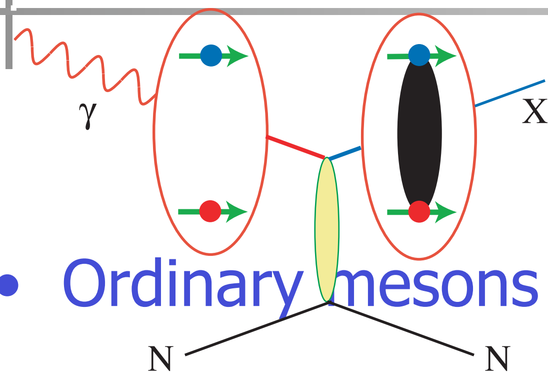
Gluonic excitations and the GlueX experiment at JLab

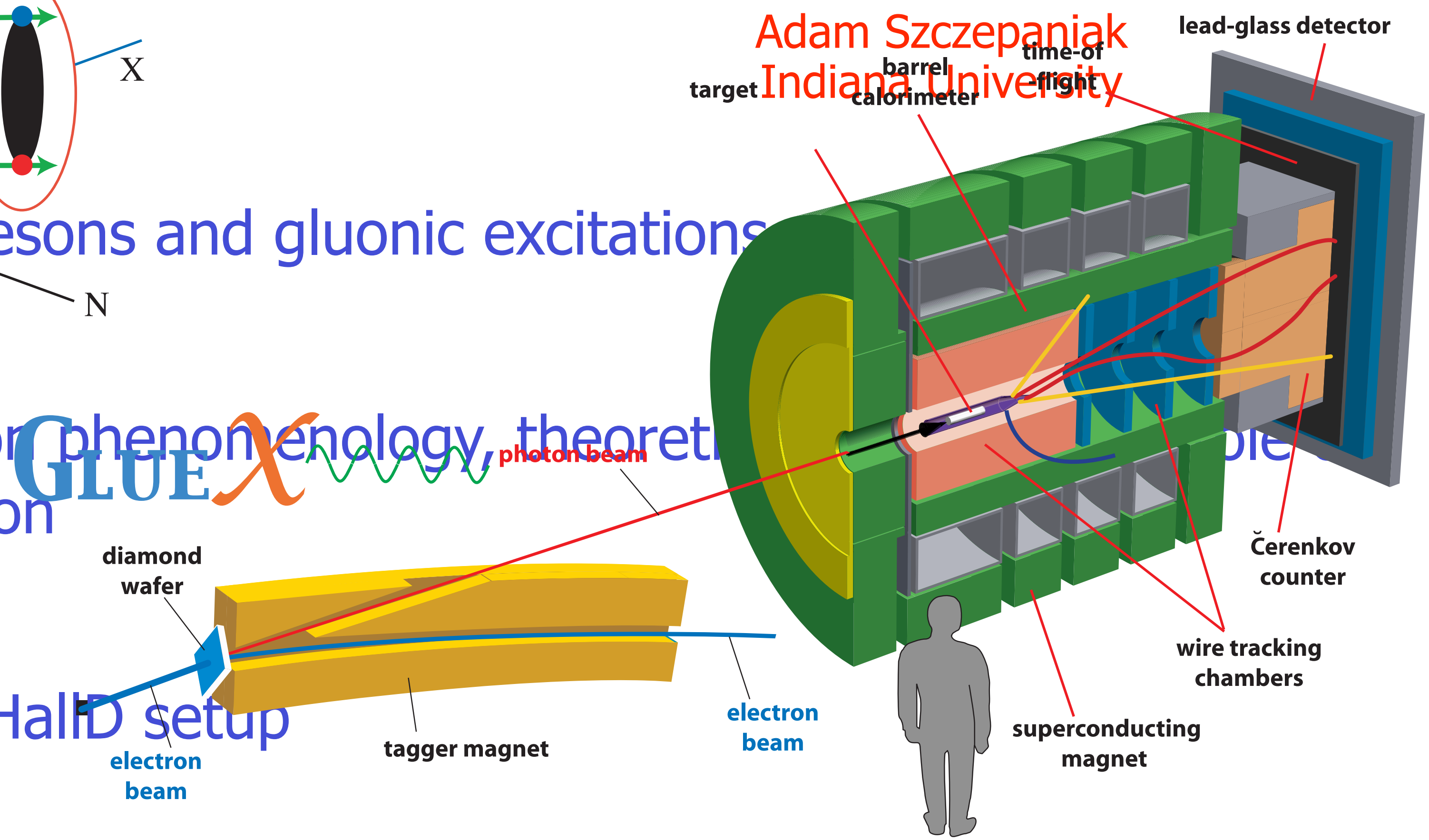
Adam Szczepaniak
Indiana University



- Ordinary mesons and gluonic excitations

- Exotic meson phenomenology, theoreti … photoproduction

- The GlueX/HallD setup



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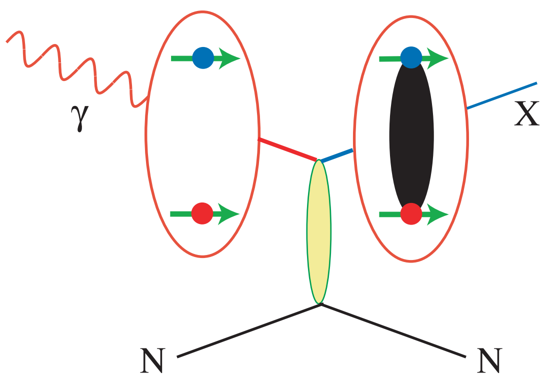
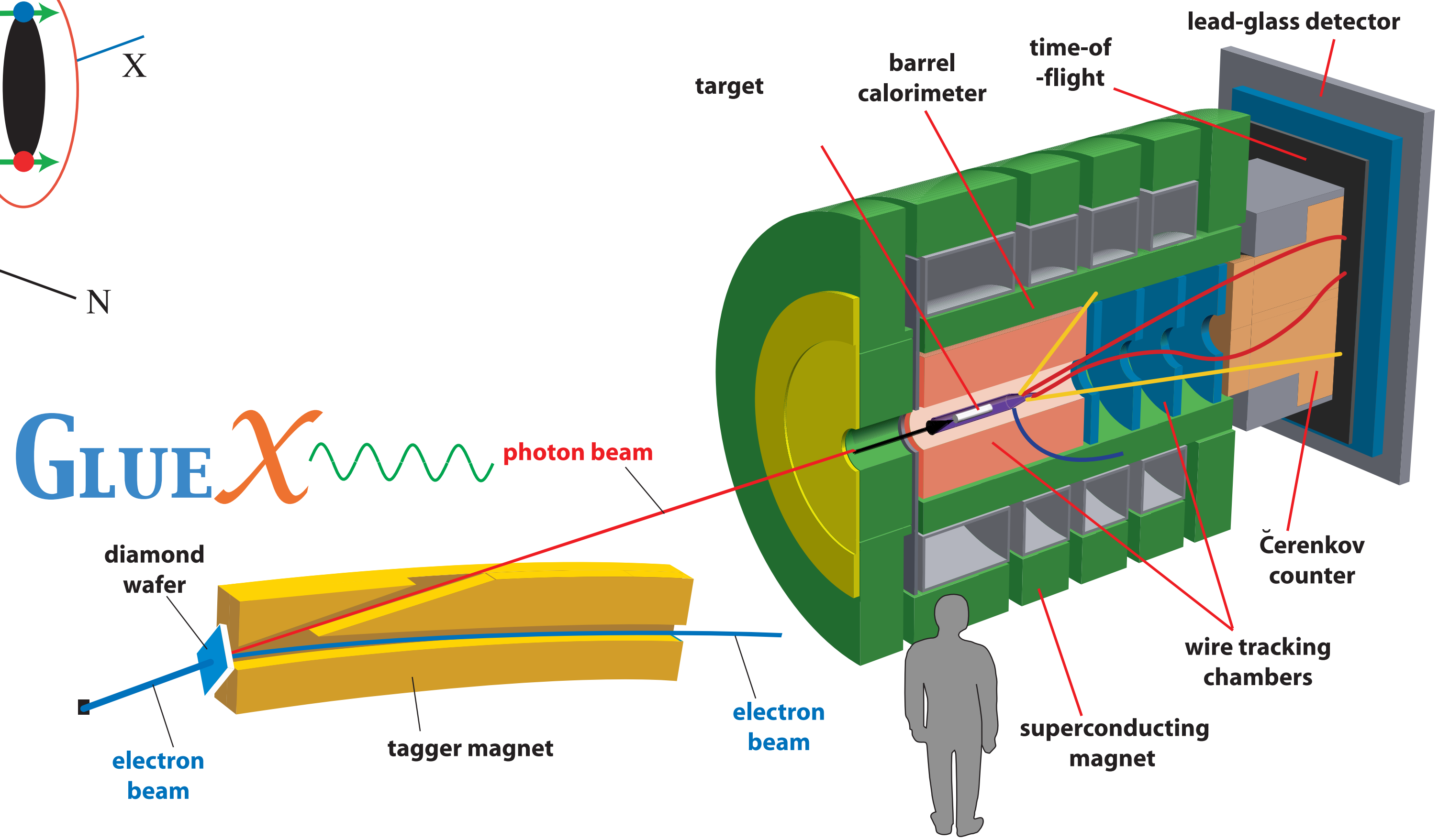
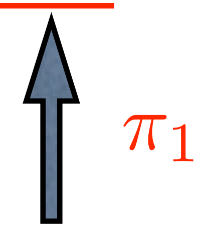
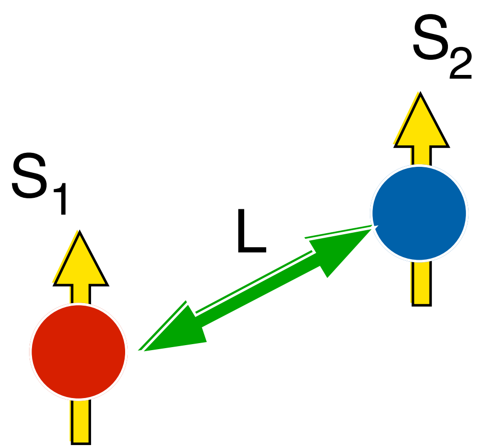




Mesons with $J^{PC} = 0^{--}, 0^{+-}, \underline{1^{-+}}, 2^{+-}$: Exotic Quantum Numbers





$S = S_1 + S_2$

$J = L + S$

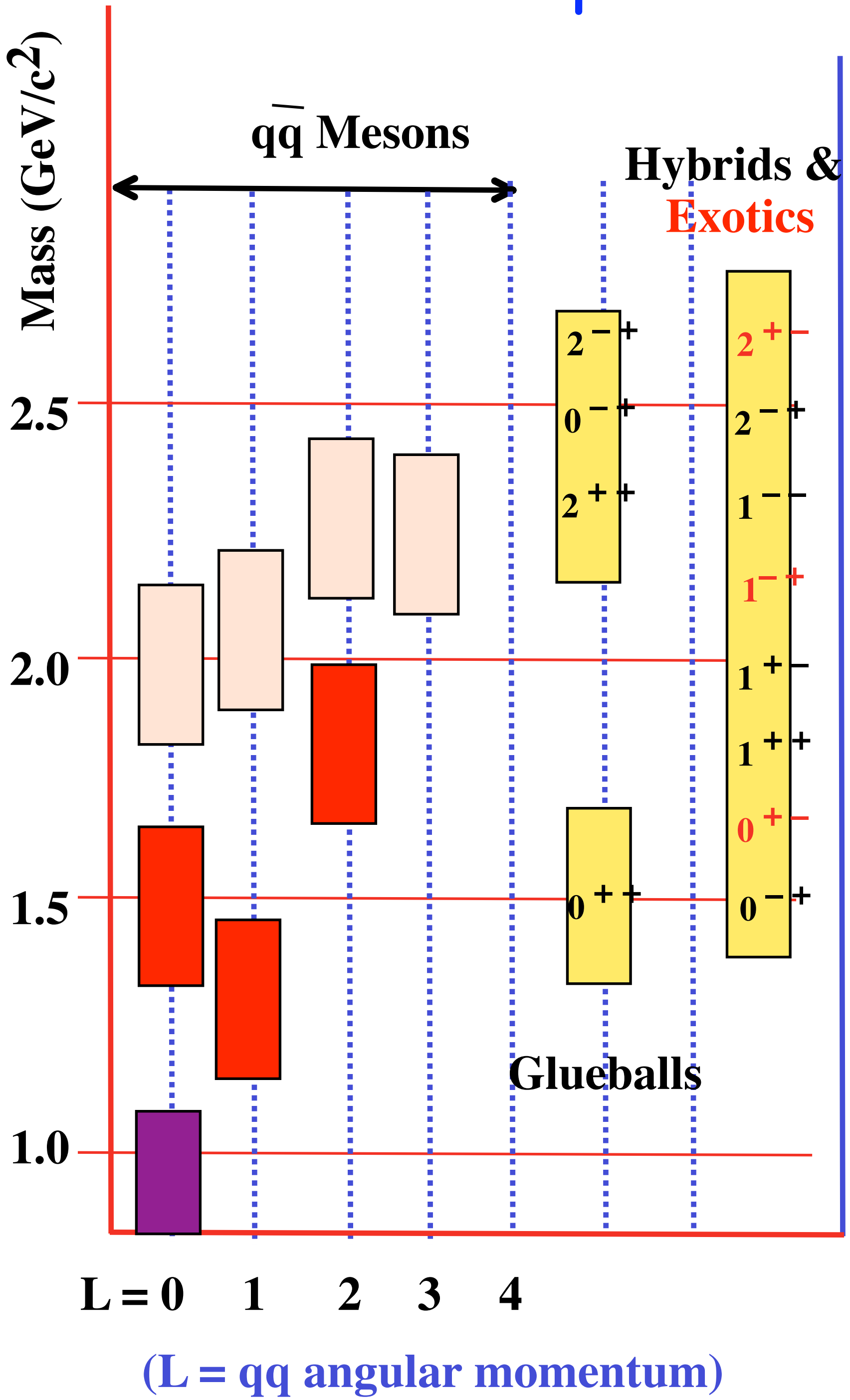
$P = (-1)^{L+1}$

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

Determine J^{PC} through Partial Wave Analysis

Don’t have to be multi-quark states
but can be from the excitations of the confining (gluon) field
→ Probe of the confinement mechanism

