Meson Spectroscopy program at CLAS12

Nicholas Zachariou
(CLAS collaboration)

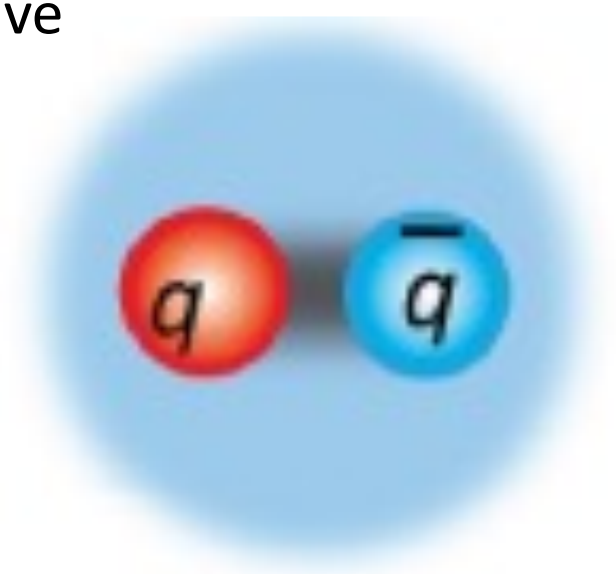
Outline

- Why spectroscopy of mesons?
- Jefferson Lab
- CLAS12 and the Forward Tagger
- MesonEX @ CLAS12

Why Meson Spectroscopy?

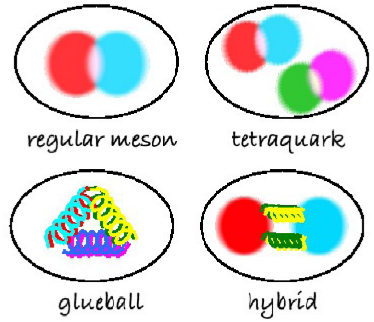
- QCD well understood in the high-energy, perturbative

  regime
- Understanding the dof in the non-perturbative regime is challenging
  - What is the role of gluons?
  - What is the origin of quark confinement?
- Measuring the spectrum of hadrons allows a comprehensive understanding of the strong force

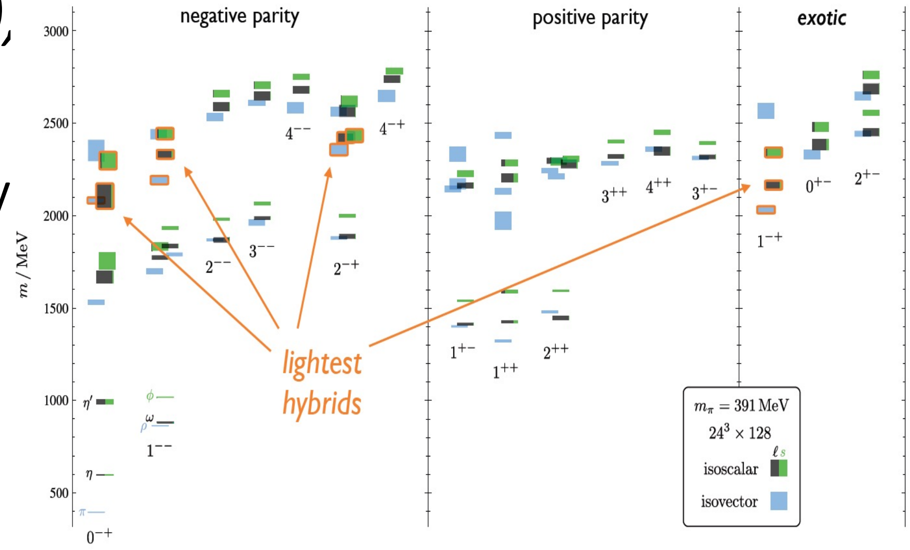


Why Meson Spectroscopy?

- Mesons→ Simplest bound system to study
- QCD does not prohibit the existence of unconventional meson states -- *hybrids (qqg), tetraquarks (qqqq),* and *glueballs*.
  - Identification can be difficult → mix with ordinary states
  - Unique signature: Exotic quantum numbers

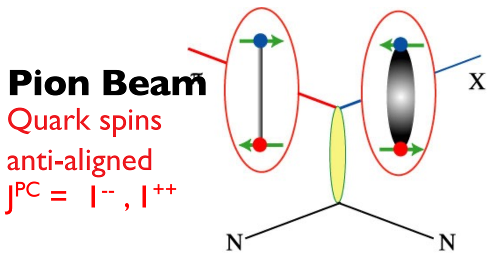


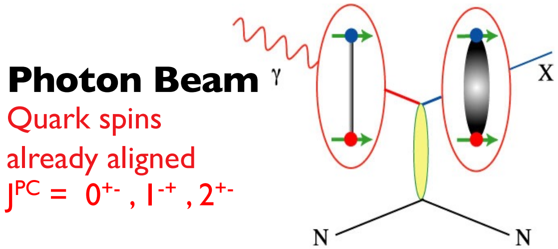
Dudek, Edwards, Guo, and Thomas, PRD 88, 094505 (2013)

