STRONG2020 Hadron Spectroscopy (HaSP) General Workshop

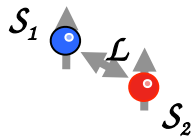
MesonEx : Meson Spectroscopy with CLAS12

Derek Glazier
University of Glasgow

Task 3: Meson Spectroscopy analysis of new and exotic states

- Task 3.1: Search for and study of light exotic mesons, charmonium and strangeonium
  Coordinator: Vincent Mathieu

Light Quark Meson Spectroscopy



$S = S_1 + S_2 \qquad J = L + S$

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

Not all the J^{PC} combinations are allowed:

0^{++} 0^{+-} 0^{-+} 0^{--} 1^{++} 1^{+-} 1^{-+} 1^{--} 2^{++} 2^{+-} 2^{-+} 2^{--} 3^{++} ...

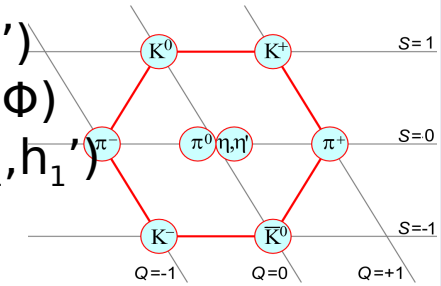
Each J^{PC} decomposed into nonet of degenerate states

$J^{PC} = 0^{-+} \Rightarrow (\pi, K, \eta, \eta')$

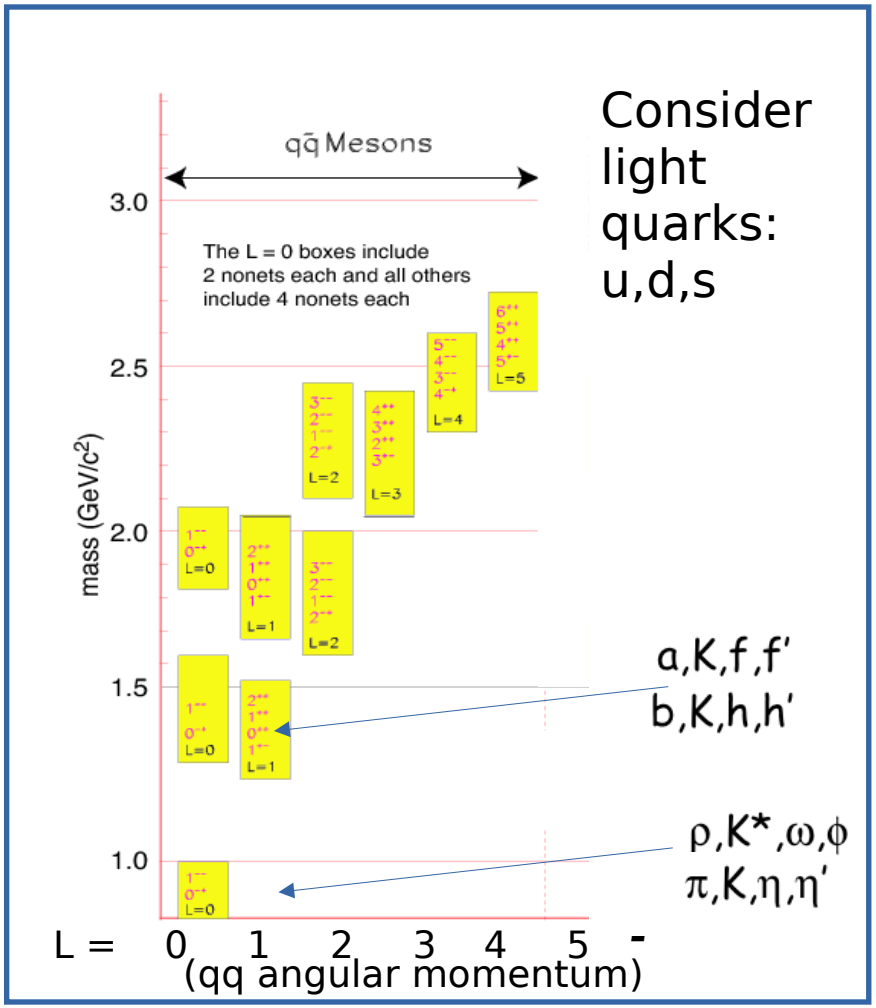
$1^{--} \Rightarrow (\rho, K^*, \omega, \Phi)$

$1^{+-} \Rightarrow (b_1, K_1, h_1, h_1')$

...



- Quark model explains much of the observed states
- Some states not well established or not definitively assigned
- Some additional unassigned states
- Particular ?? with 0++ scalars