Meson Map



well known states

$\pi, K, \eta, \eta', \rho, K^*, \omega, \phi$

radial and orbital excitations

$\pi', \rho', a_2, b_1, \rho_3, \cdots$

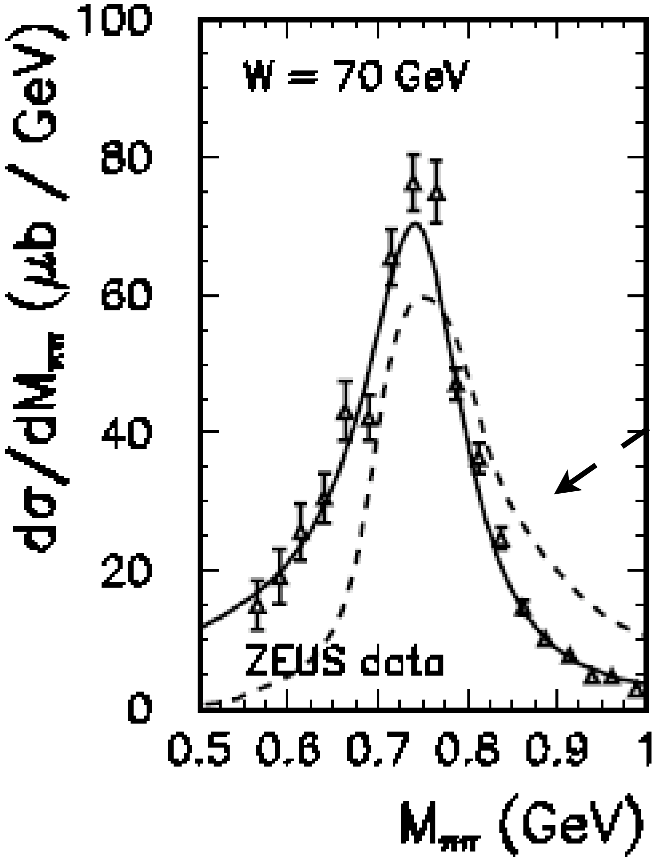
higher excitations

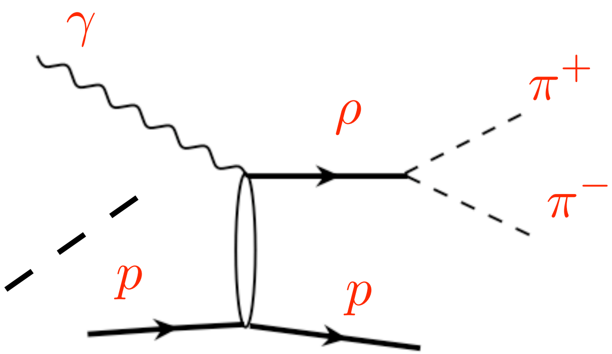
$X(1600), X(1650), X(1750), \cdots$

Most mesons are resonances and if they are broad they have to be de-convoluted from other effects (e.g. Deck production of a_1)

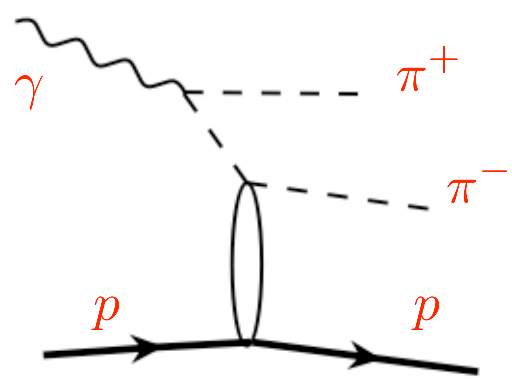
Gluex : Map out (narrow) and exotic mesons.

Backgrounds should be understood





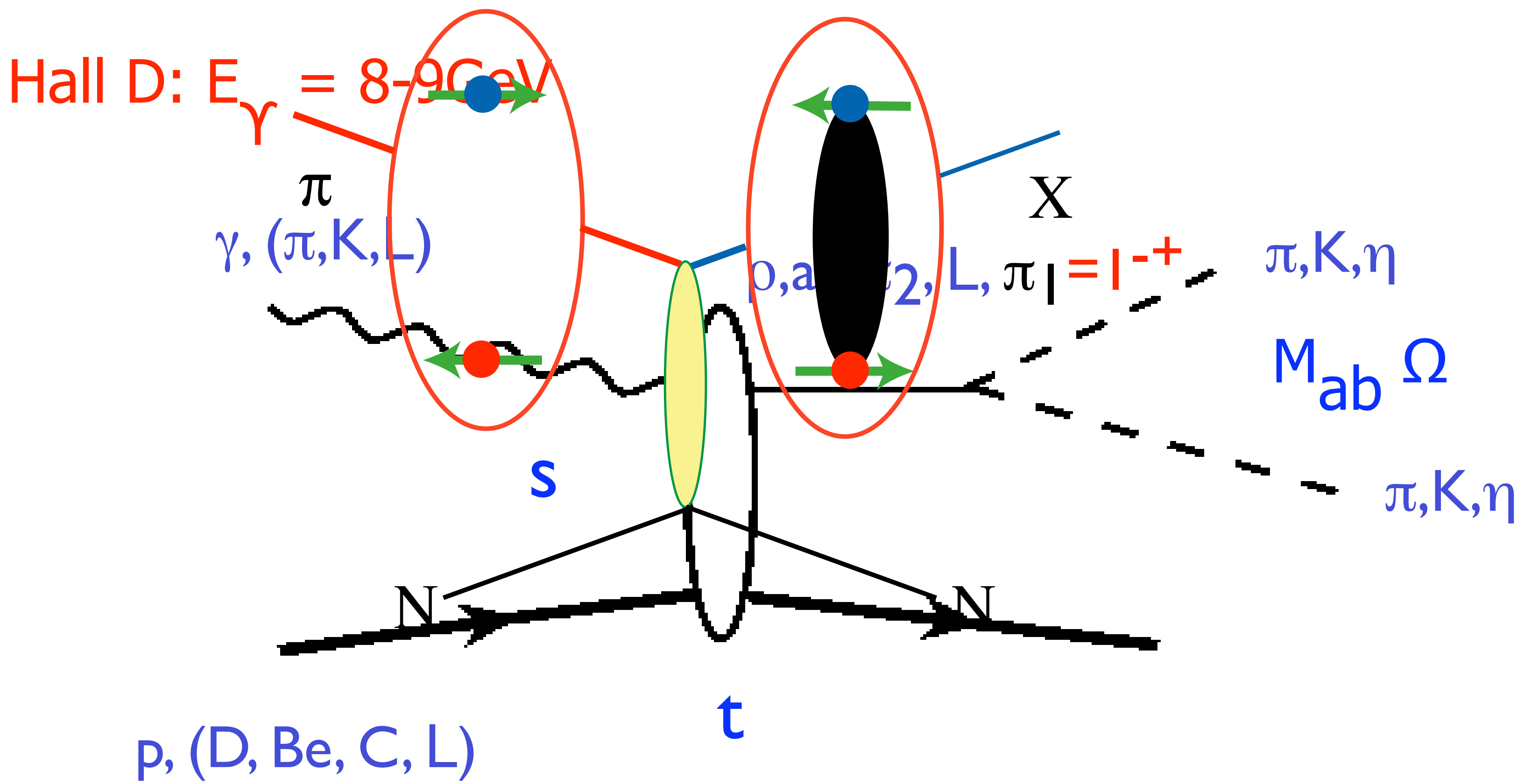
Inelastic diffraction, (W > 2 GeV)



$$\sigma(\pi^+ p \to \pi^+ p) \neq \sigma(\pi^- p \to \pi^- p)$$

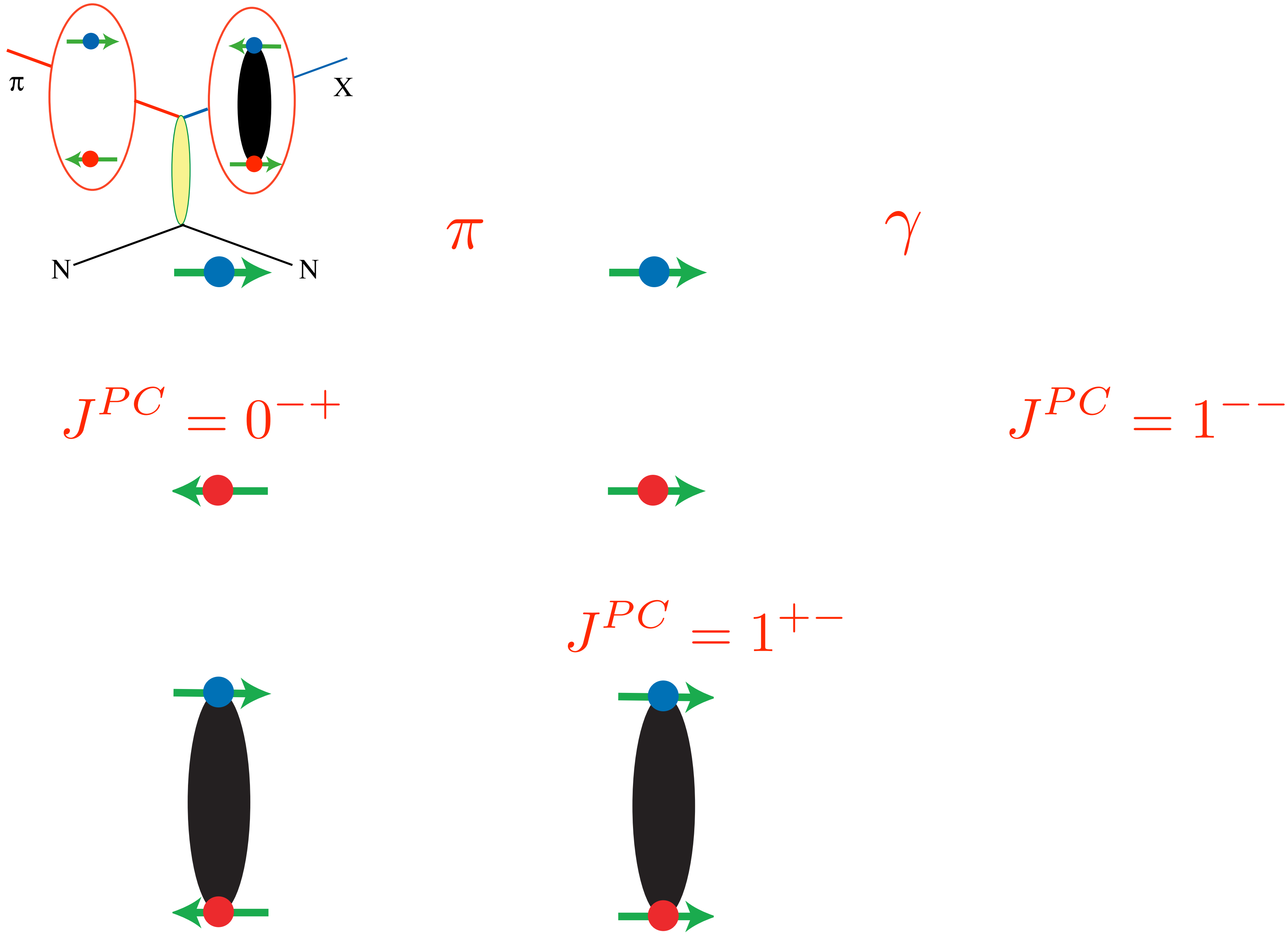
A.Szczurek, AS. (in prep.)

