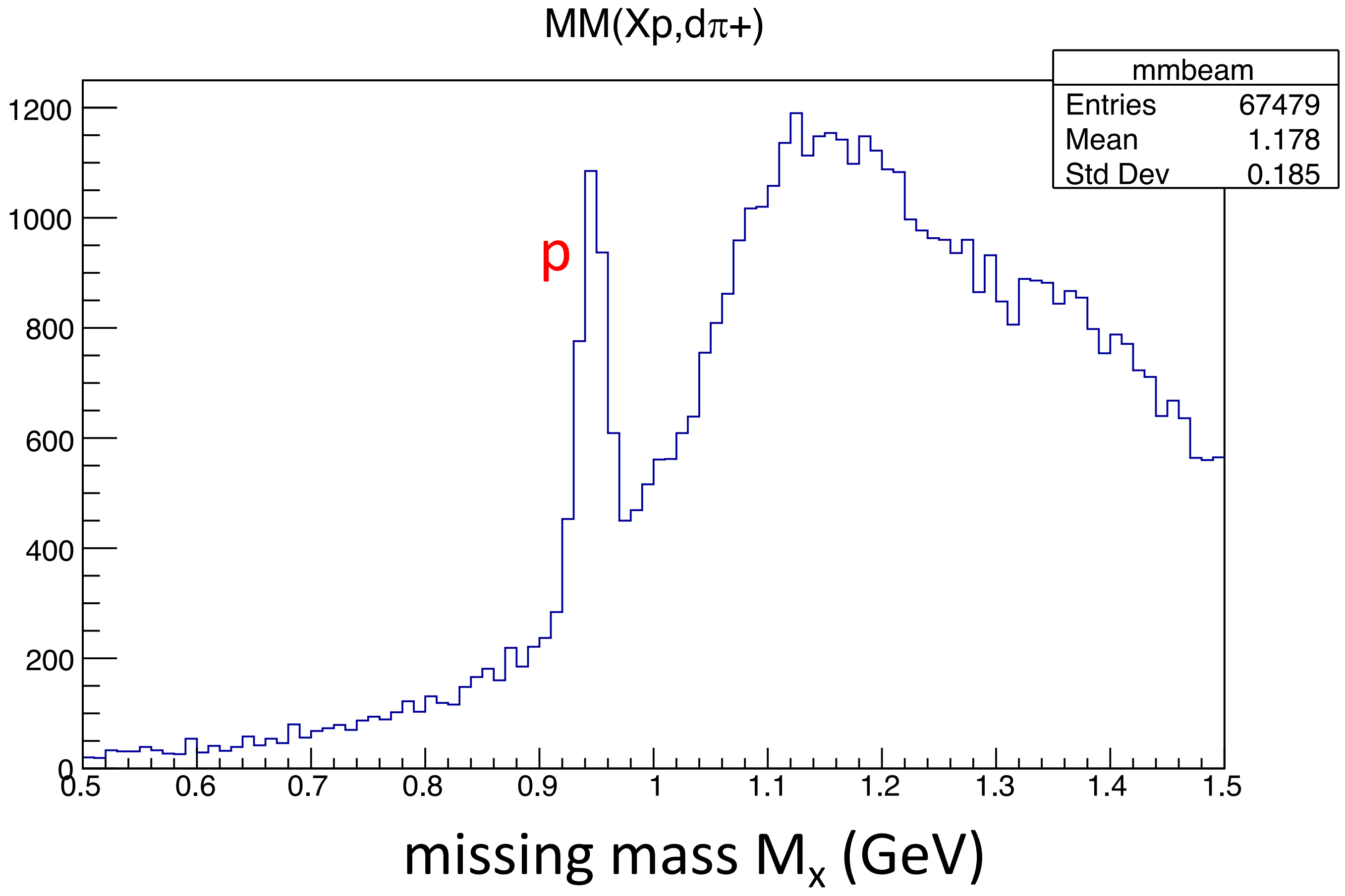
Why remeasure this at CLAS?

- To demonstrate a new technique: 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 hadron-proton reactions 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,dπ^+) for X=proton mass.
  - Step 1: pion 4-vector from MM(γp,pX) for X = pion mass.

Now look for Xp->dπ+ (X=p)

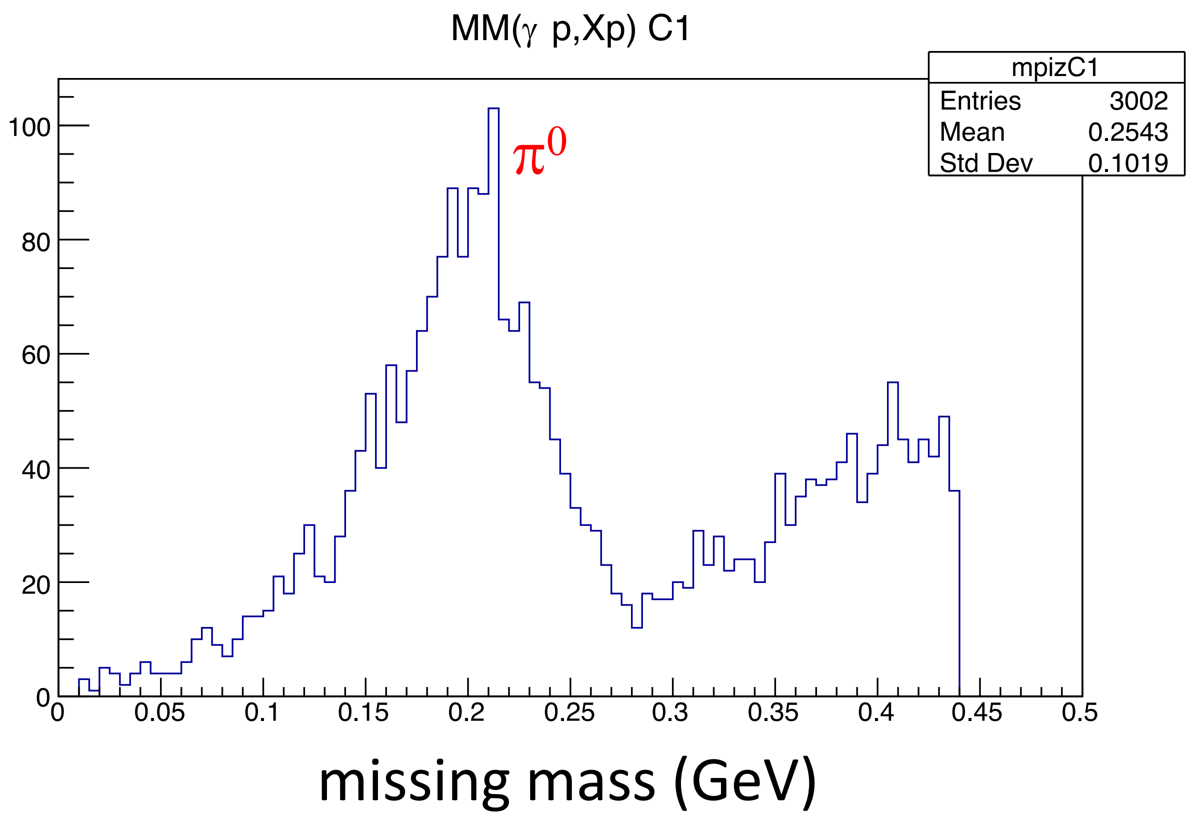


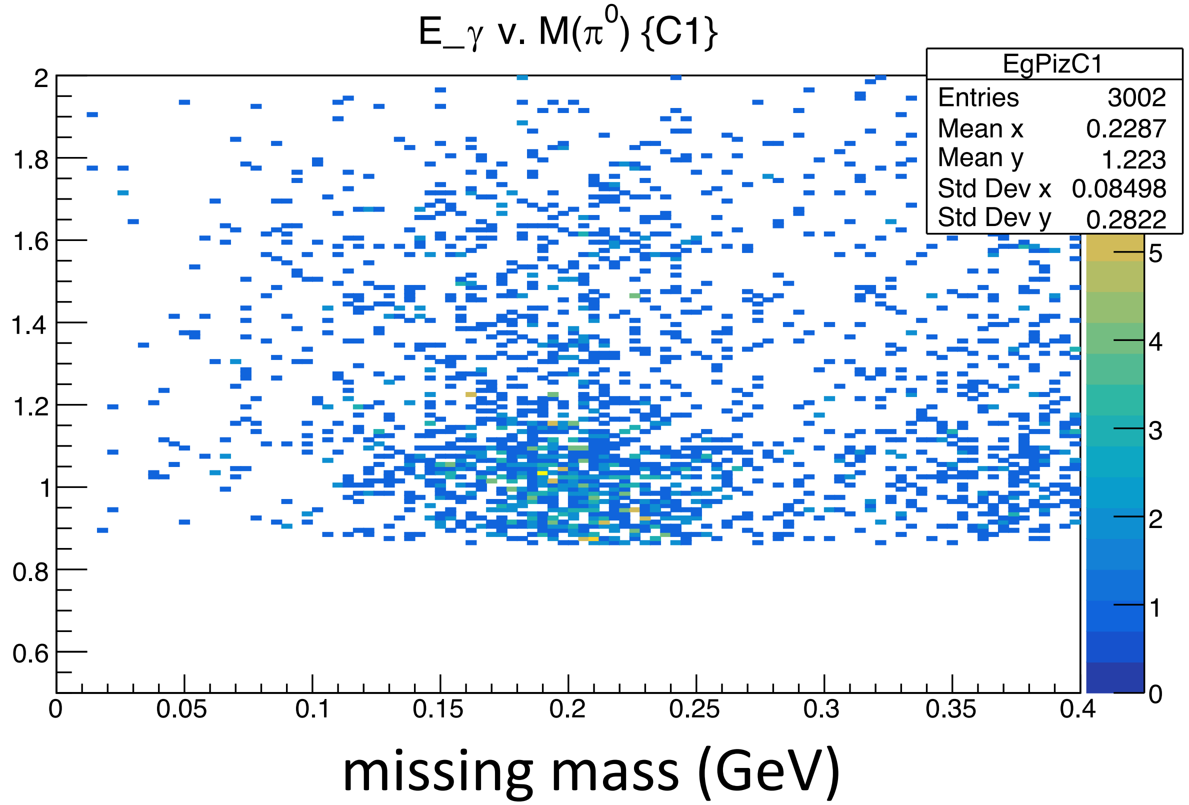
Clear peak at the proton mass. Lots of background, but most of it can be removed with kinematical cuts.