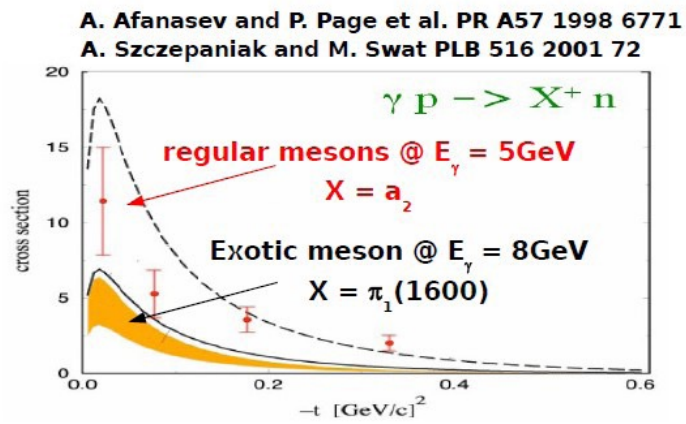


What has been done already?

- Various approaches including hadron production, NN annihilation, …
- Photoproduction – Limited due to low-quality/luminosity experiments
  - Exotic J^{PC} more likely to be produced by S=1 probe
  - Polarised beams can simplify extraction of Partial Waves
  - Production rates for exotics comparable to regular mesons

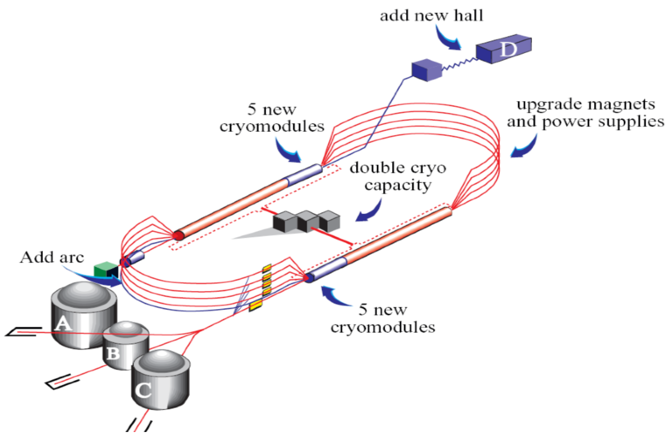






Thomas Jefferson Laboratory

- CEBAF Accelerator
- Recently upgraded to 12 GeV electron beams
  - 4 experimental halls
  - Racetrack accelerator (LINACs) allowing multi-pass beam acceleration
  - High-quality beams ~100% duty cycle
  - Highly polarized beams ~80%
  - High currents up to 100 μA (Halls A and C)

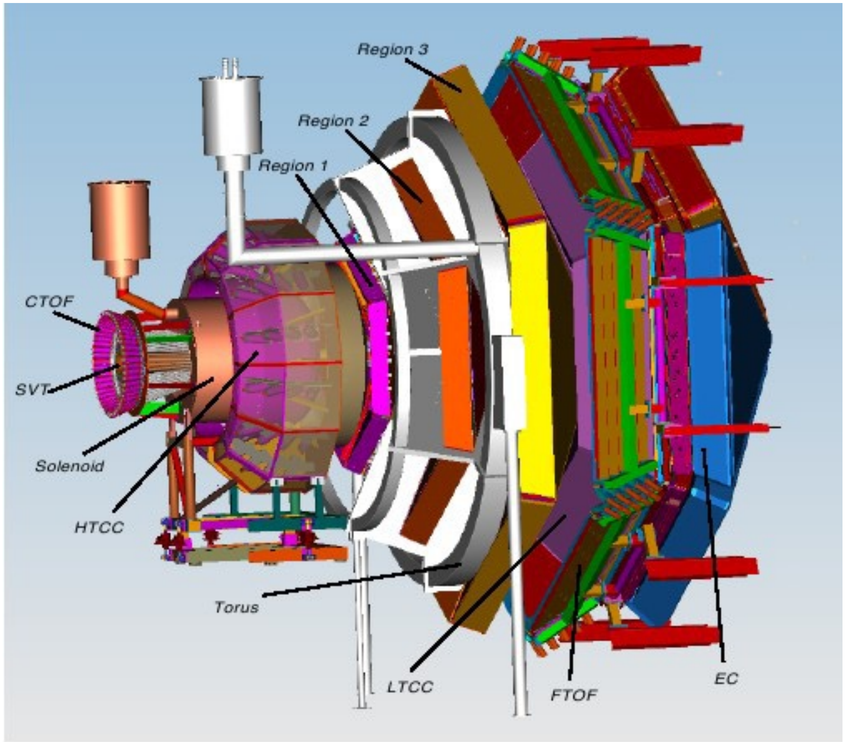


CEBAF Large Acceptance Spectrometer

- CLAS12 provides an efficient detection of charge and neutral tracks
  - Based on solenoid (CD) and toroidal (FD) magnetic fields
  - Excellent for multi-particle final states
  - Excellent PID: TOF, Cerenkov, RICH (charged), calorimeter (neutral)