Consider light quarks: u,d,s

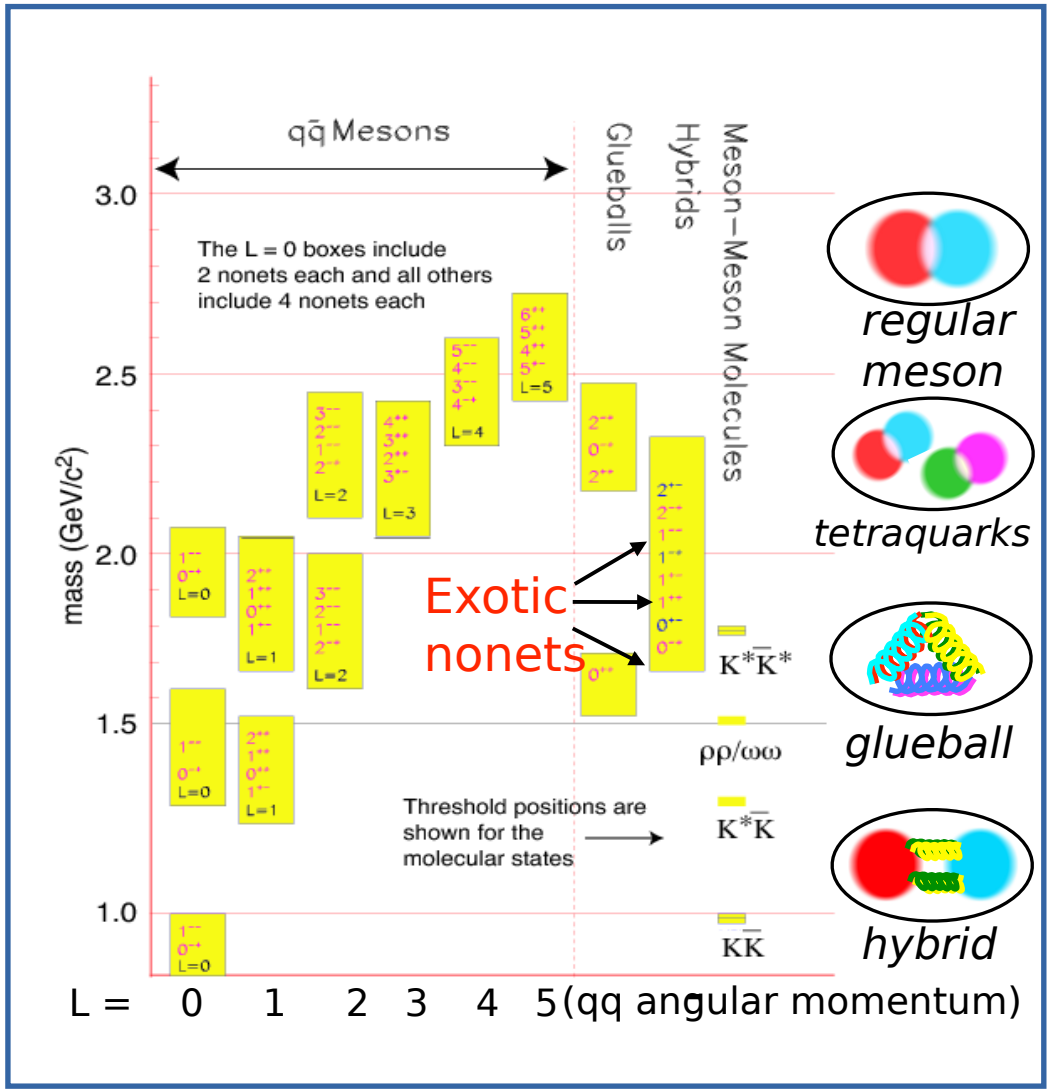
What else might exist

QCD does not forbid other compositions

Some states predicted by theory

Evidence for some states found experimentally

Hybrids include states of exotic quantum numbers



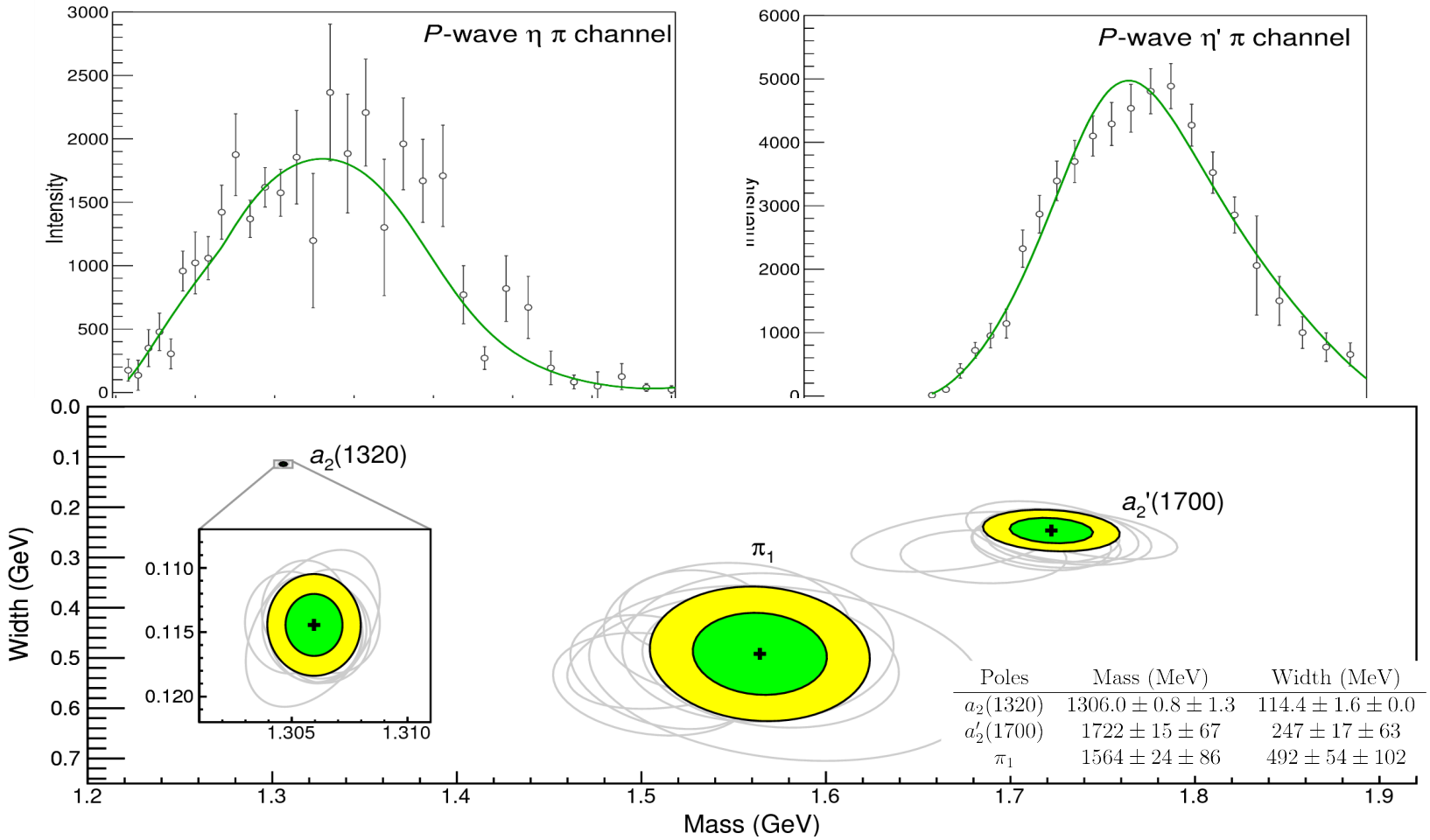
$\pi_1(1600)$ from COMPASS η(‘)π

Determination of the Pole Position of the Lightest Hybrid Meson Candidate

A. Rodas, A. Pilloni, M. Albaladejo, C. Fernández-Ramírez, A. Jackura, V. Mathieu, M. Mikhasenko, J. Nys, V. Pauk, B. Ketzer, and A. P. Szczepaniak (Joint Physics Analysis Center)

Phys. Rev. Lett. **122**, 042002 – Published 29 January 2019

Coubled analysis of ηπ and η’π

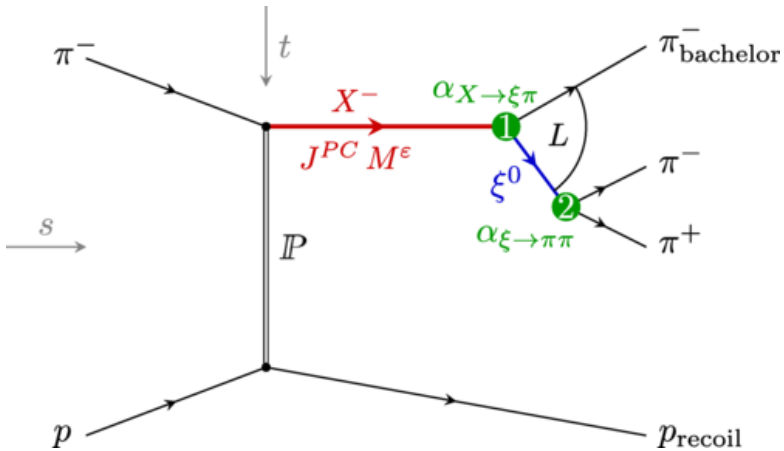


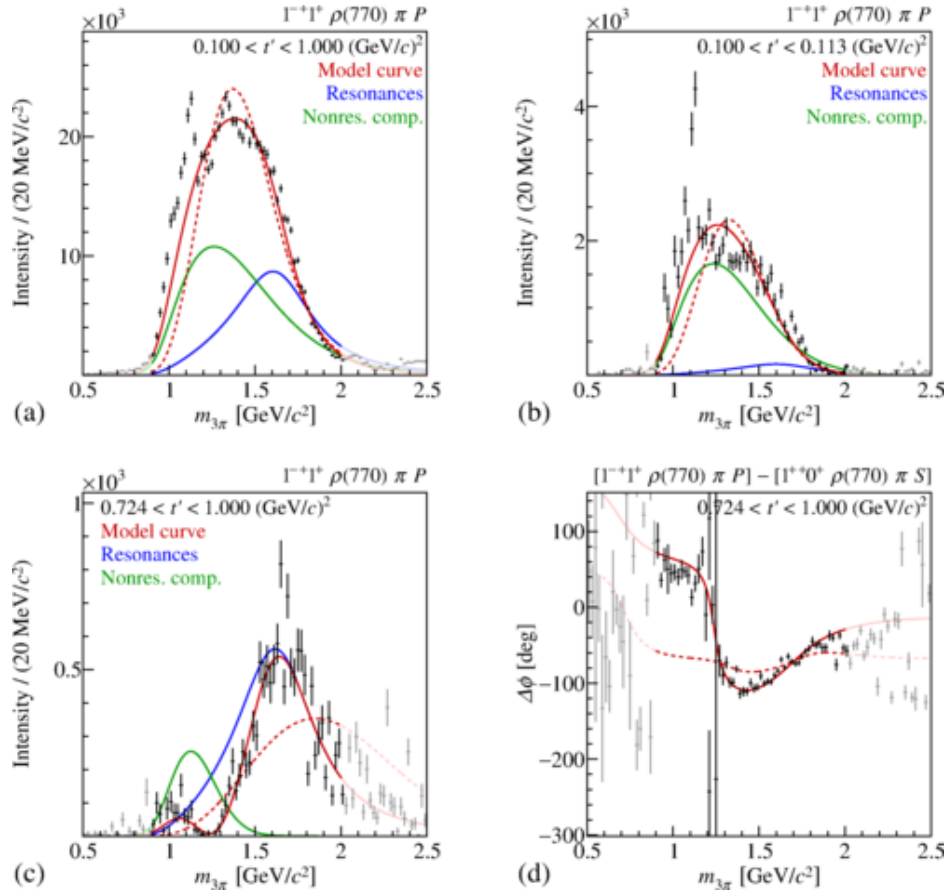
Poles	Mass (MeV)	Width (MeV)
$a_2(1320)$	$1306.0 \pm 0.8 \pm 1.3$	$114.4 \pm 1.6 \pm 0.0$
$a_2'(1700)$	$1722 \pm 15 \pm 67$	$247 \pm 17 \pm 63$
π_1	$1564 \pm 24 \pm 86$	$492 \pm 54 \pm 102$

$\pi_1(1600)$ from COMPASS 3π

Light isovector resonances in $\pi^- p \to \pi^- \pi^- \pi^+ p$ at $190\ \mathrm{GeV}/c$

M. Aghasyan *et al.*
Phys. Rev. D **98**, 092003 – Published 2 November 2018



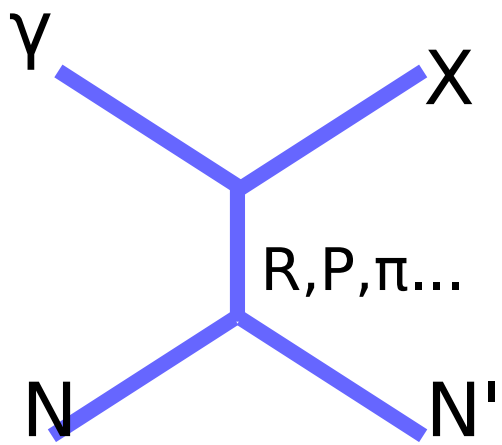


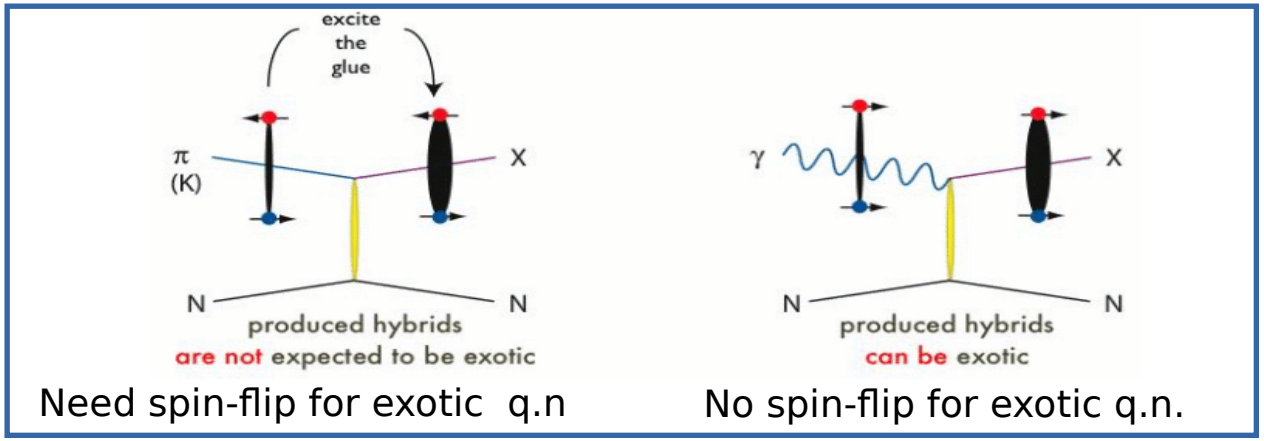
Clear signal for $\pi_1(1600)$

Large background contribution

Why photoproduction ?

