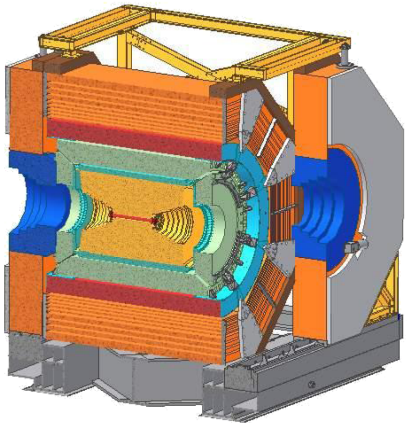
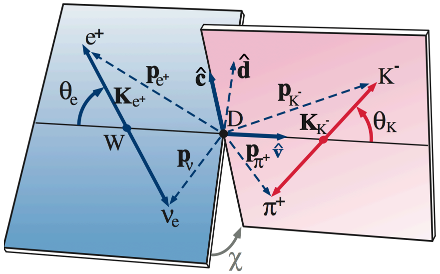
PWA of $D^+ \to K^- \pi^+ e^+ \nu_e$ @BES3





Wolfgang Gradl
Peter Weidenkaff

PWA Summer School
Flecken-Zechlin 2013

Introduction

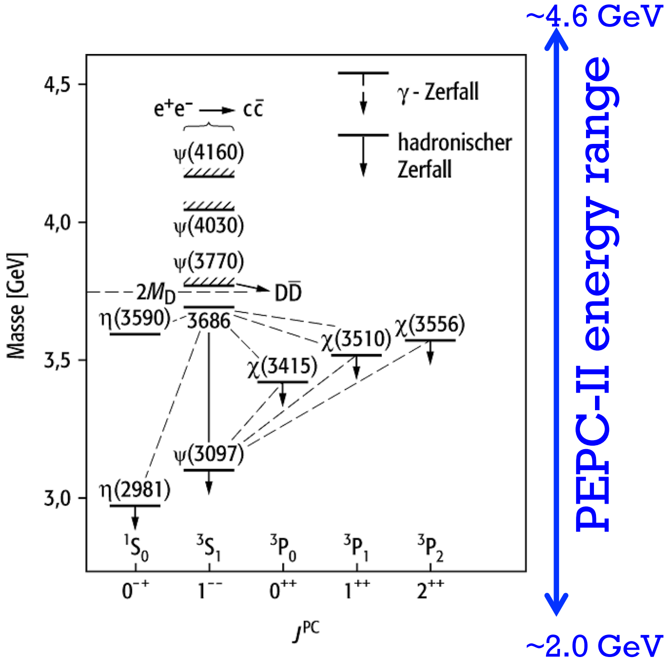
- Why do we analyse $\mathbf{D}^+ \rightarrow \mathbf{K}^-\pi^+\mathbf{e}^+\nu_\mathbf{e}$?
  - Semileptonic decay
    - Matrixelement $\mathcal{M}$ separates into hadronic and leptonic part
    - No interaction between had. and lep. system
  - Rescattering in non-leptonic decays, e.g. $\mathbf{K}^-\pi^+\pi^+$

S-wave contribution can be measured w/o FSI

- Previously analysed by BaBar (Phys.Rev.D83,072001)
  - 347.5 fb^{-1} // 244 x 10^3 signal events
  - Limitations (?)