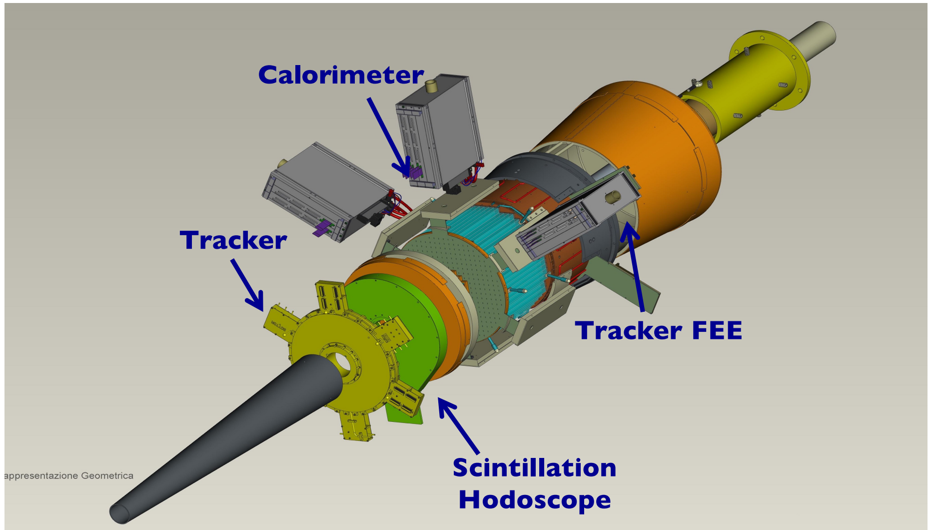
Nominal Luminosity: $L=10^{35}\ cm^{-2}\ s^{-1}$
Momentum resolution (FD): $dp/p < 1\%$
Θ resolution= 1 mrad
Φ resolution= 1 mrad/sin Θ
Timing resolution TOF = 100 ps

π/K separation: 4σ separation up to 2.8 GeV
K/p separation: 4σ separation up to 4.8 GeV
π/p separation: 4σ separation up to 5.4 GeV



The Forward Tagger

- Installed July 2017
- Composed of :
  - Tracker
  - Scintillation Hodoscope
  - Calorimeter

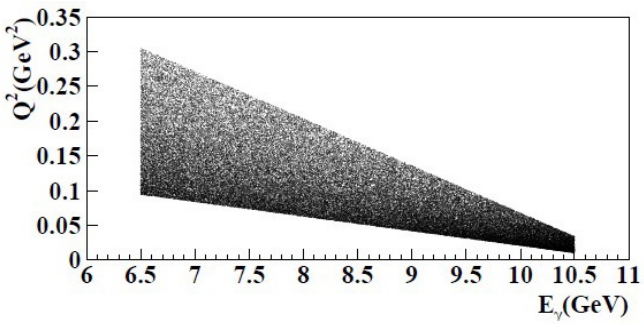


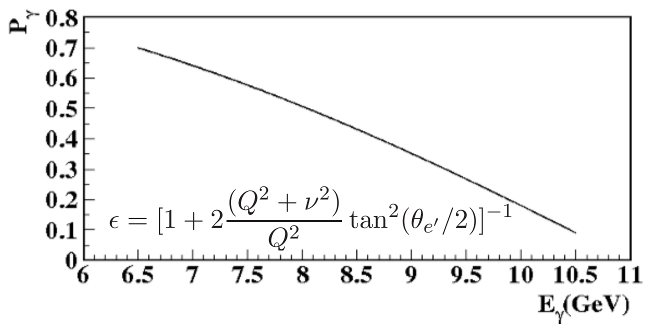
PARAMETER	DESIGN VALUE
FT-Cal	
Calorimeter type	PbWO4, homogeneous
Crystal number and size	332, 15x15x200 mm^3
Readout sensors	Hamamatsu LAAPD s8664-1010
Working Temperature	T = (0 – 18) ^oC ($\Delta T \leq 0.1\ ^oC$)
FT-Trck	
Tracking technology	two double-layers, bi-face bulk MicroMega
Detector type	Strips, 3392 channels
Spatial resolution	$\Delta X, \Delta Y \leq 150\ \mu m$
FT-Hodo	
Detector technology	2 layers of plastic scintillator tiles
Tiles number and size	74 (30x30x15 mm^3) + 42 (15x15x7 mm^3)
Readout sensors	Hamamatsu SiPM S10362-100
Expected Performance	**VALUE**
Azimuthal angular coverage	2.5^o to 4.5^o
EM shower energy range	$E_{max}-E_{min}$= (0.5 – 8.0) GeV
Energy resolution	$\sigma_E/E \leq 2\%/\sqrt{E(GeV)} \oplus 1\%$
Angular resolution	$\sigma_\vartheta/\vartheta \leq 1.5\ \%$, $\sigma_\varphi \leq 2^o$
Time resolution	≤300 ps

