Moments of Angular Distribution in K^+K^- Electroproduction at CLAS12

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Overview

- Meson Spectroscopy
- MesonEx
- Moments of Angular Distribution
- Reaction of Interest
- Event Reconstruction
- Simulations
- Extraction of Moments
- Outlook

Mesons

A meson can be classified using a set of quantum numbers J^{PC}:

- J is the spin
- P is the parity
- C is the charge conjugation parity (c-parity)

$$J = L + S$$

$$P = (-1)^{L+1}$$

$$C = (-1)^{L+S}$$

Mesons

Allowed J^{PC} in quark model:

$$J^{PC} = 0^{-+}, 0^{++}, 1^{--}, 1^{+-}, 1^{++}, \ldots$$

Exotic J^{PC} forbidden in the quark model:

$$J^{PC} = 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, \ldots ,$$

Meson Spectroscopy

Meson	M (Exp)
$\pi^+[u\bar{d}]_{J^{pc}=0^{-+}}$	139.57039 ± 0.00018
$\pi^-[d\bar{u}]_{J^{pc}=0^{-+}}$	139.57039 ± 0.00018
$\pi^0[(u\bar{u}-d\bar{d})/\sqrt{2}]_{J^{pc}=0^{-+}}$	134.9768 ± 0.0005
$\rho^+[u\bar{d}]_{J^{pc}=1^{--}}$	775.4 ± 0.4
$\rho^-[d\bar{u}]_{J^{pc}=1^{--}}$	775.4 ± 0.4
$\rho^0[(u\bar{u}-d\bar{d})/\sqrt{2}]_{J^{pc}=1^{--}}$	775.26 ± 0.23
$\omega[(u\bar{u}+d\bar{d})/\sqrt{2}]_{J^{pc}=1^{--}}$	782.66 ± 0.13

Meson	M (Exp)
$K^+[u\bar{s}]_{J^{pc}=0^{-+}}$	493.677 ± 0.016
$K^-[s\bar{u}]_{J^{pc}=0^{-+}}$	493.677 ± 0.016
$K^0[d\bar{s}]_{J^{pc}=0^{-+}}$	497.611 ± 0.013
$\overline{K}^0[s\bar{d}]_{J^{pc}=0^{-+}}$	497.611 ± 0.013
$K^{*+}[u\bar{s}]_{J^{pc}=1^{--}}$	891.67 ± 0.026
$K^{*-}[s\bar{u}]_{J^{pc}=1^{--}}$	891.67 ± 0.026
$K^{*0}[d\bar{s}]_{J^{pc}=1^{--}}$	896.00 ± 0.025
$\overline{K}^{*0}[s\bar{d}]_{J^{pc}=1^{--}}$	896.00 ± 0.025

MesonEx

The purpose of MesonEx is to conduct a meson spectrum study using quasi-real photoproduction with CLAS12 to observe rare mesons including those with exotic quantum numbers.

Why MesonEx?

- Exotics more likely in photoproduction than in hadroproduction
- Exotics produced via photoproduction and ordinary mesons have comparable cross sections

MesonEx

MesonEx requirements:

- Low virtuality (Q^2) electron beam
- Full determination of the four-momenta of the the initial state and final state
- Large acceptance and good resolution

Moments of Angular Distribution

The moments of angular distribution in terms of the experimental intensity are defined as:

$$H^0(LM) = \frac{1}{2\pi}\int_0^{2\pi}\int_0^{2\pi}\int_{-1}^{1} I(\Omega,\Phi)\, d^L_{M0}(\theta)\cos M\phi \; \mathrm{d}(\cos\theta)\mathrm{d}\phi\mathrm{d}\Phi$$

$$H^1(LM) = \frac{1}{P_\gamma \pi}\int_0^{2\pi}\int_0^{2\pi}\int_{-1}^{1} I(\Omega,\Phi)\, d^L_{M0}(\theta)\cos M\phi \cos 2\Phi \; \mathrm{d}(\cos\theta)\mathrm{d}\phi\mathrm{d}\Phi$$

Moments of Angular Distribution

The $H^0(00)$ and $H^1(00)$ moments in terms of the S, P and D partial waves are:

$$H^0(00) = H^1(00) + 2\left[|P_1^{(+)}|^2 + |D_1^{(+)}|^2 + |D_2^{(+)}|^2\right]$$

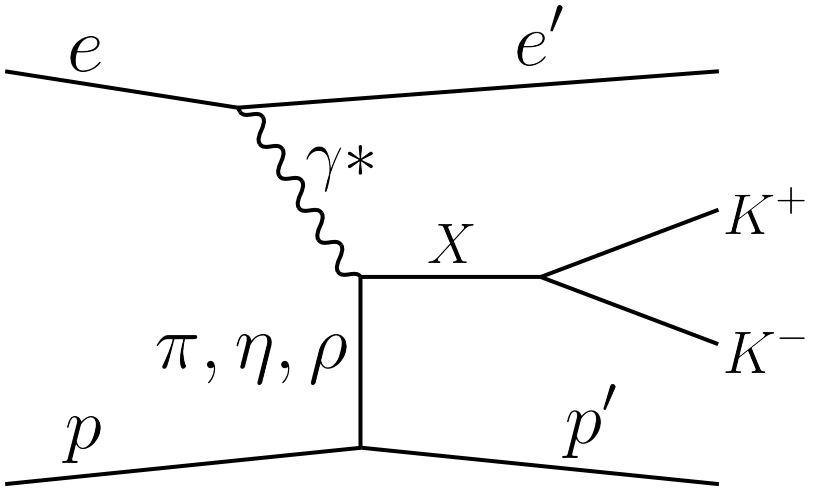
$$H^1(00) = 2\left[|S_0^{(+)}|^2 + |P_0^{(+)}|^2 + |D_0^{(+)}|^2\right]$$

Reaction of Interest

Reaction of interest:

$$ep \rightarrow ep' K^+ K^-$$

Feynman diagram of reaction:



Event Selection

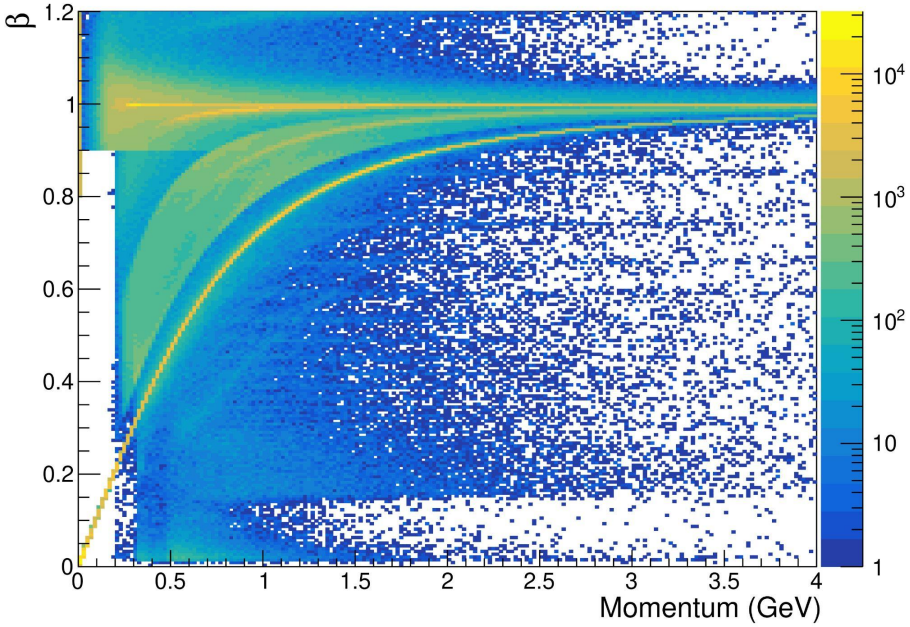
Event selection requirements:

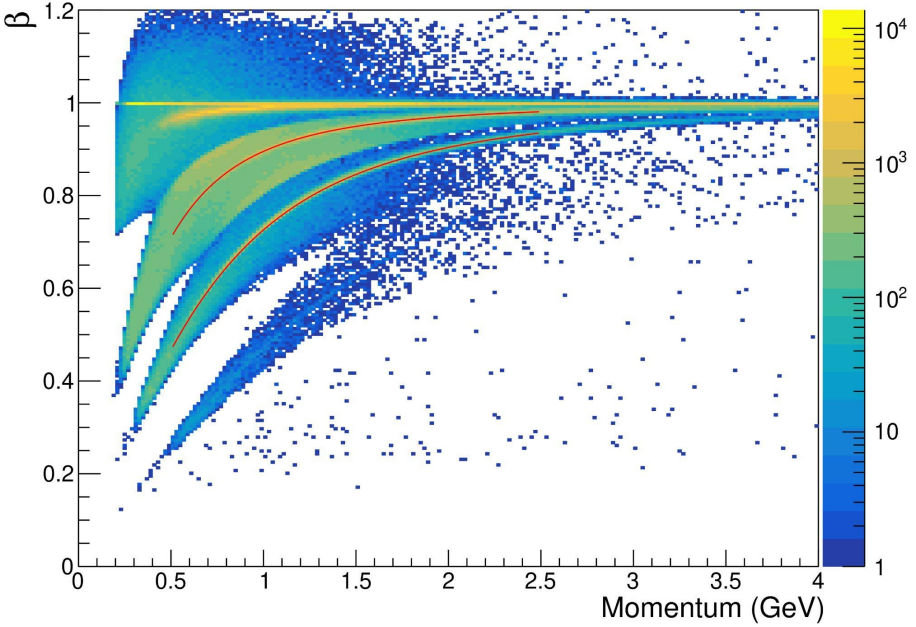
- Topologies – exclusive: $ep'K^+K^-$; other: eK^+K^-, $ep'K^-$, $ep'K^+$
- $|\chi^2_{PID}| < 3.5$
- Scattered electron: $2° < \theta < 5°$

