

Jlab E12-14-012 experiment: Update

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On behalf of the E12-14-012 collaboration

Virginia Tech



Hall A/C Collaboration Meeting
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E12-14-012:Reminder

- **Primary Goal:** Measurement of the spectral functions of Argon and Titanium through Ar-Ti ($e, e'p$) reactions
 - Data Collected (Feb-March 2017):
 - Ar/Ti/C/Dummy/Optical ($e, e'p$) reactions for five different kinematic set-ups
 - Ar/Ti/C/Dummy (e, e') reactions for one kinematic set-up
- **Primary Motivation:** To help improve the accuracy of the measurement of the neutrino-oscillation parameters, including the *CP violation in leptonic sector* (one of the top priority of the US particle physics community), in the future neutrino experiments, mainly DUNE, by:
 - Measuring spectral functions of argon nucleus (\sim initial momentum and energy distributions of nucleons bound in the argon nucleus) that can directly be used in the reconstruction of neutrino energies (which is currently the major source of uncertainty in neutrino experiments).
 - Using measured argon spectral functions to further develop (extend) a fully consistent parameter-free theoretical (neutrino-nucleus) model that can be used in (every step of) the analysis of long baseline neutrino experiments.

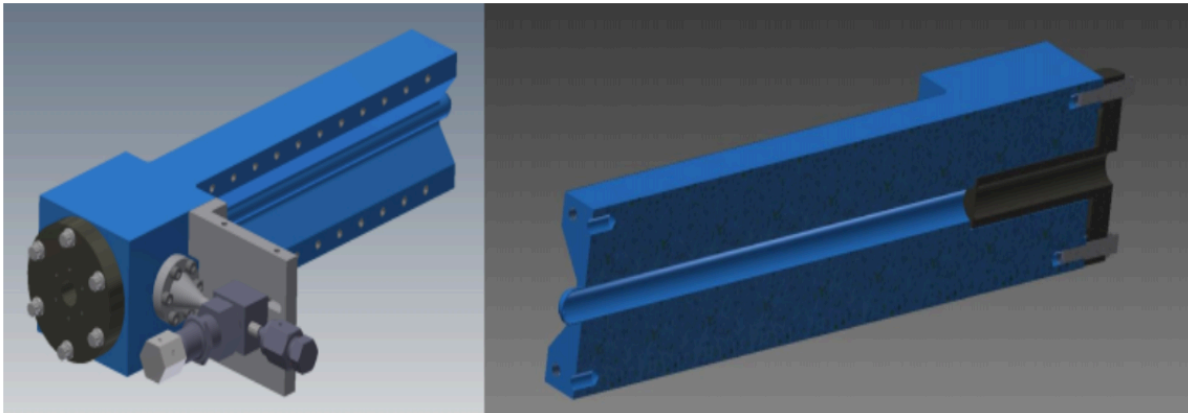
Outline

- Experimental setup
 - target
 - kinematic configurations
- (e,e') and $(e,e'p)$ processes
- Inclusive analysis - summary
- Exclusive analysis
 - Status
 - Future plans
- Summary

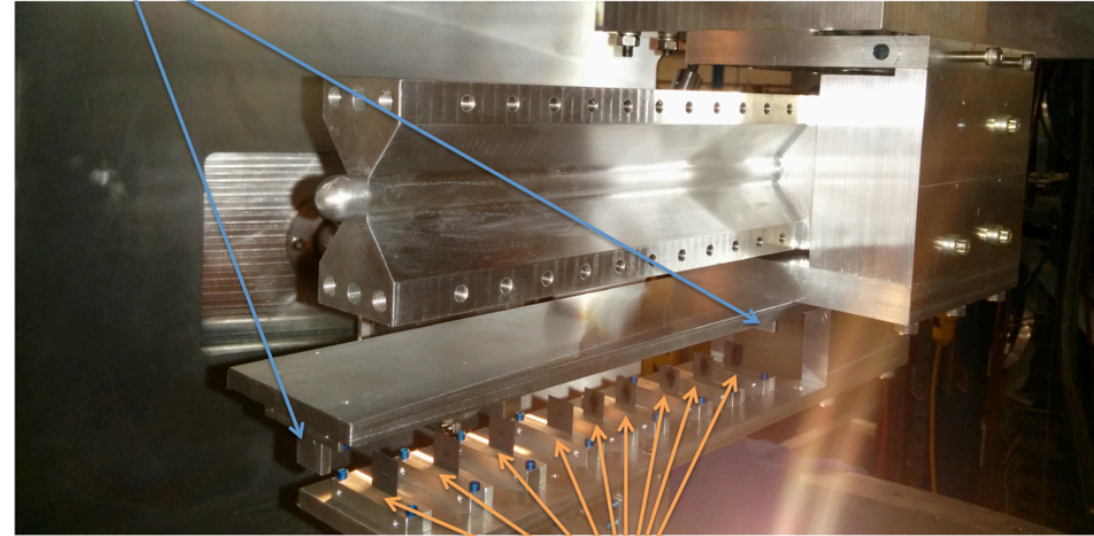
Target Setup

Ar Target

- Closed Gas Cell
- Length = 25 cm
- Pressure = 500 PSI
- Temperature = 300 K.
- Target thickness = 1.381 g cm^{-2}
- Luminosity = $4.33 \times 10^{37} \text{ atoms cm}^{-2} \text{ sec}^{-1}$.