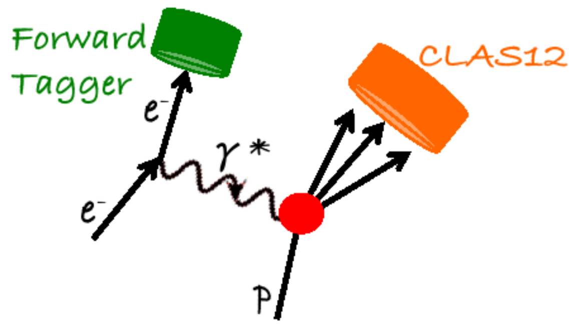
Contributors: CEA, INFN-Ge, INFN-Roma2, INFN-Torino, U. York, U. Glasgow, JLab, James Madison U., Norfolk State U., Ohio U.

MesonX Experiment

- Quasi-real photoproduction on proton target
  - Detail study of light-quark meson spectrum (1.0 – 3.0 GeV)
  - Determine masses and properties of rare qq states
  - Search and identify exotic mesons







Forward Tagger	
E’	0.5-4.5 GeV
ν	7-10.5 GeV
θ	2.5-4.5 deg
Q^2	0.007 – 0.3 GeV^2
W	3.6-4.5 GeV
Photon Flux	5 x 10^7 γ/s @ $L_e=10^{35}$

- Data collection started in 2018
- ~50% of the allocated beam time already carried out
- Dedicated trigger - coincidence on FT EM shower + 2 charged hadrons in CLAS12

Meson Experiment

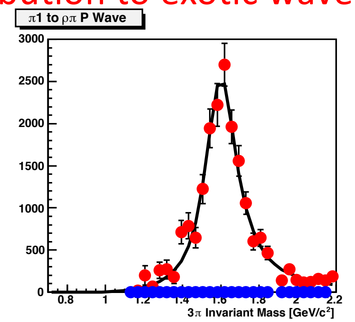
- Expected results
  - Isobar model 3pi production

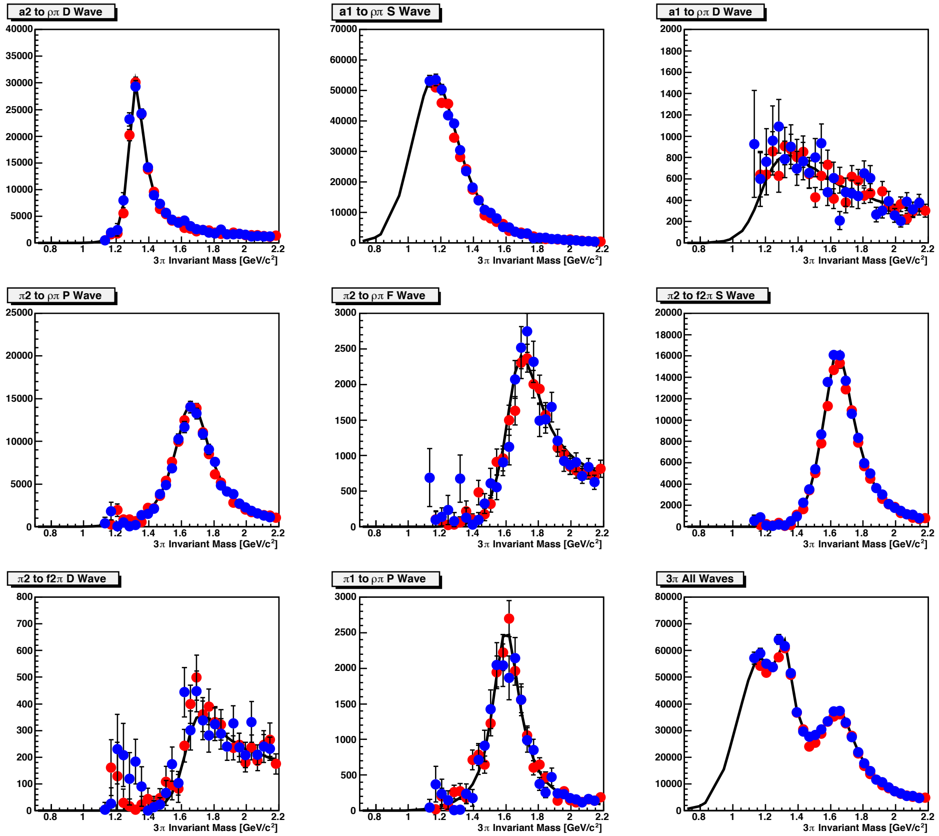
State	J^{PC}	L	Decay Mode
$a_1(1260)$	1^{++}	D	$\rho\pi$
$a_2(1320)$	2^{++}	D	$\rho\pi$
$\pi_2(1670)$	2^{-+}	P	$\rho\pi$
$\pi_2(1670)$	2^{-+}	F	$\rho\pi$
$\pi_2(1670)$	2^{-+}	S	$f_2\pi$
$\pi_2(1670)$	2^{-+}	D	$f_2\pi$
$\pi_1(1600)$	1^{-+}	P	$\rho\pi$