  $0.4 < E_\gamma < 5$ GeV
- Kaons: $5° < \theta < 35°$

Event Selection

$$|\chi^2_{PID}| < 3.5$$





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Reaction Reconstruction

Reaction reconstruction requirements:

- $|MM^2(ep \rightarrow ep'K^+K^-X)| < 0.01\ GeV^2$
- $0.7 < MM(ep \rightarrow eK^+K^-X) < 1.1\ GeV$
- $0.3 < MM(ep \rightarrow ep'K^+X) < 0.7\ GeV$
- $0.3 < MM(ep \rightarrow ep'K^-X) < 0.7\ GeV$

Reaction Reconstruction

The missing mass squared:

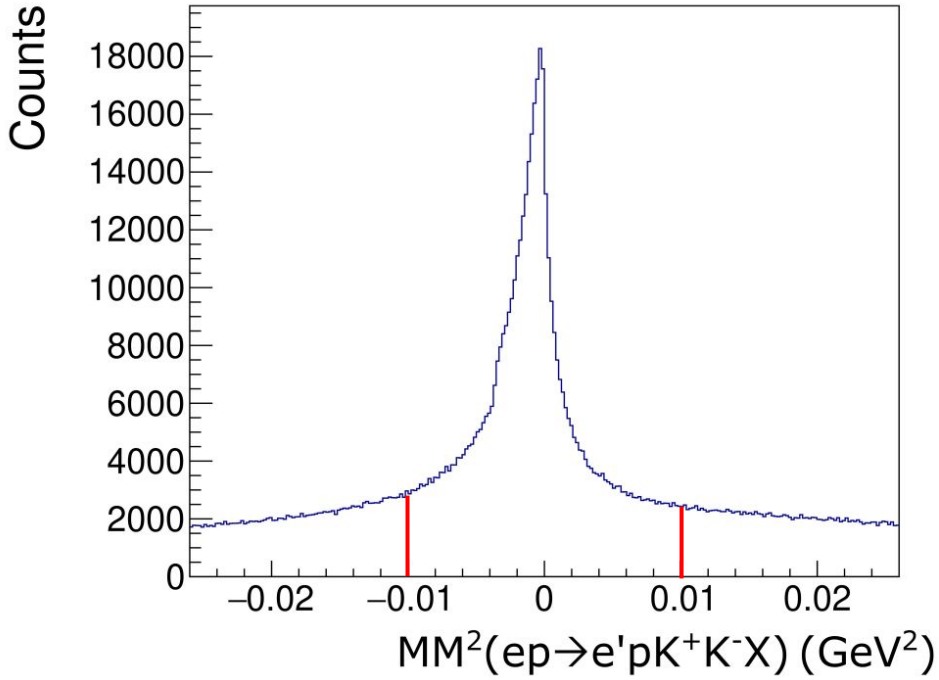
$$MM^2(ep \to e' pK^+K^-X) = |P_b + P_t|^2 - |P_{e'} + P_p + P_{K^+} + P_{K^-}|^2$$

$$= (E_b + m_t - E_{e'} - E_p - E_{K^+} - E_{K^-})^2$$

$$- |\bar{p}_b - \bar{p}'_e - \bar{p}_p - \bar{p}_{K^+} - \bar{p}_{K^-}|^2$$

Reaction Reconstruction

$|MM^2(ep \rightarrow ep'K^+K^-)| < 0.01\ GeV^2$ condition:



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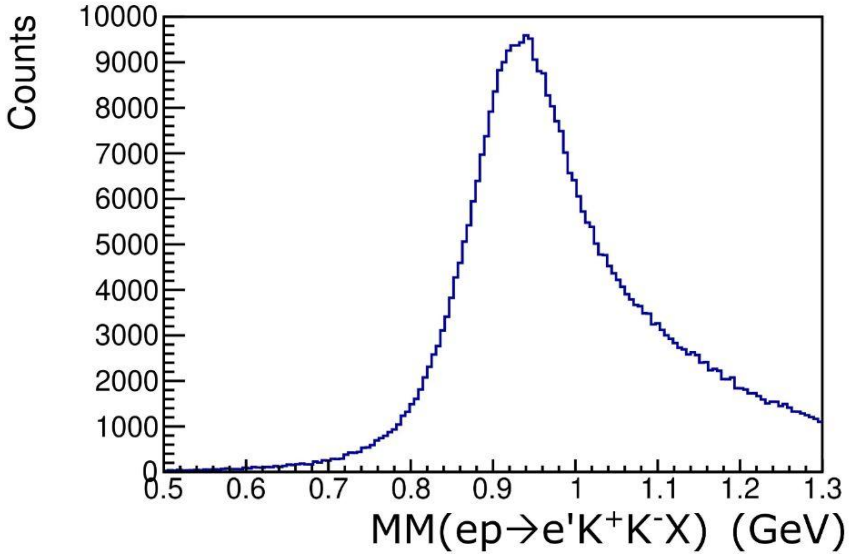
Reaction Reconstruction

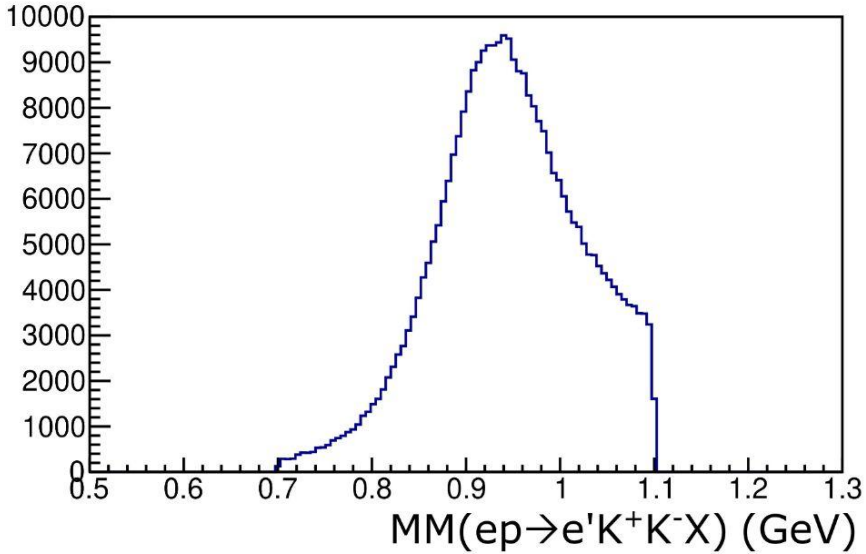
The missing proton mass:

$$MM(ep \to e'K^+K^-X) = \sqrt{|P_b + P_t|^2 - |P_{e'} + P_{K^+} + P_{K^-}|^2}$$
$$= \sqrt{(E_b + m_t - E_{e'} - E_{K^+} - E_{K^-})^2 - |\bar{p}_b - \bar{p}_{e'} - \bar{p}_{K^+} - \bar{p}_{K^-}|^2}$$

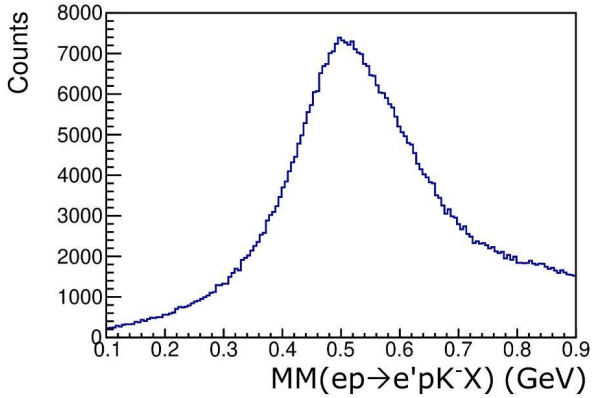
Reaction Reconstruction

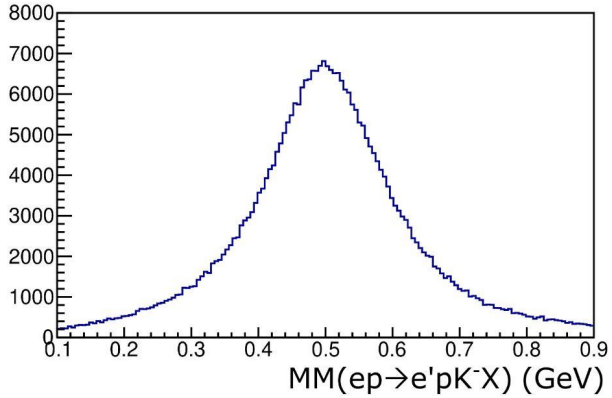
0.7 < MM(ep⟶eK$^+$K$^-$X) < 1.1 GeV condition:

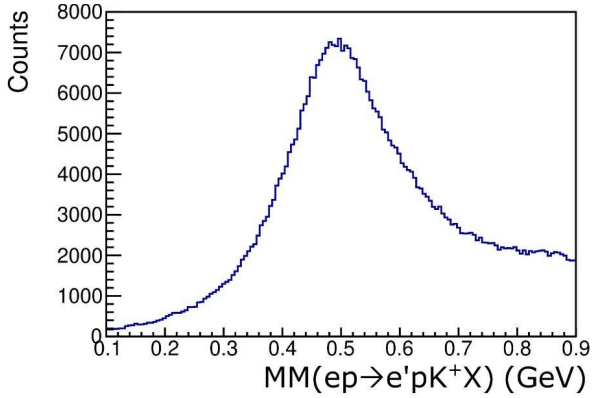


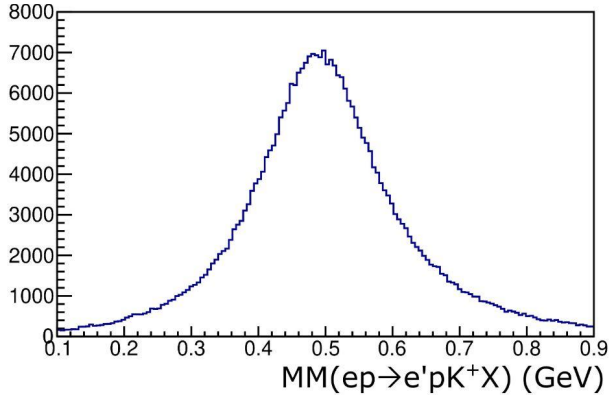


Reaction Reconstruction

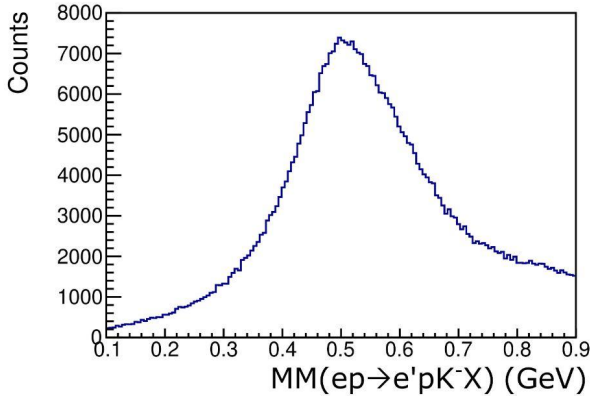


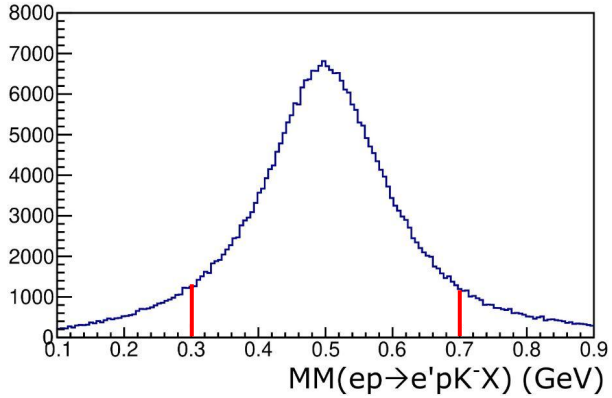


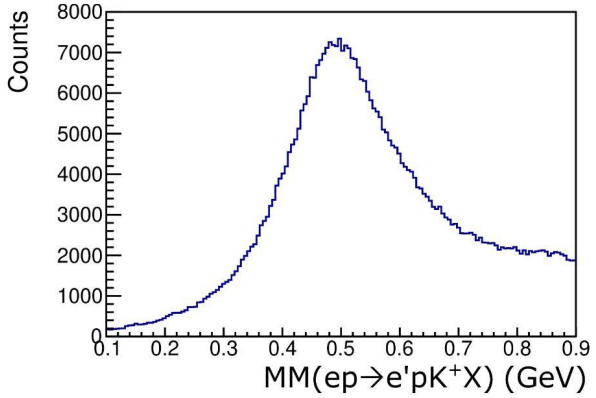


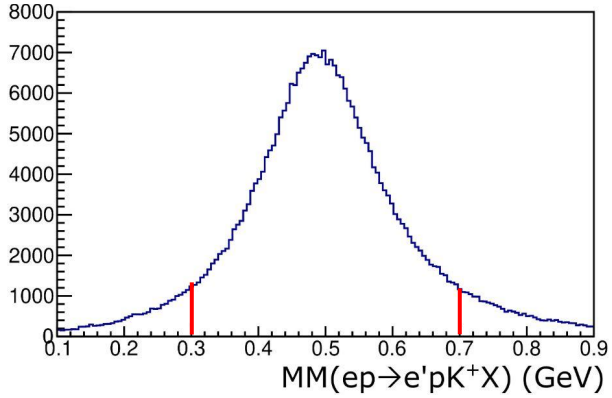


Reaction Reconstruction









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Reaction Reconstruction

Two independent values of Mandelstam variable t:

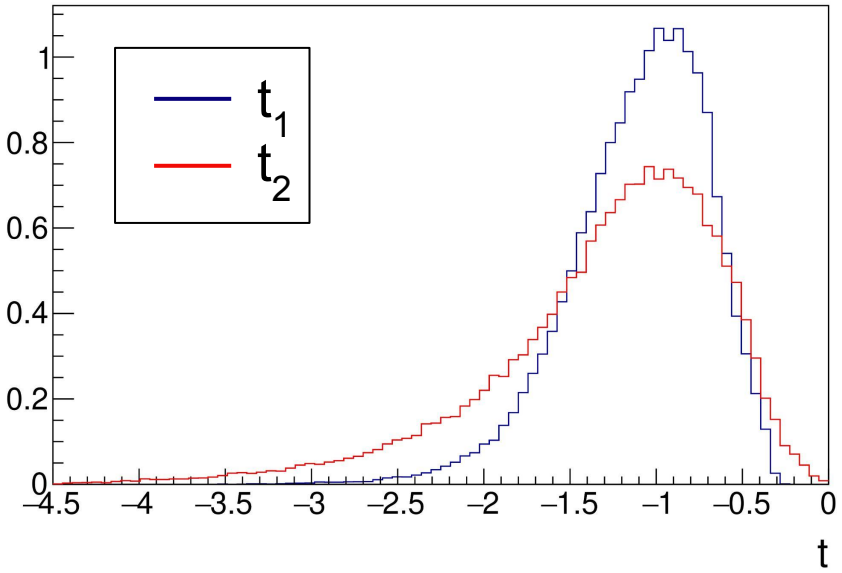
$$t_1 = \sqrt{(|P_t - P_p|^2)} = \sqrt{(m_t - E_p)^2 - |\bar{p}_p|^2},$$

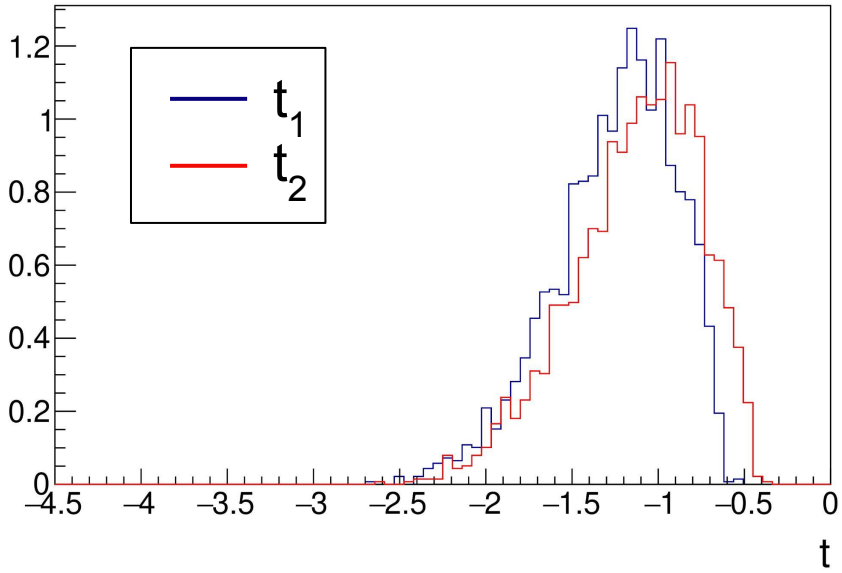
$$t_2 = \sqrt{|P_b - (P_{e'} + P_{K^+} + P_{K^-})|^2}$$

$$= \sqrt{(E_b - (E_{e'} + E_{K^+} + E_{K^-}))^2 + |\bar{p}_e - (\bar{p}_{e'} + \bar{p}_{K^+} + \bar{p}_{K^-})|^2}$$