Analysis Details

- Skim conditions:
  - Standard particle ID: select d and π^+, with $|MM(\gamma pp,d\pi^+) - m_{\pi 0}| < 0.3$ GeV.
  - keep up to 3 photons within 2.5 ns of ”trigger time” (stored by EVNT).
- Analysis conditions:
  - $MM^2(\gamma pp,d\pi^+) > -0.1$ GeV (removes much background)
  - Cut on missing nucleon peak (vertex 1): $|MM(\gamma p,\pi) – m_N| < 0.06$ GeV.
  - z-vertex within the target volume (both d and π^+)
  - nucleon momentum (between vertex 1 & 2) > 0.75 GeV/c (threshold for dπ)
- Binning:
  - $0.9 < E_\gamma < 1.5$ GeV (CM energy, W, from threshold to above resonance)
  - steps of 0.05 GeV for incident nucleon momentum from 0.9 to 1.35 GeV/c.

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





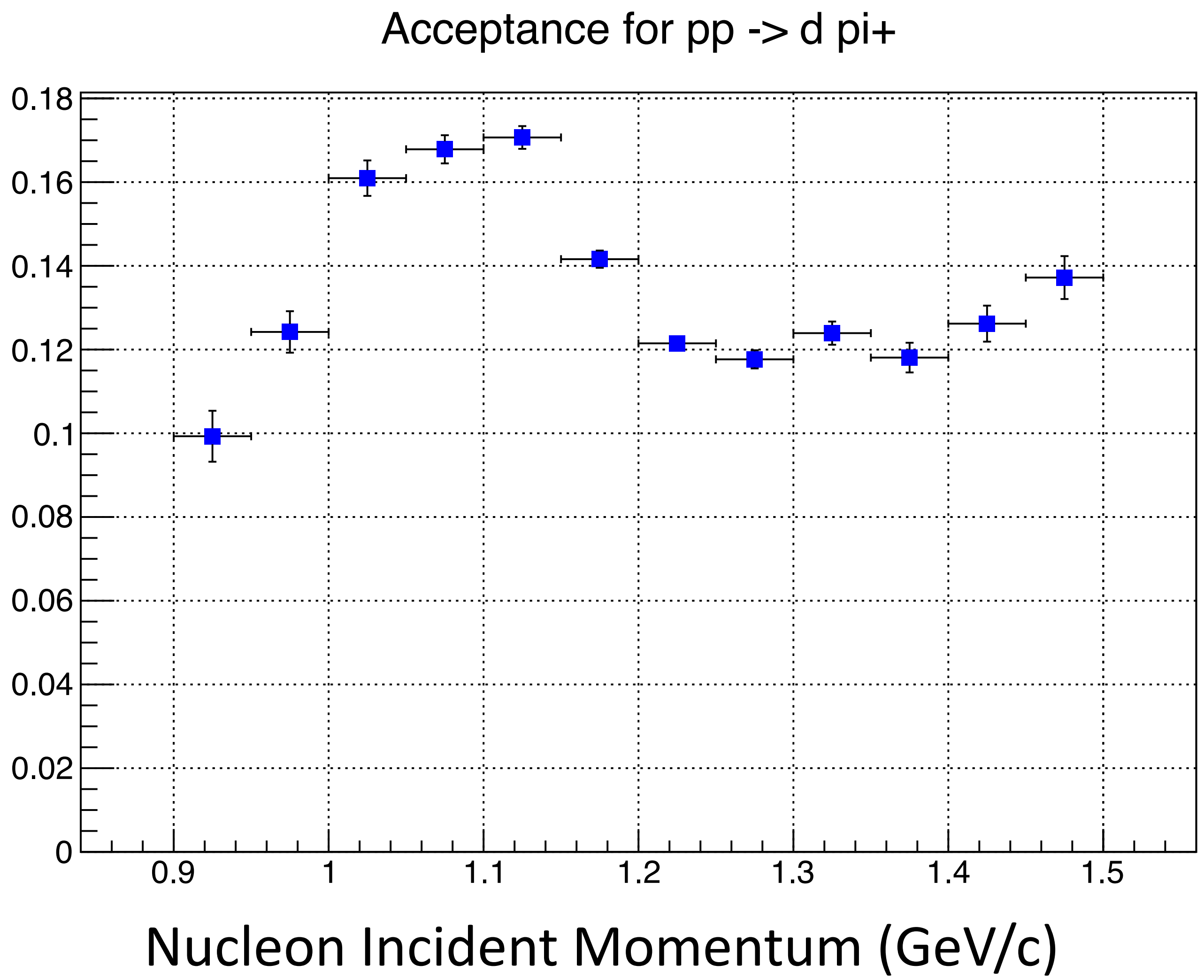
Pion mass comes out high (energy-loss).

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

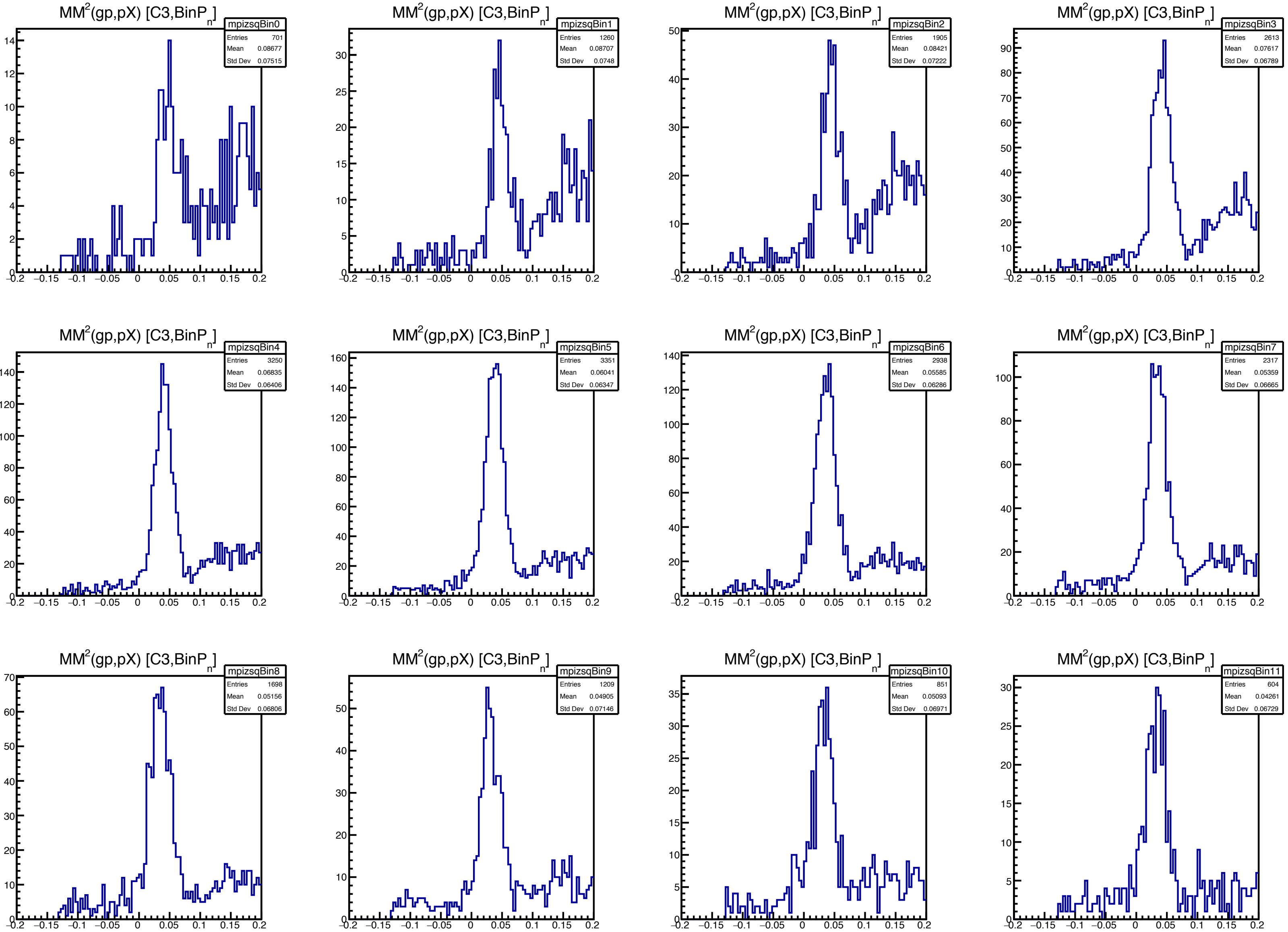
Cross section calculation

- 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!