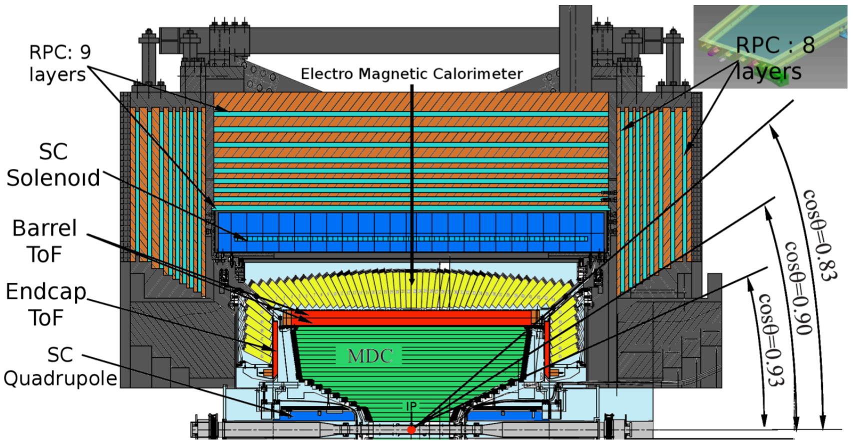
Charm physics @ BESIII

- PEPC-II: symmetric e+e- collider

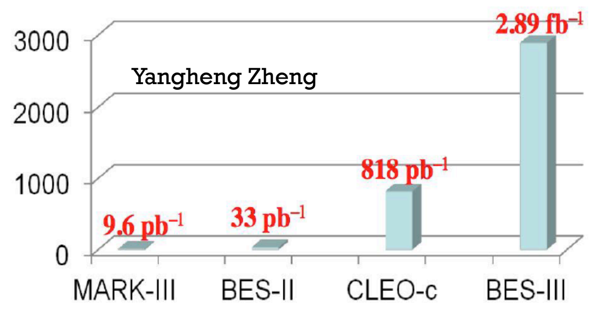


- events of quantum-correlated $D^0\overline{D^0}$ and D^+D^- decays

- Multi-purpose 4π detector

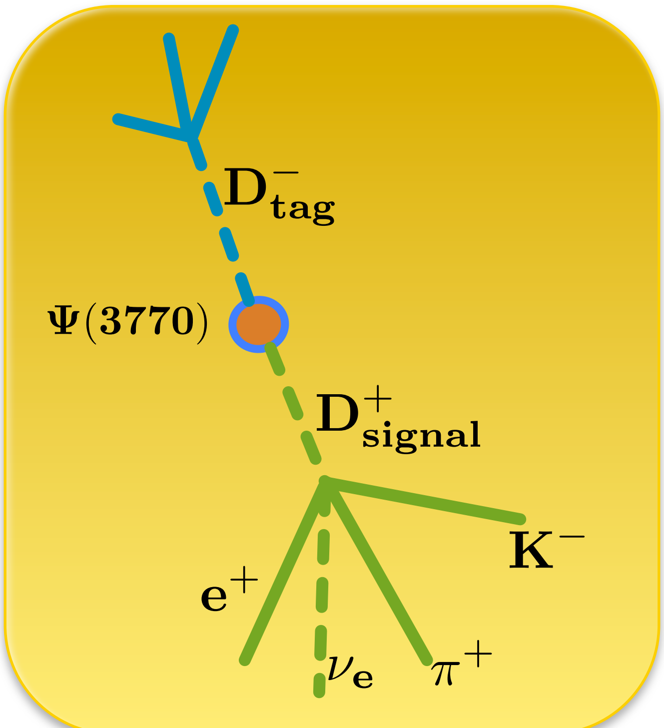


- Current data sample on $\Psi(3770)$



Double tag technique

Topology



Tag modes

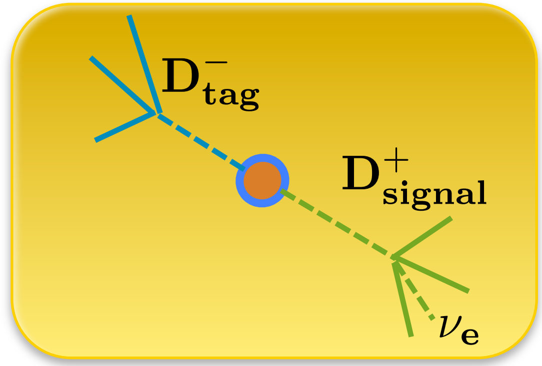
$D^+ \to K^-\pi^+\pi^+$
$D^+ \to K^-\pi^+\pi^+\pi^0$
$D^+ \to K^0_s\pi^+$
$D^+ \to K^0_s\pi^+\pi^0$
$D^+ \to K^0_s\pi^+\pi^+\pi^-$
$D^+ \to K^+K^-\pi^+$

$$\sum \mathbf{BF_i} \approx \mathbf{30\%}$$

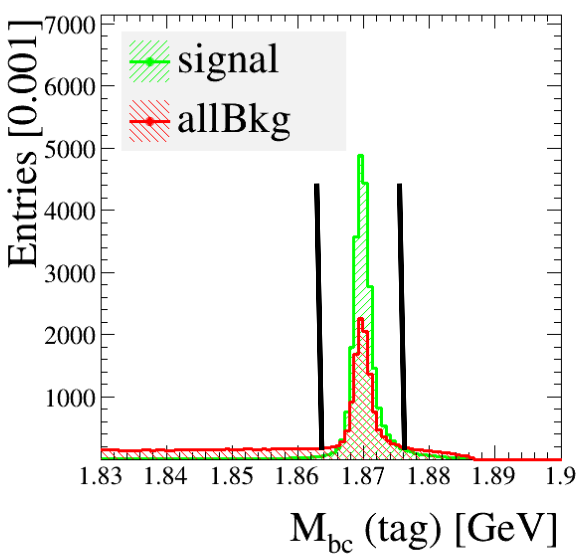
Features:

- CP tags
- Flavour tags
- Clean sample

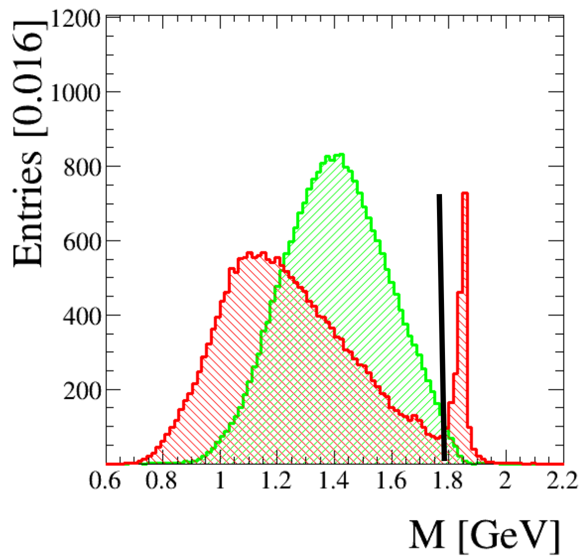
Selection



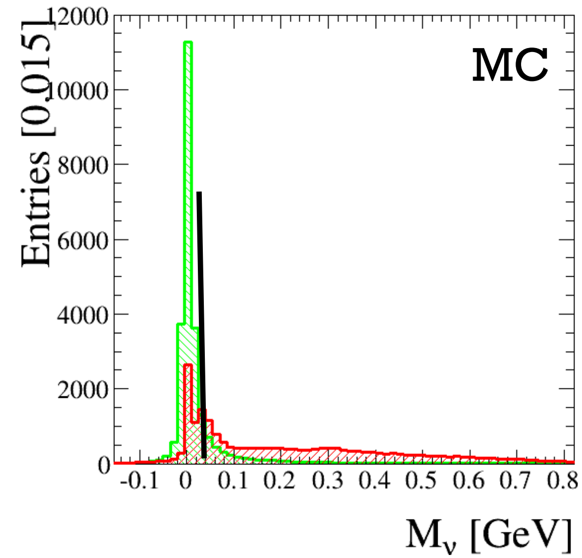
$$M^2_{bc} = E^2_{beam} - |p_{rec}|^2$$



- Select good tag

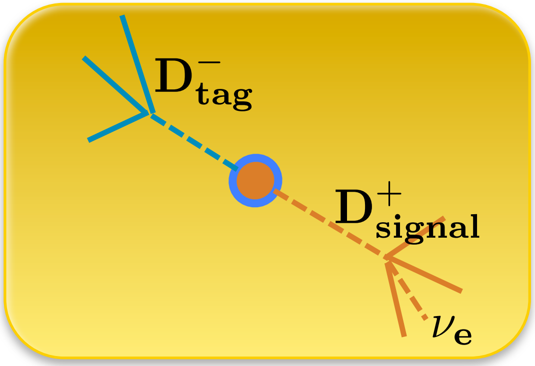


- Reject correct D+



- Missing mass ~0

Selection



Selection criteria	value
$P(e^+)$	> 0.176 GeV
$Vr(e^+)$	< 0.18 cm
$M(D^+)$	< 1.81 GeV
$M_{bc}(D^+)$	< 1.81 GeV
$P(D^-{}_{tag})$	< 0.29 GeV
$P_t(D^-{}_{tag})$	> 0.05 GeV
$M_{bc}(D^-{}_{tag})$	$[1.864, 1.874]$
$M(\nu_e)$	$[-0.193, 0.012]$
$DLL_\pi(e^+)$	> 2

Peak at $M(D^+)_{PDG}$ is background

Peak region of the tag candidate
Missing mass
PID

- Background
  - $D^+ \to K^- \pi^+ \mu^+ \nu_\mu$
  - $D^+ \to K^- \pi^+ \pi^+$ harder PID criteria

