CLAS Collaboration Meeting – April 2020

Nuclear Physics Working Group Joint Session

Update on Omega Hadronization Studies

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Outline

1. Introduction
2. The experiment
3. Particle Identification
4. Kinematic variables and observable
5. Binning
6. Electron Ratio
7. Background Subtraction
8. Results
9. Simulations
10. Next steps

Introduction

- This analysis follows a line of investigation,
  - π^0 analysis from Taisiya Mineeva
  - η meson hadronization from Orlando Soto
- First studies ever on omega meson hadronization.
- $\omega(782)$:
  - Quark content: $(u\,\bar{u} + d\,\bar{d})$
  - Mean lifetime: $7.75\ \times 10^{-23}[s]$
  - Decay channel: $\omega \rightarrow \pi^+\pi^-\pi^0 \rightarrow \pi^+\pi^-\gamma\gamma$

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

π^0 DECAY MODES	Fraction (Γ_i/Γ)
2γ	(98.823 ± 0.034) %
$e^+e^-\gamma$	$(\ 1.174 \pm 0.035)$ %

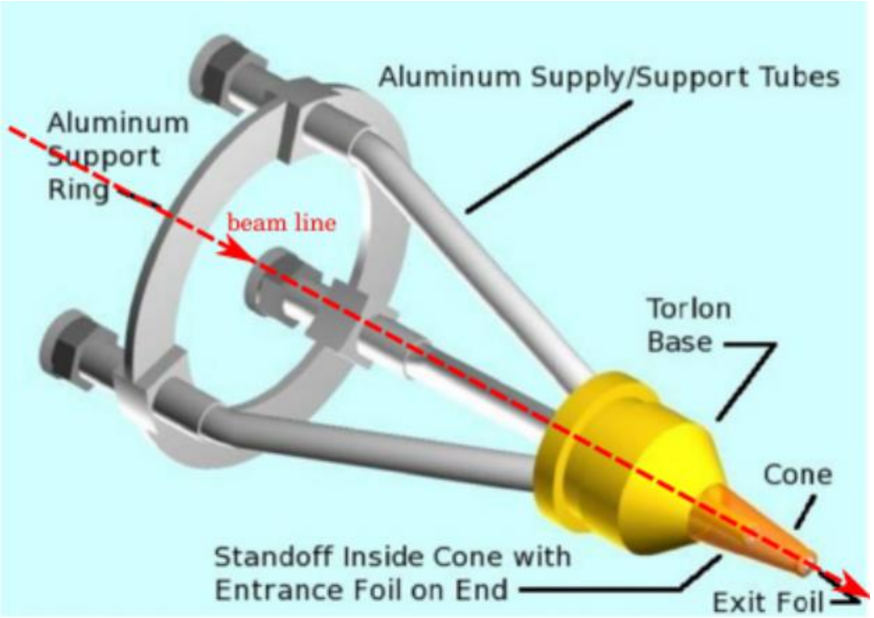
η DECAY MODES	Fraction (Γ_i/Γ)
	Neutral modes
neutral modes	(72.12 ± 0.34) %
2γ	(39.41 ± 0.20) %
$3\pi^0$	(32.68 ± 0.23) %
	Charged modes
charged modes	(28.10 ± 0.34) %
$\pi^+\pi^-\pi^0$	(22.92 ± 0.28) %
$\pi^+\pi^-\gamma$	$(\ 4.22 \pm 0.08)$ %

- Main difficulty: <u>low statistics analysis.</u>

EG2 run: E02-104 experiment

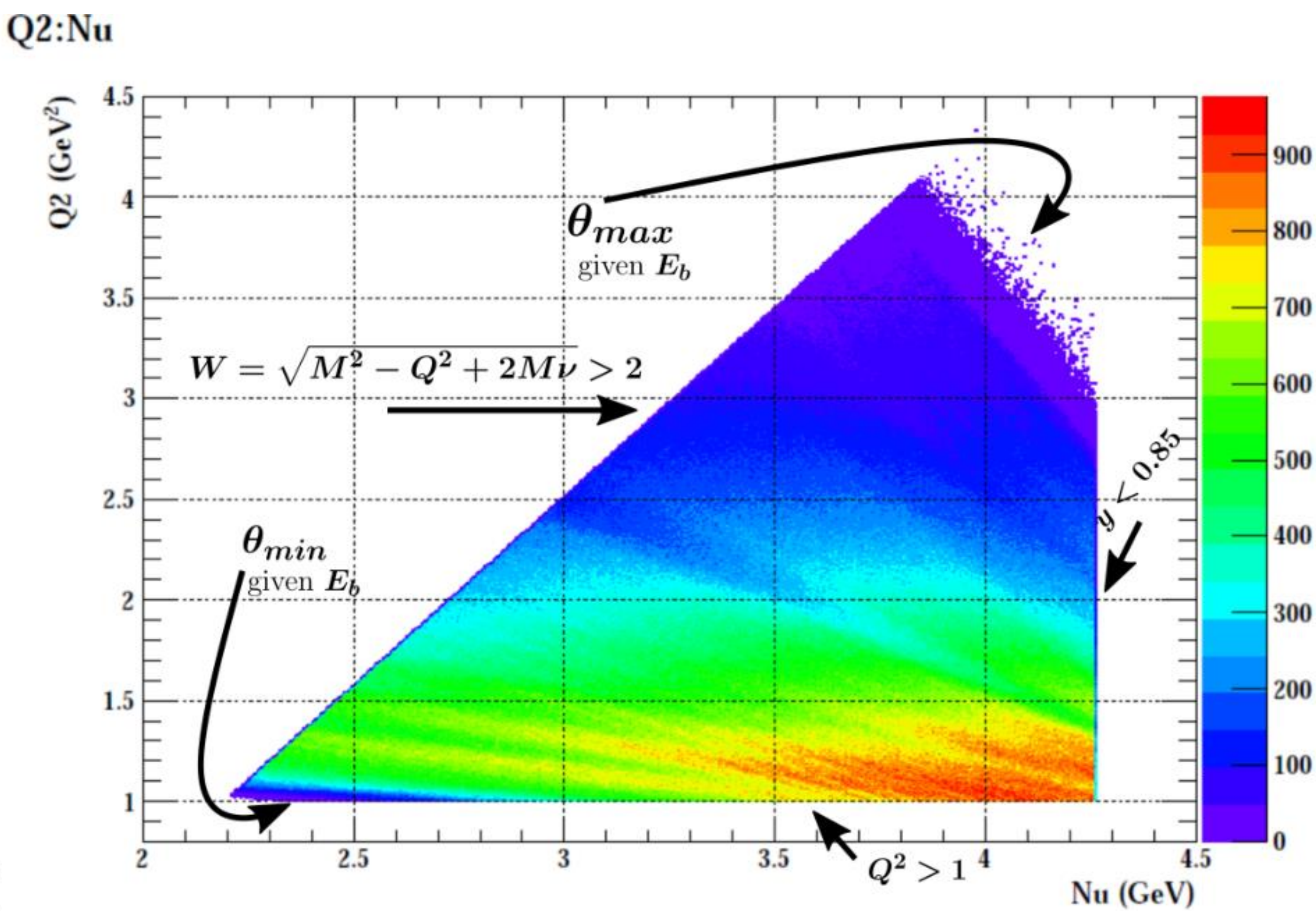
Double target system composed of a solid heavy target $A(C, Fe, Pb)$ and a liquid target D (Deuterium) positioned simultaneously in the beam line.

Main feature: same luminosity for different nuclei!

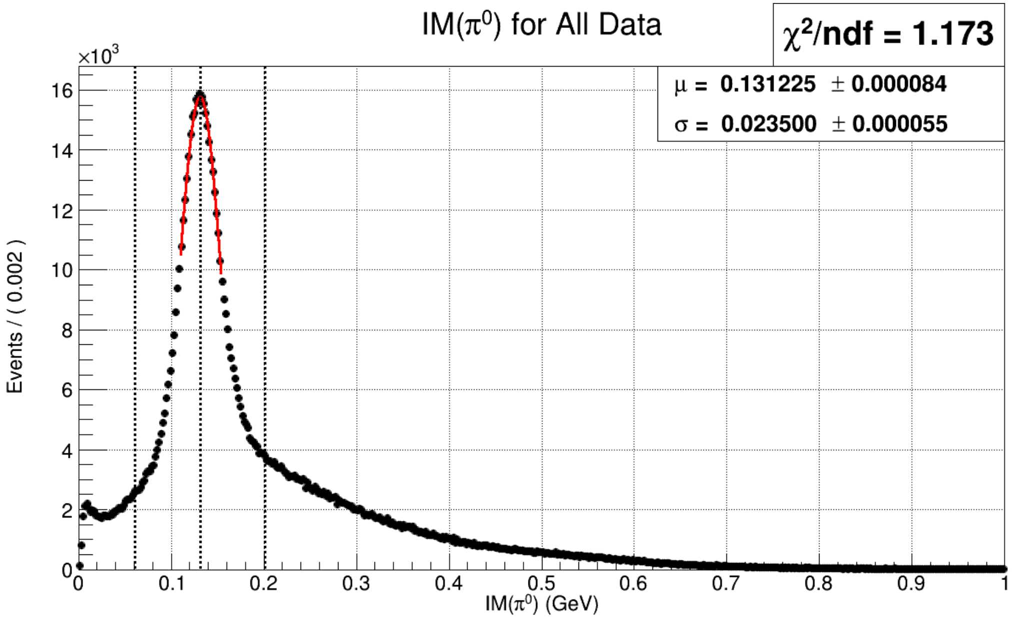


Electron Identification

The kinematic region in the DIS regime is: $Q^2 > 1,\ W > 2,\ y_B < 0.85$



Pion Identification



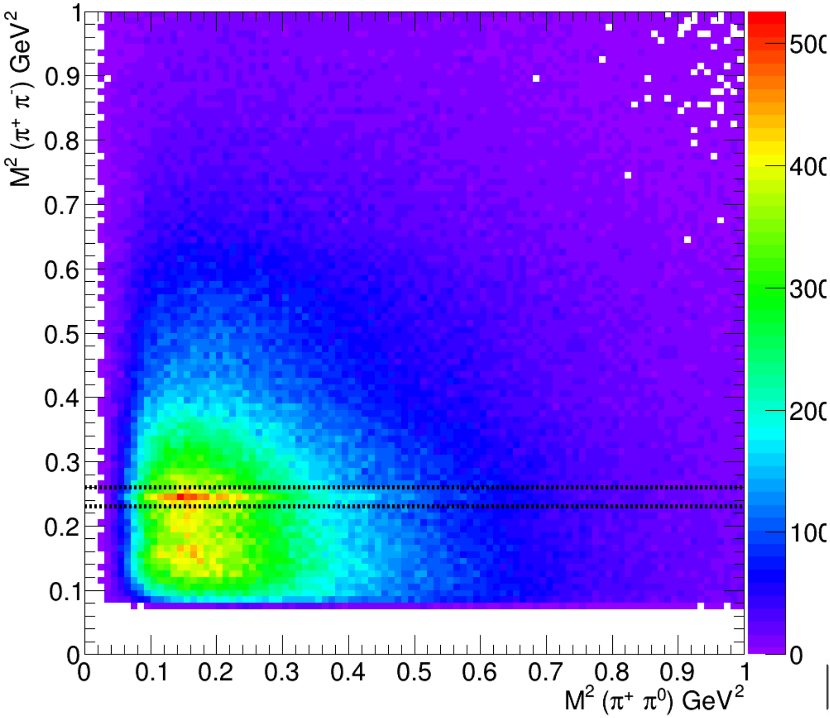
Gaussian fit around π^0 invariant mass. Horizontal lines represent the 3σ cut around obtained mean.

