Jlab E12-14-012 experiment: Update

C. Mariani

On behalf of the E12-14-012 collaboration

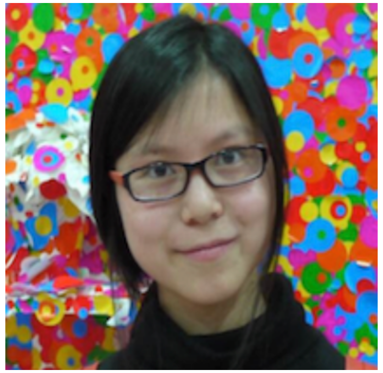
Virginia Tech

Hall A/C Collaboration Meeting

Jefferson Lab, Newport News, VA

Jul 17, 2020

E12-14-012 analyzer



Hongxia Dai

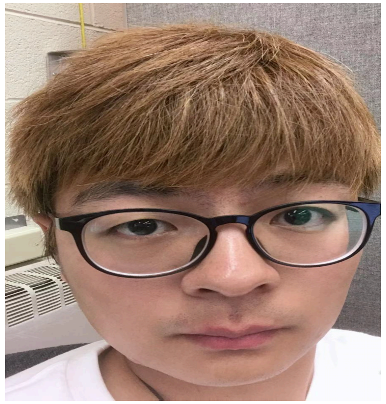
Graduate student VT (PhD 2019)

Matthew Murphy

Graduate student - VT

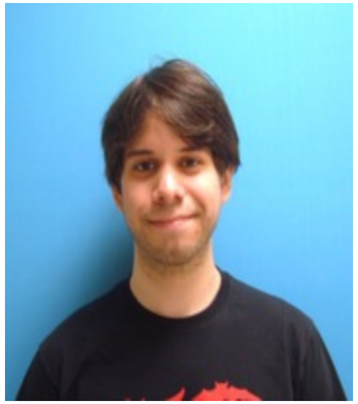
Libo Jiang

Post-doc research associate - VT



Linjie Gu

Graduate student - VT



Daniel Abrams

Graduate student - UVA

Matthew Barroso

REU student - VT

Artur Ankowski

Research associate - SLAC

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 function of argon (~ initial momentum and energy distributions of nucleons bound in argon) that can directly be used in the reconstruction of neutrino energies (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

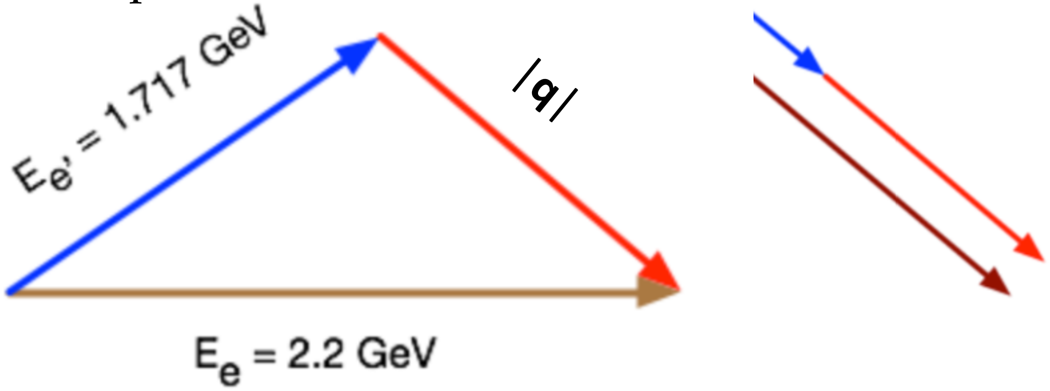
- Experimental setup
  - kinematic configurations
  - target
- Exclusive analysis
  - Analysis strategy
  - Kinematical Cuts
  - Missing Energy and Missing momentum for Kinematic 1 Ar and Ti
  - FSI
    - Analysis framework
    - Systematics
    - Results
- Summary

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
kin2	2222	1716	20.0	1030	−44.0	846.1	183.9
Inc-kin5	2222	-	15.5	-	-	730.3	299.7

Parallel kinematics

Proton's initial-momentum is parallel to the q-vector



kin1

Collected Data	Hours	Events(k)
Ar	29.6	43955
Ti	12.5	12755
Dummy	0.75	955

kin3

Collected Data	Hours	Events(k)
Ar	13.5	73176
Ti	8.6	28423
Dummy	0.6	2948

kin2

Collected Data	Hours	Events(k)
Ar	32.1	62981
Ti	18.7	21486
Dummy	4.3	5075
Optics	1.15	1245
C	2.0	2318

kin4

Collected Data	Hours	Events(k)
Ar	30.9	158682
Ti	23.8	113130
Dummy	7.1	38591
Optics	0.9	4883
C	3.6	21922

kin5

Collected Data	Hours	Events(k)
Ar	12.6	45338
Ti	1.5	61
Dummy	5.9	16286
Optics	2.9	160

kin5 - Inclusive

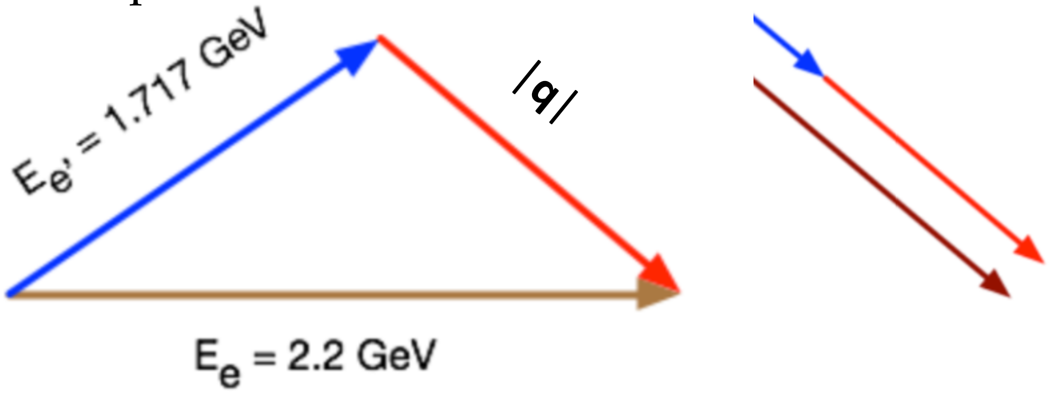
Collected Data	Minutes	Events(k)
Ar	57	2928
Ti	50	2993
Dummy	56	3235
C	115	3957

Kinematic Setup

	E_e	$E_{e'}$	θ_e	P_p	θ_p	$\lvert\mathbf{q}\rvert$	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
kin2	2222	1716	20.0	1030	−44.0	846.1	183.9
Inc-kin5	2222	-	15.5	-	-	730.3	299.7

Parallel kinematics

Proton's initial-momentum is parallel to the q-vector



kin1

Collected Data	Hours	Events (k)
Ar	29.6	43955
Ti	12.5	12755
Dummy	0.75	955

kin3

Collected Data	Hours	Events (k)
Ar	13.5	73176
Ti	8.6	28423
Dummy	0.6	2948

kin2

Collected Data	Hours	Events (k)
Ar	32.1	62981
Ti	18.7	21486
Dummy	4.3	5075
Optics	1.15	1245
C	2.0	2318

kin4

Collected Data	Hours	Events (k)
Ar	30.9	158682
Ti	23.8	113130
Dummy	7.1	38591
Optics	0.9	4883
C	3.6	21922

kin5

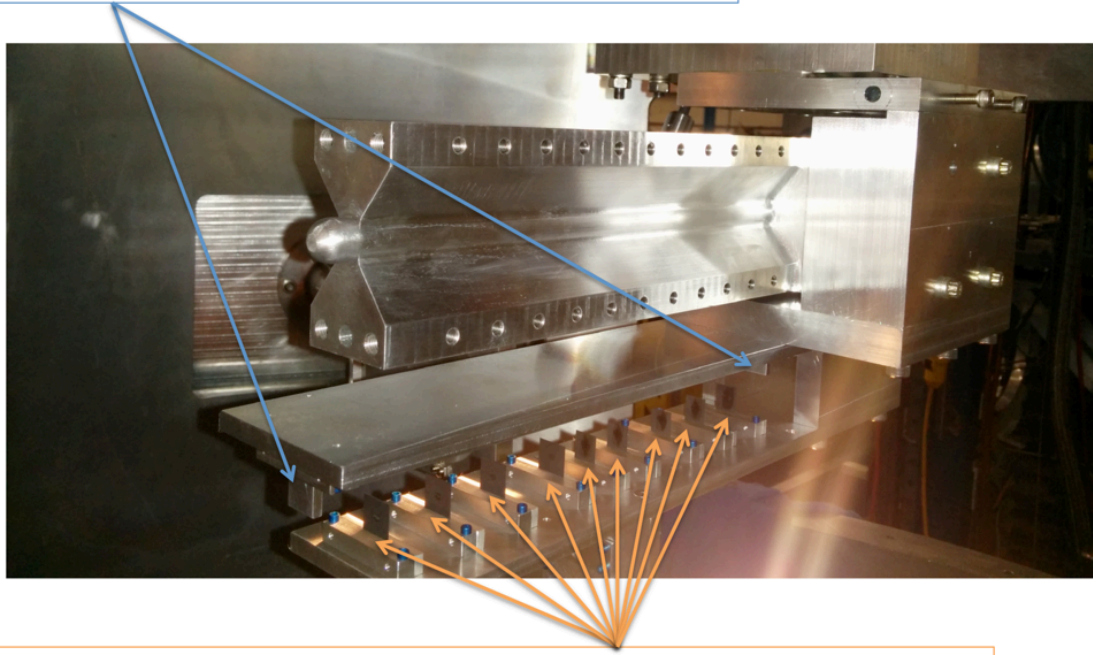
Collected Data	Hours	Events (k)
Ar	12.6	45338
Ti	1.5	61
Dummy	5.9	16286
Optics	2.9	160

kin5 - Inclusive

Collected Data	Minutes	Events (k)
Ar	57	2928
Ti	50	2993
Dummy	56	3235
C	115	3957

Target Setup

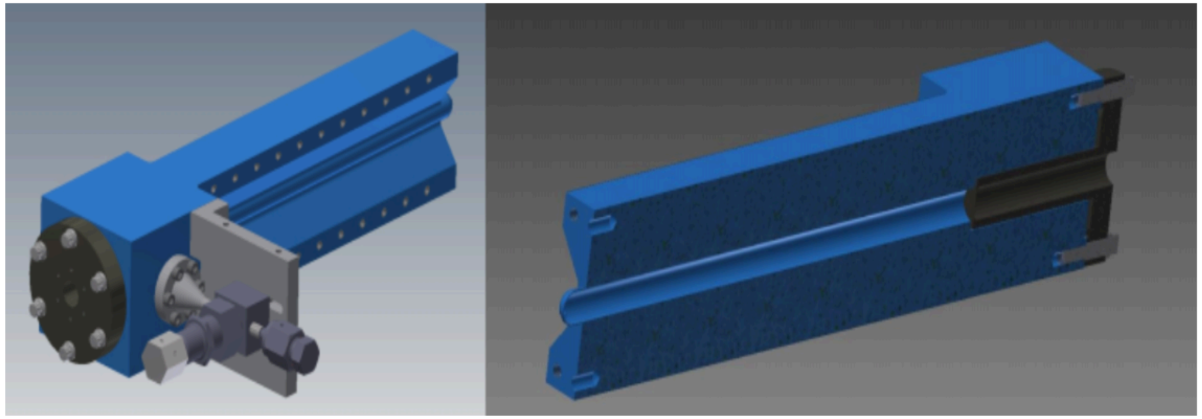
Dummy target: same as the entry and exit window as the gas target



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

<u>Ar Target</u>

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



Exclusive analysis

	Ar	Ti
Kin 1	2%	3%
Kin 2	8%	7%
Kin 3	13%	13%
Kin 4	20%	20%
Kin 5	70%	NA

Background/Signal value in different kinematics and targets

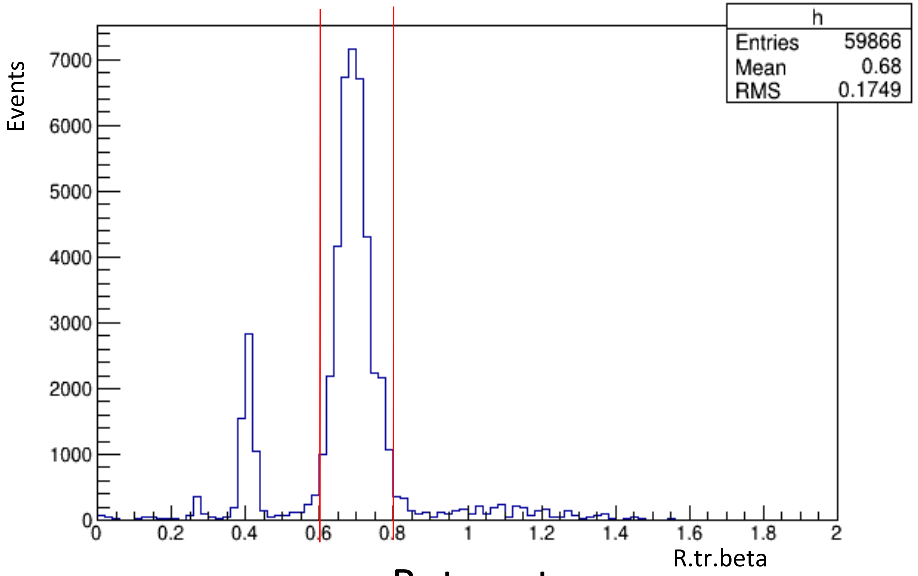
- Identify coincidence signal in LHRS and RHRS
- Kinematical and acceptance cuts
  - Characterize background:
    - Accidental
    - Target wall and end caps
- Subtract background from signal (retune cuts if needed)
- Data and MC comparison (keep in mind MC does not have FSI) – Spectral Function from A. Ankowski
- Identify set of cuts not theory or FSI dependent
- Correct for efficiency and acceptance
- Compute absolute cross section as function of missing momentum over all missing energy range (100 bins) or over a restricted integral over the missing energy distribution
- Evaluate systematic uncertainties per bin in missing momentum