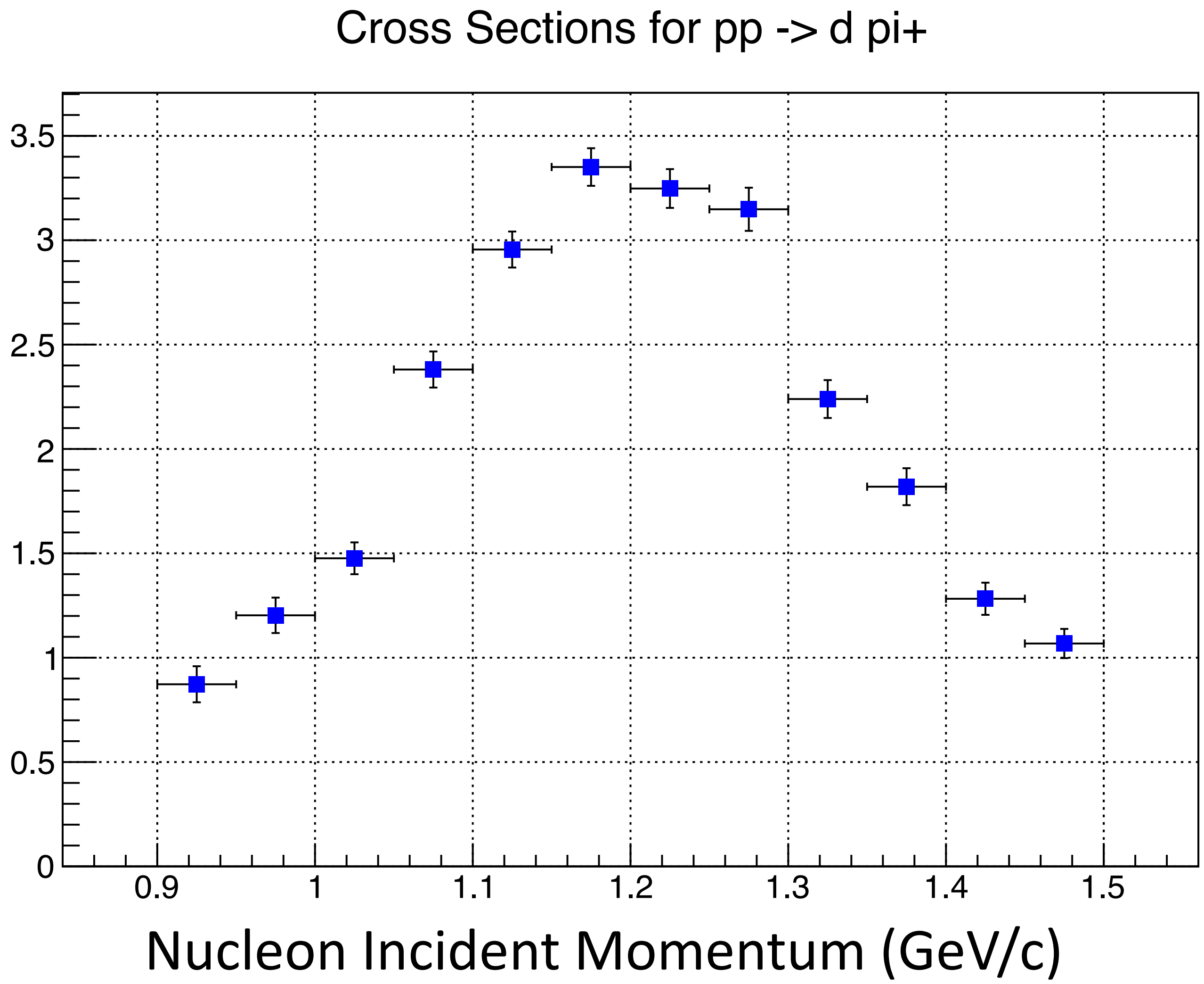
MC acceptance pp->dpi: Event gen. by Nick Z.



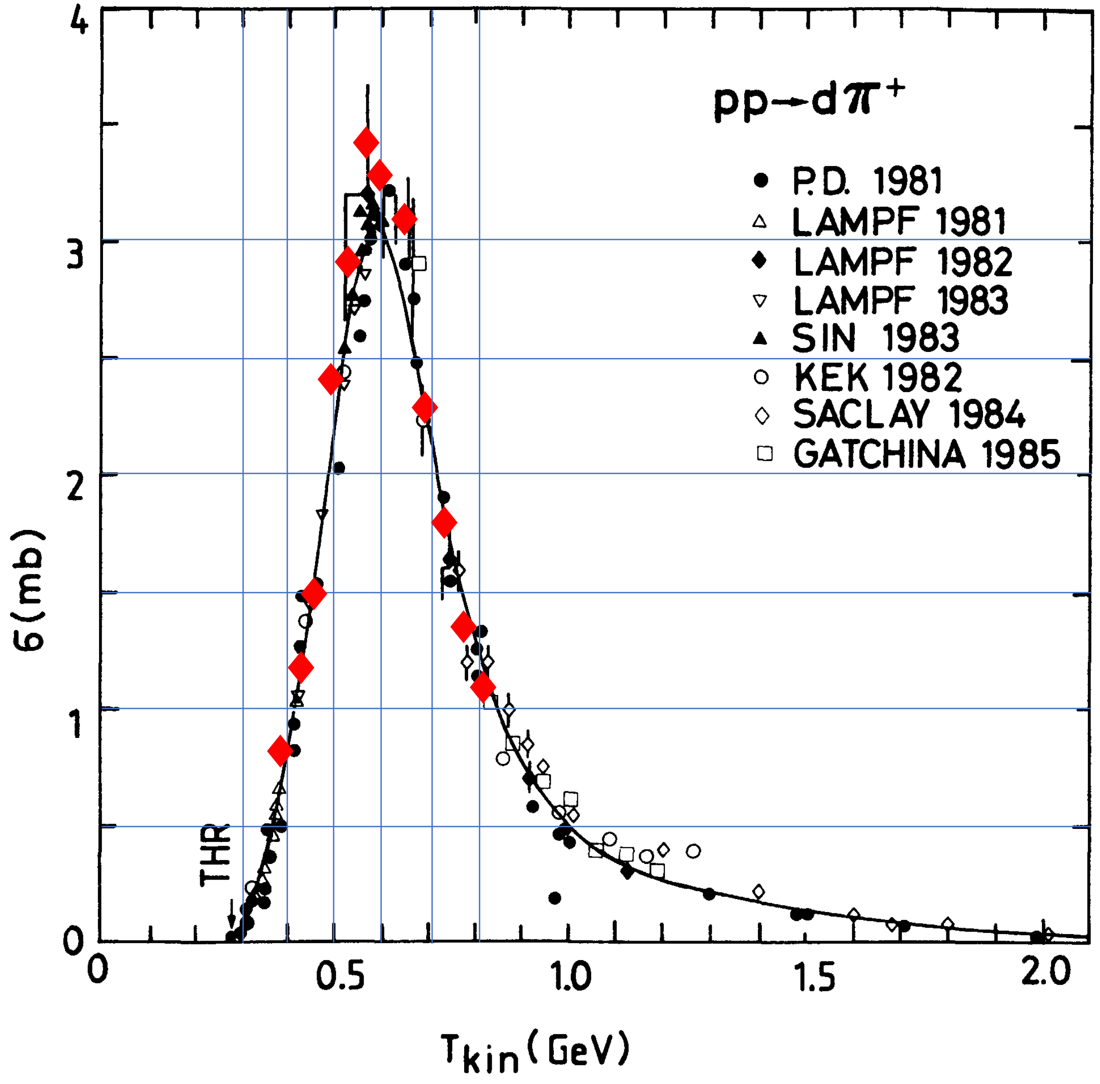
Data: peak yield (all runs, E_γ 0.9-1.5), pp->dpi



Cross sections: pp->dpi (statistical error bars)



Preliminary results (red diamonds):