$$\pi^0 \text{ mass } = 0.059 \text{ [GeV]} < M_{\gamma\gamma} < 0.204 \text{ [GeV]}$$

$$\pi^+\pi^- \text{ mass } = M^2_{\pi^+\pi^-} < 0.23 \text{ [GeV] or } M^2_{\pi^+\pi^-} > 0.26 \text{ [GeV]}$$

(to exclude kaons band)

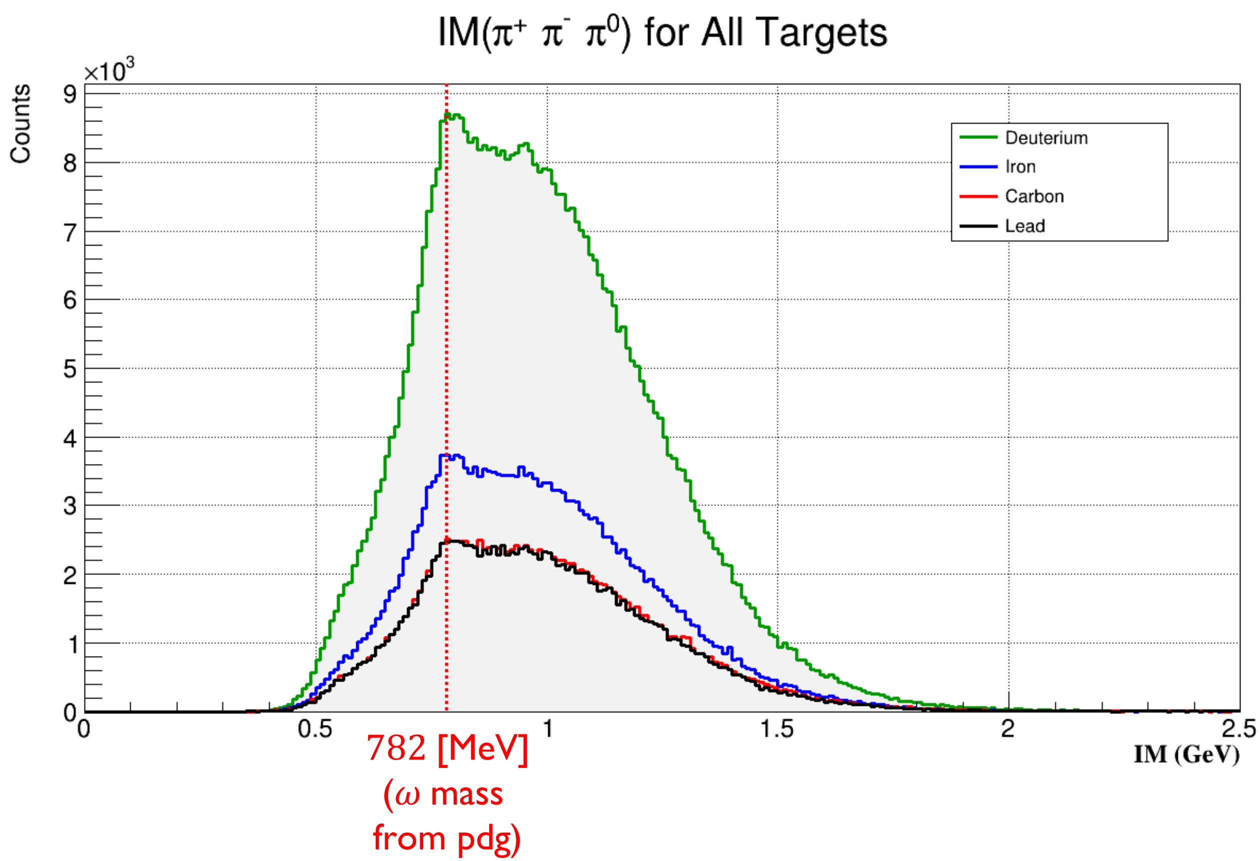
Band represented by the two horizontal lines.



ω selection

Selected events must accomplish: $N_{\pi^+} \geq 1 \wedge N_{\pi^-} \geq 1 \wedge N_{\gamma} \geq 2$

And keep all posible combinations: $\binom{N_{\pi+}}{1} \times \binom{N_{\pi-}}{1} \times \binom{N_{\gamma}}{2}$



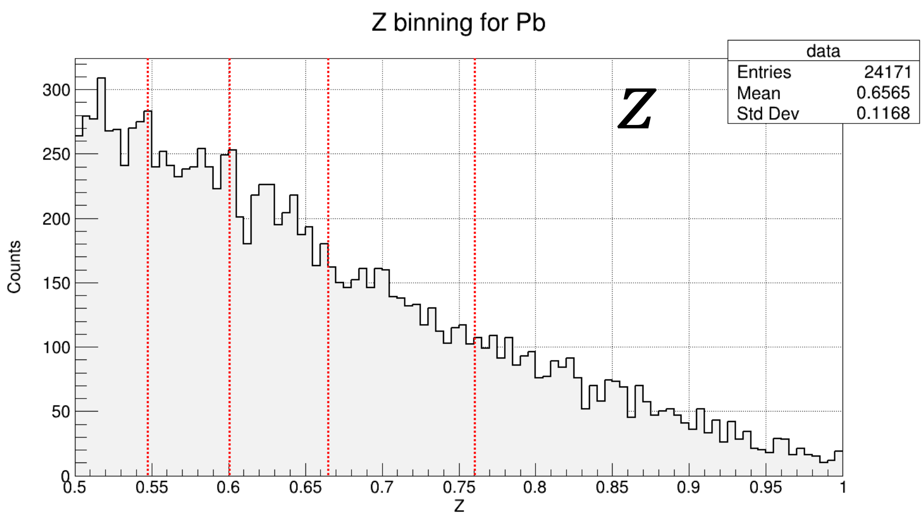
Kinematic Variables and Observable

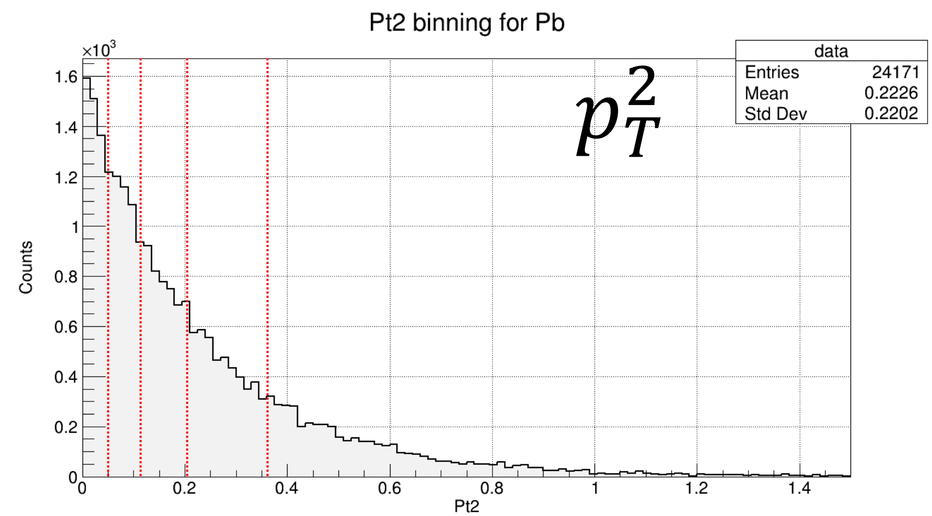
- To continue, we must define the following DIS kinematic variables in the laboratory frame.
  - $Q^2 = 4\, E_b E' \sin^2\left(\frac{\theta}{2}\right)$: virtuality of the probe electron.
  - $\nu = E_b - E'$: energy transferred from the electron to the target.
  - $z = E_h/\nu$: fraction of the virtual photon energy carried by the produced hadron.
  - $p_T^2 = p_h^2\left(1 - \cos\left(\theta_{PQ}\right)\right)$: transversal momentum w.r.t. virtual photon direction.
- Observable: **Multiplicity Ratio**.
  - For our case: $h = \omega$, $A = \{\text{Carbon, Iron, Lead}\}$ and $D = \{\text{Deuterium}\}$.

