4TH WORKSHOP ON FUTURE DIRECTIONS IN SPECTROSCOPY ANALYSIS (FDSA2022, JEFFERSON LAB, 14-16 NOVEMBER 2022)

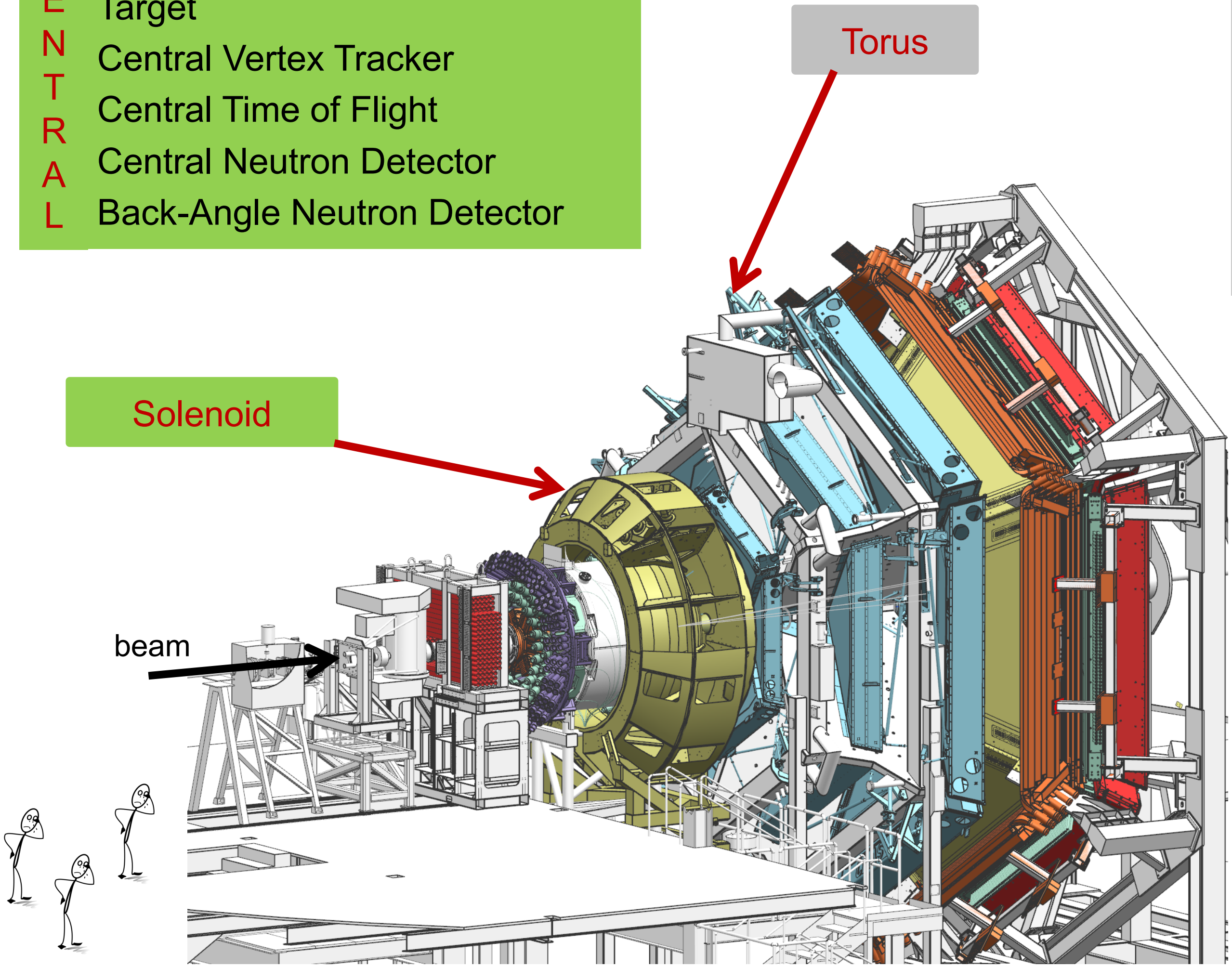
Status and Perspectives for Hadron Spectroscopy with CLAS12

Raffaella De Vita (INFN)
for the CLAS Collaboration

CLAS12

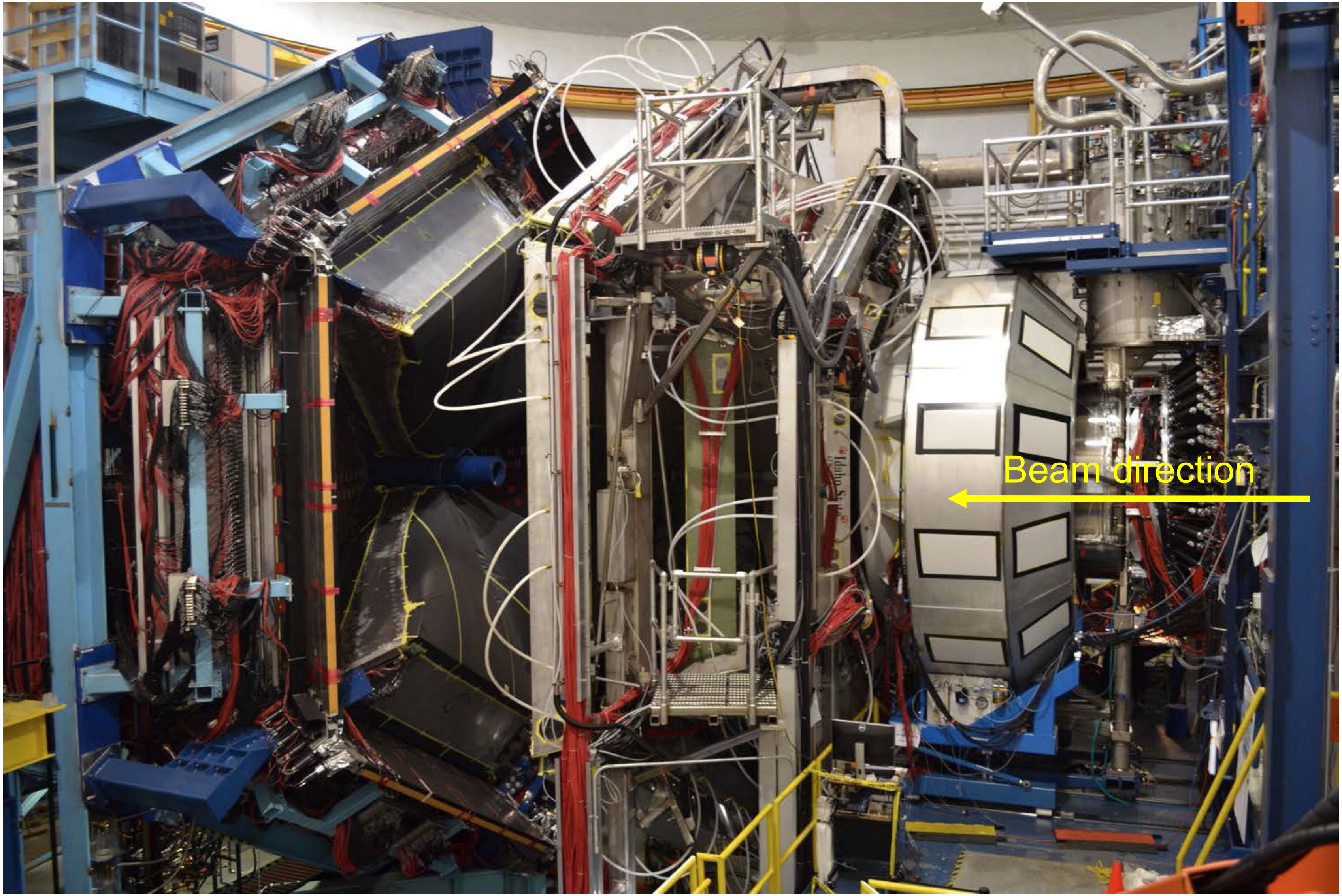
CENTRAL
- Beamline
- Target
- Central Vertex Tracker
- Central Time of Flight
- Central Neutron Detector
- Back-Angle Neutron Detector

FORWARD
- High Threshold Cherenkov
- Forward Tagger
- Drift Chambers
- Low Threshold Cherenkov
- Ring Imaging Cherenkov
- Forward Time of Flight
- EM Calorimeter

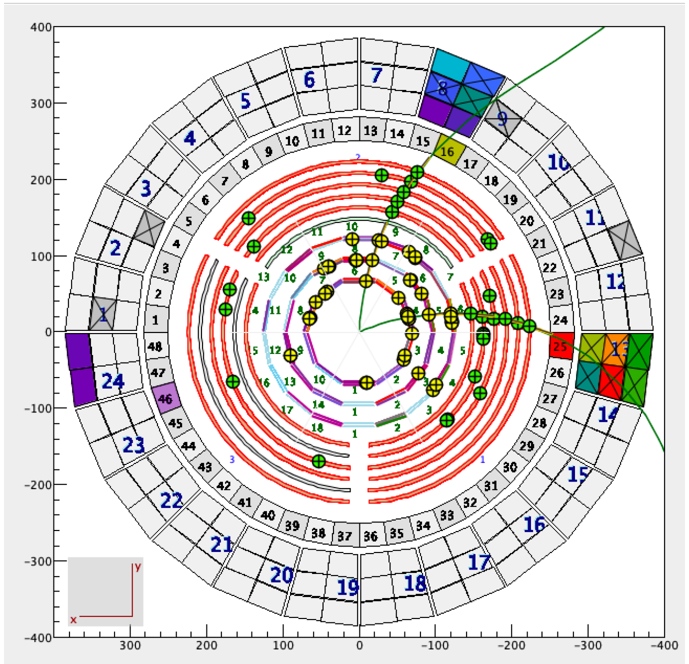


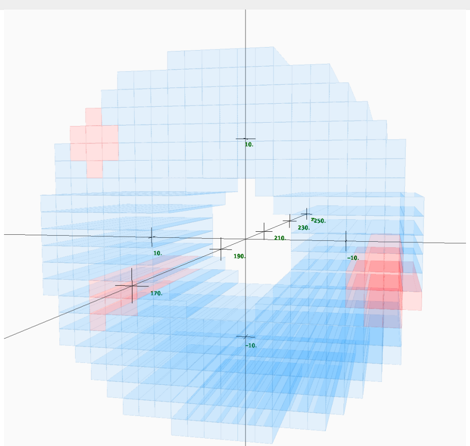
	Forward	Central
Angular coverage	5º – 35º	35º – 135º
Momentum resolution	dp/p < 1%	dp/p < 5%
θ resolution	1 mrad	5 – 10 mrad
ϕ resolution	1 mrad/sinθ	5 mrad/sinθ