Exclusive analysis (cont'd)

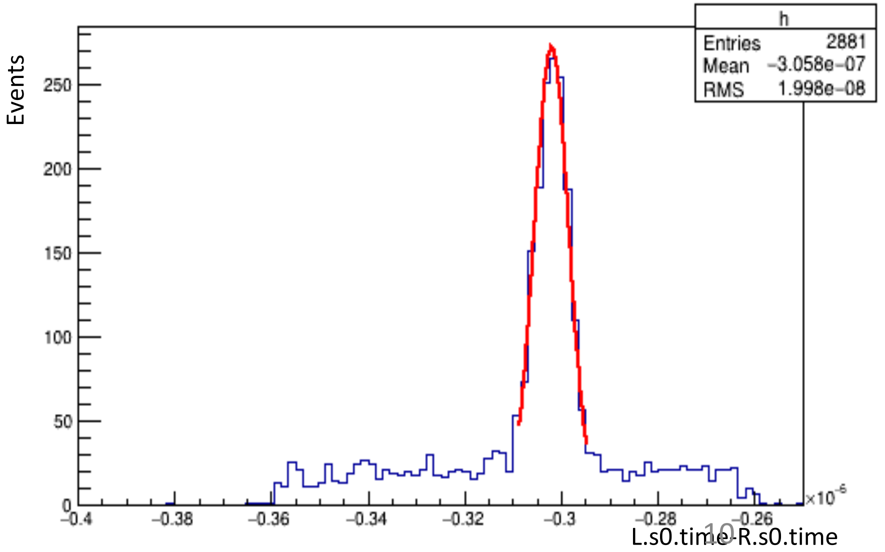
- Build a framework to compute and include FSI
- Compute DWIA vs PWIA using external code (C. Giusti/O. Benhar/L. Jiang)
  - Use various optical potentials
  - Different recipes for computing wave functions
  - Use different form factors
- Reweight missing momentum distribution in MC by DWIA/PWIA ratio bin by bin
- Compare with data
- Provide the reduced cross section
- Determine spectroscopic factors [future]
- Determine Spectral Functions [future]

Exclusive analysis – Cut summary

- 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 [-0.04,0.04]
  - theta [-0.060.06](rad)
  - phi[-0.03,0.03](rad)
- Z cut: [-10,10](cm)
- Beta cut for right arm:
  - beta [0.6,0.8]
- Coincidence time cut

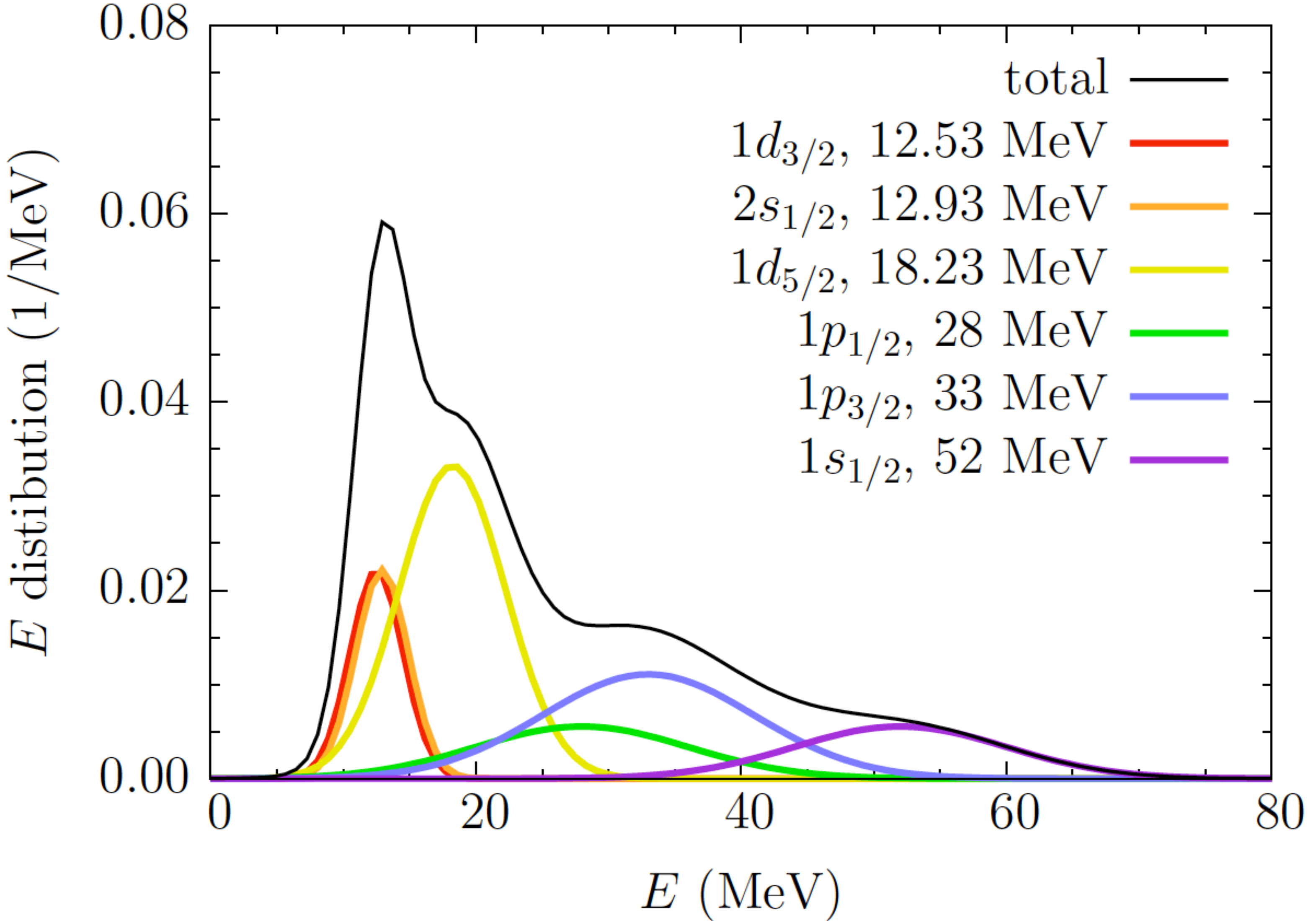


Beta cut



Coincidence time cut

Ar missing energy distribution



Work by A. Ankowski

Shapes – drawn in different colors represent the contribution of different orbitals

First three orbital shapes are estimates

Last three level are derived from data

Exclusive Analysis argon target Results

Beam energy	2.222 GeV
Left Arm angle	21.5 deg
Right Arm Angle	-50 deg
Missing momentum	57.7 MeV/c

Parallel kinematics

List of systematic uncertainties – kin1 Ar

- Statistical uncertainty ~ 0.53%
- Total systematic uncertainty ~ 2.42%
    - Beam x and y offset ~0.63%
    - HRS x and y offset ~0.83%
    - Boiling ~0.70%
    - Acceptance and z cuts ~1.16%
    - Cerenkov and Calorimeter cuts ~0.02%
    - COSY ~0.94%
    - Radiative and Coulomb corrections ~1%
    - Beta cut ~0.47%
    - Coincidence time cut ~0.92%

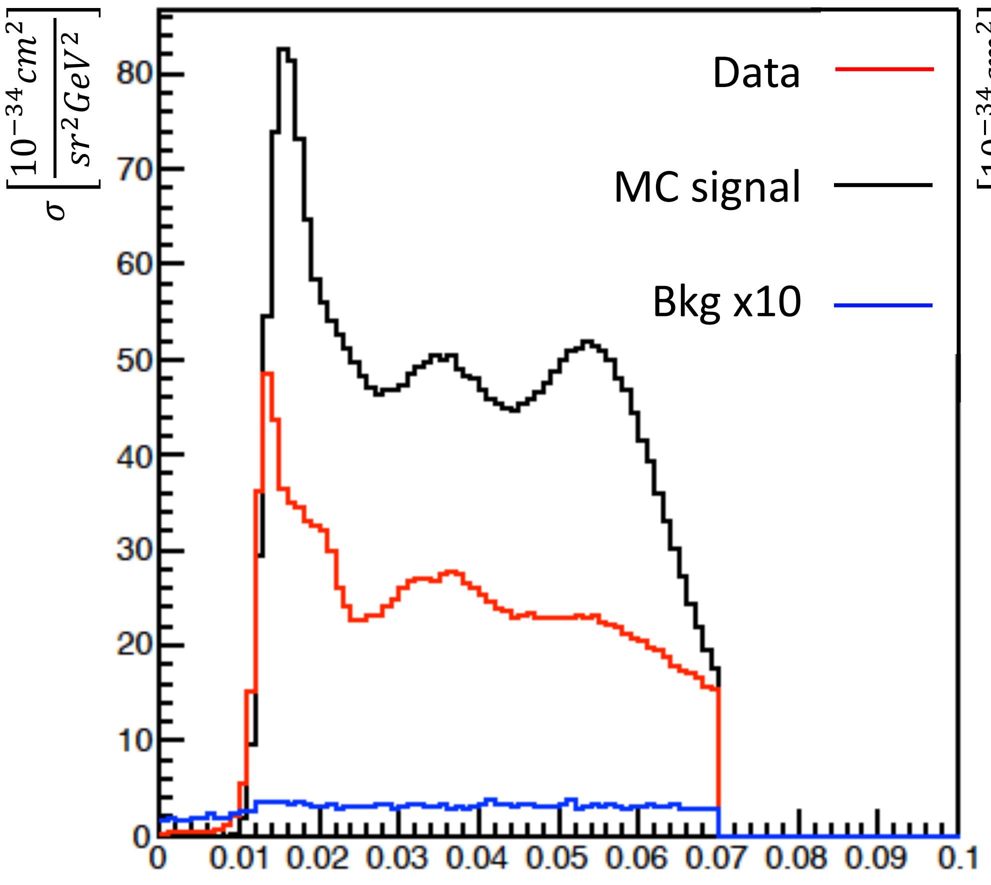
- COSY:

We use the code COSY to generate the optical matrix for simulation, to estimate the optical matrix uncertainty due to the magnetic field settings of Q1, Q2 and Q3 , we vary the individual setting by 1%

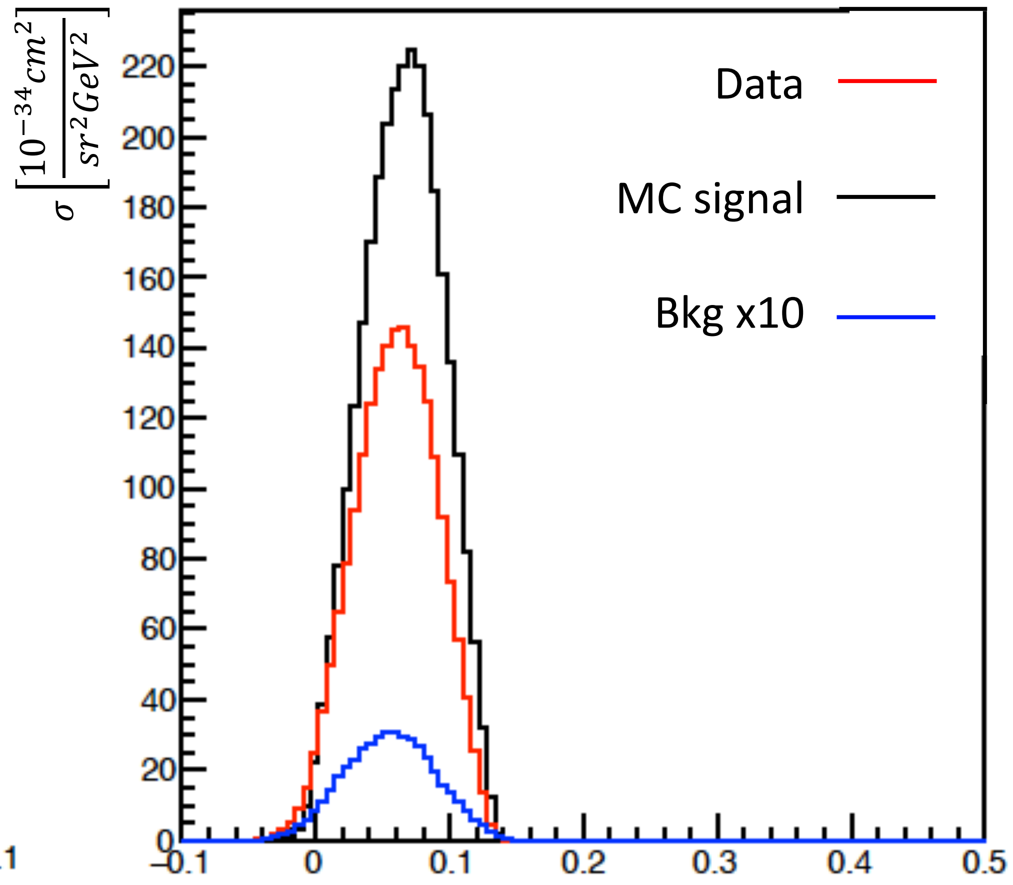
- Rad_corr dependence on Cross section model:

We scale the cross section model by $\sqrt{Q^2/2}$, and recalculate the radiative correction factor.