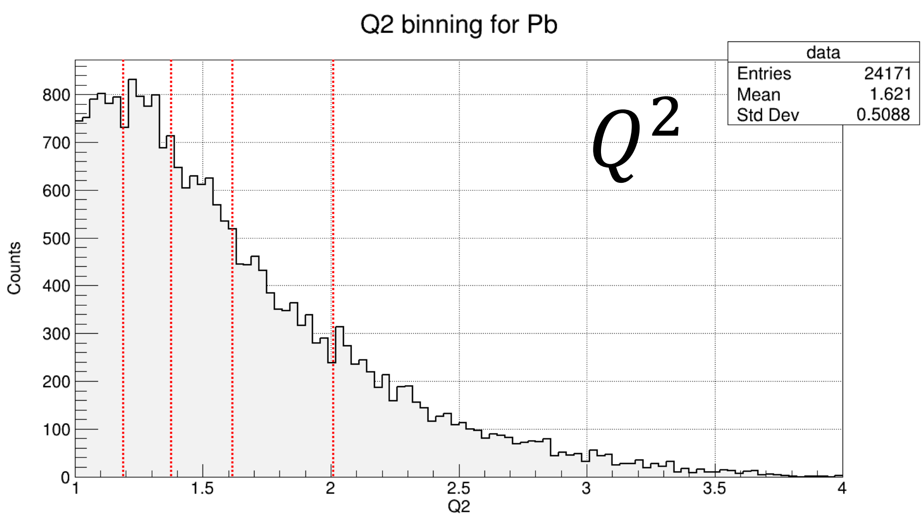
$$R_h^A \equiv \frac{\left(\dfrac{N_h(Q^2,\nu,z,p_T^2)}{N_e^{DIS}(Q^2,\nu)}\right)_A}{\left(\dfrac{N_h(Q^2,\nu,z,p_T^2)}{N_e^{DIS}(Q^2,\nu)}\right)_D}$$

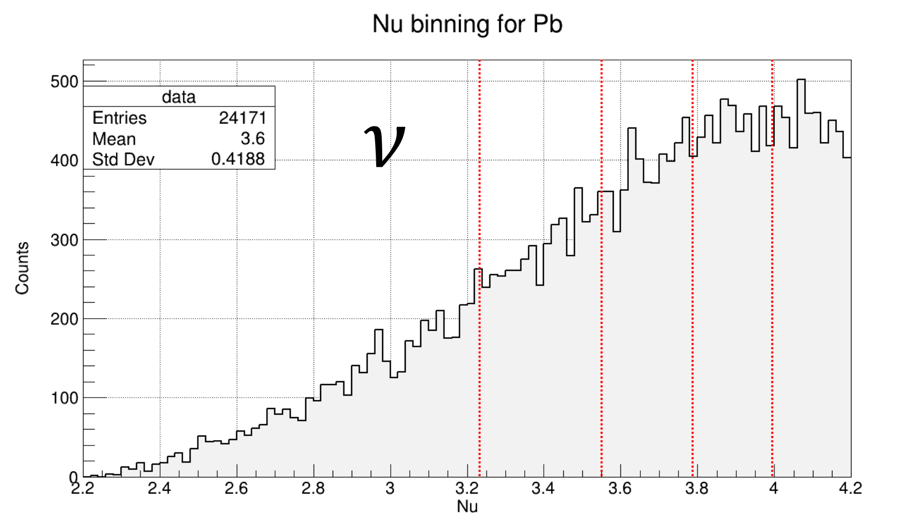
Binning

z	0.5	0.55	0.60	0.67	0.76	1.0
p_T^2	0.0	0.05	0.11	0.20	0.36	1.5
Q^2	1.0	1.19	1.38	1.62	2.00	4.0
ν	2.2	3.23	3.55	3.79	4.0	4.2









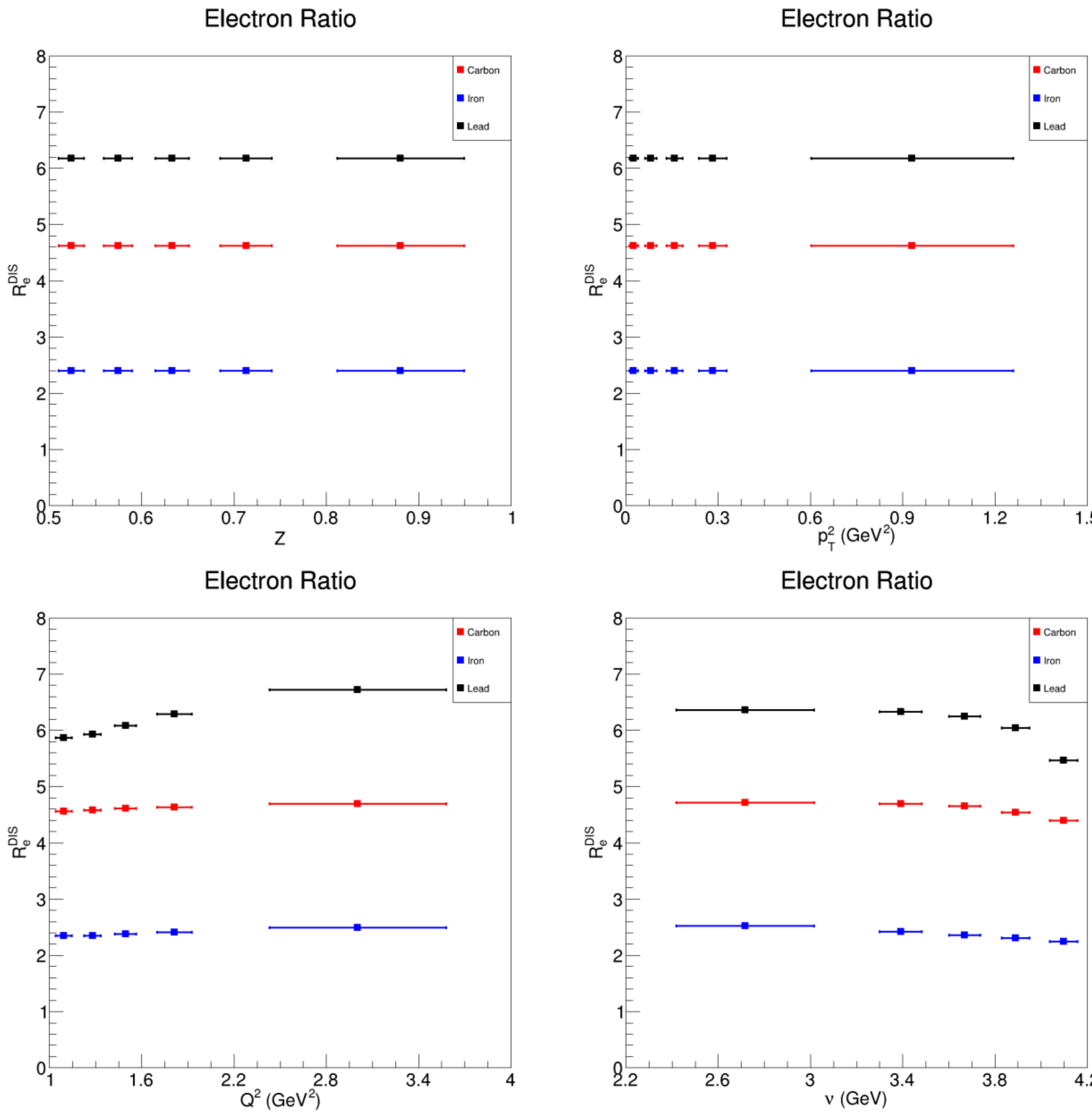
Electron Ratios

From the previous MR definition,

$$R_h^A \equiv \frac{\left(\frac{N_h(Q^2,\nu,z,p_T^2)}{N_e^{DIS}(Q^2,\nu)}\right)_A}{\left(\frac{N_h(Q^2,\nu,z,p_T^2)}{N_e^{DIS}(Q^2,\nu)}\right)_D}$$

we can extract the Electron Number Ratio:

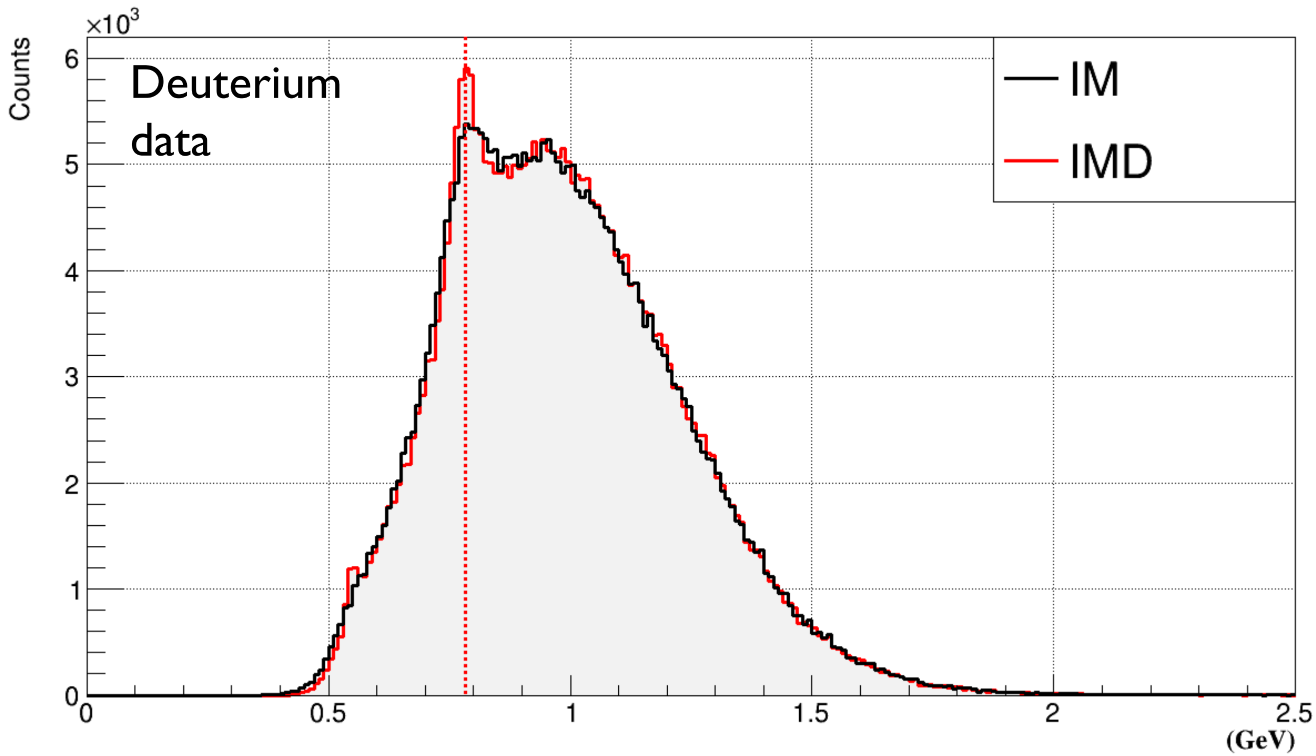
$$\mathrm{ER} \equiv \frac{\left(N_e^{DIS}(Q^2,\nu)\right)_D}{\left(N_e^{DIS}(Q^2,\nu)\right)_A}$$