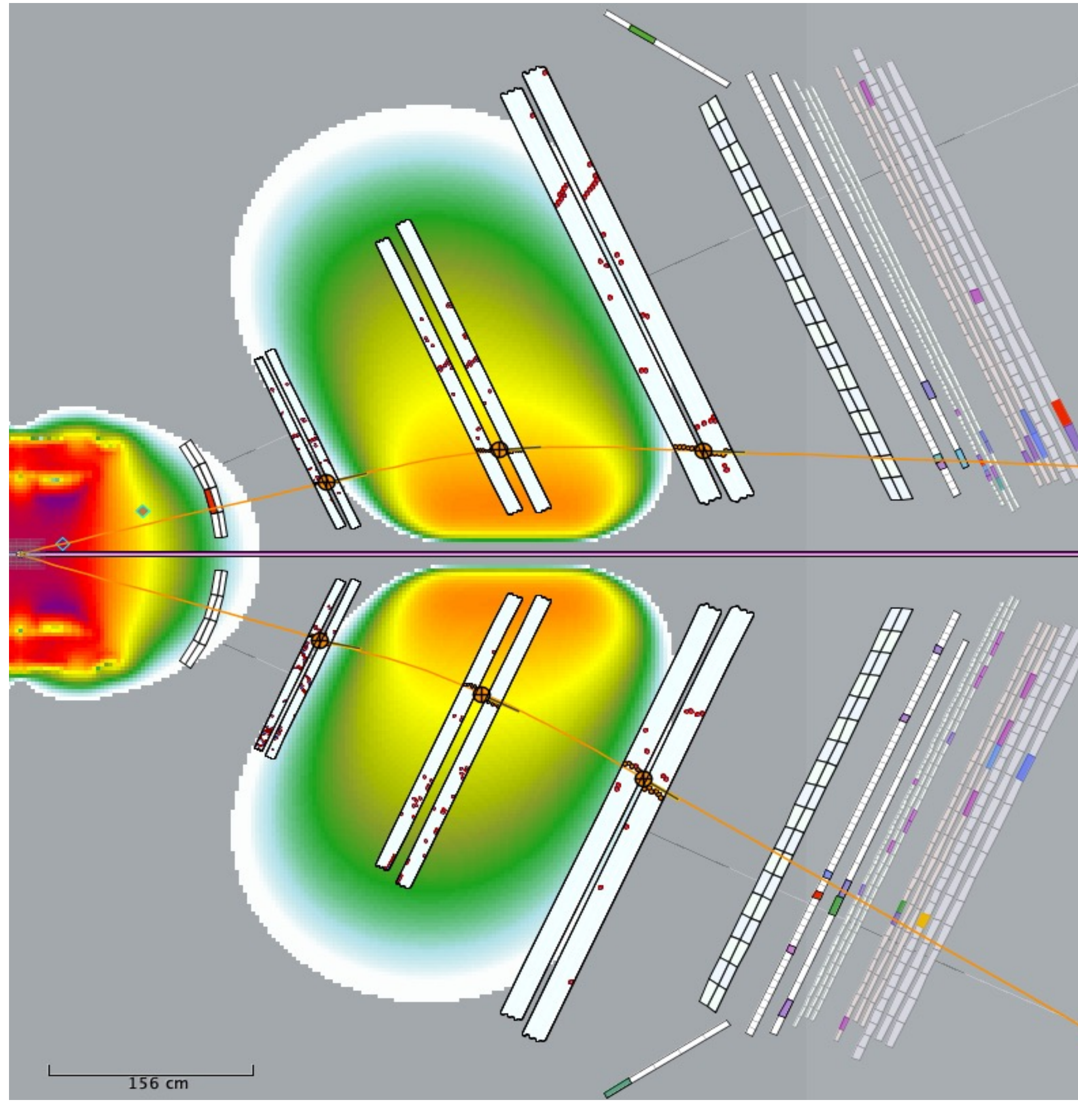
CLAS12 in Hall B



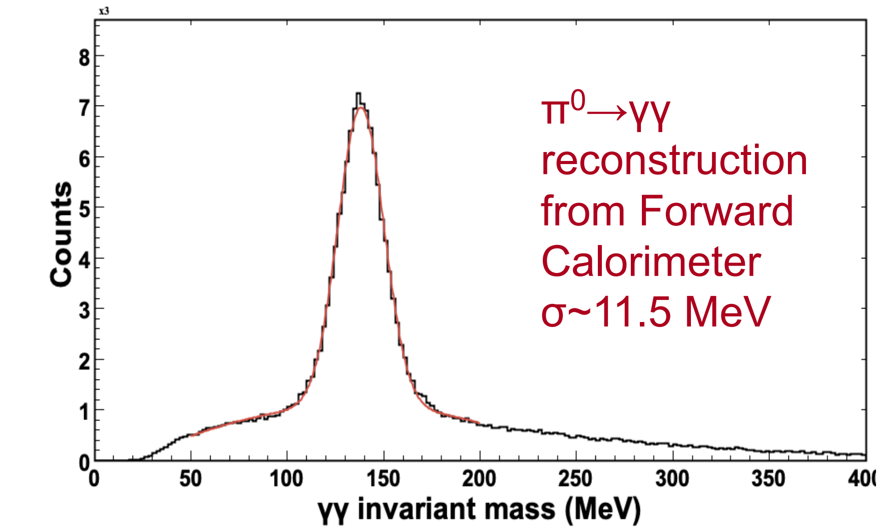
CLAS12 Event Display

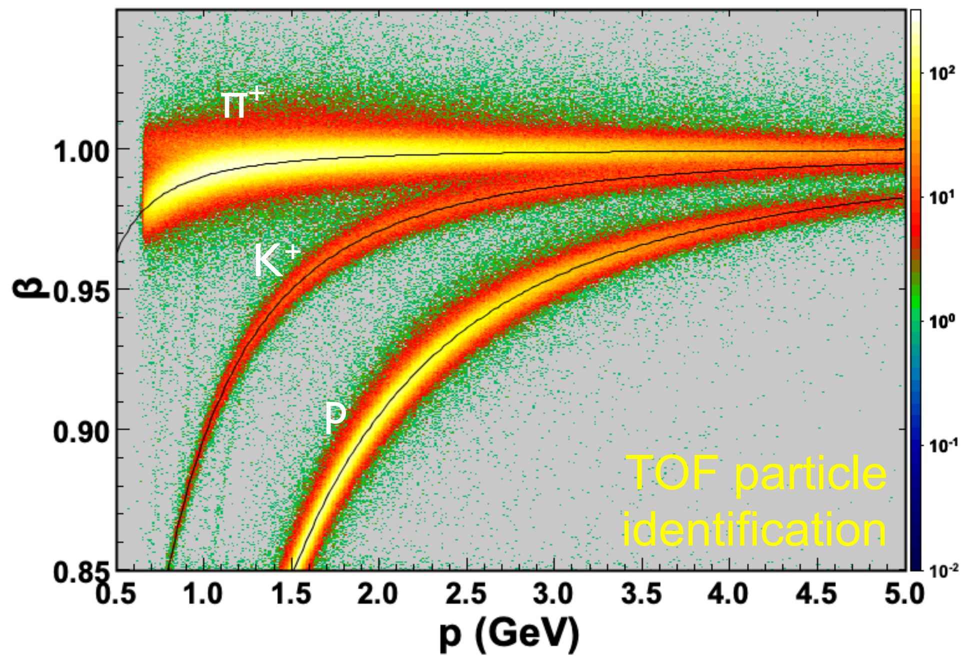


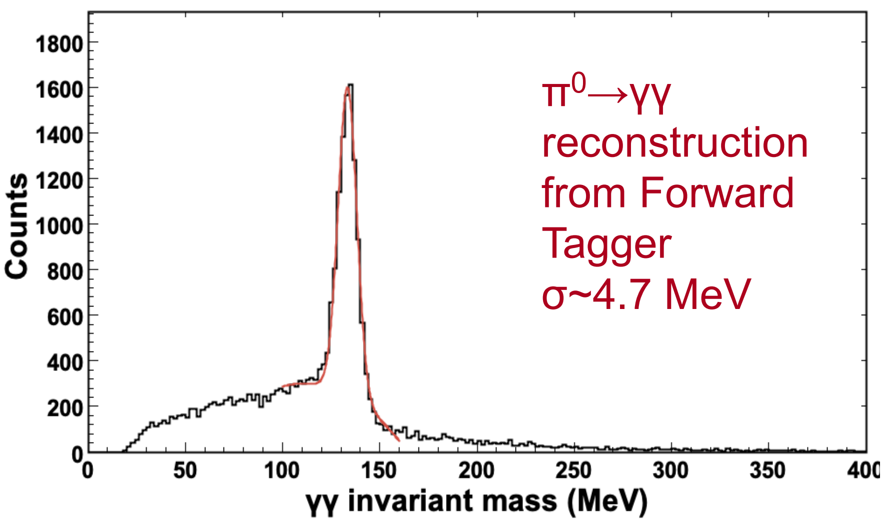


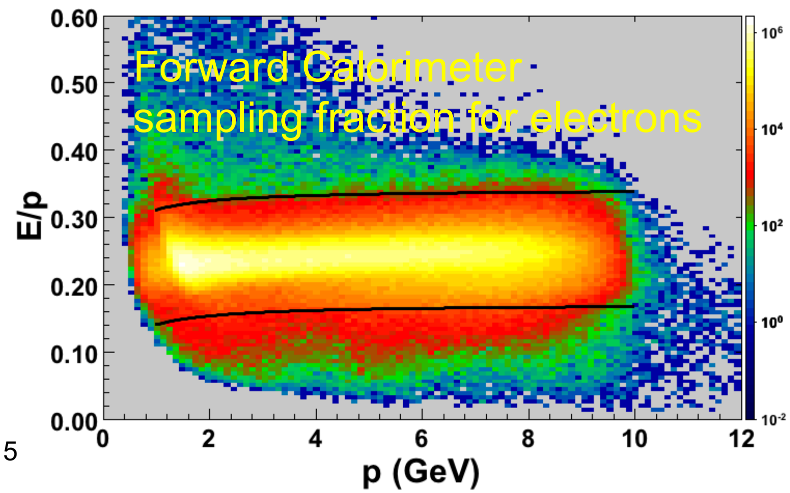


Event reconstruction





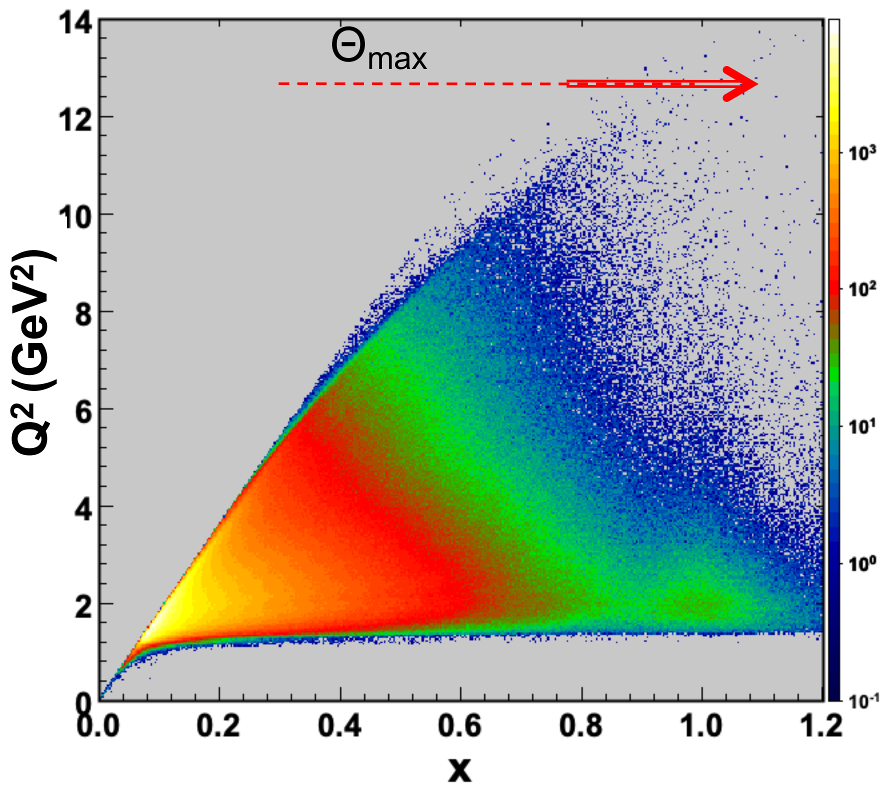


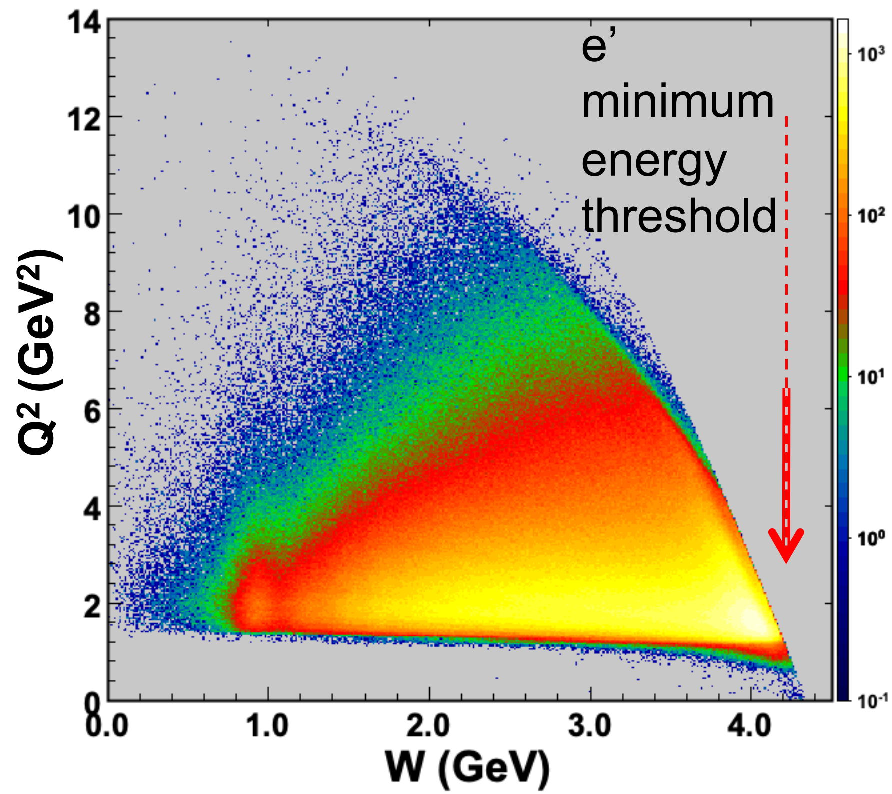


CLAS12 kinematic reach

Beam energy at 10.6 GeV Torus current 3770 A, electrons in-bending, Solenoid magnet at 2416 A.

