A study of the $\omega \to \pi^+\pi^-(\pi^0)$ decay in photoproduction at 3.6 GeV < E_{beam} < 5.45 GeV (CLAS-g12)

Status Report

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on behalf of

Andres Melo

this is his work of Master's Thesis

Universidad de la República, Uruguay

CLAS Hadron Spectroscopy Meeting , 6/18/2015

Outline

- **$p\pi^+\pi^-(\pi^0)$ (g-12) data**
- **extraction of the omega signal**
- **theory**
- **comparisons with theory**
- **summary**

Why this study of the ω decay?

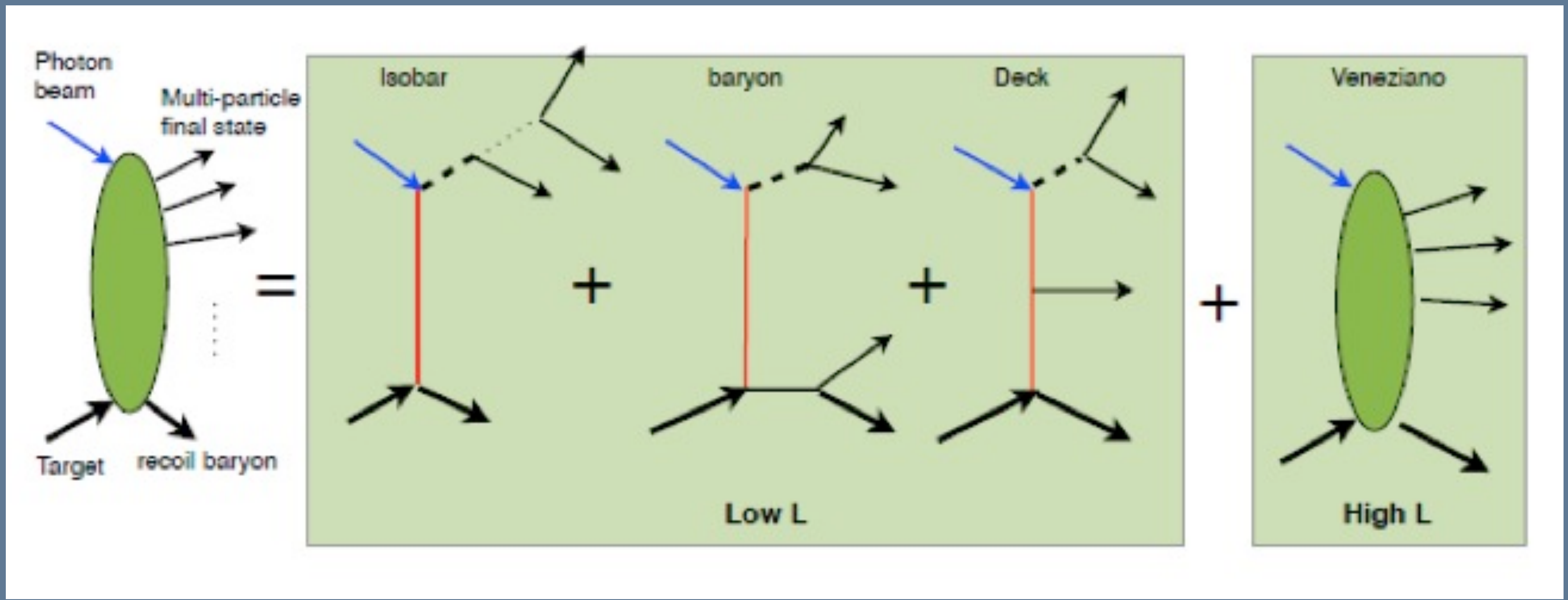
A physics model that extends the isobar model in PWA.

In this case a study of three-body decays (involved in many exotic searches)and comparison of different models with the isobar two-body calculations.

- Analyticity, Unitarity, crossing
- Regge theory
- Dispersion relations
- ...

Joint Physics Analysis Center
Igor Danilkin, et al

also B. Kubis et al.



g12 CLAS run

Search for new forms of hadronic matter in photoproduction

- Data taking completed in 2008
- Photon Energy up to 5.5 GeV
- More than 26 billion triggers (2-prong + 3-prong)
- Total Luminosity: 68 pb^{-1}
- Data processing completed and physics analysis in progress

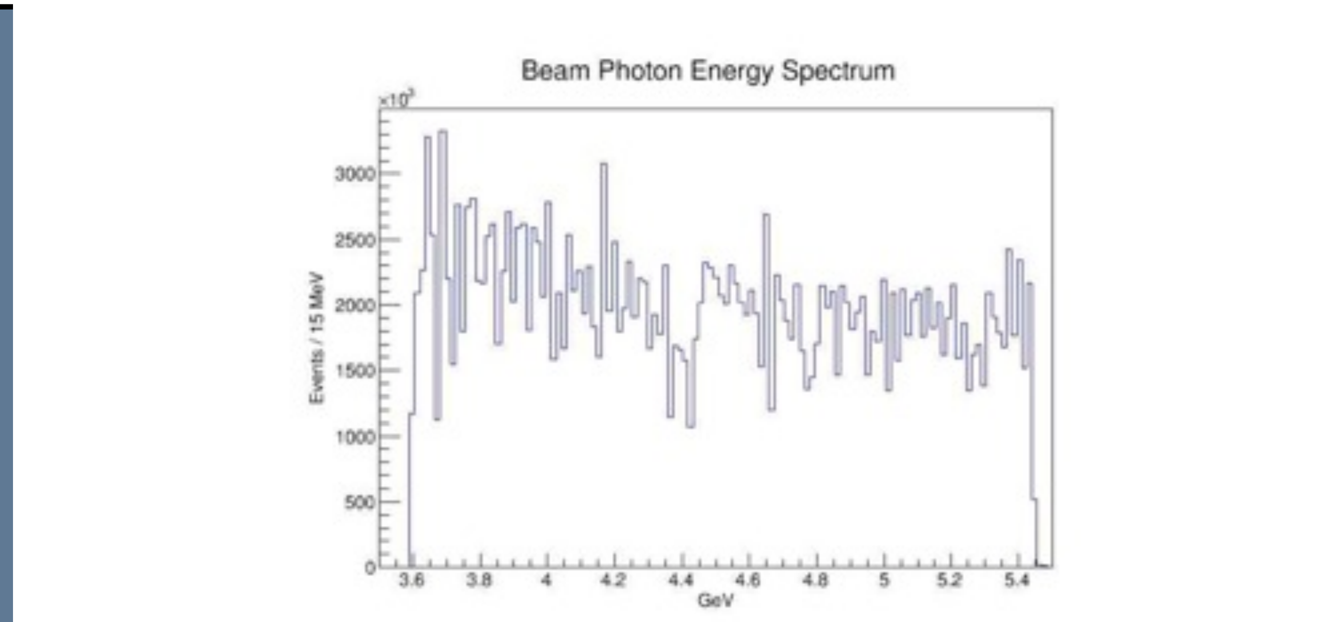
General ANALYSIS PROCEDURE being reviewed.

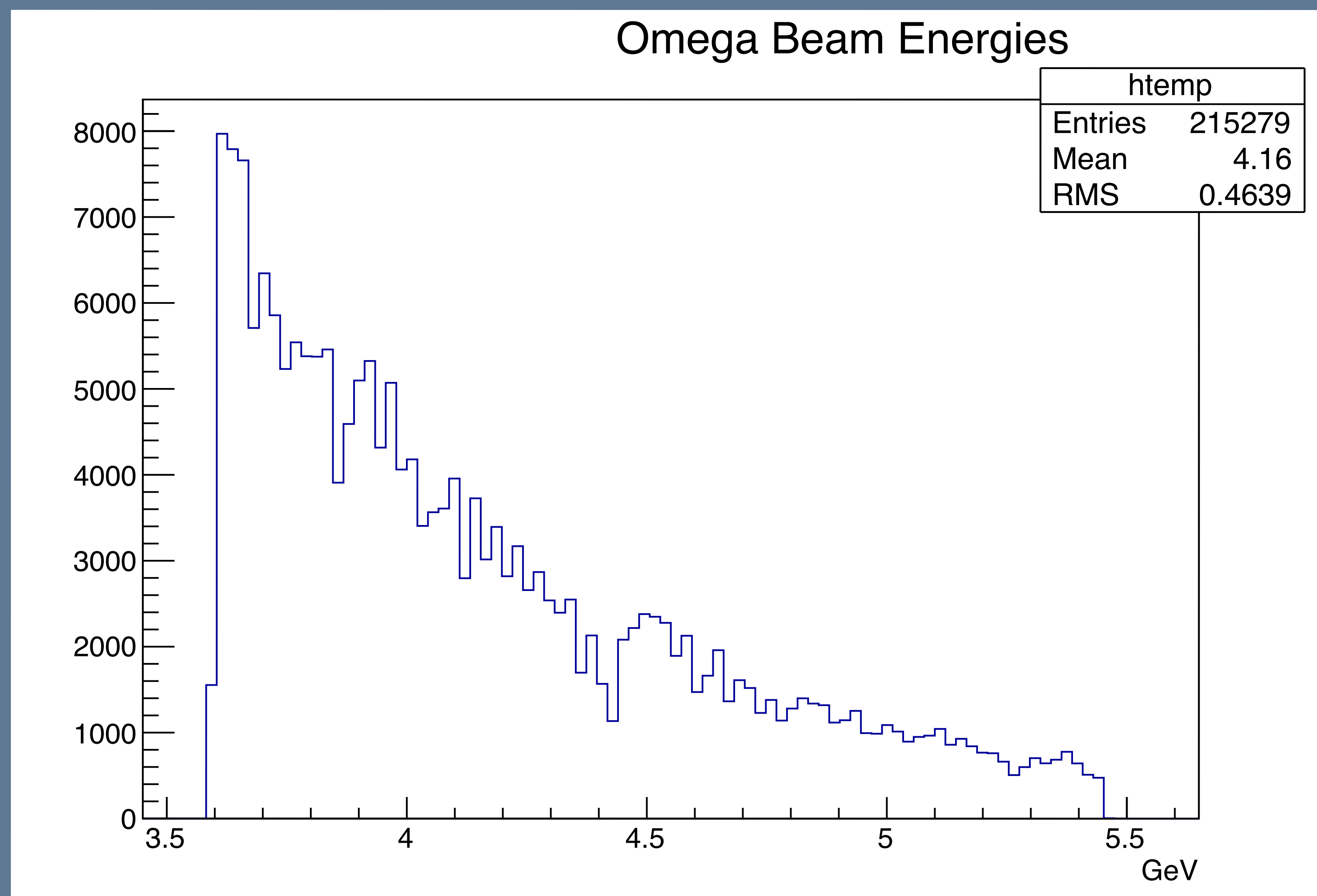
$\gamma p \rightarrow \pi^+\pi^+\pi^-(n)$
$\gamma p \rightarrow (\pi^0)\pi^+\pi^- p$
$\gamma p \rightarrow K^+K^+ (\Xi^{*-})(1530)$
$\gamma p \rightarrow pK^+K^- (\eta\Phi)$
$\gamma p \rightarrow (p\pi^{+\Delta})\ \pi^-(\eta)$
$\gamma p \rightarrow \pi^+K^+K^-(n)$
$\gamma p \rightarrow e^+e^-p$
...