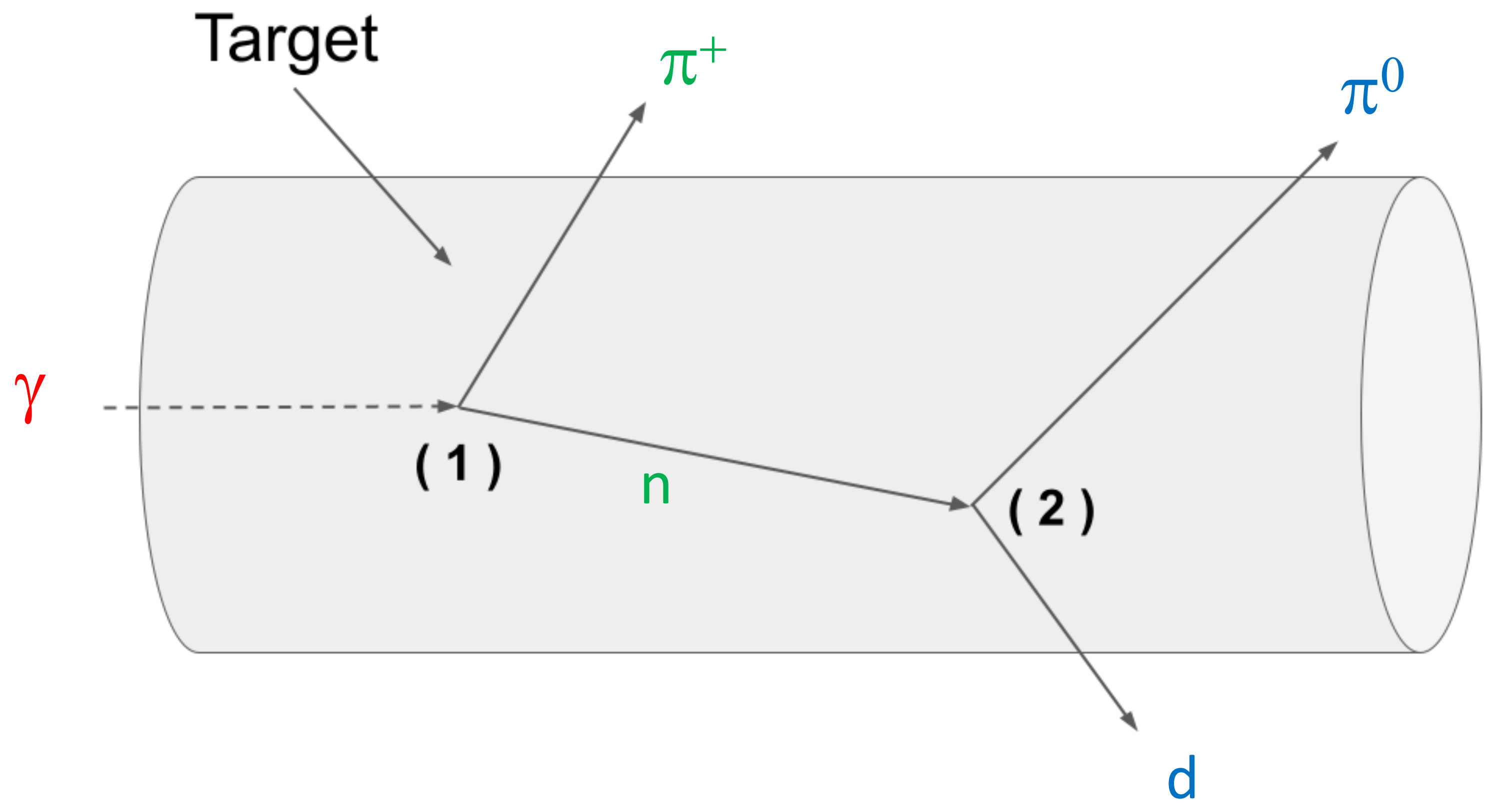


Note: statistical errors are about the size of the points.

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!

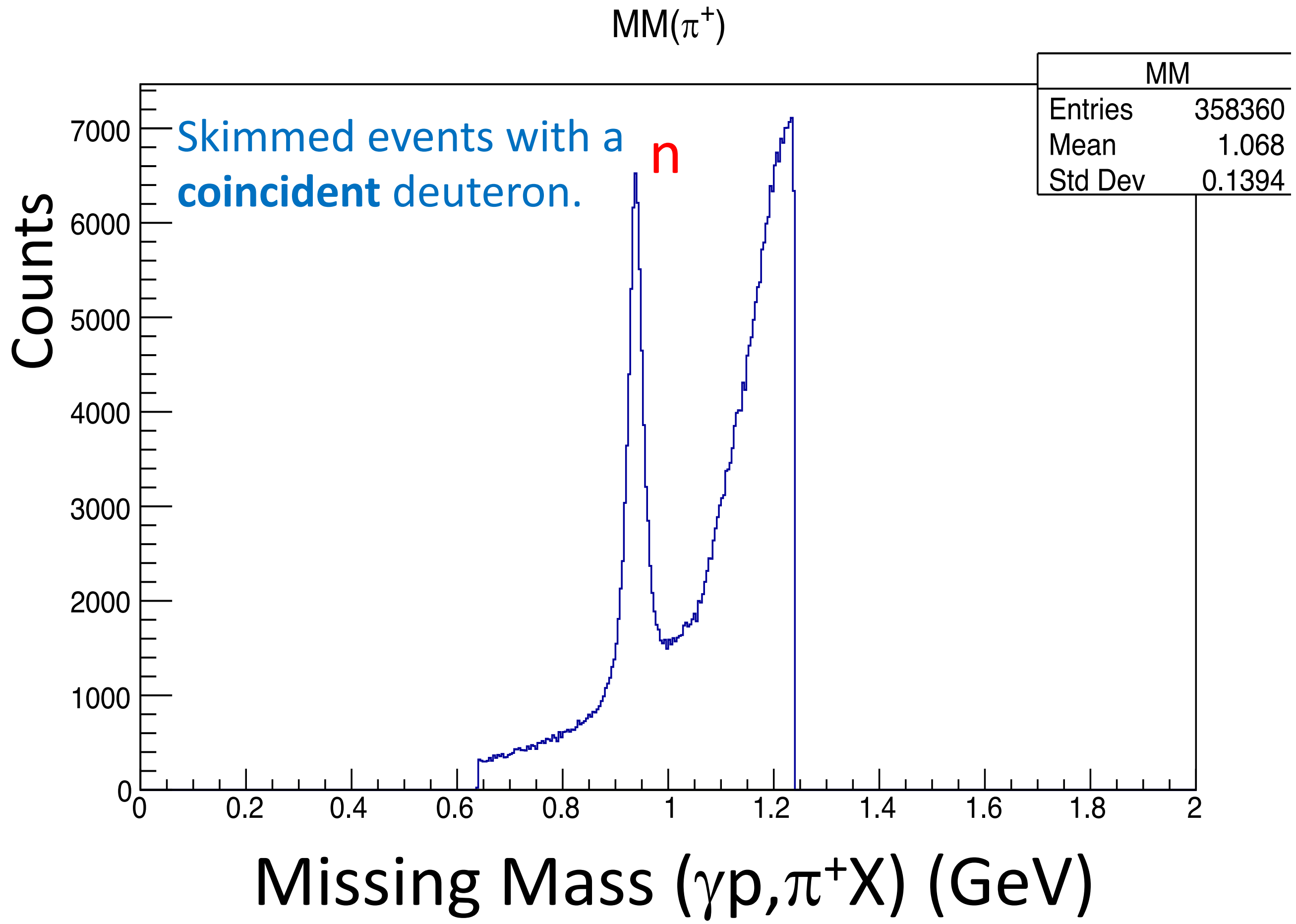


What do we measure?

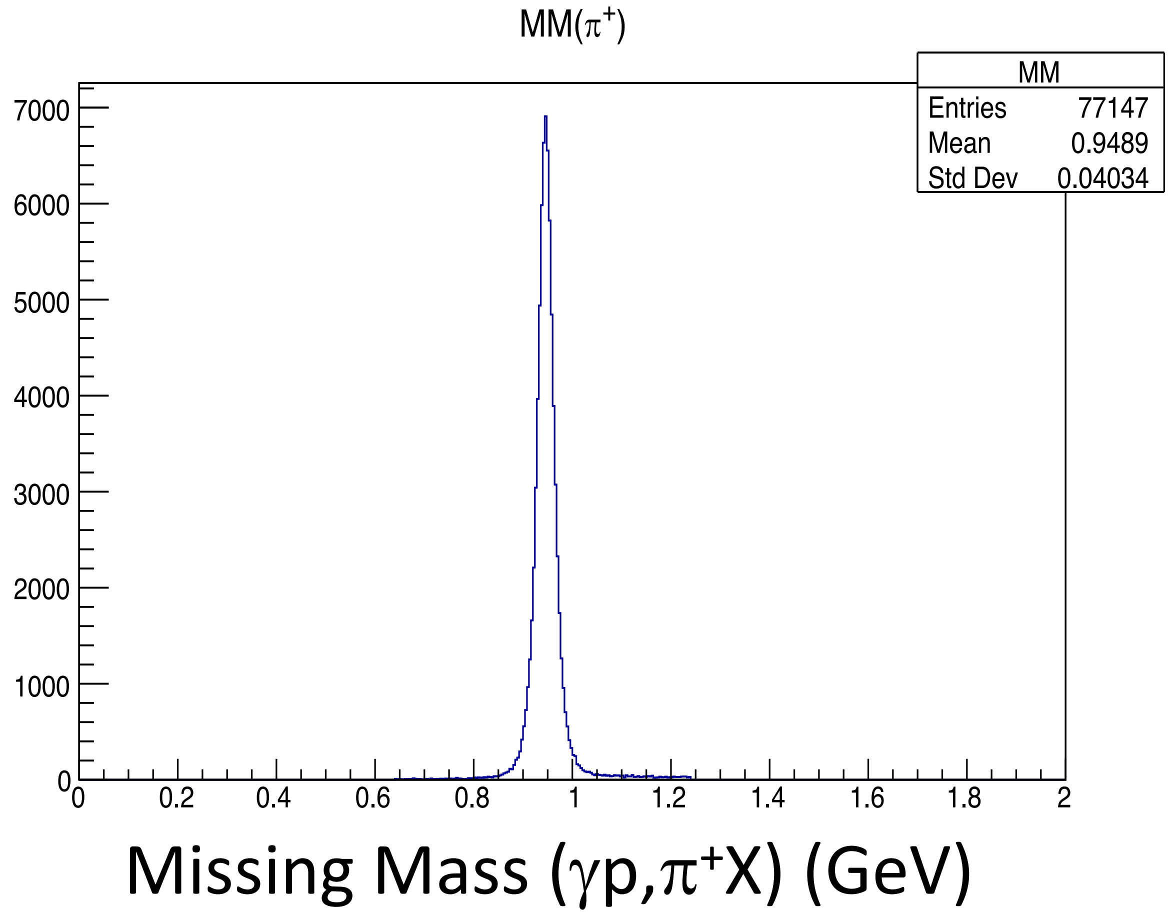
- The g11 experiment at CLAS has GeV photons on 40-cm LH2 target
- Detected particles: coincidence of π^+ and d.
- Two-step process:
  - Step 1: produce a neutron: $\gamma p \text{-->} \pi^+ n$
  - Step 2: neutron rescatters: $np \text{-->} d\, \pi^0$
- Do this using missing masses:
  - Step 1: neutron 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 γp --> π^+ n.