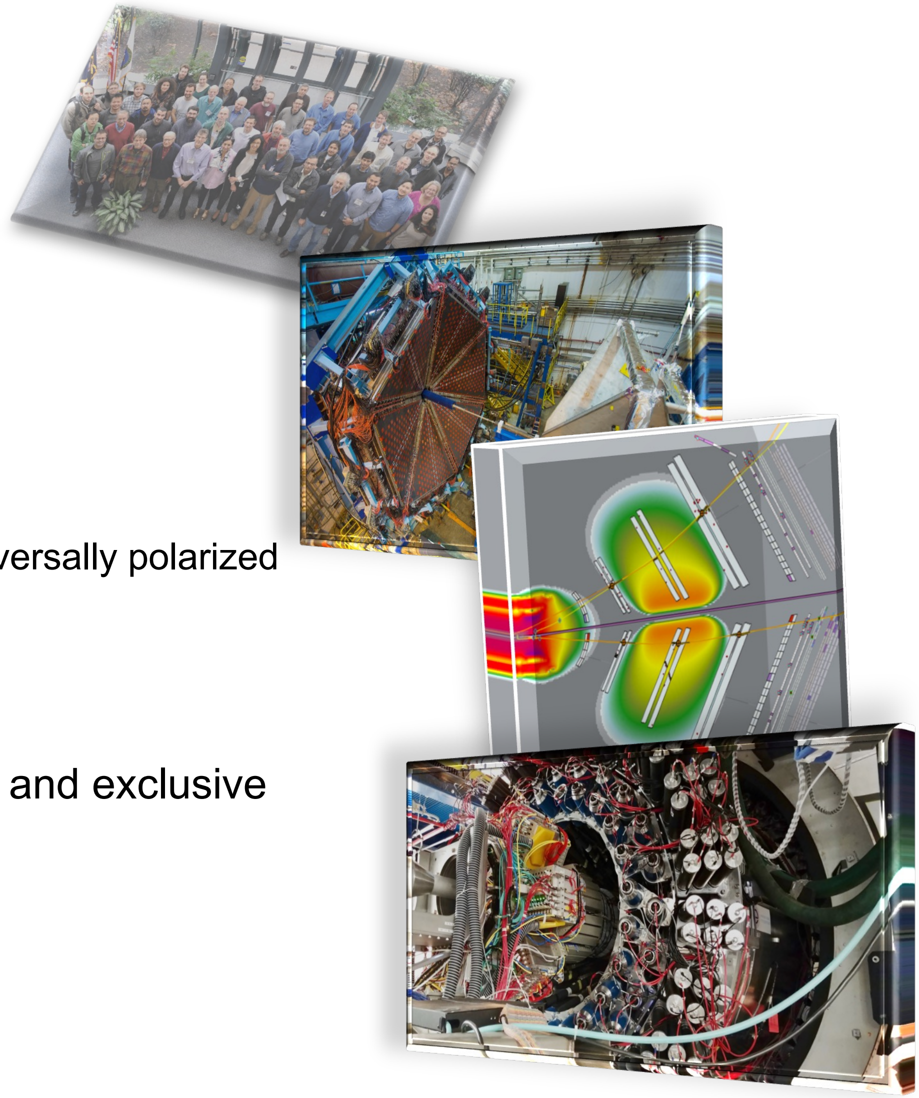
p(e,e')X





Plots based on 200 min. of data taking

CLAS12 in numbers



Collaboration:

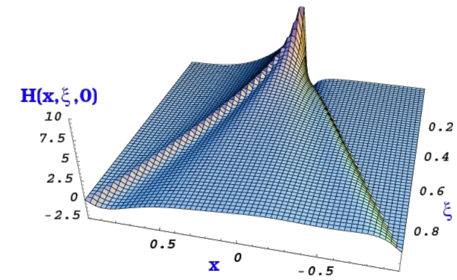
- More than 200 members
- 43 institutions
- 9 countries

Experimental program:

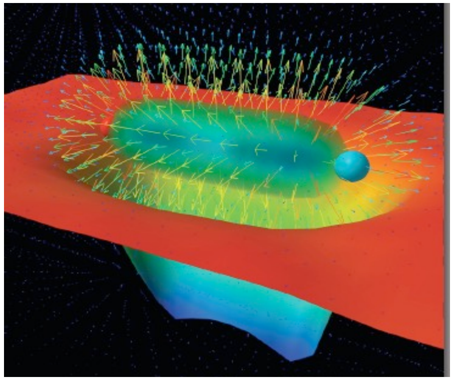
- 47 approved proposals:
  - targets:
    - proton, deuteron and nuclei
    - unpolarized, longitudinally and transversally polarized
    - solid, liquid and gas
  - beam:
    - highly polarized electron beam
    - linearly polarized quasi-real photons
  - final states: inclusive, semi-inclusive and exclusive
  - luminosity up to 10^{35} $cm^{-2}s^{-1}$
- 3188 PAC days
- 12 Run Groups
- 1171 Run Group days
- **10 years of approved data taking**

The CLAS12 physics program

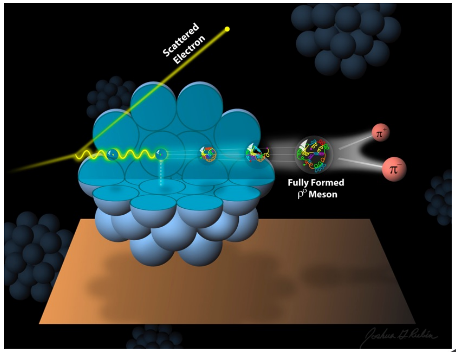
- The multidimensional structure of the nucleon – from form factors and PDFs to GPDs and TMDs



- Quark confinement and the role of the glue in meson and baryon spectroscopy

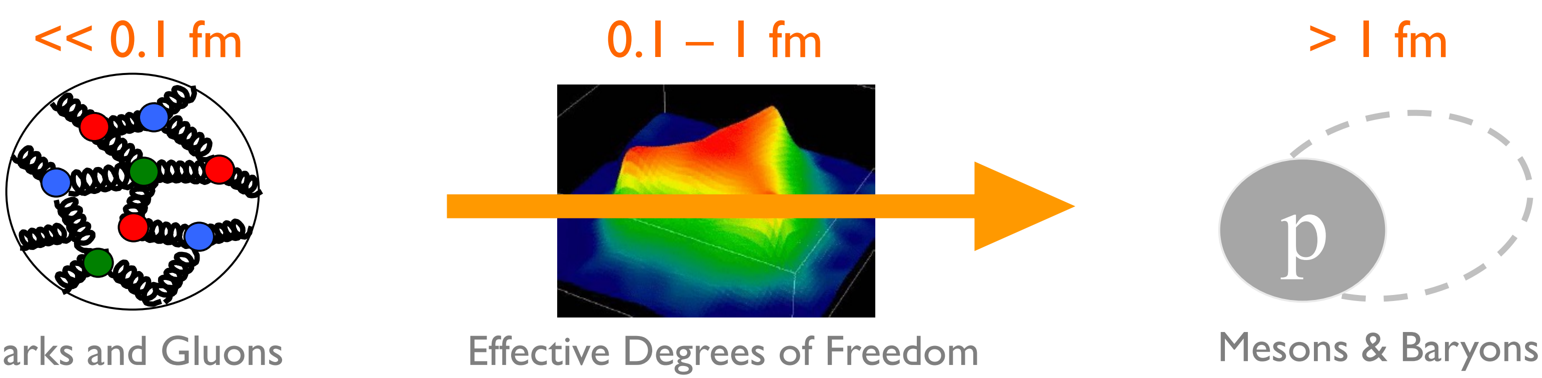


- The strong interaction in nuclei – evolution of quark hadronization, nuclear transparency of hadrons, short range correlation



Spectroscopy at CLAS12

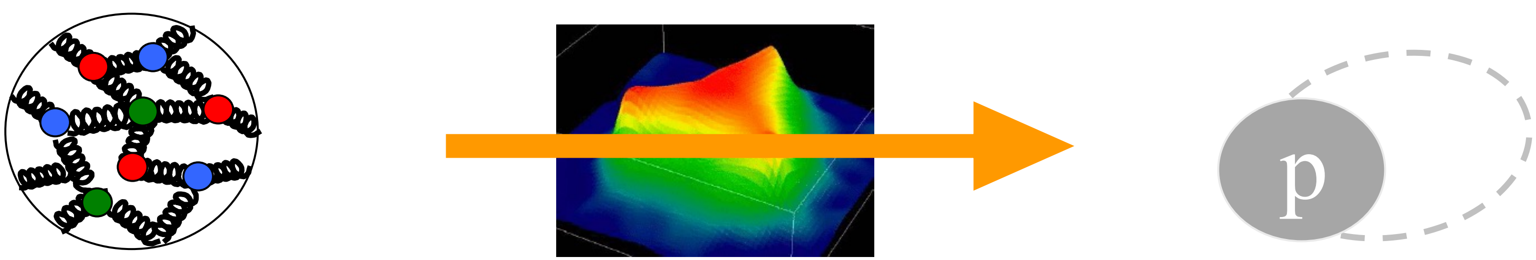
- Quark confinement and the role of the glue in meson and baryon spectroscopy:
  - What is the internal structure and what are the internal degrees of freedom of hadrons?
  - What is the role of gluons?
  - What is the origin of quark confinement?
  - Are 3-quarks and quark-antiquark the only possible configurations?