Background Subtraction

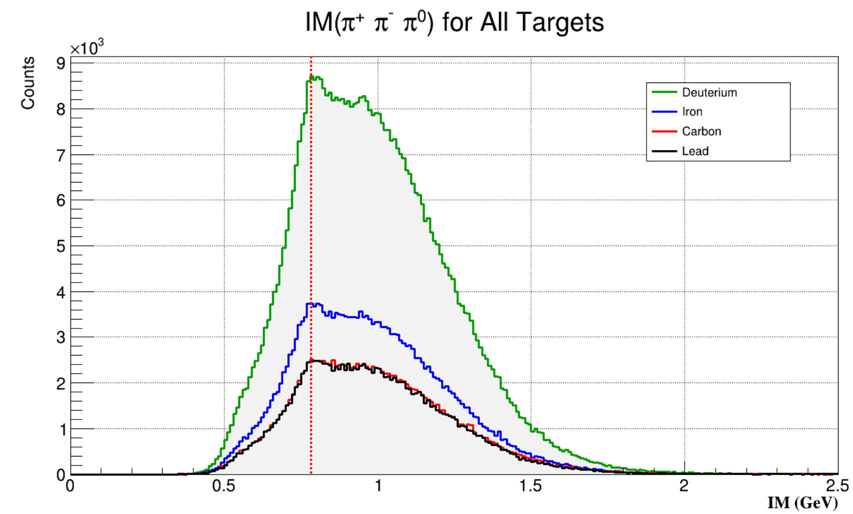
In order to enhance the signal, we use the **Invariant Mass Difference.**

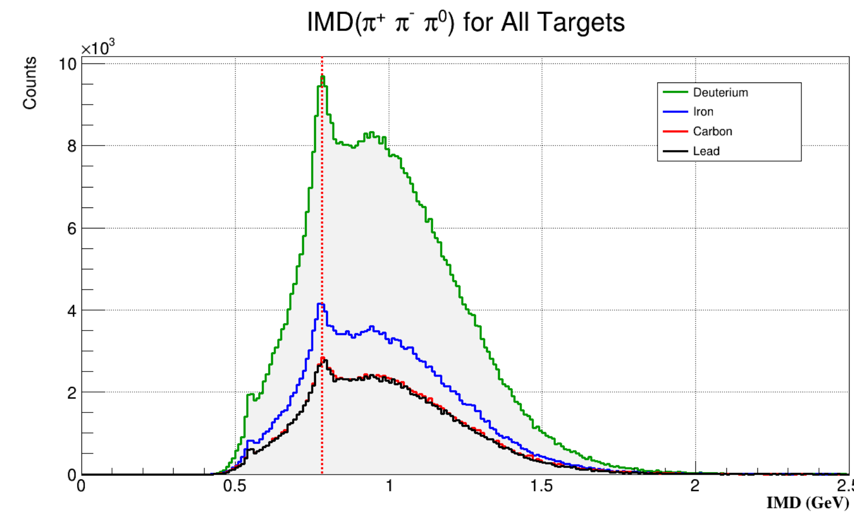
$$IMD \equiv IM(\omega) - IM(\pi^+) - IM(\pi^-) - IM(\gamma\gamma)$$

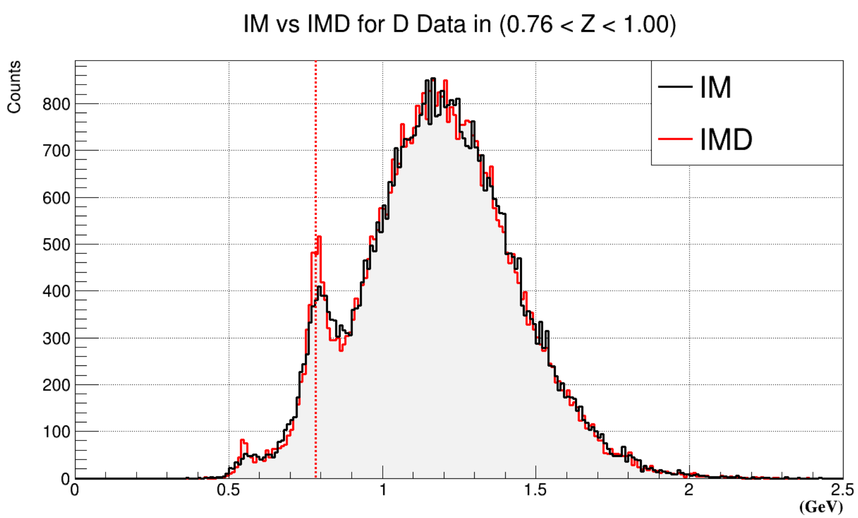


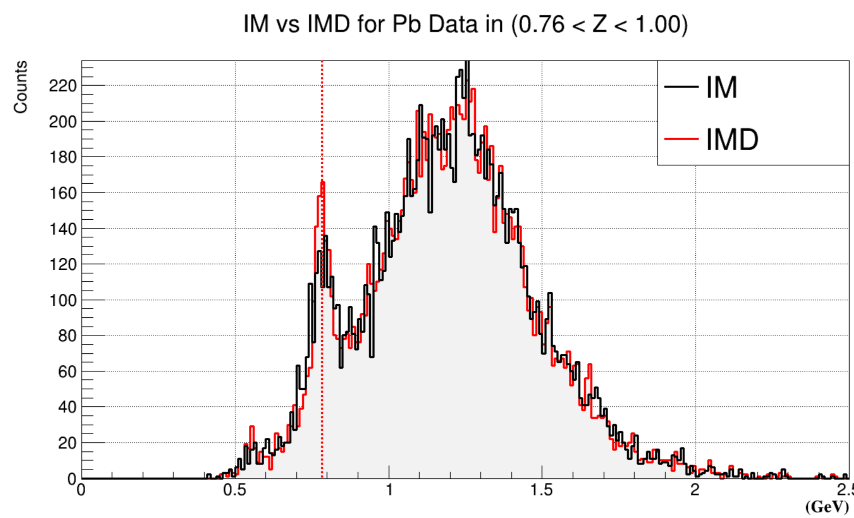
For more examples of this method,
DOI: 10.1103/PhysRevD.85.052005
DOI: 10.1016/j.nuclphysb.2012.07.009

Background Subtraction - II









Background Subtraction - III

To count the ω number, we make a composite extended fit around its peak.

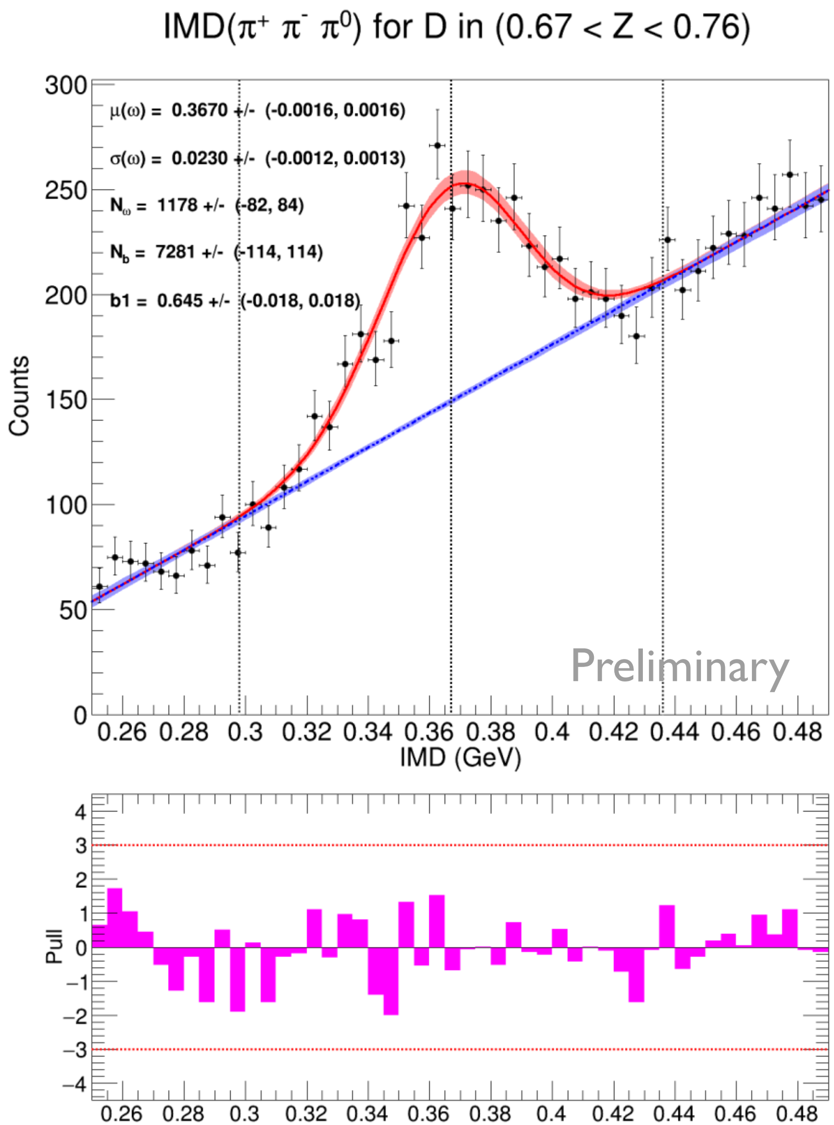
- Gaussian for the signal
- 1st order polynomial for the bkg

Software used: **RooFit**.
Error estimation: **MINOS**.
Fit method: extended maximum likelihood estimation.