2%

$\sigma_{Tot} \simeq 10\mu barn$

Leakage contribution to exotic waves from others: < 1%

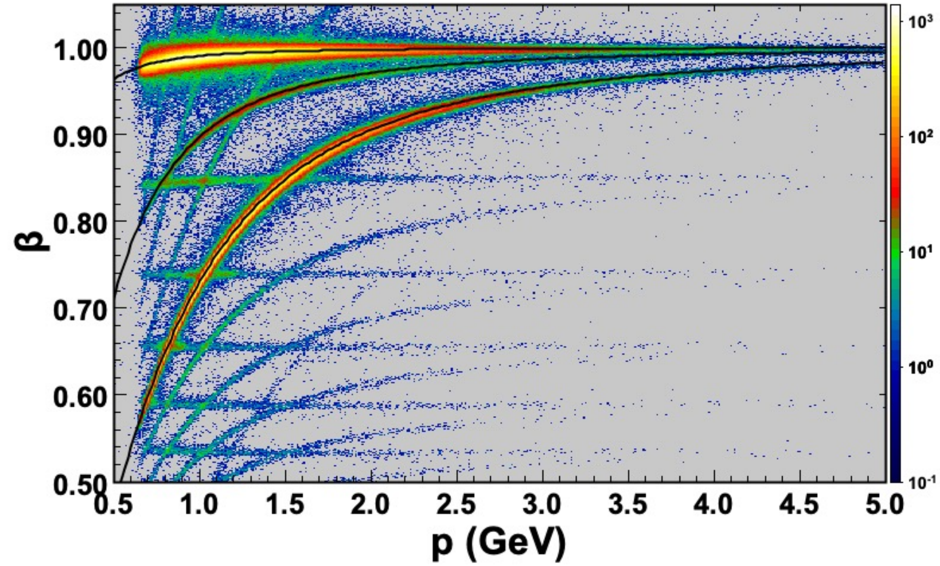


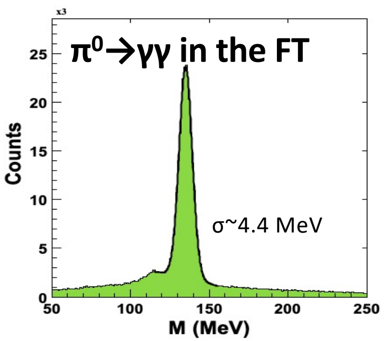


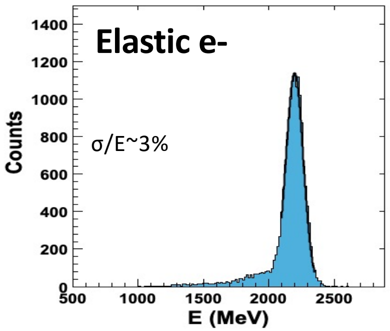
Black: generated, Red: t=-0.5 GeV^2, Blue: t=-0.2 GeV^2 (D. Glazier, U. Glasgow)

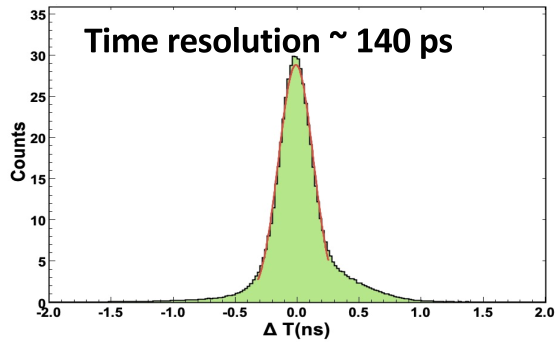
Meson Experiment

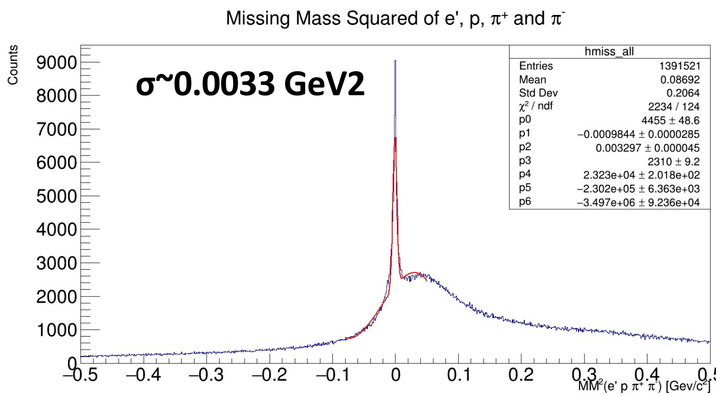
- First look at FT data
- Energy Calibrations on π^0 2-photon decay
- Timing calibration exceed specifications (300 ps)
- Energy resolution ~ 3%@2GeV still +1% higher than specs