Spectroscopy at CLAS12

- Quark confinement and the role of the glue in meson and baryon spectroscopy:
  - Study of nucleon resonances in electroproduction
  - Hyperon spectroscopy and production of very-strange states
  - J/Psi photoproduction
  - Quasi-real photoproduction of light-quark mesons

<< 0.1 fm | 0.1 – 1 fm | > 1 fm

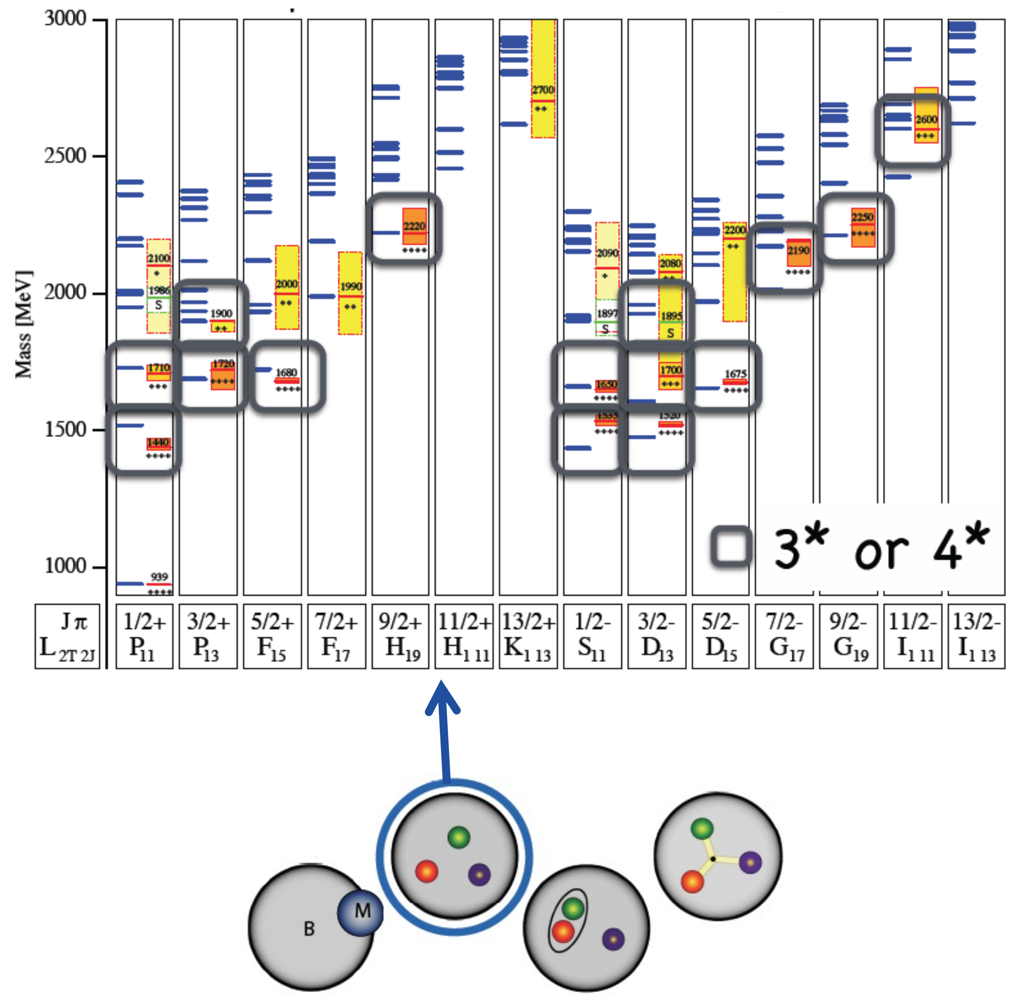


Quarks and Gluons | Effective Degrees of Freedom | Mesons & Baryons

Baryon spectroscopy

The baryon spectrum has been crucial for the development of QCD:

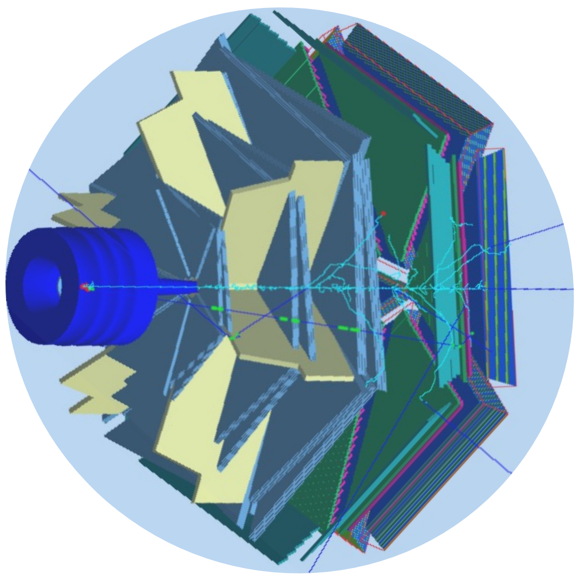
- Multiplet structure led to the proposal of the quark model
- The discovery of the Ω^- confirmed the path was correct
- Inner structure connected to number of colors



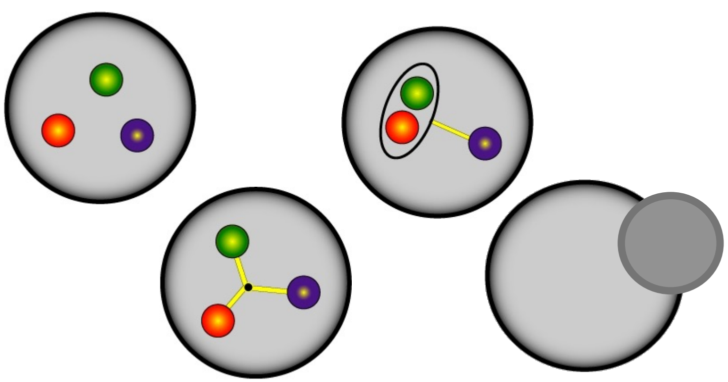
Many open questions (light quarks):

- Nucleon resonance spectrum and missing states
- Effective degrees of freedom and transition from partonic to hadronic description
- Strangeness rich states

CLAS12 N* program



N* degrees of freedom??



The N* program is one of the key physics foundations of Hall B

- CLAS12 is designed to study exclusive reaction channels over a broad kinematic range:

  πN, ωN, ϕN, ηN, $\eta' N$, $\pi\pi N$, KY, K*Y, KY*

- Goal is to explore the ***spectrum*** and ***structure*** of N* states
  - Search for "missing" states, studying poorly known or rare decay modes (strangeness-rich)
  - Probe their underlying degrees of freedom via studies of the Q^2 evolution of the electroproduction amplitudes

CLAS12 N* program

- Measure exclusive electroproduction of Np, Nh, Npp, KY final states from unpolarized proton target with longitudinally polarized electron beam

E_b = 6.6, 8.8, 11 GeV, Q^2 = 0.05 → 12 GeV^2, W → 3.0 GeV, cos θ_m^* = [-1:1]

E12-09-003	Nucleon Resonance Studies with CLAS12
E12-06-108A	KY Electroproduction with CLAS12
E12-16-010A	N* Studies Via KY Electroproduction at 6.6 and 8.8 GeV
E12-16-010	A Search for Hybrid Baryons in Hall B with CLAS12

- Study higher-lying N* states:
  - confirm signals of new baryon states observed in $\gamma p \rightarrow KY$
  - explore full regime of “missing” quark model states
- Understand active degrees of freedom that account for N* structure vs. distance scale:
  - explore dynamical structure of N* states from low to high Q^2 – meson-baryon cloud to quark degrees of freedom
  - search for predicted qqqg hybrid baryons

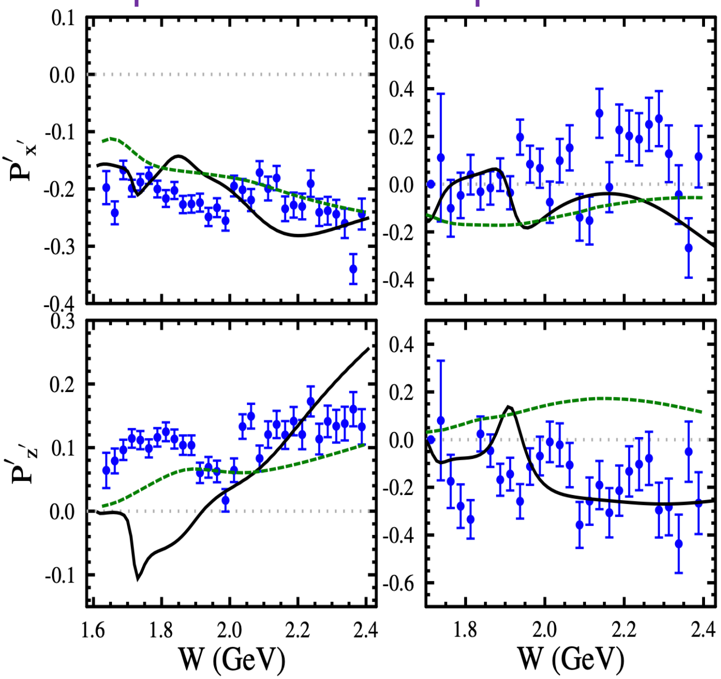
RG-A	Spr. 18 126 mC	10.2 GeV, 10.6 GeV 50% of total
	Fall 18 99 mC	
	Spr. 19 58 mC	
RG-K	Fall 18 28 mC	6.5 GeV, 7.5 GeV 10% of total

continuing in Fall 23

K⁺Y transferred polarization

CLAS12 RG-K @ 6.535 GeV

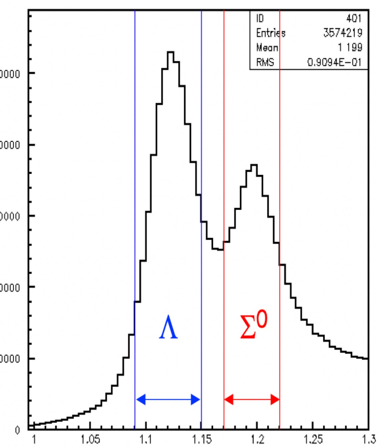
ep → e'K⁺L   ep → e'K⁺Σ⁰

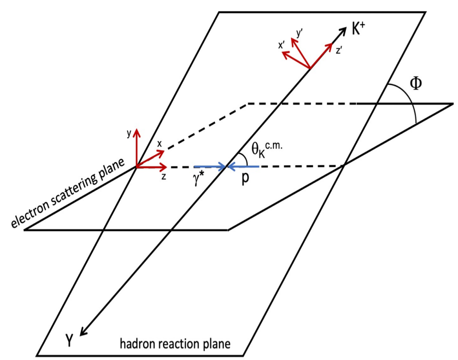


PRC 105, 065201 (2022)

KAON-MAID
RPR

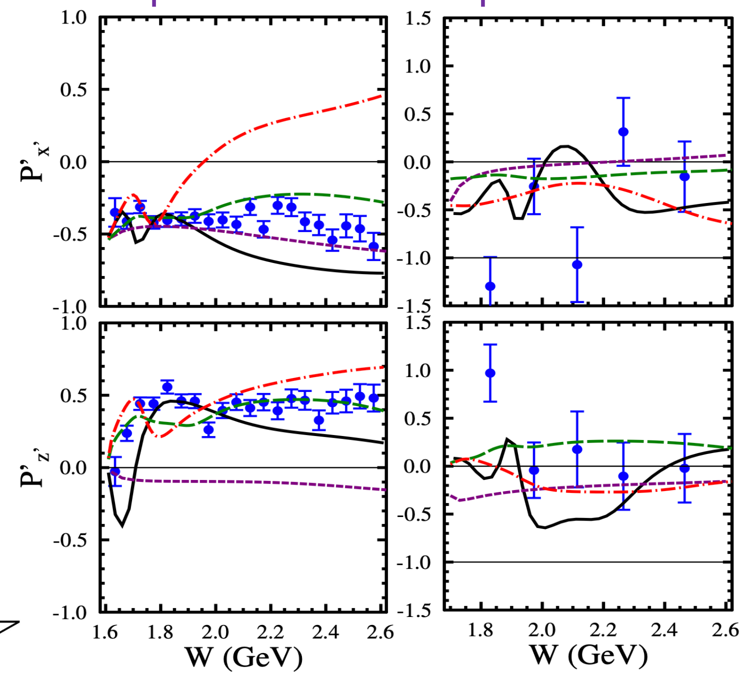
ep → e'K⁺Y





CLAS e1-6 @ 5.754 GeV

ep → e'K⁺L   ep → e'K⁺Σ⁰

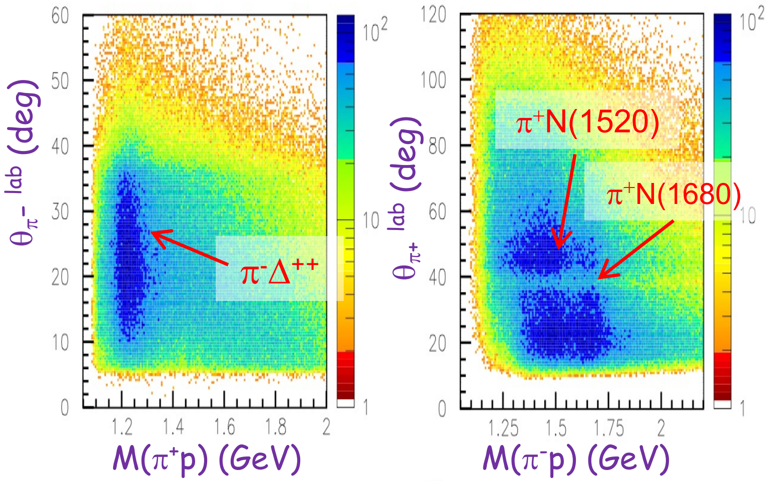


PRC 79, 065205 (2009)