G11 data: lots of background!

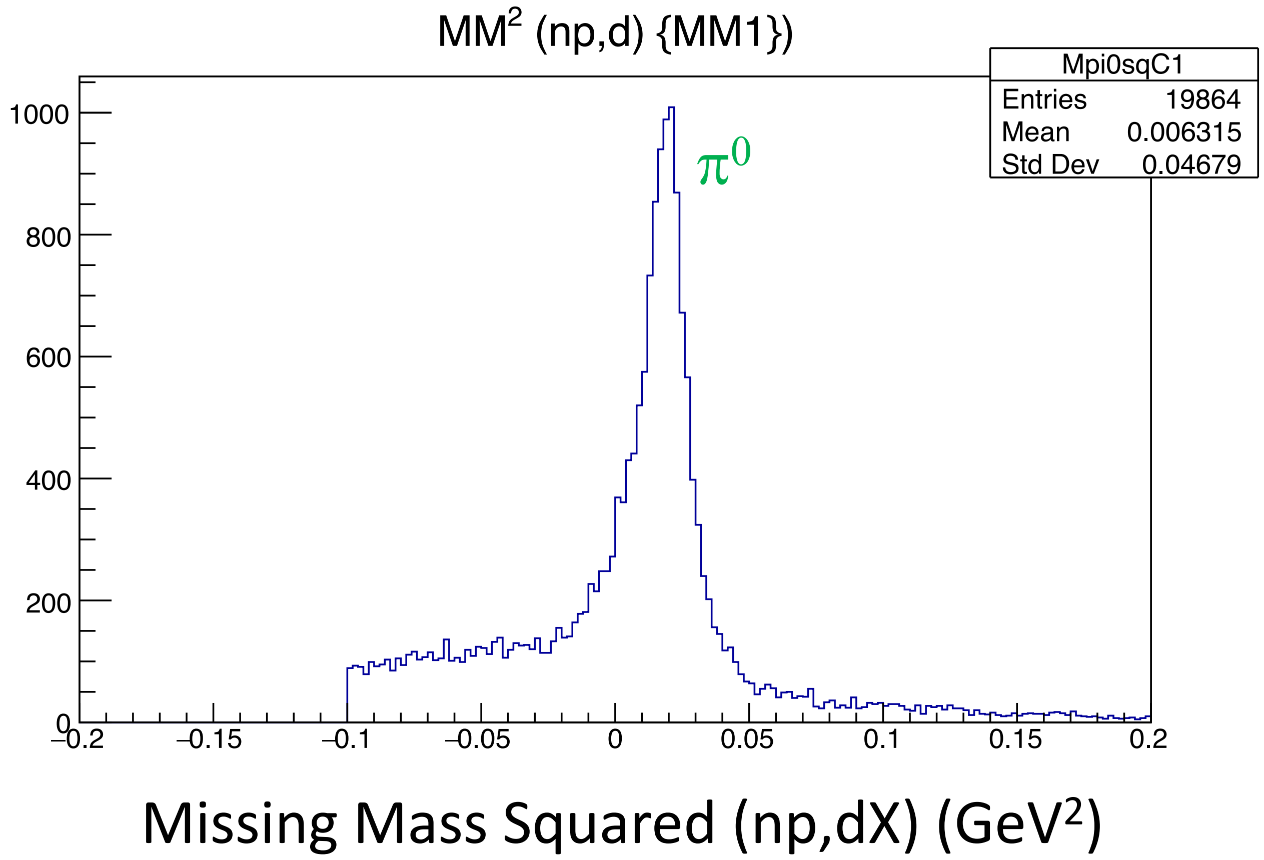


MC using N.Z.'s event generator

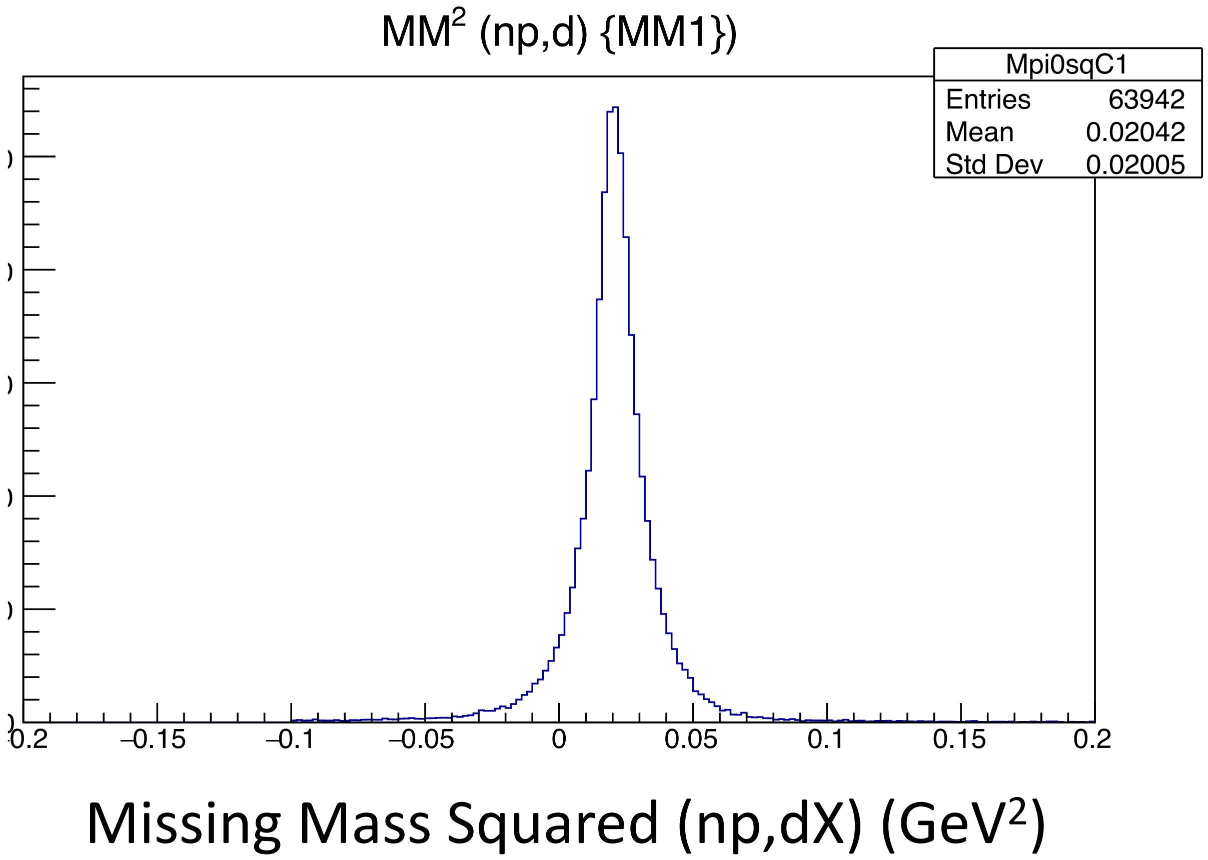


Step 2: Missing mass of np -> d π^0.