Meson Spectroscopy
- Search for exotic mesons
- Study of Strangeonia
- …

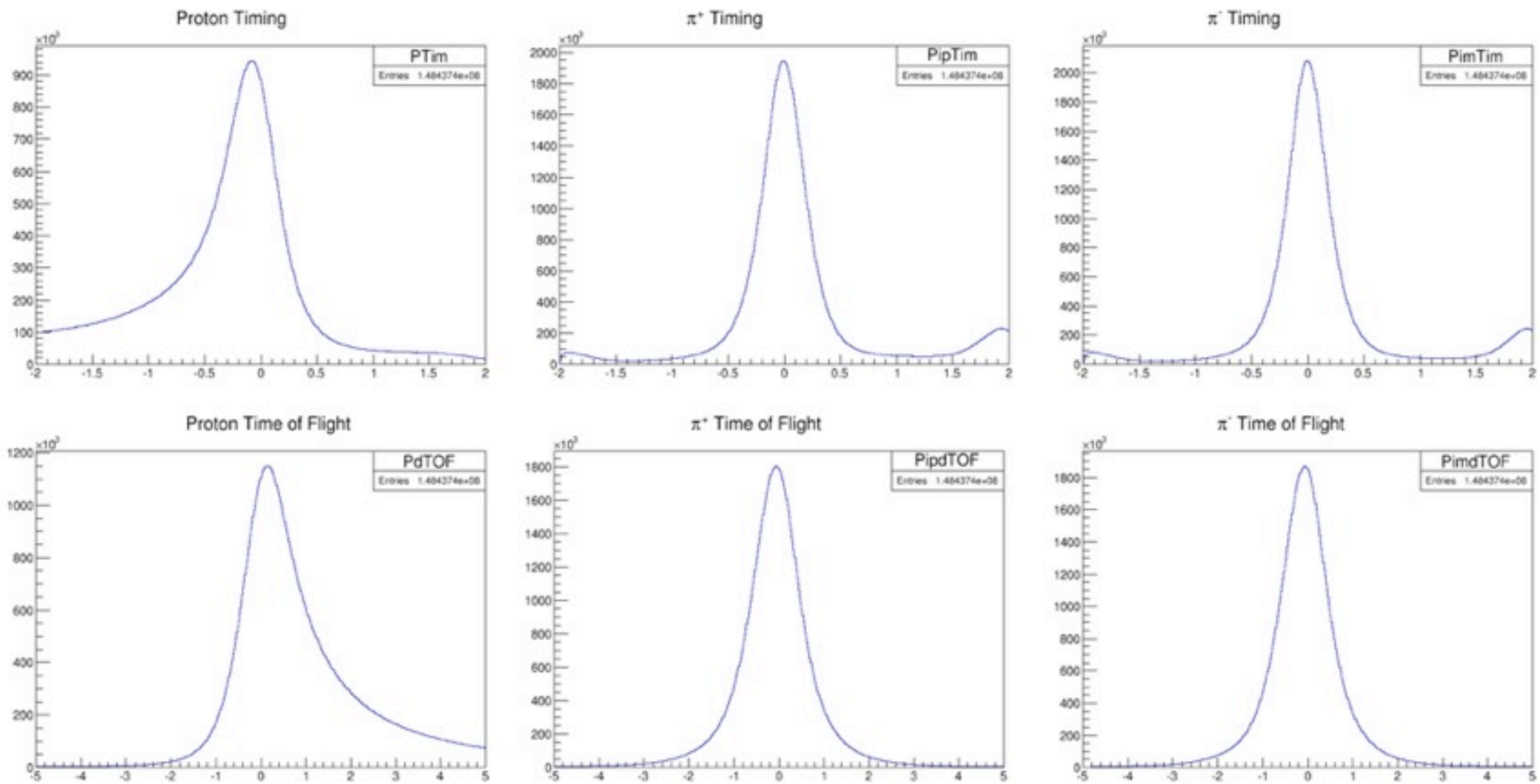
Baryon Spectroscopy
- Cascades

$\gamma p \rightarrow (\pi^0)\pi^+\pi^- p$



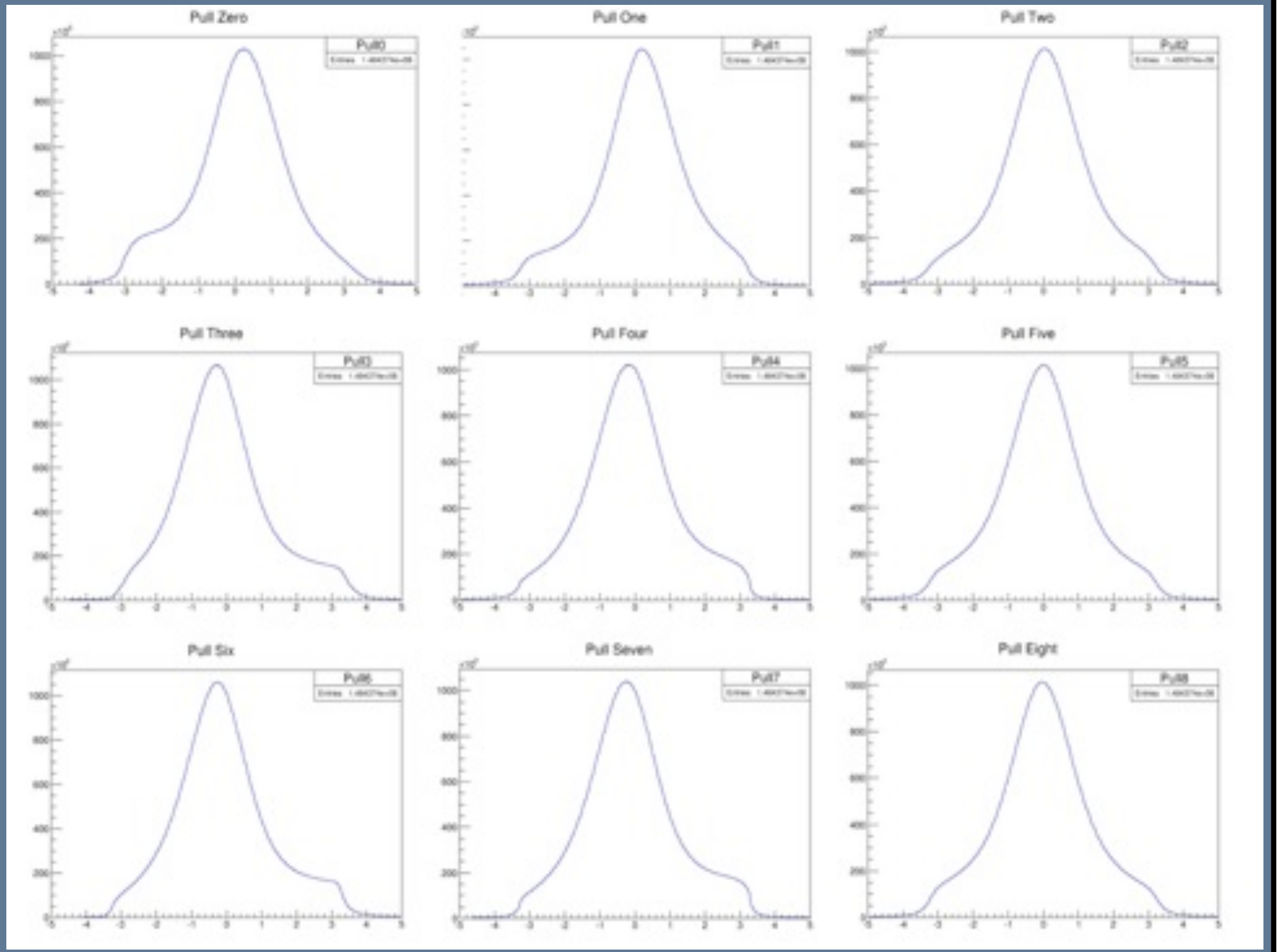


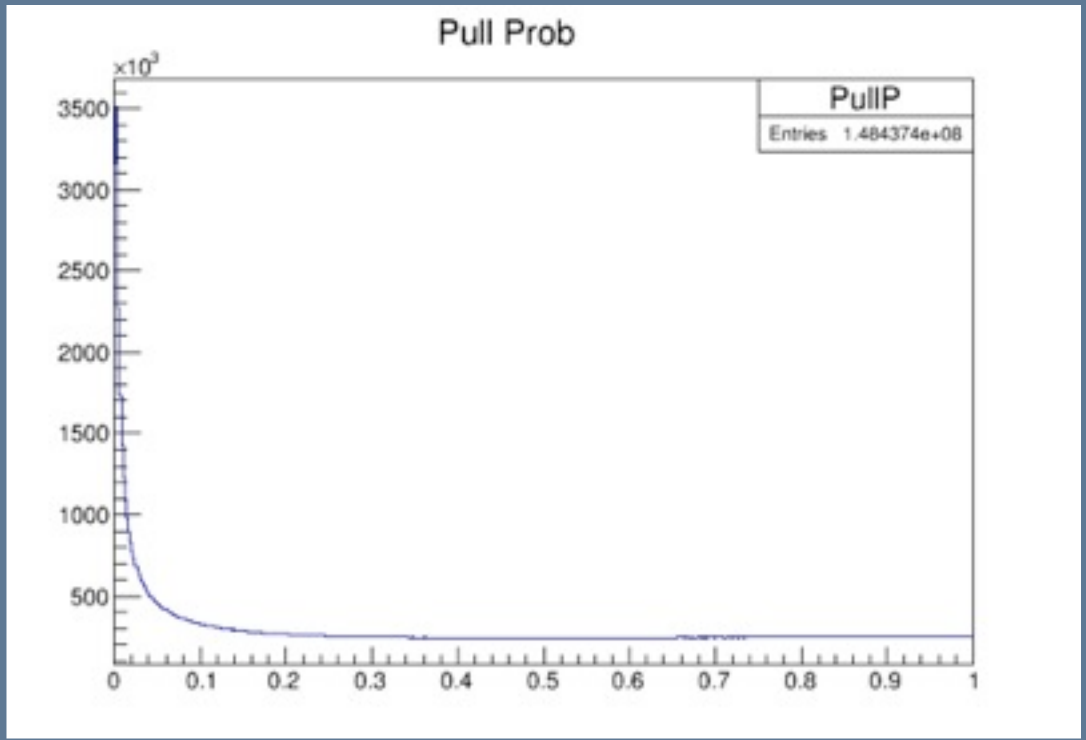
We also performed cuts on the particles timing (ToF), which is the difference between the time of flight measured (ToF-SC) and the calculated through the pathlength assuming a given ID mass. We used $(dTOF\ \pi^+)^2+(dTOF\ \pi^-)^2<4, (dTOF\ p)^2+(dTOF\ \pi^-)^2<4$



Kinematical Fit to π^0

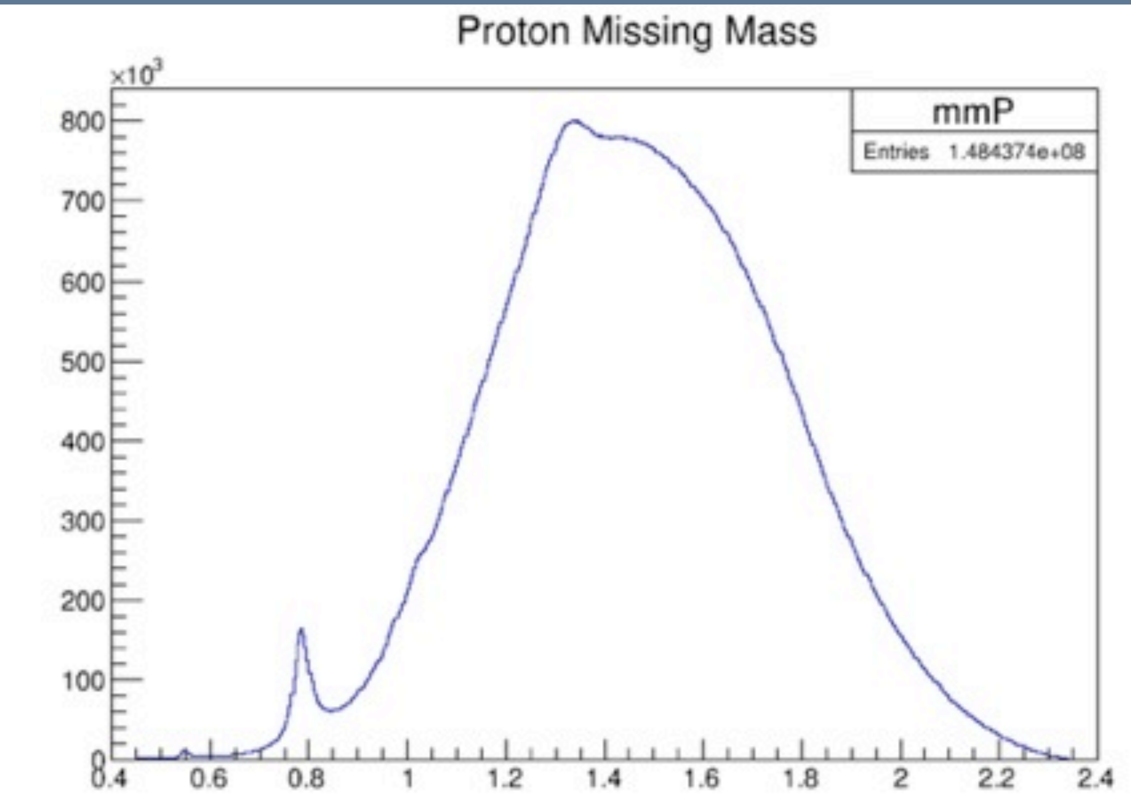
using standard g12 KF -> see g12 general procedures note



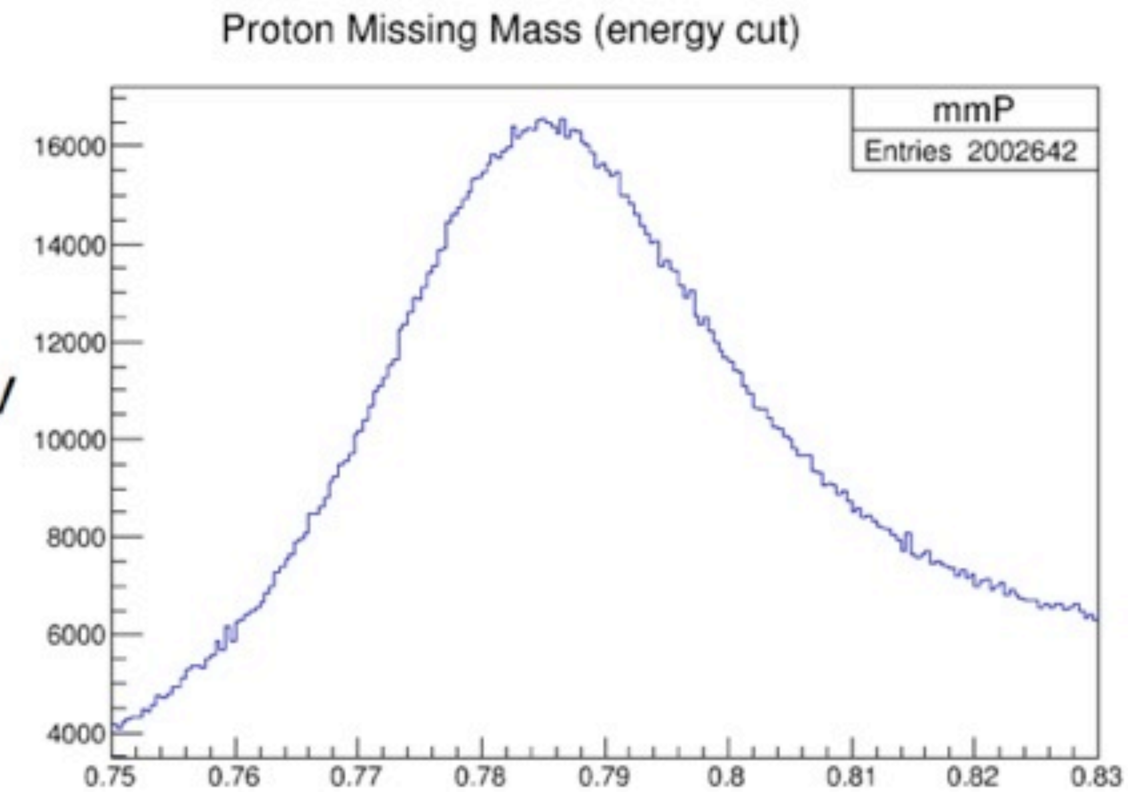


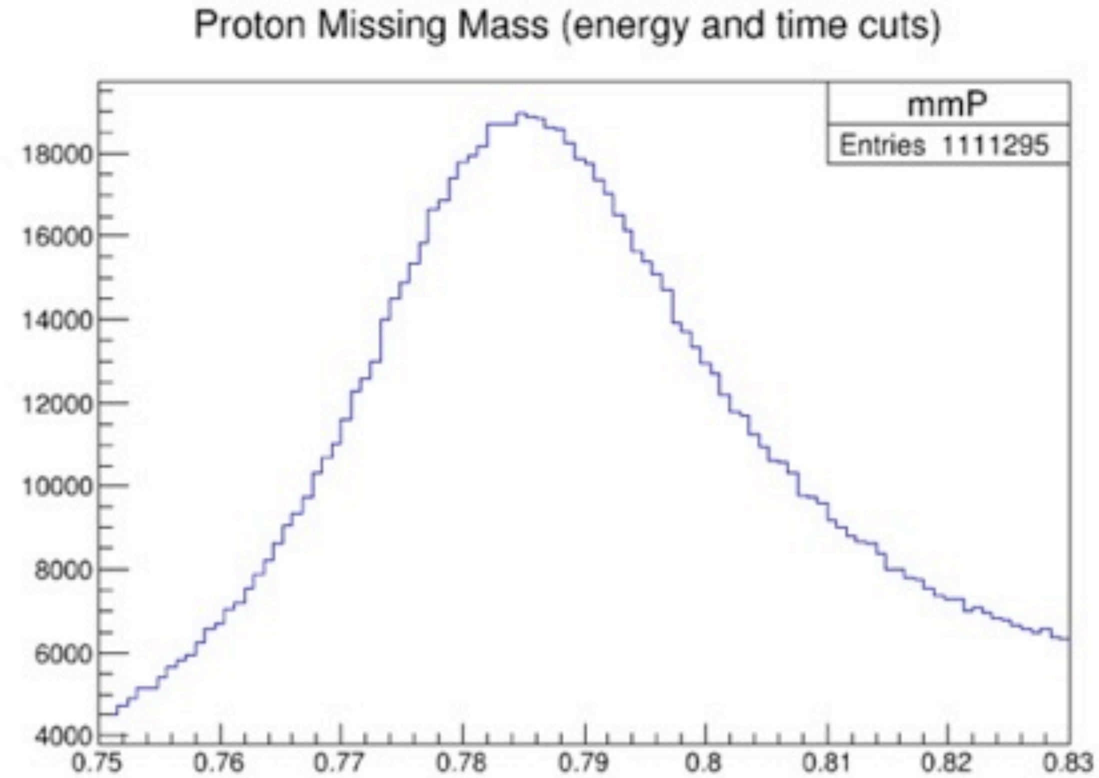
$\gamma p \rightarrow (\pi^0)\pi^+\pi^- p$