Mart/Bennhold   RPR-2
RPR-1   Regge

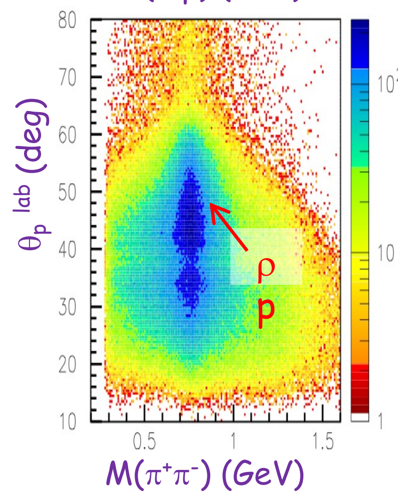
pπ+π- cross sections

ep → e'pπ⁺π⁻

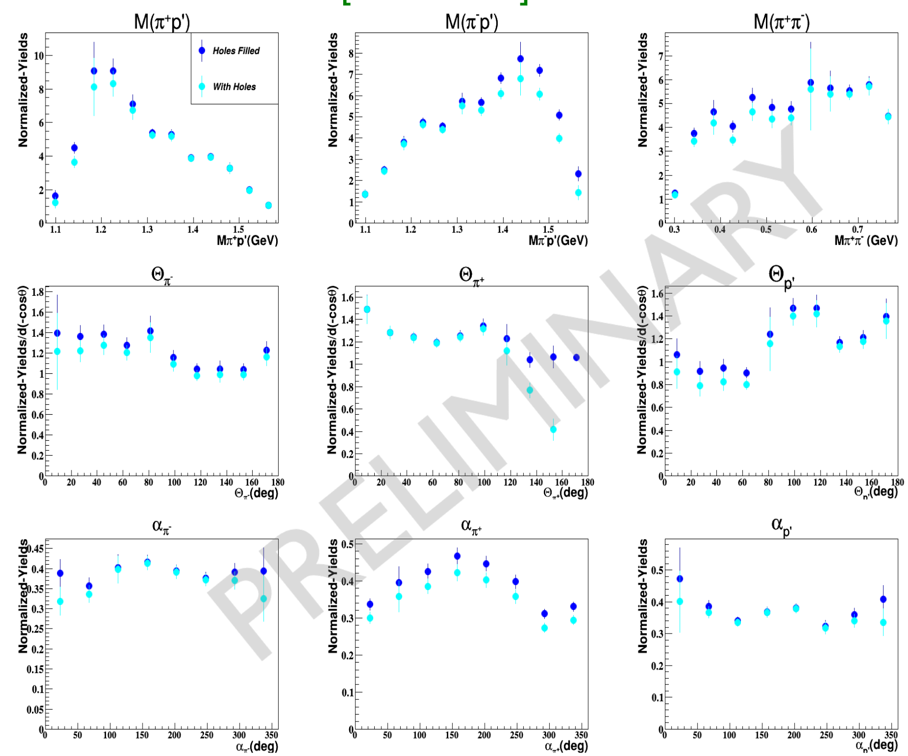


Topologies:

1) Fully exclusive
2) Missing π⁻
3) Missing π⁺
4) Missing p



Normalized yields: Q^2:[3.0-3.5] GeV^2, W:[1.725:1.750] GeV



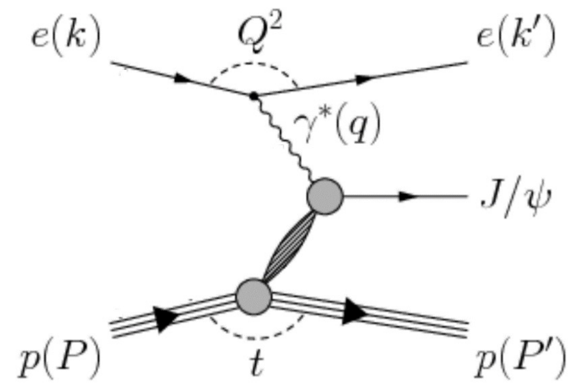
- Particle ID
- Yield extraction
- Monte Carlo acceptance (TWOPEG)
- Momentum corrections
- Radiative corrections
- Systematic studies

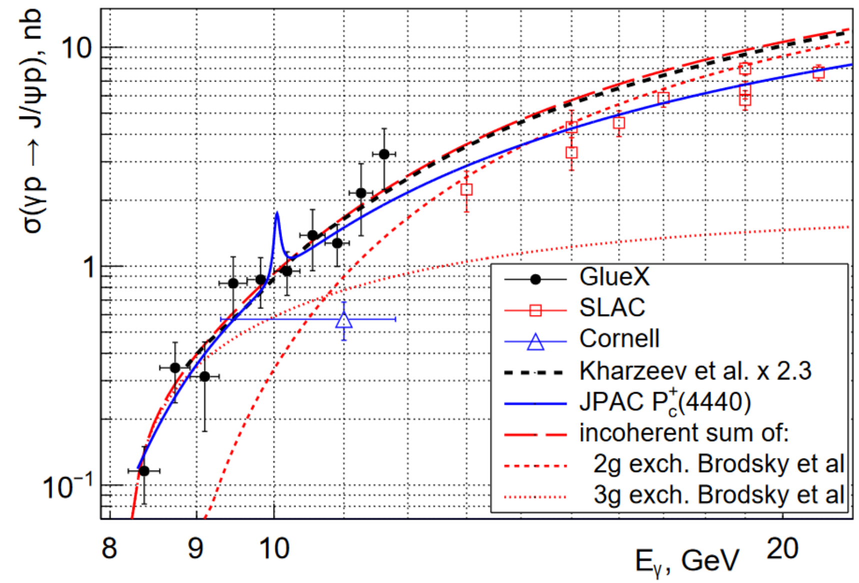
From K. Neupane, South Carolina

J/ψ Near-Threshold Photoproduction

- Clean laboratory to study $c\bar{c}$:
  - Probes gluon distribution in proton
  - Sensitive to multi-quark correlations
  - Sensitivity to the distribution of mass inside the proton via the trace anomaly
  - Search for the LHCb pentaquarks

- J/ ψ at CLAS12:
  - Quasi-real photoproduction: electron scattered at 0 deg, undetected
  - Decay into lepton pairs (e^+e^- or $\mu^+\mu^-$)
  - Measurements on proton and neutron (deuterium target)



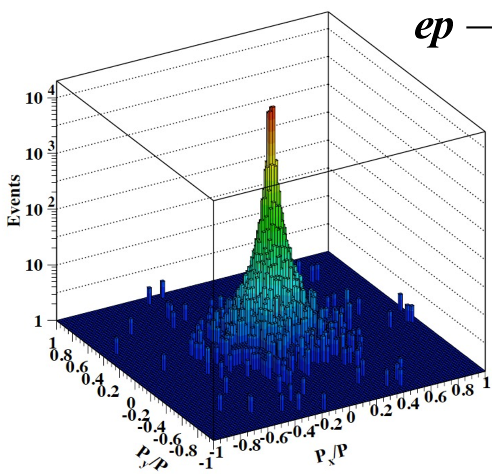


Measurements of the J/ψ total cross section as a function of the photon beam energy and theoretical predictions scaled to GlueX data

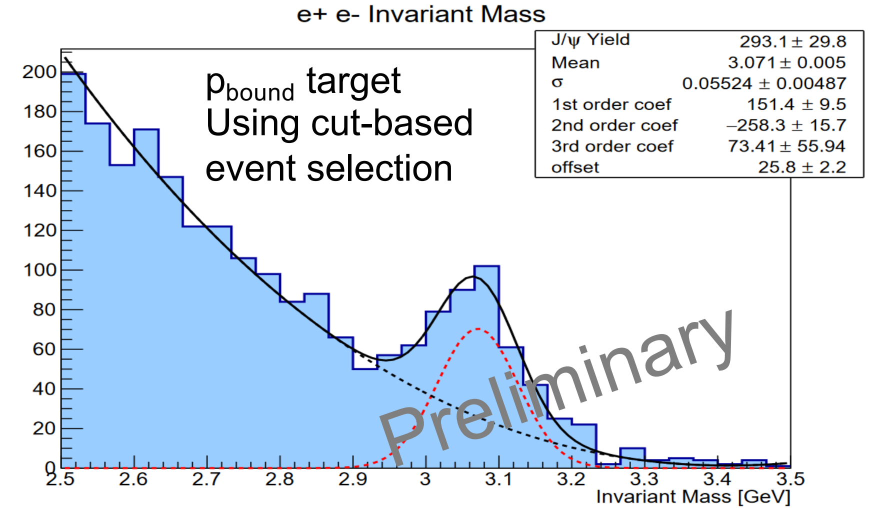
J/ψ signal extraction

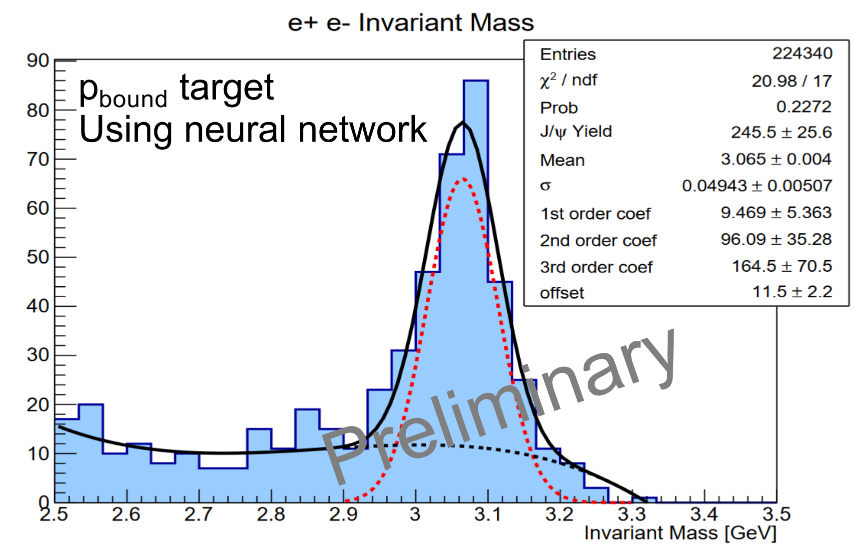
- Charged particles detected in CLAS12 forward detector
- Electron and positrons identified via Cherenkov detector and EM calorimeter
  - Machine-learning classifier to improve e-pi separation
- Selection of quasi-real scattering events:
  - e^+e^-p missing mass consistent with a scattered electron at 0 deg
  - Selection via missing momentum/energy cuts
  - Selection via neural network trained on 4-momenta of final state particle from simulations