Dummy target: same as the entry and exit window as the gas target

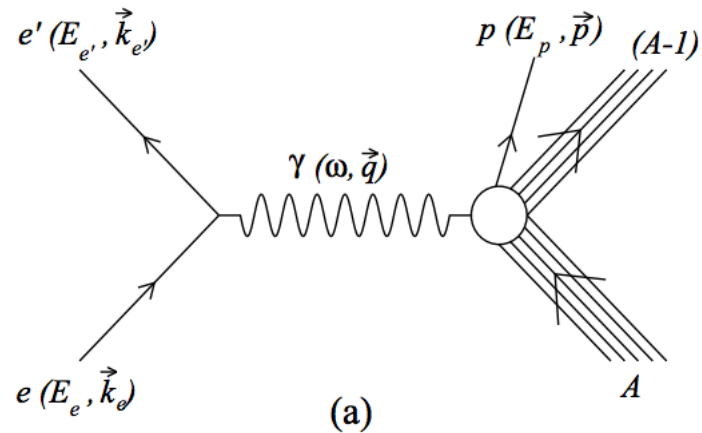
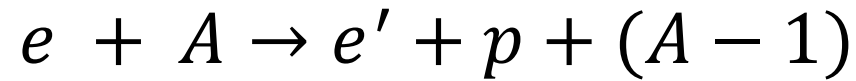


Optical target: a series of foils of carbon (9) to check the alignment of target and spectrometers (optics)

(e,e') and (e,e'p) processes

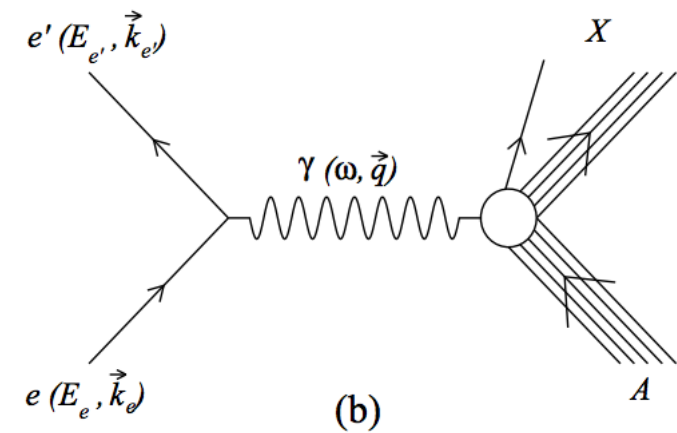
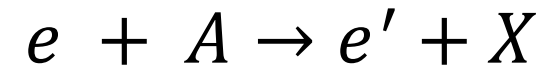
- (e,e'p) process:

Both outgoing electron and proton are detected



- (e,e') process:

Only scattered electron is detected

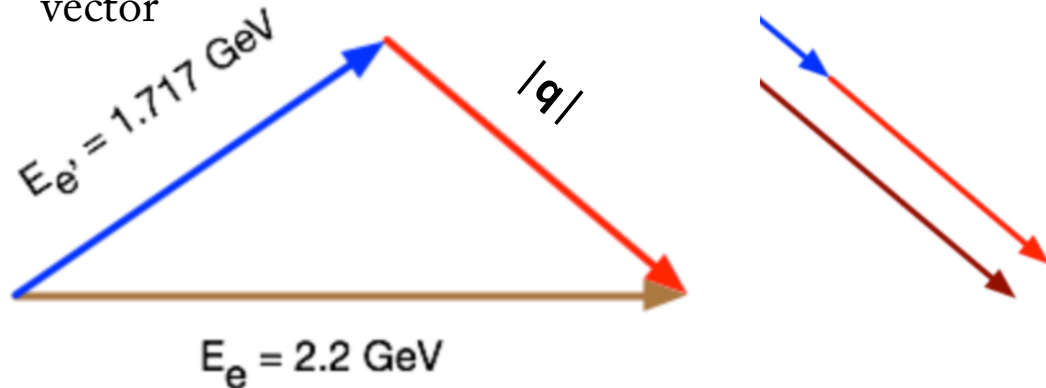


Kinematic Setup

	E_e	$E_{e'}$	θ_e	P_p	θ_p	$ \mathbf{q} $	p_m
	MeV	MeV	deg	MeV/c	deg	MeV/c	MeV/c
kin1	2222	1799	21.5	915	-50.0	857.5	57.7
kin3	2222	1799	17.5	915	-47.0	740.9	174.1
kin4	2222	1799	15.5	915	-44.5	658.5	229.7
kin5	2222	1716	15.5	1030	-39.0	730.3	299.7
Inc-kin5	2222	-	15.5	-	-	730.3	299.7