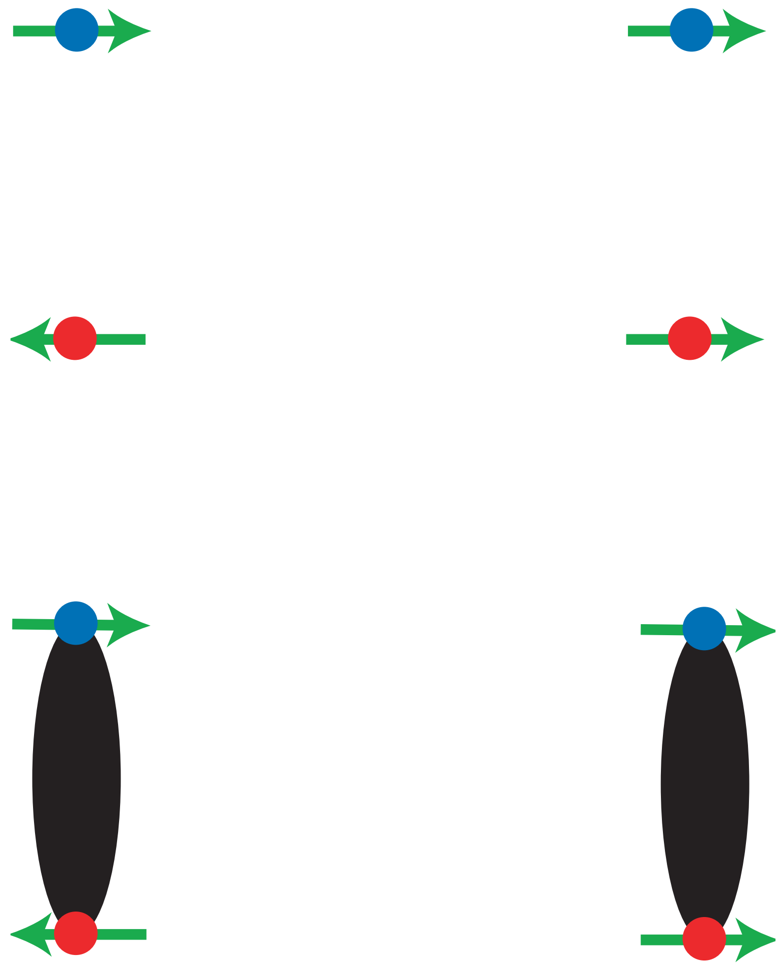
Exciting (exotic) meson resonances



Peripheral production on the “meson cloud”

It is important to determine dependence on all kinematical variables, s,t,M_{ab} Ω


π
X
N
N
π
γ
$J^{PC} = 0^{-+}$
$J^{PC} = 1^{--}$
$J^{PC} = 1^{+-}$

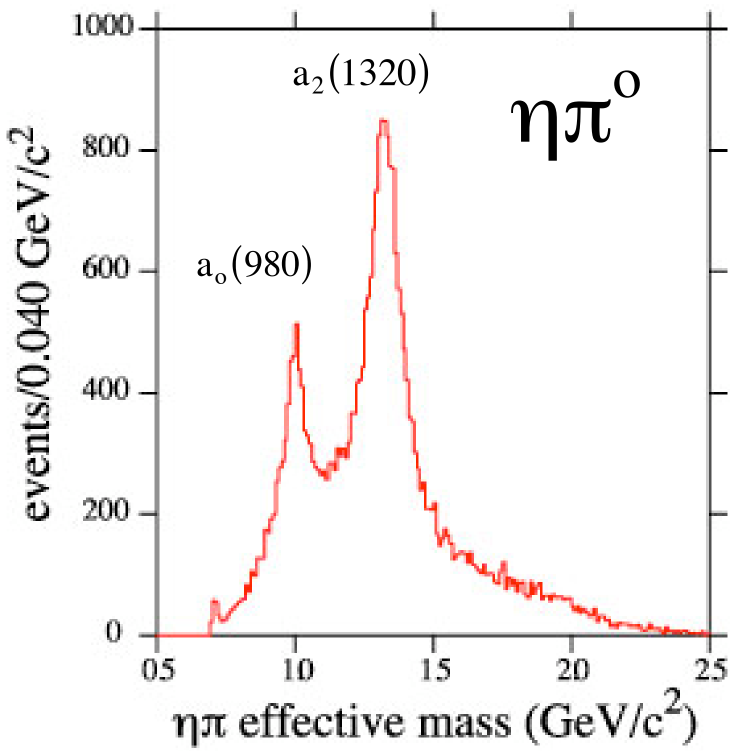


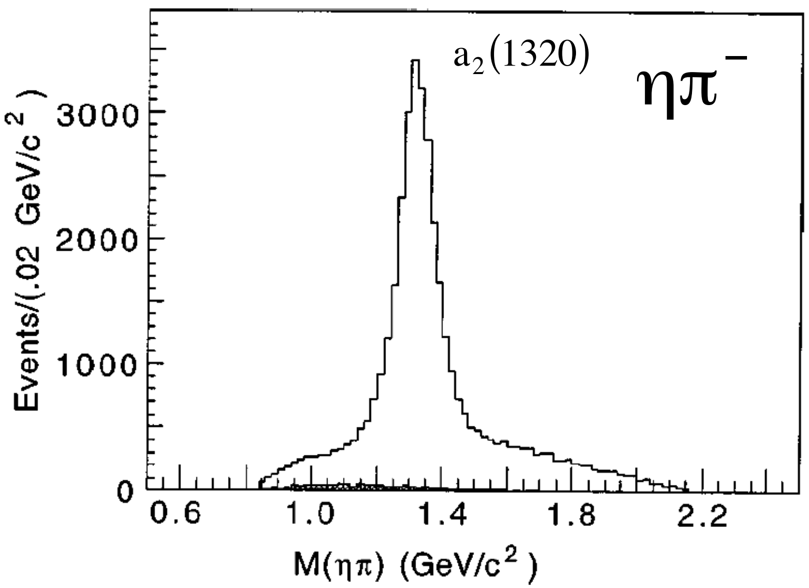
$\eta\pi$ Production

$$\pi^-(18\ \text{GeV})p \rightarrow \begin{cases} \eta\pi^0 n \\ \eta\pi^- p \end{cases}$$

Neutral vs charged production:

- ✓ C is a good quantum number
- ✓ a_0 and a_2 are produced
- ✓ only one detector involved





Exotic story

$\pi^- p \to \eta \pi^0 N$
$\to \eta \pi^- p$

$(\eta\pi^0)$ in P-wave has $J^{PC}=1^{-+}$!

$\pi^- p \to \eta \pi^- p$

$M = 1370 \pm 16^{+50}_{-30}$ MeV / c^2

$\Gamma = 385 \pm 40^{+65}_{-105}$ MeV / c^2

BNL (E852)
Confirmed by
Crystal Barrel similar mass, width

$\pi^- p \to \eta \pi^0 n$

Mass dependent P-wave present in $\eta\pi^0$ (E852)

New results: No consistent B-W resonance interpretation for the P-wave

---

$\pi^- p \to \eta' \pi^- p$

$M = 1597 \pm 10^{+45}_{-10}$ MeV / c^2

$\Gamma = 340 \pm 40^{+50}_{-50}$ MeV / c^2

(E852)

P-wave consistent with meson-meson re-scattering
(Final State Interactions)

$\pi^- p \to \rho^0 \pi^- p$

$M = 1593 \pm 8^{+29}_{-47}$ MeV / c^2

$\Gamma = 168 \pm 20^{+150}_{-12}$ MeV / c^2

(E852) Confirmed by
VES

More E852 3π data currently being analyzed

$M = 1709 \pm 24 \pm 41$ MeVc^2

$\pi^-\pi^-\pi^+\eta = f_1\pi^-$ $\quad \Gamma = 403 \pm 80 \pm 115$ MeVc^2

$\pi^+\pi^-\pi^-\pi^0\pi^0 = b_1\pi^-$ $\quad \Gamma = 185 \pm 25 \pm 28$ MeVc^2

More from (E852)

Theoretical expectations

Light quark 1^{-+}

Ref.	Method	N_f	M (GeV)
UKQCD 97	SW	0	1.87(20)
MILC 97	W	0	1.97(9)(30)
MILC 99	SW	0	2.11(10)
LaSch 99	W	2	1.9(2)

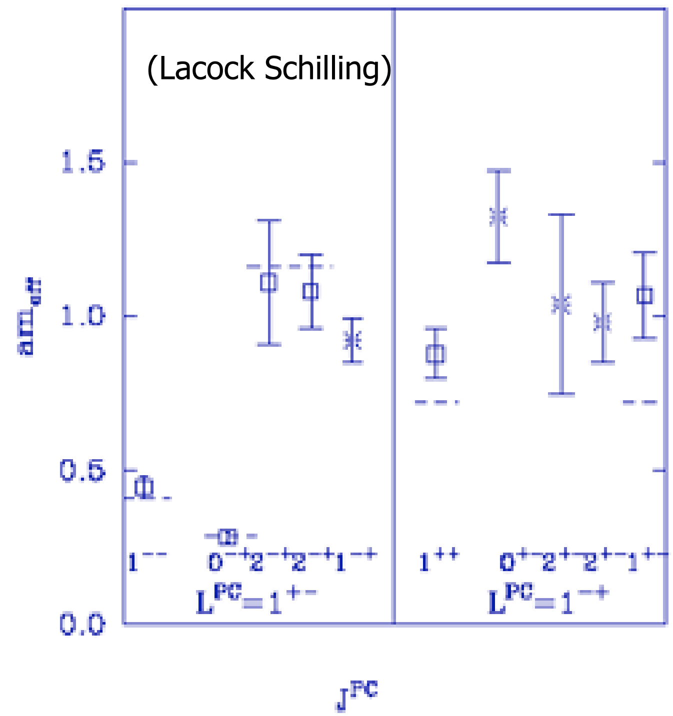
Calculation of lightest 1^{-+} Exotic suggests mass $\sim$ 2GeV

Charmonium 1^{-+}

Ref.	Method	ΔM (GeV)
MILC 97	W	1.34(8)(20)
MILC 99	SW	1.22(15)
CP-PACS 99	NR	1.323(13)
JKM 99	LBO	1.19

Excitations in excess of 1GeV

Lattice predictions



- $J^{PC} = 1^{-+}$ lowest state
- Higher masses difficult to resolve
- Chiral extrapolations 100-200 MeV

Thomas.AS

Decays

- Normal widths !

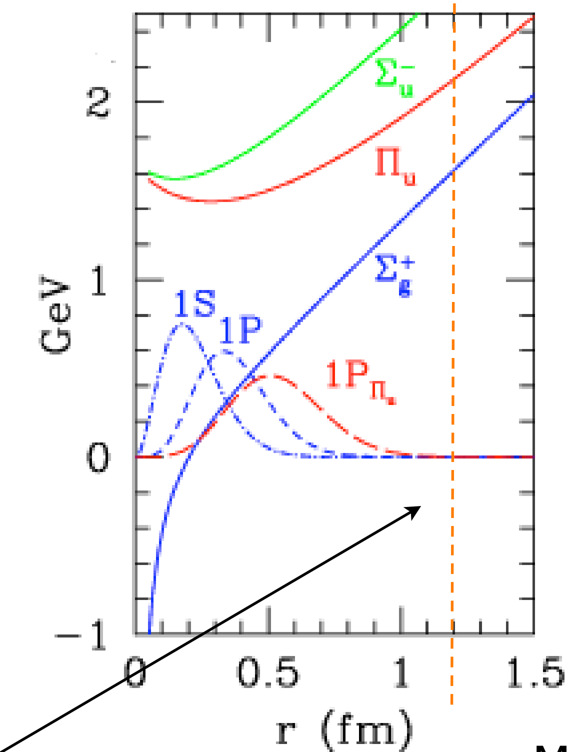
In large N_C same as for ordinary mesons $O(1/N_C)$ T. Cohen (98)

- Unusual decay modes !

Isgur, Kokosy, Paton (85)
Page, Swanson, AS (99)

1^{-+} (1.8 GeV)	$b_1\pi$	$f_1\pi$	$\rho\pi$	
PSS	S 73 D 1	S 9 D 0.04	P 13	Γ MeV
IKP	S 51 D 11	S 14 D 7	P 12	

Close, Dudek (04)



Juge, Kuti, Morningstar (99)

- Compact wave functions!