Full mass region ⟶

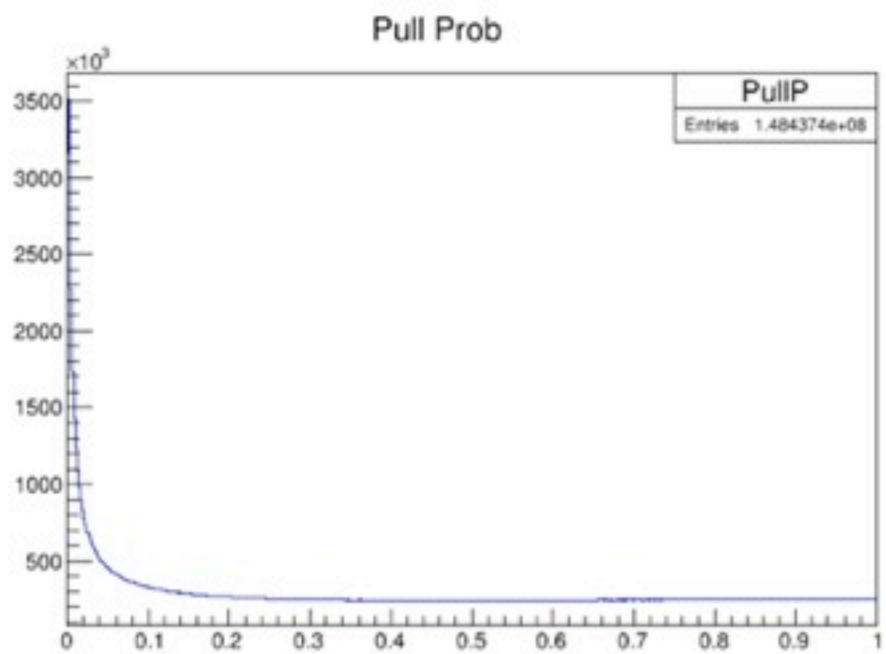


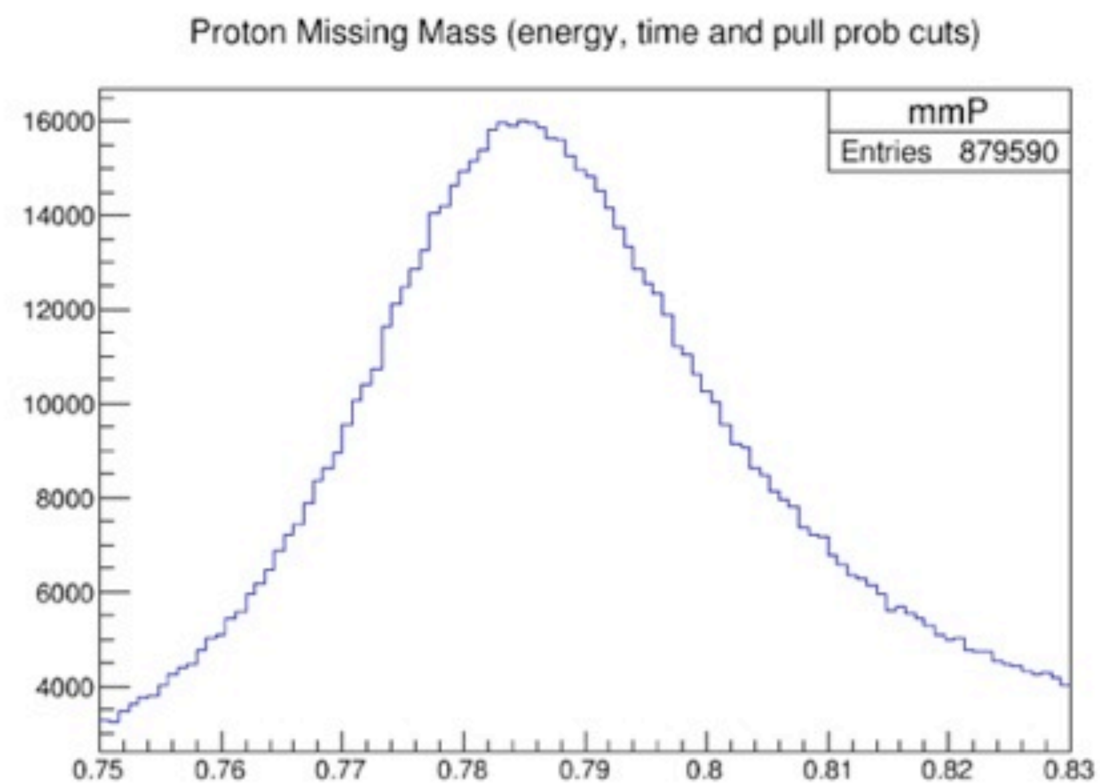
We will focus on the omega mass zone:
750 MeV < proton missing mass < 830 MeV
and perform the mentioned energy cut:
3.6 GeV < photon energy

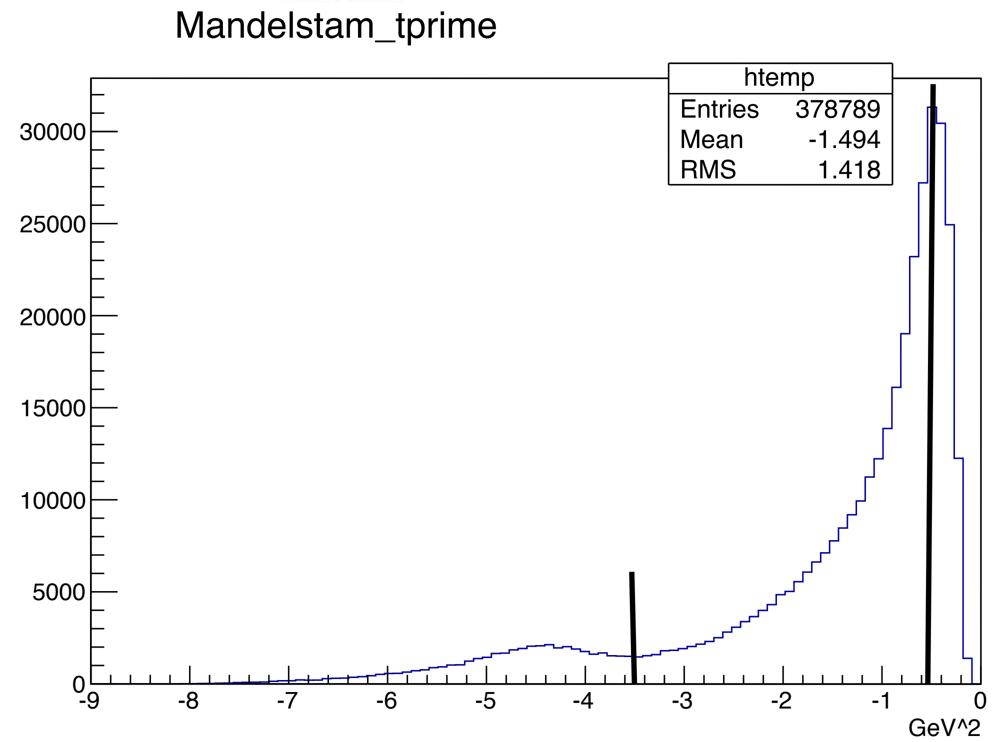


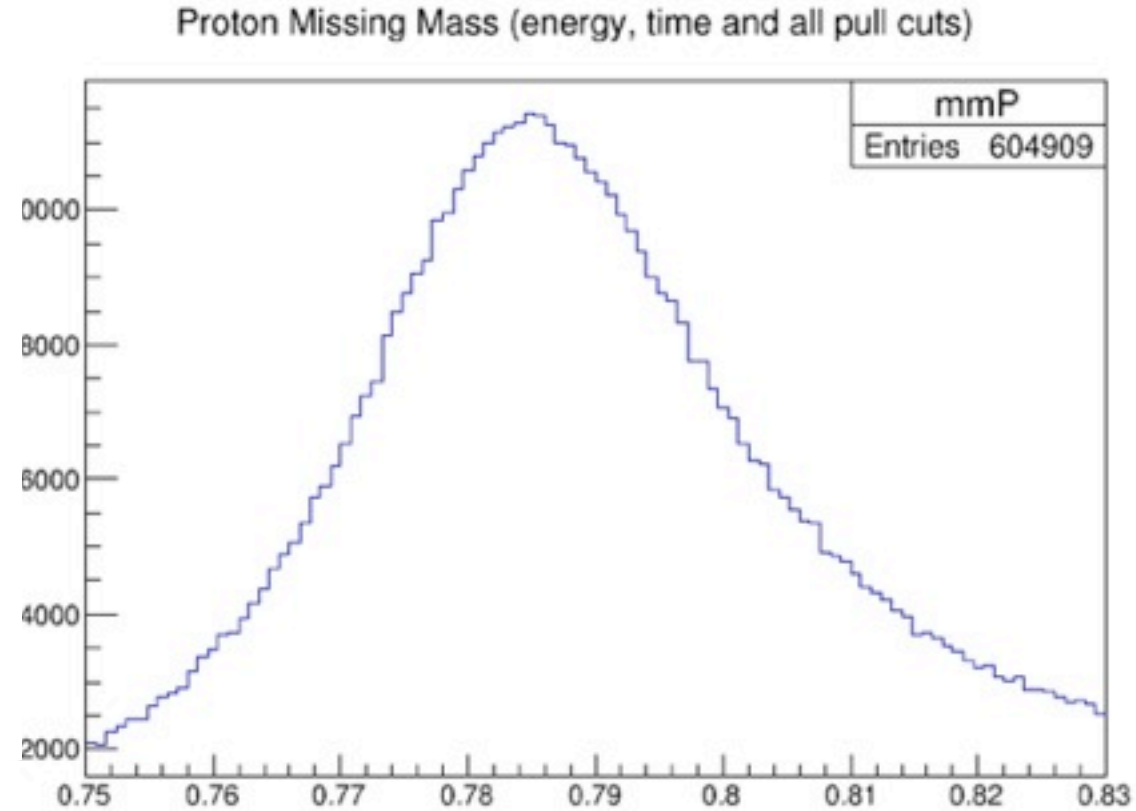


Then we impose Pull Prob > 0.15.