Exotic J^{PC} are more likely produced by S=1 probe

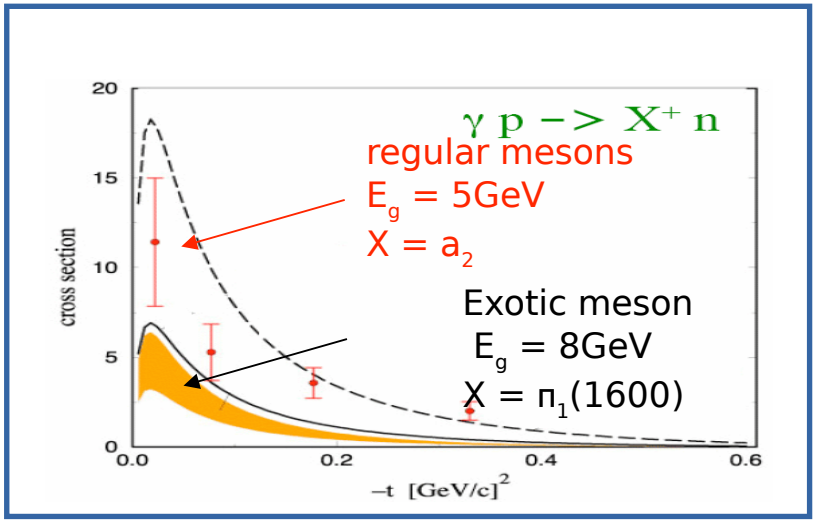




A. Afanasev and P. Page et al. PR A57 1998 6771

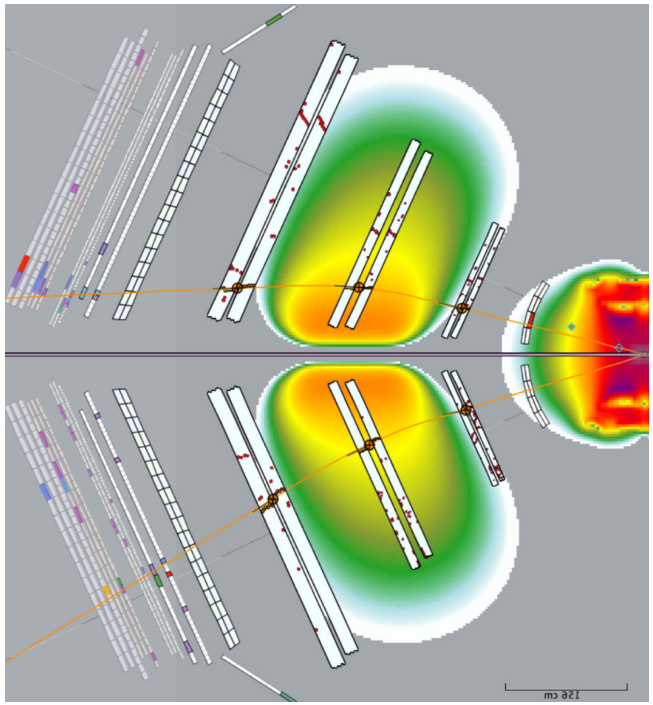
Linear polarization acts like a filter to disentangle the production mechanisms

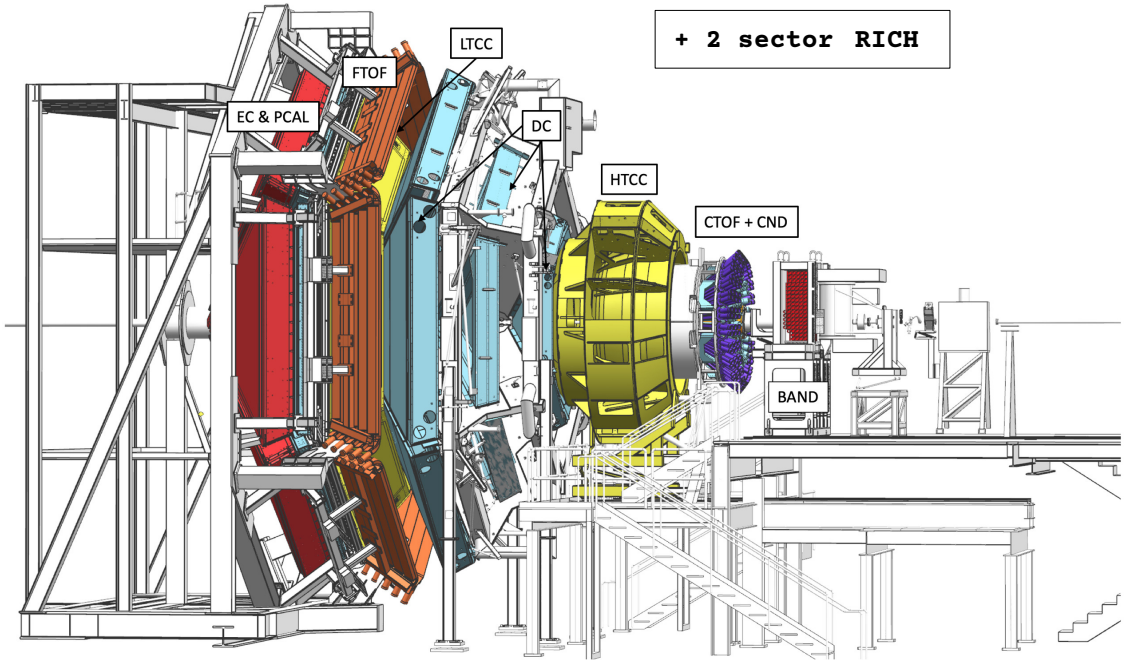
Production rate for exotics is expected comparable as for regular mesons



A. Szczepaniak and M. Swat PLB 516 2001 72

CLAS12 at Jefferson Lab





High luminosity electron scattering (10^{35} $cm^{-2}s^{-1}$) produces high flux of nearly real photons.

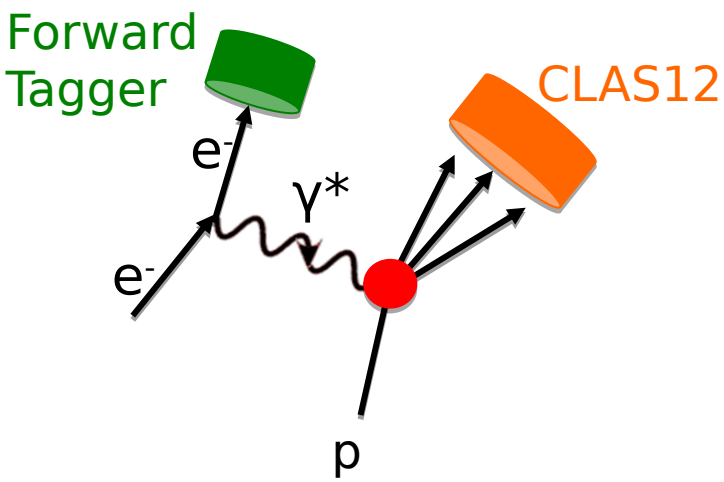
High resolution tracking spectrometer, (1% momentum, 1 mrad angle)

Excellent PID e-, K, p, π, n,γ

Can make measurements with missing particles

Can run MesonEx simultaneously with other experiments

Quasi-real photoproduction with CLAS12

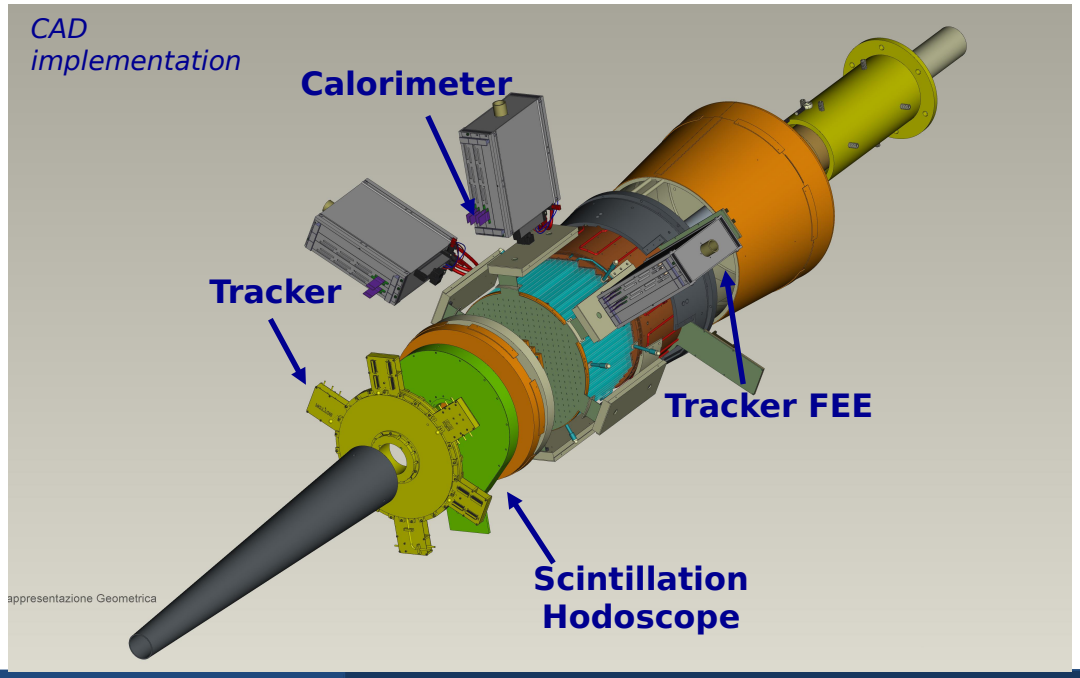


Trigger → FT e- + 2 charged CLAS12

Forward Tagger	
E’	0.5-4.5 GeV
ν	6-10 GeV
θ	2.5-4.5 deg
Q^2	0.007 – 0.3 GeV^2
W	3.6-4.5 GeV
Photon Flux	5×10^7 γ/s @ $L_e=10^{35}$

Quasi-real photoproduction:

- Detection of multiparticle final state from meson decay in the large acceptance spectrometer CLAS
- Detection of the scattered electron for the tagging of the quasi-real photon in the CLAS12 FT
- High-intensity and high-polarization tagged “photon” beam; degree of polarization determined event-by-event from the electron kinematics

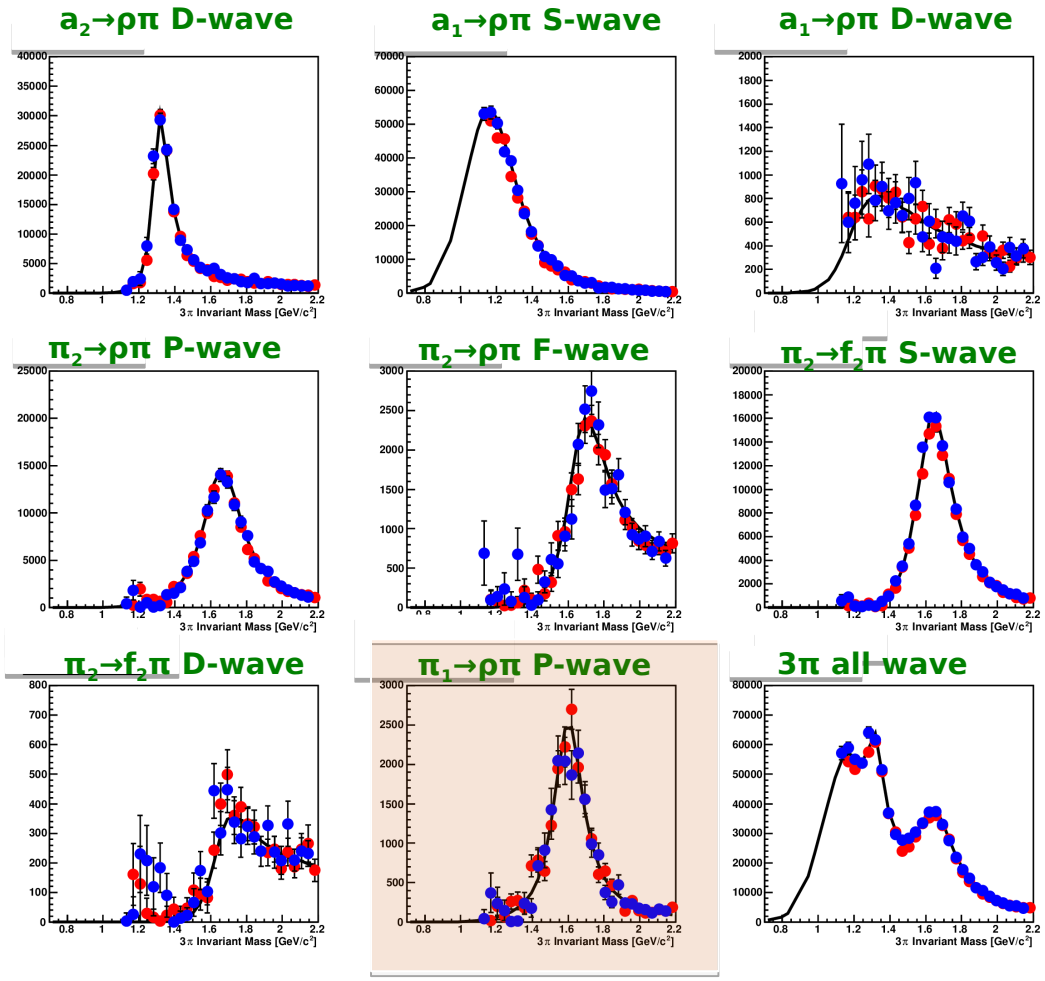


MesonEx program

Meson spectroscopy in the light-quark sector:

- Detailed mapping of the meson spectrum up to masses of 2.5 GeV
- Search for rare or poorly known states (strangeness-rich, scalars, ...)
- Search states with unconventional quark-gluon configurations

Benchmark 3π Simulations



Note poor acceptance below 1.3GeV (half field)

MesonEx : Status

Approximately 20% of expected data ready for analysis

Focus on charged decay products (better resolution)

First extract two pseudoscalar ($\pi^+\pi^-$, K^+K^-)

Fourier Analyse angular distributions == extract moments

- more general expansion than just partial waves
- check acceptance corrections
- check distortions from backgrounds
- model independent formalism

Extract partial waves from moments or directly fit partial waves

Expand to vector-pseudoscalar final states

MesonEx : Polarised 2 meson production

arXiv.org > hep-ph > arXiv:1906.04841

Search...

Help | Advanc

High Energy Physics - Phenomenology

Moments of angular distribution and beam asymmetries in $\eta\pi^0$ photoproduction at GlueX

V. Mathieu, M. Albaladejo, C. Fernández-Ramírez, A. W. Jackura, M. Mikhasenko, A. Pilloni, A. P. Szczepaniak (JPAC collaboration)

(Submitted on 11 Jun 2019)

Linear polarisation

$$I(\Omega,\Phi)=I^0(\Omega)-P_\gamma I^1(\Omega)\cos(2\Phi)-P_\gamma I^2(\Omega)\sin(2\Phi)$$

$$I^0(\Omega)=\sum_L\sum_{M=0}^{M\le L}\sqrt{\left(\frac{2L+1}{4\pi}\right)}(2-\delta_{M,0})H^0(L,M)\Re\left[Y_L^M(\Omega)\right]$$

$$I^1(\Omega)=-\sum_L\sum_{M=0}^{M\le L}\sqrt{\left(\frac{2L+1}{4\pi}\right)}(2-\delta_{M,0})H^1(L,M)\Re\left[Y_L^M(\Omega)\right]$$

$$I^2(\Omega)=2\sum_L\sum_{M=0}^{M\le L}\sqrt{\left(\frac{2L+1}{4\pi}\right)}\Im\left[H^2(L,M)\right]\Im\left[Y_L^M(\Omega)\right]$$

Moments relate directly to partial wave amplitues

$$H^0(11)=H^1(11)+2\sqrt{\frac{2}{5}}\,\mathrm{Re}(P_1^{(+)}D_2^{(+)*})\ ,$$

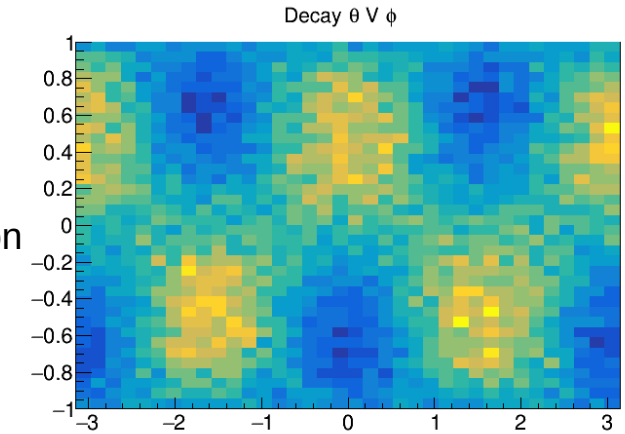
$$H^1(11)=\frac{2}{15}\left[3\sqrt{5}\,\mathrm{Re}(P_0^{(+)}D_1^{(+)*})-\sqrt{15}\,\mathrm{Re}(P_1^{(+)}D_0^{(+)*})+5\sqrt{3}\,\mathrm{Re}(S_0^{(+)}P_1^{(+)*})\right]\ ,$$

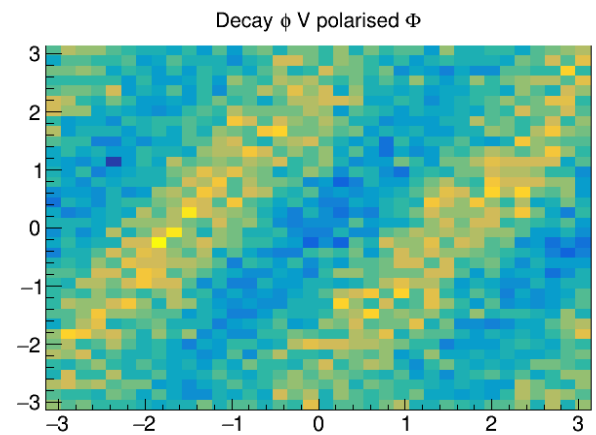
$$H^0(20)=H^1(20)-\frac{2}{35}\left[7|P_1^{(+)}|^2-5|D_1^{(+)}|^2+10|D_2^{(+)}|^2\right]\ ,$$

$$H^1(20)=\frac{4}{35}\left[7|P_0^{(+)}|^2+5|D_0^{(+)}|^2+7\sqrt{5}\,\mathrm{Re}(S_0^{(+)}D_0^{(+)*})\right]\ ,$$

$$H^0(21)=H^1(21)+\frac{2}{7}\sqrt{6}\,\mathrm{Re}(D_1^{(+)}D_2^{(+)*})\ ,$$

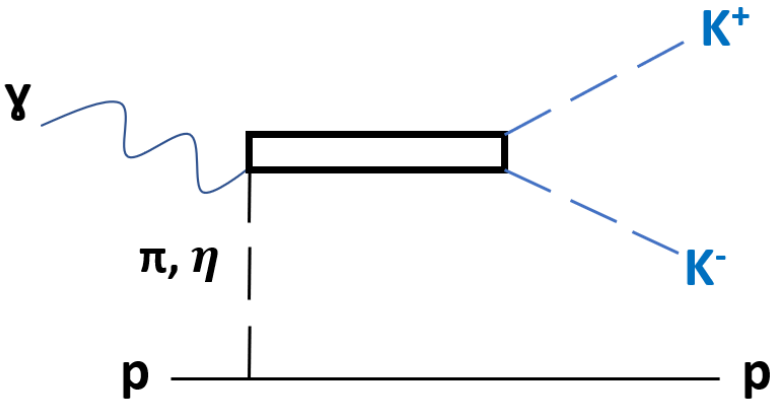
$$H^1(21)=\frac{2}{35}\left[7\sqrt{5}\,\mathrm{Re}(S_0^{(+)}D_1^{(+)*})+7\sqrt{3}\,\mathrm{Re}(P_0^{(+)}P_1^{(+)*})+5\,\mathrm{Re}(D_0^{(+)}D_1^{(+)*})\right]\ ,$$