$S \approx 2400$ @ $2.89\ fb^{-1}$

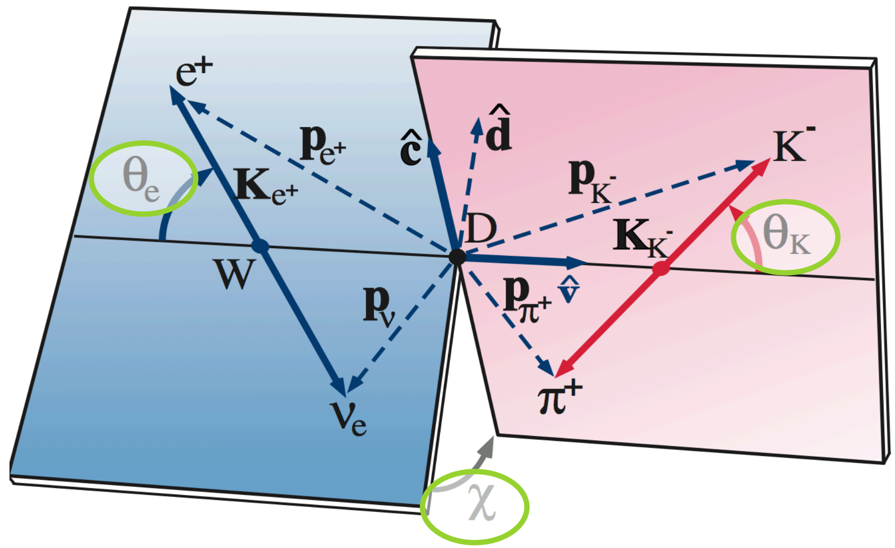
$B/S \approx 2\%$

Decay topology

$$\mathbf{D^+ \to K^-\pi^+e^+\nu_e}$$

- 4 particles final state // 5 d.o.f

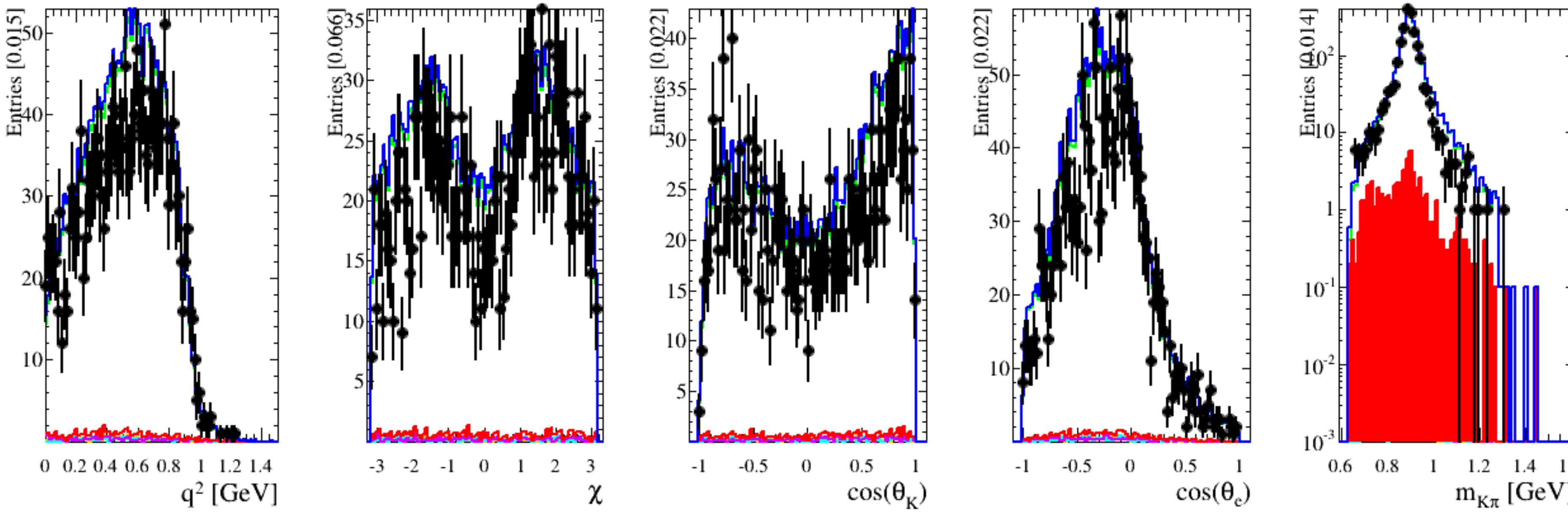
χ	Angle between decay planes
$\theta_\mathbf{K}$	Kaon helicity angle
$\theta_\mathbf{E}$	Electron helicity angle
$\mathbf{m_{K\pi}}$	Hadronic invariant mass
$\mathbf{q^2}$	Leptonic inv. mass