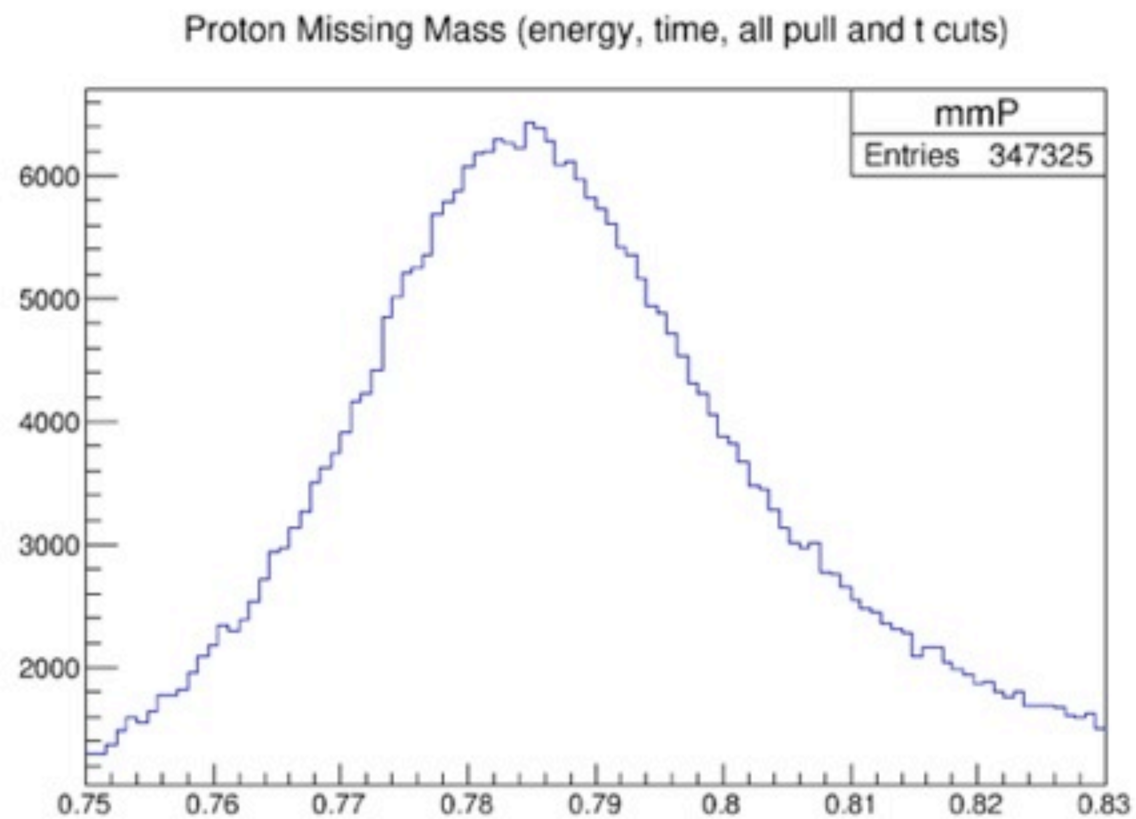






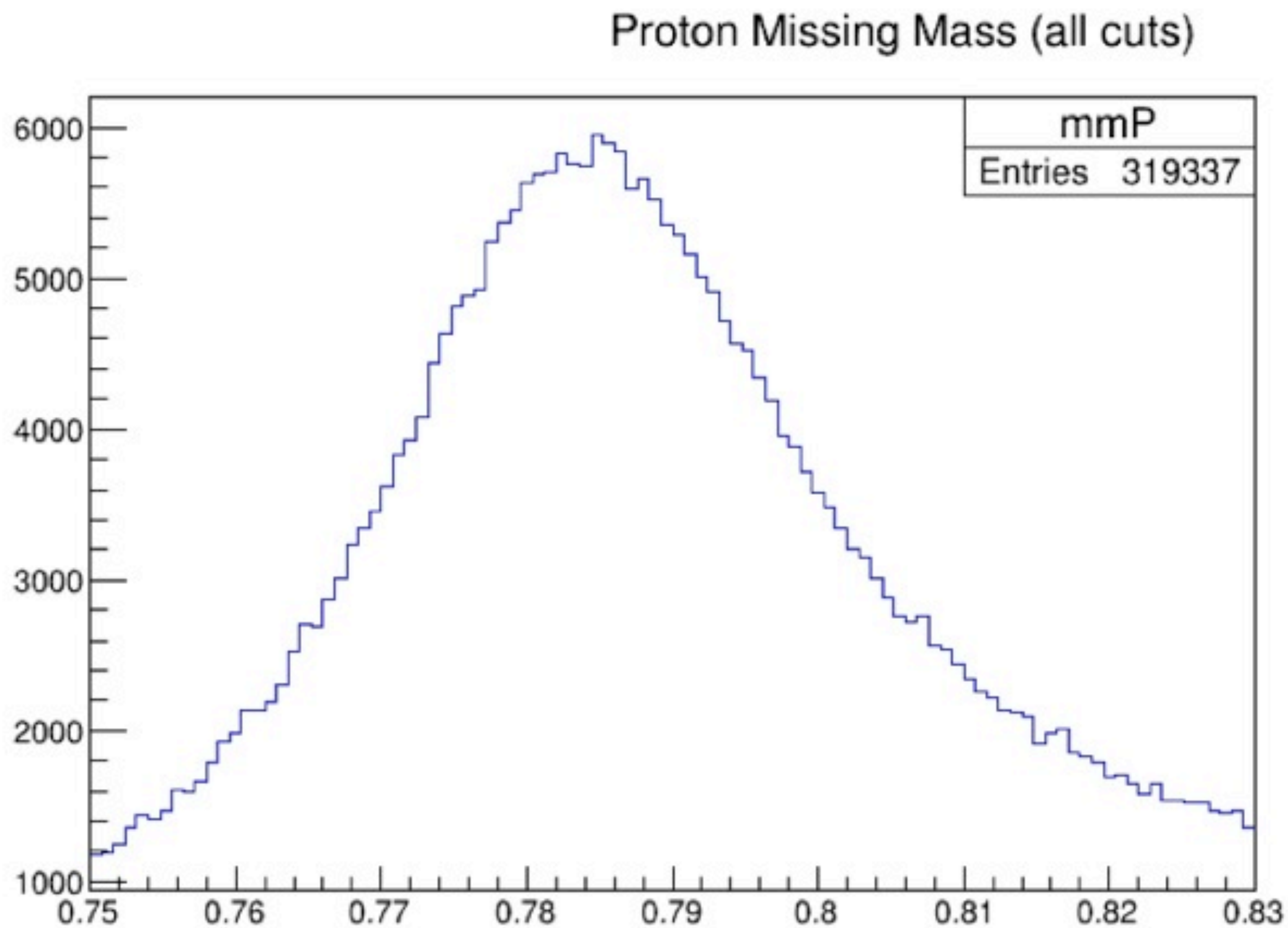


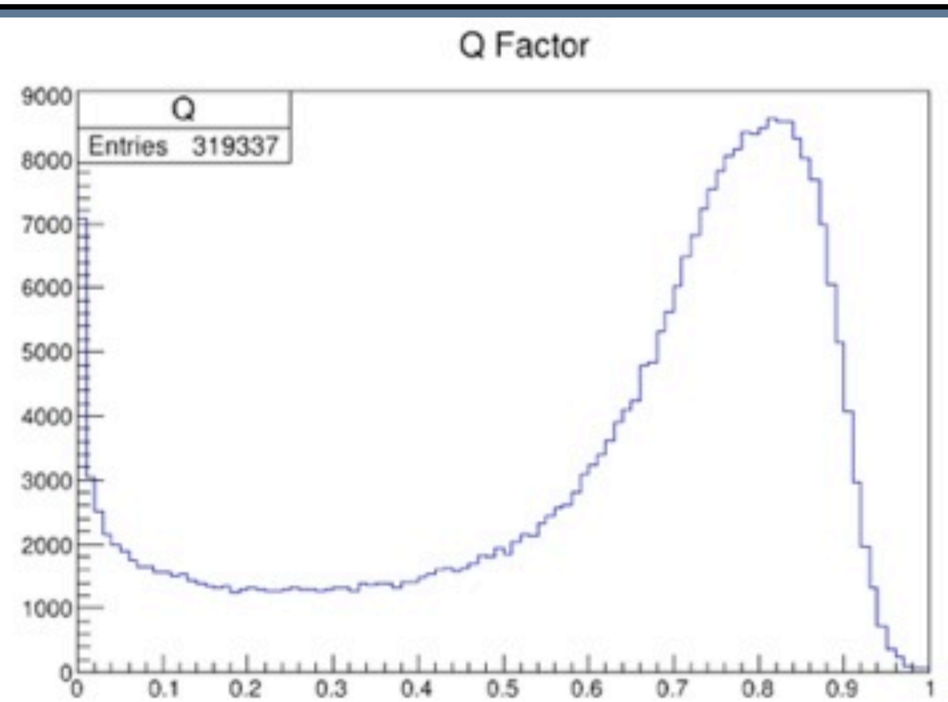
Also, a cut on the Mandelstam variable t' was performed: 3.5 < t' < -0.6



Finally, the fiducial and TOF knockout cuts are considered.

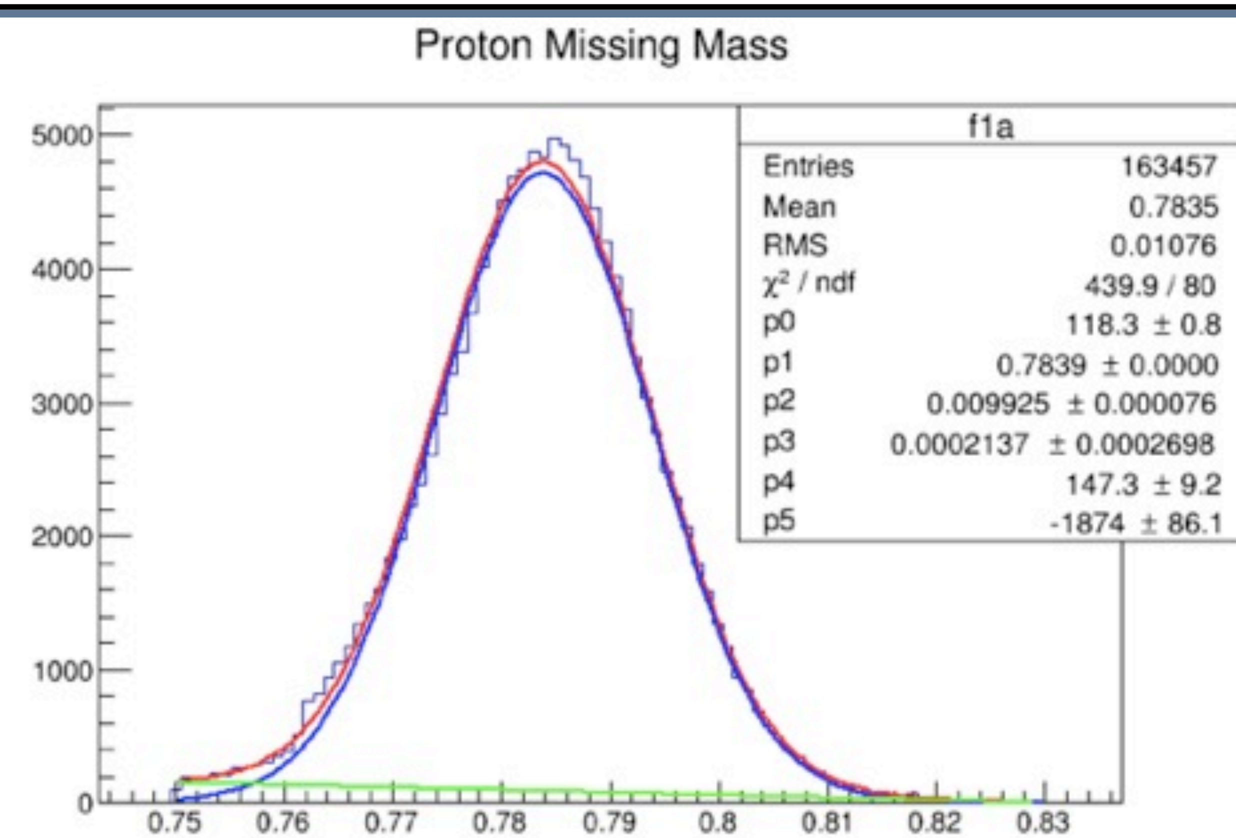
(standard g12 - see general note)

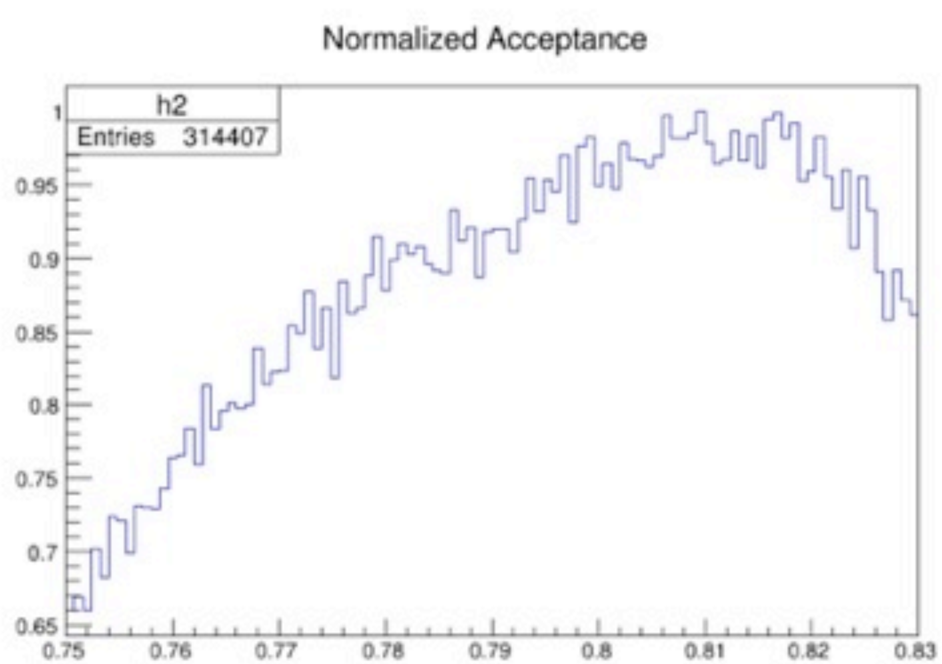


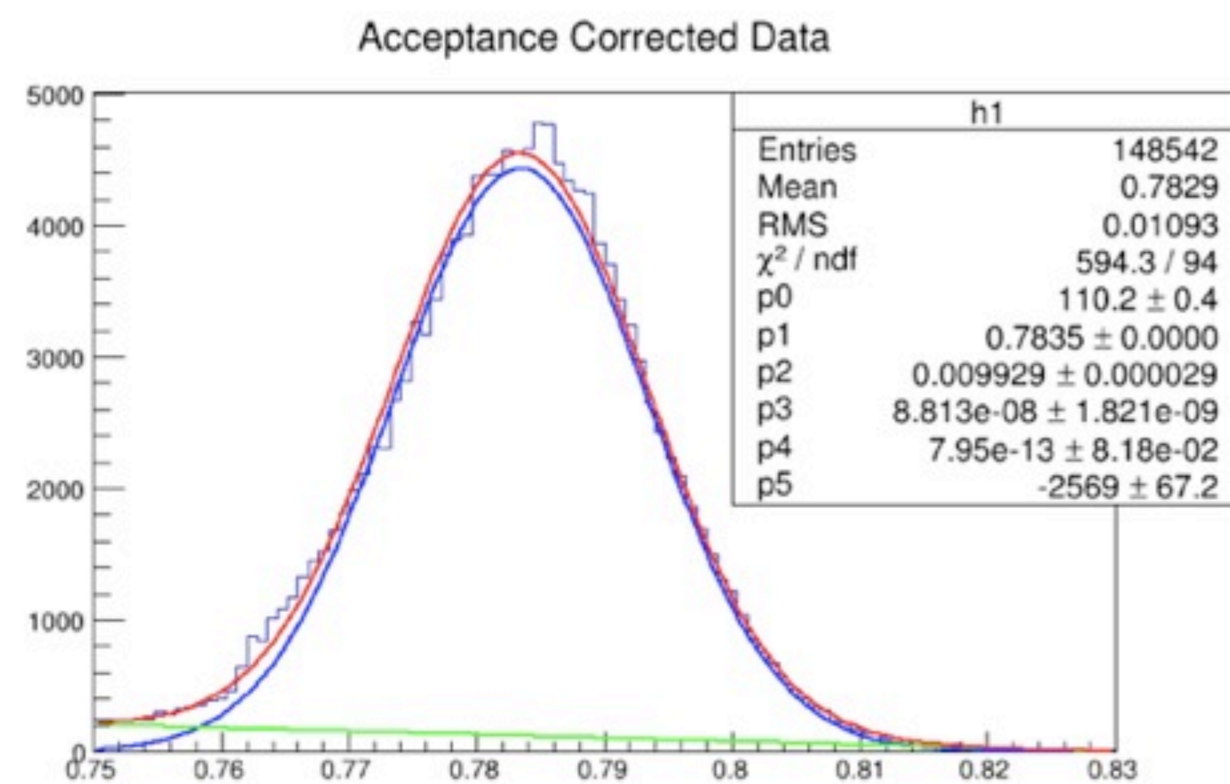


Qf > 0.7

(Qf as defined in Williams Thesis)







