An update on Omega Meson Hadronization Studies

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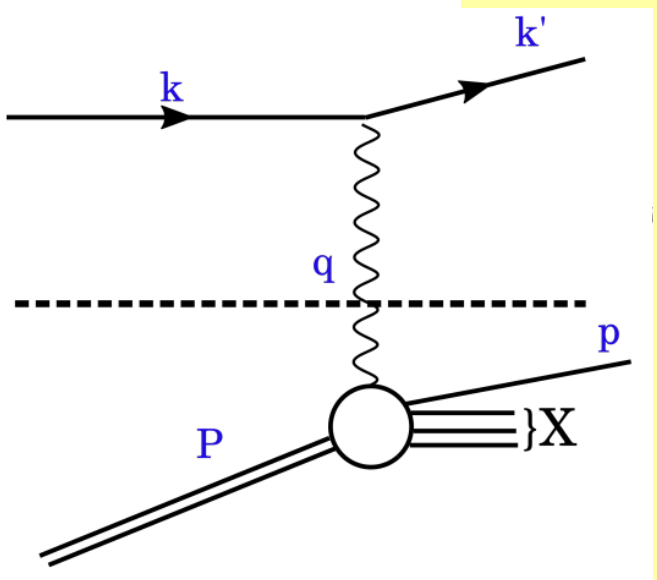
Introduction

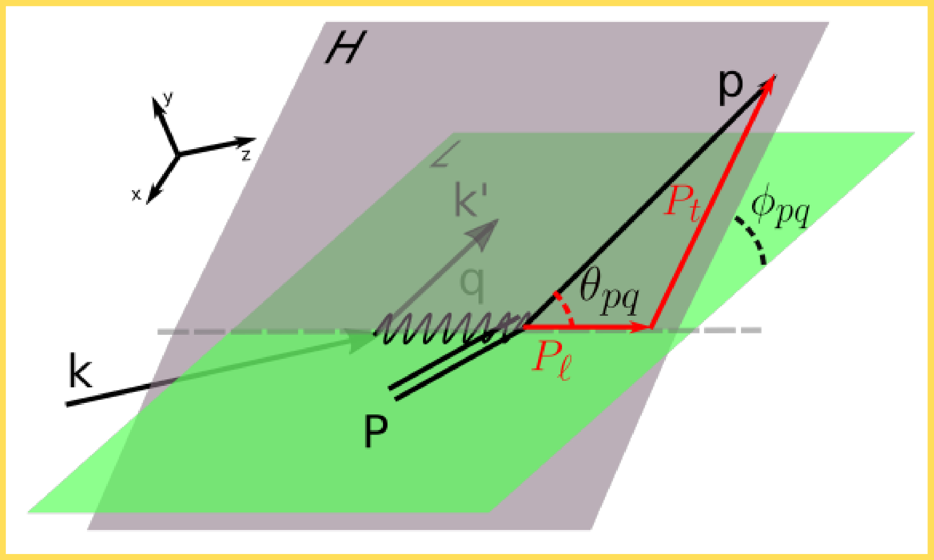
Semi Inclusive Deep Inelastic Scattering

SIDIS allows us a closer look at the proton constituents by measuring an extra hadron in the final state.

$$e + A \rightarrow e' + h + X$$



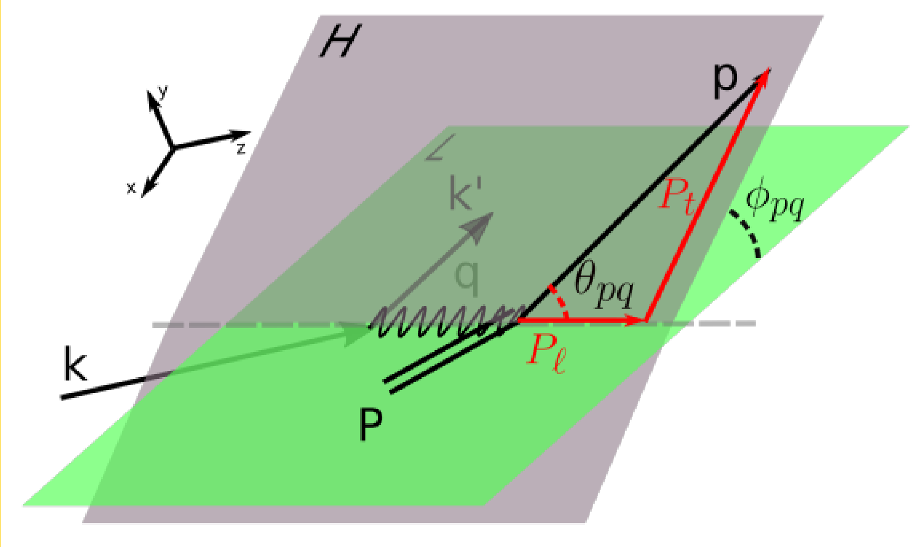
Introduction
Kinematics



$$k^\mu = (E_b, \vec{k})$$
$$k'^\mu = (E', \vec{k}')$$
$$P^\mu = (M, \vec{0})$$
$$q^\mu = (\nu, \vec{q})$$
$$p^\mu = (E_h, \vec{p_h})$$

Introduction

Kinematics



$$k^\mu = (E_b, \vec{k})$$

$$k'^\mu = (E', \vec{k'})$$

$$P^\mu = (M, \vec{0})$$

$$q^\mu = (\nu, \vec{q})$$

$$p^\mu = (E_h, \vec{p_h})$$

$$\nu = \frac{Pq}{M} \overset{Lab}{=} E_b - E'$$

$$Q^2 = -q^2 = -(k+p)^2 \overset{Lab}{\approx} 4E_bE'Sin^2(\theta/2)$$

$$z = \frac{pP}{qP} \overset{Lab}{=} \frac{E_h}{\nu}$$

$$W^2 = (q+P)^2 \overset{Lab}{=} M^2 - Q^2 + 2\nu M$$

$$x_{Bj} = \frac{Q^2}{2Pq} \overset{Lab}{=} \frac{Q^2}{2M\nu}$$

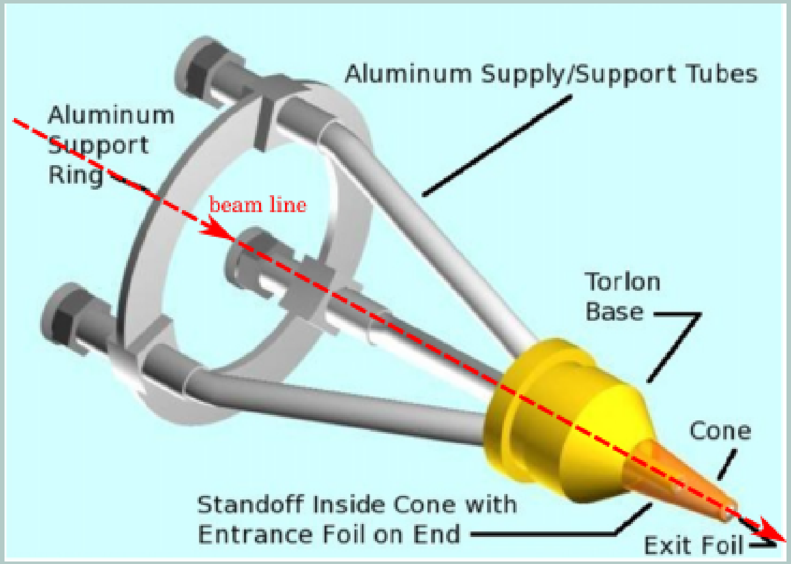
$$y = \frac{Pq}{Pk} \overset{Lab}{=} \frac{\nu}{E_b}$$

The Experiment

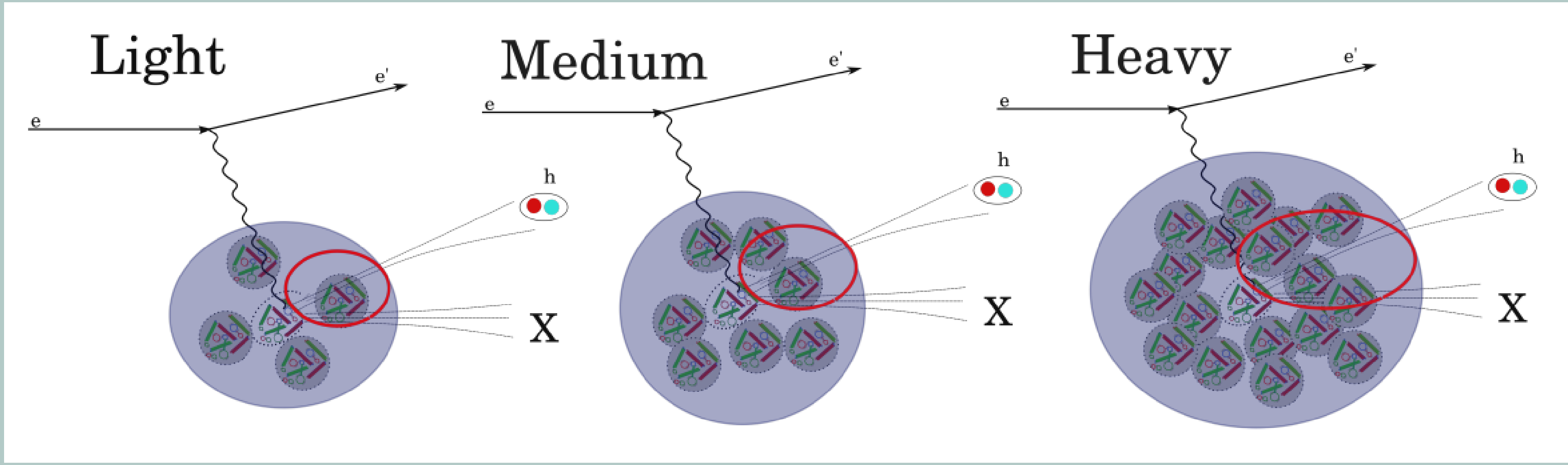
EG2 Run: E02-104 Experiment

Target is composed of a solid heavy target **A (C, Fe, Pb)** and a liquid target **D (Deuterium)**, positioned simultaneously in the beam line.

Main feature:
same luminosity for different nuclei!



Different nuclear sizes allows us to test early stages of the hadronization process.



Hadronic Multiplicity Ratio
Definition

We define the measure of Hadronic Multiplicity Ratio (MR) as

$$\mathrm{MR} \equiv \frac{\left(\frac{\mathrm{N}_{\omega}^{\mathrm{DIS}}}{\mathrm{N}_{e}^{\mathrm{DIS}}}\right)_{A}}{\left(\frac{\mathrm{N}_{\omega}^{\mathrm{DIS}}}{\mathrm{N}_{e}^{\mathrm{DIS}}}\right)_{D}}$$

Multiplicity Ratio

ω motivation

- It does not exist a previous measurement of ω Multiplicity Ratios.
- Mass: 782.65 MeV **[from pdg]**
- ω quark content: $\frac{u\bar{u} + d\bar{d}}{\sqrt{2}}$
- Mean lifetime (s): 7.75×10^{-23}

Main channel

$$\omega \to \pi^+\pi^-\pi^0 \to \pi^+\pi^-\gamma\gamma$$

	Mode	Fraction (Γ_i/Γ)
Γ_1	$\pi^+\pi^-\pi^0$	(89.3 ±0.6) %
Γ_2	$\pi^0\gamma$	(8.40±0.22) %
Γ_3	$\pi^+\pi^-$	(1.53±0.06) %

	Mode	Fraction (Γ_i/Γ)
Γ_1	2γ	(98.823±0.034) %
Γ_2	$e^+e^-\gamma$	(1.174±0.035) %

ω selection

Events selected must accomplish: $\mathrm{N}_{\pi+} \geq 1 \cap N_{\pi-} \geq 1 \cap N_{\gamma} \geq 2$

And all possible combinations are omega candidates: $\binom{N_{\pi+}}{1} \times \binom{N_{\pi-}}{1} \times \binom{N_{\gamma}}{2}$

