S-P wave phase shift extraction procedure in $D^+ \rightarrow K^- \pi^+ e^+ \nu$ decay channel (& c.c.) with BaBar

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What are you going to hear now?

- S-P wave shift?
- How has this phase shift been measured until now
- Some aspects of these measurements

- My analysis:
- BaBar
- Signal selection
- How do I extract the S-P wave phase with a semileptonic decay channel
- What do I see (for the moment)

S-P wave phase shift

S-wave:
J = 0

- **What is the Kπ S-wave is still an open question**

$$K^{*0}_{1430} \qquad \kappa(800)\,? \qquad NR\,?$$

- **The understanding of the origin of S waves in Kπ systems is important because Kπ final states appear in several analyses in B and D decays**

ex: B → K π π

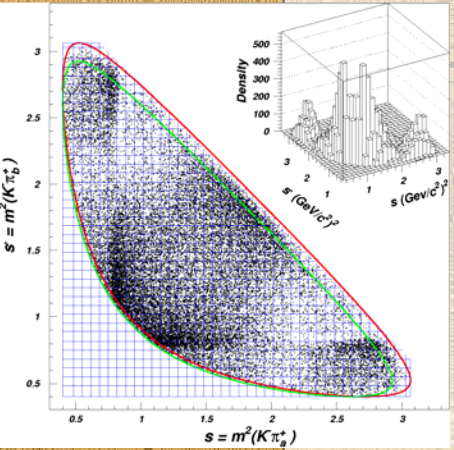
- **It allows the measurement of S-wave scattering lengths**

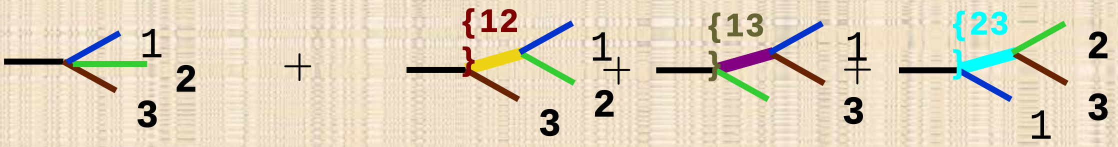
- **Important test of χPT**

How has the S-wave phase been studied until now

- **3 types of experiment have been used:**

  - Dalitz $D^+ \to K^- \pi^+ \pi^+$, (E791)





  - Scattering $K^-\pi^+$ (LASS)

$$K^- p \to K^- \pi^+ n$$

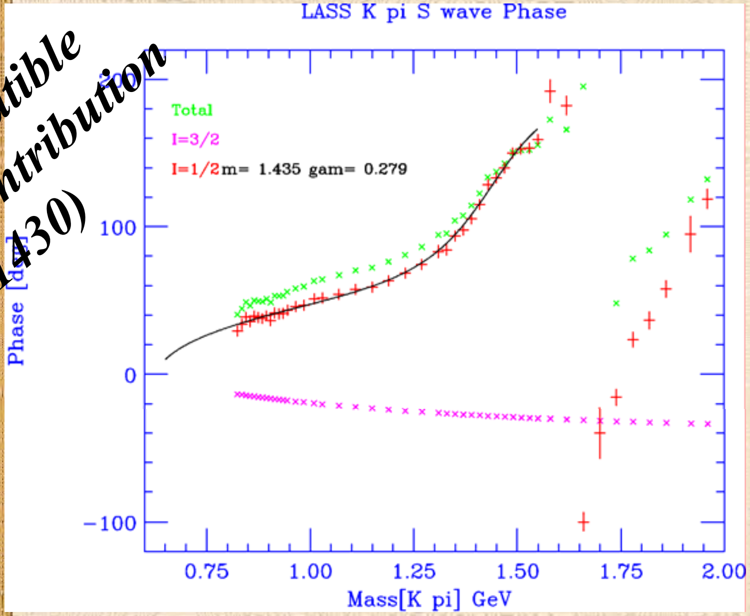
  - Semileptonic decays of D^+ (FOCUS,CLEO-C)

Some aspects of these measurements

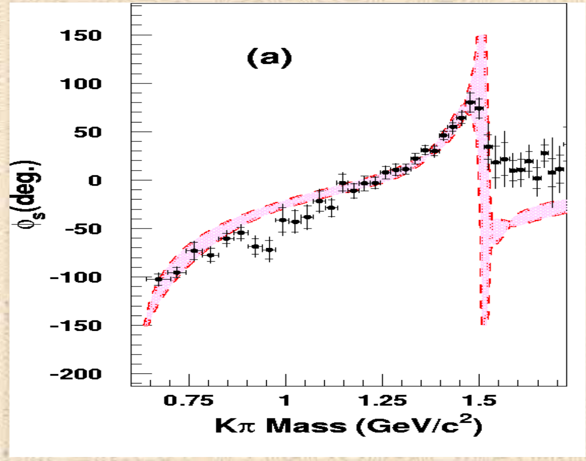
- **LASS: Most information of Kπ comes from this exp.**
  No data at low energies
  ($m_{K\pi}$ >0.825 GeV/c^2)

- **Dalitz:**
  Large statistics measurements at low $m_{K\pi}$ values

S-wave compatible with NR contribution and $K^{*0}(1430)$



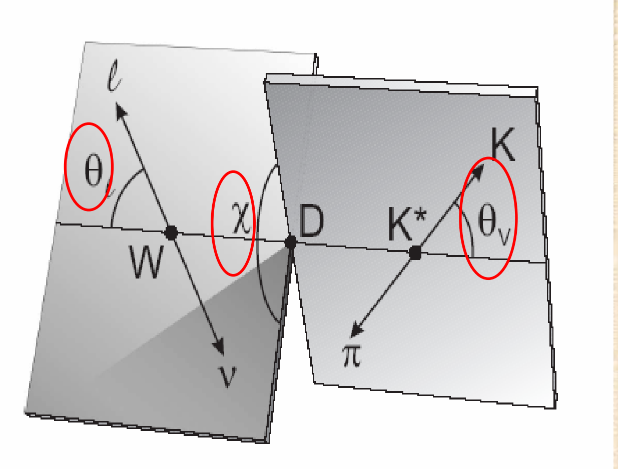
Their best fit to data includes a κ(800) resonance



Some aspects of these measurements

- **FOCUS/CLEO-C:**
  Only hadrons are K,π
  Sensitive to the interference between S-wave and P-wave at low invariant mass values

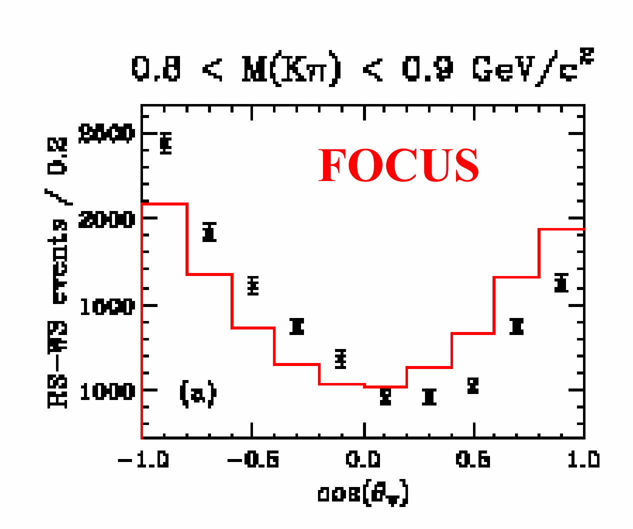
  4 body decay ↔ 5 independent variables:
  Kπ invariant mass ($m_{K\pi}$), q^2, 3 angles:

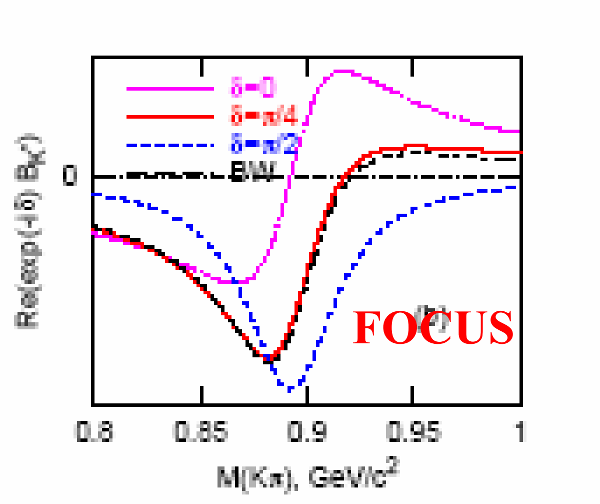


FOCUS has around 18000 events
CLEO-C has 2800 events

Some aspects of these measurements

$$\frac{d^5\Gamma}{dm_{K\pi}\ dq^2\ d\cos\theta_V\ d\cos\theta_\ell\ d\chi} \propto Kq^2 \left| \begin{array}{l} (1+\cos\theta_\ell)\sin\theta_V e^{i\chi} B_{K^{*0}} H_+ \\ -(1-\cos\theta_\ell)\sin\theta_V e^{-i\chi} B_{K^{*0}} H_- \\ -2\sin\theta_\ell(\cos\theta_V B_{K^{*0}} + Ae^{i\delta})H_0 \end{array} \right|^2$$

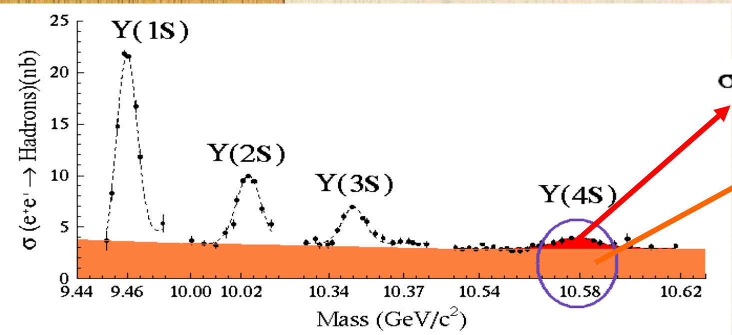




They find a good compatibility with a NR S-wave with a constant value for the phase versus $m_{K\pi}$

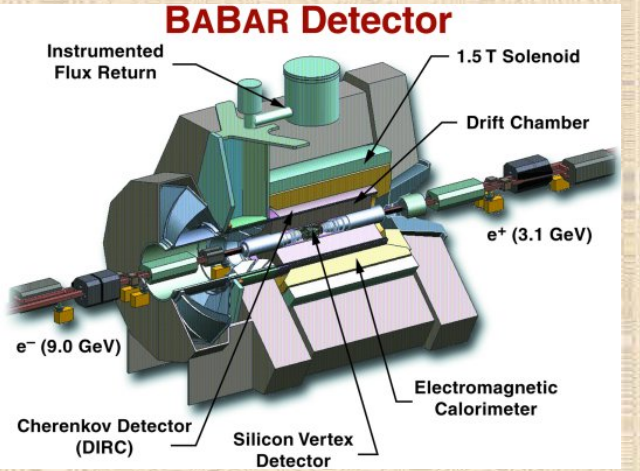
BaBar

- **Asymetric e^+e^- collider**
- **c.m. energy of 10.6 GeV**

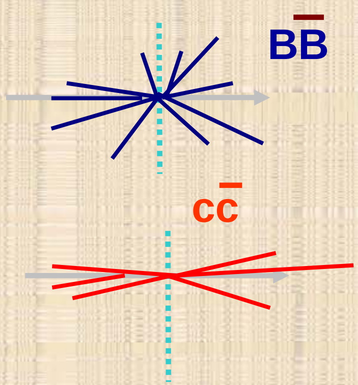


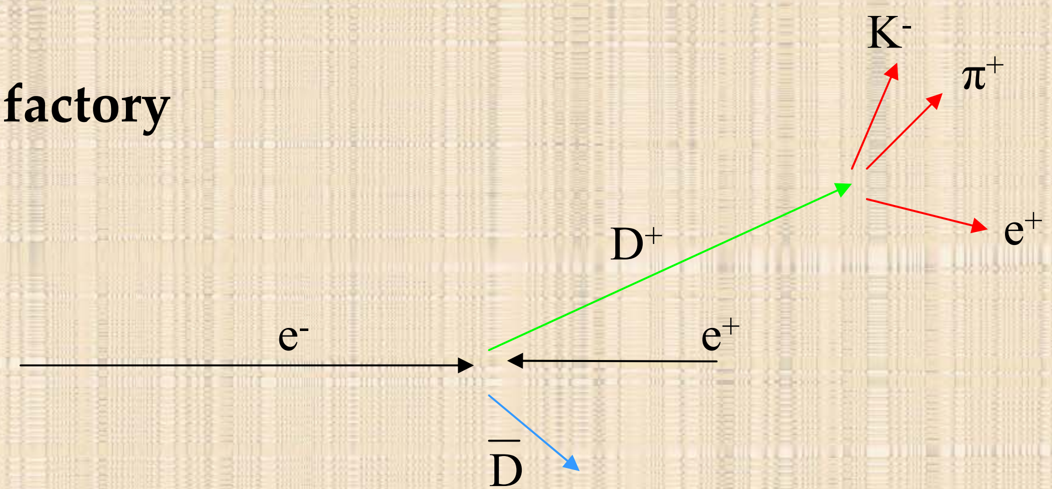
$\sigma(e^+e^- \to b\bar{b}) = 1.05$ nb

$\sigma(e^+e^- \to c\bar{c}) = 1.30$ nb



- **Enormous charm factory**

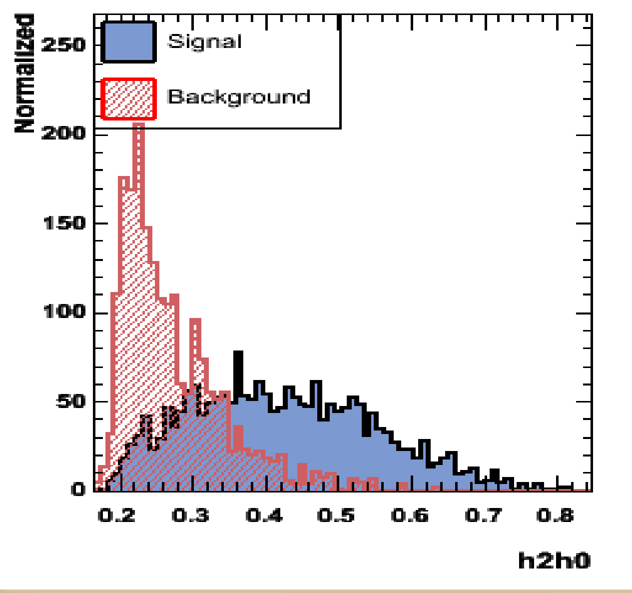




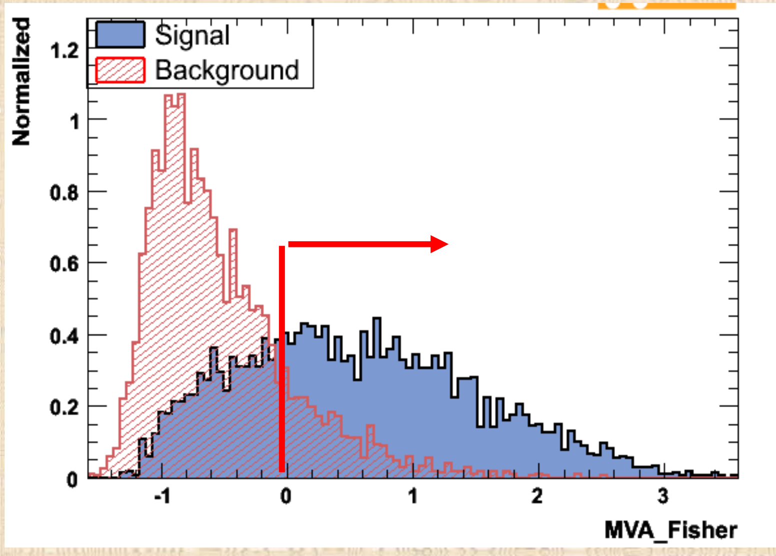
Signal selection

- We use a luminosity of $100fb^{-1}$
- Background removal based on the use of Fisher discriminant variables with the BaBar generic MC:
- Fisher discriminant is a linear combination of variables which have a different behaviour for signal and for background

h2h0 variable

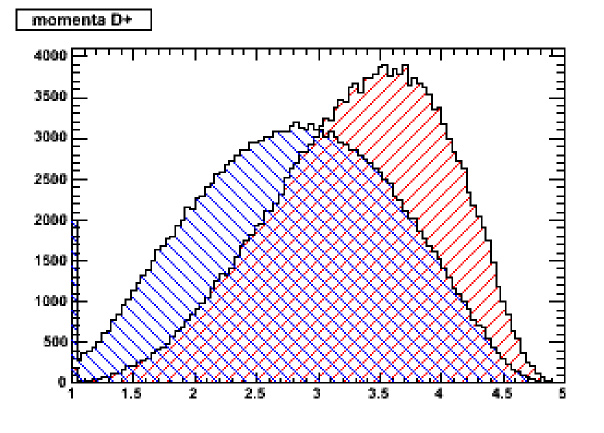


BBbar
Fisher discriminant

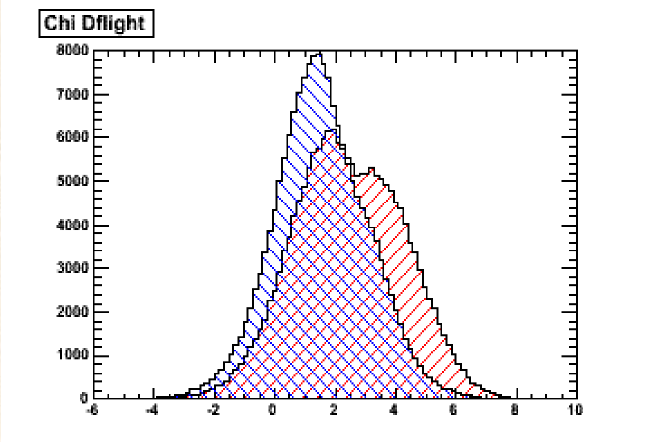


Signal selection

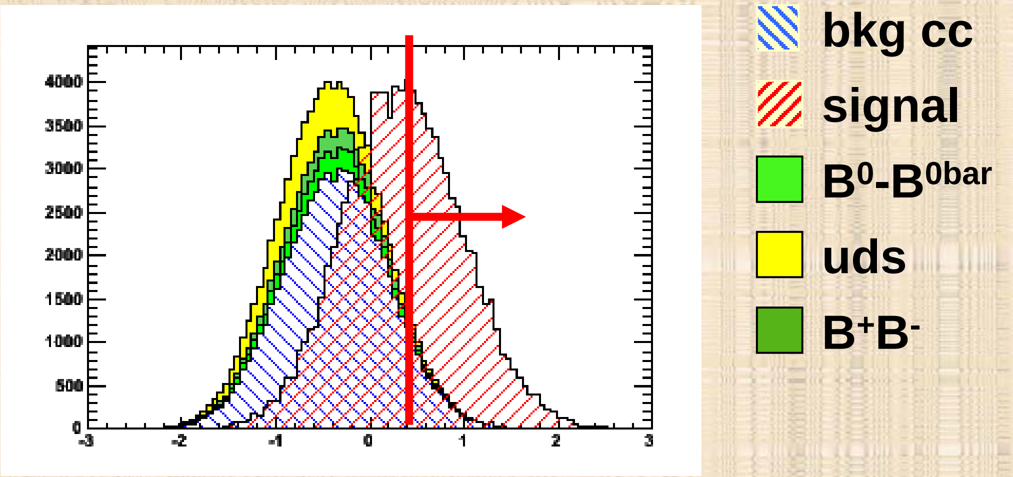
reco D momentum



D flight significance

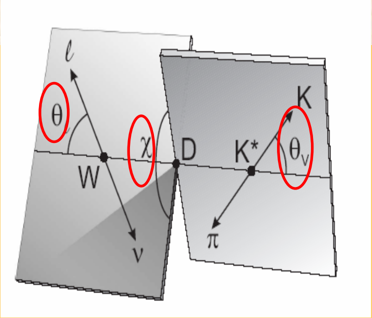


CCbar Fisher discriminant



Phase shift extraction

- **We follow the formalism of *Cabibbo & Maksymowicz***



$$d^5\Gamma \propto P_{K\pi} P^* I(m_{K\pi}, q^2, \chi, \cos\theta_l, \cos\theta_K) d^5x$$

$$P_{K\pi} = momentum\ \ of\ \ (K\pi)\ \ system\ \ in\ \ D\ \ c.m.$$

$$P^* = momentum\ of\ \ K\ in\ \ (K\pi)\ \ c.m.$$

$$I = I_1 + I_2\cos(2\theta_l) + I_3\sin^2\theta_l\cos 2\chi + I_4\sin(2\theta_l)\cos\chi + I_5\sin\theta_l\cos\chi + I_6\cos\theta_l$$
$$+ I_7\sin\theta_l\sin\chi + I_8\sin(2\theta_l)\sin\chi + I_9\sin^2\theta_l\sin(2\chi)$$

$$I_i = I_i(\cos\theta_K, m_{K\pi}, \mathrm{q})$$

- **Partial wave analysis (we consider only S and P waves)**

Phase shift extraction

These are the terms in I which are sensitive to the interference between the S-P waves

$$I_1 = \frac{1}{4}\left\{|F_1|^2 + \frac{3}{2}\sin^2\theta_K\left(|F_2|^2 + |F_3|^2\right)\right\}$$

$$I_2 = -\frac{1}{4}\left\{|F_1|^2 - \frac{1}{2}\sin^2\theta_K\left(|F_2|^2 + |F_3|^2\right)\right\}$$

$$I_4 = \frac{1}{2}\mathrm{Re}\left(F_1^* F_2\right)\sin\theta_K$$

$$I_5 = \mathrm{Re}\left(F_1^* F_3\right)\sin\theta_K$$

$$I_7 = \mathrm{Im}\left(F_1 F_2^*\right)\sin\theta_K$$

$$I_8 = \mathrm{Im}\left(F_1 F_3^*\right)\sin\theta_K$$

$$F_1 = F_{1s}e^{i\varphi_s} + F_{1p}e^{i\varphi_p}\cos(\theta_K)$$

$$F_2 = F_{2p}e^{i\varphi_p}$$

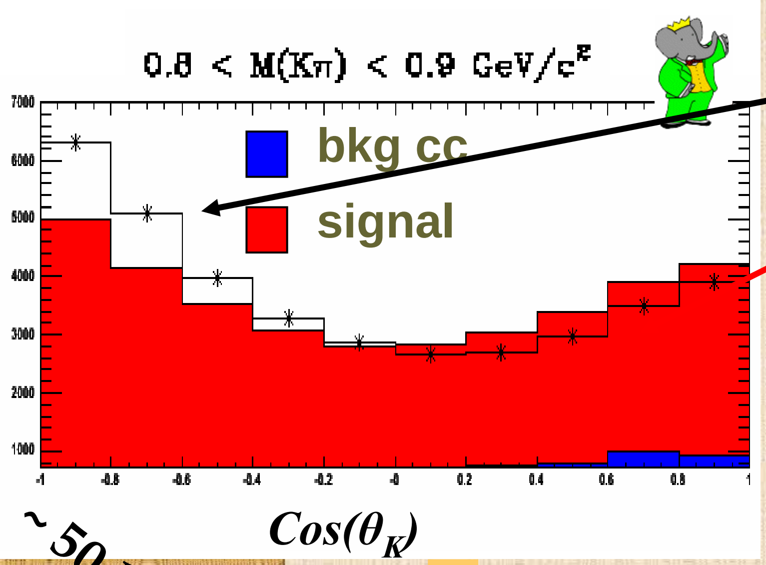
$$F_3 = F_{3p}e^{i\varphi_p}$$

$$\boldsymbol{F_{ij} = F_{ij}(m_{K\pi}, q^2)}$$

Phase shift extraction

- **If we project our data versus the $\cos(\theta_K)$ variable:**

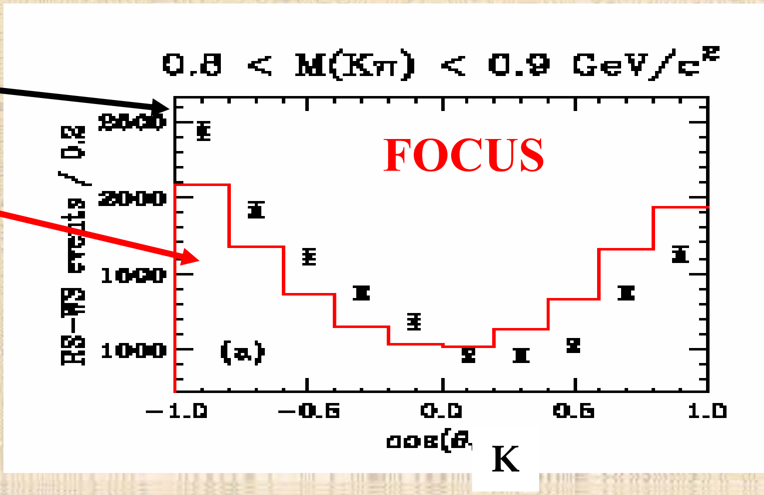
There is a large effect but it depends not only of the S-P phase shift as it is proportional also to the amplitudes of S and P waves and to the form factors.



DATA

MC P-wave

We see an asymetry like FOCUS



~50 k data signal events

$$\int I \; dq^2 dm_{K\pi} d\chi d\cos\theta_l$$

$$= \int \left(I_1 + I_2 \cos(2\theta)\right) dq^2 dm_{K\pi} d\chi d\cos\theta_l$$

Phase shift extraction

- **We follow the idea of *Pais & Treiman:***

$$\langle I_4\rangle = \frac{1}{8\pi}\langle F_1 F_{2p}\rangle \cos(\delta_s - \delta_p)$$

$$\langle I_5\rangle = \frac{-1}{4\pi}\langle F_{1s} F_{3p}\rangle \cos(\delta_s - \delta_p)$$

$$\langle I_7\rangle = \frac{1}{4\pi}\langle F_{1s} F_{2p}\rangle \sin(\delta_s - \delta_p)$$

$$\langle I_8\rangle = \frac{-1}{8\pi}\langle F_{1s} F_{3p}\rangle \sin(\delta_s - \delta_p)$$

$$\tan\left(\delta_s - \delta_p\right) = \frac{1}{2}\frac{\langle I_7\rangle}{\langle I_4\rangle} = 2\frac{\langle I_8\rangle}{\langle I_5\rangle}$$

- **$\langle I_i\rangle$ can be measured by taking moments of different angular variables over the differential decay rate:**

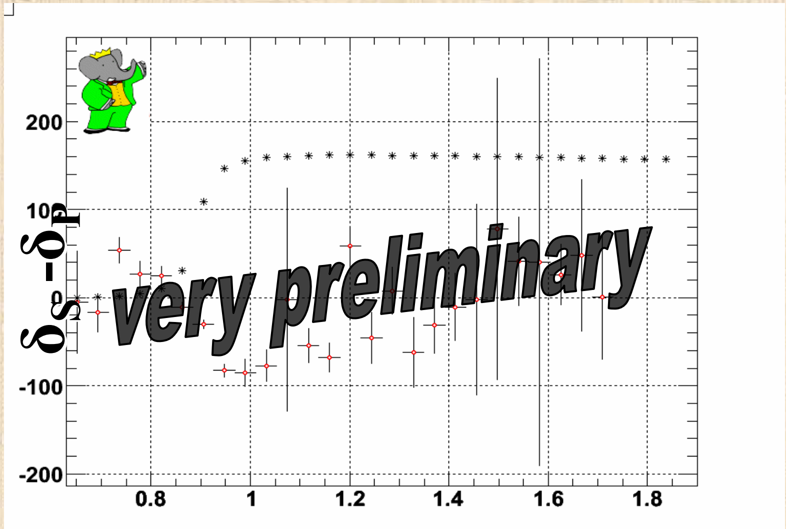
$$\frac{\int I\cos(\theta_l)\sin(\chi)dq^2 d\cos(\theta_K)d\cos(\theta_l)d\chi}{\int I\cos(\chi)dq^2 d\cos(\theta_K)d\cos(\theta_l)d\chi} = \frac{1}{2}\frac{\sin(\delta_s - \delta_p)}{\cos(\delta_s - \delta_p)}$$

What do I see (for the moment)

Considering a typical Breit-Wigner for the K^{*0} we find:

* K^{*0} BW phase

o S-P phase shift (BaBar data)

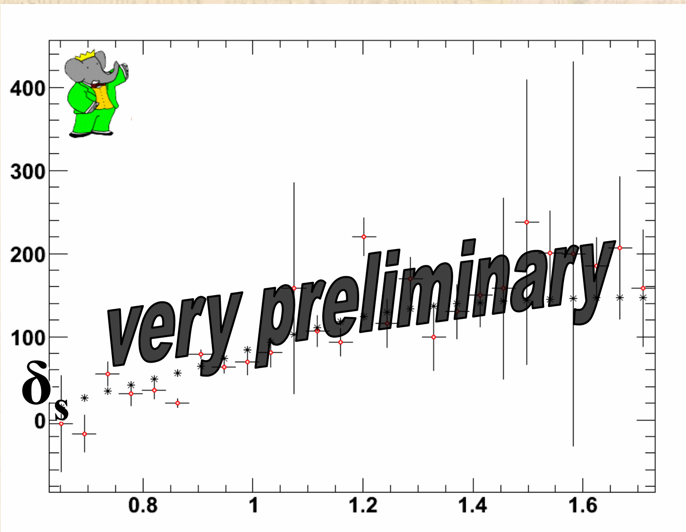


$m_{K\pi}$

And subtracting the P-wave phase in our data:

* Lass S-wave expression

o S- wave (BaBar data)



$m_{K\pi}$

Conclusion

- So:
- With this channel we don't have extra hadrons and we have a direct access to the $K\pi$ system
- We use an approach which allows a direct measurement of the phase shift between S-P waves which requires no previous knowledge of the q^2 dependence of form factors
- Encouraging results are obtained with 100 fb^{-1}. We have available 5 times this data already.
- Lots of tests still to be done before distributing these measurements. Expect results soon.