Exclusive analysis – kin1 - Ar -
Missing energy and missing momentum



Missing Energy distribution (GeV)



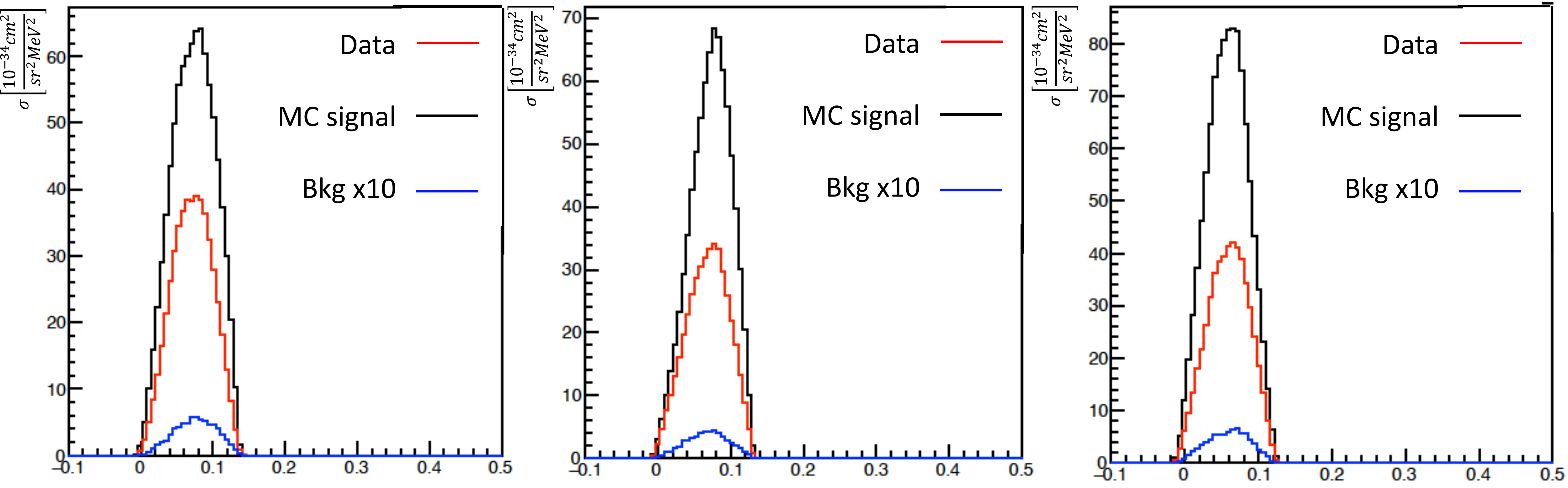
Missing Momentum distribution (GeV/c)

Effect of FSI

A reduction of the cross section which is more or less constant in the momentum range considered

- Shift of the cross section in missing momentum

Exclusive analysis – Ar Missing Momentum Distributions



P_m distribution (GeV/c) for $E_m < 27$ MeV

P_m distribution (GeV/c) for $27 \text{ MeV} < E_m < 44$ MeV

P_m distribution (GeV/c) for $44 \text{ MeV} < E_m < 70$ MeV

Exclusive Analysis titanium target Results

Beam energy	2.222 GeV
Left Arm angle	21.5 deg
Right Arm Angle	-50 deg
Missing momentum	57.7 MeV/c

Parallel Kinematics

List of systematic uncertainties – kin1 Ti

- Statistical uncertainty ~ 0.78%
- Total systematic uncertainty ~ 2.11%
  - Beam x and y offset ~0.49%
  - HRS x and y offset ~0.58%
  - Target thickness ~0.2%
  - Acceptance cuts ~1.36%
  - Cerenkov and Calorimeter cuts ~0.02%
  - COSY ~0.48%
  - Radiative and Coulomb corrections ~1%
  - Beta cut ~0.39%
  - Coincidence time cut ~0.78%

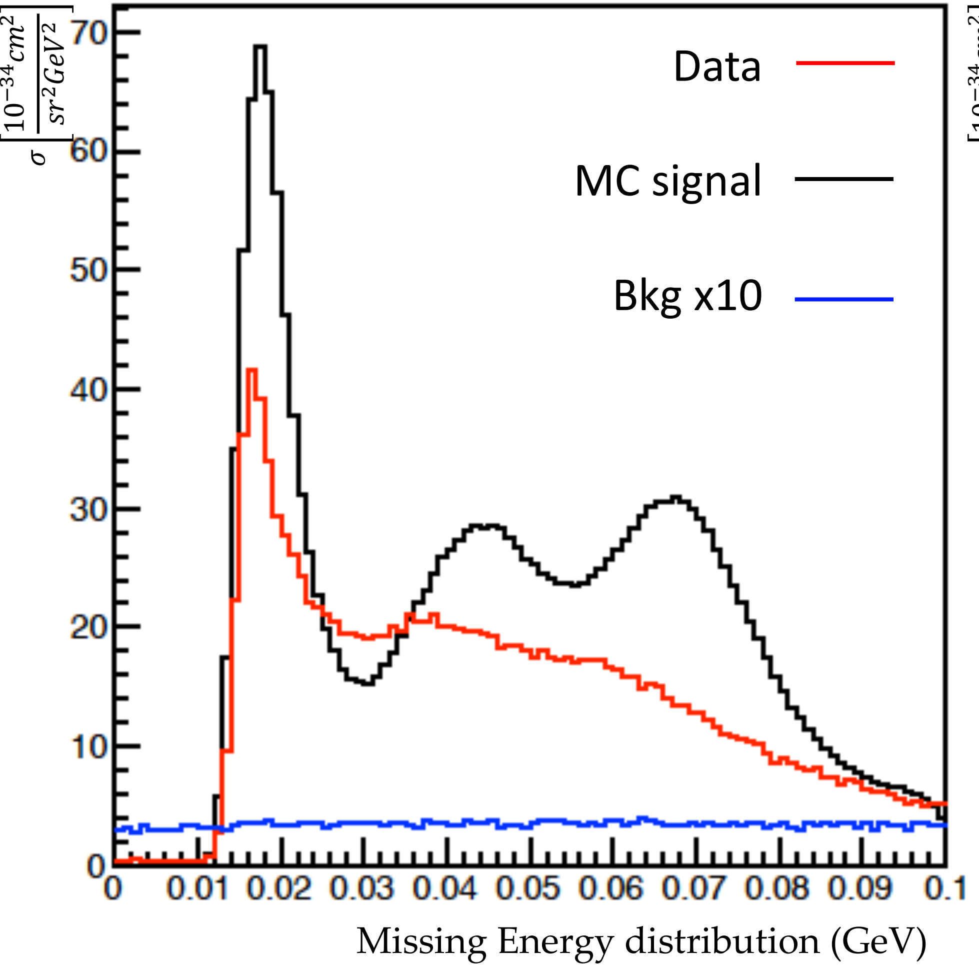
- COSY:

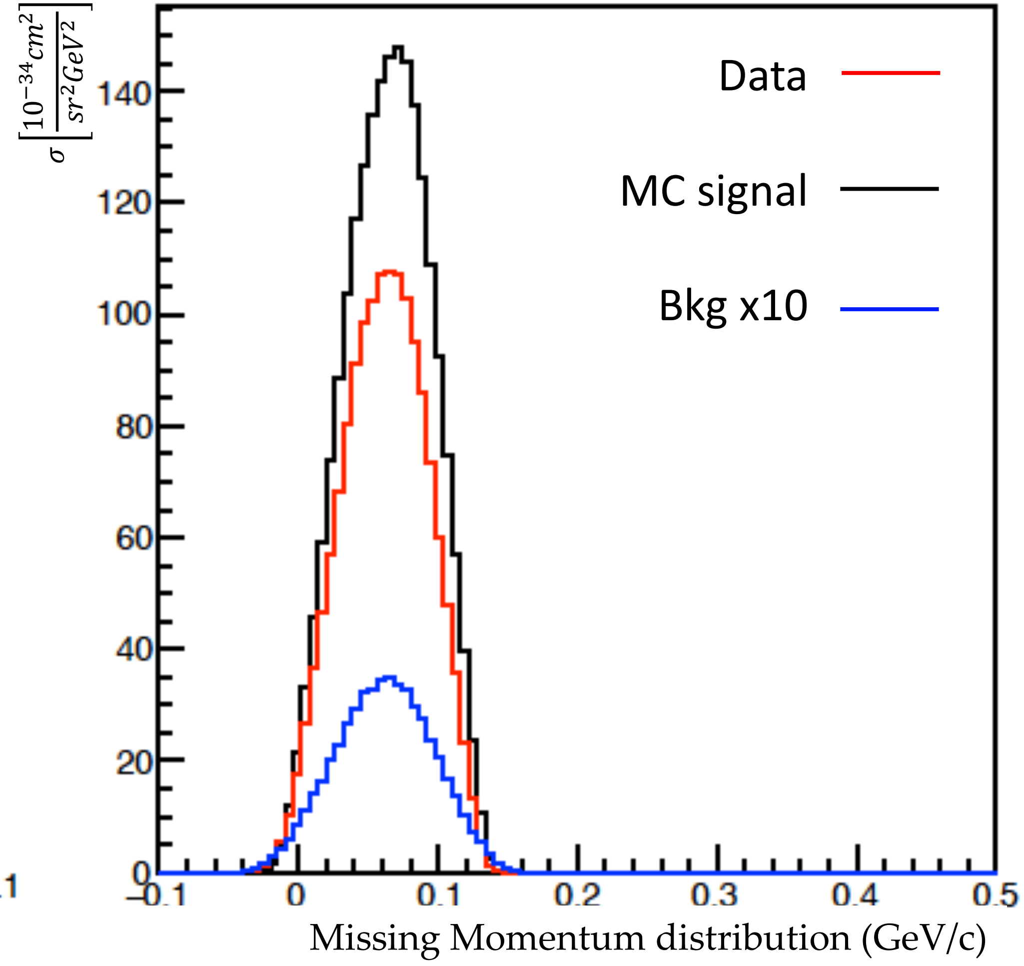
We use the code COSY to generate the optical matrix for simulation, to estimate the optical matrix uncertainty due to the magnetic field settings of Q1, Q2 and Q3 , we vary the individual setting by 1%

- Rad_corr dependence on Cross section model:

We scale the cross section model by $\sqrt{Q^2/2}$, and recalculate the radiative correction factor.

Exclusive analysis - kin1 - Ti - Missing energy and missing momentum

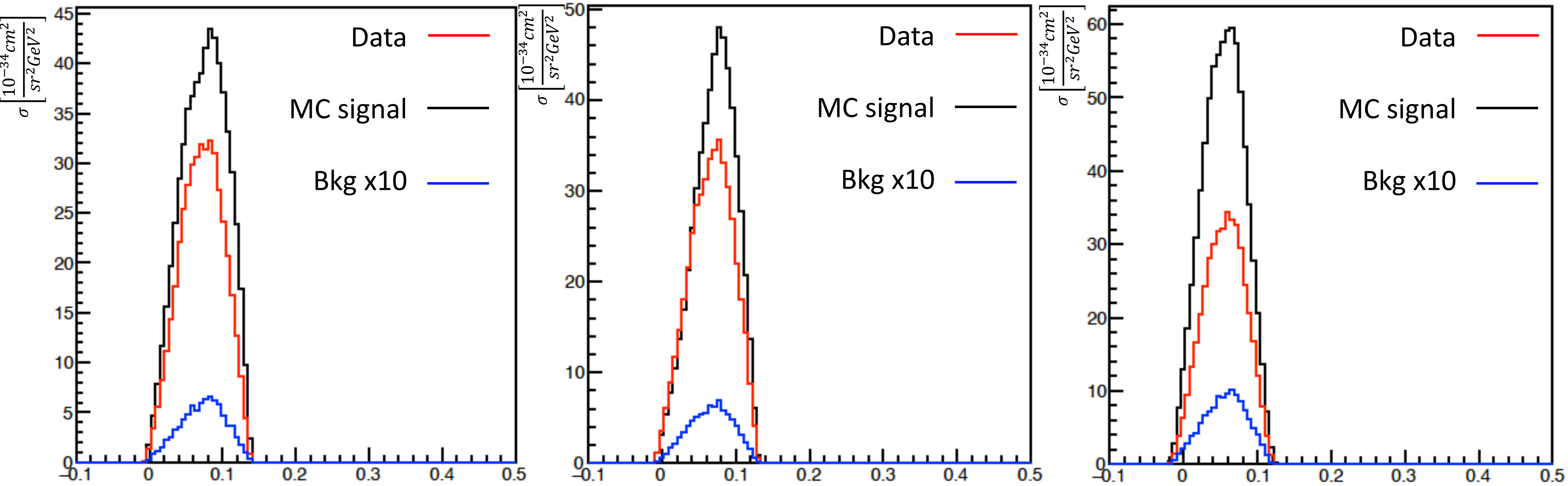




Effect of FSI

- A reduction of the cross section which is more or less constant in the momentum range considered
- Shift of the cross section in missing momentum