Reaction Reconstruction

Comparison before (left) and after (right) reaction reconstruction:





Simulations

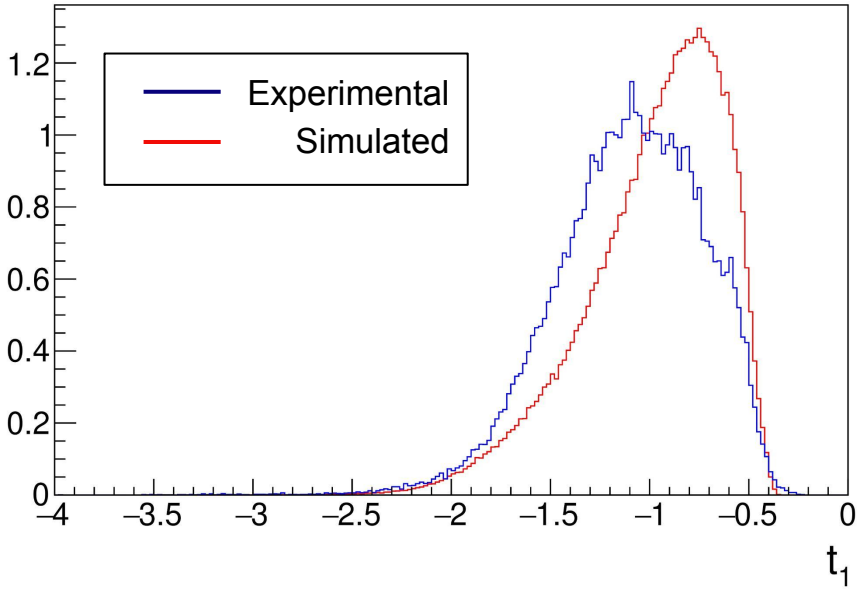
Simulations of the reaction of interest are vital to moments extraction. CLAS12-elSpectro was used for event generation.

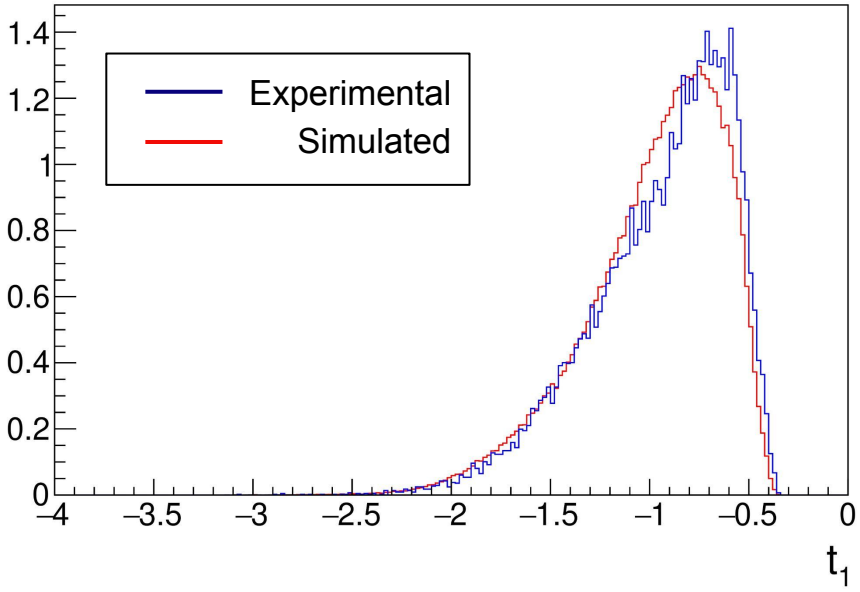
Simulations were used to obtain information on the detector that could not be extracted from experimental data such as:

- Detector acceptance
- Detector efficiencies

Simulations

Comparison before (left) and after (right) reaction reconstruction:





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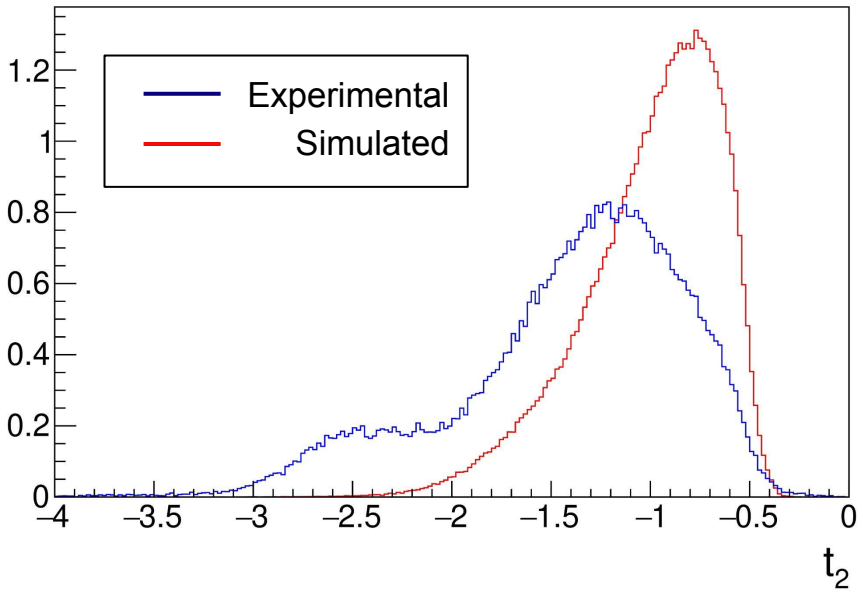