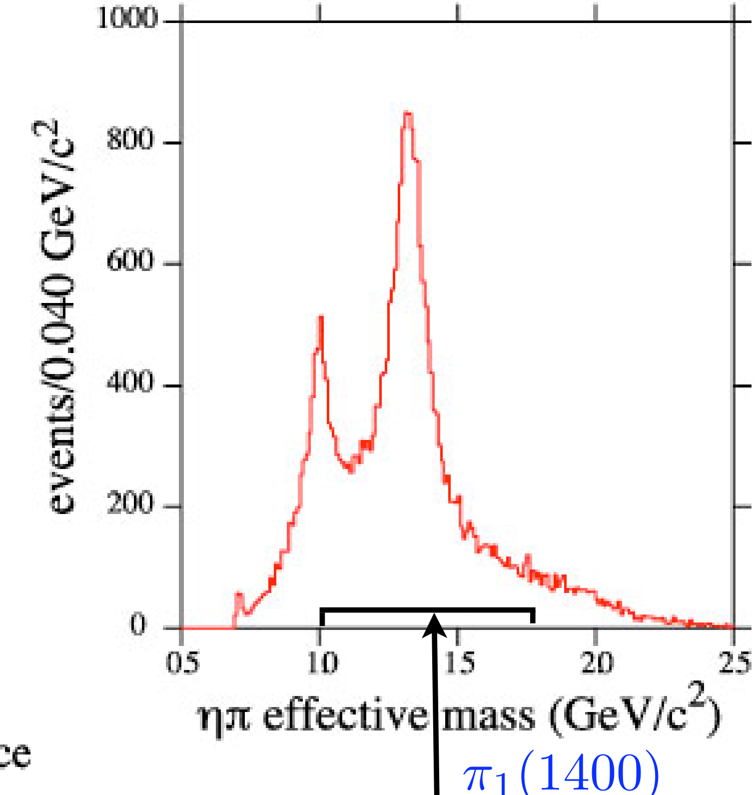
- Low lying states expected below string breaking !

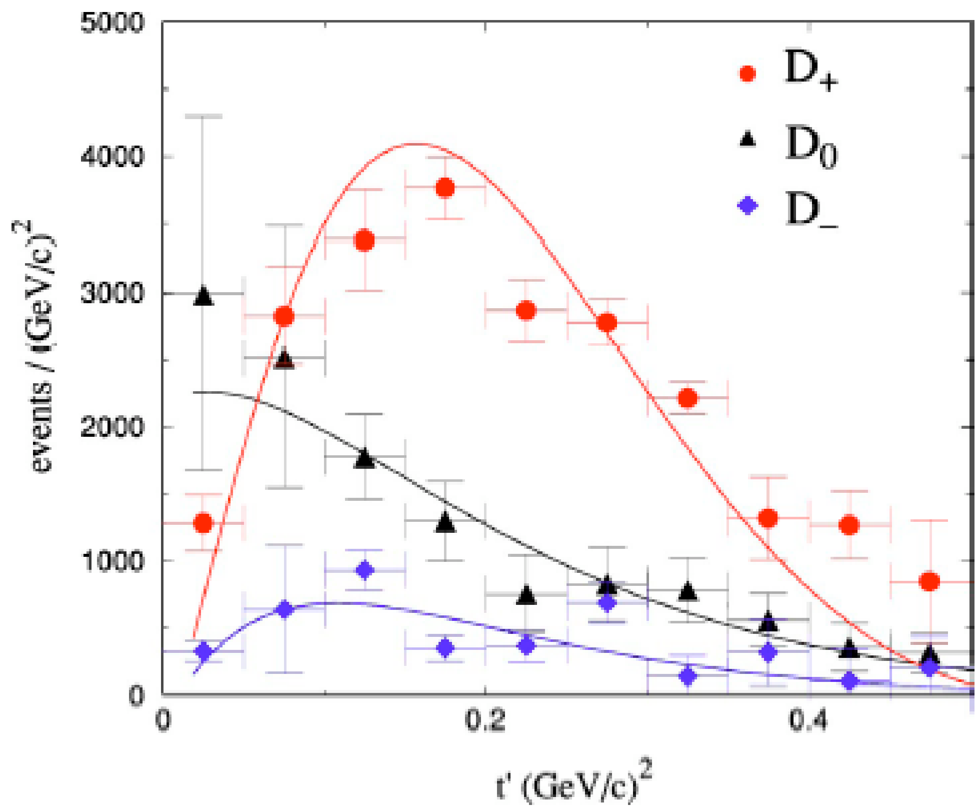
Bali (00)

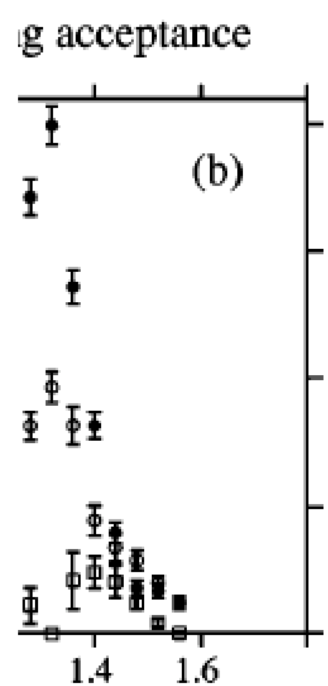
Have we seen exotic mesons
The $\pi_1(1400)$ story

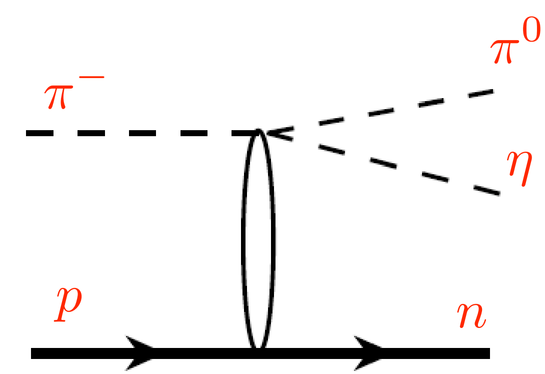
$$I(\Omega) = |SY_{00}(\Omega) + \sum_m P_m Y_{1m}(\Omega) + \cdots|^2$$

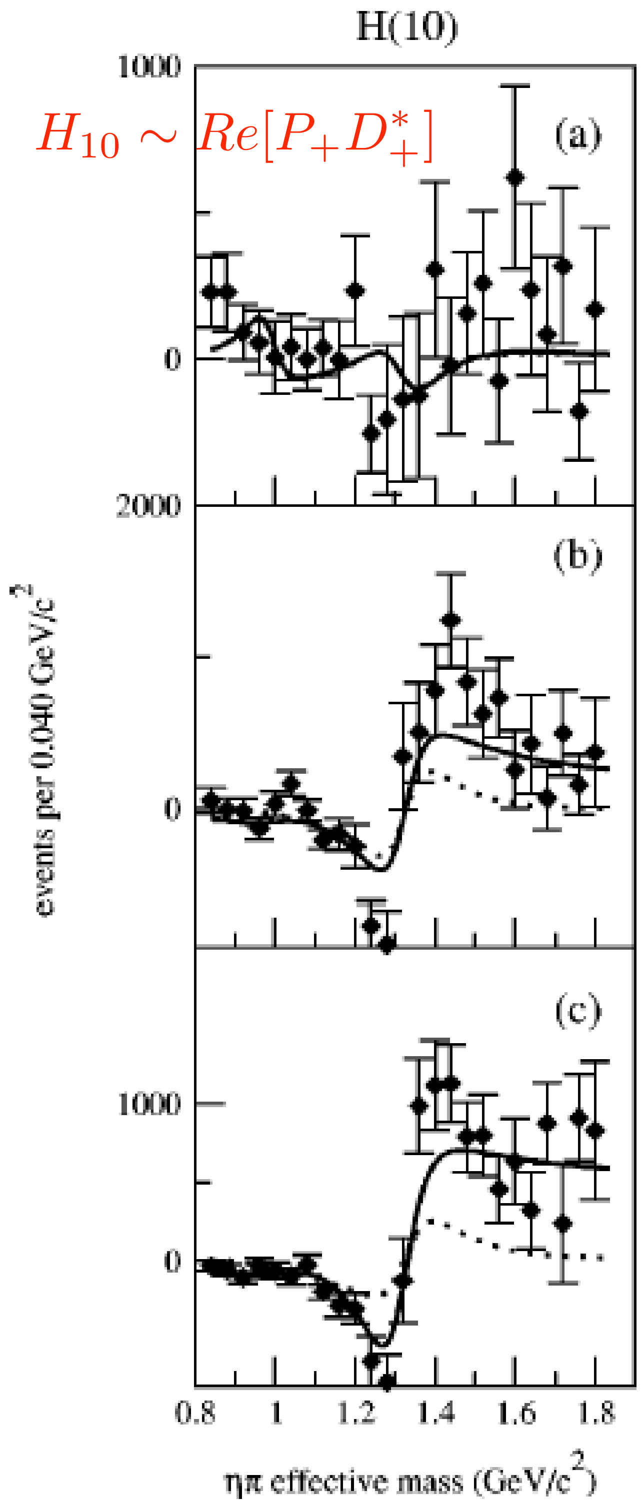
$$I(\Omega) \rightarrow I_{exp.}(\Omega) = I(\Omega) \text{ acceptance } (\Omega)$$





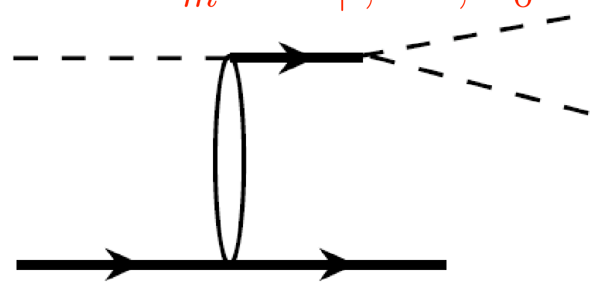




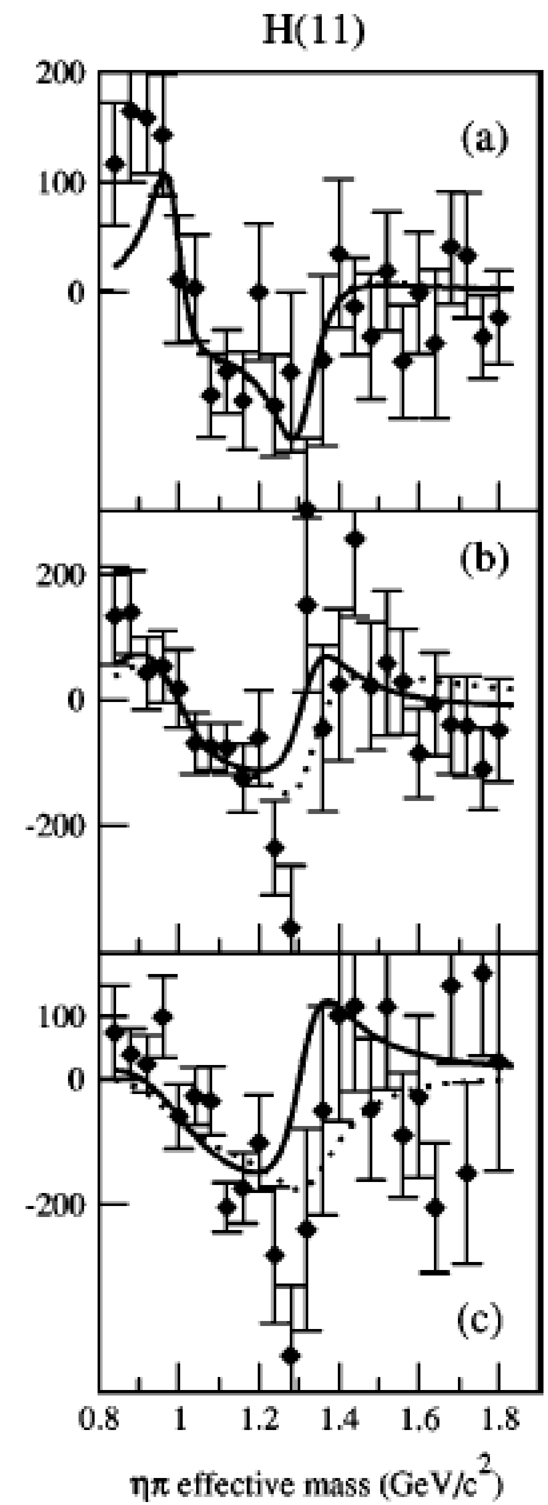


$H_{10} \sim Re[P_+ D_+^*]$

$P_m = P_+, P_-, P_0$



$H_{11} \sim Re[S_0 P_0^*], Re[P_0 D_-^*]$
$Re[P_- D_0^*]$



Assume BW resonance
in all, m=+1,0,-1 P-waves

$\pi_1(1400) \to \pi_1(900 - 5000)$!