Electrons selection

- Q^2 : $Q^2 > 1$ GeV^2
- W : W > 2 GeV

Pions selection

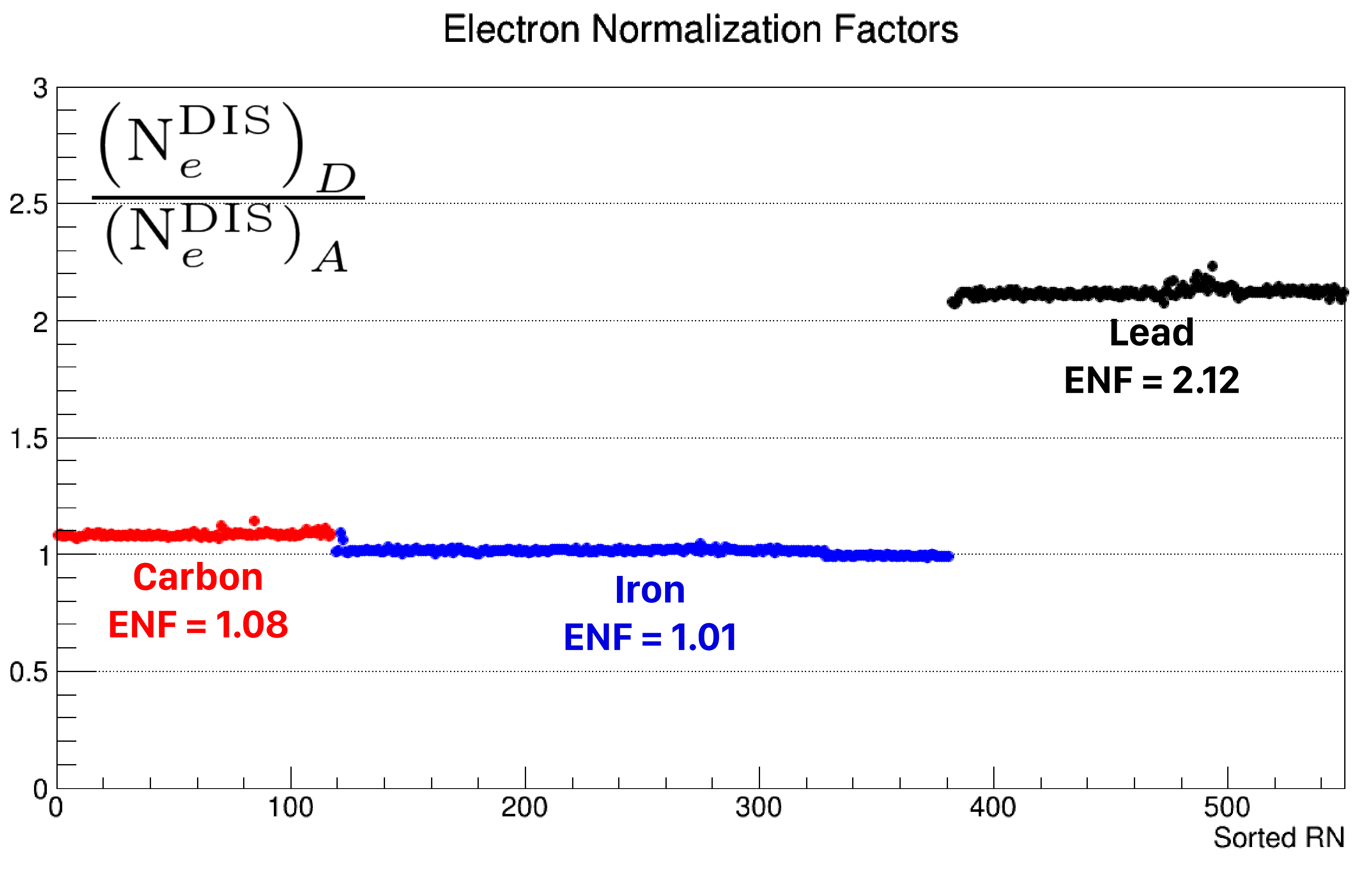
- π^0 mass : 0.059 GeV/c^2 < $M_{\gamma\gamma}$ < 0.209 GeV/c^2
- $\pi^+\pi^-$ mass : 0.48 GeV/c^2 > $M_{\pi^+\pi^-}$ or 0.51 GeV/c^2 < $M_{\pi^+\pi^-}$

Electron Normalization Factor

Definition

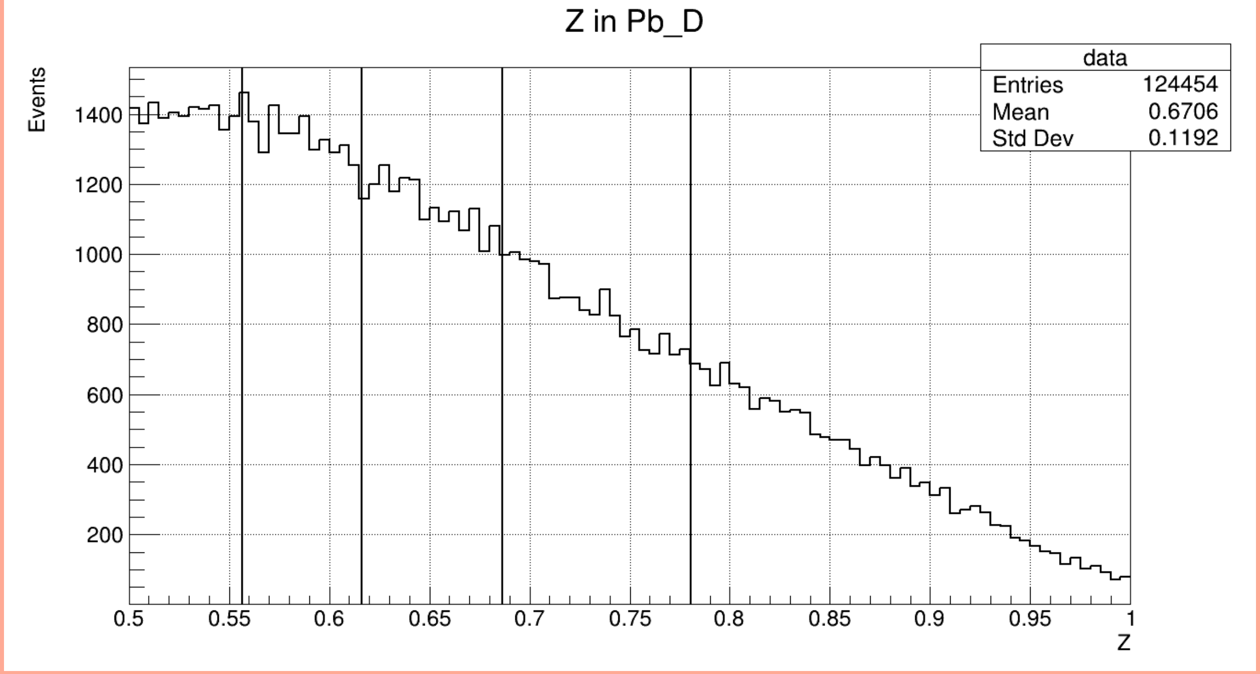
From the definition of MR, we can find the electron normalization factor.

$$\mathrm{MR} \equiv \frac{\left(\frac{\mathrm{N}_{\omega}^{\mathrm{DIS}}}{\mathrm{N}_{e}^{\mathrm{DIS}}}\right)_{A}}{\left(\frac{\mathrm{N}_{\omega}^{\mathrm{DIS}}}{\mathrm{N}_{e}^{\mathrm{DIS}}}\right)_{D}} \longrightarrow \mathrm{ENF} \equiv \frac{\left(\mathrm{N}_{e}^{\mathrm{DIS}}\right)_{D}}{\left(\mathrm{N}_{e}^{\mathrm{DIS}}\right)_{A}}$$



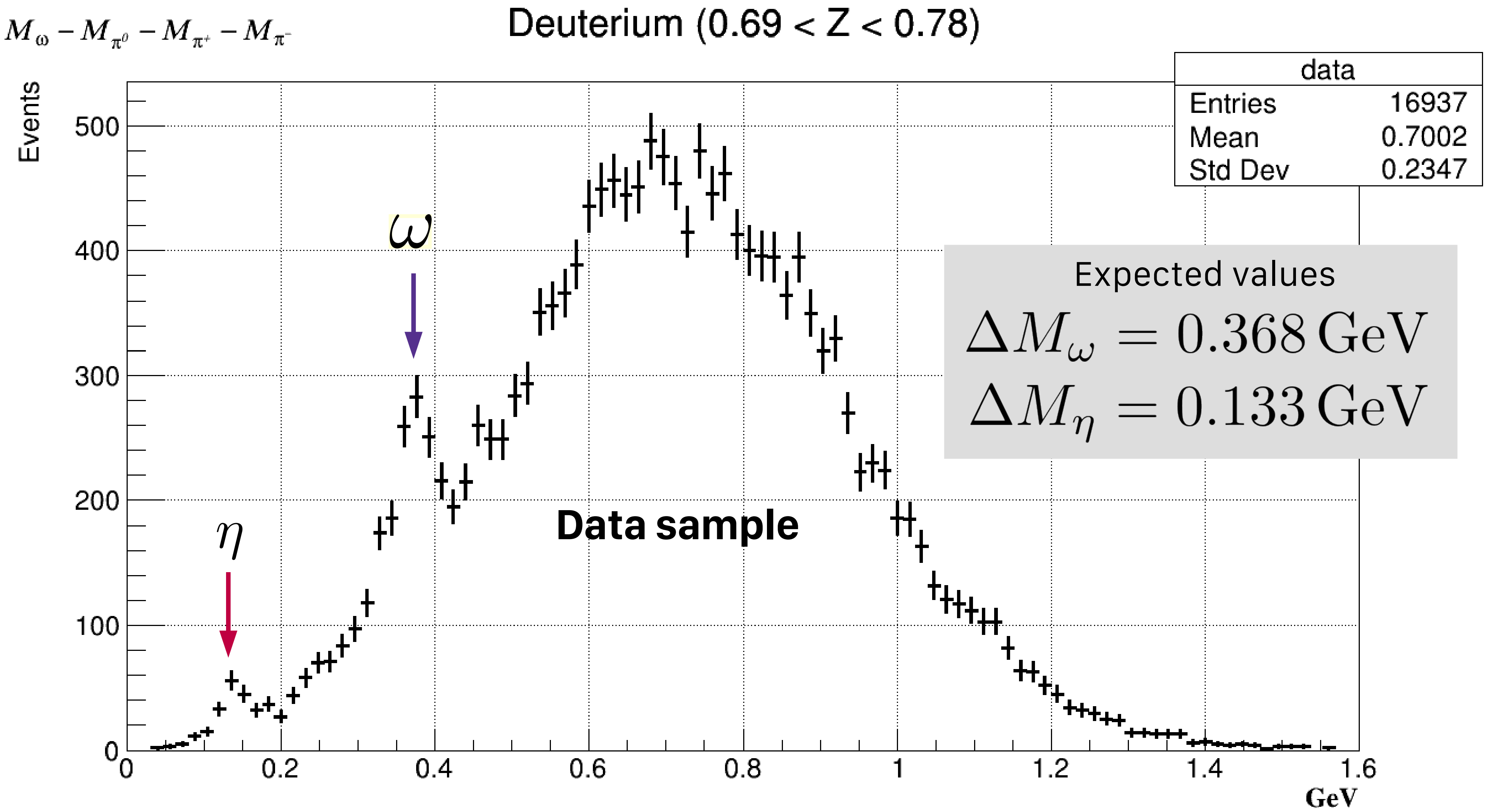
Electron Normalization Factors
$\frac{(N_e^{DIS})_D}{(N_e^{DIS})_A}$
3
2.5
2
1.5
1
0.5
0
0
100
200
300
400
500
Sorted RN
Carbon
ENF = 1.08
Iron
ENF = 1.01
Lead
ENF = 2.12

Binning



Bin number	Low edge (GeV)	Upper edge (GeV)
1	0.5	0.557
2	0.557	0.617
3	0.617	0.689
4	0.689	0.784
5	0.784	1.0

The data was organized in Z-dependent **bins.**



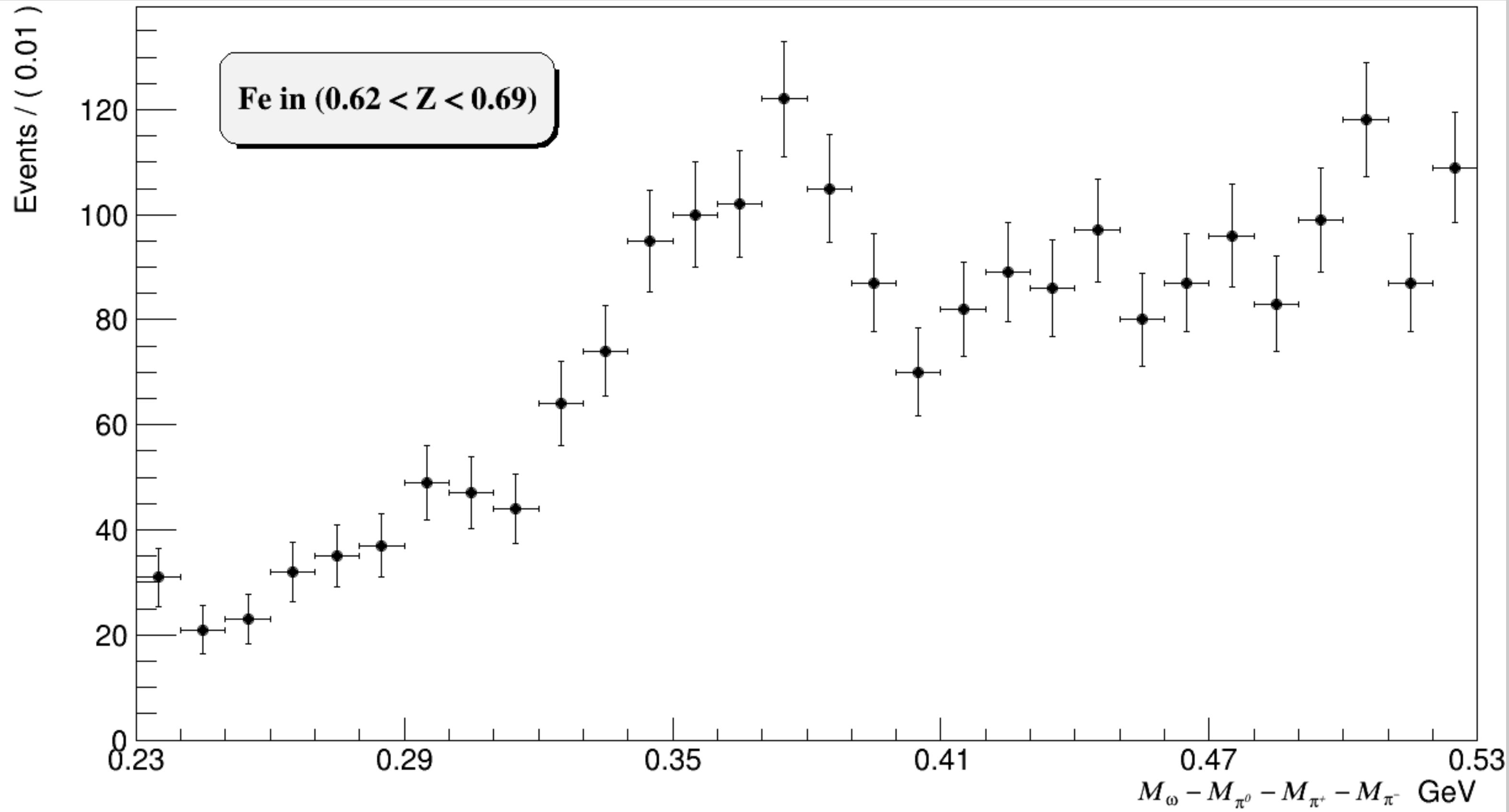
$M_\omega - M_{\pi^0} - M_{\pi^+} - M_{\pi^-}$
Deuterium (0.69 < Z < 0.78)
data
Entries 16937
Mean 0.7002
Std Dev 0.2347
Events
500
400
300
200
100
0
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
GeV
ω
η
Data sample
Expected values
$\Delta M_\omega = 0.368\,\mathrm{GeV}$
$\Delta M_\eta = 0.133\,\mathrm{GeV}$

Uncorrected MR
Procedure

Uncorrected MR: No acceptance correction nor background subtraction involved.

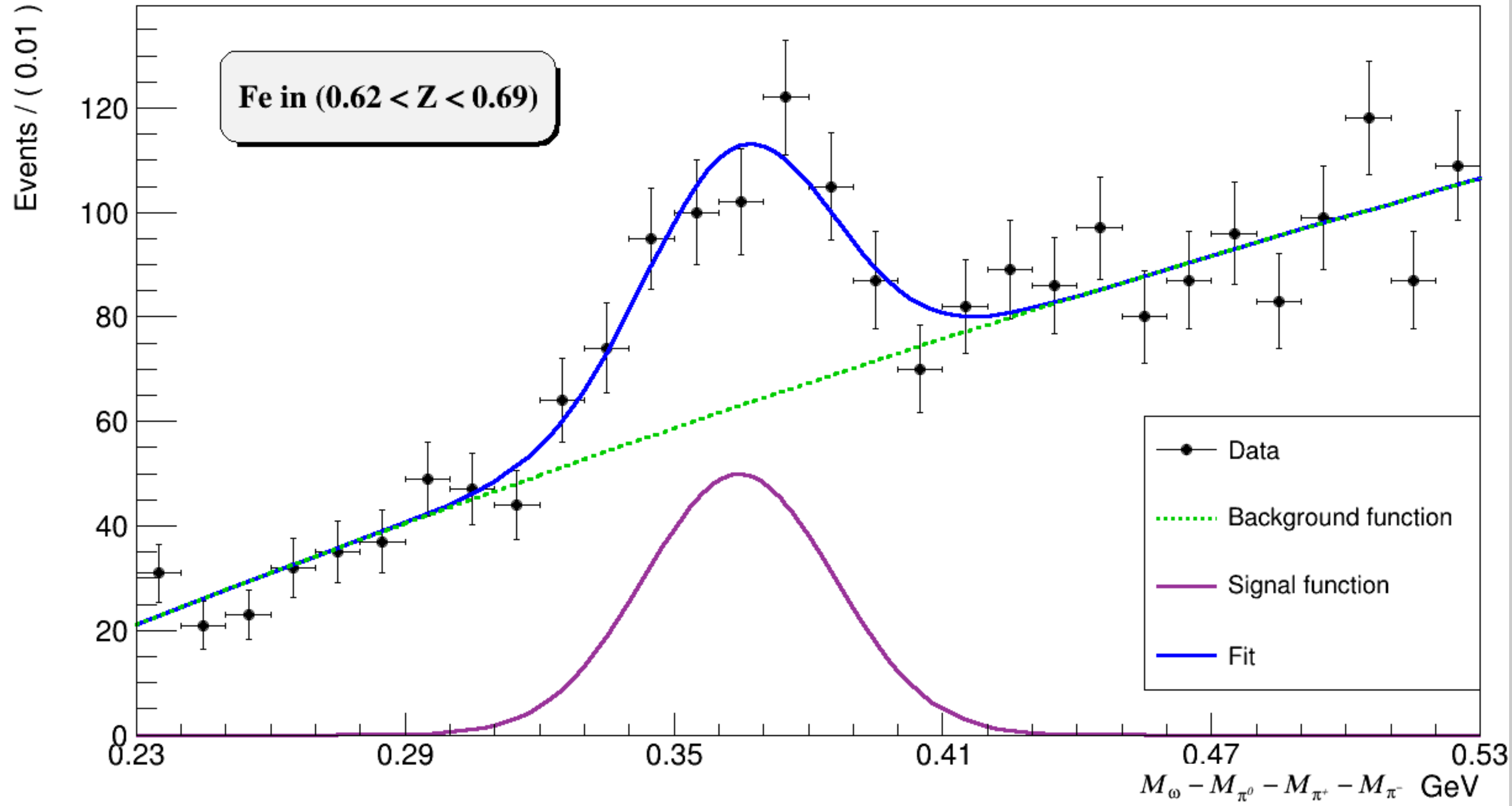
- Zooming in omega peak
- Preliminary fit to obtain width
- Cut mass spectrum around peak, using sigma ranges

Uncorrected MR
Procedure - Zoom



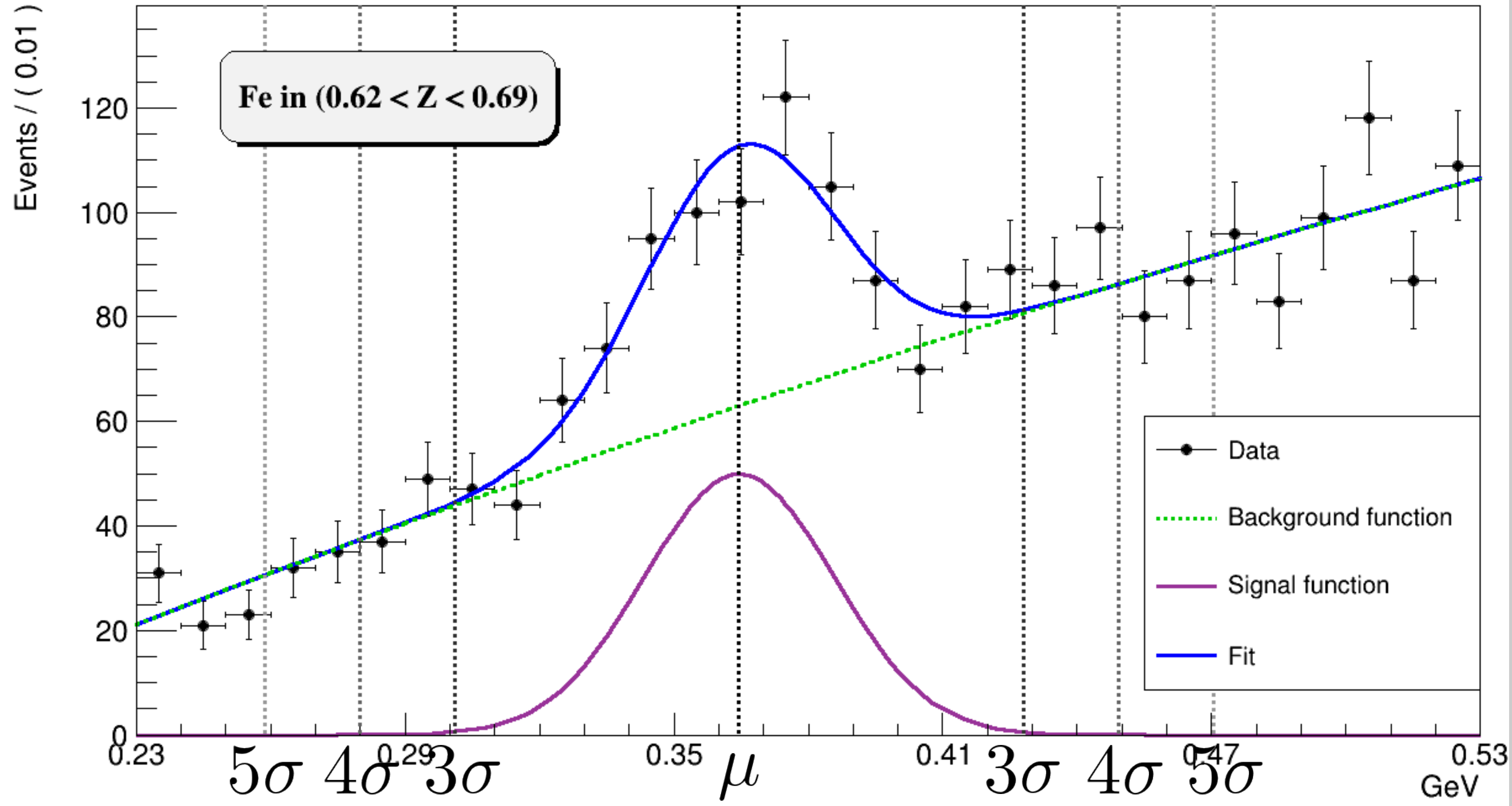
Uncorrected MR

Procedure - Fit



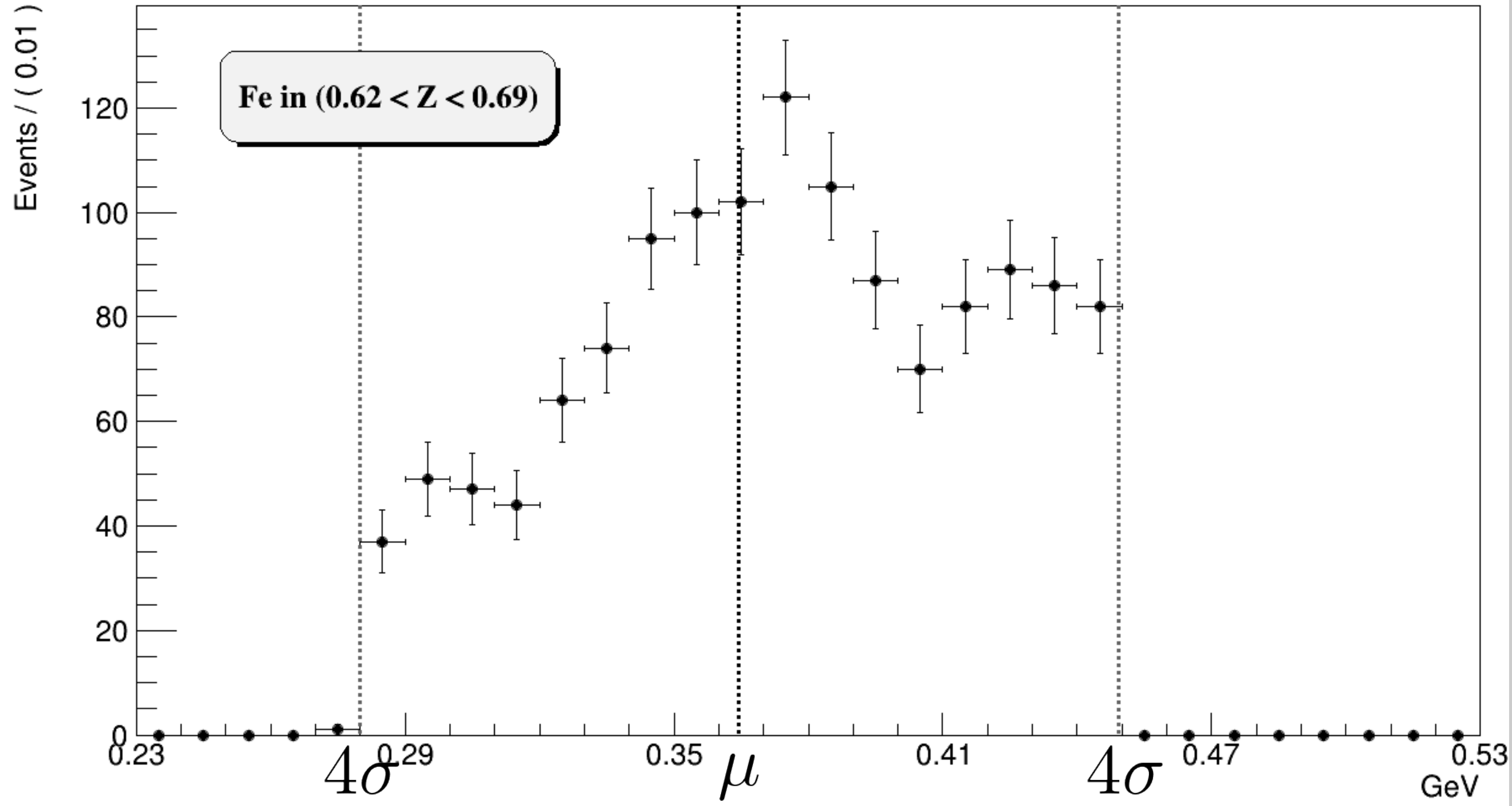
Uncorrected MR

Procedure - Fit

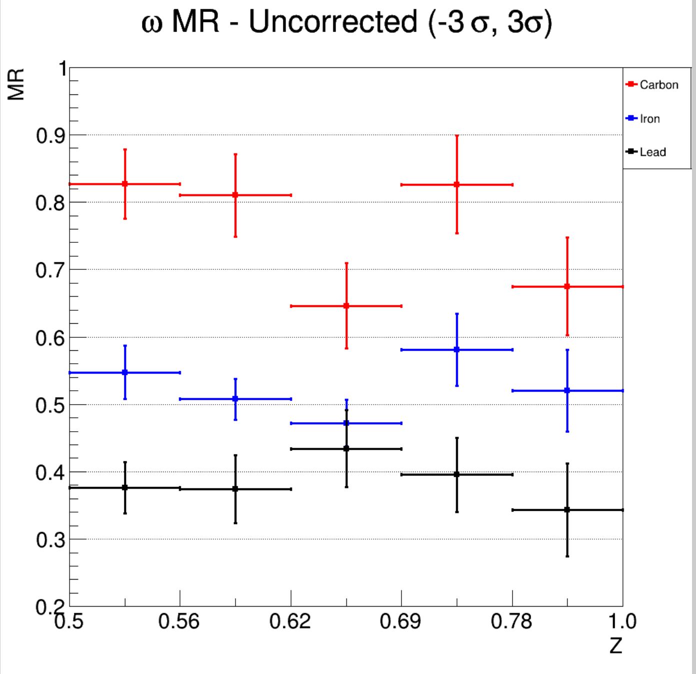


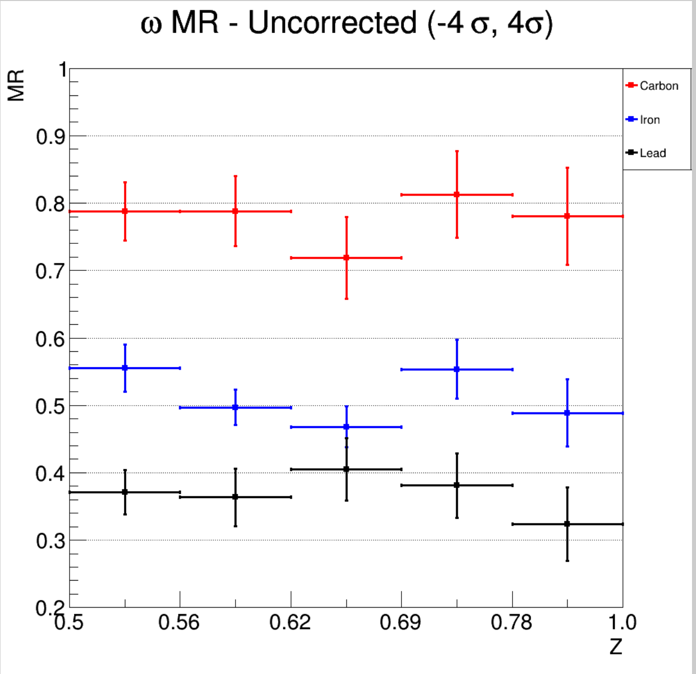
Uncorrected MR

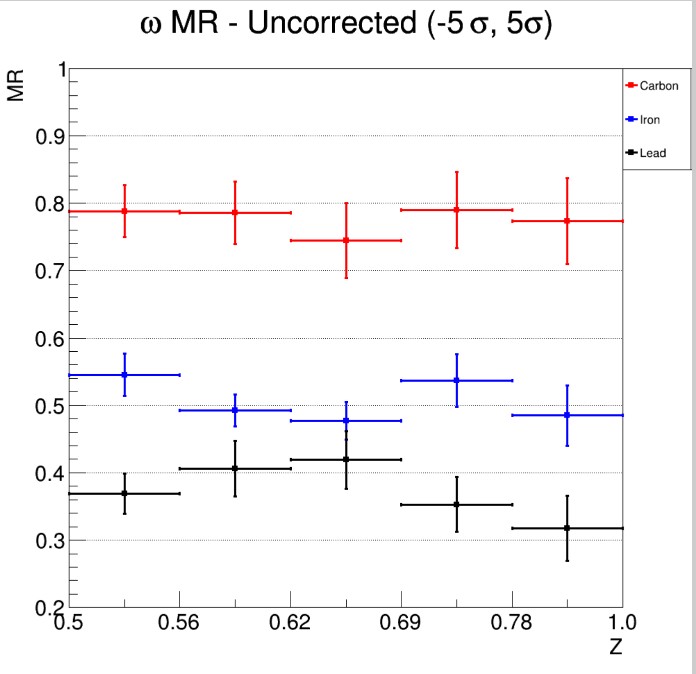
Procedure - Extract



Uncorrected MR
Results

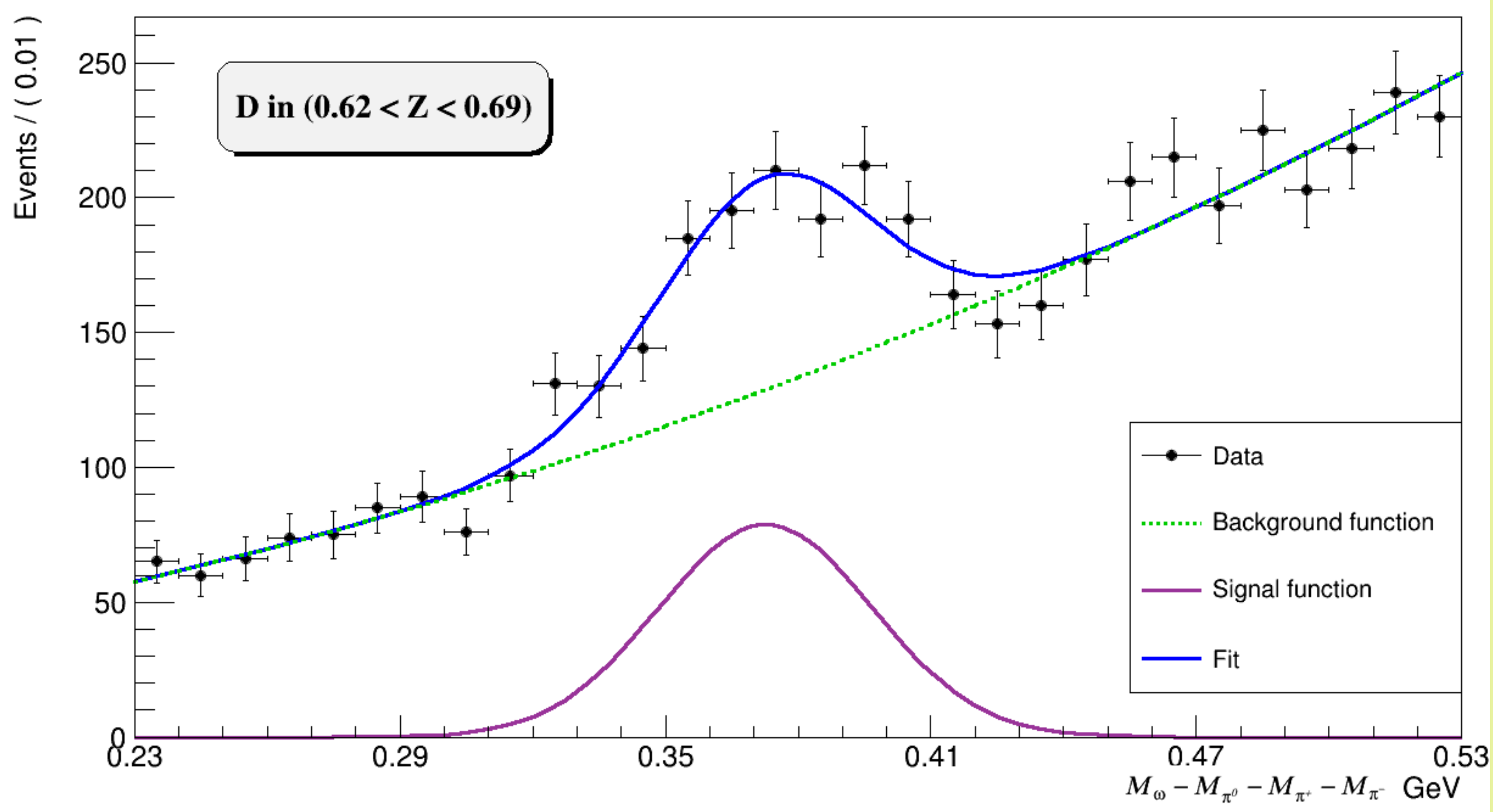






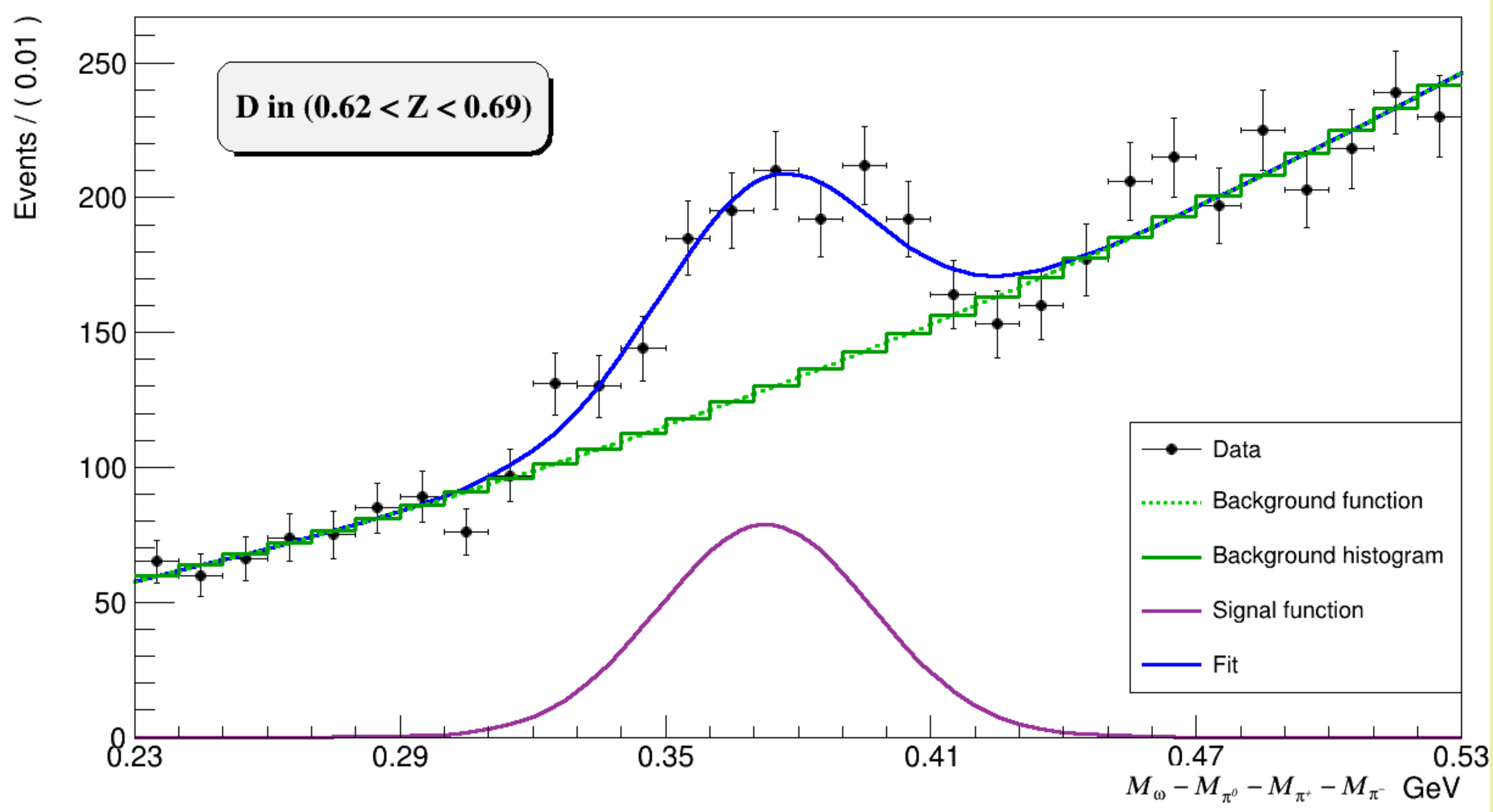
Background Subtracted MR

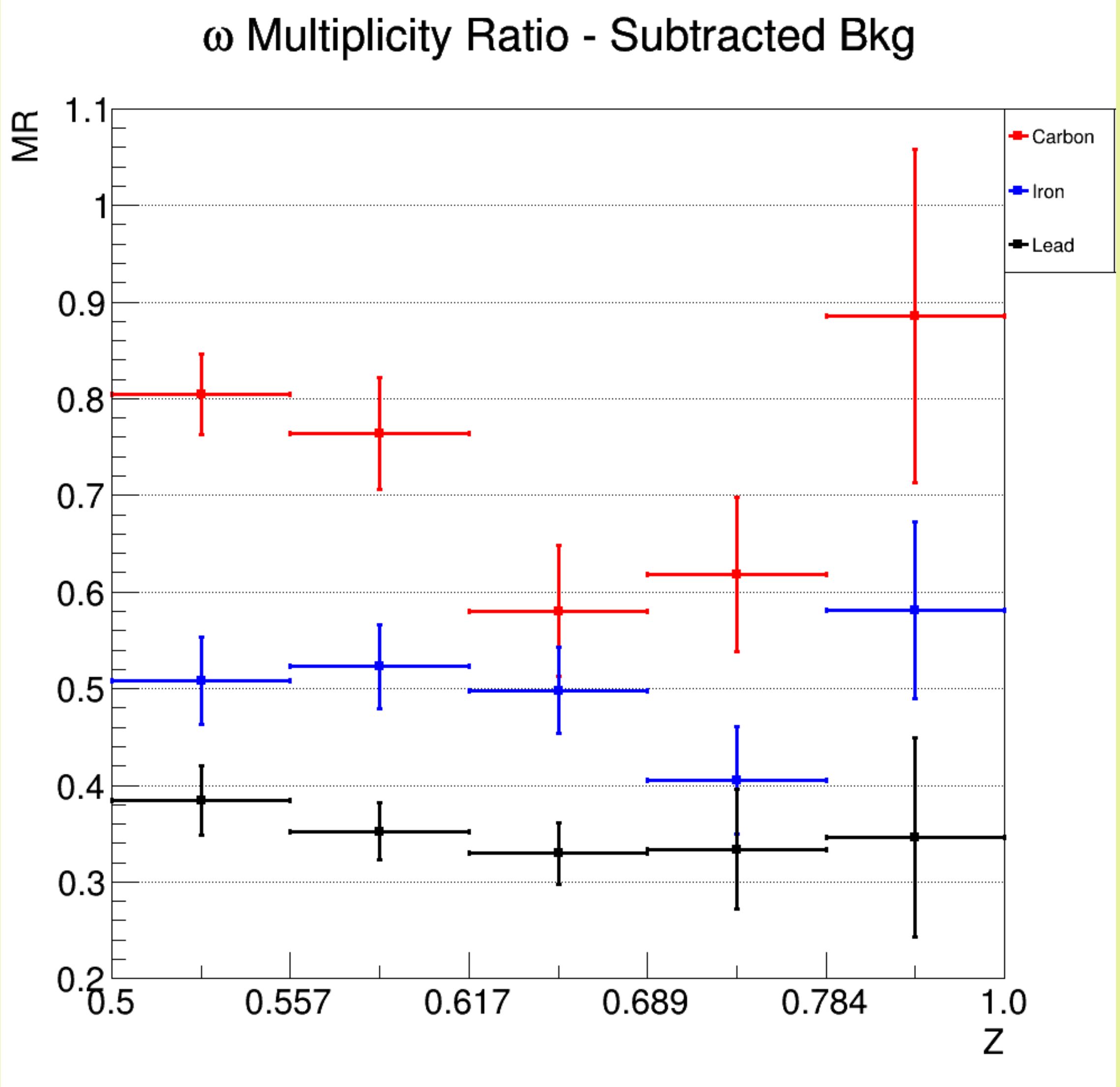
Procedure



Background Subtracted MR

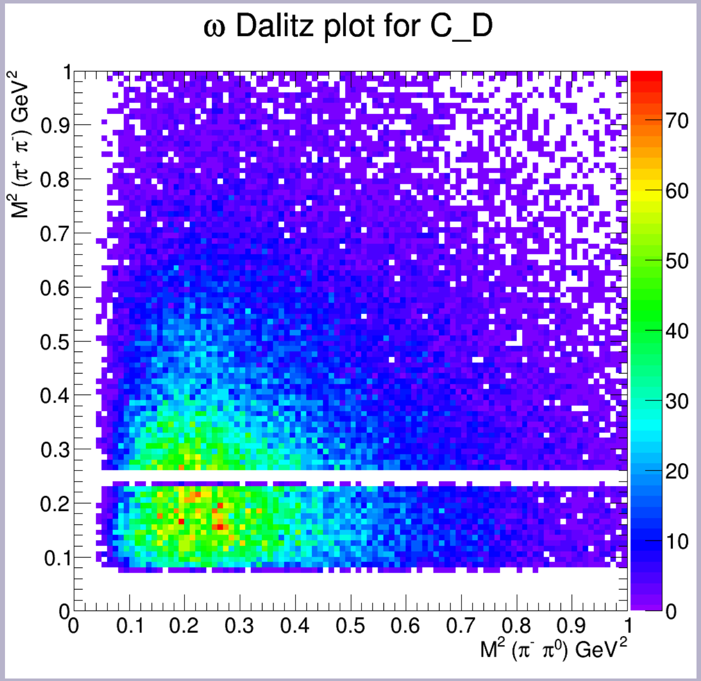
Procedure



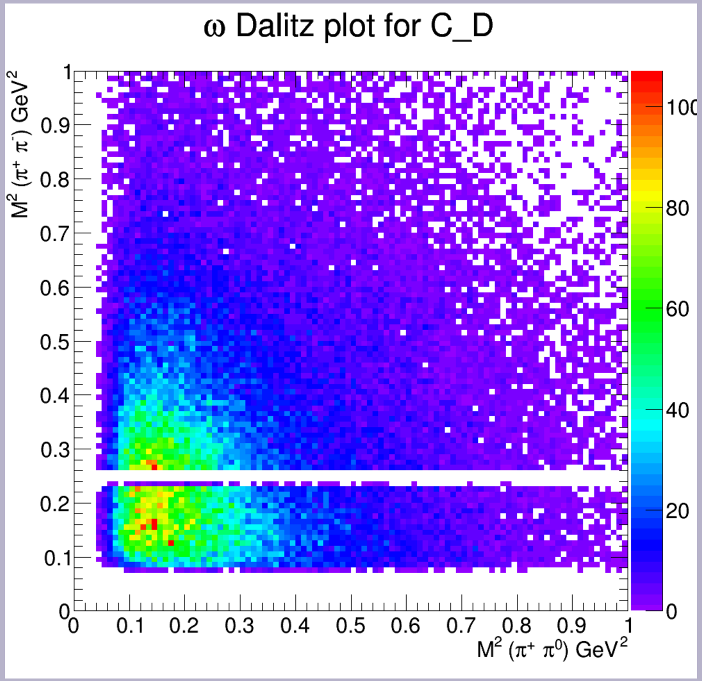

ω Multiplicity Ratio - Subtracted Bkg
MR
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.5
0.557
0.617
0.689
0.784
1.0
Z
Carbon
Iron
Lead

Dalitz Plots

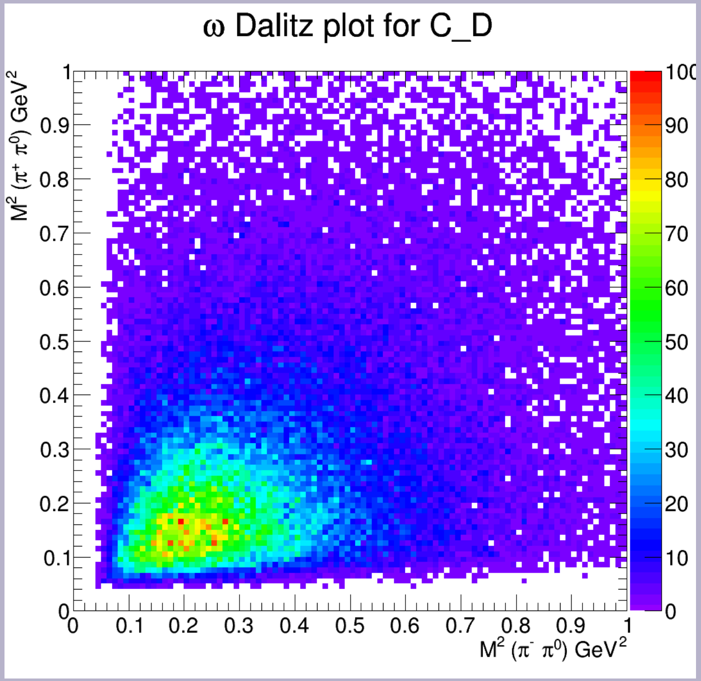
Without kinematical cuts



$\pi^+\pi^-$ vs $\pi^-\pi^0$



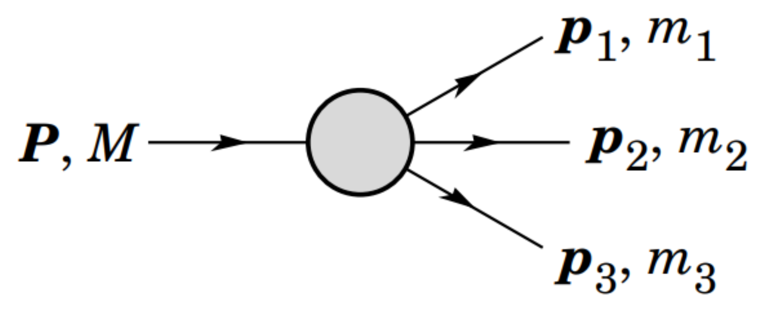
$\pi^+\pi^-$ vs $\pi^+\pi^0$



$\pi^+\pi^0$ vs $\pi^-\pi^0$

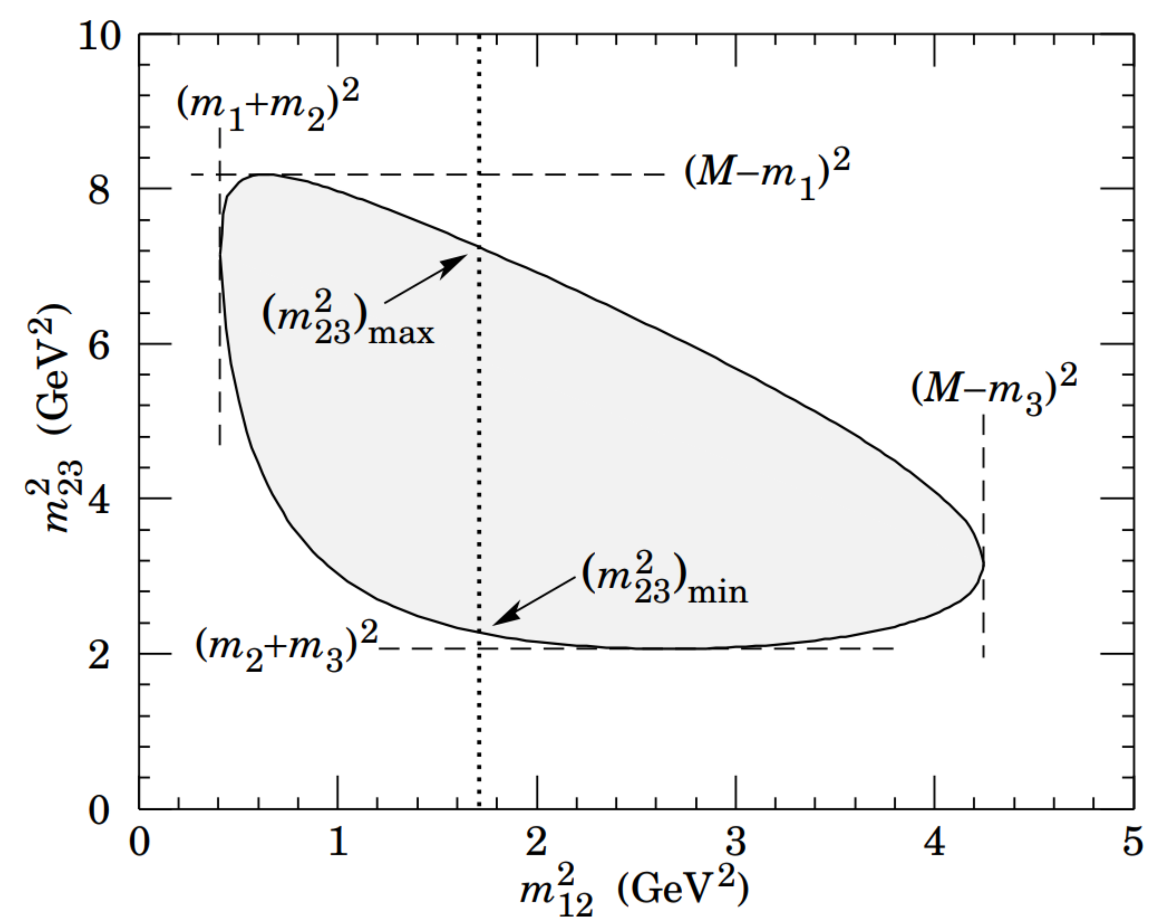
Dalitz Plots

Kinematical cuts



Three-body decay

$$p_{ij} = p_i + p_j$$
$$m_{ij}^2 = p_{ij}^2$$



More documentation in:
http://pdg.lbl.gov/2019/reviews/rpp2018-rev-kinematics.pdf