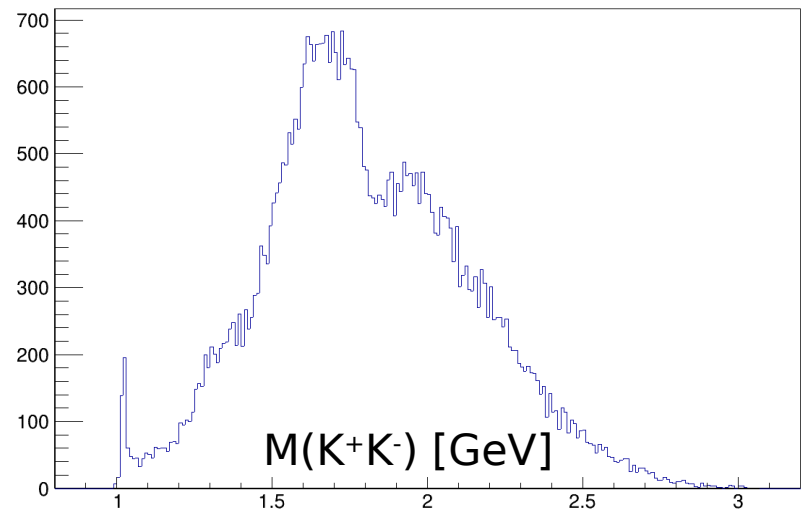




Moments can be determined from Fourier analysis of decay angles

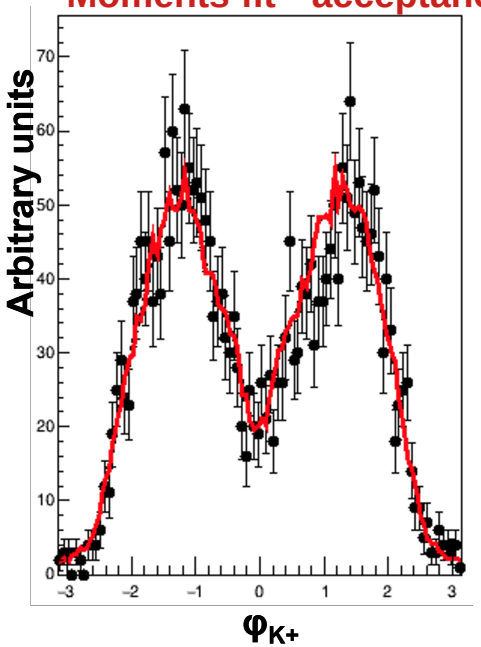
MesonEx : K^+K^- p Preliminary Data

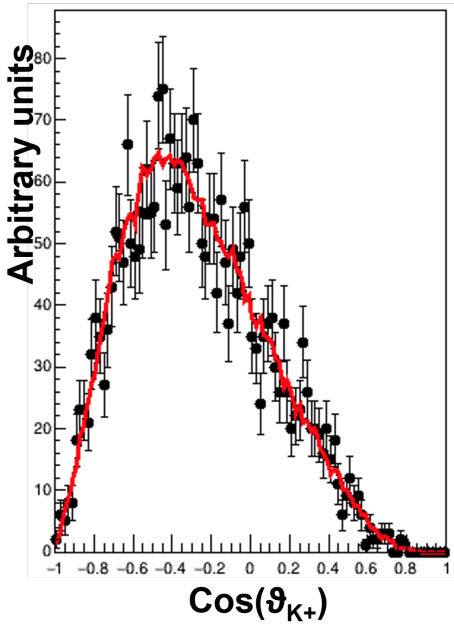


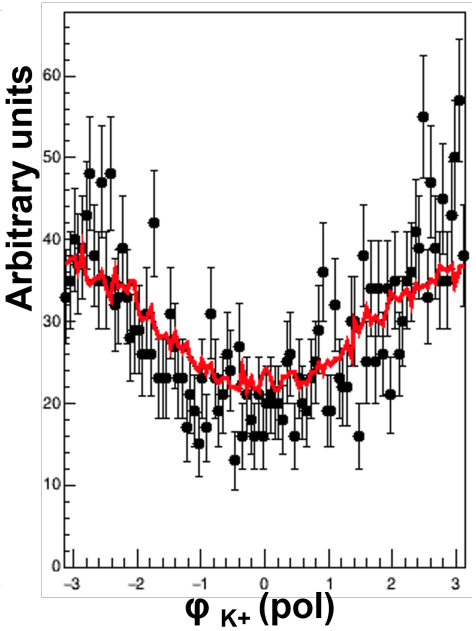


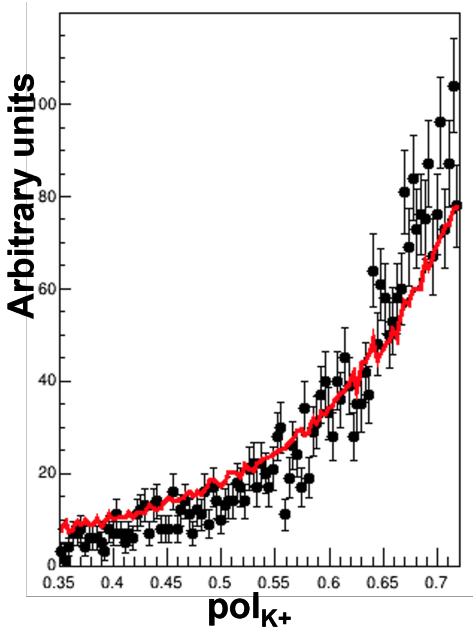
Experiment

Moments fit * acceptance







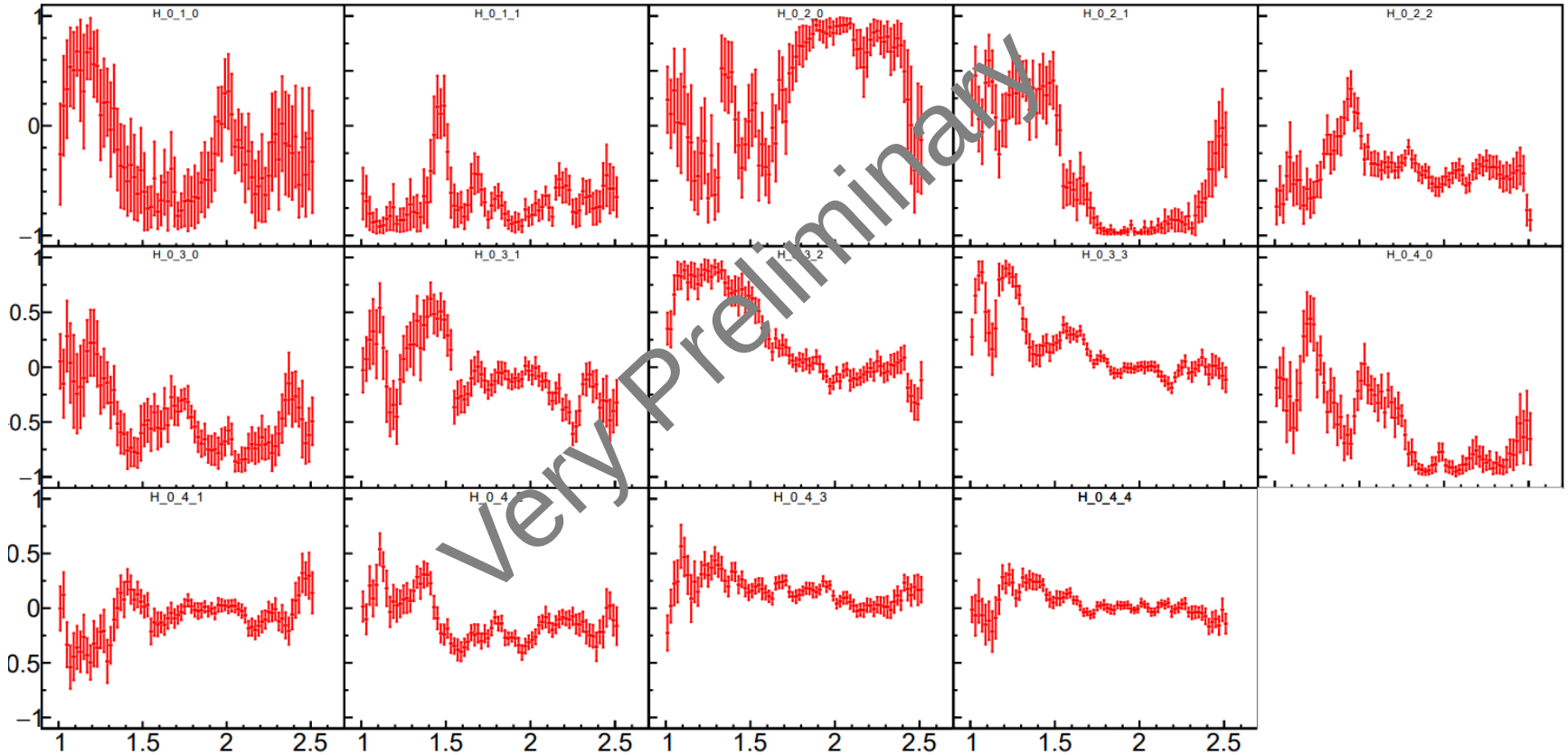


From Matthew Nicol, University of York

MesonEx : K^+K^- p Preliminary Data

Allowed partial waves J^{PC} (I^G) : $0^{++}(0^+,1^-)$, $1^{--}(0^+,1^-)$, $2^{++}(0^+,1^-)$, $3^{--}(0^+,1^-)$, ...

Unpolarised Moments

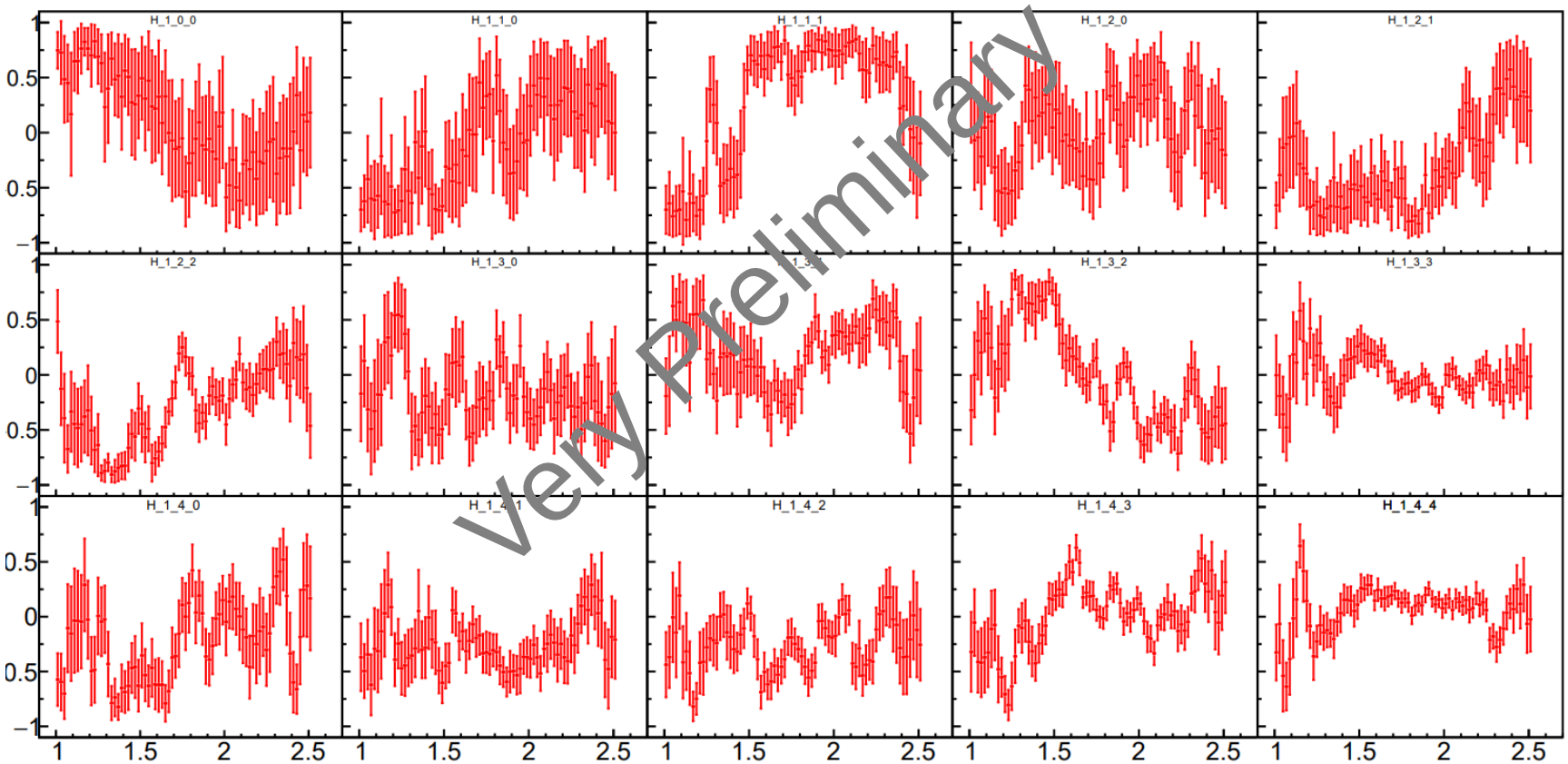


From Matthew Nicol, University of York

MesonEx : K^+K^- p Preliminary Data

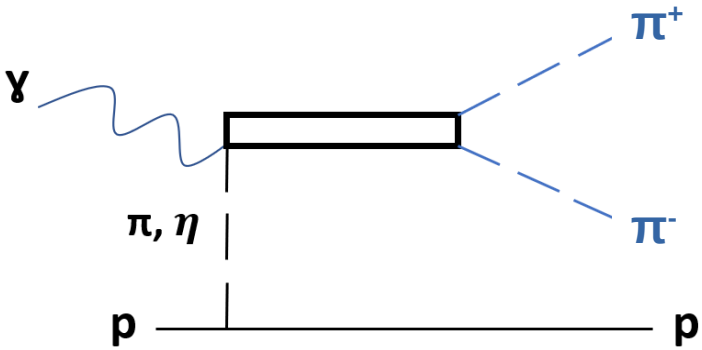
Allowed partial waves J^{PC} (I^G) : $0^{++}(0^+,1^-)$, $1^{--}(0^+,1^-)$, $2^{++}(0^+,1^-)$, $3^{--}(0^+,1^-)$, ...