Have we seen exotic mesons

The $\pi_1(1600)$ story

Clear P-wave in $\eta'\pi$

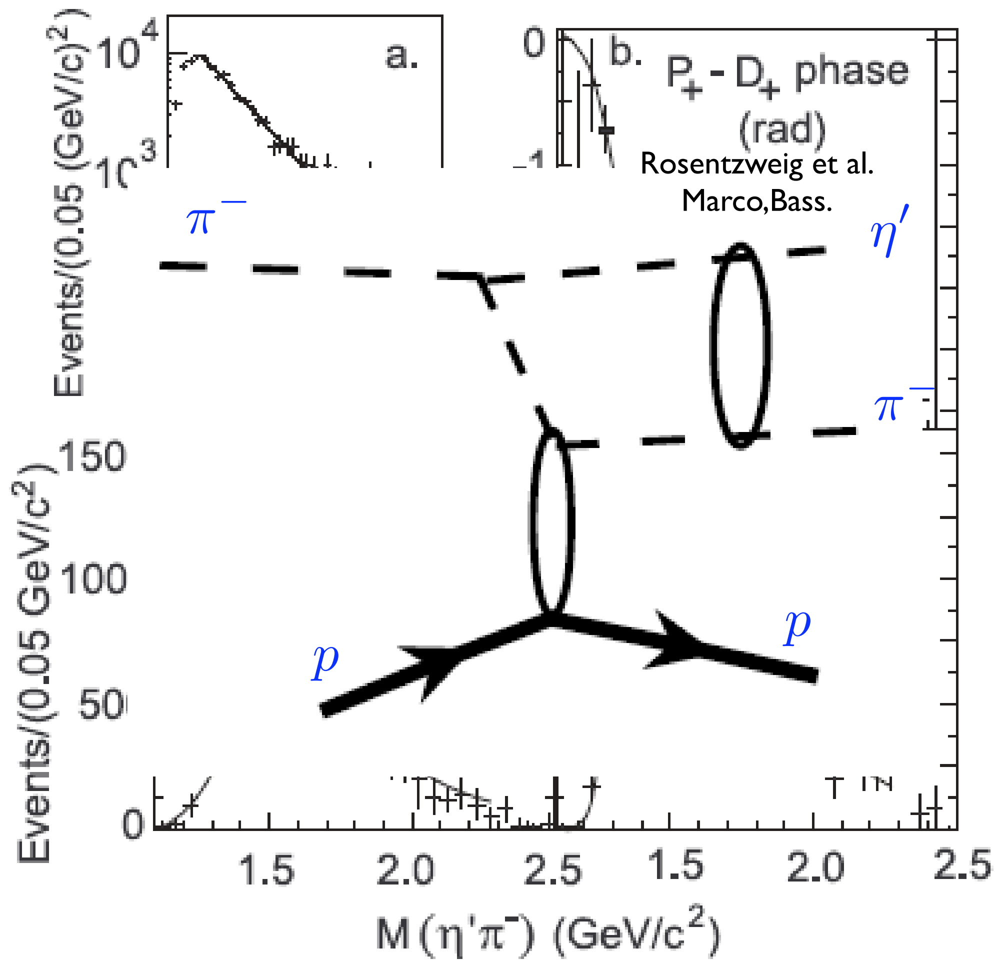
Where is the pole ?

Deck production

(no “bare” resonance)

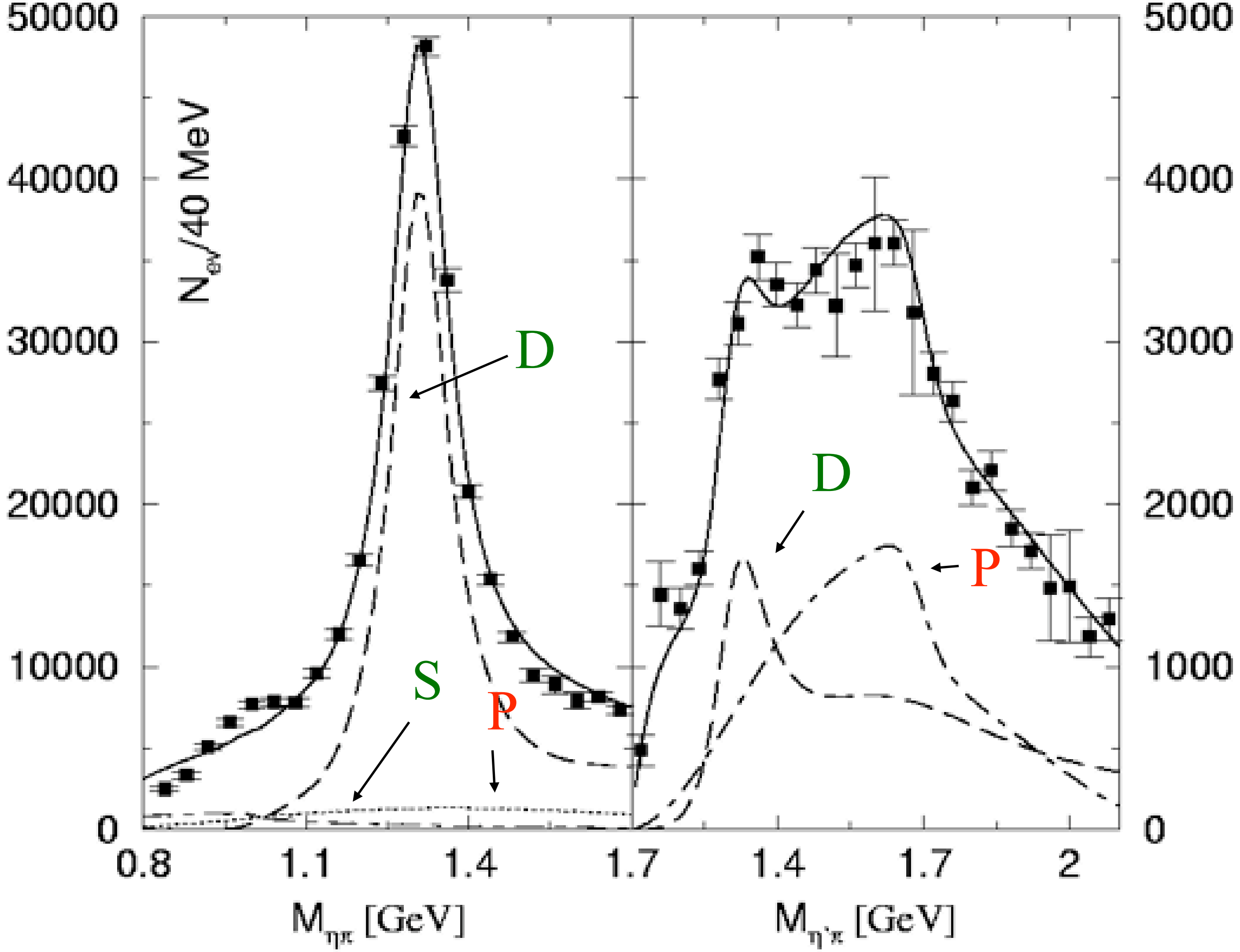
What is its origin ?

(large N_c behavior?)



Results of coupled channel analysis of $\pi^- p \to \eta\pi^- p$

$\pi^- p \to \eta'\pi^- p$

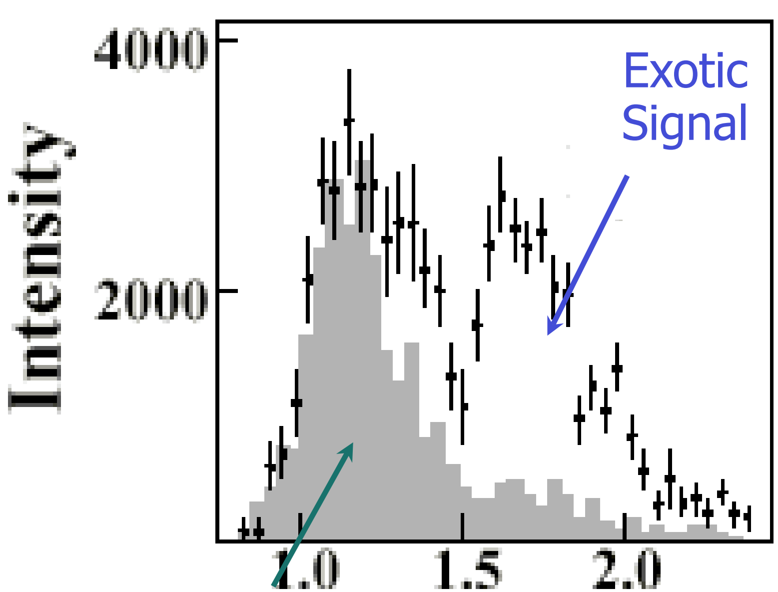


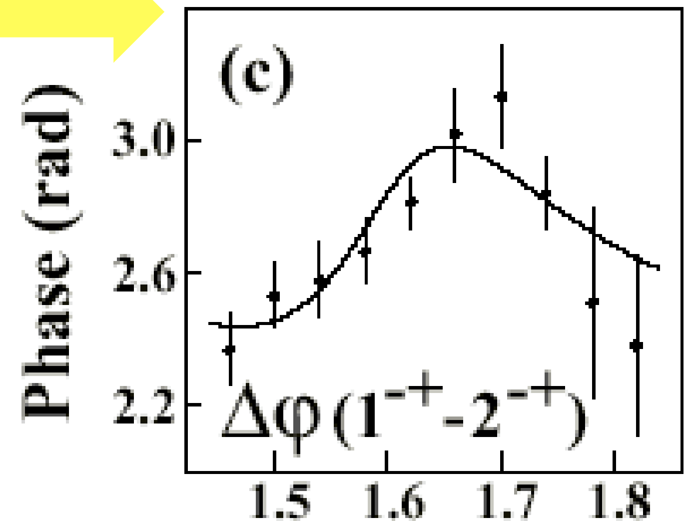
Have we seen exotic mesons

The $\pi_1(1600)$ story in $\pi^+\pi^-\pi^-$

Correlation of Phase & Intensity

1^{-+}





Leakage From Non-exotic Wave
due to imperfectly understood acceptance

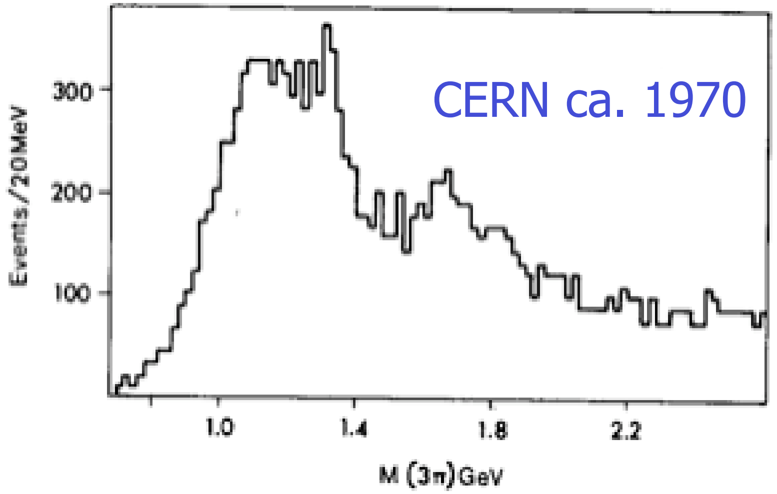
$M(\pi^+\pi^-\pi^-)\ [GeV/c^2]$

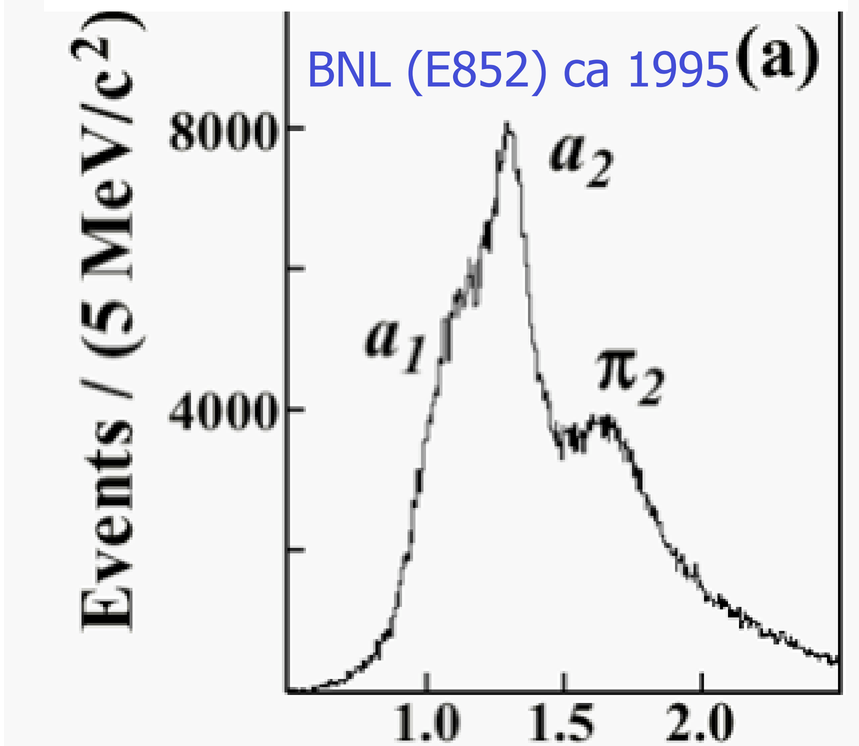
Based on 250K events Currently analyzing 10M events!