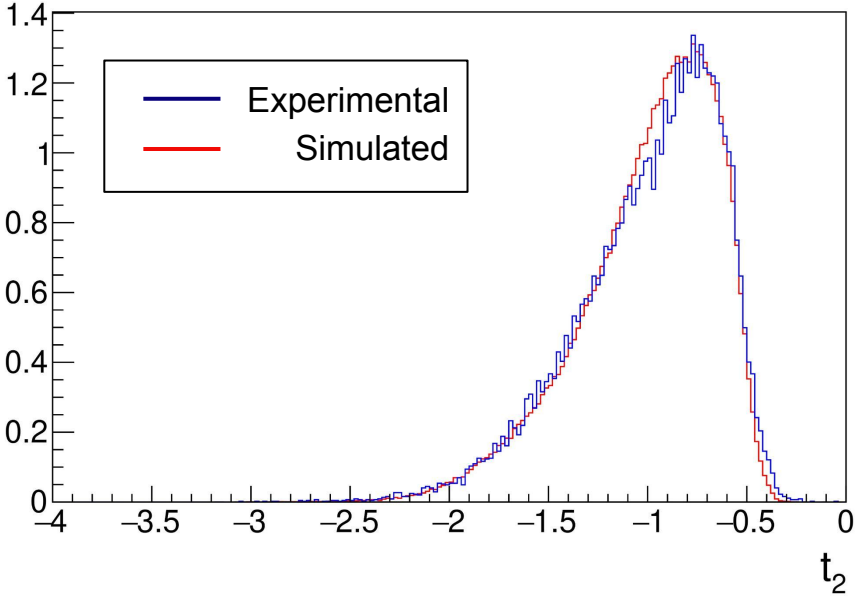

Simulations

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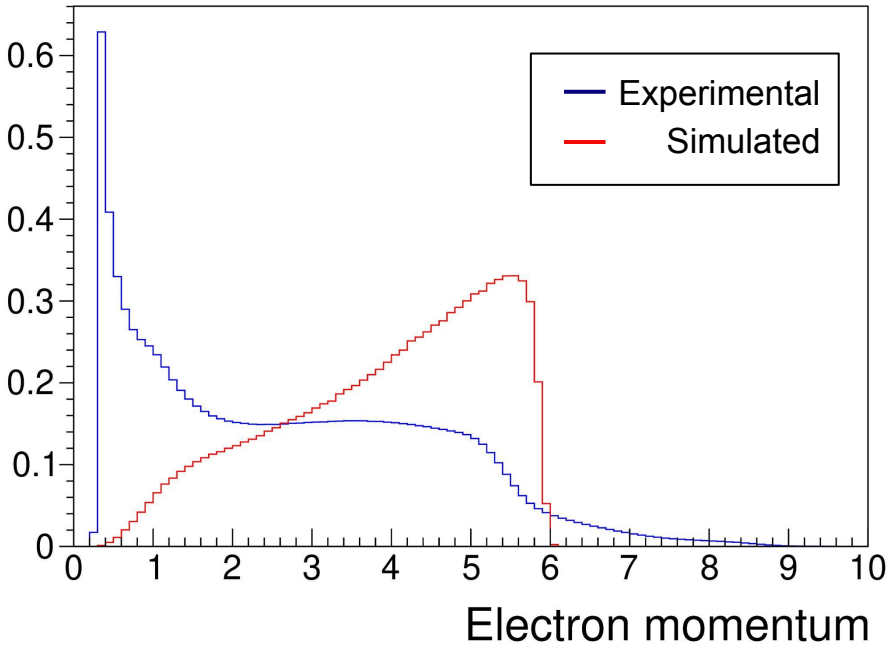
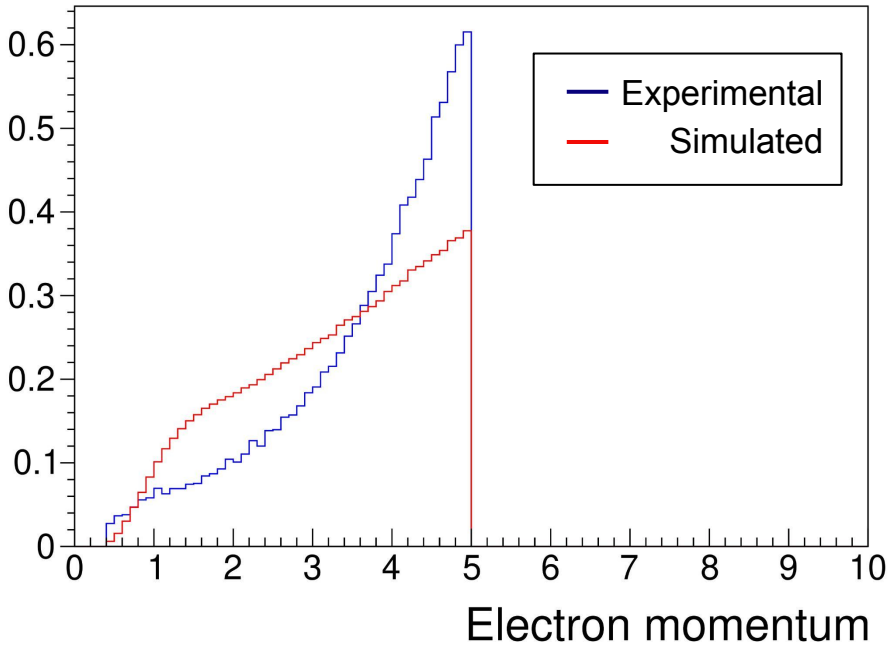
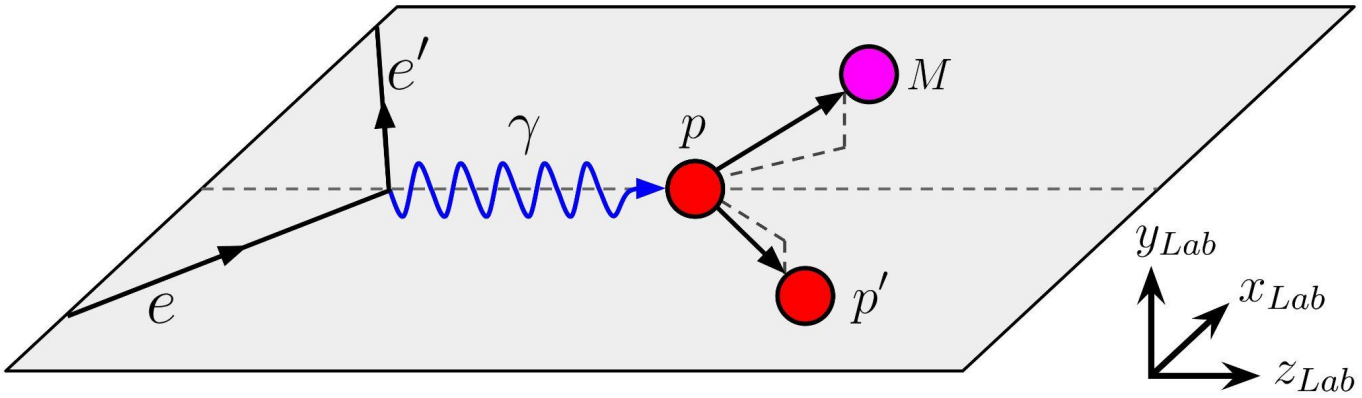




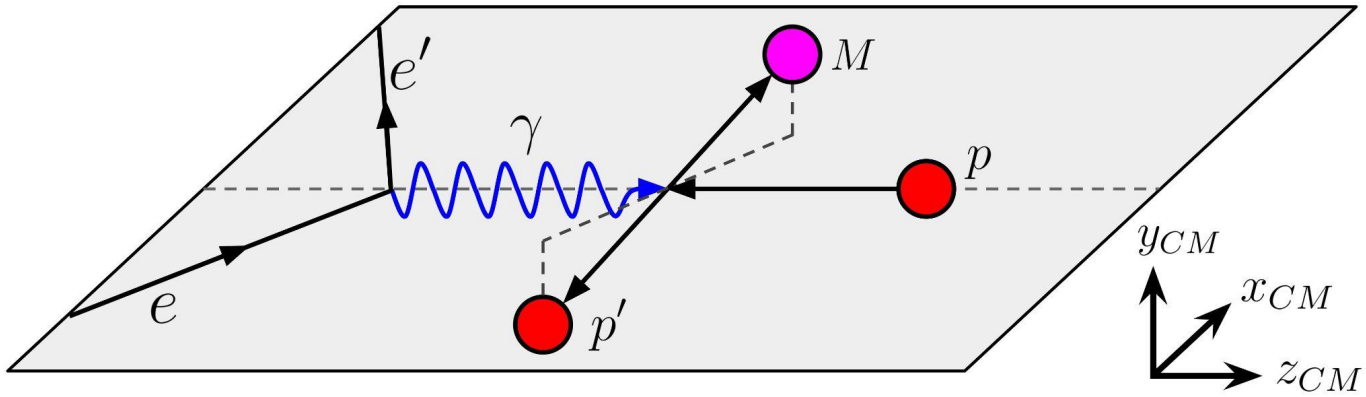
Frames of reference

Lab frame:



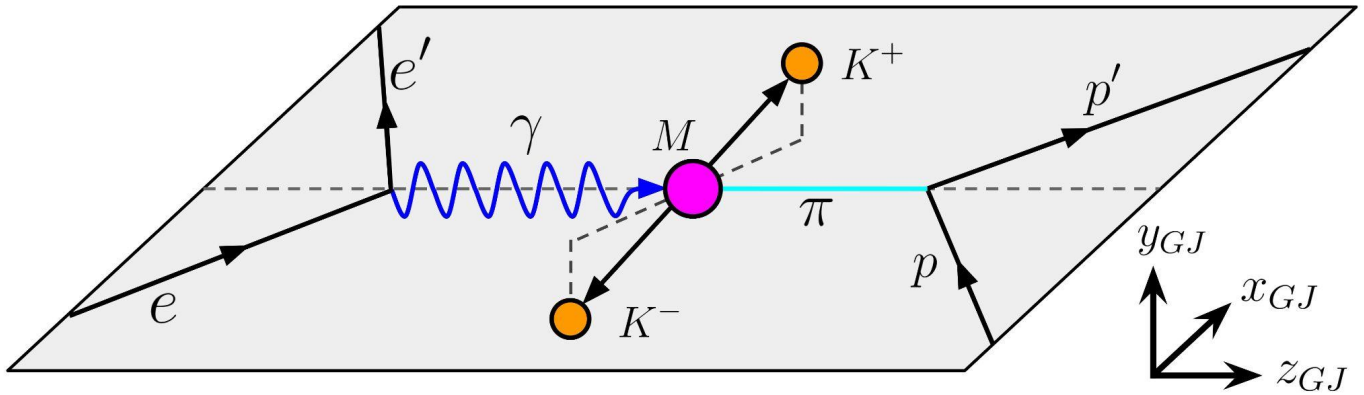
Frames of reference

Centre-of-mass frame:



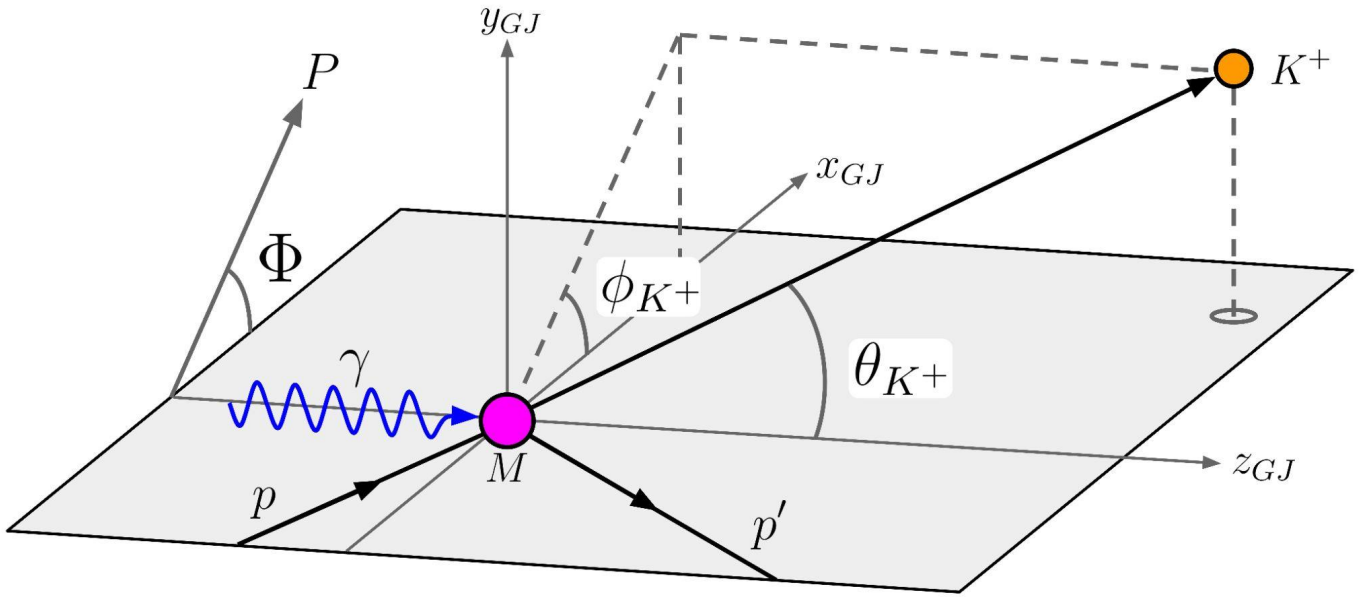
Frames of reference

Gottfried-Jackson (GJ) frame:



Frames of reference

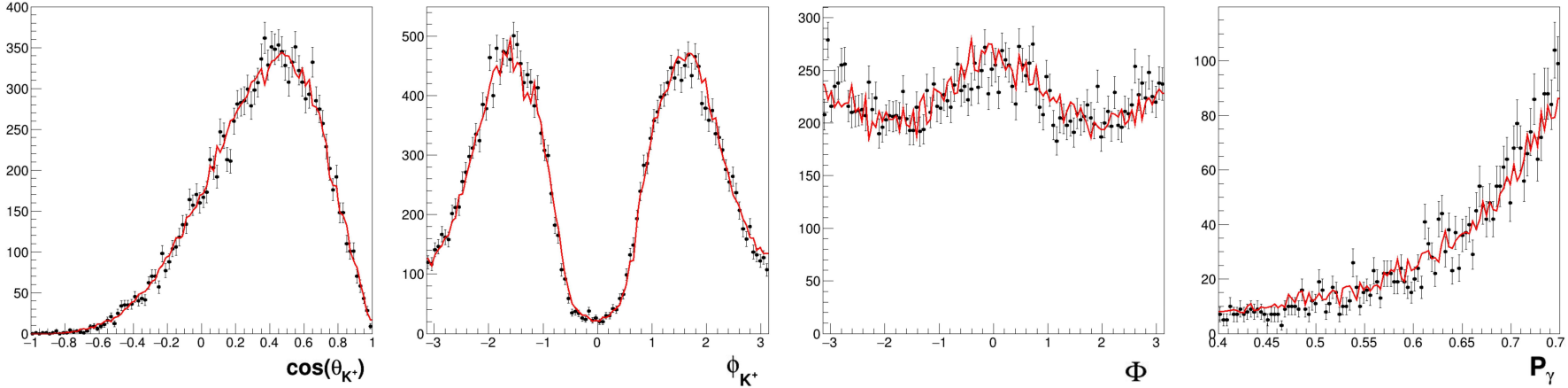
Gottfried-Jackson frame important angles:



Angular distributions

Brufit was used for event-by-event maximum likelihood fitting to the angular distributions.

Fitting simulated (red) to experimental (black) data:



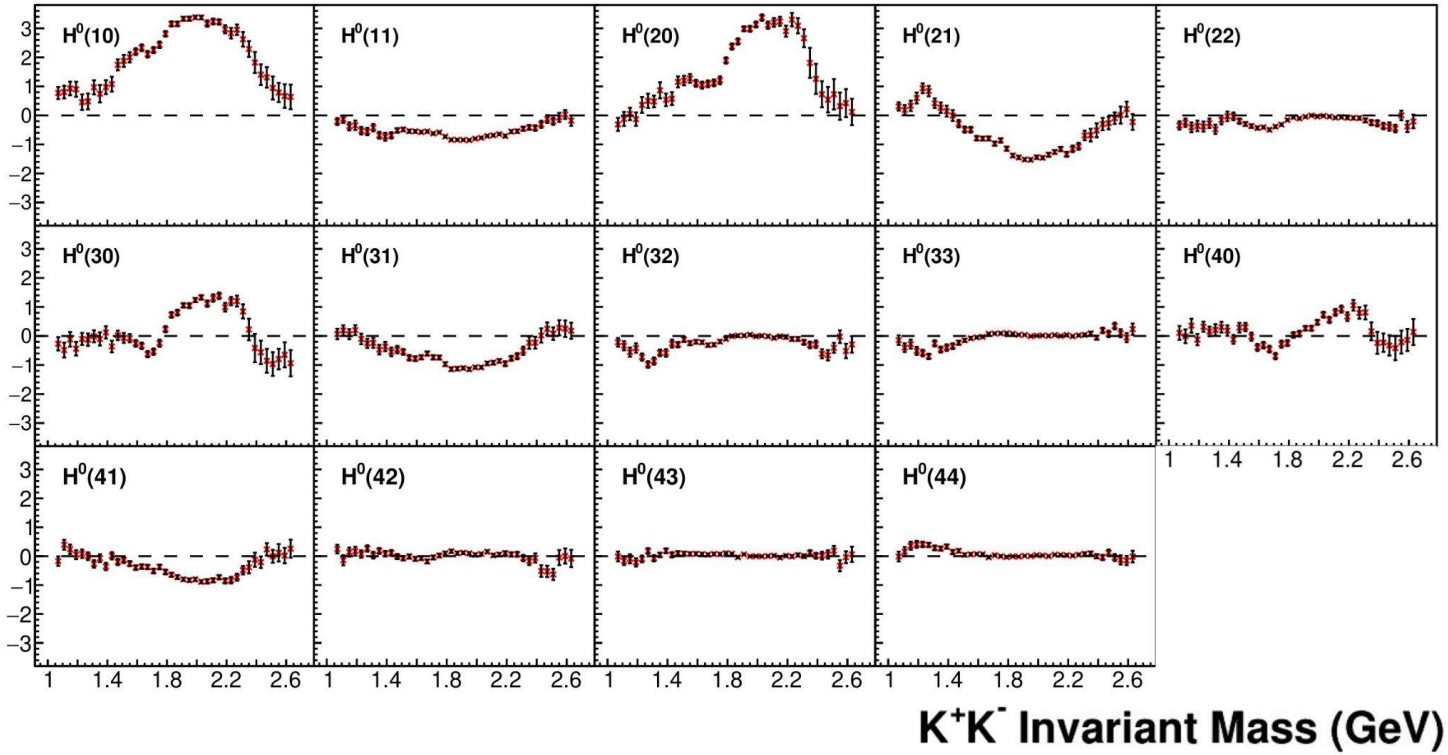
Grouping data

Experimental and simulated data were split into 40 group based on K+K- invariant mass.

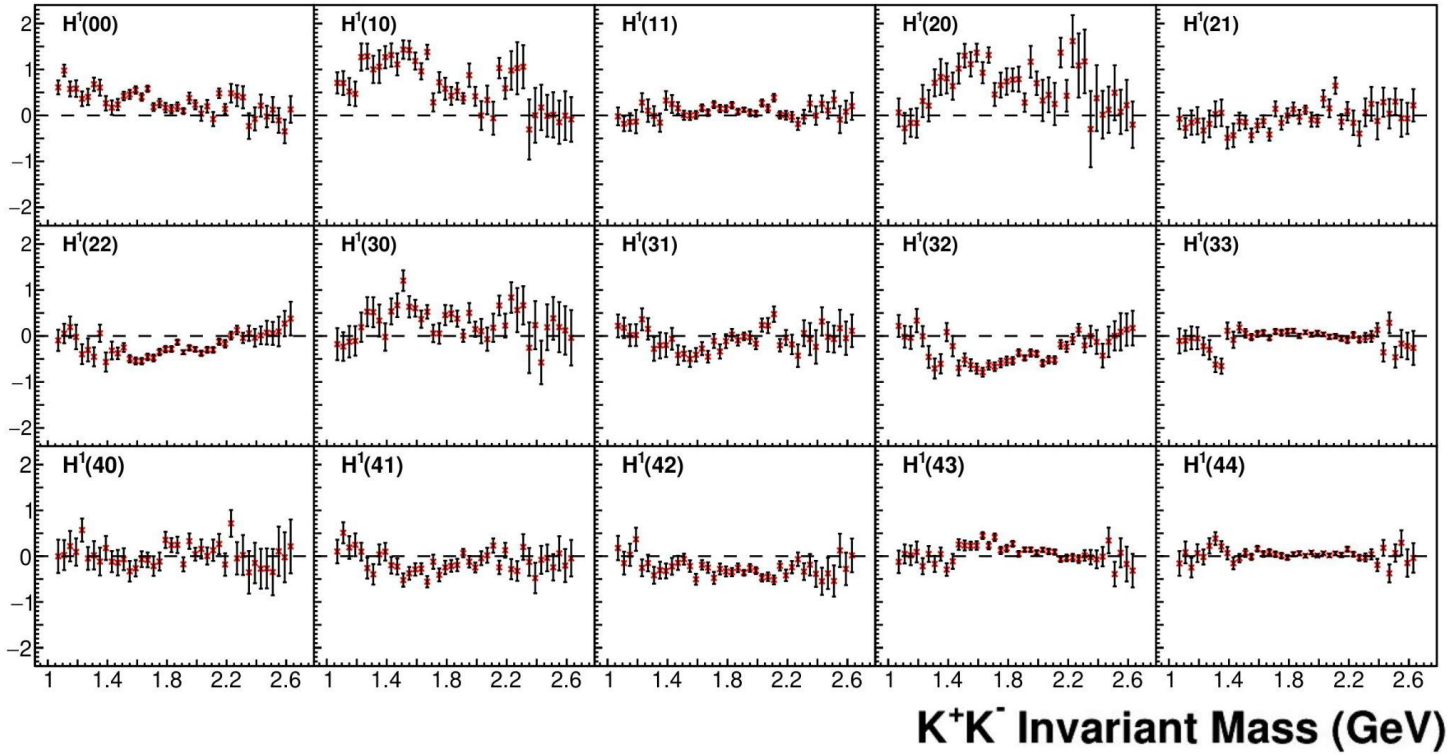
Invariant mass of K^+K^-:

$$IM(K^+K^-) = M_M = |P_{K^+} + P_{K^-}| = \sqrt{(E_{K^+} + E_{K^-})^2 - |\bar{p}_{K^+} + \bar{p}_{K^-}|^2}$$

H^0 moments

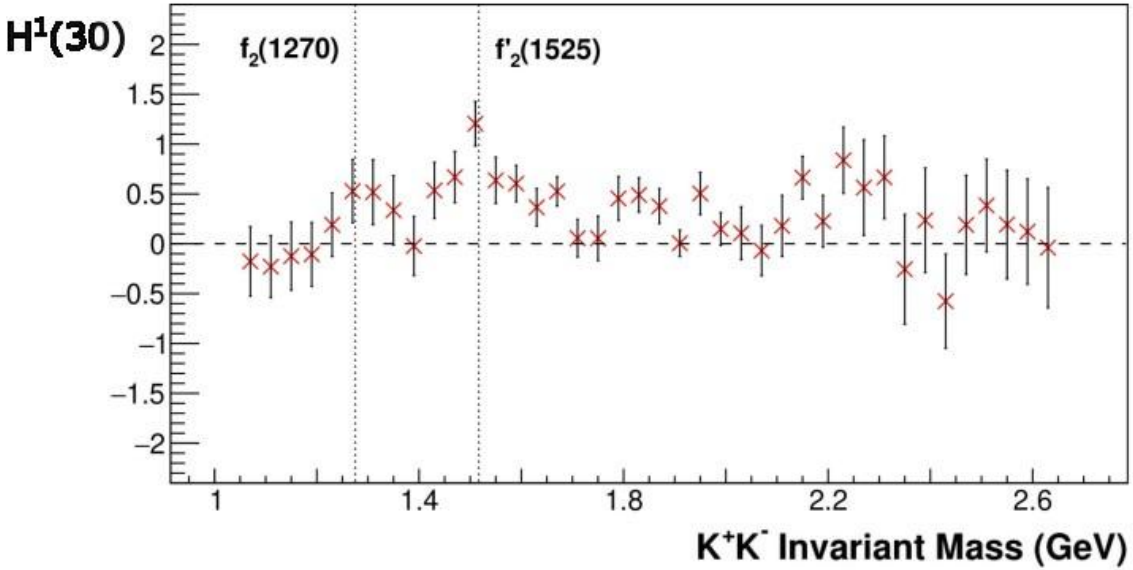

H⁰(10)
H⁰(11)
H⁰(20)
H⁰(21)
H⁰(22)
H⁰(30)
H⁰(31)
H⁰(32)
H⁰(33)
H⁰(40)
H⁰(41)
H⁰(42)
H⁰(43)
H⁰(44)
3
2
1
0
−1
−2
−3
1
1.4
1.8
2.2
2.6
K⁺K⁻ Invariant Mass (GeV)

H^1 moments


H¹(00)
H¹(10)
H¹(11)
H¹(20)
H¹(21)
H¹(22)
H¹(30)
H¹(31)
H¹(32)
H¹(33)
H¹(40)
H¹(41)
H¹(42)
H¹(43)
H¹(44)
2
1
0
−1
−2
1
1.4
1.8
2.2
2.6
K⁺K⁻ Invariant Mass (GeV)

H^1 moments

$$H^1(30) = \frac{12}{7}\sqrt{\frac{3}{5}}\mathrm{Re}(P_0^{(+)}D_0^{(+)*})$$



Outlook

Topics of future research:

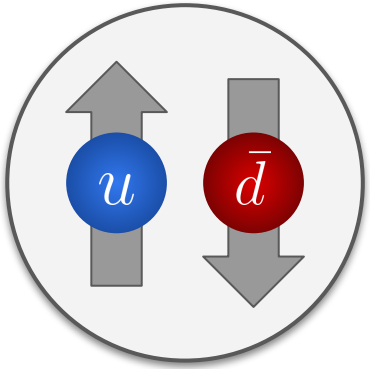
- Statistical studies on all the reaction reconstruction conditions
- Extraction of partial waves from moments
- Study of other reactions such as $ep \rightarrow ep'K^+K^-\pi^0$

Thanks for listening

Charlie Velasquez (charlie.velasquez@york.ac.uk)

Mesons

π^+ in the constituent quark model

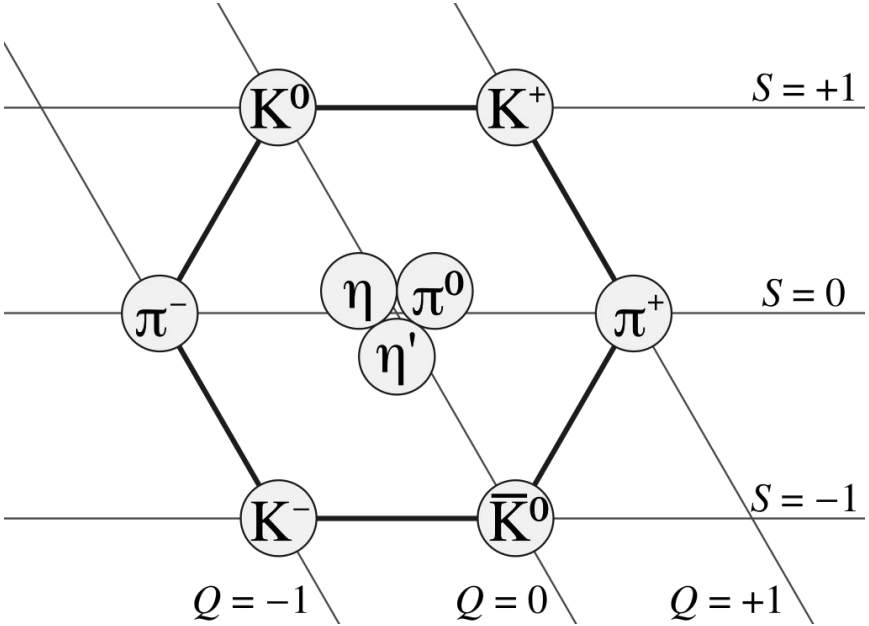


Q = +1 $\quad$ I_z = +1

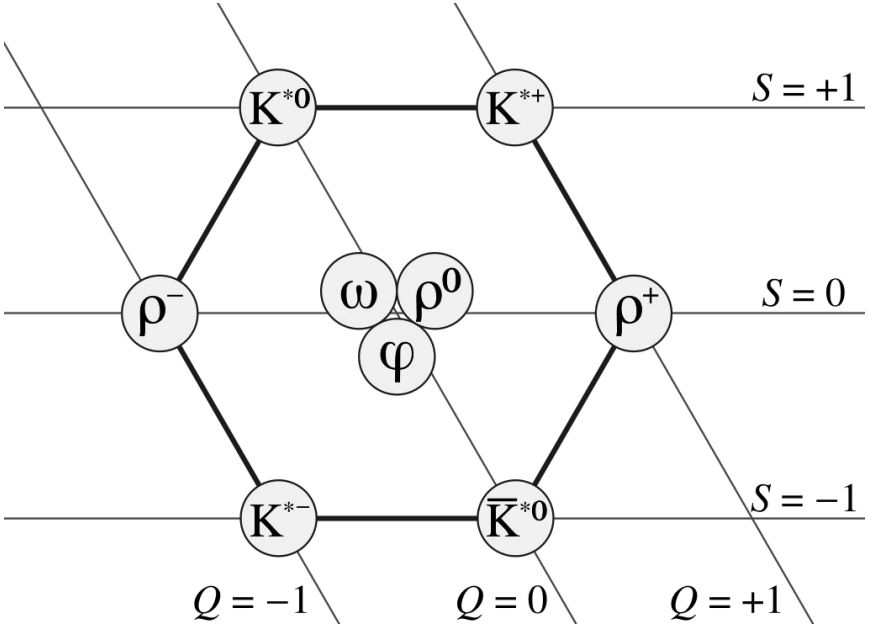
S = +1

	d	u	s
Q – electric charge	$-\frac{1}{3}$	$+\frac{2}{3}$	$-\frac{1}{3}$
I – isospin	$\frac{1}{2}$	$\frac{1}{2}$	0
I_z – isospin z-component	$-\frac{1}{2}$	$+\frac{1}{2}$	0
S – strangeness	0	0	-1