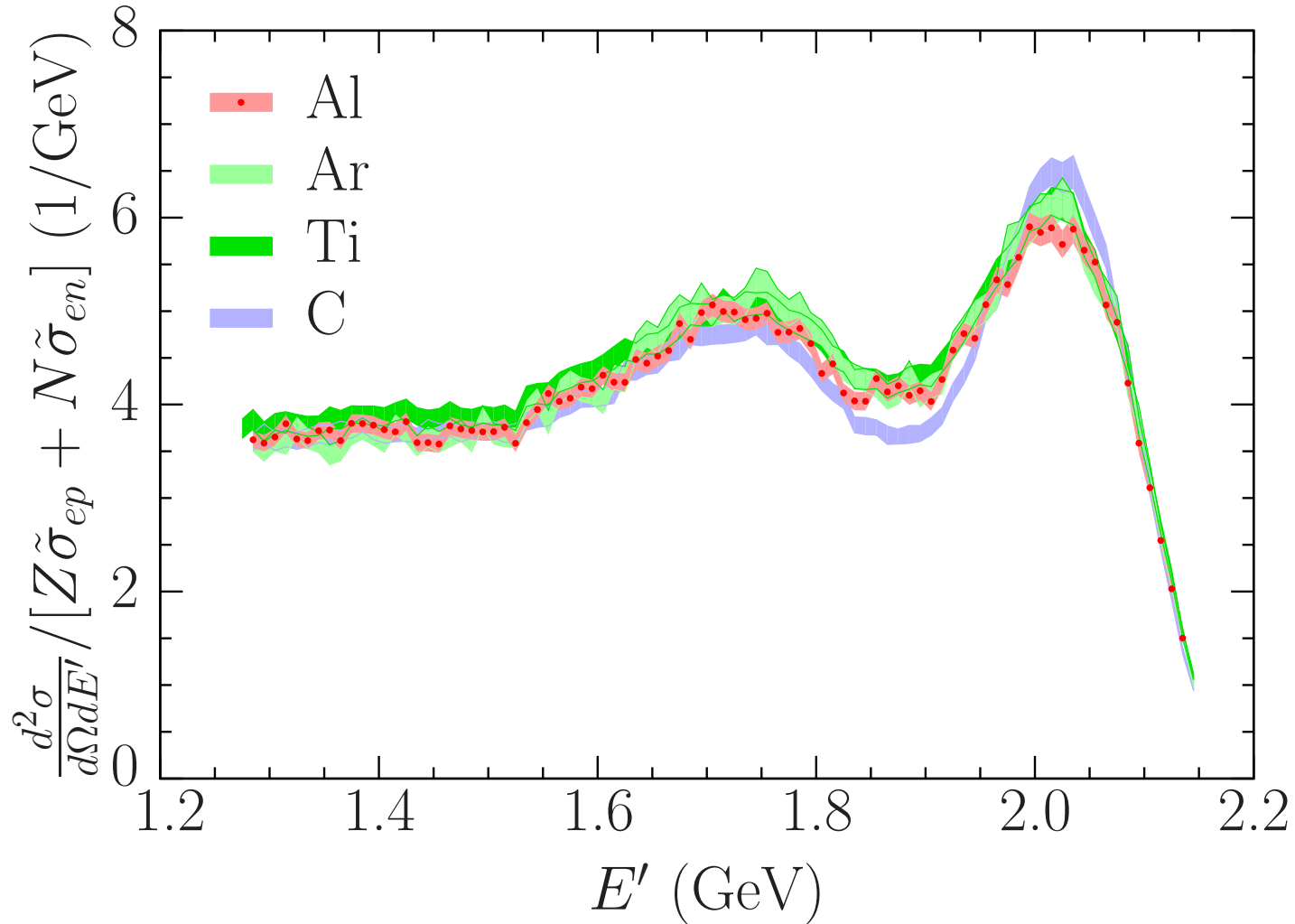
Parallel kinematics

Proton's initial-momentum is parallel to the \mathbf{q} -vector



kin1			kin3		
Collected Data	Hours	Events(k)	Collected Data	Hours	Events(k)
Ar	29.6	43955	Ar	13.5	73176
Ti	12.5	12755	Ti	8.6	28423
Dummy	0.75	955	Dummy	0.6	2948
kin2			kin4		
Collected Data	Hours	Events(k)	Collected Data	Hours	Events(k)
Ar	32.1	62981	Ar	30.9	158682
Ti	18.7	21486	Ti	23.8	113130
Dummy	4.3	5075	Dummy	7.1	38591
Optics	1.15	1245	Optics	0.9	4883
C	2.0	2318	C	3.6	21922
kin5			kin5 - Inclusive		
Collected Data	Hours	Events(k)	Collected Data	Minutes	Events(k)
Ar	12.6	45338	Ar	57	2928
Ti	1.5	61	Ti	50	2993
Dummy	5.9	16286	Dummy	56	3235
Optics	2.9	160	C	115	3957

Inclusive analysis



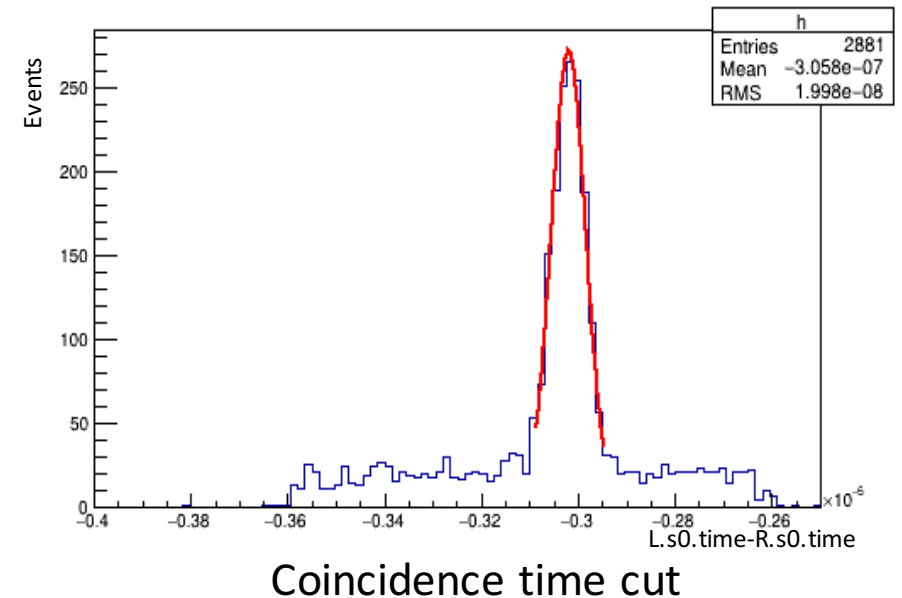
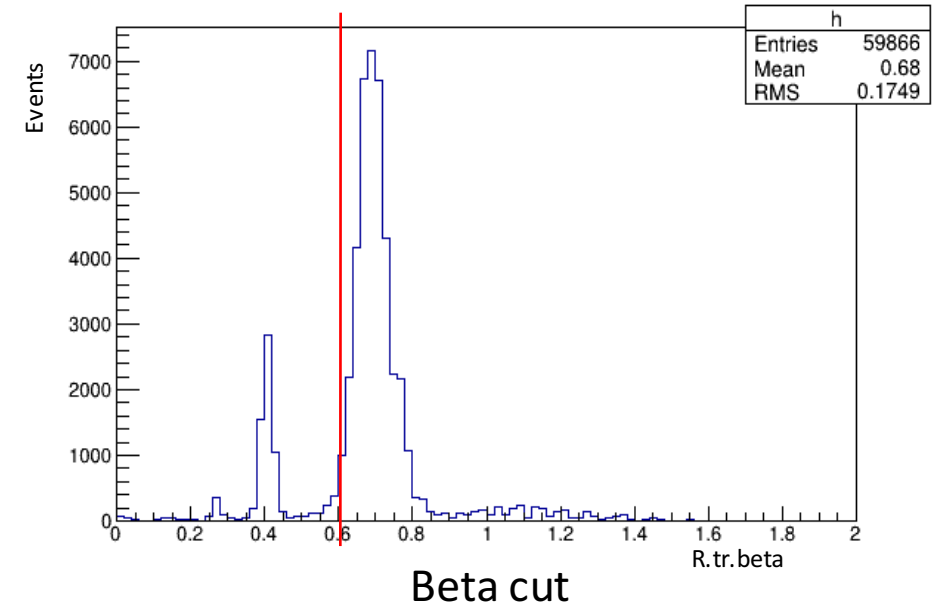
1. Total statistical uncertainty	1.7–2.9%
2. Total systematic uncertainty	1.8–3.0%
a. Beam charge and beam energy	0.3%
b. Beam offset x and y	0.4–1.0%
c. Target thickness and boiling effect	0.7%
d. HRS offset x and y + optics	0.6–1.2%
e. Acceptance cut $(\theta, \phi, dp/p)$	0.6–2.4%
f. Calorimeter and Čerenkov cuts	0.01–0.03%
g. Cross section model	1.3%
h. Radiative and Coulomb corrections	1.0%

Inclusive analysis - completed

- Ti(e,e') and C(e,e') inclusive cross sections at beam energy $E = 2.222$ GeV and scattering angle $\theta = 15.54$ deg with uncertainties $< 2.75\%$, have been reported and published in Phys. Rev. C 98, 014617 (2018)
- Ar(e,e') inclusive cross section at beam energy $E = 2.222$ GeV and scattering angle $\theta = 15.54$ deg with uncertainties $< 4\%$, has been reported and published in Phys. Rev. C 99, 054608 (2019)
- Al(e,e') inclusive cross section analysis at $E = 2.222$ GeV and scattering angle $\theta = 15.54$ deg has been completed.
- The inclusive analysis summary paper is under collaboration review. Submission to PRC expected by the end of July.

Exclusive analysis - Cuts

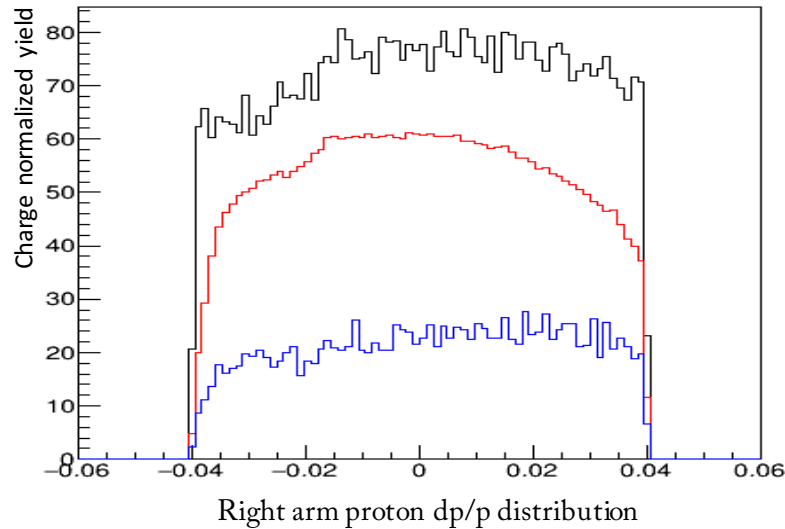
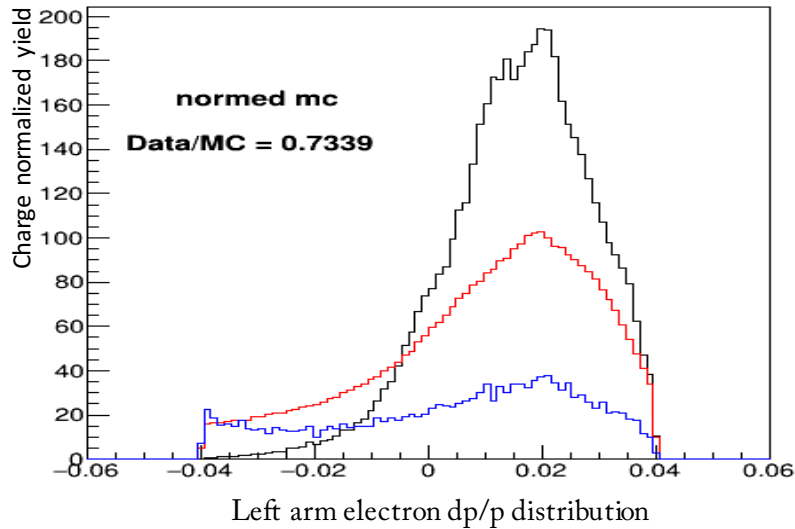
- Set of cuts:
 - Trigger cut: Trigger1
 - $(S0\&\&S2) \&\& (GC||PR)$ [LEFT] and $(S0\&\&S2)$ [RIGHT]
 - Single track cut for both arms
 - Particle Identification (PID) cut:
 - $cherenkov > 400$
 - $(preshower + shower) / p_{rec} > 0.3$
 - Acceptance cut for both arms:
 - $dp \in [-0.04, 0.04]$
 - $theta \in [-0.06, 0.06]$ (rad)
 - $phi \in [-0.03, 0.03]$ (rad)
 - Z cut: $[-9, 9]$ (cm)
 - Beta cut for right arm:
 - $beta > 0.6$
 - Coincidence time cut



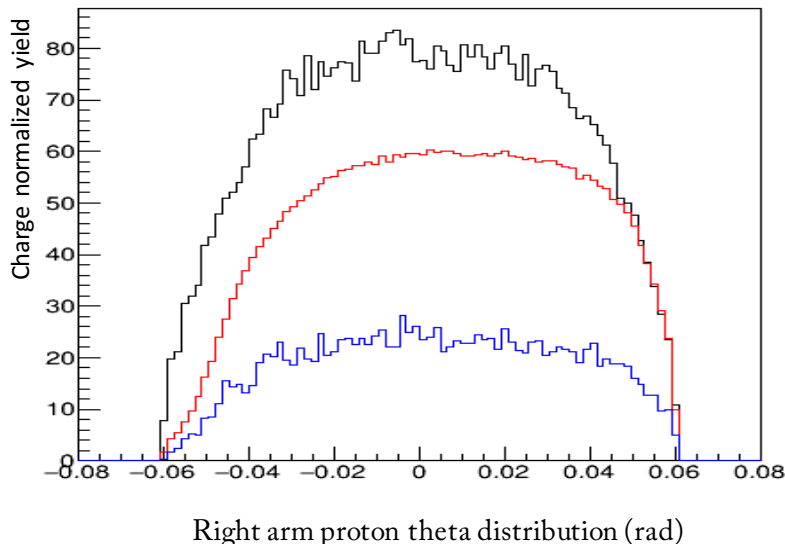
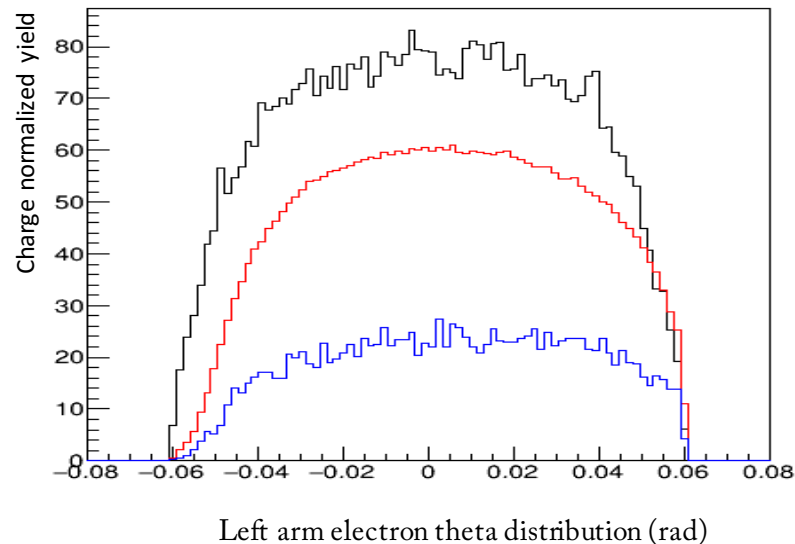
Exclusive analysis - kin1 Ar - Data/MC comparison