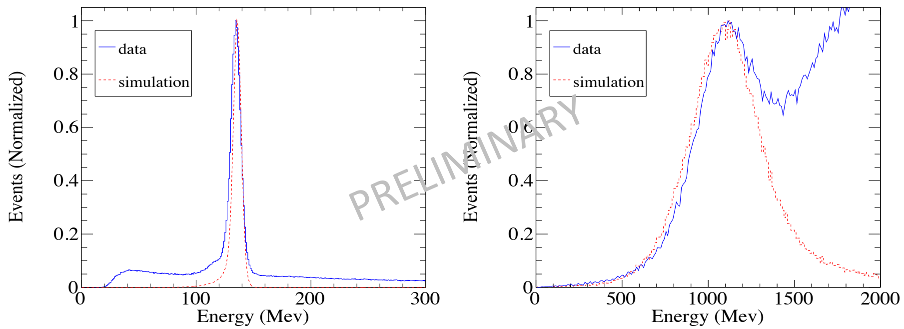


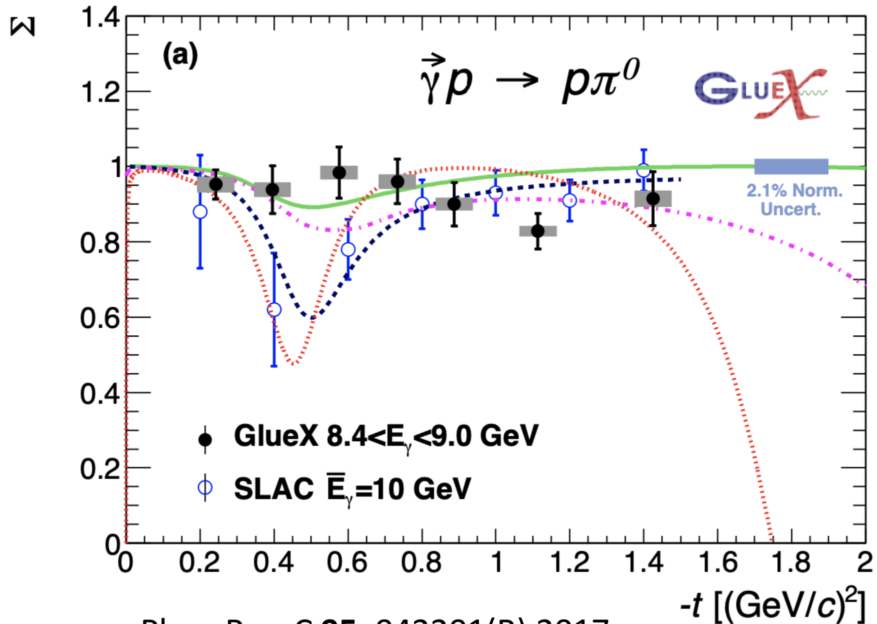
* Lucilla Lanza & Raffaella De Vita

Meson Experiment – First analysis

$$\vec{\gamma} p \rightarrow p\pi^0$$

- Inconsistent results between GlueX and SLAC
- CLAS12 - Reconstruction of reaction from π^0 and e' in FT
- Straightforward determination of Σ and dσ/dt
- Results expected early 2022





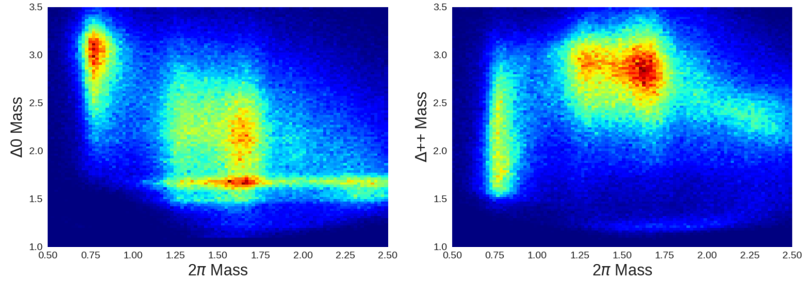
Phys. Rev. C **95**, 042201(R) 2017

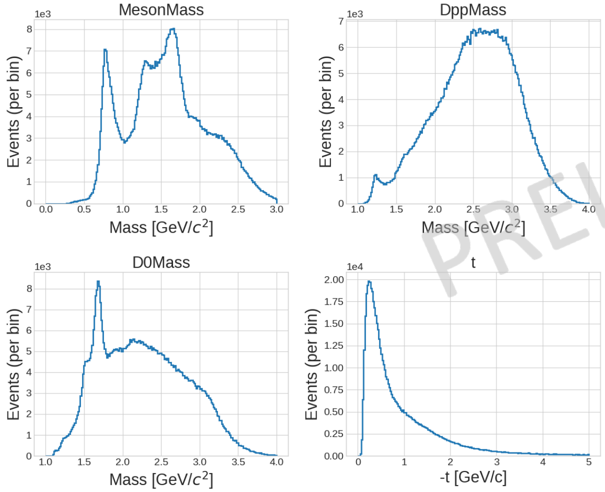
L. Biondo Messina U.