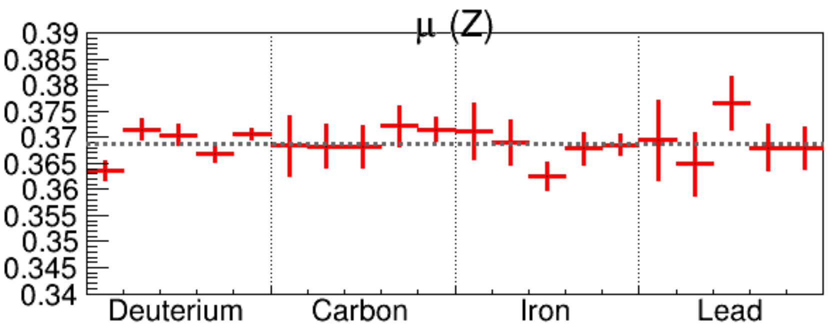
Tools:

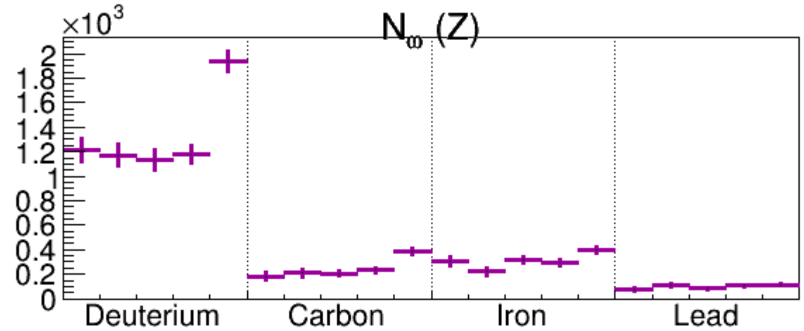
- constraint the σ parameter.
- uncertainty bands.
- pull distribution.

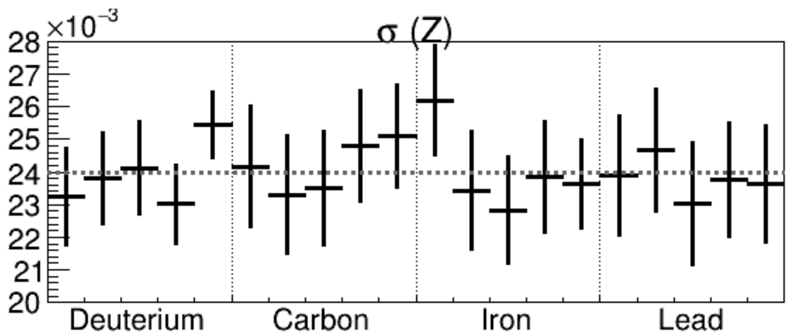
$$pull(x) = \frac{data(x) - fit(x)}{error_{data}(x)}$$

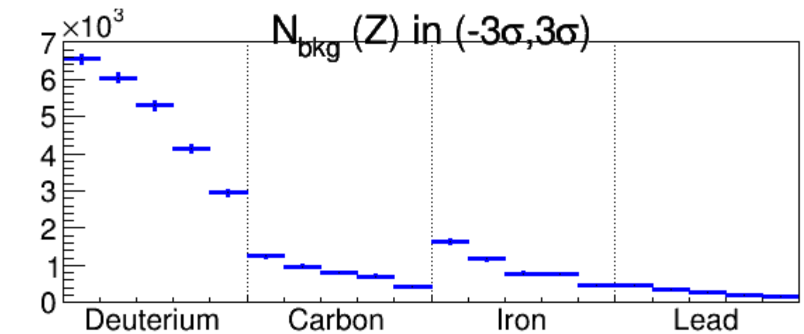


Parameters - I



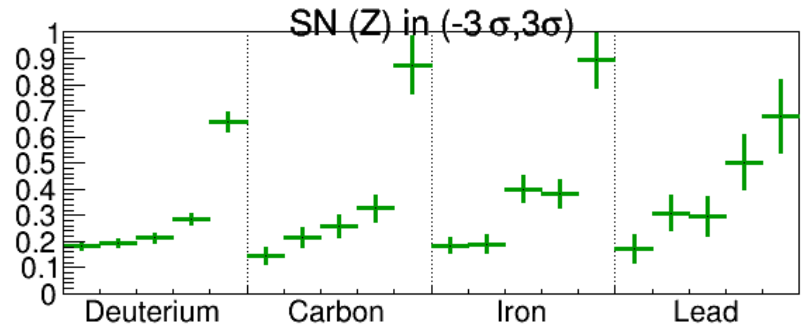




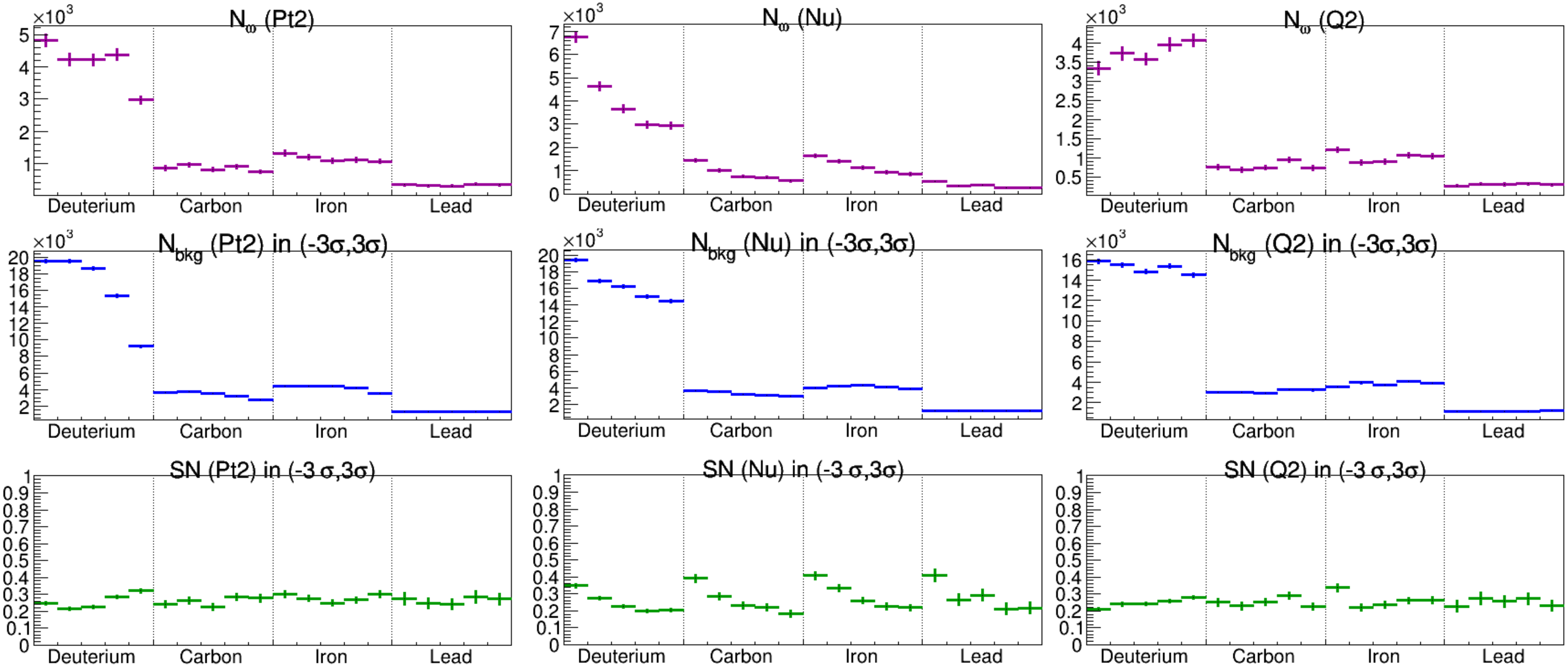


Result of the parameters obtained directly by RooFit. Increasing in z bin for each target. Gray horizontal lines represent average of the parameter values.

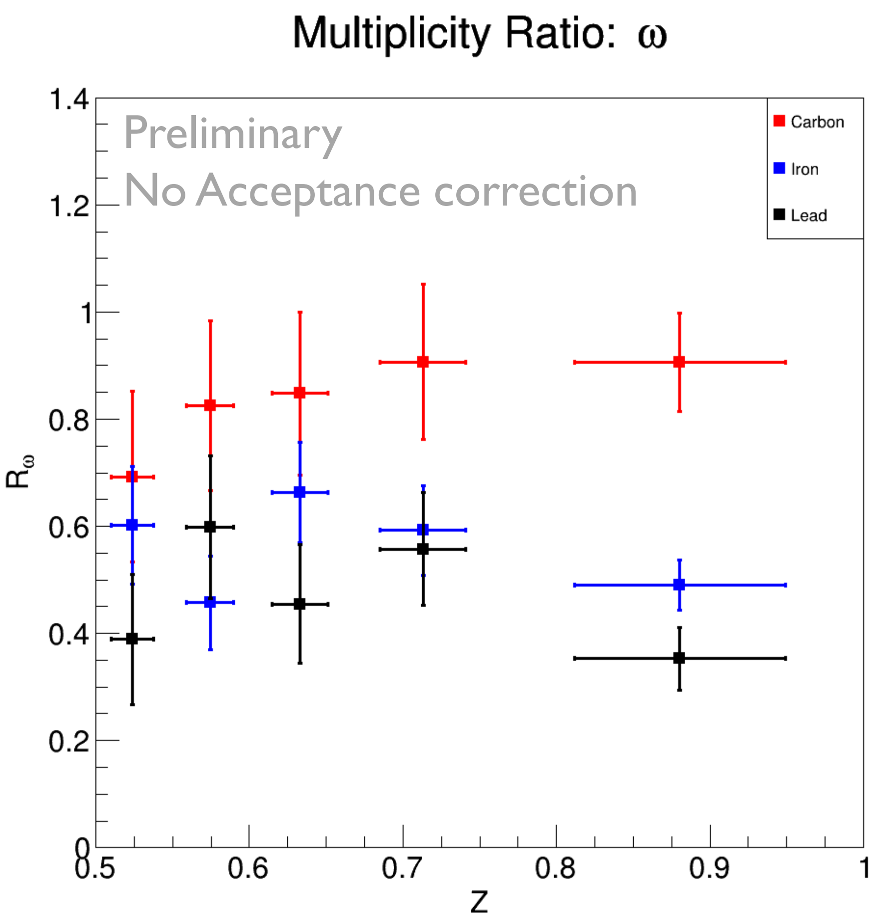
$$\mathrm{SN} \equiv \frac{N_{\omega}(-3\sigma, 3\sigma)}{N_{bkg}(-3\sigma, 3\sigma)}$$