Exclusive analysis – Ti - Missing Momentum Distributions



P_m distribution (GeV/c) for 5 MeV < E_m< 30 MeV

P_m distribution (GeV/c) for 30 MeV < E_m< 54 MeV

P_m distribution (GeV/c) for 54 MeV < E_m< 90 MeV

FSI analysis

- C. Giusti provided a relativistic code, tested against old data on ^{16}O and ^{12}C up to ^{40}Ca

$$\frac{d^6\sigma}{d\omega d\Omega_e dp d\Omega_p} = K \sigma_{ep} S^D(p_m, \varepsilon_m)$$

σ_{ep} is the half off-shell electron nucleon cross section which is related or can be expressed as a function of σ_M

Distorted

nuclear spectral function

Suitable Kinematic Factor $K = E_p|\mathbf{p}_p|$

FSI analysis

- C. Giusti provided a relativistic code, tested against old data on ^{16}O and ^{12}C up to ^{40}Ca
- Compute reduced cross section both PWIA and DWIA for various wave functions, identify the energy for each orbital

Argon

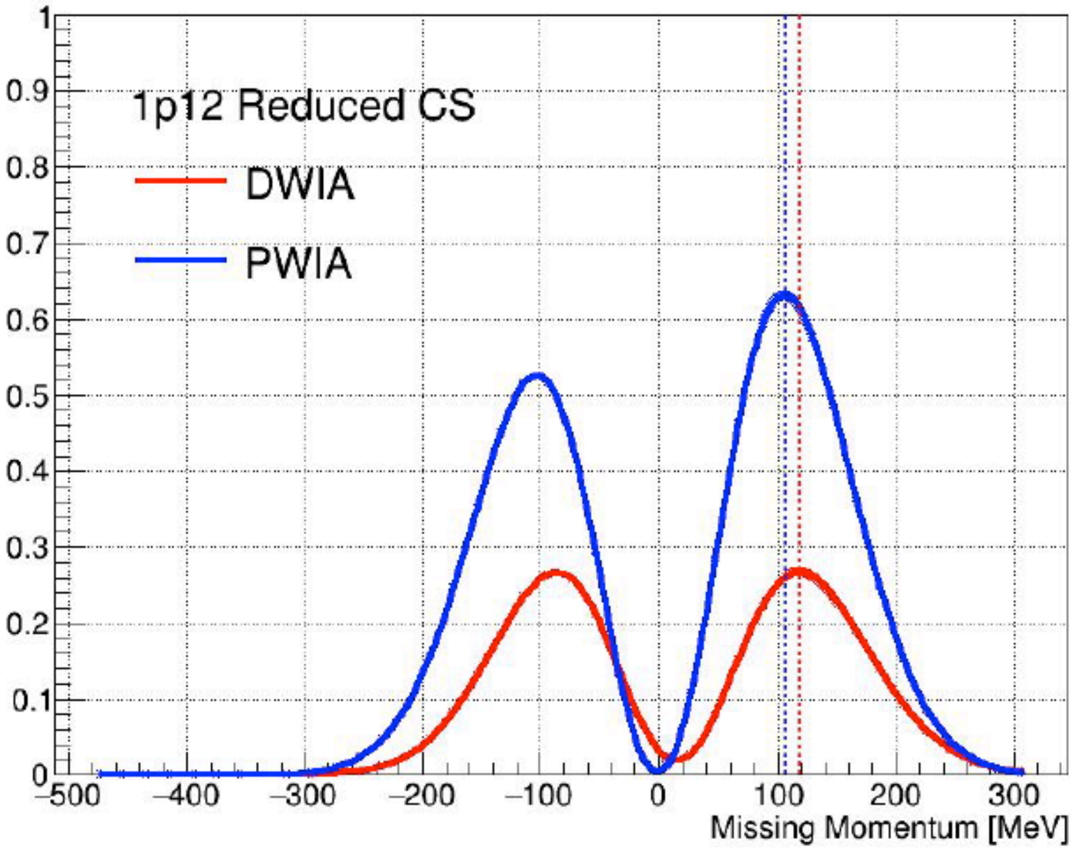
Orbital	E_{Low}	E_{High}	Emp.	DWIA value (proton-Finelli)
1f7/2	na	na	na	3.374
1d3/2	8	14	12.53	11.820
2s1/2	8	14	12.93	14.276
1d5/2	14	20	18.23	17.853
1p12	20	45		29.343
1p32	20	45		33.662
1s12	45	70		50.010

Titanium

Orbital	E_{Low}	E_{High}	Emp.	DWIA value (protons-Finelli)
1f7/2	8	14	11.32(11.45)	6.625
2s1/2	14	30	(12.84)	13.751
1d3/2	14	30	13.32(12.21)	14.775
1d5/2	14	30	(15.46)	21.065
1p12	30	54		32.687
1p32	30	54		36.135
1s12	53	80		50.762

FSI analysis (cont'd)

- Compute the DWIA vs PWIA ratio and shift in missing momentum per orbital (L. Jiang/M. Barroso)



Shift:

1. Compute the Missing Momentum bin corresponding to the maximum reduced Cross Section values in the positive missing momentum region for both DWIA (Red curve) and PWIA (Blue curve)

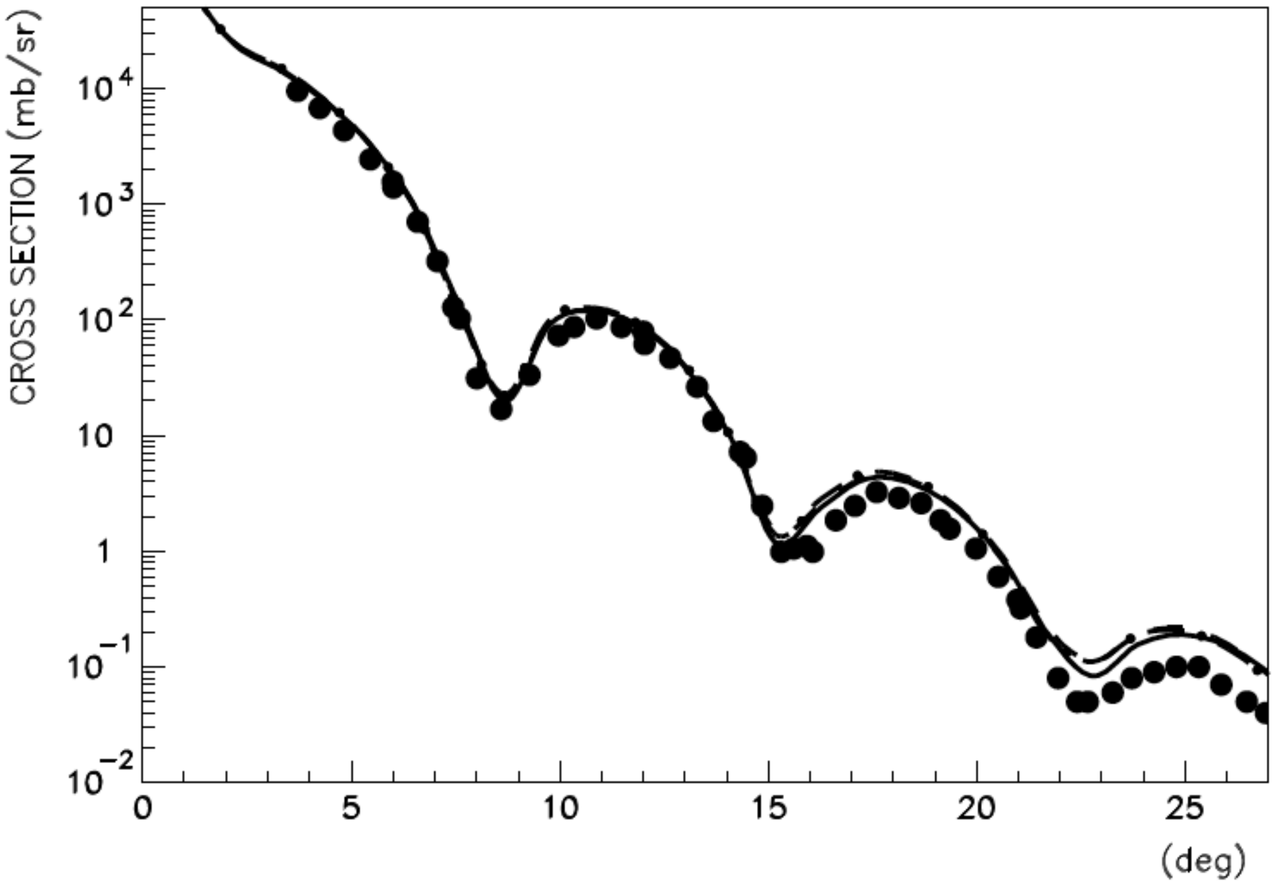
Ratio

1. Integrate the Reduced Cross Section from Around the peak (± 1 sigma) in the positive missing momentum region for both DWIA and PWIA

2. Ratio = integrated DWIA/integrated PWIA

FSI analysis (cont'd)

- Check optical potential



$^{40}Ar(p,p)$ 0.8 GeV

C. Giusti/R. Lindgren

Data is from:

Elastic and Inelastic Scattering of 0.8 GeV protons from ^{40}A
G.S. Blanpied et al - Phys Rev C 37 (1304) 1988

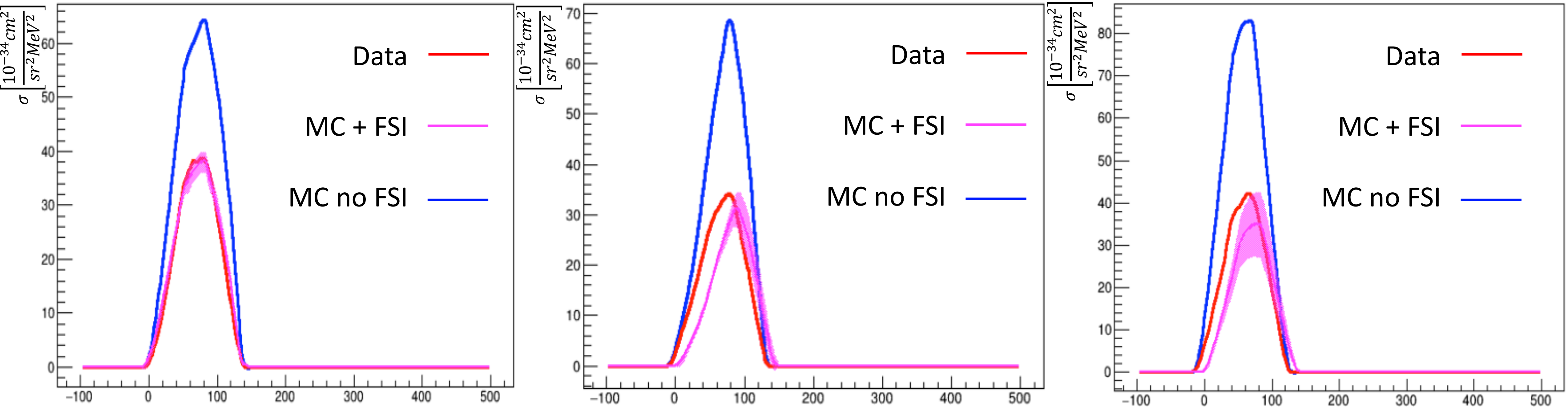
FSI analysis (cont’d)

- Reweight MC event by event
  - Use missing energy per event to identify the most probable electron shell, then apply the reweight and shift in missing momentum for that event, plot in the next slides for both Ar and Ti

- Systematic uncertainties summary (tables with details in backup slides)

• CC1 vs CC2	Ar: 11.8%	Ti: 13.7%
• Optical model	Ar: 1.5% - 5.4%	Ti: 3.3%-7.5%
• Wave function pairing	Ar: 0.4%	Ti: 5.3%

Exclusive analysis – Ar Missing momentum Distributions



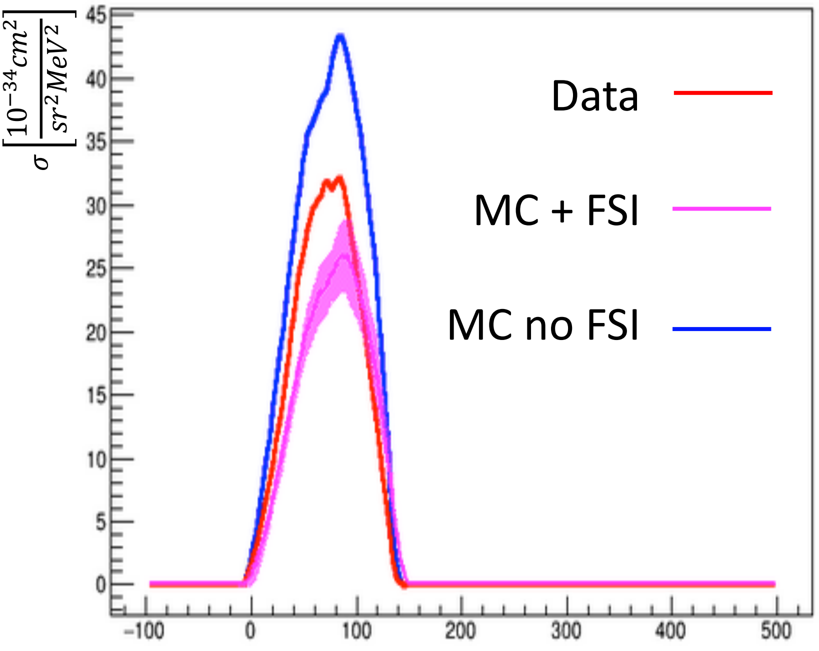
P_m distribution (MeV/c) for E_m< 27 MeV

P_m distribution (GeV/c) for 27 MeV < E_m< 44 MeV

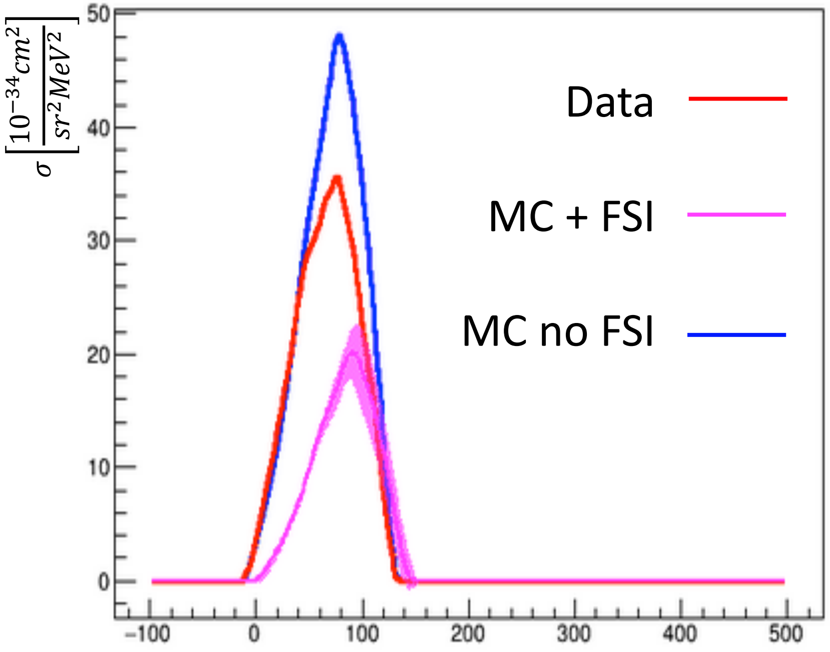
P_m distribution (GeV/c) for 44 MeV < E_m< 70 MeV

(MC + FSI) includes preliminary systematic uncertainties (σ_{ep}, form factors, optical potential, wave function pairing)

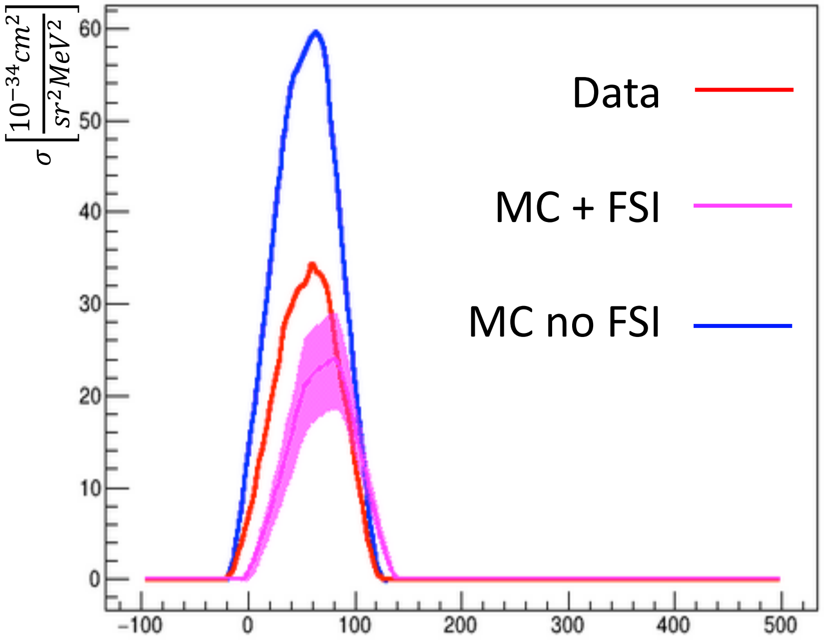
Exclusive analysis – Ti - Missing momentum Distributions



P_m distribution (MeV/c) for
5 MeV < E_m< 30 MeV



P_m distribution (GeV/c) for
30 MeV < E_m< 54 MeV



P_m distribution (GeV/c) for
54 MeV < E_m< 90 MeV

(MC + FSI) includes preliminary systematic uncertainties (σ_{ep}, form factors, optical potential, wave function pairing)

Summary

- We've completed the first part of the analysis for the (e,e'p) analysis of Kinematic 1 for both Argon and Titanium.
- We are able to see the contributions of various orbitals in missing energy spectrum
- Background is at very low level ~ 2% and we can characterize it well
- Systematic uncertainties are at the level of 2-3% as for our proposal
- FSI framework is now ready and we will use use it to extract physics quantities
- First paper for the exclusive analysis is expected to be circulated by end of summer:
  - Will focus on the data analysis and data quality and systematic uncertainties
    - We want to show that we are able to identify coincidences and measure absolute cross section as function of missing momentum
  - Extract spectroscopic factor and other physical quantities in the next papers.

Thank you

Back up

Efficiency definition

Efficiency	definition
livetime	Without any cuts
Trigger eff	(two arms acceptance + left arm z+ Current + Trigger1)/(two arms acceptance + let arm z + Current + Trigger2)
PID eff	Cer_eff: (Calo + Curent + Cer + Trigger1)/(Calo + Current + Trigger1)
	Calo_eff: (Calo+ Current + Cer Trigger1)/(Cer + Current + Trigger1)
Tracking eff	Left none_zero track: (Trigger1 + PID + Current +L.tr.n>0)/(Trigger1 + PID + Current)
	Left one track: (Trigger1 + PID + left arm acceptance + left arm z + Current +L.tr.n==1)/(Trigger1 + PID + left arm acceptance + left arm z + Current) (based on dp cut, bin by bin)
	Right none_zero track: (Trigger1 + PID + Current +R.tr.n>0)/(Trigger1 + PID + Current)
	Right one track: (Trigger1 + PID + right arm acceptance + Current +R.tr.n==1)/(Trigger1 + PID + right arm acceptance+ Current)
Beta cut eff	(Trigger1 + PID + L.tr.n==1 + R.tr.n==1 + two arms acceptance + left arm z + Current+ tight time_diff cut + beta)/(Trigger1 + PID + beta + L.tr.n==1 + R.tr.n==1 + two arms acceptance + left arm z + Current + tight time_diff cut)
Coincidence time eff	(Trigger1 + PID + tight beta cut+ L.tr.n==1 + R.tr.n==1 + two arms acceptance + left arm z + Current+ time_diff)/(Trigger1 + PID + tight beta cut+ L.tr.n==1 + R.tr.n==1 + two arms acceptance + left arm z + Current)

List of Systematic uncertainties

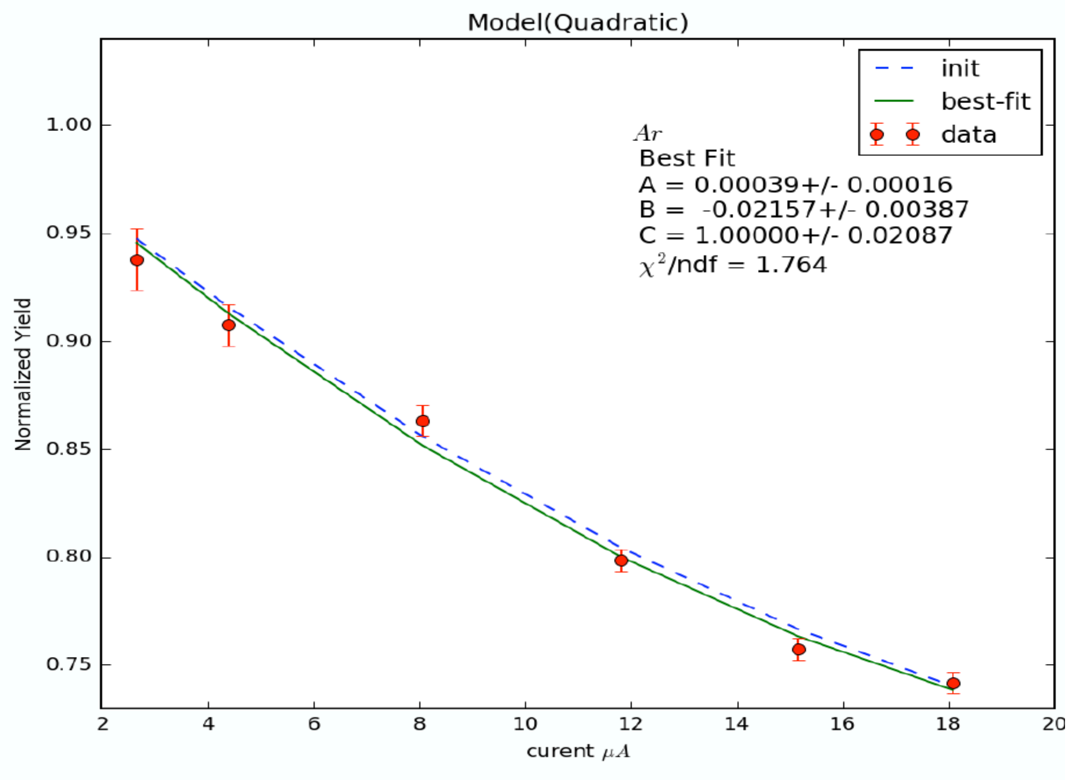
- Beta cut: [0.6,0.8]
- Beta cut efficiency is recalculated each time after each variation of the beta cut

Case No.	Rootfile Name	Change compared to original
0	original	No change
1	L_theta_cut_1	L_theta + [-0.0002,0] (rad)
2	L_theta_cut_2	L_theta + [+0.0002,0] (rad)
3	L_theta_cut_3	L_theta + [0,-0.0002] (rad)
4	L_theta_cut_4	L_theta + [0,+0.0002] (rad)
5	L_phi_cut_1	L_phi + [-0.0002,0] (rad)
6	L_phi_cut_2	L_phi + [+0.0002,0] (rad)
7	L_phi_cut_3	L_phi + [0,-0.0002] (rad)
8	L_phi_cut_4	L_phi + [0,+0.0002] (rad)
9	R_dp_cut_1	R_dp + [-0.0002,0]
10	R_dp_cut_2	R_dp + [+0.0002,0]
11	R_dp_cut_3	R_dp + [0,-0.0002]
12	R_dp_cut_4	R_dp + [0,+0.0002]
13	R_theta_cut_1	R_theta + [-0.0002,0] (rad)
14	R_theta_cut_2	R_theta + [+0.0002,0] (rad)
15	R_theta_cut_3	R_theta + [0,-0.0002] (rad)
16	R_theta_cut_4	R_theta + [0,+0.0002] (rad)
17	R_phi_cut_1	R_phi + [-0.0002,0] (rad)
18	R_phi_cut_2	R_phi + [+0.0002,0] (rad)
19	R_phi_cut_3	R_phi + [0,-0.0002] (rad)
20	R_phi_cut_4	R_phi + [0,+0.0002] (rad)
21	z_cut_1	z + [-0.6,0] (cm)
22	z_cut_2	z + [+0.6,0] (cm)
23	time_diff_1	coincidence time cut sigma vary +0.3ns
24	time_diff_2	coincidence time cut sigma vary -0.3ns
25	beta_1	beta + [-0.05,0]
26	beta_2	beta + [+0.05,0]
27	beta_3	beta + [0,-0.05]
28	beta_4	beta + [0,+0.05]
29	beam_x_1	targ_x_offset - 0.04 (cm)
30	beam_x_2	targ_x_offset + 0.04 (cm)
31	beam_y_1	targ_y_offset - 0.05 (cm)
32	beam_y_2	targ_y_offset + 0.05 (cm)
33	HRS_ex_1	spec_E_arm_x_offset - 0.0005 (cm)
34	HRS_ex_2	spec_E_arm_x_offset + 0.0005 (cm)
35	HRS_ey_1	spec_E_arm_y_offset - 0.0005 (cm)
36	HRS_ey_2	spec_E_arm_y_offset + 0.0005 (cm)
37	HRS_px_1	spec_P_arm_x_offset - 0.0005 (cm)
38	HRS_px_2	spec_P_arm_x_offset + 0.0005 (cm)
39	HRS_py_1	spec_P_arm_y_offset - 0.0005 (cm)
40	HRS_py_2	spec_P_arm_y_offset + 0.0005 (cm)
41	COSY_q1	COSY Q1 shift up 1% (Both arms)
42	COSY_q2	COSY Q2 shift up 1% (Both arms)
43	COSY_q3	COSY Q3 shift up 1% (Both arms)

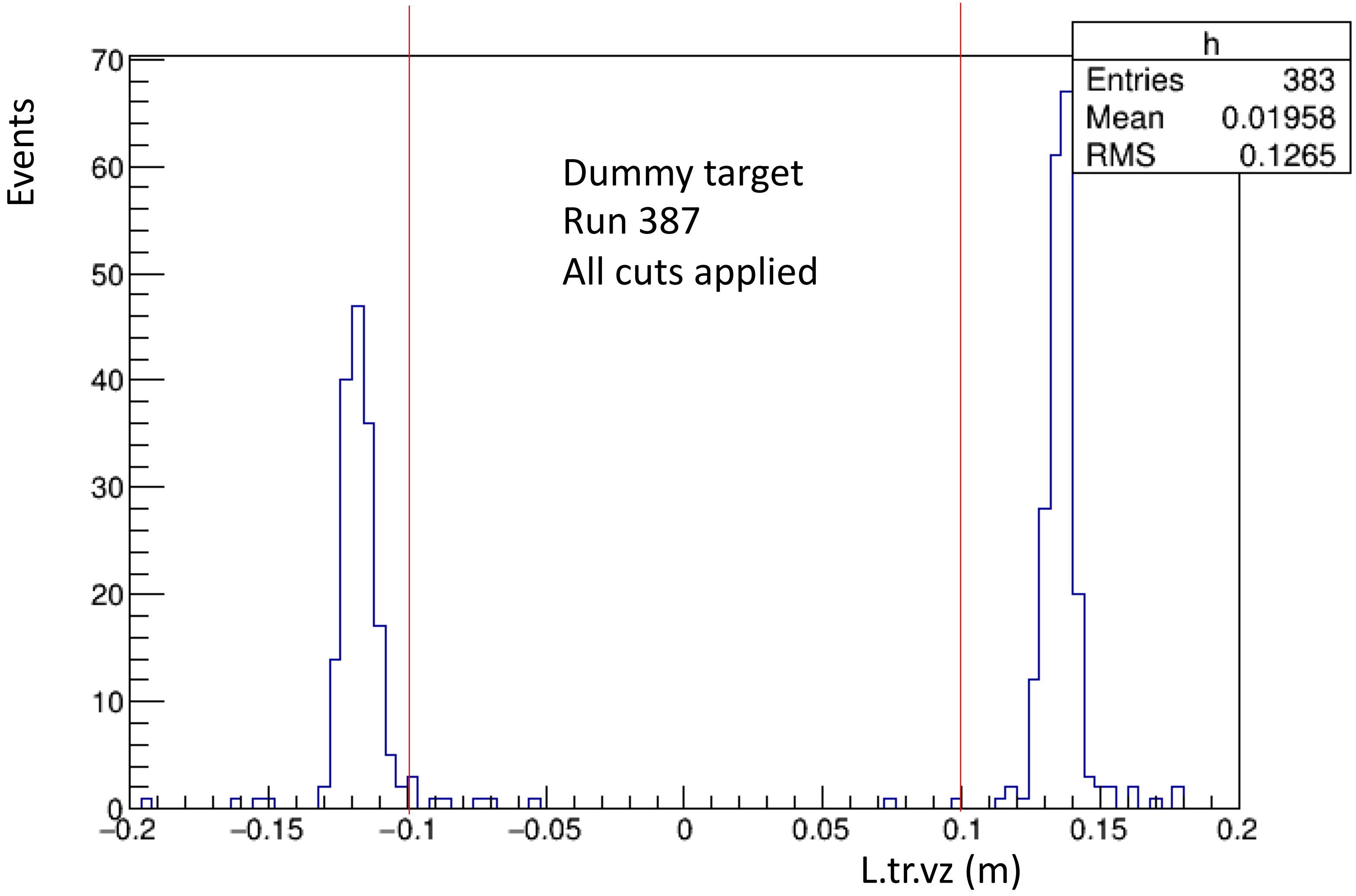
Boiling Study-----Nathaly Santiesteban and H. Dai

- We calculated the normalized yield for different currents, and the change in yield represents change in target density
- The normalization is done with respect to the lowest current
- We fit the numbers with quadratic function and fix the I=0 point to 1
- When $I = 9.67\mu A$, within 2% for all the runs, the boiling effect is 17.2%, with 0.7% uncertainty.

Current (µA)	Number of events	Yield (ev/µC)	Normalized Yield
2.65 +/- 0.14	4898	1571.63 +/- 23.86	1 +/- 0.015
4.39+/-0.14	10283	1523.80 +/- 15.97	0.97 +/- 0.01
8.06 +/- 0.15	17460	1454.32 +/- 11.69	0.925 +/- 0.007
11.81 +/- 0.17	26848	1352.62 +/- 8.77	0.860 +/- 0.005
15.15 +/- 0.19	25764	1287.83 +/- 8.52	0.8194 +/- 0.0054
18.08 +/- 0.21	26065	1263.59 +/- 8.31	0.804 +/- 0.0053

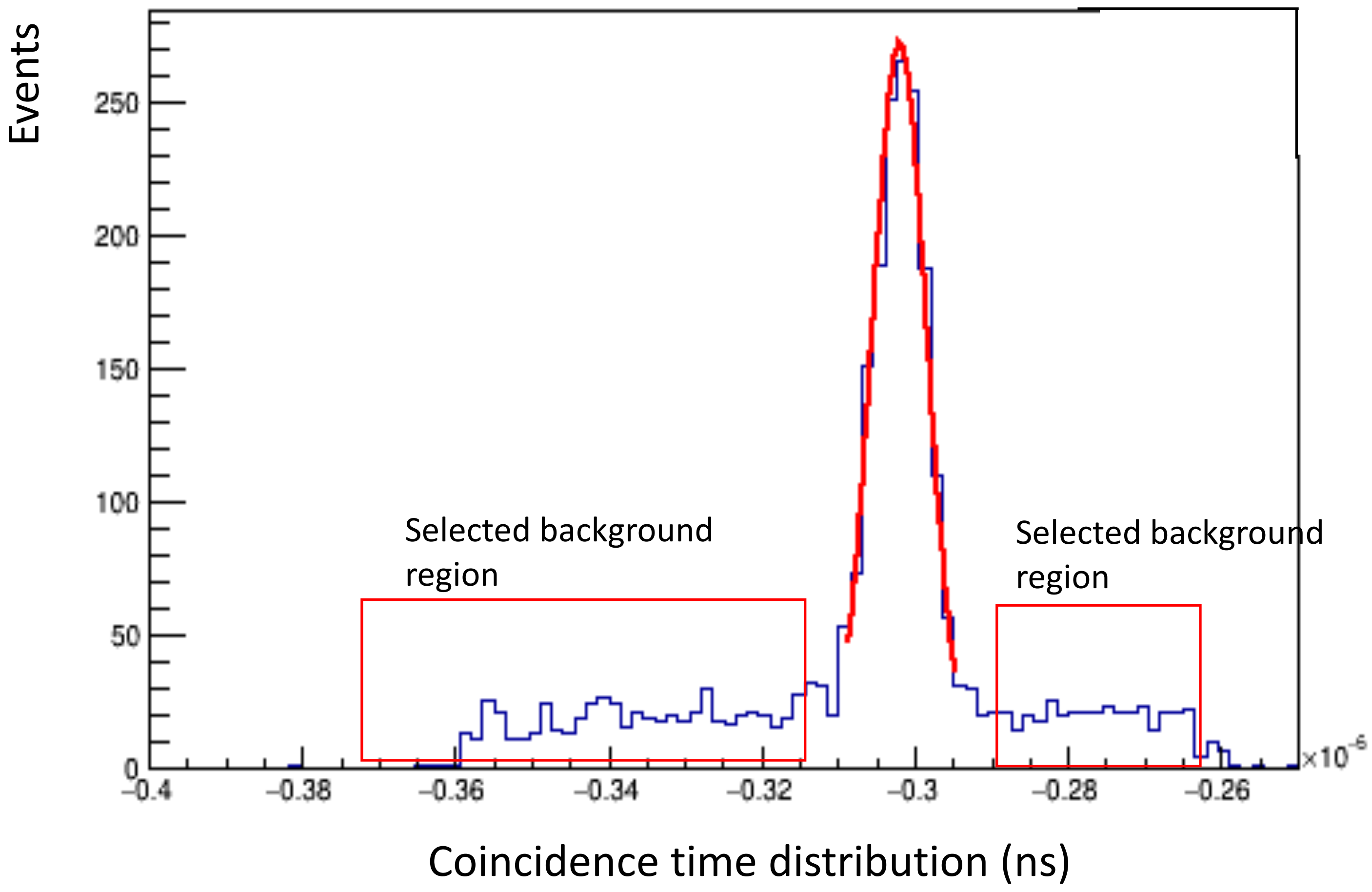


Background study in Kin1
Ar - from cell walls and endcaps



- Background from dummy is ignorable in selected z cut range [-0.1,0.1](m)

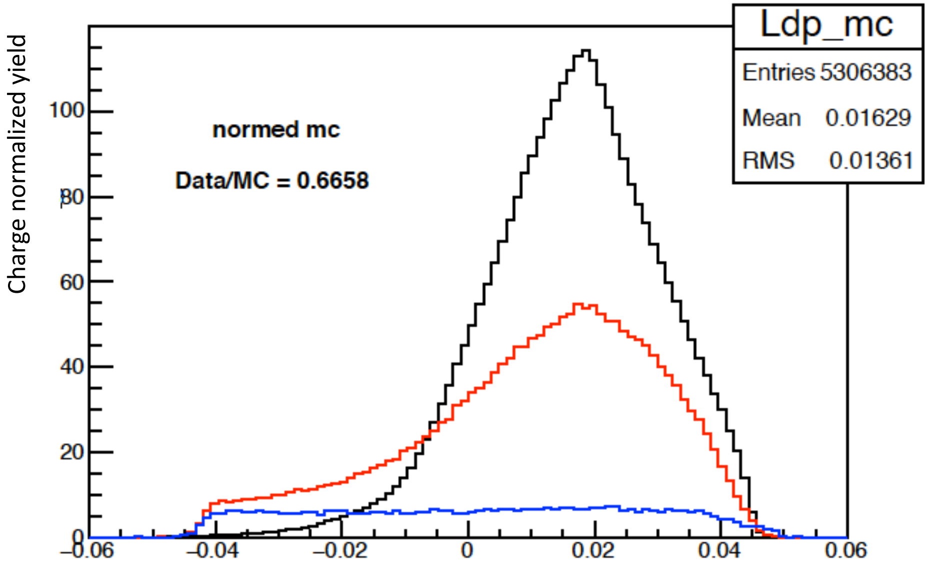
Background study in Kin1 Ar – from accidental



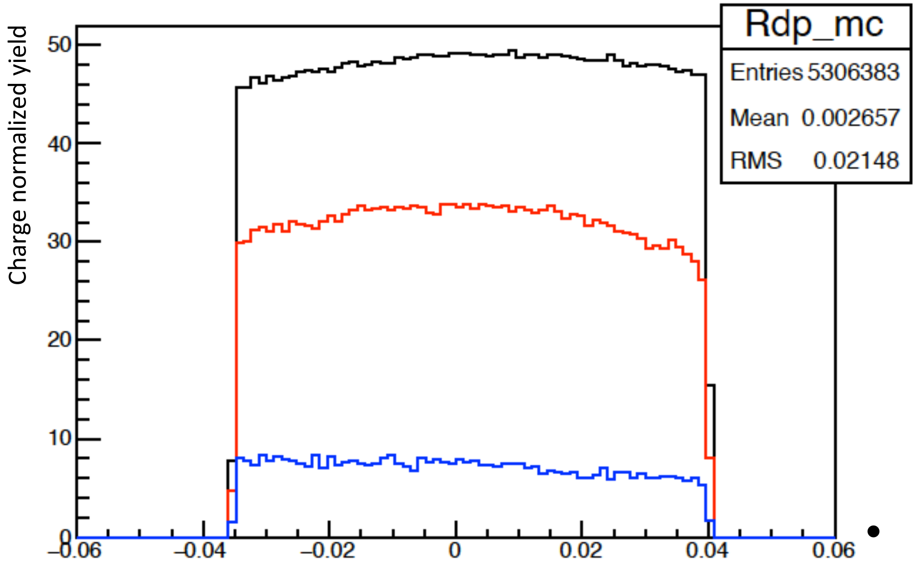
Steps for calculating the background from accidental:

- Pick one or two (both sides) background region
- Find the background range width and events number in the region
- Scaled background events = 2*sigma*(background events/background range)
- Background rate = scaled background events/ total events

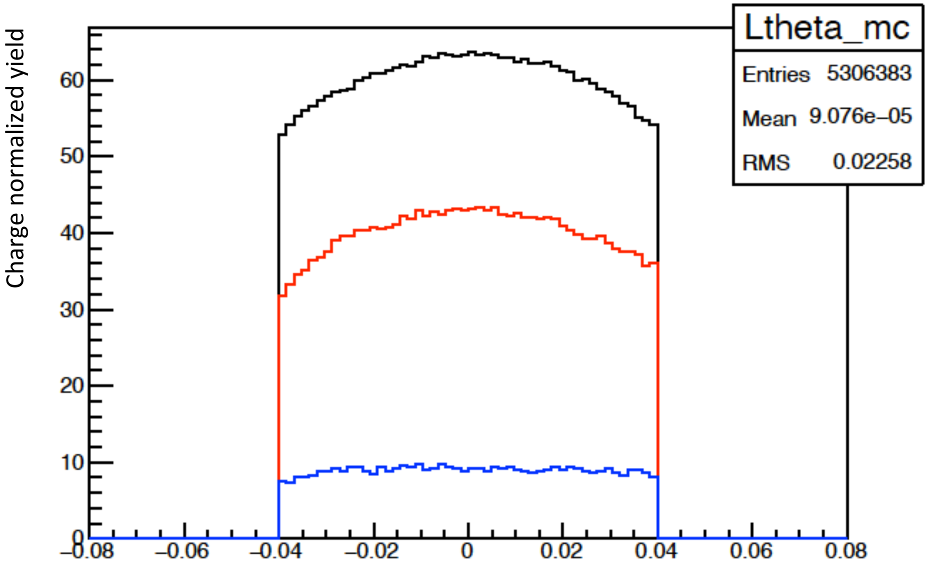
Exclusive analysis - kin1 Ar - Data/MC comparison



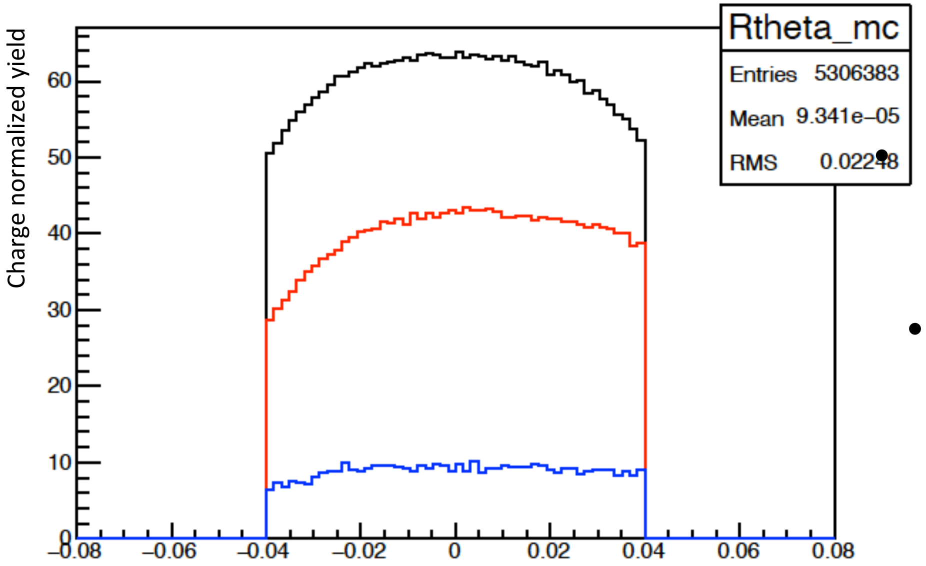
Left arm electron dp/p distribution



Right arm proton dp/p distribution



Left arm electron theta distribution (rad)



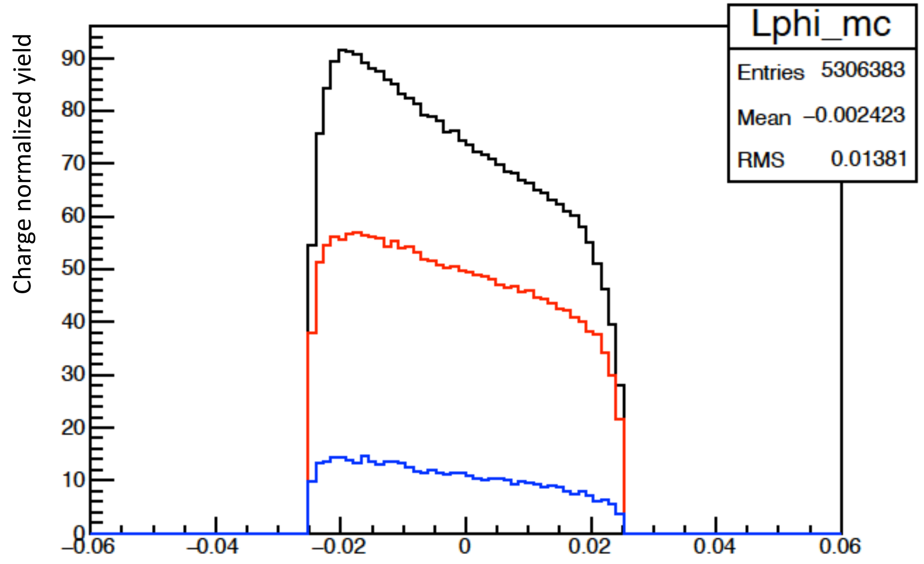
Right arm proton theta distribution (rad)

Red: data
Black: SIMC no FSI
Blue: background x 10

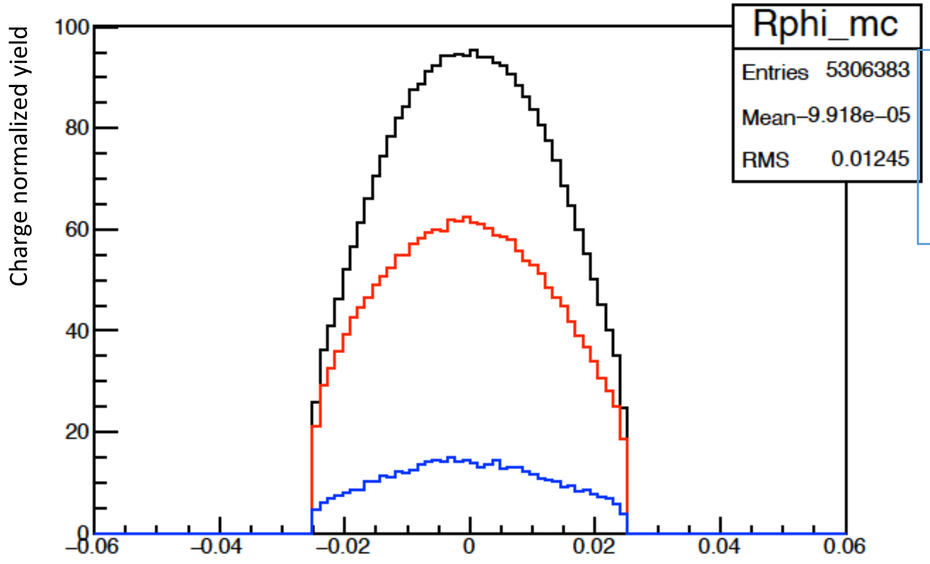
Data/mc ratio = 0.67

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

Exclusive analysis - kin1 Ar - Data/MC comparison

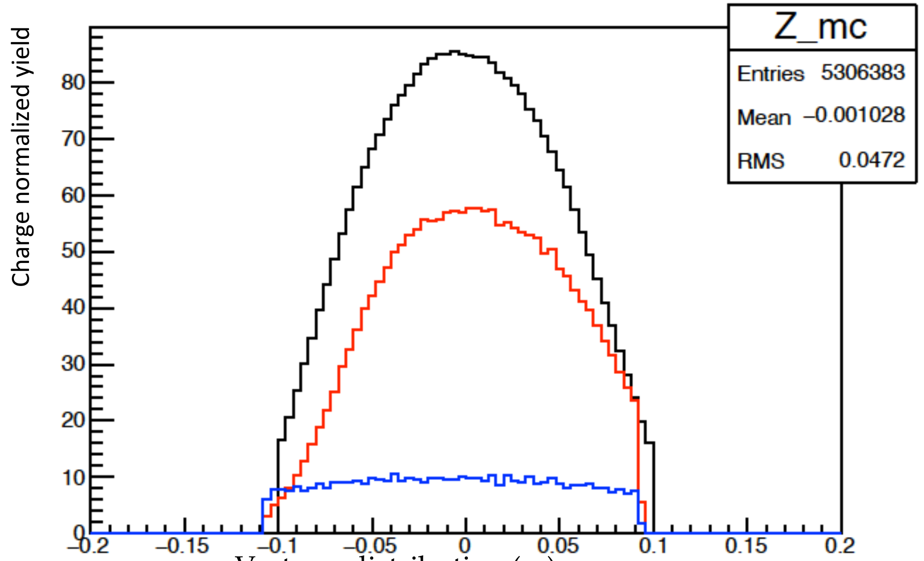


Left arm electron phi distribution (rad)

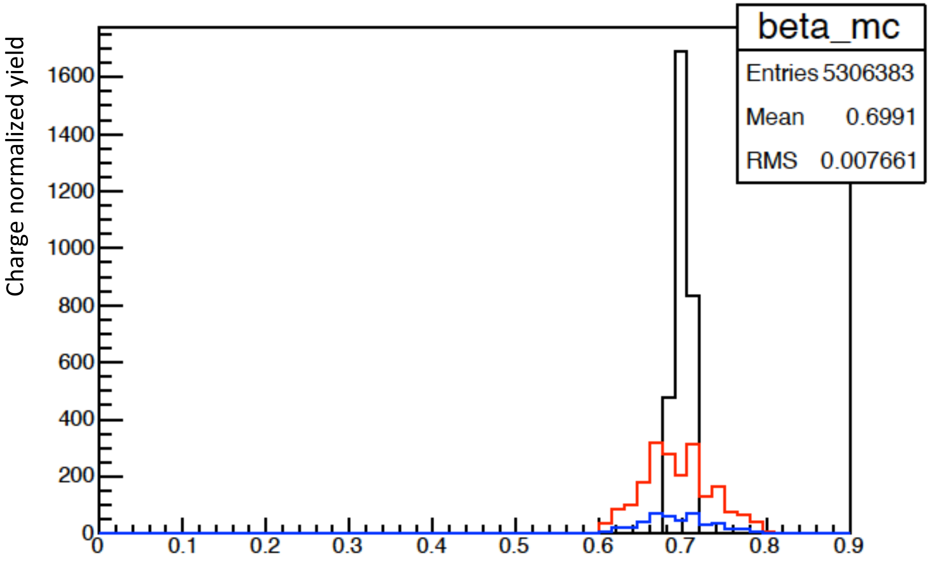


Right arm proton phi distribution (rad)

Red: data
Black: SIMC no FSI
Blue: background x 10

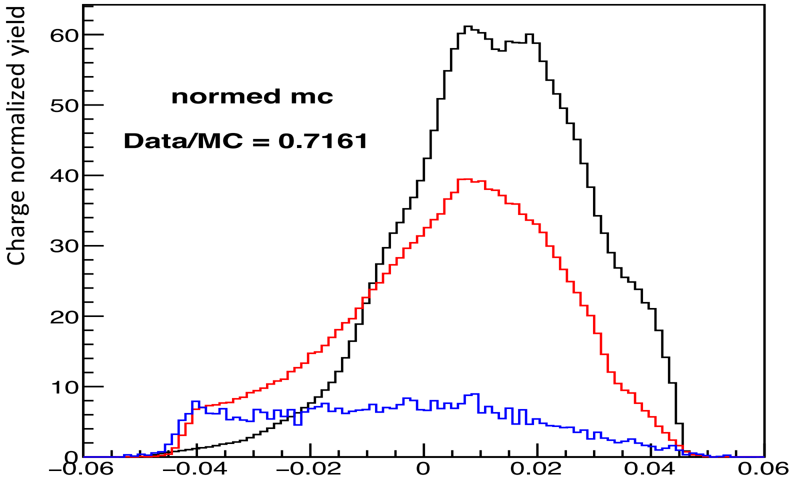


Vertex z distribution (m)

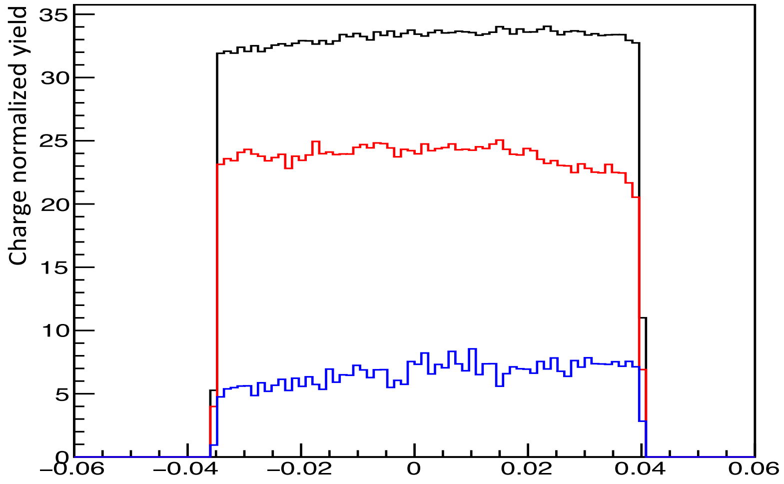


Right arm proton beta distribution

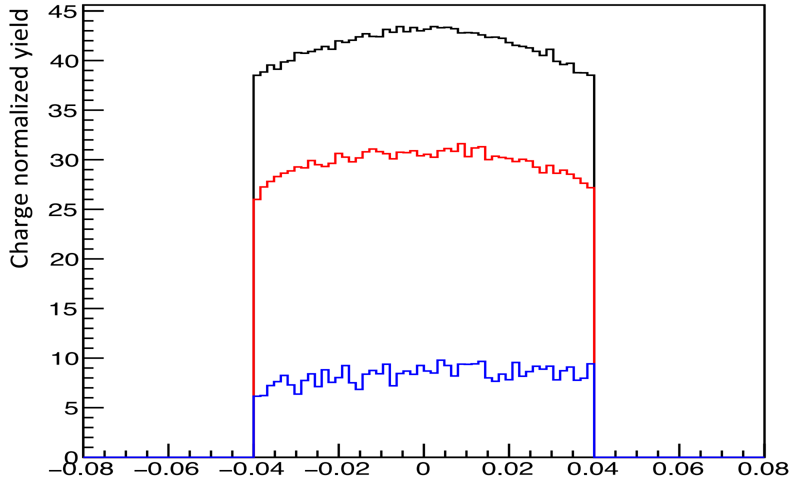
Exclusive analysis - kin1 Ti - Data/MC comparison