Polarised Moments

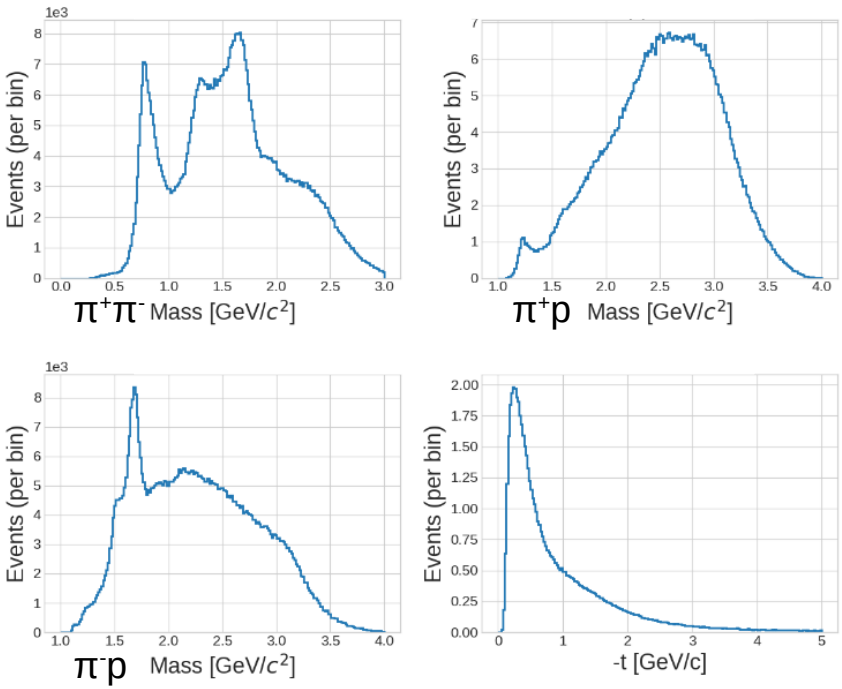


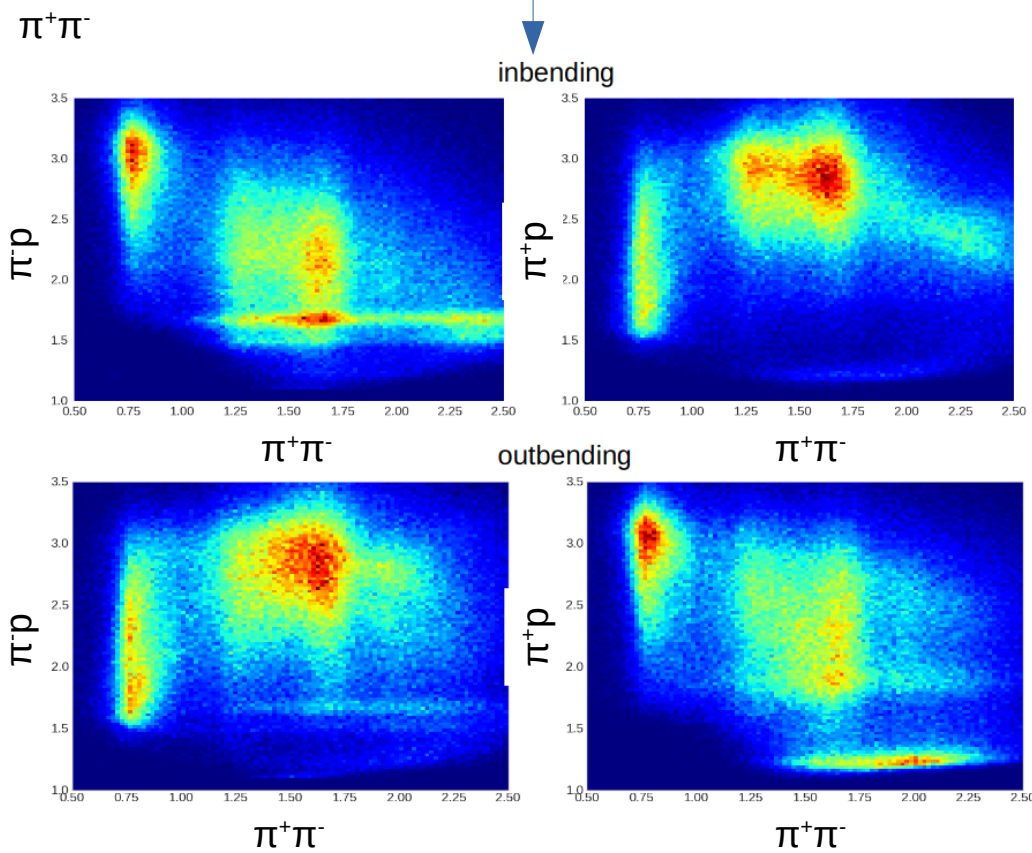
From Matthew Nicol, University of York

MesonEx Trigger : $\pi^+\pi^-p$ Final State



Data taking with toroidal field bending negative particles inward or outward

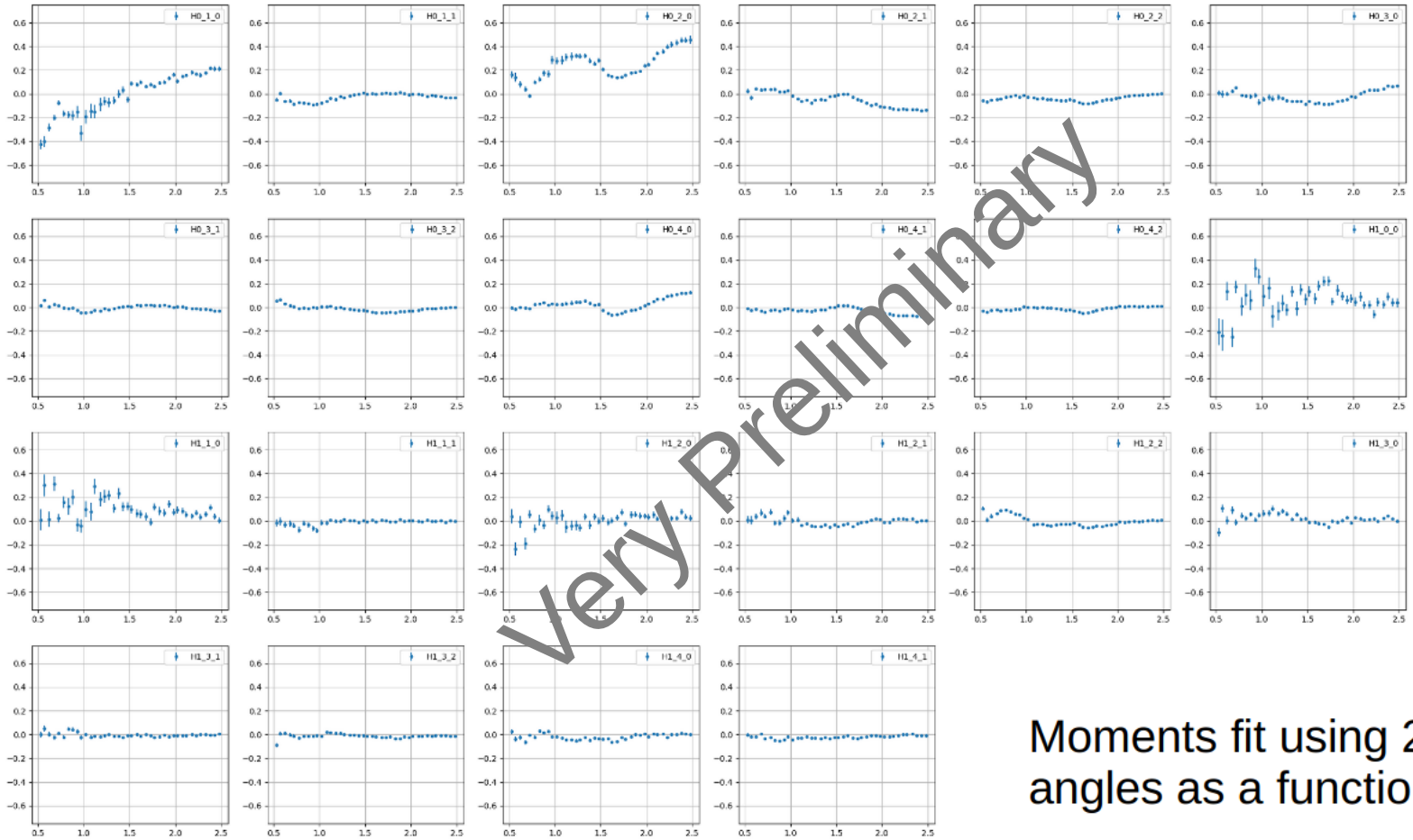




Data with both fields gives improved acceptance

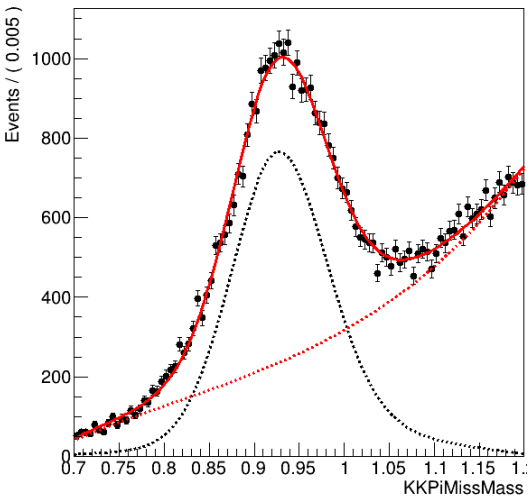
MesonEx : $\pi^+\pi^-$ p Preliminary Moments

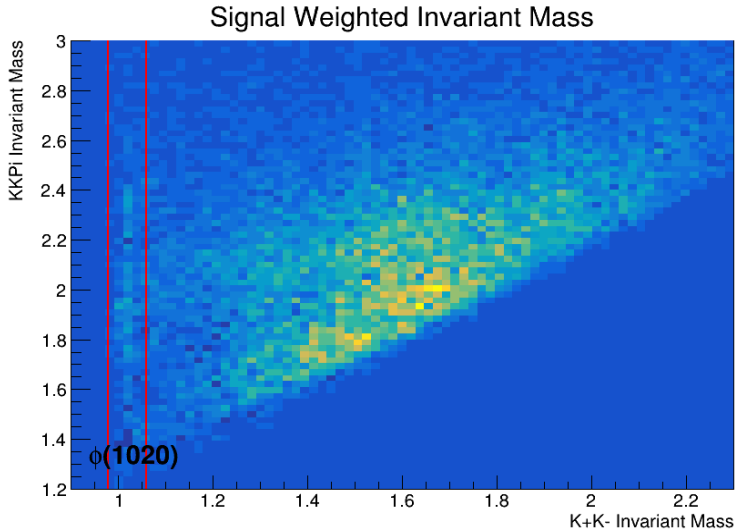
Allowed partial waves J^{PC} (I^G) : : $0^{++}(0^+)$, $1^{--}(1^+)$, $2^{++}(0^+)$, $3^{--}(1^+)$, ...