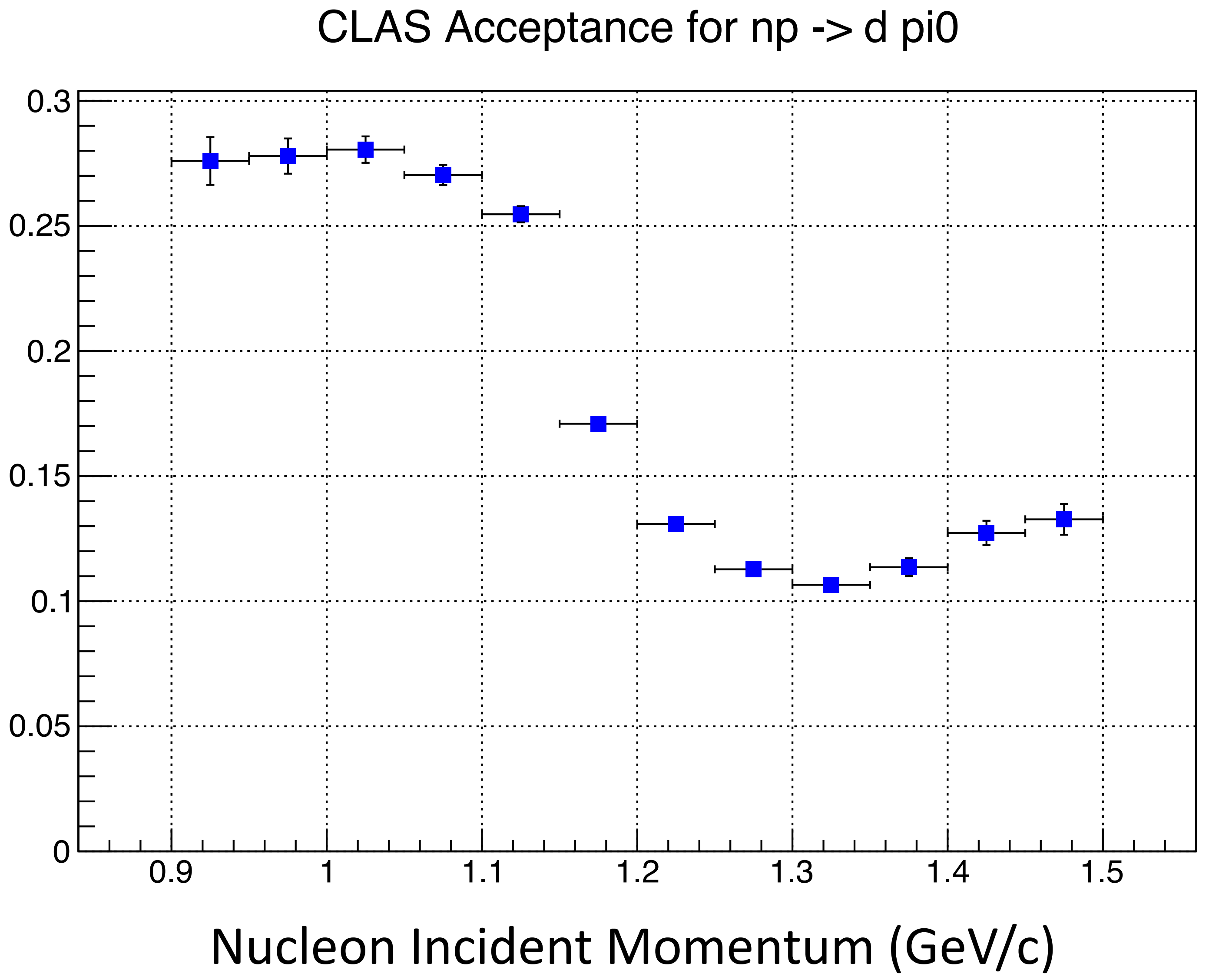
g11: after kinematical cuts



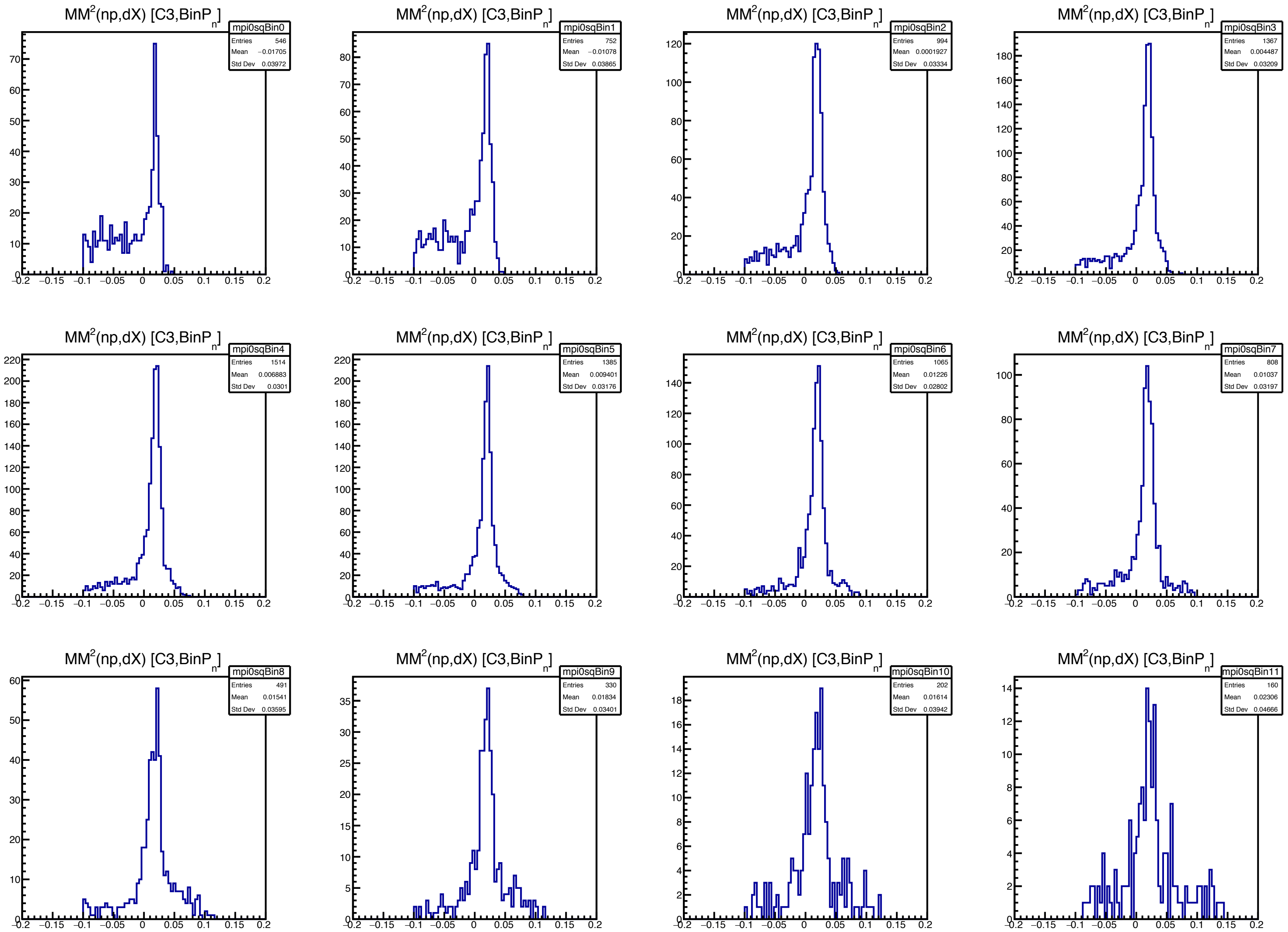
MC: ~17% loss of events



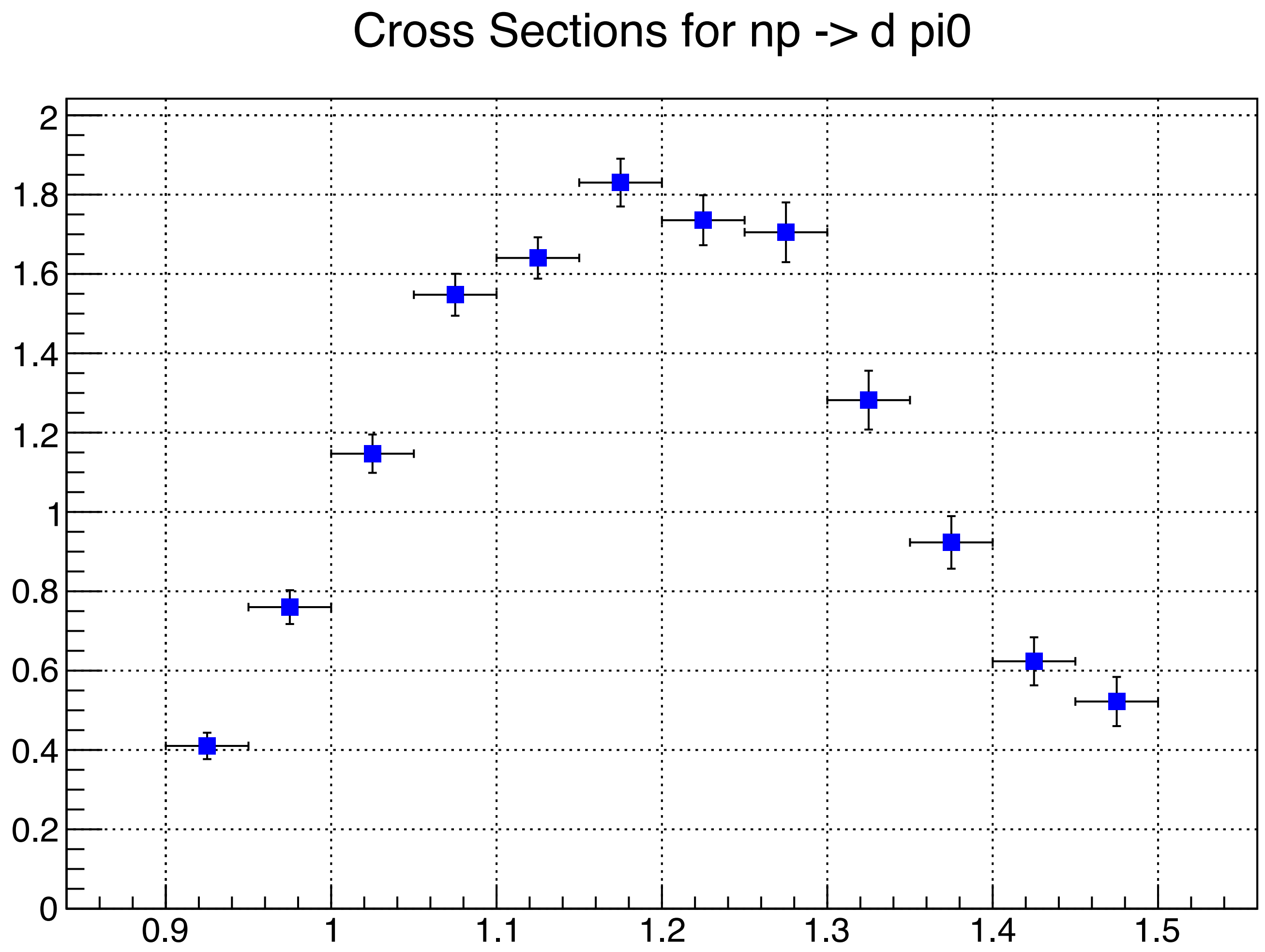
Acceptance: event generator by Nick Z.