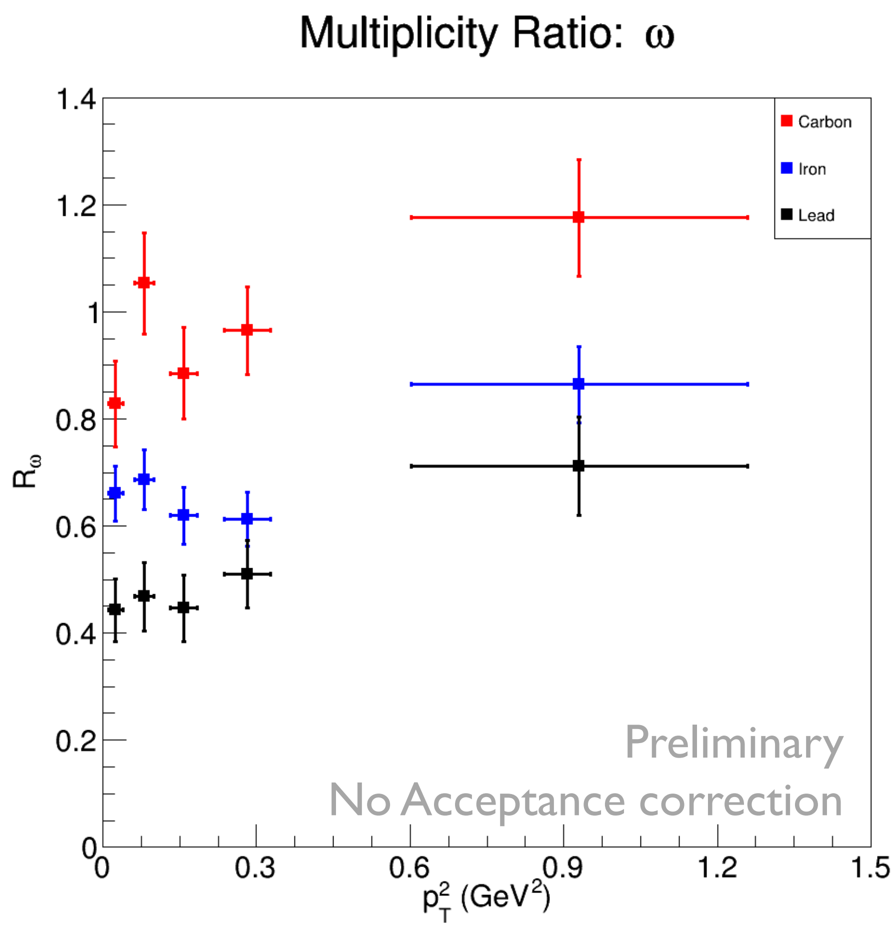
Parameters - II



Results - I

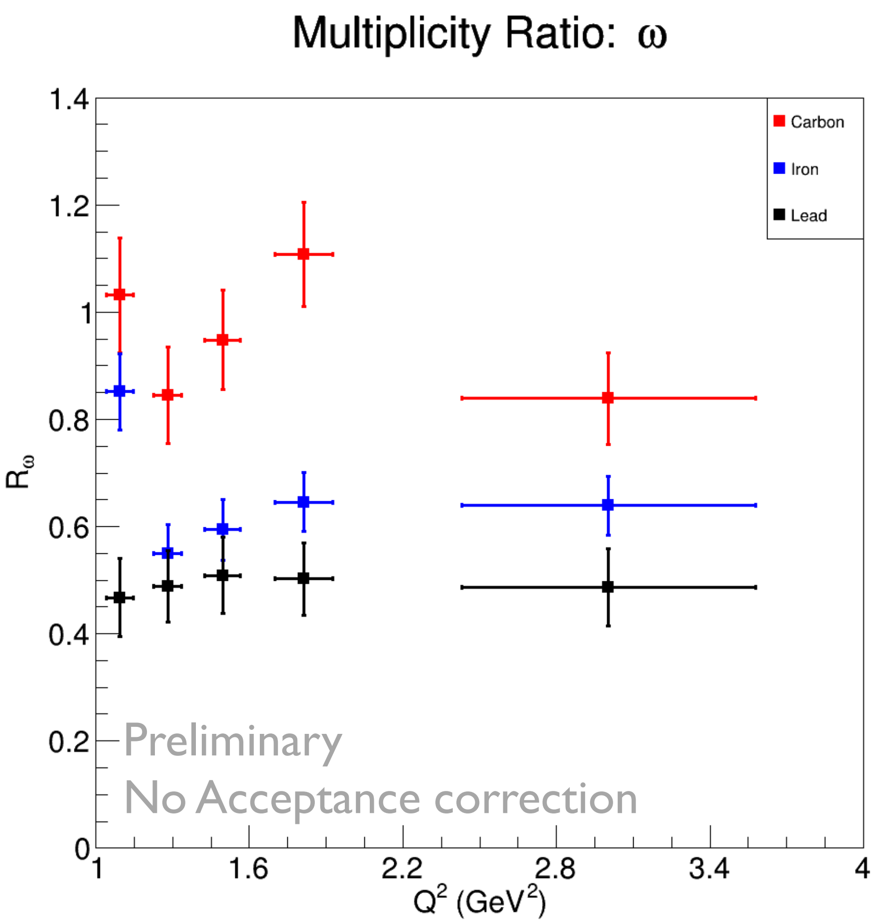


Multiplicity Ratio: ω
Preliminary
No Acceptance correction
Carbon
Iron
Lead
R_ω
Z
0.5
0.6
0.7
0.8
0.9
1
0
0.2
0.4
0.6
0.8
1
1.2
1.4

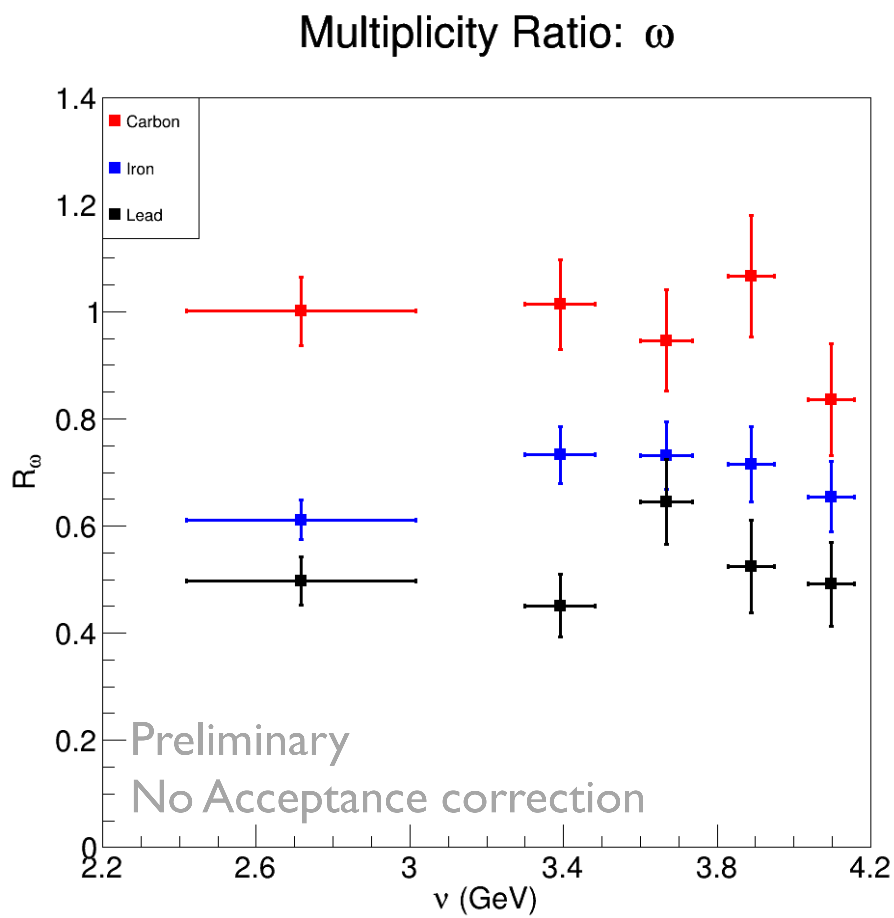


Multiplicity Ratio: ω
Preliminary
No Acceptance correction
Carbon
Iron
Lead
R_ω
p_T^2 (GeV^2)
0
0.3
0.6
0.9
1.2
1.5
0.2
0.4
0.6
0.8
1
1.2
1.4

Results - II



Multiplicity Ratio: ω
Carbon
Iron
Lead
R_ω
Q^2 (GeV^2)
Preliminary
No Acceptance correction