JLAB-THY-14-1960

Dispersive Analysis of $\omega/\phi \to 3\pi$, $\pi\gamma^*$

I.V. Danilkin,[1,*] C. Fernández-Ramírez,[1] P. Guo,[2,3] V. Mathieu,[2,3] D. Schott,[4] M. Shi,[1,5] and A. P. Szczepaniak[1,2,3]
(Joint Physics Analysis Center)

Dispersive analysis of $\omega \to 3\pi$ and $\phi \to 3\pi$ decays

F. Niecknig, B. Kubis, and S. P. Schneider, Eur.Phys.J. **C72**, 2014 (2012).

Franz Niecknig, Bastian Kubis, Sebastian P. Schneider

Helmholtz-Institut für Strahlen- und Kernphysik (Theorie) and Bethe Center for Theoretical Physics, Universität Bonn, D–53115 Bonn, Germany

$$\boxed{\frac{d^2\Gamma}{ds\,dt} = \frac{1}{(2\pi)^3}\frac{1}{32M^3}\frac{1}{3}P(s,t)\,|F(s,t,u)|^2}$$

$$\text{P(s,t)} = \; s\,t\,u - m_\pi^2\left(M^2 - m_\pi^2\right)^2 .$$

$$F(s) = \Omega(s)\left(\frac{1}{\pi}\int_{s_\pi}^{s_i} ds' \frac{\rho(s')\,t^*(s')}{\Omega^*(s')}\frac{\hat{F}(s')}{s'-s} + \Sigma(s)\right). \tag{31}$$

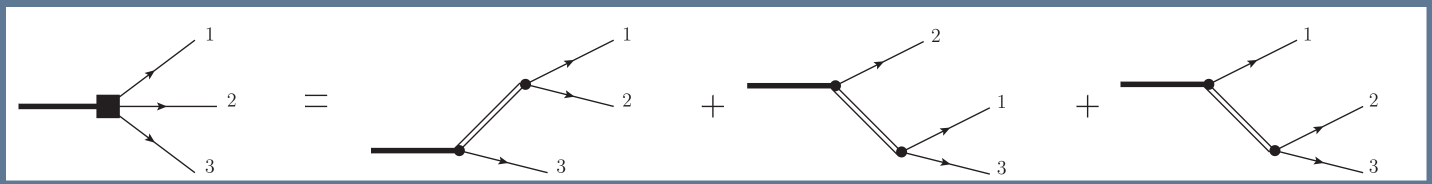


FIG. 1: Isobar decomposition.

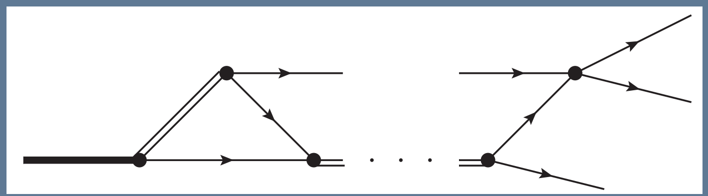


FIG. 2: Crossed channel rescattering effects.

$$\Sigma(s) = \sum_{i=0}^{\infty} a_i\, \omega^i(s)$$

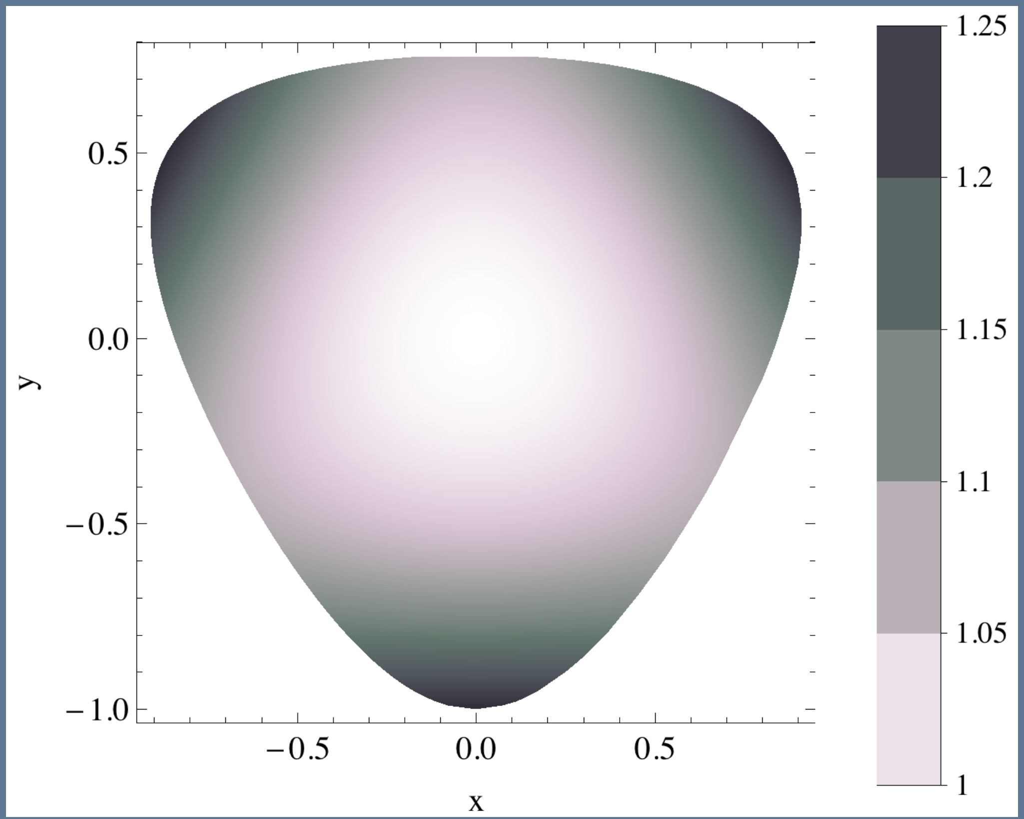
$$\boxed{F(s,t,u)=F_o(s,t)+a_oF_1(s,t)}$$

The variable

$$\omega(s) = \frac{\sqrt{s_i - s_E} - \sqrt{s_i - s}}{\sqrt{s_i - s_E} + \sqrt{s_i - s}}$$

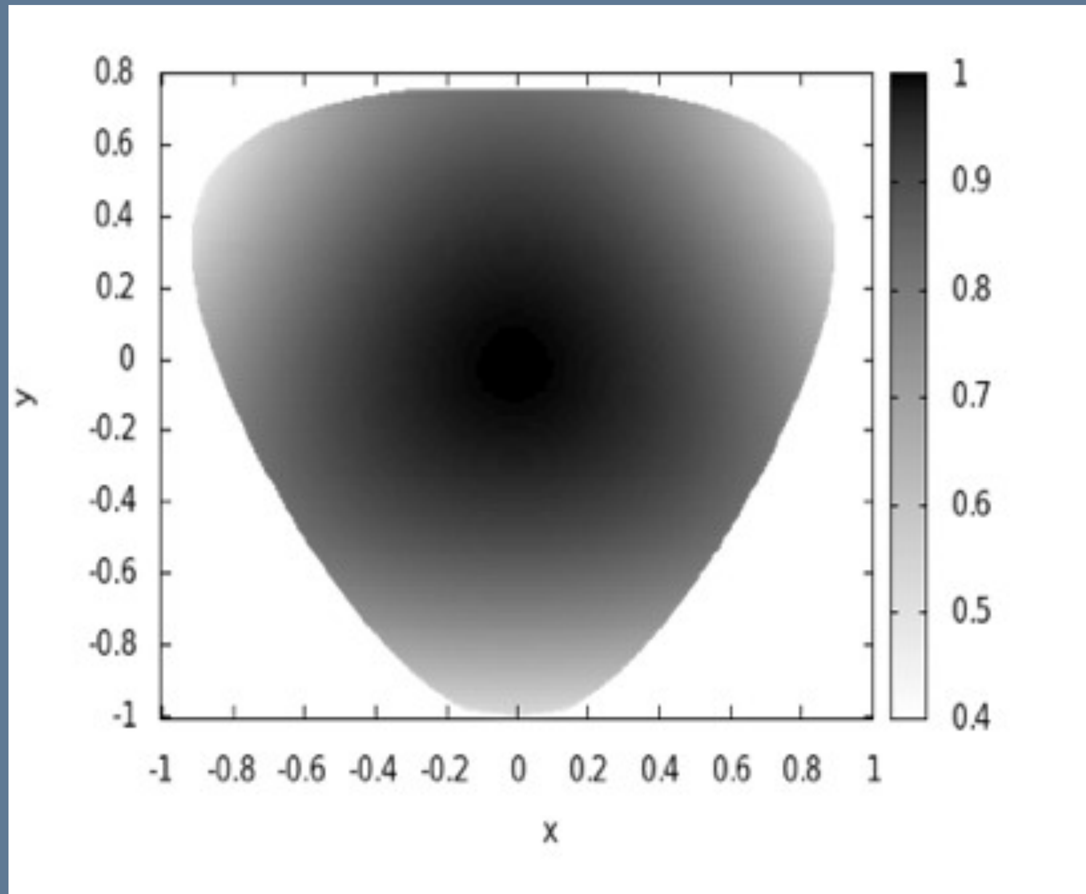
(code available in the web at: http://cgl.soic.indiana.edu/jpac/)

Dalitz Analysis in x vs y

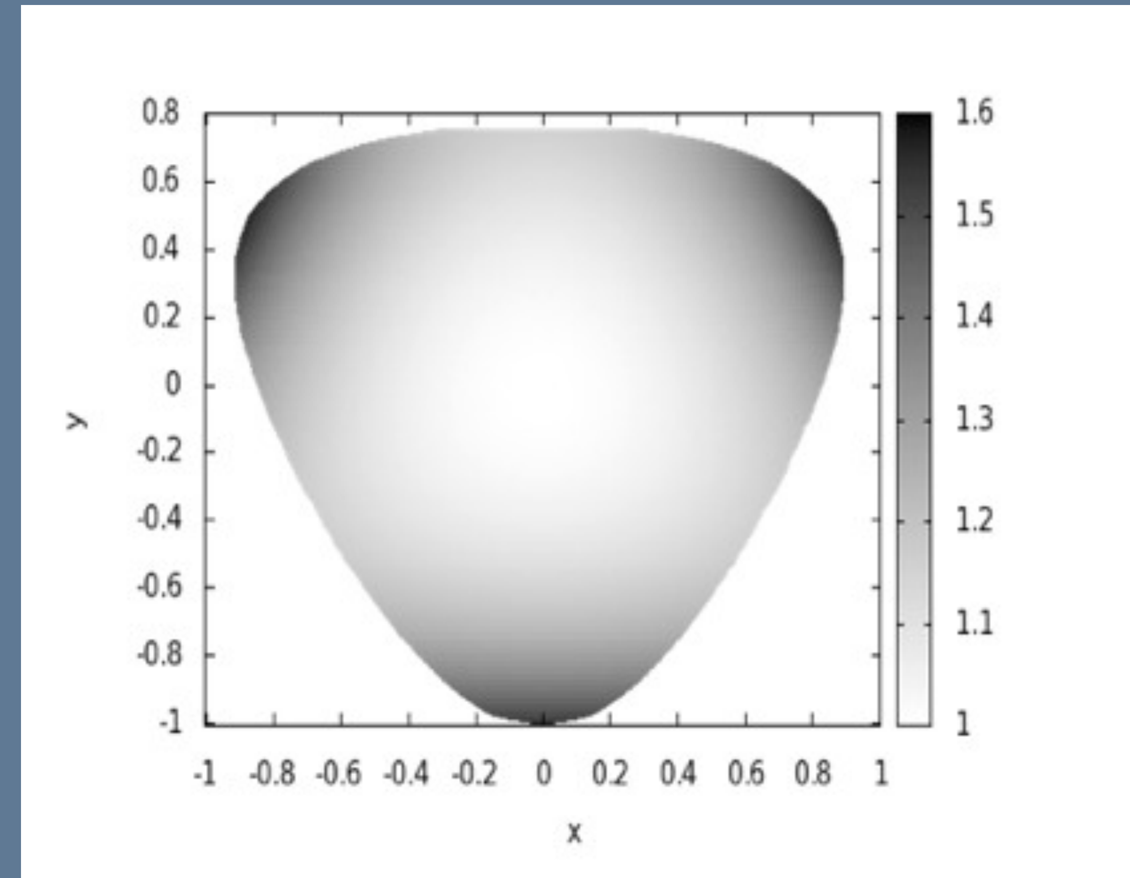


$$x = \frac{\sqrt{3}}{Q}(T_1 - T_2) = \frac{\sqrt{3}(t-u)}{2M(M-3\,m_\pi)},$$
$$y = \frac{3\,T_3}{Q} - 1 = \frac{3(s_c - s)}{2M(M-3m_\pi)}\,.$$