Data: peak yield (all runs, E_γ 0.9-1.5), np->dpi

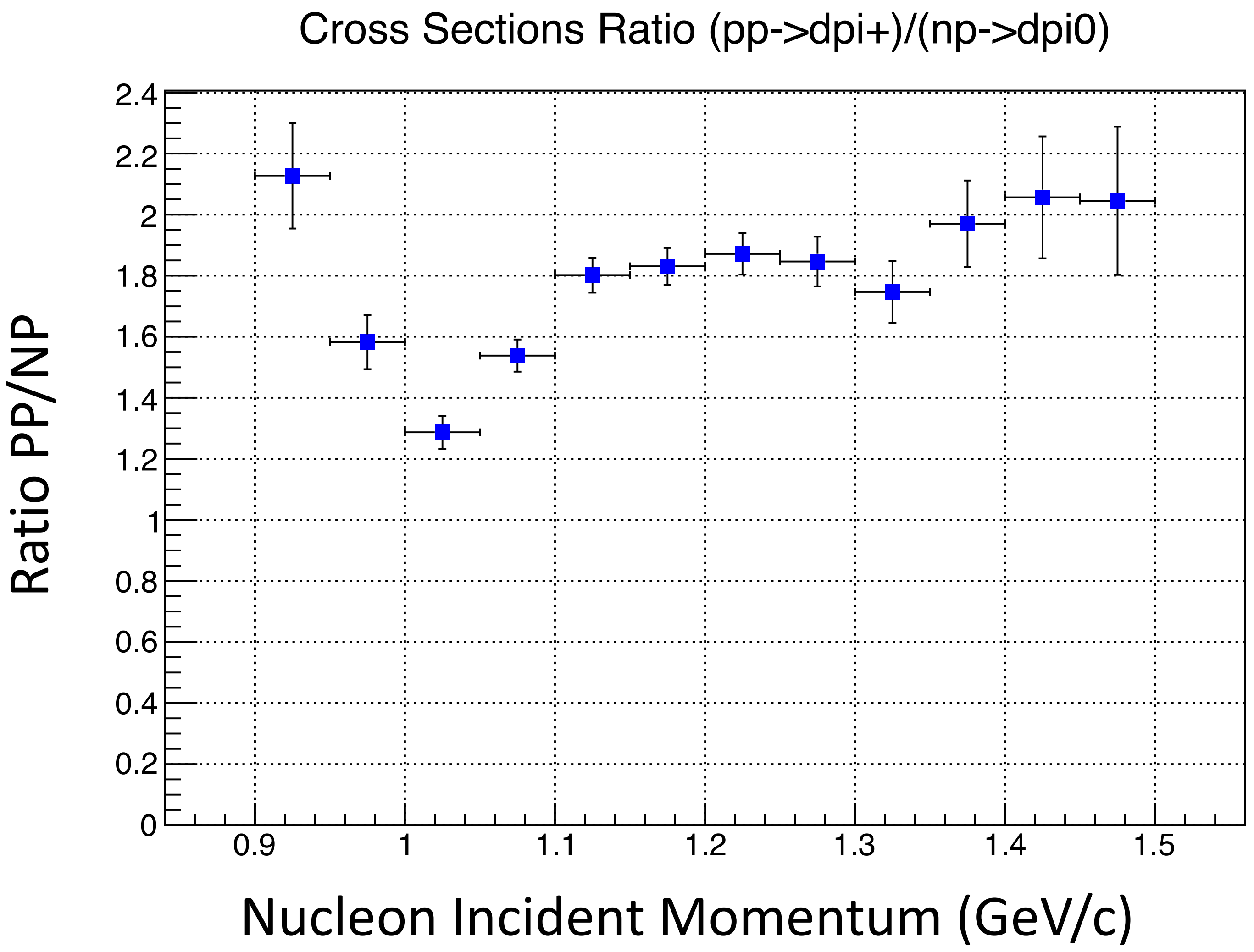


Cross sections: np->dπ^0 (statistical error bars)



Nucleon Incident Momentum (GeV/c)

Ratio of cross sections (preliminary)



Summary

- These results are still preliminary!
  - Systematic uncertainties are still being evaluated.
- 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->dπ^+ and np->dπ^0 in the same data set.
- The expected ratio (charge independence) of (pp->dπ^+)/(np->dπ^0) = 2.
  - Assumes no isospin-breaking in the interference of resonance & background.
  - Note: only a single absolute cross section for np->dπ^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 just above threshold.

Backup

ISOSPIN INVARIANCE IN THE REACTION $n+p \rightarrow \pi^0+d$ *

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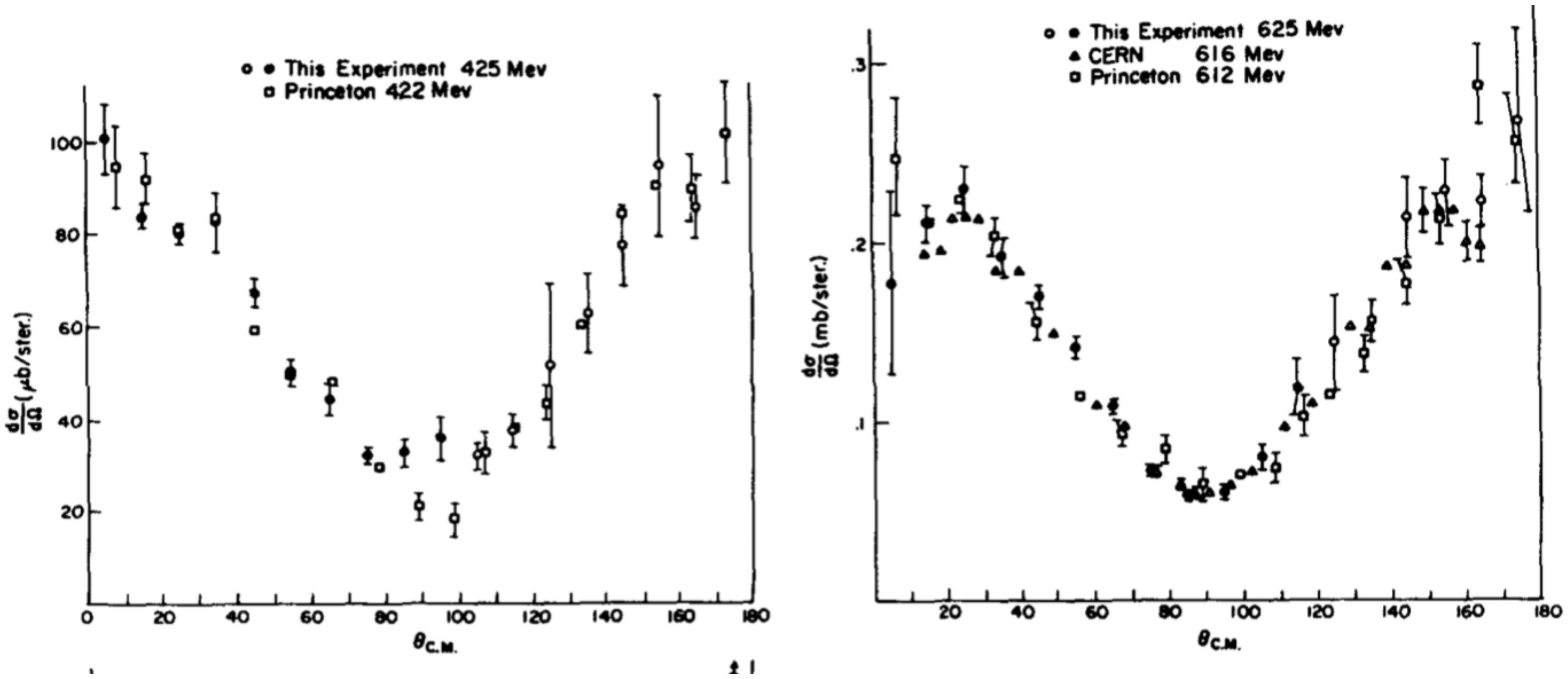
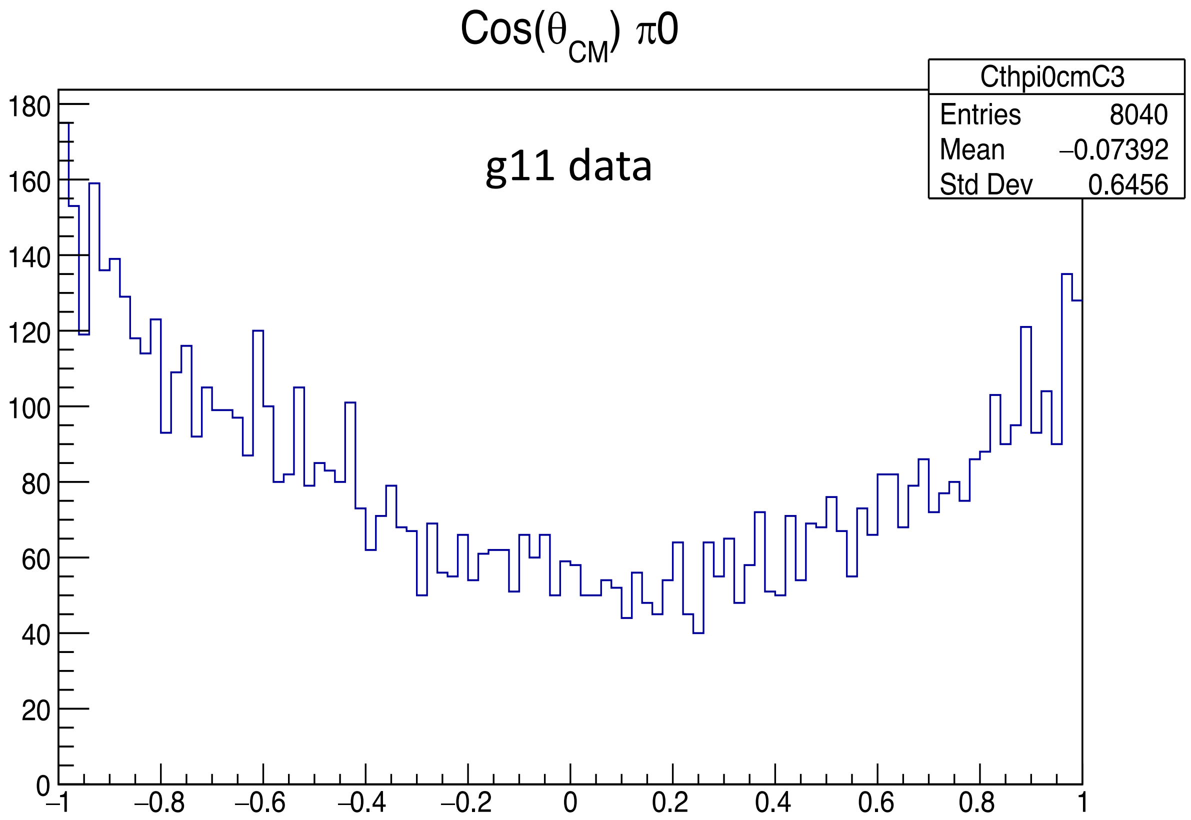
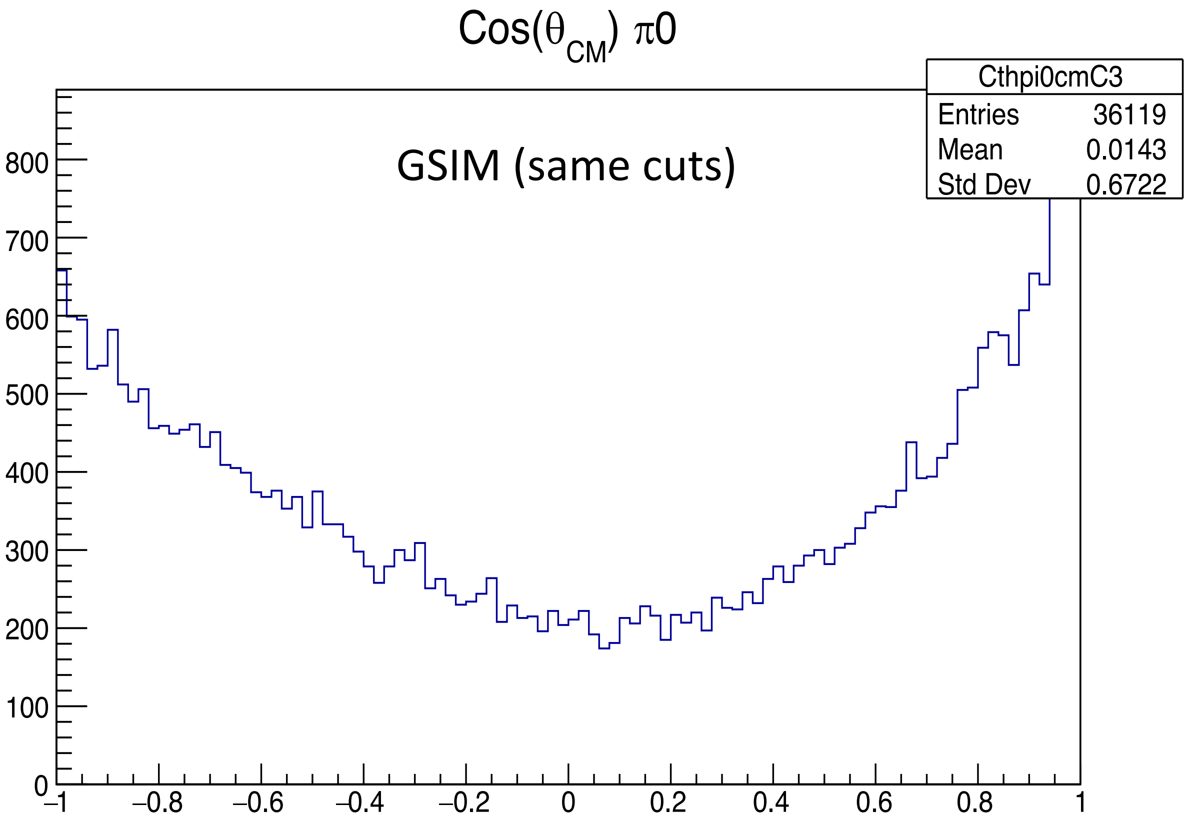


