Status of $4\pi^{\pm}$

Overview:

- Better treatment of K_L^0 modes (selection and background estimation)
- $K^{\pm}\pi^{\mp}\pi^0$ and $\pi^+\pi^-\pi^0$ ΔE cut changed
- Double and single tag efficiency studies
- Single tag yields
- $4\pi^{\pm}$ vs $4\pi^{\pm}$ K_S^0 veto
- Peaking background for $4\pi^{\pm}$ vs $\pi^+\pi^-\pi^0$
- Kinematic reweighting

Most recent double tag yields

$CP+$ tags:

- K^+K^-: 19.4 ± 6.3
- $\pi^+\pi^-$: 3.3 ± 8.2
- $K^0_S\pi^0\pi^0$ 18.6 ± 5.1
- $K^0_L\pi^0$: 61.5 ± 9.4
- $K^0_L\omega$: 31.9 ± 6.8

$CP-$ tags:

- $K^0_S\pi^0$: 112.8 ± 11.0
- $K^0_S\eta(\gamma\gamma)$: 18.8 ± 4.5
- $K^0_S\omega$: 41.0 ± 6.7
- $K^0_S\eta(\pi^+\pi^-\pi^0)$: 3.0 ± 2.7
- $K^0_S\eta'(\pi^+\pi^-\eta)$: 9.3 ± 3.2

Mixed-CP tags:

- $K^0_S\pi^+\pi^-$: 216.6 ± 16.0
- $\pi^+\pi^-\pi^0$: 88.8 ± 15.3
- $4\pi^\pm$: 41.0 ± 16.3

Double and single tag efficiency studies

After some investigation it appears the denominator in the efficiency should be the number post DSkim, instead of post MCP2

Decay mode	ST eff. (%)	ST eff. $\times$ $4\pi^{\pm}$ ST eff. (%)	DT eff. (%)	Ratio
		Efficiencies at generator level		
K^+K^-	36.1 ± 0.3	13.2 ± 0.2	22.6 ± 0.2	0.58 ± 0.01
$\pi^+\pi^-$	42.2 ± 0.3	15.4 ± 0.2	26.8 ± 0.2	0.58 ± 0.01
$K^{\pm}\pi^{\mp}$	40.1 ± 0.3	14.7 ± 0.2	25.3 ± 0.2	0.58 ± 0.01
$K^0_S\pi^0$	25.0 ± 0.2	9.2 ± 0.1	12.9 ± 0.2	0.71 ± 0.01
$K^0_S\omega$	12.5 ± 0.2	4.6 ± 0.1	6.1 ± 0.1	0.75 ± 0.02
$\pi^+\pi^-\pi^0$	32.0 ± 0.2	11.7 ± 0.1	17.2 ± 0.2	0.68 ± 0.01
$4\pi^{\pm}$	36.6 ± 0.3	13.4 ± 0.2	17.2 ± 0.2	0.78 ± 0.01
$K^0_S\pi^+\pi^-$	28.2 ± 0.2	10.3 ± 0.1	14.5 ± 0.2	0.71 ± 0.01
		Efficiencies after DSkim		
K^+K^-	49.2 ± 0.4	23.6 ± 0.3	25.8 ± 0.2	0.91 ± 0.01
$\pi^+\pi^-$	50.2 ± 0.3	24.0 ± 0.2	28.9 ± 0.2	0.83 ± 0.01
$K^{\pm}\pi^{\mp}$	51.0 ± 0.4	24.4 ± 0.3	28.1 ± 0.2	0.87 ± 0.01
$K^0_S\pi^0$	35.3 ± 0.3	16.9 ± 0.2	15.4 ± 0.2	1.10 ± 0.02
$K^0_S\omega$	15.9 ± 0.2	7.6 ± 0.1	6.7 ± 0.1	1.14 ± 0.02
$\pi^+\pi^-\pi^0$	43.8 ± 0.3	21.0 ± 0.2	19.5 ± 0.2	1.08 ± 0.02
$4\pi^{\pm}$	47.9 ± 0.4	22.9 ± 0.3	18.2 ± 0.2	1.26 ± 0.02
$K^0_S\pi^+\pi^-$	34.0 ± 0.3	16.3 ± 0.2	15.8 ± 0.2	1.03 ± 0.02

Single tag yields

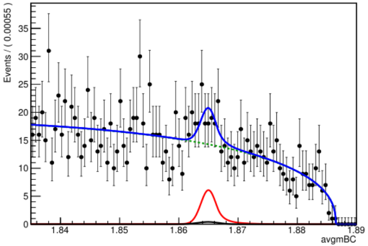
Compare ST yields in data to naive calculation

Efficiency taken using post-DSkim number as denominator

Decay mode	Single tag yield	$2N_{D^0\overline{D}^0}\mathcal{B}(X)\varepsilon(X)$
K^+K^-	11939 ± 118	11651 ± 345
$\pi^+\pi^-$	5682 ± 111	4209 ± 108
$K^\pm\pi^\mp$	132253 ± 374	118332 ± 2971
$K_S^0\pi^0$	20148 ± 154	17175 ± 679
$K_S^0\omega$	8205 ± 121	6436 ± 370
$\pi^+\pi^-\pi^0$	32807 ± 553	37006 ± 1740
$K_S^0\pi^+\pi^-$	58030 ± 278	57540 ± 4258
$4\pi^\pm$ (FS < -2)	20403 ± 374	19346 ± 684
$4\pi^\pm$ (FS < 0)	23827 ± 401	21254 ± 758

$4\pi^\pm$ vs $4\pi^\pm$ K_S^0 veto

If the $4\pi^\pm$ vs $4\pi^\pm$ K_S^0 veto is tightened from < 0 to < -2, number of events selected goes from 87 ± 19 to 41 ± 16.



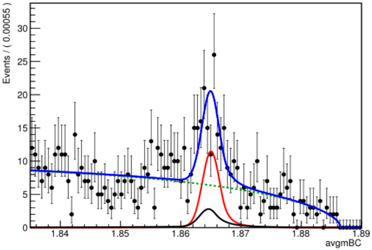
Single tag number doesn't change much

Don't anticipate large contribution from track-swap due to use of ΔE as discriminator

(A back of the envelope calculation shows $F_+(1 - F_+)$ is still 'too large', but by nowhere near as much as before. To be confirmed officially. . .)

Peaking background for $4\pi^{\pm}$ vs $\pi^{+}\pi^{-}\pi^{0}$

Expected high $CP+$ content of $4\pi^{\pm}$ means that peaking background due to $K_S^0\pi^0$ is larger than calculated from generic MC.
Multiply amount of this background by 1.5 and rerun fit



Find 81 ± 15 → 76 ± 15.
Treatment to be decided when other systematics known.

Kinematic reweighting

Reweight $4\pi^{\pm}$ data to account for non-flat efficiency

Determine normalised efficiency in bins of kinematic variables

Either

$$\prod_{i=1}^{4} \varepsilon^{\mathbf{p}}_{\pi_i}$$

Randomise momenta of each pair of like-sign pions

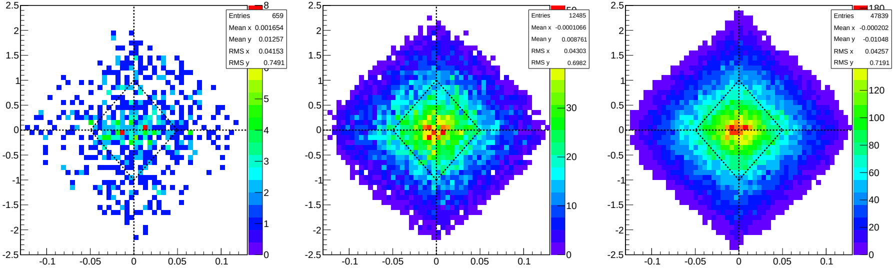
Or 2D plot of Jonas' variables

$$s \equiv s_{13} - s_{24}, \qquad r \equiv \epsilon_{abcd} \mathrm{P}^{a}_{\pi_1} \mathrm{P}^{b}_{\pi_2} \mathrm{P}^{c}_{\pi_3} \mathrm{P}^{d}_{\pi_4}$$

where pion ordering is $+, -, +, -$.

The variables r and s

Examples for $4\pi^{\pm}$ vs $K^{\pm}\pi^{\mp}$
Eight bins defined to get normalised efficiency
Left: data, centre: reco MC, right: gen MC



Shift in weighted data yield small with these variables (0.2% for $K^{\pm}\pi^{\mp}$)
Shift is larger for product of efficiencies in momentum (3.7% for $K^{\pm}\pi^{\mp}$)
Overall anticipate small systematic

Status of $h^+h^-\pi^0$ vs $K^0_{S,L}\pi^+\pi^-$

- Incorporation of Gaussian constraints and correction for T_i mixing
- Better background estimation
- Comparison of fit methods

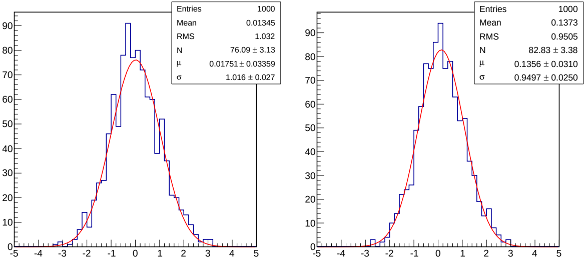
Comparison of fit methods

Two fit procedures considered:

- Likelihood fit to uncorrected fields, incorporating background and efficiency in the floating term
- χ^2 fit to corrected yields

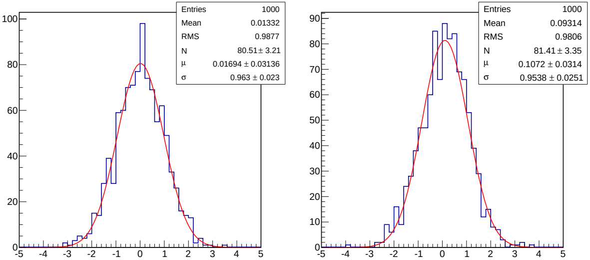
Find the former unbiased, latter biased

Pull plots for $\pi^+\pi^-\pi^0$ for (left) likelihood fit (right) χ^2 fit



Comparison of fit methods

Pull plots for $K^+K^-\pi^0$ for (left) likelihood fit (right) χ^2 fit



Likelihood fit results

Fit type	$F_+^{\pi^+\pi^-\pi^0}$		$F_+^{K^+K^-\pi^0}$	
	$K_S^0\pi^+\pi^-$	$K_L^0\pi^+\pi^-$	$K_S^0\pi^+\pi^-$	$K_L^0\pi^+\pi^-$
Separate	1.034 ± 0.051	0.969 ± 0.073	0.578 ± 0.145	0.896 ± 0.161
Combined	1.011 ± 0.044		0.721 ± 0.106	
CP-tagged values (σ_{stat} only)	0.968 ± 0.017		0.731 ± 0.058	