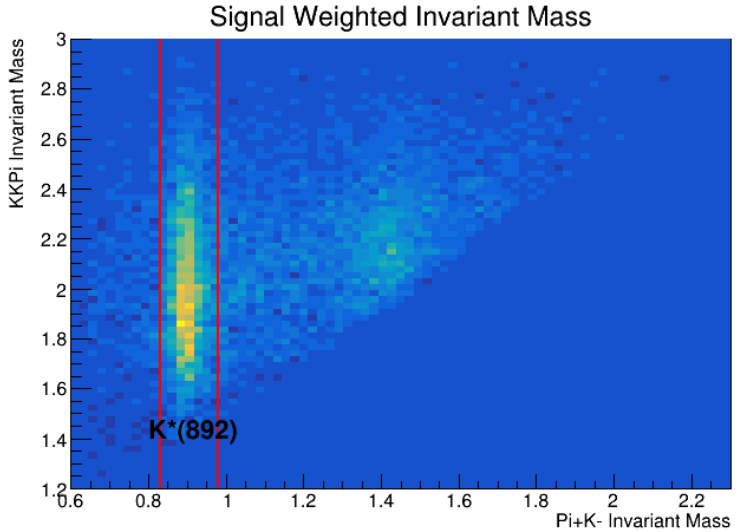
Moments fit using 2pi decay angles as a function of 2pi mass

MesonEx : $\pi^+K^+K^-$ n Preliminary Data

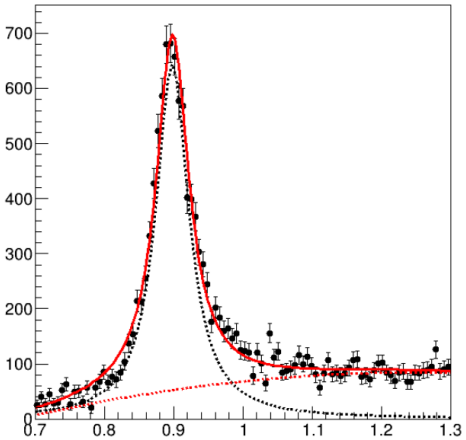




Reconstruct neutron mass to subtract backgrounds via sPlot technique

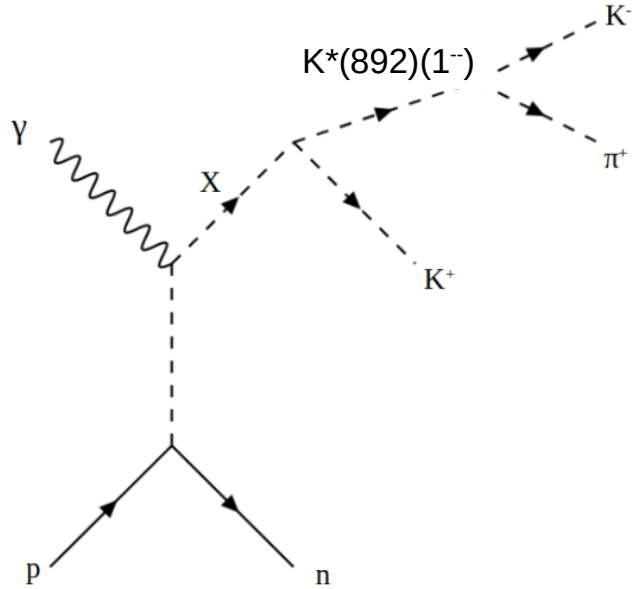


Use sPlot to isolate K*(892)



From Robert Wishart, University of Glasgow

Vector-Scalar Formalism



Write intensity in terms of decay angles and linear polarisation

$$\mathcal{I}(\Omega,\Phi) = \mathcal{I}_0(\Omega) - \mathcal{P}_\gamma.\mathcal{I}_1(\Omega)\cos 2\Phi - \mathcal{P}_\gamma.\mathcal{I}_2(\Omega)\sin 2\Phi.$$

Expand polarised intensity components in moments of D-Wigner function products (depend on 4 decay angles)

$$\mathcal{I}^\alpha(\Omega) = \sum_{JMS\Lambda}\left(\frac{2J+1}{4\pi}\right)\left(\frac{2S+1}{4\pi}\right)H^\alpha(JMS\Lambda) \times D^{J*}_{M,\Lambda}(\phi_{GJ},\theta_{GJ},0)D^{S*}_{\Lambda,0}(\phi_{HF},\theta_{HF},0).$$

Relate moments to production Spin Density Matrix Elements

$$b = \{j = J_X, l = L_X, m = M_X, s = S_X\}$$

$$H^\alpha(JMS\Lambda) = \sum_{b,b'}\sum_{\lambda,\lambda'}\left(\frac{\sqrt{(2l'+1)(2l+1)}}{2j'+1}\right)\left(\sqrt{\frac{2s+1}{2s'+1}}\right)(l,0;s,\lambda|j,\lambda)(l',0;s',\lambda'|j',\lambda') \times (s,\lambda;S,\Lambda|s',\lambda')(s,0;S,0|s',0)(j,m;J,M|j',m')(j,\lambda;J,\Lambda|j',\lambda') \times \rho^\alpha_{bb'} \times R_{Yi}(m_Y)R^*_{Yi'}(m_Y),$$

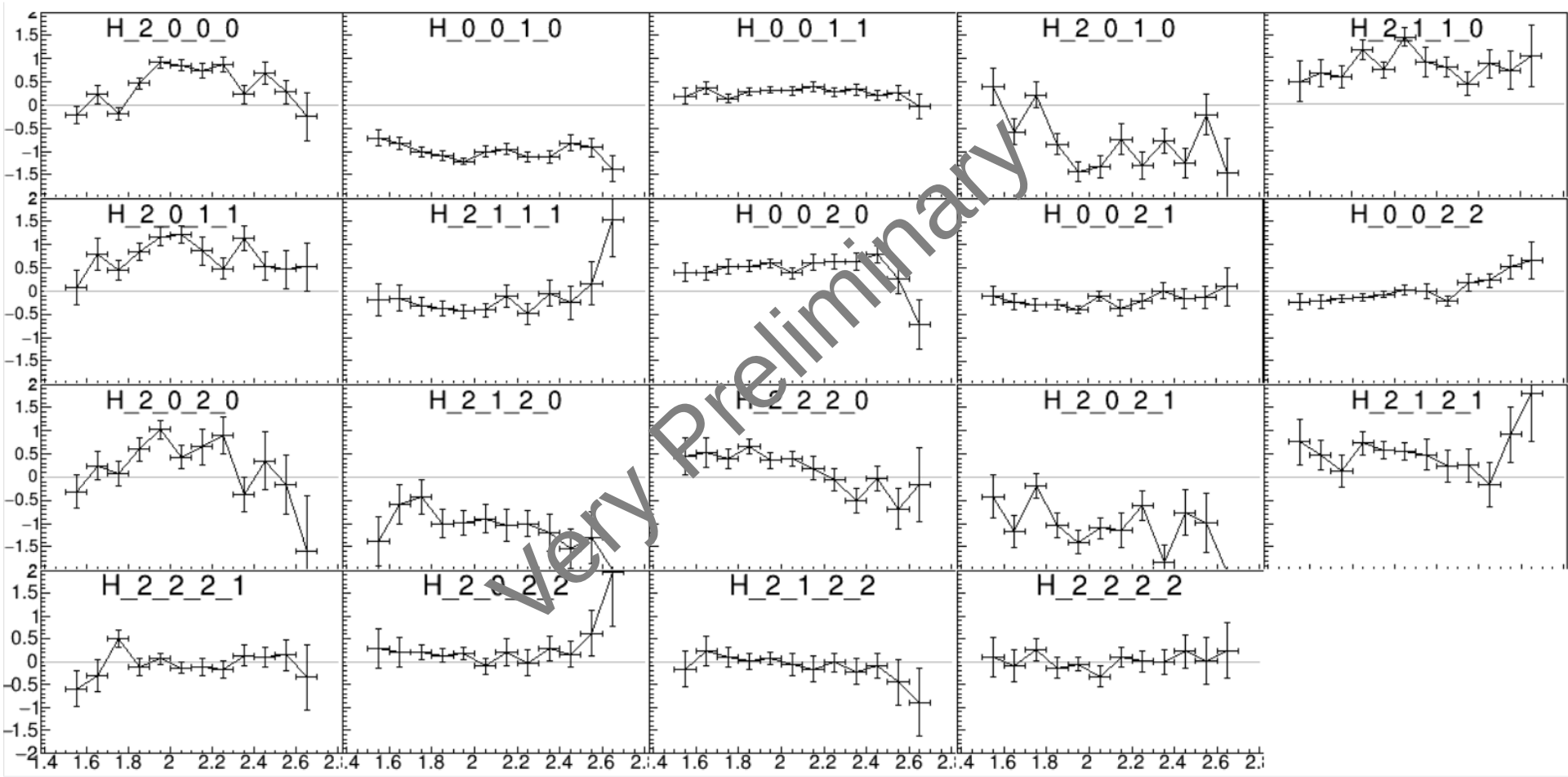
=1

Relate Spin Density Matrix Elements to Partial Waves dependent On meson X spin and parity

$${}^{(\varepsilon)}\rho^0_{ii',mm'} = \sum_k [J_X^{P_X}]^{(\varepsilon)}_{m,k}[J_X'^{P_X'}]^{(\varepsilon')*}_{m',k} + \eta_X\eta_X'(-1)^{m+m'}[J_X^{P_X}]^{(\varepsilon)}_{-m,k}[J_X'^{P_X'}]^{(\varepsilon')*}_{-m',k},$$