47.4.3.1. *Dalitz plot:* For a given value of m_{12}^2, the range of m_{23}^2 is determined by its values when $\boldsymbol{p}_2$ is parallel or antiparallel to $\boldsymbol{p}_3$:

$$(m_{23}^2)_{\max} =$$

$$(E_2^* + E_3^*)^2 - \left(\sqrt{E_2^{*2} - m_2^2} - \sqrt{E_3^{*2} - m_3^2}\right)^2 ,$$

$$(m_{23}^2)_{\min} =$$

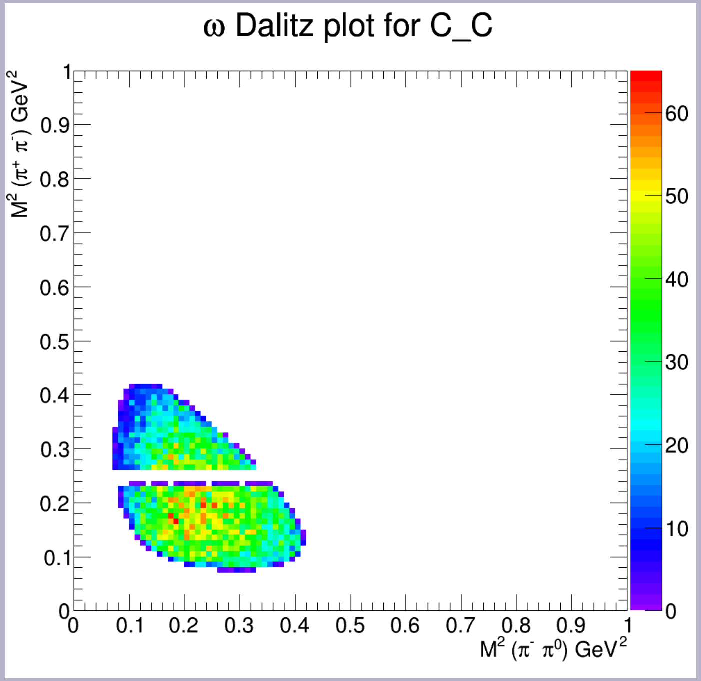
$$(E_2^* + E_3^*)^2 - \left(\sqrt{E_2^{*2} - m_2^2} + \sqrt{E_3^{*2} - m_3^2}\right)^2 .$$

Here $E_2^* = (m_{12}^2 - m_1^2 + m_2^2)/2m_{12}$ and $E_3^* = (M^2 - m_{12}^2 - m_3^2)/2m_{12}$ are the energies of particles 2 and 3 in the m_{12} rest frame.

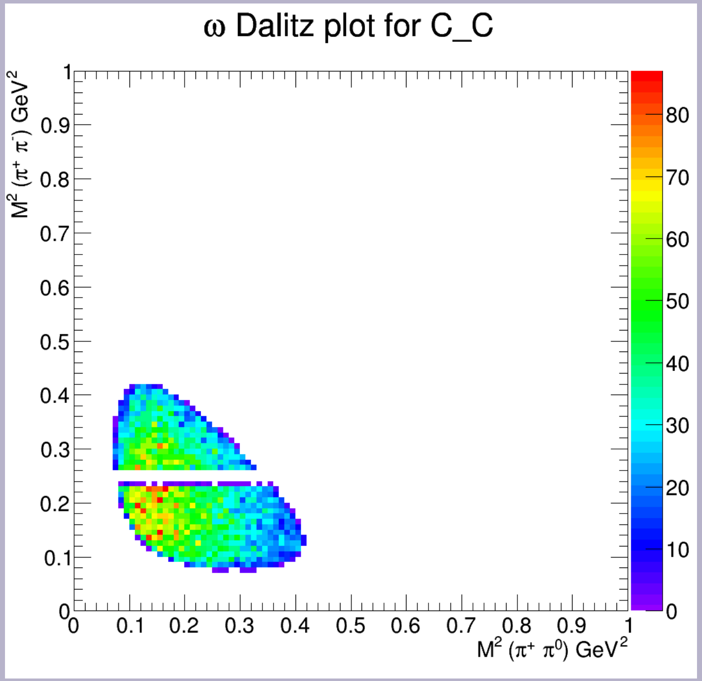
More documentation in:
http://pdg.lbl.gov/2019/reviews/rpp2018-rev-kinematics.pdf