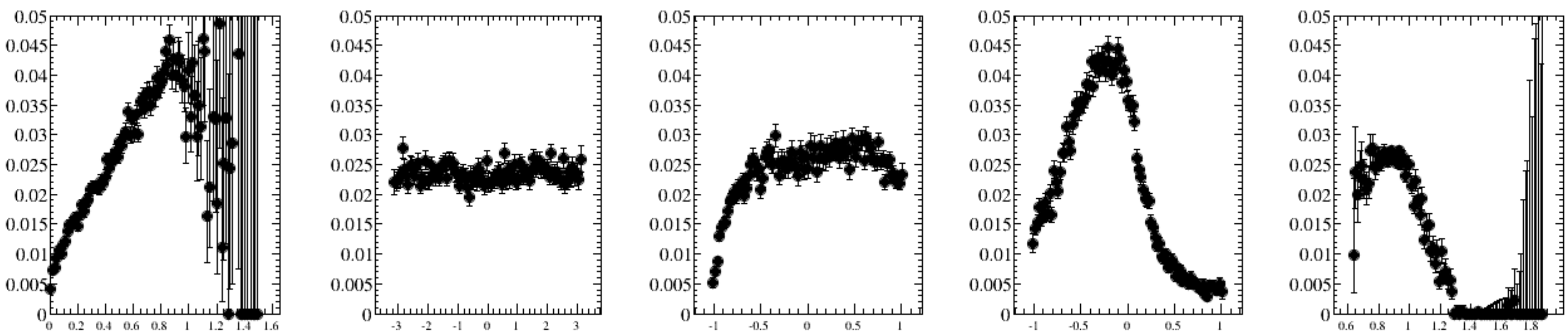
Phys.Rev.D83,072001

Analysis variables

Monte-Carlo
Background
Data

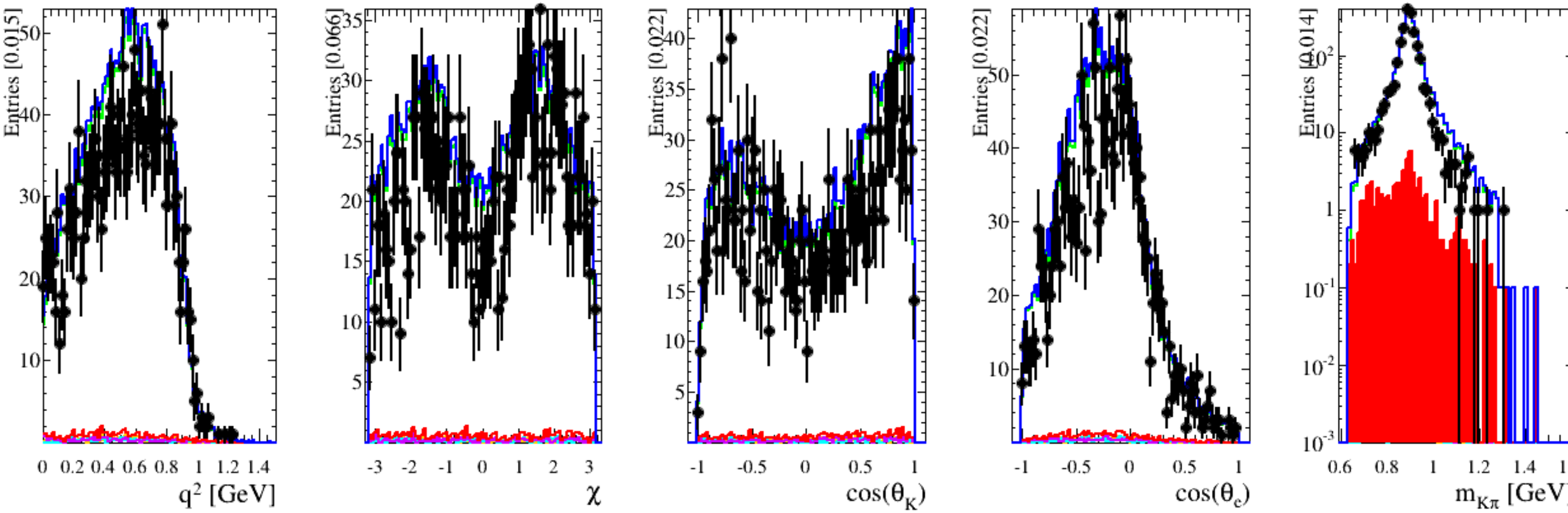


- Efficiency

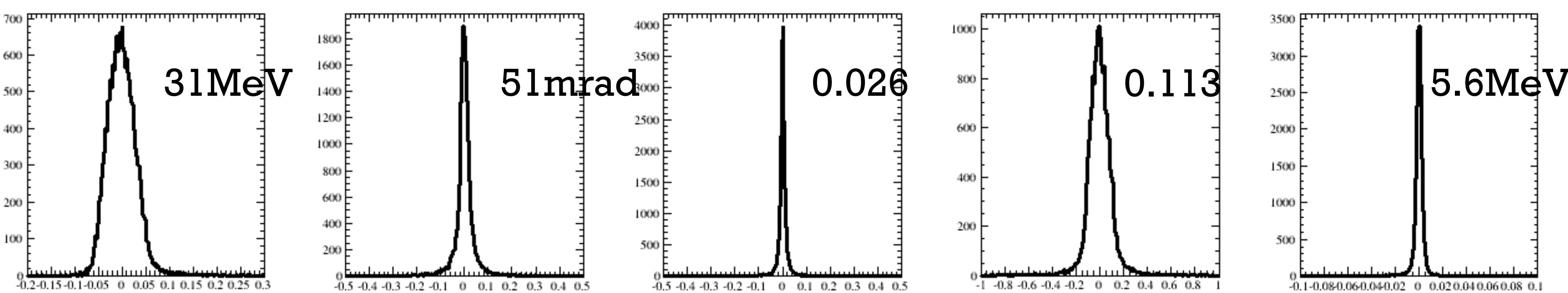


Analysis variables

Monte-Carlo
Background
Data



- Resolution (RMS)



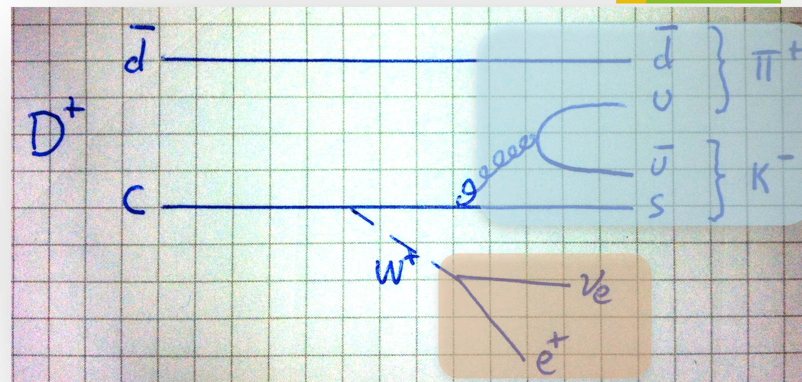
PWA analysis

Decay rate formalism

- Matrix element

$$M_{fi} = \frac{G_F}{\sqrt{2}} |V_{cs}| \langle \pi K | \bar{s} \gamma_\mu (1 - \gamma_5) c | D \rangle$$

$$\times \ \bar{u} \gamma_\mu (1 - \gamma_5) v$$



  - Hadronic part described by 3 FF: $\omega_\pm$ **axial-vector**
    $\mathbf{h}$ **vector**

- Decay rate

$$\mathbf{d^5\Gamma \sim \frac{G_F^2 ||V_{cs}||^2}{m_D^3} I(q^2, \chi, \theta_K, \theta_e, m_{K\pi}^2) dq^2 d\chi d\theta_K d\theta_e dm_{K\pi}^2}$$

PWA analysis

$$\mathbf{d^5\Gamma \sim I(q^2, \chi, \theta_K, \theta_e, m^2_{K\pi})}$$

- Define form factors $\mathbf{F_i(q^2, \theta_K, m^2_{K\pi})}$

$$F_1(w_+, w_-) = X_1 w_+ + X_2 w_-$$

$$F_2(w_-) = X_3 w_-$$

$$F_3(h) = X_4 h$$

- Expand form factors in partial waves

$$F_1 = F_{10} + F_{11} \cos\theta_K + F_{12} \frac{1}{2}(3\cos\theta_K - 1)$$

$$F_2 = F_{21} \frac{1}{\sqrt{2}} + F_{22} \sqrt{\frac{3}{2}} \cos\theta_K$$

$$F_3 = F_{31} \frac{1}{\sqrt{2}} + F_{32} \sqrt{\frac{3}{2}} \cos\theta_K$$

S P D

Form factor parametrization

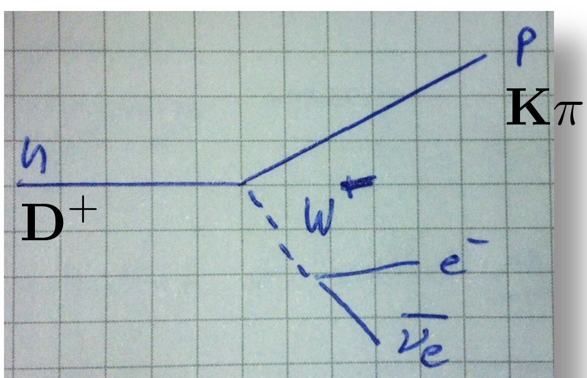
Motivation for $\mathbf{q^2}$ and $\mathbf{m^2_{K\pi}}$ dependence of $\mathbf{F_{1,2,3}(q^2, m^2_{K\pi})}$

$\mathbf{q^2}$	$\mathbf{m^2_{K\pi}}$

- Using a ‚single pole' parametrization:

$$G(q^2) \sim \frac{1}{1 - \frac{q^2}{m_P}}$$

- Analogy: neutron decay



- Insert resonance as BW:

S-wave	$K_0^*(1430)$
P-wave	$K^*(892)$
	$K^*(1410)$
D-wave	$K_2^*(1430)$

$$A(m_{K\pi}) \sim \frac{1}{m_R^2 - m_{K\pi}^2 - i m_R \Gamma_R}$$

- A bit more complicated for S-wave

Form factor parametrization

$K\pi$ scattering theory

Watson theorem: In elastic regime phases in $K\pi$ scattering are the same as in decay (modulo π, w/o rescattering)

- Partial wave expansion:

$$T(s,t,u) \sim \sum_{l=0}^{\infty}(2l+1)P_l(\cos\theta)t_l(s)$$

- Expand real part and phase @ threshold:

$$Re\ t_l(s) = \frac{1}{2}\sqrt{s}(p^*)^{2l}\{a_l + b_l(p^*)^2 + \ldots\}$$

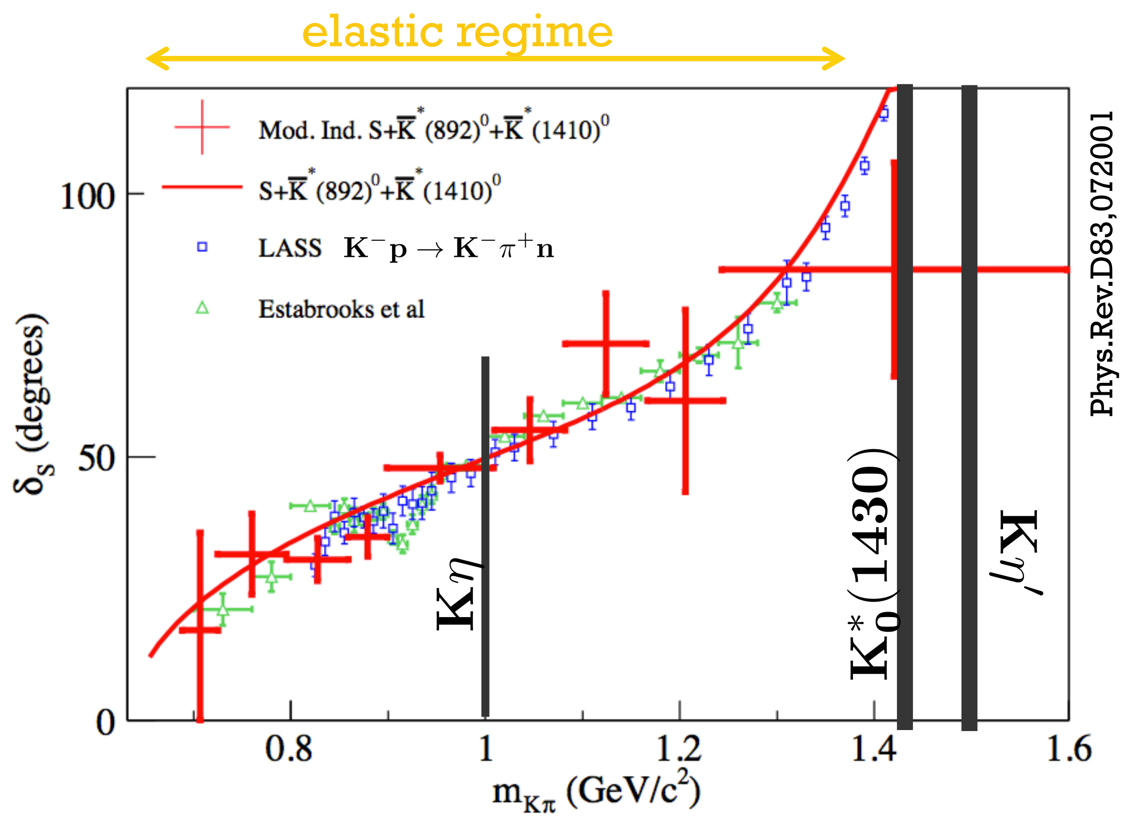
$$\delta_l = (p^*)^{2l+1}\{\alpha + \beta(p^*)^2\}$$

→ relate α and β to scattering length and effective range

- S-wave parametrization:

$$\mathbf{A_S}(\mathbf{m^2_{K\pi}}) = \mathbf{P}(\mathbf{m_{K\pi}}) \times \exp(\mathbf{i}\ \delta(\mathbf{m_{K\pi}}))$$

BaBar result



- Other results:
  - $\mathbf{K^*(892)}$ parameters
  - Hadronic form factors

Summary

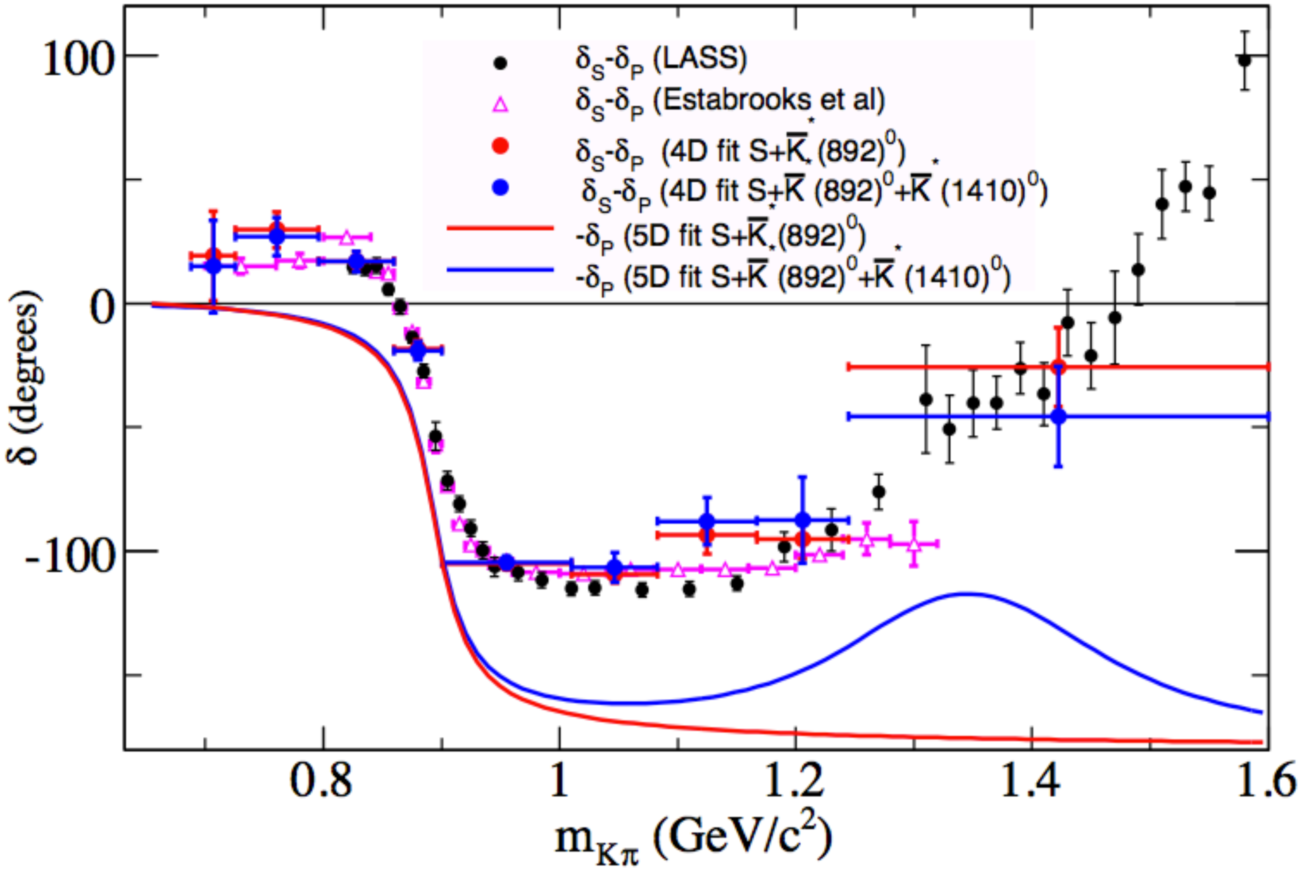
- Selection

$S \approx 2400$ @ $2.89\ \mathrm{fb}^{-1}$

$B/S \approx 2\%$

- Lower background compared to BaBar
- Next step: PWA

Backup



100
0
-100
δ (degrees)
0.8
1
1.2
1.4
1.6
m_Kπ (GeV/c²)
δS-δP (LASS)
δS-δP (Estabrooks et al)
δS-δP (4D fit S+K̄*(892)⁰)
δS-δP (4D fit S+K̄*(892)⁰+K̄*(1410)⁰)
-δP (5D fit S+K̄*(892)⁰)
-δP (5D fit S+K̄*(892)⁰+K̄*(1410)⁰)