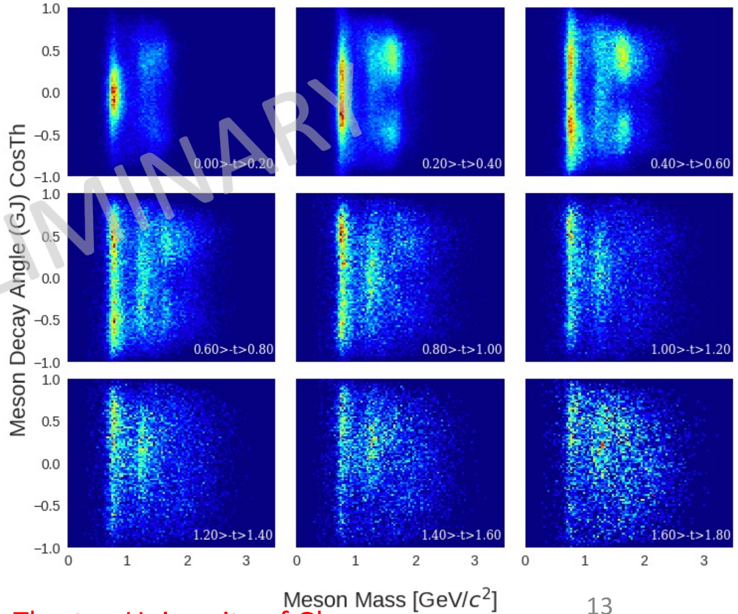
Meson Experiment – Benchmark reaction

$$\vec{\gamma} p \to p\pi^+\pi^-$$

- Fully exclusive reaction
- Determination of moments
  - Phys. Rev. D 100, 054017
- Moments fit using 2pi decay angles as a function of 2pi mass
- Technique successfully applied to CLAS6 data:
  - PHYSICAL REVIEW D 80, 072005 (2009)
  - PHYSICAL REVIEW D 98, 052009 (2018)







A. Thorton University of Glasgow

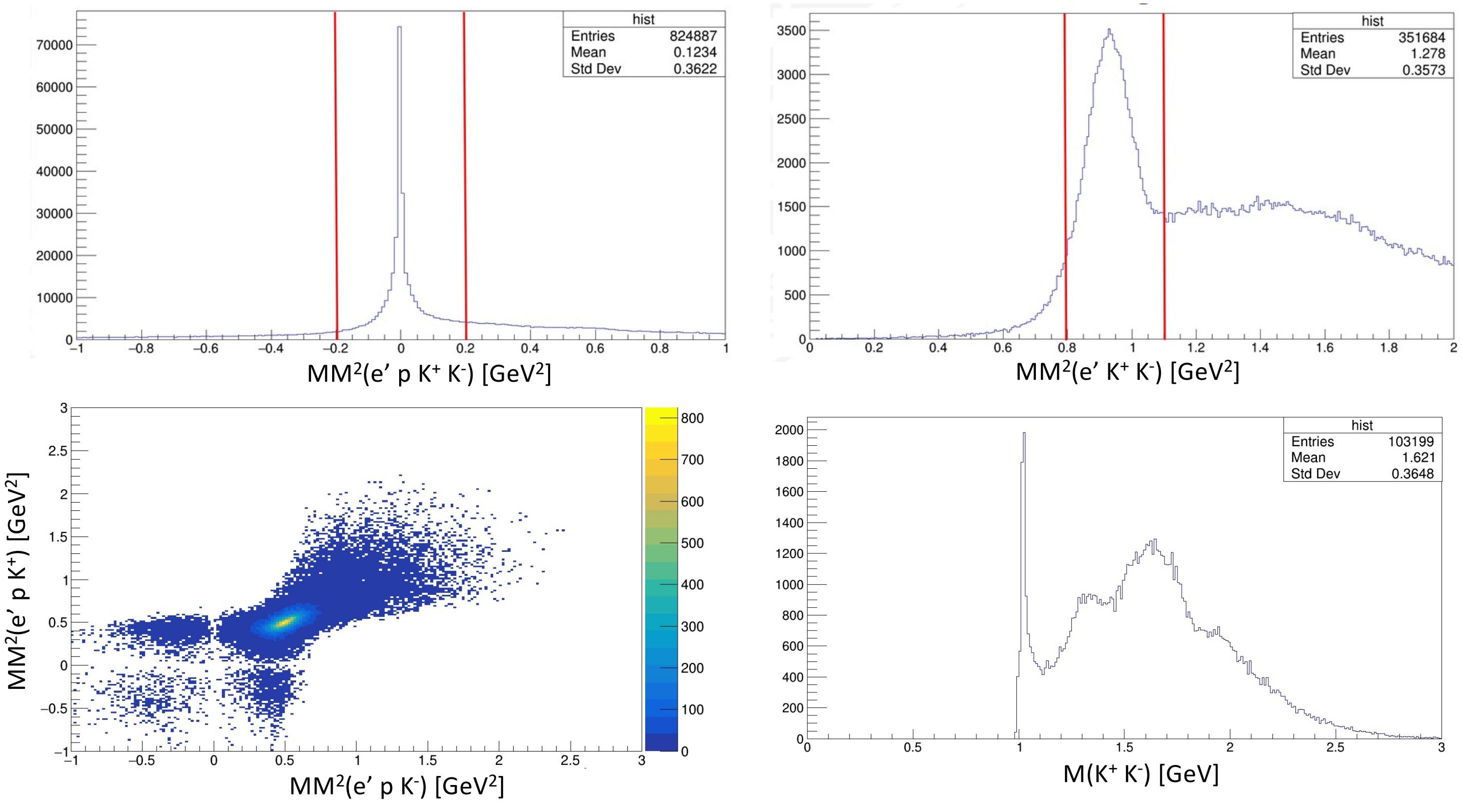
Meson Experiment
$$\vec{\gamma} p \rightarrow p K^+ K^-$$