Angular Distributions: np->d π^0

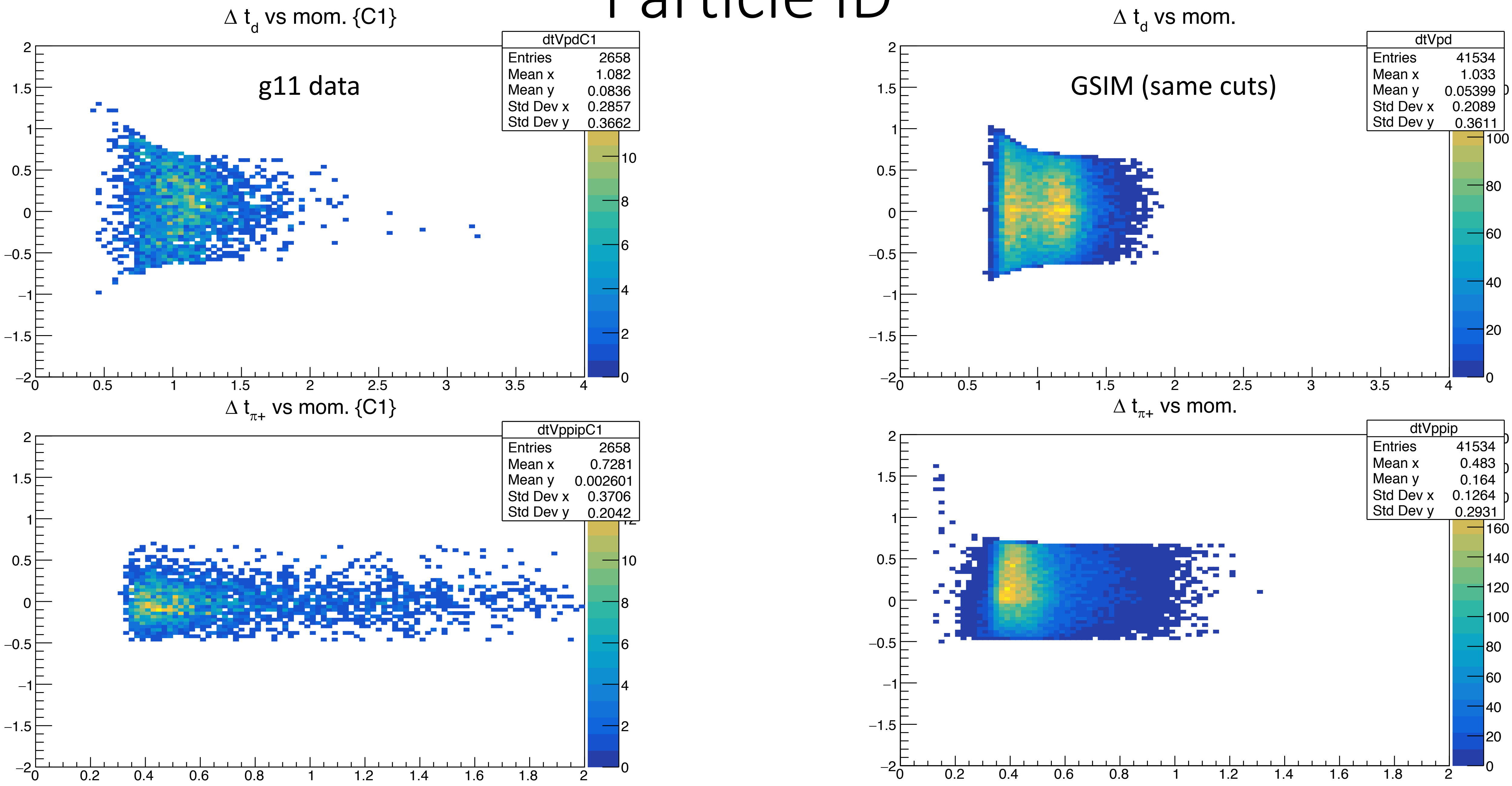


$\text{Cos}(\theta_{\pi 0})_{CM}$



$\text{Cos}(\theta_{\pi 0})_{CM}$

Particle ID


Δ t_d vs mom. {C1}
dtVpdC1
Entries 2658
Mean x 1.082
Mean y 0.0836
Std Dev x 0.2857
Std Dev y 0.3662
g11 data
Δ t_d vs mom.
dtVpd
Entries 41534
Mean x 1.033
Mean y 0.05399
Std Dev x 0.2089
Std Dev y 0.3611
GSIM (same cuts)
Δ t_π+ vs mom. {C1}
dtVppipC1
Entries 2658
Mean x 0.7281
Mean y 0.002601
Std Dev x 0.3706
Std Dev y 0.2042
Δ t_π+ vs mom.
dtVppip
Entries 41534
Mean x 0.483
Mean y 0.164
Std Dev x 0.1264
Std Dev y 0.2931
−2 −1.5 −1 −0.5 0 0.5 1 1.5 2
0 0.5 1 1.5 2 2.5 3 3.5 4
0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2
0 2 4 6 8 10
0 20 40 60 80 100
0 20 40 60 80 100 120 140 160