$$ep \rightarrow e^+e^- pX$$



Missing electron transverse momentum



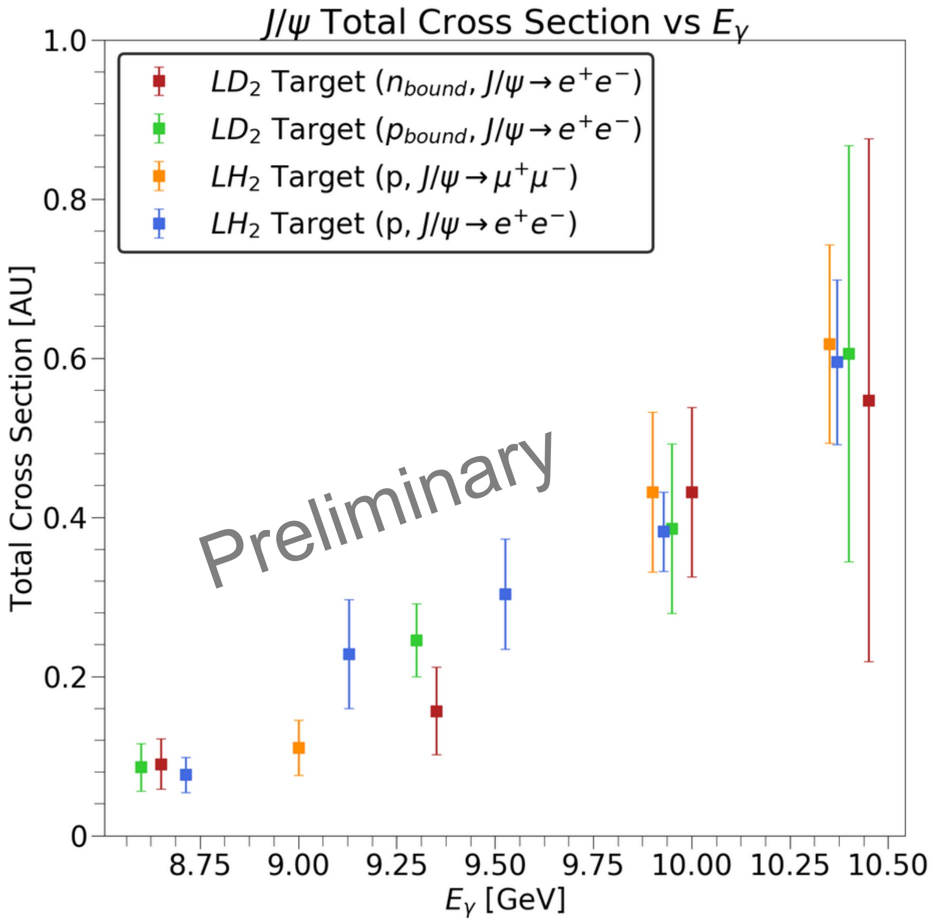


From R. Tyson, University of Glasgow

J/ψ cross section

- Extraction of the total cross section from proton (RG-A) and deuteron (RG-B) data
  - Preliminary results from a fraction of the available data
- Determination of the absolute normalization in progress
- Analysis being extended to low-q electrons

$$en_{bound} \rightarrow (e')e^+e^-n$$
$$ep_{bound} \rightarrow (e')e^+e^-p$$
$$ep \rightarrow (e')\mu^+\mu^-p$$
$$ep \rightarrow (e')e^+e^-p$$



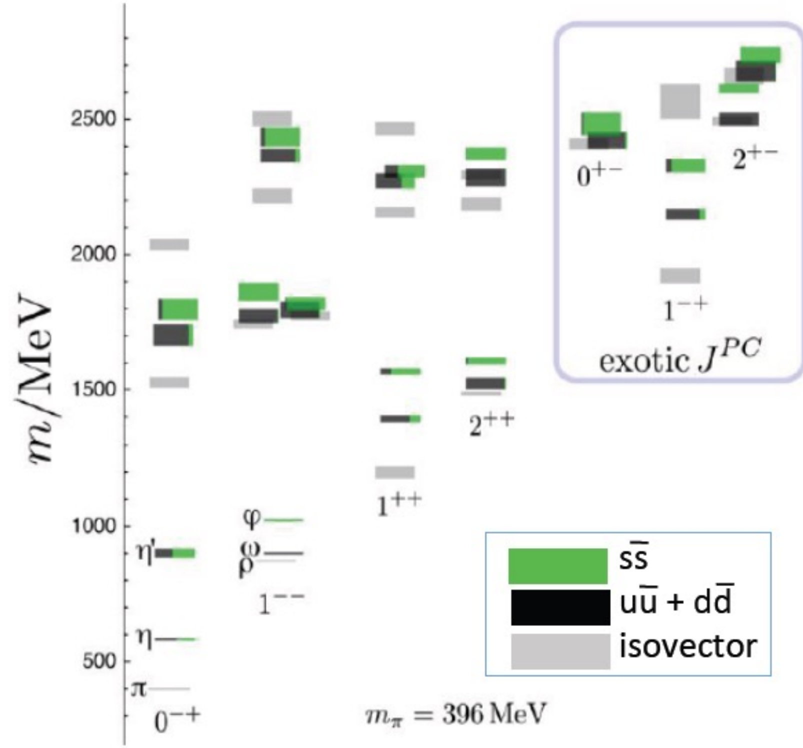
Meson spectroscopy at CLAS12

Predictions of the light quark meson spectrum now available from lattice QCD:

- Spectrum includes meson state with large gluonic content (hybrids) with both regular and exotic quantum numbers
- Experimental signature: a multiplet of gluonic mesons with exotic J^{PC}, i.e. non quark-antiquark
- Searches in progress at several facilities, world-wide

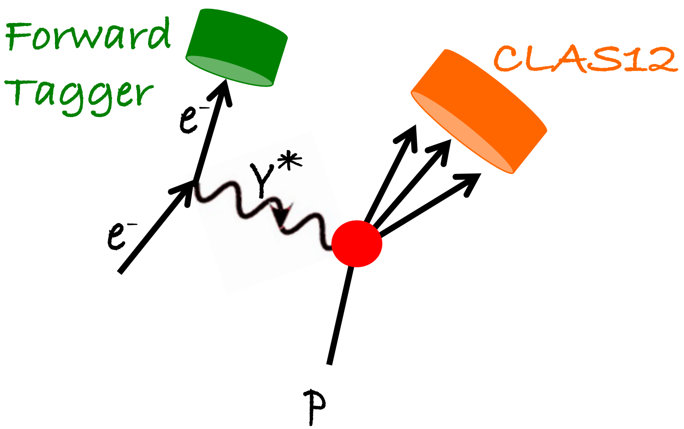
CLAS12 uses quasi-real photo-production to investigate the light quark meson spectrum and search for hybrid meson states

Meson Spectrum in LQCD



Dudek, Edwards, Guo and Thomas, PRD 88, 094505 (2013)

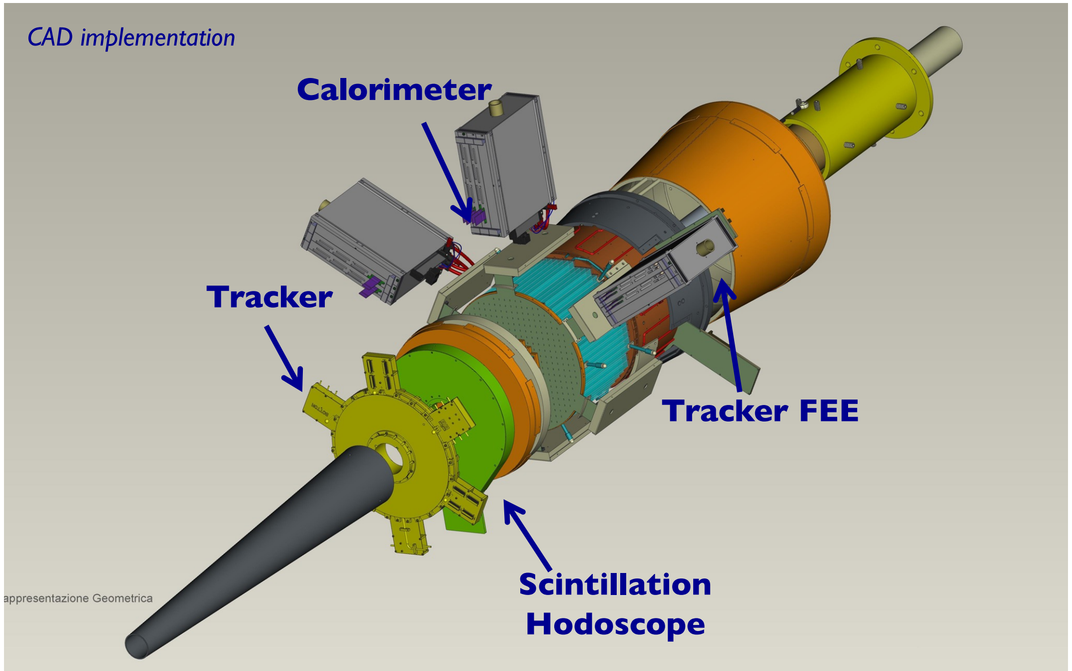
Quasi-real photoproduction



- Detection of multiparticle final state from meson decay in the large acceptance spectrometer CLAS12
- Detection of the scattered electron for the tagging of the quasi-real photon in the CLAS12 Forward Tagger
- High-intensity and high-polarization tagged "photon" beam; degree of polarization can be determined event-by-event from the electron kinematics

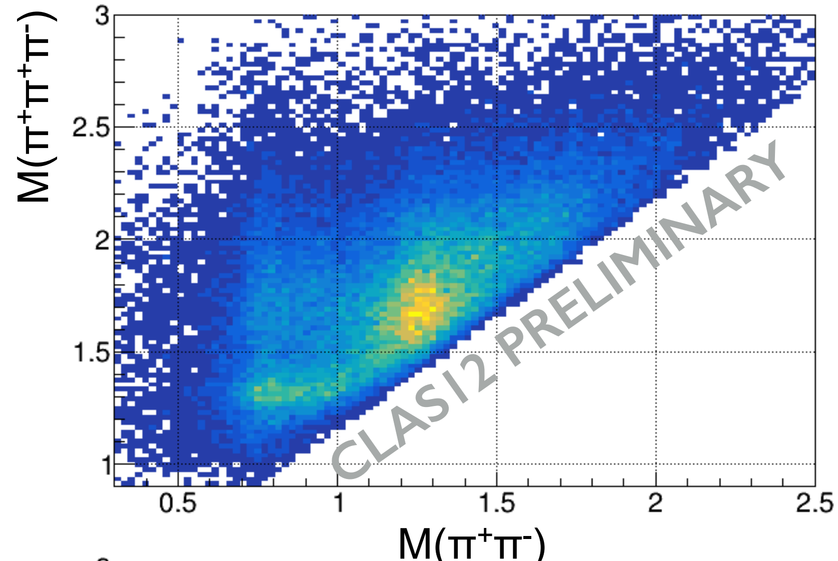
MesonEx:

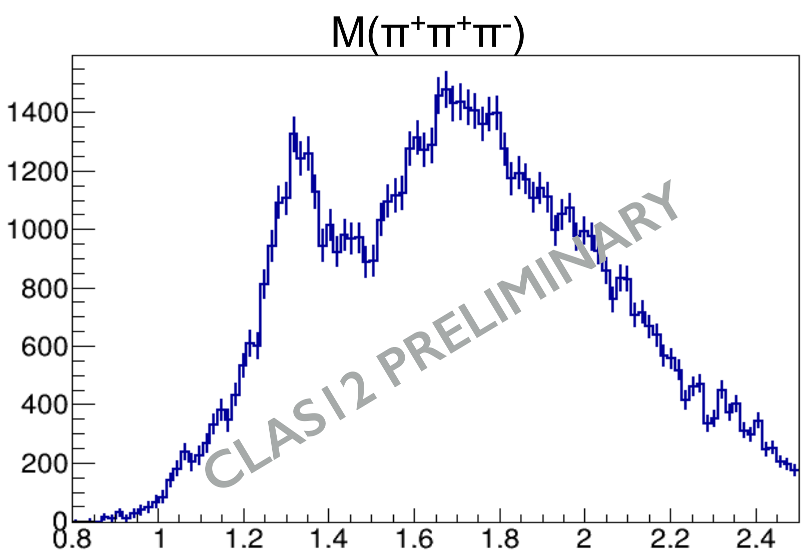
- Detailed mapping of the meson spectrum up to masses of 2.5 GeV
- Search for rare or poorly known states (strangeness-rich, scalars, …)
- Search states with unconventional quark-gluon configurations