What's new

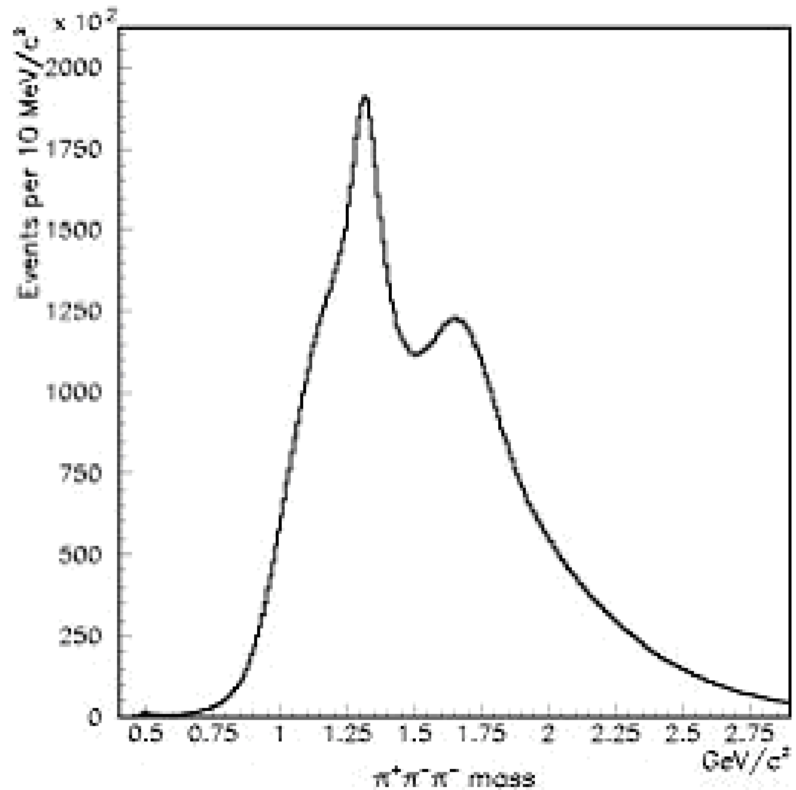
- Huge statistics
- Computational resources
- New theoretical developments :
  low energy, (chiral) phenomenology
  QCD, lattice
- High quality photon beams (exotic searches)

$\pi^- p$ -> $\pi^-\pi^+\pi^- p$





E852 2003
Full sample



Role of Photons

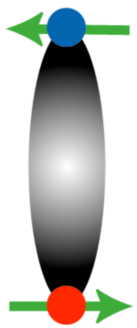
Quarks ⊕ **Excited Flux Tube** → **Hybrid Meson**

$S = 0$

$L = 0$

$J^{PC} = 0^{-+}$

like π, K



$$J^{PC} = \begin{cases} 1^{+-} \\ 1^{-+} \end{cases}$$

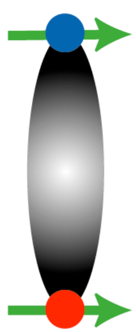
$$J^{PC} = \begin{cases} 1^{--} \\ 1^{++} \end{cases}$$

$S = 1$

$L = 0$

$J^{PC} = 1^{--}$

like γ, ρ



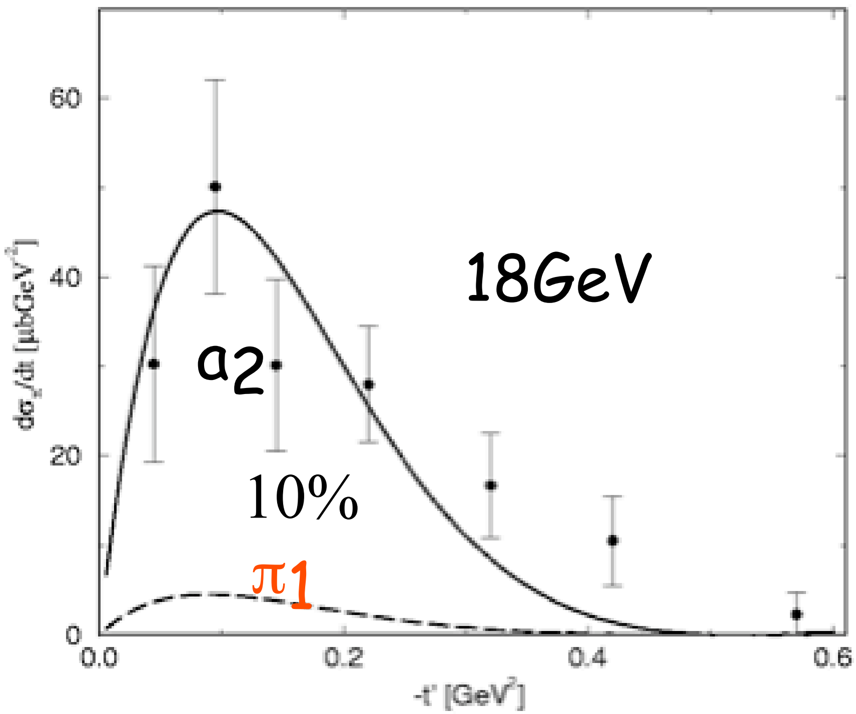
$$J^{PC} = \begin{cases} 1^{+-} \\ 1^{-+} \end{cases}$$

Exotic

$$J^{PC} = \begin{cases} 0^{-+} \quad 1^{-+} \quad 2^{-+} \\ 0^{+-} \quad 1^{+-} \quad 2^{+-} \end{cases}$$

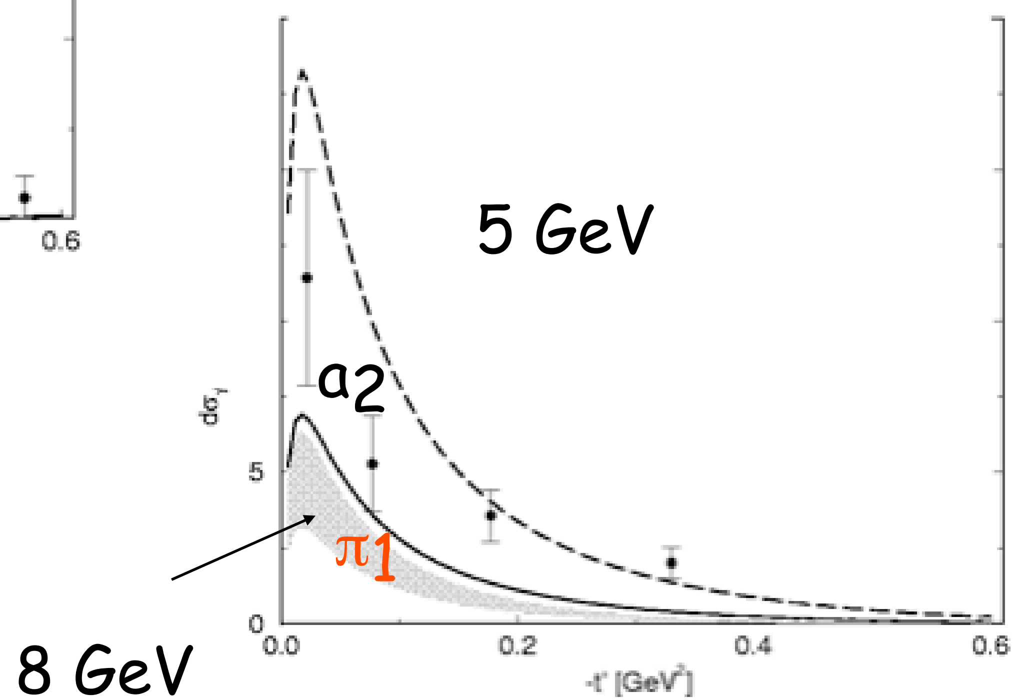
So only parallel quark spins lead to exotic J^{PC}

$\pi^- p \to X^0 n$



M.Swat, AS

$\gamma p \to X^+ n$



In photoproduction

$\frac{\pi_1}{a_2} \sim 50\% - 100\%$

γp vs πp data

Compare statistics and shapes

Adams '93 (E852) $\pi^- p \to \rho^0 \pi^- p \to \pi^+ \pi^- \pi^+ p$ @ 18 GeV   Condo'93 $\gamma p \to \rho^0 \pi^+ n \to \pi^+ \pi^- \pi^+ n$ @ 19.3 GeV

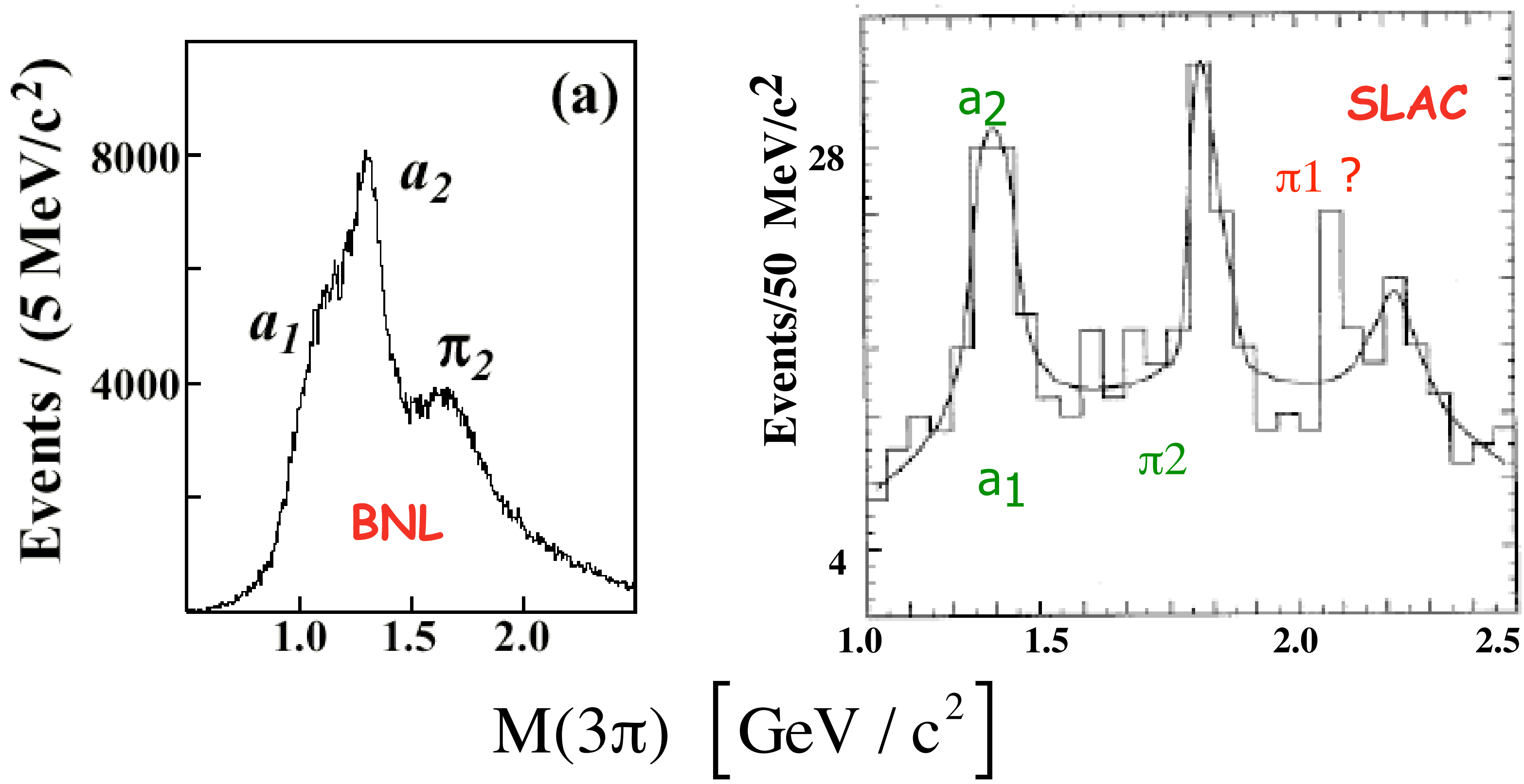
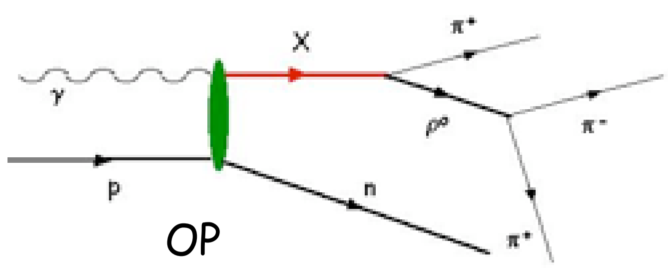
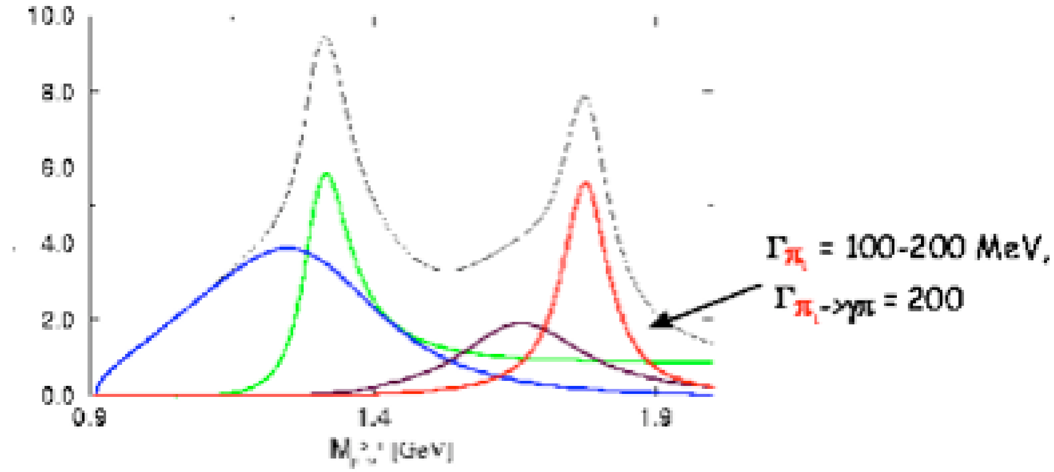