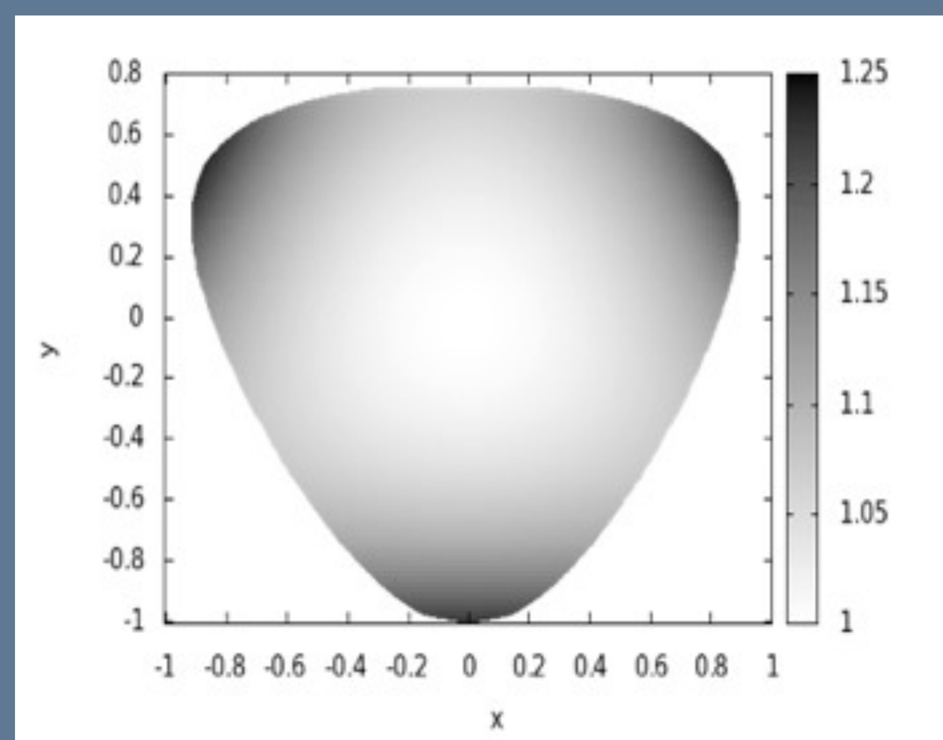
$a_o=0$



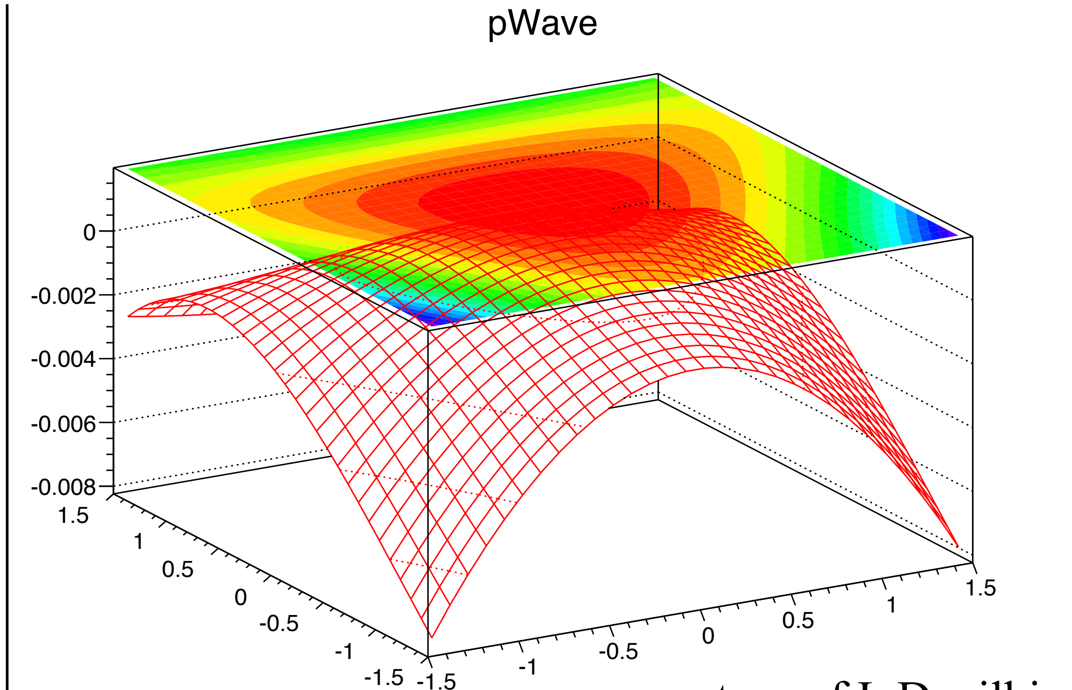
a_o=-10



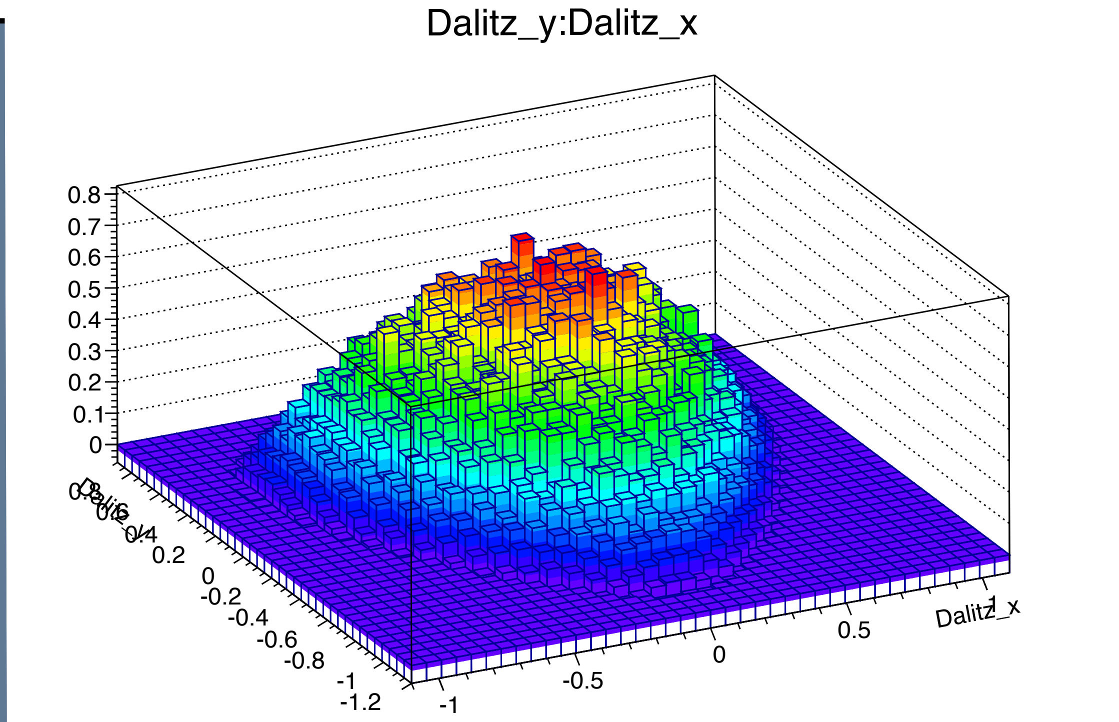
a_o=10

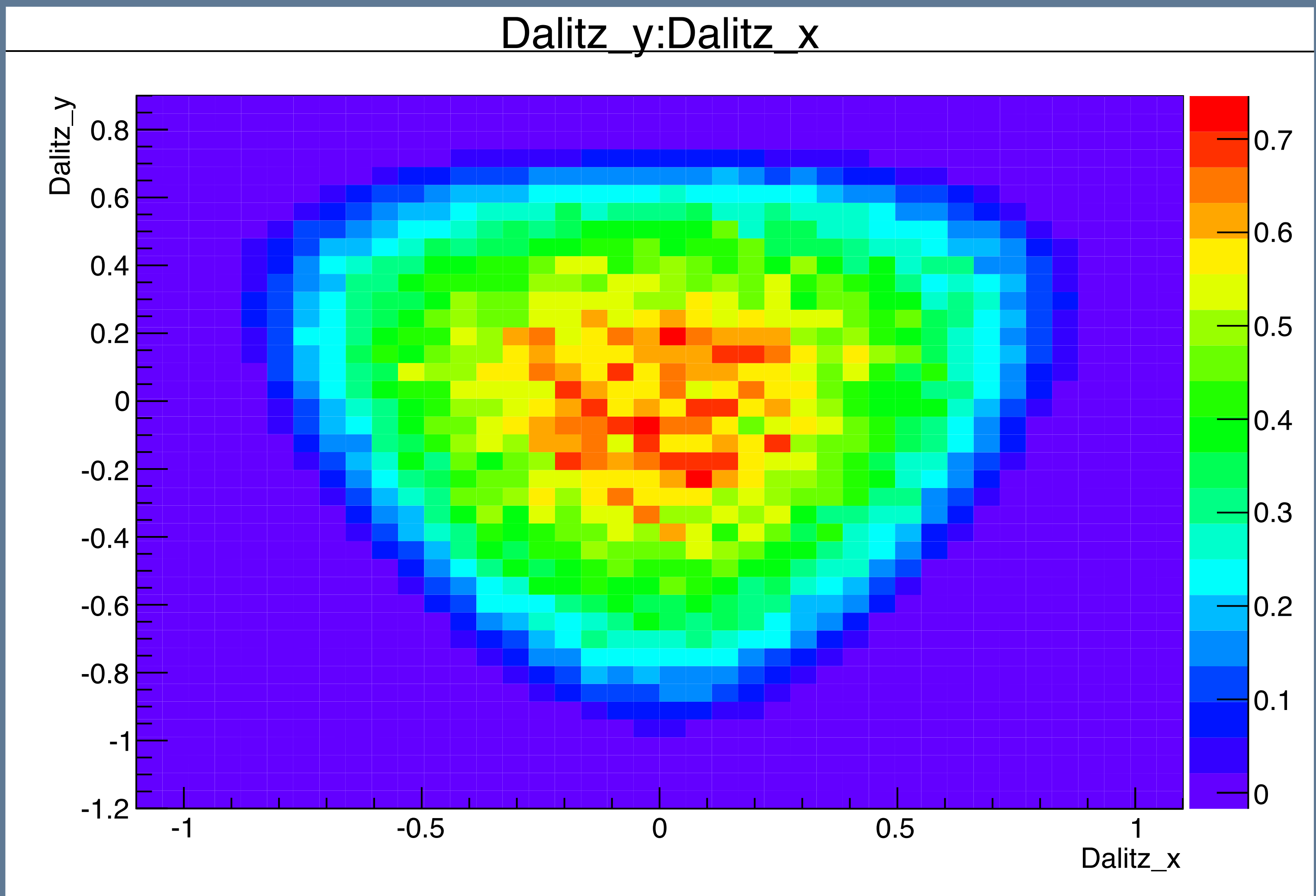


a_o=0



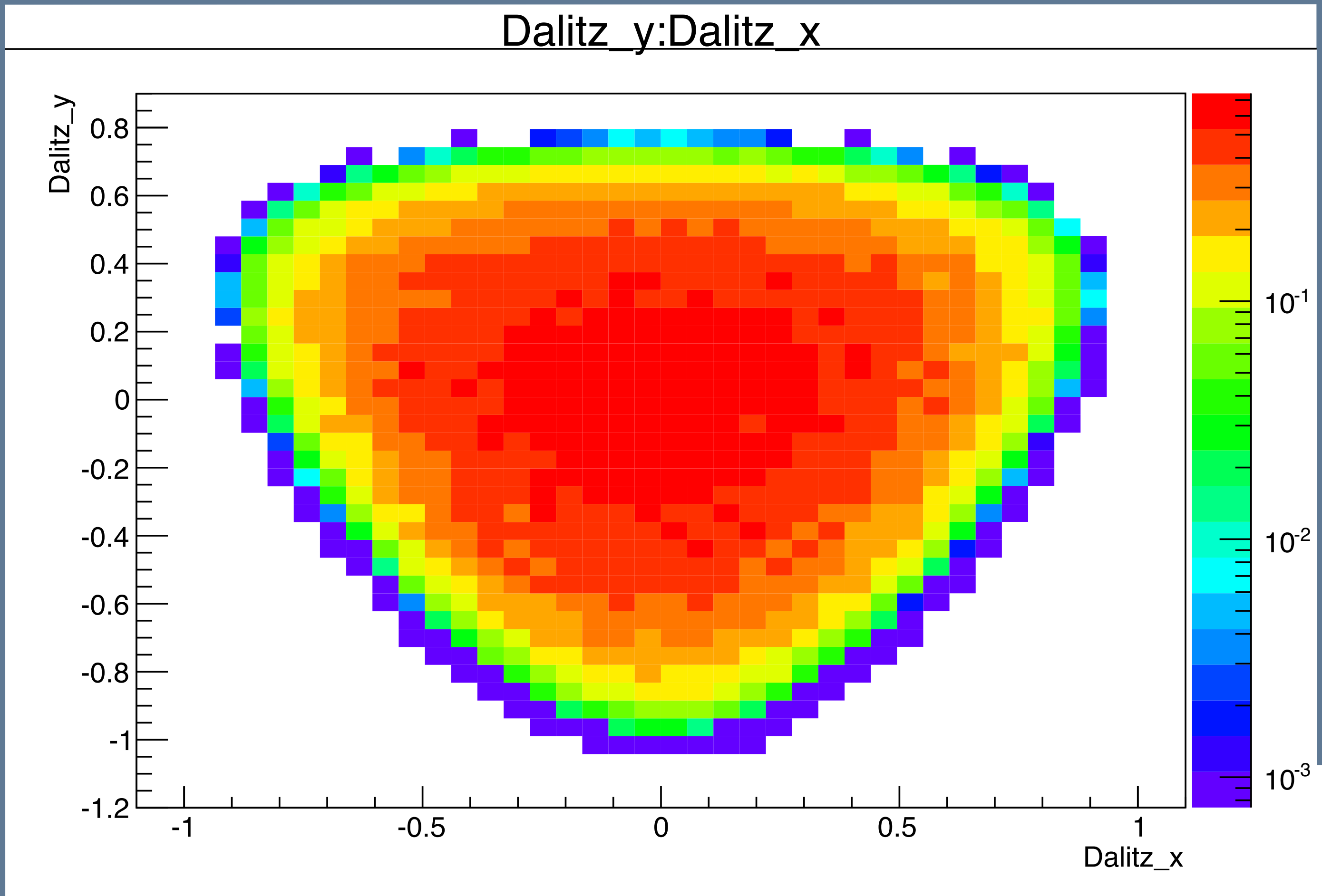
courtesy of I. Danilkin

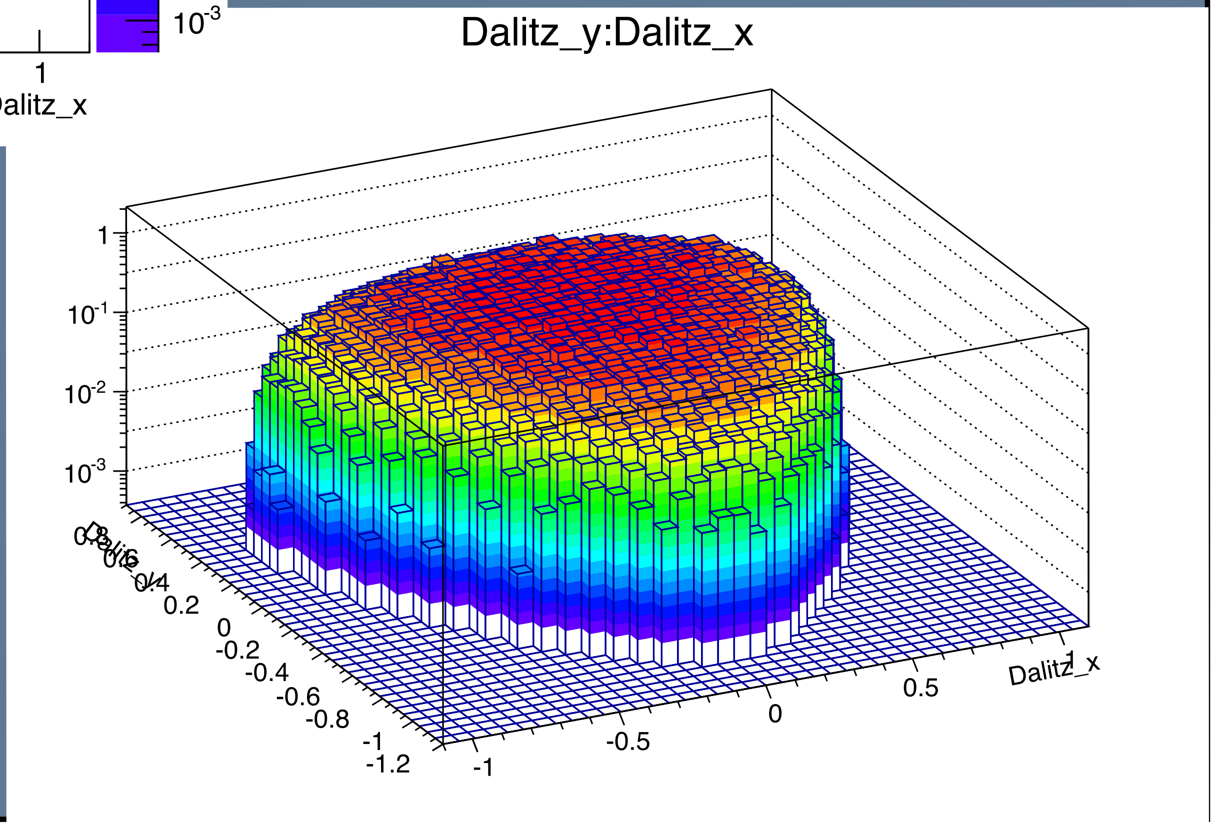