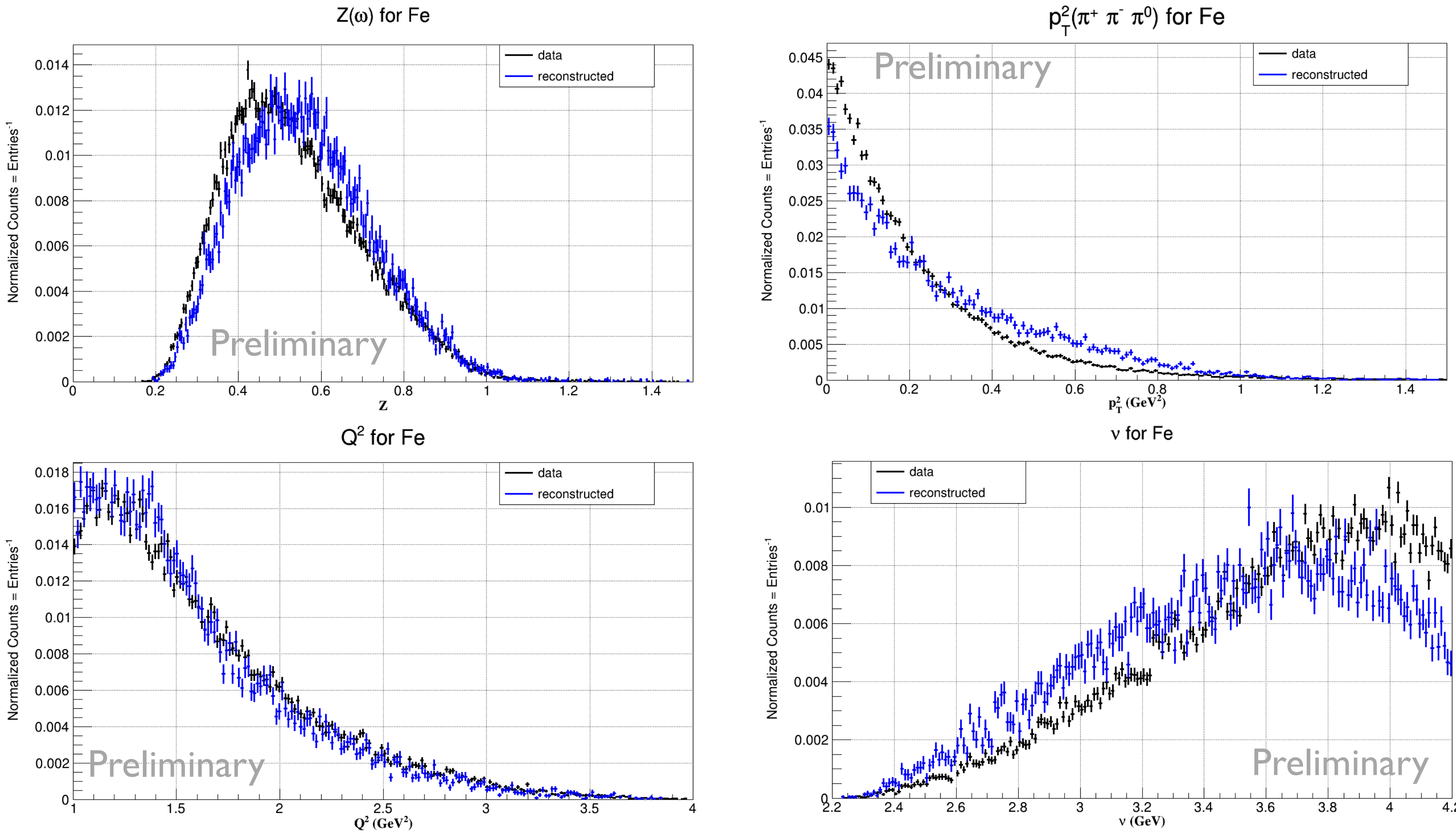
Multiplicity Ratio: ω
Carbon
Iron
Lead
R_ω
ν (GeV)
Preliminary
No Acceptance correction

Acceptance Correction

- Correction that covers the imperfections of the detector, such as: detection, track reconstruction and event selection efficiencies.
- Simulation chain:
  - LEPTO: MC event generator
  - GSIM
  - GPP
  - user_ana
  - ClasTool

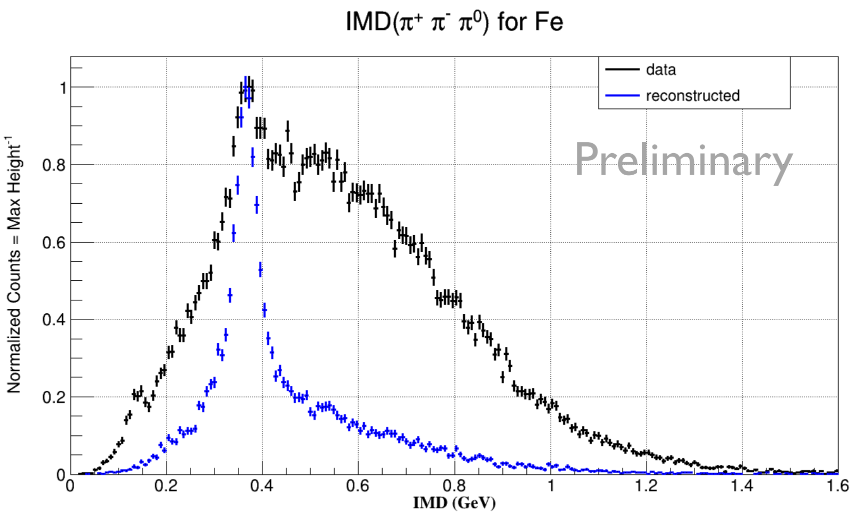
  (GSIM, GPP, user_ana, ClasTool: CLAS reconstruction chain)
- Condition: **at least one omega meson must have been generated**
- So far, there is this quantity of generated events.
  - D: 800M (need 850M more!)
  - C: 335M (ready to filter!)
  - Fe: 405M (ready to filter!)
  - Pb: 125M (ready to filter!)

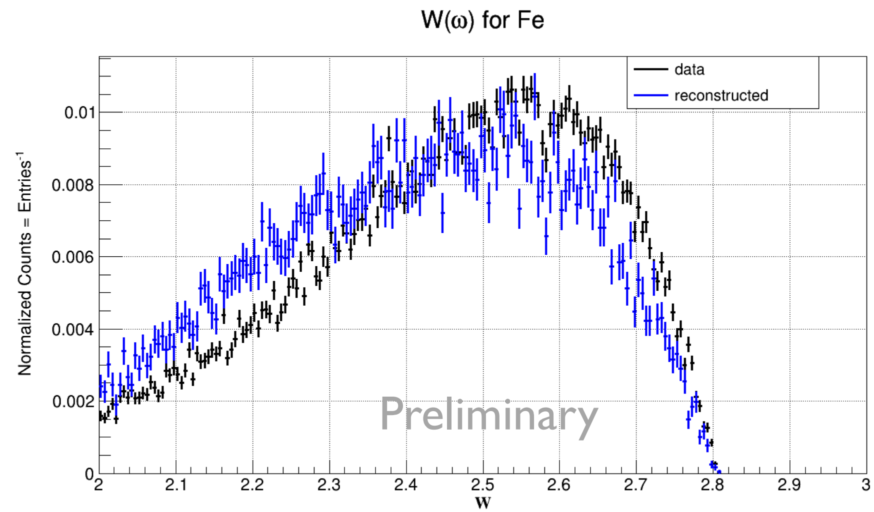
Comparison (Data vs Simulations) - I

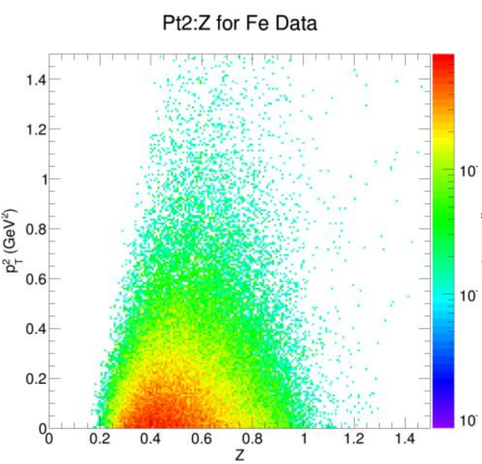


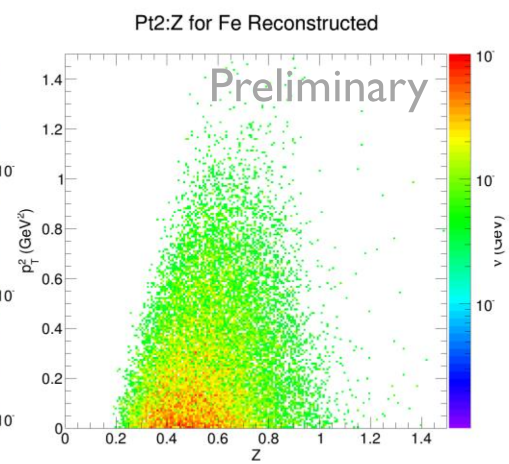
Reconstructed events sample from 12M generated events.

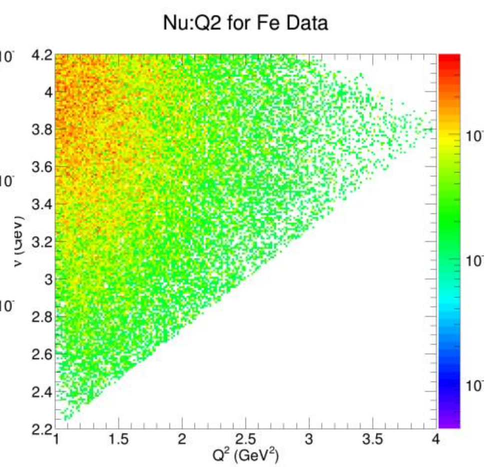
Comparison (Data vs Simulations) - II

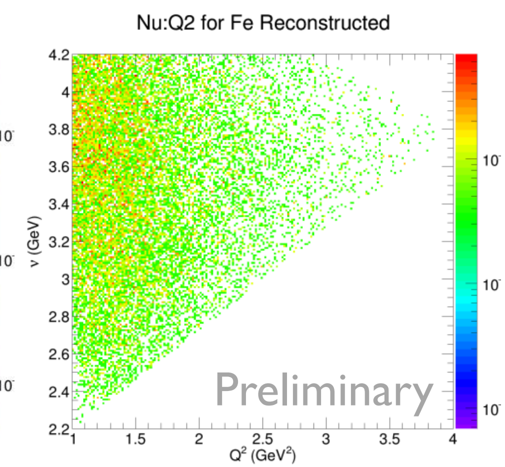












Reconstructed events sample from 12M generated events.