Photo production enhances exotic mesons



OP
E

Condo'93



1^{-+} exotic : S=1, L=1

γ --> $\rho(J^{PC}=1^{--})$ --> $\pi_1(J^{PC}=1^{-+})$

VM
D

"pluck" the string (S=1,L_{QQ}=0->L_g=1)

	J^{PC}	$\rho\pi$ decay mode	Mass (MeV)	Γ (Mev)	$\Gamma_{3\pi}/\Gamma$	σ_γ (μb)
a_1	1^{++}	S D	1260	400	99% 1%	~0.03
a_1	2^{++}	D	1320	110	70%	~0.50
π_2	2^{-+}	P F	1670	260	30% 1%	~0.02
π_1	1^{-+}	P	1600	160	50%	~0.02

Finding the Exotic Wave

Double-blind M. C. exercise

An exotic wave ($J^{PC} = 1^{-+}$) was generated at level of 2.5 % with 7 other waves. Events were smeared, accepted, passed to PWA fitter.

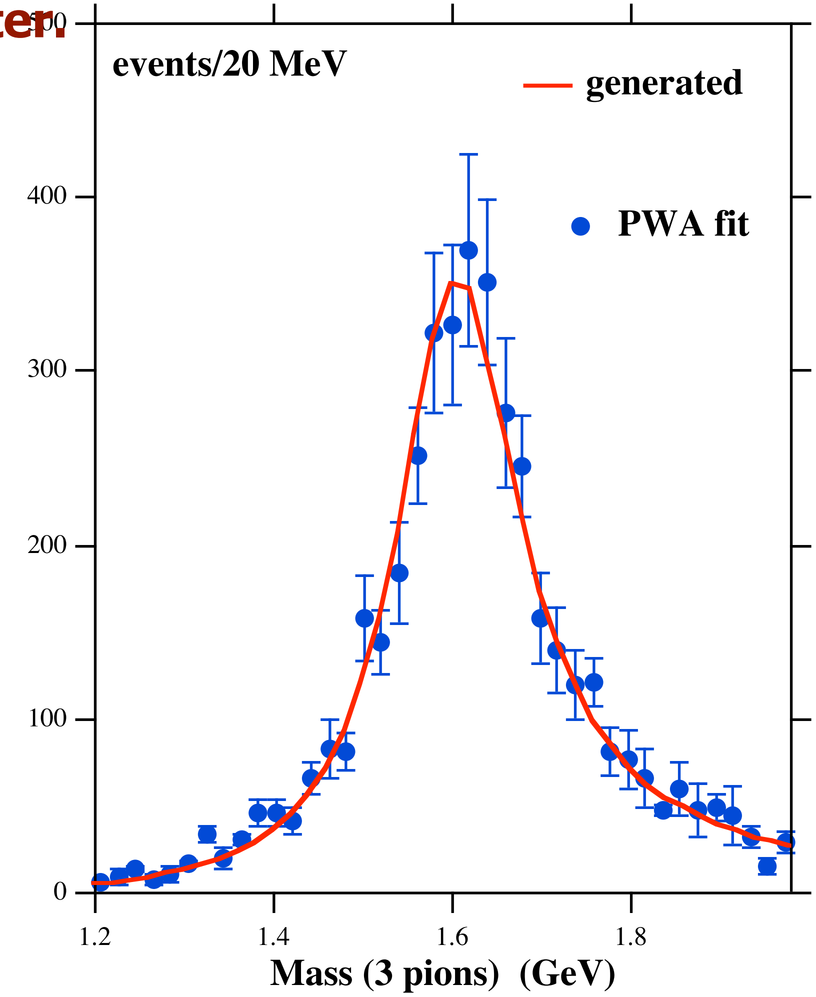
$$X(\text{exotic}) \rightarrow \rho\pi \rightarrow 3\pi$$

Mass

Input: 1600 MeV
Output: 1598 +/- 3 MeV

Width

Input: 170 MeV
Output: 173 +/- 11 MeV



Statistics shown here correspond to a few days of running.

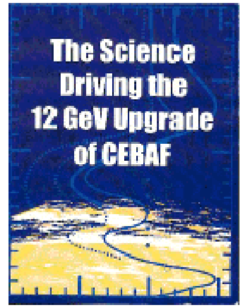
How GlueX Fares Compared to Existing Data

We will use for comparison – the yields for production of the well-established and understood a_2 meson

Experiment	a_2 yield	Exotic Yield
SLAC	10^2	--
BNL (published)	10^4	250
BNL (in hand - to be analyzed)	10^5	2500
GlueX	10^7	$5x\ 10^6$

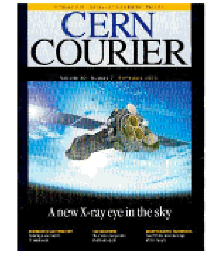
More than 10^4 increase

The GlueX numbers are based on 1 year of low-intensity running at 10^7 photon/sec. The exotic meson yield is based on model calculations.
But even if the exotic were to be produced at the suppressed rate with π beams - we would still see 250,000 exotic mesons !

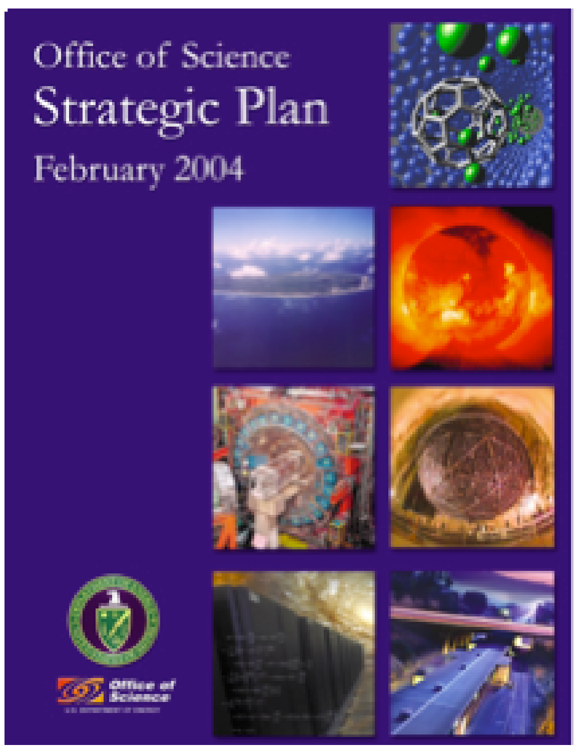


Upgrade Whitepaper
Jan 2001

Cover Story
Sep/Oct 2000



Cern Courier
Sep 2000



What is Needed?

Hermetic Detector:

- PWA requires that the entire event be kinematically identified - all particles detected, measured and identified. It is also important that there be sensitivity to a wide variety of decay channels to test theoretical predictions for decay modes.

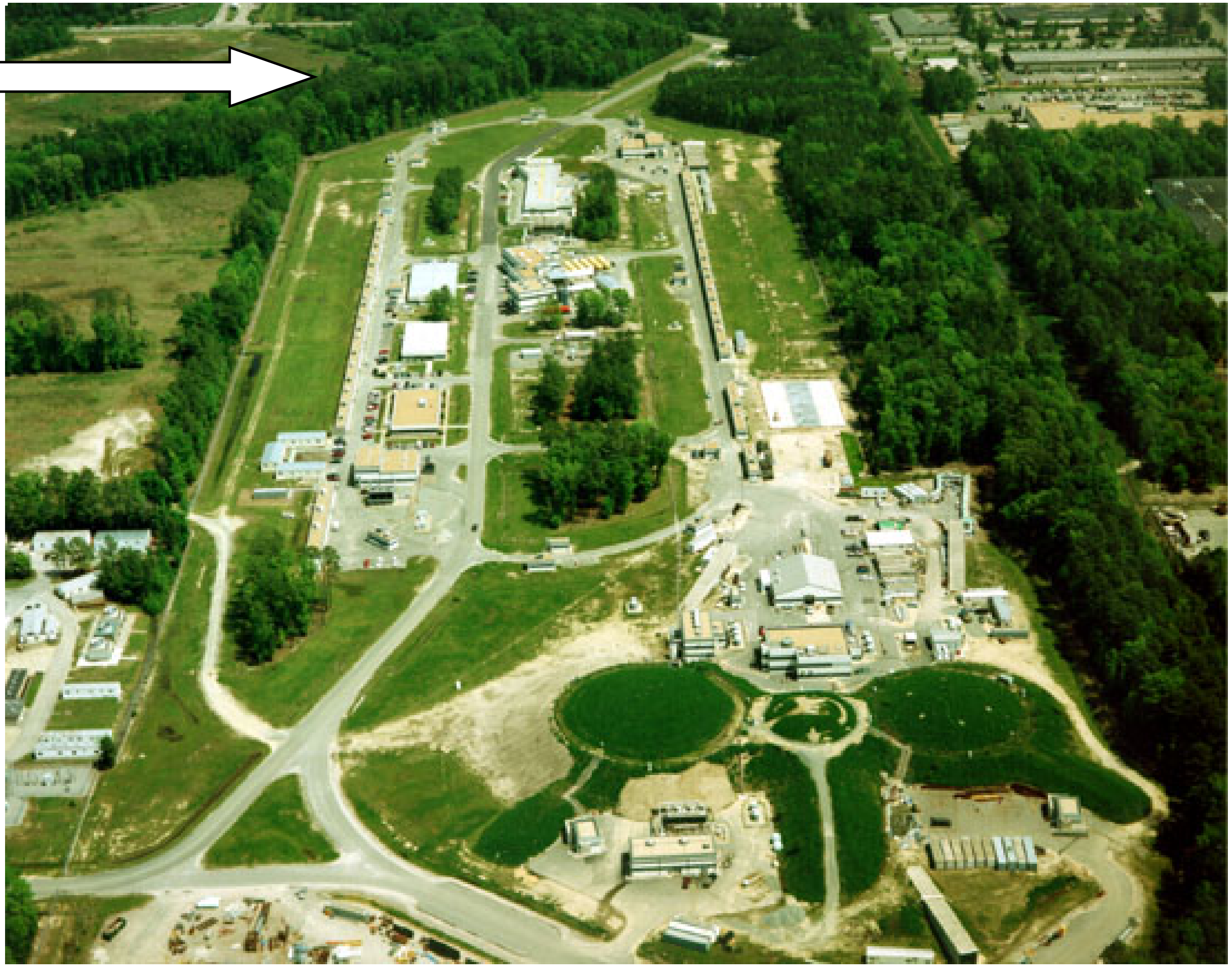
The detector should be hermetic for neutral and charged particles, with excellent resolution and particle identification capability. The way to achieve this is with a solenoidal-based detector.