Dalitz Plots

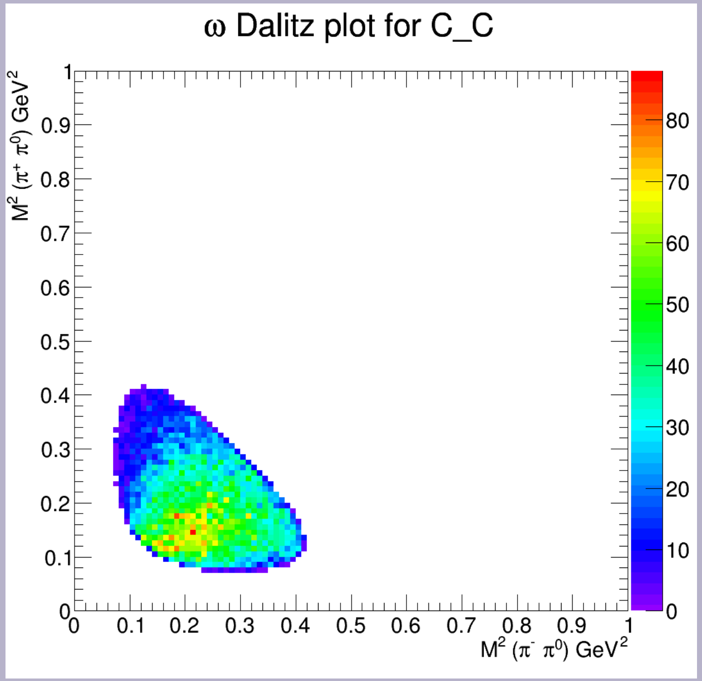
With kinematical cuts



$\pi^+\pi^-$ vs $\pi^-\pi^0$



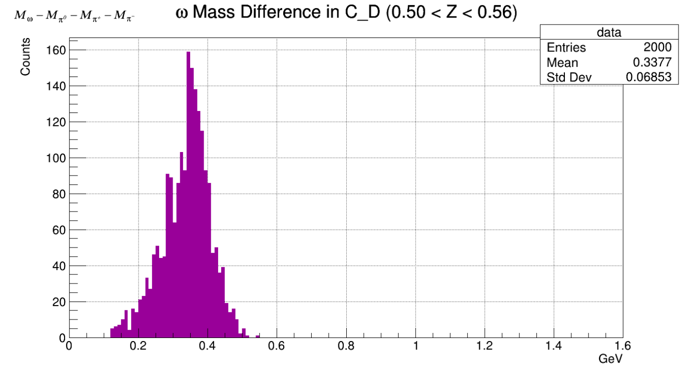
$\pi^+\pi^-$ vs $\pi^+\pi^0$

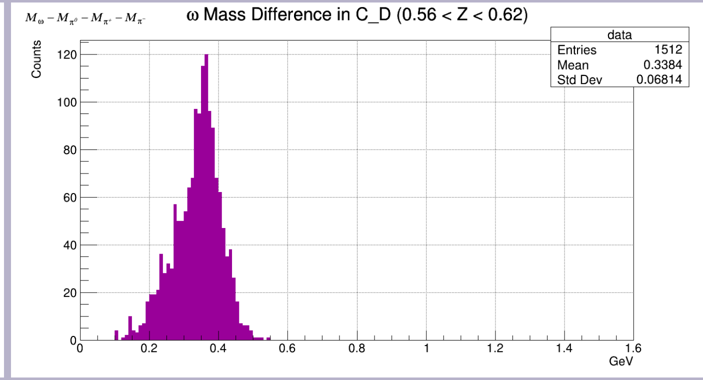


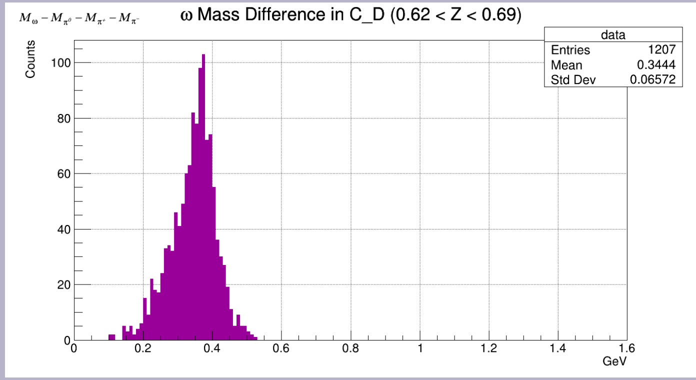
$\pi^+\pi^0$ vs $\pi^-\pi^0$

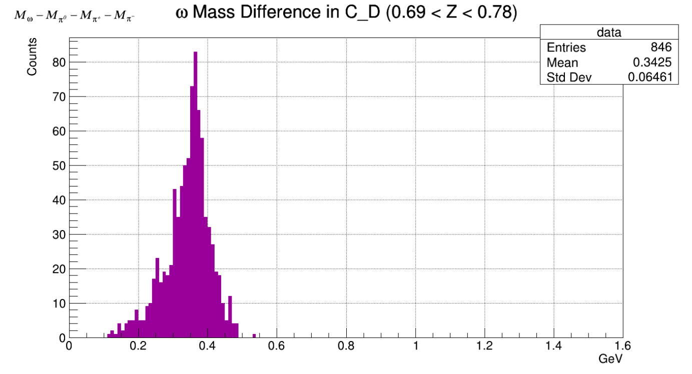
Dalitz Plots

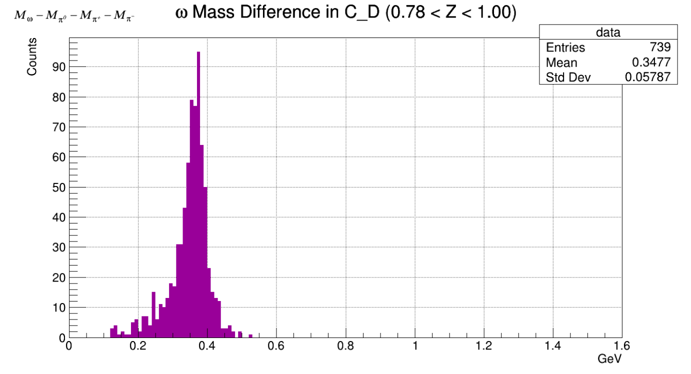
Mass spectrum with kinematical cuts

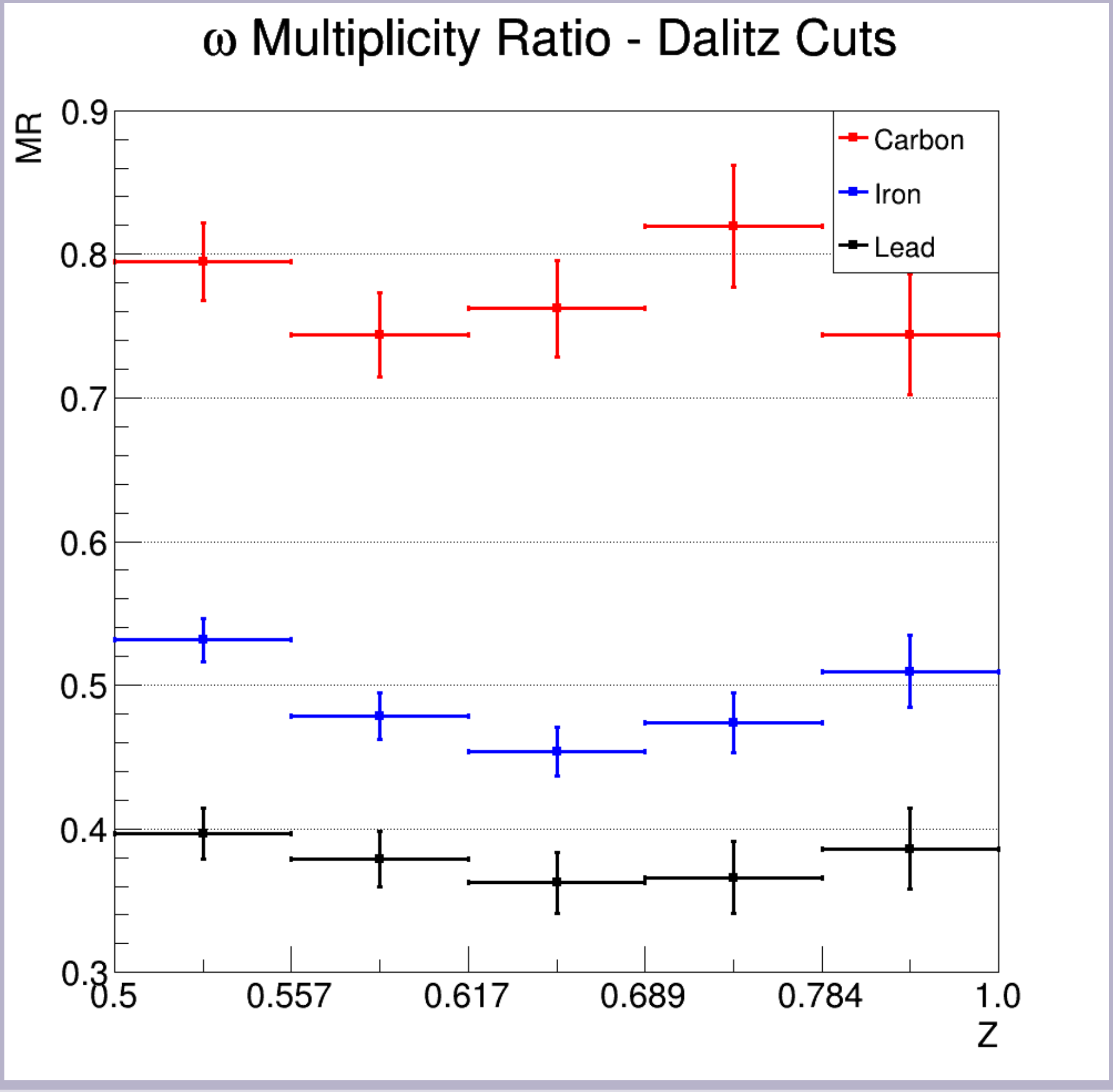


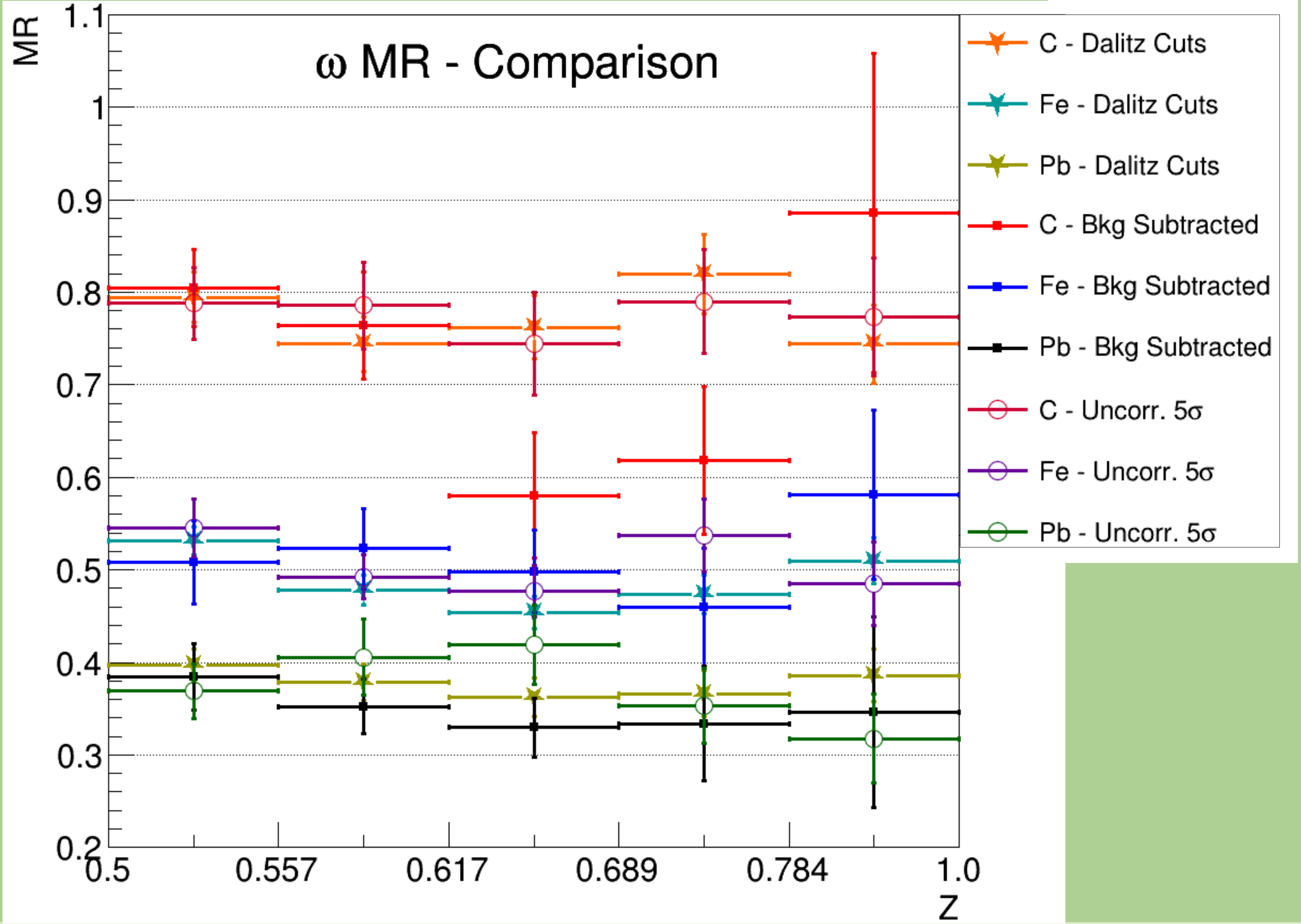








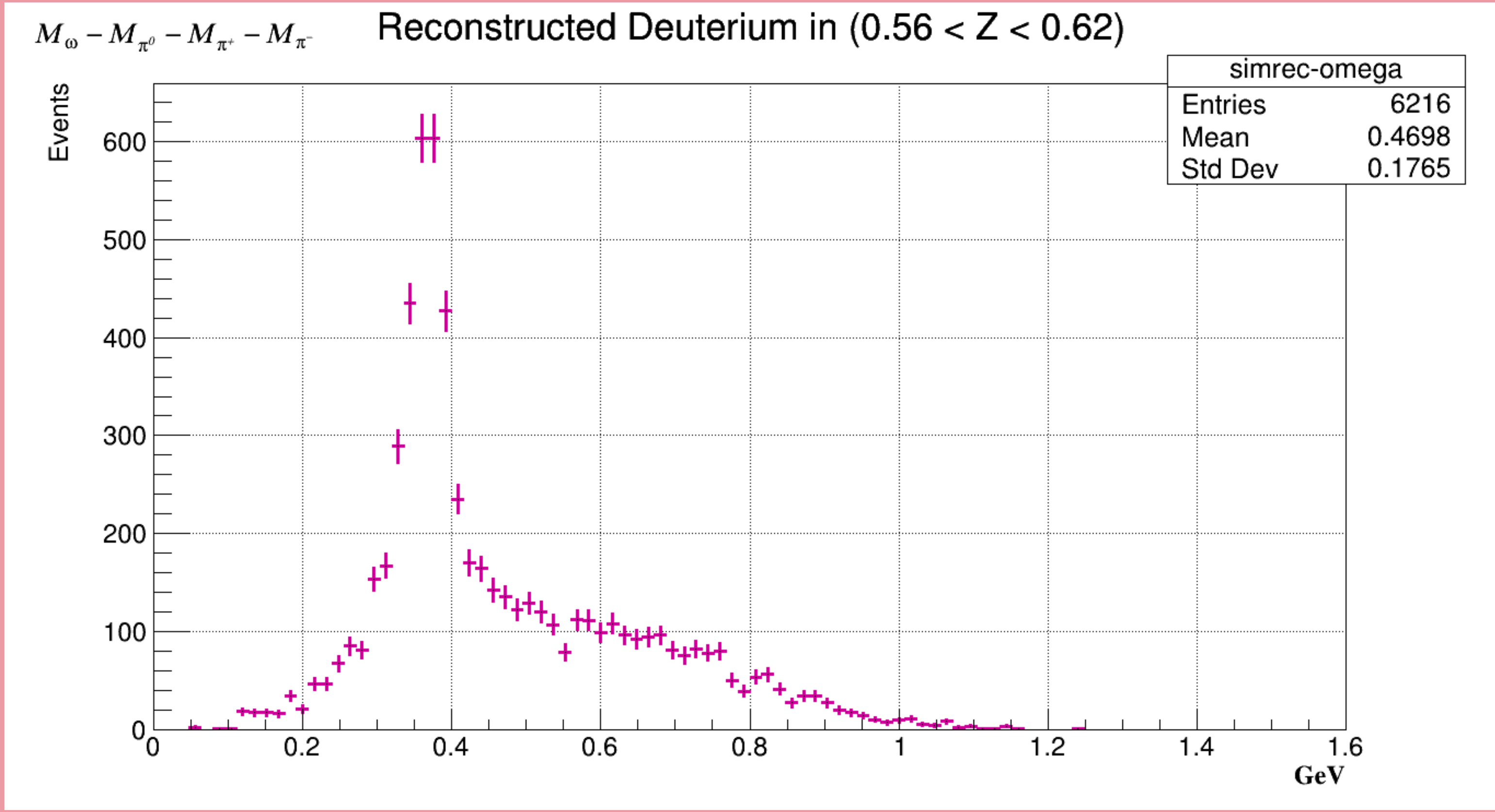

ω Multiplicity Ratio - Dalitz Cuts
MR
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.5
0.557
0.617
0.689
0.784
1.0
Z
Carbon
Iron
Lead


ω MR - Comparison
MR
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.5
0.557
0.617
0.689
0.784
1.0
Z
C - Dalitz Cuts
Fe - Dalitz Cuts
Pb - Dalitz Cuts
C - Bkg Subtracted
Fe - Bkg Subtracted
Pb - Bkg Subtracted
C - Uncorr. 5σ
Fe - Uncorr. 5σ
Pb - Uncorr. 5σ

Simulations

The Process

1. **Lepto64**
2. **GSIM**
3. **GPP**
4. **user_ana**
5. **WriteRootDst**



Next steps

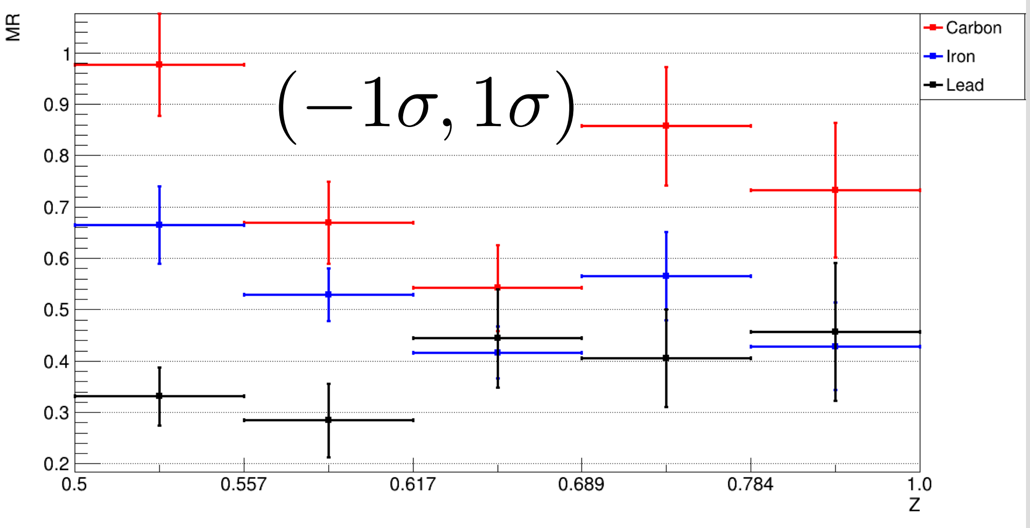
- MR(Q2), MR(Nu), MR(Pt2)
- Run more simulations
- Acceptance Correction
- Radiative Corrections
- Systematic Uncertainties