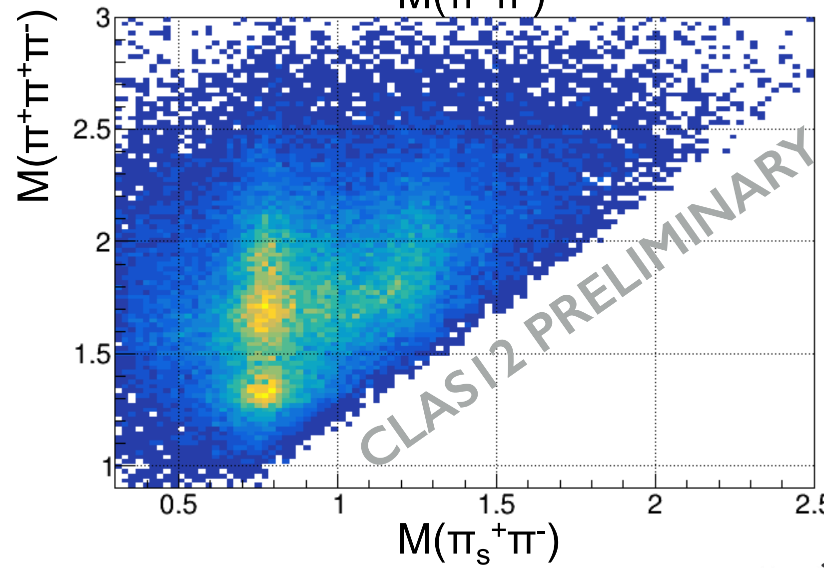


CLAS12 $\pi^+\pi^+\pi^-n$ preliminary data

- First analysis of 3 pion channel from the 10.6 GeV data
- Candidate for search of the exotic $\pi_1(1600)$
- Richness spectrum already accessible with few % of the expected data







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, i.e. extract moments
  - more general expansion than just partial waves
  - check acceptance corrections
  - check distortions from backgrounds
  - model independent formalism
  - already applied to CLAS di-meson photoproduction data
- Extract partial waves from moments or directly fit partial waves
- Expand to vector-pseudoscalar final states

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)

$$\langle Y_{\lambda\mu}\rangle(E_\gamma, t, M) = \frac{1}{\sqrt{4\pi}} \int d\Omega_\pi \frac{d\sigma}{dt\,dM\,d\Omega_\pi} Y_{\lambda\mu}(\Omega_\pi)$$

Moments relate directly to partial wave amplitudes

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

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

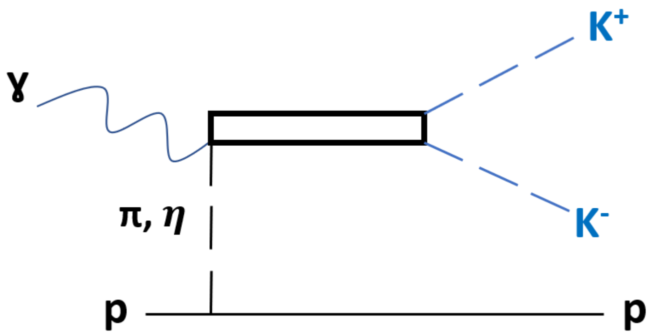
$$H^0(20) = H^1(20) - \frac{2}{35}\left[7|P_1^{(+)}|^2 - 5|D_1^{(+)}|^2 + 10|D_2^{(+)}|^2\right] \ ,$$

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

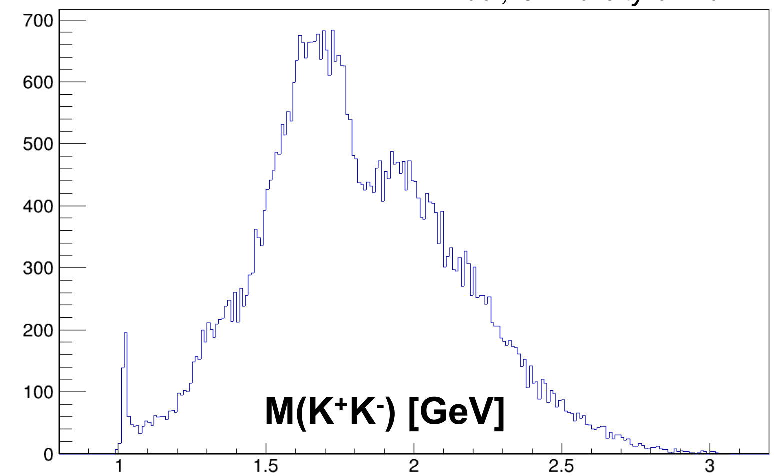
$$H^0(21) = H^1(21) + \frac{2}{7}\sqrt{6}\,\mathrm{Re}(D_1^{(+)} D_2^{(+)*}) \ ,$$