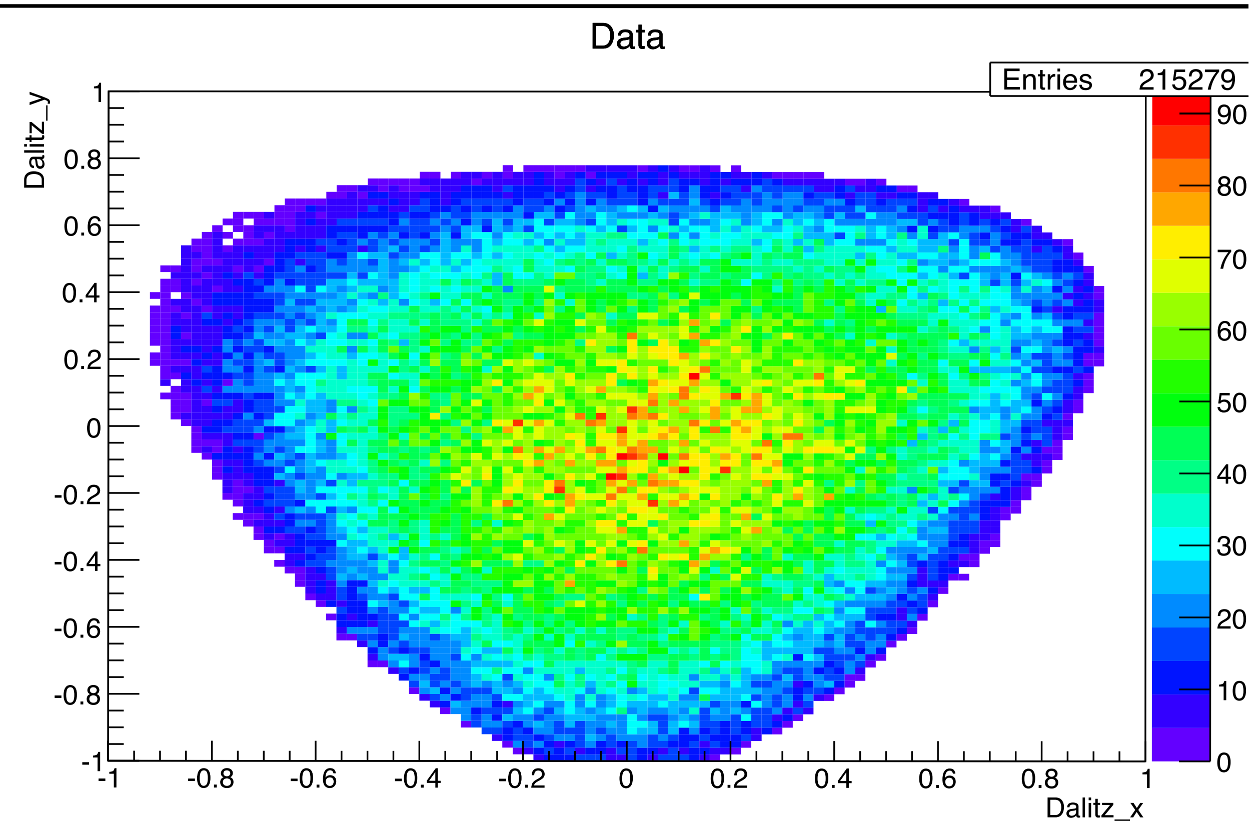


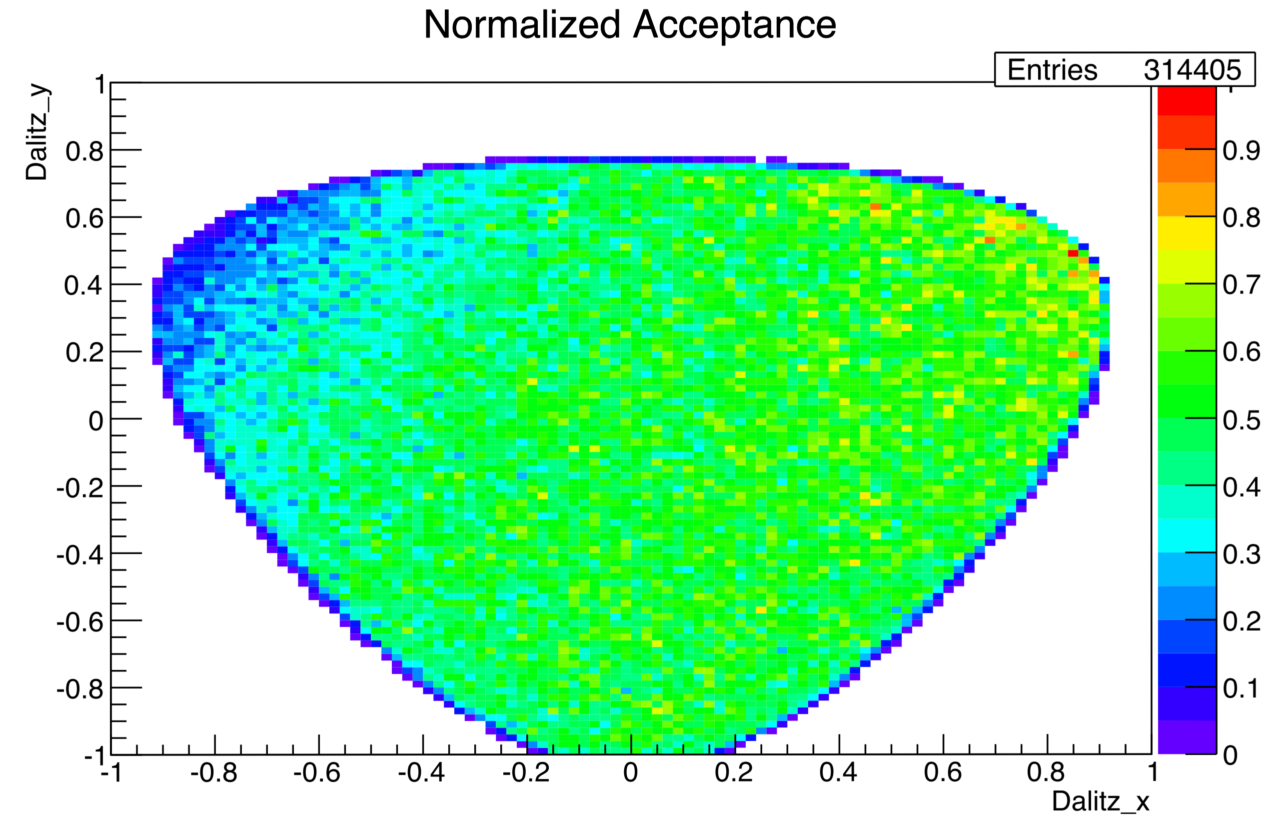
P(s,t) factor

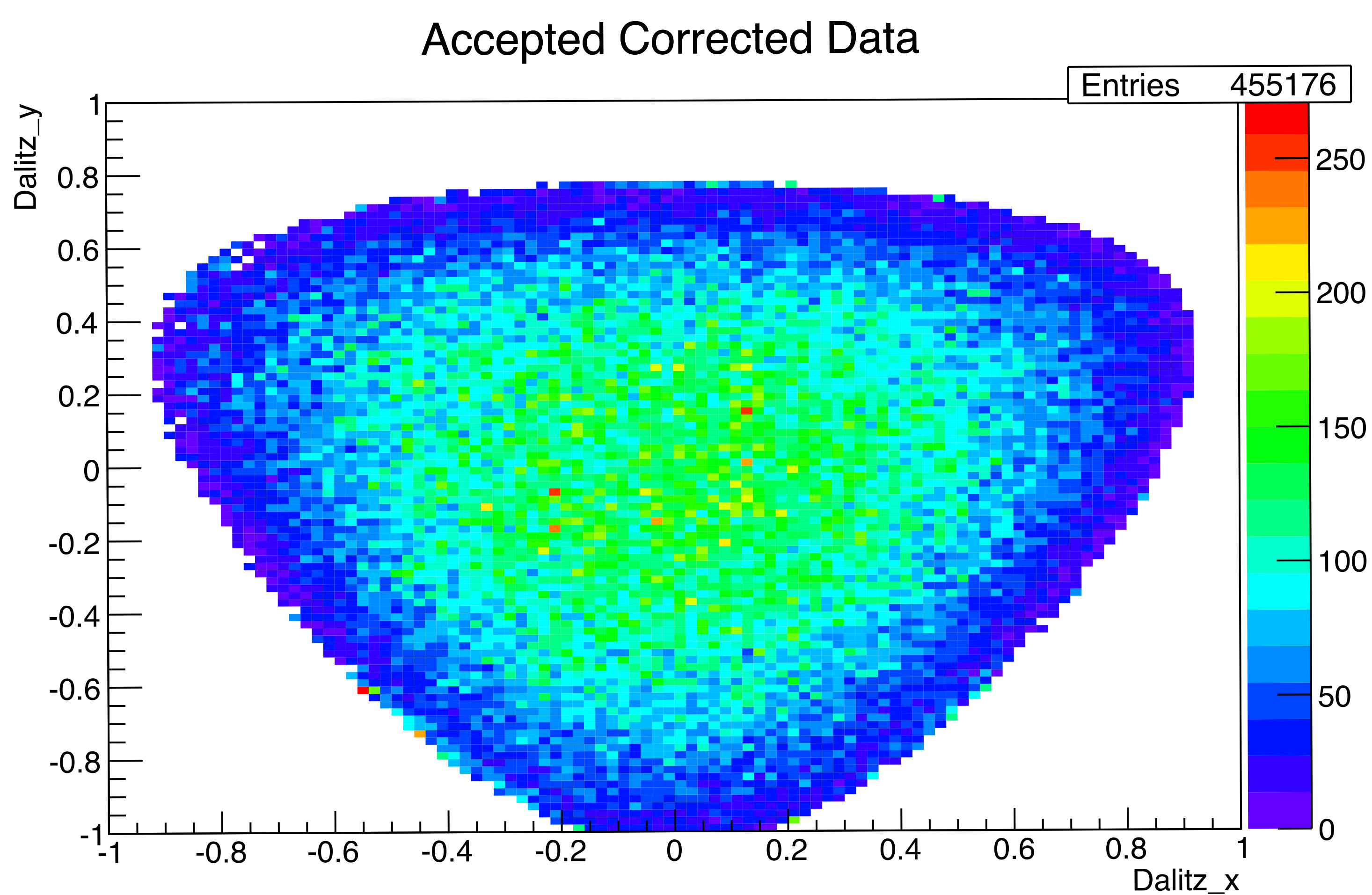
P-factor on log-z scale





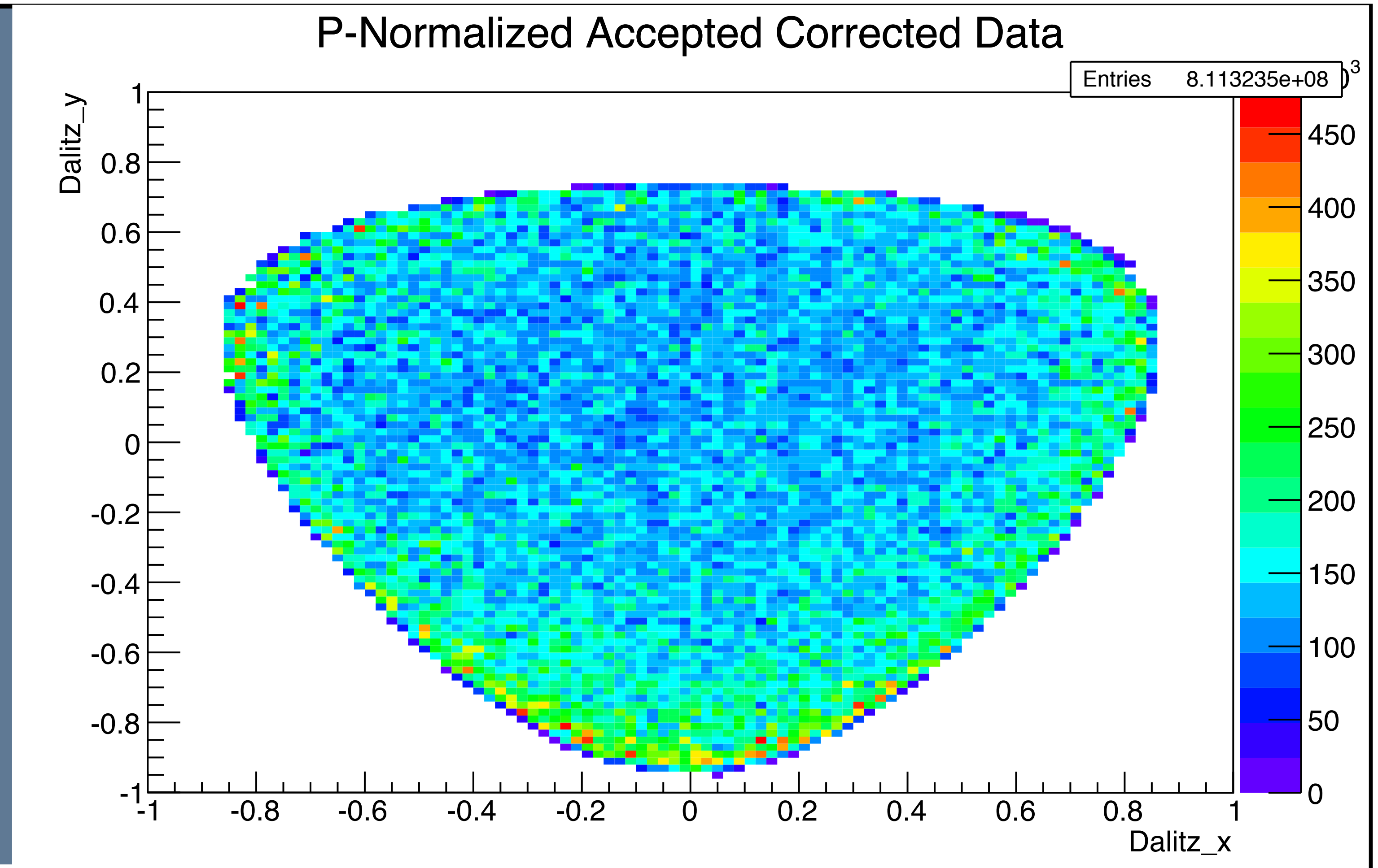

Data
Entries 215279
Dalitz_y
Dalitz_x
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
90
80
70
60
50
40
30
20
10
0