MesonEx : $\pi^+K^+K^-$ n Preliminary Data

Vector-Scalar Moments fit results (unpolarised only)



Moments to Partial Waves

$$H^0(LM) = \sum_{\substack{\ell\ell' \\ mm'}} \left(\frac{2\ell'+1}{2\ell+1}\right)^{1/2} C^{\ell 0}_{\ell' 0 L 0} C^{\ell m}_{\ell' m' L M} \; \rho^{\alpha,\ell\ell'}_{mm'},$$

$$\boldsymbol{H}(LM) = -\sum_{\substack{\ell\ell' \\ mm'}} \left(\frac{2\ell'+1}{2\ell+1}\right)^{1/2} C^{\ell 0}_{\ell' 0 L 0} C^{\ell m}_{\ell' m' L M} \; \boldsymbol{\rho}^{\ell\ell'}_{mm'}$$

$$^{(\epsilon)}\rho^{0,\ell\ell'}_{mm'} = \kappa \sum_k \left([\ell]^{(\epsilon)}_{m;k} [\ell']^{(\epsilon)*}_{m';k} + (-1)^{m-m'} [\ell]^{(\epsilon)}_{-m;k} [\ell']^{(\epsilon)*}_{-m';k} \right) ,$$

$$^{(\epsilon)}\rho^{1,\ell\ell'}_{mm'} = -\epsilon\kappa \sum_k \left((-1)^{m} [\ell]^{(\epsilon)}_{-m;k} [\ell']^{(\epsilon)*}_{m';k} + (-1)^{m'} [\ell]^{(\epsilon)}_{m;k} [\ell']^{(\epsilon)*}_{-m';k} \right) ,$$

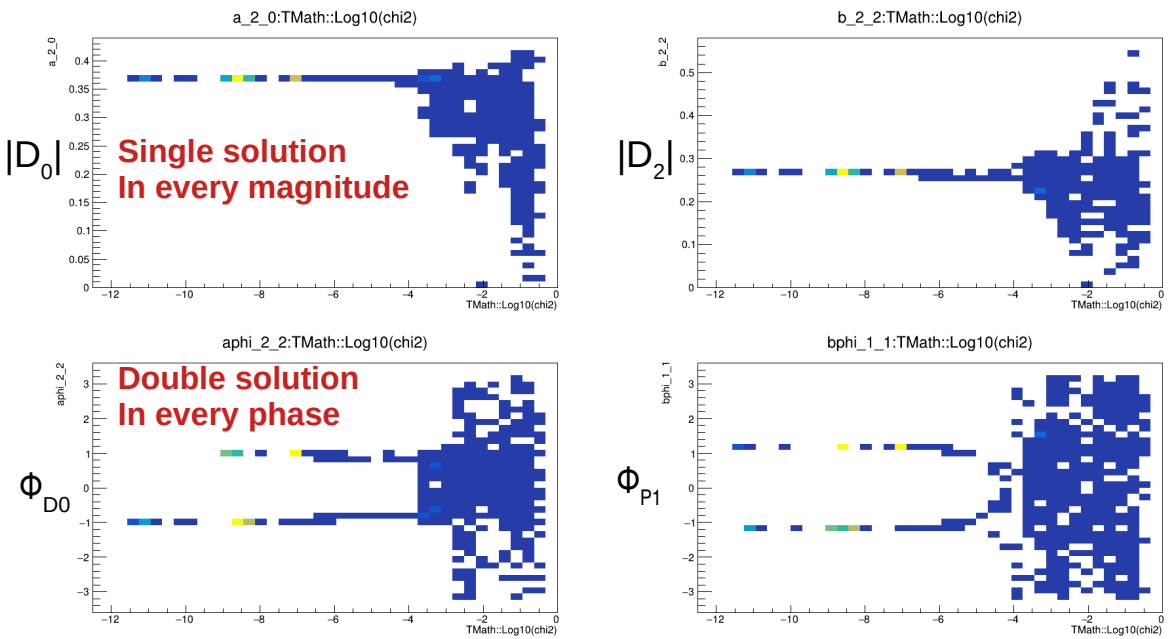
$$^{(\epsilon)}\rho^{2,\ell\ell'}_{mm'} = -i\epsilon\kappa \sum_k \left((-1)^{m} [\ell]^{(\epsilon)}_{-m;k} [\ell']^{(\epsilon)*}_{m';k} - (-1)^{m'} [\ell]^{(\epsilon)}_{m;k} [\ell']^{(\epsilon)*}_{-m';k} \right) ,$$

$$^{(\epsilon)}\rho^{3,\ell\ell'}_{mm'} = \kappa \sum_k \left([\ell]^{(\epsilon)}_{m;k} [\ell']^{(\epsilon)*}_{m';k} - (-1)^{m-m'} [\ell]^{(\epsilon)}_{-m;k} [\ell']^{(\epsilon)*}_{-m';k} \right) .$$

The moments can be expanded in partial waves via the SDMEs (ρ)

=> a system of simultaneous equations

=> if sufficient moments can numerically extract the partial waves (e.g. with Minuit)



Need to run many times!

For linearly polarised photoproduction find we can invert equations with 2 (trivial) complex conjugate solution sets of partial waves.

i.e. there are 2 solutions,
Or 1 if 1 partial wave is forced +ve real part

Summary

CLAS12 has successfully taken data for ~ 4 years

Several analyses on beam spin asymmetries already published

Data with forward tagger allow large rate of meson photoproduction events

Currently analysing several two-body final states

Working on extracting moments of angular distributions then partial waves

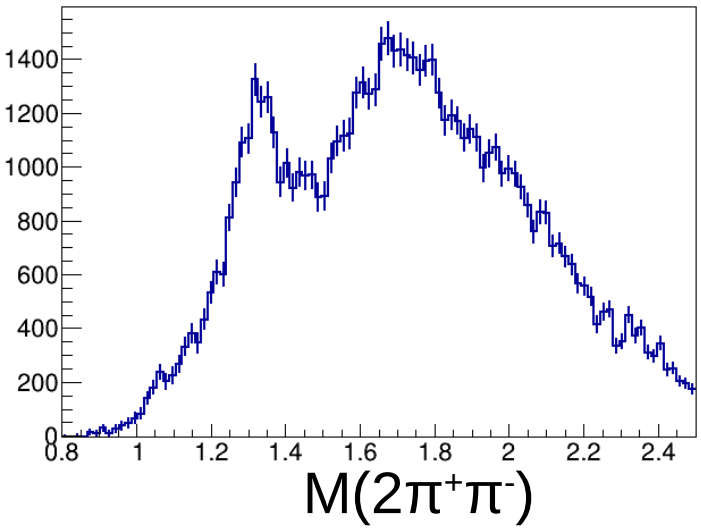
Extending moments and partial waves formalisms as part of Strong2020 work package

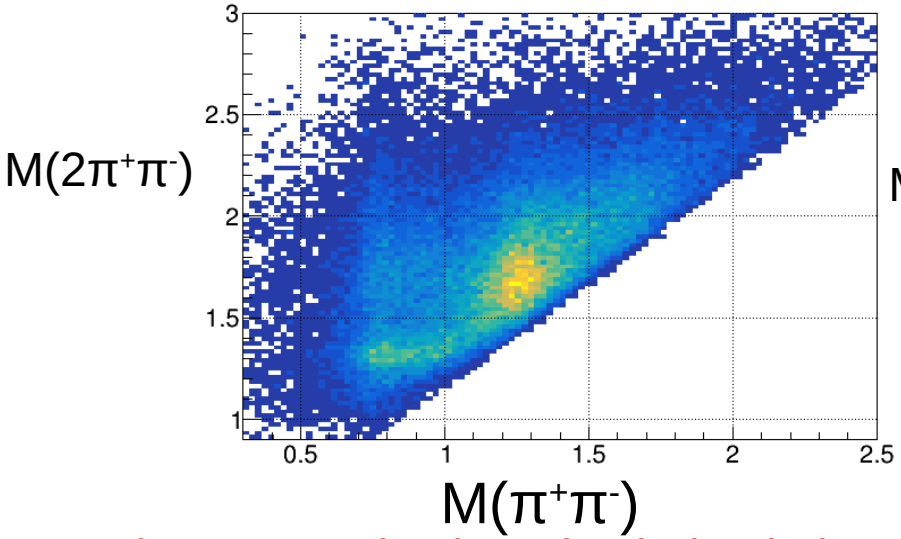
MesonEx : $\pi^+\pi^+\pi^-$ n Preliminary Data

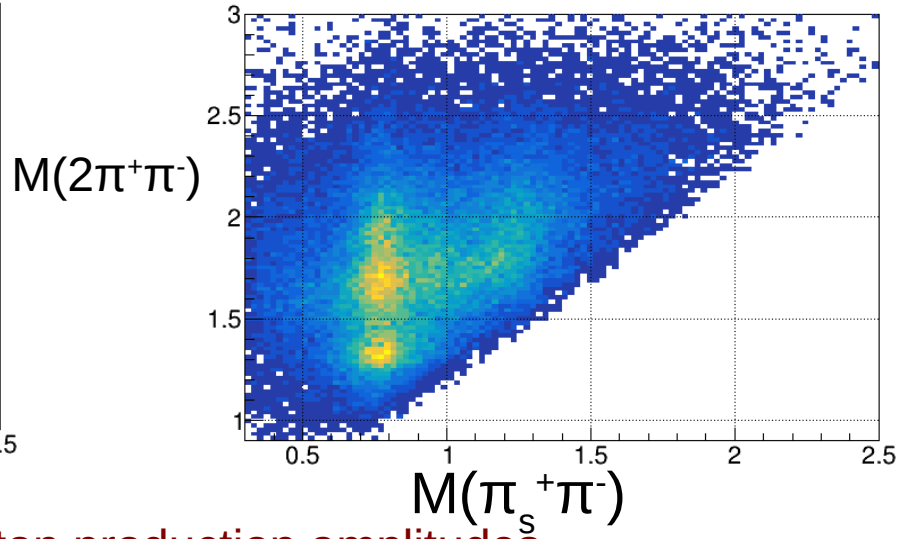
Missing neutron final state

|t|>2 and 6<Eg<10 Gev

Trigger/Torus Field /Detector
=> Low acceptance below 1.3 GeV







Need parameterisation of polarised photon production amplitudes

Need to include 2π + N* contributions (not shown)

MesonEx : $\pi^+\pi^-$ p Preliminary Data