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

MesonEx: K^+K^- p preliminary data

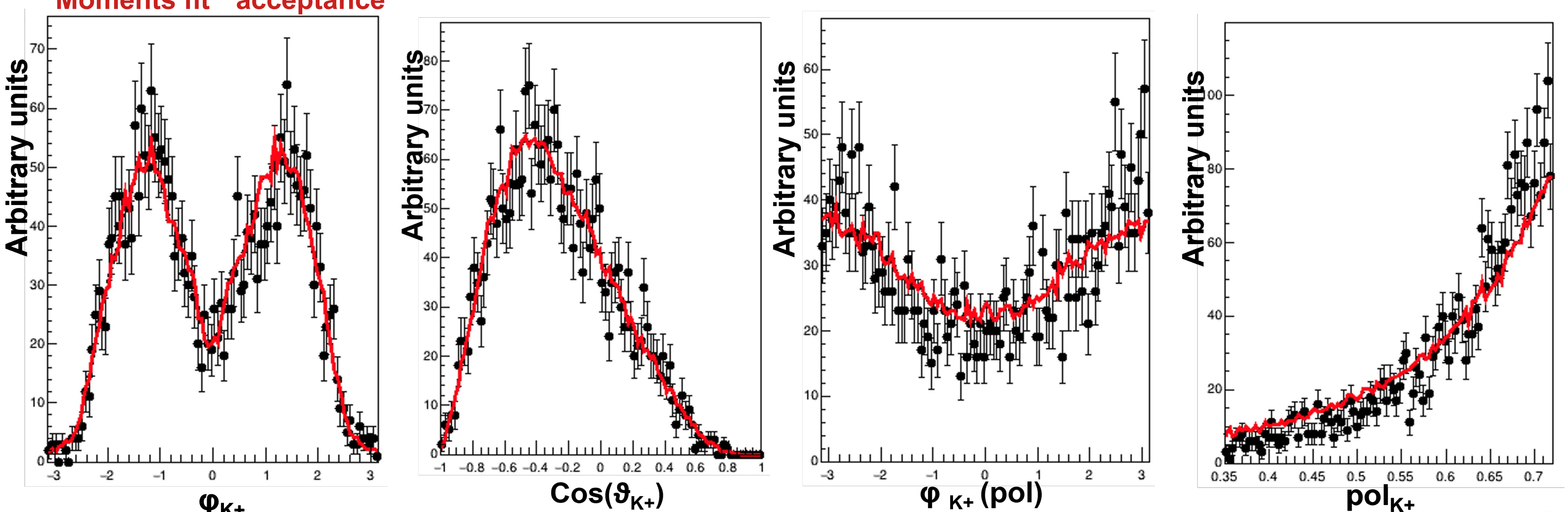


M. Nicol, University of York



Experiment

Moments fit * acceptance

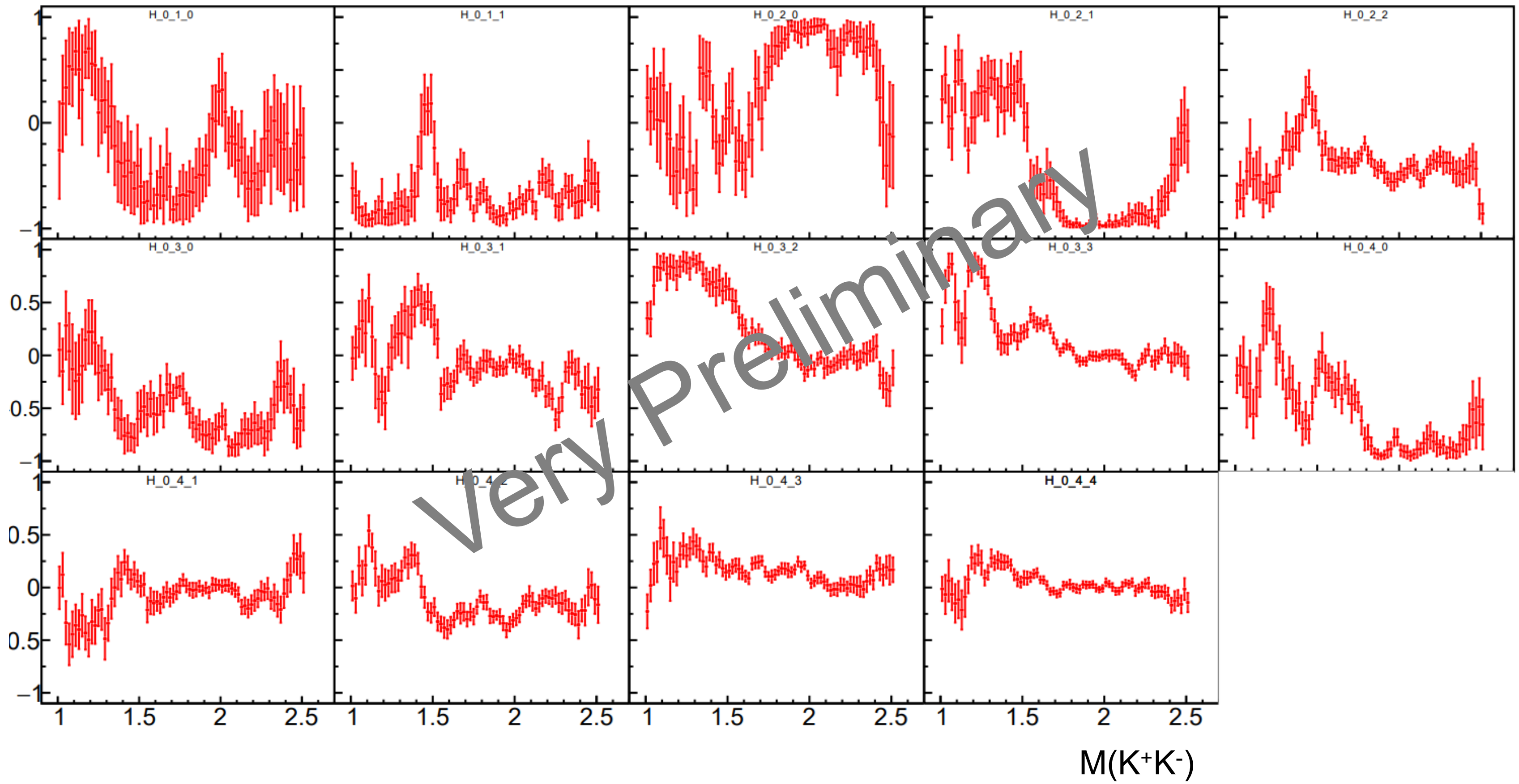


MesonEx: K^+K^- p preliminary data

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

Unpolarised Moments

M. Nicol, University of York

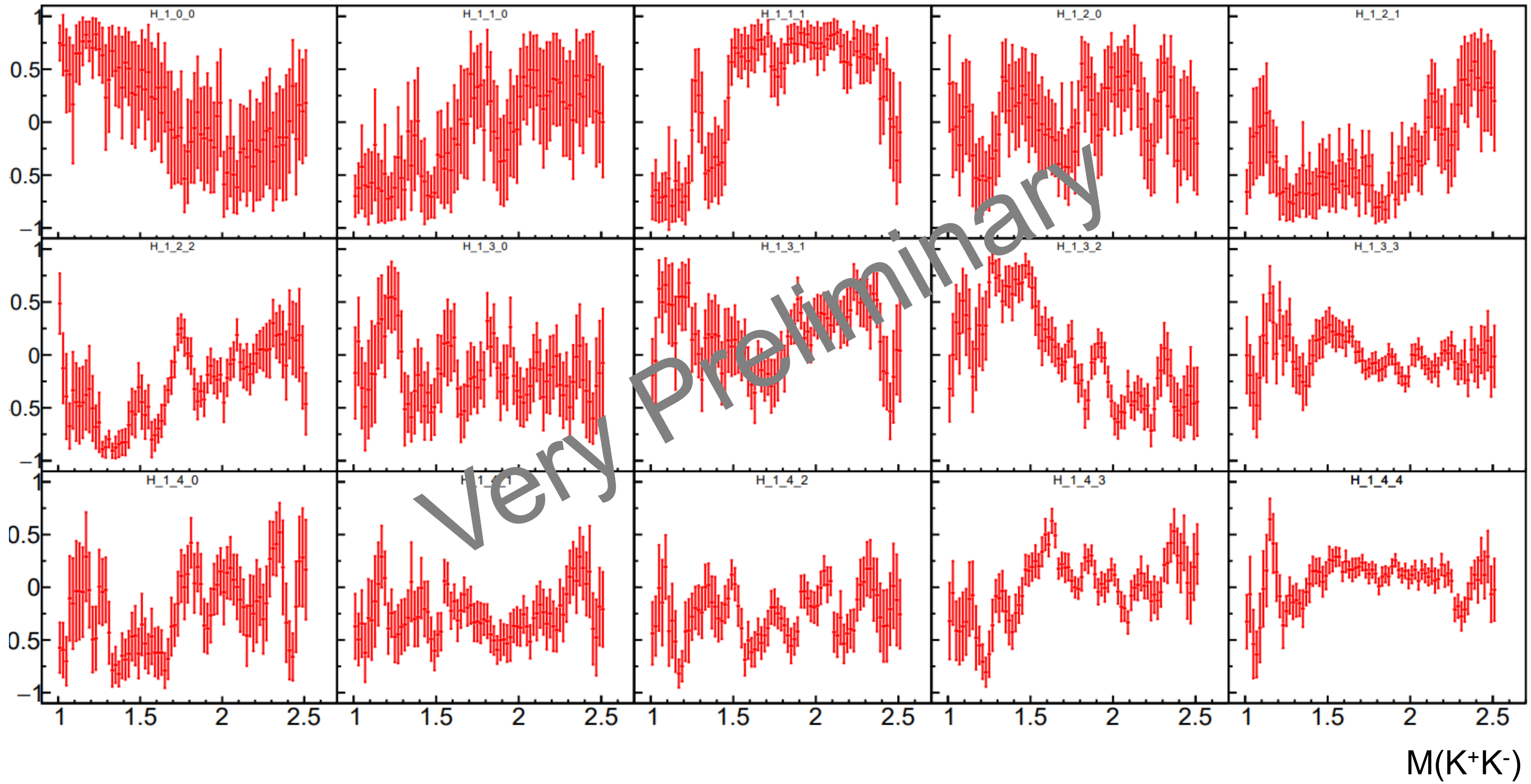


MesonEx: K^+K^- p preliminary data

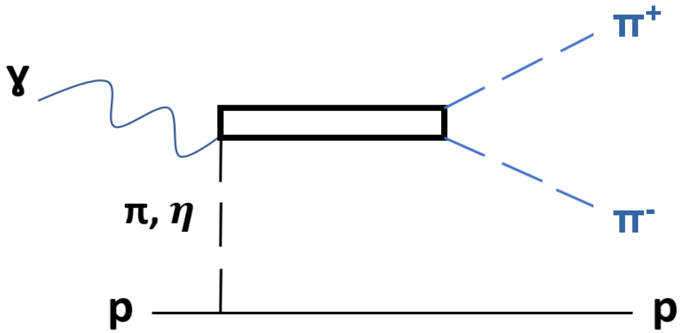
Allowed partial waves J^{PC} (I^G) : $0^{++}(0^+,1^-)$, $1^{--}(0^+,1^-)$, $2^{++}(0^+,1^-)$, $3^{--}(0^+,1^-)$, ...

Polarised Moments

M. Nicol, University of York

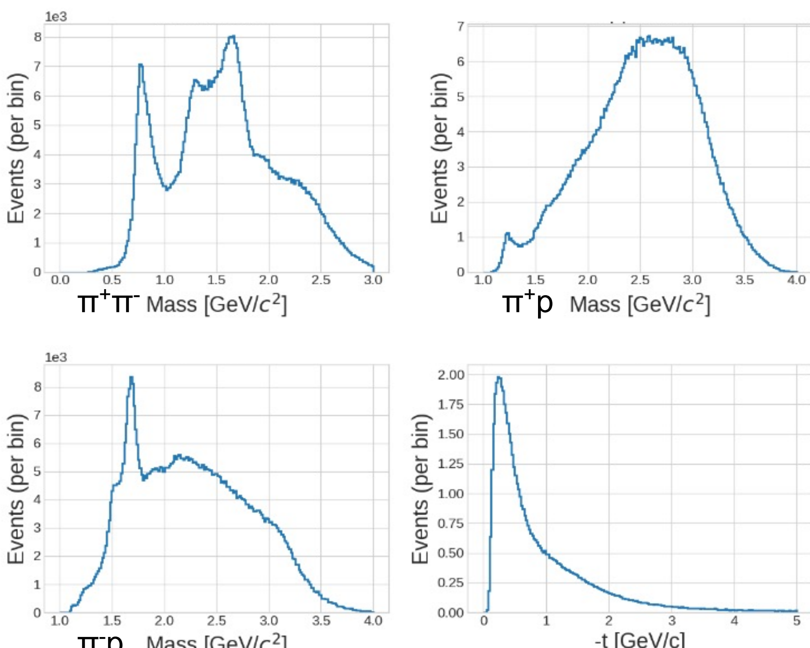


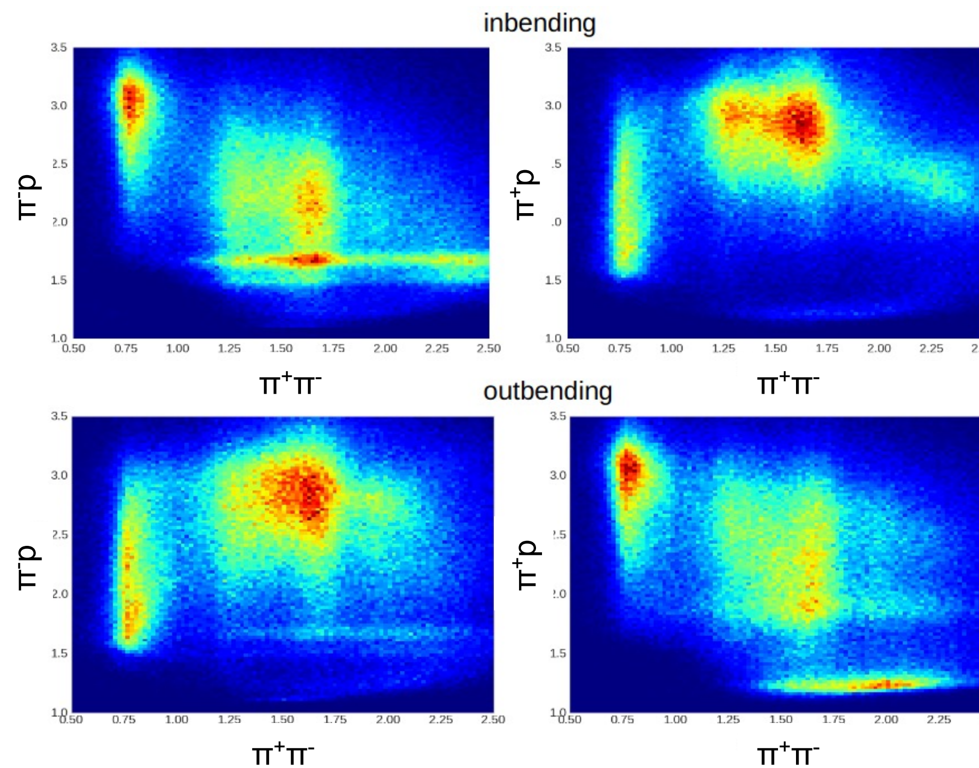
MesonEx: $\pi^+\pi^-$ p preliminary data



Data taking with toroidal field bending negative particles inward or outward

Data with both fields gives improved acceptance

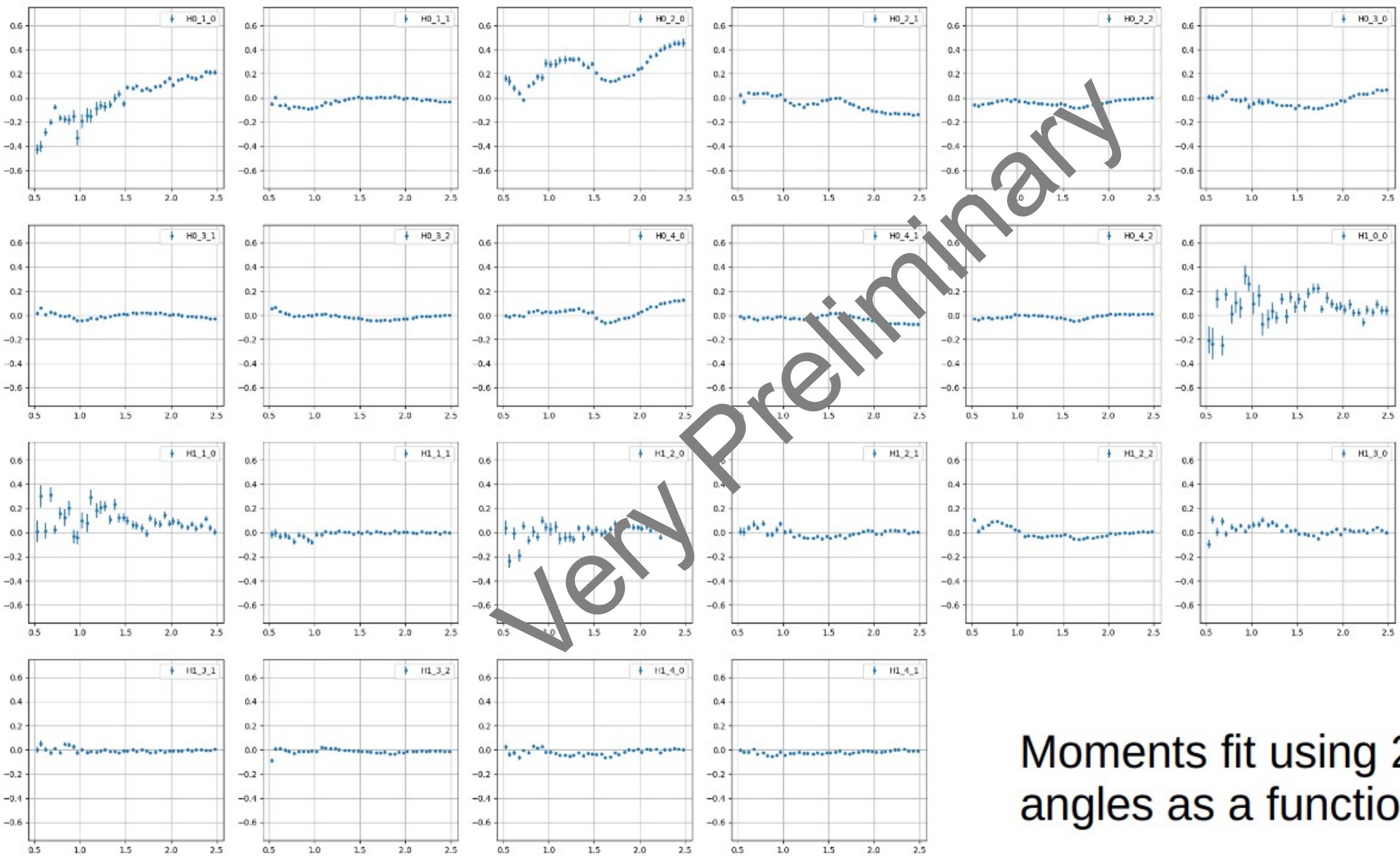




A. Thornton, University of Glasgow

MesonEx: $\pi^+\pi^-$ p preliminary data

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

A. Thornton, University of Glasgow

Summary

- CLAS12 spectrometer successfully in operation since 2018
- Data taking for realization of extensive physics program in progress
- Several analyses on beam spin asymmetries already published, including first spectroscopy results (N*)
- More to come from ongoing analyses in both baryon and meson sectors
- Statistics and reach to be extended with already approved data taking (>8 y)
- High luminosity upgrade (x2) already approved and being implemented