Mesons

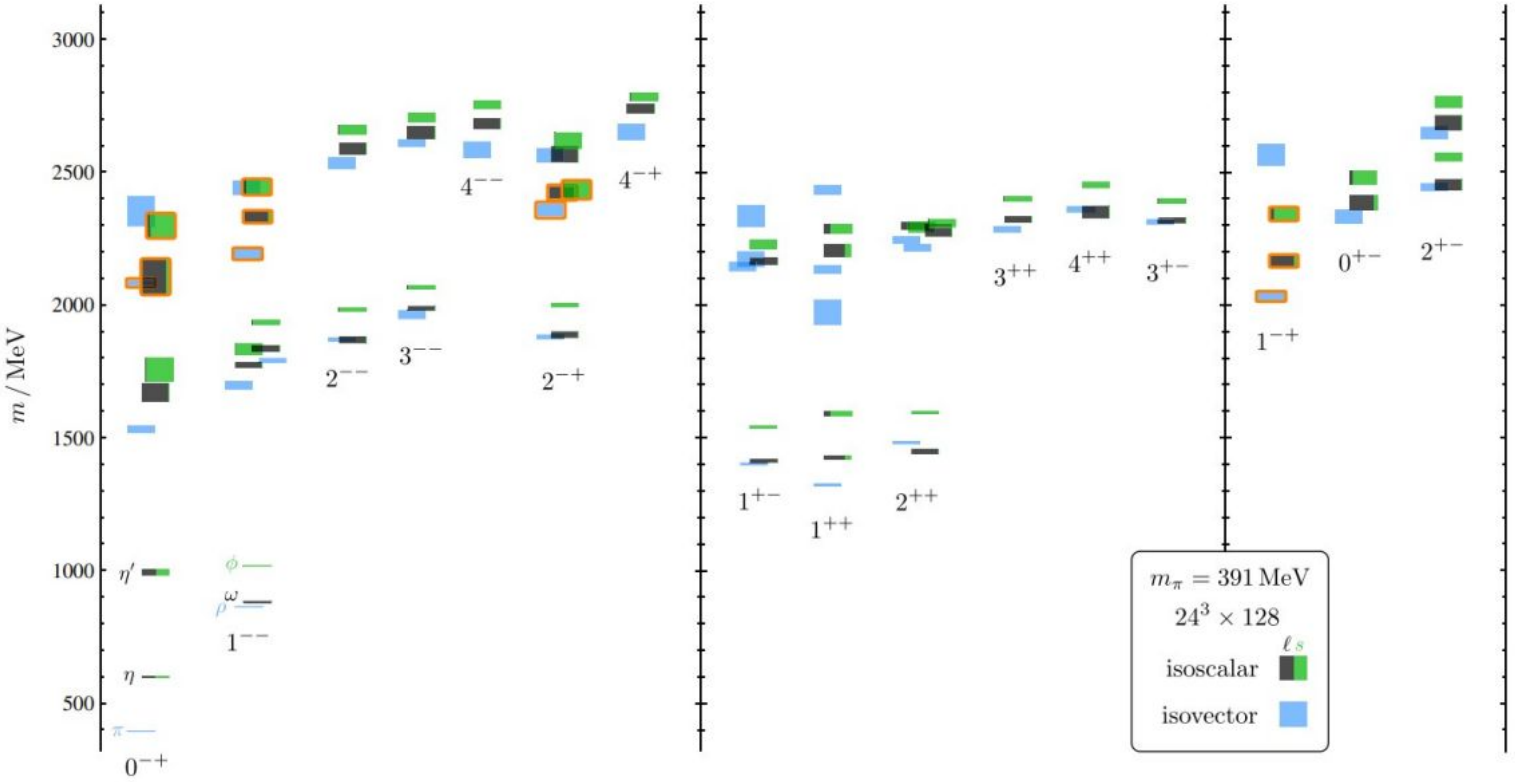


Pseudoscalar, J=0

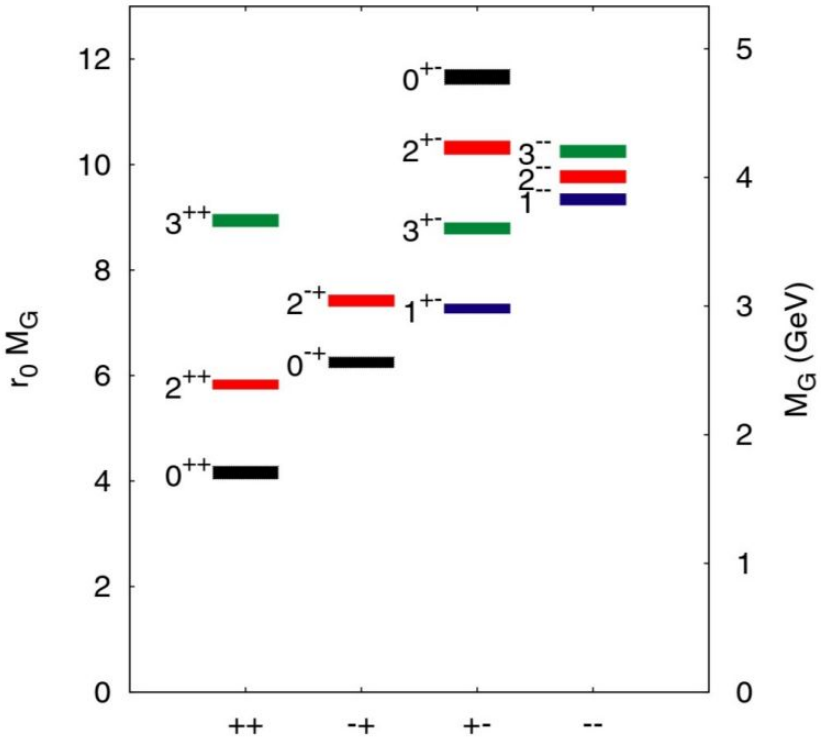


Vector, J=1

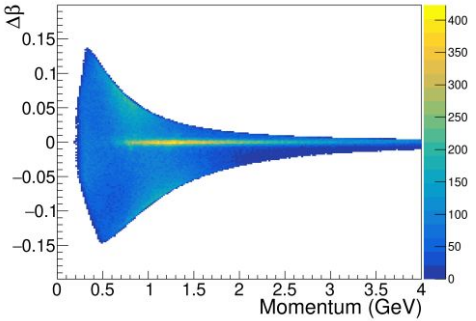
Mesons


3000
2500
2000
1500
1000
500
m / MeV
0^{-+}
1^{--}
2^{--}
3^{--}
4^{--}
2^{-+}
4^{-+}
1^{+-}
1^{++}
2^{++}
3^{++}
4^{++}
3^{+-}
1^{-+}
0^{+-}
2^{+-}
η'
ϕ
ω
ρ
η
π
$m_\pi = 391\,\mathrm{MeV}$
$24^3 \times 128$
ℓs
isoscalar
isovector

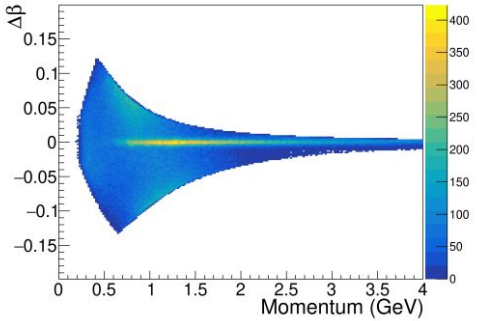
Mesons



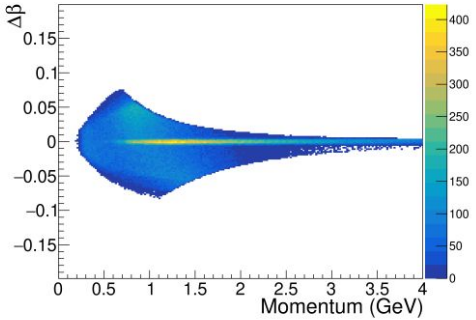
Event selection



(a) $\Delta\beta$ plot when $|\chi^2_{PID}| < 5.5$



(b) $\Delta\beta$ plot when $|\chi^2_{PID}| < 3.5$



(c) $\Delta\beta$ plot when $|\chi^2_{PID}| < 1.5$

Event selection

Before (blue) and after (red) angle and energy selection on scattered electron: