Gluonic Excitations Workshop
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Partial Wave Analysis results from JETSET

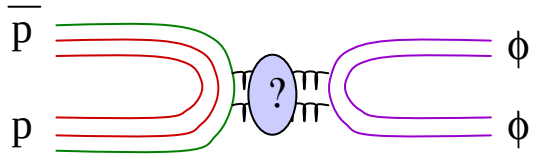
Richard Jones
University of Connecticut

representing the Jetset collaboration
with members from
Bari, CERN, Erlangen, Freiburg, Genova, Illinois, Jülich, Oslo, Uppsala

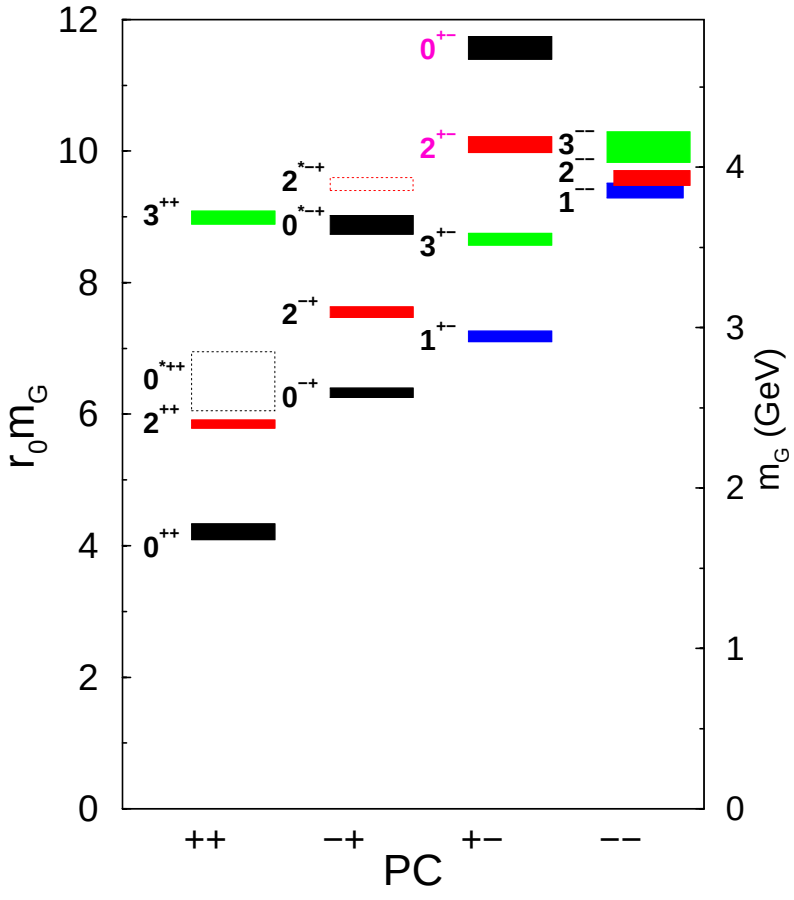
- the Jetset experiment
- PWA formalism and MC tests
- results from analysis of full data set

The Jetset Experiment

- Measures in-flight pbar annihilation: $\bar{p}p \rightarrow \phi\phi$

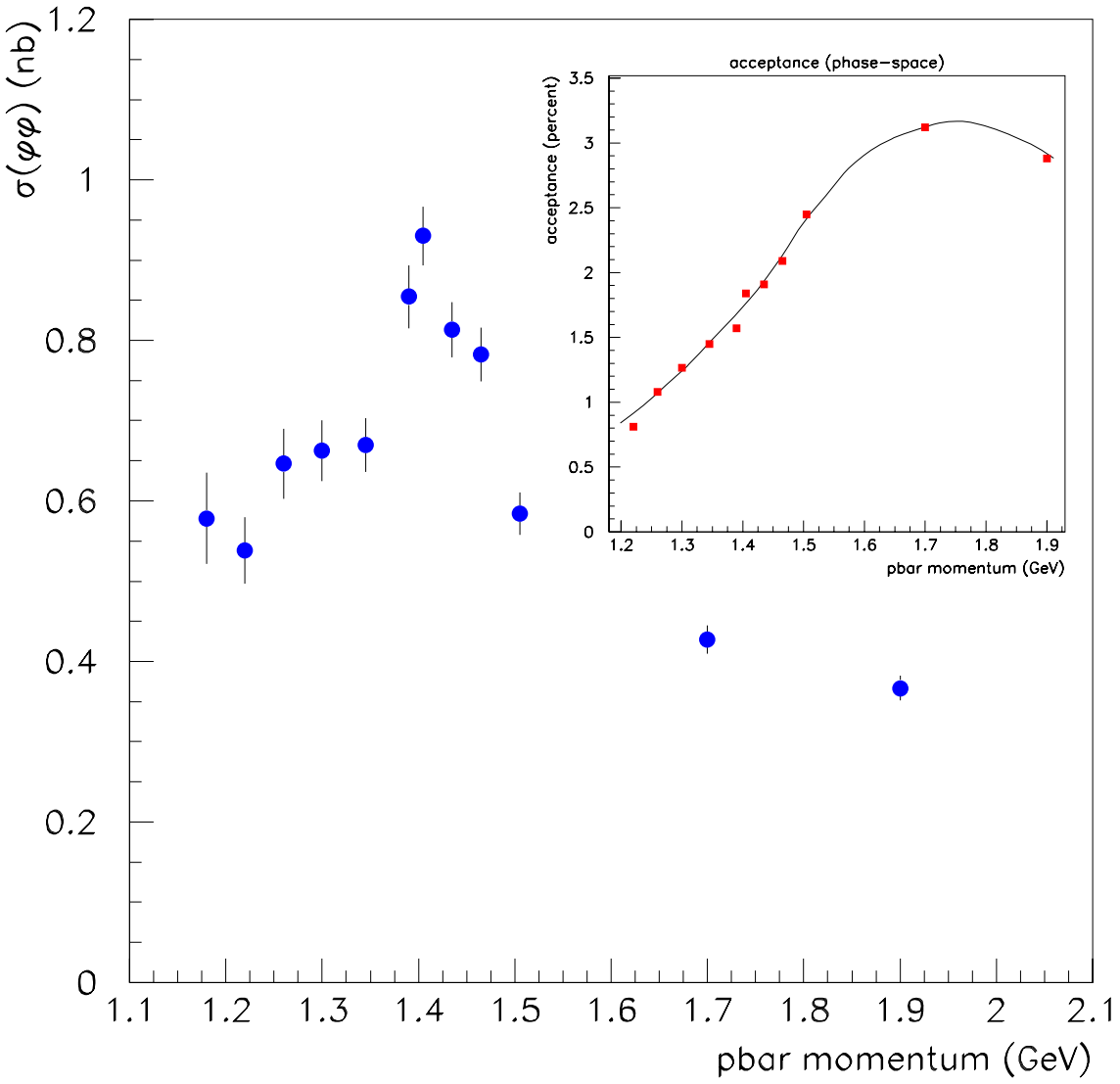


- OZI-suppressed, may form glueball resonances in s-channel



Morningstar et.al., LAT991004

Total cross section $\bar{p}p \rightarrow \phi\phi$



Complete data set from Jetset

point	N(φφ)	N(b.g.)	point	N(φφ)	N(b.g.)	point	N(φφ)	N(b.g.)
1	326	95	5	1005	589	9	1318	877
2	414	225	6	1262	585	10	1056	943
3	626	270	7	1782	886	11	936	1592
4	840	369	8	1375	868	12	707	1666

PWA Accounting

J values of the waves included in the partial wave analysis.
All waves up to J=4, L=4 in the final state were allowed.

wave	J^{PC}	L initial	S initial	L final	S final
1	0−+	0	0	1	1
2	0++	1	1	0	0
3	0++	1	1	2	2
4	1++	1	1	2	2
5	2++	1	1	0	2
6	2++	1	1	2	0
7	2++	1	1	2	2
8	2++	1	1	4	2
9	2−+	2	0	1	1
10	2−+	2	0	3	1
11	2++	3	1	0	2
12	2++	3	1	2	0
13	2++	3	1	2	2
14	2++	3	1	4	2
15	3++	3	1	2	2
16	3++	3	1	4	2
17	4−+	4	0	3	1
18	4++	3	1	2	2
19	4++	3	1	4	0
20	4++	3	1	4	2
21	4++	5	1	2	2
22	4++	5	1	4	0
23	4++	5	1	4	2

PWA Procedure

Getting started:

- Fit with all waves free
  - gives full freedom to the fit -> definition of “good fit”
  - errors on amplitudes are large, meaningless
- Reduce the set of allowed waves in search of a minimal set that gives a good description of the entire data set
  - gives priority to an economical description
  - adequacy judged in comparison with full fit
  - require same set of waves for all mass bins

We found 3 dominant waves

all 2^{++}

Method:

1. Group the data into mass bins with sufficient statistics
2. For each bin, try all waves one-by-one, keep best, repeat
   - Sets agreed on 3 top waves.
3. Go back to beginning and put in waves two-by-two trying all pairs of waves together, then add one-by-one
   - Sets chose same set of 3 waves as dominant.

Ambiguities

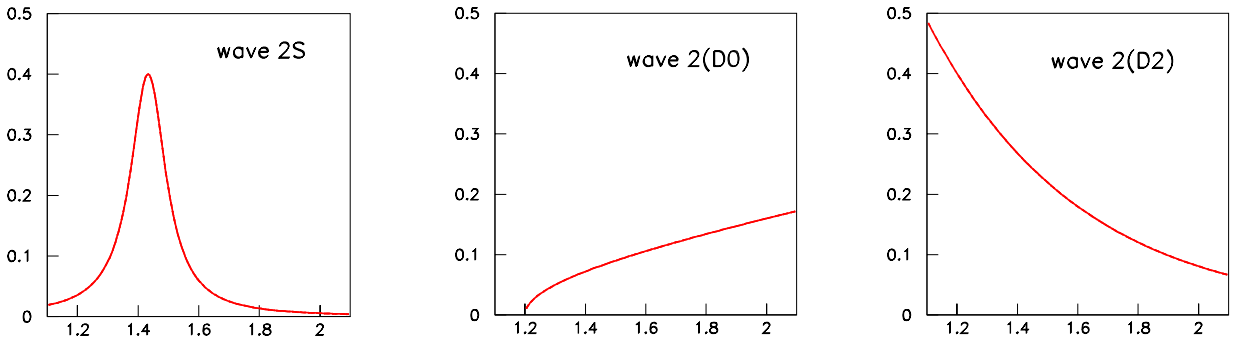
2 kinds:

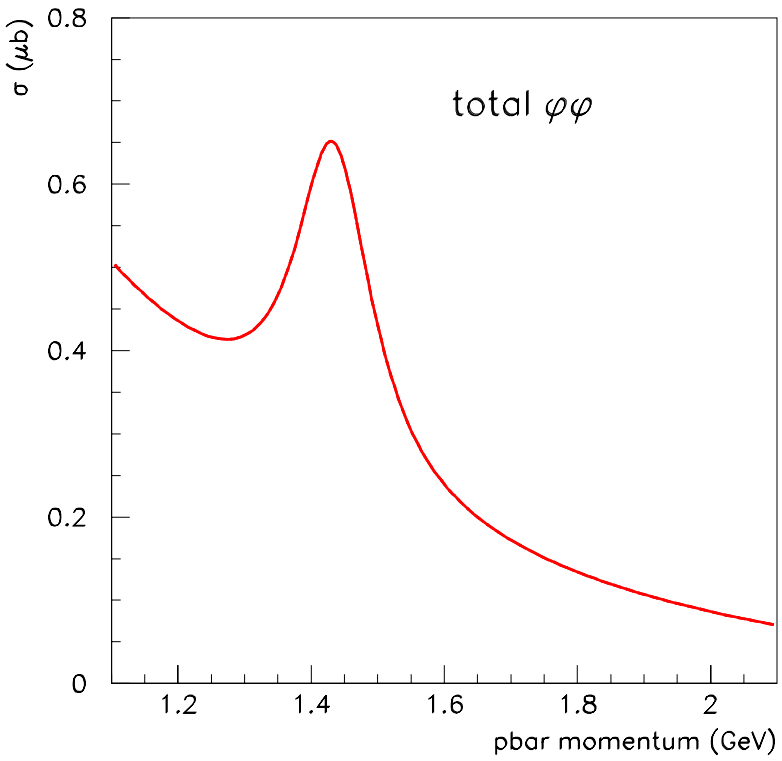
1. Essential ambiguities
   - correspond to **invariances** in angular distributions from PWA expansion
   - continuous invariances : global phases (2)
   - discrete invariances: undetermined signs (4)
   - no others believed to exist for 2($V \rightarrow 2P$)
   - irreducible even in limit of good acceptance and high statistics

2. Statistical ambiguities
   - correspond to different angular distributions which cannot be discriminated given the available data
   - discrete (different local maxima in likelihood)
   - discovered by systematic numerical search
   - reducible by good acceptance and high statistics
   - relatively few in this data set

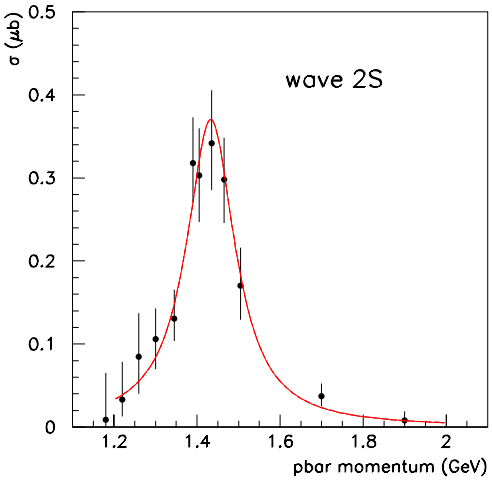
Monte Carlo test

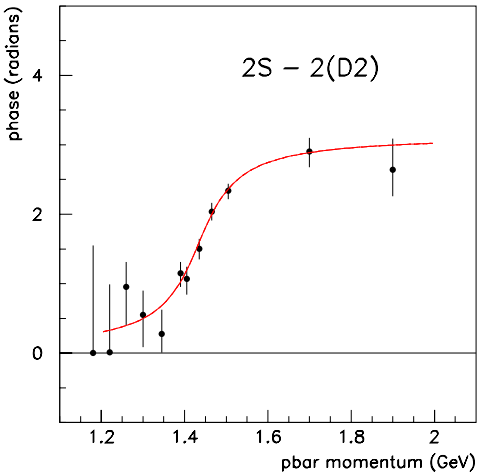
Ingredients:
- ✔ 1 resonant wave, two non-resonant
- ✔ experimental acceptance through simulation
- ✔ same reconstruction, analysis as for real data

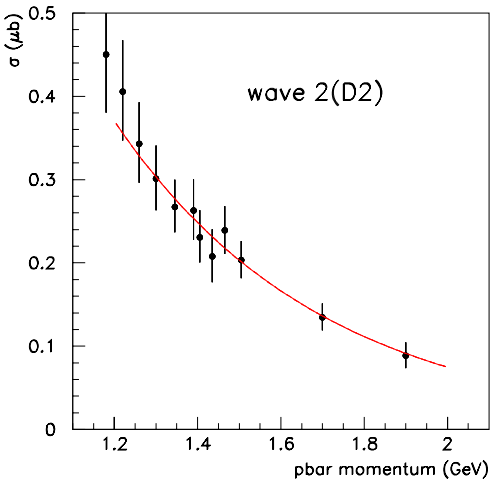


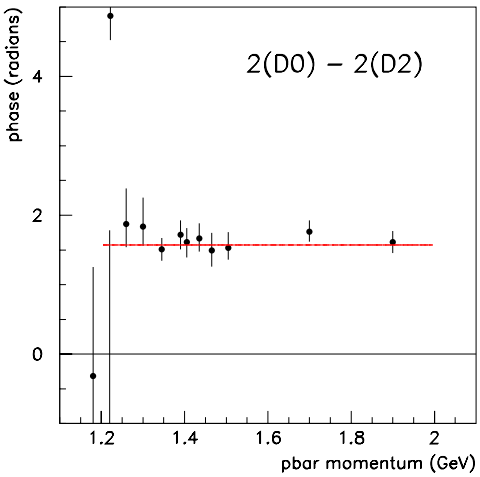


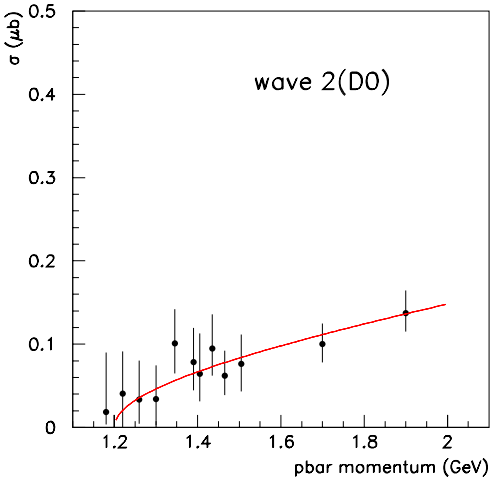
Results of Monte Carlo test





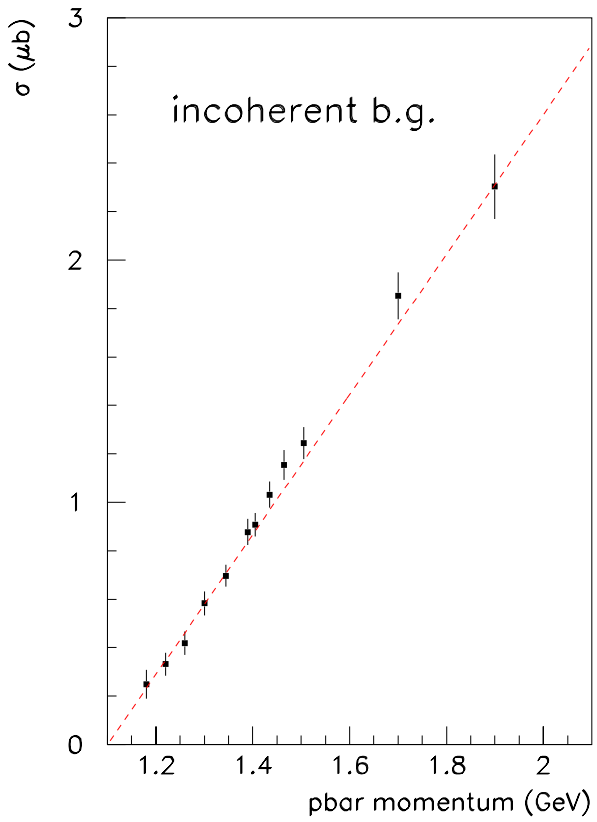


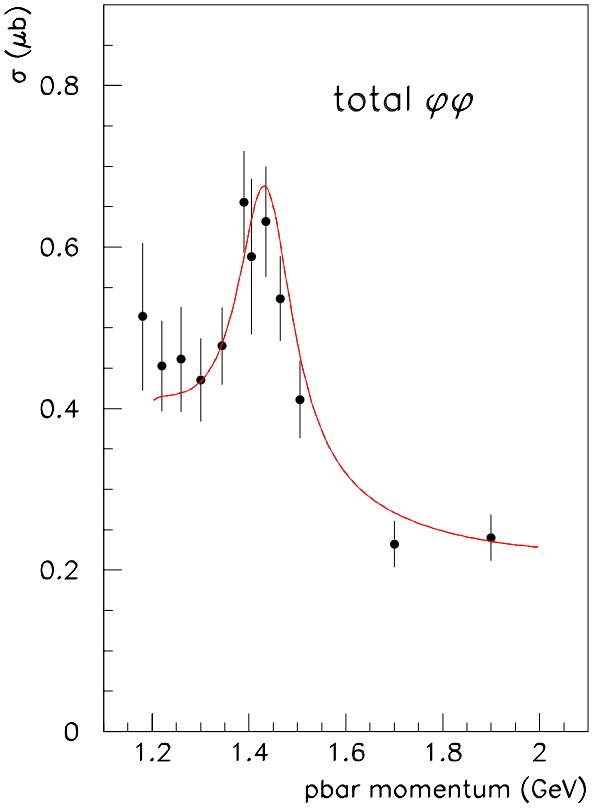




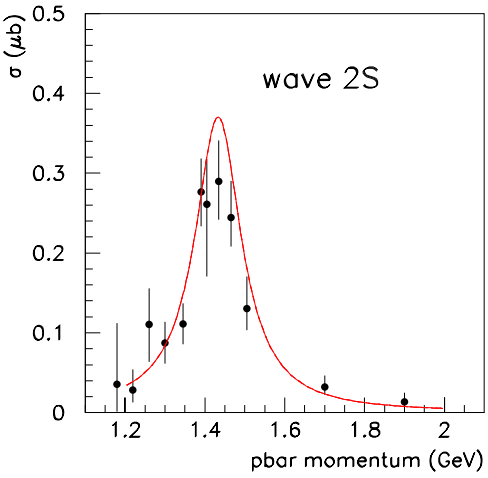
Monte Carlo test #2

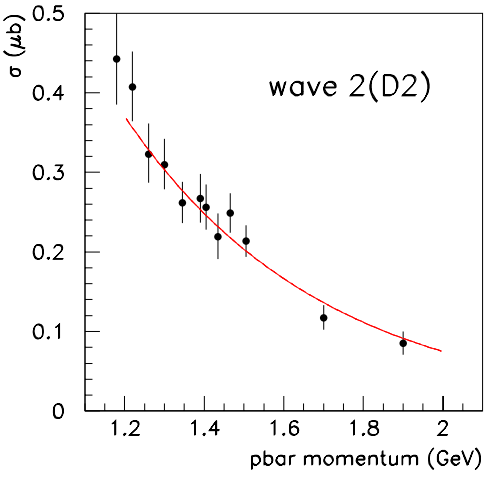
- include incoherent background
- uniform angular distribution for background
- not orthogonal to waves -- check for leakage

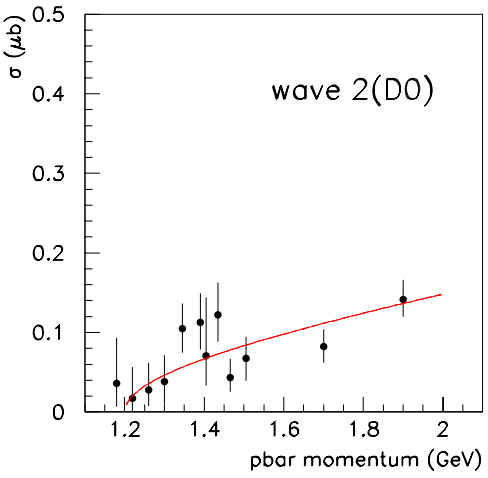


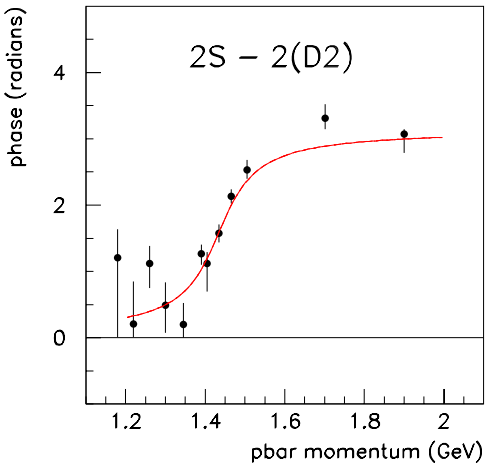


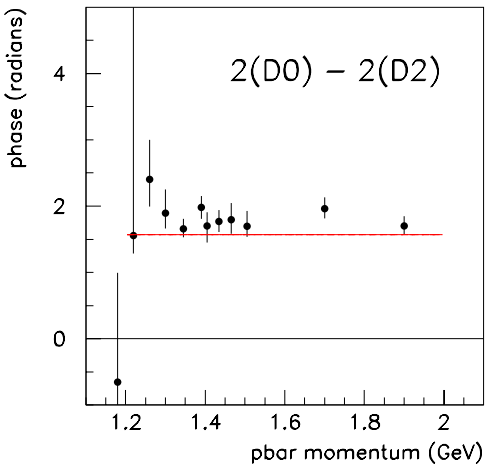
Results of Monte Carlo test #2





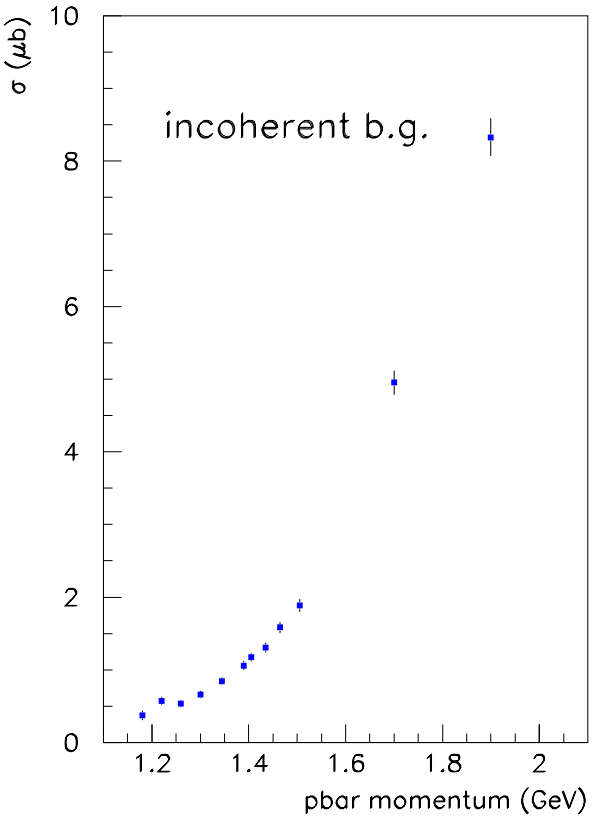


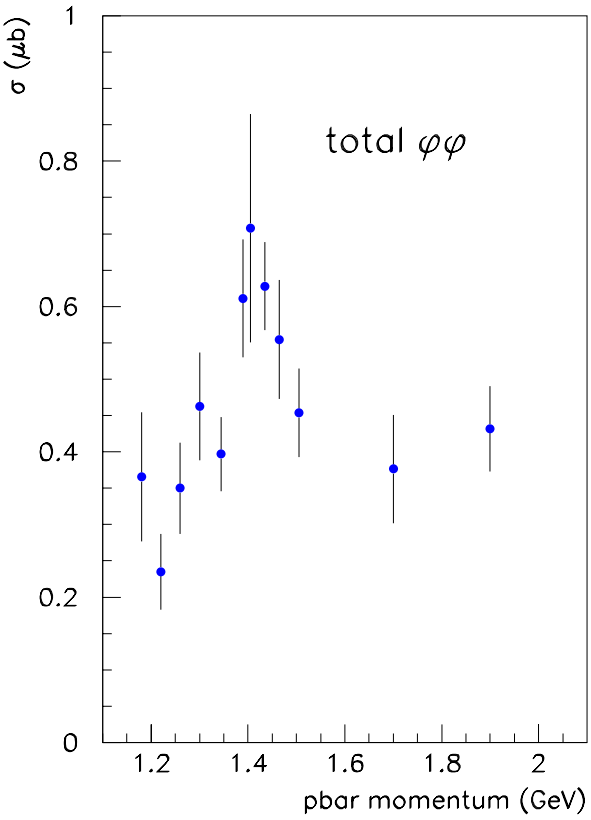




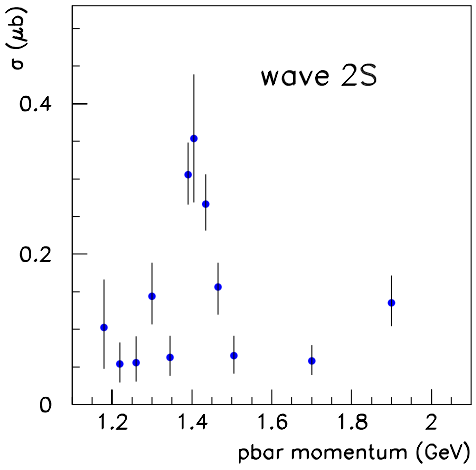
PWA Results

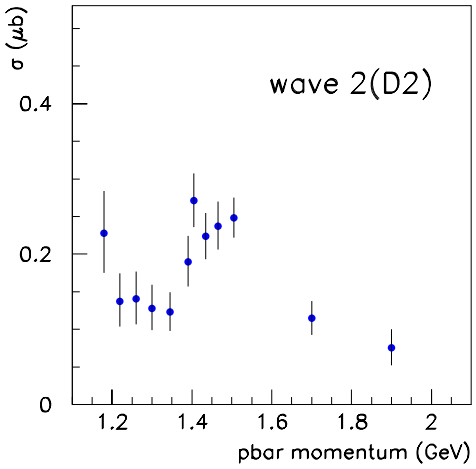
- 3-wave fit identical to Monte Carlo test #2
- simultaneous fit in mass and angular distributions
- $\phi\phi$ cross section now corrected for acceptance based on measured angular distribution

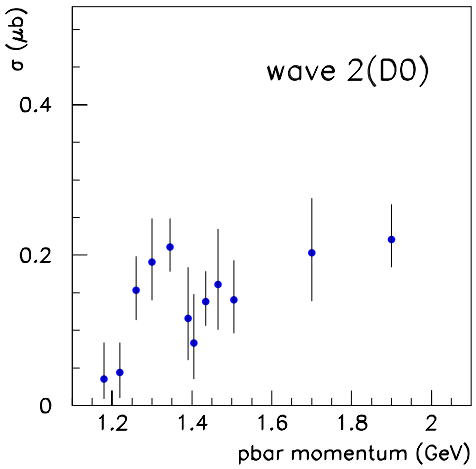


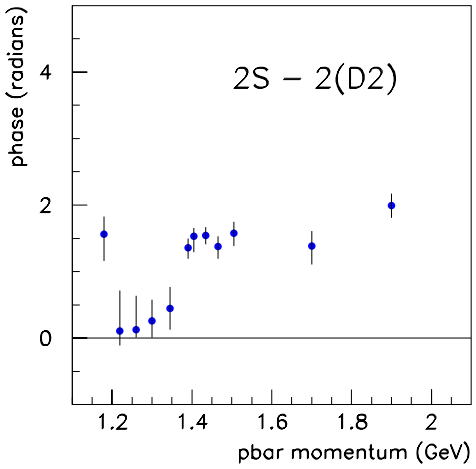


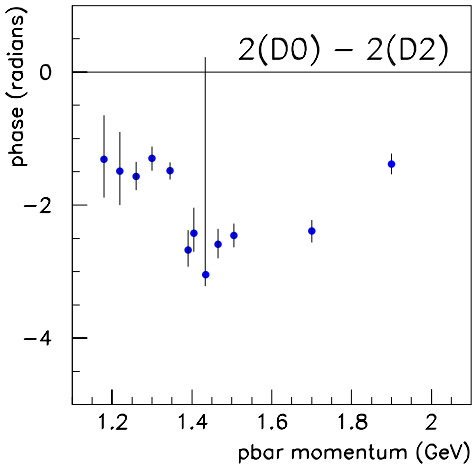
3-wave fit


σ (μb)
wave 2S
0.4
0.2
0
1.2
1.4
1.6
1.8
2
pbar momentum (GeV)

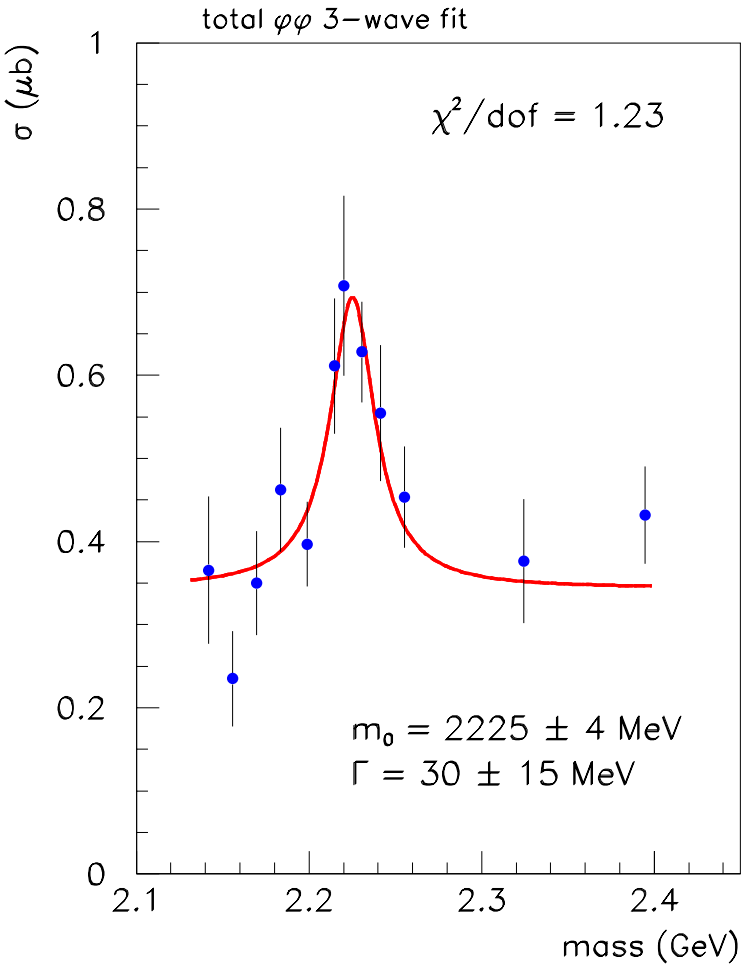

σ (μb)
wave 2(D2)
0.4
0.2
0
1.2
1.4
1.6
1.8
2
pbar momentum (GeV)


σ (μb)
wave 2(D0)
0.4
0.2
0
1.2
1.4
1.6
1.8
2
pbar momentum (GeV)


phase (radians)
2S – 2(D2)
4
2
0
1.2
1.4
1.6
1.8
2
pbar momentum (GeV)


phase (radians)
2(D0) – 2(D2)
0
−2
−4
1.2
1.4
1.6
1.8
2
pbar momentum (GeV)

Possible Interpretation



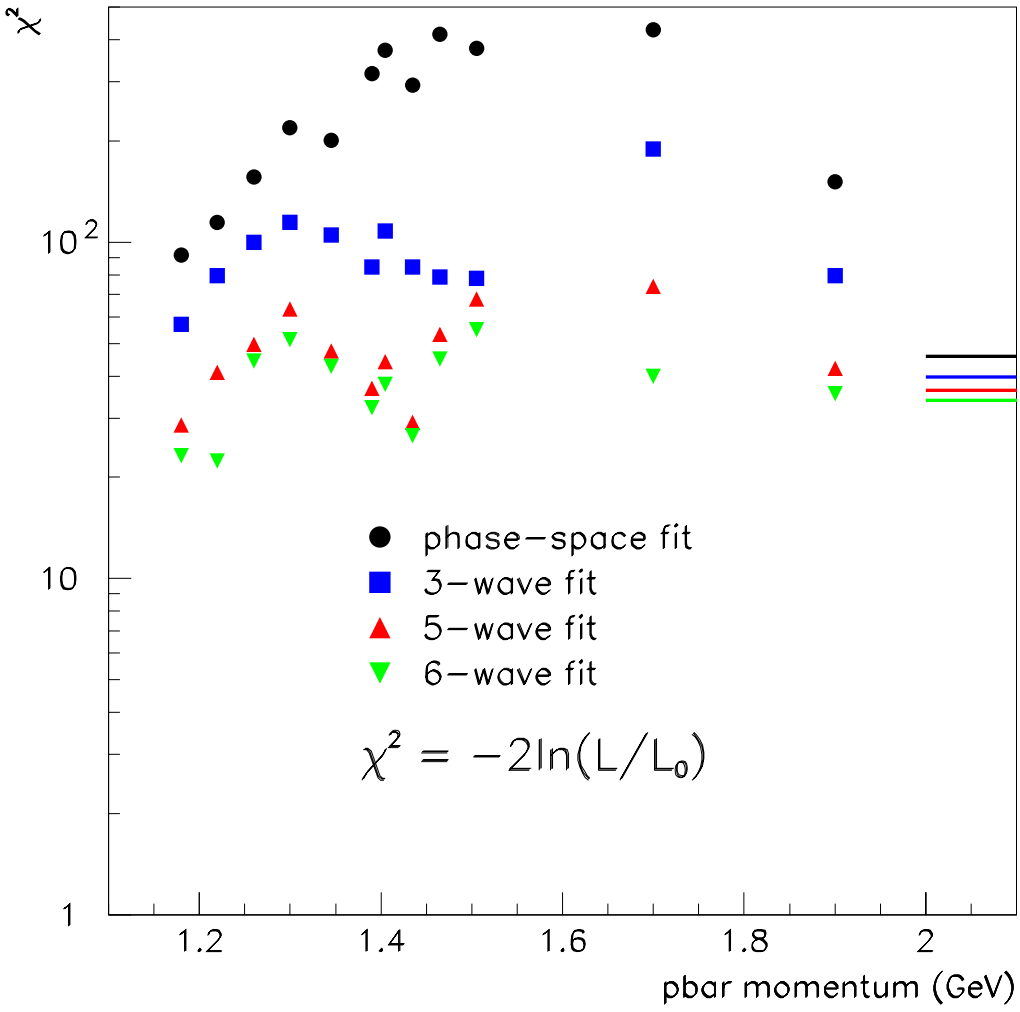
- ☆ narrow peak seen in raw cross section
- ☆ PWA reveals 3 dominant waves in 2^{++}
- ☆ rapid phase motion seen in two waves as expected for a Breit-Wigner resonance

Quality of the fit

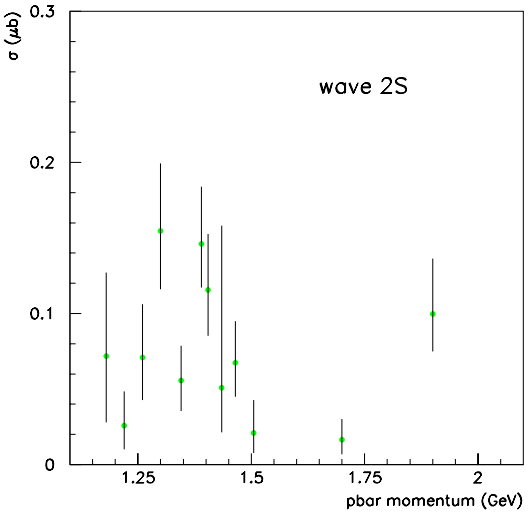
- To check goodness of fit, use likelihood ratio test
  - Define $\chi^2 = -2 ln\left(\frac{L}{L_0}\right)$

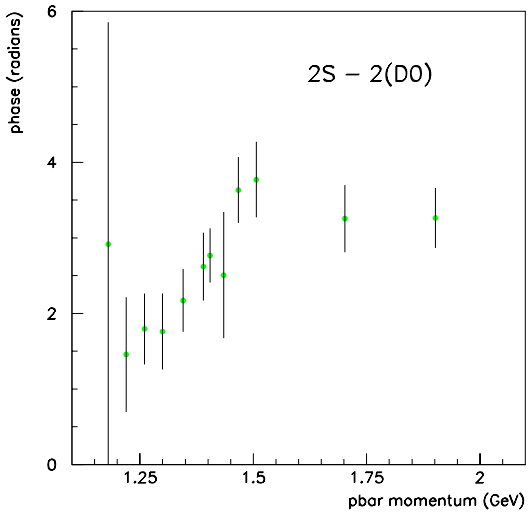
    where L_0 is the likelihood maximum over the full parameter space and L is the likelihood maximum over some restricted part.

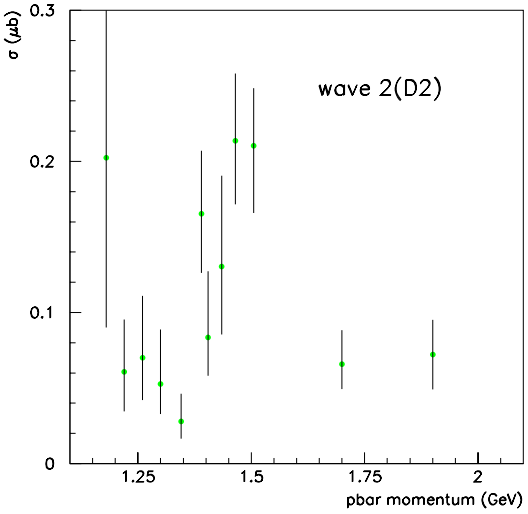
- For large N, behaves like chi-square with $n-n_0$ d.o.f.

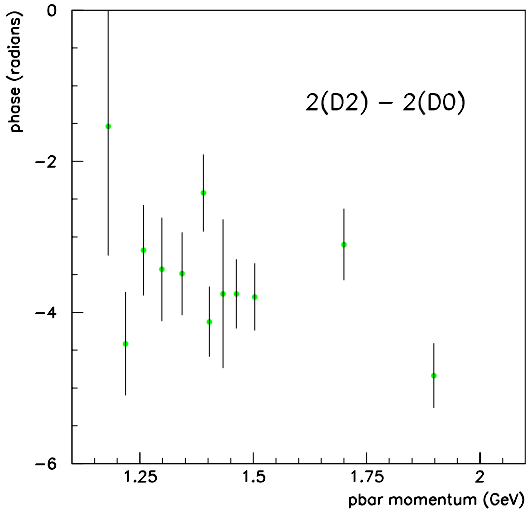


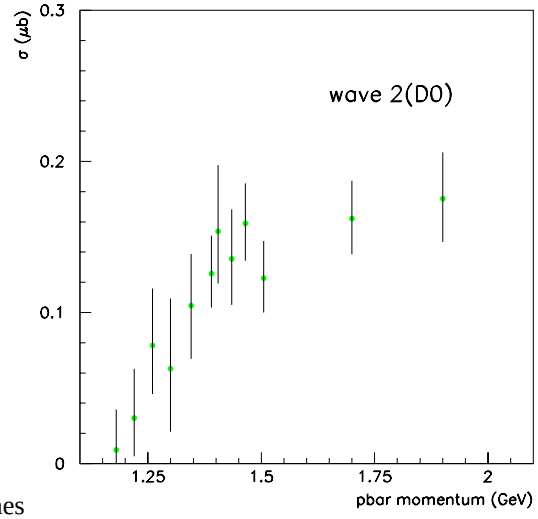
6-wave fit


wave 2S
σ (μb)
pbar momentum (GeV)

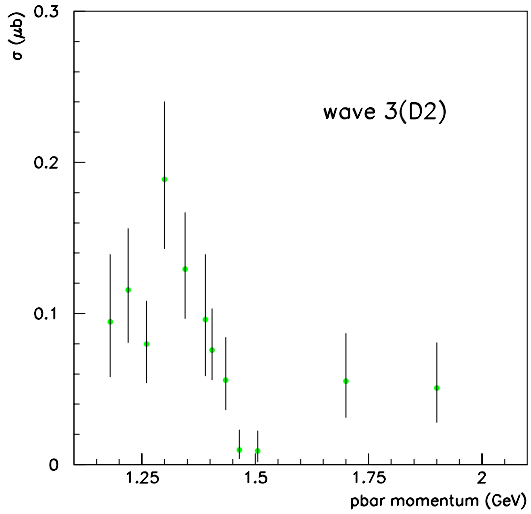

2S − 2(D0)
phase (radians)
pbar momentum (GeV)

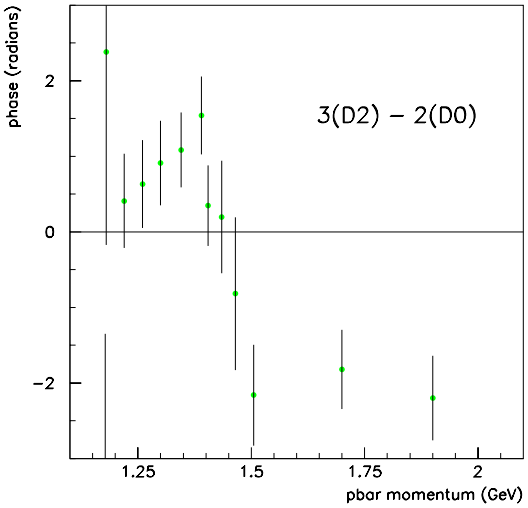

wave 2(D2)
σ (μb)
pbar momentum (GeV)

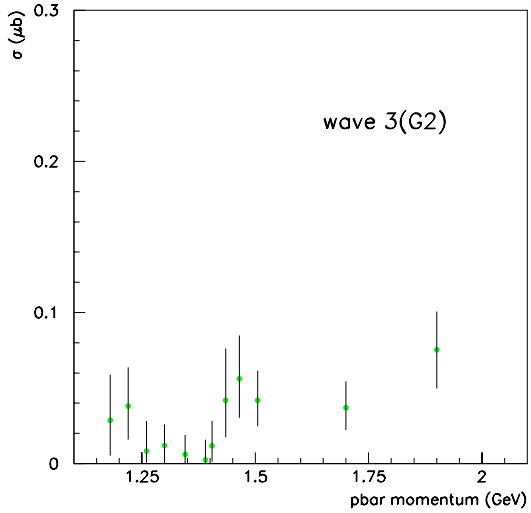

2(D2) − 2(D0)
phase (radians)
pbar momentum (GeV)

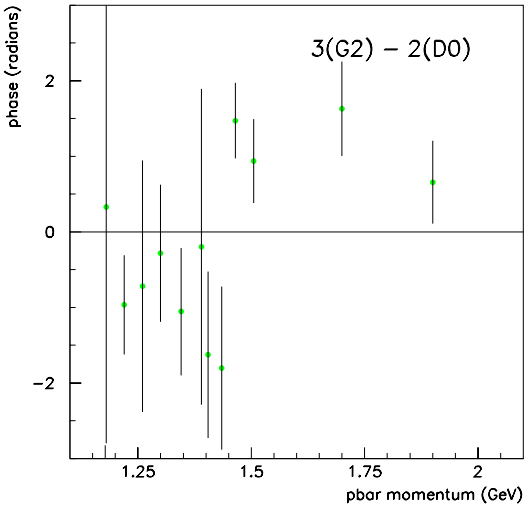

wave 2(D0)
σ (μb)
pbar momentum (GeV)

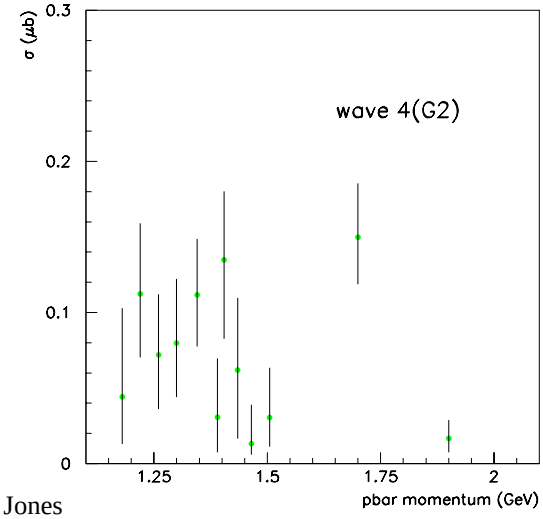
6-wave fit

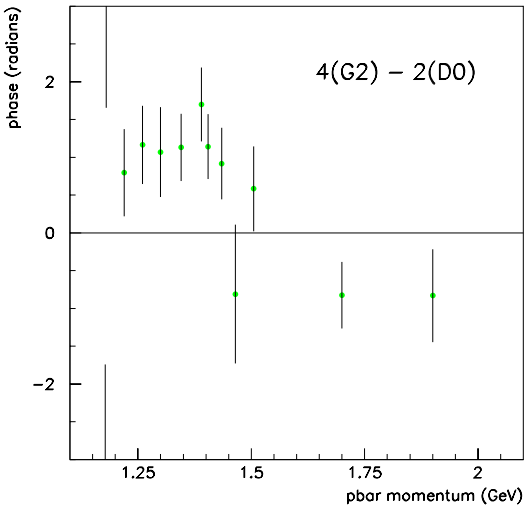

σ (μb)
wave 3(D2)
pbar momentum (GeV)


phase (radians)
3(D2) – 2(D0)
pbar momentum (GeV)

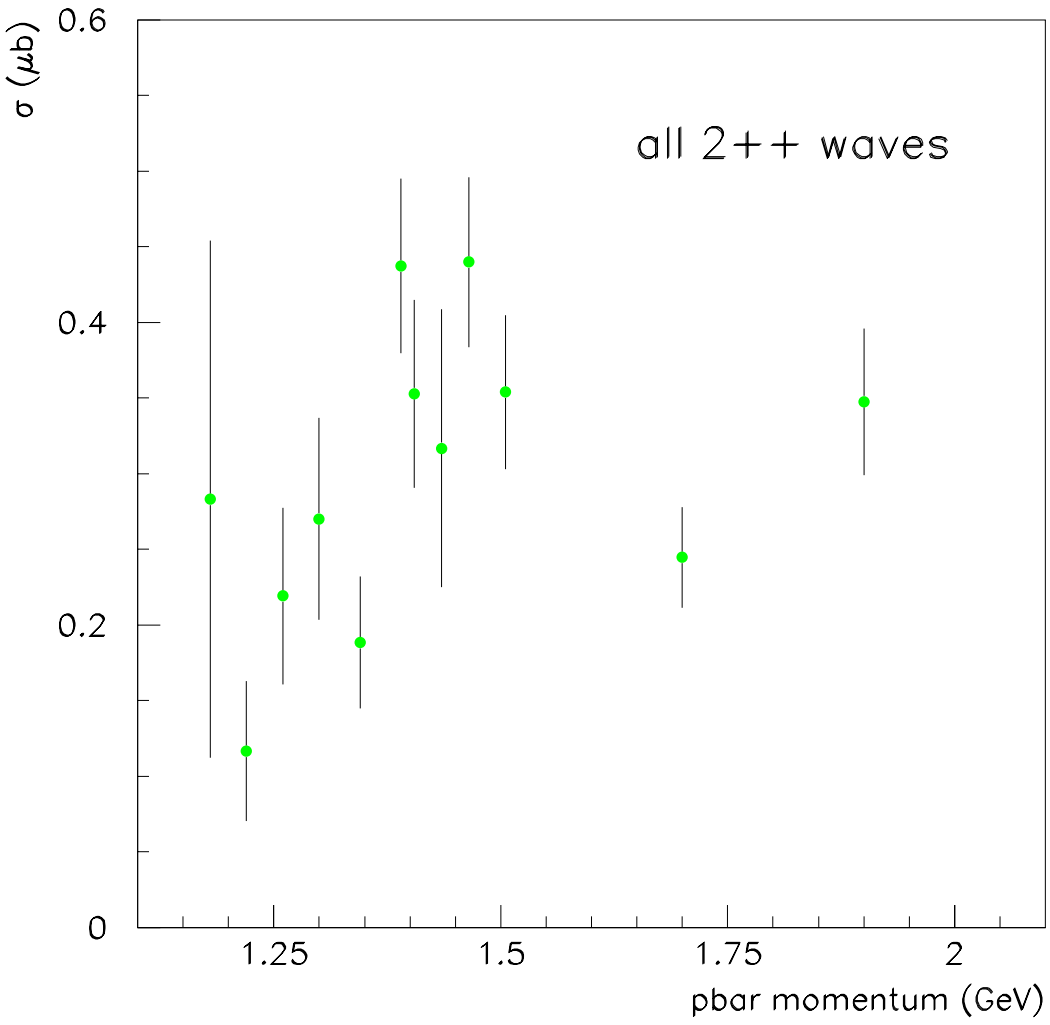

σ (μb)
wave 3(G2)
pbar momentum (GeV)


phase (radians)
3(G2) – 2(D0)
pbar momentum (GeV)


σ (μb)
wave 4(G2)
pbar momentum (GeV)


phase (radians)
4(G2) – 2(D0)
pbar momentum (GeV)

Total 2^{++} from 6-wave fit



- ☆ Some strength in 2^{++} has moved to 3^{++}
- ☆ No obvious narrow structure is visible in 2^{++}
- ☆ Phase motion seen does not correspond to a simple Breit-Wigner resonance
- ☆ Statistical errors do not justify a serious attempt to perform a multiple-pole fit

Conclusions

- PWA has been performed of the reaction

$$p\,\bar{p} \rightarrow \phi\phi$$

- 3 dominant waves were found, all 2^{++}.
- Rapid phase motion seen in two waves consistent with a narrow 2^{++} resonance.

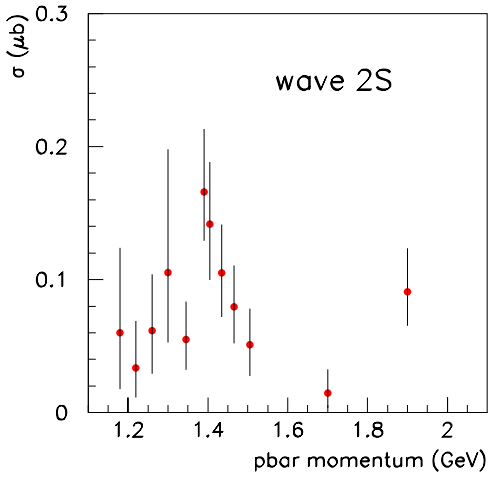
BUT

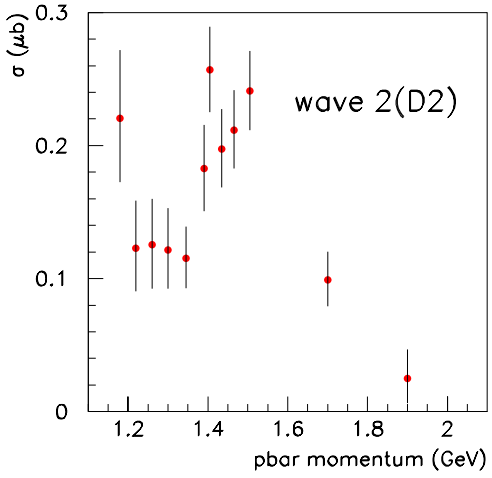
- The fit shows significant improvement if more waves are added, up to 6.
- Statistical errors do not permit a clear interpretation of 6-wave solution, but it does not favour a single narrow resonance.

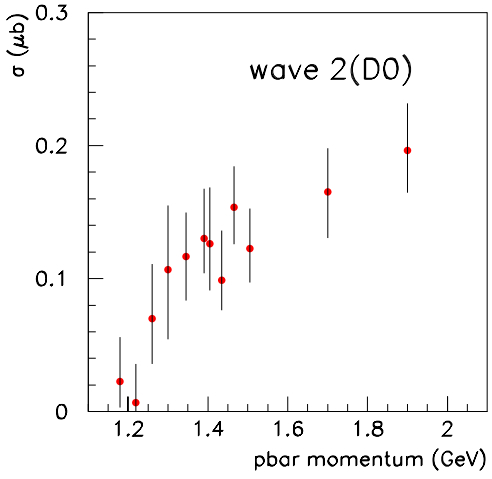
AND

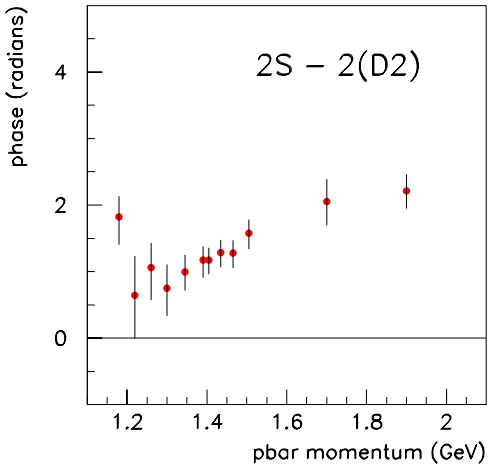
- Possible interference between the $\phi\phi$ and an underlying f_0,f_0 background should be taken into account.

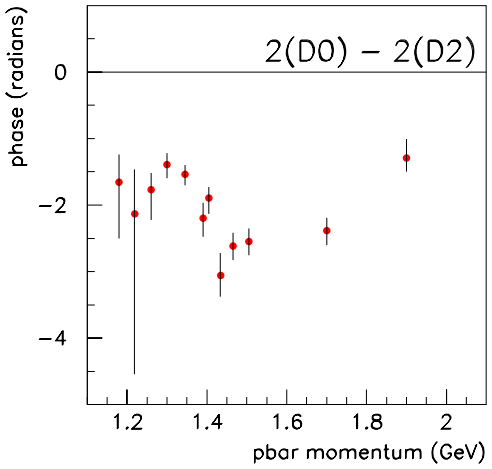
5-wave fit


wave 2S
σ (μb)
0.3
0.2
0.1
0
1.2
1.4
1.6
1.8
2
pbar momentum (GeV)

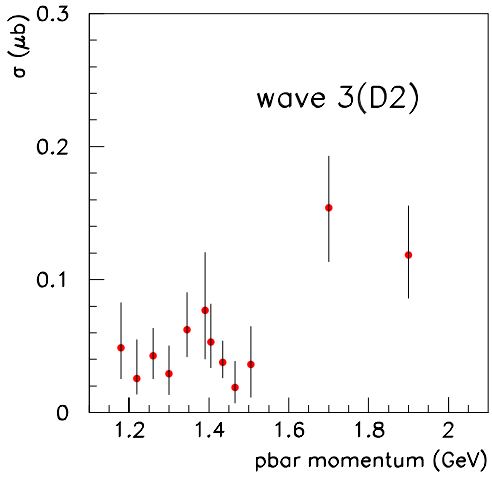

wave 2(D2)
σ (μb)
0.3
0.2
0.1
0
1.2
1.4
1.6
1.8
2
pbar momentum (GeV)

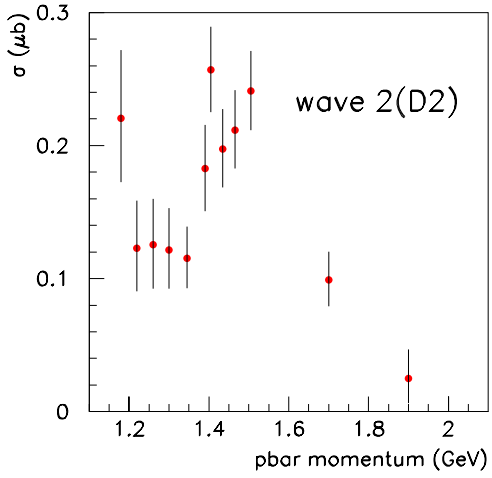

wave 2(D0)
σ (μb)
0.3
0.2
0.1
0
1.2
1.4
1.6
1.8
2
pbar momentum (GeV)

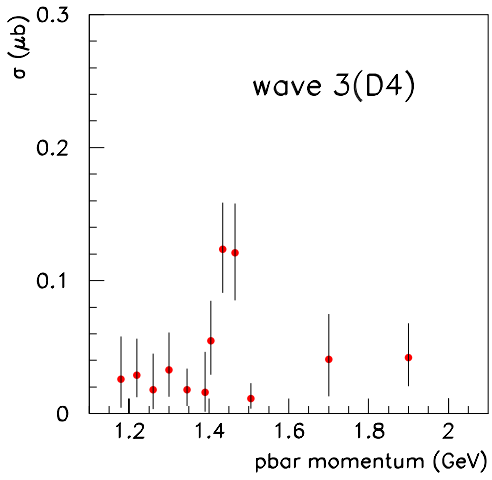

2S – 2(D2)
phase (radians)
4
2
0
1.2
1.4
1.6
1.8
2
pbar momentum (GeV)

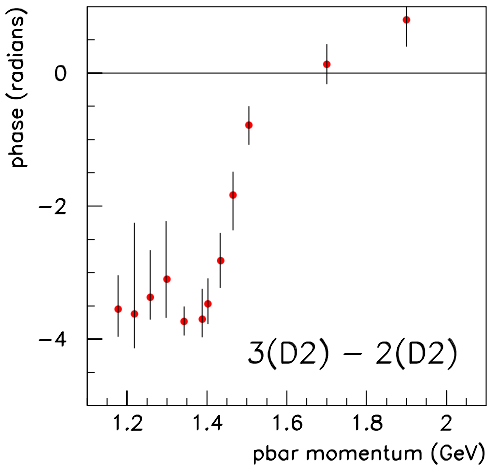

2(D0) – 2(D2)
phase (radians)
0
−2
−4
1.2
1.4
1.6
1.8
2
pbar momentum (GeV)

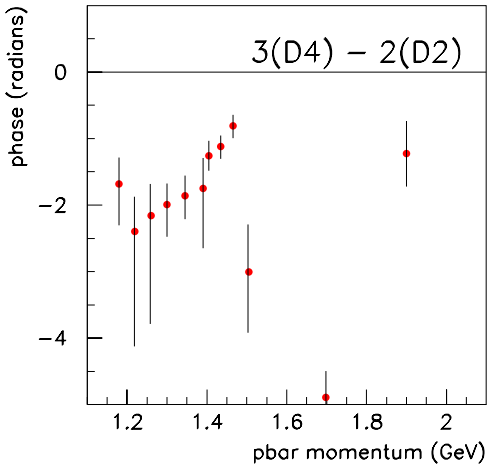
5-wave fit


σ (μb)
wave 3(D2)
pbar momentum (GeV)


σ (μb)
wave 2(D2)
pbar momentum (GeV)


σ (μb)
wave 3(D4)
pbar momentum (GeV)


phase (radians)
3(D2) − 2(D2)
pbar momentum (GeV)


phase (radians)
3(D4) − 2(D2)
pbar momentum (GeV)