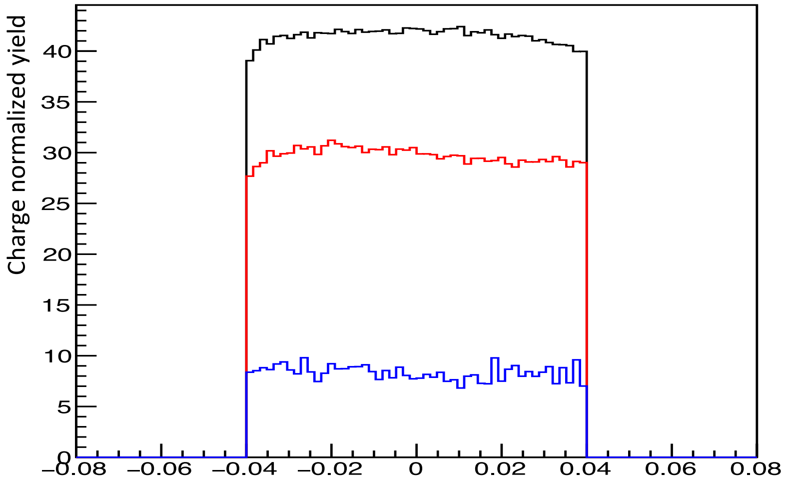
Left arm electron dp/p distribution



Right arm proton dp/p distribution



Left arm electron theta distribution (rad)



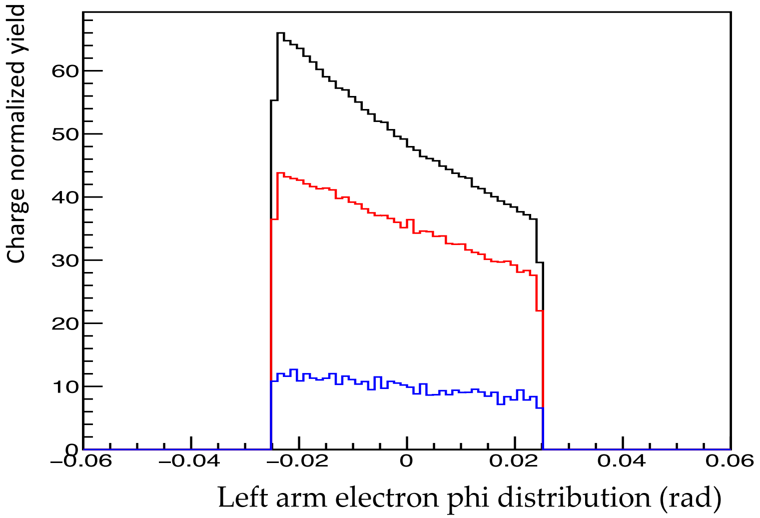
Right arm proton theta distribution (rad)

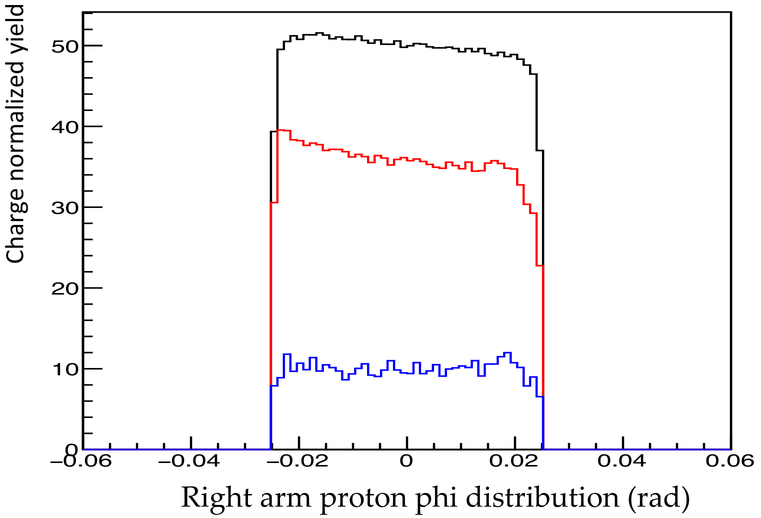
Red: data
Black: SIMC
Blue: background x10

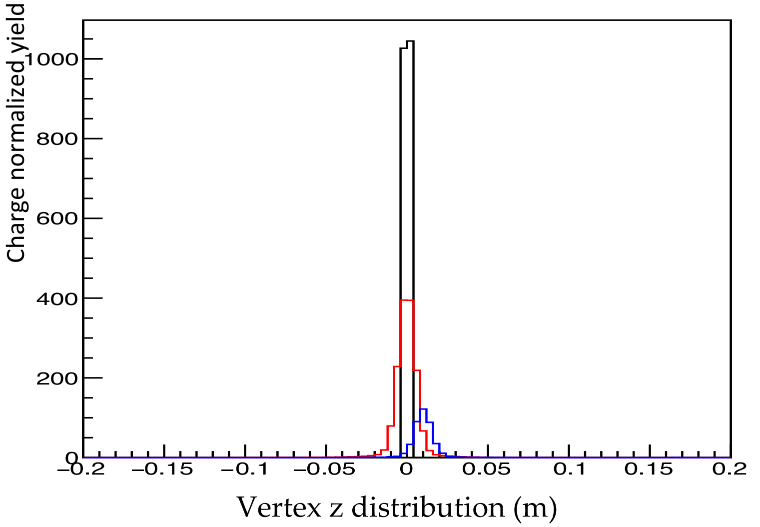
Data/mc ratio = 0.72

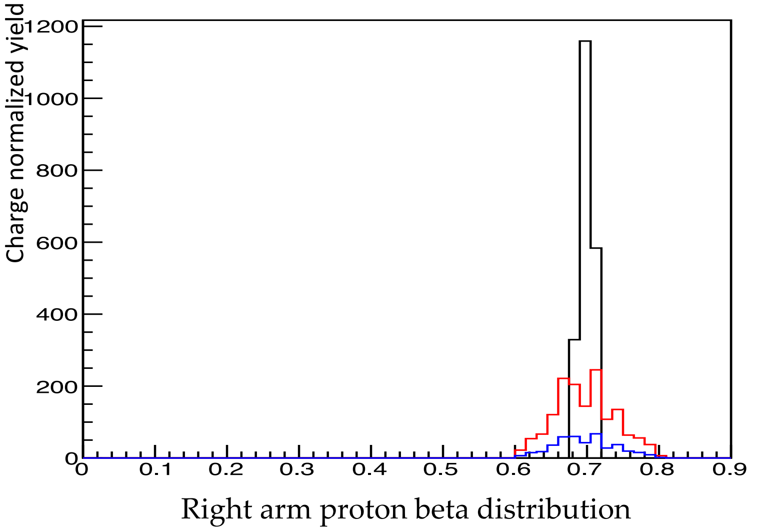
- Corrections of efficiencies and livetime have been applied in the plots
- The events are normalized by the total charge
- FSI is not included yet in the MC

Exclusive analysis - kin1 Ti - Data/MC comparison









The $(e, e'p)$ cross section within PWIA

- Factorization of the final state of the semi-exclusive process

$$e + A \to e' + p + (A-1)_n$$

leads to the simple expression

$$\frac{d\sigma_A}{dE_{e'} d\Omega_{e'} dE_p d\Omega_p} = \mathrm{K}\, \sigma_{ep}\, P(p_m, E_m) ,$$

with the missing momentum and missing energy defined by

$$\mathbf{p}_m = \mathbf{p} - \mathbf{q} ,$$

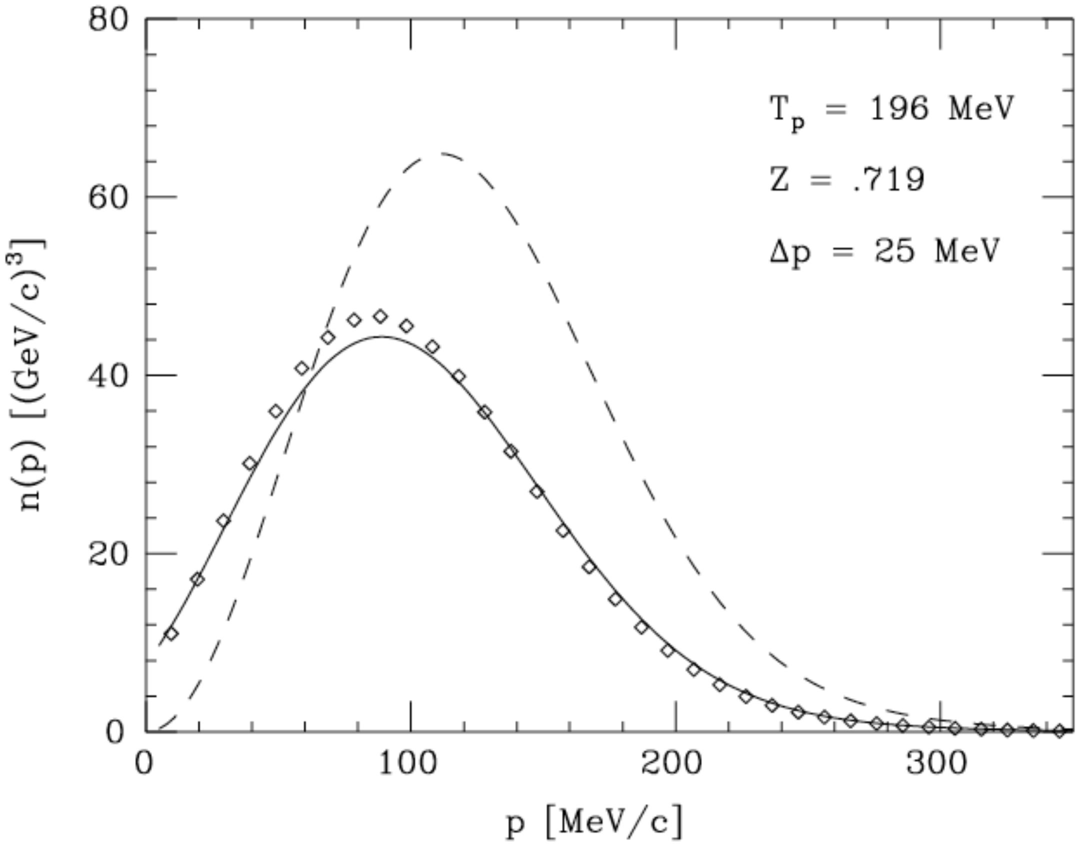
$$\omega + M_A = \sqrt{(M_A - m + E_m)^2 + |\mathbf{p}_m|^2} + \sqrt{\mathbf{p}^2 + m^2} \to E_m \approx \omega - T_{\mathbf{p}} ,$$

$\mathbf{q}$ and ω being the momentum and energy transfer, respectively

- Warning: while providing a clear interpretation of the reaction mechanism, PWIA fails to account for final state interactions of the outgoing nucleon

Inclusion of Final State Interactions (FSI)

- ⋆ Distorted Wave Impuse Approximation (DWIA). The plane-wave describing the outgoing nucleon is replaced by a *distorted wave*, obtained from a complex optical potential fitted to proton-nucleus scattering data
- ⋆ The momentum distributions of the shell model states are shifted by an amount Δ_p and quenched by a factor $\tilde{Z}$
- ⋆ For $A \leq 16$, the accuracy of the optical potential approach has been tested comparing to the results of many-body calculations of the relevant overlaps



- ⋆ FSI effects beyond DWIA are minimized in *parallel kinematics*

FSI analysis (cont'd)

- Check dependence from form factors

	Results using different form factors but same choice of CC1 cross section			
	BBBA form factors		Dipole form factors	
Orbital	Shift (MeV)	DWIA/PWIA	Shift (MeV)	DWIA/PWIA
1d32	3.5	0.65	3.5	0.65
2s12	8.9	0.81	8.9	0.81
1d52	0.5	0.65	0.5	0.65
1p12	17.5	0.46	17.5	0.46
1p32	11	0.56	11	0.56
1s12	14.1	0.51	14.1	0.51

FSI analysis (cont'd)

- Check dependence from CC1 or CC2

	Results using BBBA form factors			
	Using CC1		Using CC2	
Orbital	Shift (MeV)	DWIA/PWIA	Shift (MeV)	DWIA/PWIA
1d32	3.5	0.65	1.5	0.58
2s12	8.9	0.81	8	0.78
1d52	0.5	0.65	-2.	0.58
1p12	17.5	0.46	12.5	0.43
1p32	11	0.56	9.5	0.47
1s12	14.1	0.51	13	0.42

FSI analysis (cont'd)

- Check dependence from optical potential choices

	Comparison between different optical potentials (CC2)					
	IFIT=12 (Democratic Fit)		IFIT=10(EAD Fit3)		IFIT=8(EAD Fit1)	
Orbital	Shift (MeV)	DWIA/PWIA	Shift (MeV)	DWIA/PWIA	Shift (MeV)	DWIA/PWIA
1d32	1.5	0.58	-2.0	0.57	1.5	0.58
2s12	8.0	0.78	7.0	0.78	8.0	0.78
1d52	-2.0	0.58	-6.5	0.57	-3.0	0.58
1p12	12.5	0.43	9.0	0.39	12.5	0.42
1p32	9.5	0.47	5.0	0.44	9.0	0.46
1s12	13.0	0.42	10.0	0.38	13.0	0.41