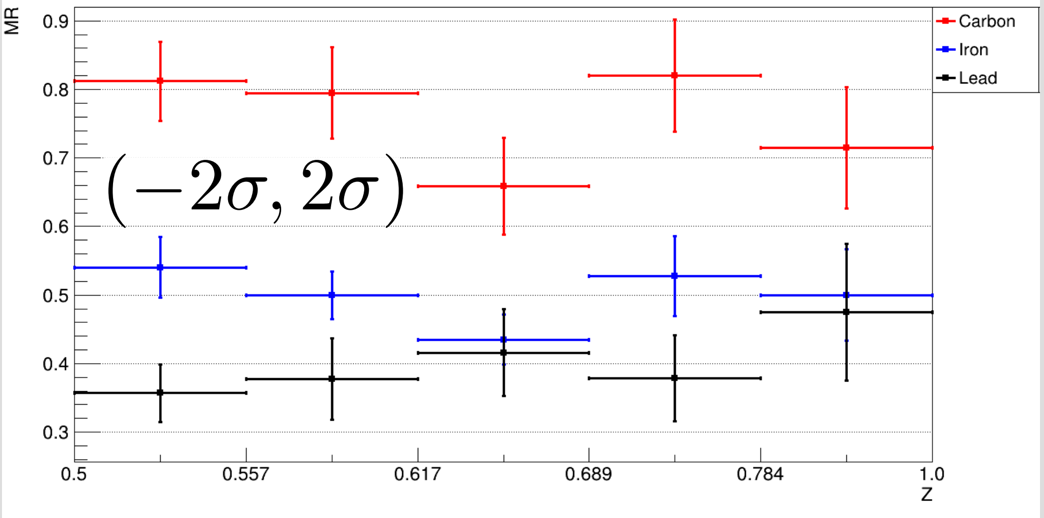
Backup

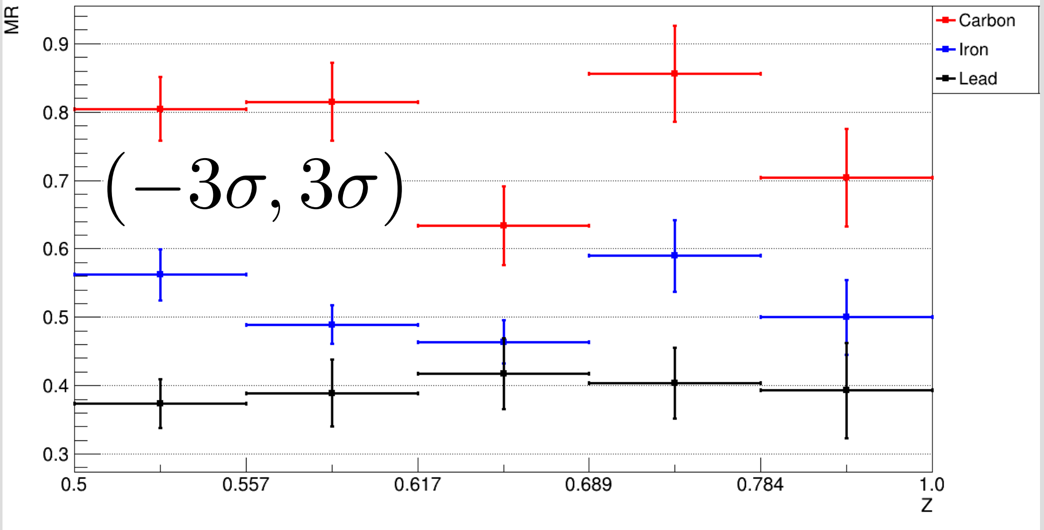
References for the use of mass difference spectrum (CERN papers)

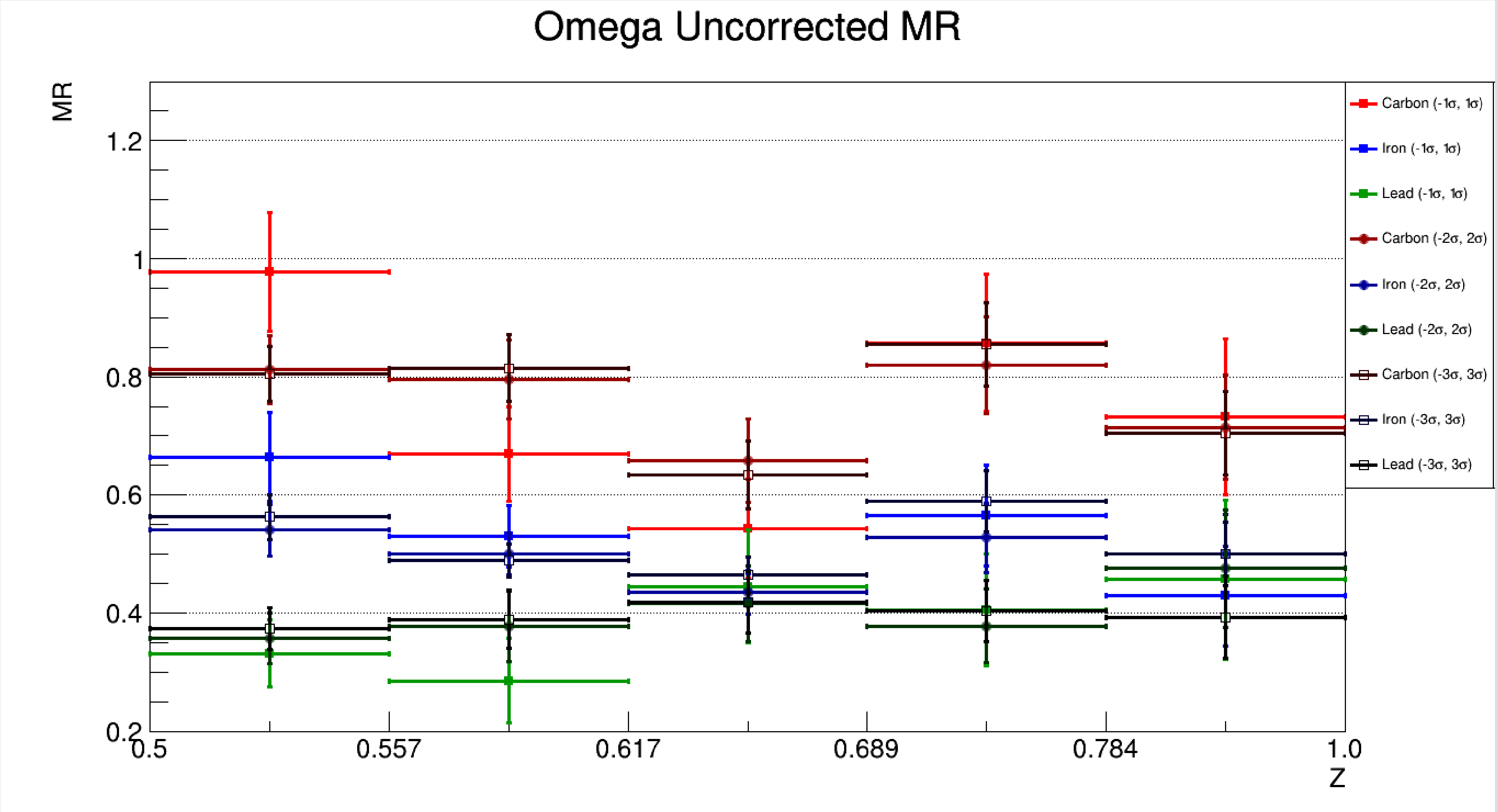
- Phys. Rev. D 85, 052005 (2012)
- Nucl. Phys. B 864 (2012) 341-381

Uncorrected MR

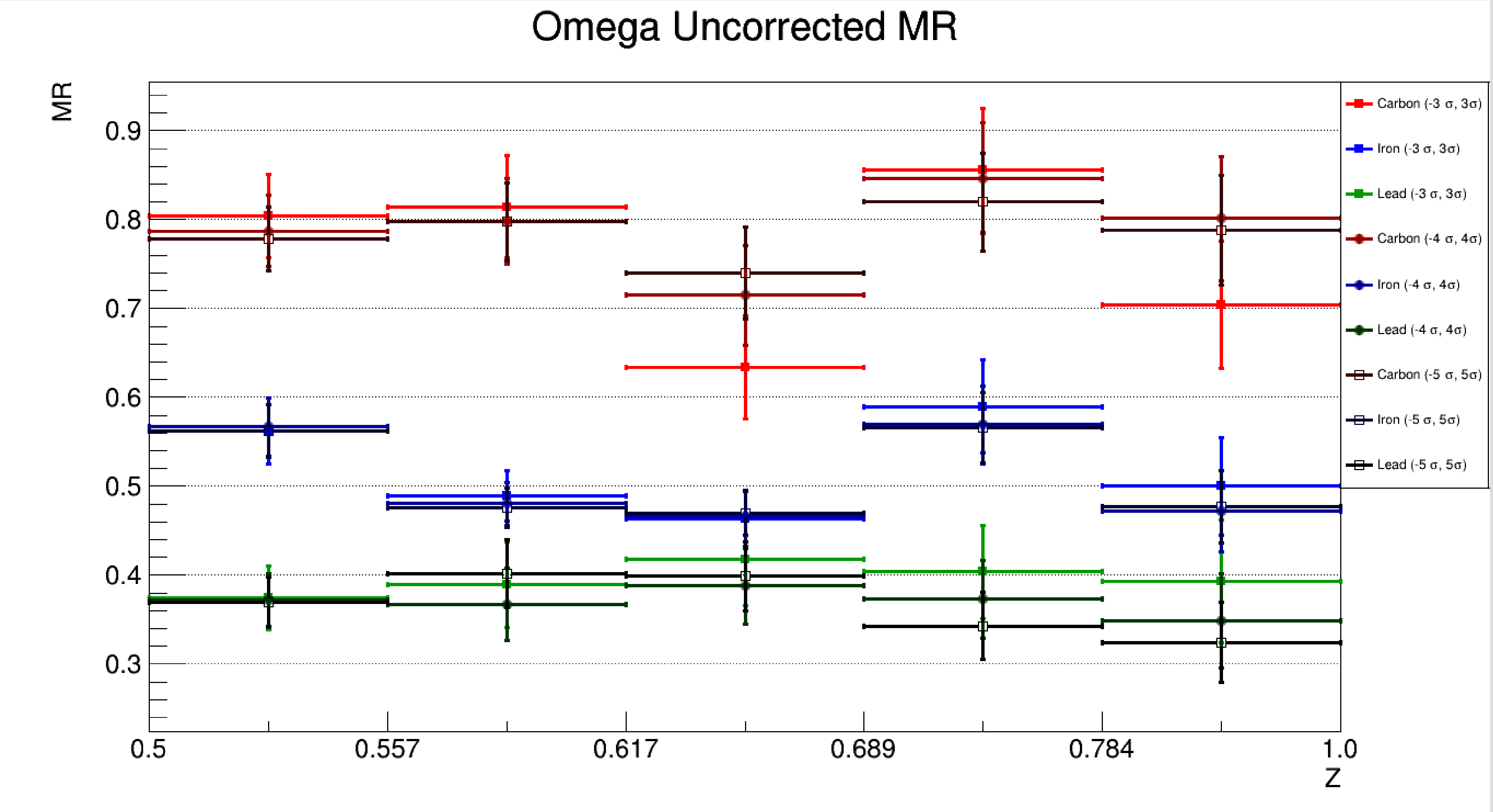








Omega Uncorrected MR
MR
1.2
1
0.8
0.6
0.4
0.2
0.5
0.557
0.617
0.689
0.784
1.0
Z
Carbon (-1σ, 1σ)
Iron (-1σ, 1σ)
Lead (-1σ, 1σ)
Carbon (-2σ, 2σ)
Iron (-2σ, 2σ)
Lead (-2σ, 2σ)
Carbon (-3σ, 3σ)
Iron (-3σ, 3σ)
Lead (-3σ, 3σ)



Omega Uncorrected MR
MR
0.3
0.4
0.5
0.6
0.7
0.8
0.9
0.5
0.557
0.617
0.689
0.784
1.0
Z
Carbon (-3 σ, 3σ)
Iron (-3 σ, 3σ)
Lead (-3 σ, 3σ)
Carbon (-4 σ, 4σ)
Iron (-4 σ, 4σ)
Lead (-4 σ, 4σ)
Carbon (-5 σ, 5σ)
Iron (-5 σ, 5σ)
Lead (-5 σ, 5σ)