Next steps

Andrés Bórquez
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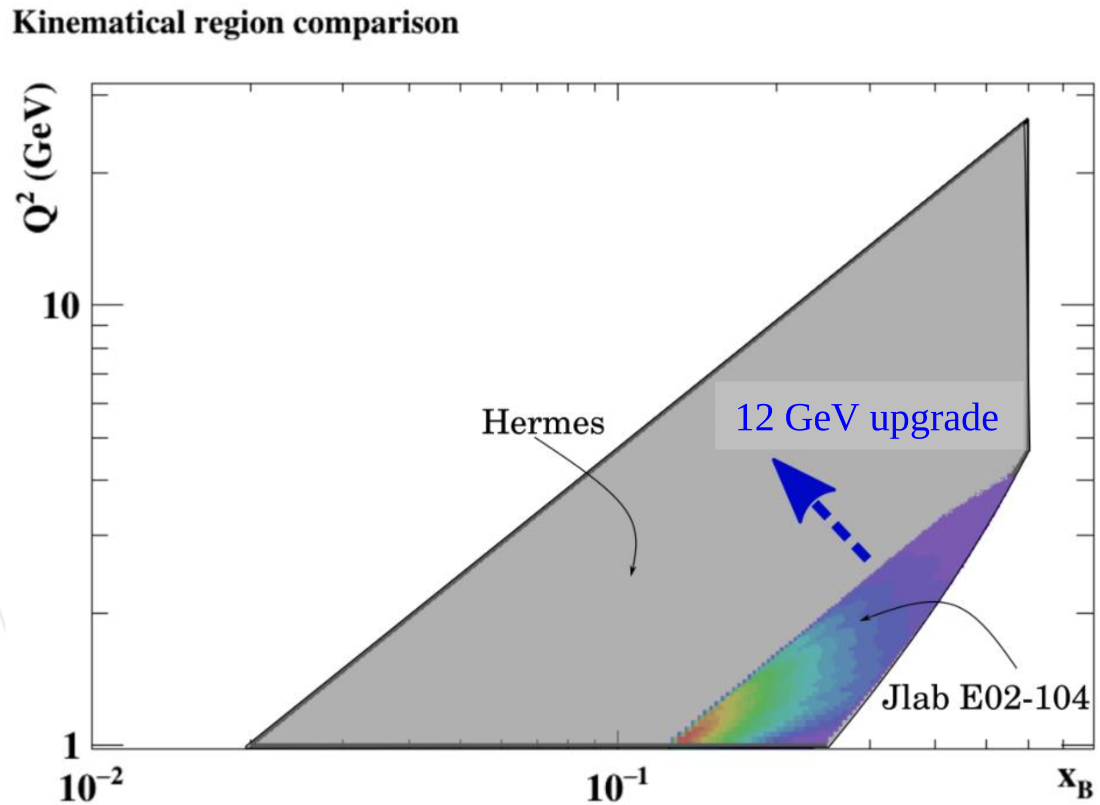
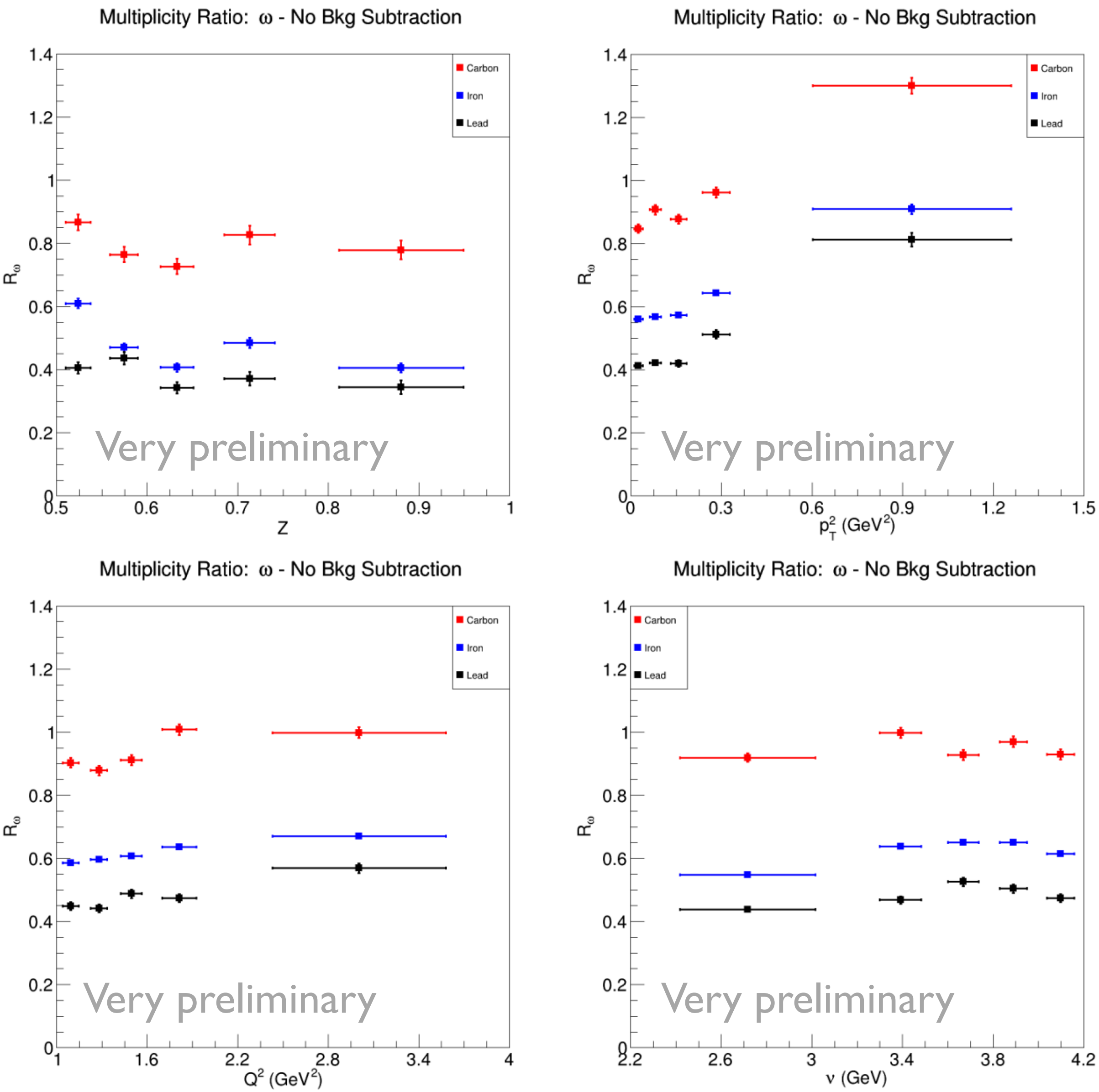
- Acceptance correction
- Radiative corrections
- Systematic studies
- Submit η and ω CLAS Analysis Note



Thank you for your attention!

Backup

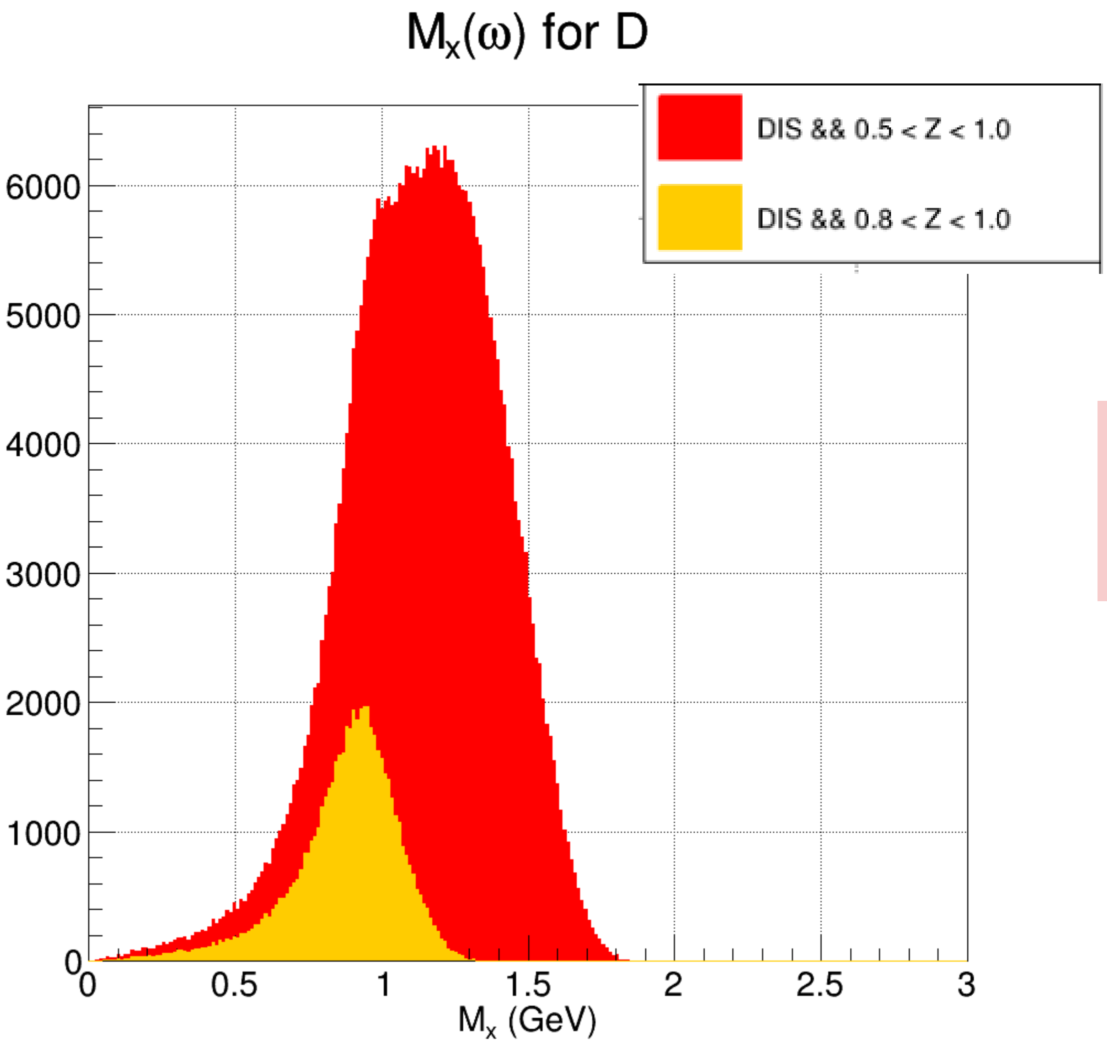
Results without Background Subtraction



These results were obtained from the fits, just by applying a 3σ cut around the ω peak.

It integrates both background and signal in that range.

Missing Mass



Diffractive ω production appears at higher z, mostly for Deuterium target.