Background $\sim 0.4\%$, is scaled by 100 times

Red: data
Black: SIMC
Blue: background

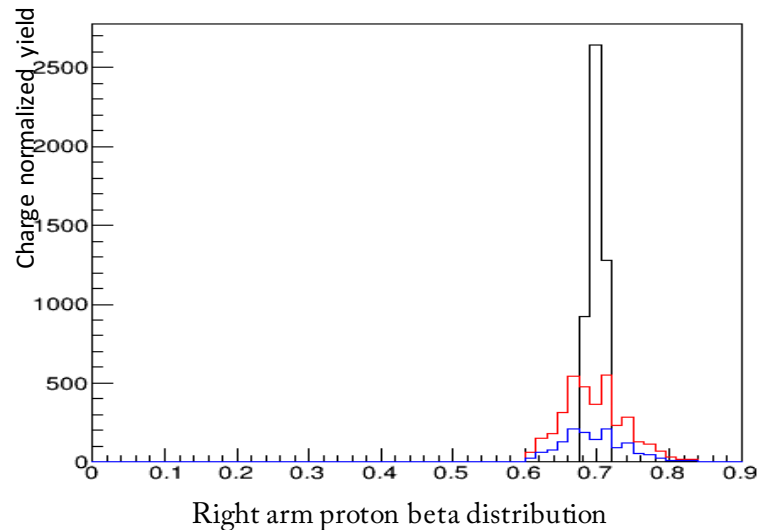
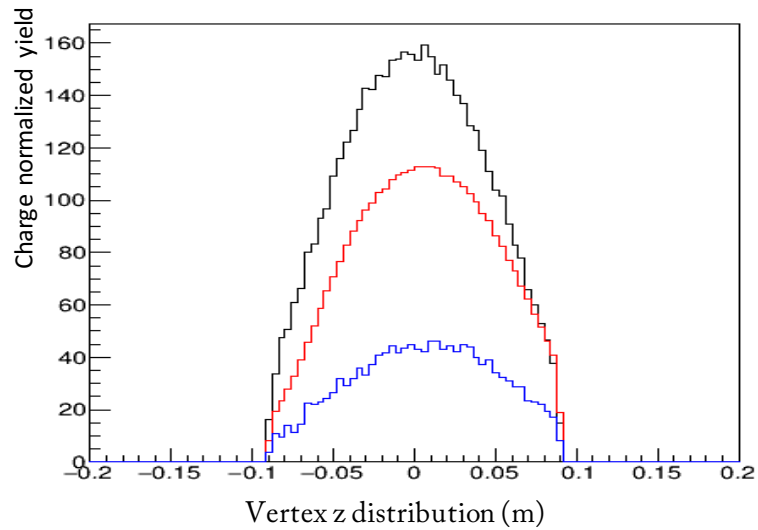
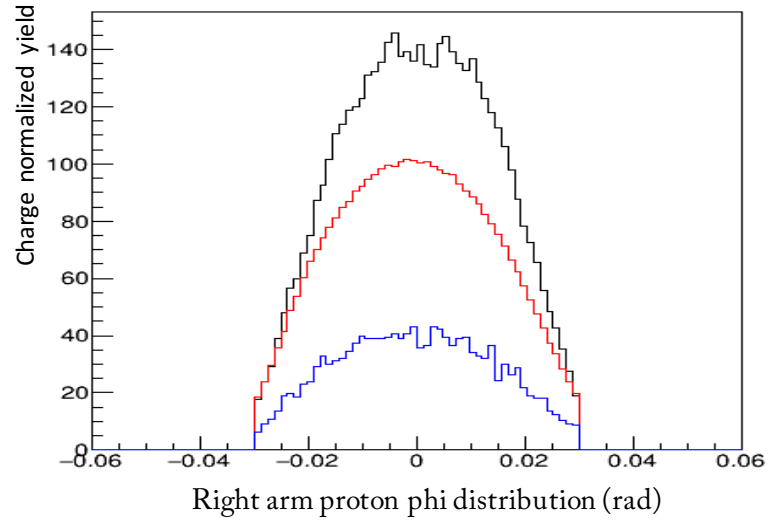
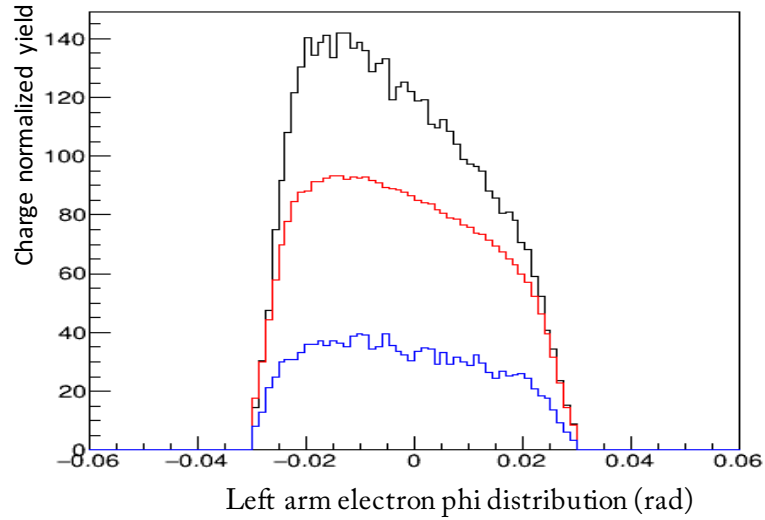


Data/mc ratio = 0.73

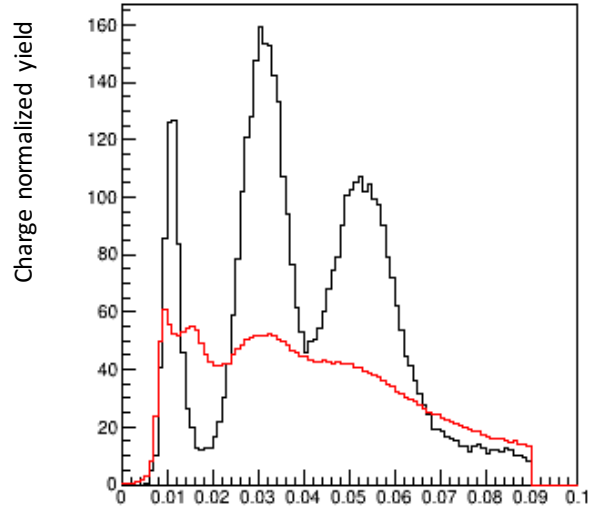


- Corrections of efficiencies, livetime and boiling effect have been applied in the plots
- Background is subtracted from the data
- The events are normalized by the total charge
- FSI is not included yet in the MC

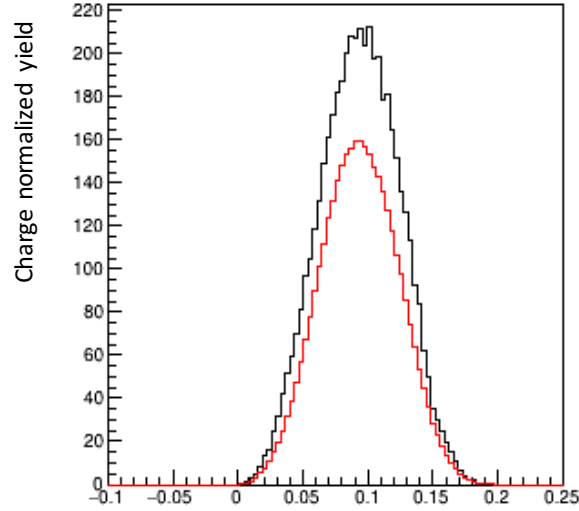
Exclusive analysis - kin1 Ar - Data/MC comparison