Linearly Polarized, CW Photon Beam:

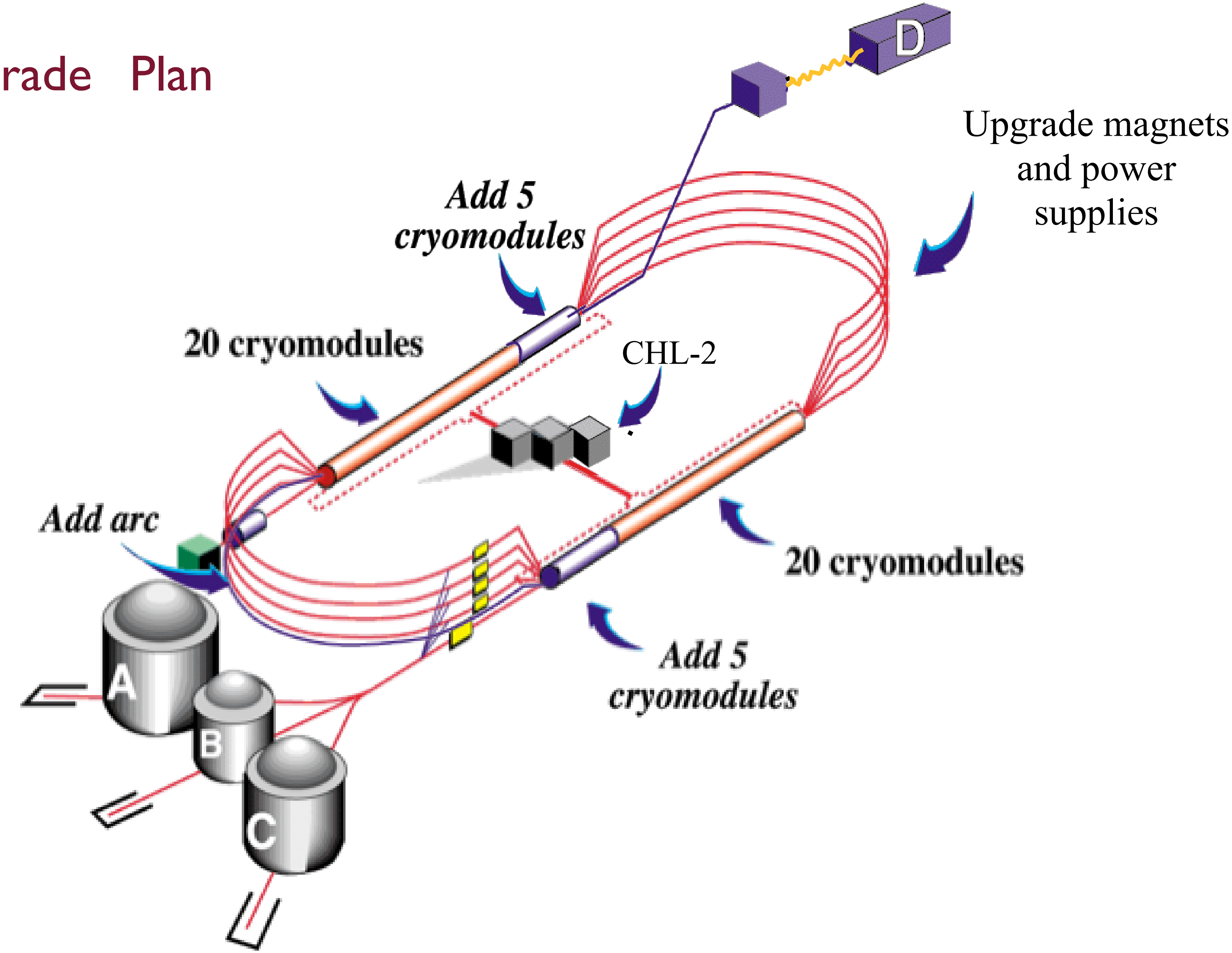
- Polarization is required by the PWA - linearly polarized photons are eigenstates of parity.

JLab Facility

Hall D will be located here

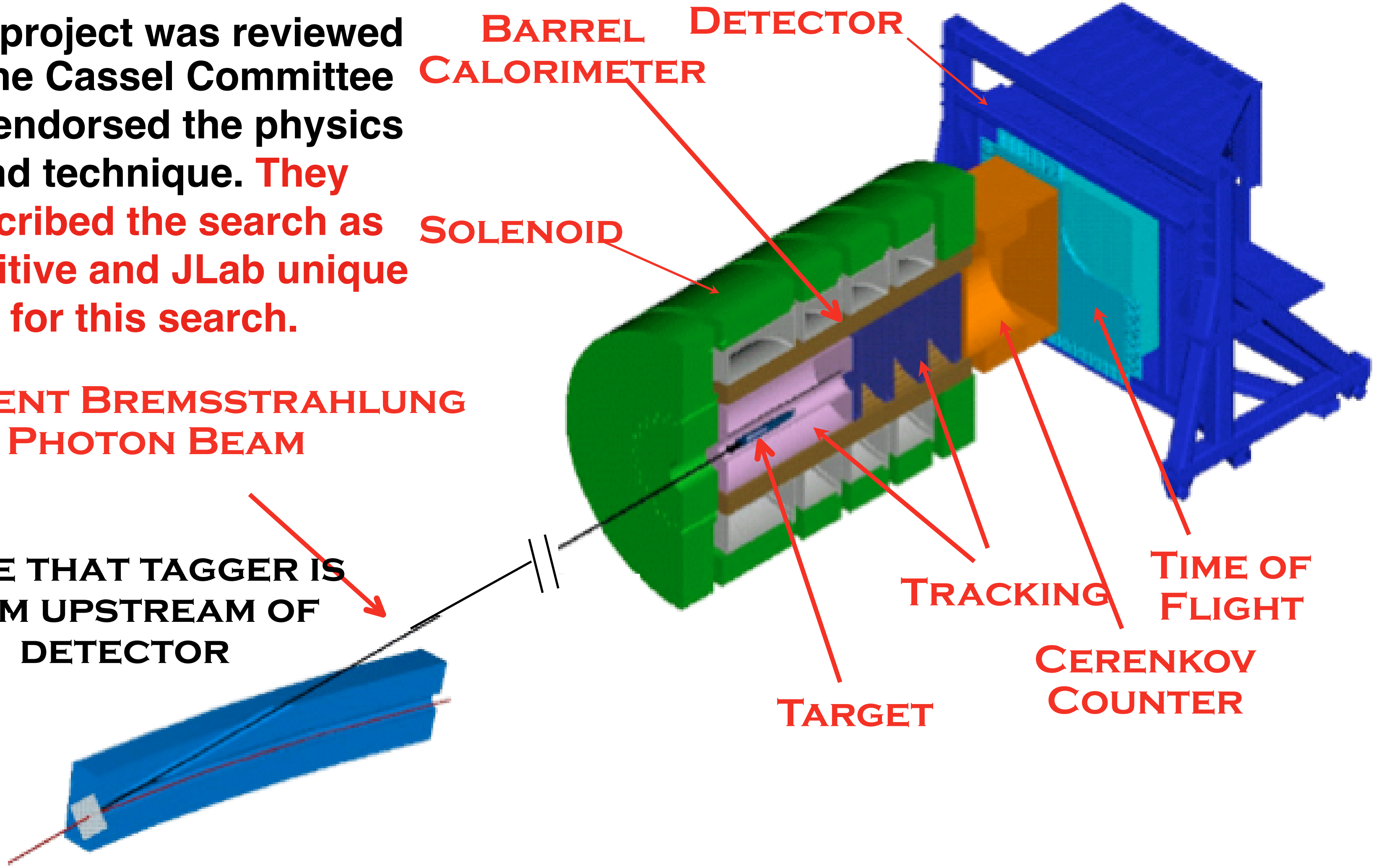


Upgrade Plan



Detector

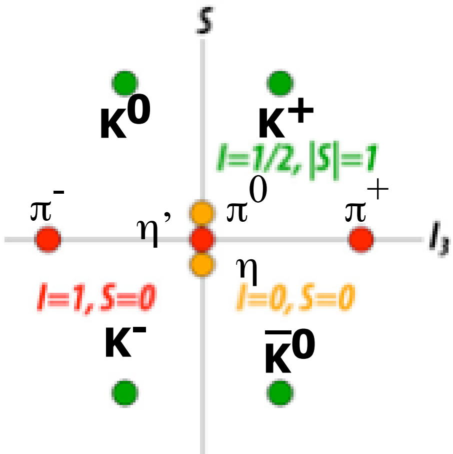
This project was reviewed by the Cassel Committee that endorsed the physics and technique. They described the search as definitive and JLab unique for this search.



Other physics topics

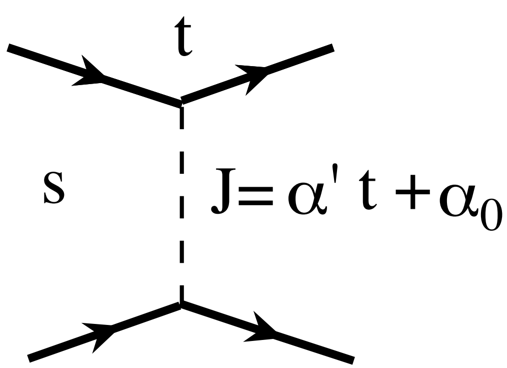
Other physics with a 4π detector and 9 GeV photon beam

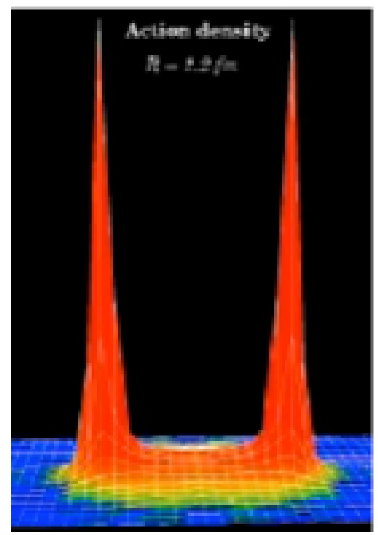
- Rare decays, η, η', ϕ and chiral symmetry tests
- Physics of the ϕ, and $K\bar{K}$ system, CP and CPT studies
- Threshold charm production
- High p_T meson photoproduction

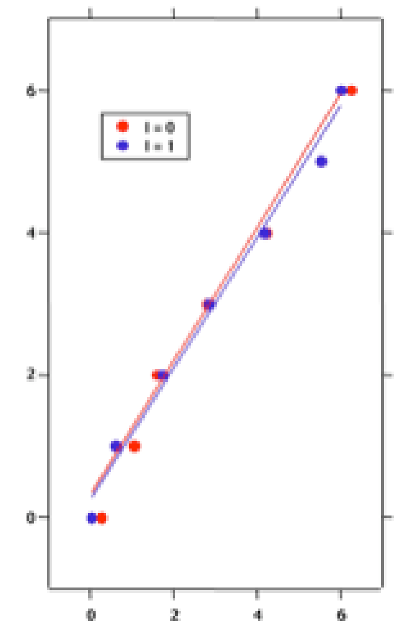


SU(3) flavor multiplets (Gell-Mann & Zwike)

Linear Regge trajectories...

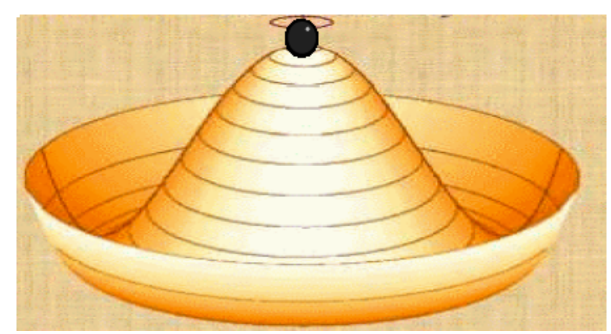




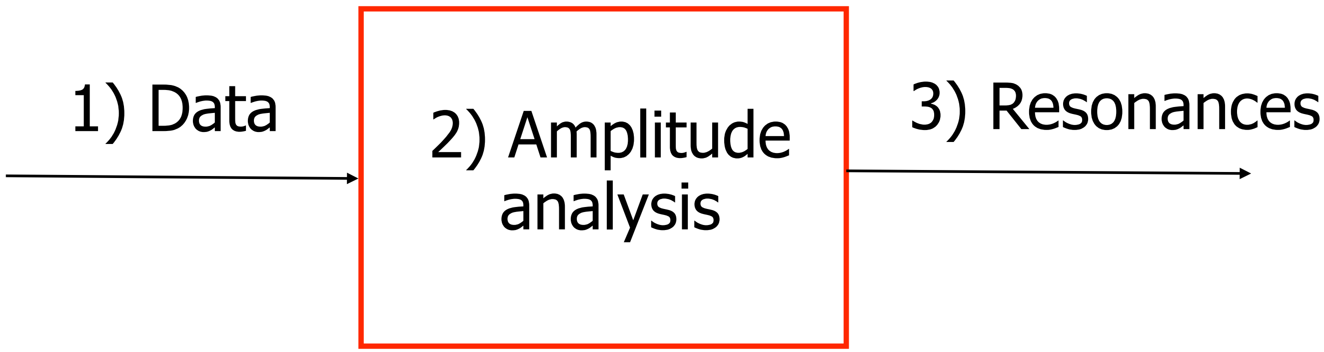


...and gluonic strings

$SU_L(3) \times SU_R(3) \supset SU_V(3)$ + Goldstone bosons



How to determine if there exists a resonance



1) Use data (“physical sheet”) input to constrain theoretical amplitudes

2) Resonances appear as a result of amplitude analysis and are identified as poles on the “un-physical sheet”

3) then need the interpretation: composite or fundamental, structure, etc