Analysis procedure is identical to 2 pion channel

Exclusivity of the reaction allows clean(er) signal

Rich mass spectrum observed

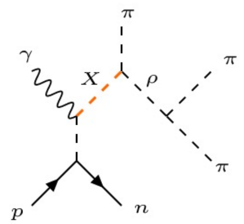
Next steps: Study of angular distribution in 2K system



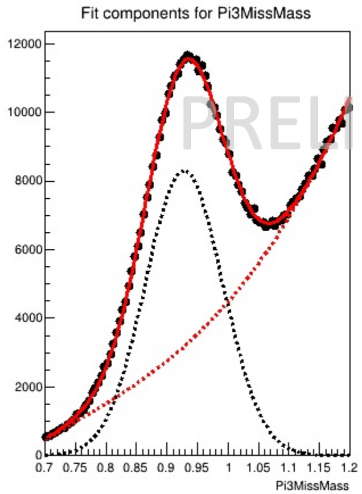
M. Nicol University of York

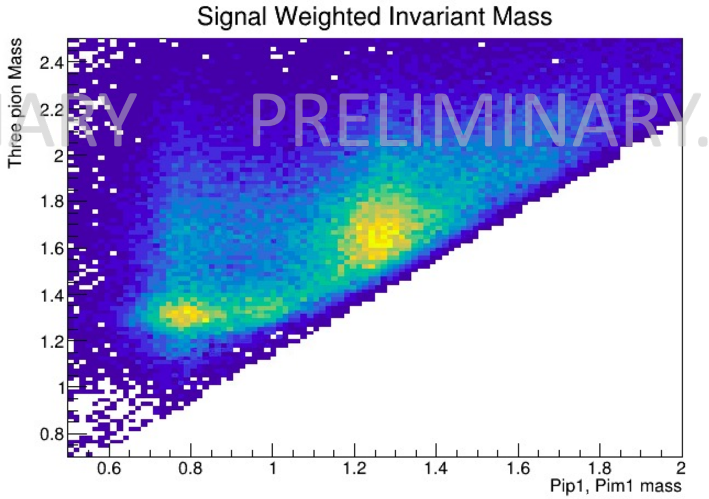
Meson Experiment – Exotic search

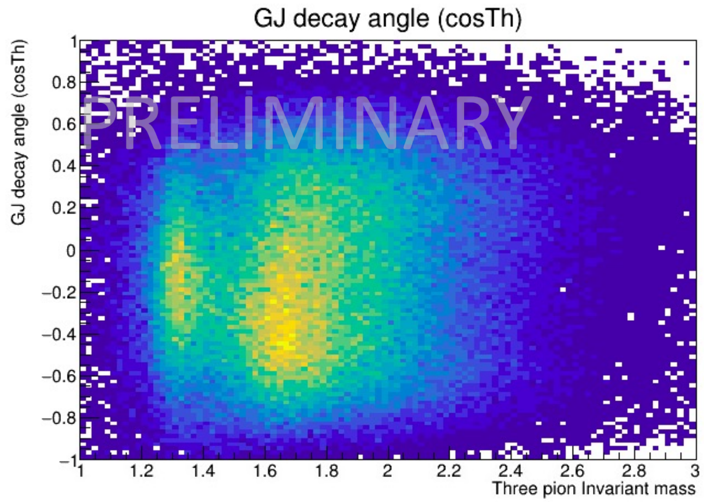
$$\vec{\gamma} p \to \pi^+ \pi^+ \pi^- n$$



- Key reaction for exotic search
- Missing-mass technique with 3 pion ID
- Background significant but contributions understood







First fits to 3 body final state via 4 decay angles have been done on small data set

Summary

- Recent developments in accelerator and detector advancements allow the detailed study of meson spectrum via photoproduction experiments
- MesonX aims at searching for exotic mesons and studying in detail the light-quark meson spectrum up to masses of 2.5 GeV.
- Data analysis well underway (50% of statistics)
- First results expected in 2022