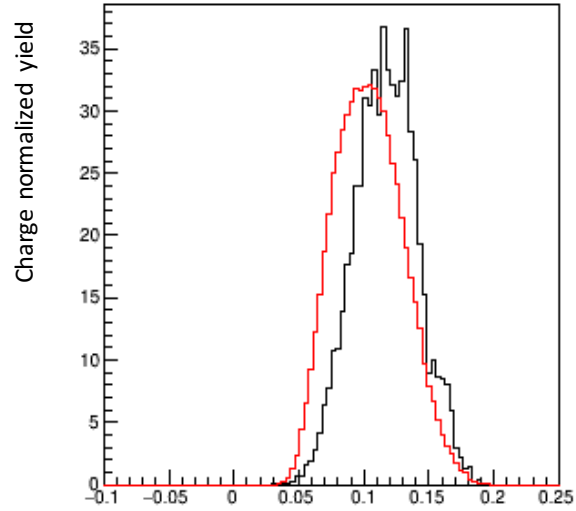
Exclusive analysis - kin1 Ar - Data/MC comparison



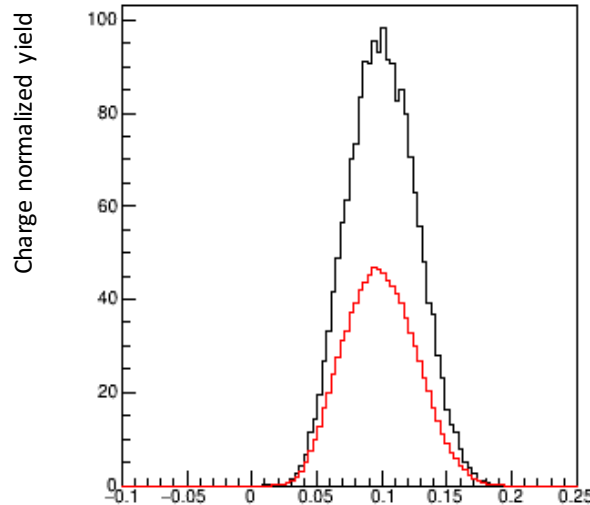
Missing energy distribution (GeV)



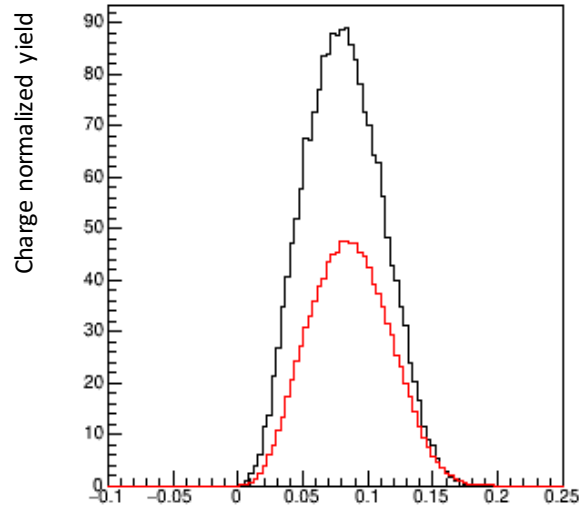
Missing momentum distribution (GeV/c)



Pm1 distribution (GeV/c)



Pm2 distribution (GeV/c)



Pm3 distribution (GeV/c)

Pm1: $0.005 < E_m < 0.02$
Pm2: $0.02 < E_m < 0.04$
Pm3: $0.04 < E_m < 0.07$

Effect of FSI

- Shift towards smaller momentum
- A reduction of the cross section which is more or less constant in the momentum range considered
- Broaden the extracted energy distribution

Systematic uncertainties

- Beam charge
- Beam energy
- Beam x and y offset
- HRS x and y offset
- Boiling effects and corrections
- Acceptance cuts
- Cherenkov and Calorimeter cuts
- Optics
- Radiative corrections
- Cross section models - theory file from SF
- Final State Interaction - Theory model

Summary

- We've finished all the inclusive analysis of Carbon, Aluminum, Titanium and Argon at $E=2.222\text{GeV}$ and $\theta = 15.54$ deg, two papers published on Physics Review C, the other one is under collaboration review.
- Currently we are working on $(e,e'p)$ analysis of Argon and Titanium. Next step will be estimating the effect of FSI and calculating the systematic uncertainties.
- First result is expected to be reported by this December.