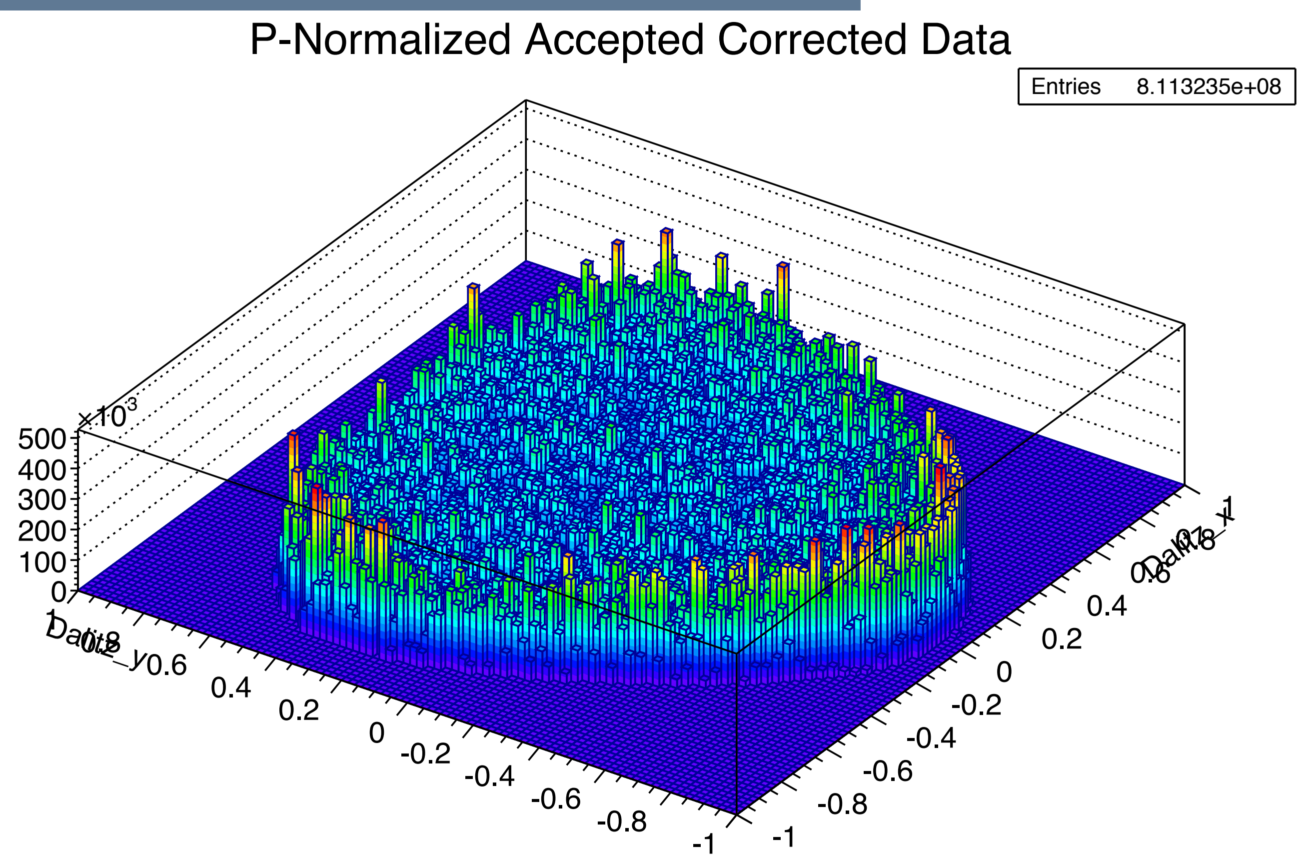

Normalized Acceptance
Entries 314405
Dalitz_y
Dalitz_x
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0


Accepted Corrected Data
Entries 455176
Dalitz_y
Dalitz_x
250
200
150
100
50
0

g12 Data

$\gamma p \rightarrow (\pi^0)\pi^+\pi^- p$





Fit parametric model to data using the PyPWA framework - (generalShell module) see https://pypwa.jlab.org

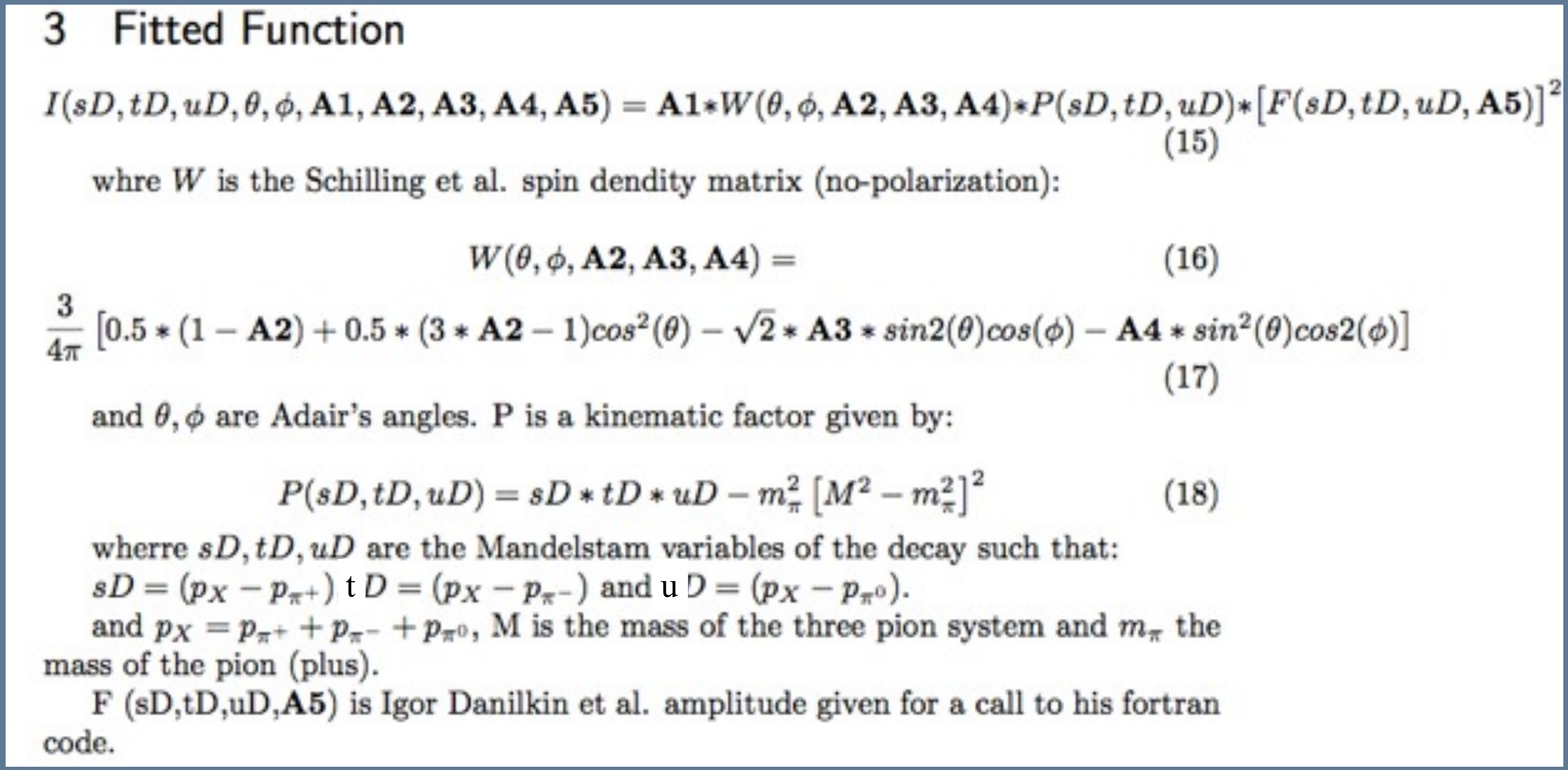
Performing an Unbinned Extended Likelihood fit：

$$\boxed{-ln\mathscr{L} = -\sum_{i=1}^{N} Q_i ln\left[I(\vec{x}_i, \vec{a})\right] + \frac{1}{N_g}\sum_{i=1}^{N_a} I(\vec{x}_i, \vec{a})}$$

Minimized the negative log-likelihood on the model parameters

In our case:

$$I(sD, tD, \theta_{Adair}, \phi_{Adair}, \text{parameters}) = \text{production} * \text{decay}$$



3 Fitted Function

$$I(sD,tD,uD,\theta,\phi,\mathbf{A1},\mathbf{A2},\mathbf{A3},\mathbf{A4},\mathbf{A5}) = \mathbf{A1}*W(\theta,\phi,\mathbf{A2},\mathbf{A3},\mathbf{A4})*P(sD,tD,uD)*[F(sD,tD,uD,\mathbf{A5})]^2 \tag{15}$$

whre W is the Schilling et al. spin dendity matrix (no-polarization):

$$W(\theta,\phi,\mathbf{A2},\mathbf{A3},\mathbf{A4}) = \tag{16}$$

$$\frac{3}{4\pi}\left[0.5*(1-\mathbf{A2})+0.5*(3*\mathbf{A2}-1)cos^2(\theta)-\sqrt{2}*\mathbf{A3}*sin2(\theta)cos(\phi)-\mathbf{A4}*sin^2(\theta)cos2(\phi)\right] \tag{17}$$

and θ,ϕ are Adair's angles. P is a kinematic factor given by:

$$P(sD,tD,uD) = sD*tD*uD - m_\pi^2\left[M^2-m_\pi^2\right]^2 \tag{18}$$

wherre sD,tD,uD are the Mandelstam variables of the decay such that: $sD=(p_X-p_{\pi^+})$ t $D=(p_X-p_{\pi^-})$ and u $D=(p_X-p_{\pi^0})$.
and $p_X=p_{\pi^+}+p_{\pi^-}+p_{\pi^0}$, M is the mass of the three pion system and m_π the mass of the pion (plus).
F (sD,tD,uD,**A5**) is Igor Danilkin et al. amplitude given for a call to his fortran code.

MC was generated with a t-slope of 3 GeV^{-2} to match data low t distributions. - all t are included in current fits. (future analysis of t dependence is planned).

Thursday, June 18, 2015

Preliminary Fits results

All	A2	A3	A4	A5
3.5-4.0	0.315	-0.016	-0.021	-12.53
4.0-4.5	0.315	-0.016	-0,021	-12.78
4.5-5.0	0.315	-0.016	-0.021	-12.82
5.0-5.5	0.191	0.018	-0.007	-12.8

nonF	A2	A3	A4
3.5-4.0	0.27	-0.018	-0.023
4.0-4.5	0.28	-0.026	-0,068
4.5-5.0	0.29	-0.022	-0.039
5.0-5.5	0.31	0.016	-0.021

F	A2	A3	A4	A5
3.5-4.0	0.194	-0.016	-0.007	0 (fixed)
3.5-4.0	0.299	-0.018	-0,08	1 (fixed)
3.5-4.0	0.191	-0.018	-0.007	-12.8 (fixed normalization)

Still studying stability of fits: next steps

(ii) Circular polarization of helicity $\lambda_\gamma = \pm 1$:

$$W^{\pm}(\cos\theta, \phi) = W^{0}(\cos\theta, \phi) \pm P_\gamma W^{3}(\cos\theta, \phi) .$$

$$W^{0}(\cos\theta, \phi) = \frac{3}{4\pi}\left(\tfrac{1}{2}(1-\rho^{0}_{00}) + \tfrac{1}{2}(3\rho^{0}_{00}-1)\cos^2\theta - \sqrt{2}\,\mathrm{Re}\,\rho^{0}_{10}\sin 2\theta\cos\phi - \rho^{0}_{1-1}\sin^2\theta\cos 2\phi\right),$$

Schilling et al

$$W^{3}(\cos\theta, \phi) = \frac{3}{4\pi}\left(+\sqrt{2}\,\mathrm{Im}\,\rho^{3}_{10}\sin 2\theta\sin\phi + \mathrm{Im}\,\rho^{3}_{1-1}\sin^2\theta\sin 2\phi\right)$$

Parametrization of Dalitz intensity through:

$$x = \sqrt{z}\,\cos\vartheta\,, \quad y = \sqrt{z}\,\sin\vartheta\,, \qquad (39)$$

and fit the following polynomial expansion

$$|F_{par}(z,\vartheta)|^2 = |N|^2\big(1 + 2\,\alpha\,z + 2\,\beta\,z^{3/2}\sin(3\vartheta) + 2\,\gamma\,z^2 + 2\,\delta\,z^{5/2}\sin(3\vartheta) + \mathcal{O}(z^3)\big) \qquad (40)$$

Kubis et al

Preliminary Results and Things still to be done

- $\omega \rightarrow \pi^+\pi^-(\pi^0)$ events for $3.6 < E_{photon} < 5.4$ GeV have been extracted given a mass for the ω of 783.5 MeV and width of 9.92 MeV (PDG: 782.65,8.49). Sample with very small background.
- Comparison with theory has started:
    - Data seems dominated by P-wave (as expected).
    - The extra-terms of the three-body decay models are important at the edges of the Dalitz plots where acceptance/statistics are very limited.

Next steps:
- Study Fit stability.
- Introduce other parametrization (and polarization,...)
- Study Energy and t dependancies.